University of Stuttgart
Institute of Space Systems

Determining Reentry Breakup Forces in an Impulse Facility

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HEFDiG

Motivation

- How do large spacecraft break-up?
- Debris on ground
- Failure criteria for break-up tools
- DLR funded project
- Comparison to observation data[1]

Figures from nasa.gov

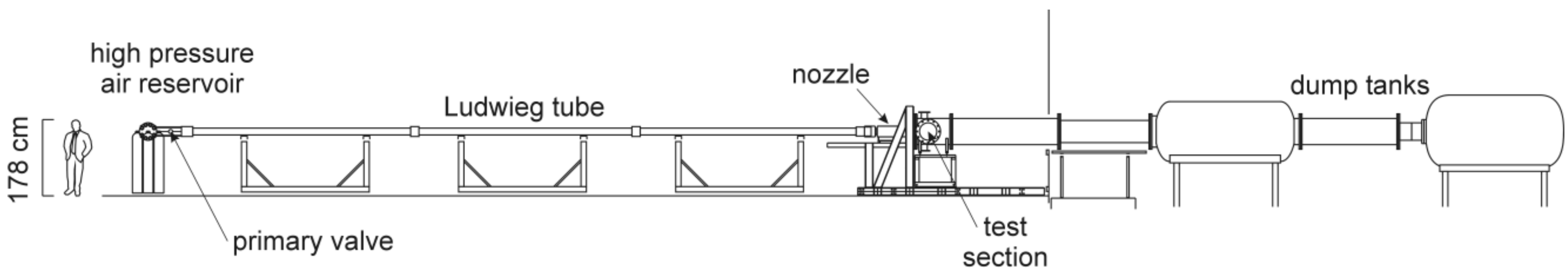
[1]Loehle, S. et al "Airborne Observations of Re-entry Break-up: Results and Prospects," *7th European Conference on Space Debris,* Darmstadt, Germany, 2017.

Facility

TUSQ Ludwieg Tube

- Ludwieg tube impulse facility[2]
- Mach 7 nozzle
  - 73-84km Reynolds analogy
  - 200ms steady flow
- Two models tested

- German Academic Exchange Service (DAAD)
- University of Southern Queensland (USQ)

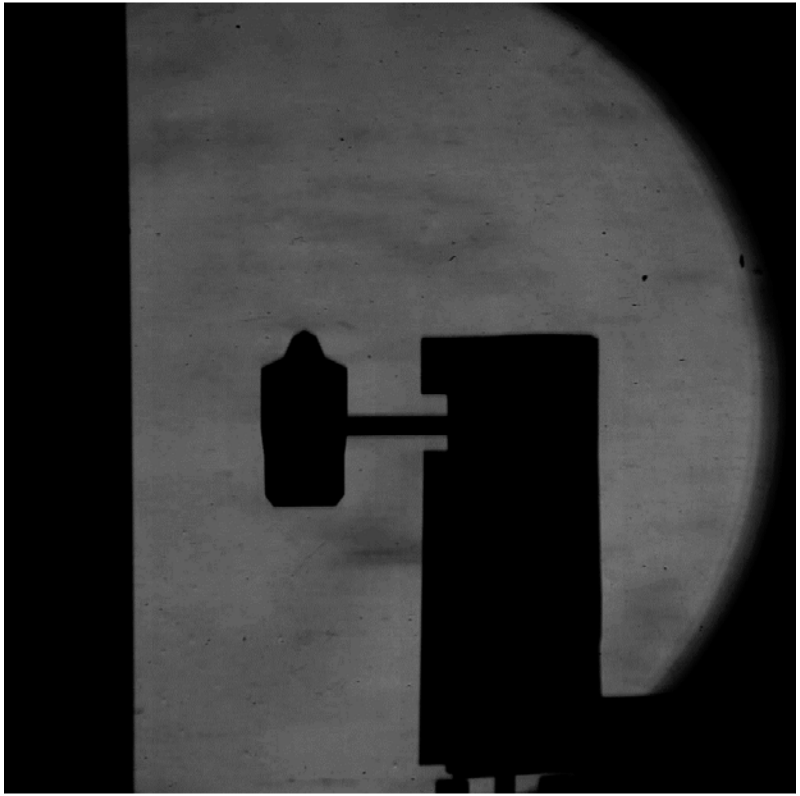


[2]Buttsworth, D. R., "Ludwieg tunnel facility with free piston compression heating for supersonic and hypersonic testing," *9th Australian Space Science Conference,* Sydney, 2010, pp. 153–162

