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Rocket engine digital twin

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TFAWS
LaRC 2019

Thermal & Fluids Analysis Workshop
TFAWS 2019
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NASA Langley Research Center
Hampton, VA

Agenda

- **Introduction**
- RL-10 engine model
- Integrated framework for mission analysis
- Impact of cooling jacket temperature on engine start-up
- Conclusions and prospects

Introduction

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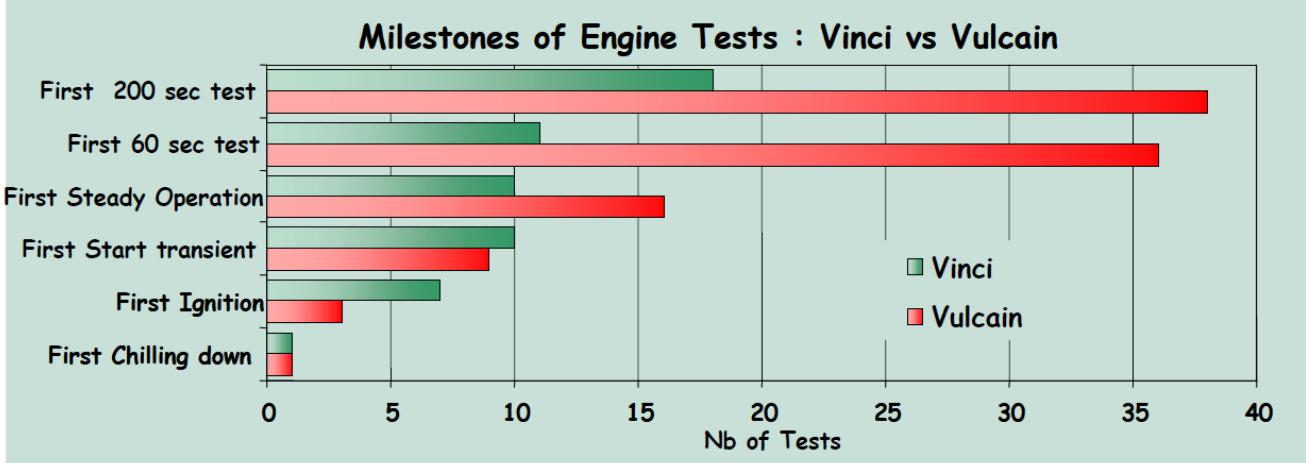
- Motivations for a computational transient model
  VINCI cryogenic upper stage example



Comparison of milestones of engine tests for both Vinci and Vulcain engines

Source: Stéphane Durteste, "A Transient Model of the VINCI Cryogenic Upper Stage Rocket Engine", 43rd AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit 8 - 11 July 2007, Cincinnati, OH

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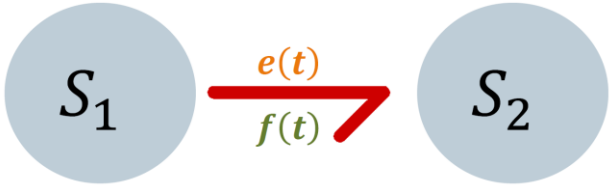
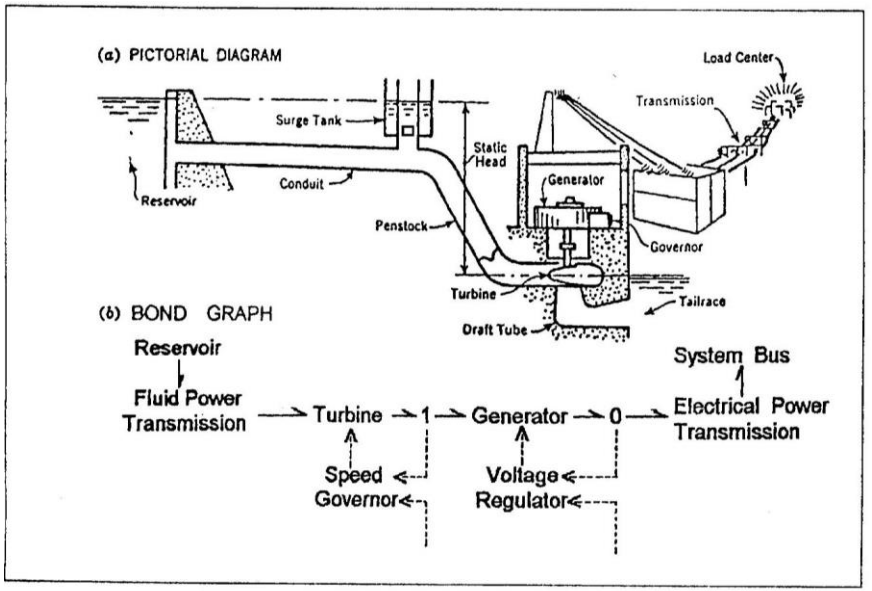
Modeling principles

- Bond graph representation



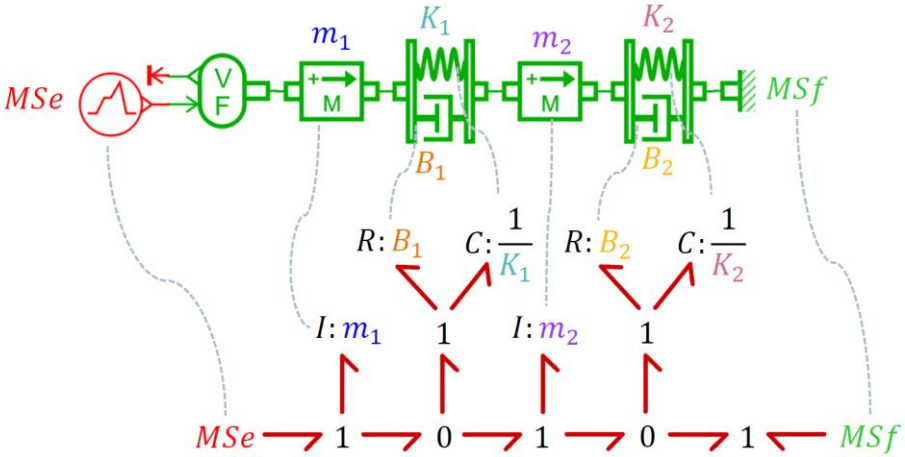
The instantaneous power transfer between the two systems S1 and S2 is $\boldsymbol{P(t)=e(t)\cdot f(t)}$



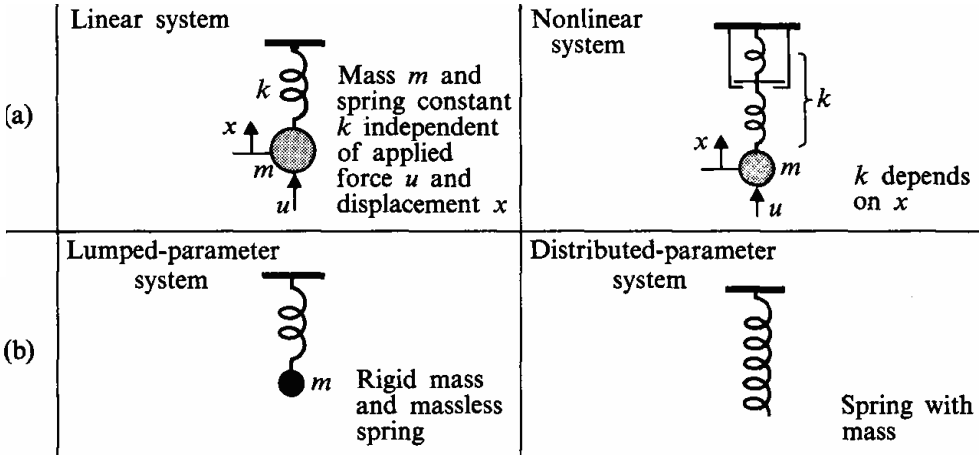
Hydroelectric plant.

