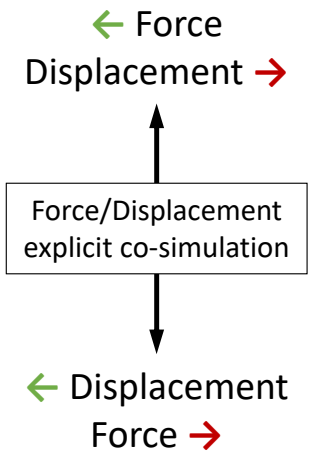
Chrono::Vehicle Tutorial

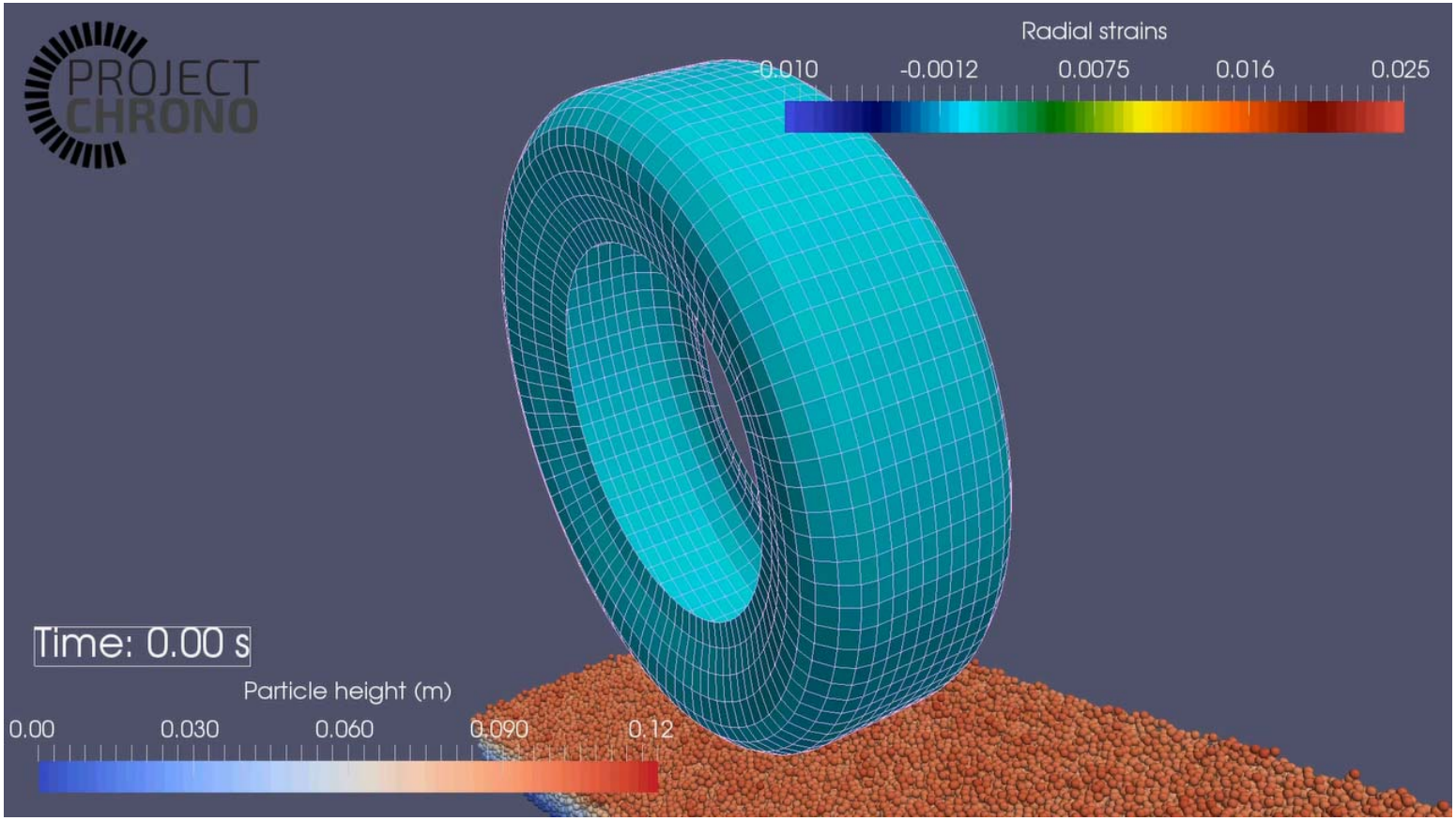
Co-simulation framework

Tire test rig (2-way) co-simulation framework

- Rig node
  - Simulates rig mechanism + deformable tire (ANCF)
  - Terrain interaction through external applied tire mesh vertex forces
  - Adaptive HHT integrator + MKL solver
  - OpenMP parallelization (internal force and Jacobian, MKL solver)
- Terrain node
  - Simulates terrain particles (spherical contact) + proxy bodies
  - Proxy bodies:
    - State dictated by tire mesh state on rig node
    - Associated with tire mesh faces (triangle contact shapes)
    - Contact shape adjusted at each synchronization time
  - DEM-P simulation (semi-implicit Euler)
  - Contact forces accumulated on each proxy body and distributed to corresponding mesh vertices
  - OpenMP parallelization (Chrono::Parallel)

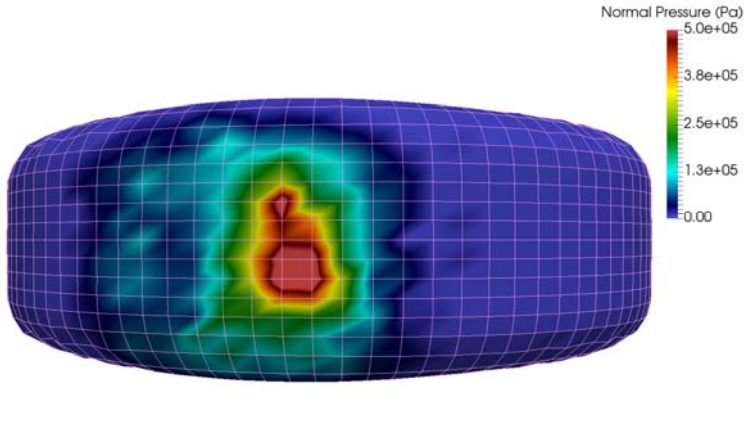


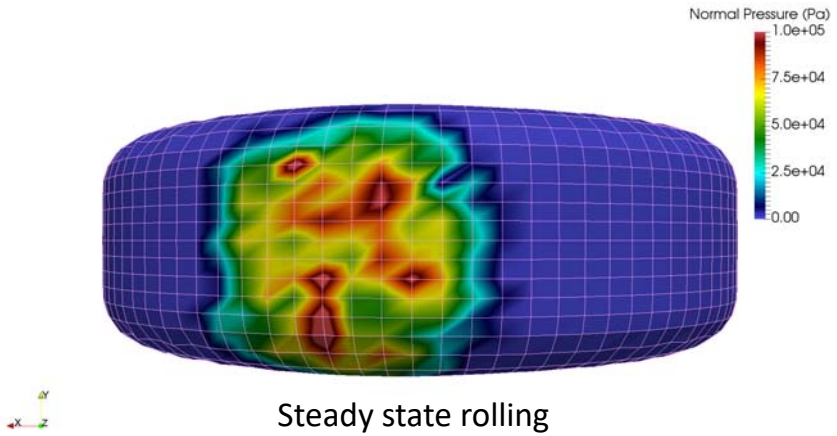
Nonlinear FEA tire on granular terrain



"Simulation and mobility analysis of an ANCF tire in a tire rig on deformable granular terrain," TR-2016-07, SBEL, UW Madison, 2016

