An advanced physical modeling approach for brake system performance analysis

Lionel Broglia
Product Manager Fluids & Electrical solutions

Vehicle Dynamics Expo 2011
Messe Stuttgart, Germany 17-19 May 2011

Leading Partner in
Test & Mechatronic Simulation

LMS ENGINEERING INNOVATION

Presentation: Table of Content

Brake system modeling for vehicle performance evaluations

Presentation: Table of Content

Brake system modeling for vehicle performance evaluations

APG, Zhejiang Asia Pacific Mechanical & Electronic Company

- One of the major supplier of Brake Systems in China.
- This supplier is specialized in research, development & manufacturing of:
  - Brake disc/drum assemblies
  - Vacuum pump
  - Master Cylinder
  - Brake Booster
  - ABS/ASR systems.
  - ESP systems

Annual production capacity of 100K sets

Historical View

- Main customers: FAW-Volkswagen, Dongfeng-PSA, Chery, Chang’an Automotive,…

APG – R&D Program

APG, Zhejiang Asia Pacific Mechanical & Electronic Company

- The current R&D process of the company is mainly based on **intensive test campaigns**
- APG is now looking for new R&D processes relying on simulation:
  - Improve the understanding of their systems
  - Decrease the testing effort
  - Accelerate development time/reduce time to production
  - Assist the development and validation of electronic controllers such as ABS/ASR/ESP control units

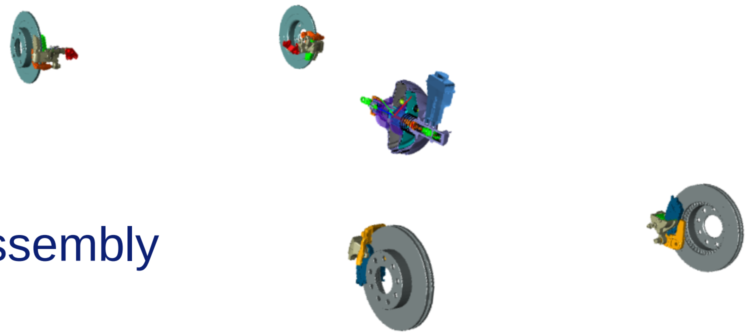
Brake system modeling for vehicle performance evaluations

Project Global Overview

MODELING PROCESS

Brake system modeling for vehicle performance evaluations

1. **Component modeling and behavior validation (one after one)**
   - Dual Brake Booster
   - Master Cylinder
   - Front floating Caliper
   - Rear floating Caliper with park brake assembly



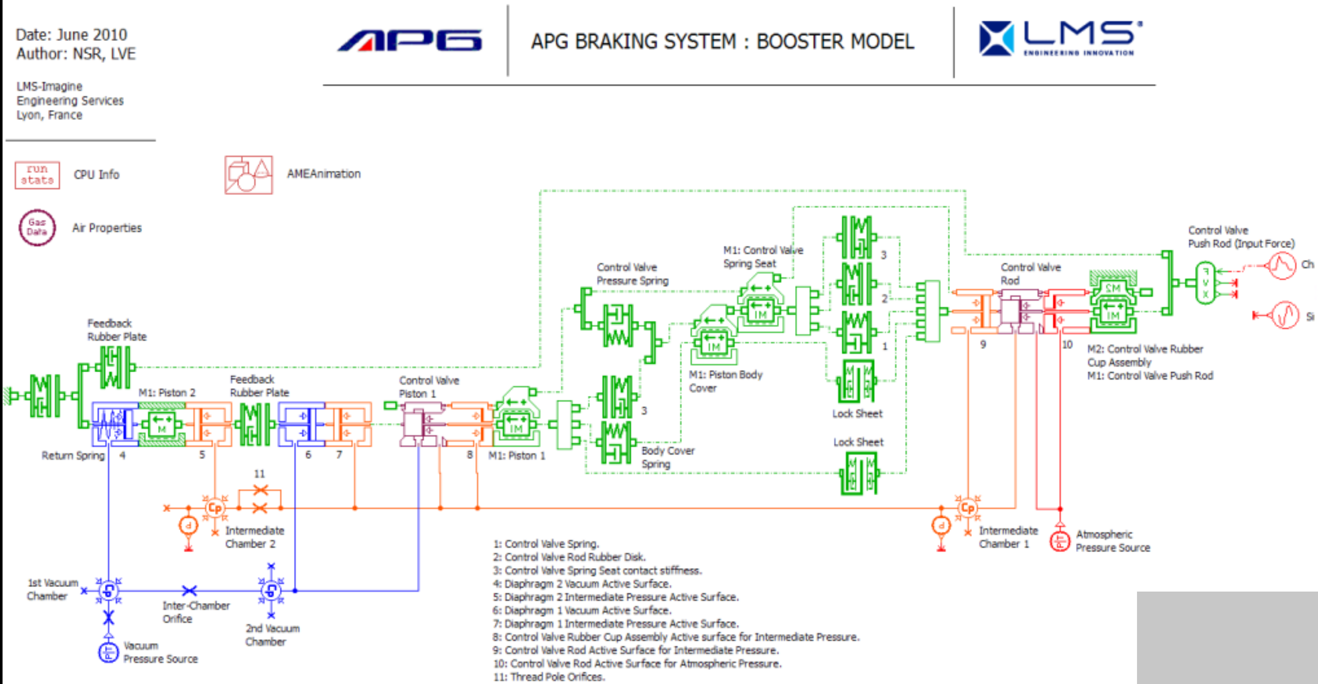
2. **Hydraulic piping & hoses:** modeling according to the frequency range of interest

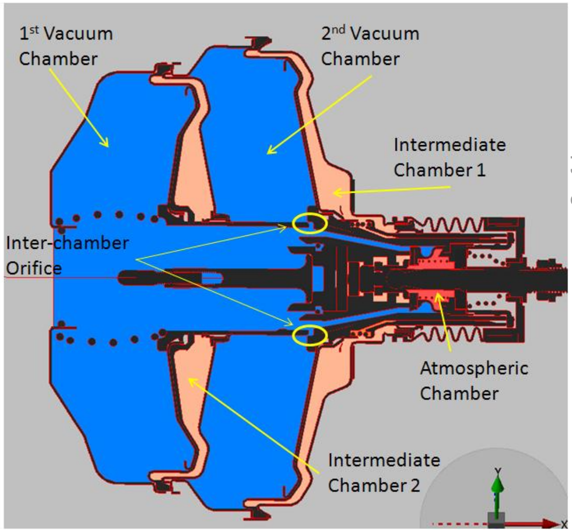
3. **Complete Brake System assembly:** parameter adaptation and validation

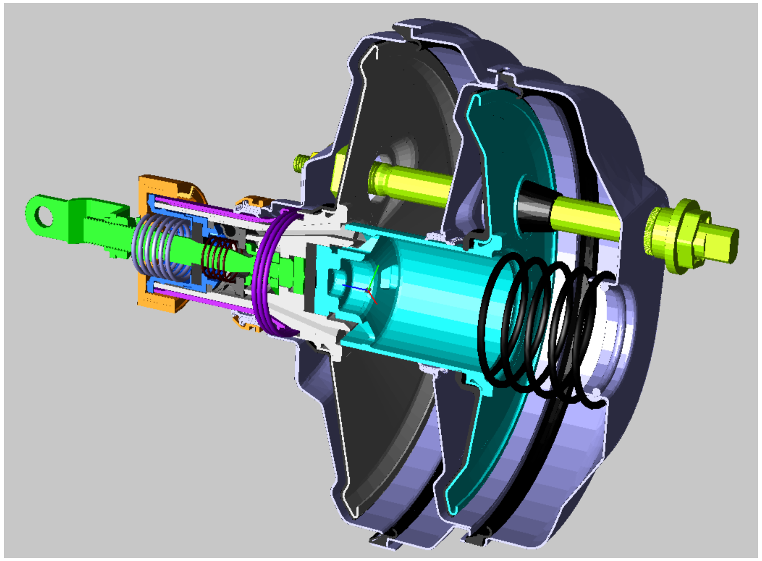
4. **Final validation of the Brake System Modeling Platform**

Component Modeling and Unitary Validations

- **Vacuum Dual Brake Booster**







✓ Functional springs & body relative endstops (Mechanical Domain).

✓ Vacuum vs. atmo. pressure: functional assistance with typical active surfaces (Pneumatic domain)