Models

ATV

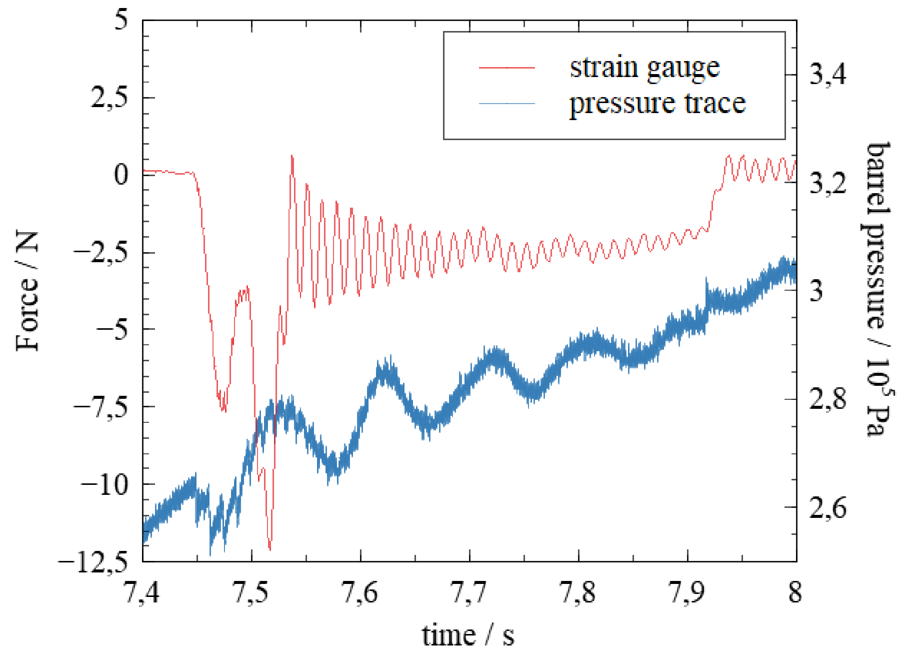
- ATV model with 6-DOF strain gauge
- 1:200 scale (77-84 km)
- 8 different angles of attack



Forces

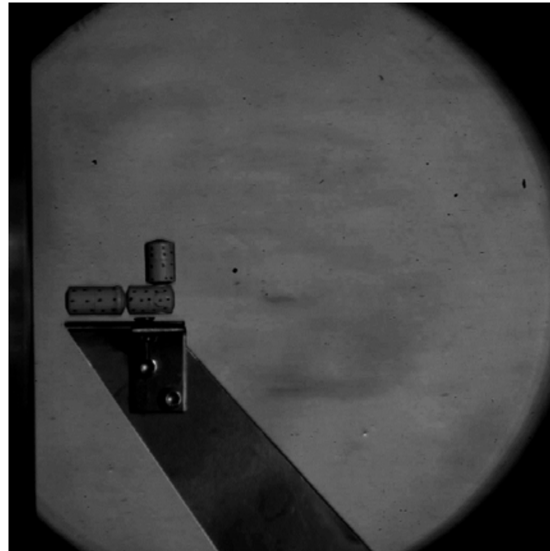
ATV

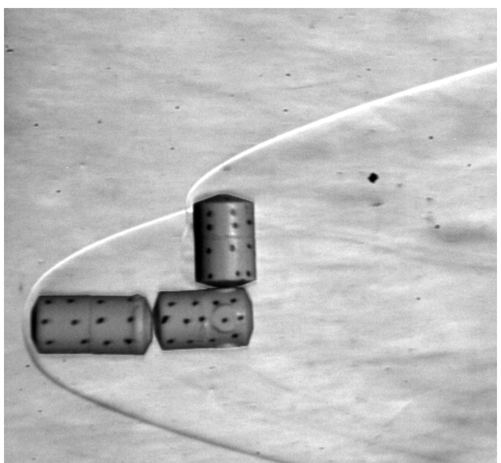
- Forces can be directly measured
- Correlations to the flow
  - Pressure trace
- Drag Coefficients



