VIRTUAL DRIVING EXPERIENCE IN BRAKING SYSTEMS DEVELOPMENT: WORKFLOW AND USE CASES

GCF R&D - VSE

14/05/25

AGENDA

1. Introduction
2. MIL / HIL environment
3. DIL / DHIL environment
4. Conclusions

Strictly Confidential. This presentation in its entirety is the property of Brembo and subject to copyright. It cannot be copied, edited, reproduced, or shared without prior, written permission from Brembo.

SENSIFY

SW PLATFORM

OPEN & PER-FUNCTION

Vehicle level

Component level

LEVELS

LEVEL 2 functions
Vehicle control

LEVEL 1 functions
Corner control

LEVEL 0 functions
Actuator control

FUNCTIONS

ABS

EBD

Brake light Control

Traction Control

Regen brake blending

Stability Control

Service routines

Emergency Brake Assist

- Slip control management for the single corner

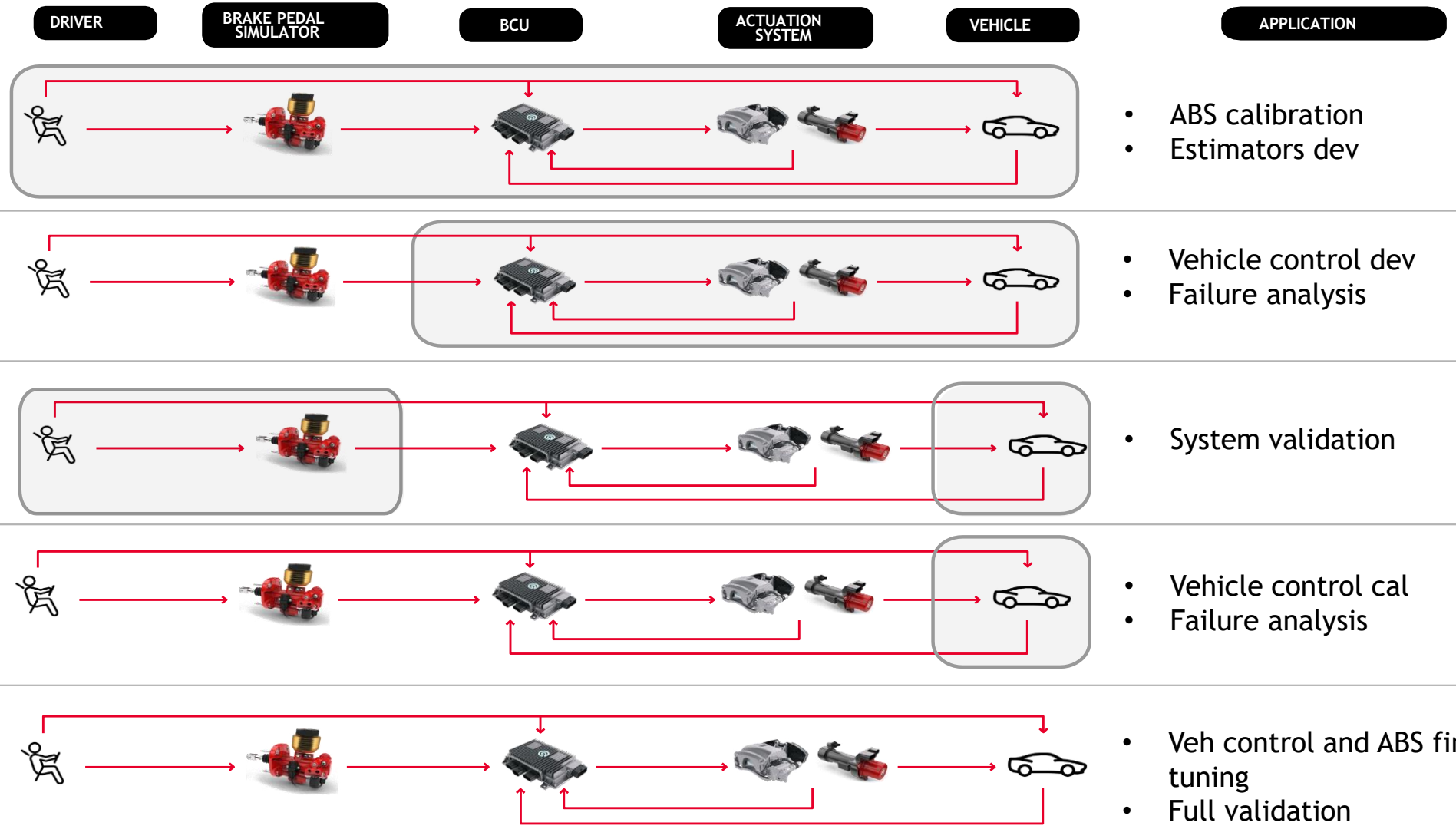
- Brake Apply (normal, slow, fast)
- Brake Release (normal, silent)
- Parking Brake functions
- Service functions
- Diagnostic routines
- Functional safety monitoring

Strictly Confidential. This presentation in its entirety is the property of Brembo and subject to copyright. It cannot be copied, edited, reproduced, or shared without prior, written permission from Brembo.