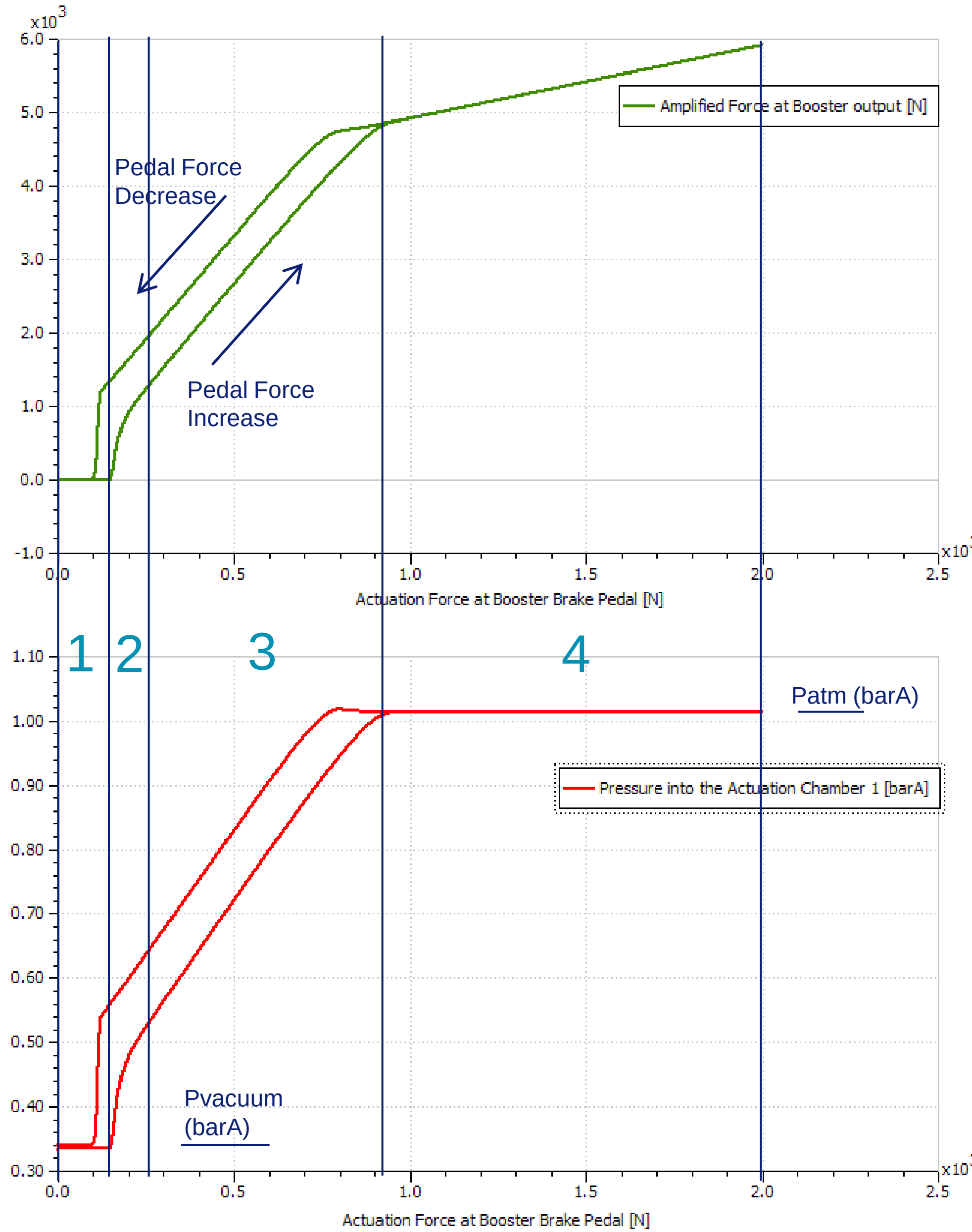
Component Unitary Validation

- **Vacuum Dual Brake Booster**

The booster behaves according to 4 main phases:

1. Spring preloads overcome
2. Closing of valves with contact flexibilities
3. Amplification due to vacuum assistance
4. Saturated assistance → ratio = input/output = 1

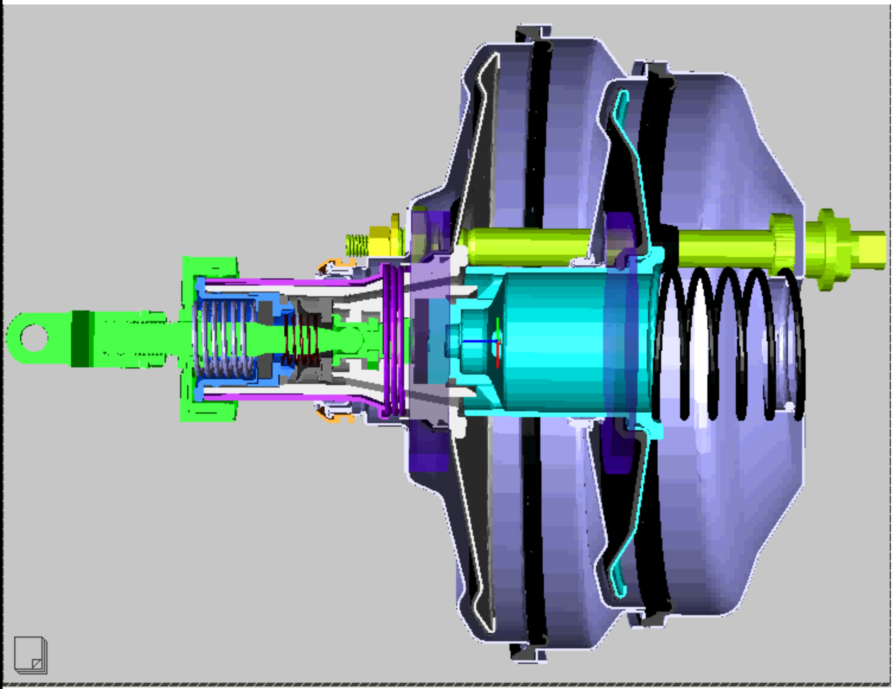
Boundaries: <u>"Quasi-Static Actuation"</u>
→ Validation of booster alone
with an Artificial Master Cylinder modeled by means of an equivalent stiffness

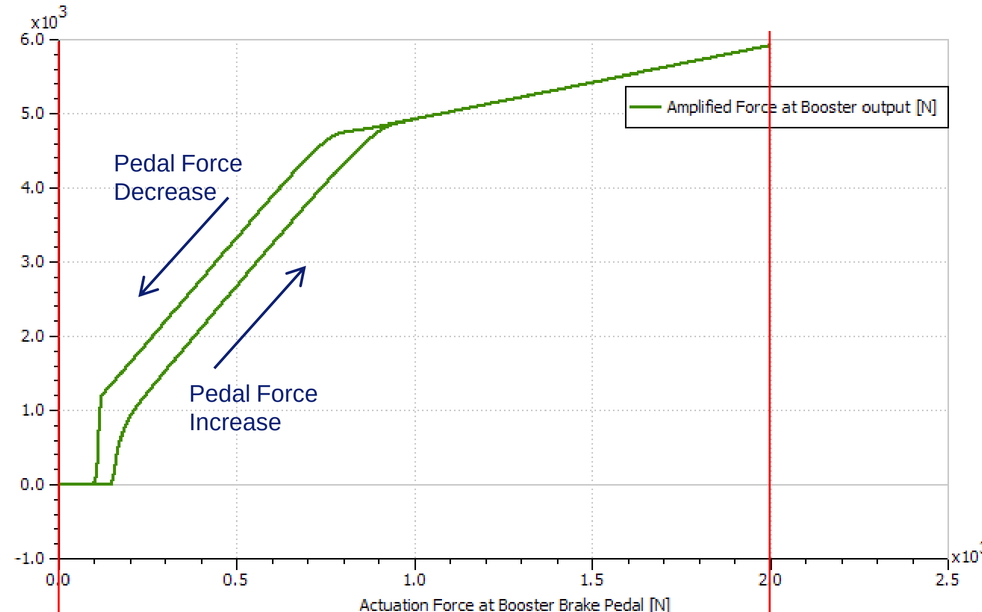


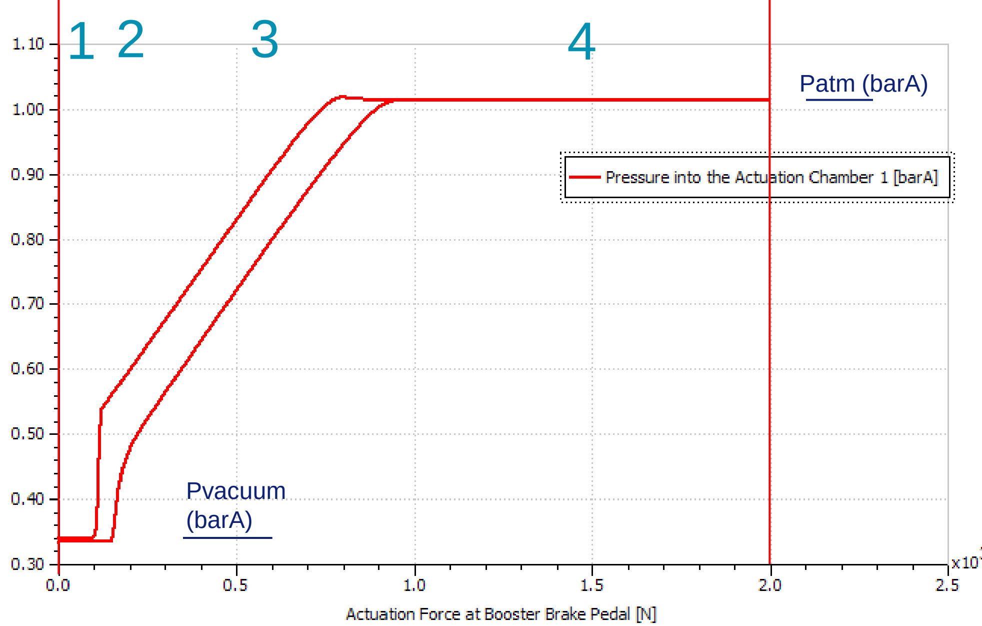
Leading Partner in
Test & Mechatronic Simulation

