TIMS / LaMI
Mechanical Engineering Research Group

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Clermont-Ferrand II

IFMA
French Institute for Advanced Mechanics

A New Concept of FAST Mobile Rover with Improved Stability on Rough Terrain

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7th IARP Workshop
Robotics and Mechanical assistance in Humanitarian De-mining and Similar risky interventions
HUDEM'2010
10-12 May, 2010
National Engineering School of Sousse, Tunisia

Why going FAST ?

What ?

- FAST deployment
- Rapid analysis of broad areas
- Unstructured environment

Haiti earthquake
January 2010

Why ?

- Natural catastrophes
- De-mining
- Agriculture
- Security

Team of de-miners
in Afghanistan
(Reuters / L'Express)

FAST de-mining

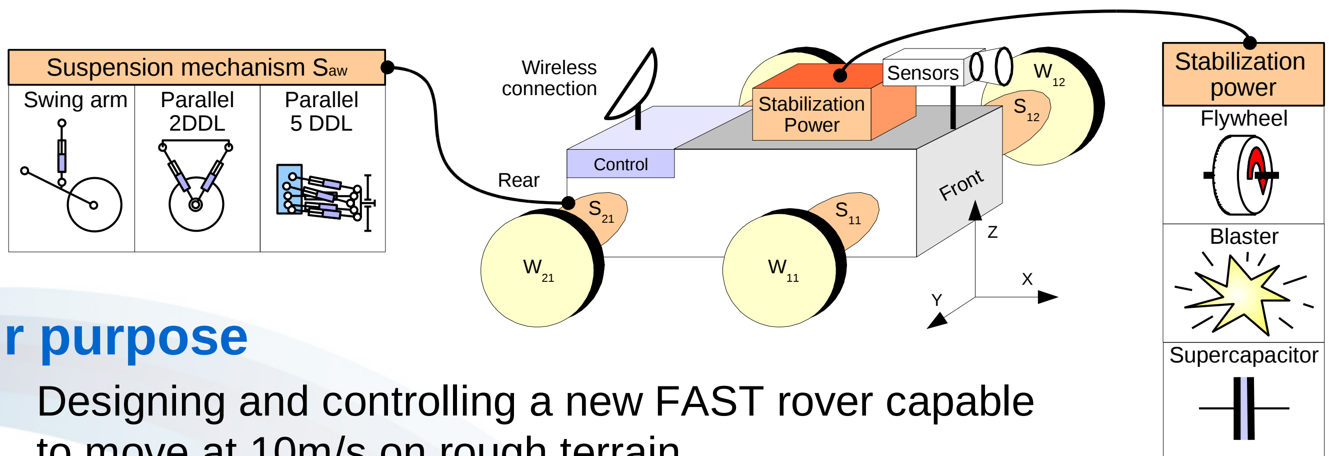
- Fast and safe
- More efficient than manual team de-mining
- Less destroying than mechanical de-mining
- A good compromise could be **a float of inexpensive small collaborating robots**

Krohn KMMC
www.mechanical-demining.com

The ANR FAST project

Who ?

- ANR Project of the French National Research Agency
- 2008-2011
- 3 academic partners / 1 enterprise
  TIMS / LAAS / ISIR / Robosoft



Our purpose

- Designing and controlling a new FAST rover capable to move at 10m/s on rough terrain
- 3 prototypes : 400kg, 150kg, 10kg
- Double purpose
  - High speed turning with lateral slipping
  - <u>Obstacle crossing in straight line</u>
- New mechatronics architectures
- Innovative suspensions

Types of grounds and obstacles

Ground description

- Mathematical surface (e.g. B-spline surface)
- Continuity: C^0 (no hole), C^1(tangency), C^2(curvature)...
- Modelling depends on the size of the vehicle (wheel radius $r = 0{,}25m$)

Ex: a structured ground for a man can be unstructured for an insect

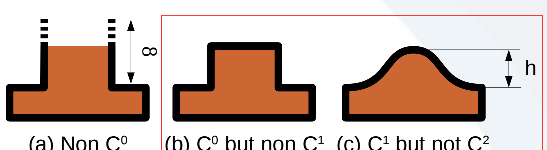
Structured ground for FAST robot

Unstructured ground to be addressed by FAST

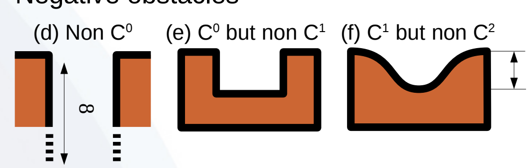
Addressed obstacles

- Obstacle = local perturbation in the general shape of the ground
- Obstacles that cannot be crossed → named Walls (a) and Holes (d)
- This work focuses on bumps (c) and steps (b)
- Steps (b) are worst case of C^1 bumps (c). Generally $h < r$

Positive obstacles



Negative obstacles



Existing all-terrain suspensions

Different suspension architectures

- Objective : to improve dynamics of the vehicle on irregular grounds
- **Rigid and semi-rigid axles** : the first to appear, heavy loads, comfort
- **Independent suspensions** (double wishbone, Mc Pherson, trailing arm, multi-link...) : comfortable, adjustable, load

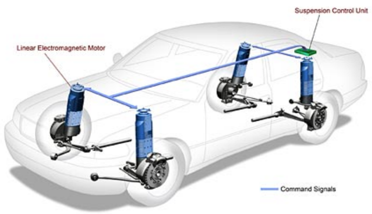
Ford F350 4x4
rigid axle suspension

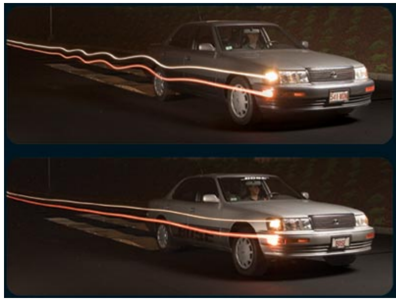
Rigid axle with leaf
springs on a trailer

Mini-Baja vehicle at Oregon State University
with double wishbone suspension

Existing all-terrain suspensions

- **Active suspensions** (i.e. That integrate actuators)
  - Bose suspension: a Mc Pherson with spring replaced by a linear electromagnetic motor (LEM) adapted from loudspeakers
  - High translation speed
  - Energy provided for extension is recycled at compression ($E_{susp} = E_{AC}/3$)