INTRODUCTION

VIRTUAL

brembo



Strictly Confidential. This presentation in its entirety is the property of Brembo and subject to copyright. It cannot be copied, edited, reproduced, or shared without prior, written permission from Brembo.

MIL PLATFORM

TARGET

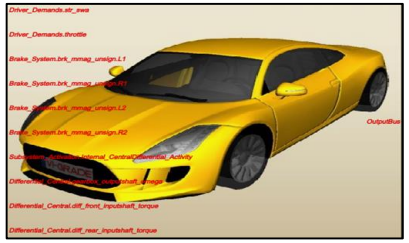
- Virtual development tool to evaluate the impact of braking system **design iterations on vehicle dynamic behavior** (car and motorcycle)

Desktop PC

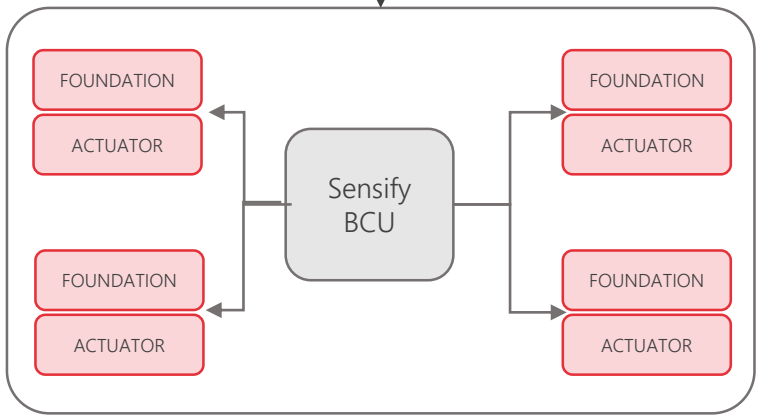
VI-GRADE

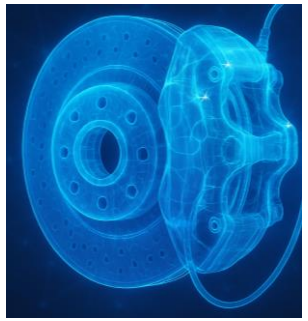
MATLAB

VEHICLE MODEL



SENSIFY - VIRTUAL





- **Actuators virtual model** from experimental characterization or from design
- **Foundation brake** virtual model
- **Model based** Sensify SW

MAIN USAGE

1. Vehicle estimators and control functions development.
2. Control functions pre-calibrations (ABS).
3. Safety function development and failure analysis.

Strictly Confidential. This presentation in its entirety is the property of Brembo and subject to copyright. It cannot be copied, edited, reproduced, or shared without prior, written permission from Brembo.

HIL PLATFORM

TARGET

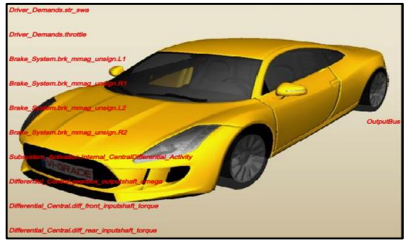
- Vehicle model (car and motorcycle) introduction within Sensify system test benches

NI PXI

VI-GRADE

VeriStand

VEHICLE MODEL



FOUNDATION
ACTUATOR
FOUNDATION
ACTUATOR
Sensify BCU
FOUNDATION
ACTUATOR
FOUNDATION
ACTUATOR

SENSIFY - REAL

- **Real time simulation platform** with external real braking system
- Sensify actuators and calipers
- Sensify **ECUs connected** with **virtual vehicle model signals**
- **Clamping forces measurement**

