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Improving skid-steering on a 6x6 all-terrain vehicle

A preliminary experimental study

KOKOON project
www.kokoon.fr.st

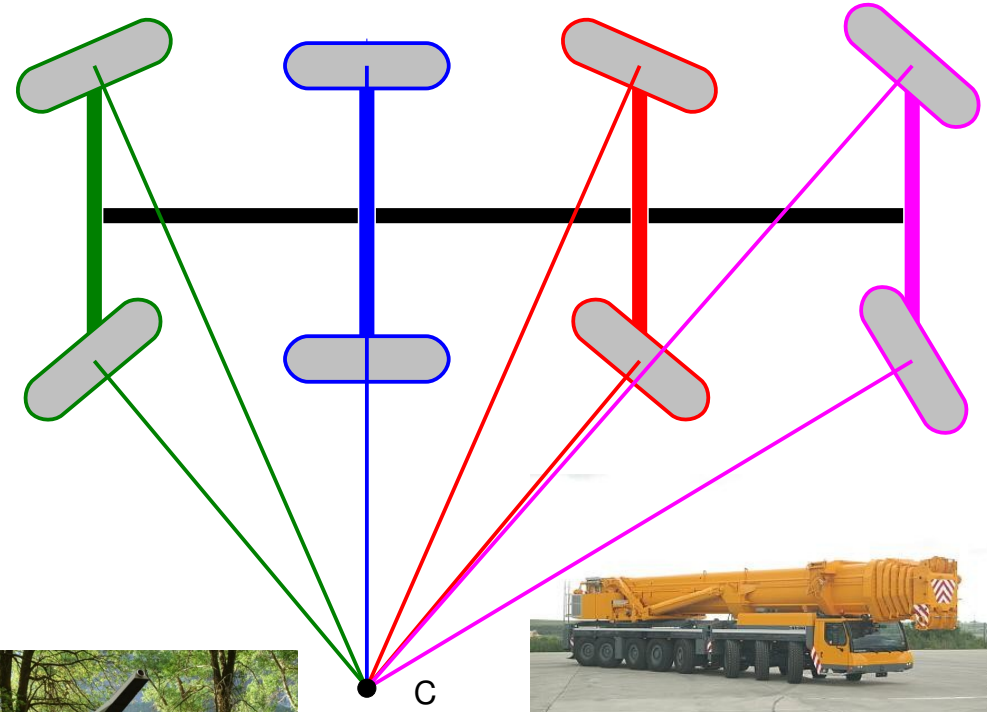
IFToMM 2007, The 12th World Congress in Mechanism and Machine Science
June 17-21, Besançon, FRANCE

Introduction to the problem

- Two existing principles for steering a wheeled vehicle
  - **Ackermann** steering
  - **Skid**-steering
- Our purpose
  - To keep the **robustness** and mechanical **simplicity** of skid-steering vehicles
  - Trying to minimize the **energy consumption** of such vehicles during steering
- A complex phenomenon, difficult to model
- Preliminary experimental results to check consistency
  - Evaluate the **ripping forces**
  - Try to **minimize** them...
  - ...by adjusting **normal contact forces**

Ackermann steering

- Ackermann (1817) / Jeantaud (1870)
- For wheeled vehicles that steer with **minimal skid**
- With **N** axles, **(N-1)** axles must steer at least
- Mostly for hard ground



Tricycle scooter, Piaggio MP3

Power lift truck, Manitou M26

Mobile mortar, Patria NEMO

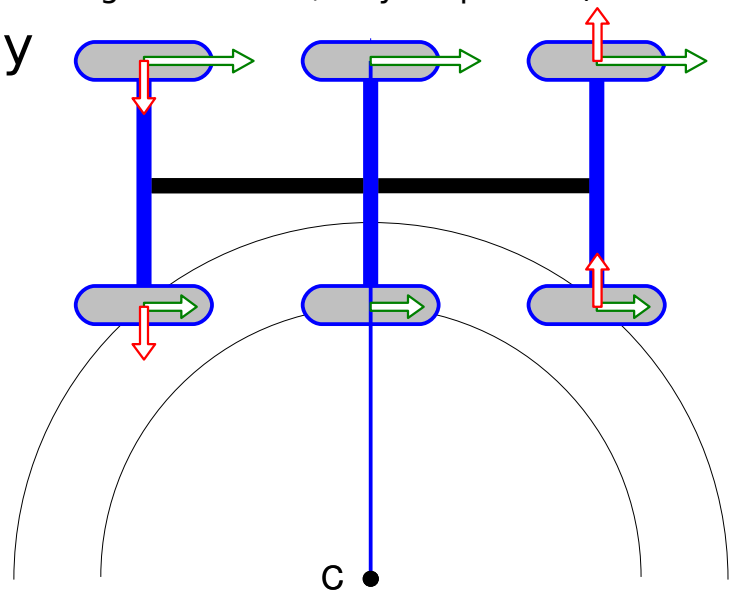
Mobile crane, Liebherr 1500-8.1
6 steering axles out of 8

Semi-trailer
1 steering axle out of 5 + 1R

- **Minimal skid** vs. **complexity**

Skid-steering

- For wheeled and tracked vehicles
- Mechanical **simplicity** (no steering mechanism, only suspension)
- Wheels cannot roll laterally
- Mostly for low friction / soft grounds



Two versions of the same mobile mortar Ackermann and Skid-steering tracked, Patria AMOS

Amphibian ATV, Oasis LLC Max 6x6

Tracked tractor, Caterpillar D6R III

Mobile robot, Pioneer 3 AT

AT wheelchair, Modul Evasion

- **Simplicity** vs. **turning resistance**

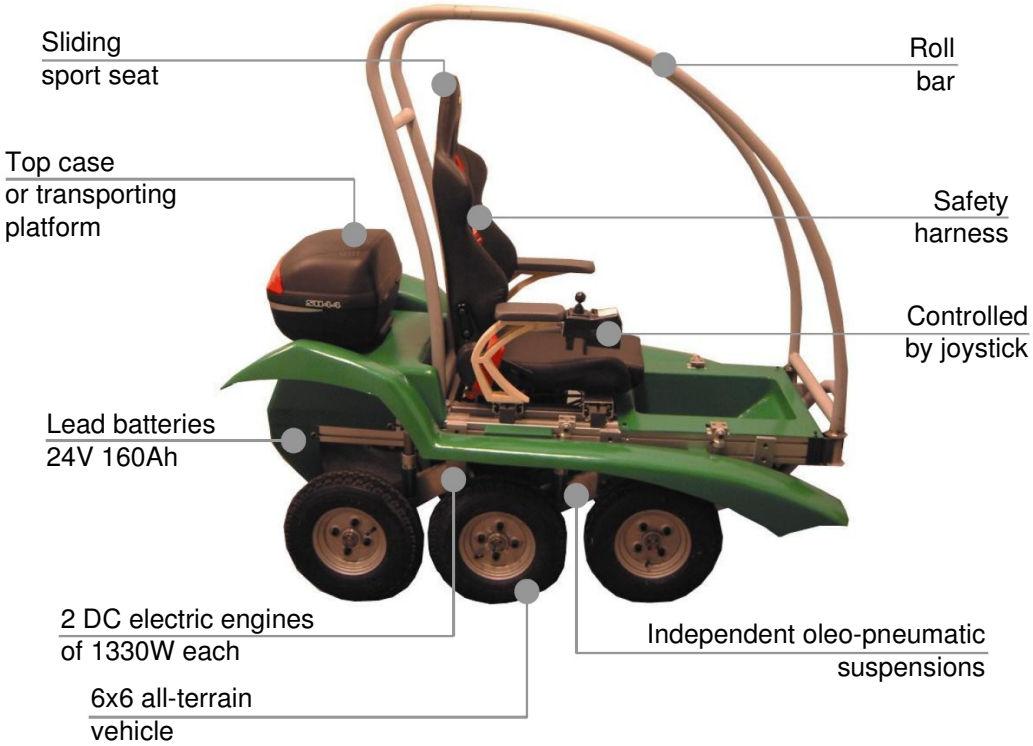
Overview of the 6x6 Kokoon vehicle

- An **ATW** (**A**ll-**T**errain **W**heelchair)
- **6x6** transmission and **2x**1330W **electric engines**
- Oleo-pneumatic **suspension** on all wheels
- **Climbing** capacity: 20cm obstacles, 36% slopes
- **Speed**: 8 km/h **Autonomy**: 4h

