Vehicle functional design – from PSA in-house software to AMESim standard library with increased modularity

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Agenda

1 **From PSA in-house software to AMESim standard solution**

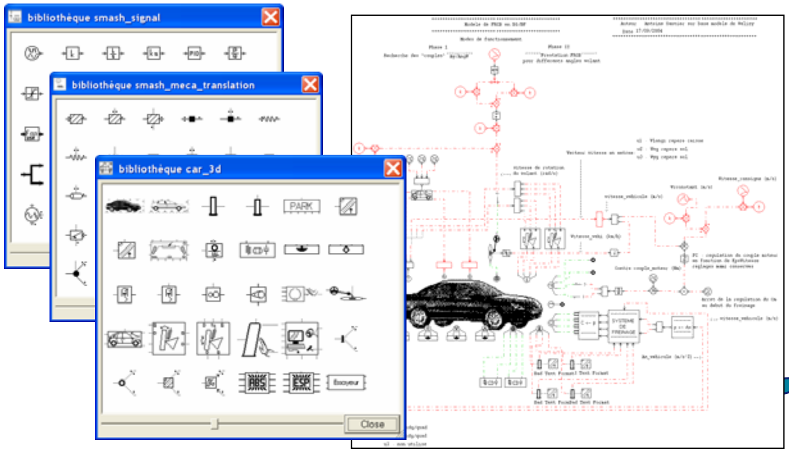
2 **Analysis, Porting and Validation of PSA models**

3 **AMESim : Open platform & modular approach for vehicle design**

4 **Conclusions**

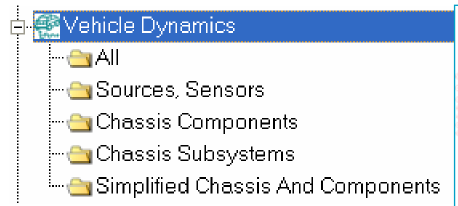
From PSA in-house software to AMESim standard solution

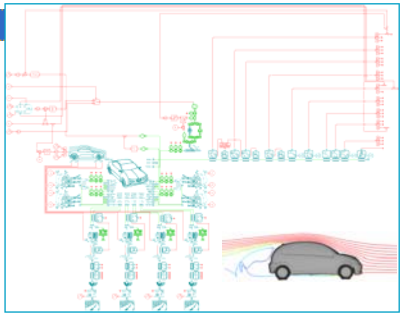
PSA in house application

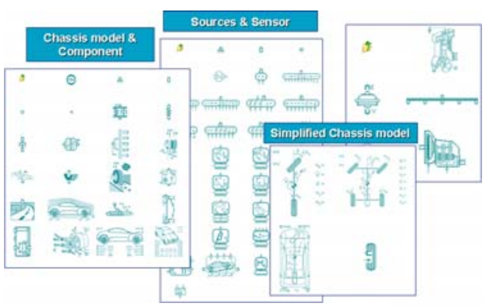


- 10 years of knowledge and capitalization at PSA using AMESim in house application
- PSA wishes a standard software solution, sharing capability with suppliers and potentially with other OEMs
- A software dedicated to functional design of the vehicle

LMS Vehicle Dynamics 1D Solution







- Main improvements versus in house code :
  - ✓ Overall C code optimization for real time capability
  - ✓ Higher mechanical fidelity for Multibody dynamics (accelerations & gyroscopic effects, kinematics, Lagrange multiplier)
  - ✓ Bushing compliance formulations and modularity
  - ✓ Tire kinematics, formulations and modularity
  - ✓ Sources for individual elementary tests
  - ✓ Sensor models
  - ✓ Data Import / Export (FDV)
  - ✓ **Misc :** aero, jacking effect, viscoelastic models …

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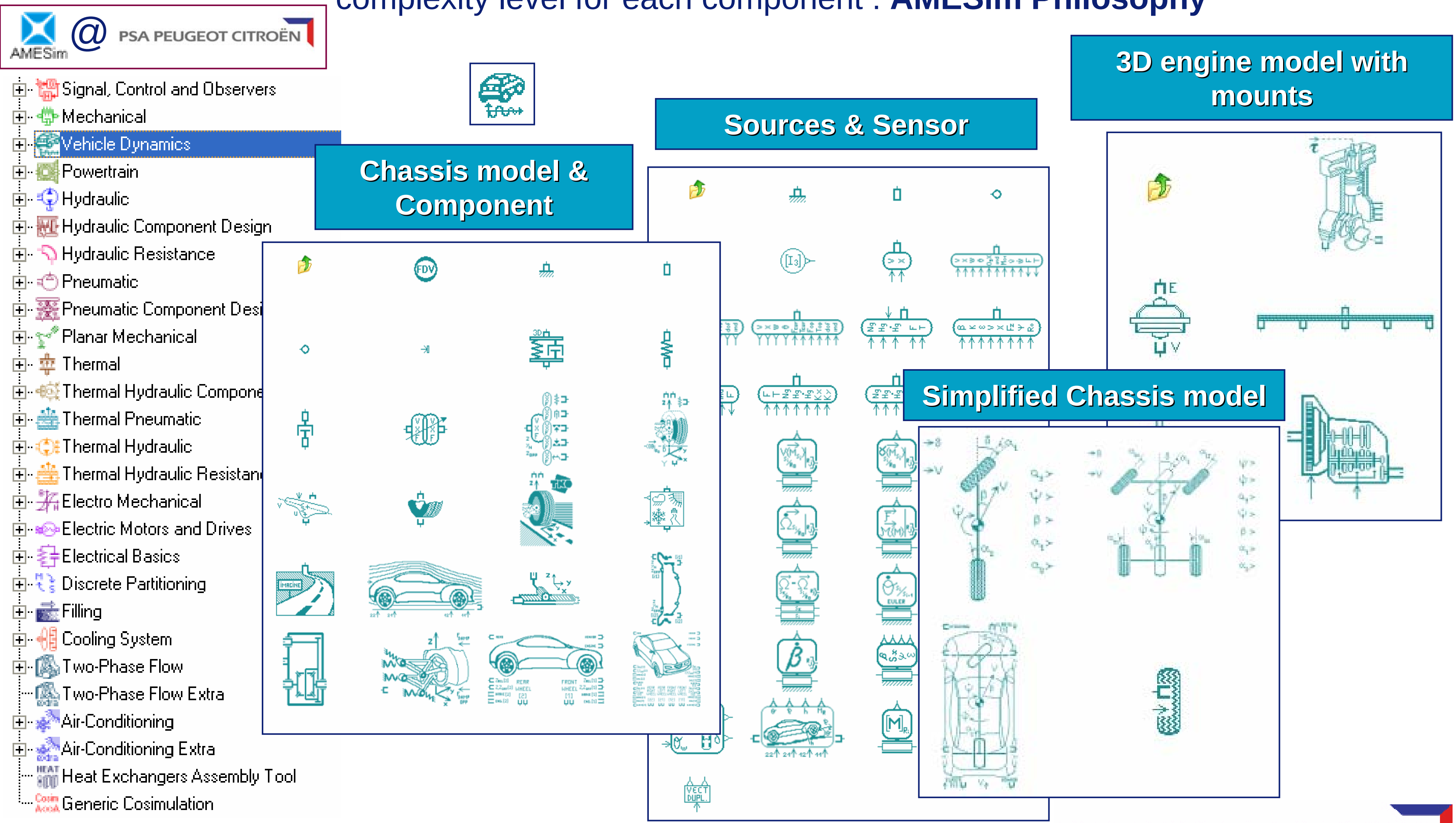
Vehicle Dynamics : Component approach & Modularity

