RPA S6.1
Aircraft Braking Friction Program

Presented to: REDAC Sub-Committee on Airports

By: Dr. Michel Hovan and Joseph Breen P.E.

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Aircraft Braking Friction

- Airport Runway Conditions (i.e. Wetted and Contaminated) Can Cause Degraded Wheel Braking During Aircraft Landings.
- Degraded Aircraft Wheel Braking Has Contributed to Runway Overruns and Collisions (e.g. Southwest Airlines Flight 1248 Landing at MDW Under Snow Conditions).
- FAA Aircraft Braking Friction Research Initiated in Response to NTSB Issued Safety Recommendations.

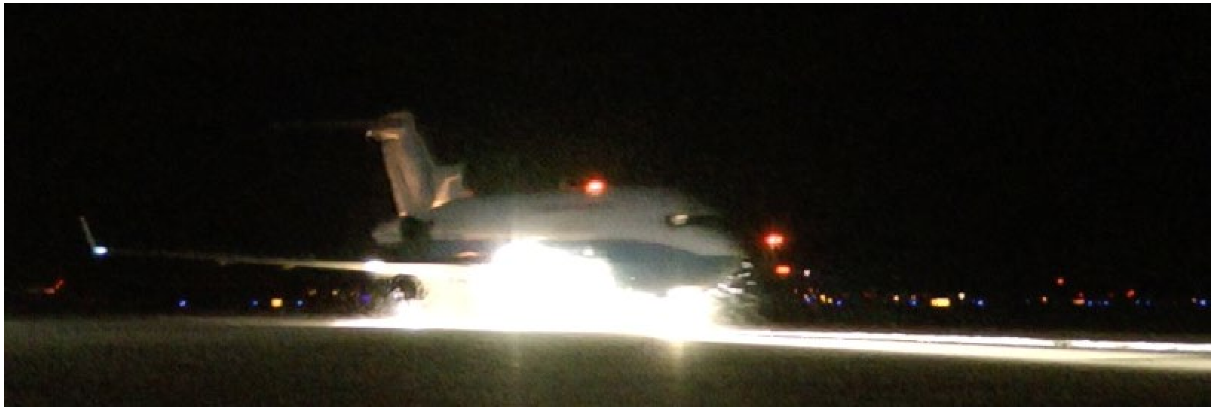
NTSB Safety Recommendations

- NTSB, (2007), *Safety Recommendation* A-07-64: (Closed – Acceptable Action/Superseded – 2016) "Demonstrate the technical and operational feasibility of outfitting transport-category airplanes with equipment and procedures required to routinely calculate, record, and convey the airplane braking ability required and/or available to slow or stop the airplane during the landing roll. If feasible, require operators of transport-category airplanes to incorporate use of such equipment and related procedures into their operations." (Safety Recommendation A-07-064 is superseded by Safety Recommendations A-16-023 and A-16-024)
- NTSB, (2016), *Safety Recommendation* A-16-023:
- "Continue to work with industry to develop the technology to outfit transport-category airplanes with equipment and procedures to routinely calculate, record, and convey the airplane braking ability required and/or available to slow or stop the airplane during the landing roll."
- NTSB, (2016), Safety Recommendation A-16-24:
- "If the systems described in Safety Recommendation A-16-23 are shown to be technically and operationally feasible, work with operators and the system manufacturers to develop procedures that ensure that airplane-based braking ability results can be readily conveyed to, and easily interpreted by, arriving flight crews, airport operators, air traffic control personnel, and others with a safety need for this information."

- **FAA Aircraft Braking Friction Research Has Included the Following Elements:**
  - **Instrumented B727 Aircraft Used to Measure Degraded Braking Friction on Wetted and Contaminated Runways.**
  - **BAA Contracts with Metron/Airbus and Aviation Safety Technologies (AST) to Investigate Feasibility of Using Aircraft Flight Data to Identify Inferred Level of Braking Performance.**
  - **CRDA Between FAA and Zodiac Aerospace to Test Alternate Sensing Mechanisms Installed Onboard Aircraft.**

FAA Aircraft Braking Friction Research

- **Airport Technology R&D Used Instrumented B727 Aircraft to Directly Measure Degraded Braking Friction Under Snow and Wetted Runway Conditions.**
- **Aircraft Instrumented with Strain Gauges on the Main Landing Gear Axles Allowing for Direct Measurement of Wheel Braking Coefficients.**
- **Instrumentation also allows for Direct Measurement of Wheel Slip Ratios and Brake Pressures Upstream and Downstream of Anti-Skid Valves.**



FAA Aircraft Braking Friction Research (Continued)

- FAA BAA Contracts awarded to Metron/Airbus and AST demonstrated the feasibility of creating an *inferred* level of braking performance using the flight data that can be currently collected from the aircraft.
- At this time, these are the only two systems available and in use with the industry.
- While these methods were found to have value, there exists no independent standard where these methods can demonstrate their accuracy, precision, and compatibility between airplane models.