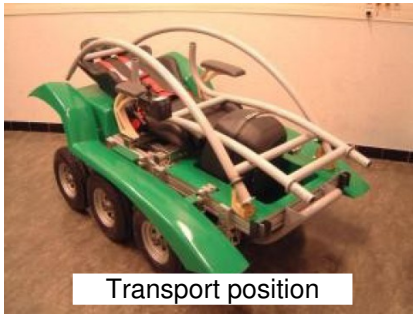
Designed at IFMA from 1999

Overview of the 6x6 Kokoon vehicle

- Multiple functions



Improved access: sliding seat



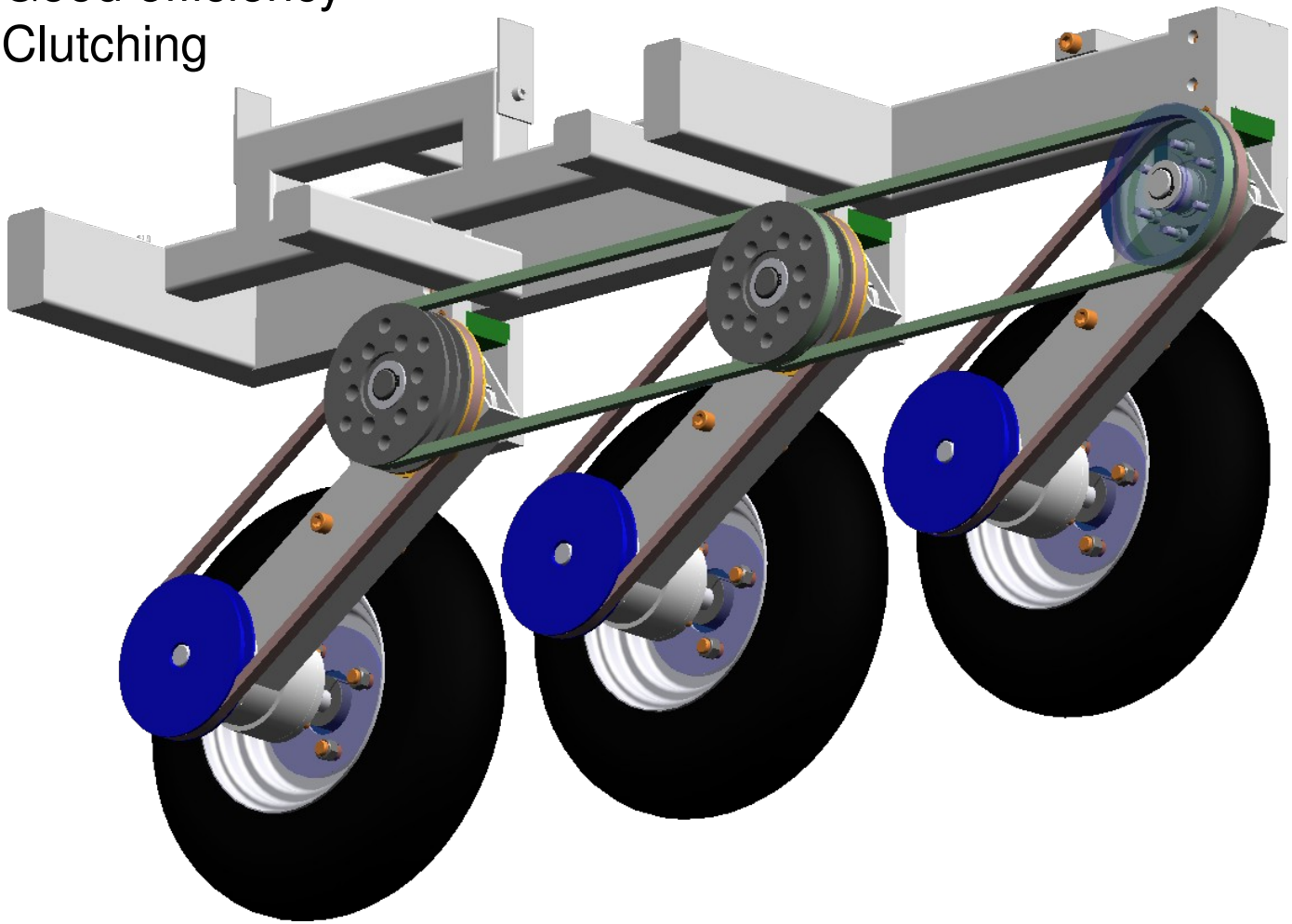
Transport position

- **Skid steering** for robustness and all-terrain mobility
- A **reconfigurable** vehicle
- A research platform with **sensors**

Research configuration with onboard camera, double acquisition laptop and suspension sensors

Vehicle transmission

- Belt transmission: 3 wheels at the same speed
- Compatible with suspension displacements
- Good efficiency
- Clutching