Contact normal pressure





Steady state rolling

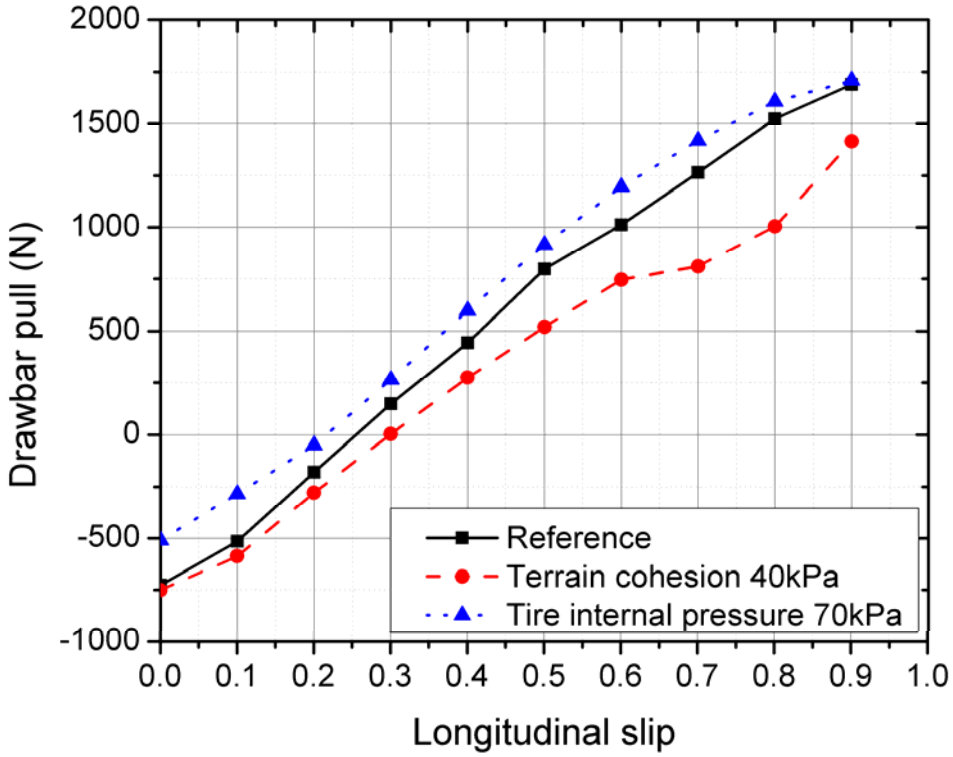
Upon impact on the granular terrain

- Peak in normal contact pressure ~ 500kPa

Steady state rolling

- Average normal pressure ~ 70 kPa

Drawbar pull



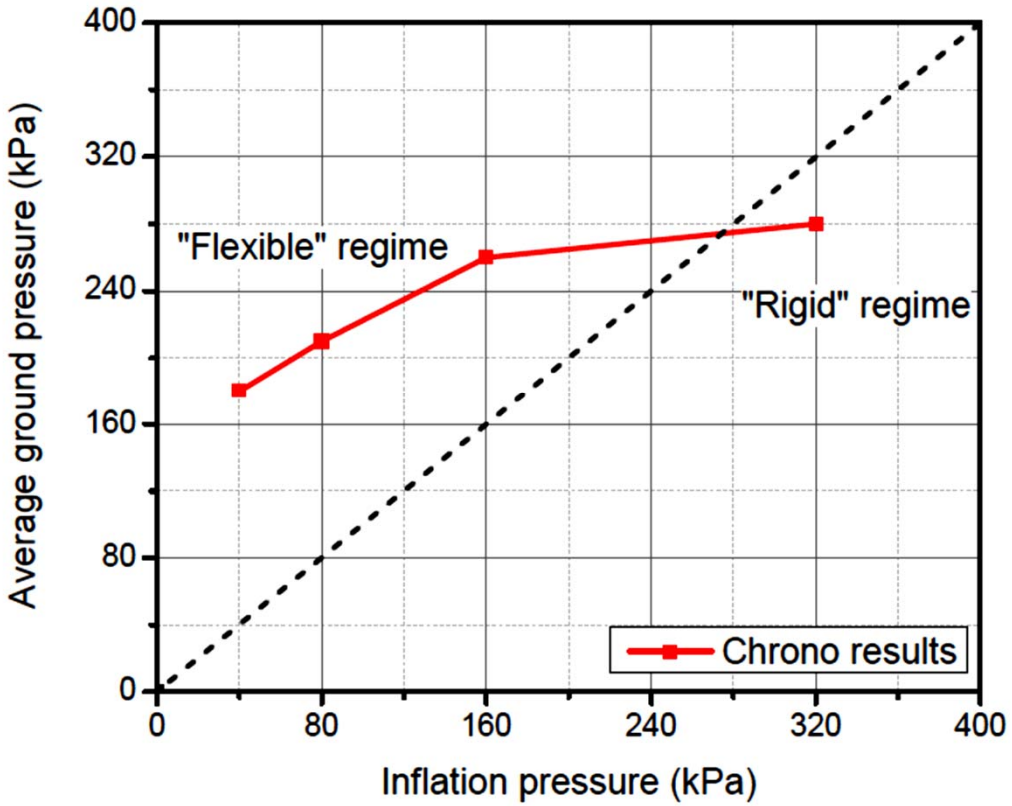
Reference

- Tire pressure: 200 kPa
- Soil cohesion: 80 kPa
- Load: 450 kg

Trends

- Lower cohesion → less available drawbar pull
- Lower tire pressure → increased pull

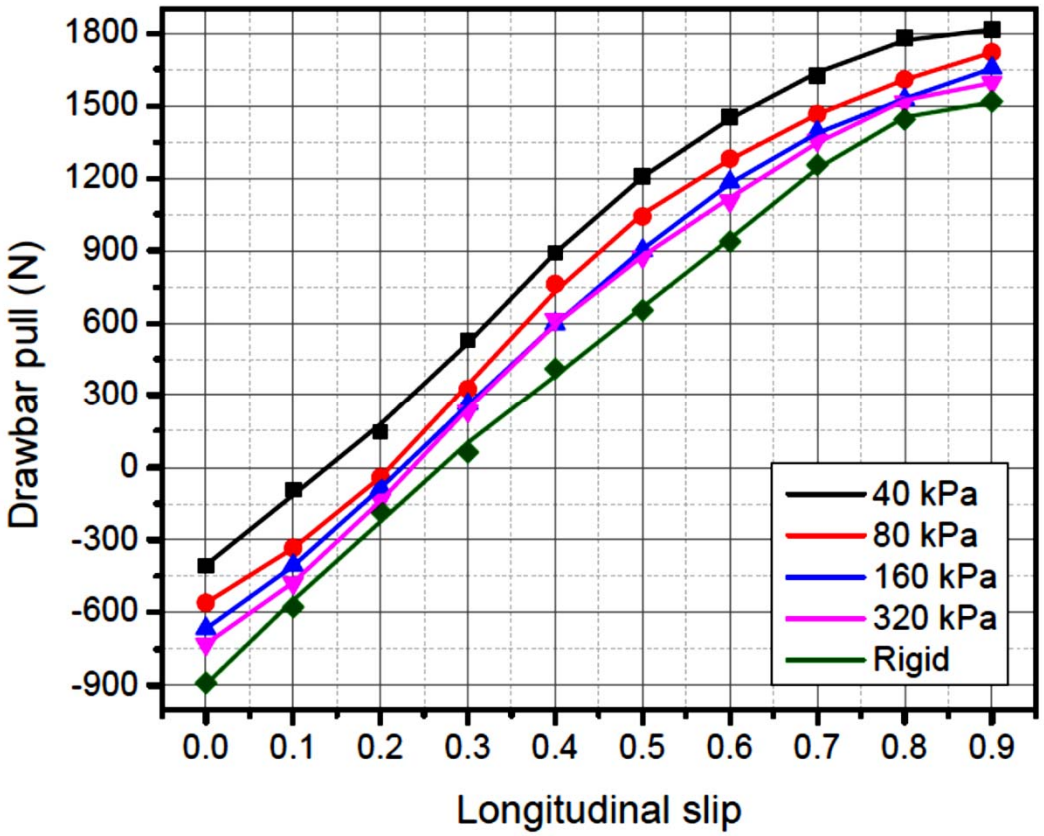
Drawbar pull – effect of tire inflation pressure



