MODPROD 2010 – Linkoping, Sweden

Overview of 3DROV
A Planetary Exploration Rover Design & verification Tool

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Automation and Robotics Section
European Space Agency

Overview

- **Introduction**
- ESA needs for such a tool
- 3DROV design overview
- Utilisation Example: wheel-walking function design
- Conclusions

Introduction

- 3DROV is an ESA R&D activity performed by TRASYS Space (Belgium).
- It was initiated in September 2006 and completed end of 2008.
- The tools is currently being assessed in ESA Robotic Lab and in Industry
- Aims to be a system design tool to support:

  → Concept studies

  → Specific engineering studies (e.g. mobility, autonomy, operations)

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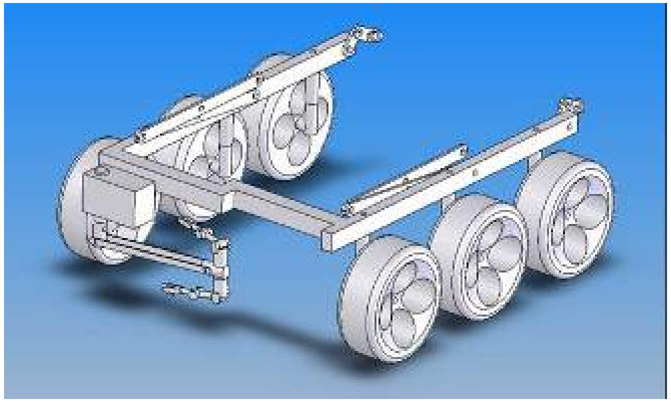
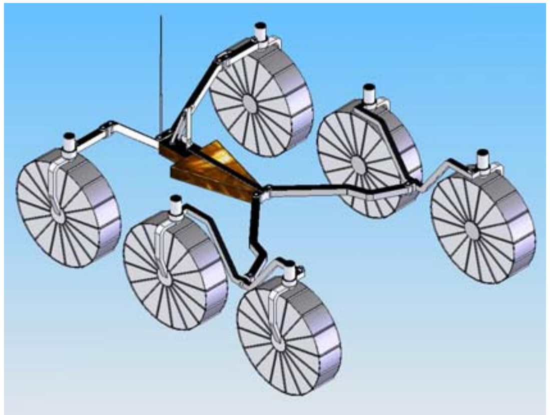
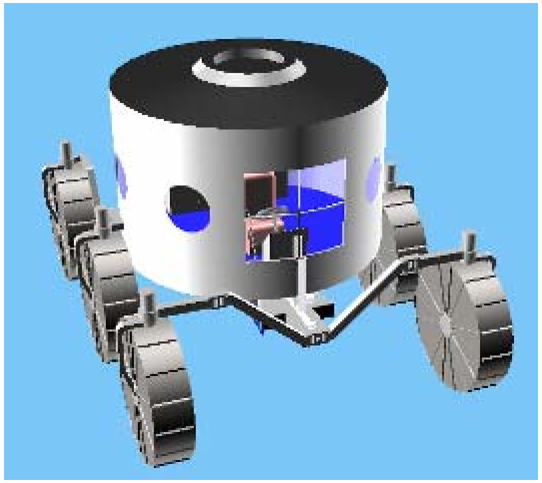
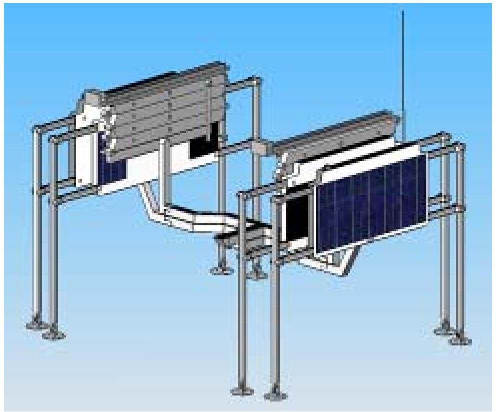
ESA Need for such a Tool :
1- Assist early system design

