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2nd European Multibody User Group Meeting 2017: Comparison of Semi-Analytical Methods for Frame Load Evaluation on a Recreational Vehicle

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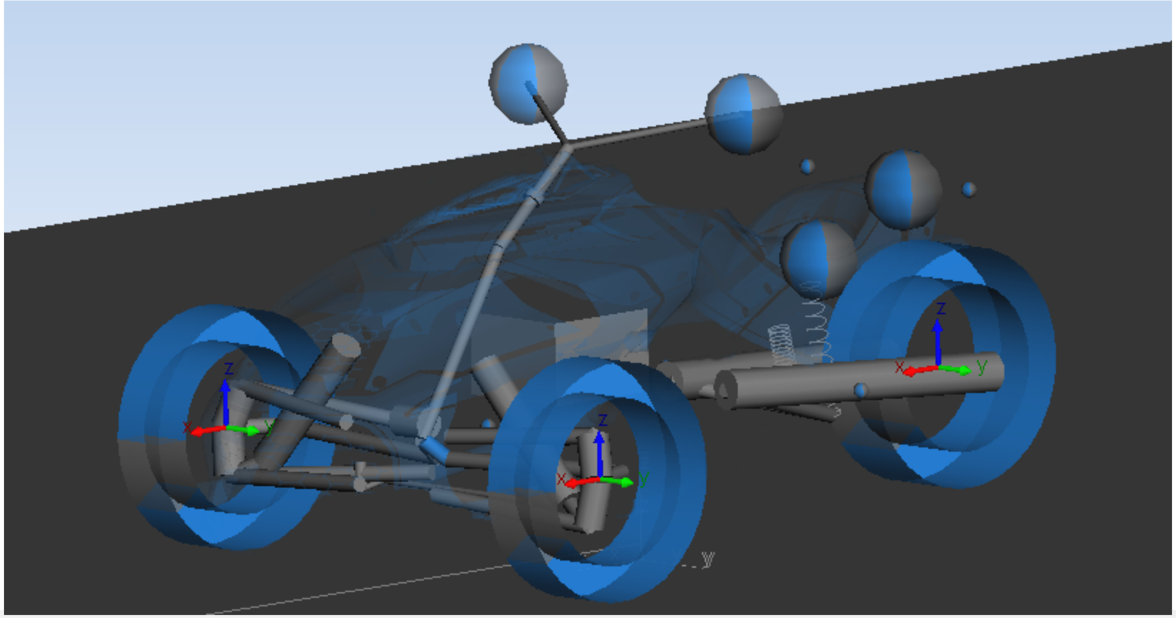
Context

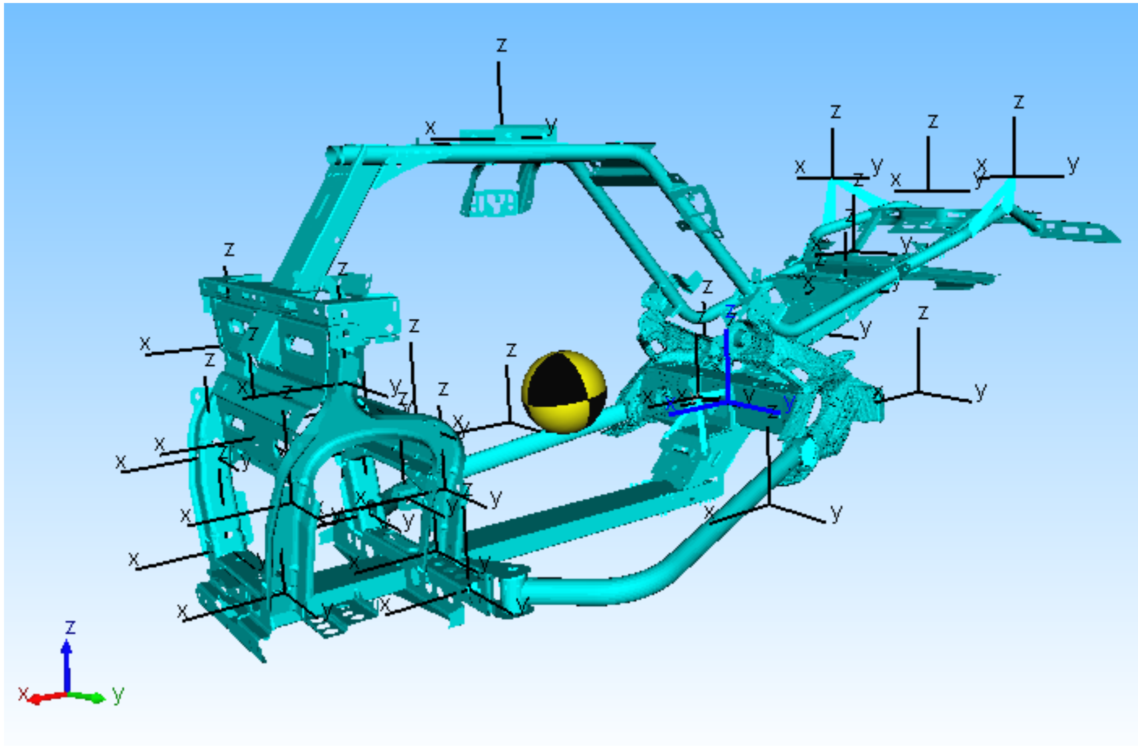
- Durability analysis on a three-wheeled recreational vehicle frame:
  - Test data is available
    - Wheel force transducers (WFT) and GPS IMU
  - WFT don't provide frame loads but wheel loads
    - Wheel→frame transfer path is complex
    - Dynamics of the suspension, bushings and vehicle can't be neglected
  - Frame loads must be accurate for steady state as well as for transient dynamics



