Contaminated Operations Analysis: Challenges and Opportunities for Large Transport Aircraft

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FUTURE SKY SAFETY

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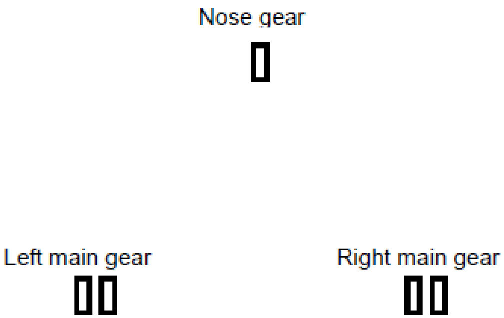
Putting things into context

- The characterization of **braking friction** on **water-contaminated** runways is one of the main objectives of Future Sky Safety P3.
- The ulterior target is to provide evidence for updation current AMC 25.1591 curves, used as certification basis for contaminated conditions.
- As part of P3, two analogous test campaigns were carried out on Twenthe Airport (EHTW), in 2016 and 2017.
- Contamination was simulated on a specially constructed 100 m pond facility, filled with water ~ 15 mm depth.
- The following aircraft were used:
  - **2016 Campaign**: Cessna Citation (NLR)
  - **2017 Campaign**: A400M (Airbus D&S and NLR)

How was it done for Cessna Citation?



- Cessna has a **single row** of tires on the MLG:
  - All tires see the same amount of contaminant.
  - All tires experience similar braking friction reduction.

- It is possible to derive the braking friction coefficient from **global aircraft loads.**

$$\mu_{braking\ a/c} = \mu_{braking\ wheel}$$

$$\mu_{braking} = \frac{F_{braking\ MLG}}{N_{MLG}}$$

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  - $F_{braking\ MLG}$ derived from **test campaign philosophy:**

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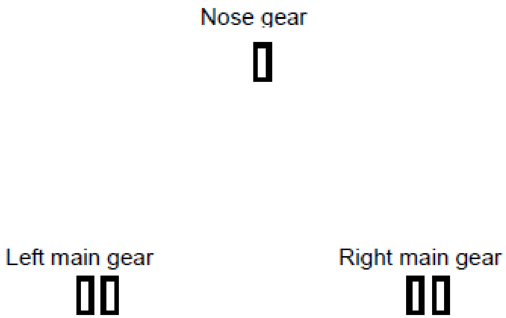

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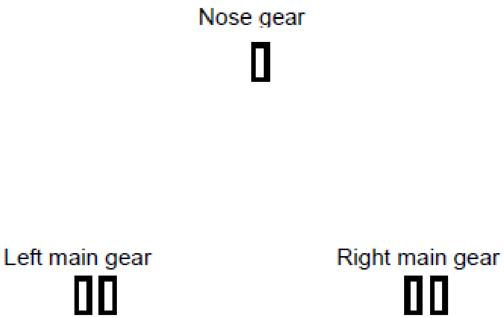

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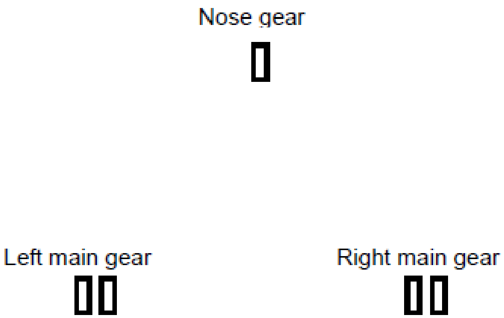

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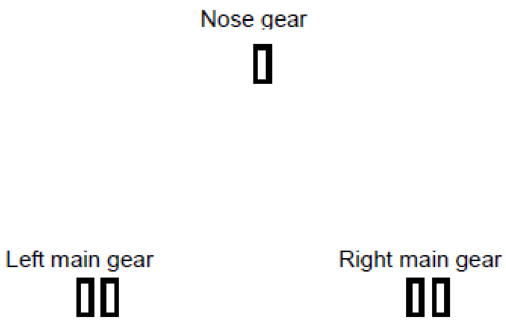

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$$F_{braking\ MLG} = m.a_{ubr} - m.a_{brk}$$

What about A400M?