Bose suspension
www.bose.com

Fauroux / Dakhlallah /Bouzgarrou
TIMS / LaMI, IFMA, France

Existing all-terrain suspensions

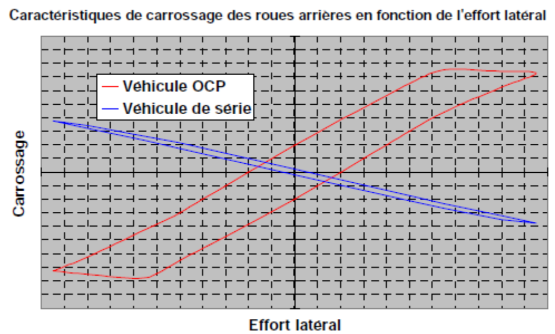
Active suspensions

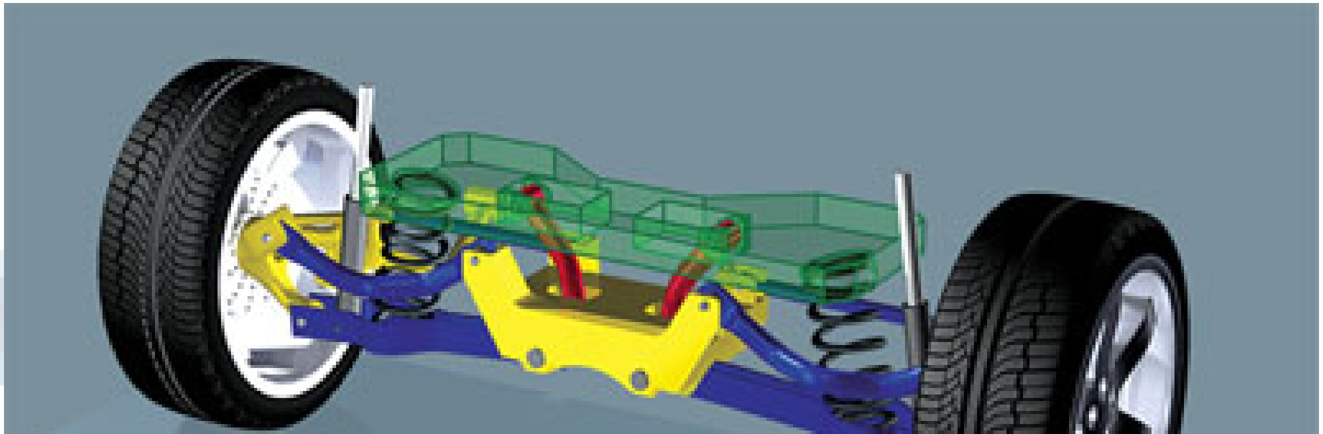
- Michelin Active Wheel : integrated concept (traction, brake, active suspension)
- Short travelling distance for ATVs

Existing all-terrain suspensions

Suspensions with 2DOF per wheel

- OCP suspension (Optimized Contact Patch)
- Supplemental cambering DOF of the wheels
- Passive actuation via inertial forces
- Lower wear of contact patch
- +10% race cornering performance
- Joint WR Patents IFMA / Michelin



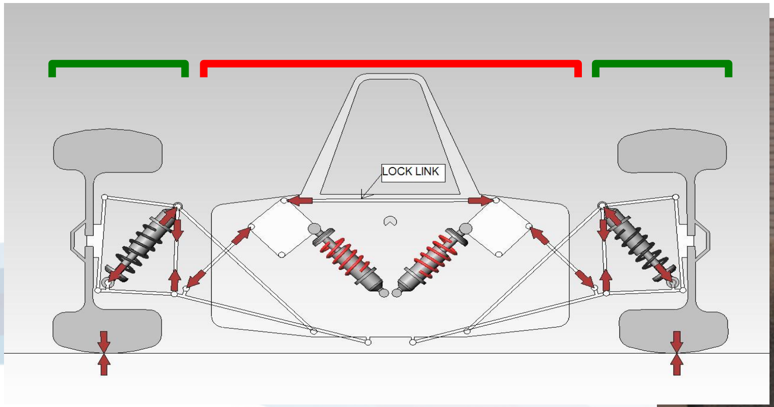


Existing all-terrain suspensions

Suspensions with 2DOF per wheel

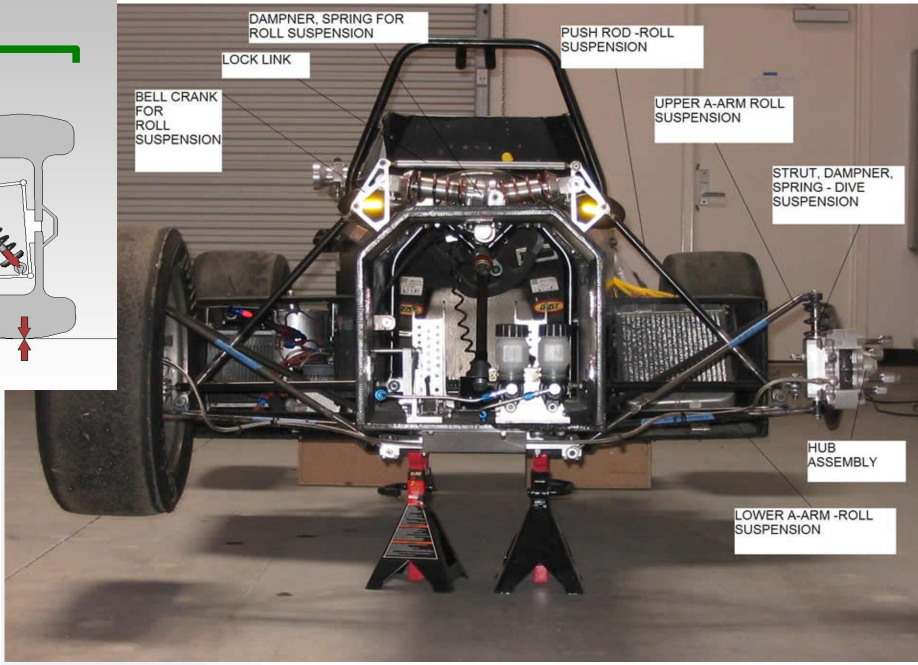
- Sacli Suspension with 2 suspension in series for dissociated vertical and roll behaviours
- In the wheels : **dive** suspension
- In the central frame : **roll** suspension
- Ability to roll with low cambering → lower wear and better traction on the contact patch during cornering

typical sports car tire wear



2nd prototype turn front

2nd prototype turn rear



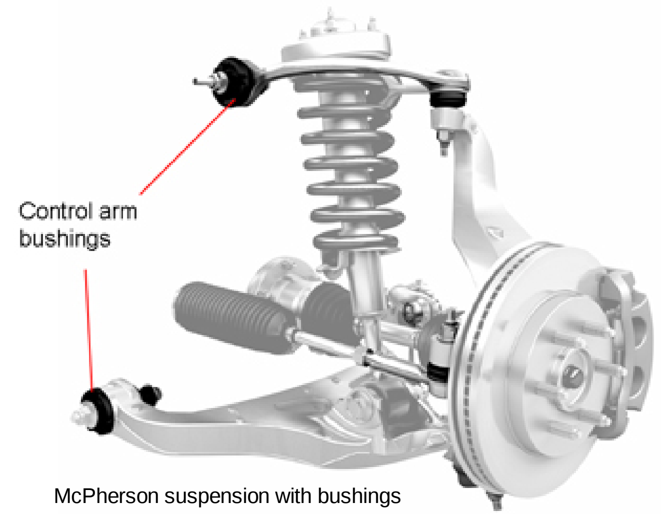
Sacli suspension
www.saclisuspension.com

Existing all-terrain suspensions

Longitudinal DOF

- Classical joints are replaced by rubber bushings
- A longitudinal DOF exists with limited amplitude (a few mm)
- Useful for longitudinal comfort (high frequency small motions)