One of the first example given by Prof. Henry PAYNTER

Modeling principles



simple mechanical system represented with the bond graph formalism



lumped vs. distributed parameter approach

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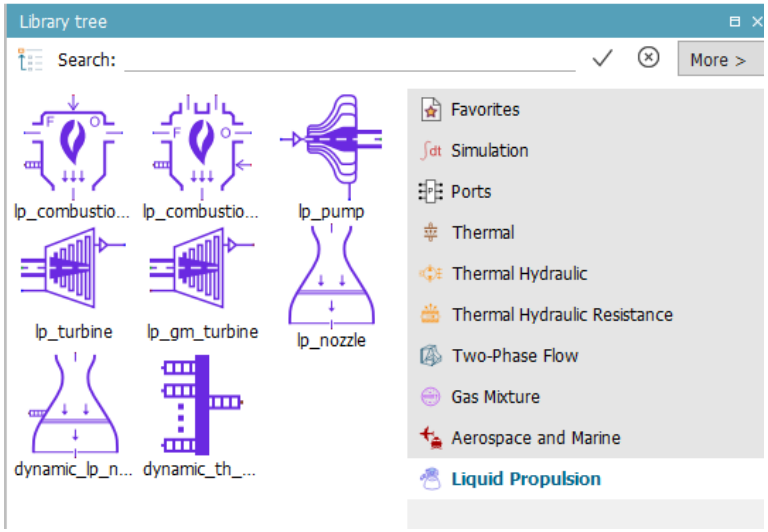

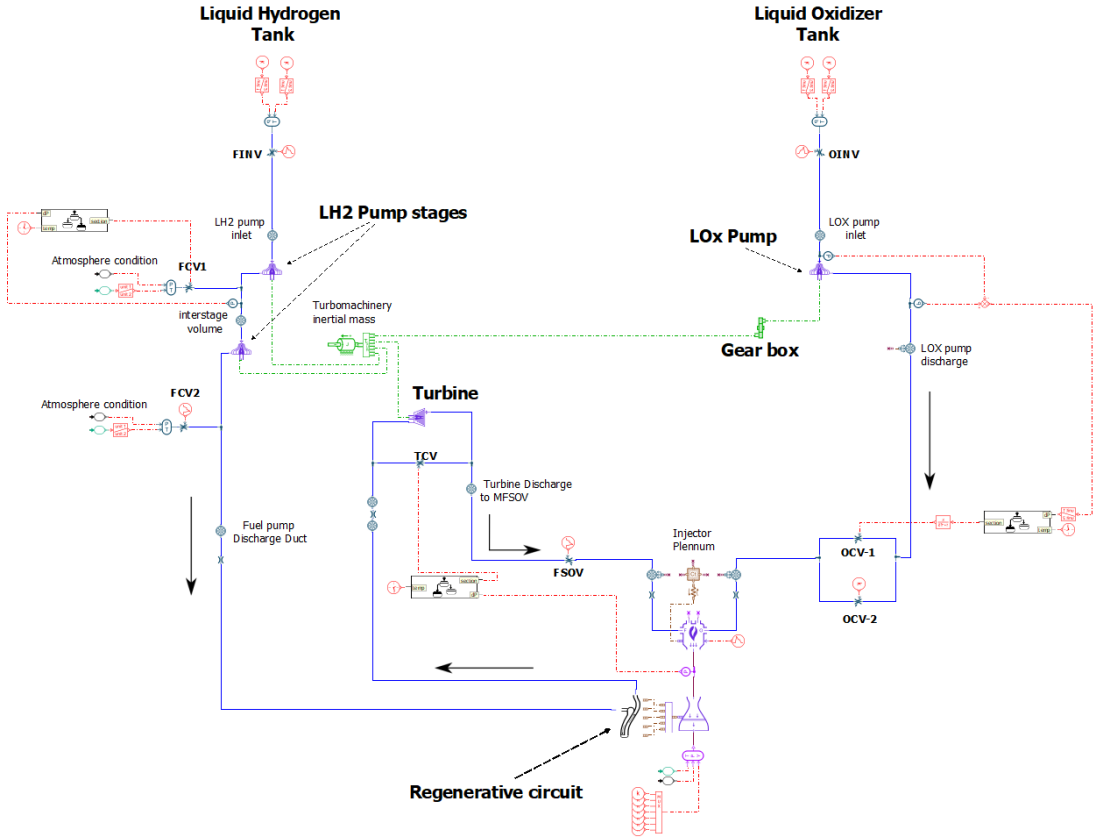

RL-10 engine

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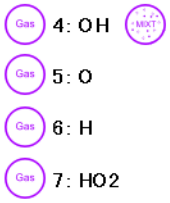
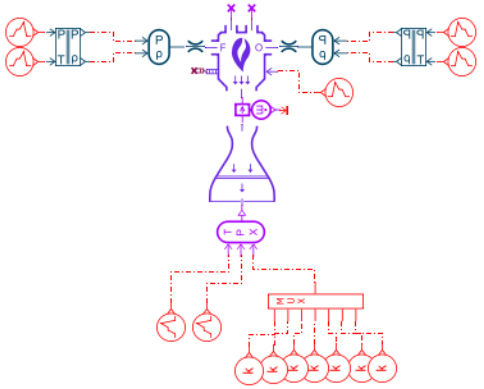
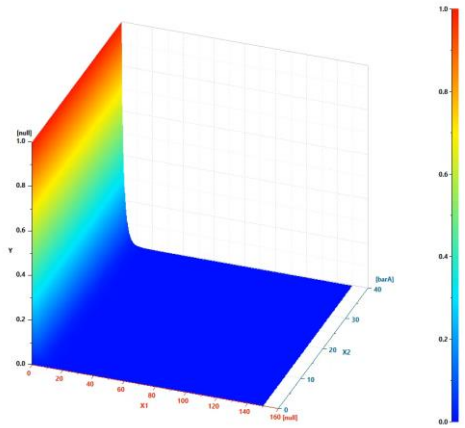
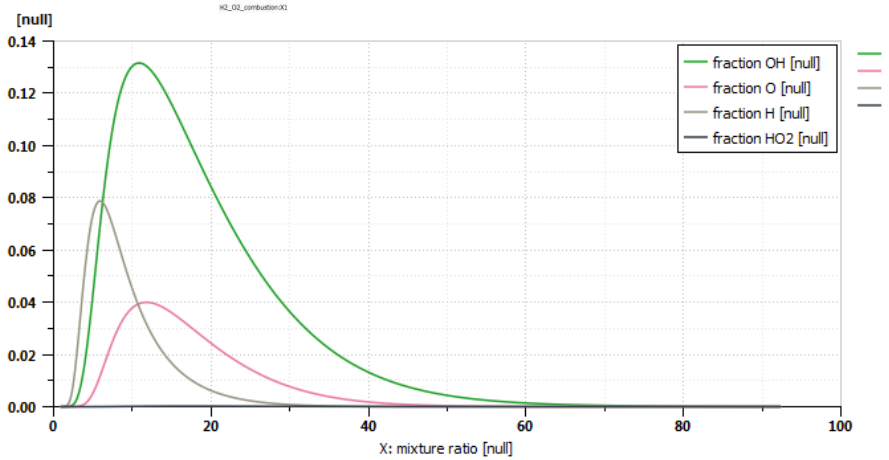
- Combustion