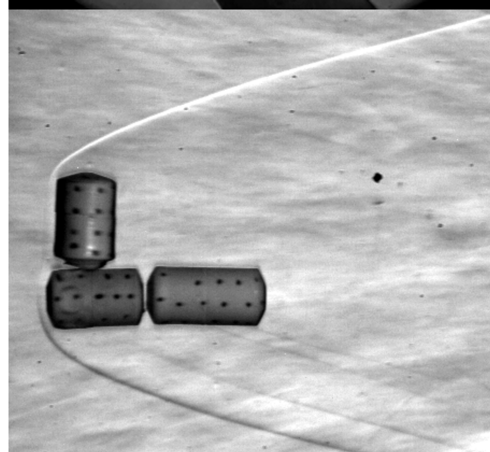
Models

- USOS 3 body segment
- 1:400 scale (73-79 km)
- Three flight configurations

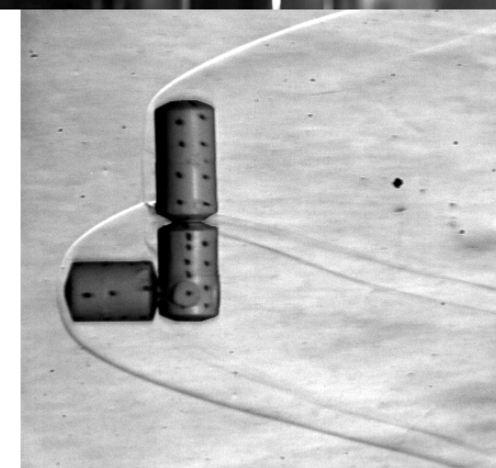




reverse

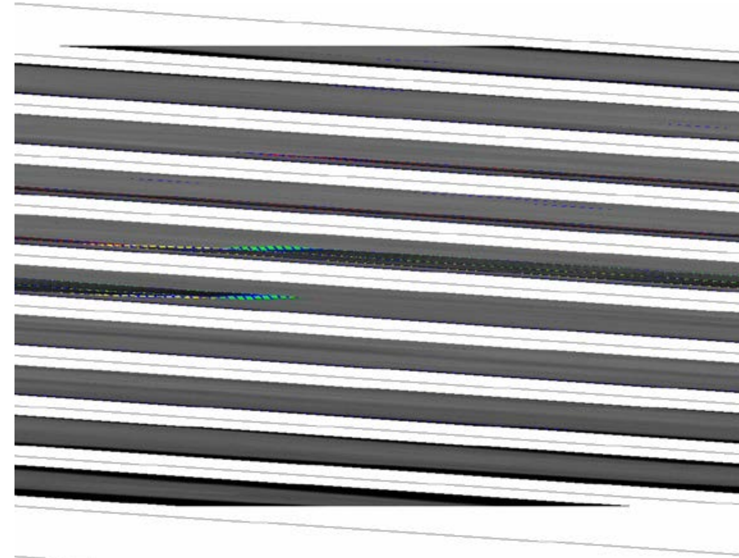


normal

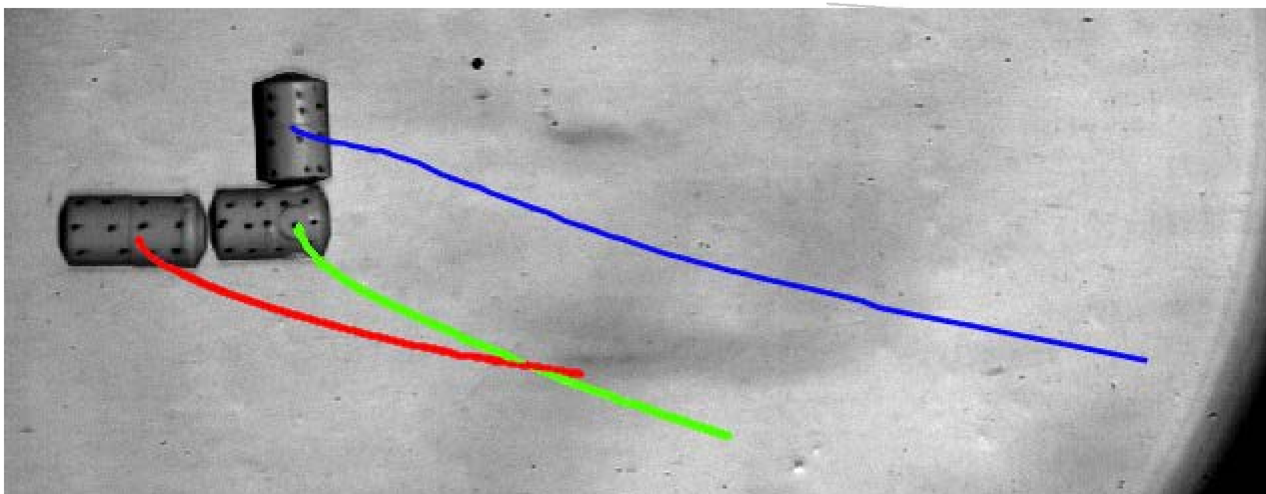


vertical

Tracking



- Edge detection
- Shape fit tracking[3]
- Tracking while visible



[3]Laurence, S. J., “On tracking the motion of rigid bodies through edge detection and least-squares fitting,” *Experiments in Fluids*; Vol. 52, No. 2, 2012, pp. 387–401. doi: 10.1007/s00348-011-1228-6.

