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Computation of the Re-entry of spacecraft with on-board tanks after orbital decay

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HTG

Contents

- Introduction
- Spacecraft re-entry with tanks
- Tank re-entry
- Sample computations for a re-entering tank
- Discussion of extended tank analysis
- Conclusions

Introduction

- General: Re-entering spacecraft with surviving parts pose risk to population on ground
  - Examples: Large spacecraft, rocket stages, parts made of heat-resistant materials
- Subclass: Spacecraft with tanks on board
  - Examples: ATV, rocket stages
- General: Computation in three steps
  - Initial re-entry until break-up
  - Generation of fragments
  - Computation of fragments

Introduction

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- Special fragments: Tanks
- Special problem: Tanks of spacecraft re-entering from orbit may be 'cold' (content may be frozen)
- This presentation:
  - Summary of general computation approach for re-entering spacecraft with tanks (with SCARAB)
  - Sample computations for a re-entering fuel tank ('warm' and 'cold' case)

Spacecraft Re-entry with Tanks

- Spacecraft model built from primitives, volume panelized
- Trajectory and attitude
  - Numerical integration of 6D equations of motion
  - External forces and torques: Gravitation, Aerodynamics
- Aerodynamics
  - Summation of local surface pressure and shear coefficients
  - Free-molecular and continuum limits, bridging method
- Aerothermal heating
  - Stagnation point heat flux
  - Local flow inclination method

SCARAB model example: ESC-A

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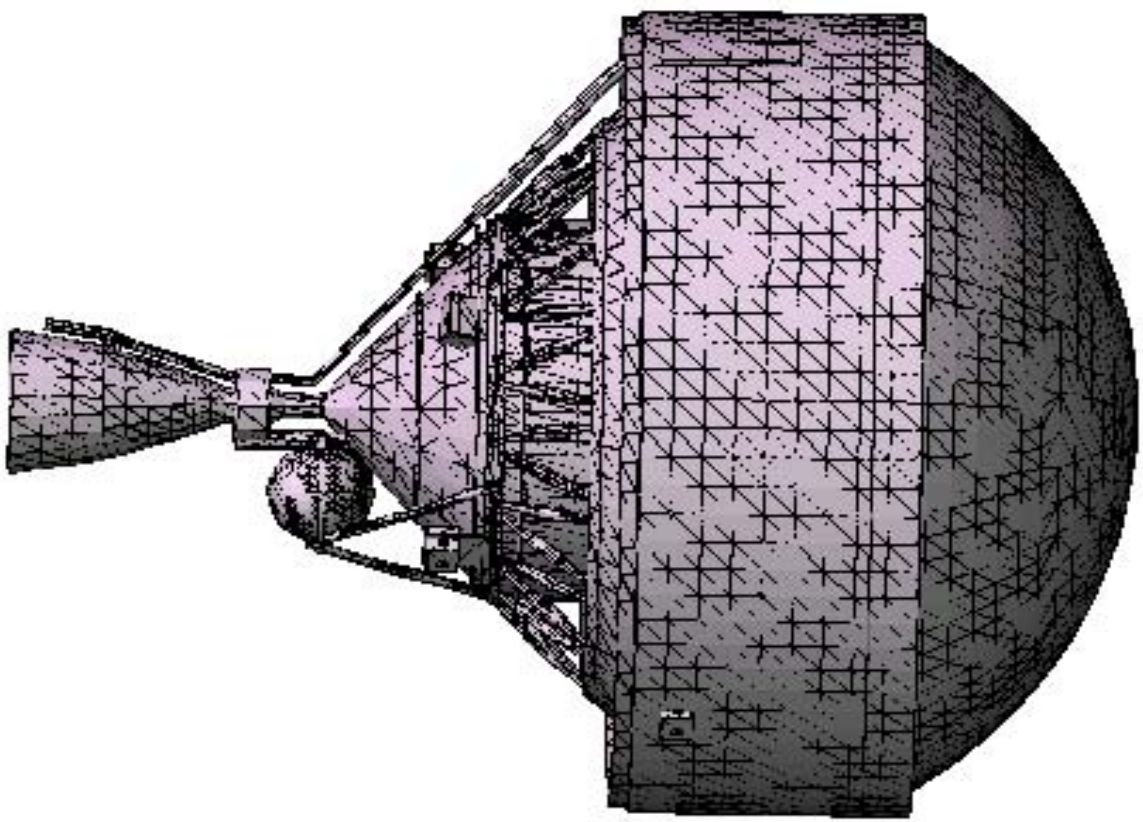

Spacecraft Re-entry with Tanks

- Thermal analysis
  - Heat conduction
  - Re-radiation to space
  - Tank state analysis
- Break-up
  - Mechanical break-off at predefined cuts
  - Thermal fragmentation for melting gaps (determined by automatic local connectivity check algorithm)
- Fragment models generated and new calculation jobs automatically generated

Tank Re-entry

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- Tank state
  - Equilibrium liquid-vapor system + pressure gas
  - State change by heat exchange with wall (content and wall have different temperatures)
- Tank bursting
  - Tank pressure computed from thermal state
  - Burst pressure computed from strength of wall material as function of wall temperature
- Tank explosion
  - Explosion likelihood for ignitable fuels after bursting

Sample computations for a fuel tank

- Sample tank:
  - Titanium sphere, 1 m diameter, 3 mm thickness, content: Hydrazine
- Two cases:
  - 'warm': tank initially on room temperature
  - 'cold': tank initially on freezing temperature of Hydrazine
- Initial state vector:
  - h = 122 km, v = 7.41 km/s, γ = 0.1˚
  - Roll / Pitch / Yaw angle = 0°
  - Roll / Pitch / Yaw rate = 5˚, 10˚, 15˚

Case 1: Trajectory

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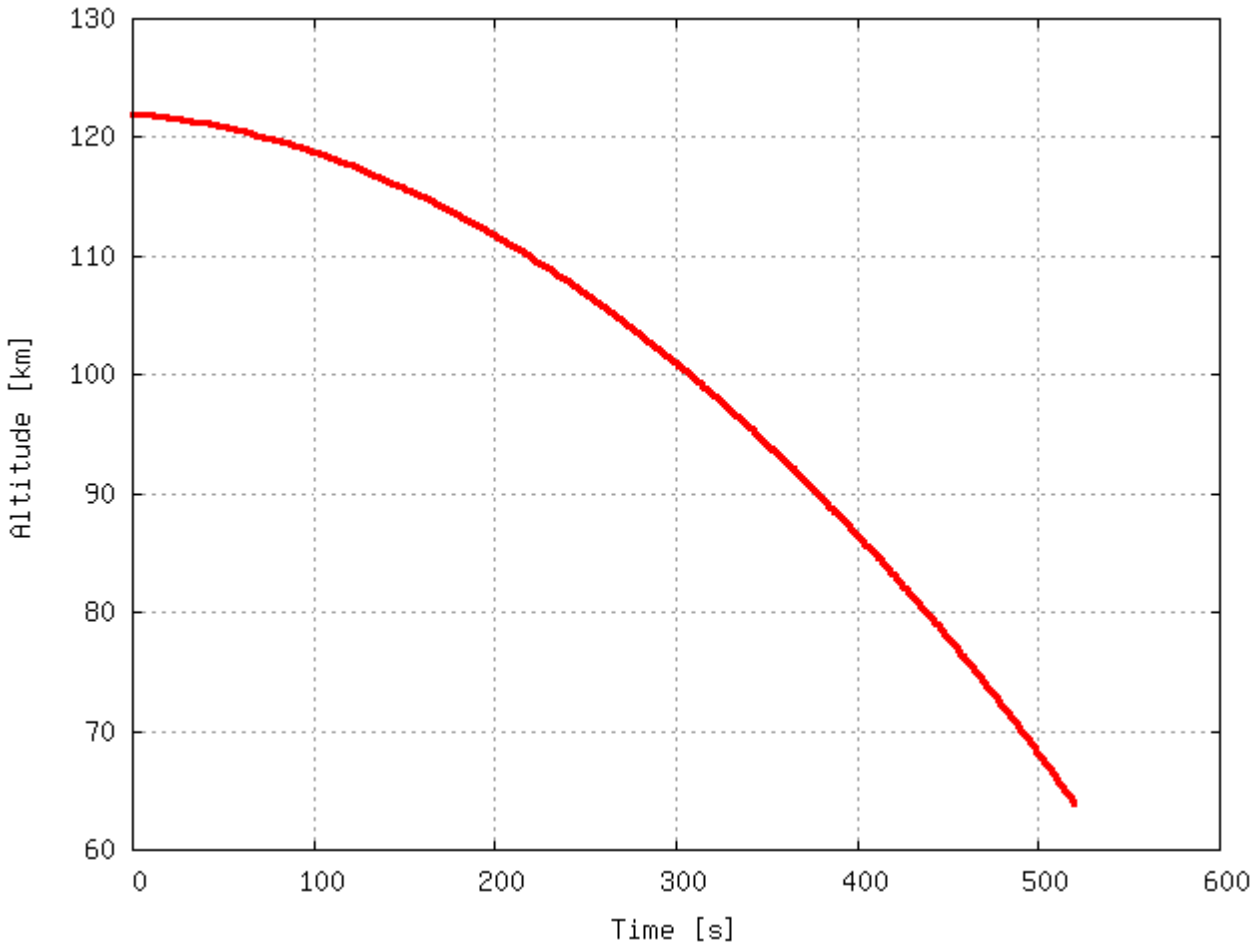
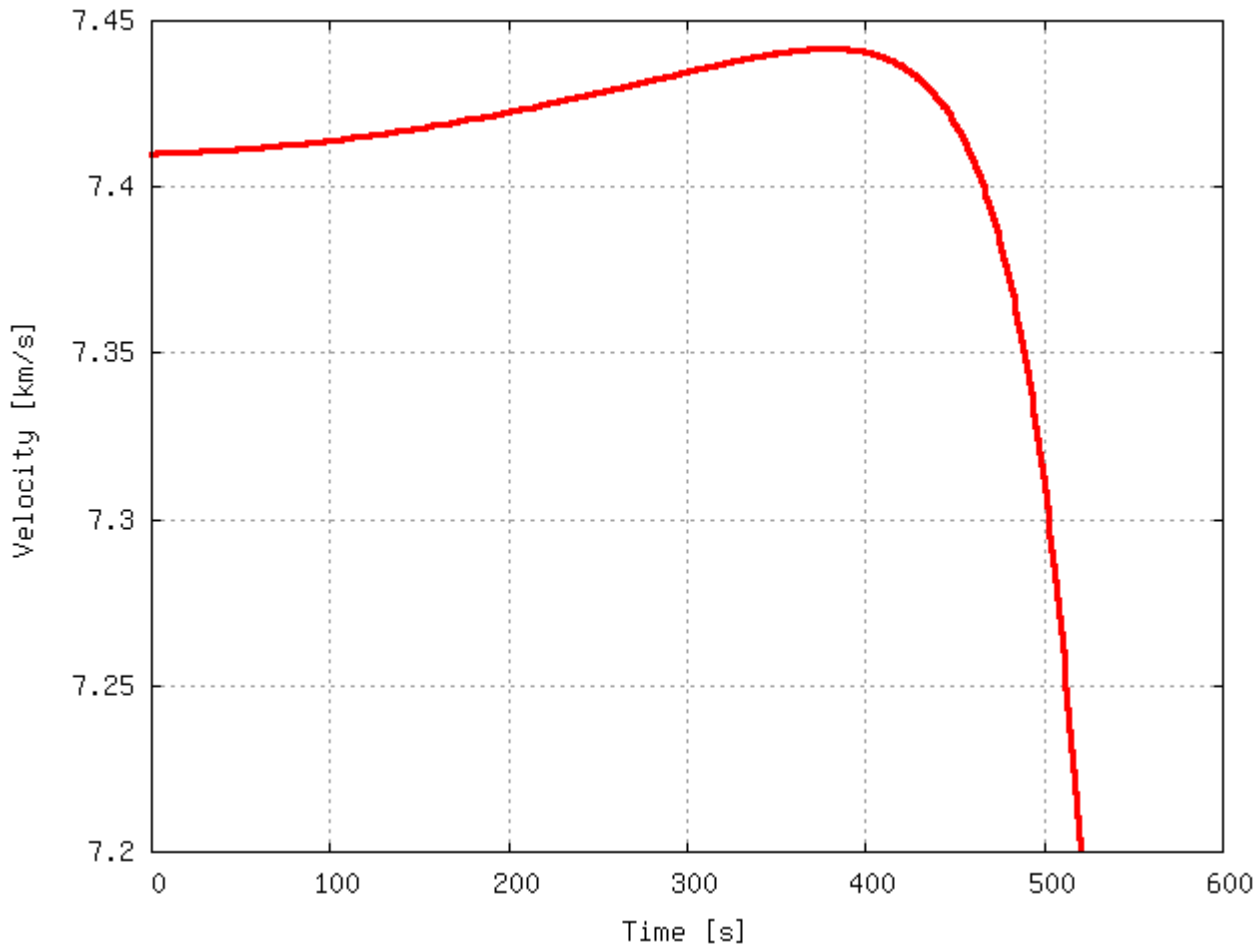
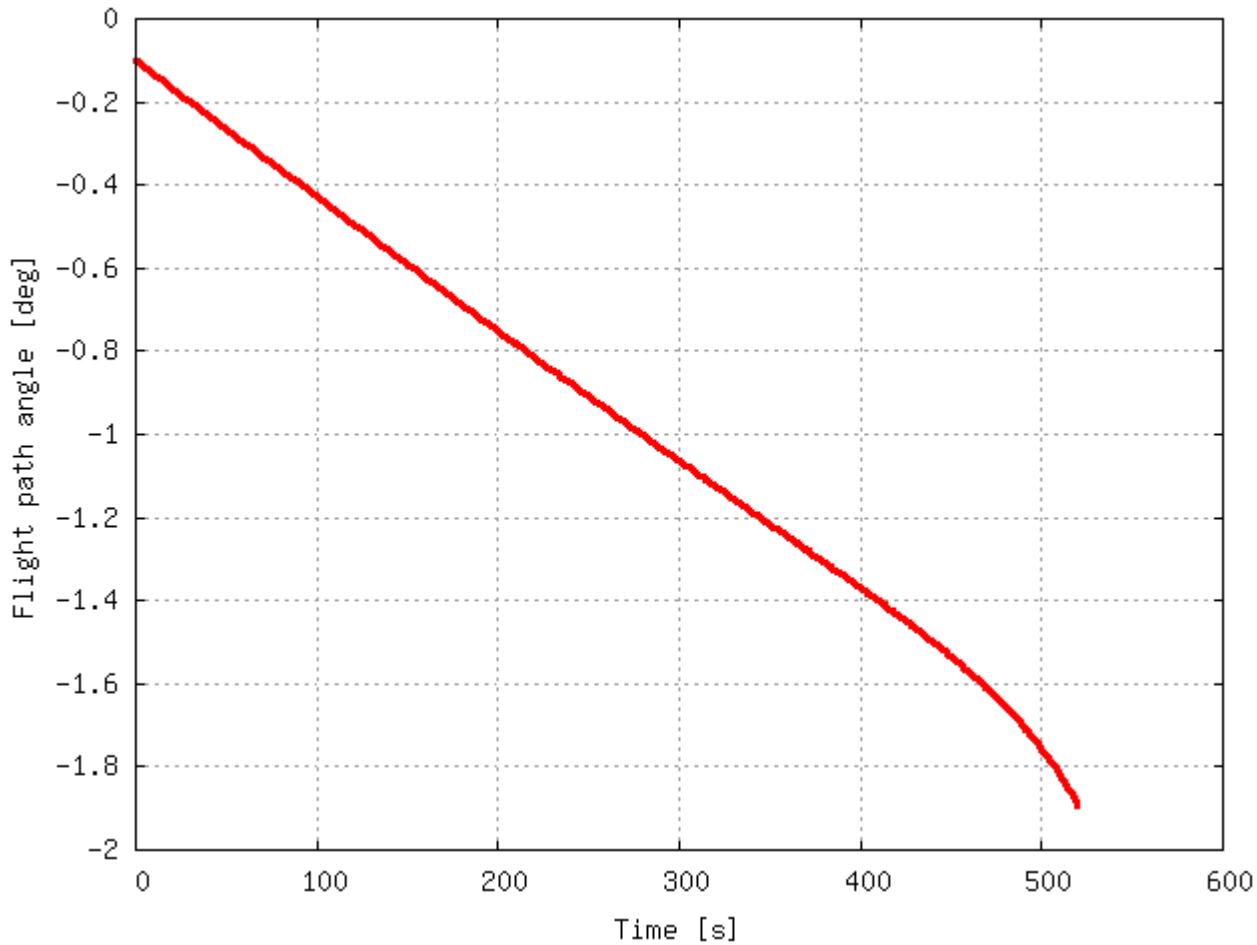