Multi-link suspension with a massive trailing-arm bushing



McPherson suspension with bushings

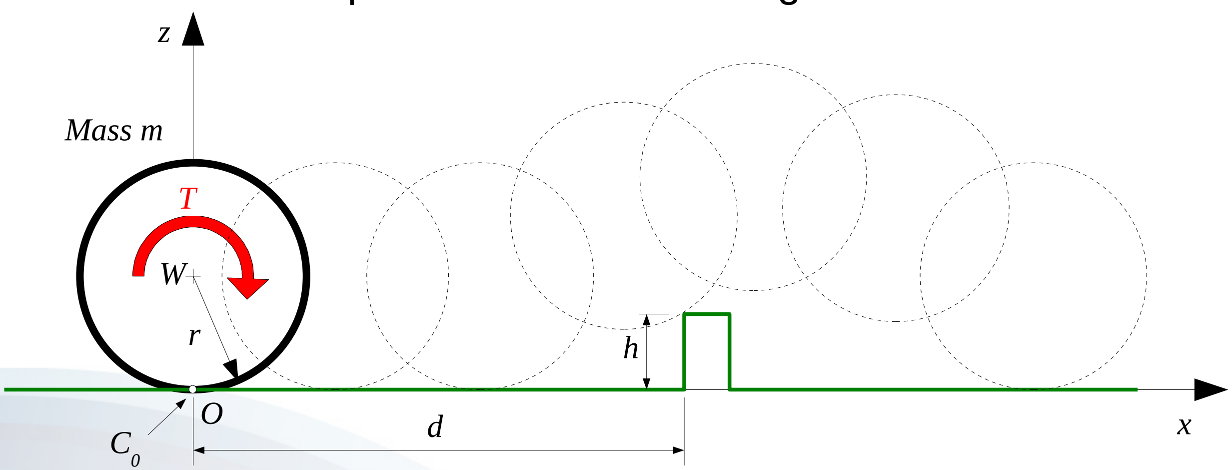
Conclusion of bibliography

- Existing suspensions are not suitable for fast obstacle crossing
- Shock absorbers and wheel motions are rather vertical (except roll)
- This work will try to create innovative suspensions for this purpose

Single wheel model

Introducing the simplified model

- Rigid wheel of mass m, radius r, submitted to constant torque T
- Starts at null speed and rolls with slipping along distance d_r
- Contact and impact on obstacle of height h



Multibody calculations

- Adams multibody software
- For a set of five parameters (m, r, T, h, d_r)...
- ...a trajectory can be traced
- Useful to check the realism of the model, particularly contact

Single wheel model: Contact

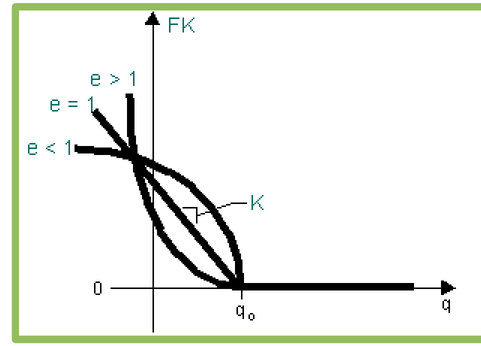
Contact model in Adams

- Unilateral elastic contact with normal force N

$$N = Max\left(0, k.(q_0 - q)^e - C\,\dot{q}\,.STEP\left(q, q_0 - d, 1, q_0, 0\right)\right)$$