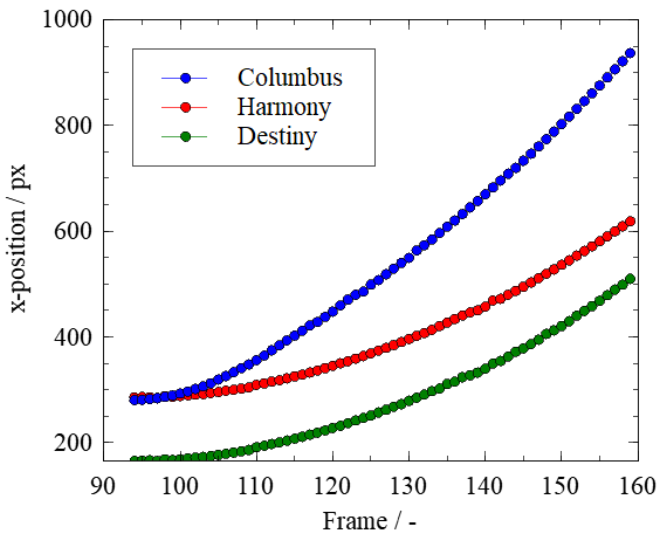
Forces

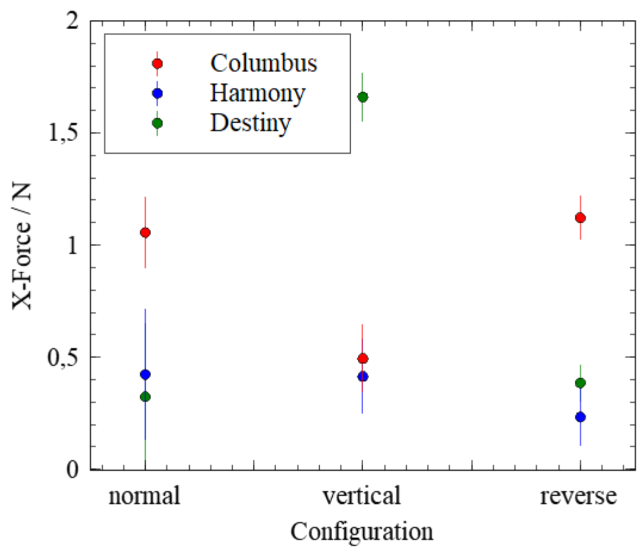
ISS

- X-Forces principal
- 2nd order polynomial fit

$$d = a \cdot t^2 + v \cdot t + d_0$$

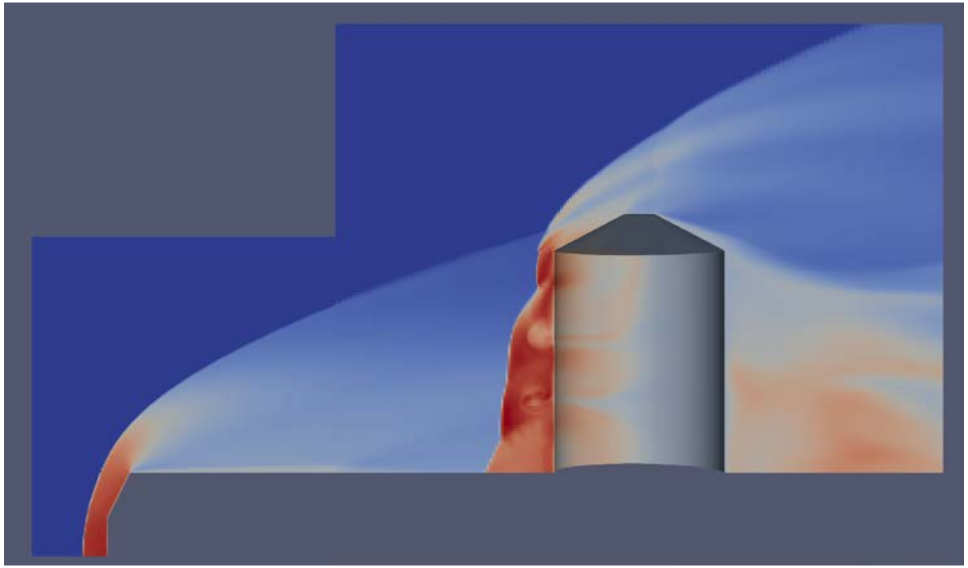
$$F = m \cdot a$$





CFD

- Eilmer4[4]
- Currently only one configuration
- 2D axisymmetric and 3D combined[5]