Recurrent example: The Lunar Utility Truck concept



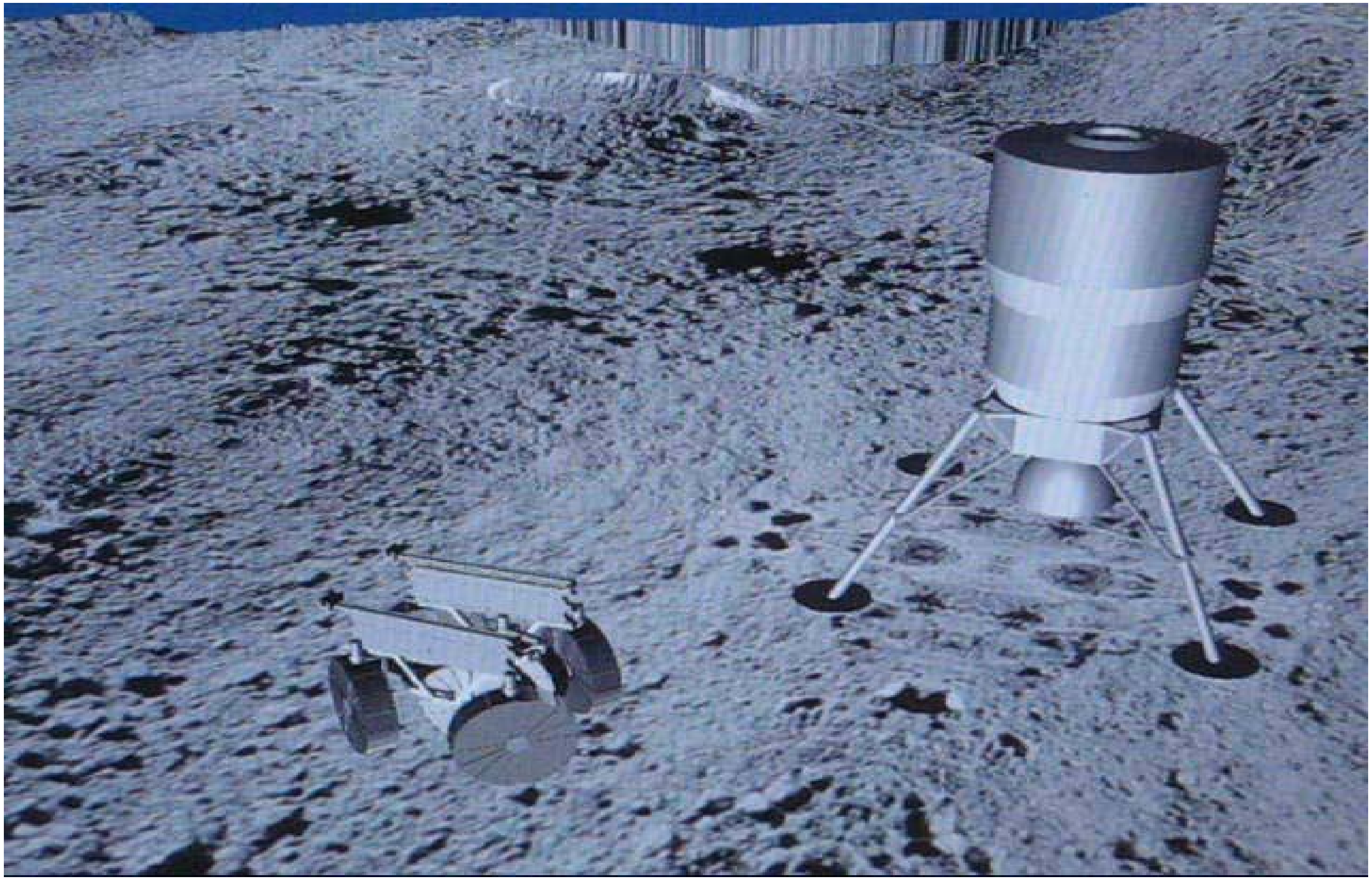






CDF - HSV

ESA Need for such a Tool :
2- Demonstration of system concepts & scenarios

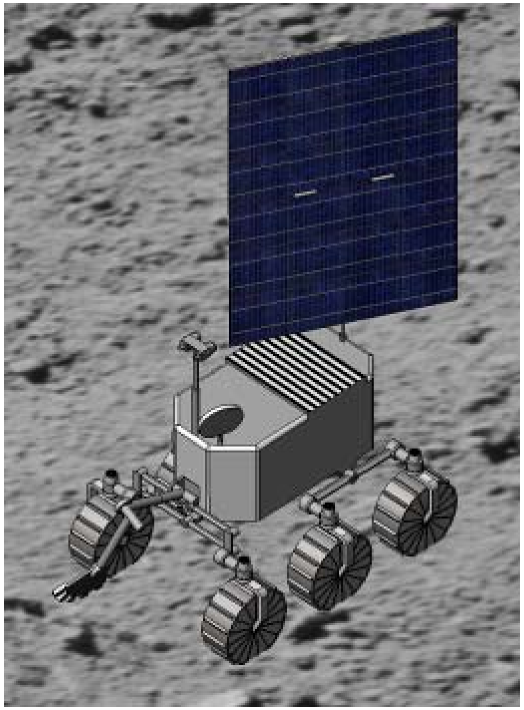


ESA Need for such a Tool :
3. Placing the rover system into context

- Rover concepts are designed based on the constraints imposed by the target environment.
- Thus *terrain profile* and *sun illumination conditions* are major drivers for mission concept selection.

E.g. because of the low elevation of the sun on the lunar poles long shadows are encountered on the terrain.

→ Martian rover navigation based on stereo images would not work!



CDF – LES3 Study

ESA Need for such a Tool :
4. Feed a reactive system

- Previous ESA R&D activities *Formal Specification and Verification of Robotic Activities for Reactive Systems* (MUROCO2) was demonstrated with manual triggering of events during validation through simulation. This is:
  - Not convenient for complex systems
  - Not systematic
  - Not realistic

Necessity of a simulation environment that triggers events (e.g. failures, anomalies, environmental events) to test reactions of the system.

ESA Need for such a Tool :
5. Prepare for rover autonomy

- Demonstration of autonomy requires that the targeted rover system, the instruments & associated controls are available to a sufficient level of development.

Need to assess:

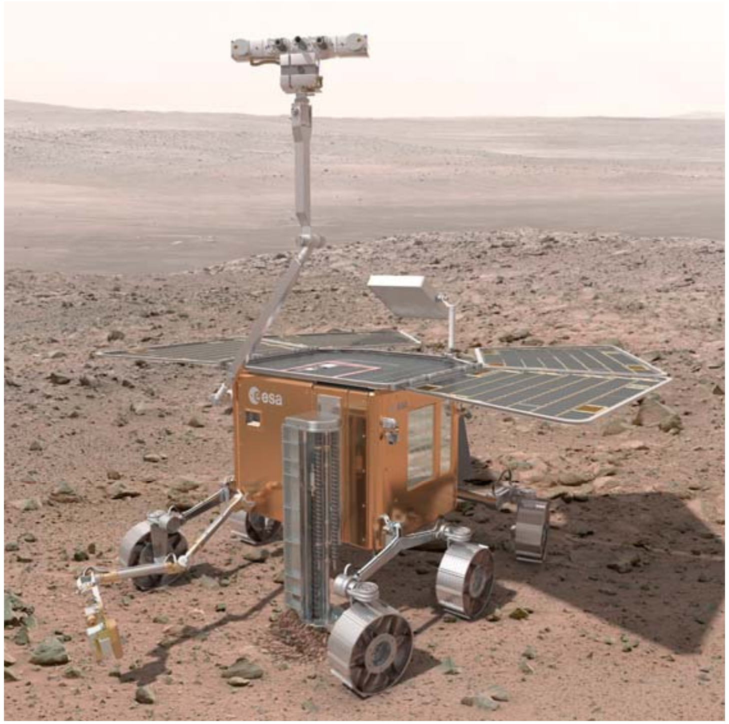
→ Fault Detection Isolation&Recovery concepts

→ Deliberative algorithms for on-board re-planning/scheduling

→ Science autonomy (on-board instrument data processing triggering decisions, possibly leading to re-planning)

ESA Need for such a Tool :
6. Early insight to rover operations

- ExoMars project support:
  - Early understanding of rover operations
    - → Driving and science target specification
    - → Scientific instruments simulation
  - Understanding of the Rover Ground Control needs
  - End-to-End rover operation rehearsal



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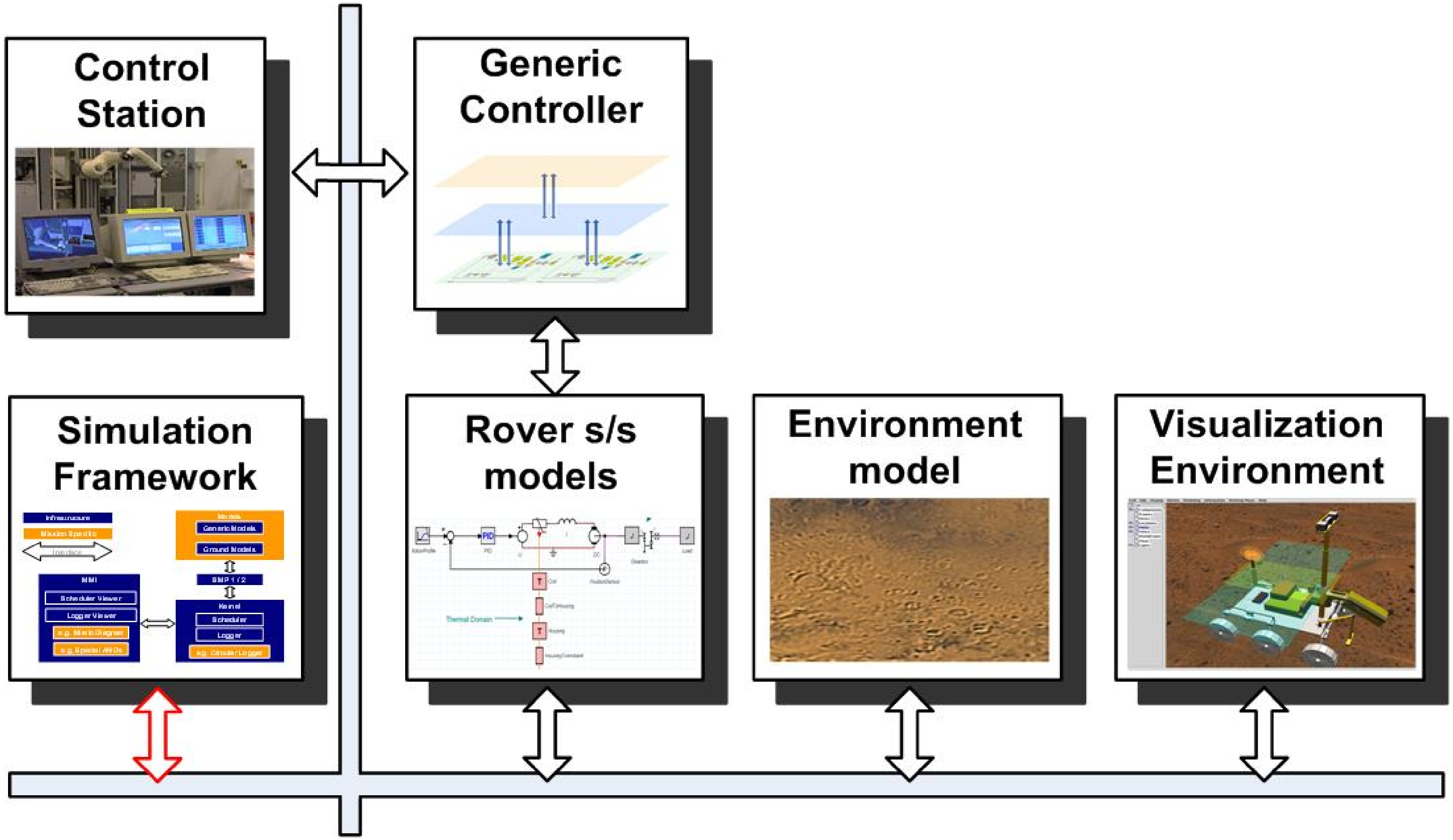
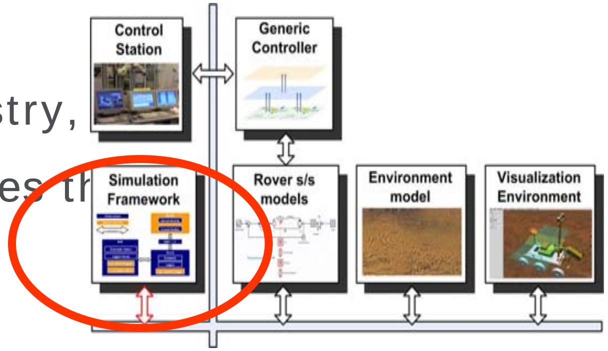
3DROV design overview
3DROV Architecture