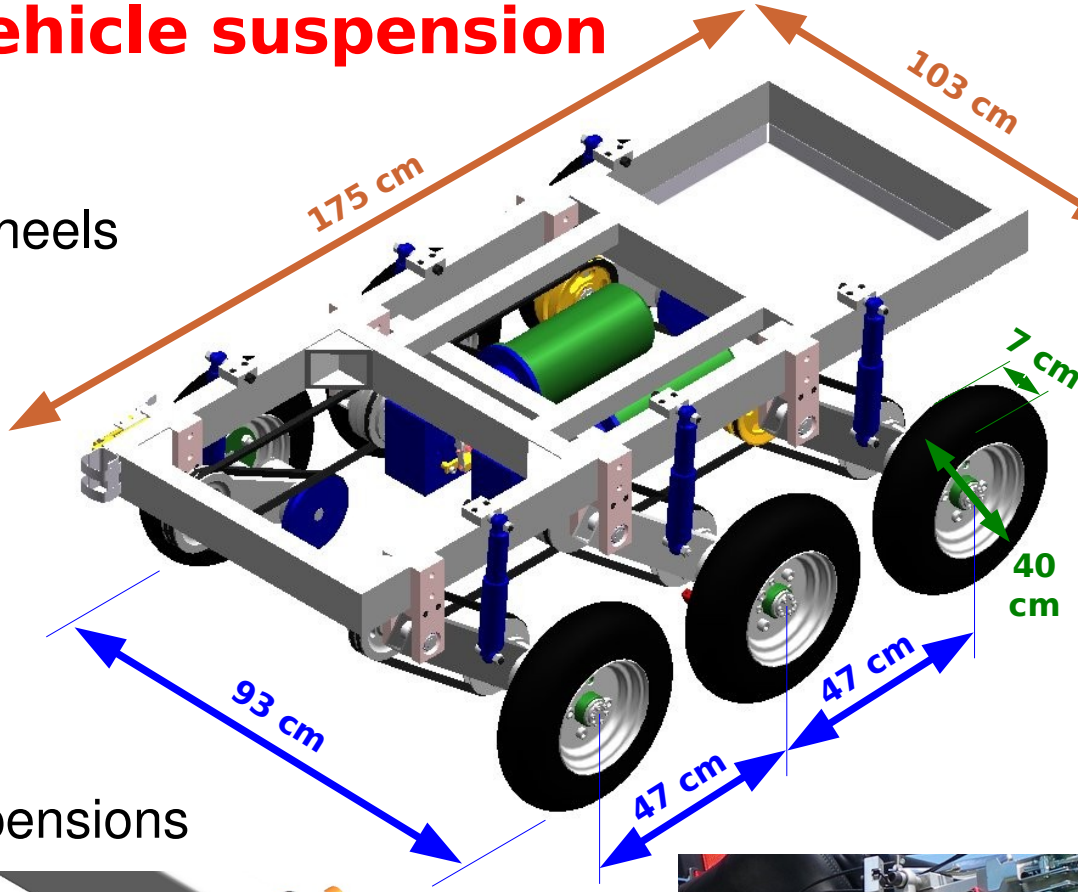
Vehicle suspension

- 6 Independent wheels

  - Length = 175 cm
  - Width = 103 cm

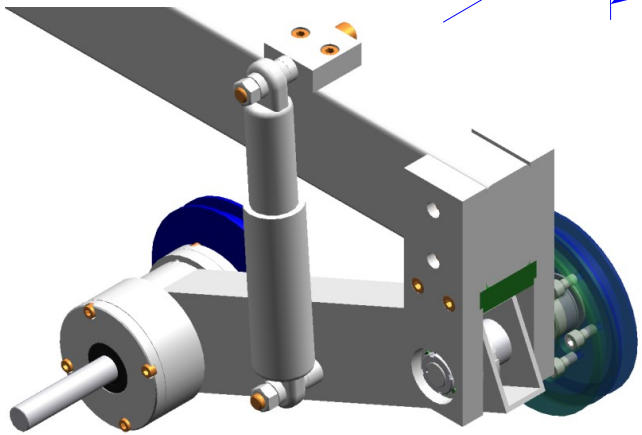
  - Track width = 93 cm
  - Wheel base = 47 cm

  - Wheel diam. = 40 cm
  - Wheel width = 7 cm



- Trailing arm suspensions

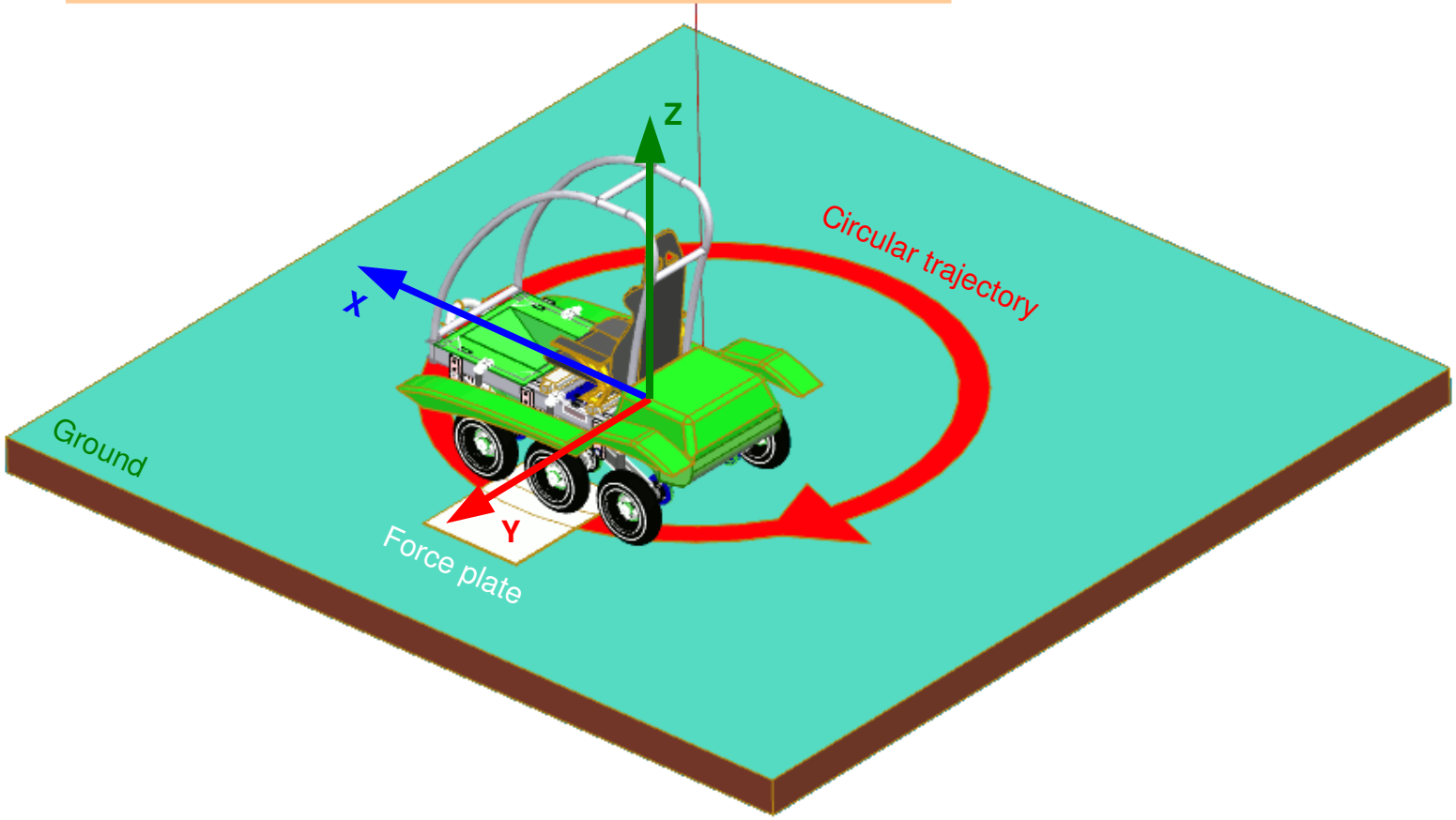
  - Robust
  - Easy to adjust
  - Oleo-pneumatic shock-absorber



The force plate

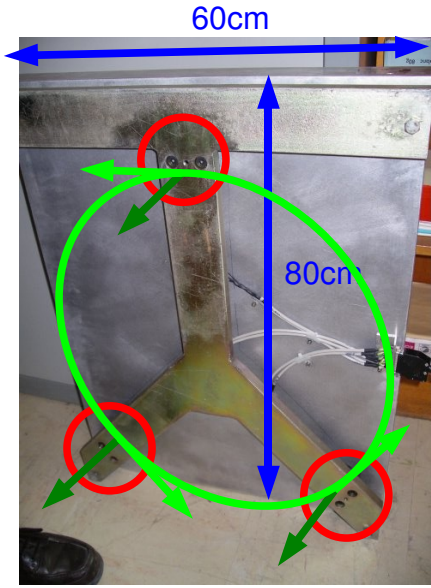
- **Steady-state** circular turning
- A force plate to measure contact reaction forces

- **Rx** longitudinal force provided by the engines
- **Ry** lateral force due to ripping
- **Rz** normal force due to mass dispatching