FAA Aircraft Braking Friction Research (Continued)

- **Under CRDA Between FAA and Zodiac Aerospace Brake Testing of the Global 5000 Aircraft Was Conducted Under Wetted Runway Conditions.**
- **Testing Demonstrated that Alternate Sensing Mechanisms are capable of Recording Flight Data for Aircraft Wheel Braking performance that can Distinguish between Different Runway-Related Braking Conditions.**

REDAC Recommendations/FAA Actions

- In 2016 REDAC Sub-Committee on Airports Requested Formation of a Technical Working Group to Review FAA Research on Aircraft Braking Friction and Make Recommendations Regarding Direction of Future Efforts.
- Airport Technology R&D Formed a Technical Working Group in February 2017 to Evaluate FAA Aircraft Braking Friction Research.
- Technical Working Group Included Representation from the FAA, Academia, Aircraft Braking System Manufacturers, and Others that 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 Test Aircraft and Runway to Conduct Controlled Condition Flight Testing.**
- **Controlled Condition Flight Testing to be Conducted on Wetted and Contaminated Runway Conditions.**
- **Details of White Paper were Presented to REDAC Sub-Committees in 2018.**
- **White Paper Document was Supplied to REDAC Sub-Committees in 2018.**

REDAC Recommendations/FAA Actions (Continued)

- 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.

REDAC Recommendations/FAA Actions (Continued)

- **Modified White Paper Identifies the following Objectives For Future FAA Research:**
  - **Analysis of Aircraft Recorded Braking Performance.**
  - **Controlled Condition Flight Testing.**
  - **International Standards Development.**

Analysis of Aircraft Recorded Braking Performance

- Data collected from the aircraft and analyzed in such a manner as to create an accurate model of wheel braking performance that is mapped to the TALPA/Global Recording Format (GRF) performance scale.
- Machine Learning Model to be Developed to Extract Relationships Between Contributing Features and Resultant Degraded Braking Performance.
- Development of these Relationships would enable the current TALPA/GFE Matrix to reduce unexpected exposure to risk through a redefined mapping of contaminant to runway condition code as used in FICON’s.

Analysis of Aircraft Recorded Braking Performance (Continued)

- Large Scale Data Analysis will Involve Comparison of Aircraft Performance Data with Data Collected External to the Aircraft.
- Big Data Methods Used to Develop Statistical Methods that Describe Degraded Wheel Braking on Various Runway Contaminants.
- FAA Investigating Agreement with Aviation Safety Technologies (AST) to Obtain Data From Aircraft Landings Generated over a Two Year Period (2017 and 2018). AST to provide Technical Support in Big Data Analysis.
- AST Data would Represent Several Million Aircraft Landings Including Thousands of Friction Limited Landings.
- Processed Data, Weather Data, and Runway Data to be Supplied.

Analysis of Aircraft Recorded Braking Performance (Continued)

- Data Collected External to Aircraft would include Pilot Braking and Field Condition Reports (FICON NOTAMS) and Airport Surface Detection Equipment (ASDE-X).
- Big Data Analysis to be Performed by the FAA and MIT. MIT Work to be Funded Under the FAA Joint University Program (JUP).

Controlled Condition Flight Testing

- Test Aircraft Used to Conduct Brake Testing on Wetted and Contaminated Runways to Assess Degraded Braking.
- Flight Testing will be Complimentary to Big Data Study in that it Helps Validate Statistical Models from Study.
- Flight Testing Can Isolate the Contribution of Particular Factors Related to Degraded Braking such as Pavement Micro- and Macro-Texture.

Controlled Condition Flight Testing

- Model to Be Developed Based on Flight Test Data to Determine Where Tire to Ground Friction Departs from Established FAA/ESDU Model.
- Model Would Consider New Types of Runway Specific Factors as Well as Weather Observation Methods.