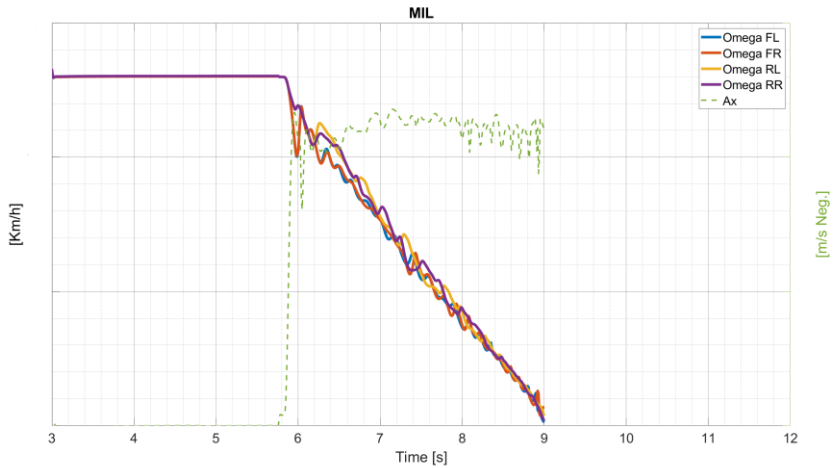
MAIN USAGE

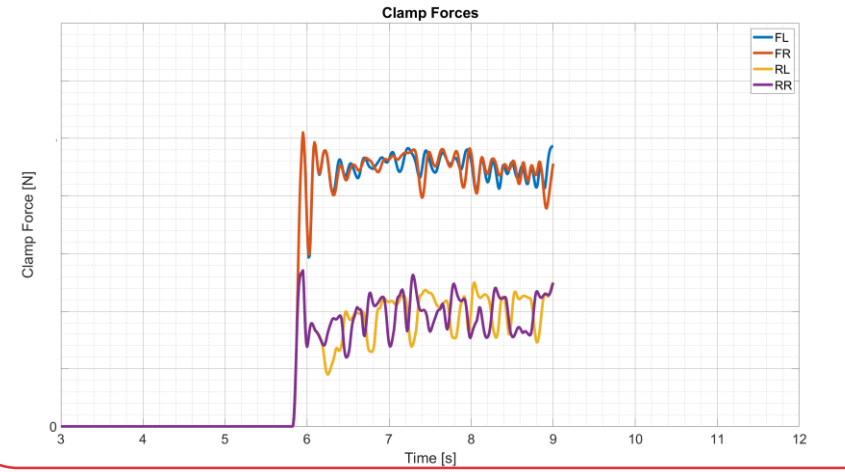
1. Sensify system **development** activities.
2. Sensify system requirements based **validation** activities.

Strictly Confidential. This presentation in its entirety is the property of Brembo and subject to copyright. It cannot be copied, edited, reproduced, or shared without prior, written permission from Brembo.

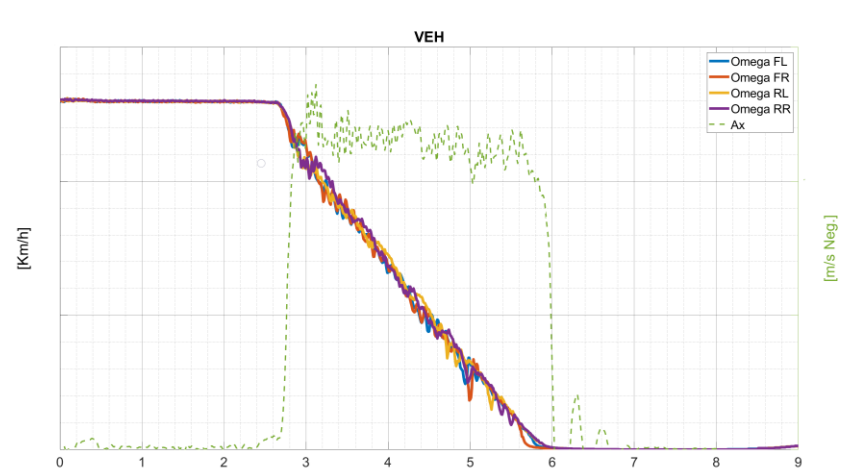
MIL USE CASE: ABS

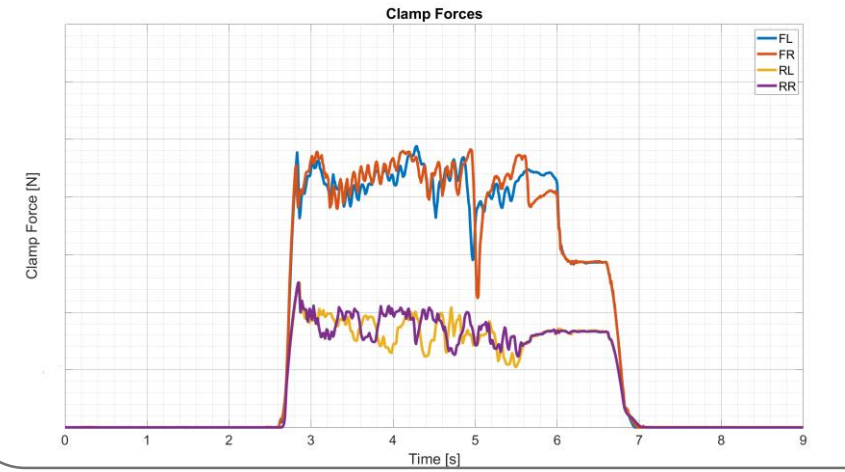
MIL





VEHICLE





- ABS calibration on high adherence flat road.
- First deceleration drop is usually deeper in simulation → introducing an advanced friction model between disc and pads to improve correlation on high transition maneuvers.
- Key role is played by the tire model.

Strictly Confidential. This presentation in its entirety is the property of Brembo and subject to copyright. It cannot be copied, edited, reproduced, or shared without prior, written permission from Brembo.