Context

- How to use wheel force transducers signals to recover the frame loads

- Investigate the sensitivity of the chosen method
  - Rigid/Flexible bodies
  - Rigid suspension
  - Internal forces



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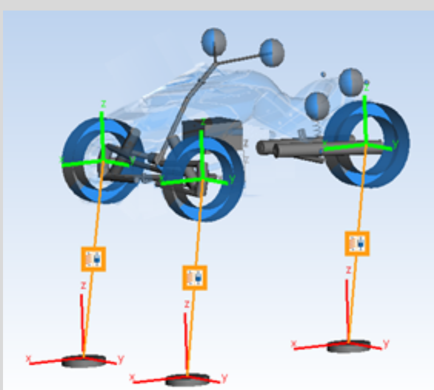
State of the art for frame load evaluation using MBD

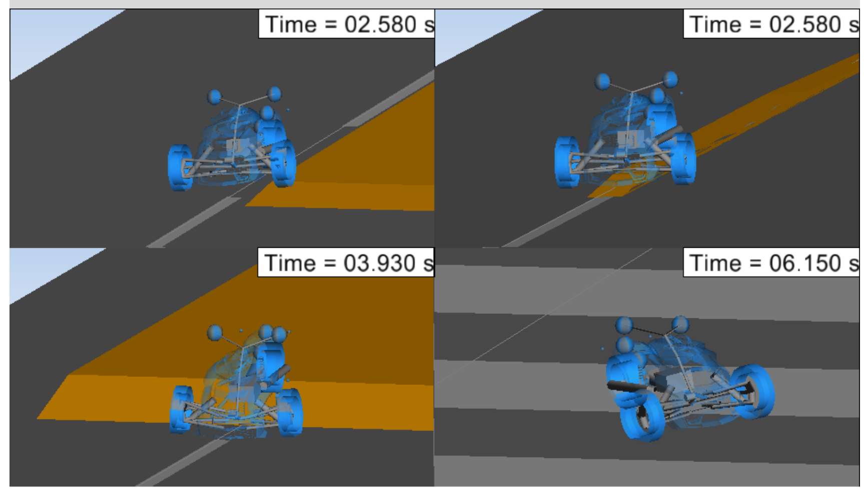
Semi analytical simulation :

- Wheel force transducer time series and GPS data
- No tire model nor road scan
- Prototype or a very similar vehicle run on the test-track
- Limited by the data acquired on the test track
- [Da Cruz et al. (2003)] [Tebbe et al. (2006)] [Backer et al. (2005)]



Full analytical simulation:

- Precise tire model of the tire, up to 100Hz and above
- Scanned road to feed the tire model
- Full model based development
- Confidence in the MBD model
- [Sawa et al. (2010)]



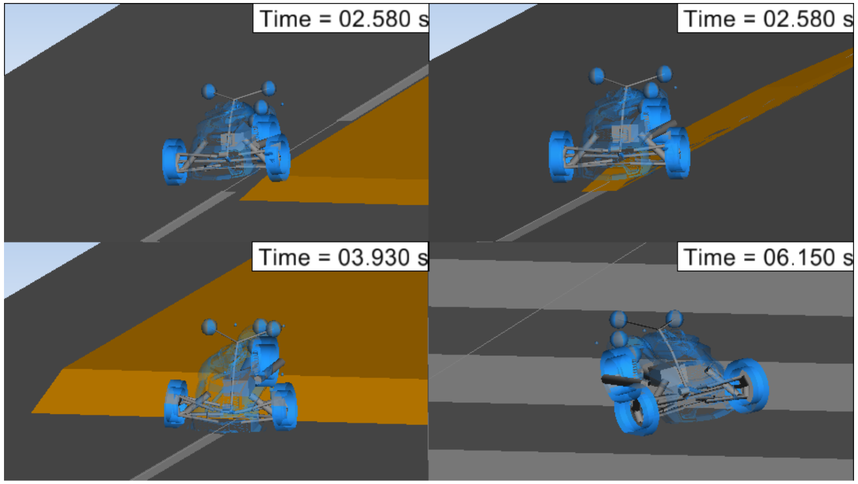
Methodology

- WFT and GPS data are available. Semi-analytical method seems adequate
- Many methods exist. Which one provides the best results?
- The different semi-analytical methods must be compared and their quality evaluated
- To compare the quality of the methods, we need to know the frame loads and get rid of the correlation issues

Full-analytical	Semi-analytical	Evaluation
Reference simulation Wheel forces GPS data Reference frame loads	Several methods Frame load calculation	Comparison of frame loads Choice of the best method

Simpack Full-analytical model for reference data

- Full-analytical simulation are made using different scenarios.
  - Small bump on one wheel
  - Steep ramp for the full vehicle
  - Slalom
  - Hard braking