Nose gear

Left main gear

Right main gear

What about A400M?

Nose gear

Left main gear

Right main gear

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What about A400M?

Nose gear

Left main gear

Right main gear

Nose gear

Left main gear

Right main gear

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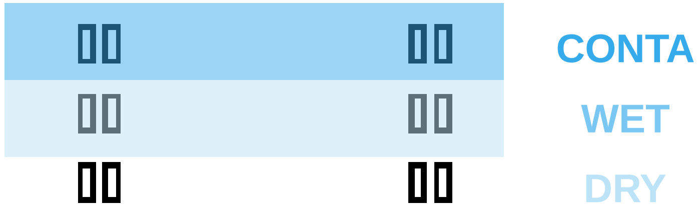
What about A400M?

- A400M has **three rows** of tires on the MLG:
  - Each row sees **a different amount** of contaminant.



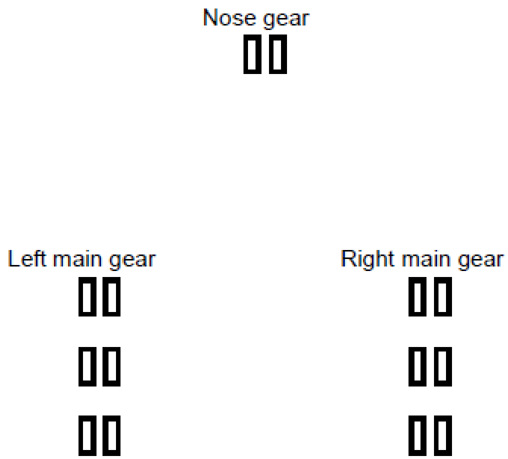
  - Each row experiences **a different** braking friction reduction.

- It is **NOT** possible to derive the braking friction coefficient from **global aircraft loads**

$$\mu_{brk\ a/c} \neq \mu_{brk\ wheel}$$

$$\mu_{brk\ wheel\ front} \neq \mu_{brk\ wheel\ mid} \neq \mu_{brk\ wheel\ aft}$$

- The interest is to obtain $\mu_{brk\ wheel\ front}$ (first row).



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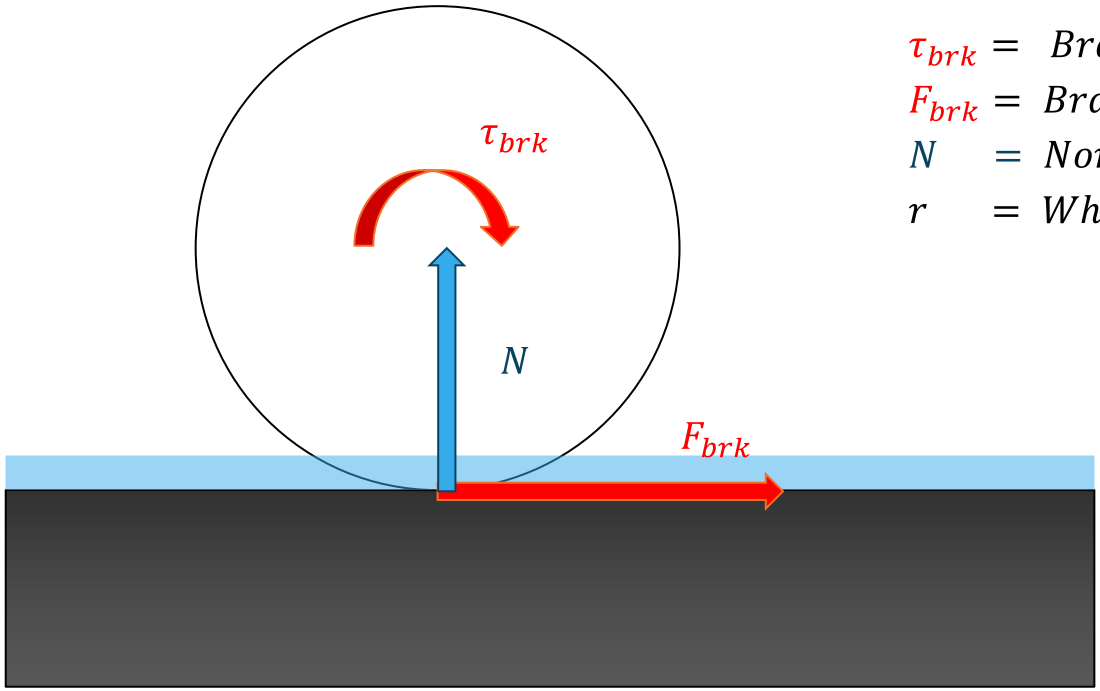
A400M: Challenge