Vehicle Dynamics Modeling with a **component** approach and several complexity level for each component : **AMESim Philosophy**



Vehicle Dynamics : AMESim use at PSA

Vehicle Dynamics Reference tool

- Ride and Handling simulation :
  - Road inputs sensibility
  - Wind sensitivity / Aerodynamics
  - Stability (Lane change, Braking in curves, …)
  - Comfort (low frequency analysis)
- For :
  - Vehicle Dynamics Global Synthesis
  - Specification / Validation (Masses, Axle ,…)
  - Competitor analysis
- During :
  - Car Development Projects
  - Preliminary Projects
  - Research Project / Pilot Studies

Reference models examples

- **Full vehicle :**
  - Global Analysis (all open-loop / closed loop maneuvers)
  - Sensitivity to lateral wind
- **Kinematics & Compliance test bench « K & C »**
- **Flat-Track test bench**
- **Comfort test bench**

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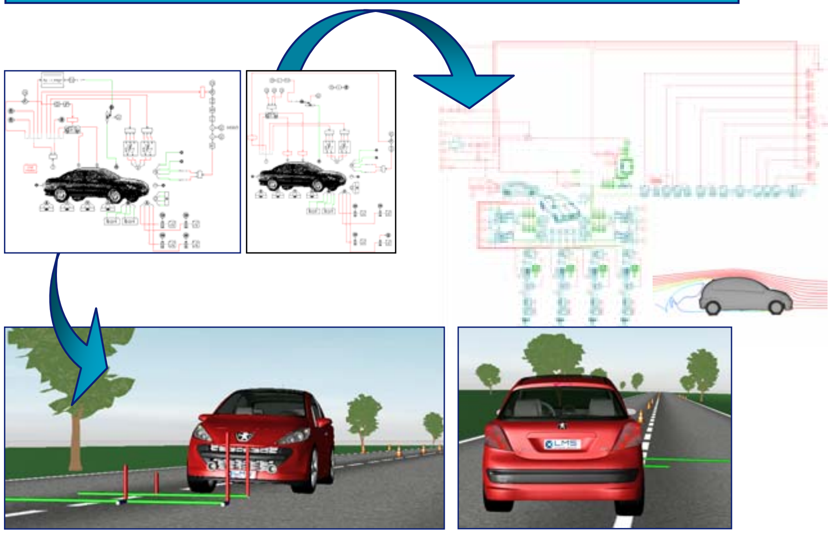
3	AMESim : Open platform & modular approach for vehicle design
4	Conclusions

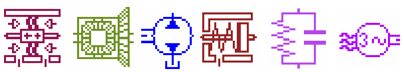
Analysis and Porting PSA Synthesis models

Global Analysis & Wind Sensitivity

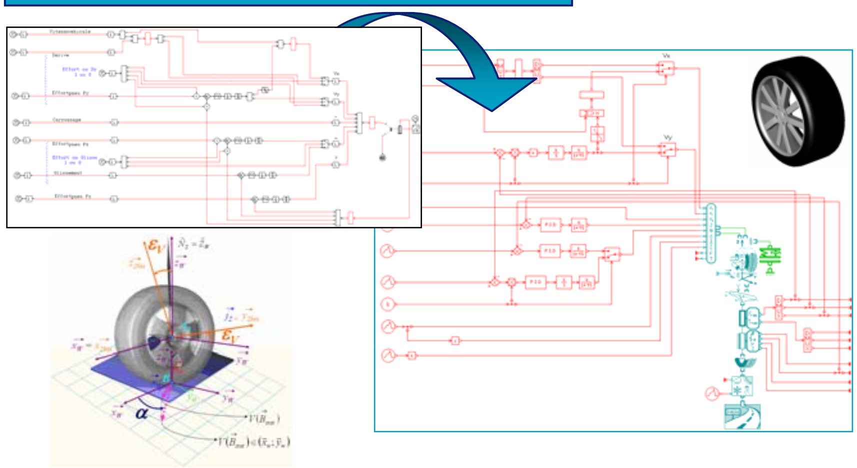


- Full vehicle modeling (*including Multibody chassis model with 15 DOF, compliance, modular tire models, advanced suspension modeling*).
- Open / closed loop for longitudinal and/or lateral driver inputs
- Sensors models facility (control loop & post processing)
- All Sources can be provided with AMESim Standard signal library
- Open to model extension with other Imagine.Lab AMESim libraries (part and component elements – Hydraulic, Electric, Powertrain,…) :

AMESim



Flat Track – tire test bench



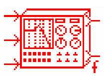
- Tire modular modeling (kinematics, belt, slip, stiffness):
  - linear / non linear / viscoelastic vertical stiffness
  - Relaxation length and scale factor even with Pacejka 92 formulae
  - Van Der Jagt effect for car park maneuvers
- External solicitations :
  - Lateral force (closed loop) or side slip (open loop)
  - Longitudinal force (closed loop) or longi. slip (open loop)
  - Vertical force
  - Camber angle
  - Steering angle / steering velocity
  - Adherence (constant, variable)
- Sensors models facility (control loop & post processing)

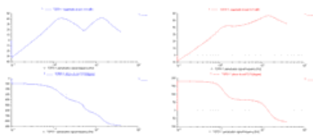
Analysis and Porting PSA Synthesis models

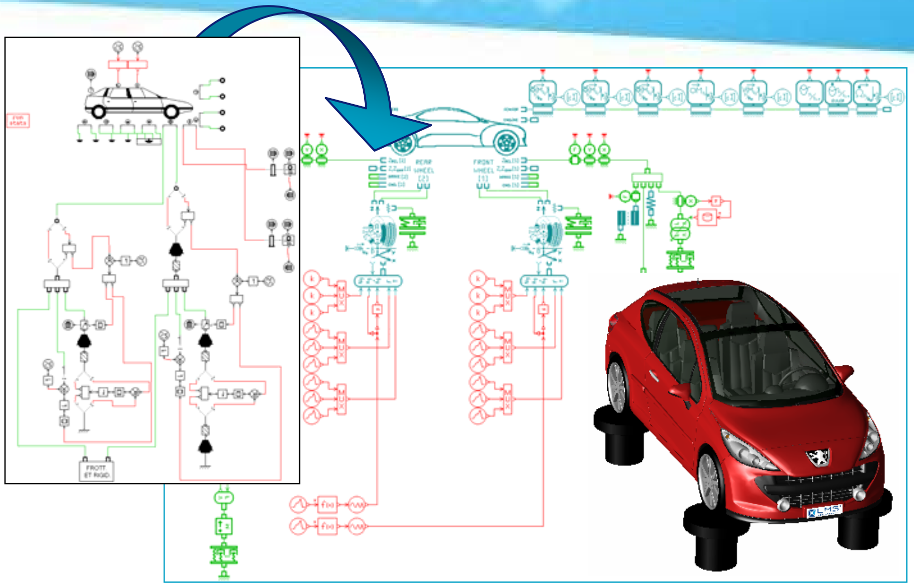
Comfort test bench

- Advanced suspension modeling for comfort (damper masses, viscoelastic models for bushings, dry friction model with stick/slip phenomena, suspension ratio, non linear stiffnesses and damping law)
- Using tire modularity with excitation sources (All Sources can be provided with AMESim Standard signal library)
- Sensors models facility
- Frequency analysis capabilities with standard transferometer models (response of non linear mechanical systems)