Component Animation

- **Vacuum Dual Brake Booster**



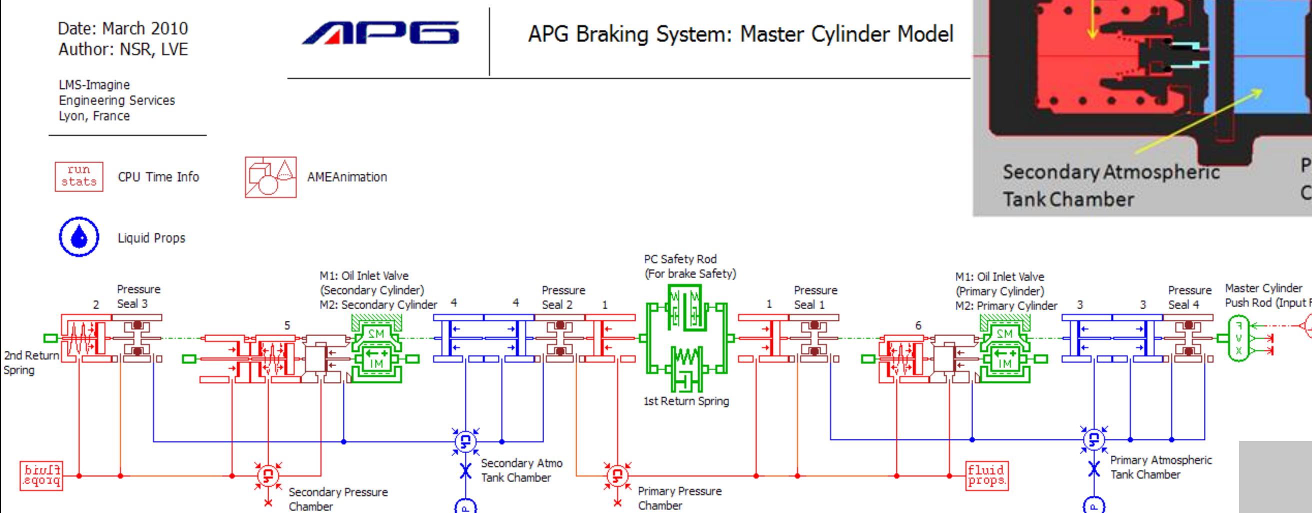


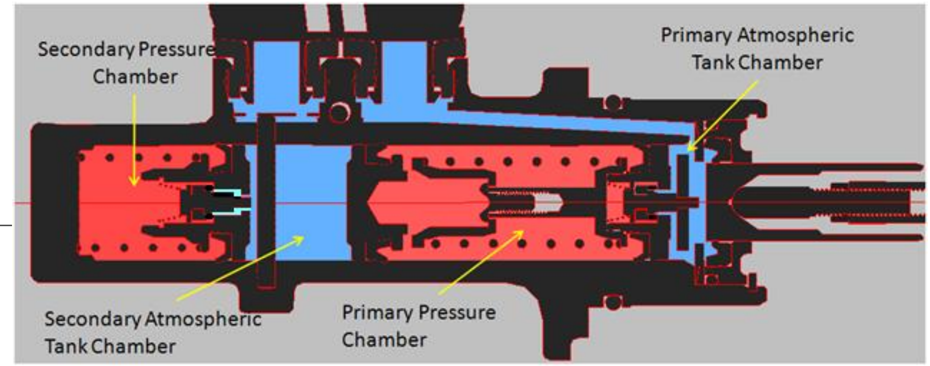


Leading Partner in
Test & Mechatronic Simulation

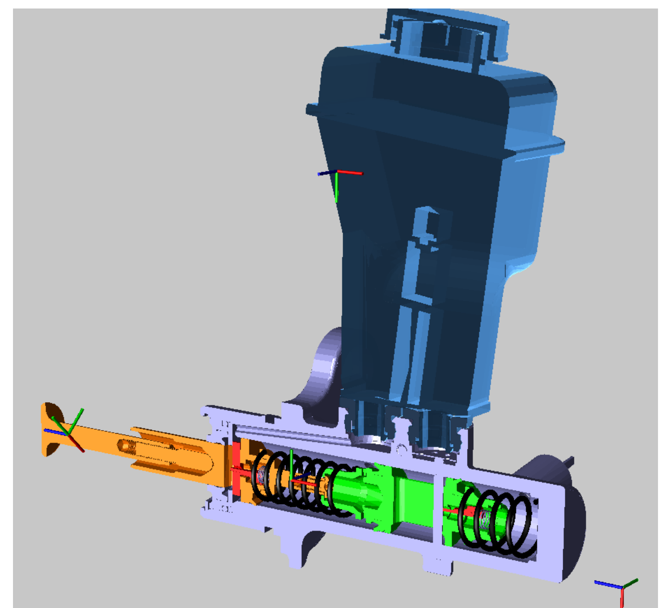
Component Modeling and Unitary Validations

Master-Cylinder





✓ Functional springs & body relative endstops (Mechanical domain).
✓ Brake vs. atmo. pressure: functional primary & secondary chambers with typical active surfaces (Hydraulic domain)

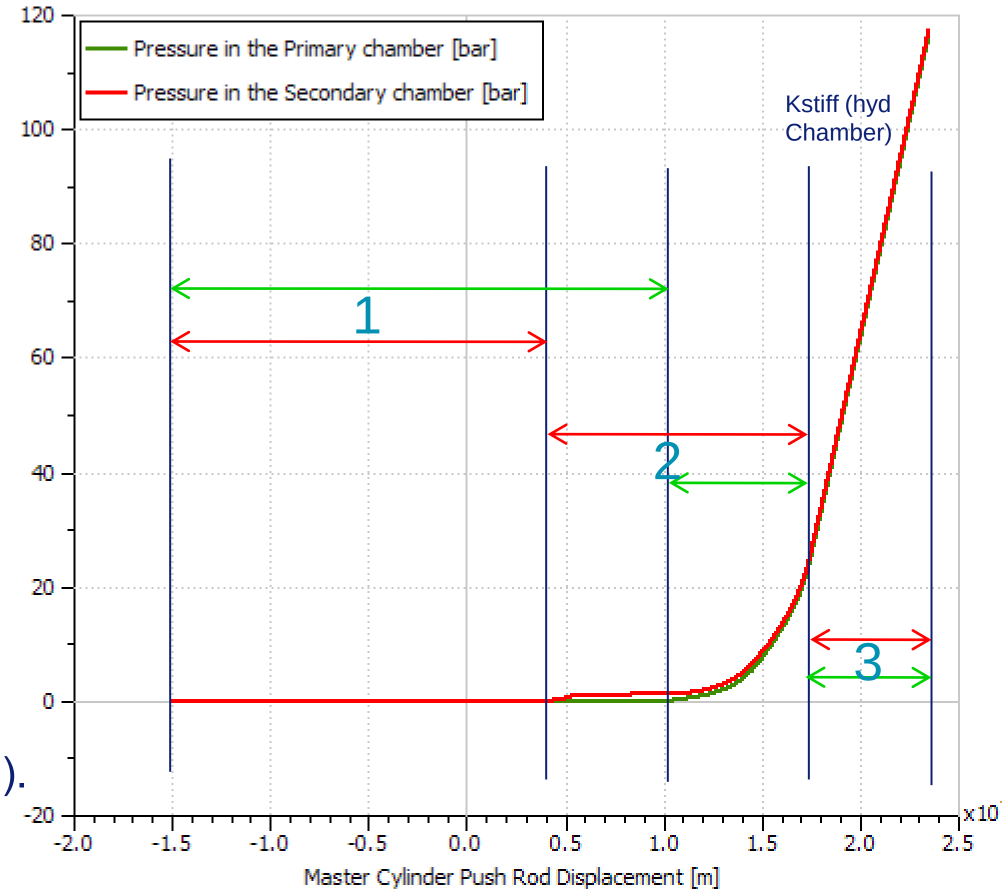


Component Modeling and Unitary Validations

- **Master-Cylinder**

The Master-Cyl. behaves according to 4 main phases:

1. Dead stroke (Valves are opened).
2. → Closing of 2nd and 1st valve with contact flexibilities.
   → Fluid compression and air gas content dissolution (quadratic shape).
3. Pressure rise up according to hydraulic closed volume and spring loads (linear behavior "Kstiff").

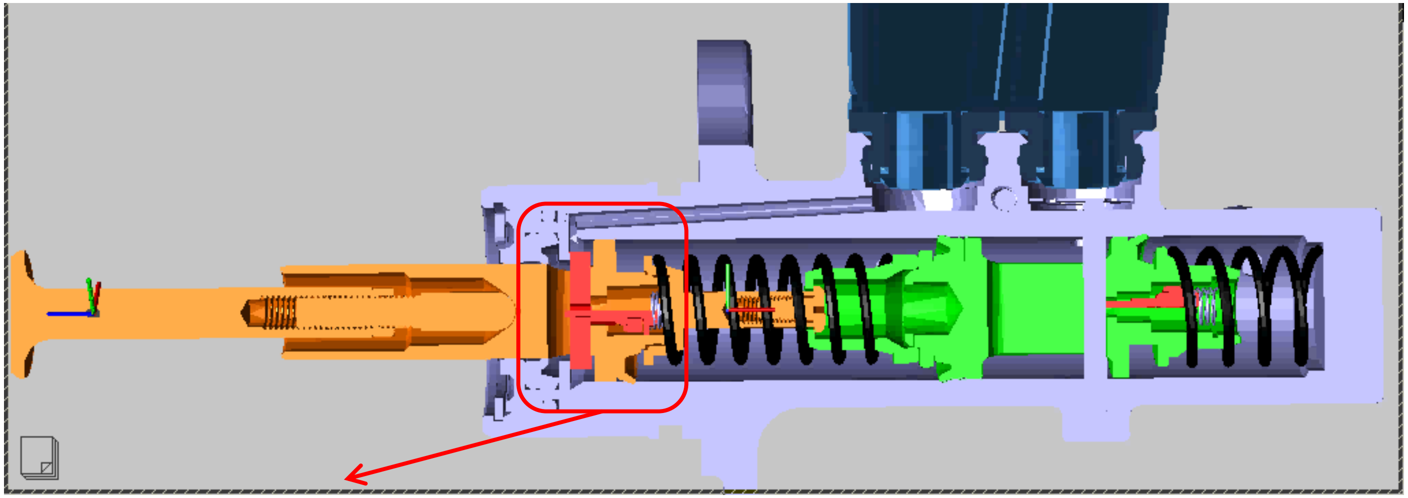


Boundaries: <u>"Quasi-Static Actuation"</u>

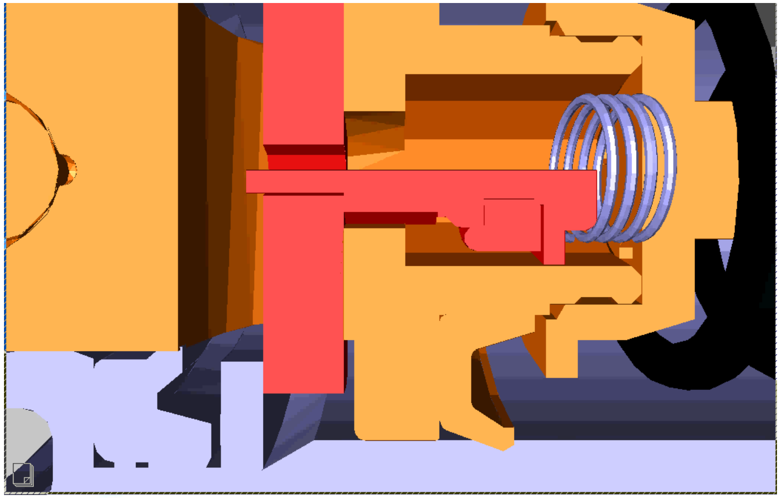
→ 1st and 2nd Hydraulic chambers outlets in closed condition

Component Animation

- **Master-Cylinder: → Behaviors of 1st Valve (Primary Chamber) and 2nd Valve (Secondary Chamber)**