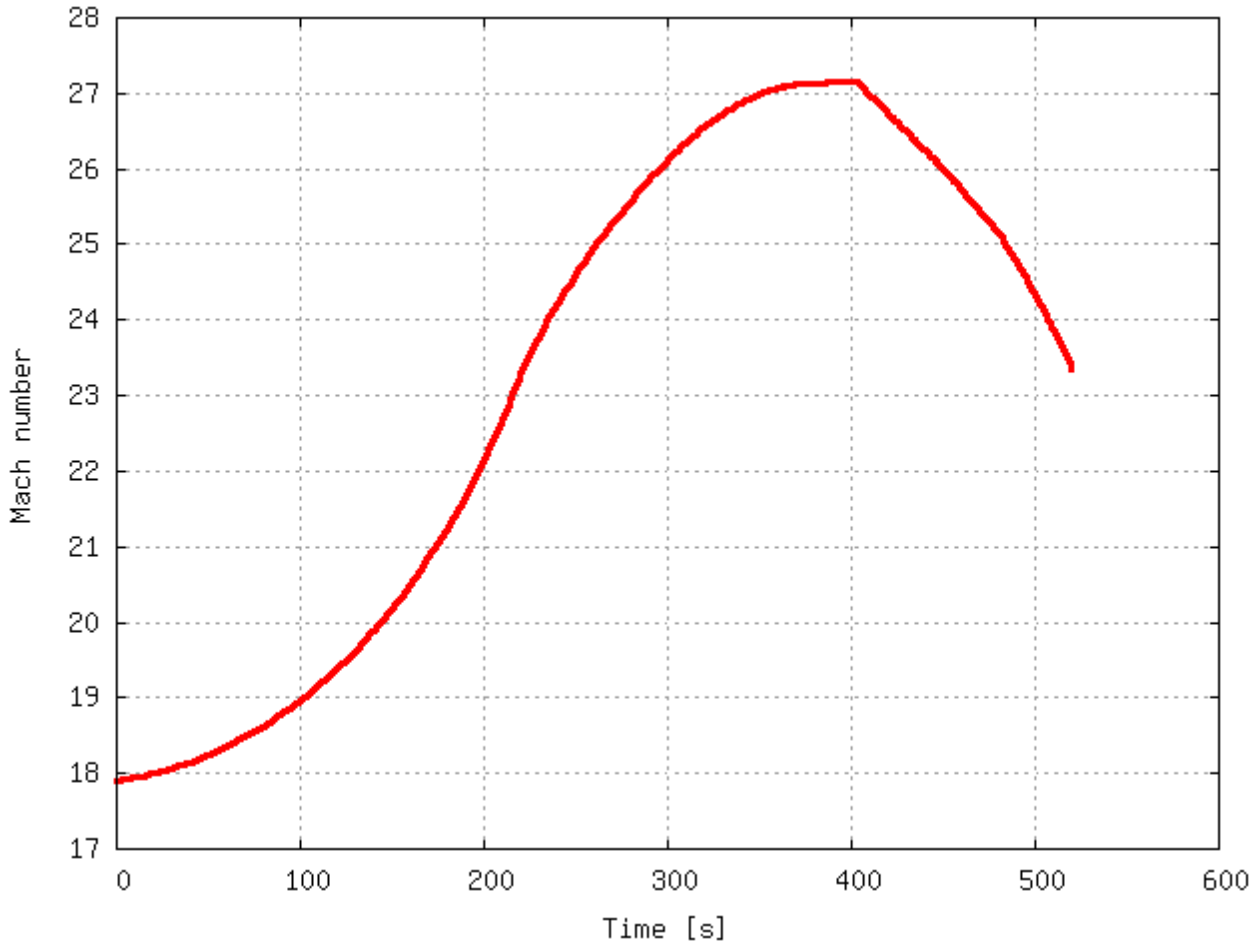
Case 1: Velocity



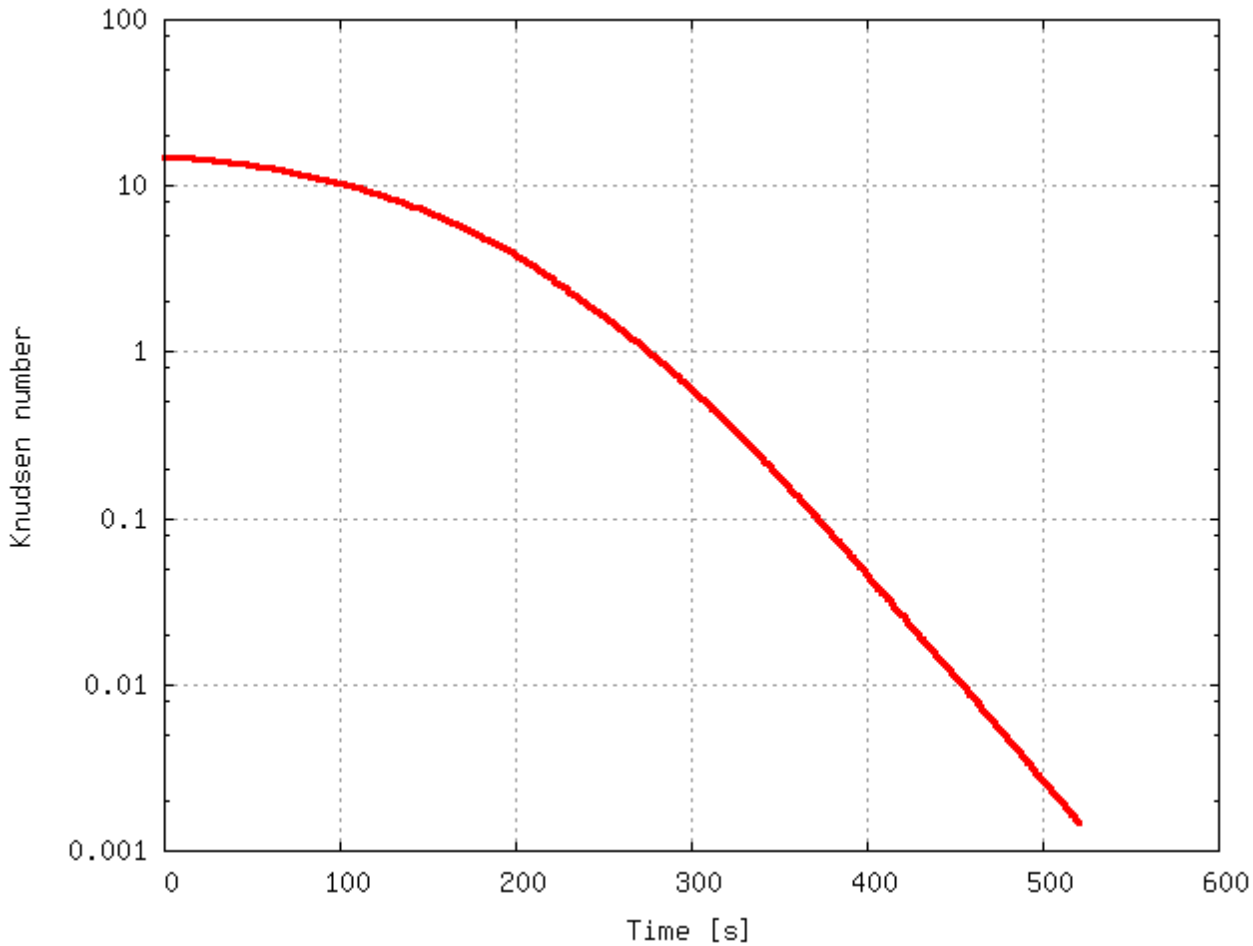
Case 1: Flight path angle



Case 1: Mach number



Case 1: Knudsen number



Case 1: Drag coefficient

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