The Mars-Rover Case Study Modelled Using INTO-CPS

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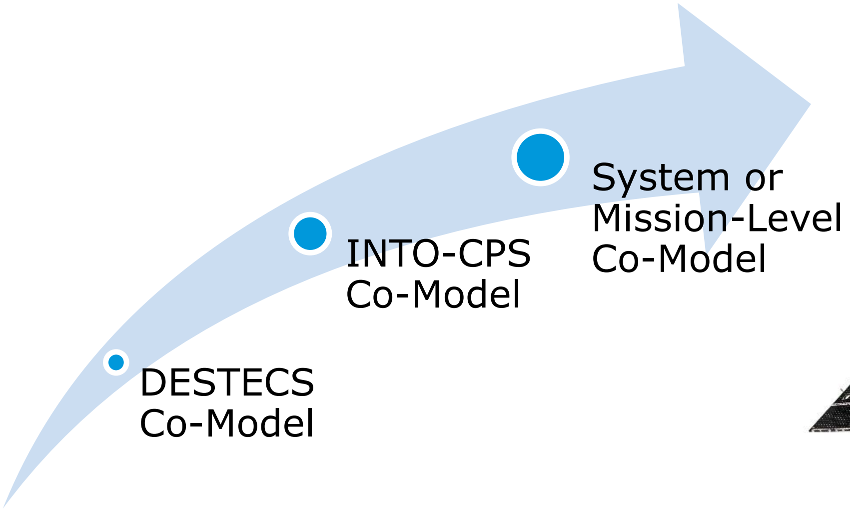
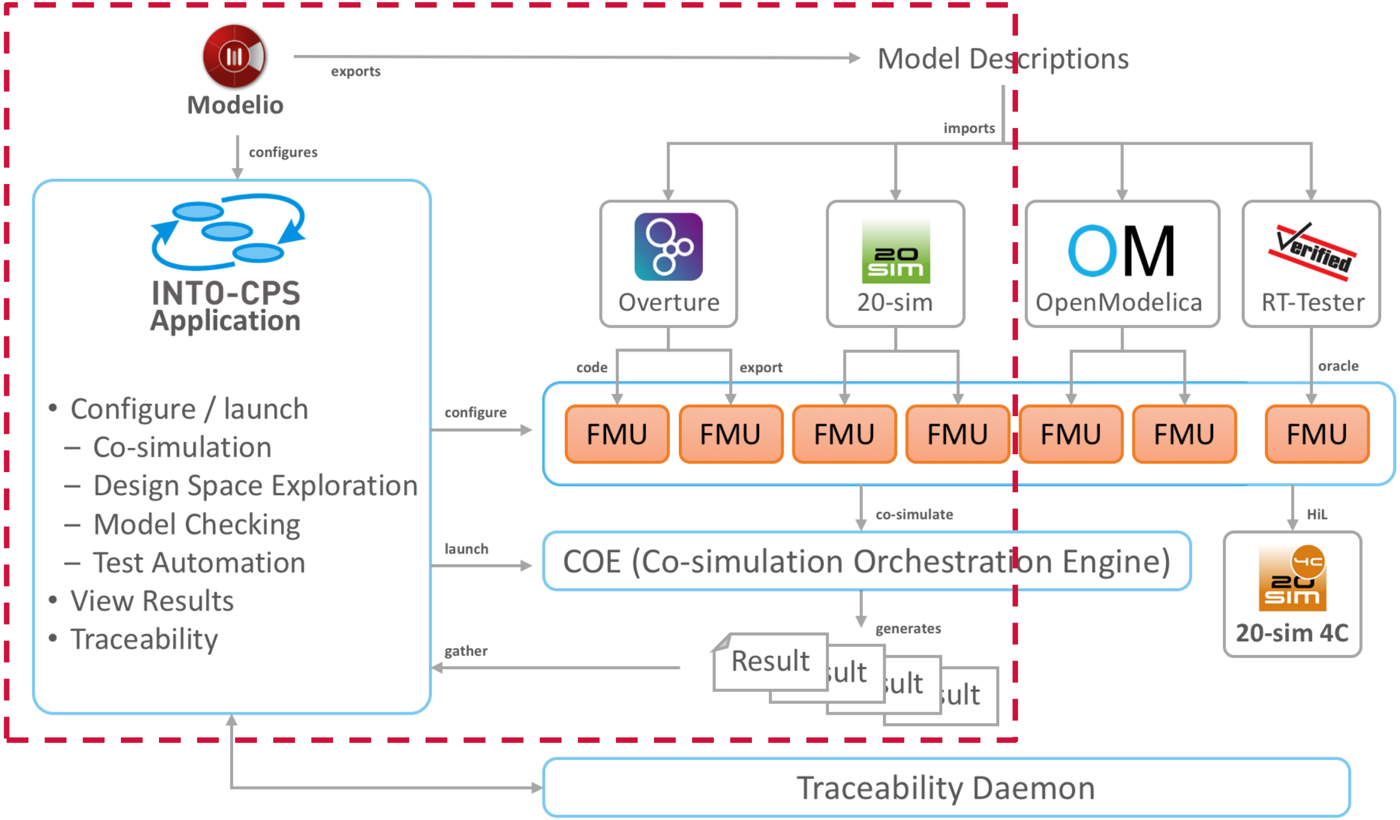
Goals of the Study