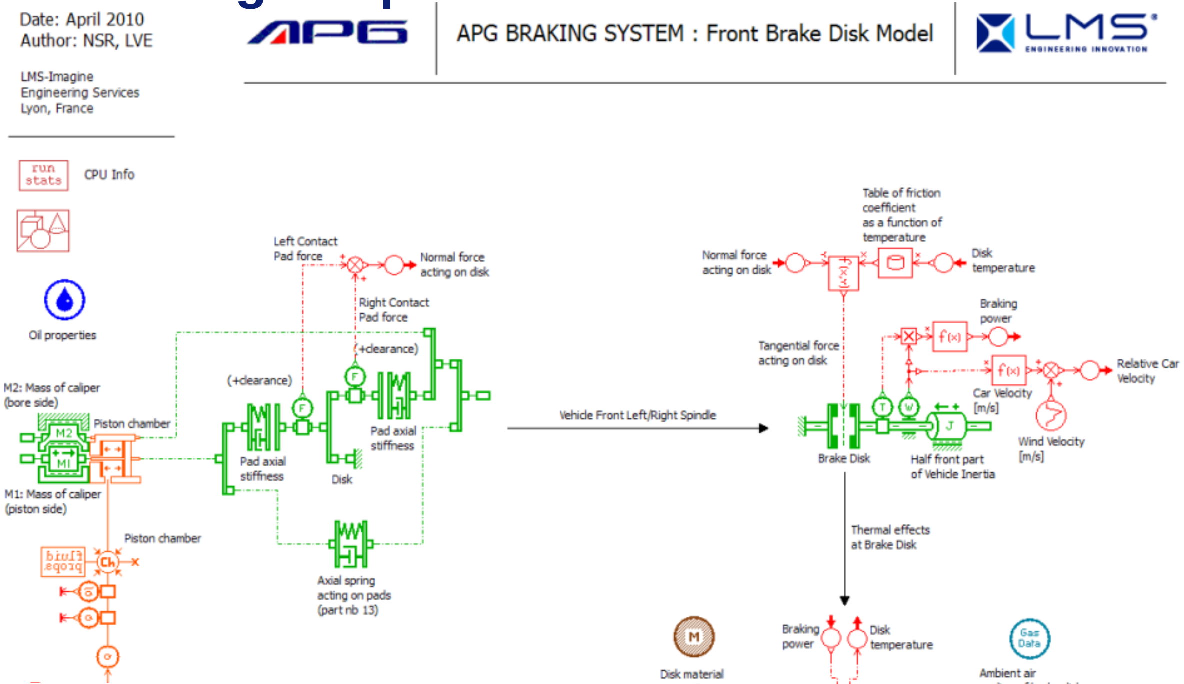


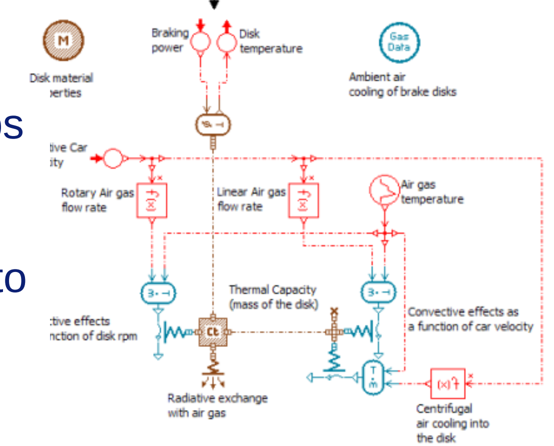
Primary Chamber Valve

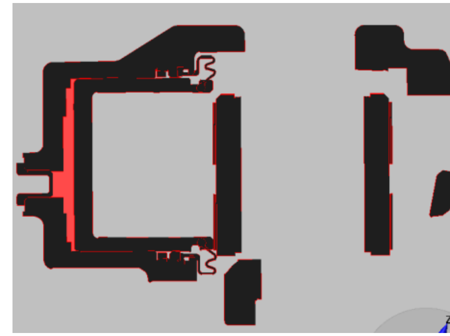


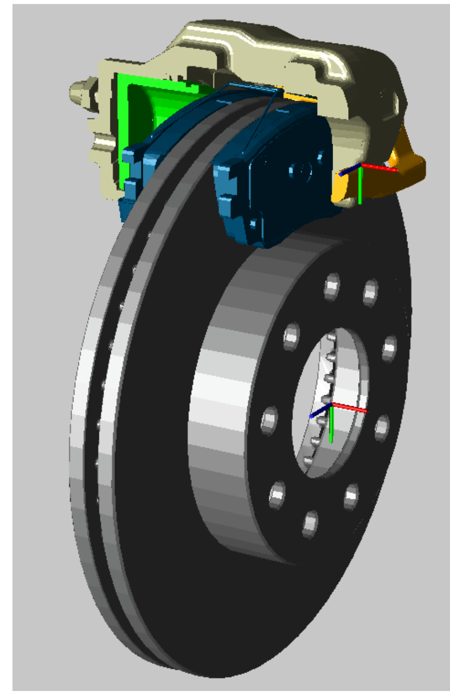
Component Modeling and Unitary Validations

- **Front Floating Caliper**





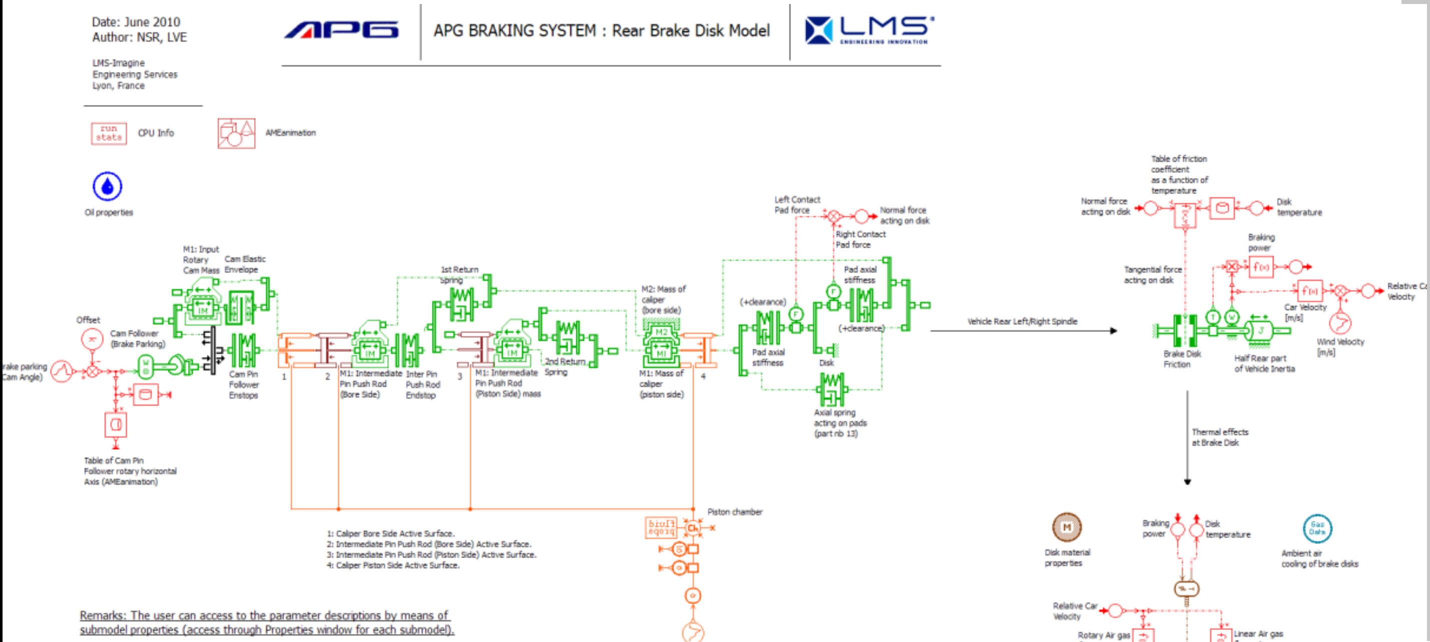


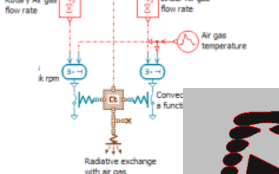


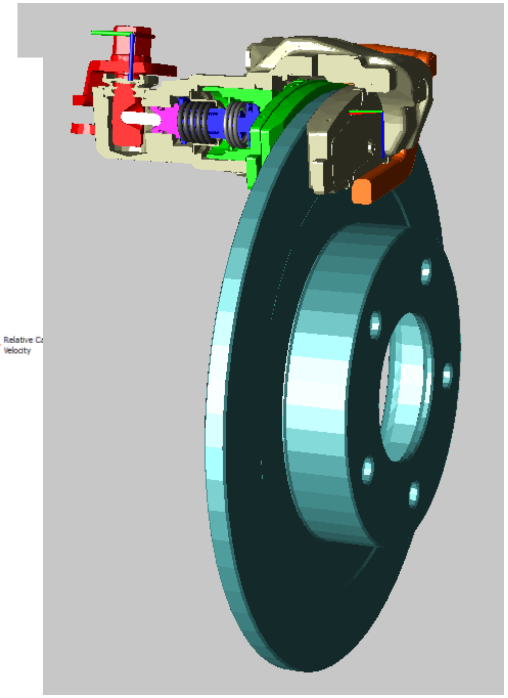
✓ Functional springs & body relative endstops
✓ Hydraulic pressure: functional front caliper chamber with typical active surfaces
✓Cooling of the brake disc: 1D compromise to identify the brake temperature and then the friction coefficient

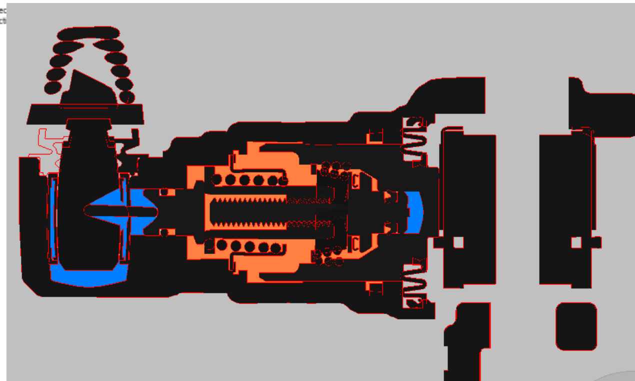
Component Modeling and Unitary Validations