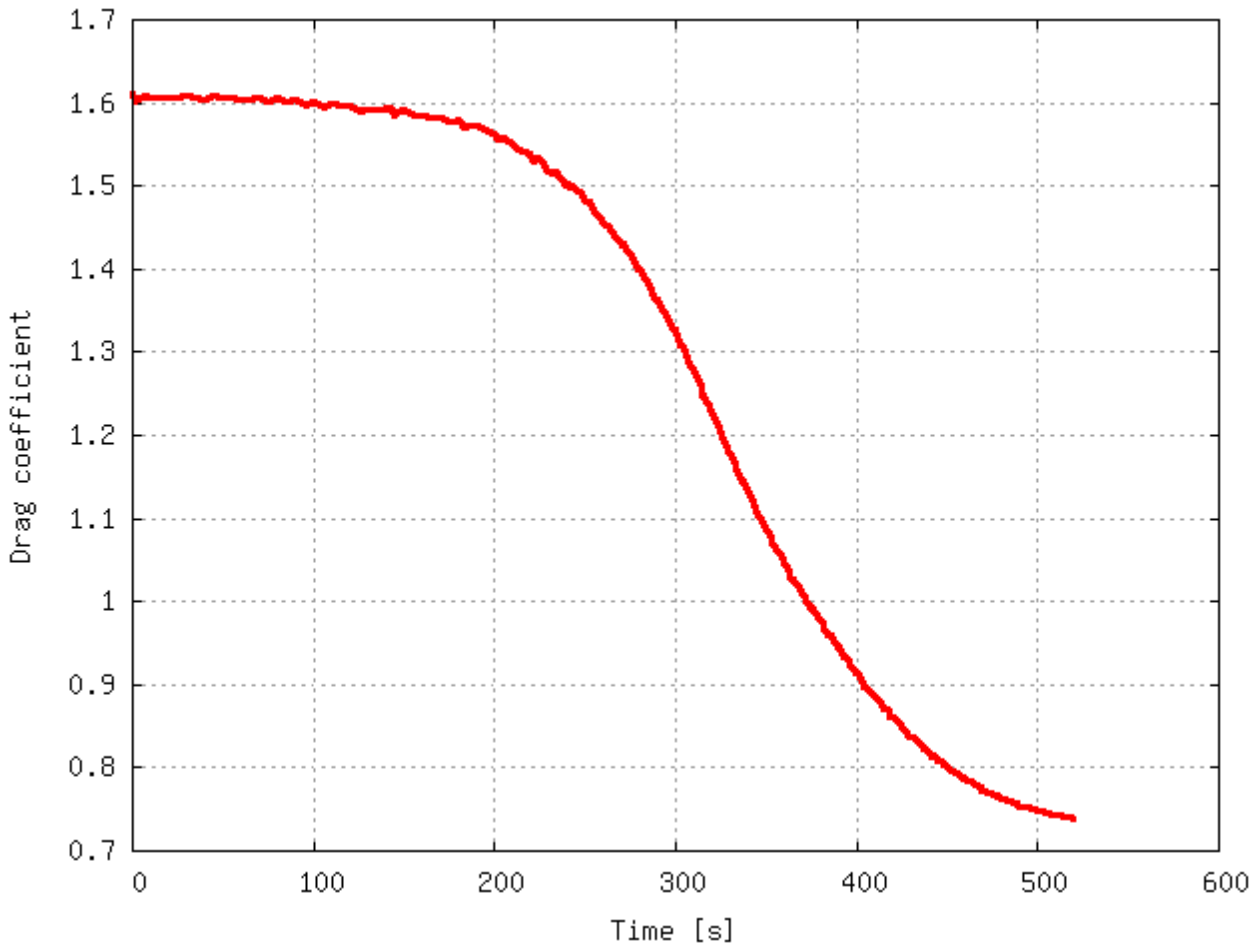
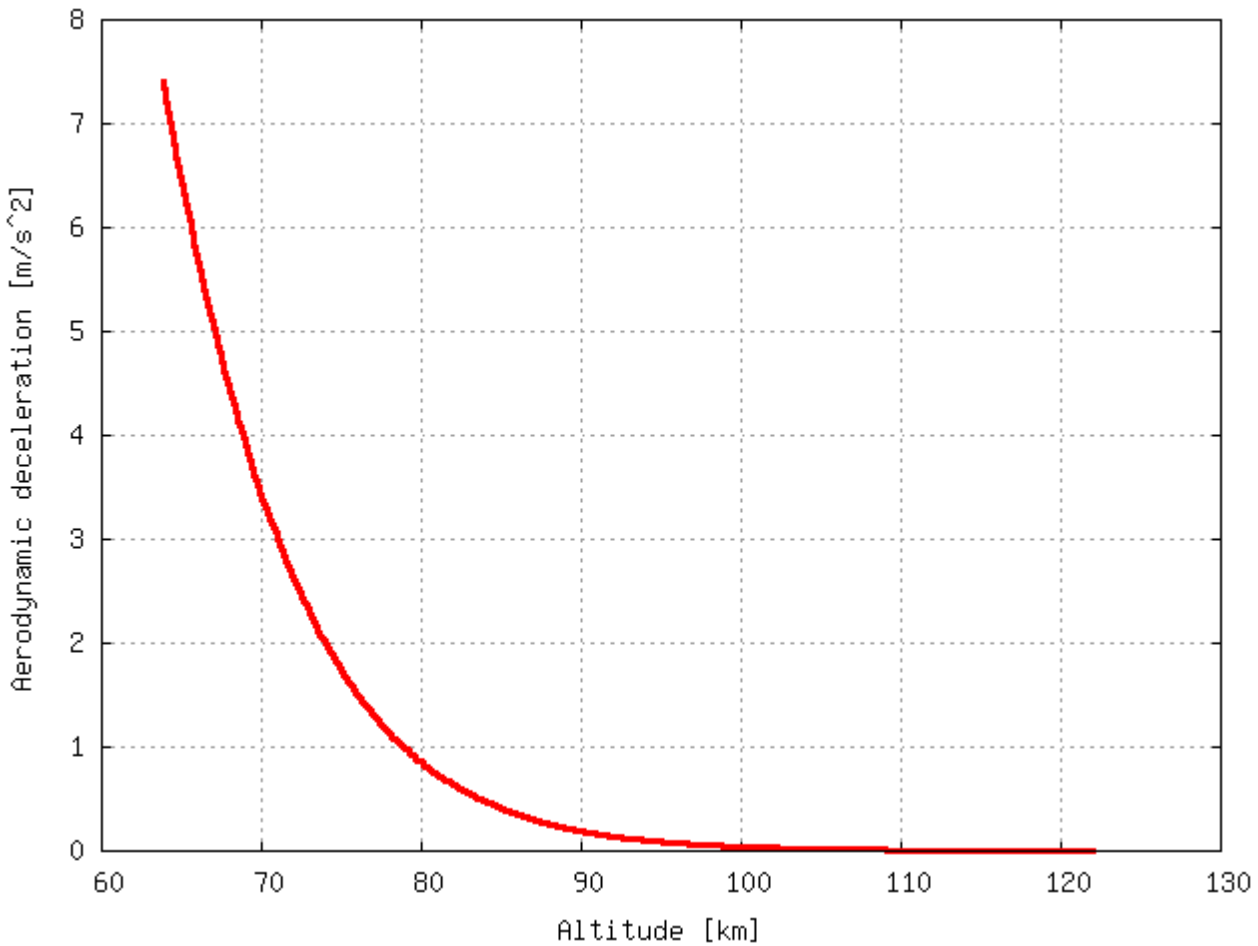


Case 1: Deceleration



Case 1: Aerothermal heating

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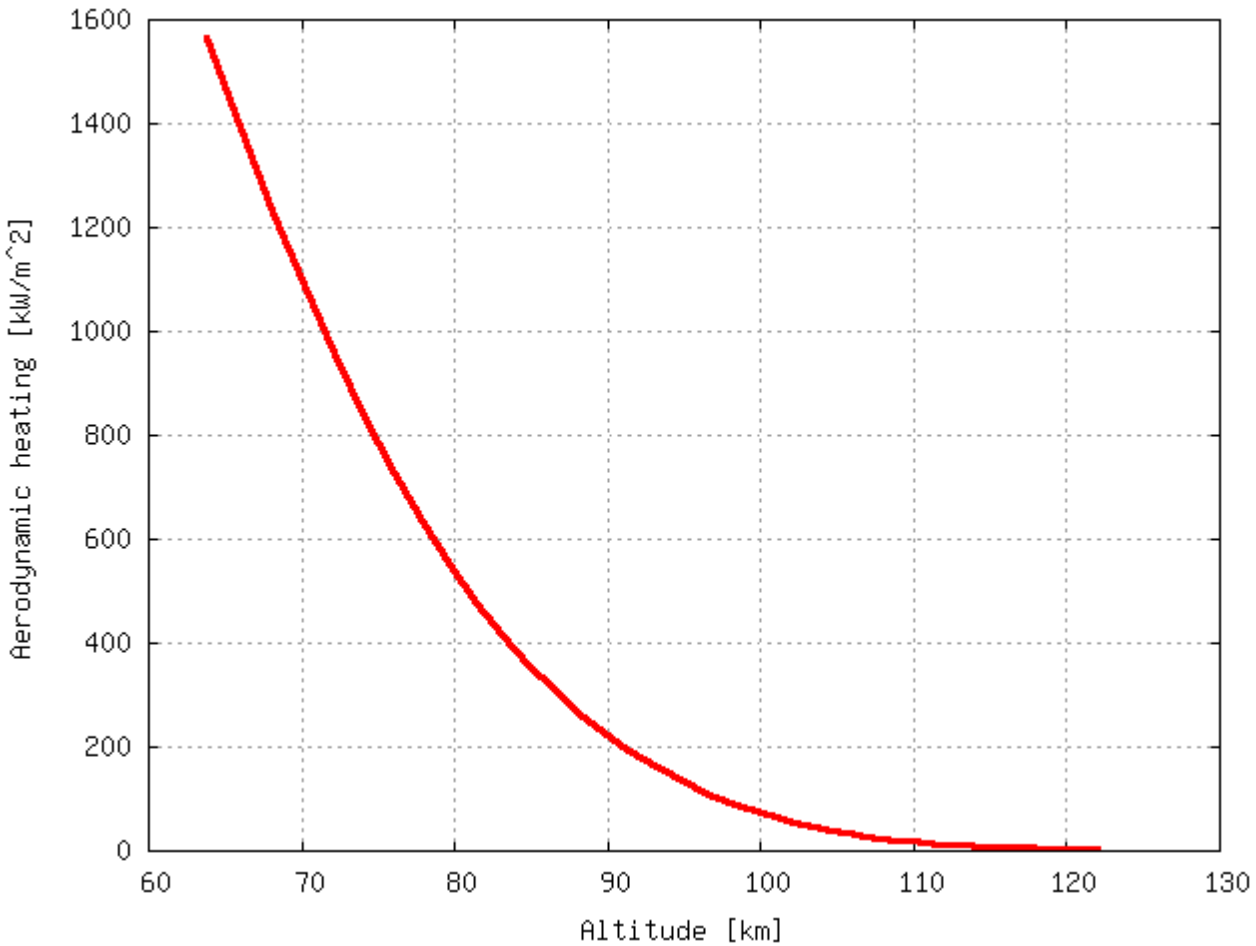