- It is not useful to work with an horizontal loads balance **aircraft** level → **Need for a new methodology**
- **Proposal:** Work at **tire** level, applying **torque** balance around wheel axis.



$\tau_{brk} = \textit{Braking Torque}$

$F_{brk} = \textit{Braking Force}$

$N = \textit{Normal Reaction}$

$r = \textit{Wheel Radius}$

$$\left.\begin{aligned} \tau_{brk} &= F_{brk} \,.\, r \\ F_{brk} &= \mu_{brk} \,.\, N \end{aligned}\right\} \quad \boxed{\mu_{brk} = \frac{\tau_{brk}}{r.N}}$$

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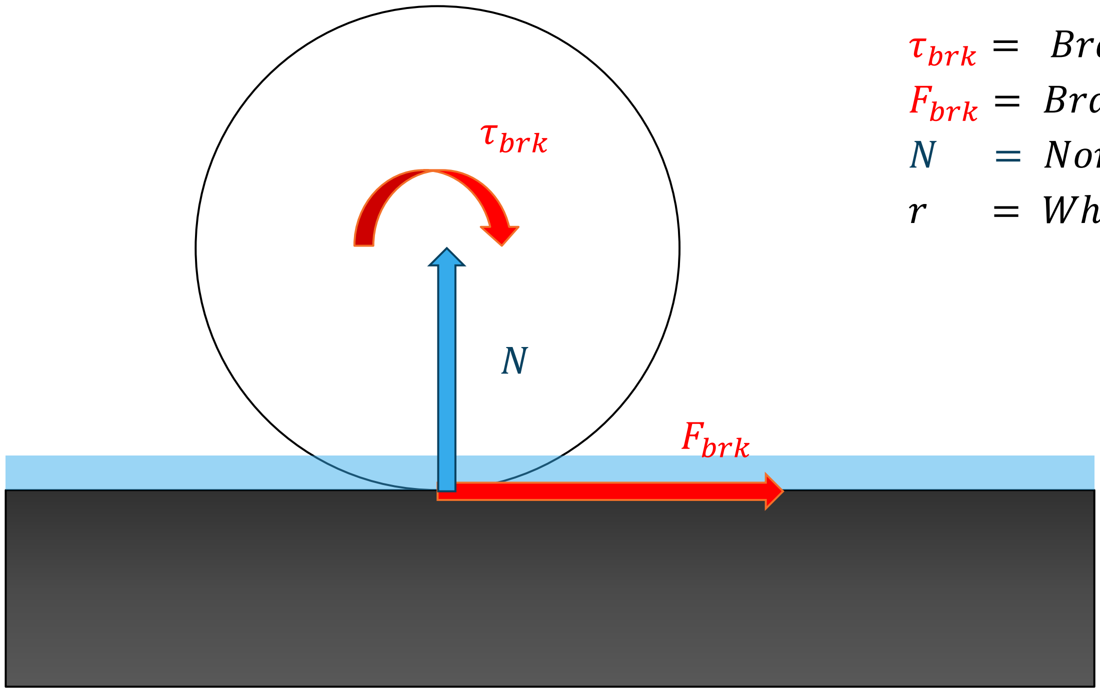