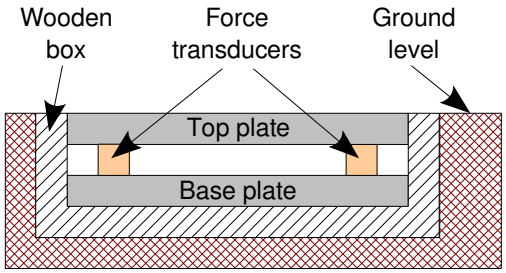


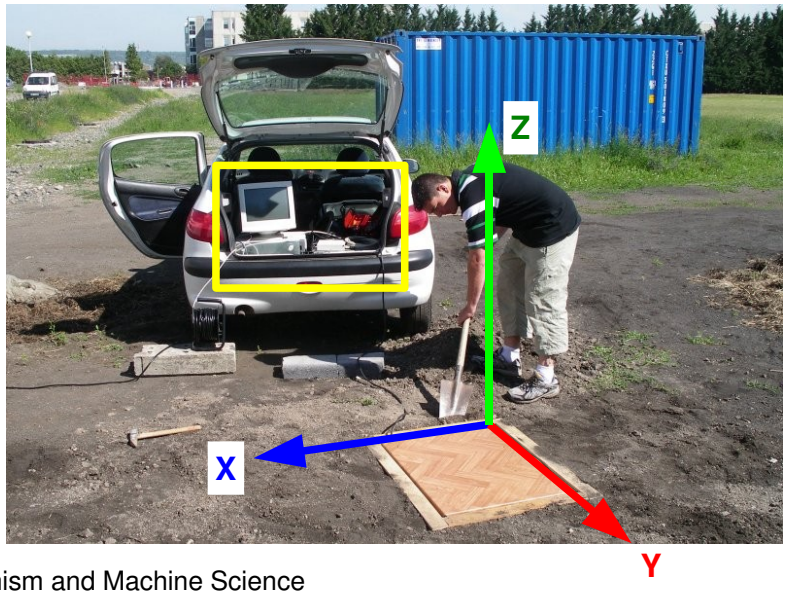
The force plate

- A **six-component** force plate (TSR, France)
- Force measurement **ranges**:
  Rx: 1000N **Ry: 900N** **Rz: 2000N**
- 3 two-component strain gauge transducers at 120°
- 3 **tangential** components (**Rx**-**Ry**)
- 3 **normal** components (**Rz**)
- Acquisition chain: 6 channels, 16 bits, 100Hz, Labview
- Wrench = 6x6 Calibration matrix **x** Tensions



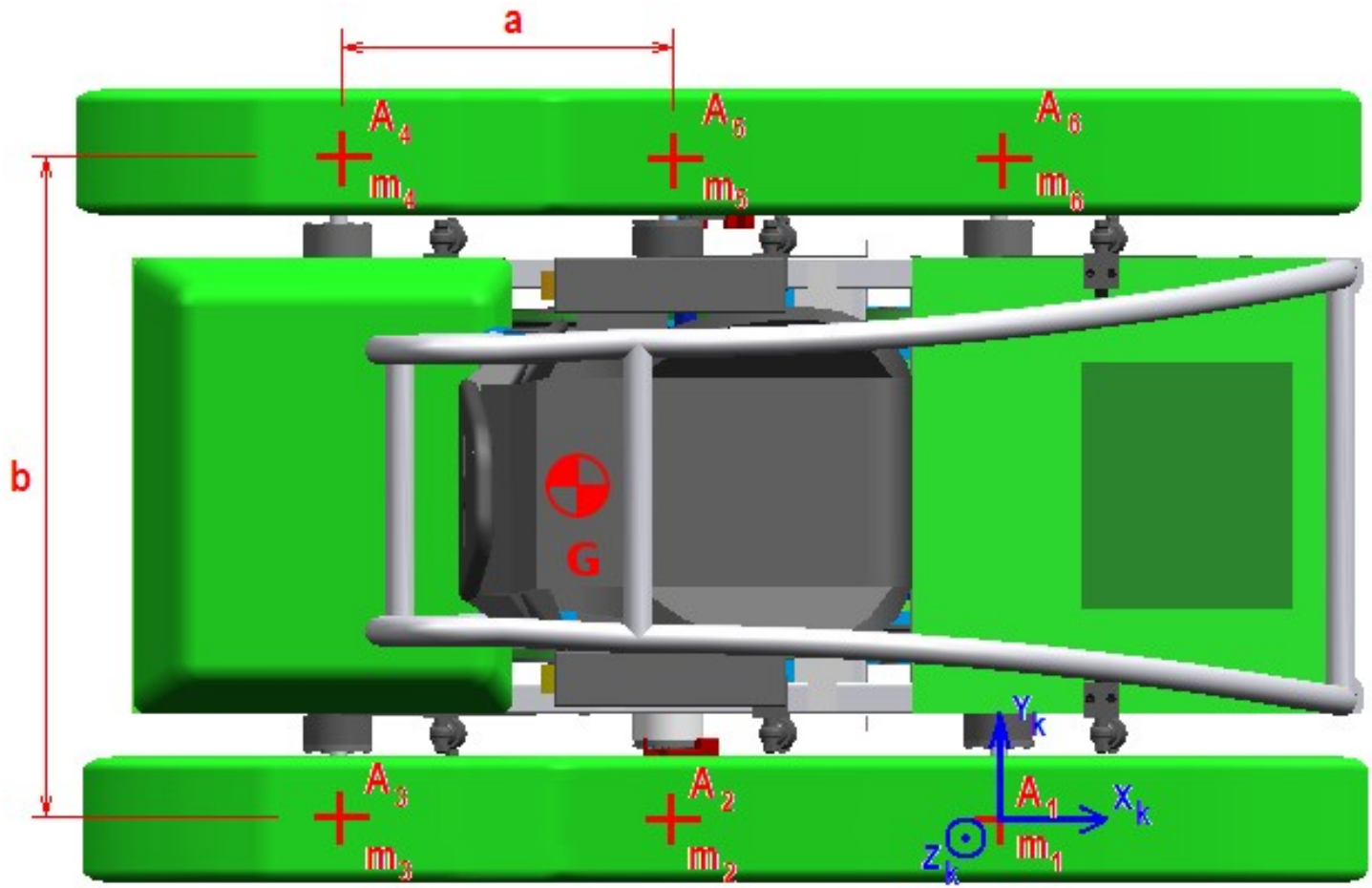
$$\begin{pmatrix} F_x \\ F_y \\ F_z \\ M_x \\ M_y \\ M_z \end{pmatrix} = [C] \begin{pmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \\ V_5 \\ V_6 \end{pmatrix}$$





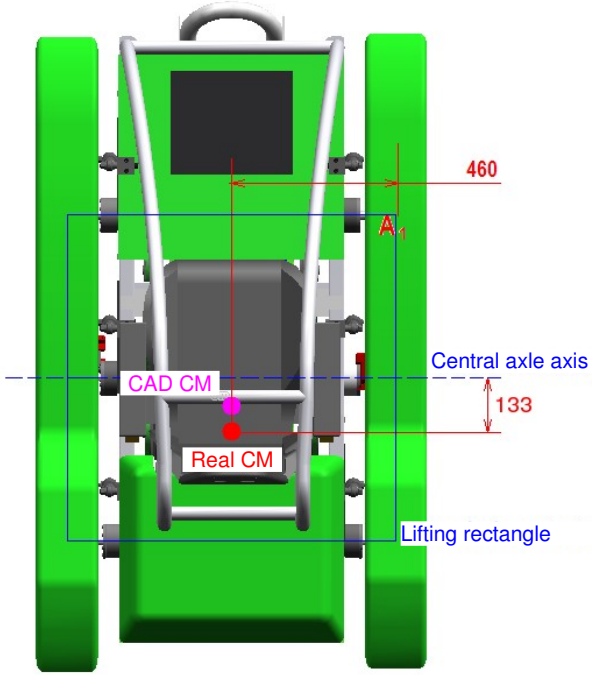
Mass dispatching

- Centre of mass is computed with the CAD model
- Hypothesis : uniform density in each part
- Empty mass: 367 kg