- Pressures integrated over surface area

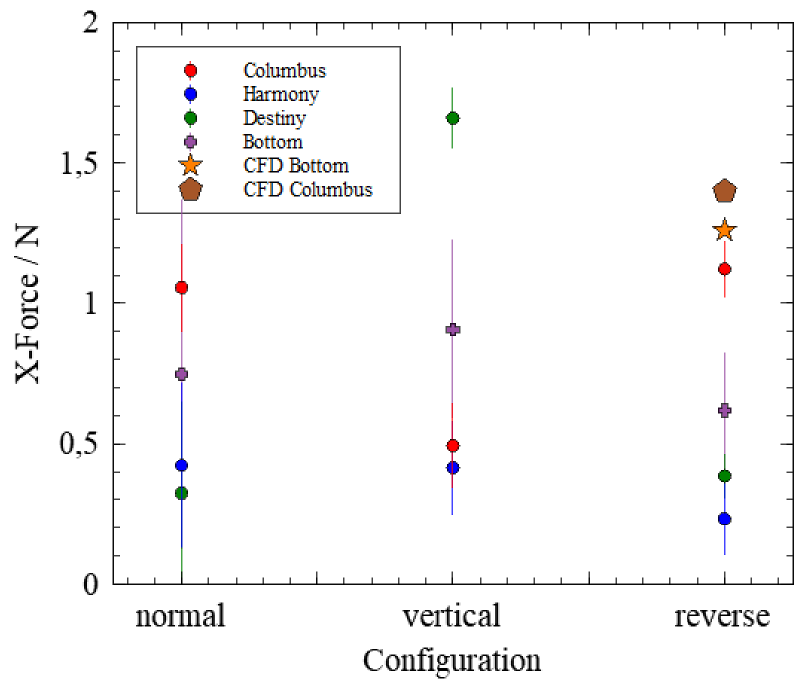


[4]Jacobs, P., and Gollan, R., “Implementation of a Compressible-Flow Simulation Code in the D Programming Language,” *Applied Mechanics and Materials*; Vol. 846, 2016, pp. 54–60. doi: 10.4028/www.scientific.net/AMM.846.54.