Modes of operation of a tire

- Rigid
- Flexible

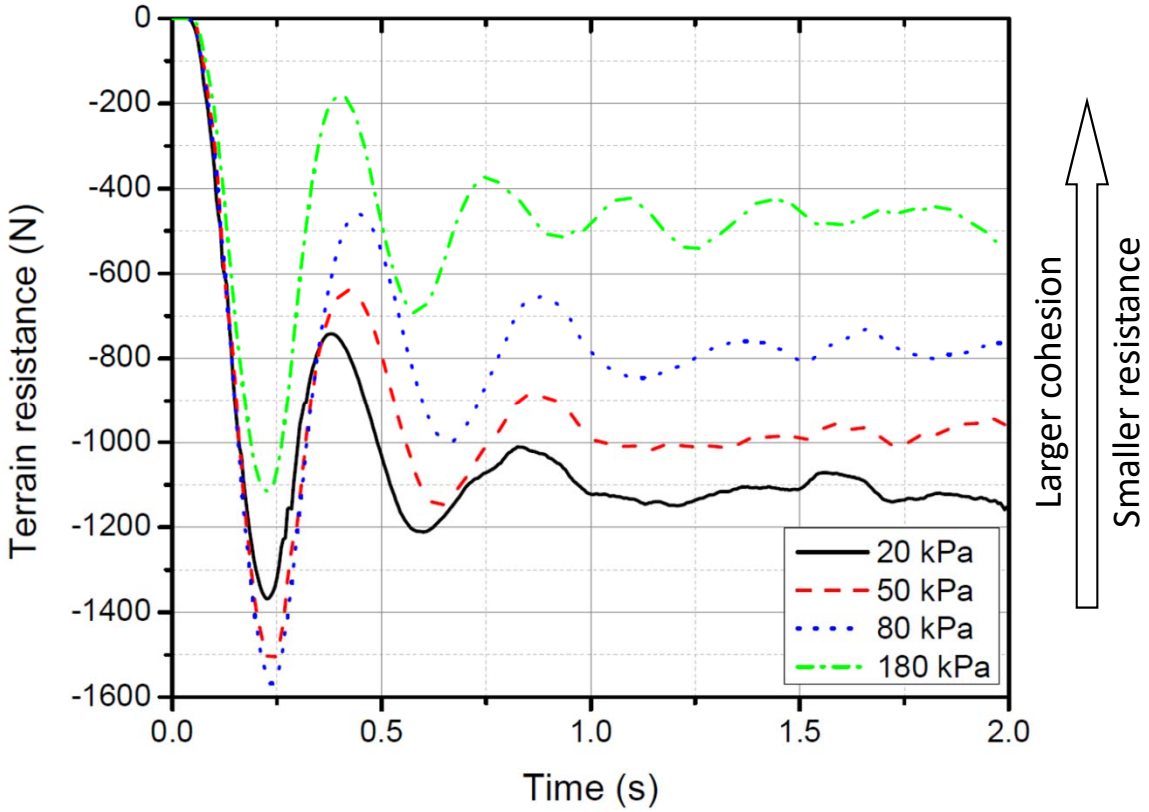
Drawbar pull – effect of tire inflation pressure



Trends

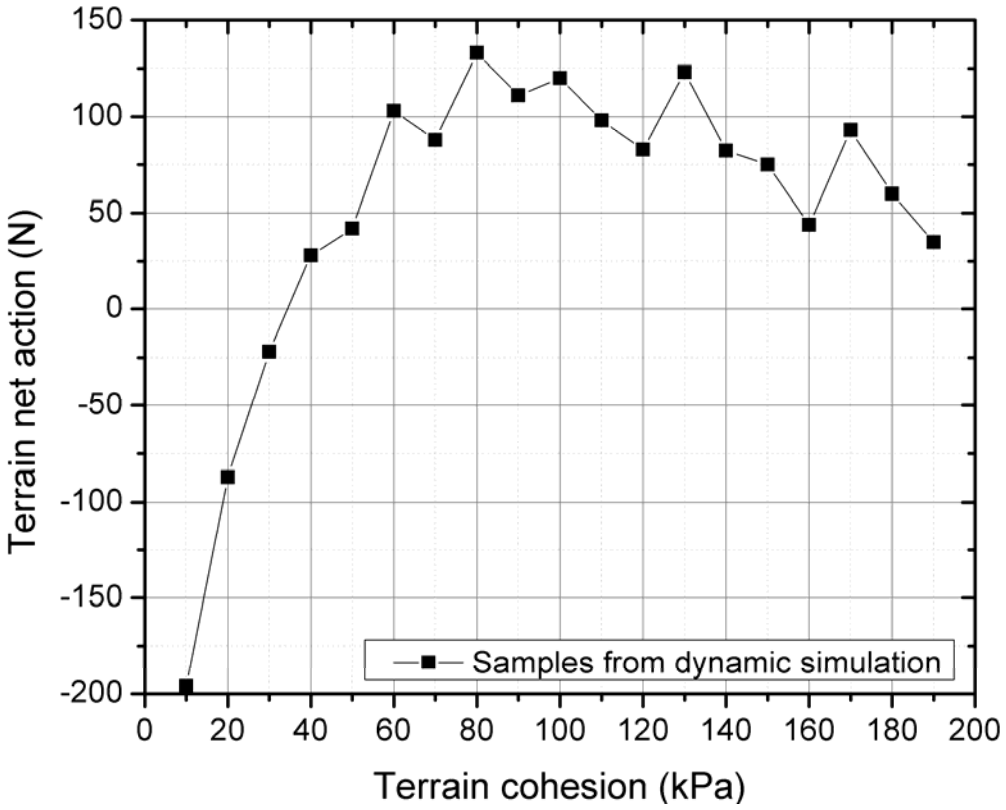
- Drawbar pull curve plateaus at large slip
- Drawbar pull trend with varying inflation pressure