Rear Floating Caliper with park brake system









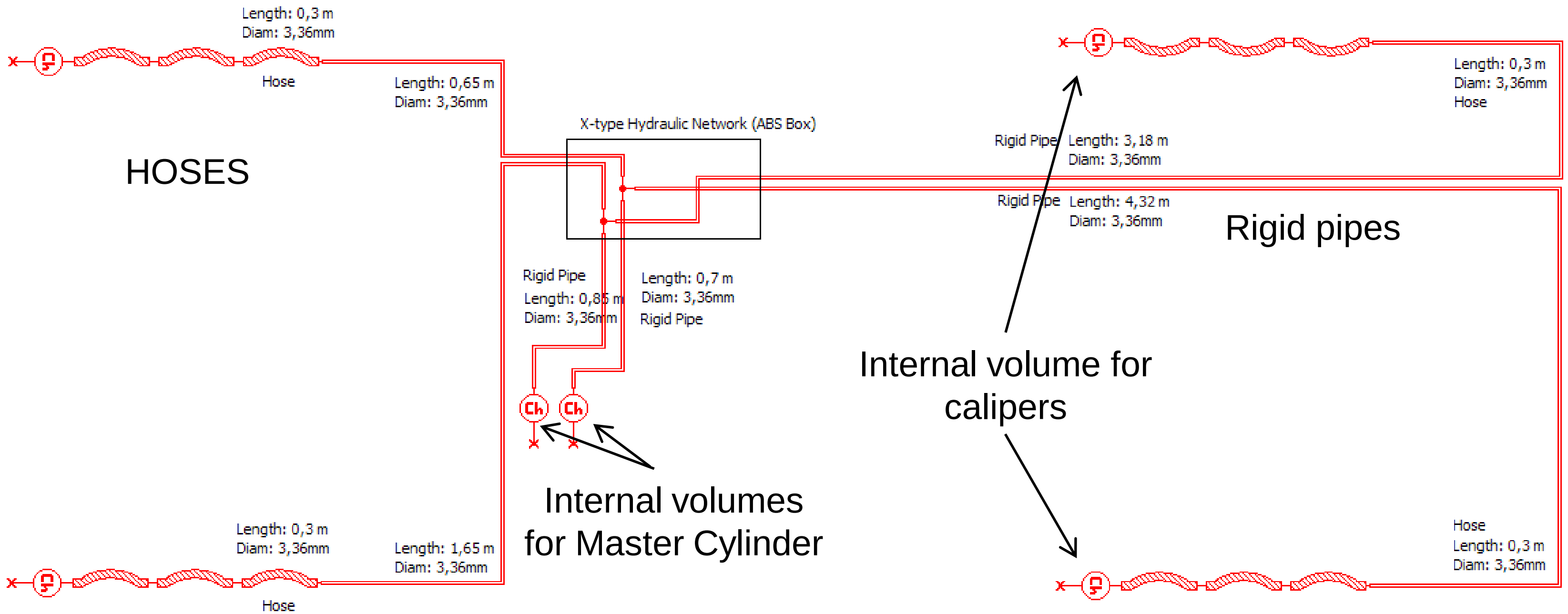
✓ Spring & body relative endstops, Cam Follower for the park brake system

✓ Hydraulic pressure: functional rear caliper chamber with typical active surfaces

✓ Cooling of the brake disc: 1D compromise to identify the brake temperature and then the friction coefficient

Hydraulic Piping Modeling

- **Identification of the targeted frequency range for the braking application:**
  - Our model does not include ABS/ESP system which can imply fast dynamics. Hence, no need to go above the maximum excitation frequency that the driver can generate at the brake pedal.
  - In agreement with APG engineers, we assumed that the driver is able to apply at the brake pedal up to 3 Hz excitation.
  - <u>Then, the frequency range of interest was 0-3 Hz for the brake model.</u>

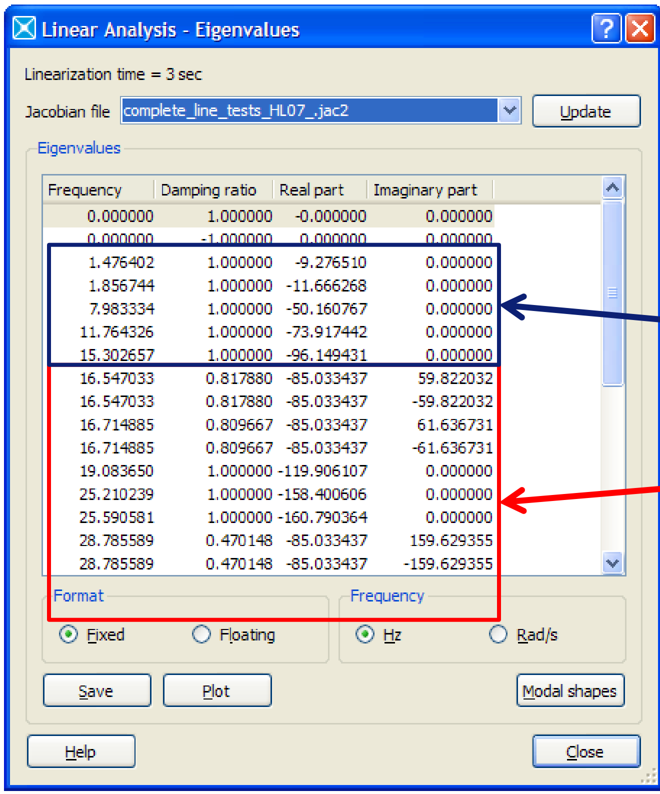


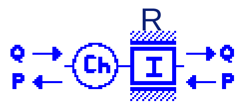
Leading Partner in Test & Mechatronic Simulation

LMS ENGINEERING INNOVATION

Hydraulic Piping Modeling

- Methodology for selection of the appropriate lines & hoses:
  - ✓ Eigenvalues of the Hydraulic Network with HL07 (pipes, IR-C) and HH04R (hoses, same level C-IR):





Time Constant: 1st order lag due to RC elements

piping modes: <u>from 16 Hz up to 160 Hz</u>

<u>Conclusions:</u>

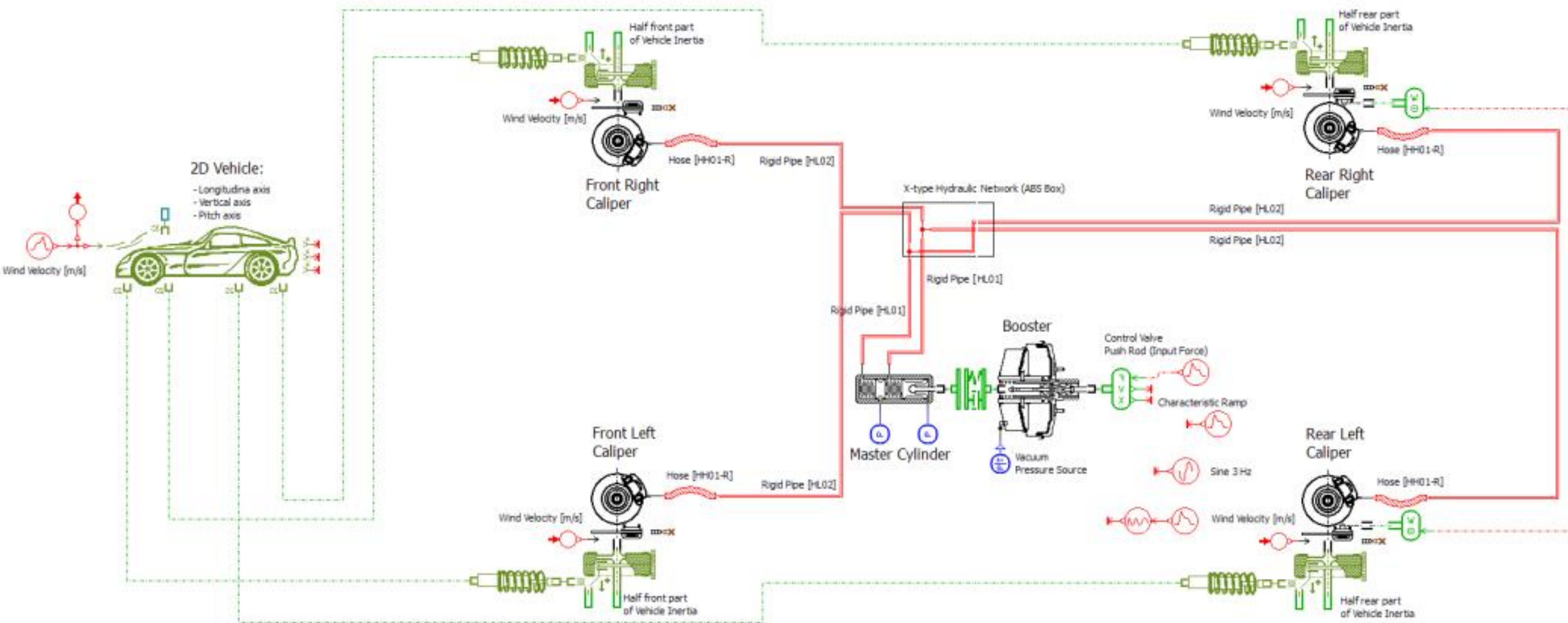
the line & hose natural frequencies begin at 16 Hz. The frequency range of interest for our model is below this frequency (3 Hz).

We can decrease the modeling complexity and remove the line modes being not excited. HL07 and HH04R are replaced with HL01 lines (RC elements)

Brake Systems integration with the Hydraulic Network

- **Integration of the sub-systems:**

The complete model is composed of a 2D Vehicle model (3 DOF: longitudinal axis, vertical axis, pitch axis) as a 1st approximation (no cornering, no ABS/ASR/ESP analysis).