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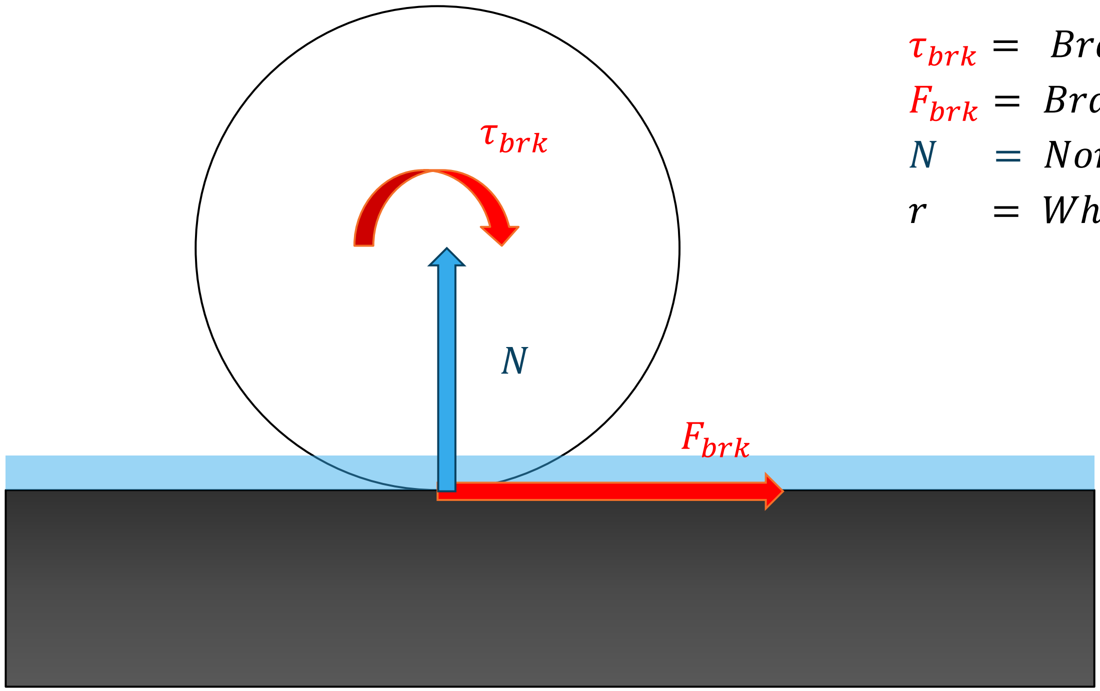