Terrain forces



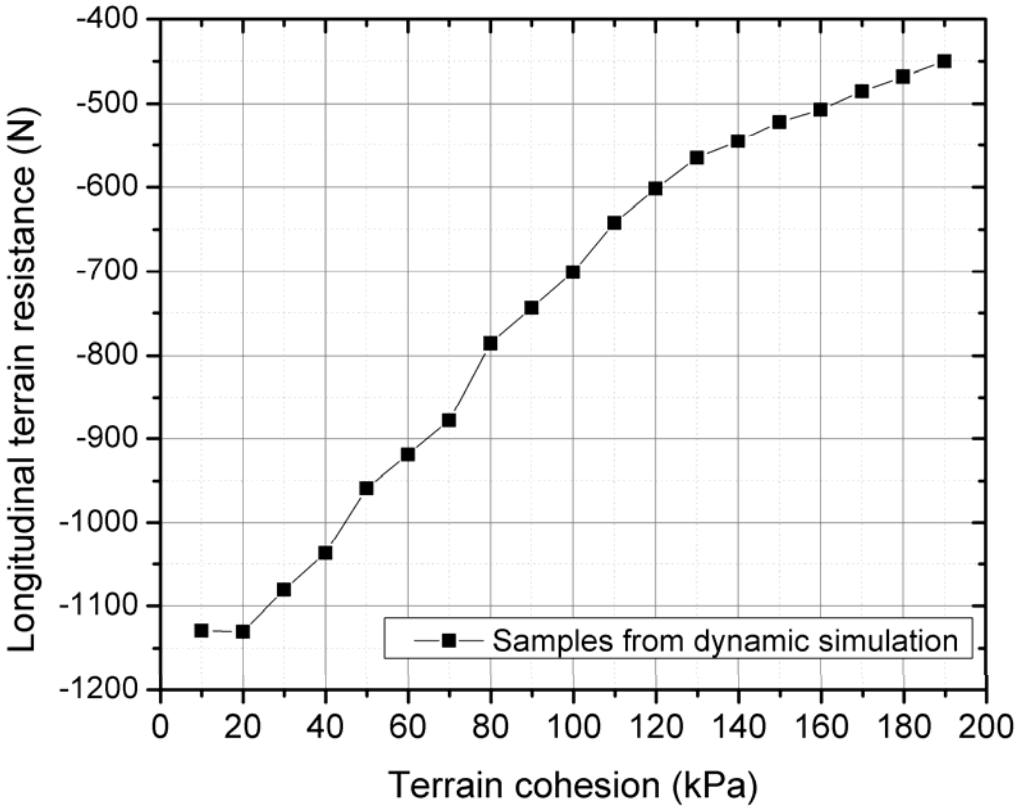
- Time evolution of normal contact forces projected in the longitudinal direction – opposing motion
- Steady-state values, obtained after t=1.2 s, are averaged to obtain reference metrics on following slides

Parametric study: influence of cohesion



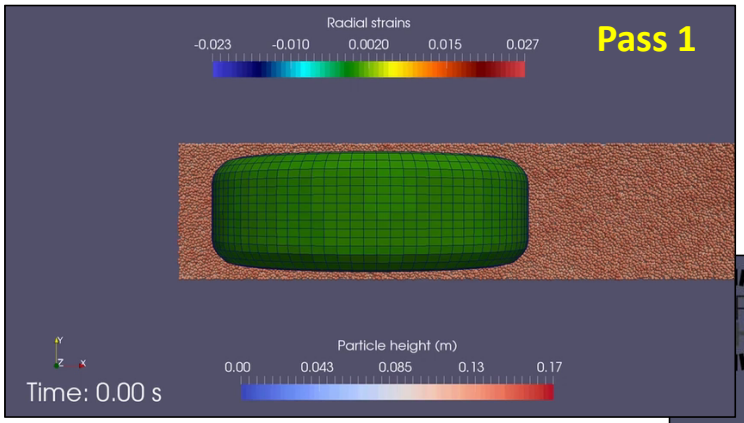
- Longitudinal resultant of terrain contact forces acting on the tire
- Samples are taken from steady state results towards the end of simulation
- For lower values of cohesion 10kPa-40kPa, no available drawbar pull at a slip of 0.3

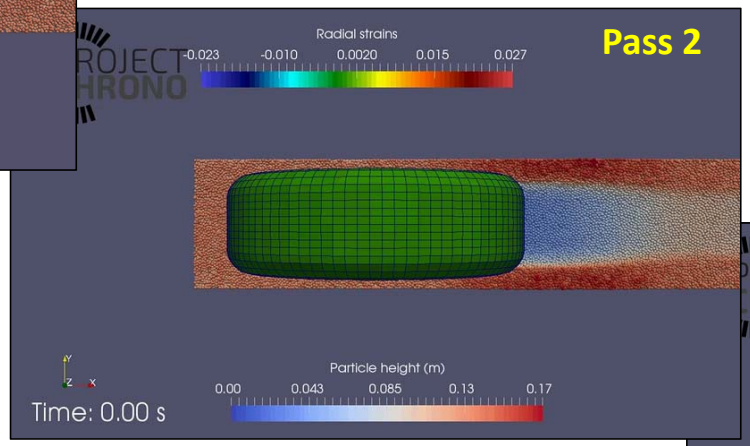
Parametric study: influence of cohesion

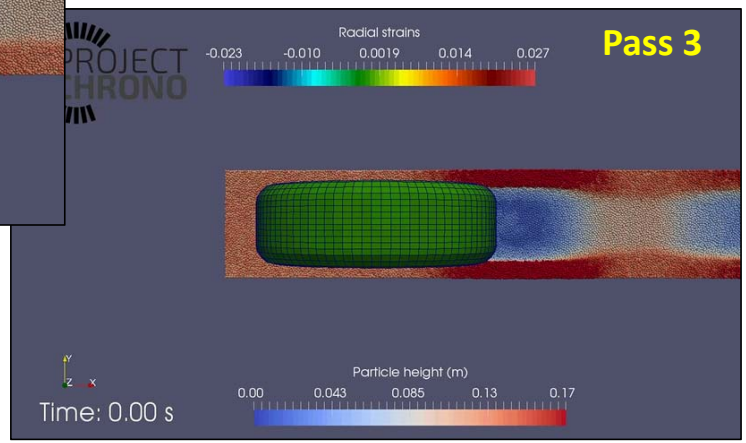


- Longitudinal resultant of terrain normal contact forces acting on the tire
- Samples are taken from steady state results towards the end of simulation
- For lower values of cohesion, larger terrain resistance

