Atmospheric Reentry Simulation

Not Exactly Rocket Science

Julian Köllermeier
Berlin, April 26th 2016
1. Introduction to Atmospheric Reentry

2. Rarefied Gases: From Science Fiction to Simulation

3. PhD Topic

Atmospheric Reentry Talk
Julian Köllermeier
Berlin, April 26th 2016
Introduction to Atmospheric Reentry

Atmospheric Reentry Talk
Julian Köllermeier
Berlin, April 26th 2016
Reentry hard facts

Atmospheric entry is the movement of human-made objects as they enter the atmosphere of a celestial body from outer space.

- Reentry starts at Karman line (Earth 100km, Mars 80km)
- Velocity of reentry vehicle up to 14km/s (Mars return)
- Surface temperature more than 1000K
- Energy exchange between kinetic and thermal energy
Main objectives:

1. search for trace atmospheric gases
2. test critical technology for future missions

- Trace gas orbiter
- Entry, decent and landing demonstrator module
Rarefied Gases: From Science Fiction to Simulation
Why simulations?

Development and optimization needs testing

1. Real-world experiments
2. Wind tunnel experiments
3. Simulations

Problems of experiments:
- Small parameter range
- Limited measurement capabilities
- Expensive

Benefits of simulations:
- Variable conditions
- Detailed measurements possible
- Repeatable

Atmospheric Reentry Talk
Julian Köllermeier
Berlin, April 26th 2016
Numerical simulations

1. Develop mathematical model and implement numerical solution method

2. Set up test case and run computer program on big machines

3. Get simulation results

Atmospheric Reentry Talk
Julian Köllermeier
Berlin, April 26th 2016
What to simulate?

- Edge of space: vacuum plus molecules, particle model
- High altitude: rarefied gas, new model
- Ground level: dense gas, continuum model

Rarefied flow characterized by large Knudsen number:

$$Kn = \frac{\text{mean free path}}{\text{characteristic length}} = \frac{\lambda}{L}$$
Standard Solution methods

Stochastic particle method: Direct Simulation Monte-Carlo

- Single particles that move through space and collide
- Needs many particles
- Stochastic noise in results

Continuum models

- Derive equations from conservation of mass, momentum and energy
- Example: Euler or Navier-Stokes equations

\[ \frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0 \]
\[ \frac{\partial (\rho \mathbf{u})}{\partial t} + \nabla \cdot (\mathbf{u} \otimes (\rho \mathbf{u})) + \nabla p = 0 \]
\[ \frac{\partial E}{\partial t} + \nabla \cdot (\mathbf{u}(E + p)) = 0 \]
Moment model

Rarefied gases:
• Continuum models too inaccurate
• Particle models too expensive

Extension of standard continuum model: additional equations and variables

Prediction of new effects:
• Heat flux from cold to warm
• Knudsen paradox
PhD Topic

Atmospheric
Reentry Talk
Julian Köllermeier
Berlin, April 26th 2016
Limits of the models

- Not whole mission, only EDL
- Not whole EDL, only entry
- Not whole entry, only high-altitude
- No chemistry, electro-mechanics
- No polyatomic gases (only He, Ar,…)
- Not fully 3D, only 1D and 2D tests
Phase 0: Model derivation

State of the art:
- Existing models (1950s) lack important properties
- New Chinese model (2012) successful

Idea: Understand, analyse and extend model

Master thesis 05/2013 – 09/2013
- Derivation of new model
- Analytical comparison to existing models
- Proof of desirable model properties
Phase 1: Model extension and analysis

1st PhD year 10/2013 – 10/2014

- Model extension (3D, …) [JK, 2014]
- Analysis of properties
- Development of new model framework [JK et al., 2016]
Phase 2: Numerical software development

2nd Phd year 10/2014 – 10/2015

• Development of simulation tool
• Implementation of several solution methods
• First results [JK, submitted]

\[ u_{i+1} = u_i - \frac{\Delta t}{\Delta x} \left( F_{i+1/2} - F_{i-1/2} \right) \]
Phase 3: Tests

3rd PhD year 10/2015 – now

- Tests of numerical methods
- Advanced solution methods
- Simulations of model equations
  [JK, submitted]
Phase 4: Finish

ToDo

• 2D tests [JK, in preparation]

• Dissertation
Thank you for your attention!