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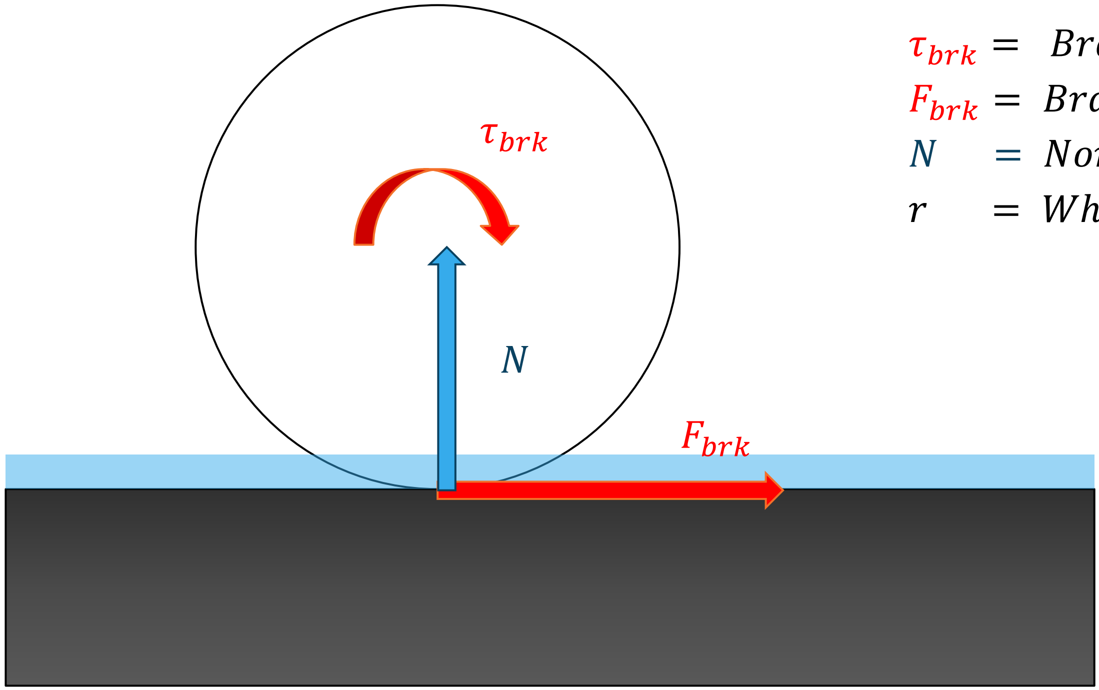
Is this possible?

YES

A400M: Opportunity 1 – Fully Instrumented Aircraft

- For the test campaign, a **fully instrumented** test aircraft was used.
- As a results, **individual measurements** of the required parameters were available for **all tires.**