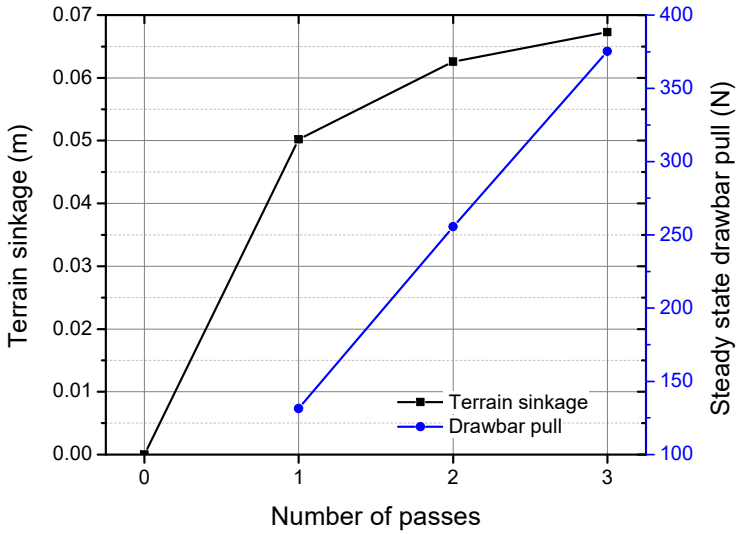
Multipass simulations

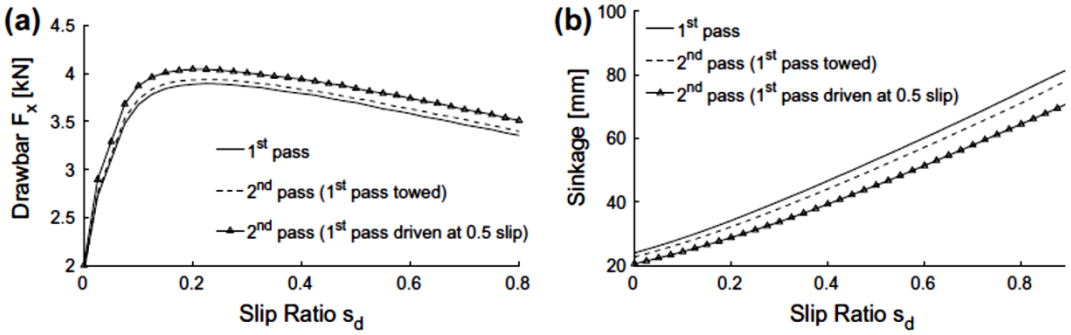






Multipass effects





Senatore and Sandu, Off-road tire modeling and the multi-pass effect for vehicle dynamics simulation, Journal of Terramechanics, 2011

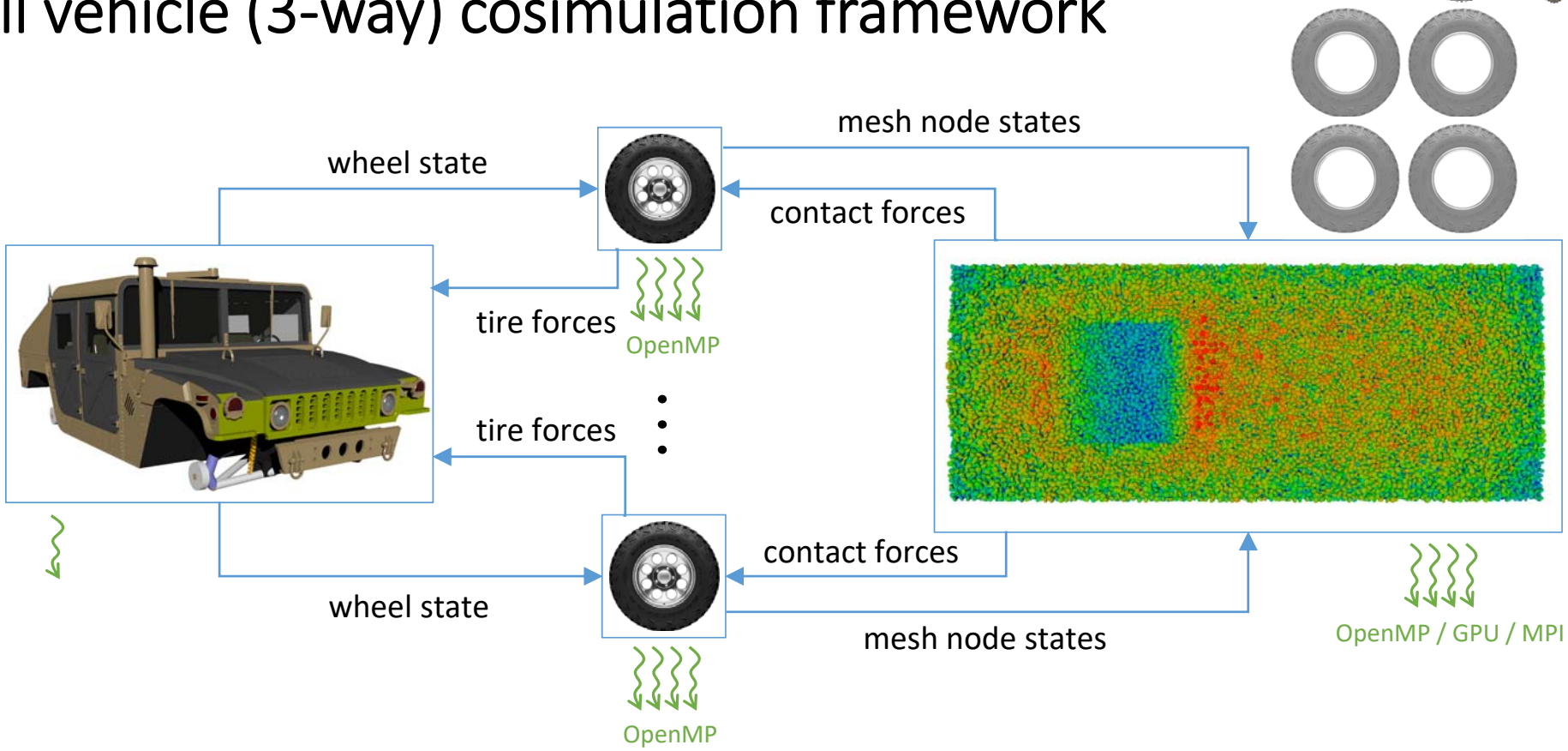
Rig, ANCF Tire

- 90x24 ANCF multilayered, orthotropic shell elements
- ANCF mounted in test rig: Linear and angular velocity imposed
- Longitudinal slip fixed at 0.3
- Linear velocity at zero slip 4.0 m/s
- System mass: 465 kg; inflation pressure: 200 kPa