transferometer

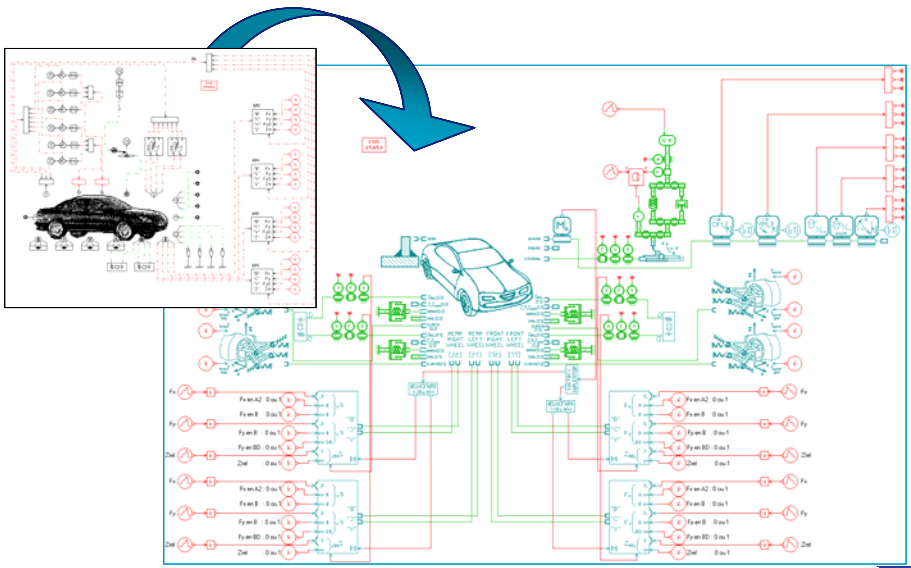






Kinematics & Compliance bench

- Carbody Fixed to the ground
- Functional modeling for excitation jack
- Controlled loop for suspension stroke
- Excitation Jack fixed to the spindle, allowing input forces at
  - Wheel Center
  - Base of wheel
  - Base of wheel with offset, taking into account the caster offset effect
- Input forces in all usual frame (Galilean, carbody, spindle,…)
- Sensors models facility
- All Source can be provided with AMESim Standard signal library



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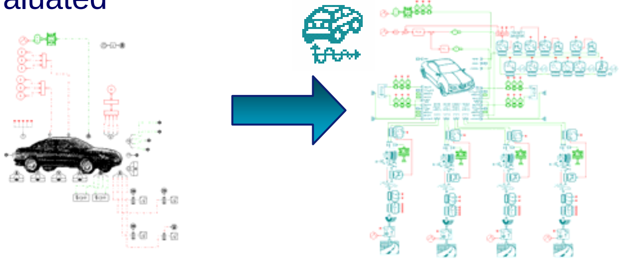
Validation example of PSA Synthesis models

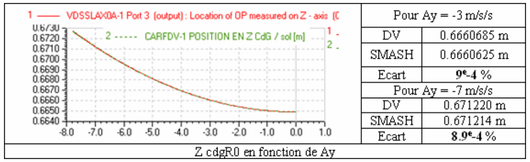
Validation scheme

- Validation scheme
  - Validation on 3 maneuvers :
    - Steady state cornering (measurement at 0,3 g and 0,7 g)
    - Step steer 0,5 g
    - Step steer 0,8 g
  - Measurement variables :
    - Steady state cornering : Tire motor (F_x, F_y, F_z, M_z), Z_{cog}, Yaw & Roll velocity, steering rack position, Force on steering rack.
    - Step steer : yaw and roll velocity overshoots (max value and phase)
- Referential definition (starting point) :
  - Initial model with all PSA modeling assumption reproduced.
  - Definition of a model architecture where both modeling *(former in-house code and new VD implementation)* lead “exactly” to the same results *(differences less than 0.05% on all observed variables)*
  - In this reference case, 60 operating points are evaluated

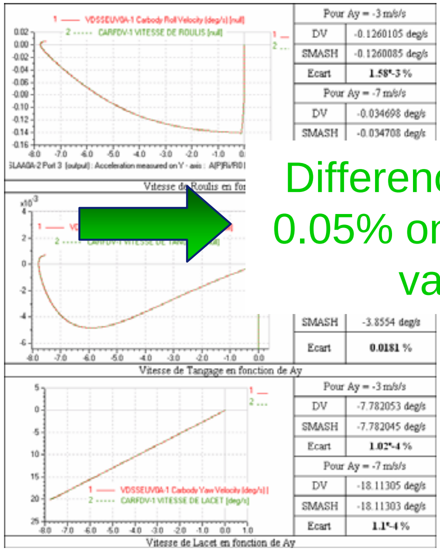


Referential Definition : Model comparison

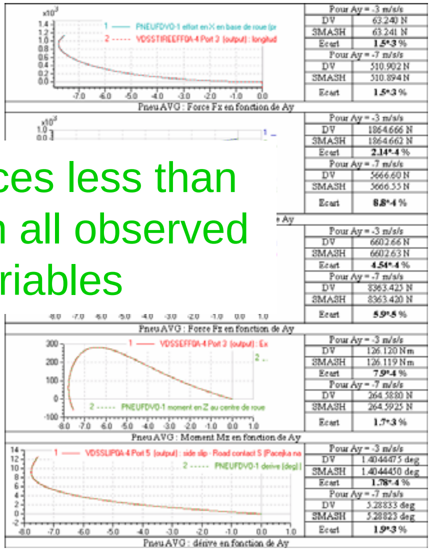
- Z_{cog} position vs. Ay



- Roll, Pitch, Yaw Velocities vs. Ay

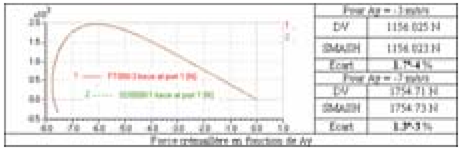


- Tire motor & side slip vs. Ay

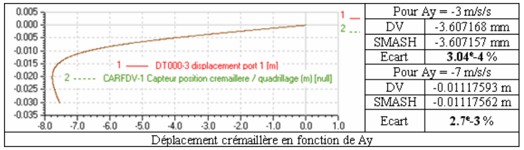


Differences less than 0.05% on all observed variables

- Force on steering rack vs. Ay



- Steering rack position vs. Ay



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Validation example of PSA Synthesis models

Modeling improvements
Quantification of the differences

Example # 1 : Multibody model

Modeling Improvements :
- Accelerations & Gyroscopic effects
- Axle Kinematics formulation
- Interpolation algorithm