BREMBO - MICHELIN PROJECT

brembo

brembo

SENSIFY

Pioneering intelligent braking system from Brembo that optimizes the best of two worlds: **Driving pleasure and total safety.**

MICHELIN

Connected Solutions

New software solutions to monitor the **tire status** for improved **driving experience**, **safety** and **sustainability.**

Methodology

- **Integrate Michelin** algorithms and tyre ID in **Sensify** SW to enhance its calibration in all conditions.
- Massive **tyre model generation.**
- **Virtual pre calibration** on MIL.
- **Track tests for fine tuning** and validation.

Target

Combine the **two know-hows** to improve **safety** features through ABS: Sensify controls can be improved with knowledge of tire status.

Results

- Up to **4m braking distance reduction.**
- Increased braking **comfort.**

Next Steps

- Model development (aquaplaning).

Strictly Confidential. This presentation in its entirety is the property of Brembo and subject to copyright. It cannot be copied, edited, reproduced, or shared without prior, written permission from Brembo.

DIL PLATFORM

TARGET

- To **include the driving experience** within the Sensify virtual development workflow.
- To evaluate in an early stage development the **impact** of Sensify design modifications **on driver feeling**.

DRIVING SIMULATOR

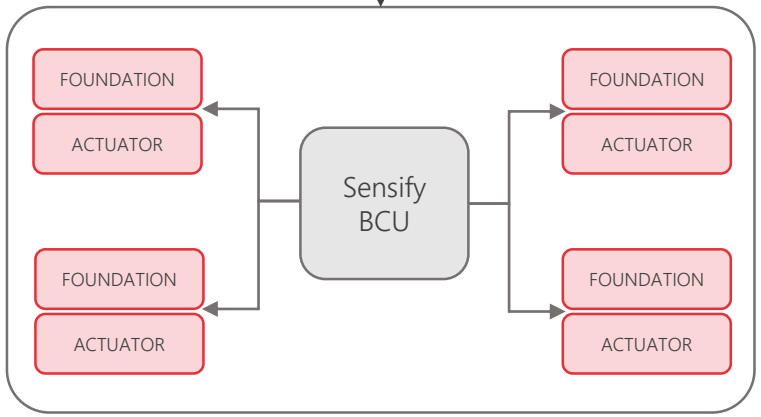
COMPACT SIMULATOR

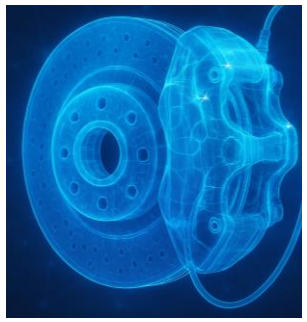
VEHICLE MODEL

MAIN USAGE

1. Vehicle estimators and control functions development.
2. Control functions pre-calibrations (ESC, monitoring).
3. Safety functions development and fault analysis.

SENSIFY - VIRTUAL





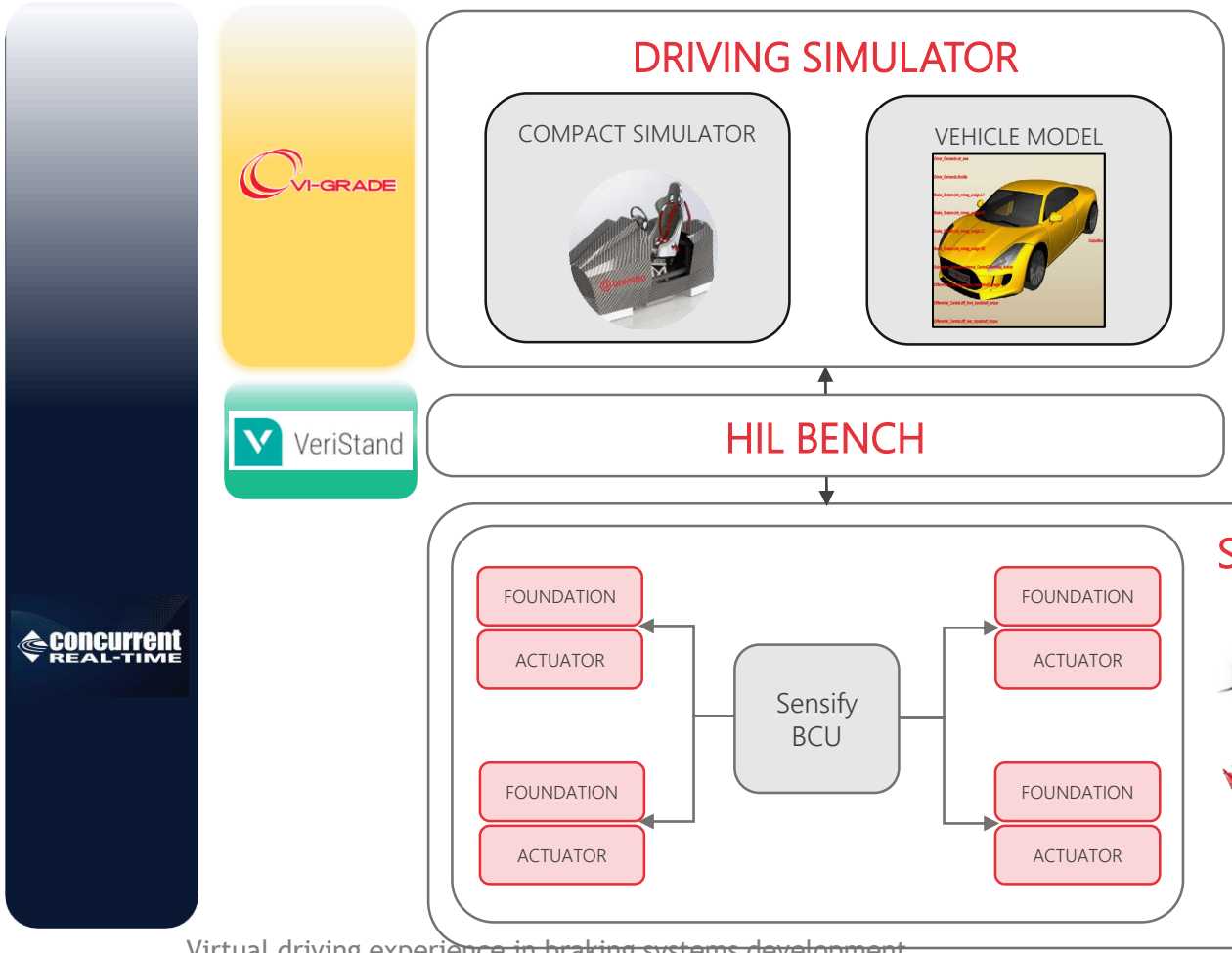
- **Actuators virtual model** from experimental characterization or from design .
- **Foundation brake** virtual model.
- **Model based** Sensify SW compiled on Concurrent.

