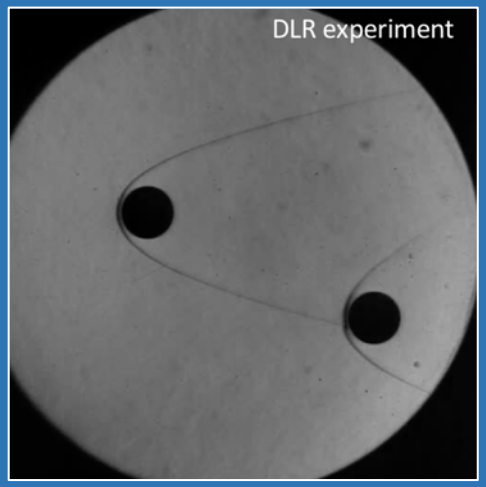
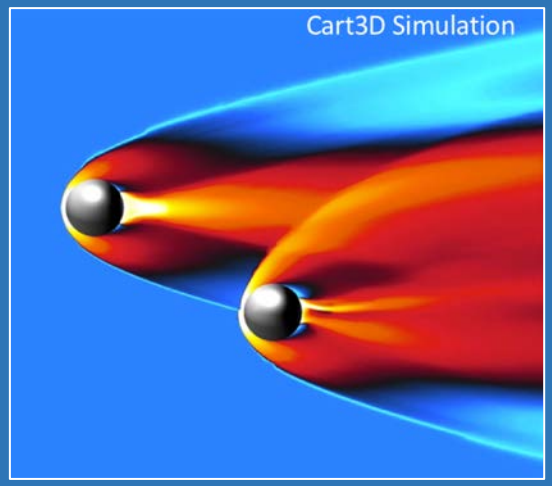
IPPW-Enabled International Collaborations in EDL: Lessons Learned and Recommendations

Ethiraj Venkatapathy	Ali Gülhan	Michelle Munk
Senior Technologist	DLR	Principal Technologist
NASA ARC	Cologne, Germany	STMD, NASA LaRC





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Acknowledgements

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- HEEET and Common Probe

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DLR:

- DLR –USA Relationship, Legal Aspects and Export Licence

  Thorsten Nix, Helena Weissenberger, Yvonne Richter, Michael Baumann
- Hypersonic Testing in H2K

  Dr. Sebastian Willems, Patrick Seltner, Dominik Neeb, Ansgar Marwege
- Dusty Flow in the Arc Jet Test Facility

  Dirk Kerkhoff, Dr. Burkard Esser, Lars Steffens
- COMARS Sensors

  Thomas Thiele, Dr. Frank Siebe, Rolf Kronen

ESA

- HERA and Ice-Giant Mission Proposals to ESA
  Olivier Mousis (PI)

Outline

- IPPW and International Collaboration
- Unique Capabilities at DLR – Dr. Ali Gülhan
- NASA Needs and Collaborations
  - Fundamental aspects as well as enabling missions.
- Concluding Remarks

IPPW and International Collaboration: Opportunities, Challenges and Constraints

- International Collaborations
  - EDL / technology areas are more challenging
- Challenges and Constraints
  - Cost/benefit analysis has to benefit all sides
  - Export Control and ITAR regulations and restrictions
  - Institutional requirements and organizational responsibilities
  - Long lead time to establish collaboration
- IPPW – Provides an opportunity space
  - Presentations, posters, student mentoring, short courses and professional interactions
  - An opportunity for one-on-one in-depth discussions