Presentation: Table of Content

Brake system modeling for vehicle performance evaluations

Brake Pedal Feel

- **Booster and Master Cylinder Assembly + Calipers and Hydraulic Hoses & Pipings**

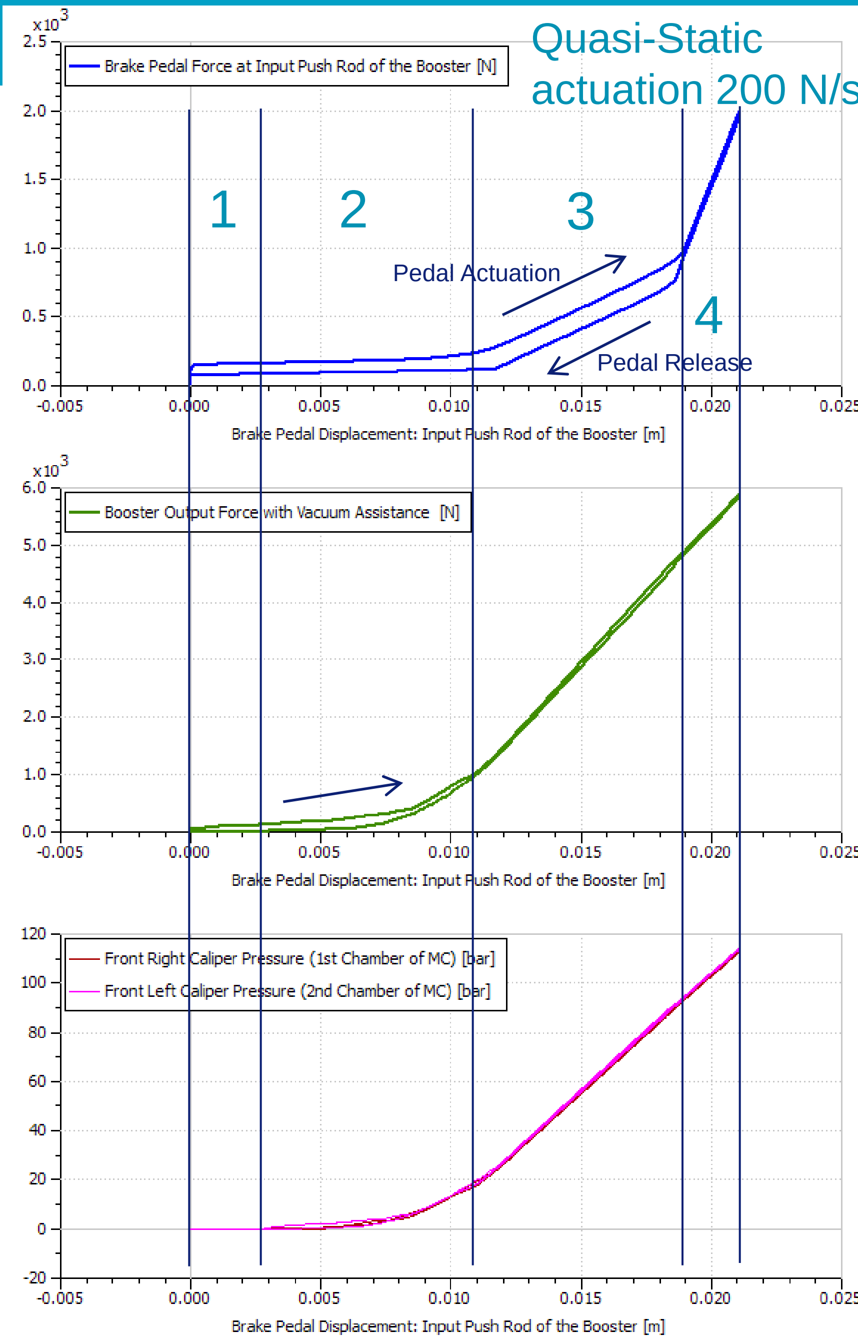
The Driver Brake Pedal Feel is mainly conditioned by the here below aspects:

1. Pedal Dead Stroke (non reaction travel)
→ Due to clearances before closing of Valves in the Master Cylinder.

2. Pedal Pumping Stroke (low reaction travel)
→ Air gas content dissolution contained into the brake and valve contacts deflection in the booster.

3. Pedal Assisted Stroke (max reaction travel)
→ The Booster Vacuum Assistance is acting on the pedal amplifying the brake torque (caliper pressure)

4. Pedal Hard Stroke (regular reaction travel)
→ Saturated assistance in the booster



Brake Pedal Feel

- **Sensitivity of the Brake Pedal Feel as a function of Actuation Velocity**

Batch Run Boundaries, Pedal Actuation:

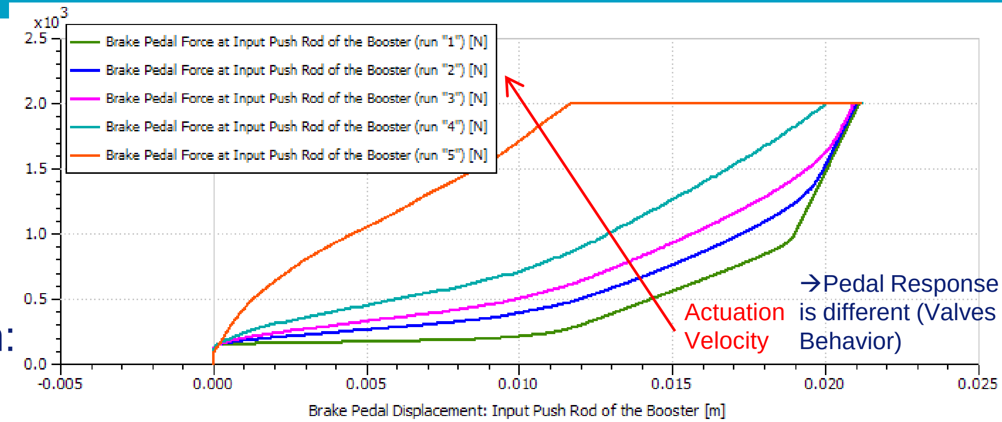
→ **Run 1: 22,2 N/s** (Quasi-Static Actuation: 2000 N in 90 sec).

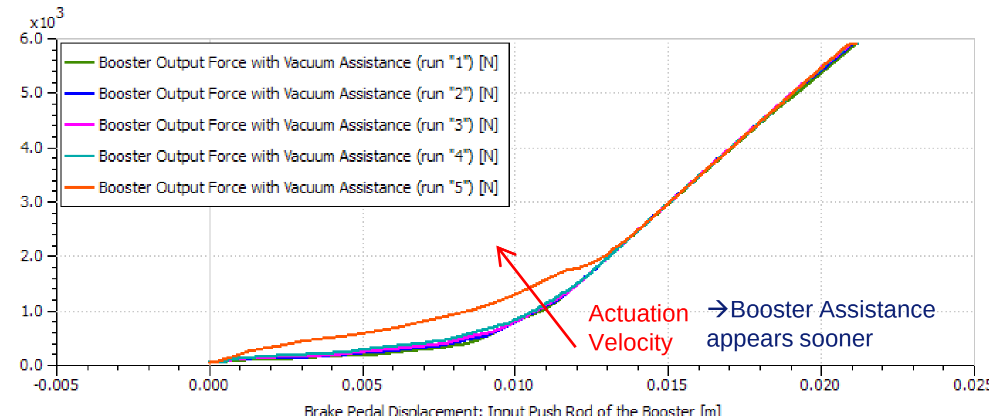
→ **Run 2: 200 N/s** (Long brake Actuation: 2000 N in 10 sec).

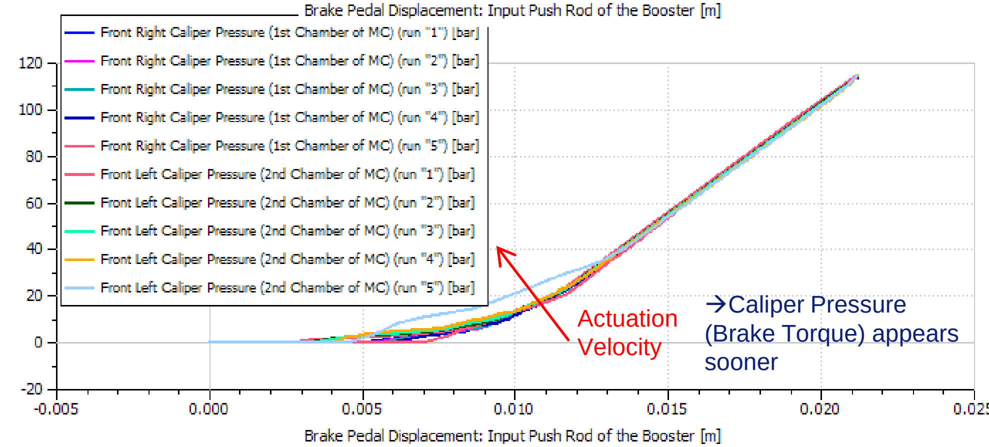
→ **Run 3: 400 N/s** (Medium brake Actuation: 2000 N in 5 sec).

→ **Run 4: 1000 N/s** (Short and Strong Brake Actuation: 2000 N in 2 sec).

→ **Run 5: 10000 N/s** (Emergency Brake Actuation: 2000 N in 0,2 sec).







Brake Distance

- **Sensitivity of the Brake distance as a function of Brake Disk Temperature**

Disk Temperatures:

→ **Run 1:** **Front** Disks **20°C**, **Rear** Disks **20°C**.

→ **Run 2:** **Front** Disks **50°C**, **Rear** Disks **30°C**.

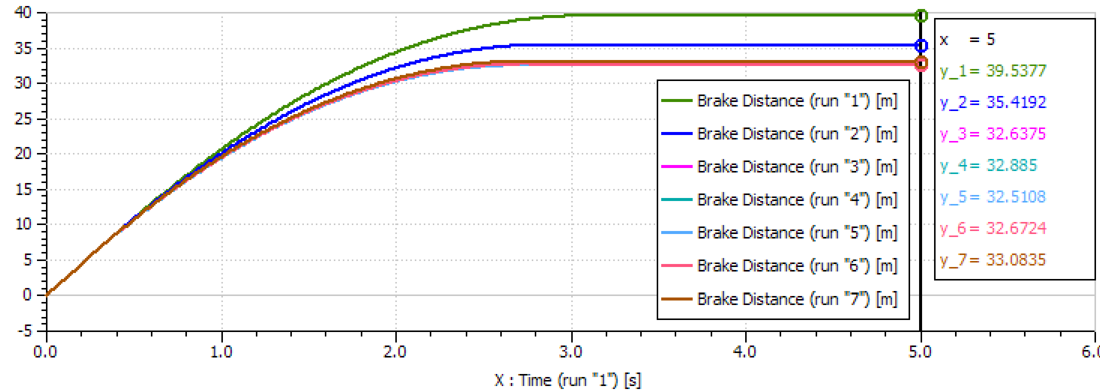
→ **Run 3:** **Front** Disks **80°C**, **Rear** Disks **60°C**.