Strictly Confidential. This presentation in its entirety is the property of Brembo and subject to copyright. It cannot be copied, edited, reproduced, or shared without prior, written permission from Brembo.

DHIL PLATFORM

TARGET

- To **include the driving experience** within the Sensify virtual development workflow.
- To evaluate in an early stage development the **impact** of Sensify design modifications **on driver feeling**.



MAIN USAGE

1. Vehicle estimators and control functions development.
2. Control functions pre-calibrations (ESC, monitoring).
3. Safety functions development and fault analysis.

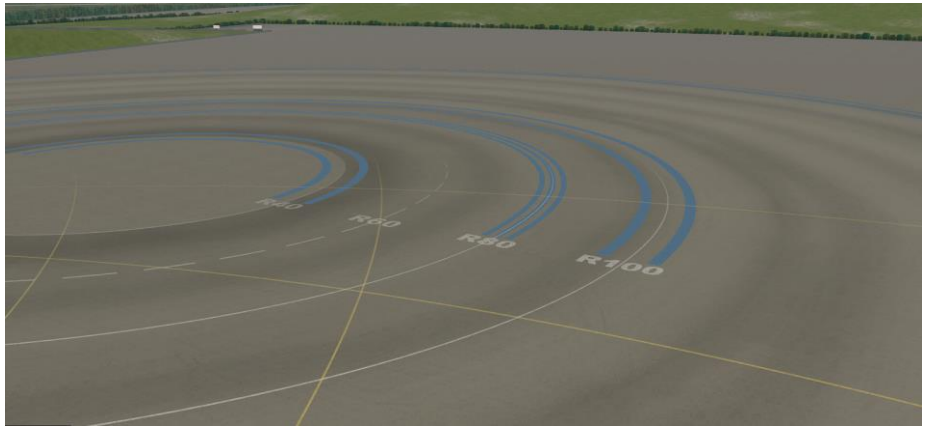
SENSIFY - REAL

- **Real time simulation platform** with external real braking system
- Sensify actuators and calipers
- Sensify **ECUs connected** with **virtual vehicle model signals**
- **Clamping forces measurement**

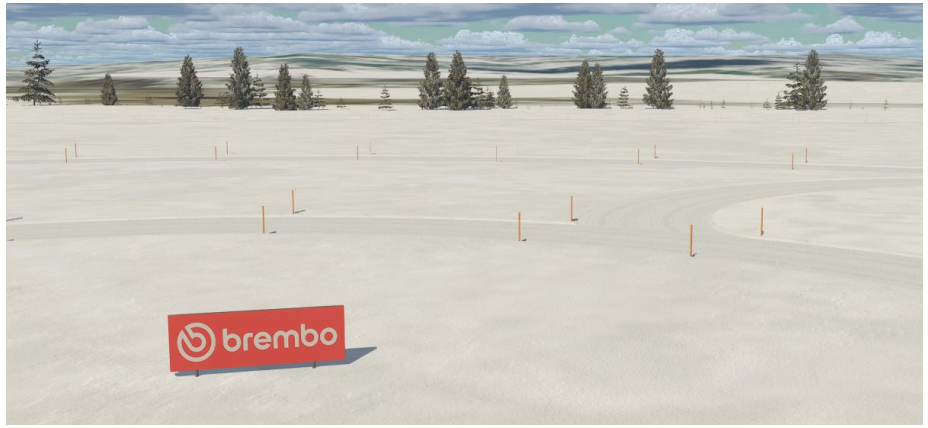
Strictly Confidential. This presentation in its entirety is the property of Brembo and subject to copyright. It cannot be copied, edited, reproduced, or shared without prior, written permission from Brembo.