Advanced combustion (LPCCP01)



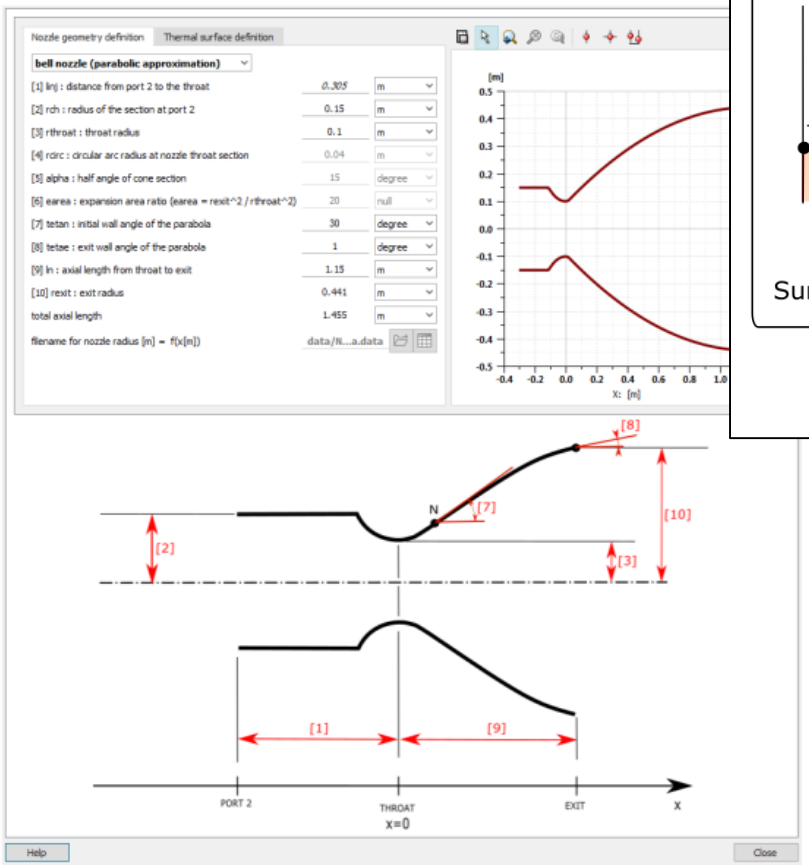


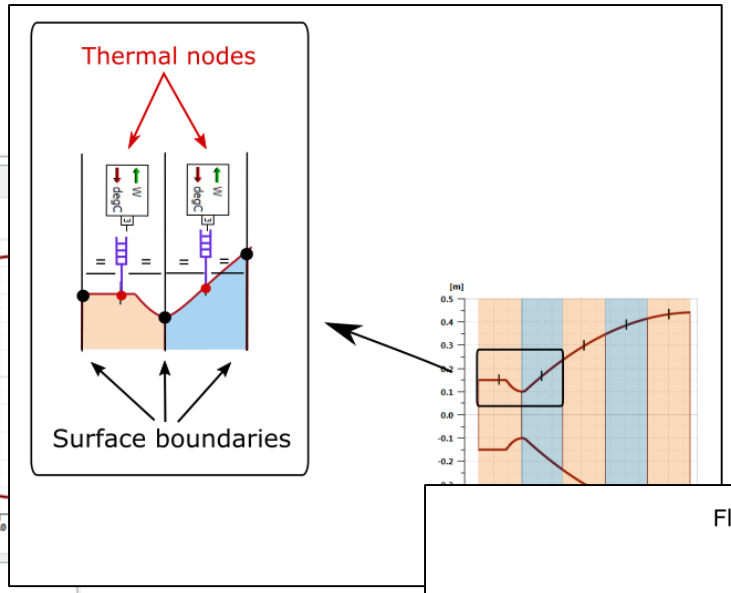


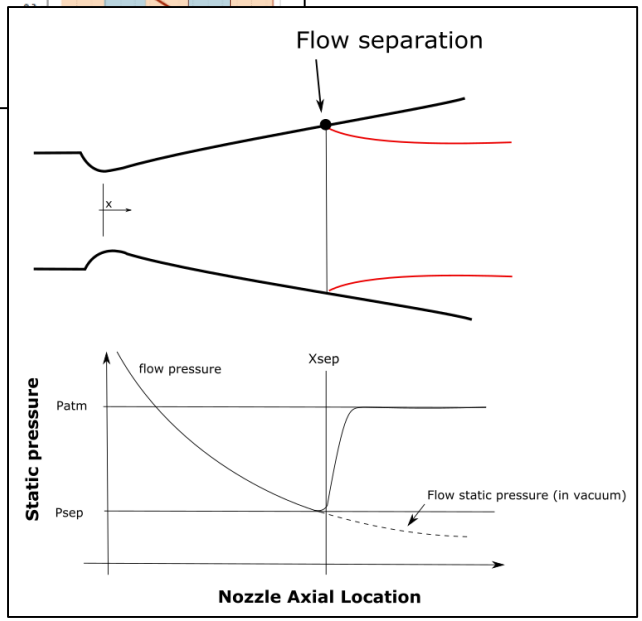
Fractions function of chamber pressure and mixture ratio