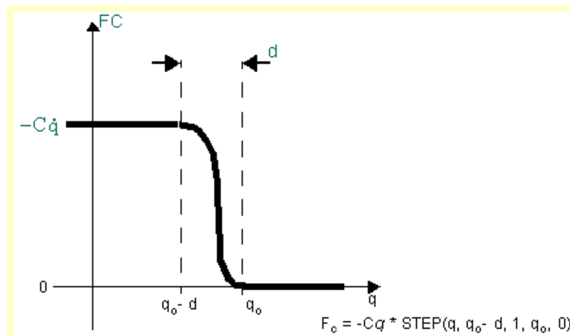
- Elastic term

k = contact stiffness
q_0-q = geometric penetration
e = positive exponent

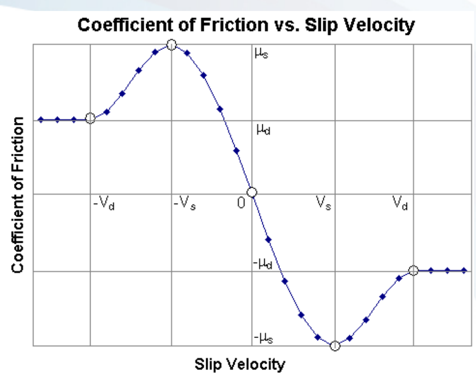


- Damping term

C = damping coefficient
$\dot{q}$ = penetration speed
d = limit distance



- Tangential force T such as $T/N=\mu$
- μ depends on the slipping velocity V

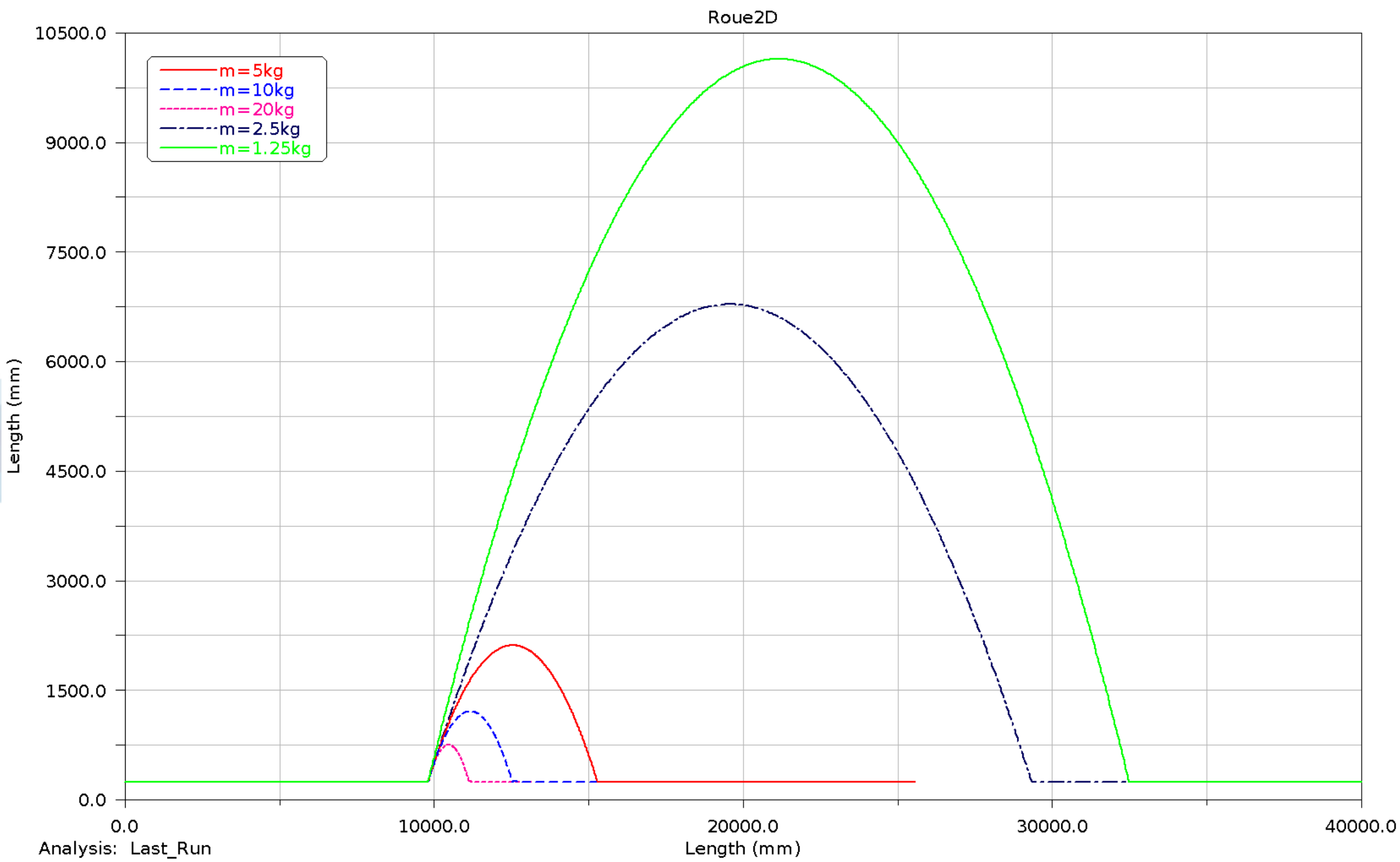


m = 5kg, r=250mm, h=100mm, T=10Nm, k=1E5N/mm
e=2, C=100Ns/mm, μ_s=0.8, μ_d=0.7, V_s=10mm/s, V_d=100mm/s

Single wheel model: Results

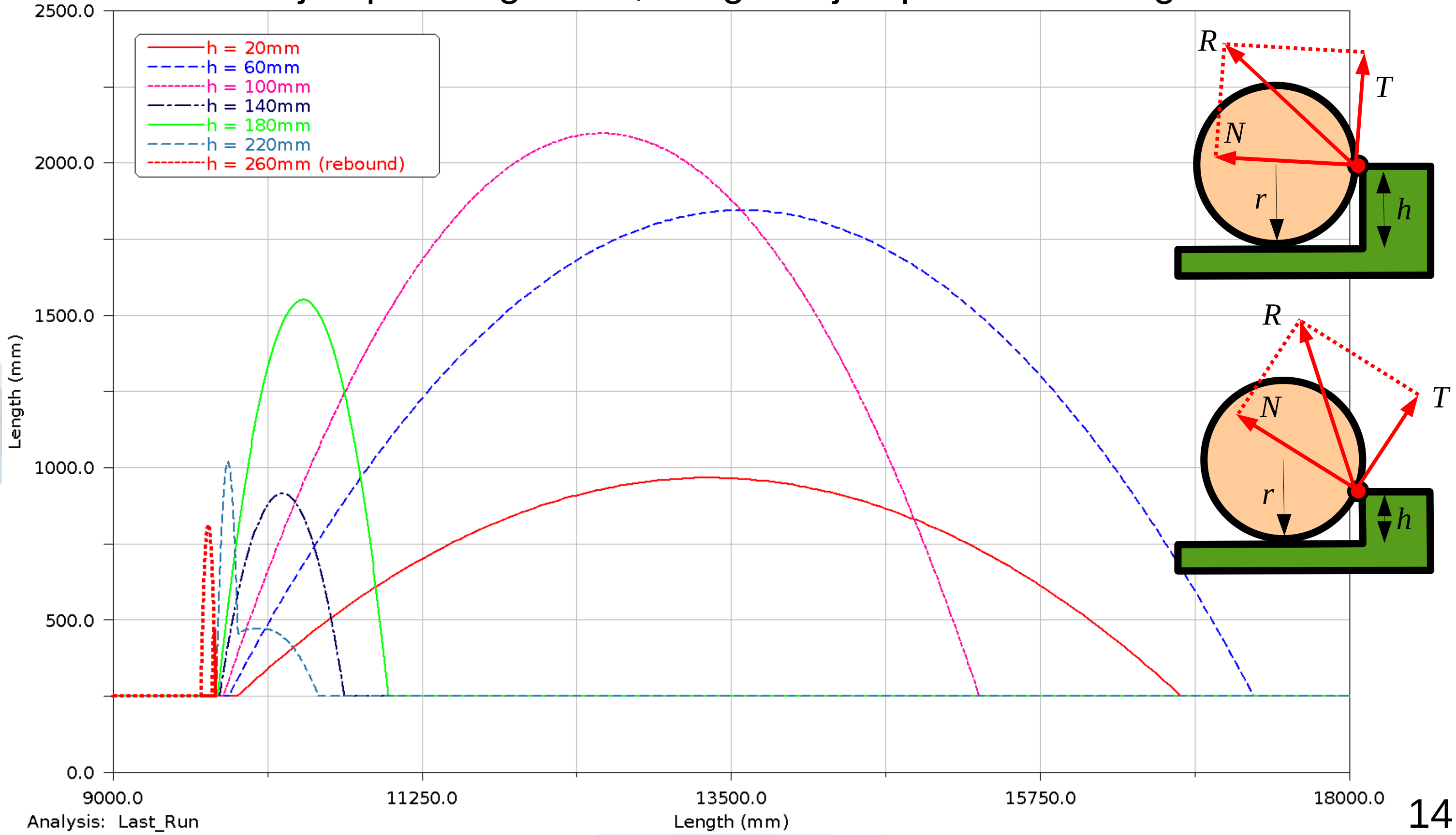
Influence of mass *m*

- A lighter wheel jumps longer/higher
- Same shape / Scale factor between trajectories