- Understand the effort required to migrate existing co-simulation models from DESTECS into INTO-CPS.
- Explore the advantages and limitations of using INTO-CPS for co-simulation workflows. In particular, the FMU/FMI paradigm.



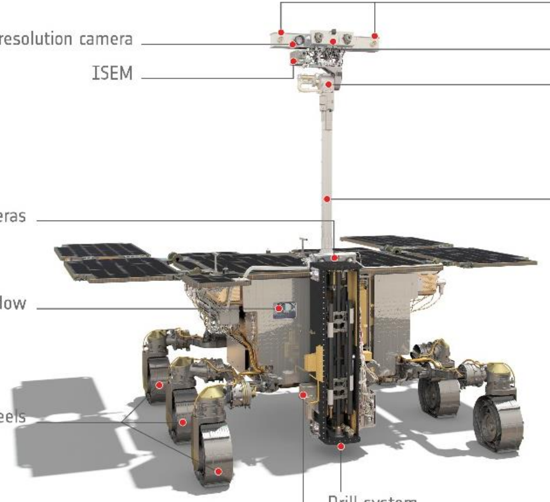
INTO-CPS

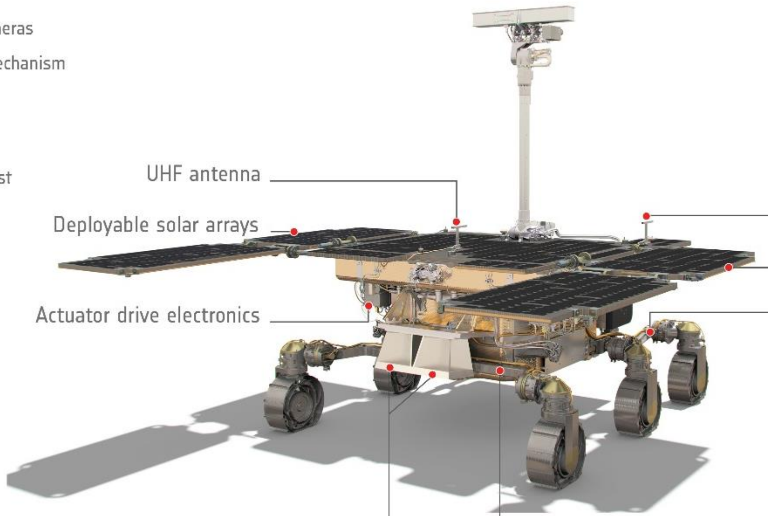


Modelio
exports
Model Descriptions
imports
configures
INTO-CPS Application
• Configure / launch
– Co-simulation
– Design Space Exploration
– Model Checking
– Test Automation
• View Results
• Traceability
Overture
20-sim
OpenModelica
RT-Tester
code
export
oracle
configure
FMU
FMU
FMU
FMU
FMU
FMU
FMU
co-simulate
HiL
launch
COE (Co-simulation Orchestration Engine)
20-sim 4C
generates
gather
Result
Traceability Daemon