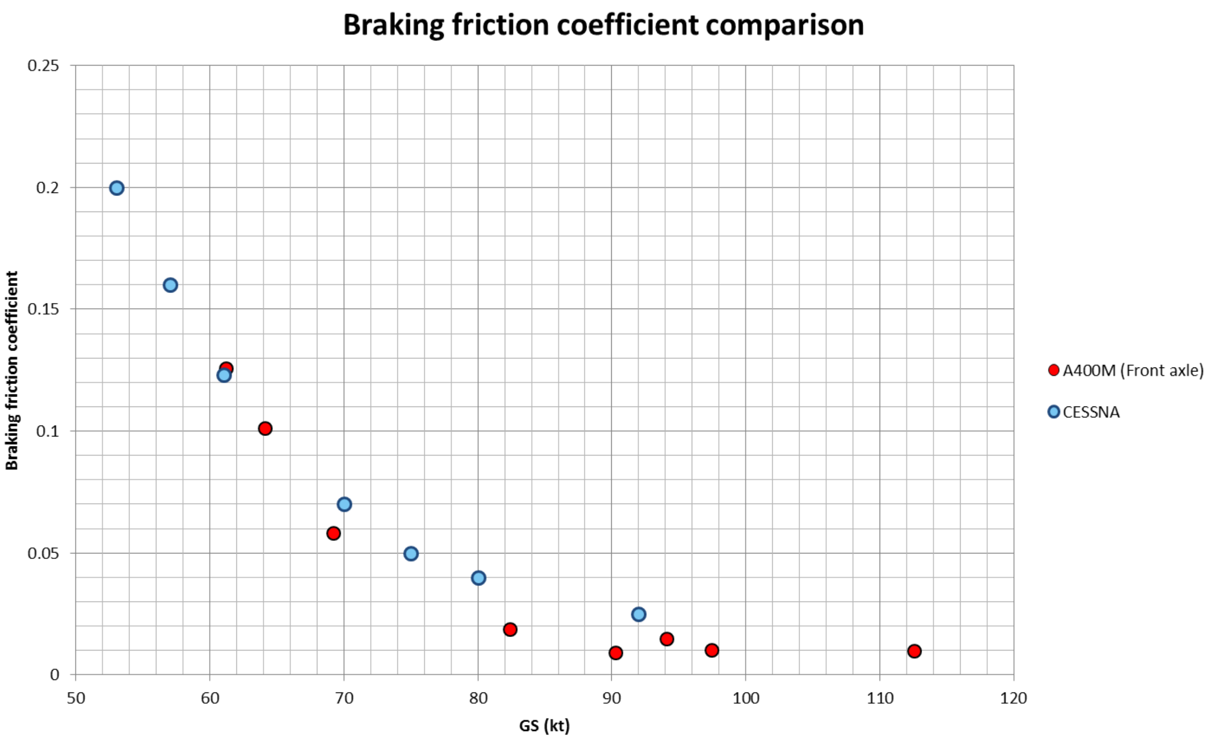


τ_{brk} = *Braking Torque* → 128 Hz
F_{brk} = *Braking Force* → 128 Hz
N = *Normal Reaction* → 128 Hz
r = *Wheel Radius*

$$\left.\begin{array}{l}\tau_{brk} = F_{brk} \, . \, r \\ F_{brk} = \mu_{brk} \, . \, N\end{array}\right\} \quad \boxed{\mu_{brk} = \frac{\tau_{brk}}{r.N}}$$

A400M: Opportunity 1 – Fully Instrumented Aircraft

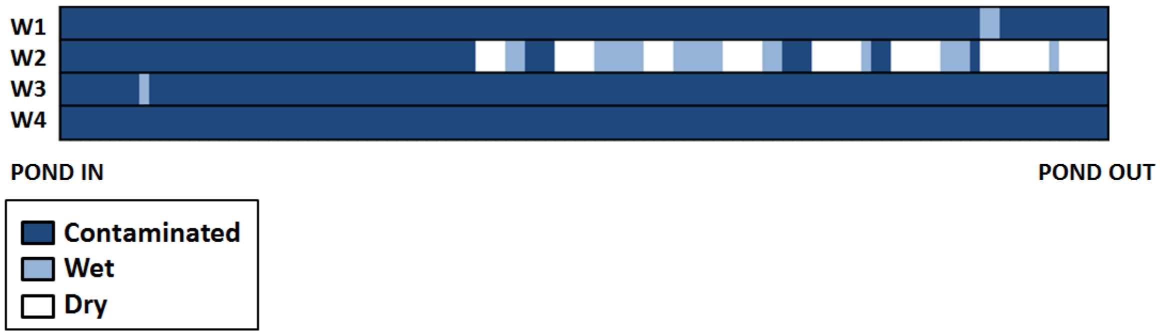
- It has been possible to characterize $\mu_{brk} = f(GS)$ at **front wheel** level on highly contaminated (15 mm water) conditions.
  - Results show strong alignment with previous Cessna tests.
- Additionally, the combination of **"analysis by wheel"** methodology and **fully instrumented aircraft** has led to **further opportunities:**
  - Assessment of **inhomogeneities**.
  - Characterization of **aquaplaning speed**.
  - Characterization of **displacement drag**.



A400M: Opportunity 2 – Assessment of inhomogeneities

- Tests were performed on **artificially contaminated** conditions (pond where contaminant depth showed reasonable homogeneity).

- Nevertheless, **naturally contaminated** runways are, in general, inhomogeneous.