Mass dispatching

- Experimental measurement
- 6 scales with the same height



- Good correlation Experiment / CAD

Suspension reconfiguration

Reconfigurable suspension

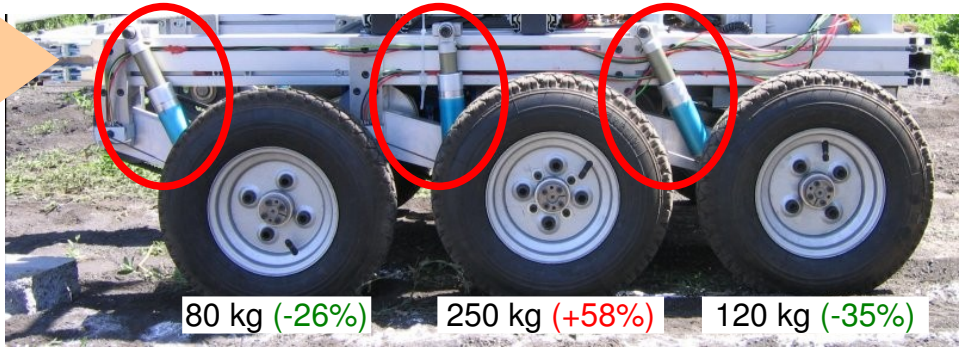
- **Reference** configuration
- Three identical suspensions

- Includes a 83kg driver

- **Modified** configuration
- Differentiated suspensions

- Central suspension becomes **more loaded**

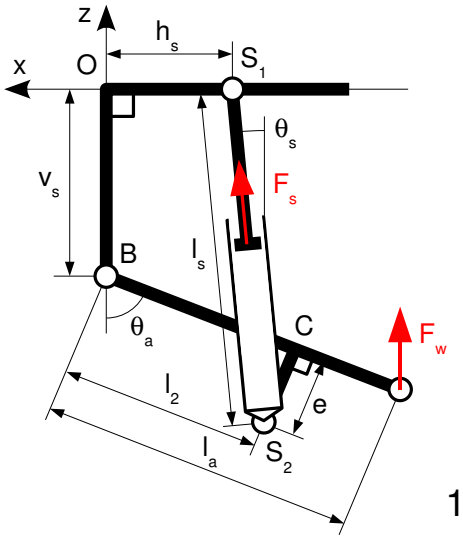
- A new **mass dispatching**



Reference dimensions

- Adjustment with $\mathbf{h_s}$
- **Initial** $h_s = 145$mm
- **New** $h_s = 045$mm

Parameter	Value
v_s	180 mm
$h_{s\,std}$	145 mm
$h_{s\,mod}$	45 mm
l_s	210-280 mm
l_2	170 mm
l_a	350 mm
e	15 mm