Only this improvement is considered here

Steady state cornering

RGP à 3 m/s/s	Ecarts (%)	RGP à 7 m/s/s	Ecarts (%)
Psip (vitesse de Lacet)	4e-3 %	Psip (vitesse de Lacet)	4.6e-3 %
Phip (vitesse de Roulis)	0.7 %	Phip (vitesse de Roulis)	1.2 % (écart abs de 5e-4 deg/s)
Yn (position crémaillère)	5e-3 %	Yn (position crémaillère)	0.39 % (écart abs de 0.044 mm)
Fyn (effort sur crémaillère)	0.18 %	Fyn (effort sur crémaillère)	0.72 % (écart abs de 13 N)
Zcdg R0	1.3e-3 %	Zcdg R0	0.02 %
Fy pneu AVG	0.02 %	Fy pneu AVG	0.42 % (écart abs de 24 N)
Fy pneu AVD	0.02 %	Fy pneu AVD	0.89 % (écart abs de 18 N)
Fy pneu ARG	0.04 %	Fy pneu ARG	0.38 % (écart abs de 15 N)
Fy pneu ARD	0.06 %	Fy pneu ARD	1.49 % (écart abs de 15 N)
Fz pneu AVG	0.05 %	Fz pneu AVG	0.31 % (écart abs de 26 N)
Fz pneu AVD	0.05 %	Fz pneu AVD	1.14 % (écart abs de 23 N)
Fz pneu ARG	0.02 %	Fz pneu ARG	0.29 % (écart abs de 18 N)
Fz pneu ARD	0.11 %	Fz pneu ARD	1.78 % (écart abs de 20 N)
Mz pneu AVG	0.10 %	Mz pneu AVG	0.003 % (0.35% à 0.65g)
Mz pneu AVD	0.02 %	Mz pneu AVD	0.92 % (écart abs de 0.3 Nm)
Mz pneu ARG	0.08 %	Mz pneu ARG	0.52 % (écart abs de 1 Nm)
Mz pneu ARD	0.07 %	Mz pneu ARD	2.63 % (écart abs de 0.36 Nm)

Neglected at 0.3g

Impact at 0.7g (average of 1%, i.e. 20N on tire Fy and 10 on $F_{steering}$)

Step steer 0,5 g

1ère Surtension à la mise en virage	Ecarts (%)	Stabilisé	Ecarts (%)	Transitoire	Déphasage
ECH 4.1					
Psip (vitesse de Lacet)	0.048 %	Ay	0.057 %	Psip	Aucun
Phip (vitesse de Roulis)	0.062 %				

No significant impact

Step steer 0,8 g

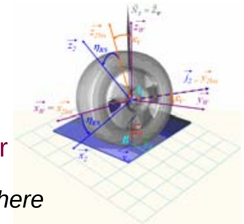
1ère Surtension à la mise en virage	Ecarts (%)	Stabilisé	Ecarts (%)	Transitoire	Déphasage
ECH 4.2					
Psip (vitesse de Lacet)	0.063 %	Ay	0.26 %	Psip	Aucun
Phip (vitesse de Roulis)	0.065 %				

No significant impact

Example # 2 : Tire kinematics

Modeling Improvements :
- Side slip computation
- Longi. slip computation
- Tire motor formulation at wheel center

Only this improvement is considered here

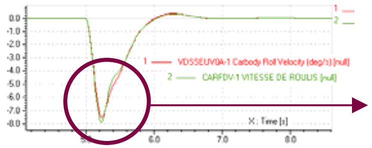


Steady state cornering

RGP à 3 m/s/s	Ecarts (%)	RGP à 7 m/s/s	Ecarts (%)
Psip (vitesse de Lacet)	2.57e-4 %	Psip (vitesse de Lacet)	0.016 %
Phip (vitesse de Roulis)	9.52e-4 %	Phip (vitesse de Roulis)	0.288 %
Yn (position crémaillère)	1.6e-3 %	Yn (position crémaillère)	0.062 %
Fyn (effort sur crémaillère)	0.0211 %	Fyn (effort sur crémaillère)	0.255 %
Zcdg R0	7.65e-4 %	Zcdg R0	5.9e-4 %
Fy pneu AVG	3.2e-3 %	Fy pneu AVG	0.011 %
Fy pneu AVD	8.2e-4 %	Fy pneu AVD	0.034 %
Fy pneu ARG	3.2e-3 %	Fy pneu ARG	0.012 %
Fy pneu ARD			
Fz pneu ARG			
Fz pneu ARD	8e-3 %	Fz pneu ARD	0.15 %
Mz pneu AVG	7.1e-3 %	Mz pneu AVG	0.056 %
Mz pneu AVD	8.9e-3 %	Mz pneu AVD	0.2 %
Mz pneu ARG	5.6e-3 %	Mz pneu ARG	0.054 %
Mz pneu ARD	0.013 %	Mz pneu ARD	0.26 %

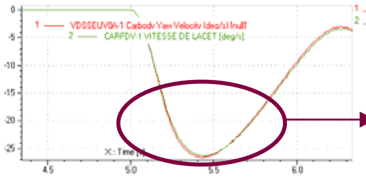
No significant impact

Step steer 0,5 g



Impact on roll velocity overshoot : 4%

Step steer 0,8 g



Impact on yaw velocity overshoot : 1% and phase shift : 0.01 sec

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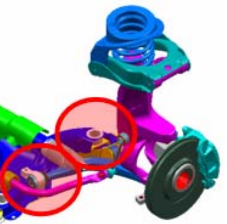
Validation example of PSA Synthesis models

Modeling improvements
Quantification of the differences

Example # 3 : Axle Compliance
Including previous modifications



Modeling Improvements :
- Lagrangian multiplier formulation
- Bushing modeling

Steady state cornering

RGP à 3 m/s/s	Ecarts (%)	RGP à 7 m/s/s	Ecarts (%)
Psip (vitesse de Lacet)	6.7^-3 %	Psip (vitesse de Lacet)	0.014 %
Phip (vitesse de Roulis)	2.06 %	Phip (vitesse de Roulis)	2.94 % (écart abs de 0.001 deg/s)
Yn (position crémaillère)	0.55 %	Yn (position crémaillère)	1.44 % (écart abs de 0.22 mm)
Fyn (effort sur crémaillère)	0.32 %	Fyn (effort sur crémaillère)	1.12 % (1.42% à 0.6g soit 26 N)
Zcdg R0	5.7^-3 %	Zcdg R0	0.05 %
Fy pneu AVG	0.91 %	Fy pneu AVG	1.28 % (écart abs de 71 N)
Fy pneu AVD	1.14 %	Fy pneu AVD	2.88 % (écart abs de 61.6 N)
Fy pneu ARG	0.04 %	Fy pneu ARG	0.62 % (écart abs de 25 N)
Fy pneu ARD	0.61 %	Fy pneu ARD	4.80 % (écart abs de 43 N)
Fz pneu AVG	0.33 %	Fz pneu AVG	0.90 % (écart abs de 75 N)
Fz pneu AVD	0.42 %	Fz pneu AVD	3.45 % (écart abs de 70 N)
Fz pneu ARG	0.28 %	Fz pneu ARG	0.88 % (écart abs de 54.4 N)
Fz pneu ARD	0.75 %	Fz pneu ARD	4.98 % (écart abs de 59.2 N)
Mz pneu AVG	0.99 %	Mz pneu AVG	0.61 % (écart abs de 1.62 Nm)
Mz pneu AVD	1.16 %	Mz pneu AVD	1.86 % (écart abs de 0.55 Nm)
Mz pneu ARG	0.20 %	Mz pneu ARG	1.31 % (écart abs de 2.38 Nm)
Mz pneu ARD	1.01 %	Mz pneu ARD	6.80 % (écart abs de 1.14 Nm)

Low impact at 0.3g (1% on tire forces, 2% on roll velocity)

Impact at 0.7g (average of 2.5% on tire Forces, 3% on roll velocity and 1.5% on rack position)