[5]Zander, F. et al., “Numerical Analysis of the ISS Re-entry,” *7th European Conference on Space Debris*, 2017.

Comparison

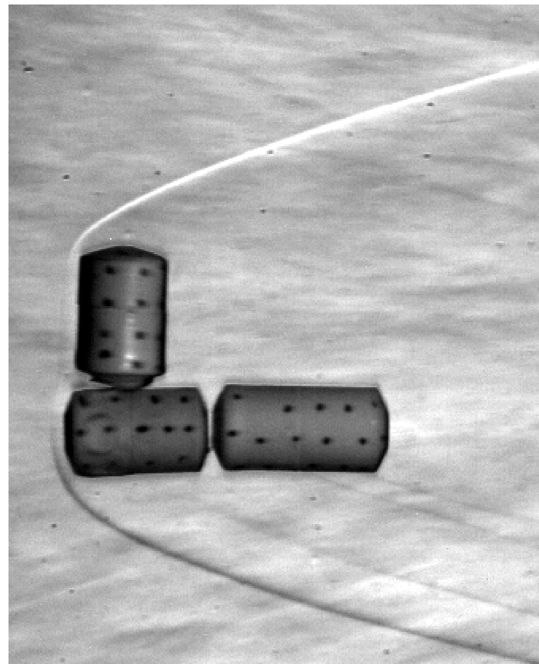
- Reasonable agreement between CFD and measured data
- Similar flow structure
- CFD forces on bottom elements are higher