- Flat road and MF-Tire model

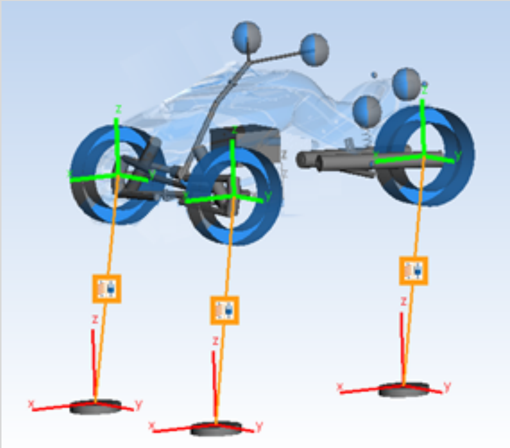
- Co-simulation to control wheel slip for the braking scenario

Simpack model : Semi analytical

Two main categories of semi-analytical methods are used

Fixed frame

- Frame linked by a joint on a Marker
  - Marker can be fixed on the reference system (Grounded)
  - Marker can be a moved marker following the GPS position(1-6 DoF)
  - Non-causal movement implies no inertia forces



Free frame

- Chassis can move around a point (6DoF)
  - This point can move or not
- The displacement is limited and can controlled via a Bushing or Simpack Control modules
- Methods used:
  - Free around 0
  - Free around GPS position(1 to 6 DoF)

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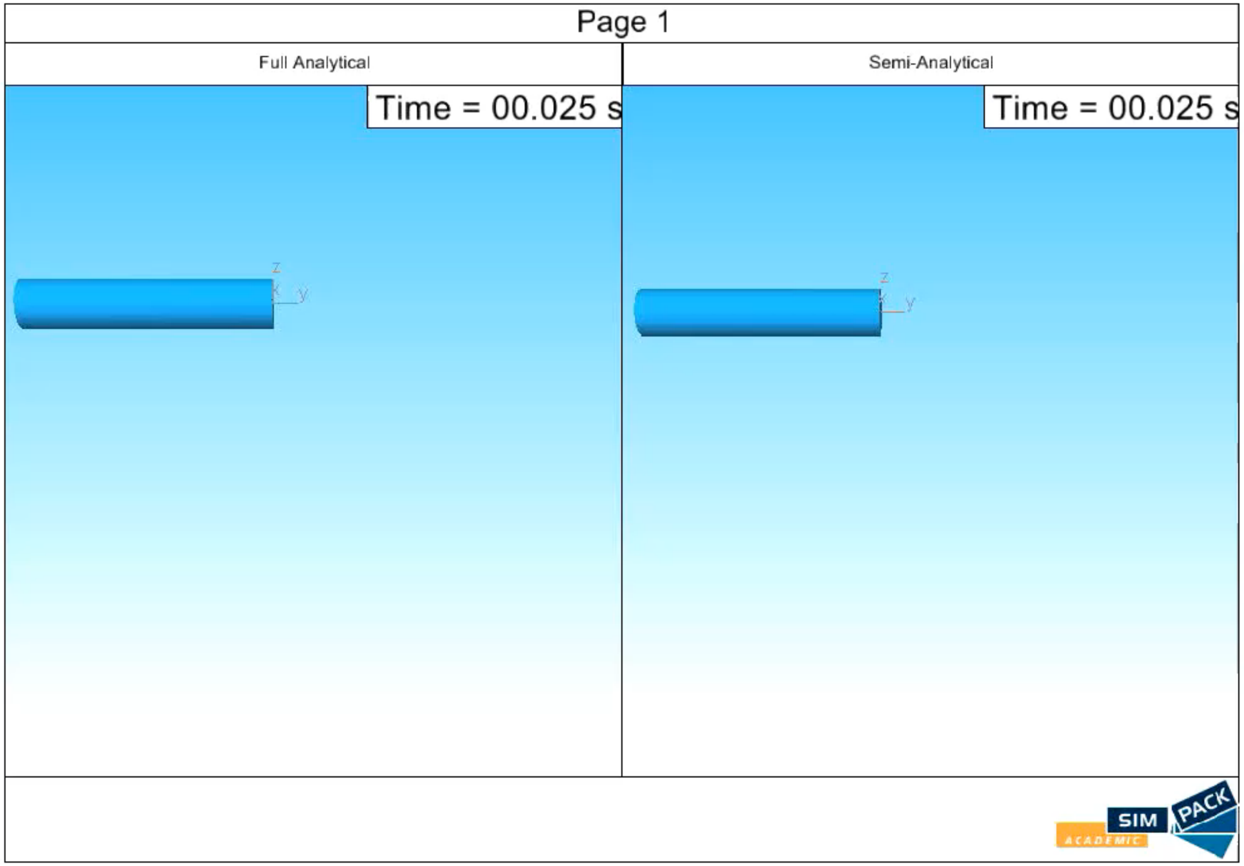
Simpack model: Control