Single wheel model: Results

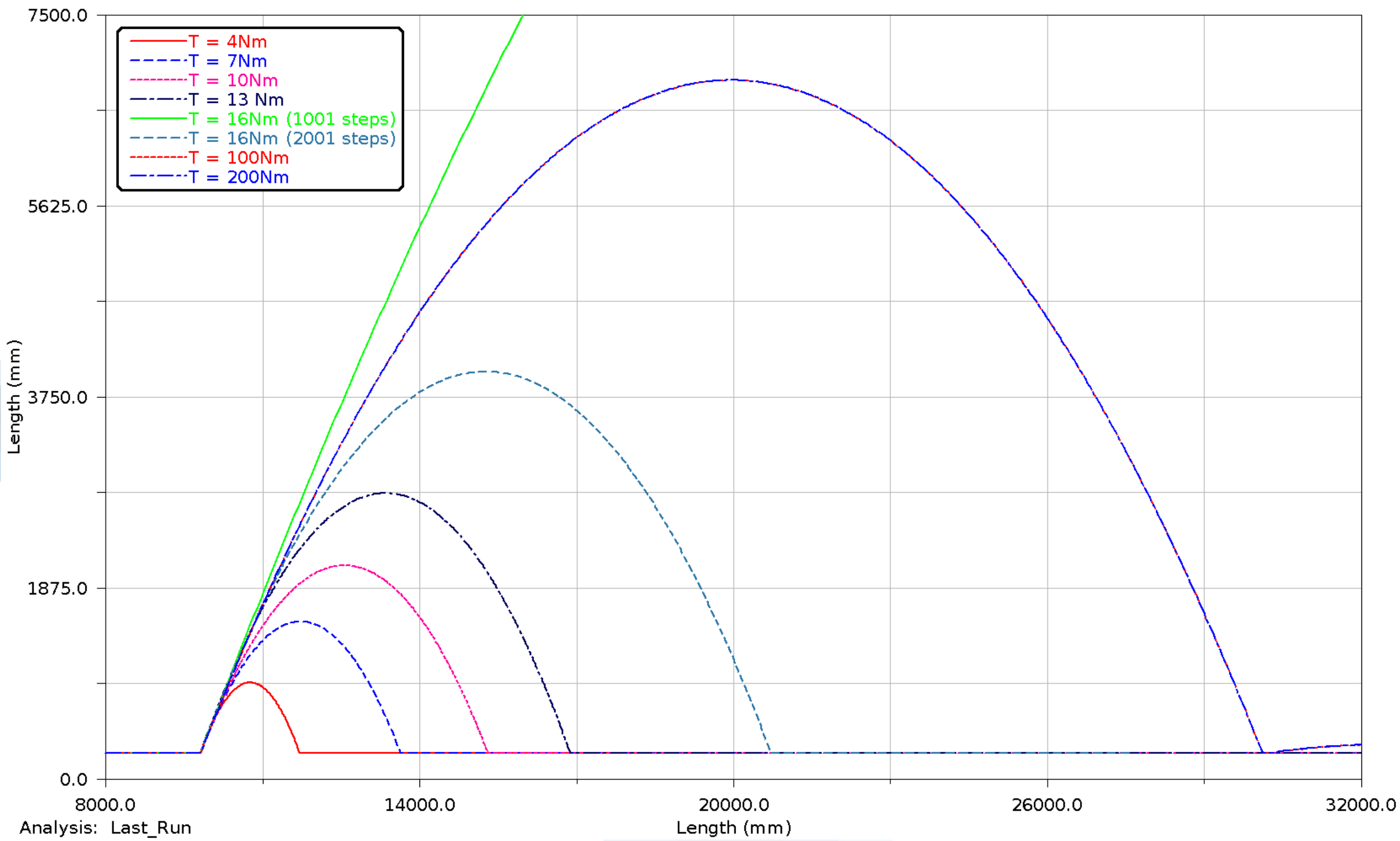
- **Influence of obstacle height *h***
  - h has a major influence the trajectory (defines shooting direction)
  - With $h>r$, rebound (as expected)
  - Here : $h=100mm$ for the highest jump, $h=60mm$ for the longest jump
  - h low → jump is long & low, h high → jump is short & high



Single wheel model: Results

Influence of torque *T*

- Higher torques *T* generate higher jumps with same shape (scale factor)
- Torque saturation: same curve for *T=100Nm* and *T=200Nm*
- Sensitivity to time discretization (artefact at 16Nm , 1001 steps)



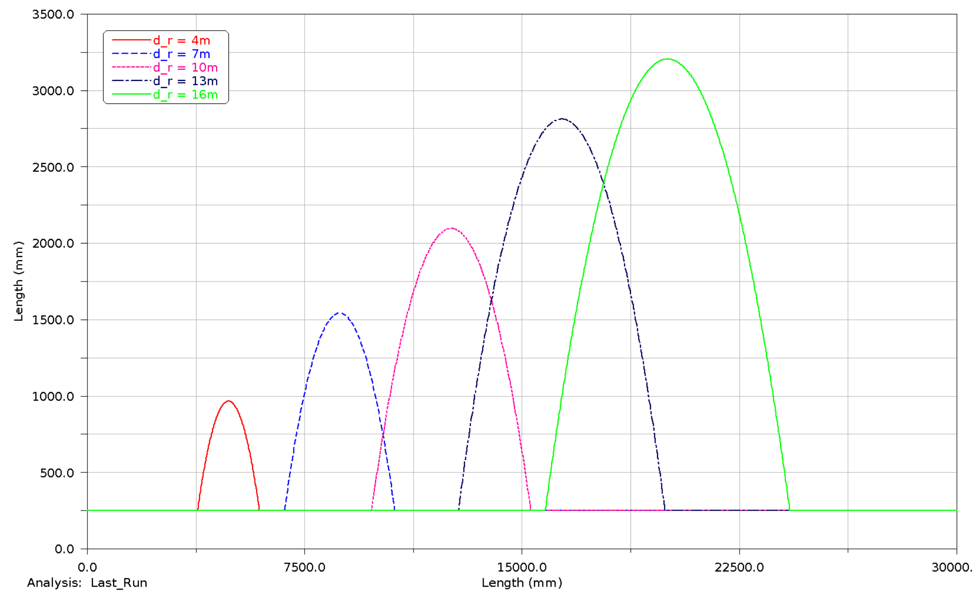
Fauroux / Dakhlallah /Bouzgarrou
TIMS / LaMI, IFMA, France

Single wheel model: Results

- Introduction
- Grounds
- Suspensions
- **Single wheel**
- Innovation
- Two wheels
- Conclusion

Influence of d_r

- Longer runs generate higher homothetic jumps
- Longer run → higher impact speed → higher kinetic energy



Other studies

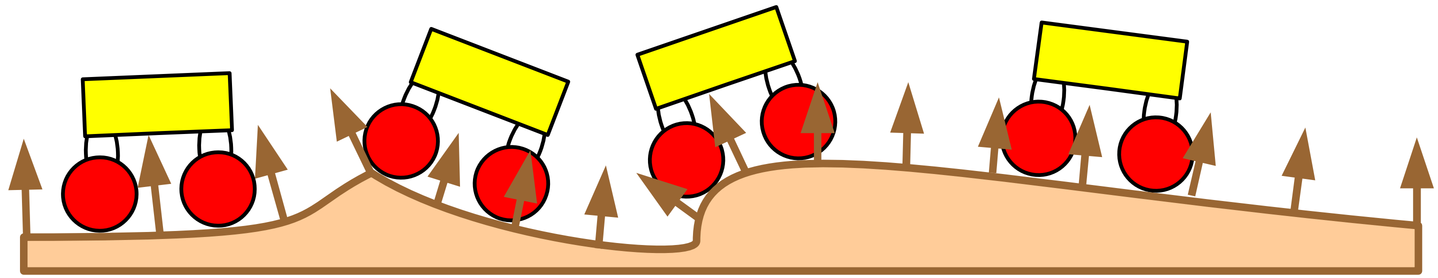
- Contact stiffness k: no effect on the trajectory if $k<1E6N/mm$. Higher values of k → numeric convergence problems
- Exponent e: no big effect. e too low (e = 0.25) → small oscillations
- Contact damping coefficient C: very strong influence: values of 1 and $10\ Ns/mm$ lead to very different trajectories. Above $100Ns/mm$, results tend to converge