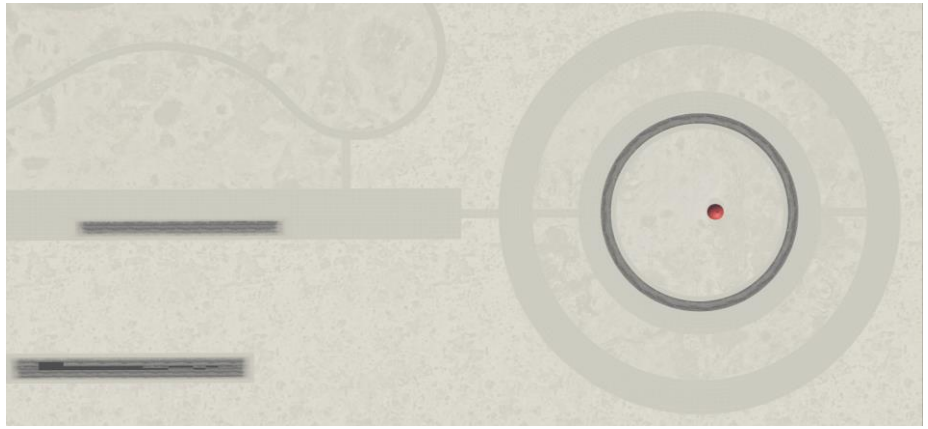
DIL/DHIL PLATFORM
PROVING GROUNDS

Brembo dynamic platform



Brembo winter scenario





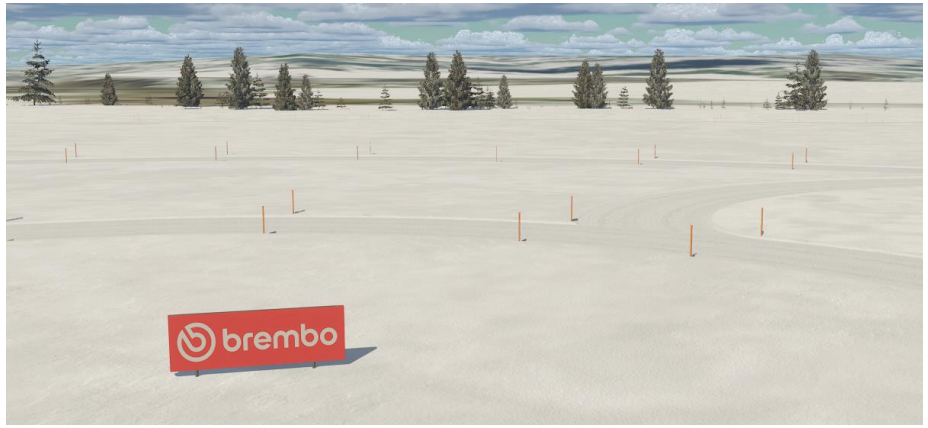
Strictly Confidential. This presentation in its entirety is the property of Brembo and subject to copyright. It cannot be copied, edited, reproduced, or shared without prior, written permission from Brembo.

DIL/DHIL PLATFORM
PROVING GROUNDS

Brembo dynamic platform

- Functional scenario aimed at testing either **specific working conditions** (slope, banking, braking lanes, adherence split and jump) and **generic handling**.
- Focus on compactness and KPI oriented.

Brembo winter scenario



- Based on a **real winter proving ground**, extended to enlarge testing capabilities.
- Focus on graphic design to enhance the **driver immersion** and realism perception.

Strictly Confidential. This presentation in its entirety is the property of Brembo and subject to copyright. It cannot be copied, edited, reproduced, or shared without prior, written permission from Brembo.

DIL/DHIL ACTIVITIES

SENSIFY DEVELOPMENT AND CALIBRATION

Standardization of driving simulator activities within product development workflow:

- New SW releases **pre-calibrations and debug** before testing on real vehicle.
- **Preliminary testing** to reduce time spent on proving ground (i.e. stability control).
- Support to **validation** through objective and subjective assessment.