- Control elements are necessary due to numerical drift



Simpack model: Control

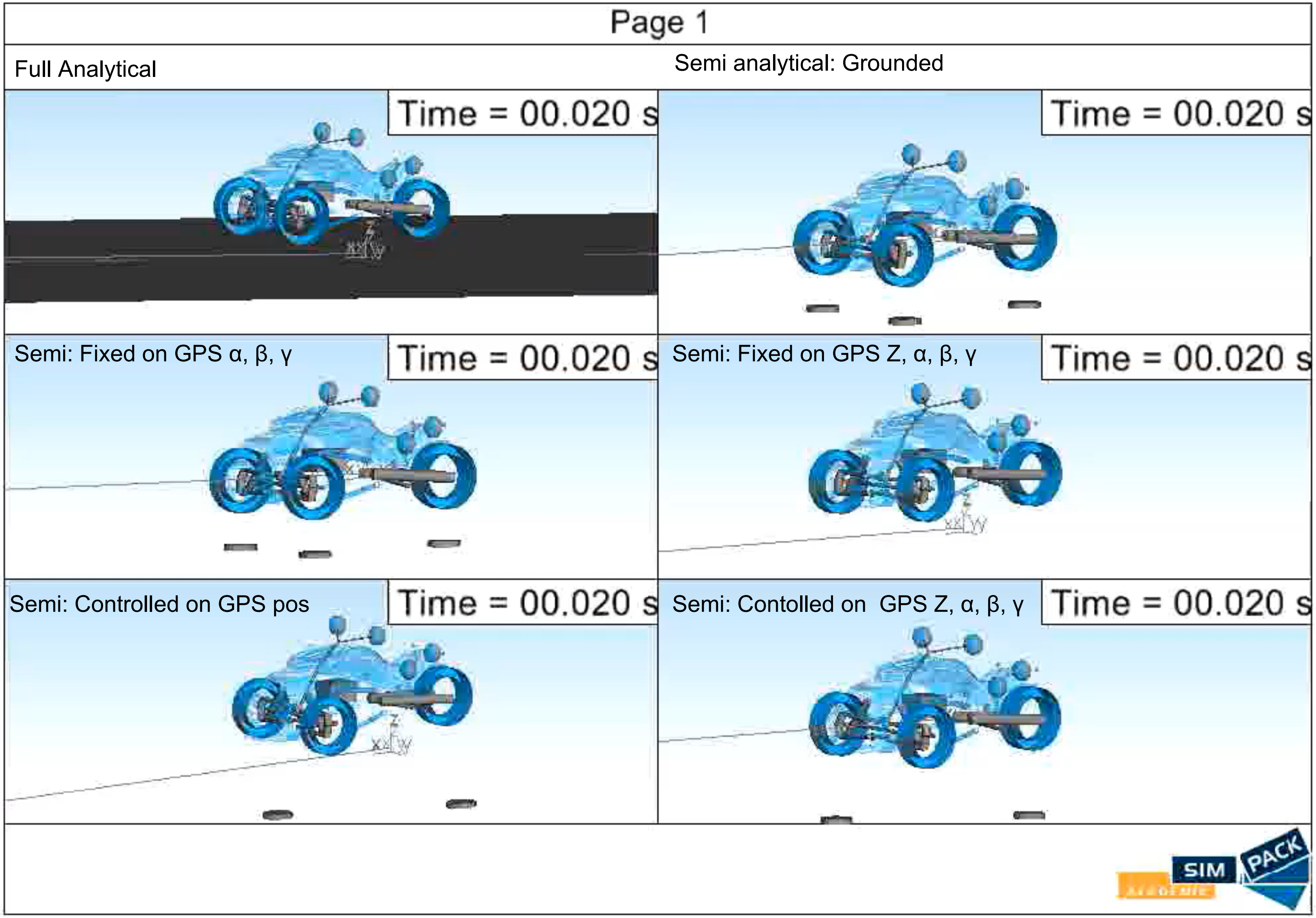
- Chassis position control
  - 4 Simpack Control Elements
  - 2 Position sensor to know position and angular error
  - 2 PDT1 Controller (Proportional + Derivative + Low Pass Filter)
  - 6 Force elements applying forces and torques on the vehicle frame

$C_CGPositionErr
$C_CGAngleErr
$C_CGPosController
$C_CGAngController

- Wheel speed control
  - 4 Simpack Control Elements per wheel
  - 1 Sensor for position error
  - 1 Reference coming from an input function
  - 1 PDT1 controller for 2 wheels
  - 1 Force element per wheel

$C_WheelsSpeed
$C_WheelsSpeedRef
$C_WheelSpeedErrL
$C_WheelSpeedErrR
$C_WheelsSpeedControl

Simpack model: Semi-analytical methods



Evaluation of the methods

Evaluation of the error in the loads

- The error is evaluated between the full-analytical reference signal and the semi-analytical result