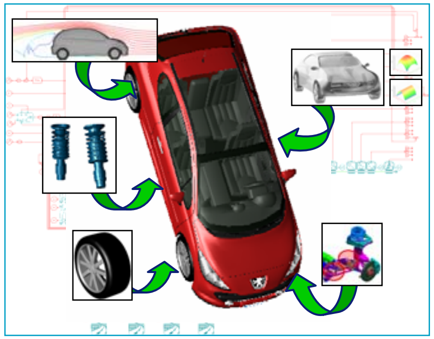
Step steer 0,5 g

1ère Surtension à la mise en virage	Ecarts (%)	Stabilisé	Ecarts (%)	Transitoire	Déphasage
ECH 9.1					
Psip (vitesse de Lacet)	2.85 %	Ay	0.16 %	Psip	0.02 sec
Phip (vitesse de Roulis)	3.23 %				

Step steer 0,8 g

1ère Surtension à la mise en virage	Ecarts (%)	Stabilisé	Ecarts (%)	Transitoire	Déphasage
ECH 9.2					
Psip (vitesse de Lacet)	2.46 %	Ay	0.66 %	Psip	0.02 sec
Phip (vitesse de Roulis)	3.03 %				

Example # 4 : All modifications
→ Coupling all the effects



Modeling Improvements:
- Chassis (Multibody, Compliances)
- Tire formulation (kinematics, coupling effects, motor formulation at wheel center)
- Aerodynamics
- Suspension
- Overall Interpolation algorithms / methods

Steady state cornering

RGP à 3 m/s/s	Ecarts (%)	RGP à 7 m/s/s	Ecarts (%)
Psip (vitesse de Lacet)	0.013 %	Psip (vitesse de Lacet)	0.029 %
Phip (vitesse de Roulis)	2.79 %	Phip (vitesse de Roulis)	17.1 % (écart abs de 0.0053 deg/s)
Yn (position crémaillère)	0.81 %	Yn (position crémaillère)	4.25 % (écart abs de 0.66 mm)
Fyn (effort sur crémaillère)	0.57 %	Fyn (effort sur crémaillère)	7.60 % (écart abs de 127 N)
Zcdg R0	3.6^-3 %	Zcdg R0	0.05 %
Fy pneu AVG	0.86 %	Fy pneu AVG	0.30 % (écart abs de 16 N)
Fy pneu AVD	1.05 %	Fy pneu AVD	1.54 % (écart abs de 31 N)
Fy pneu ARG	0.02 %	Fy pneu ARG	0.56 % (écart abs de 22.5 N)
Fy pneu ARD	0.56 %	Fy pneu ARD	4.71 % (écart abs de 40.2 N)
Fz pneu AVG	0.33 %	Fz pneu AVG	0.89 % (écart abs de 74 N)
Fz pneu AVD	0.42 %	Fz pneu AVD	3.42 % (écart abs de 69.3 N)
Fz pneu ARG	0.25 %	Fz pneu ARG	0.85 % (écart abs de 52.5 N)
Fz pneu ARD	0.72 %	Fz pneu ARD	5.06 % (écart abs de 60 N)
Mz pneu AVG	0.70 %	Mz pneu AVG	5.15 % (écart abs de 13.2 Nm)
Mz pneu AVD	1.36 %	Mz pneu AVD	2.71 % (écart abs de 0.86 Nm)
Mz pneu ARG	0.13 %	Mz pneu ARG	1.25 % (écart abs de 2.3 Nm)
Mz pneu ARD	1.01 %	Mz pneu ARD	7.07 % (écart abs de 1.175 Nm)

Impact at 0.3g (1% on tire forces, 3% on roll velocity)

Impact at 0.7g (average of 4% on tire Forces, 4% on rack position, 7% on steering force)

Step steer 0,5 g

1ère Surtension à la mise en virage	Ecarts (%)	Stabilisé	Ecarts (%)	Transitoire	Déphasage
ECH 11.1					
Psip (vitesse de Lacet)	3.66 %	Ay	1.94 %	Psip	0.02 sec
Phip (vitesse de Roulis)	3.18 %				

Step steer 0,8 g

1ère Surtension à la mise en virage	Ecarts (%)	Stabilisé	Ecarts (%)	Transitoire	Déphasage
ECH 11.2					
Psip (vitesse de Lacet)	5.03 %	Ay	1.76 %	Psip	0.02 sec
Phip (vitesse de Roulis)	2.74 %				

Global impact on transients : **roll velocity overshoot** (mainly due to tire kinematics) and **yaw velocity overshoot** (mainly due to compliance)

Global impact on phase shift

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4	Conclusions

LMS ENGINEERING INNOVATION

Modularity : Increasing complexity for suspension

Suspension Modeling

Modeling the damper subsystem technology

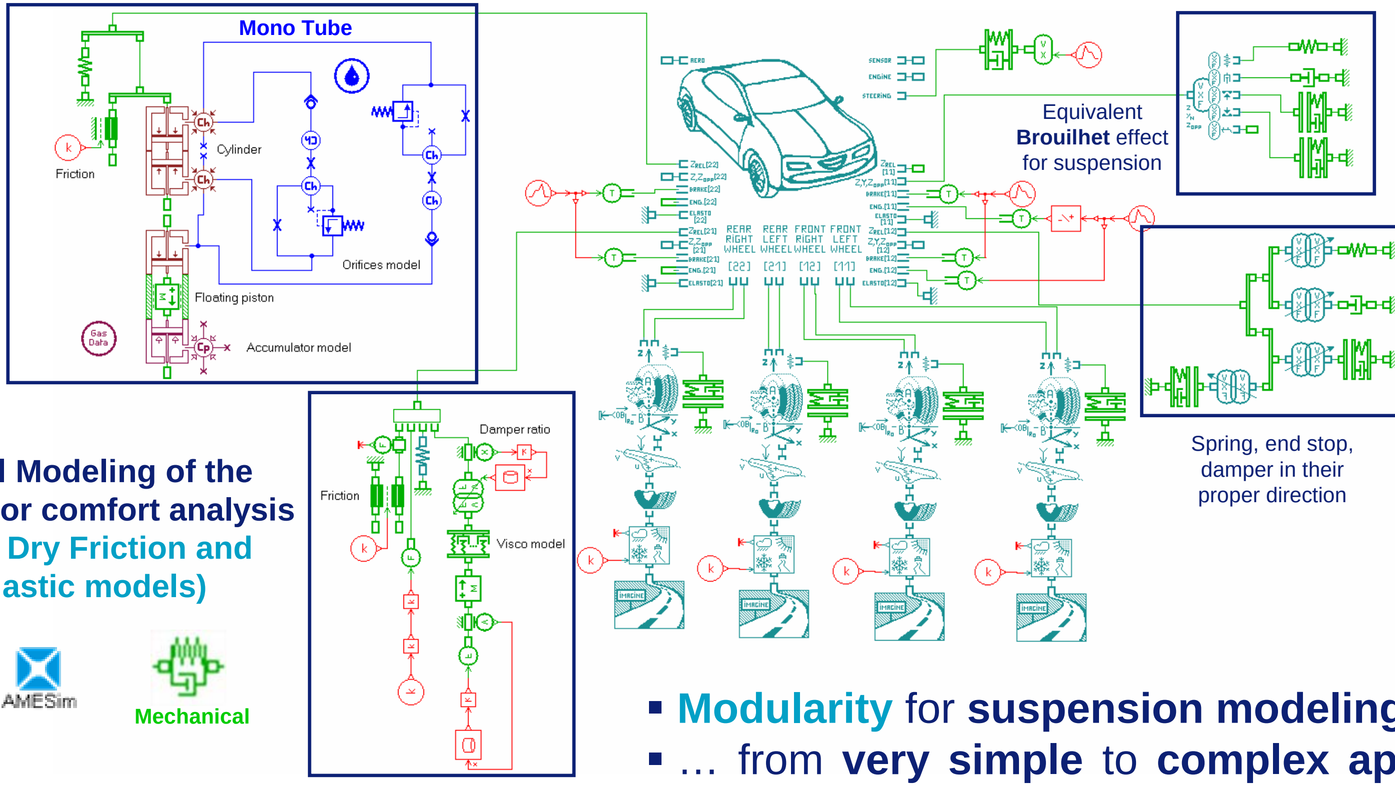
Advanced suspension interface for jacking effect