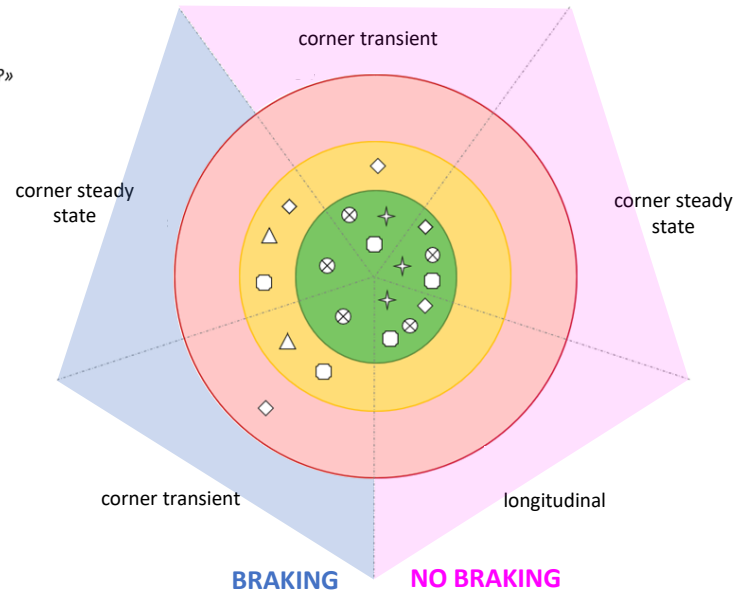
Subjective assessment

DHiL alignment with vehicle feeling (subjective assessment)

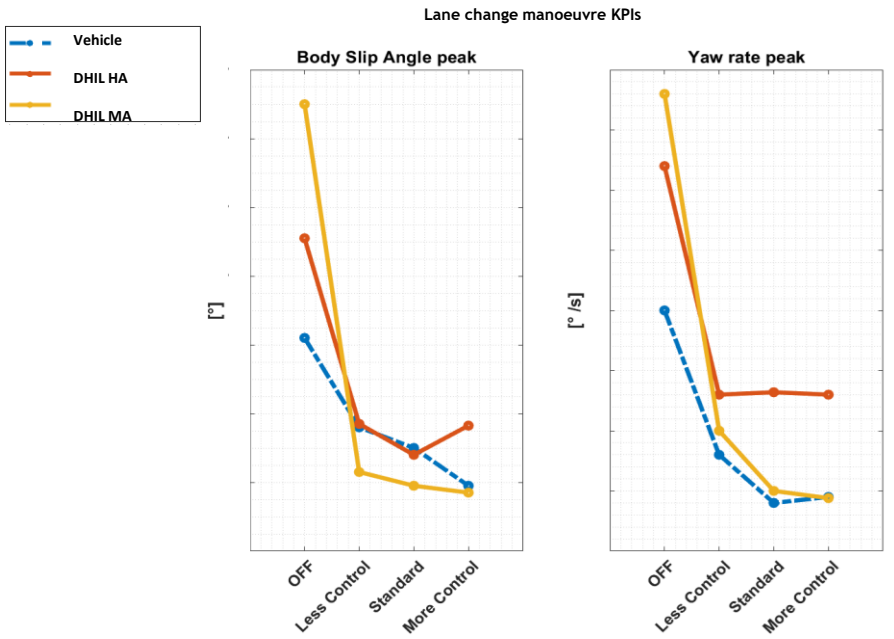
«Is the behaviour similar in both environments?»

Yes, aligned
Partially aligned
No, not Aligned

Criteria	
Stability	◇
Steerability	⊗
Brake intervention	✧
Deceleration	△
Consistency	▢



Objective assessment



Strictly Confidential. This presentation in its entirety is the property of Brembo and subject to copyright. It cannot be copied, edited, reproduced, or shared without prior, written permission from Brembo.