Case 1: Tank temperature

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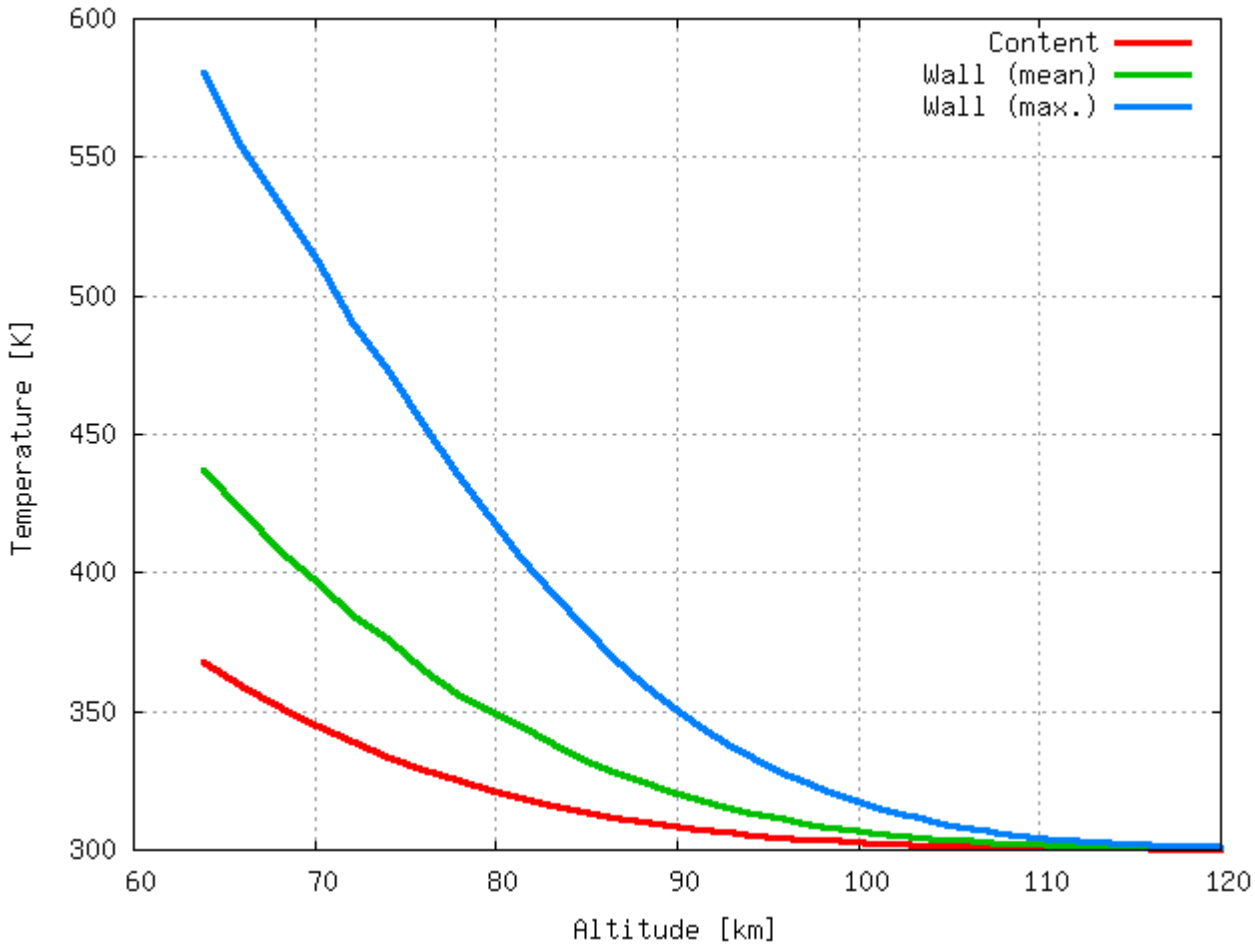
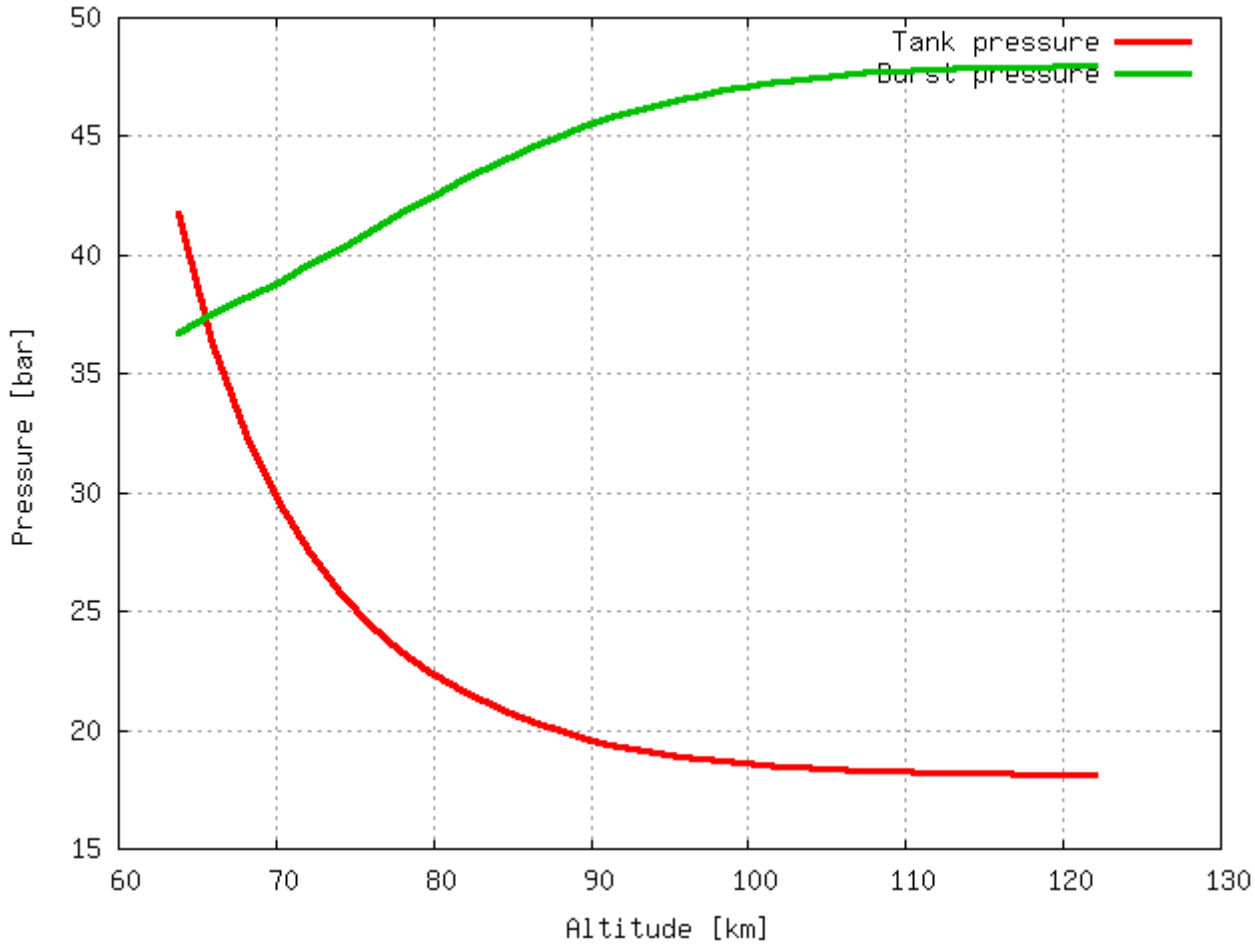
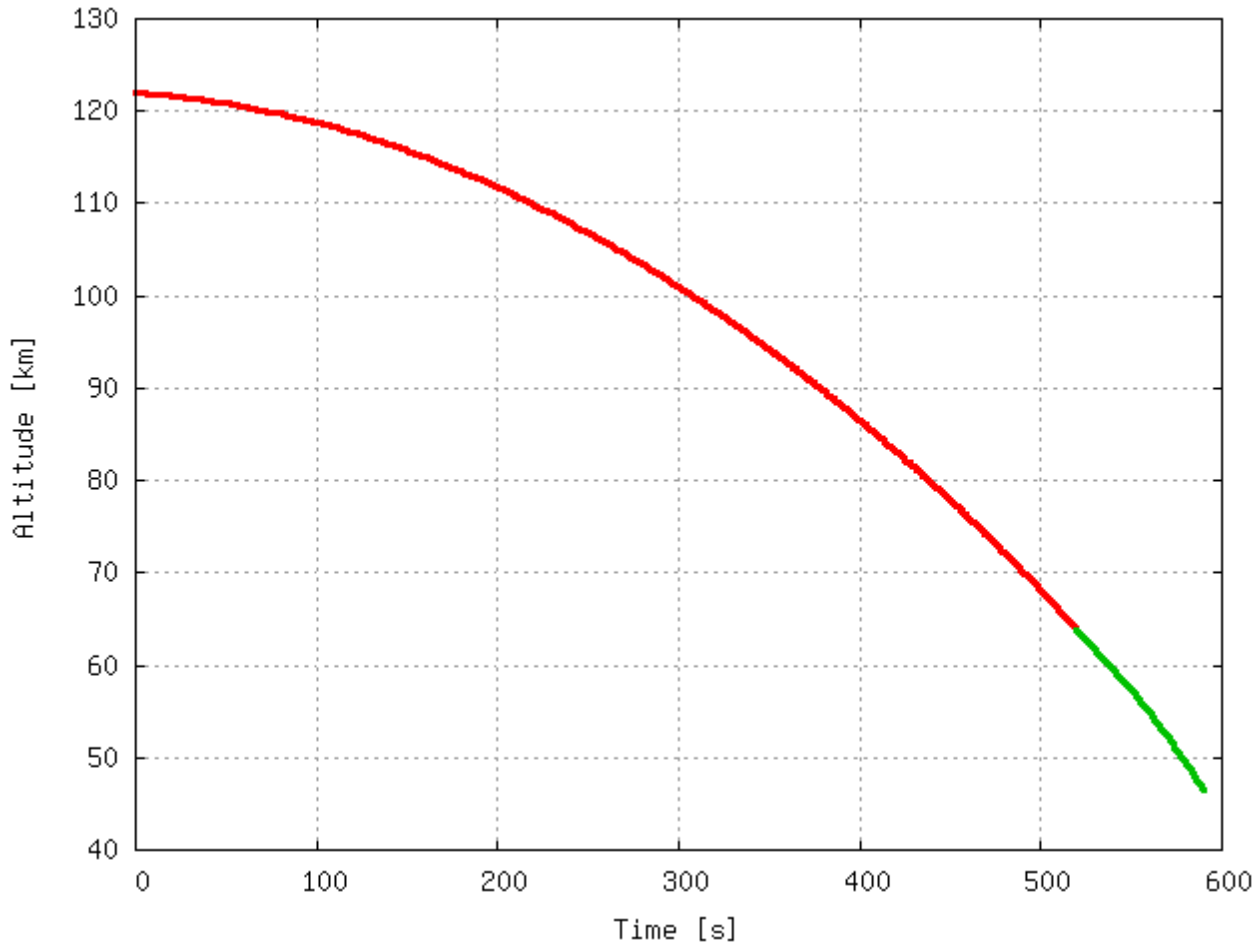