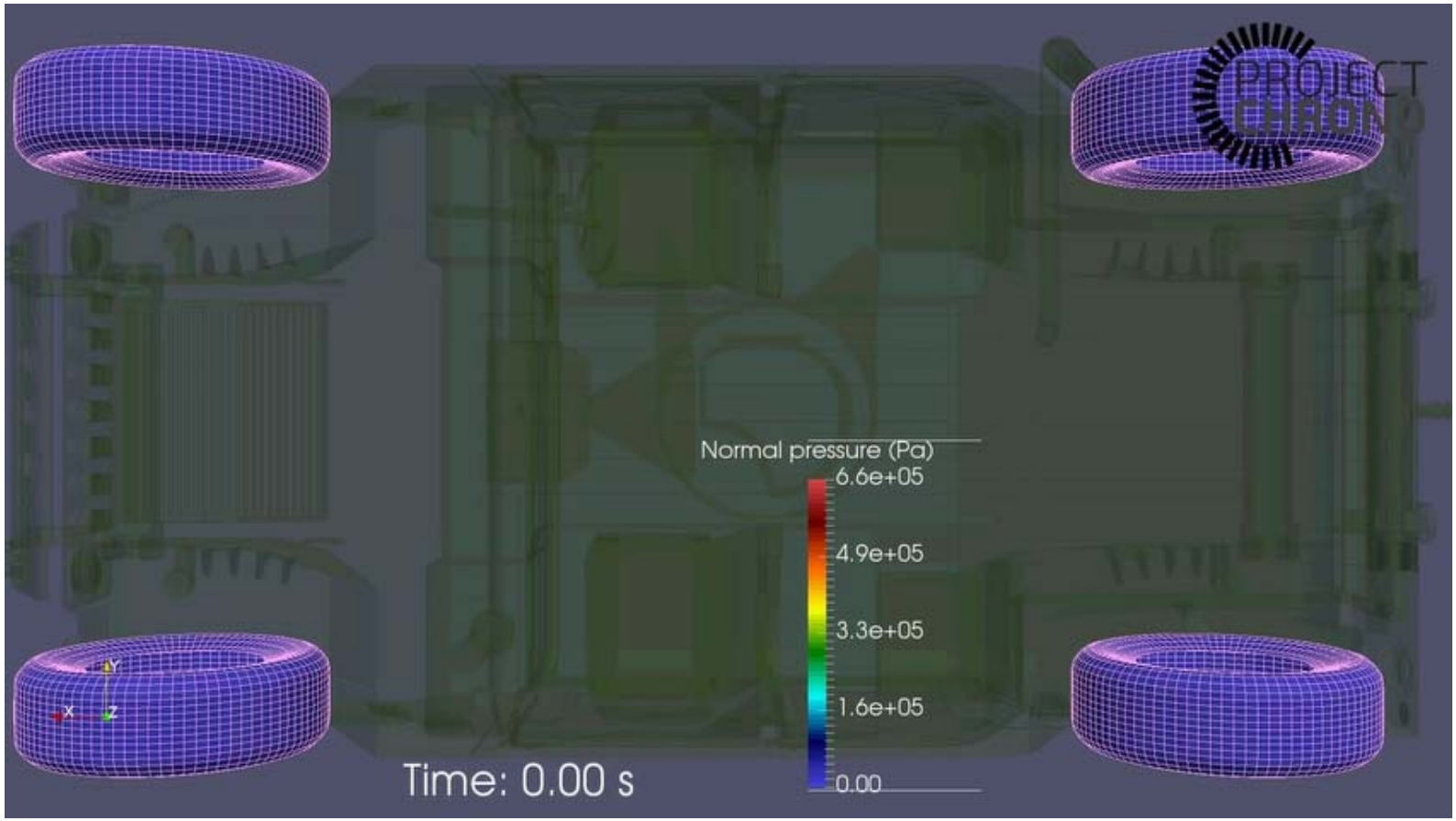
Granular Terrain

- Particle radius: 6 mm
- 20 layers of particles: 424,000
- Terrain: 10m x 0.5m
- Cohesion: 80 kPa
- Time step: 1e-4 s

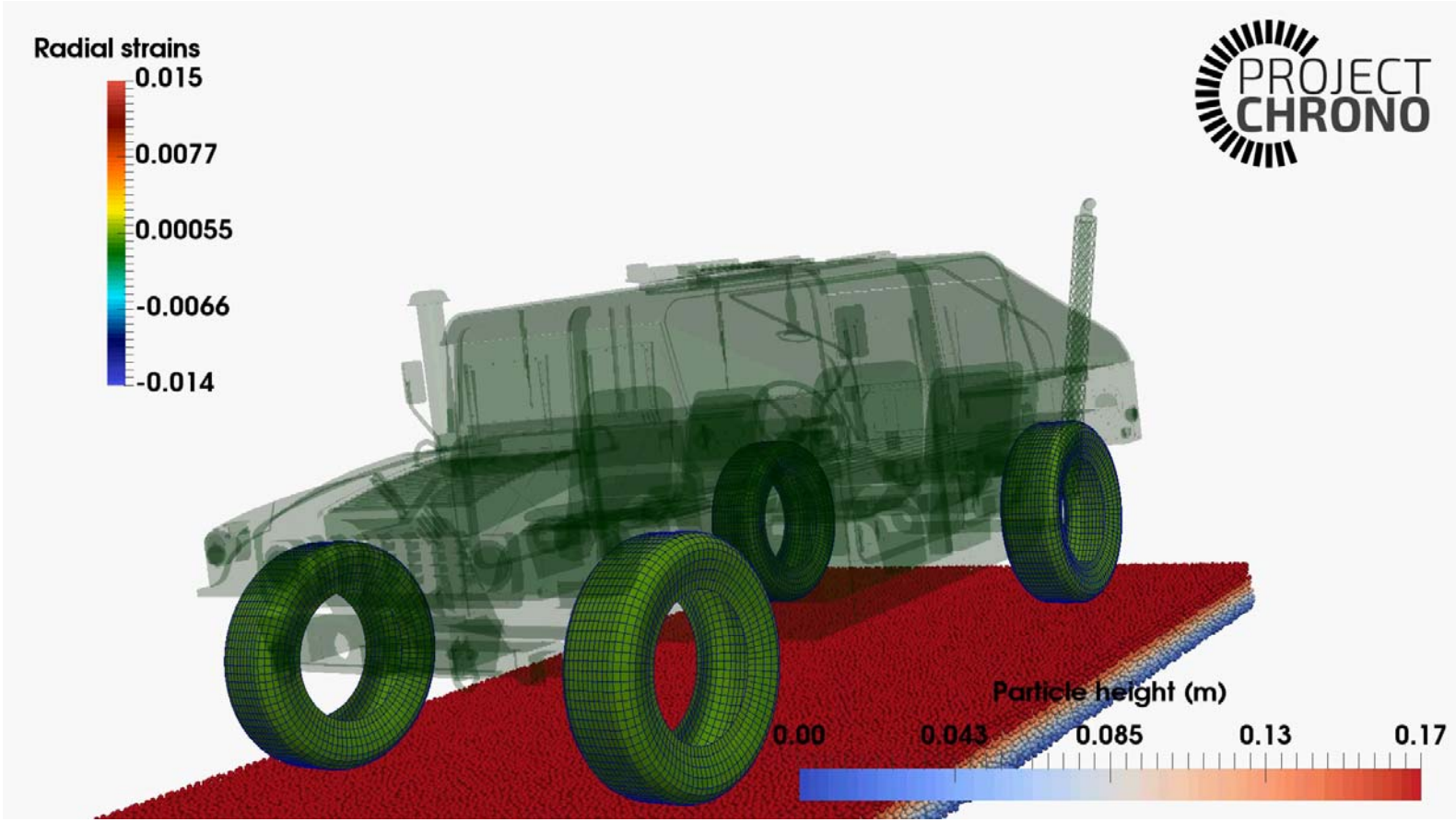
Full vehicle (3-way) cosimulation framework