International Standards Development

- Technical Working Group members should support participation in the Society of Aircraft Performance and Operations Engineers (SAPOE)/ASTM Standards effort for the collection and reporting of friction limited aircraft braking information.
- Technical and philosophical challenges remain in MU-brake mapping to the TALPA/GRF reporting scale as well as other areas.

Connection to Trapezoidal Grooving Research

- Original Research Request dated 11/14/2014 Prescribed High Speed Braking Runs on Wetted Transverse Grooving Test Bed Using Instrumented B727 Aircraft.
- Test Bed to Include Both FAA Standard Grooving and Trapezoidal-Shaped Grooving (Full Depth and Half Depth).
- Testing to Evaluate Capabilities of Grooving for Maintaining Aircraft Tire Skid-Resistance and Prevention of Hyroplaning.

Connection to Trapezoidal Grooving Research

- **Airport Technology R&D and Airport Engineering Division (AAS-100) Drafted Revised Research Request Including the Following Elements:**
  - **Instrumented Test Aircraft to Be Used for Evaluating Braking Friction on Runways with Full-Depth Trapezoidal-Shaped and FAA Standard Runway Grooving Under Wetted Conditions.**
  - **Aircraft Brake Testing to be Conducted at Speeds of 140 Knots or Greater with 3 Seconds of Friction Limited Braking Minimum.**

Connection to Trapezoidal Grooving Research

- **Reduced Scale Laboratory Testing (Lab Testing) and Finite Element Based Computer Modeling (FE Modeling) will Initially be Utilized to Assess Braking Friction Under Conditions Directly Relatable to Instrumented Test Aircraft.**
- **Braking Friction Data Generated from High Speed Instrumented Aircraft Testing will be Used to Validate Results of Lab Testing and FE Modeling.**
- **Once Validation is Completed, Lab Testing and FE Modeling will be Used to Assess the Influences of Runway Groove Depth and Groove Shape, Water Depth, Tire Tread Depth, and Aircraft Speed on Friction Limited Braking Coefficients.**

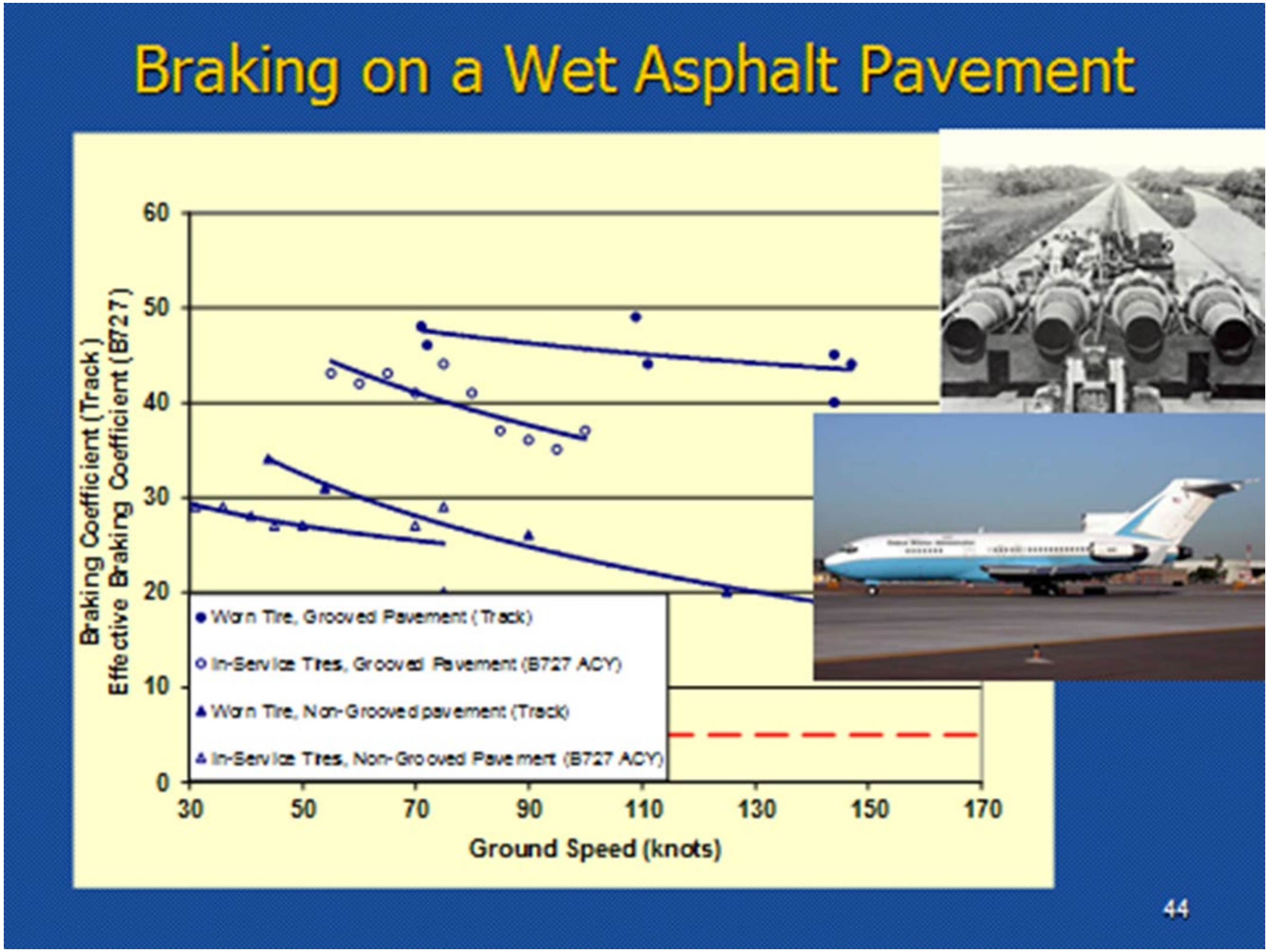
Connection to Trapezoidal Grooving Research