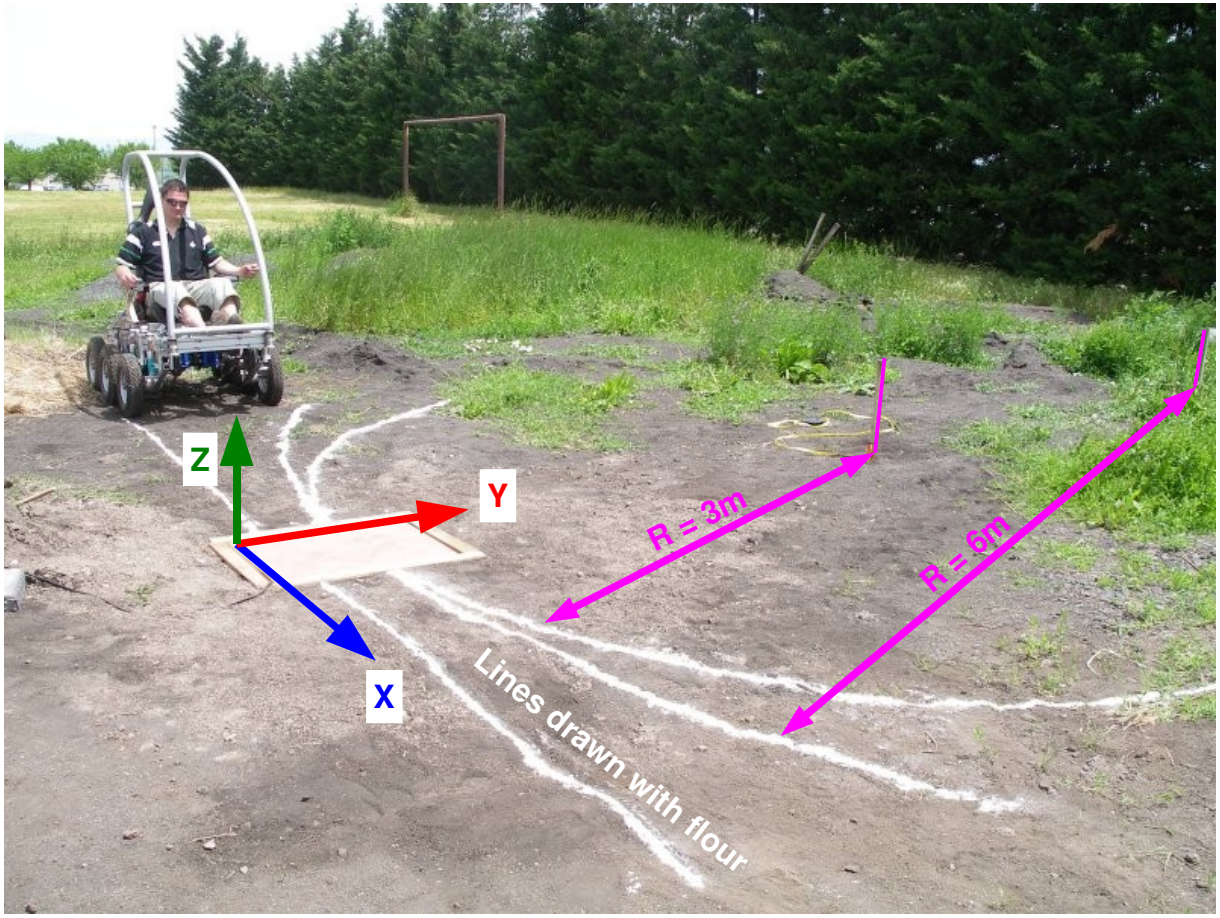


Turning experiment

- **Three** types of trajectories for the **external** wheels

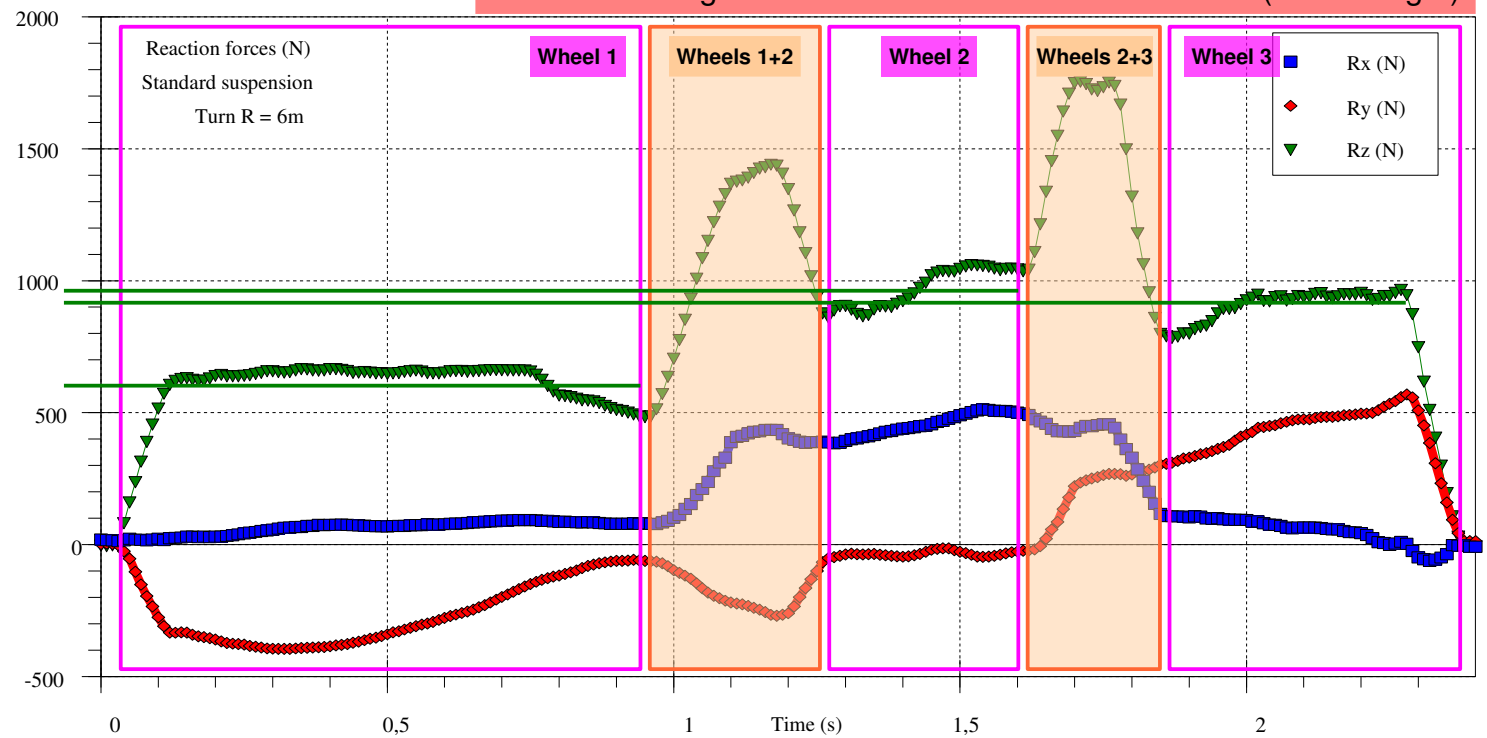
Radius R	Infinite (=> straight line)	6m	3m

- Acquisition at 100Hz is enough for low speed (around 4-5 kph)
- Duration: from **1.5s** (straight line) to **2.5s** (3m turn)



Typical curves

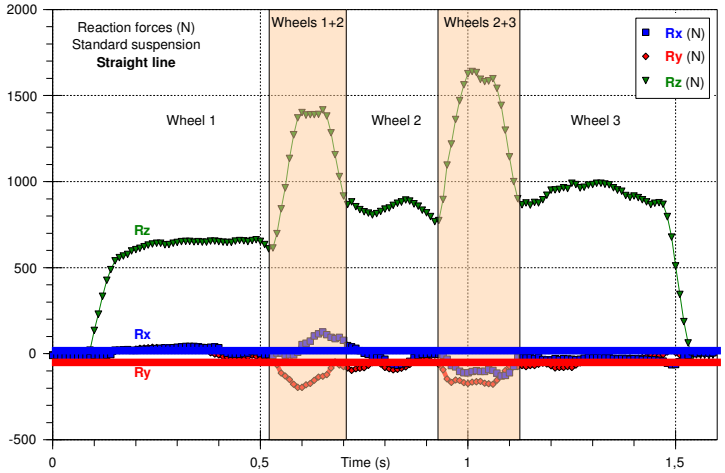
- Curves of **Rx**, **Ry**, **Rz** are provided
- **One** or **two wheels** on the force plate **at the same time**
- **Five zones** appear on the time axis
- **Average values** on each zone (vibrations on gravel and electric perturbations)
- **Rz1** = 627N **Rz2** = 972N **Rz3** = 905N (one side only)
- Main results:
  - Wheels **2** and **3** prevail for **Rz** -> confirms weight dispatching
  - Wheels **1** and **3** prevail for **Ry** and turning moment
  - Wheel **2** generates most of the traction force **Rx** (belt sliding ?)

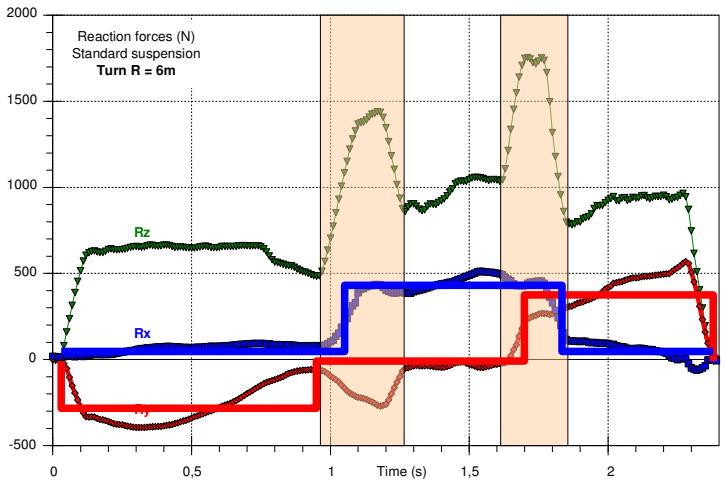


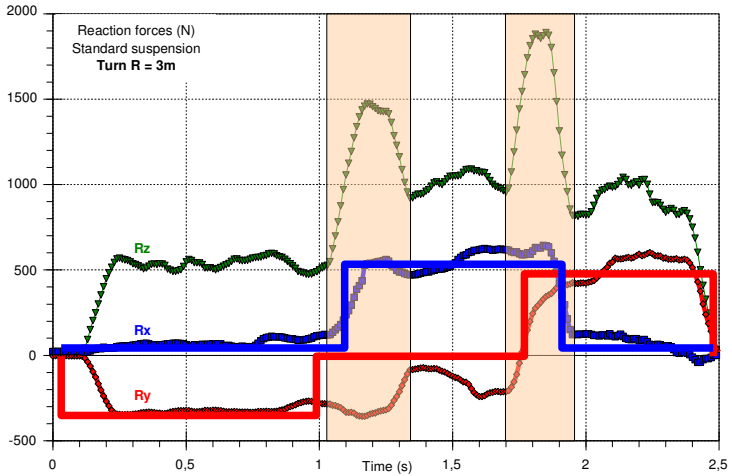
Improving Skid-steering

Fauroux / Vaslin / Douarre

- Introduction
- Vehicle
- Experiment
- Results
  - Curves
  - Reference
  - Modified
  - COP
  - Explanation
- Conclusion
- Future work







Results for reference vehicle

- Influence of **radius R**
- **Rz** does not changes with R
- **Ry** is quasi null in straight line
- **Ry** increases when R decreases
- **Rx** is quasi null in straight line
- **Rx** increases when R decreases
- This phenomenon was experienced by the driver