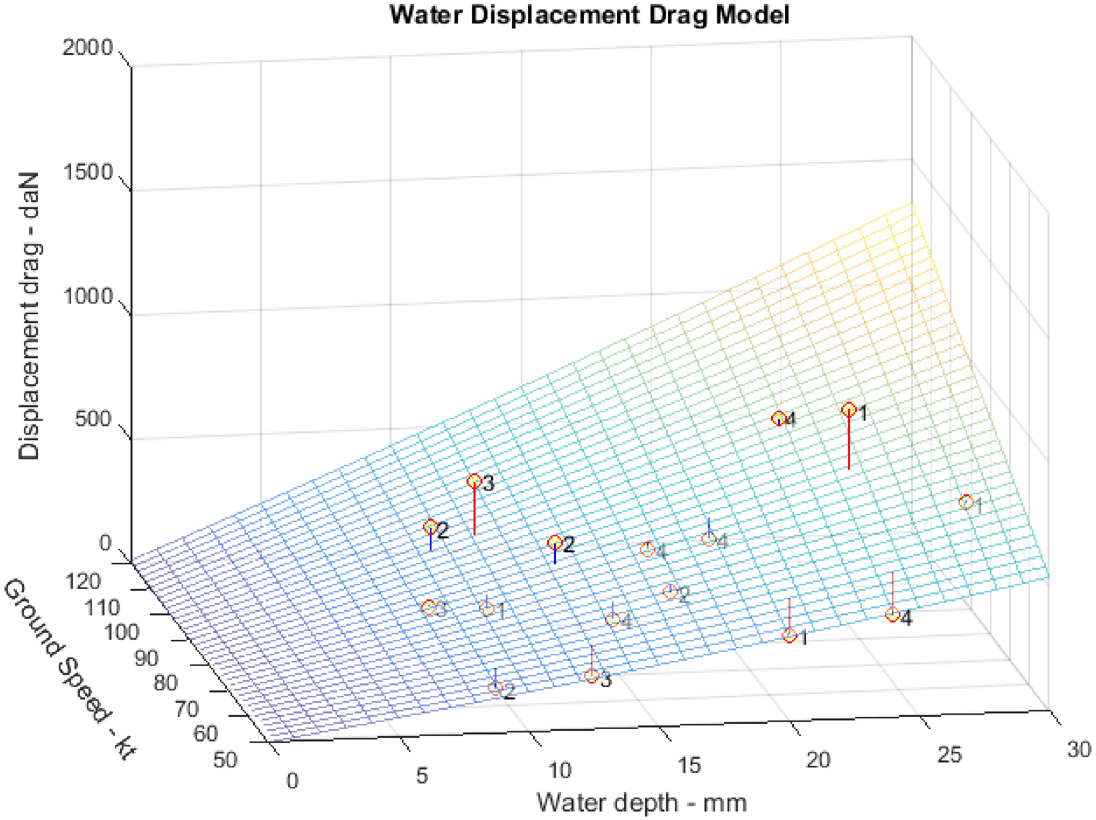


- Analysis by wheel (supported, of couse, by a fully instrumented aircraft) allow to tackle these (and other) inhomogeneities, and lead to a **more comprehensive outcome.**

A400M: Opportunity 3 – Characterization of Displacement Drag

- Results from unbraked runs allowed to develop a **regression** model of Displacement Drag as a function of:
  - Ground Speed (GS).
  - Contaminant depth.

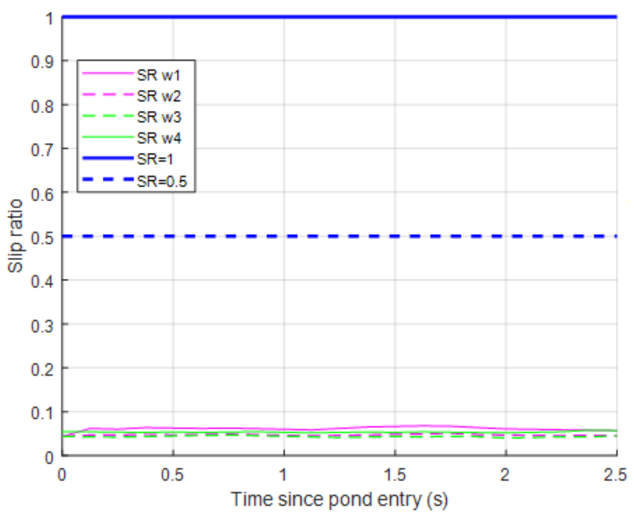
- The use of depth as a regression variable has been possible thanks to **individual wheel instrumentarion**.