The Mars Rover Case Study

- Aim: to develop a co-model to evaluate controller strategies through simulation
- Proprietary ESA Model of vehicle dynamics
- Wish to evaluate different controller proposals without disclosing the model

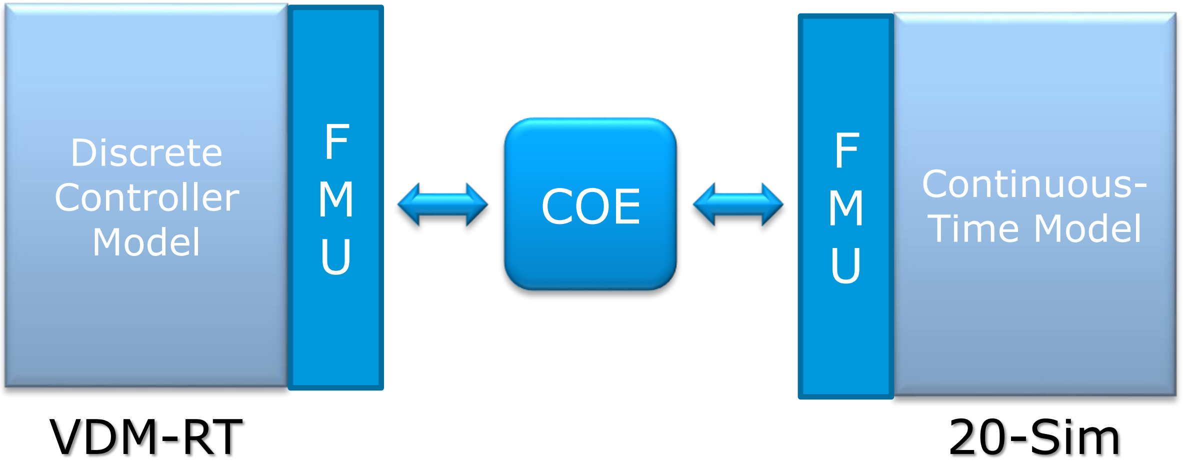




Co-Simulation Model

- Control strategies
- Mode switching
- Safeguard mechanism

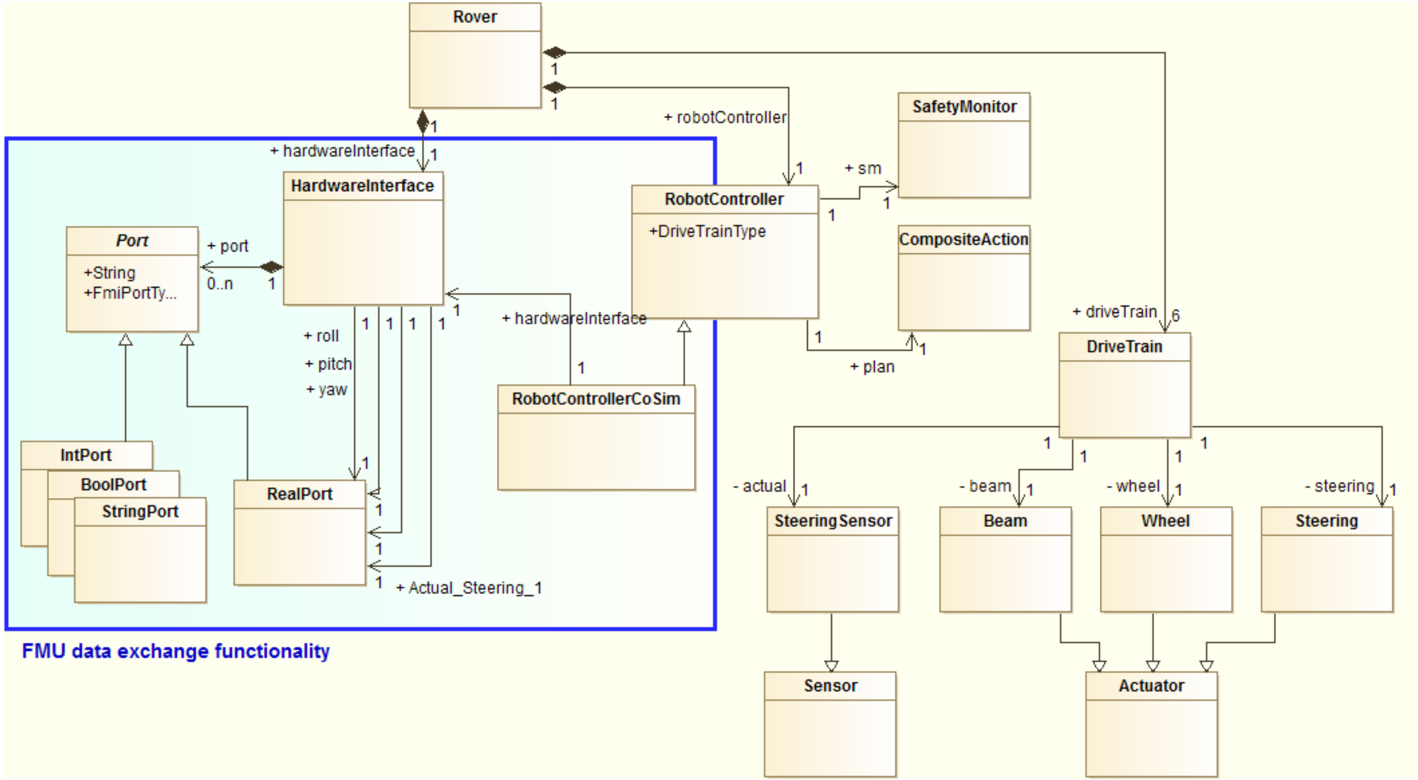
- Simplified geometry
- Environment model
- Contact model



Overture FMI Extension

- Automatic inclusion of FMU library
- Automatic import of model descriptions from Modelio
- Requires modifying models:
    1. Add `HardwareInterface` class containing exchange ports, their types (bool, int, real and string) and exchange directions (input / output)
    2. Adapt model to read and write from the hardware interface using dedicated methods
- Automatic generation of FMU
    - Tool wrapper
    - Source code