AMESim

Hydraulic

Hydraulic Comp. Design

Pneumatic Comp. Design



Simple suspension modeling

Functional Modeling of the suspension for comfort analysis (including Dry Friction and Viscoelastic models)

AMESim

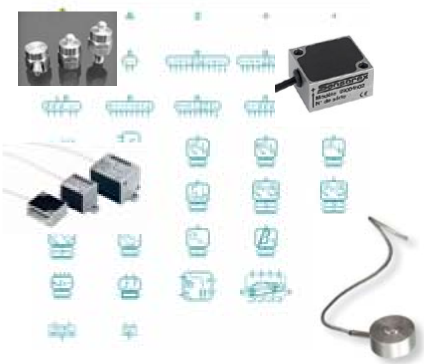
Mechanical

- **Modularity** for **suspension modeling**…
- … from **very simple** to **complex approach**, according to analysis :
  - Ride and handling, vehicle stability
  - Comfort
  - Damper analysis, design and optimization

LMS ENGINEERING INNOVATION

Modularity : Sensors & Simplified vehicle models

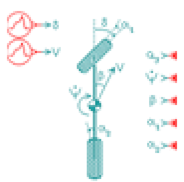
Sensors category



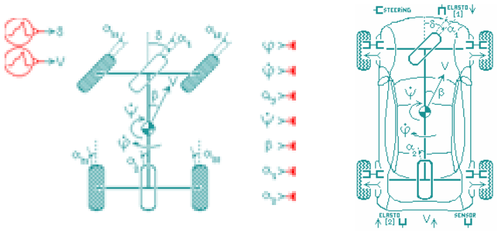
- **Current mechanical quantities**
- **Current OEM trade quantities**
- All quantities available for **post-processing** and/or **control loop**

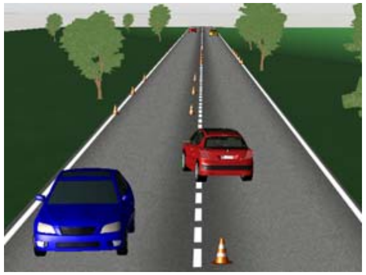
Simplified Chassis models

- Yaw plane model



- Several Yaw plane model with roll motion



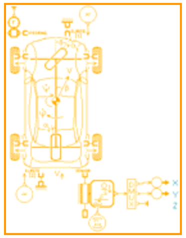


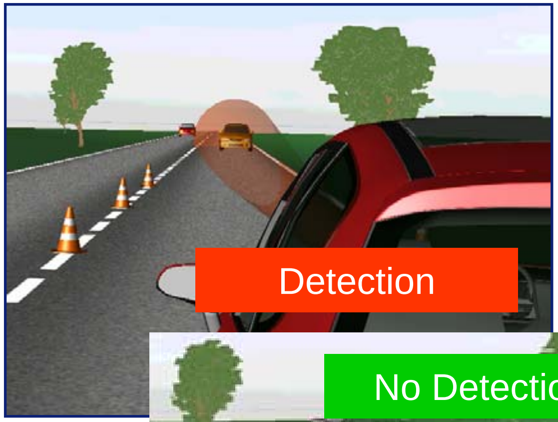
- Connection for Subsystem design (Power Steering,…)
- Traffic modeling
- Vehicle dynamics understanding
- Educational

Traffic detection / ACC

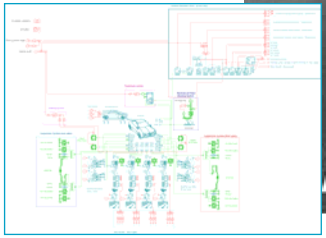
- Using **sensor** facility and **simplified models** for **traffic and vehicle detection**

traffic vehicle #1





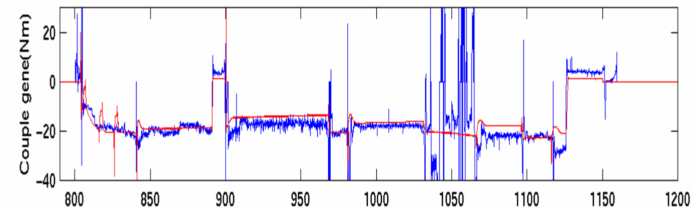
Main vehicle



Modularity : Ready for Fuel Efficiency Analysis

Powertrain : Series & Parallel Hybrid architecture

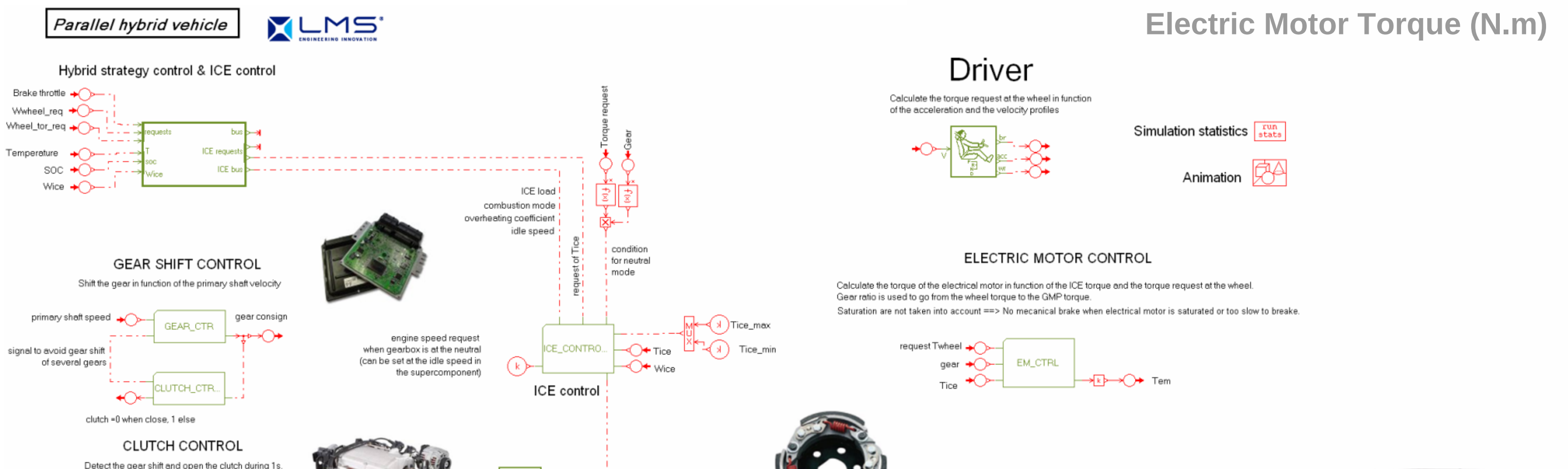
- **Connection with chassis** to analyze the **control strategies** (tip in and back out in curves, slip μ, interaction with the ESP system…)
- All electric motor types available for real time.