3DROV design overview
SIMSAT Simulation Framework



- SimSat is developed by ESA/ESOC with European industry, as a spacecraft operation simulation framework, provides the infrastructure to build upon.
- The SIMSAT framework provides :

→ *Man Machine Interface*: used to build up the simulator as a set of interconnected components, control the evolution of the execution and monitor its internal parameters and provides the means for anomaly and failure injection.

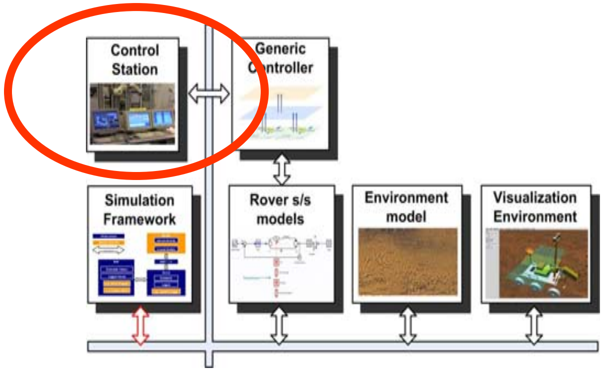
→ *The Kernel*: handles processes and data, provides event scheduling and time management.

→ *Model interconnection and management*: SimSat integrates and manages the models via the *SMP 2.0* standard established by ESA (soon to become ECSS standard).

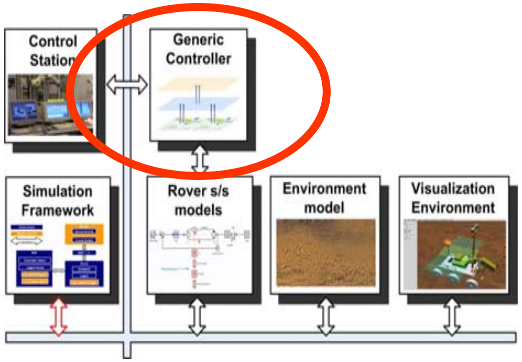
3DROV design overview
Control Station

- Serves as the mission *Ground Control Station*
- As such, offers:

1. *Telemetry (TM) acquisition and processing.*
2. *Rover housekeeping data monitoring and assessment.*
3. *Science data monitoring and assessment.*
4. *Activity preparation, validation and telecommand (TC).*

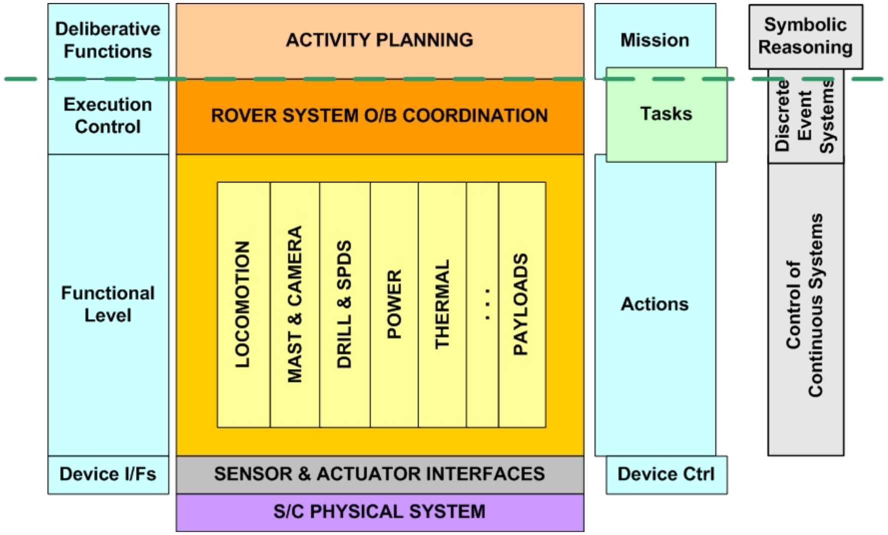


3DROV design overview
Generic Controller

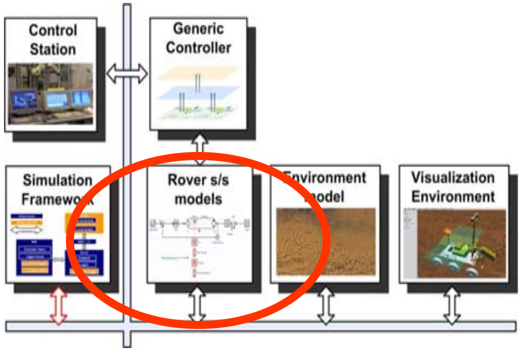


- Substitutes the onboard flight software within the simulation environment.
- Receives and executes *activity plans* as prepared and uploaded from the Ground Control Station and generates *housekeeping* and *science data*.
- Is based on previous R&D activity (MUROCO2) which implements a *3-layer architecture* controller using the ESTEREL language to specify *Tasks* and *Actions*.

→ Using Formal Verification methods the controller building blocks are exported in C-code and linked to the 3DROV environment to create the reactive executive & functional layer.