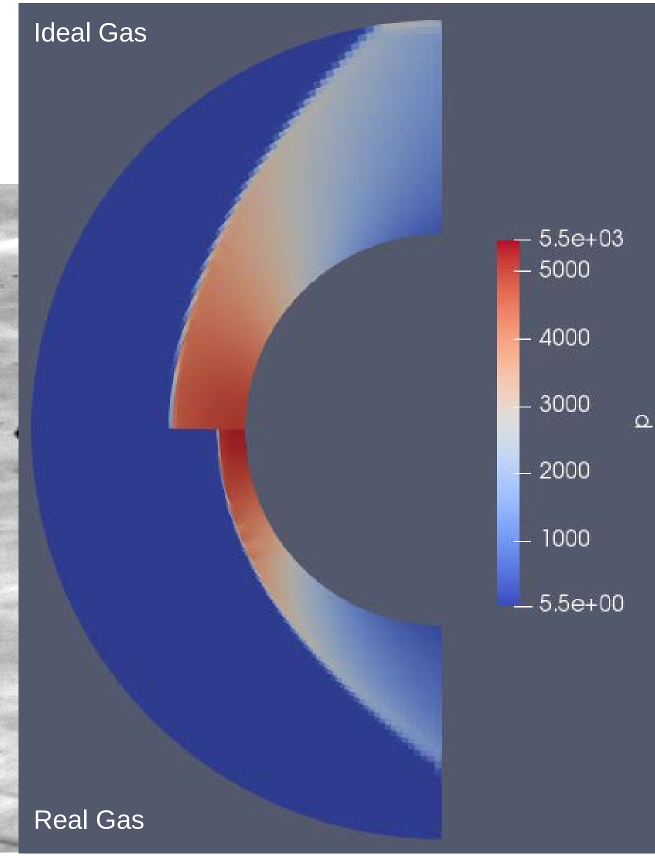


Scaling Ideal-Real Gas

Normal Shock

- Chemistry
- +10% Pressure[6]
- Shock Structure



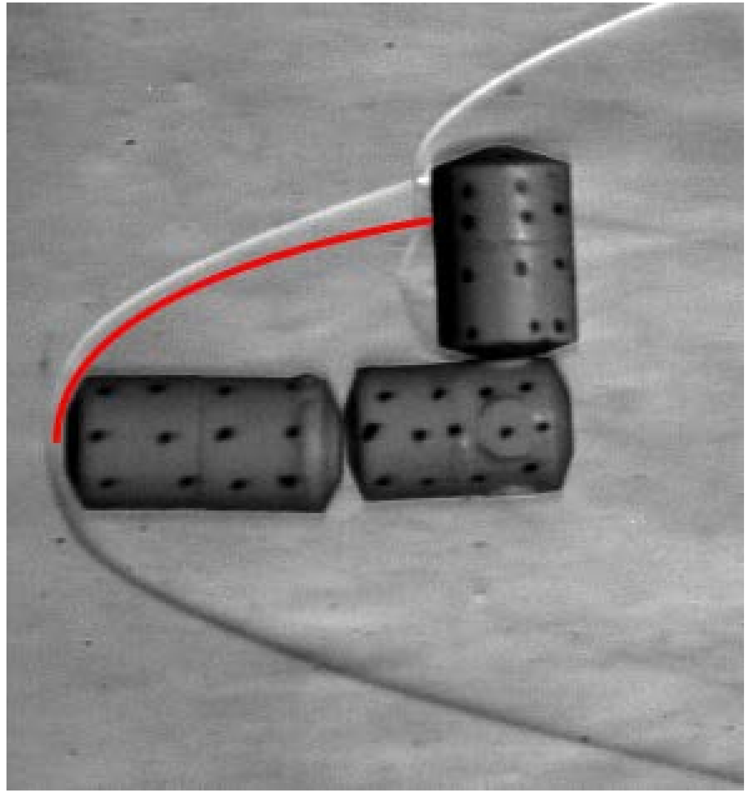


[6]Huber, P. W., "Hypersonic shock-heated flow parameters for velocities to 46,000 feet per second and altitudes to 323,000 feet," NASA TR R-163, 1963.