Overture FMI Extension



Overture FMI Extension

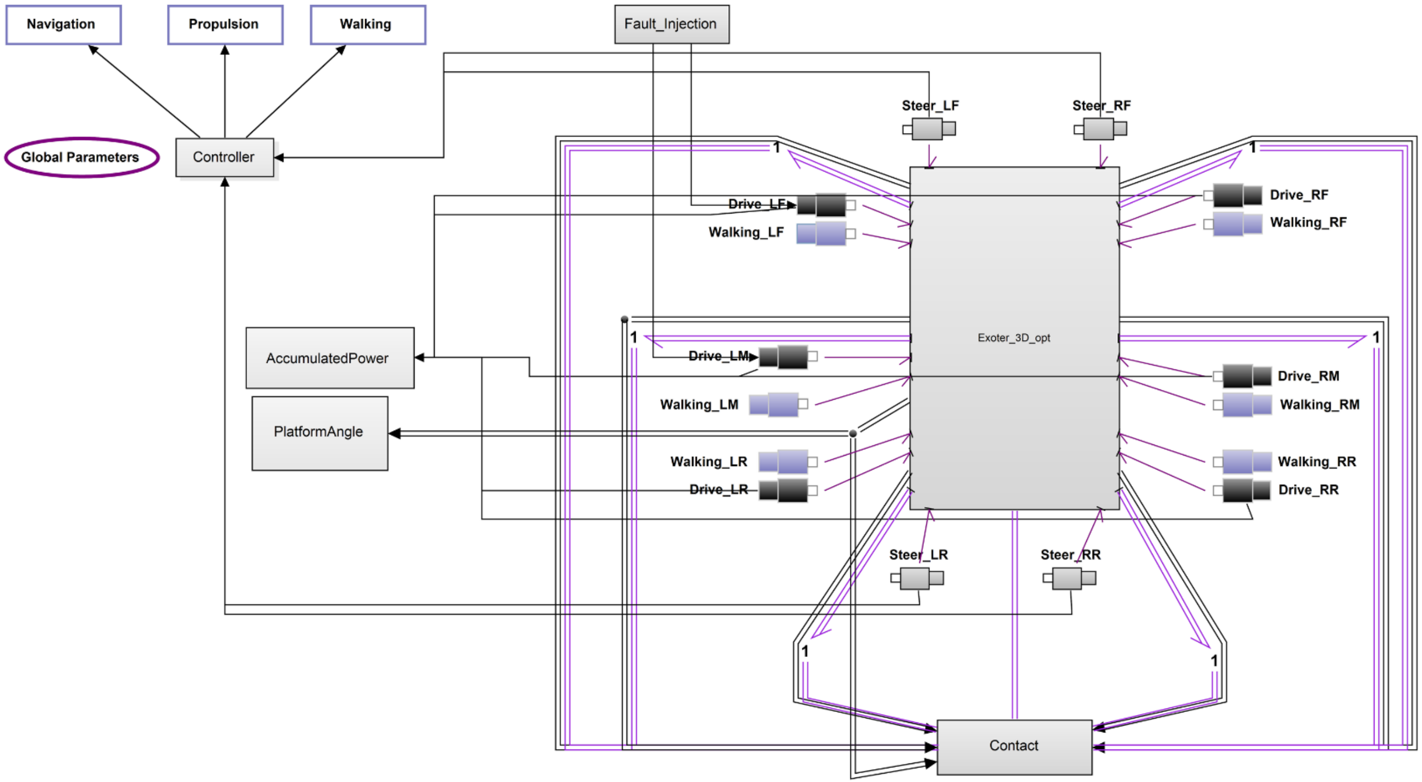
```
class HardwareInterface
values
  -- @ interface: type = parameter;
  public v : RealPort = new RealPort(1.0);

instance variables
  -- @ interface: type = input;
  public distanceTravelled : RealPort := new RealPort(0.0);
  -- @ interface: type = output;
  public setAngle : RealPort := new RealPort(0.0);

end HardwareInterface
```

20-Sim FMI Extension

- Declaration of external variables specifying type and direction
- No need to use dedicated functions for reading or writing
- Support code generation (20-Sim 4C) and code-based FMU (experimental)
- Support tool wrapper FMU generation

```
externals
  // External variables
  real global export Actual_Steering_1;
  real global export Actual_Steering_2;
  real global export Actual_Steering_3;
  ...
  real global import steering_1;
  real global import steering_2;
  real global import steering_3;
  ...
equations
  ...
```