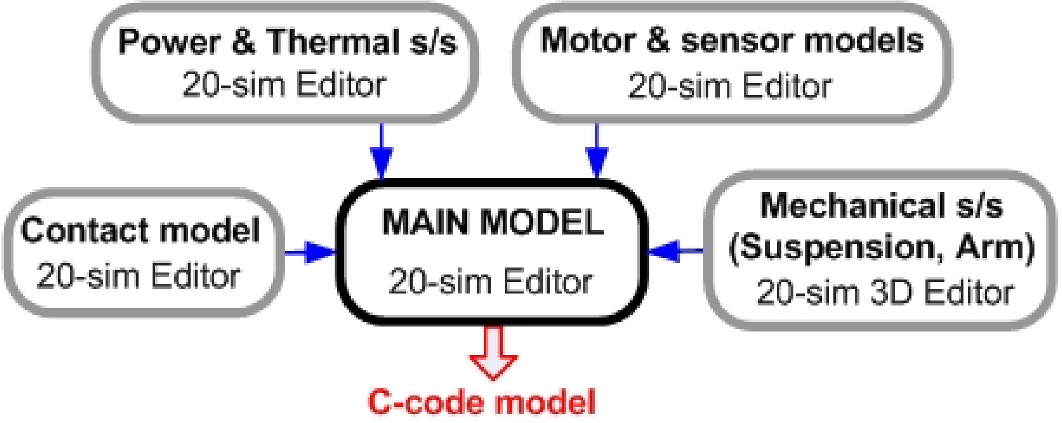


3DROV design overview
Rover physical s/s models



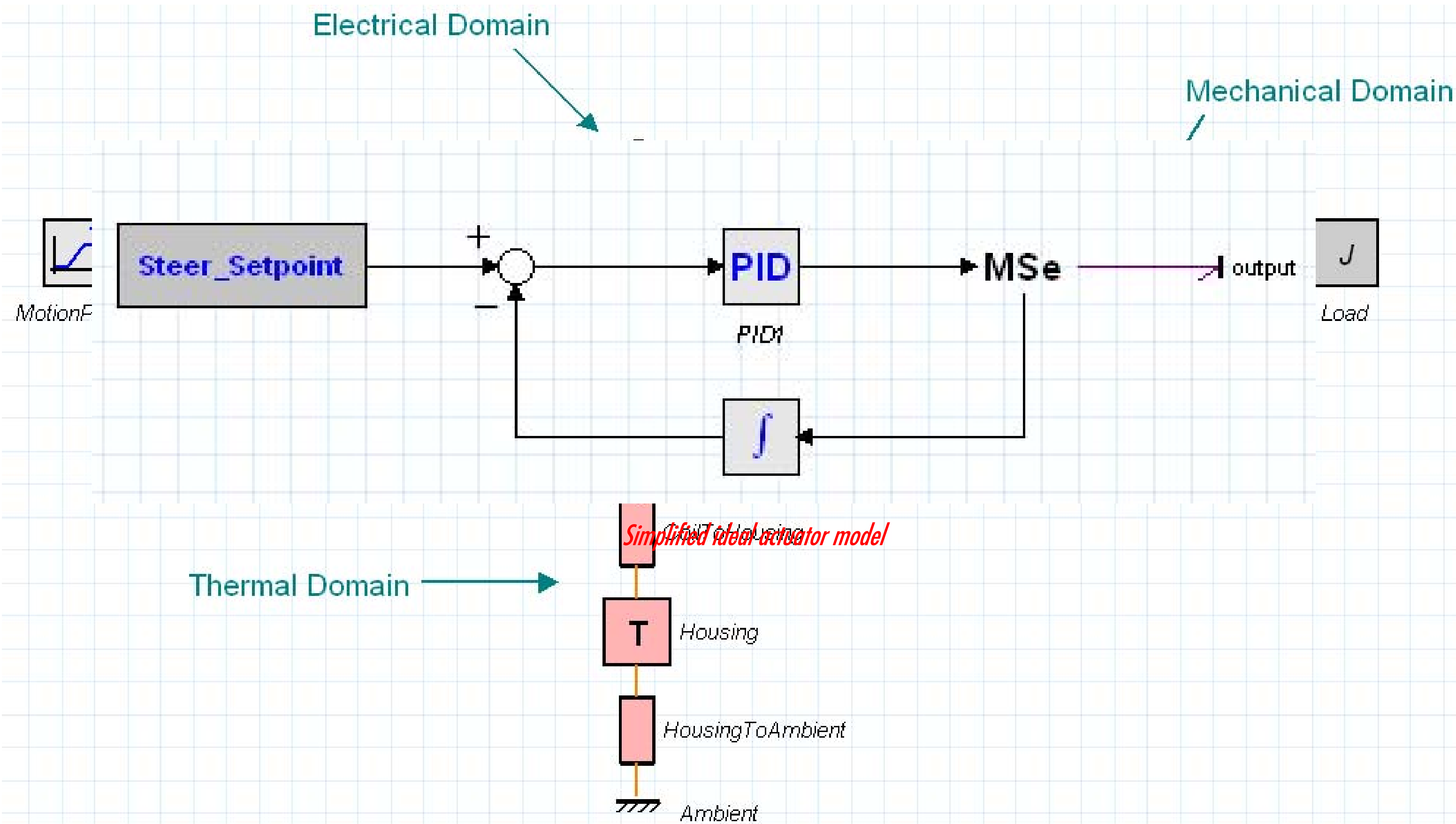
- Use of 20Sim Tool as engineering front-end

  Enabling multi-domain modelling focused on power



- Different levels of fidelity for models within 3DROV depending on the simulation objectives.

3DROV design overview
Rover physical s/s models, example



High Fidelity actuator model

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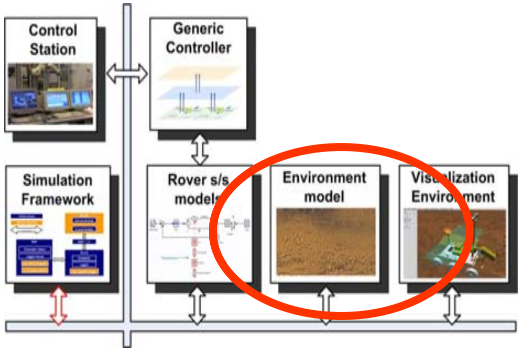
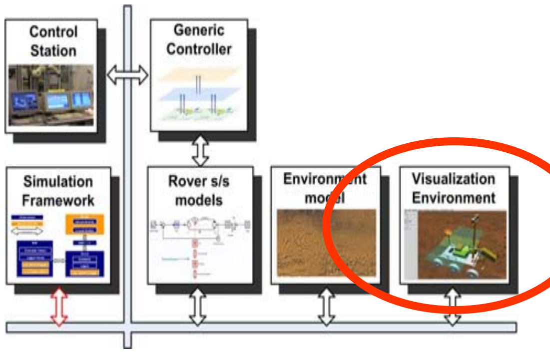
3DROV design overview
Environment model



- Provides Atmospheric data via the Mars Climate Database (temperature, illumination, wind etc…)
- Provides terrain data gathered in the Geographical Information System GRASS GIS (DEMs, Orbital images at various resolutions…)
- Provides Time and Orbital computation (sun, orbiters, Earth visibility)
- Provides terramechanics parameters for soil-wheel interaction computation
- Provides multi-body dynamic motion solving (currently handled with PhysX)
- Provides scientific instruments measurements co-registered with terrain

3DROV design overview
Visualization tool



- Realistic visualisation to feed properly the vision-based algorithms enabled by use of Open source OGRE and NVIDIA graphic card programming
- The Visualisation Tool is used:

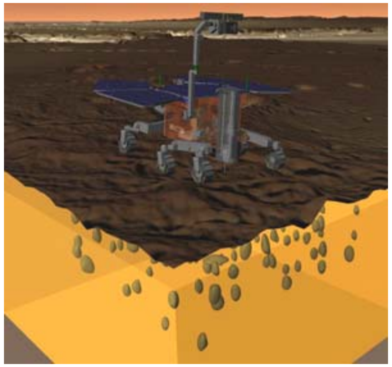
→ by the Ground Control Station for activity preparation

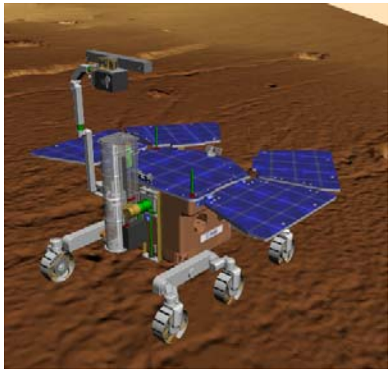
→ by the Simulator for camera emulation and monitoring

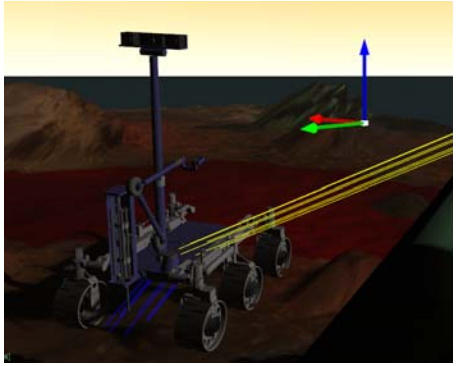
→ by the Simulator for view factors computation needed by the thermal models

→ by the Simulator for contact computation needed by the multi-body dynamic simulator

→ by user to record simulation run for easier communication







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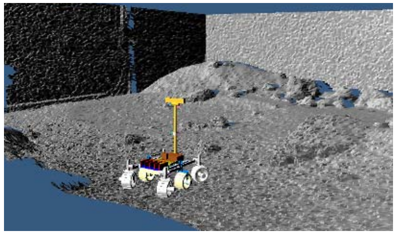
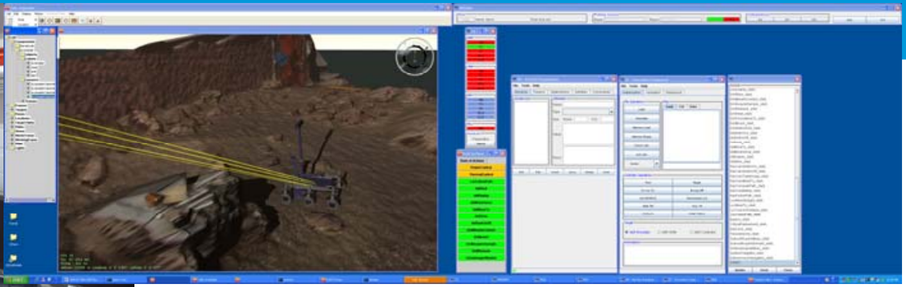
Utilisation Example: wheel-walking function design
ESTEC A&R Lab Rover Facilities