Conclusion on the single wheel model

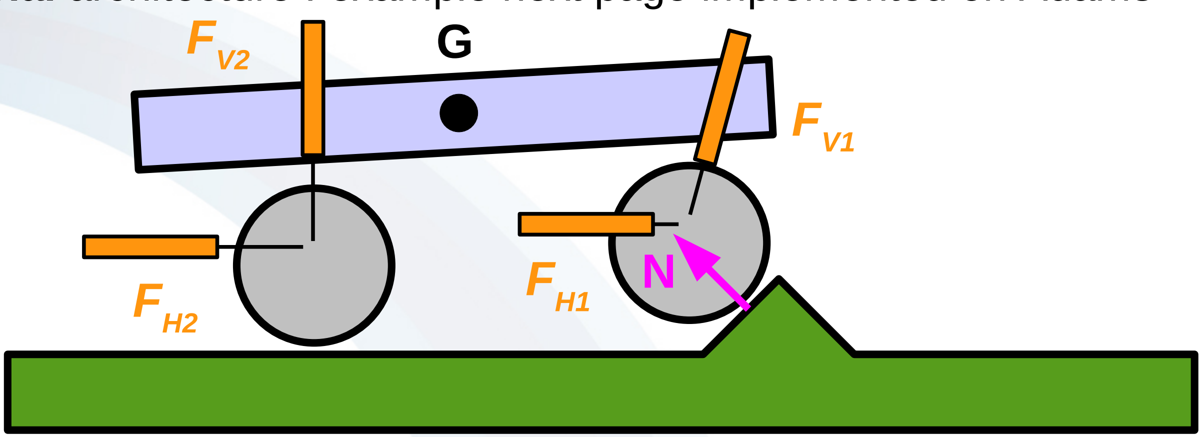
- The model is plausible although contacts give singularities

Innovative suspension

- **Longitudinal DOF**
  - The **horizontal force** cannot be neglected for fast obstacle crossing
  - It depends on the orientation of the **ground normal**



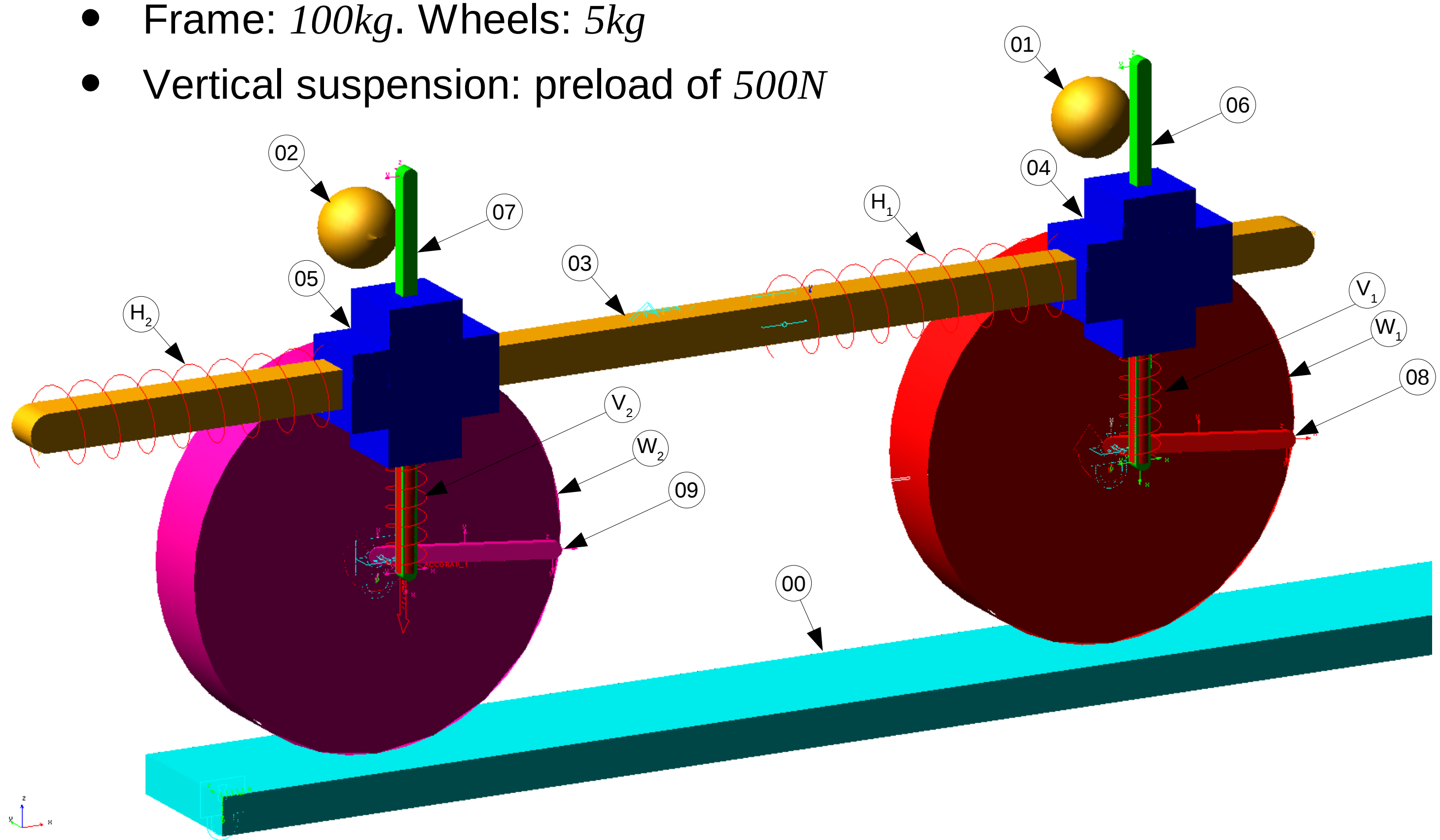
- **Implementing a horizontal DOF**
  - **Parallel** architecture : cylinders connected in // to the hub-carrier
  - **Serial** architecture : example next page implemented on Adams



Two-wheel model

Serial architecture

- Frame mass dispatched on spheres 1-2. Parts 3-9 have no mass
- Frame: $100kg$. Wheels: $5kg$
- Vertical suspension: preload of $500N$



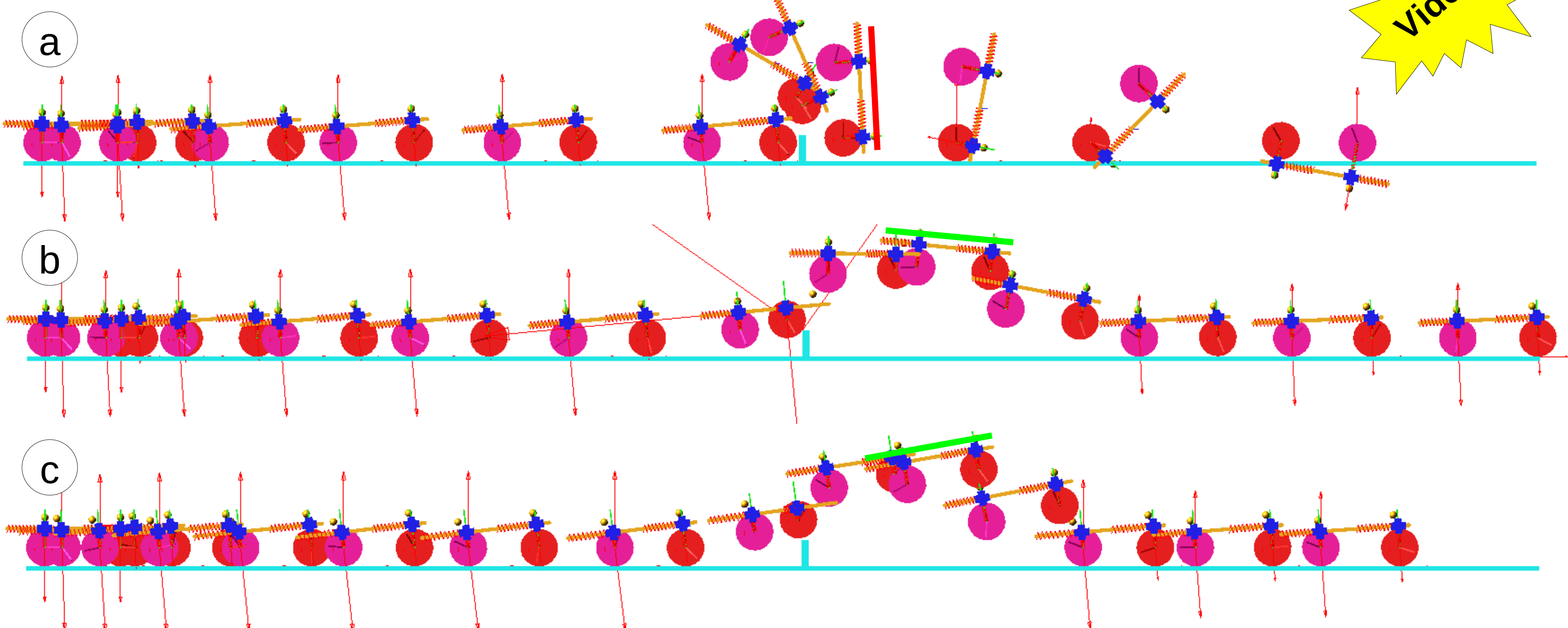
$r=250mm,\ h=350mm,\ T=110Nm,\ k_V=5N/mm,\ C_V=3Ns/mm,\ k_H=5N/mm,\ C_H=1Ns/mm$