20-Sim Model

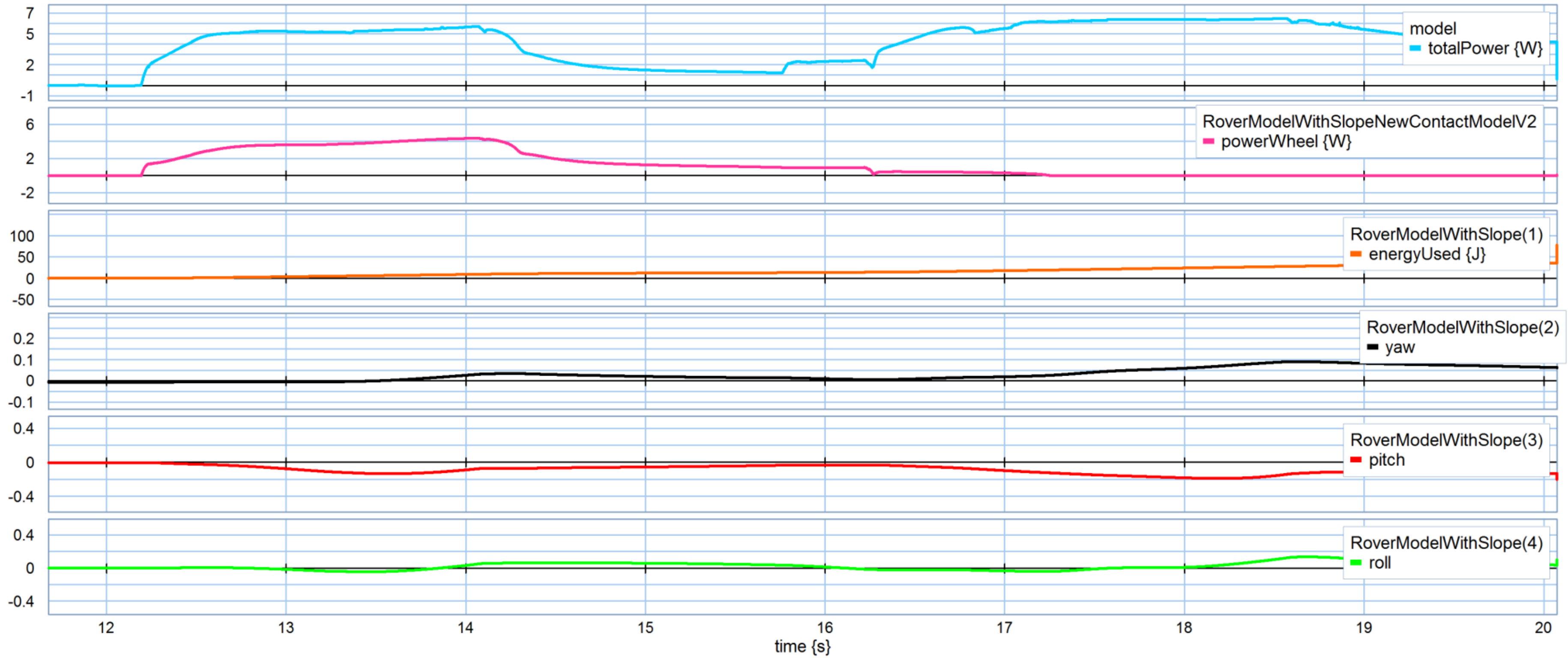


Navigation
Propulsion
Walking
Fault_Injection
Global Parameters
Controller
Steer_LF
Steer_RF
Drive_LF
Walking_LF
Drive_RF
Walking_RF
AccumulatedPower
PlatformAngle
Exoter_3D_opt
Drive_LM
Walking_LM
Drive_RM
Walking_RM
Walking_LR
Drive_LR
Walking_RR
Drive_RR
Steer_LR
Steer_RR
Contact
1