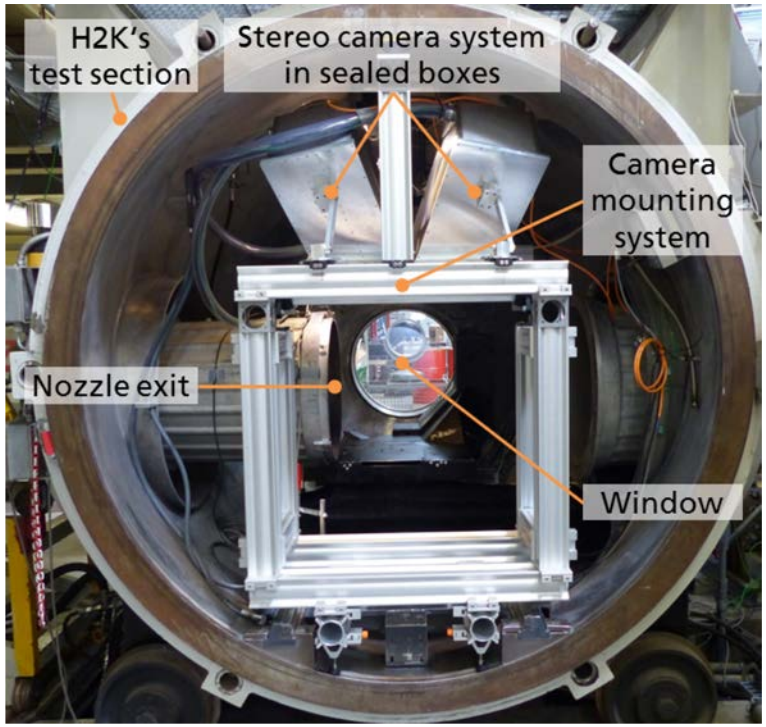
DLR Unique Capabilities

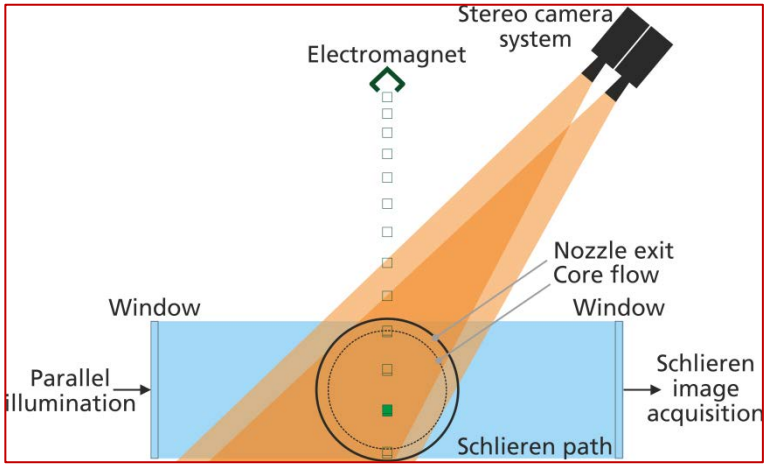
Ali Gulhan

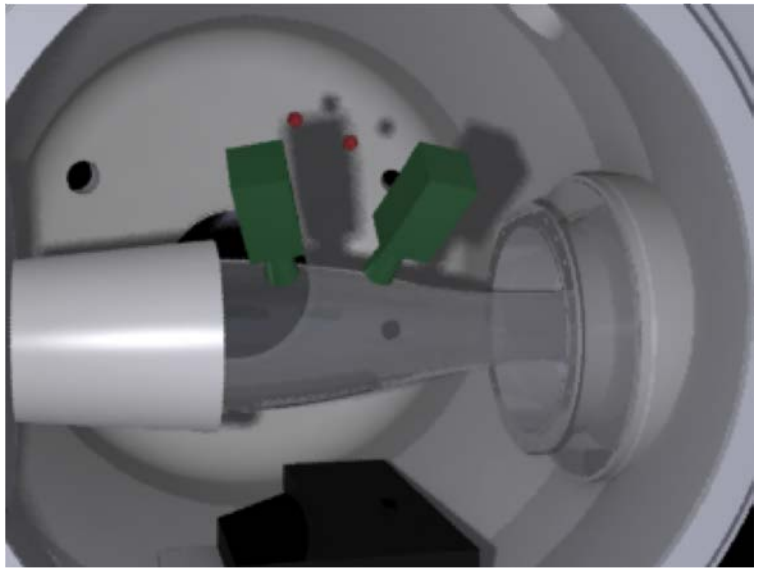
Importance of Collaboration : DLR perspective

- The DLR's supersonic and hypersonic technologies:
  - Unique testing capabilities in support of design and development
  - Instrumentation for flight and ground experiments.
- DLR's high speed test facilities in Cologne are
  - Equipped with modern diagnostics and allow gathering important data for the improvement of physical modelling and validation of numerical tools.
- DLR has limited interplanetary missions and flight expertise.
- NASA has extensive long term flight expertise and unique capability in numerical simulation.
- The complementary capabilities of both institutions are the main motivation for DLR to explore long term co-operation with NASA.

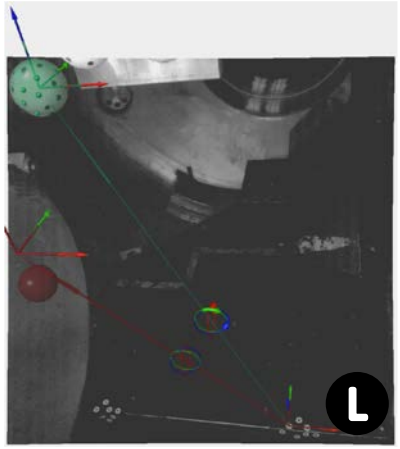
DLR Capabilities:
Experimental set-up of free flight testing in H2K