Scaling Ideal-Real Gas

Oblique shock

- Increase of freestream area
- Change in postshock flow

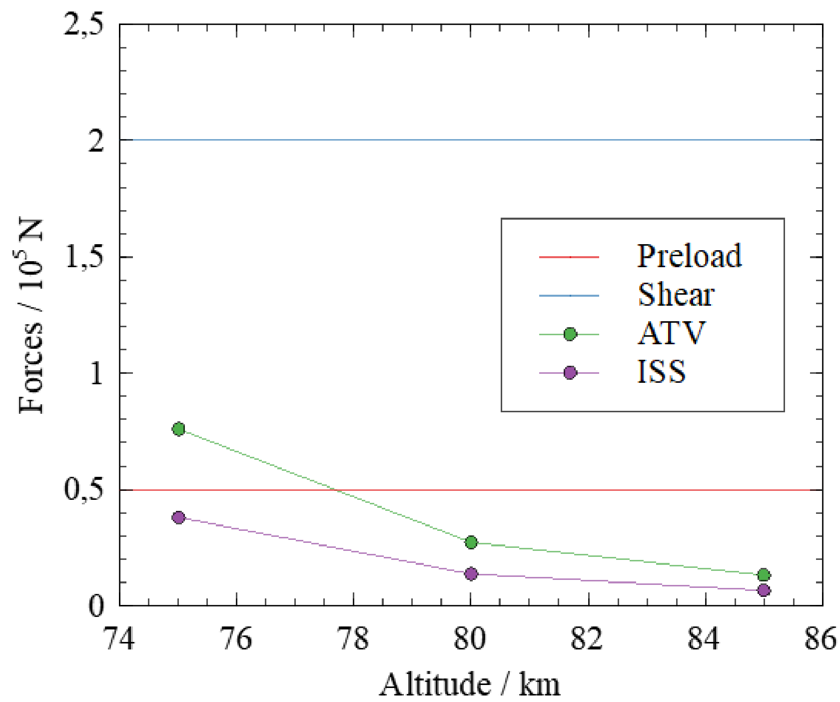


Failure Criteria

- 5-100 kN of absolute lateral force
- 2-40kN shear force

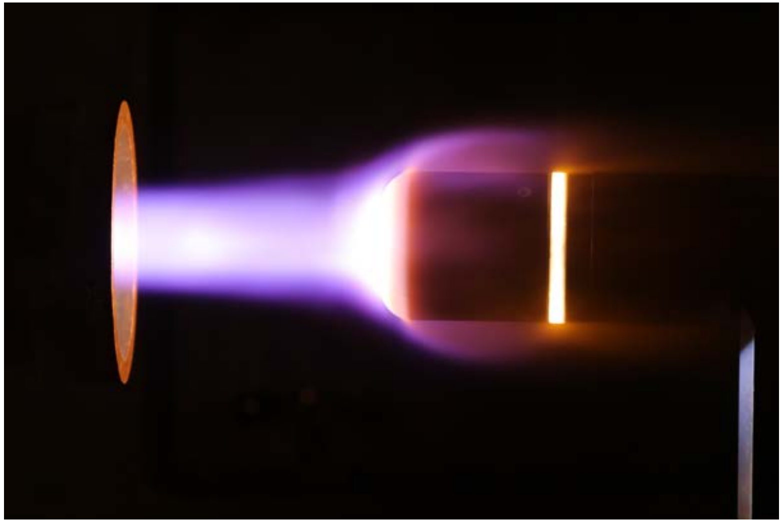
- CBM 16 bolts:
  - preloaded to 50kN per bolt
  - shear strength 200kN per bolt

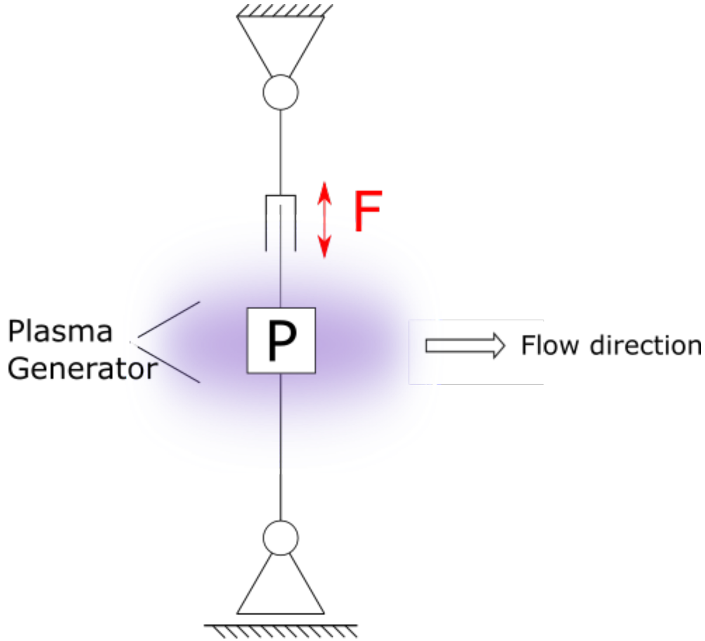
- Ideal aerodynamic forces lead to failure after 75km



Next Steps

- 3D CFD with chemistry
- Applying forces to materials in PWK[7]





[7]Loehle, S., et.al. "The Plasma Wind Tunnels at the Institute of Space Systems," *32nd AIAA Aerodynamic Measurement Technology and Ground Testing Conference,* American Institute of Aeronautics and Astronautics, 2016.

Conclusion

- Models were tested in a shock tunnel
- Shear forces were calculated from models and CFD
- Scaling of forces to flight for ATV/ISS for ideal gas

- Outstanding real gas effects
  - Thermochemistry
  - Viscous effects
  - Flow field changes
- Combined thermomechanical loads

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Thank you!

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