DIL/DHIL ACTIVITIES

VEHICLE CONTROLLABILITY - FAULT INJECTION

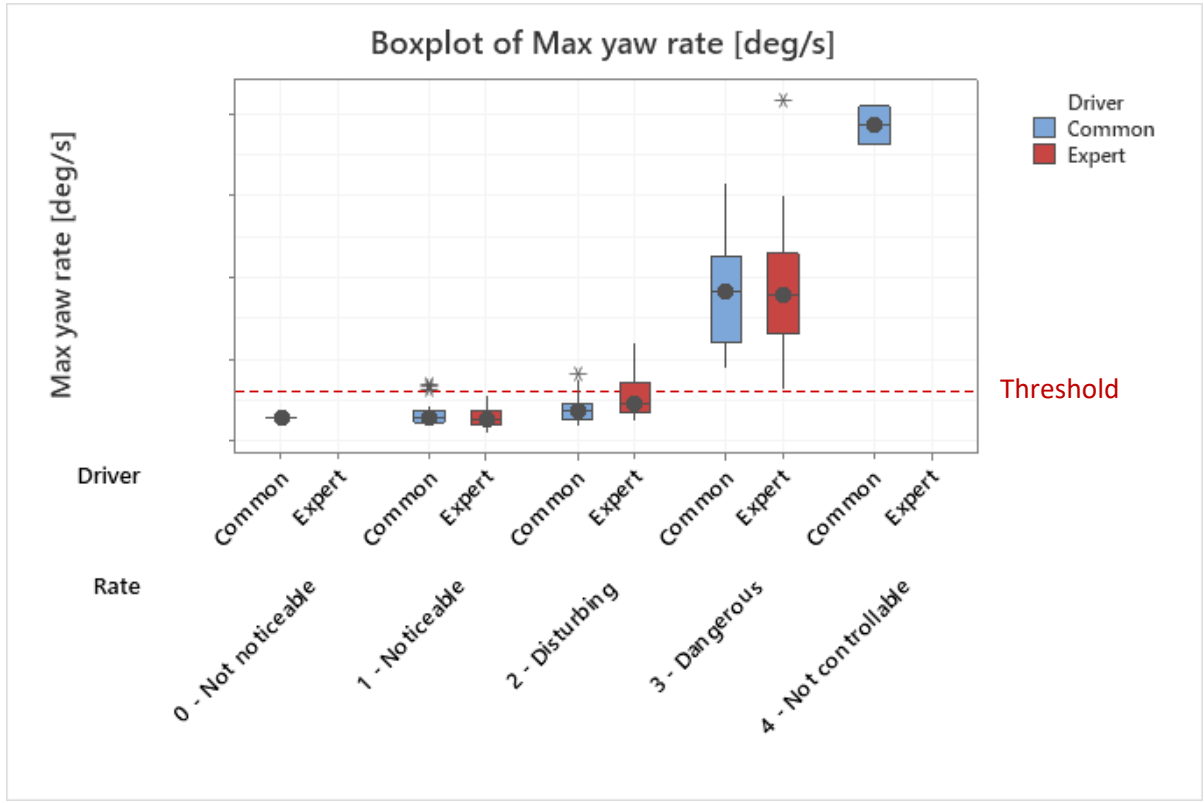
Target

- To define/validate by a **subjective evaluation** the yaw rate threshold value **between a "disturbing" and a "dangerous" vehicle response** in case of corner fault.

Not noticeable	Noticeable	Disturbing	Dangerous	Not controllable

Methodology

- **Maneuver:** straight line braking with brake fault injection.
- **Expert drivers** → extended test list:
  - Different safety goals.
  - Variable value of deceleration, injected fault amplitude, vehicle speed.
- **Common drivers** → subjective evaluation on best and worst test cases per each safety goal.



Main results

- Evaluate drivers' perception on variable fault injection amplitudes at high vehicle speed (**never done on real vehicle**).
- Collect a **statistically relevant** number of subjective evaluations in a safe and fast testing environment.

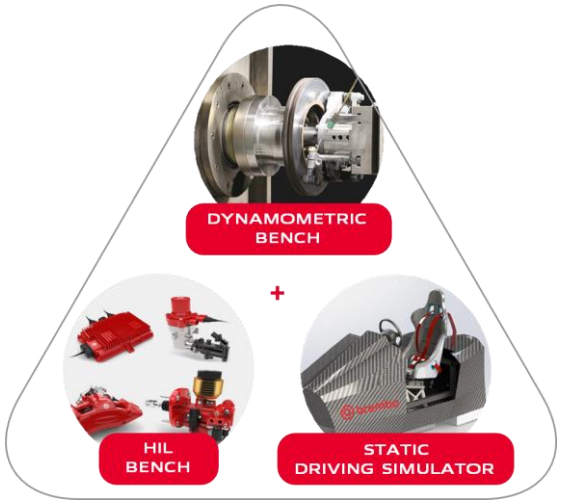
Strictly Confidential. This presentation in its entirety is the property of Brembo and subject to copyright. It cannot be copied, edited, reproduced, or shared without prior, written permission from Brembo.

CONCLUSIONS

- An overview on part of XiL environment used within product development was presented, focusing on:
  - **MIL** for early stage development, fast objective assessment and optimization.
  - **HIL** for HW/SW integration and validation.
  - **DIL/DHIL** as further step toward the whole development process, including subjective evaluation.

- **A virtual development process is nowadays mandatory** in the development of Brembo solutions. A dedicated **virtual models exchange** process with customers is needed to maximize all the benefits of the described virtual development tools.
  - Vehicle models → to evaluate and customize software solutions in early stage development or PoC evaluation.
  - Tire models → to anticipate and speed up calibration process (e.g. **Brembo/Michelin collaboration**).

- An additional **extension of the available testing environment** comprehensive of vehicle dynamics model has been internally developed, connecting the driving simulator to an HiL system test bench and a dynamometric test bench → DDYHIL environment.
- The architecture is needed to **account for the tribological variation** of the friction material within Sensify development in virtual environments.



Strictly Confidential. This presentation in its entirety is the property of Brembo and subject to copyright. It cannot be copied, edited, reproduced, or shared without prior, written permission from Brembo.

THANK YOU