- **Trapezoidal Grooving Has Been Installed on Runways at Several Domestic Airports Including:**
  - **Northern Colorado Regional Airport (FNL)**
    (8,500 ft. x 100 ft. Asphalt Runway 15-33)
  - **Centennial Airport, Denver, CO (APA)**
    (10,000 ft. x 100 ft. Asphalt Runway 17L-35R)
  - **Great Falls International Airport, Montana (GTF)**
    (6,030 ft. x 150 ft. Asphalt Runway 17-35)

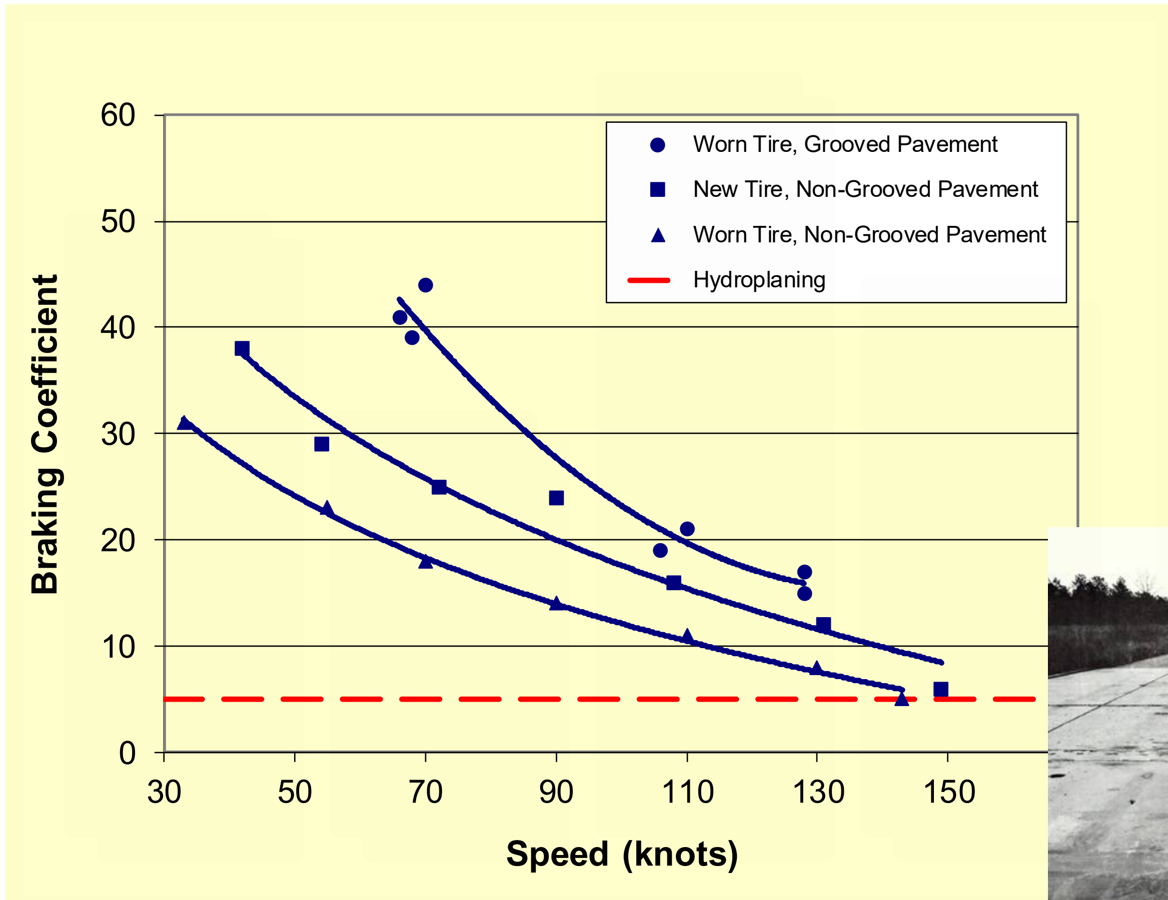
Past Full-Scale Testing

- Evaluation of Current FAA Standard Runway Grooving Configuration was Conducted with Full-Scale Testing.
- Full-Scale Testing was Accomplished utilizing a Dynamic Test Track (Joint FAA/Navy 1975-1983) and an Instrumented B727 Aircraft (R&D 40) (FAA 1980's).