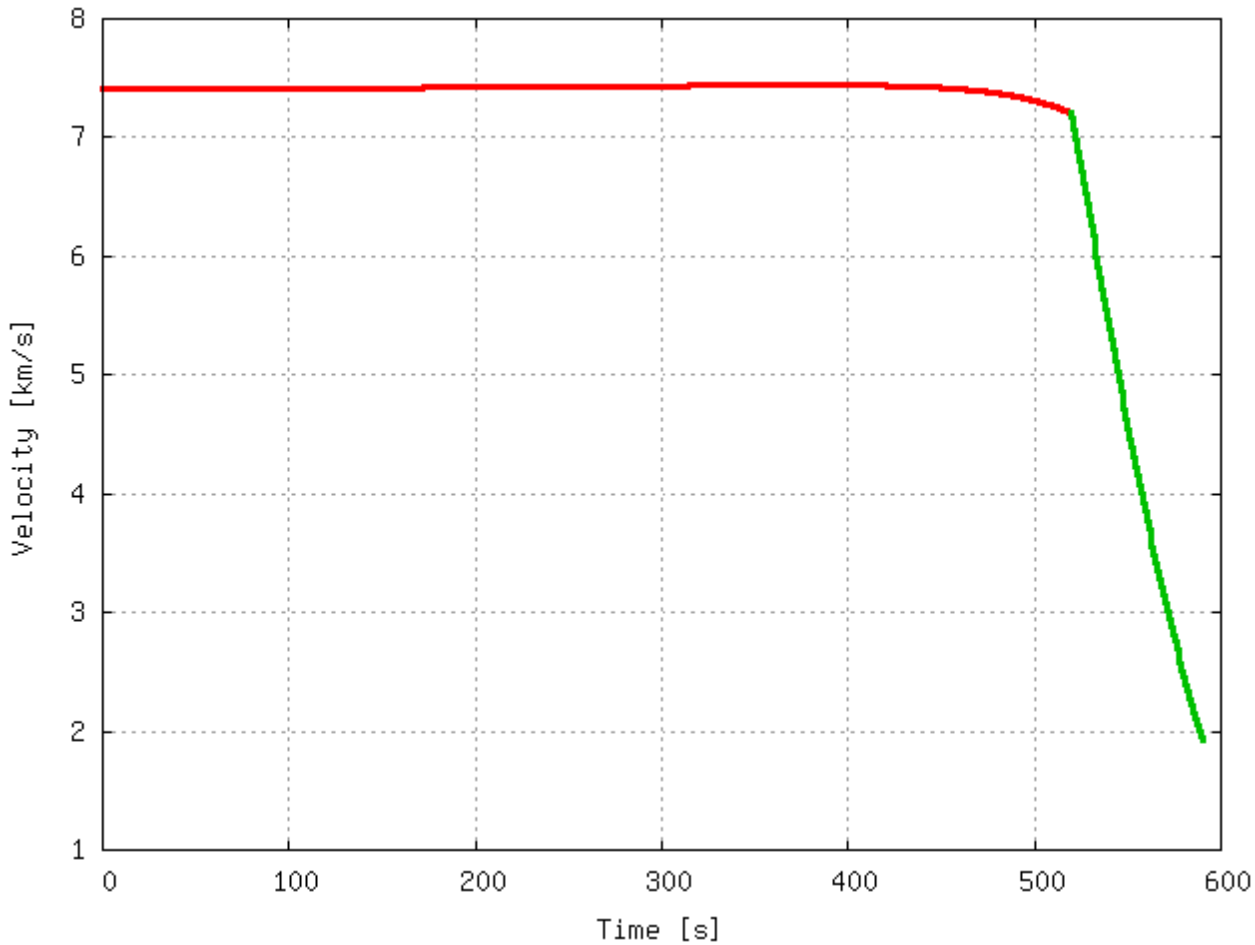
Tank pressure



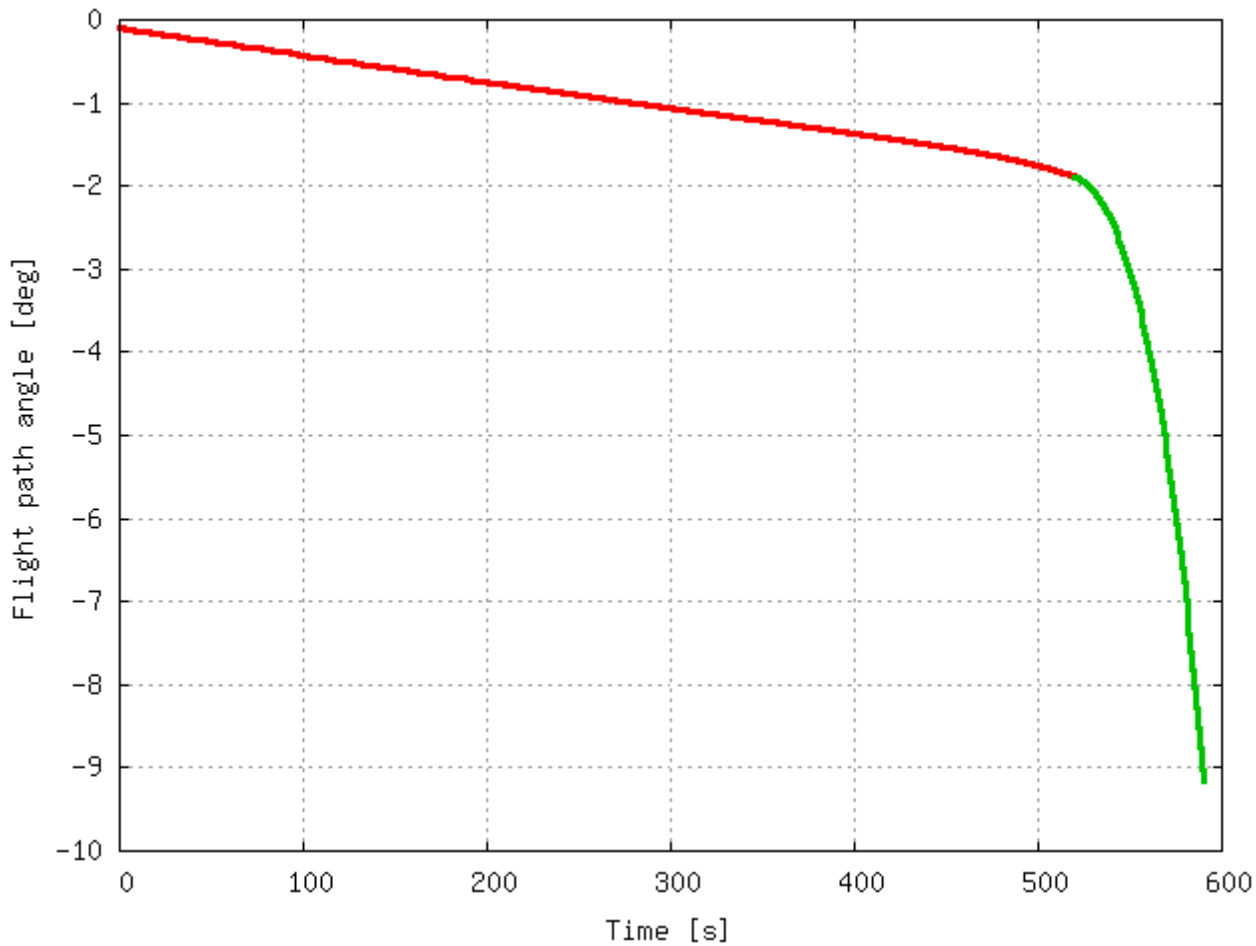
Case 1: Trajectory



Case 1: Velocity



Case 1: Flight path angle



Case 1: Mach number

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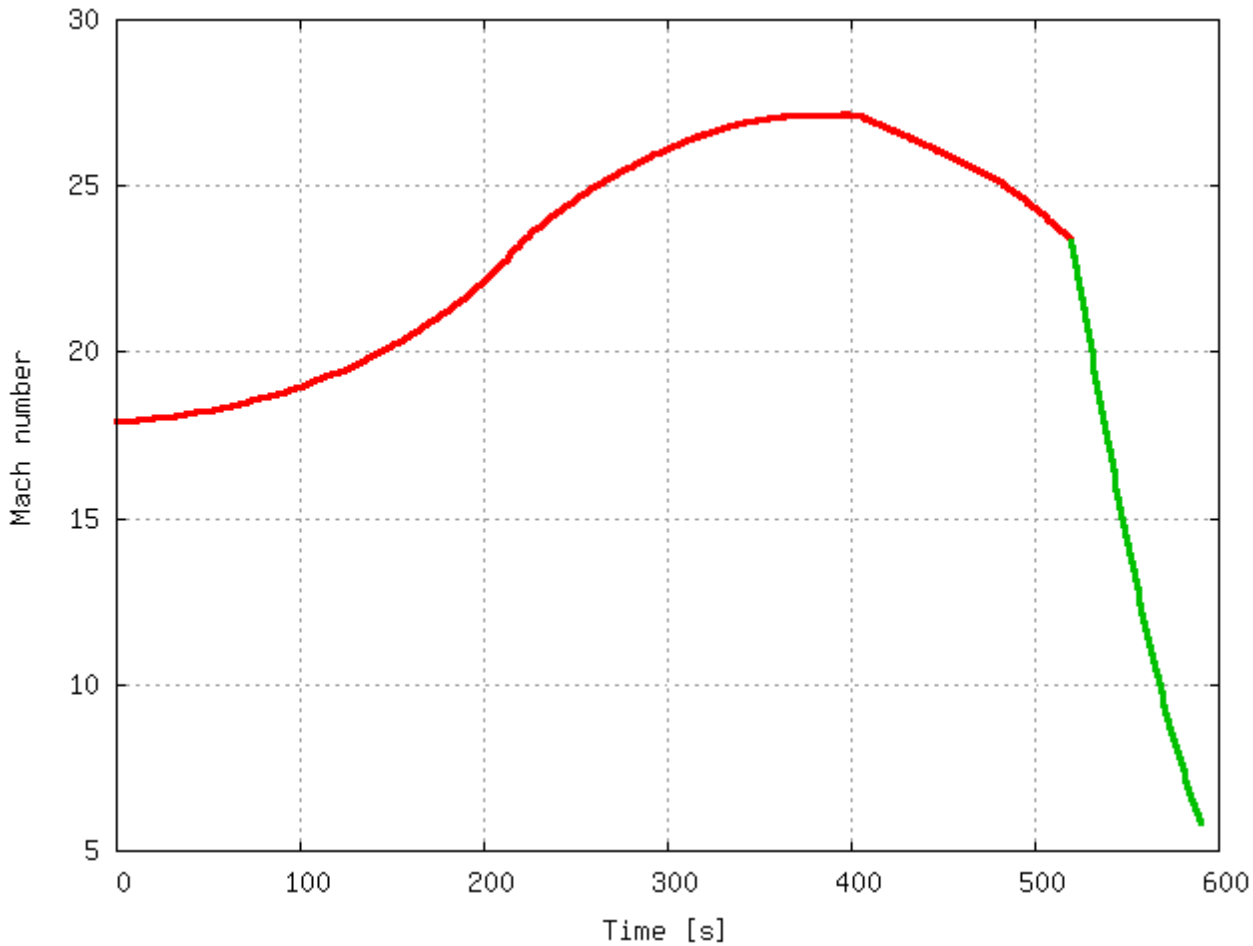

Case 1: Deceleration

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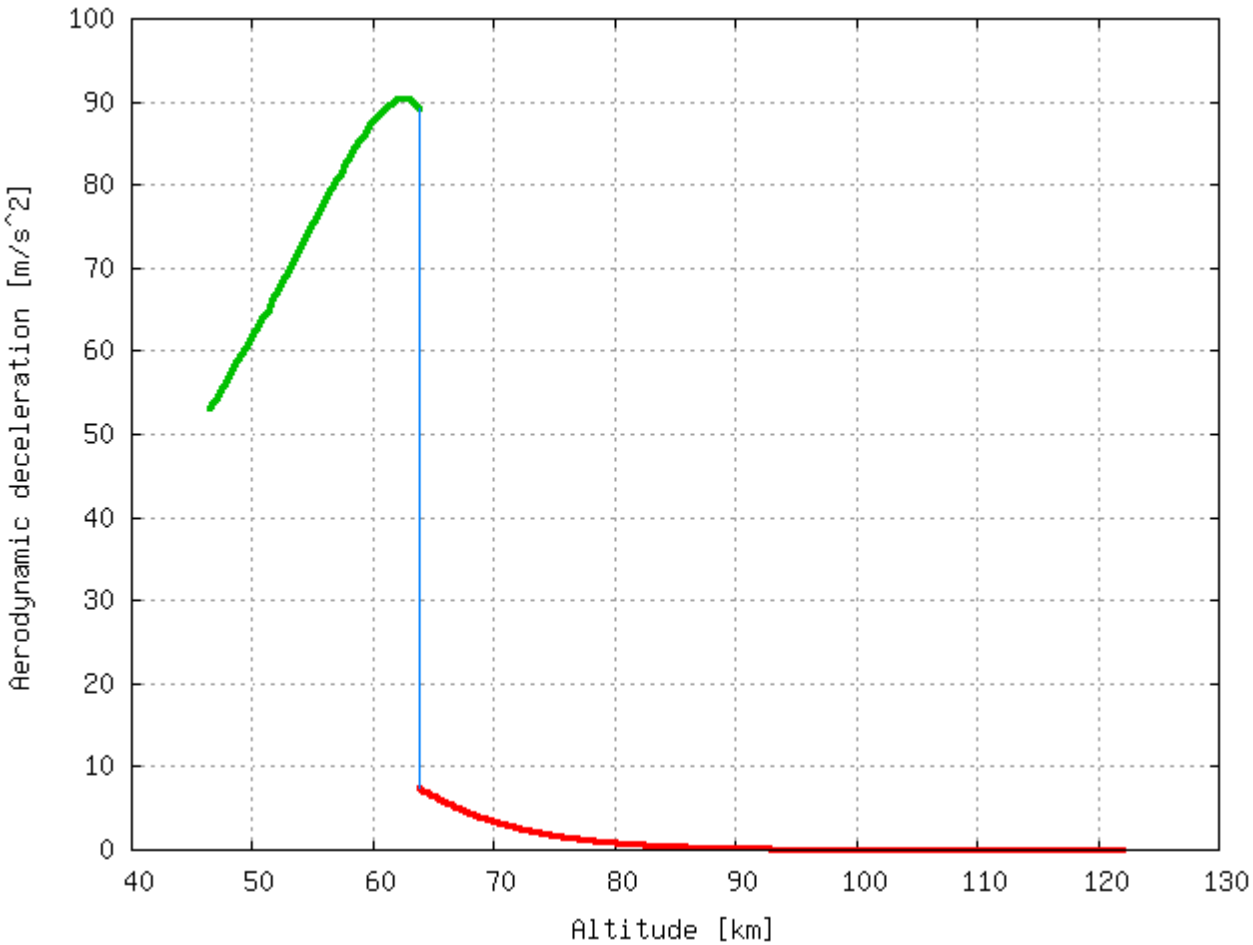