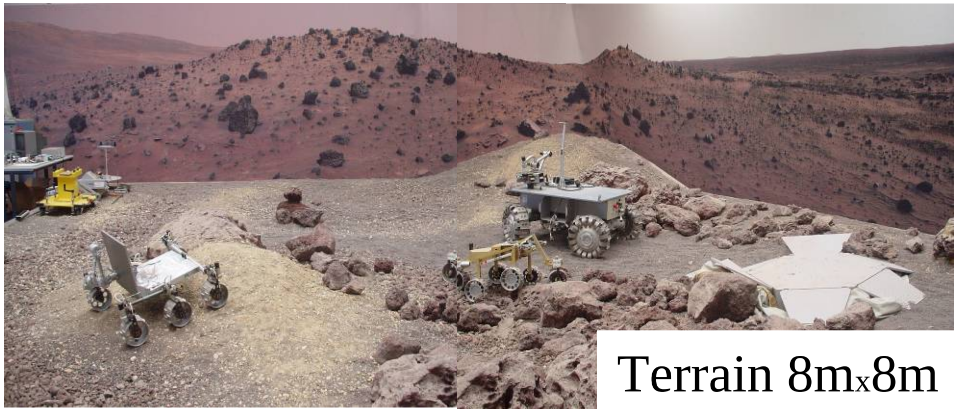
RIEGL Laser Scanner





Ground Station DREAMS + 3DROV

VICON
Motion Tracking



Terrain 8mx8m

ExoMader

LRM

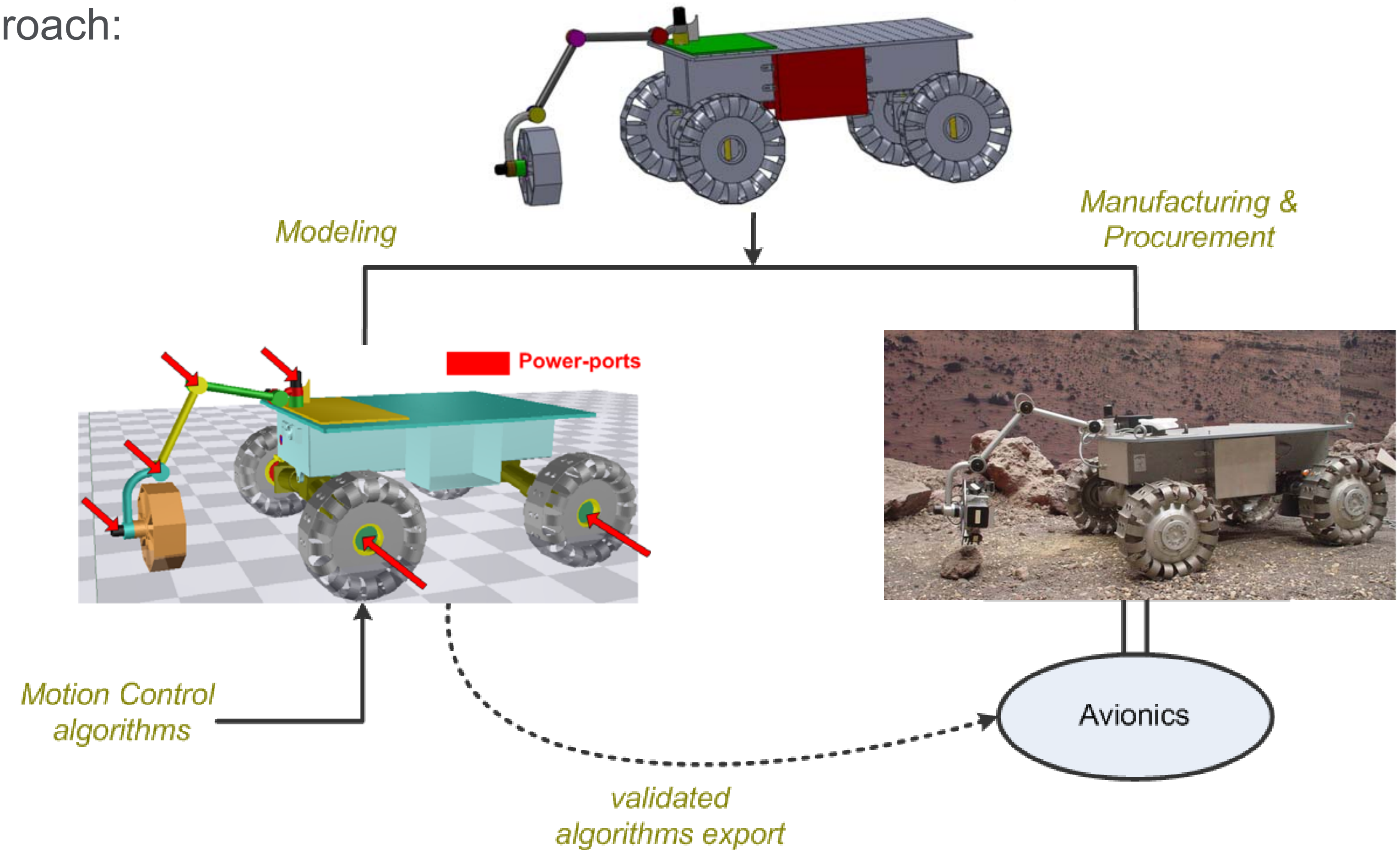
ExoTer*

Landing platform mock-up

* Not currently moving

Utilisation Example 1: Generic Rover Motion Control Design

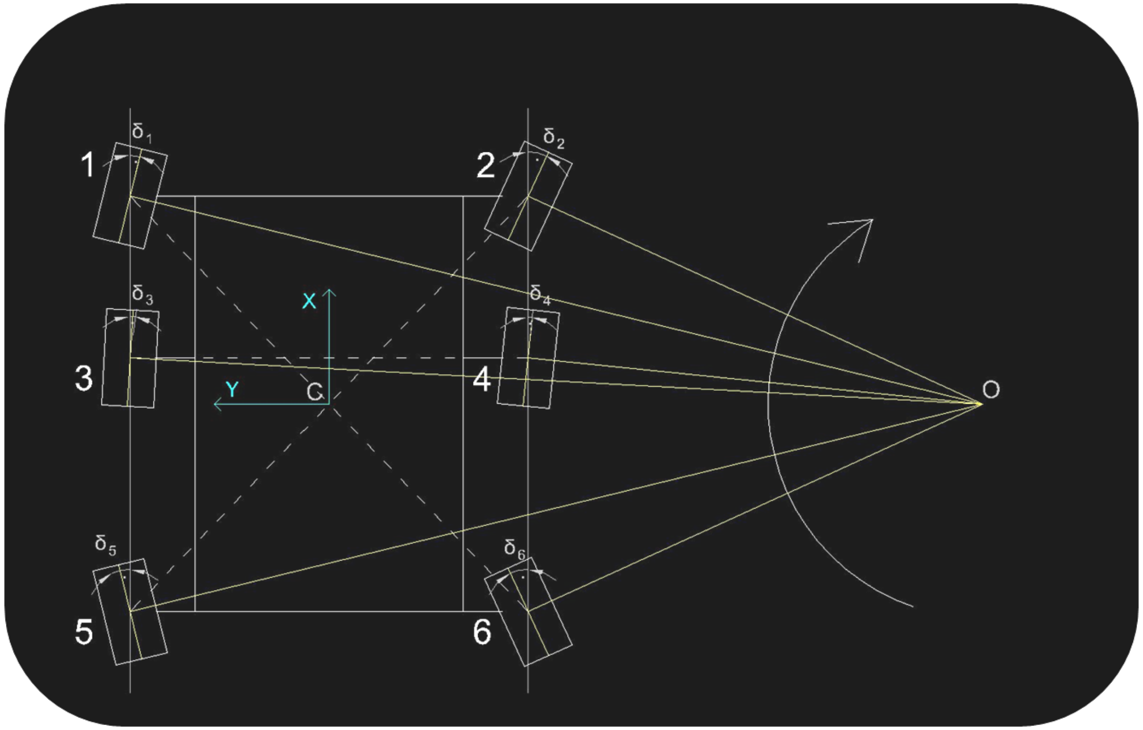
- The Automation & Robotics Lab development cycle: a *correctness-by-design* approach:



Utilisation Example 1:
Generic Rover Motion Control Design

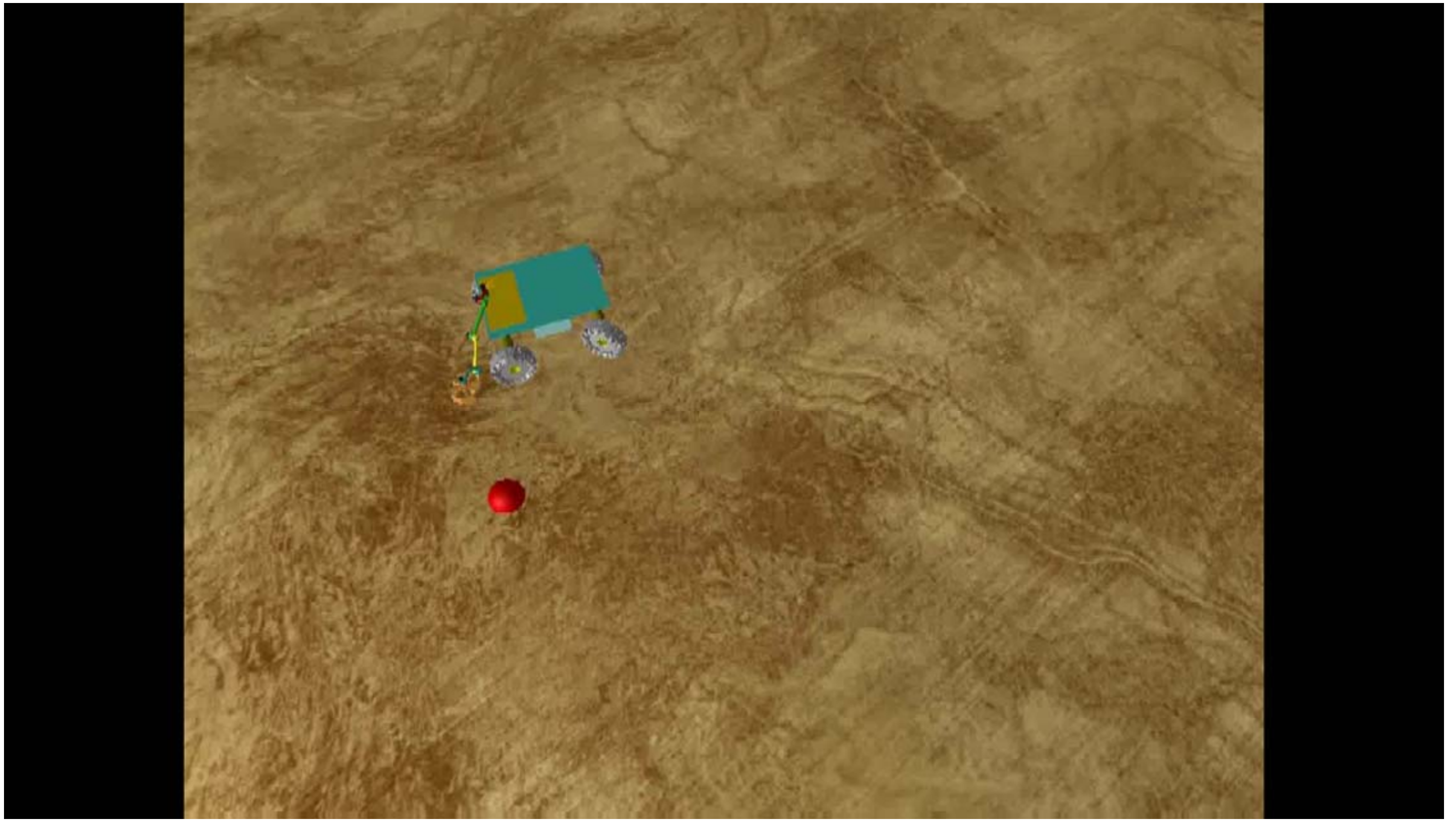
- Case: development of a generic library implementing all possible locomotion modes for up to 6x6x6+6W rovers