RL-10 engine

- Nozzle







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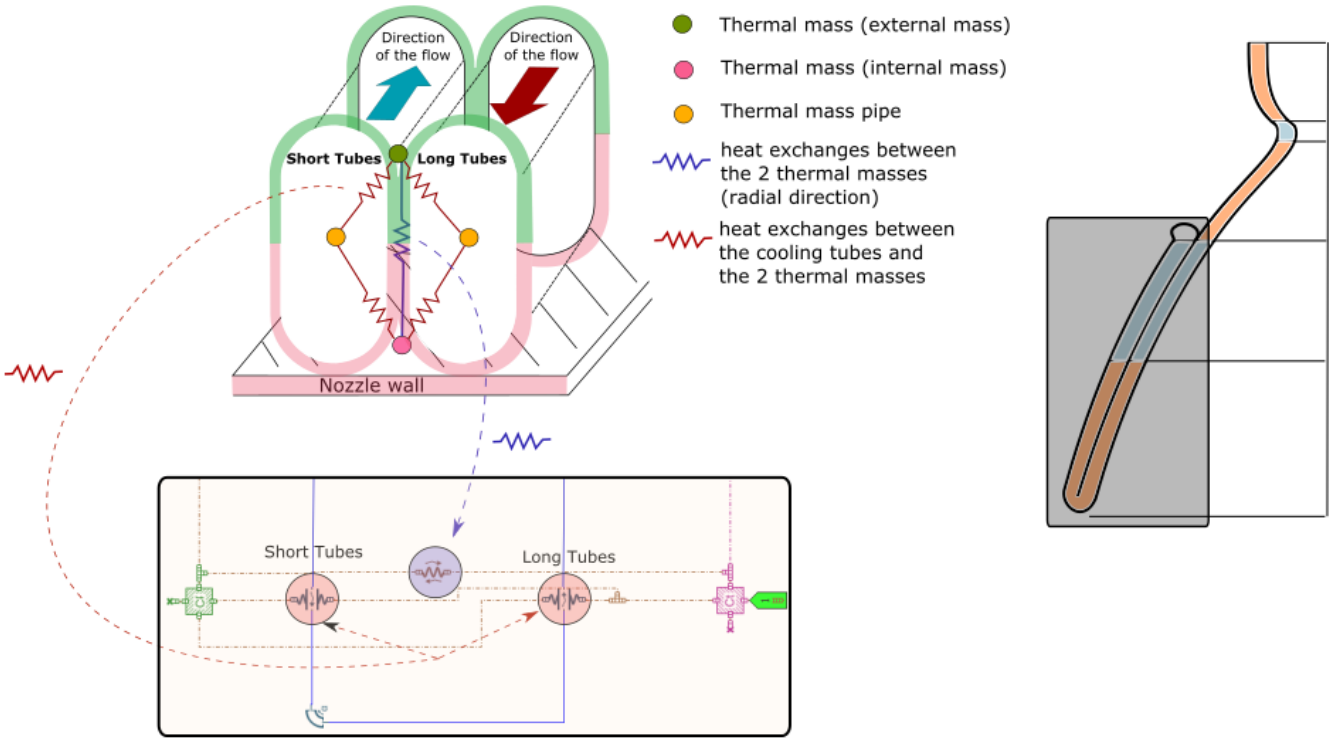
- Regenerative cooling jacket



Example of thermal discretization - Same methodology applied along the nozzle axis

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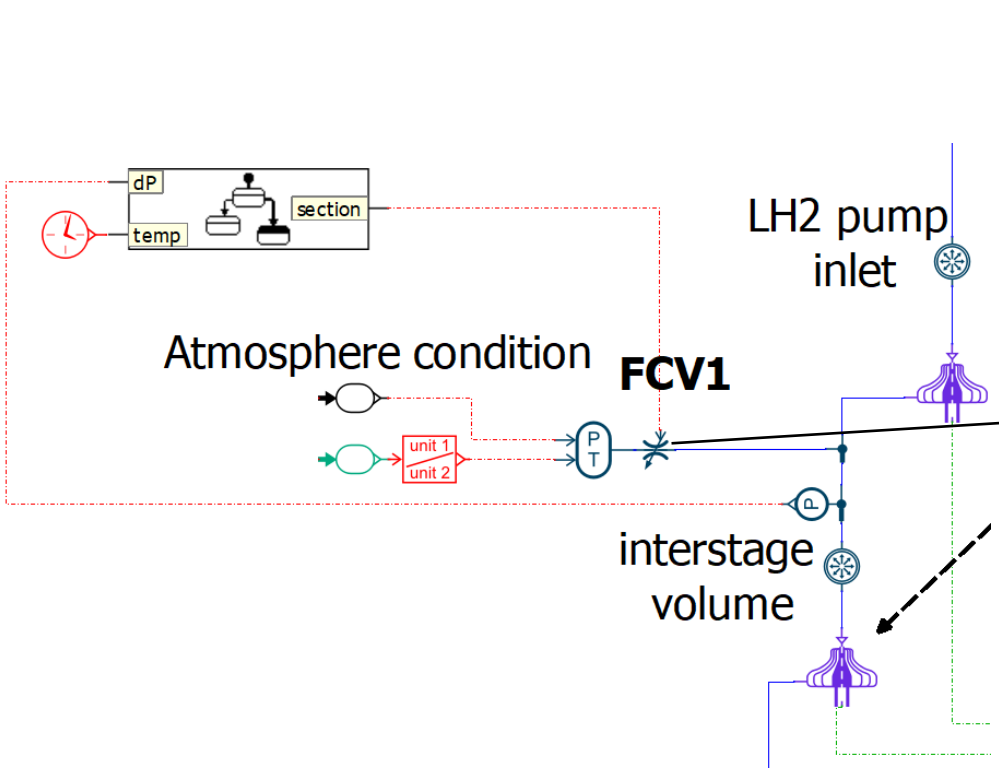
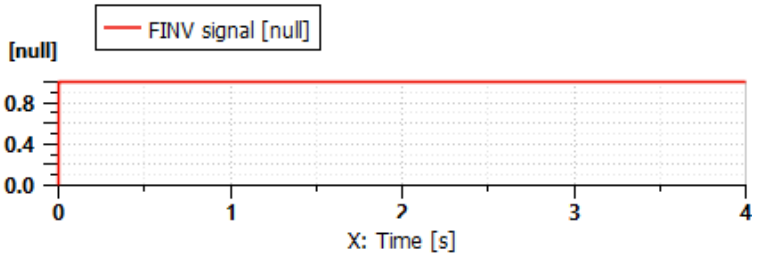
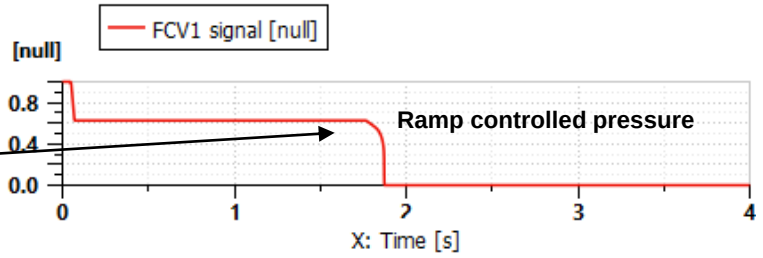
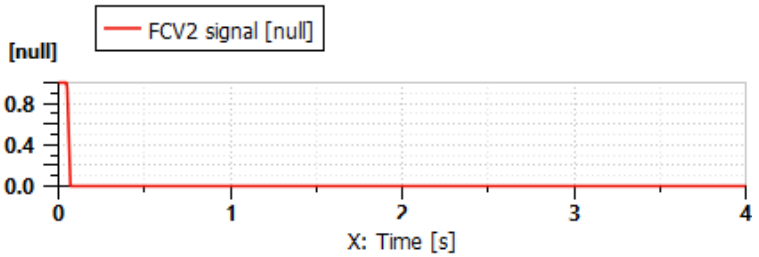
- Valves and control