Results

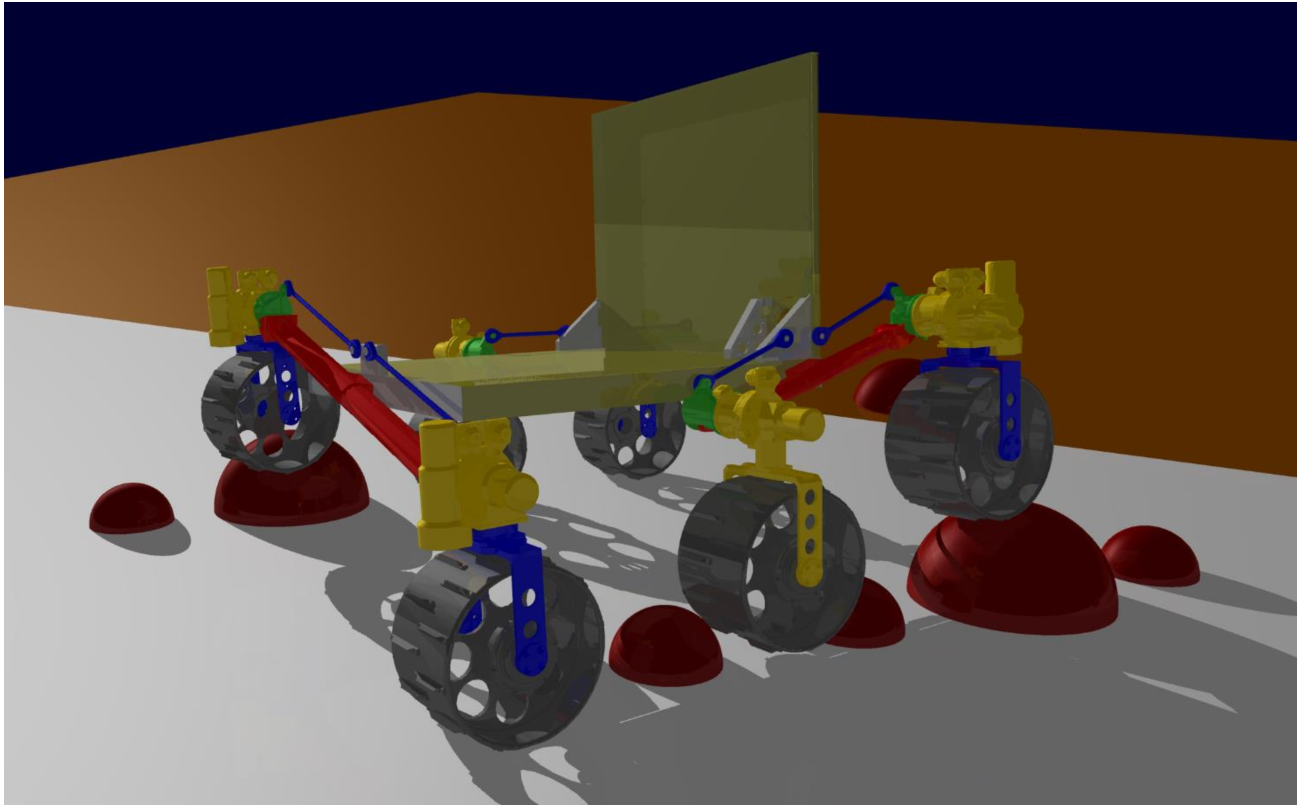
- Performed model adaptation for FMI generation
- Created an INTO-CPS co-model from generated FMUs
- Effort required:
  - ~20 work hours for model modification: learning curve, addition of FMI-specific constructs, configuration of the co-model, debugging
  - Involvement of tool vendors for the resolution of issues with software components (20-sim FMU generation, contact model update)
- Able to reproduce the simulation outcome of the INTO-CPS setup

Results



7
5
2
-1
model
totalPower {W}
6
2
-2
RoverModelWithSlopeNewContactModelV2
powerWheel {W}
100
50
0
-50
RoverModelWithSlope(1)
energyUsed {J}
0.2
0.1
0
-0.1
RoverModelWithSlope(2)
yaw
0.4
0
-0.4
RoverModelWithSlope(3)
pitch
0.4
0
-0.4
RoverModelWithSlope(4)
roll
12
13
14
15
16
17
18
19
20
time {s}

Results



Challenges Encountered

- Model compatibility issues, update required for current tool versions
  - Interface definitions
  - VDM reserved keywords
  - Upgraded contact model
- Experimental status of the tools involved.
- No support for interrupt-like events in co-simulation mode. Requires additional effort.
- No support for vector types. Requires either:
  a. Encoding/Decoding via strings.
  b. Naming conventions plus additional tooling layer.

Advantages and Outlook

- Management of intellectual property
- Possibility of distributed model construction
- Possibility of distributed, heterogeneous simulation
- Possibility of “system of systems” mission analysis
- Possibility of early validation of on-board software
    - Currently working on code generation from discrete models (vdm2c)
    - Allow integration into co-models as well as deployment into hardware targets using TASTE