- Example: Double Ackerman steering with variable centre of rotation



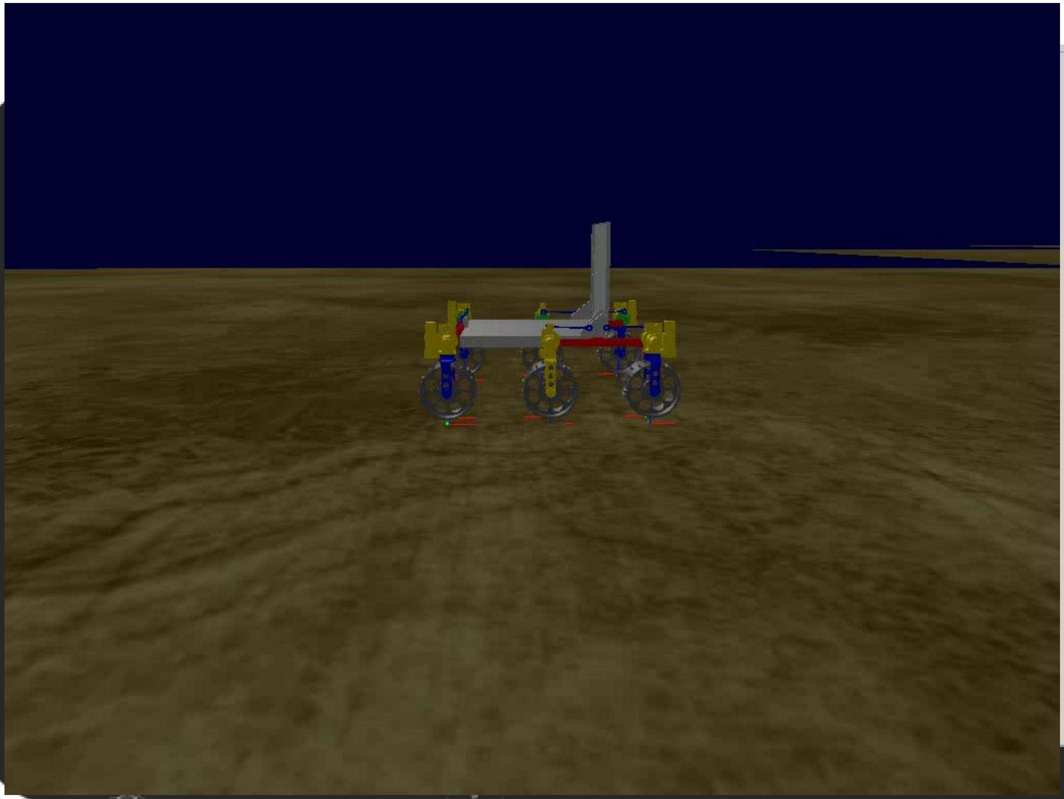
Utilisation Example 1: Generic Rover Motion Control Design

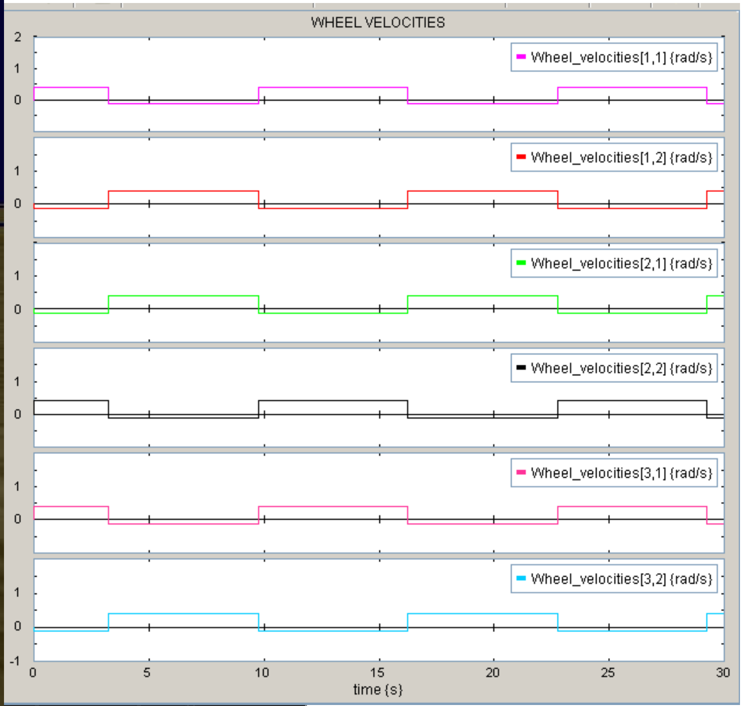
- Application on LRM 4x4x4 rover: point of rotation in extension of the instrument head



Utilisation Example 2:
The wheel-walking function

- The rover wheel-walking mode needed to be investigated
- 5 wheel walking gaits were analysed and simulated using the ExoTeR laboratory breadboard. A fully parametric control library was developed