Case 1: Aerothermal heating

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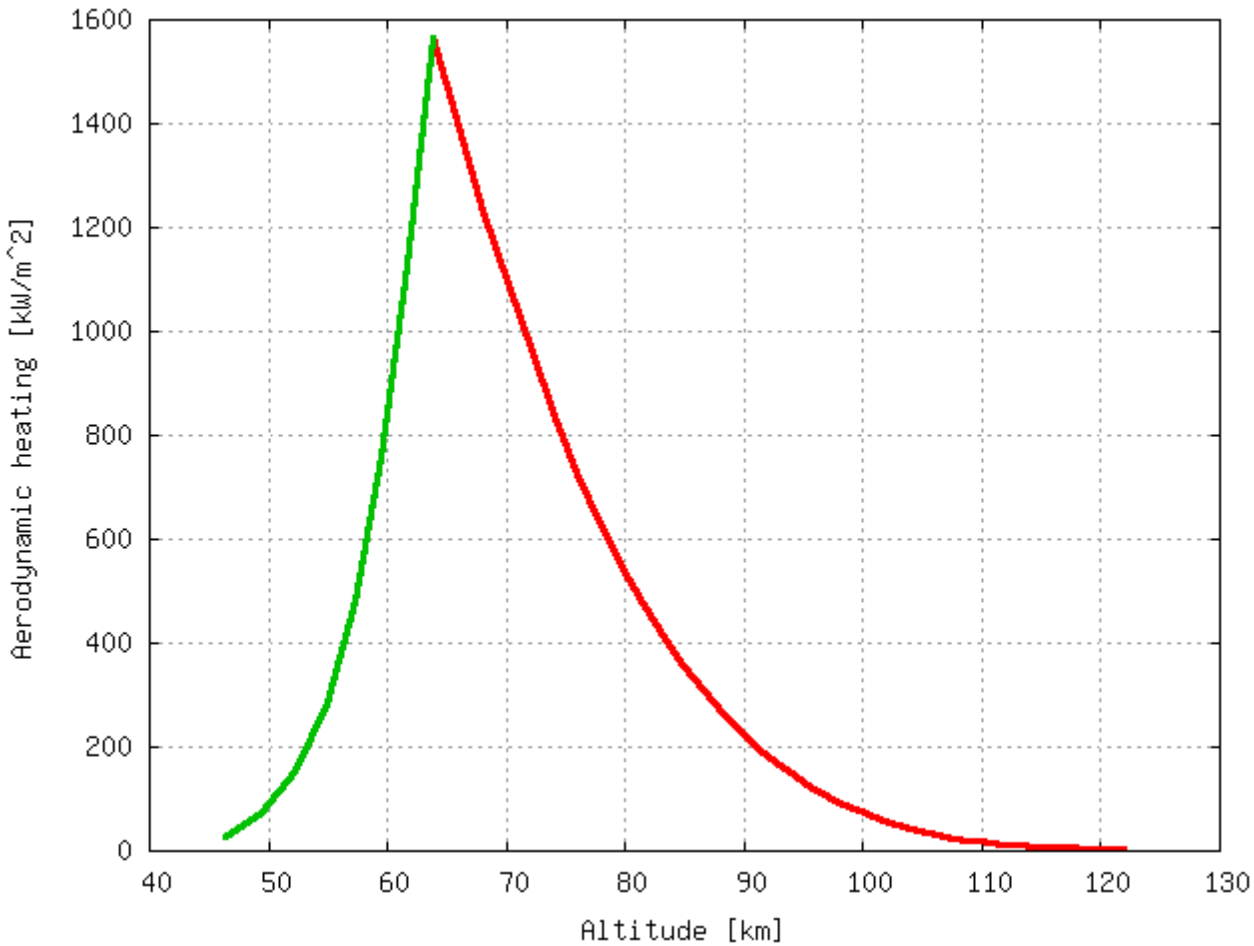

Case 1: Tank temperature

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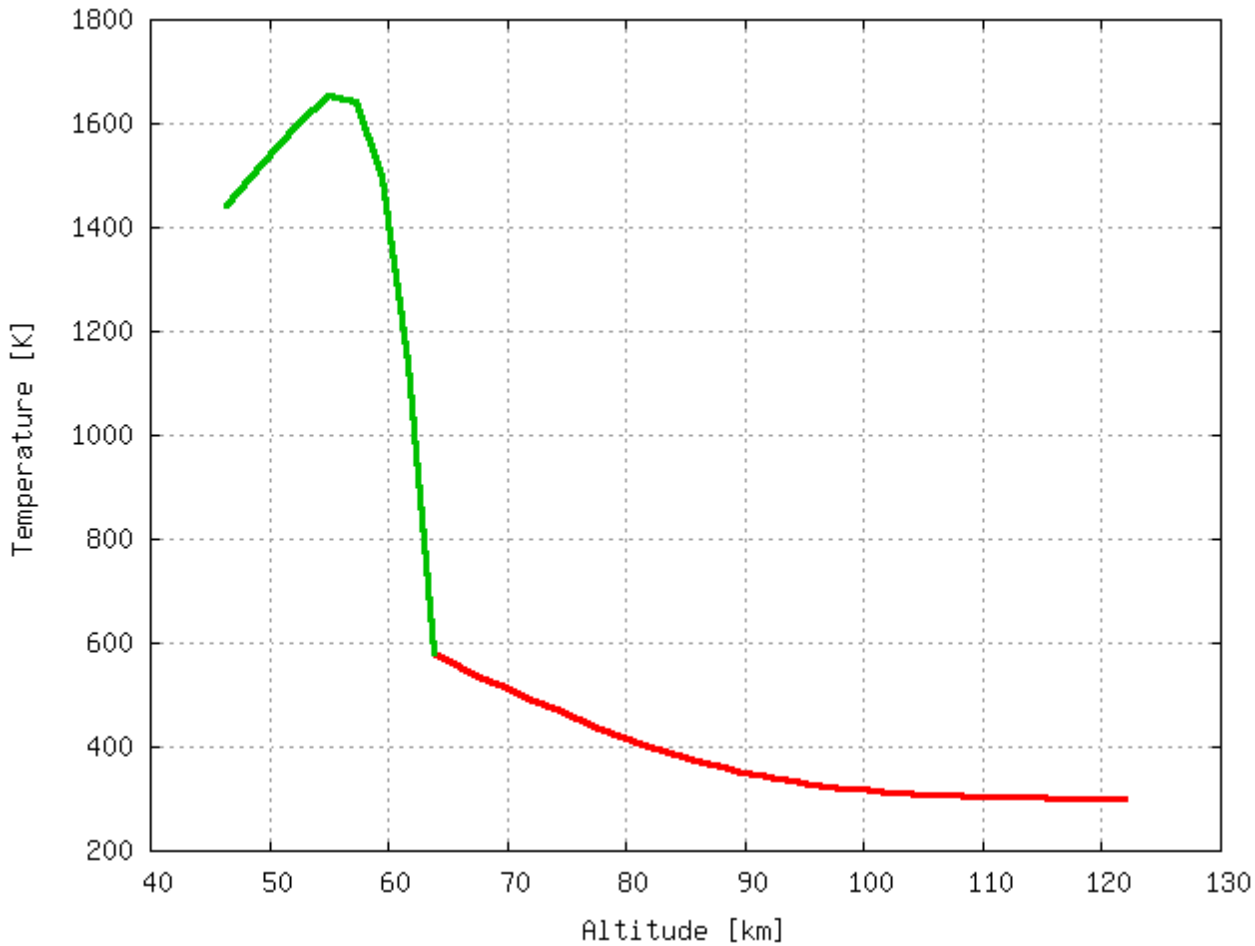
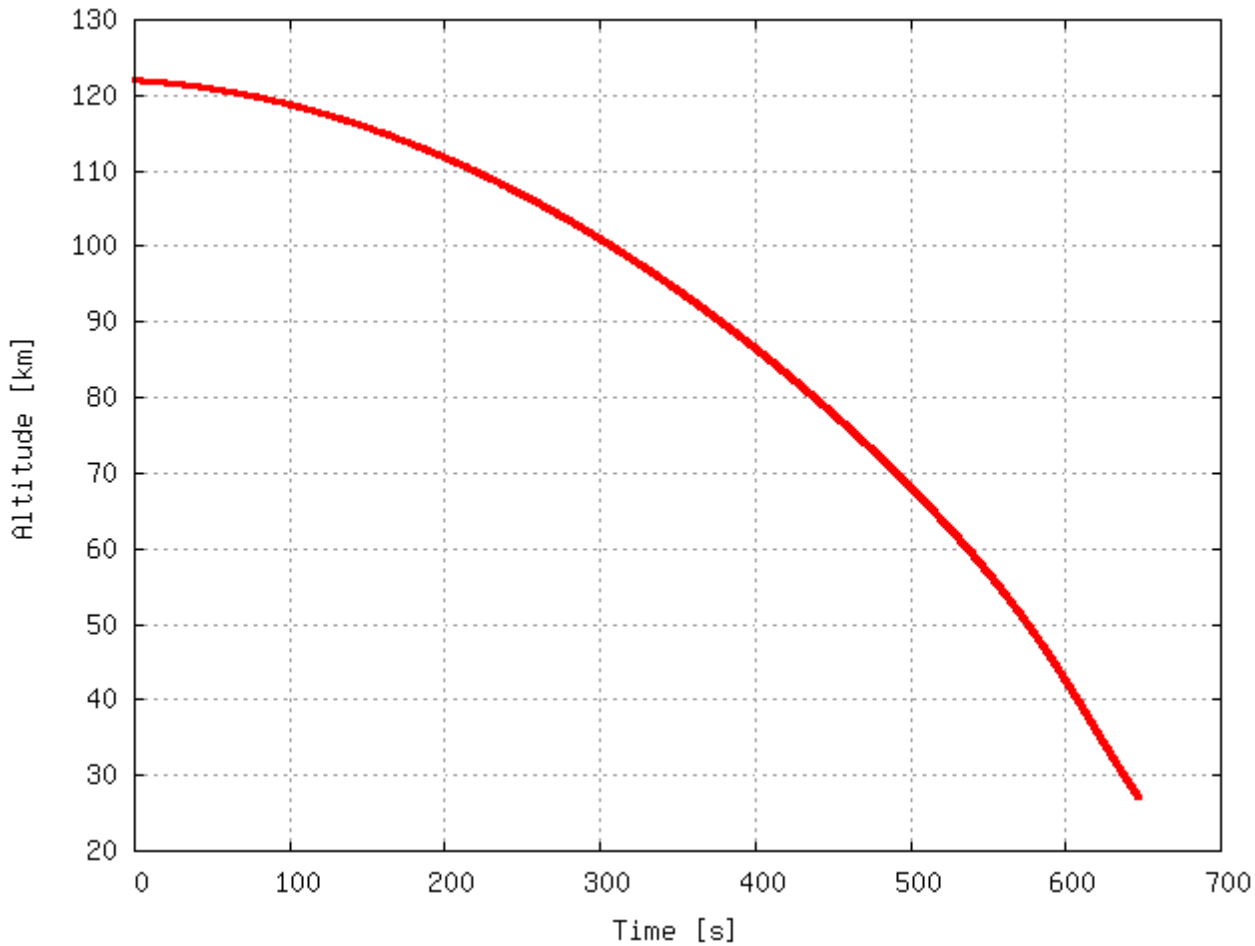


Case 2: Trajectory



Case 2: Velocity

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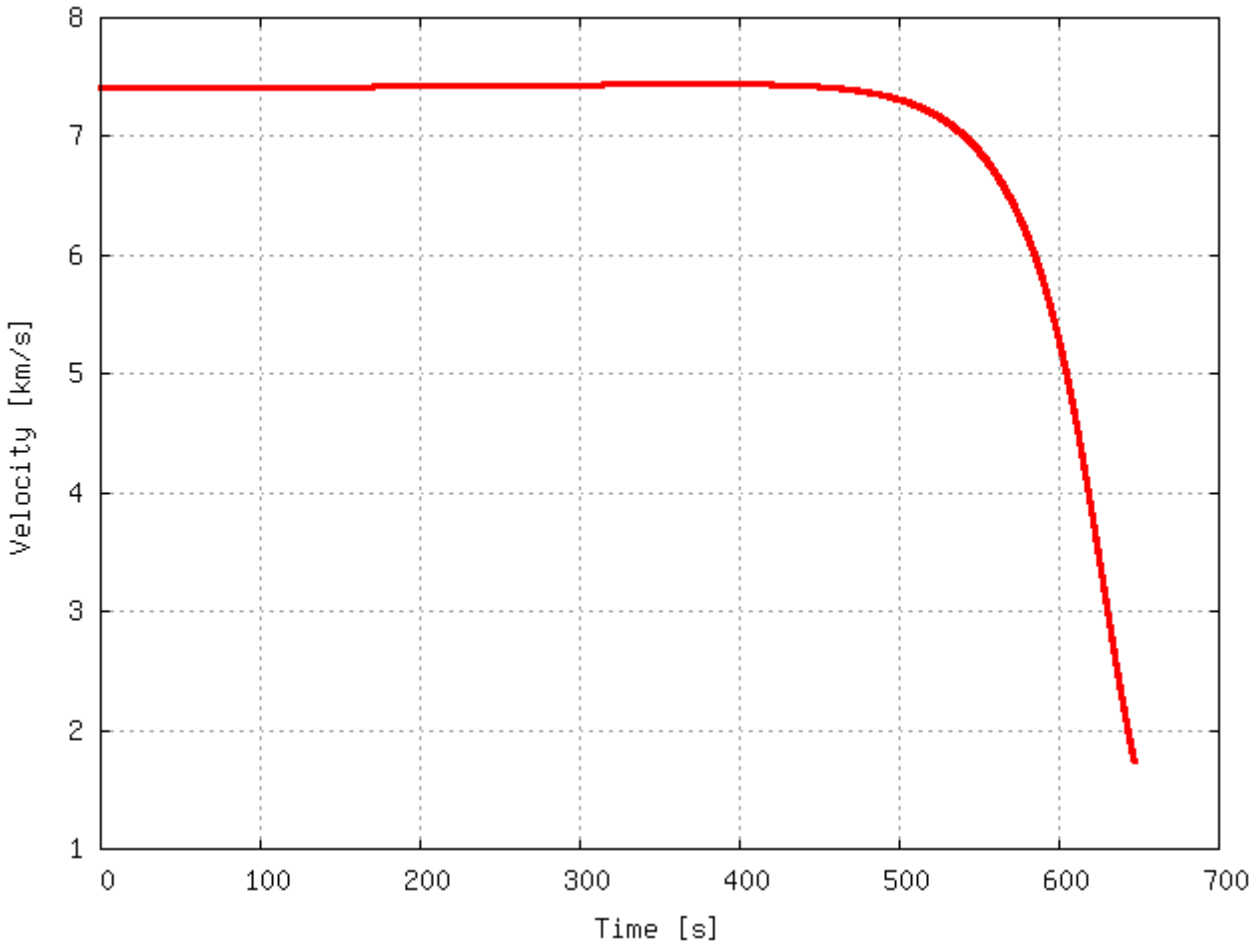