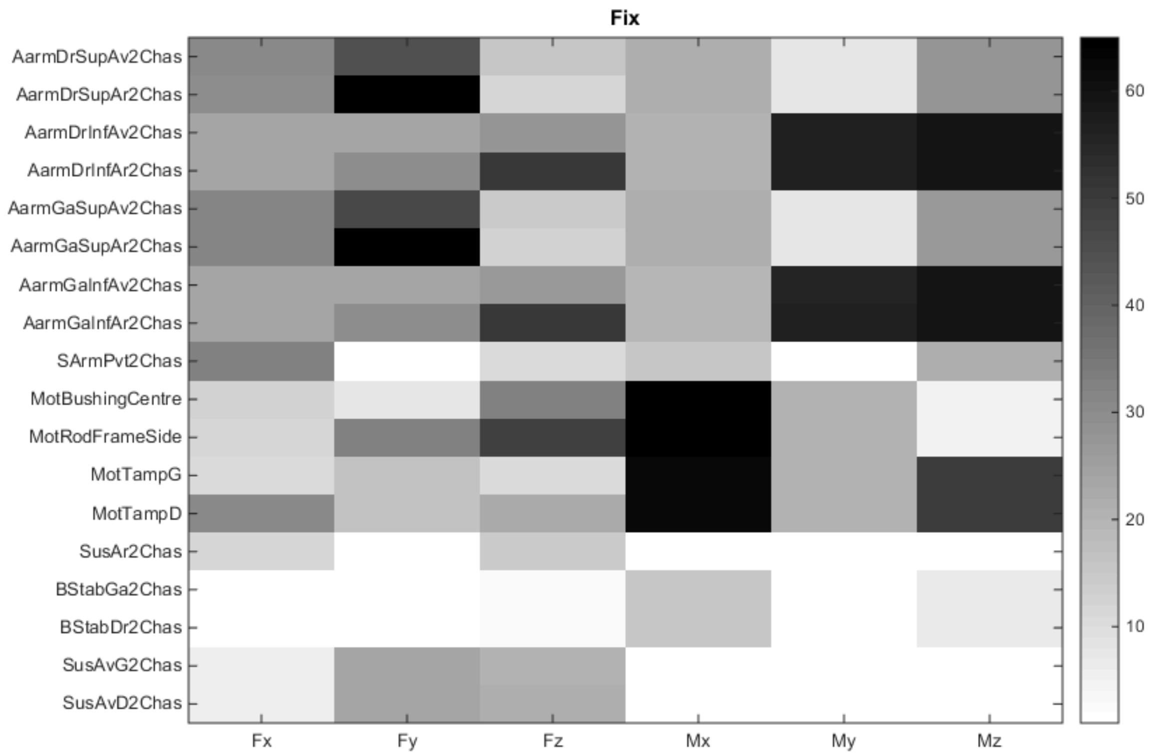
- The error is then affected by a gain factor depending on the sum of the abs value of the reference and the abs value of the result, thus neglecting error when both reference and result are of very low amplitude.

- The error coefficient obtained is the ratio between the RMS value of the weighted error and the RMS value of the reference

$$R = \frac{RMS(g(ref,res)e)}{RMS(ref)} \qquad g = \min\left(1, \frac{abs(ref) + abs(res)}{[500;5]}\right) \qquad e = ref - res$$

Evaluation of the methods

Steep ramp: Grounded chassis



Mean error	Max error	Standard deviation
24,32%	77,04%	19,34%

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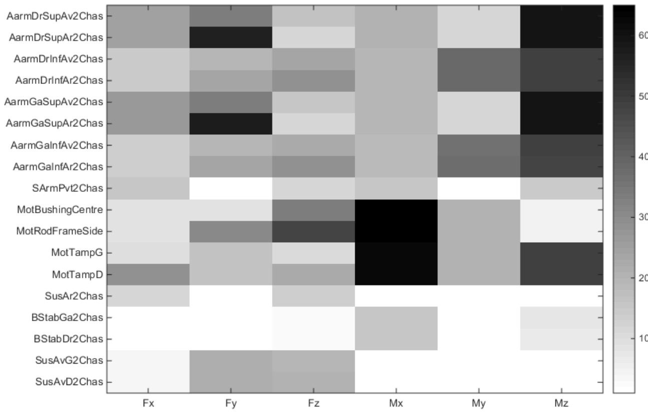
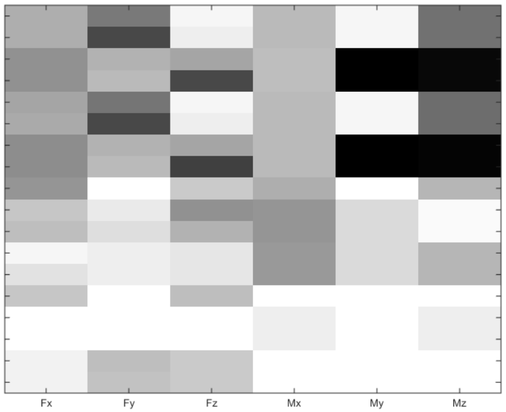
Evaluation of the methods