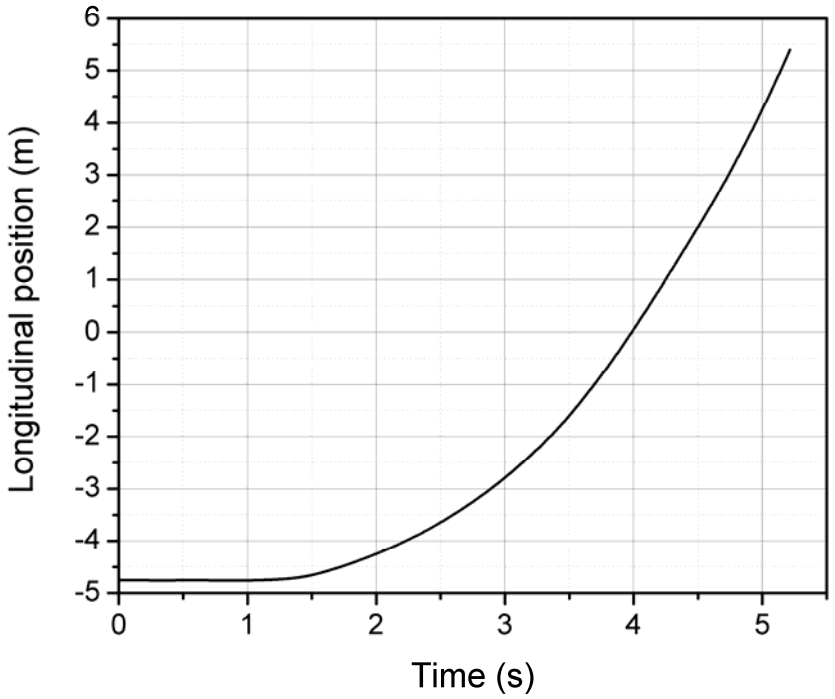
Full HMMWV with ANCF tires on rigid terrain