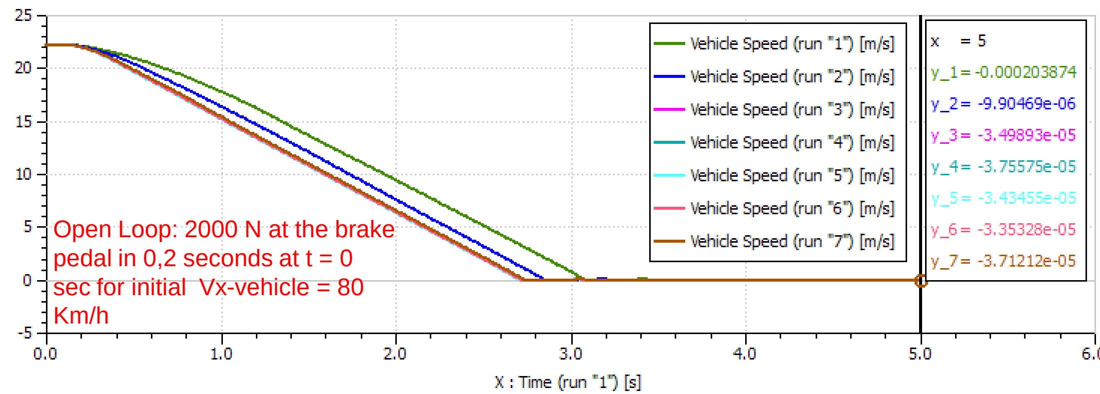
→ **Run 4:** **Front** Disks **110°C**, **Rear** Disks **80°C**.

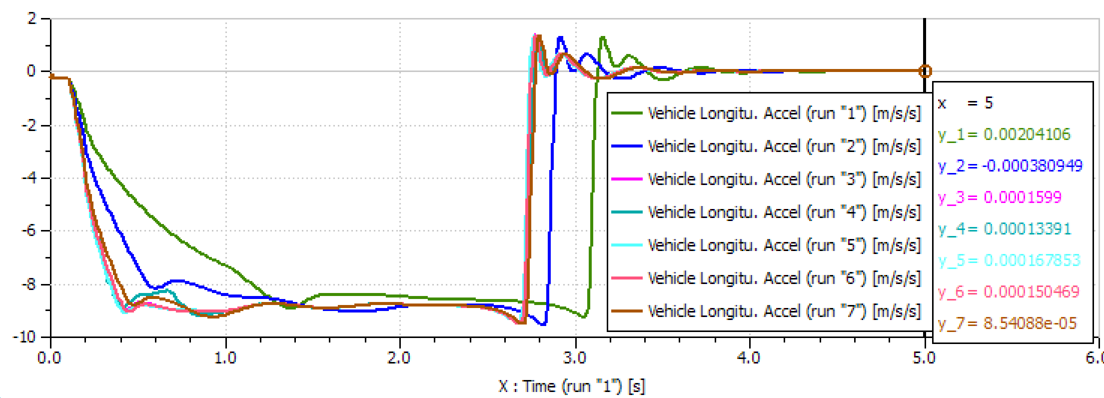
→ **Run 5:** **Front** Disks **140°C**, **Rear** Disks **110°C**.

→ **Run 6:** **Front** Disks **200°C**, **Rear** Disks **170°C**.

→ **Run 7:** **Front** Disks **300°C**, **Rear** Disks **270°C**.







Presentation: Table of Content

Brake system modeling for vehicle performance evaluations

Brake Distance with System Failures

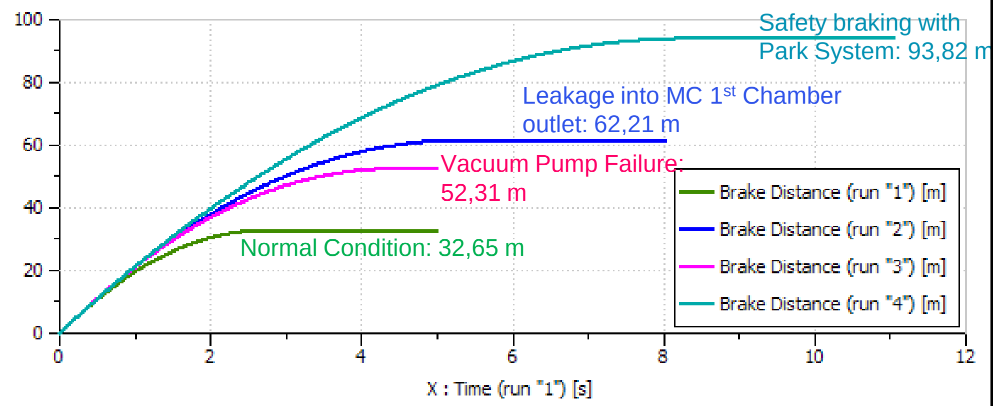
- **What's happened in case of any sub-system failure ?**

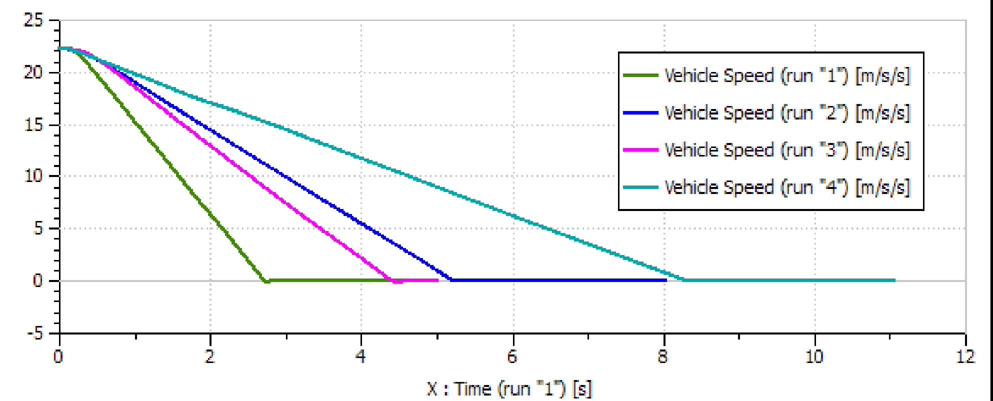
Simulated Failure Conditions:

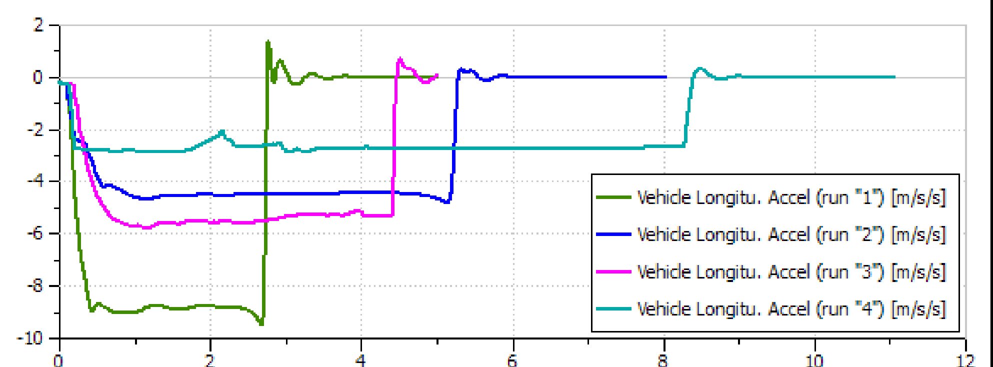
→ **Run 1: Normal Conditions.**
→ **Run 2: Brake Fluid Leakage at outlet of MC 1st Chamber.**
→ **Run 3: Failure of Vacuum Assistance.**
→ **Run 4: Braking by means of Parking System** (Leakage at outlets of 1st and 2nd Chamber of Master Cylinder).

Boundaries: Open Loop (in terms of Lslip)

✓ 2000 N at the Brake Pedal in 0,2 second wit initial vehicle Speed of 80 Km/h.
✓ Front Disk Temperatures: 80 °C.
✓ Rear Disk Temperatures: 60 °C.



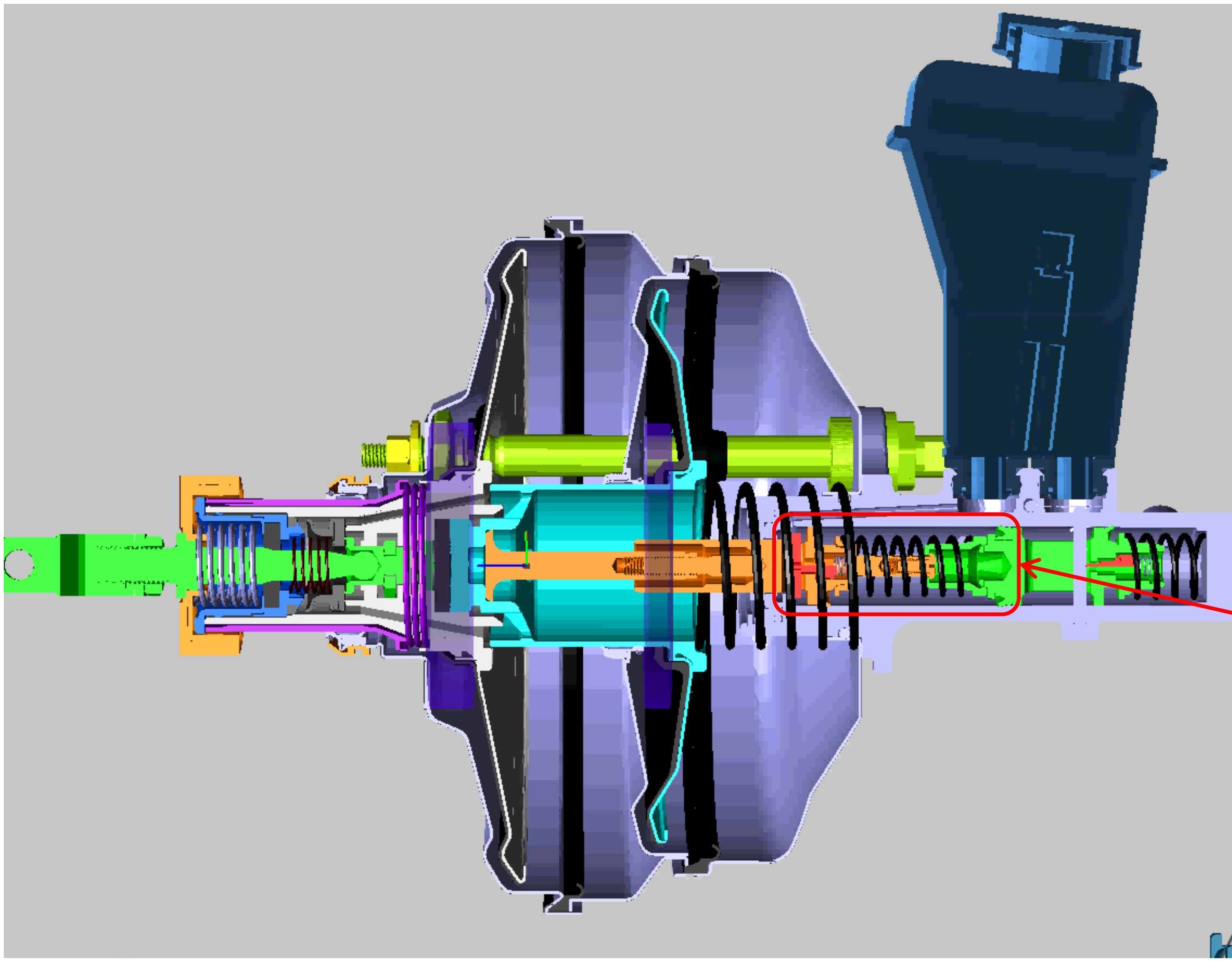




Brake Distance with System Failures

- **What's happened in case of any Sub-system failure ? AMEanimation View**

Simulated Failure Conditions: → **Run 2: Brake Fluid Leakage at outlet of MC 1st Chamber.**