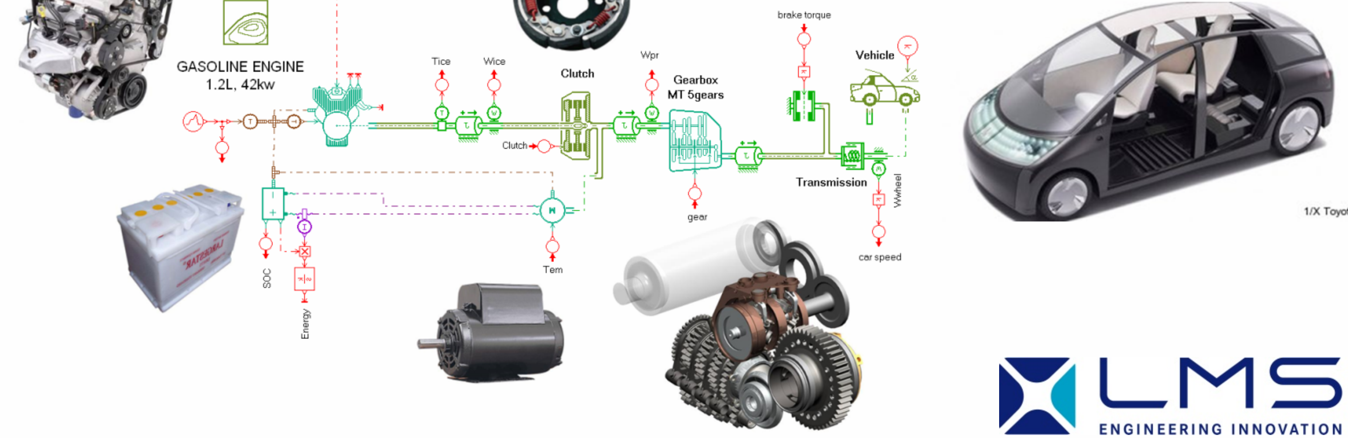


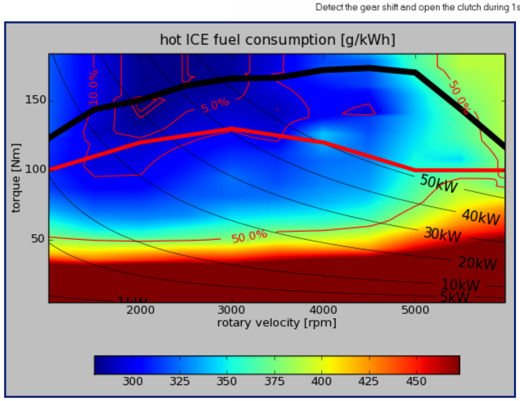
Electric Motor Torque (N.m)

AMESim

Powertrain







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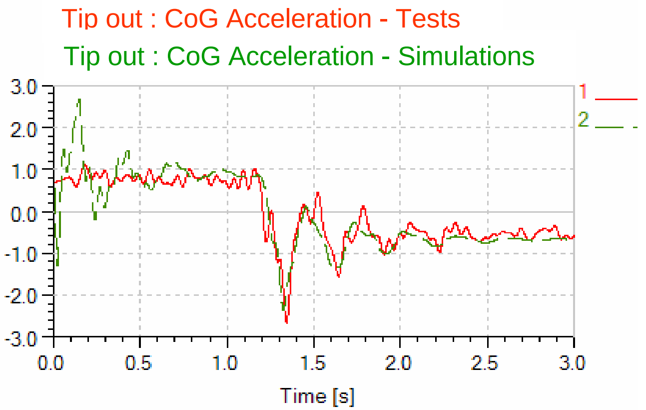
Modularity : Powertrain related features

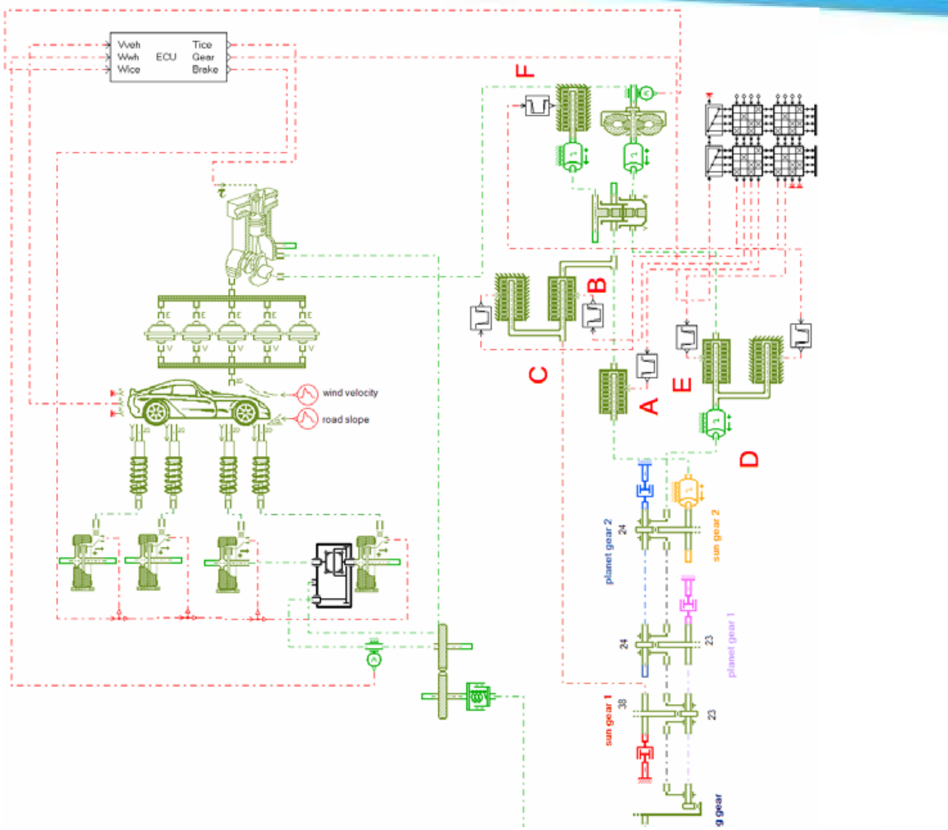
Powertrain : Drivability

- Modeling Complex interaction between **3D engine block,** carbody and driveline : **vehicle comfort, engine harmonic filtering**, **Drivability**
- All engine block topology available