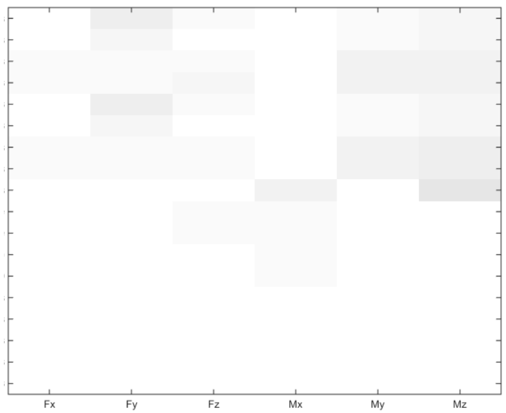
Steep ramp: Comparison of methods



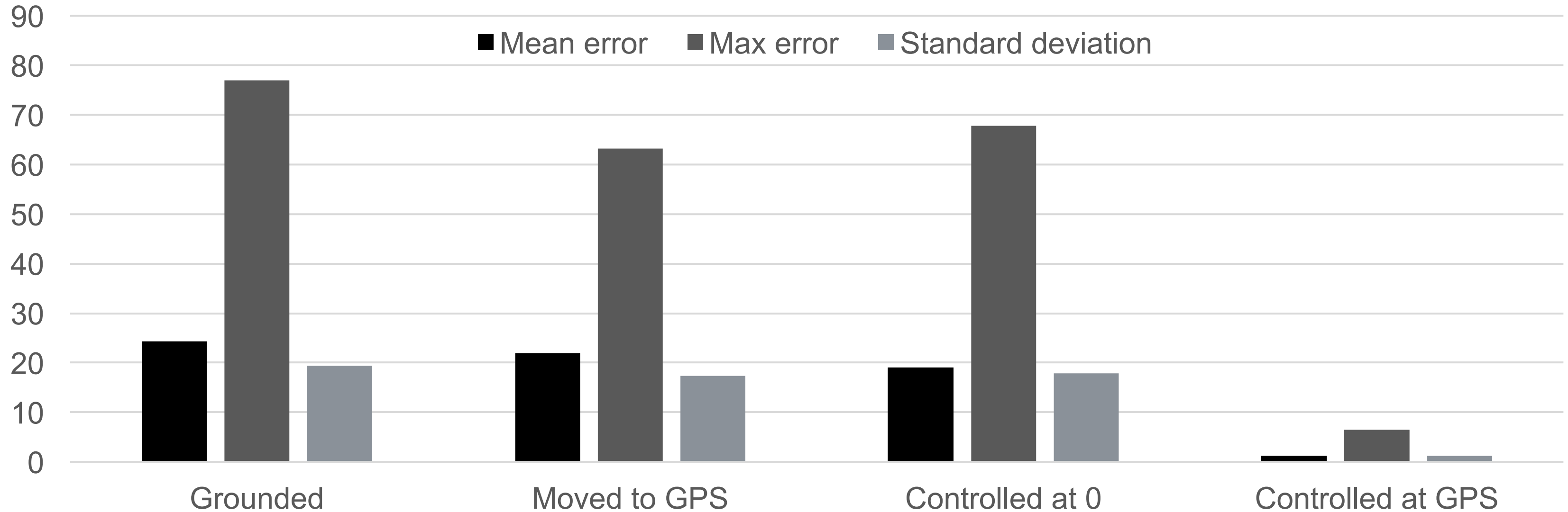
Chassis moved to GPS pos.



Chassis controlled around origin

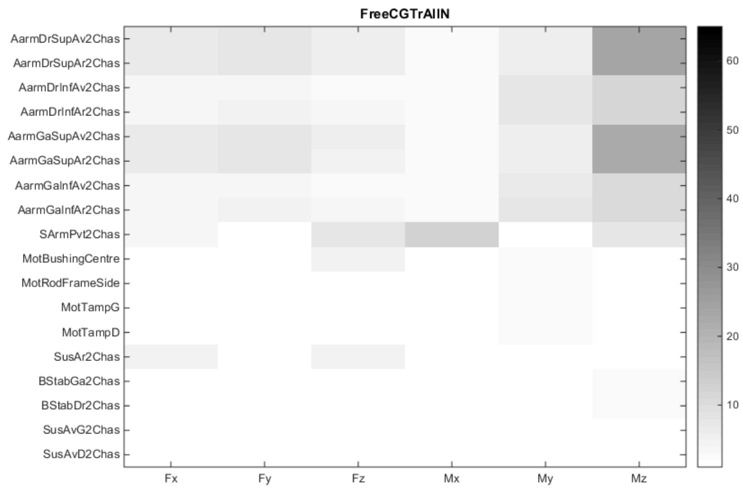


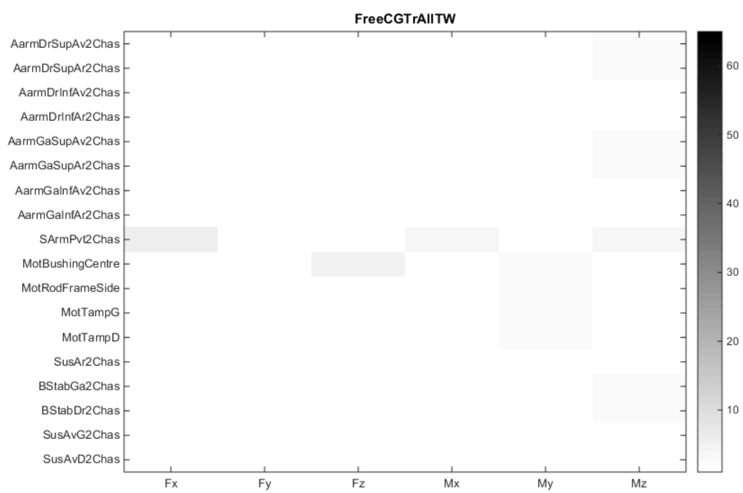
Chassis controlled around GPS pos.