"tripod" gait

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The wheel-walking function

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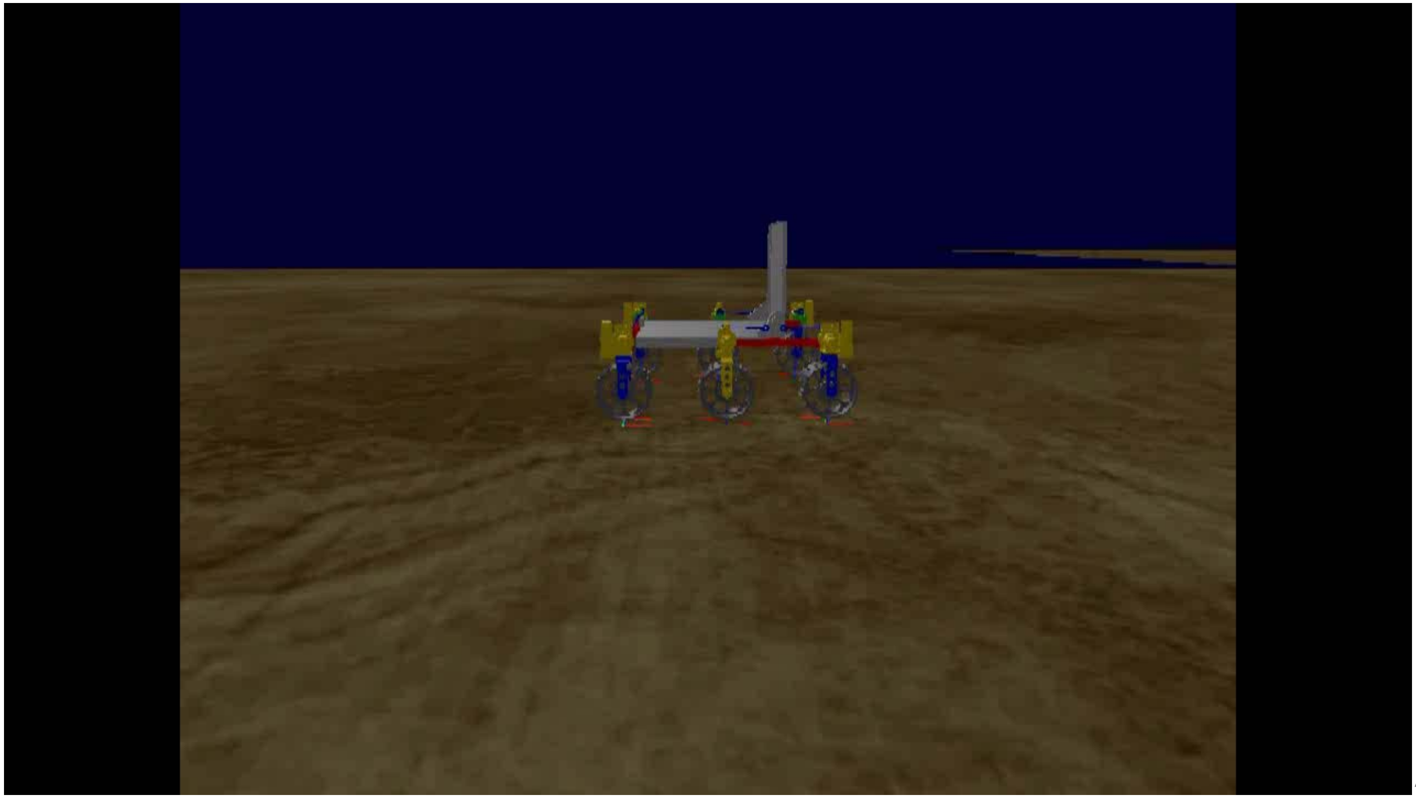
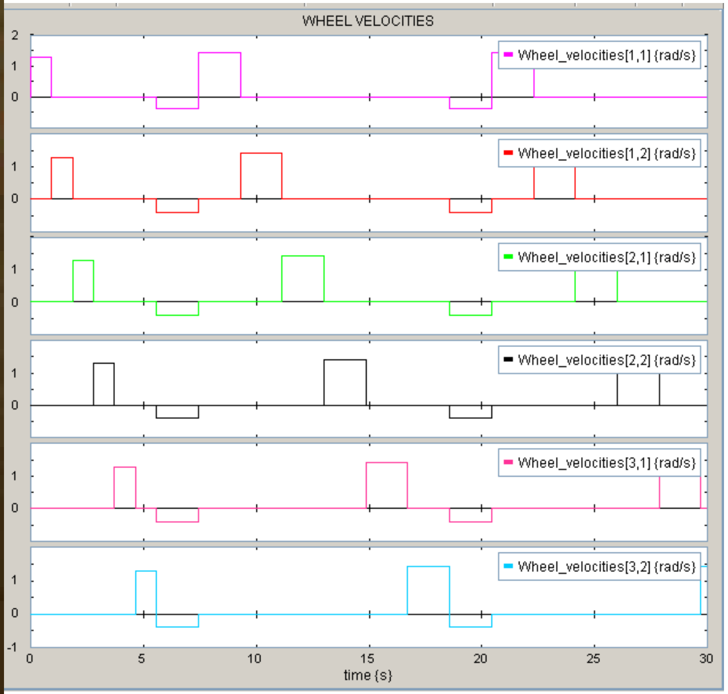


"two-by-two" gait

Utilisation Example 2: The wheel-walking function

➢ WW control library ported to 3DROV and runs on the rover Generic Controller



"one-by-one" gait

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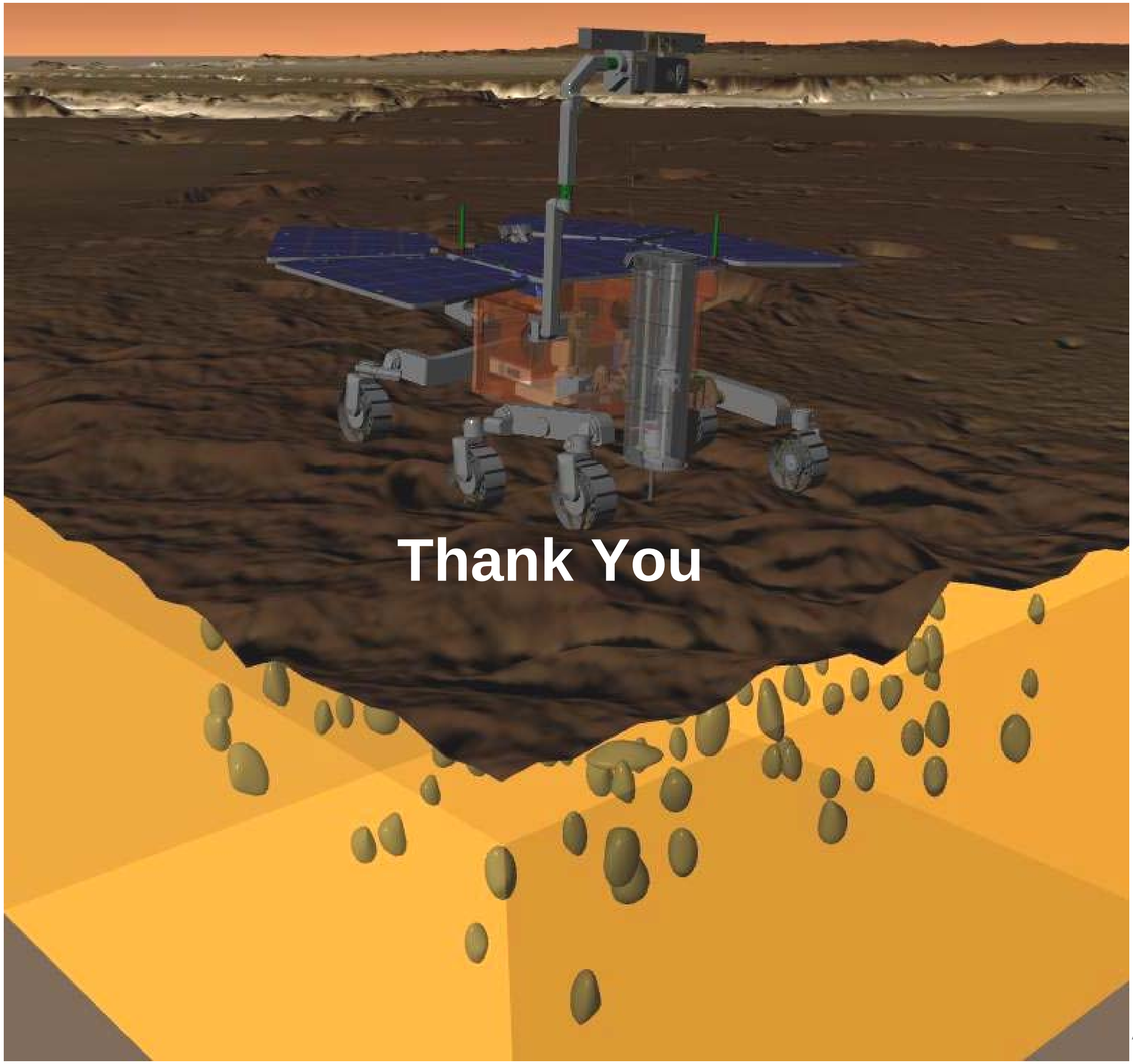
Conclusions

3DROV is being used to create and validate new rover functionalities before HW implementation.

3DROV is being used in a real space project "ExoMars" due to launch in 2018 to support space system engineering work.

3DROV validation against real system tests remains to be performed => ESTEC Lab under preparation for this next step!

3DROV to evolve toward full mission simulation.



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