- The Dynamic Test Track used a Rail-Mounted Four-Wheeled Jet-Powered Pusher Car and Dead-Load Carriage with Dynamometer and Tire/Wheel Assembly.
- Testing was Conducted at Ground Speeds from 30 to 150 knots on the Dynamic Test Track at NAEC Lakehurst, NJ under Wet, Puddled (0.10 inch Standing Water), and Flooded Conditions (0.25 inch Standing Water).
- Aircraft Testing was Conducted at ACY at Ground Speeds from 30 to 100 knots under Wet Runway Conditions (i.e. Tanker Wet).
- Maximum Braking Friction was Measured and Recorded.

Dynamic Test Track and B727 Plots for Wet Asphalt Pavement



Dynamic Test Track Plots for Puddled Asphalt Pavement



QUESTIONS?

Background

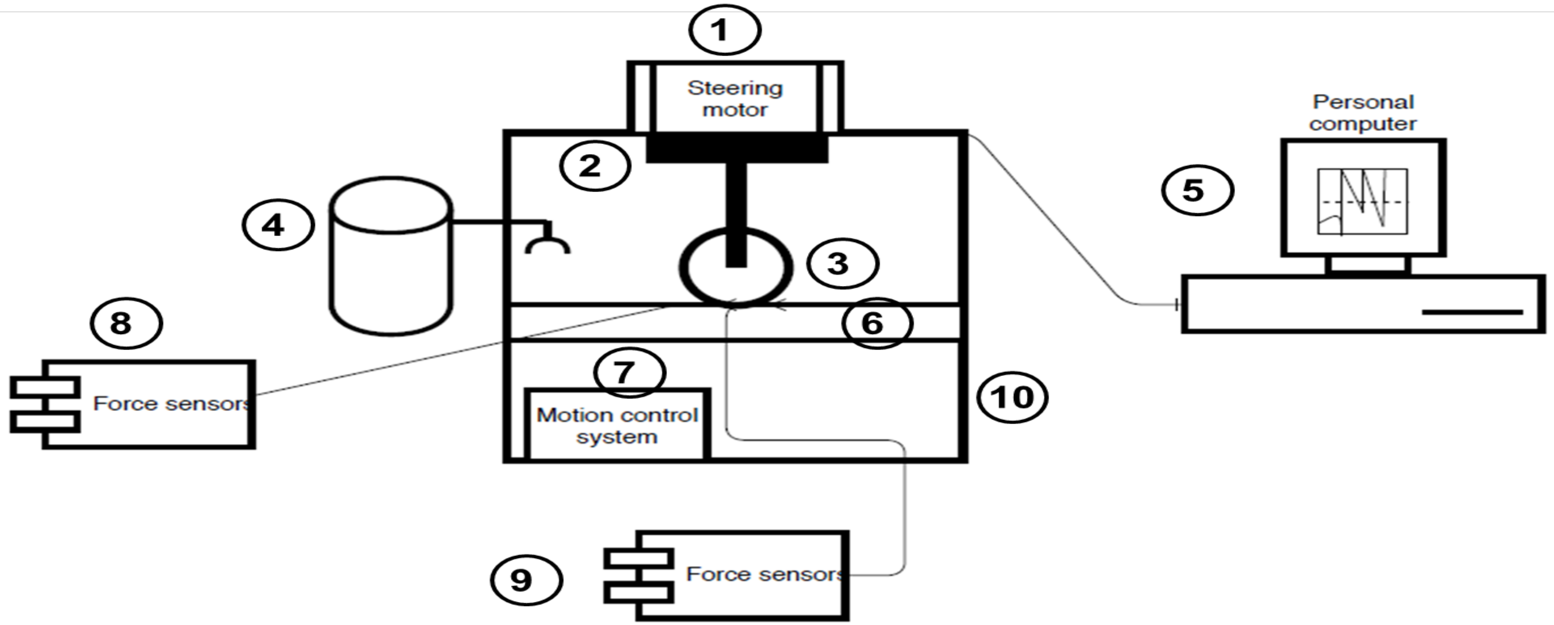
Task 1 – Develop Tire-Water-Pavement Interaction Model