Results for modified vehicle

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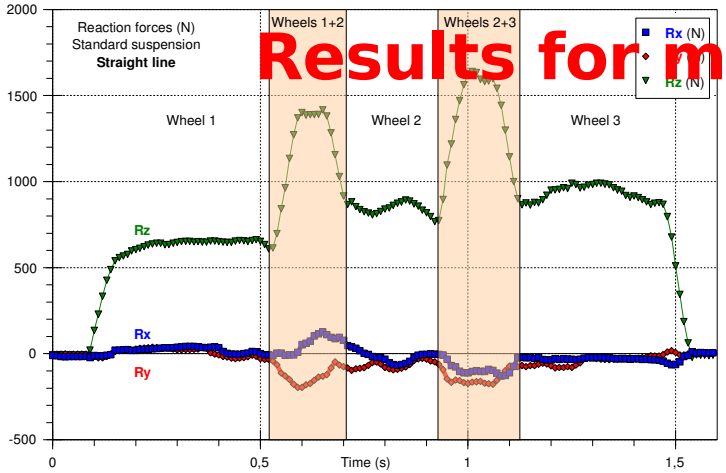
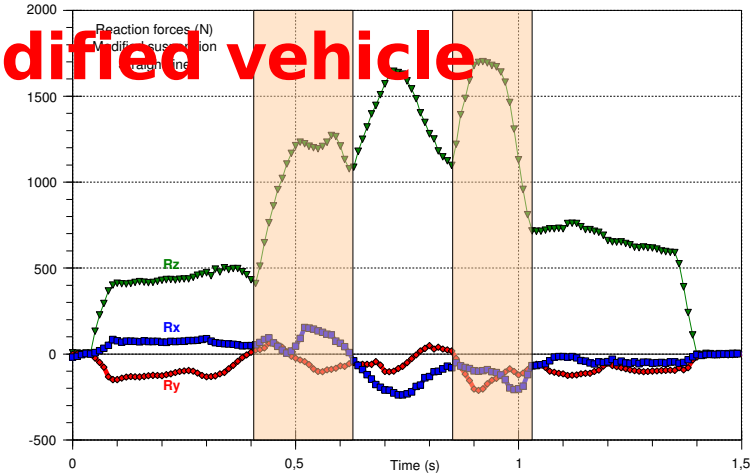
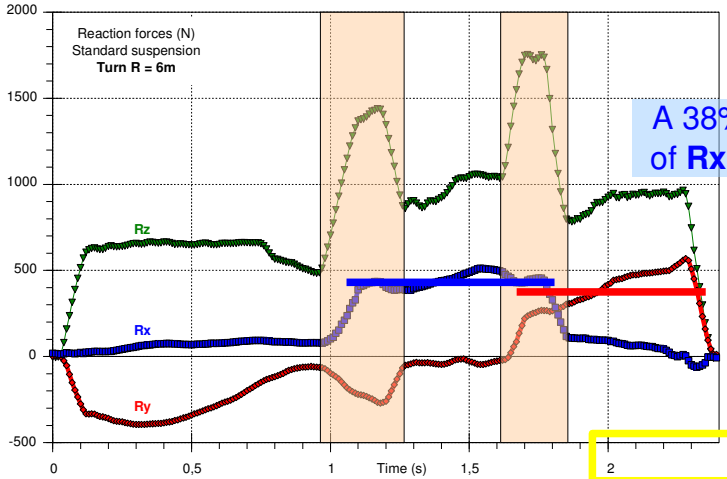
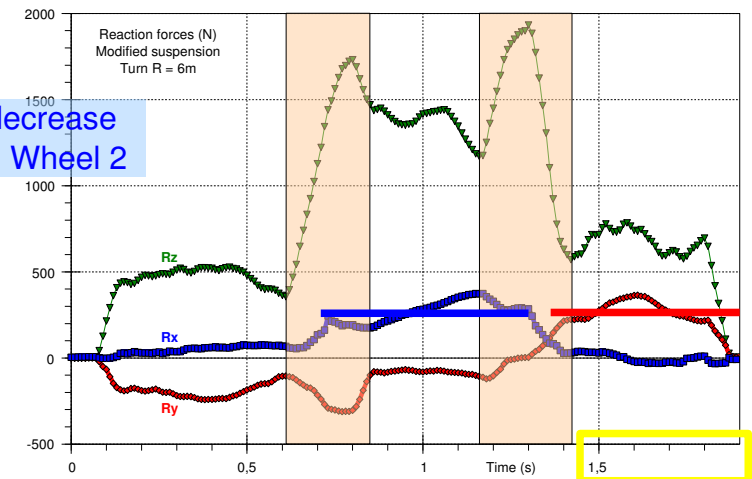
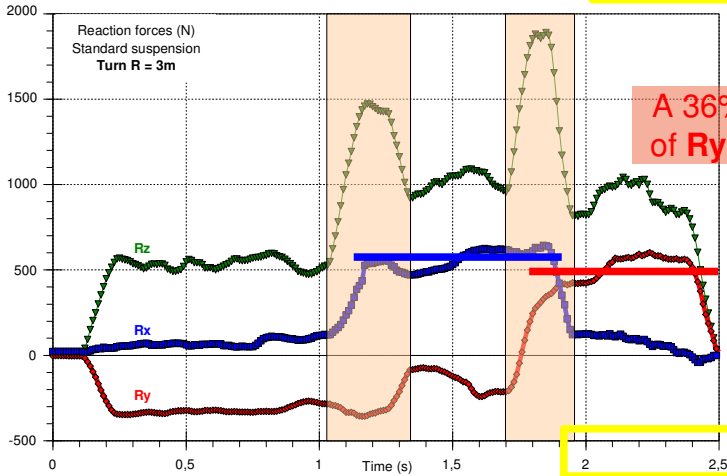