Case 2: Flight path angle

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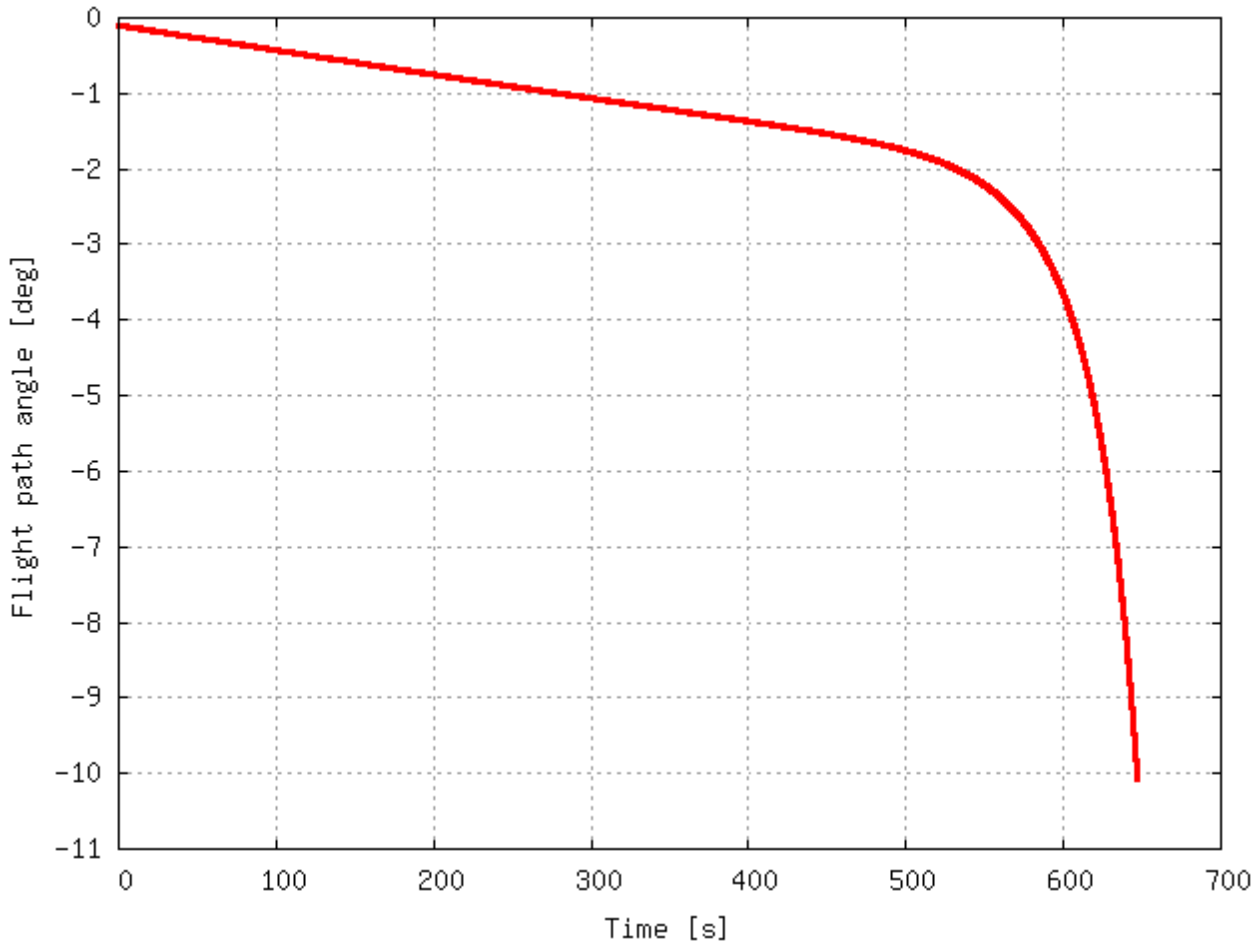
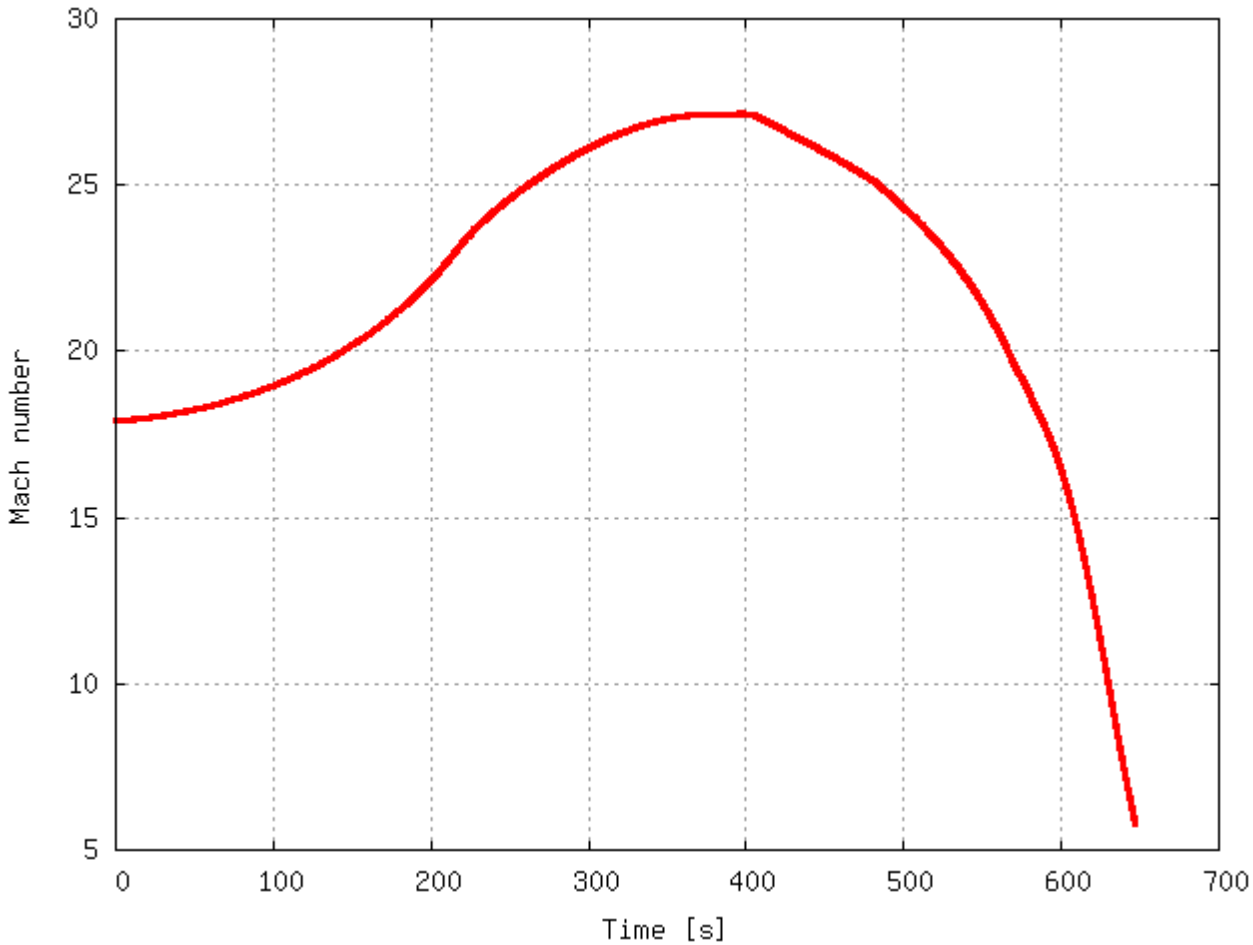


Case 2: Mach number



Case 2: Aerodynamic deceleration

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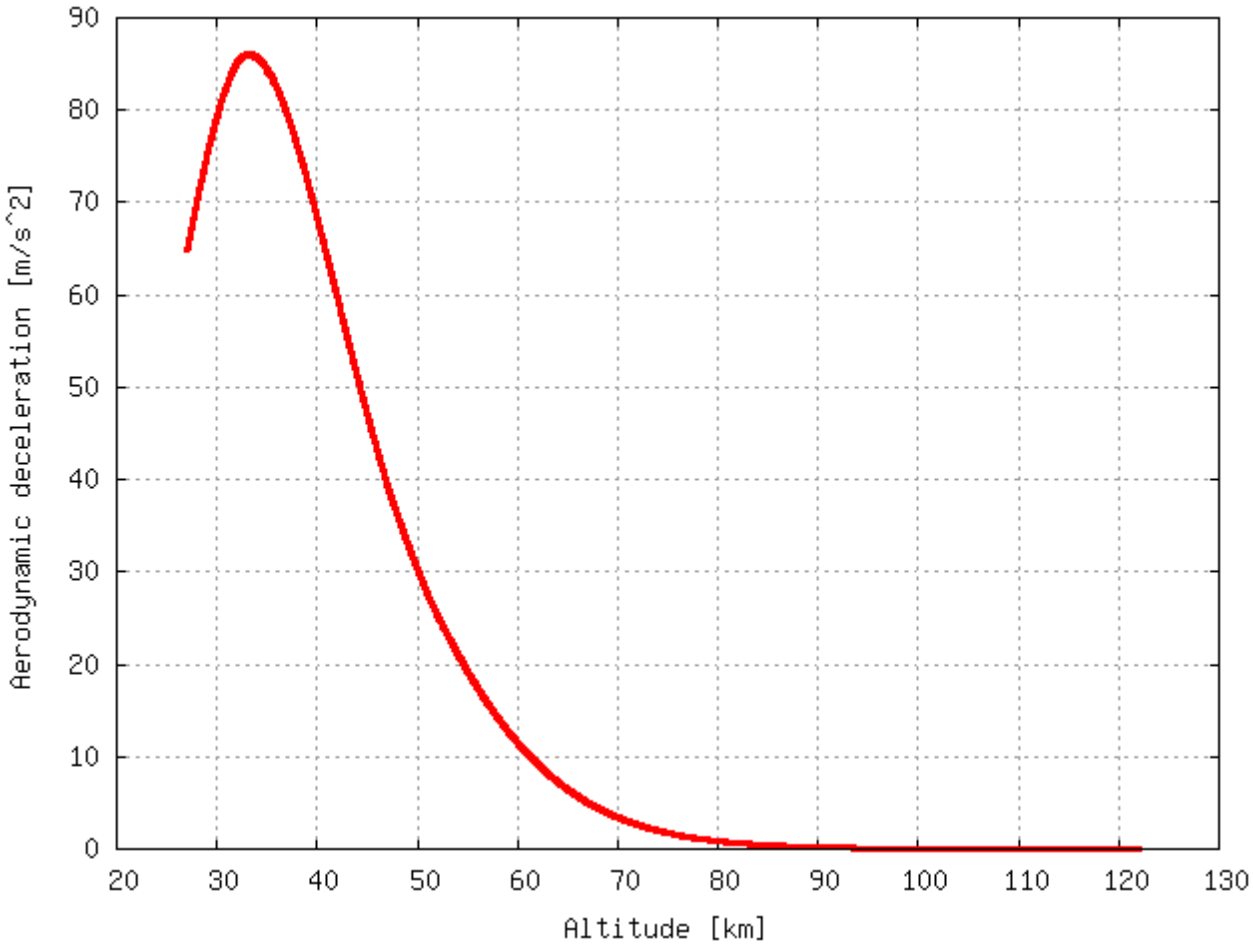