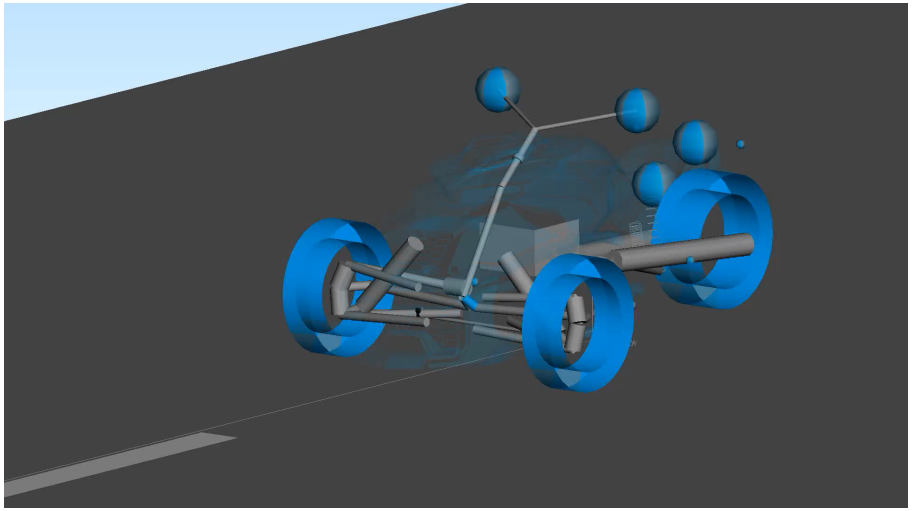


Evaluation of the sensitivity to simplifications

Effect of the wheels dynamic: Hard braking



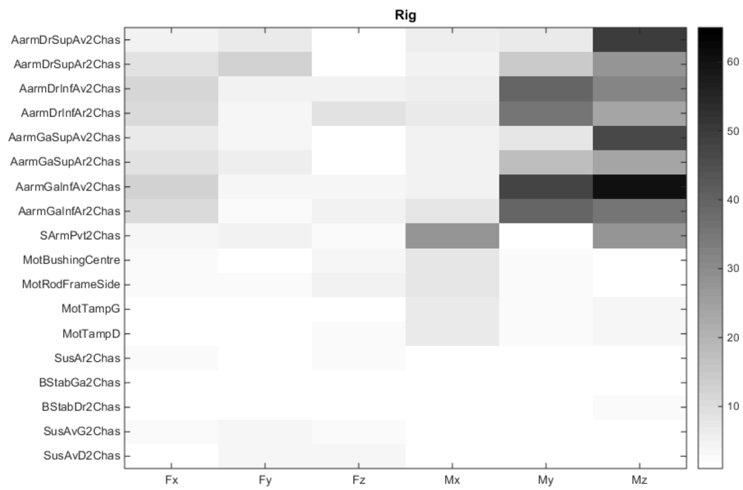


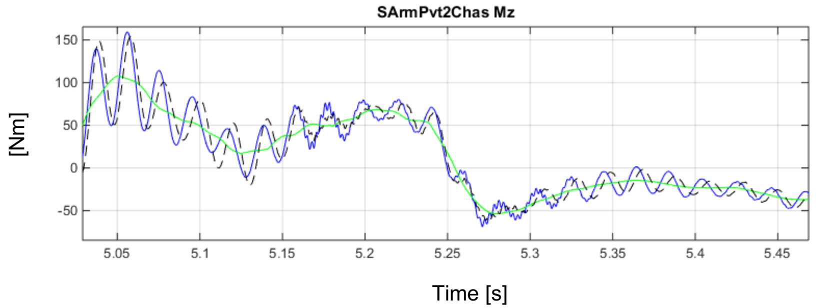


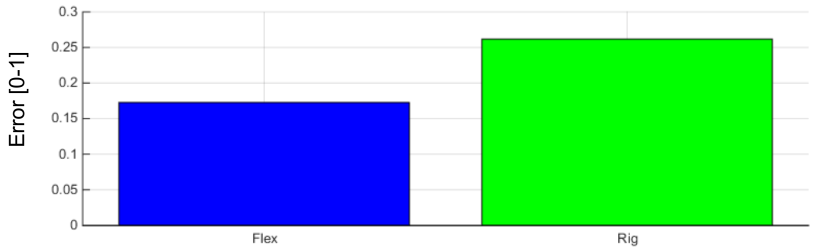
	Mean error	Max error	Standard deviation
Friction	3,37%	22,25%	4,68%
Control	0,42%	4,11%	0,69%

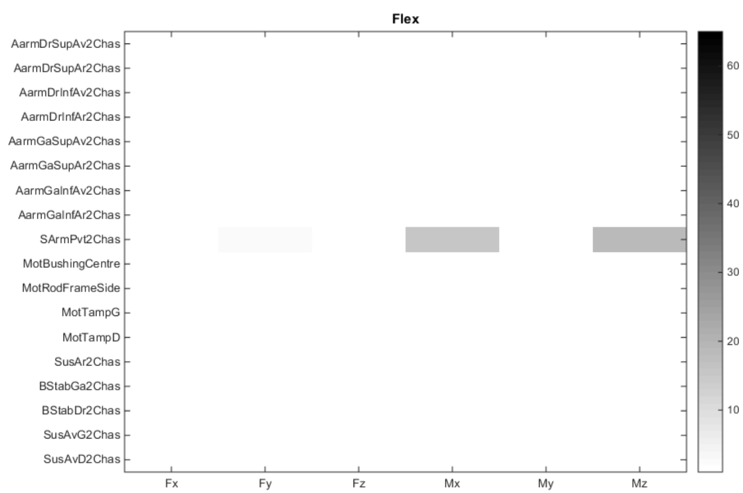
Evaluation of the sensitivity to simplifications

Flexbodies: rear swing arm - Steep ramp test at 2000 Hz









	Mean error	Max error	Standard deviation
Rigid	7,78%	59,62%	12,45%
Flexible	0,46%	17,27%	2,24%

Conclusions

- MBD semi-analytical simulation allows to retrieve frame loads with sufficient accuracy
- Best semi-analytic method tested
  - Controlled frame on GPS position, controlled wheel speed and flexible A-arm

- Flexibility of the suspension parts must be taken into account
- Internal forces must be taken into account
  - Brake
  - Motor torque and drivetrain
- Some aspects are still in progress:
  - Flexible chassis
  - More fatigue-relevant comparison method

References

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- Tebbe, James C., Vivek Chidambaram, Jason T. Kline, Sam Scime Jr., Manish P. Shah, Mine Tasci, et David Zheng. 2006. « Chassis loads prediction using measurements as input to an unconstrained multi-body dynamics model ». In *2006 SAE World Congress, April 3, 2006 - April 6, 2006*. SAE Technical Papers. SAE International. doi:10.4271/2006-01-0992.