RL-10 engine

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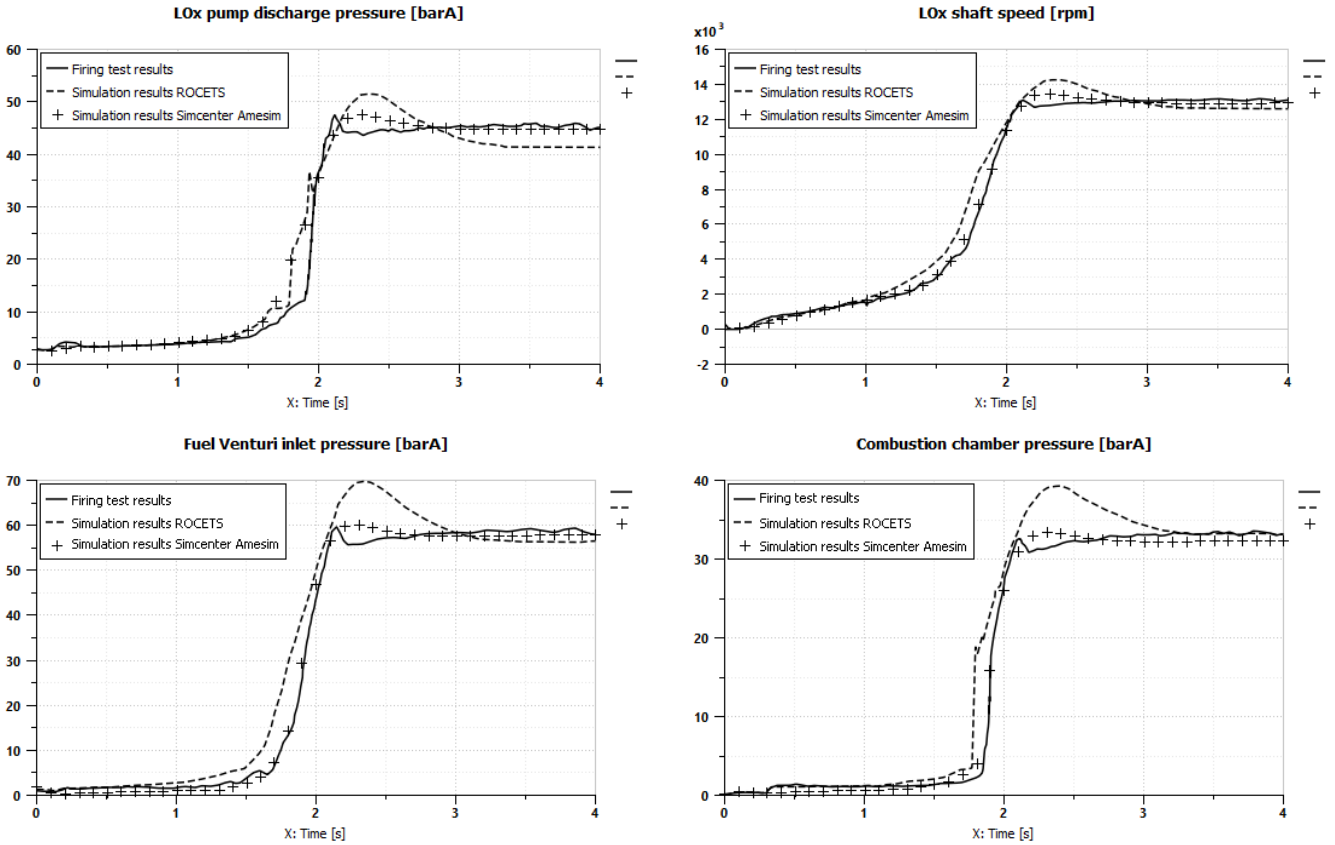