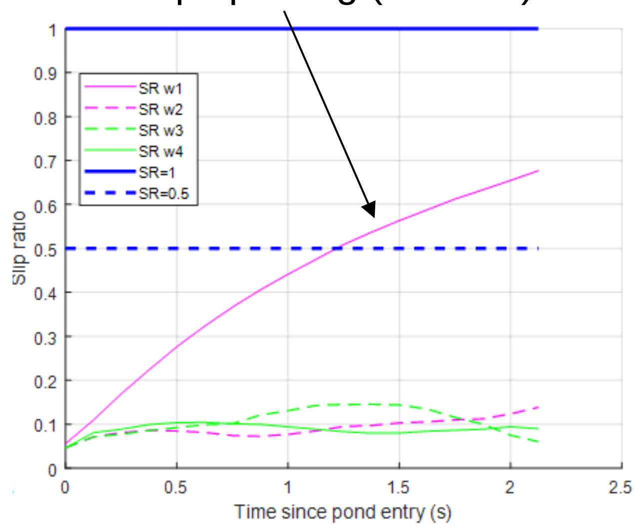
A400M: Opportunity 4 – Characterization of Aquaplaning

- Individual instrumentation on all wheels allowed to study the evolution of **aquaplaning,** as well as a more precise acotation of **aquaplaning speed**.
- The following graphs show the evolution of slip ratio $\left(1 - \frac{wheel\ speed}{GS}\right)$ with GS for A400M front wheels (w1 to w4)
  - Slip ratio > 0.5 indicates aquaplaning

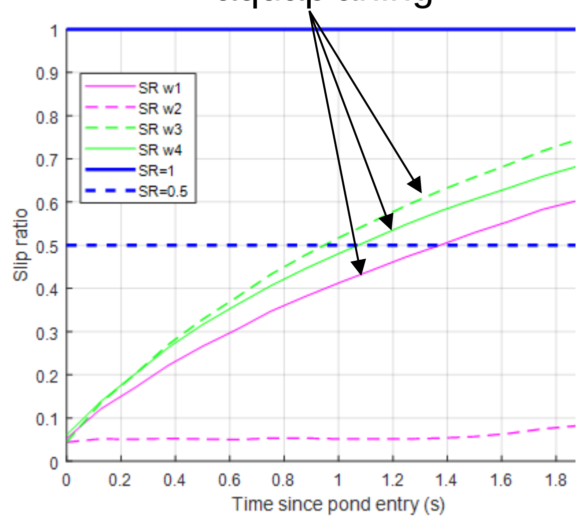
80 kt: no aquaplaning



90 kt: incipient aquaplaning (wheel 1)



100 kt: fully developed aquaplaning



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So… what comes next?

Possible Areas of Future Work & Collaboration

- The results obtained in this test campaing are **indicative**, but by no means robust for a consistent change in the certification basis.

- A great stress has been placed on the assessment of braking friction. Nevertheless, a realistic assessment of retarding force should also include an appropriate characterization of **contaminant drag.**

- A strong need for **further testing** has been identifying, using:
  - Longer pond facilities (~ 500 m), which allow for more representative braking times.
  - **Naturally contaminated conditions:** essential for a realistic assessment.

- The use of a **fully instrumented** aircraft, equipped with a **multi-row** landing gear, is **crucial** for the success of **future** campaigns:
  - It allows for both wheel-level and aircraft-level assessment.
  - It permits results generalization for all undercarriage configurations.
  - It leads to more accurate estimations of displacement drag and aquaplaning speed.

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Thank you