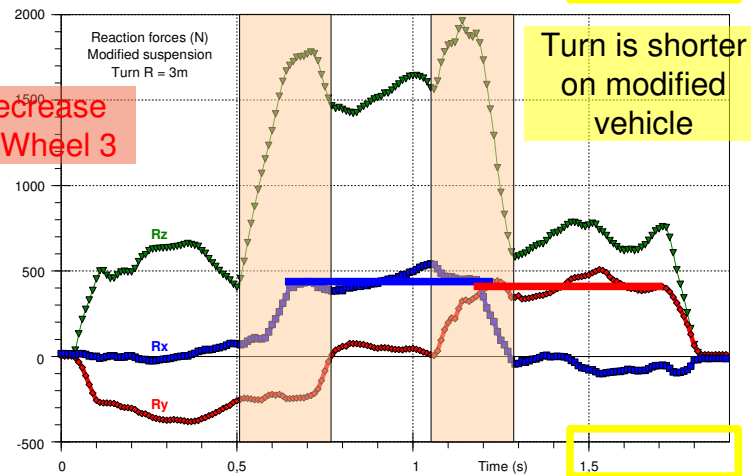


A 38% decrease of **Rx** on Wheel 2





A 36% decrease of **Ry** on Wheel 3



Turn is shorter on modified vehicle

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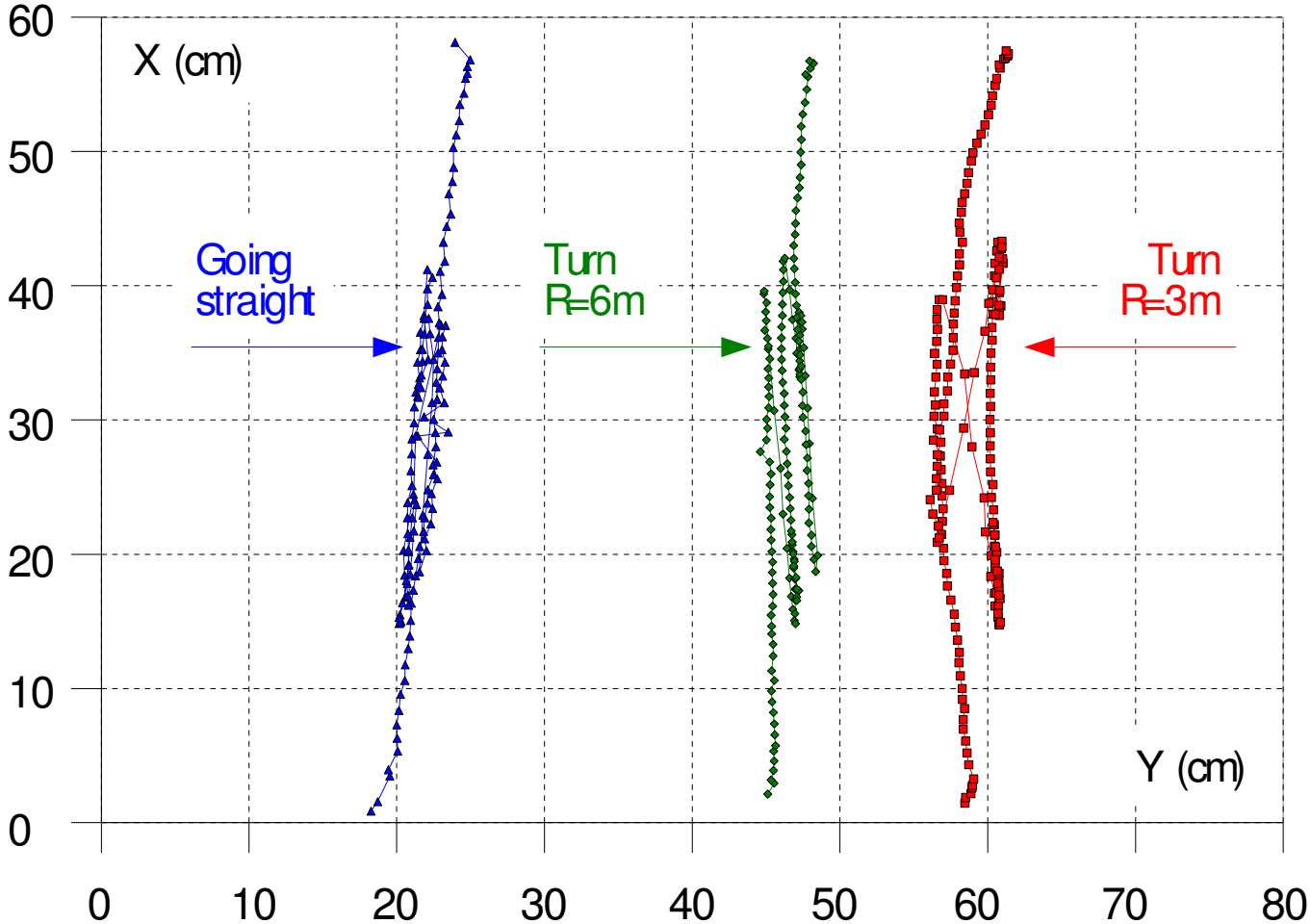
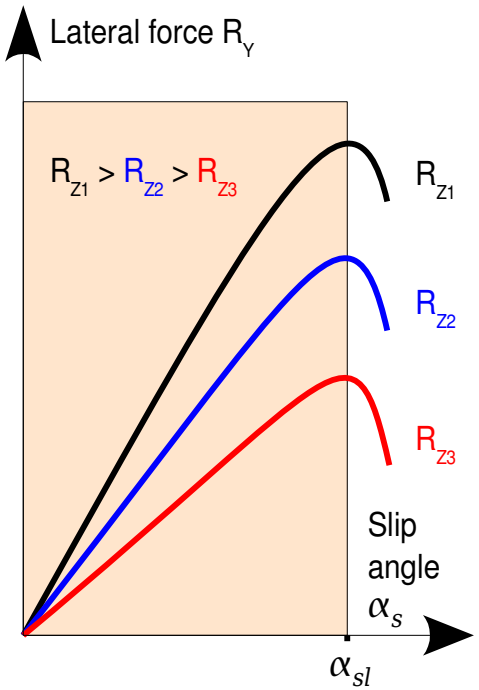
Centre of pressure (COP)

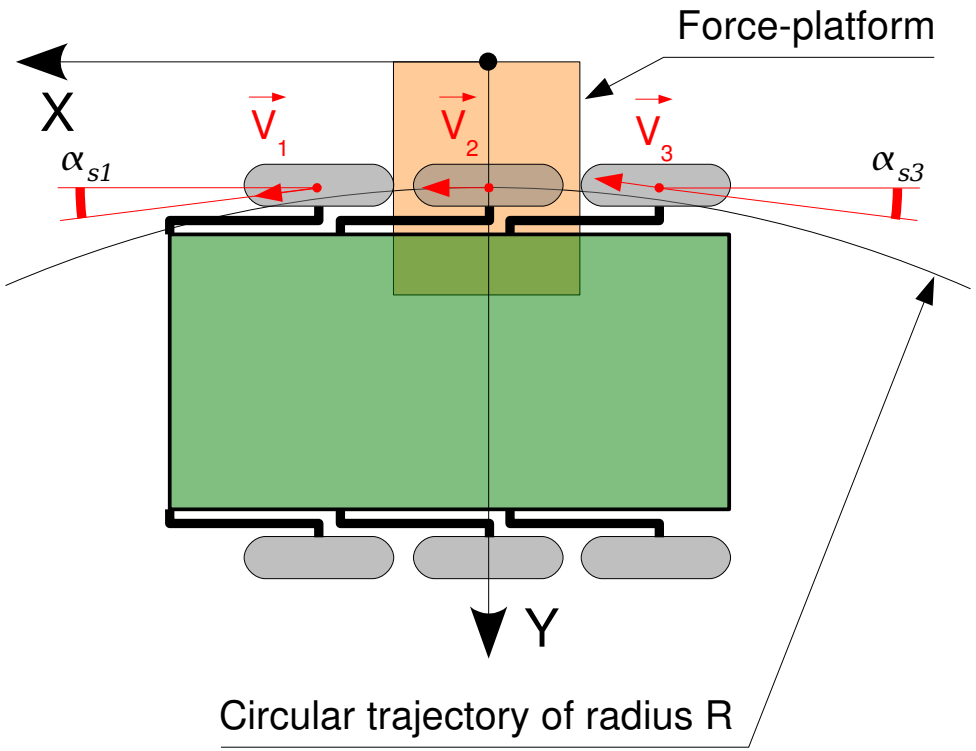
- **COP** = the point where the moment of contact wrench is null
- **Phases** are visible (one or two wheels on the force plate)
- The COP follows **circles** => Trajectories were correct



Physical explanations

- Strong influence of mass dispatching on turning ability
- Analogy with the behaviour of a road tire
  - Lateral force **Ry** increases with normal force **Rz**
  - Lateral force **Ry** depends also on slip angle α_s
  - Linear behaviour up to α_{sl}
  - During skid-steering, two slip angles α_{s1} and α_{s3} appear on wheels 1 and 3





Conclusion

- **Skid-steering** can be greatly **improved**...
- ...only by **minor** adjustments on the suspensions
- **10cm** adjustments only decreased normal force of **30%** on front and rear axles
- Propulsion forces decreased of **30%** when steering
- **Multi-axles vehicles** without steering systems are **robust**. They can now be **efficient** when skid-steering

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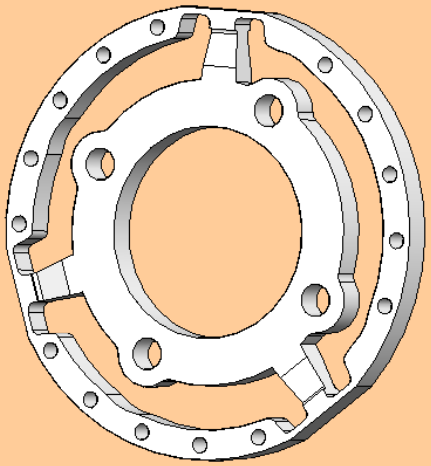
Future work

- Replace belts by chains to suppress sliding
- Add 6 force sensors inside the wheels for continuous measurement
- Build analytical model
- Towards an active correction system



TSR force sensor in a wheel

Acknowledgement

ANVAR : French National Agency for Development of Research

TIMS Research Federation Mobility pole

Michelin Company

...and many more on www.kokoon.fr.st

3 Videos