Engine performance simulated compared to firing test conditions

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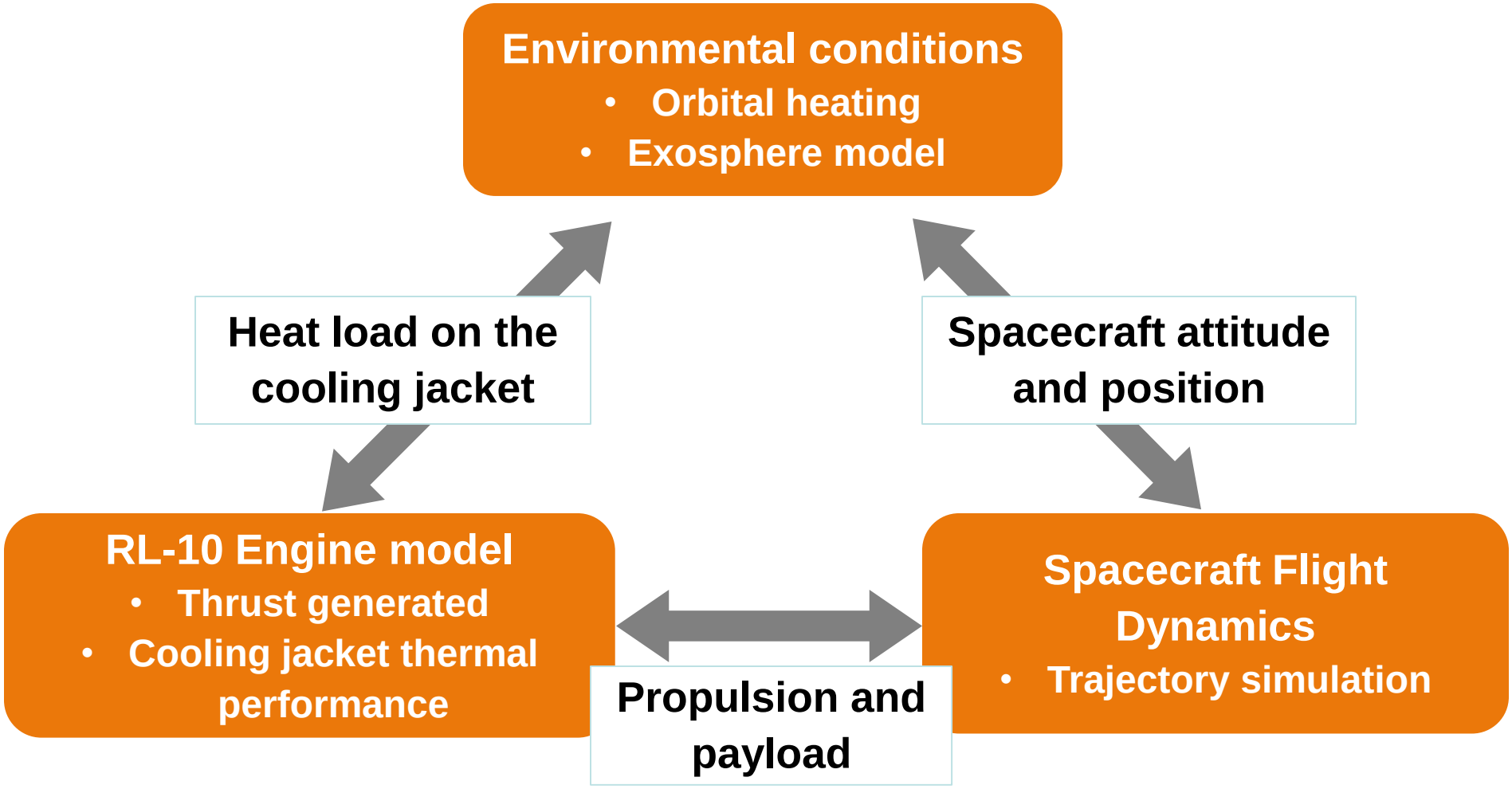
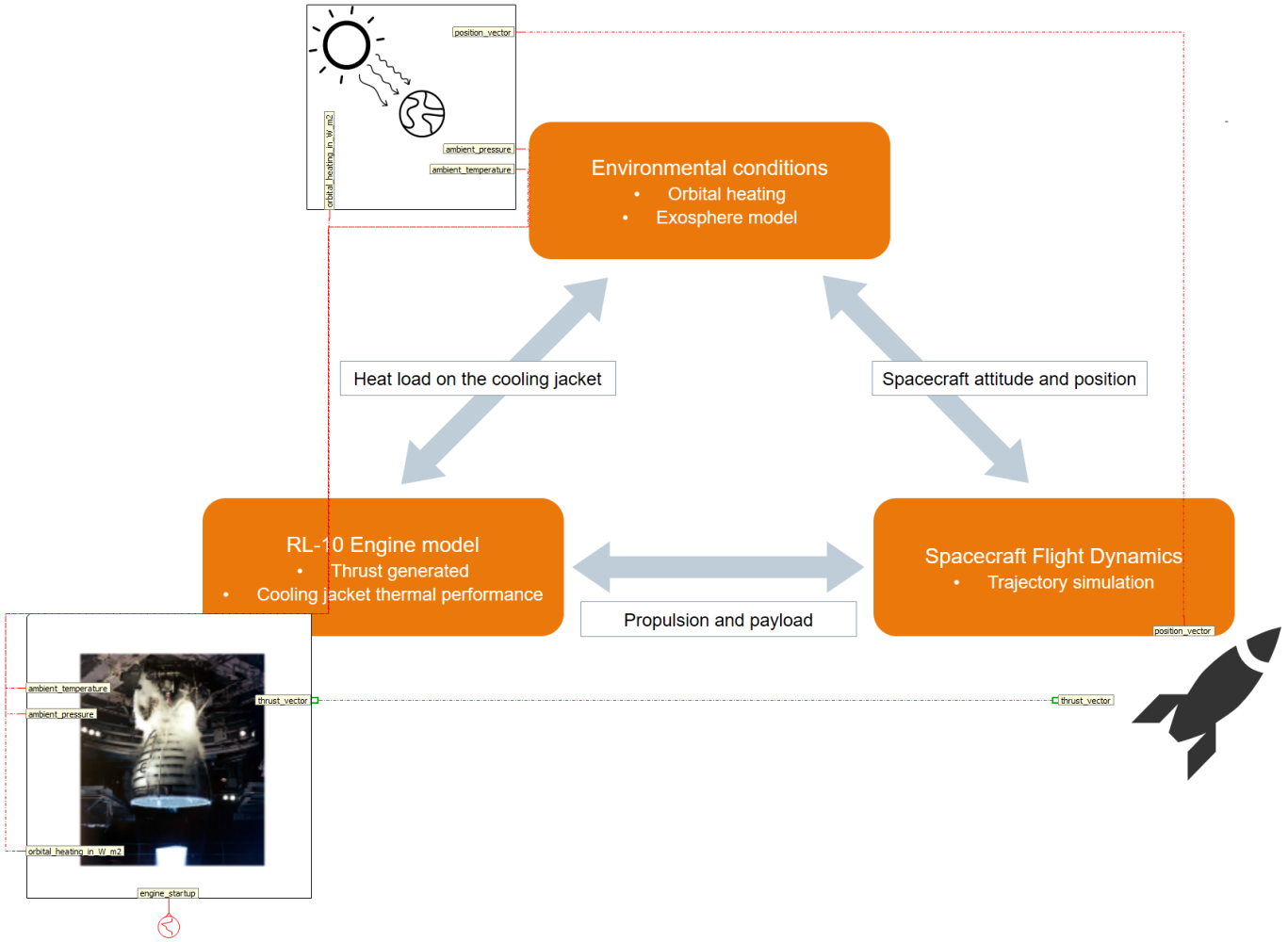
Simulation framework

- Integrated simulation for mission analysis



Simulation framework

- Realization in Simcenter Amesim



Flight dynamics and mission definition

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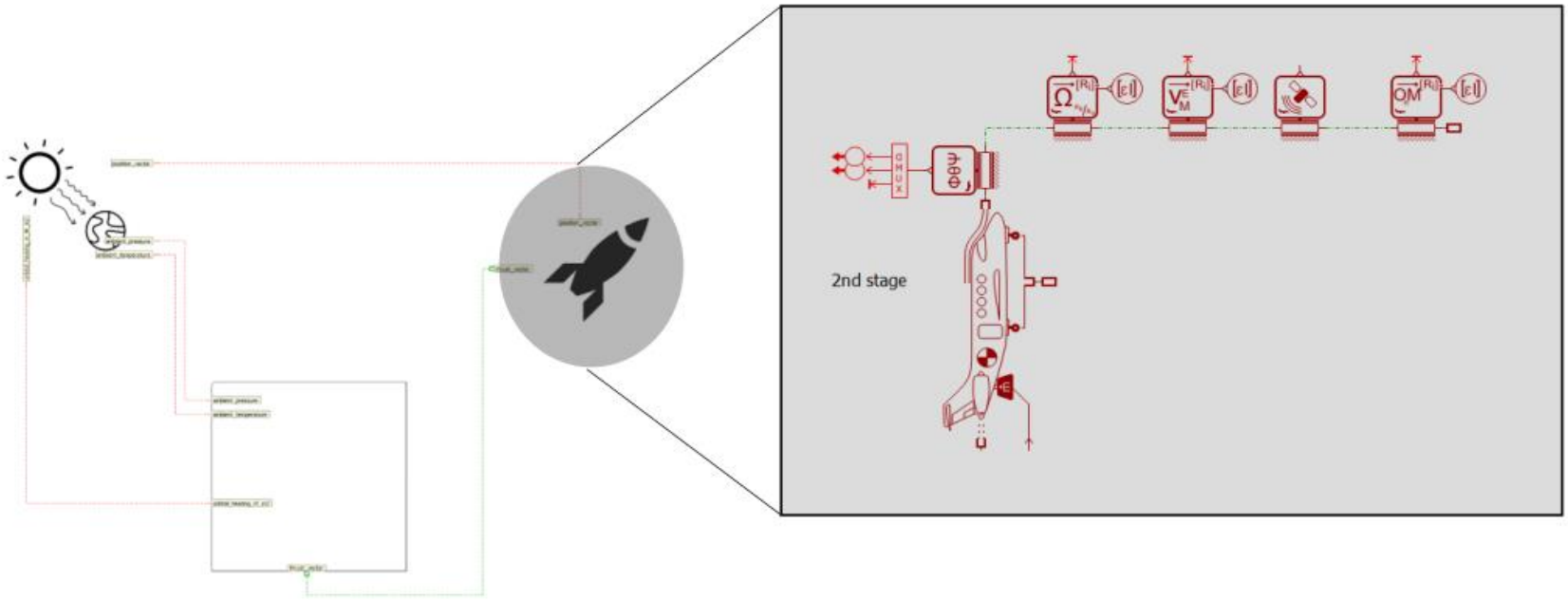