$k=1E5N/mm\ e=2,\ C=100Ns/mm,\ \mu_s=0.8,\ \mu_d=0.7,\ V_s=10mm/s,\ V_d=100mm/s$

Two-wheel model: Results

Comparison of three configurations

- H1 = front horizontal suspension, H2 = rear horizontal suspension
- Configuration a) without H1 without H2
- Configuration b) with H1 without H2
- Configuration c) with H1 with H2

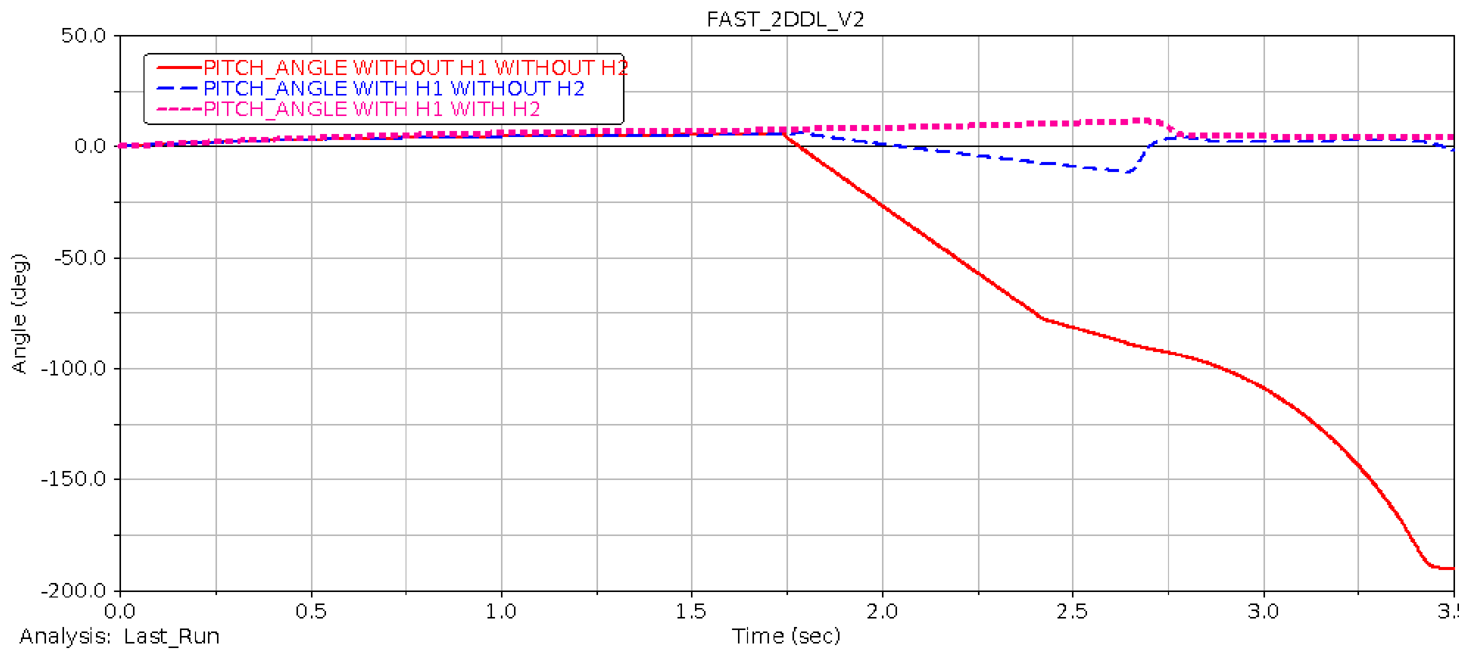


Two-wheel model: Results

- Introduction
- Grounds
- Suspensions
- Single wheel
- Innovation
- Two wheels
- Conclusion