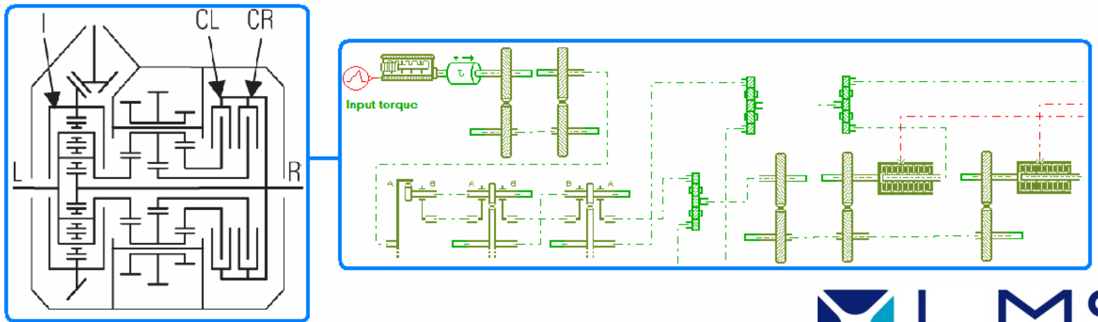


AMESim

Powertrain



- **Torque Vectoring** : Wheel torque management, piloted differential and all wheel drive



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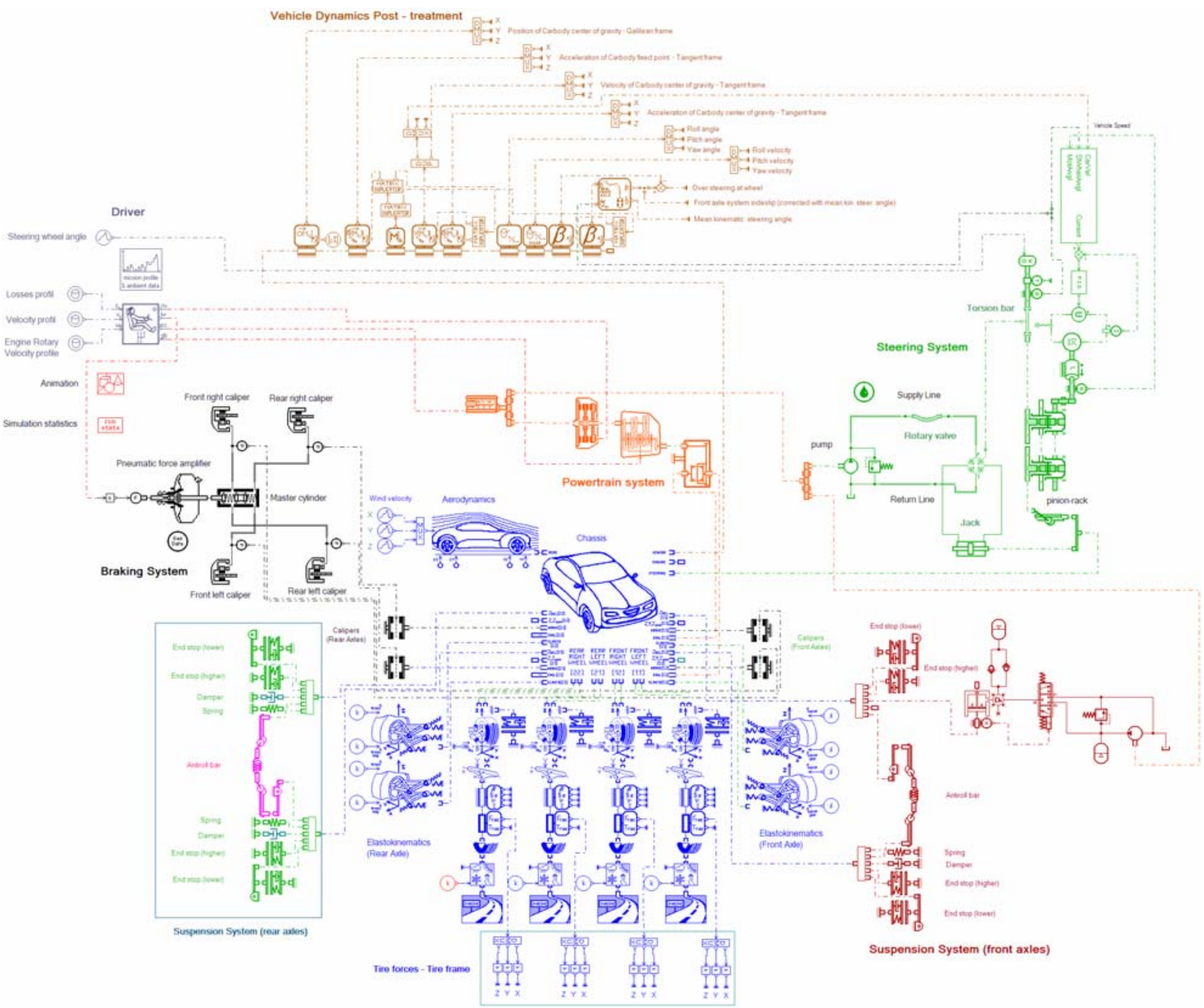
Modularity : Solution Coupling for Subsystems

Modularity Synthesis



Vehicle Dynamics

Transmission

Steering systems

Suspension

Braking circuit

Active roll bar

Sensors

AMESim

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Agenda

1	From PSA in-house software to AMESim standard solution
2	Analysis, Porting and Validation of PSA models
3	AMESim : Open platform & modular approach for vehicle design
4	**Conclusions**

Conclusions

PSA PEUGEOT CITROËN

- PSA wishes to share a standard software solution with its suppliers and potentially other OEMs
- PSA reference frame for simulation has been improved
- High fidelity models, Robustness, CPU time reduction, Real time capabilities, **links with optimization and PSA internal data management**
- **A unique platform for a system approach in Vehicle Dynamics :**
  - **System view** : Chassis, Steering, Suspension and Transmission modeling with all AMESim libraries
  - **Process integration** : functional specification & design and functional validation

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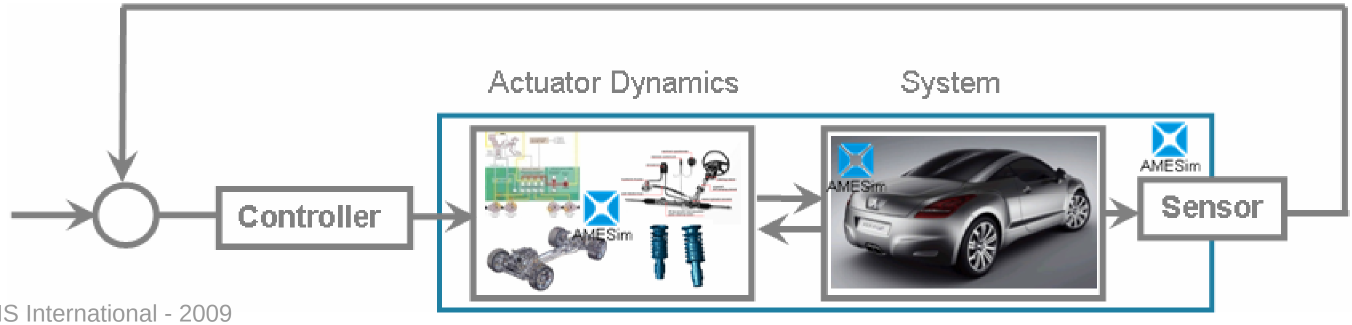
- Open **platform** with **modular approach** for vehicle design
- … from simple functional to advanced & detailed modeling for subsystems



PSA PEUGEOT CITROËN

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Thank you !

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Marc ALIRAND, Julien LAGNIER (LMS)

Vehicle Dynamics Expo 2009 – Germany – June, 17nd