Overview of the flight dynamic super-component

Orbit thermal environment

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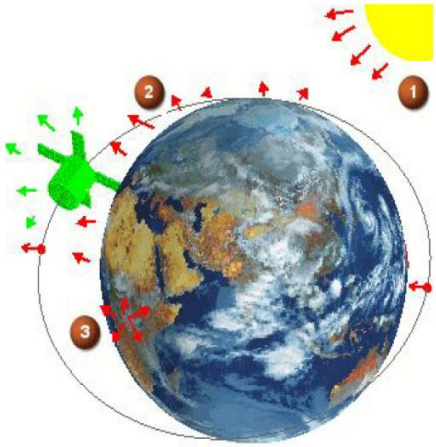
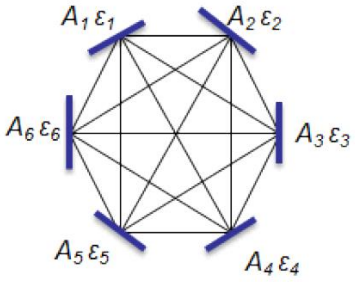
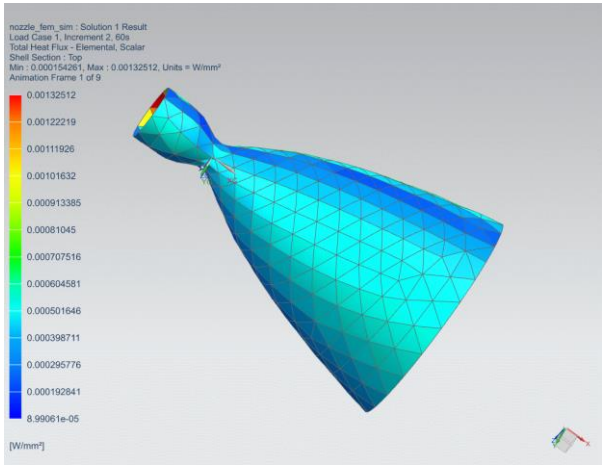


Orbital heat sources considered in the study



6 element radiation enclosure
and the view factors



Resulting heat load on nozzle (spin = 1.5 deg/s)

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Application case

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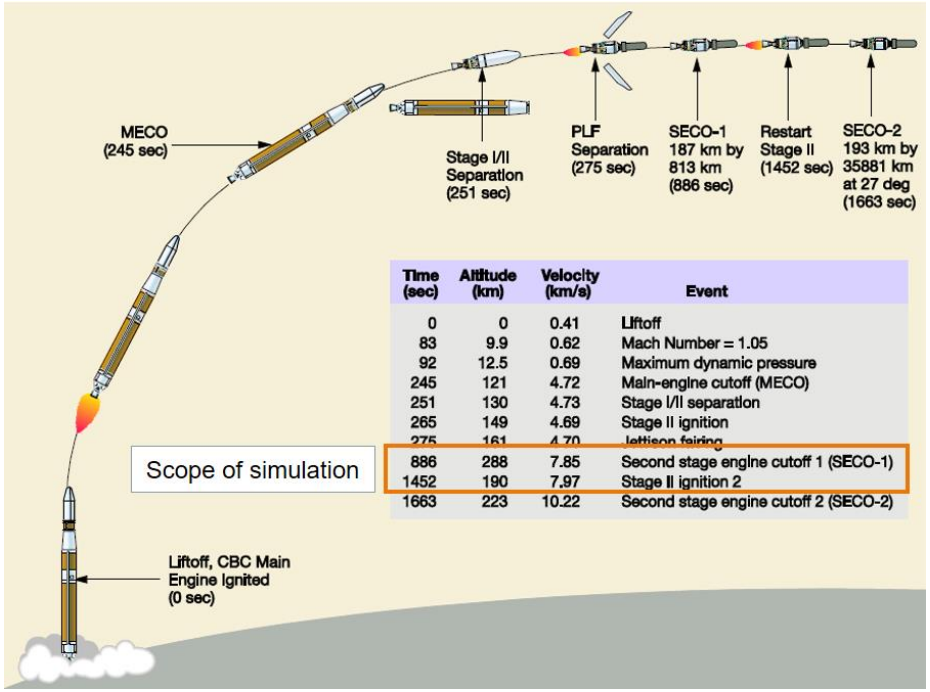
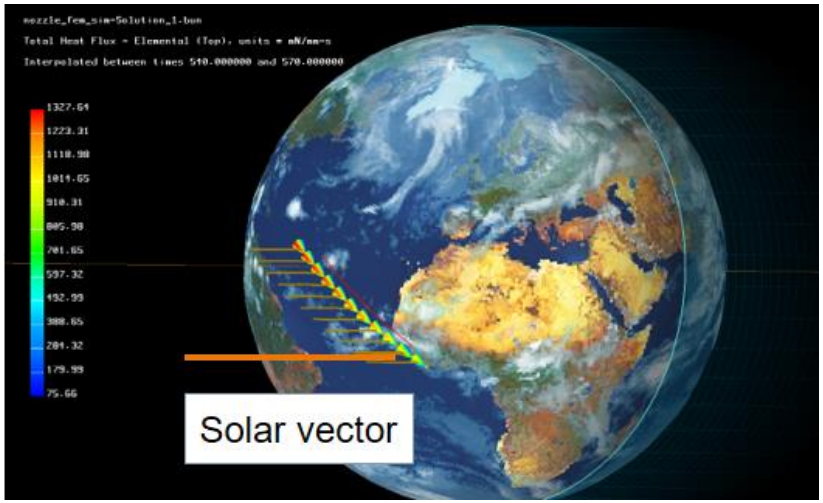


Time (sec)	Altitude (km)	Velocity (km/s)	Event
0	0	0.41	Liftoff
83	9.9	0.62	Mach Number = 1.05
92	12.5	0.69	Maximum dynamic pressure
245	121	4.72	Main-engine cutoff (MECO)
251	130	4.73	Stage I/II separation
265	149	4.69	Stage II ignition
275	161	4.70	Jettison fairing
886	288	7.85	Second stage engine cutoff 1 (SECO-1)
1452	190	7.97	Stage II ignition 2
1663	223	10.22	Second stage engine cutoff 2 (SECO-2)

Delta IV Medium Sequence of Events for a GTO Mission (Eastern Range)
Source: Delta IV Launch Services User's Guide June 2013