Case 2: Aerothermal heating

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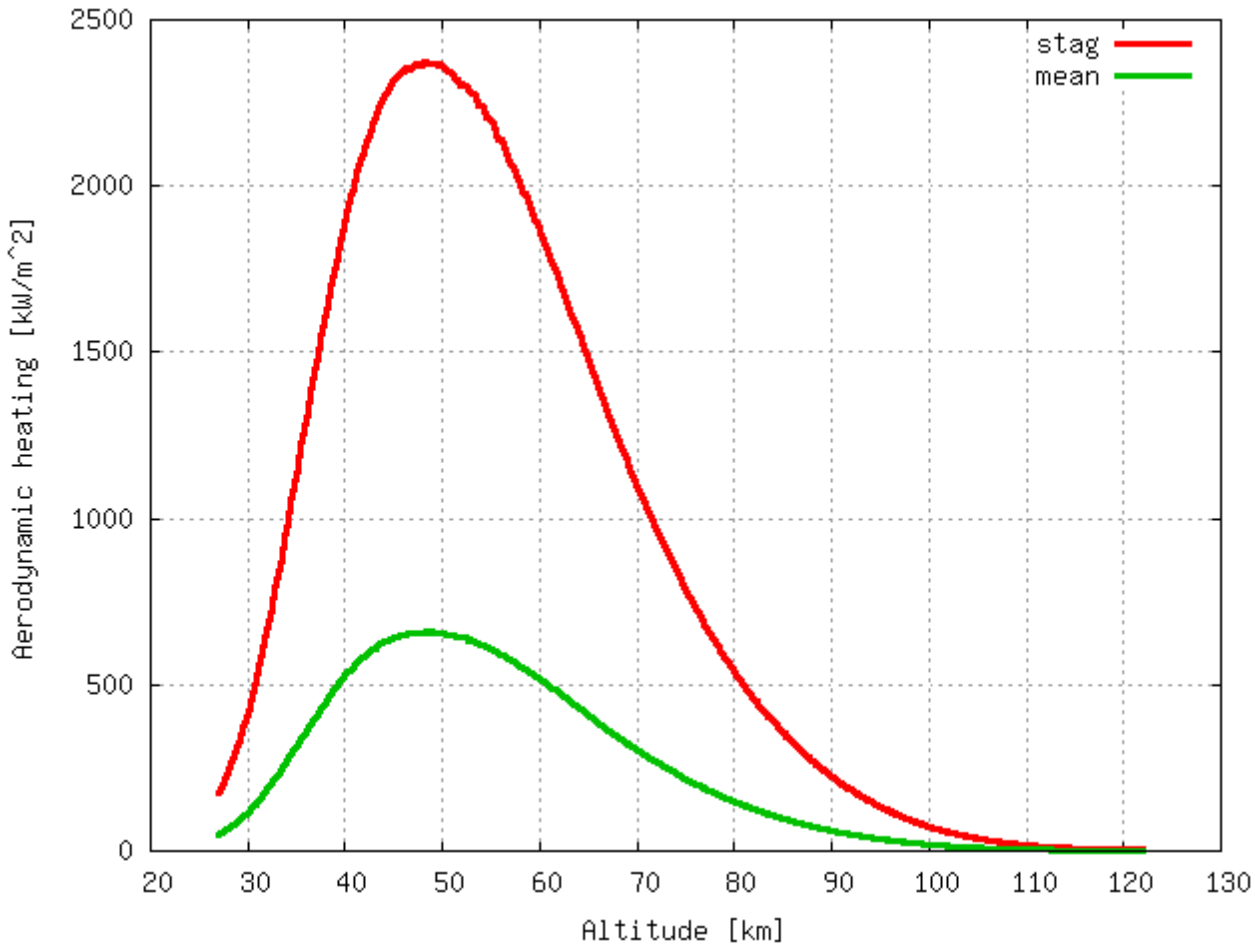

Case 2: Tank temperature

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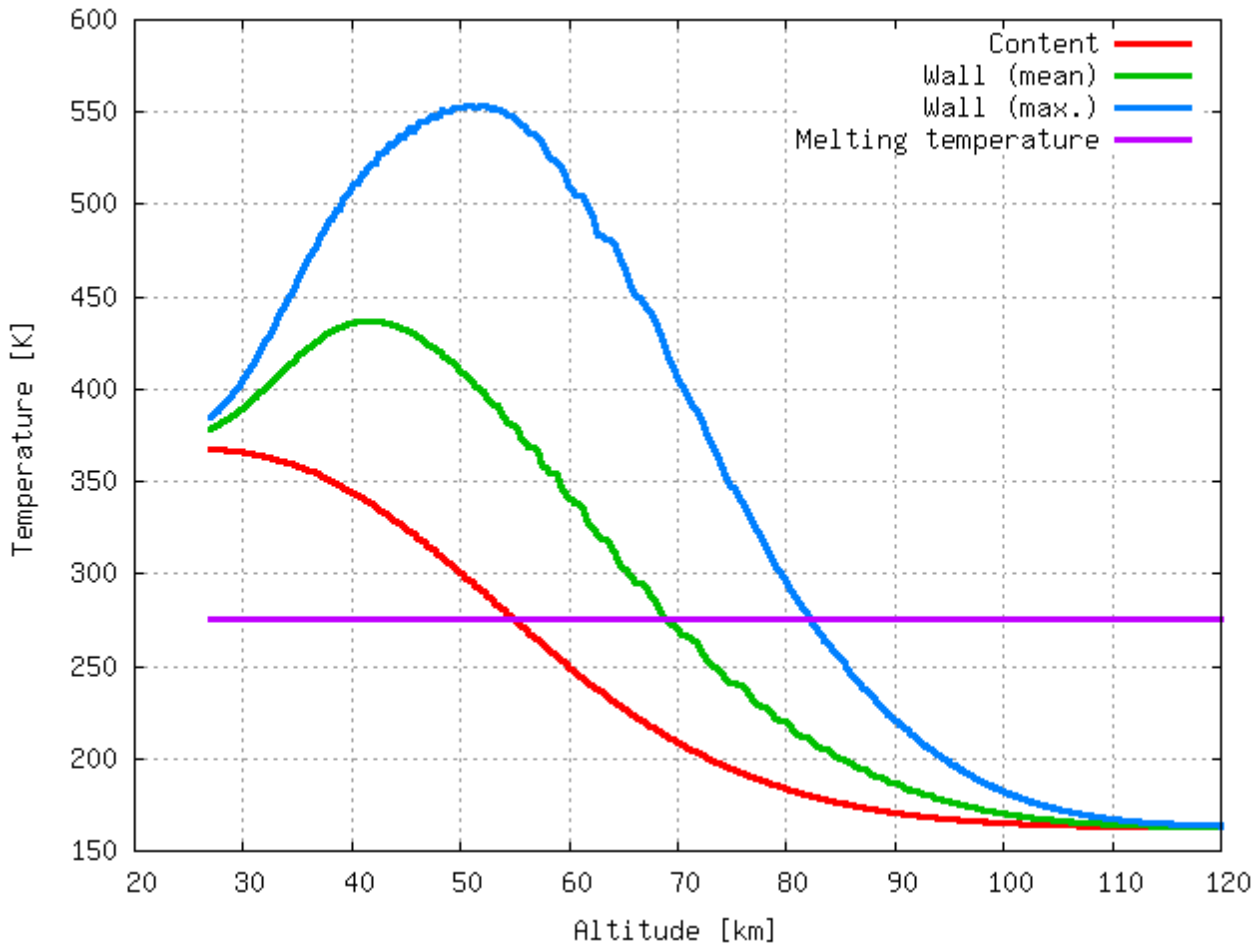

Case 2: Tank pressure

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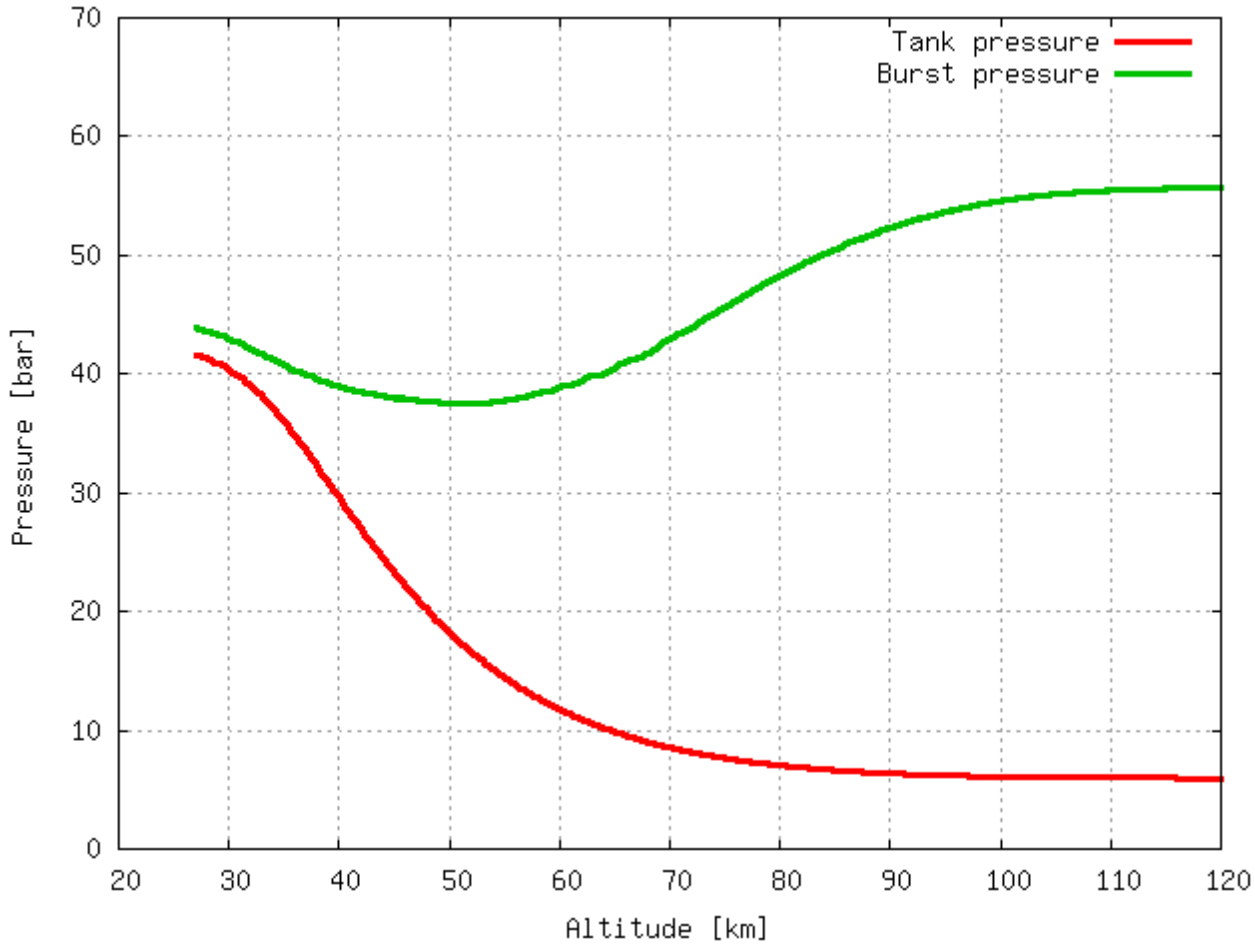

Discussion of extended tank analysis

- Tank state
  - Frozen content should be modeled as real solid
  - Heat conduction will be smaller, the wall temperature higher
  - No simple change due to complicated interactions
    - Local melting/evaporation near the hot wall
    - Non-uniform heating
- Initial state
  - For a long time in orbit before re-entry the tank content may cool down below the freezing point → additional heating needed to reach the melting point

Conclusions

- The re-entry of spacecraft with on-board tanks can be computed in detail with the SCARAB software
- The software has been applied to such cases in the past, e.g. to the ATV
- In the present case the re-entry of a fuel tank was studied for different initial thermal states
- Depending on the initial temperature bursting may occur or not
- For further studies the frozen content should be modeled a real solid, including boundary effects