Result analysis – Pitch angle

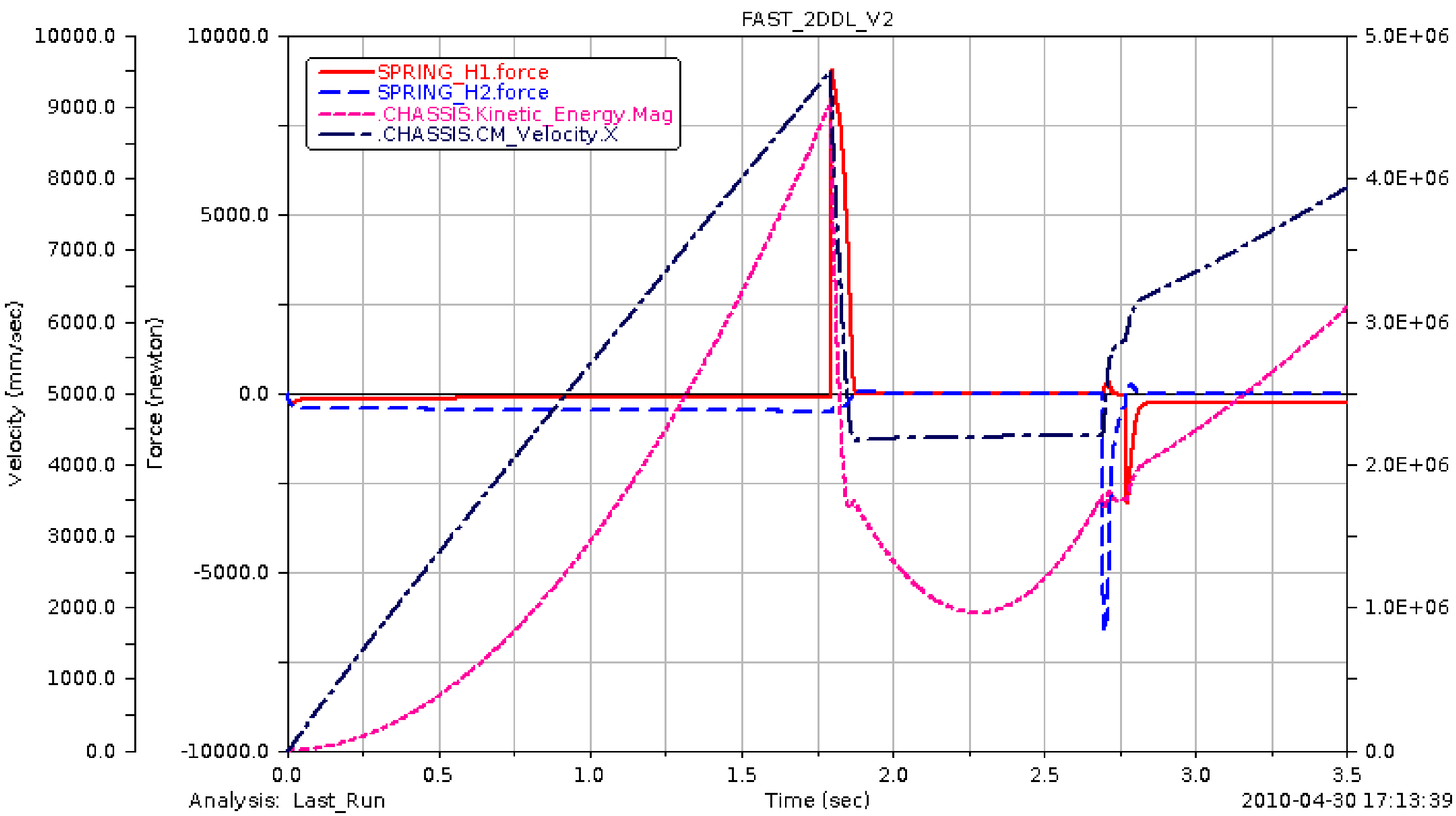
- Case a) → tip-over. Case b) and c) → no tip-over
- H1 seems to be efficient and compulsory for obstacle crossing.
- H2 looks optional
- b) and c) differ only by the sign of the pitch angle after the shock



Two-wheel model: Results

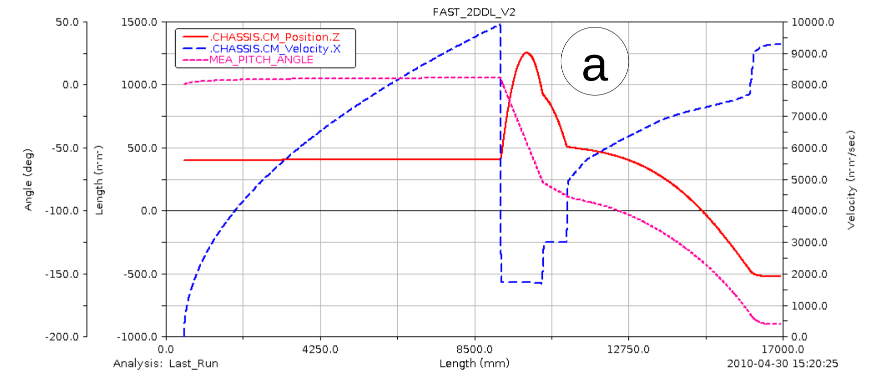
Force and energy

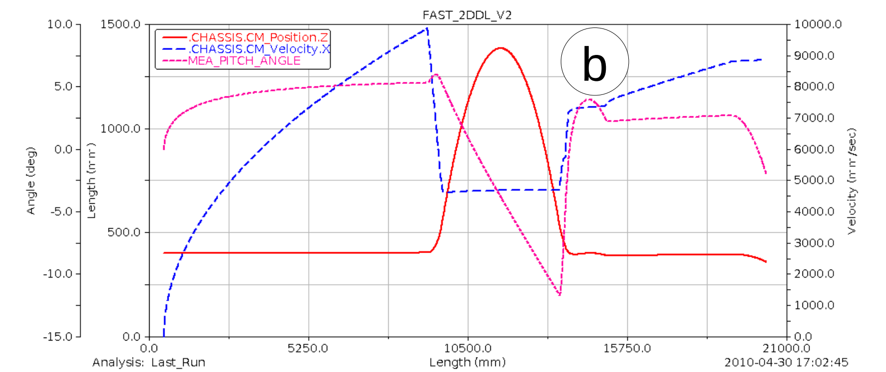
- Front suspension has 2 force peaks : shock & landing
- Rear suspension has no shock and only a landing peak

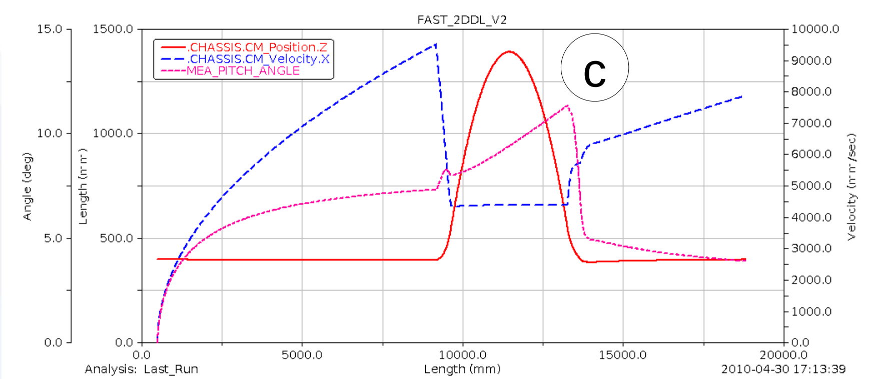


Two-wheel model: Results

- **Horizontal speed decrease after impact**
  - a) speed divided by **5** (10m/s → 1.8 m/s) Kinetic energy /25
  - b) c) speed divided by **2** (9.5m/s → 4.5m/s) Kinetic energy /4
  - The horizontal suspension allows a smoother motion

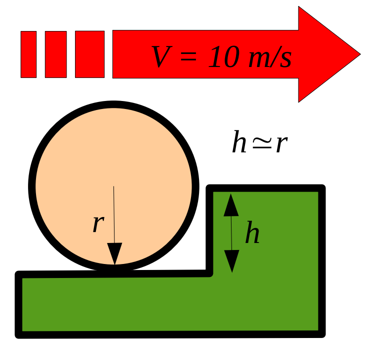






Conclusion

Main results



- Obstacle-crossing on rough terrain at high speed (10 m/s)
- Innovative principle of **suspension with 2 DOF**
- A **vertical DOF** like every suspension
- A **specific horizontal DOF** for steep obstacle crossing
- Can cross obstacles **as high as the wheel radius**
- Validated on a **multibody** Adams model
- Improves **ride** and **irregular ground isolation** at high speed
- Improves **longitudinal stability**, **crossing speed** & **avoids tip-over**

Future work

- Experimental work with Design Of Experiment (speed, obstacle height)
- Impact force measurement
- Analytical model FAST exploration of design and control space
- 3 Scenarii :
  - **passive** (constant stiffness & damping)
  - **low actuation** (adjustable stiffness & damping)
  - **full power actuation** (force injection)

PCT Patent in progress

- Patent TIMS / IFMA

Video Experiments