Ground trace and solar exposition on 3D earth

Engine performance

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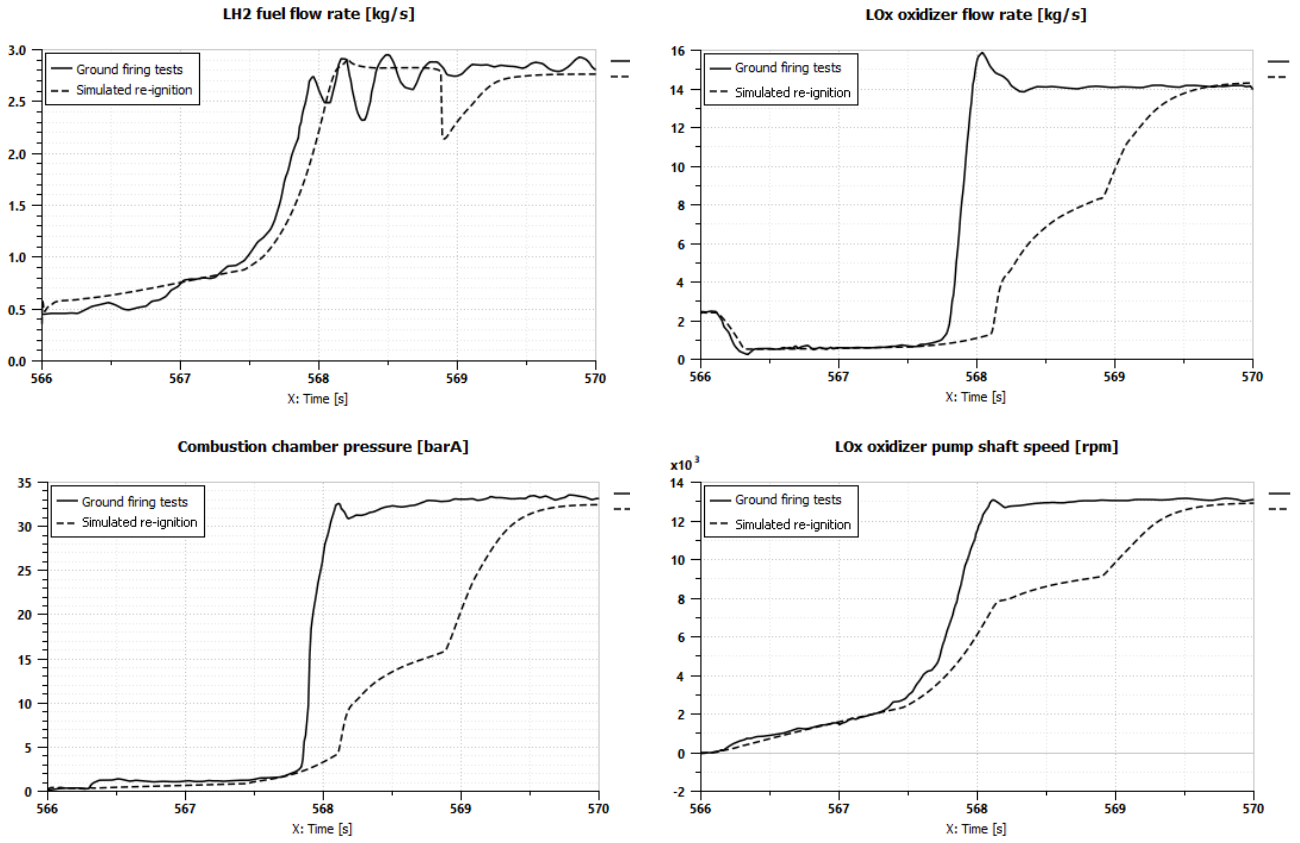

Engine performance in real flight conditions and ground firing test conditions

Spacecraft trajectory

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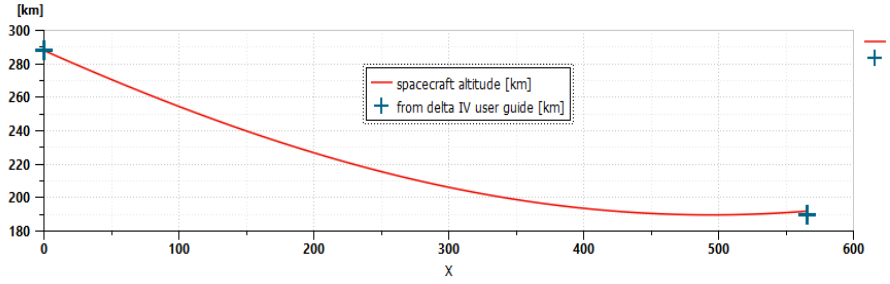

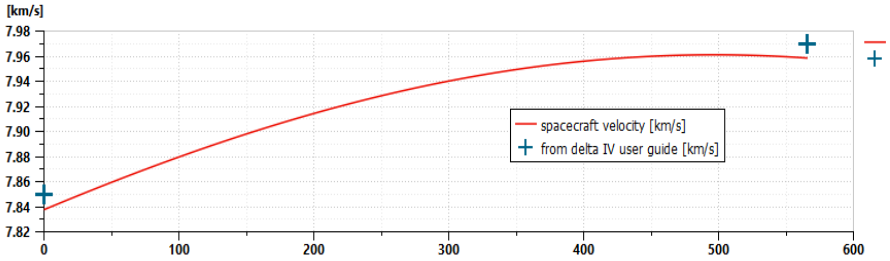

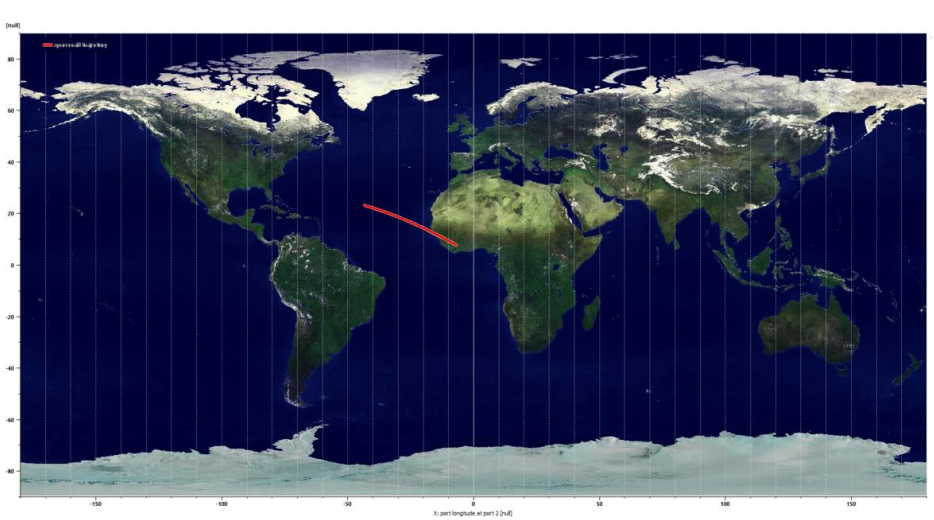

Altitude profile, velocity profile and ground trace on 2D earth

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Conclusions and prospects

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- **Benefits of transient simulation model**
  - Support design and test activities (control design among others)
  - Connect simulation models from different disciplines
  - Ability to simulate complex sequences like a ballistic flight segment followed by an engine re-ignition
  - Refine, enrich and support test campaign specifications
- **Prospects**
  - Upper stage flight dynamics simulation in support of GNC development: fuel system, separation mechanisms, thrust vectoring control, engine start-up and shut-down
  - Stage recovery simulation: 6-DoF flight dynamics, aerodynamics, fuel system, landing gear