- **Calibrate aircraft tire model**
  - ❑ Aircraft tire dimensions (Goodyear 2002)
  - ❑ Measured tire deflection and footprint data (NASA data)
  - ❑ Measured tire contact stresses and area using the test tire used at NAPTF
- **Fluid-structure interaction model**
  - ❑ Calculate water uplift force and friction force
  - ❑ Predict hydroplaning speed

Task 2 – Develop Laboratory Test Platform

- **Controlled environment to measure tire deformation and friction force on wet surface**
  - ❑ Scaled aircraft tire is controlled by one drive motor and another steering motor
  - ❑ Treadmill belt with support plate and textured/grooved top layers to simulate different pavement surfaces
  - ❑ Motion control system and cable potentiometer to regulate position and tilt angles of plate
  - ❑ Water spray system to generate water film depth in the chamber
  - ❑ Force sensors to measure normal load between tire and plate
  - ❑ Friction forces are measured by flexible piezoelectric sensor embedded in tire rubber
  - ❑ High-resolution camera is used to measure tire deformation

Proposed Test Platform



1. Steering motor; 2. Driving motor; 3. Scaled aircraft tire; 4. Water spray system; 5. Personal computer with control system; 6. Treadmill with support plate and top surfacing; 7. Motion control; 8 & 9. Force sensors; 10. Supporting frame

Task 3 – Calibrate Numerical Model with Laboratory and Field Testing Data

- **Model calibration and validation**
  - ❑ Laboratory testing data from controlled platform
  - ❑ Field testing data from existing NASA studies
    - ❑ Braking friction coefficient; hydroplaning speed
  - ❑ Field testing data from the planned full-scale test of Instrumented Aircraft
    - ❑ Braking friction coefficient; braking distance

Task 4 – Analyze Effects of Groove Configurations

- **Water flow capacity**
  - Standard FAA groove pattern
  - Trapezoidal-shaped groove pattern
- **Braking performance**
  - Braking distance
  - Hydroplaning speed
- **Effects of groove configurations**
  - Groove width, depth, and spacing
  - Roughness of groove

Task 5 –Analyze Effects of Aircraft Operating Conditions

- **Aircraft operating conditions**
  - ❑ Wheel load
  - ❑ Tire inflation pressure
  - ❑ Speed
  - ❑ Slip ratio
  - ❑ Uplift force of airplane
- **Identify critical operating condition considering different aircraft types**

Task 6 – Analyze Effects of Airport Location and Runway Geometry

- **Airport location**
  - Weather records
  - Historic data on rainfall intensities
- **Runway geometry and condition**
  - Runway width
  - Longitudinal and transverse slope
  - Rut depth (pond water)
  - Wet friction coefficient (rubber contamination)