1st Chamber of Master Cylinder:

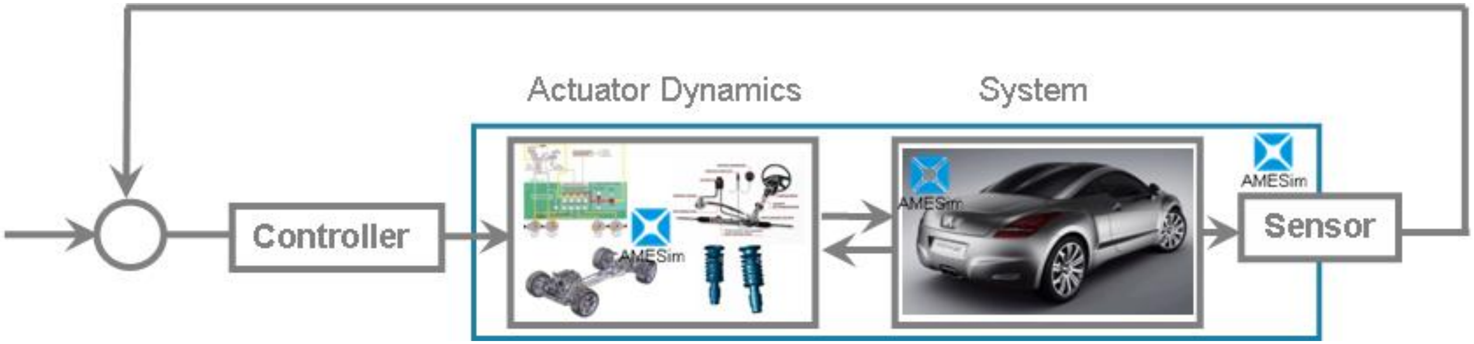
→ Leakage of Brake Fluid at piping outlet

Presentation: Table of Content

Brake system modeling for vehicle performance evaluations

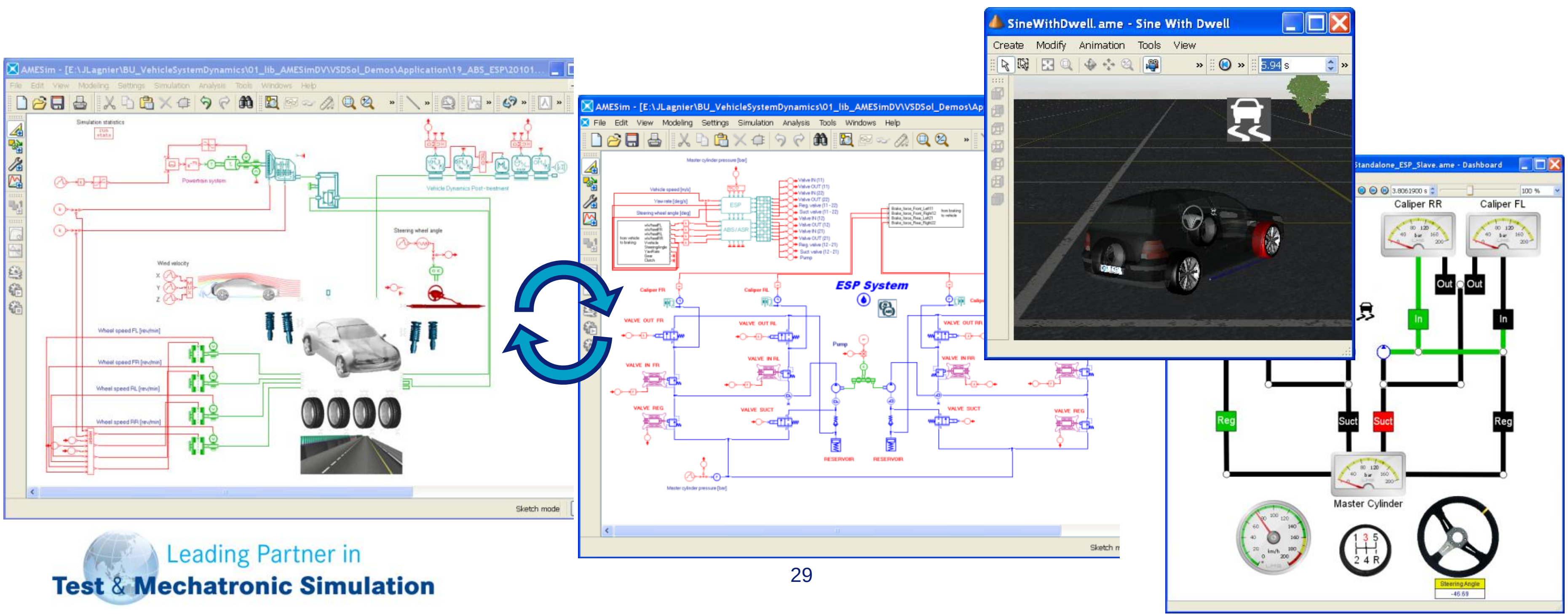
Conclusions & Synthesis

- **AMESim Added Values**:
  - The model combines Mechanical + Hydraulic + Pneumatic + Thermal phenomena libraries in a single platform.
  - Scalability in the modeling assumptions.
  - The AMEAnimation feature allows animating the CAD of the components in order to get a bit more insights into the booster, master cylinder and caliper behaviors.
  - Even if the system does not include any “active” component, the solution is open to include an hydraulic block from an ABS/ESP and an interface to the control law.

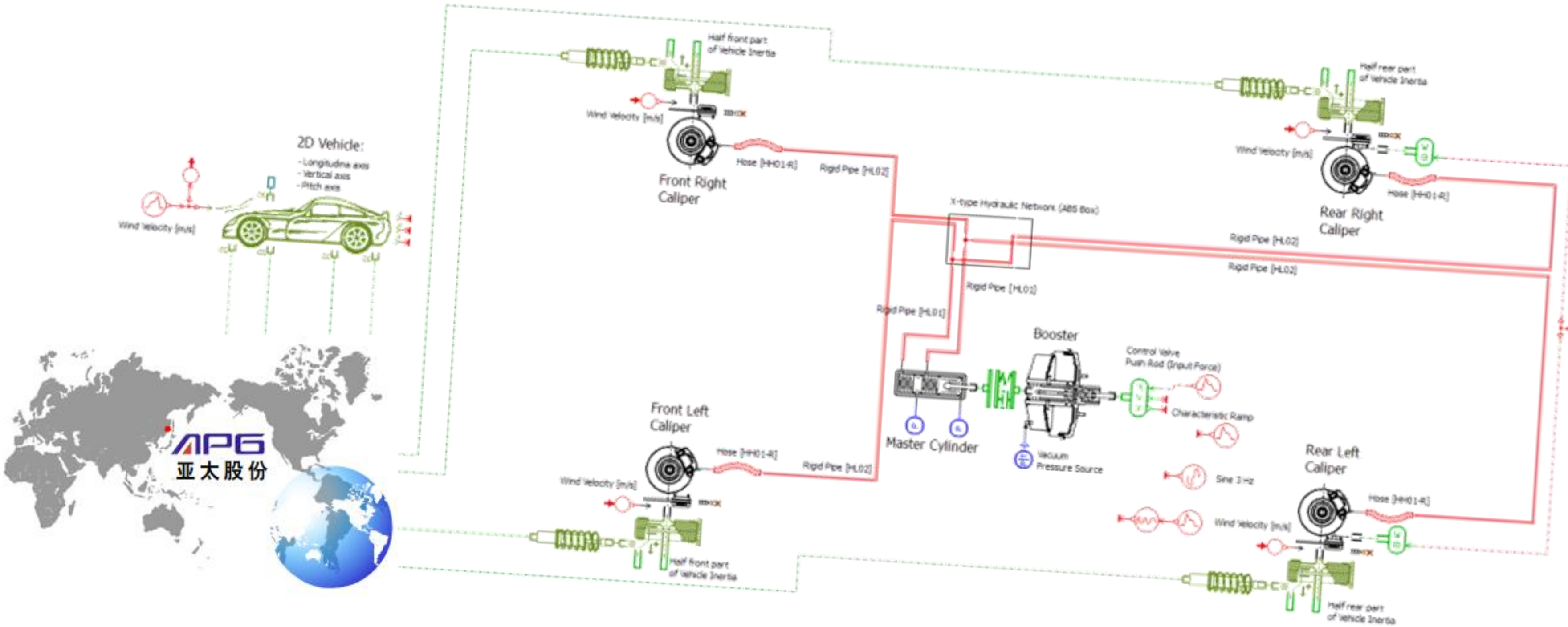


Future Extensions

- **APG Future … involving ABS-ESP**:
  - The Hydraulic Component Design Library allows the design and analysis of any valve technology involved into ABS/ESP hydraulic block (HCU).
  - AMESim includes special features for model simplification starting from the current model to reduce it in a way to be able to run it real time i.e. HiL testing.
  - The Vehicle Dynamics library to take into account the 3D vehicle contributions when ABS/ESP is involved.



Leading Partner in
Test & Mechatronic Simulation



Thank you for your attention

lionel.broglia@lmsintl.com

Vehicle Dynamics Expo 2011
Messe Stuttgart, Germany 17-19 May 2011

LMS®
ENGINEERING INNOVATION