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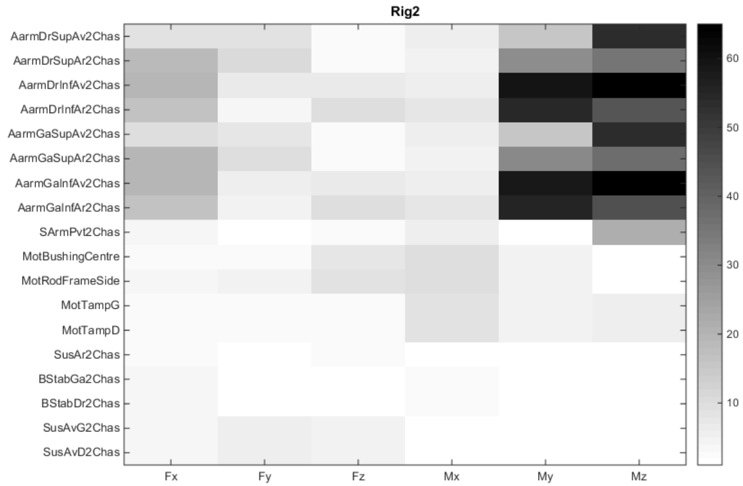
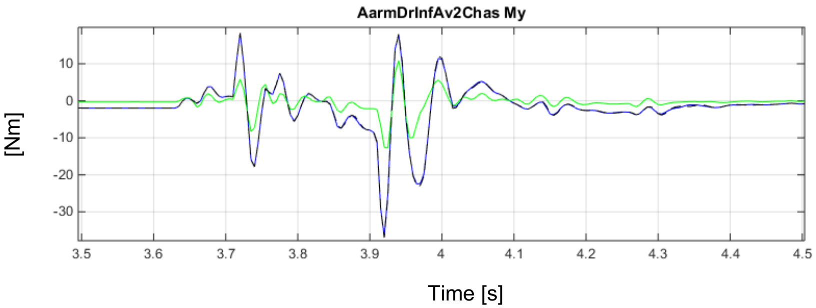
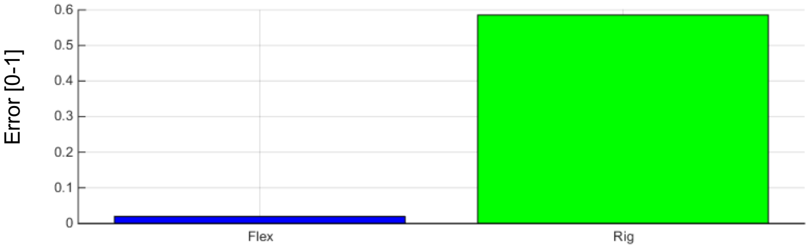
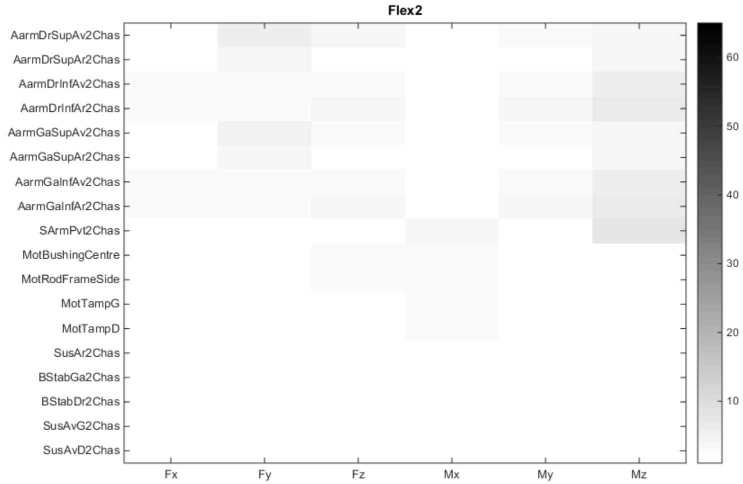
Evaluation of the sensitivity to simplifications

Flexbodies: front A-Arms - Steep ramp test





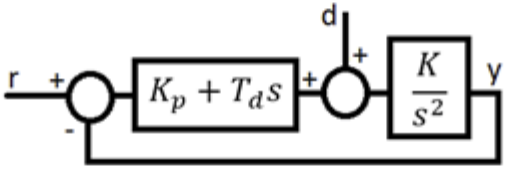




	Mean error	Max error	Standard deviation
Rigid	11,47%	88,11%	18,01%
Flexible	1,28%	6,55%	1,16%

Control : Details

- R: reference position   y: actual position
  K is representing the mass or inertia of the system, d is the interaction between degrees of freedom



$$\frac{Y(s)}{r(s)} = \frac{KT_d s + KK_p}{S^2 + KT_d s + KK_p}$$

$$\frac{Y(s)}{d(s)} = \frac{K}{S^2 + KT_d s + KK_p}$$

- For stability according to Routh-Hurwitz, Td and Kp must be greater than 0

$$\begin{array}{cc} 1 & KK_p \\ KT_d & \\ \frac{KK_dT_d}{K_d} & \end{array}$$