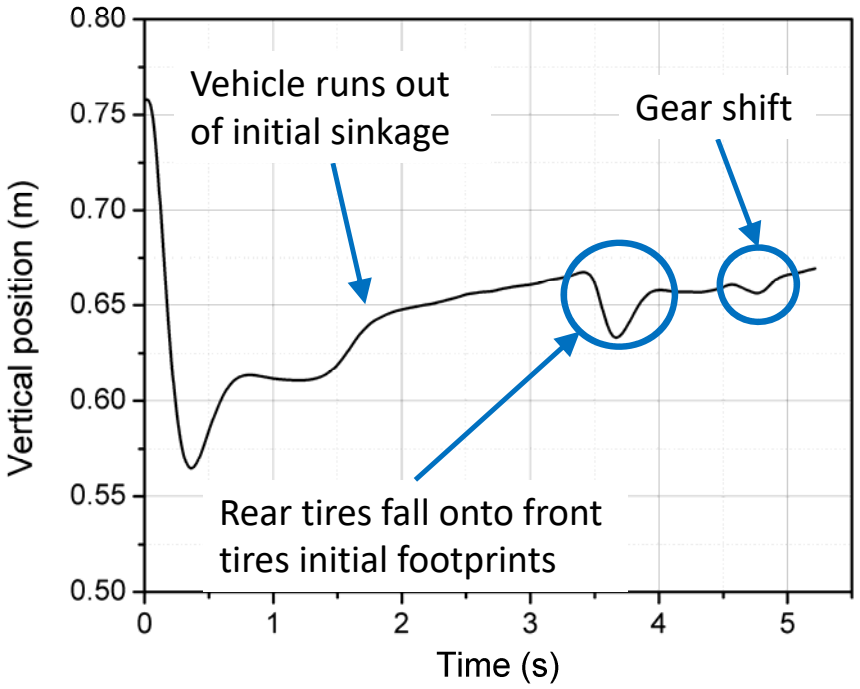


Full HMMWV with ANCF tires on granular terrain

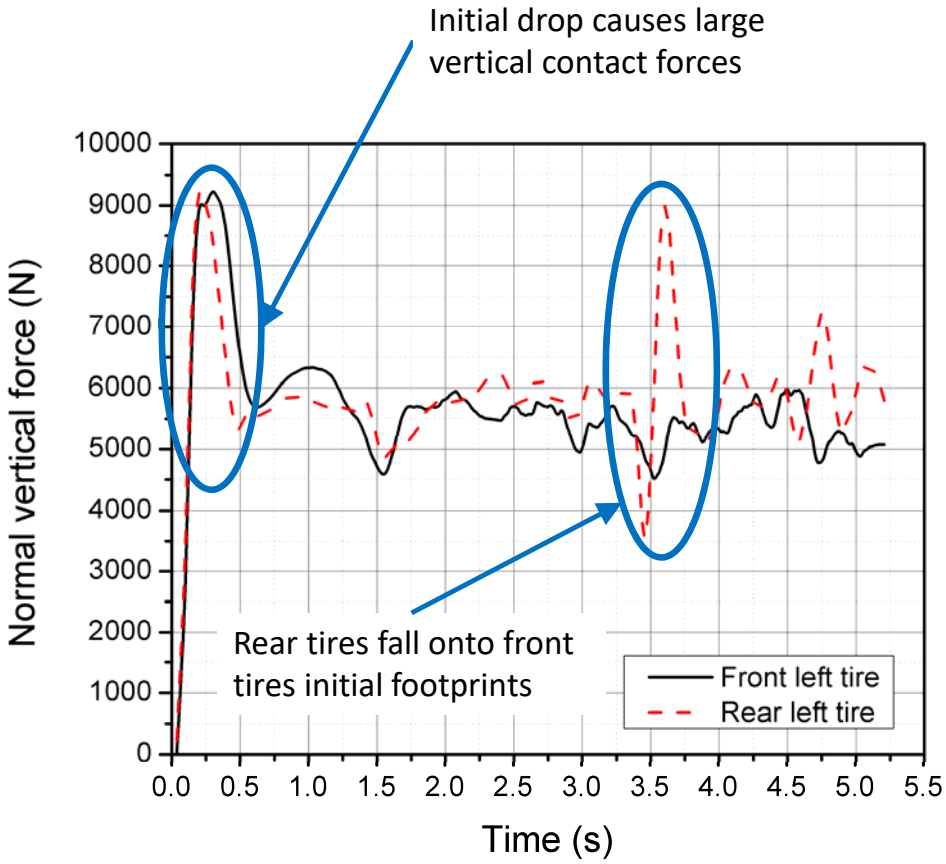


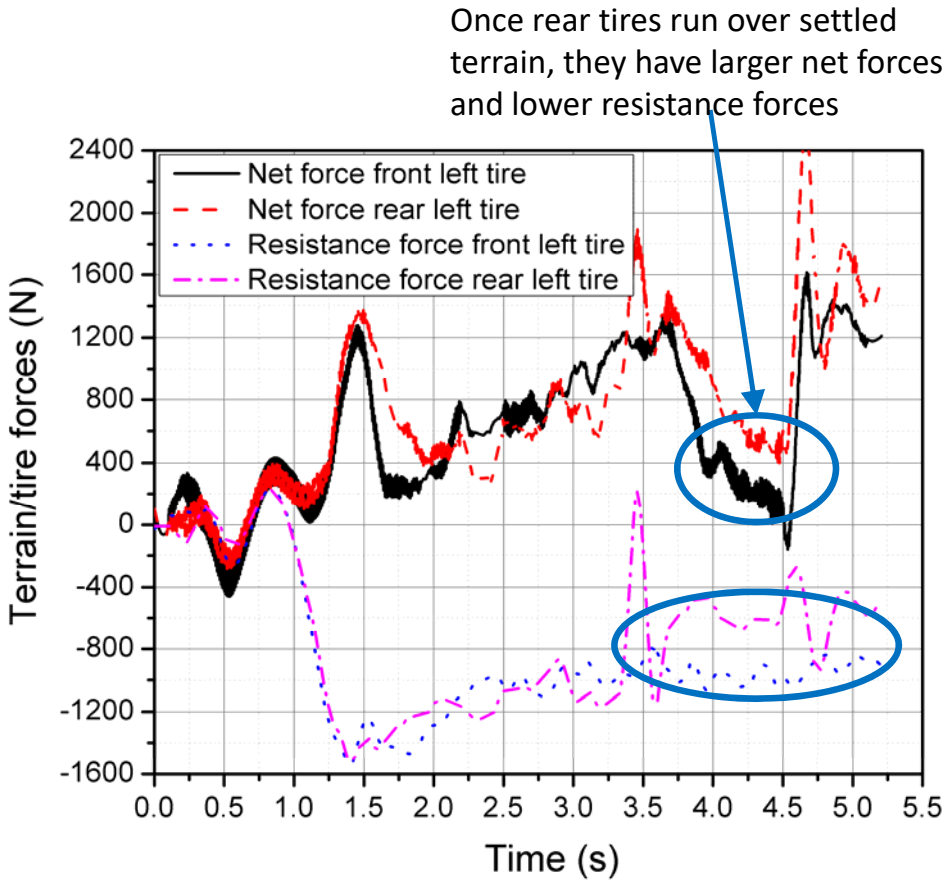
Straight-line acceleration: chassis



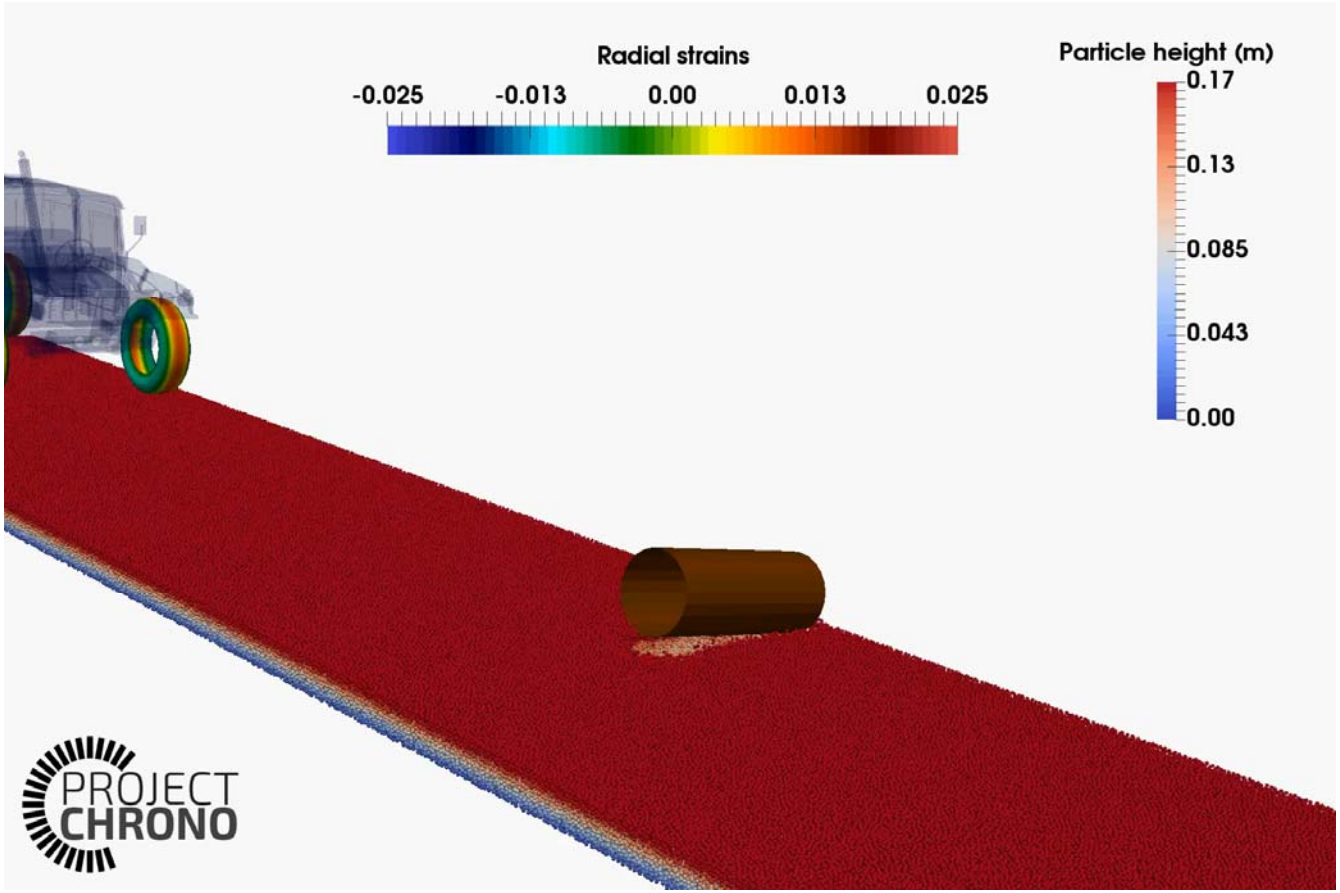


Straight-line acceleration: contact and resistance forces

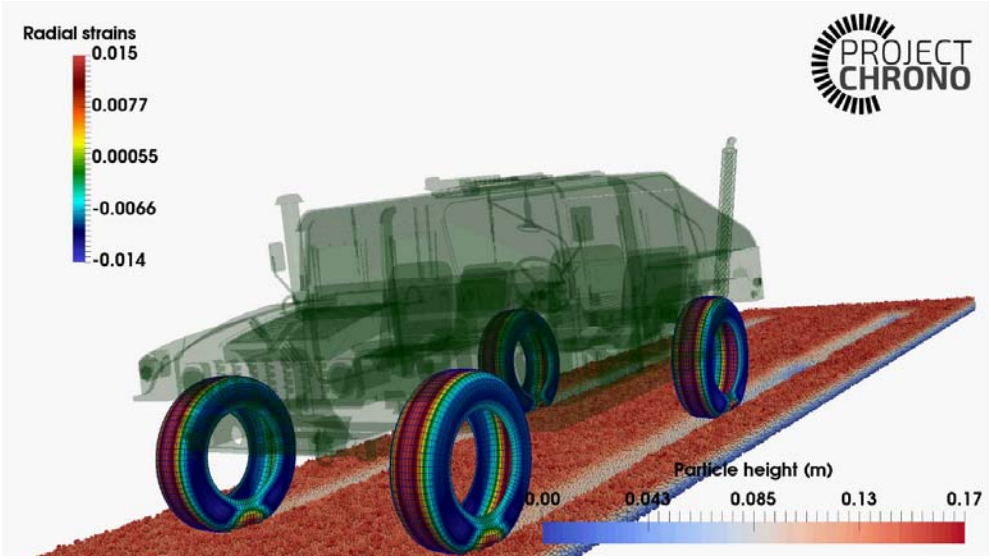




Full HMMWV with ANCF tires on granular terrain over obstacle



Performance – full vehicle on granular terrain simulation



HMMWV vehicle
- Tires: 90 x 24 ANCF multilayered, orthotropic shell elements
- Inflation pressure: 200 kPa
- Acceleration test (80% throttle after 0.5s)
- 2 OpenMP threads / tire

Granular Terrain
- Particle radius: 12 mm
- 16 layers of particles: 923,000
- Terrain: 20m x 3.3m
- Cohesion: 100 kPa
- 24 OpenMP threads

- Time step: 3.5e-5 s
- Comp time: 5.5 days for 7.65 s
- Real time ratio: ~ 61900 s/s