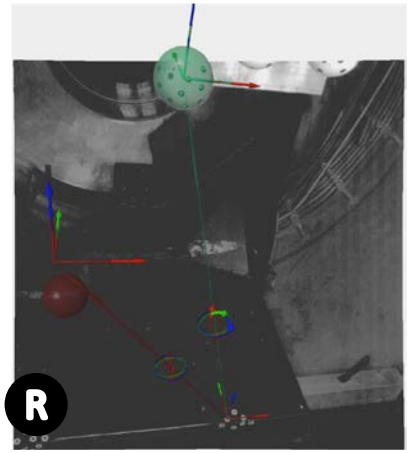


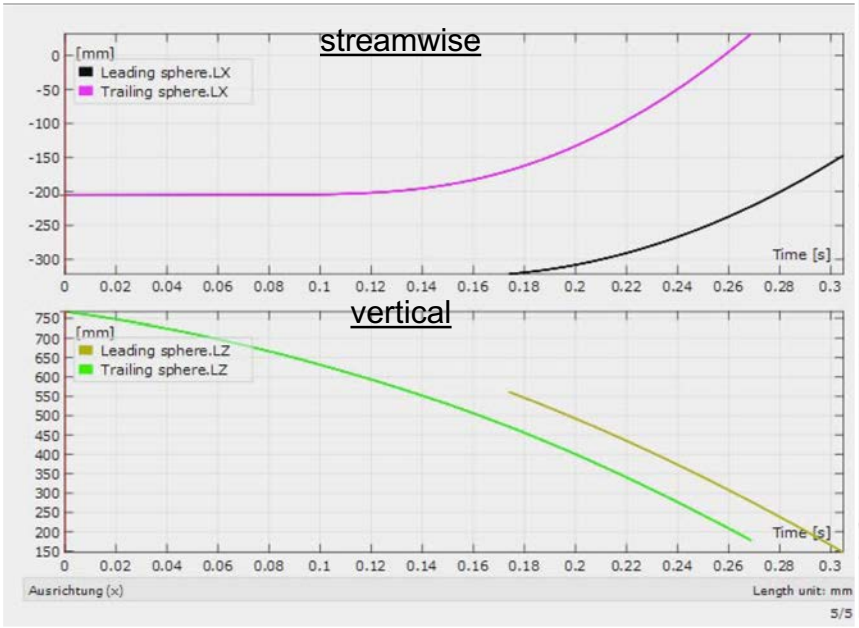


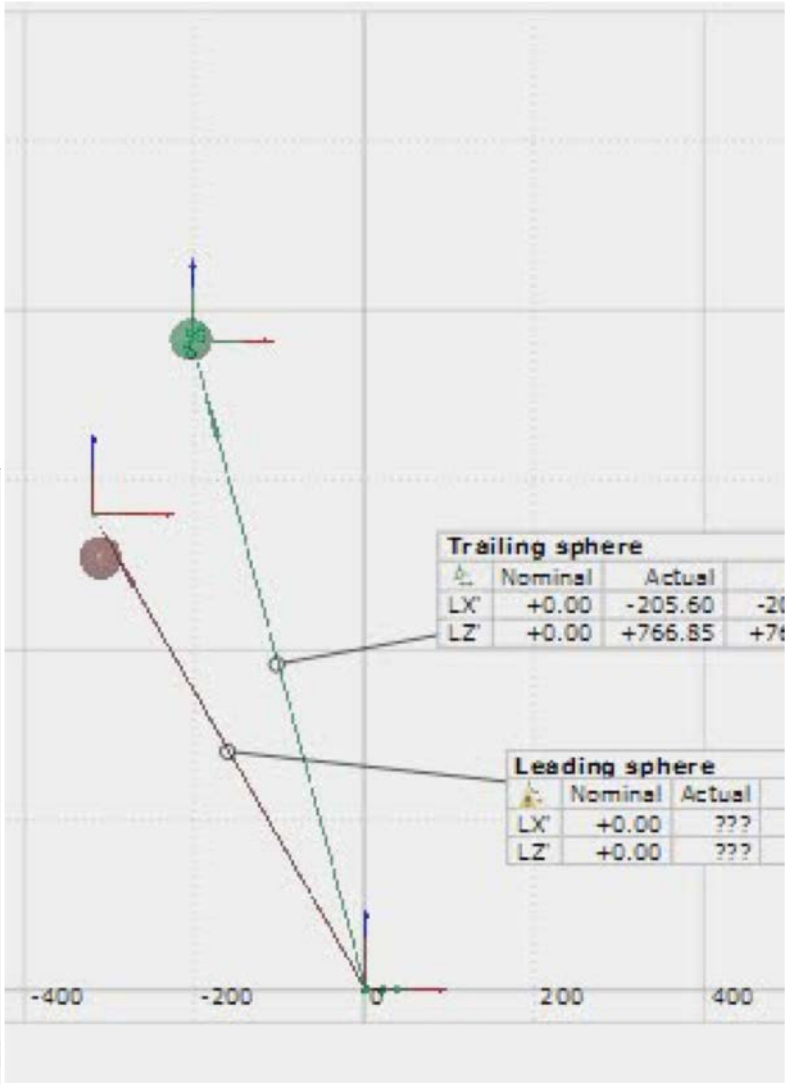


DLR Capabilities:
Stereo Tracking in H2K









DLR Capabilities - Free flight testing in H2K
Two Spheres Interaction

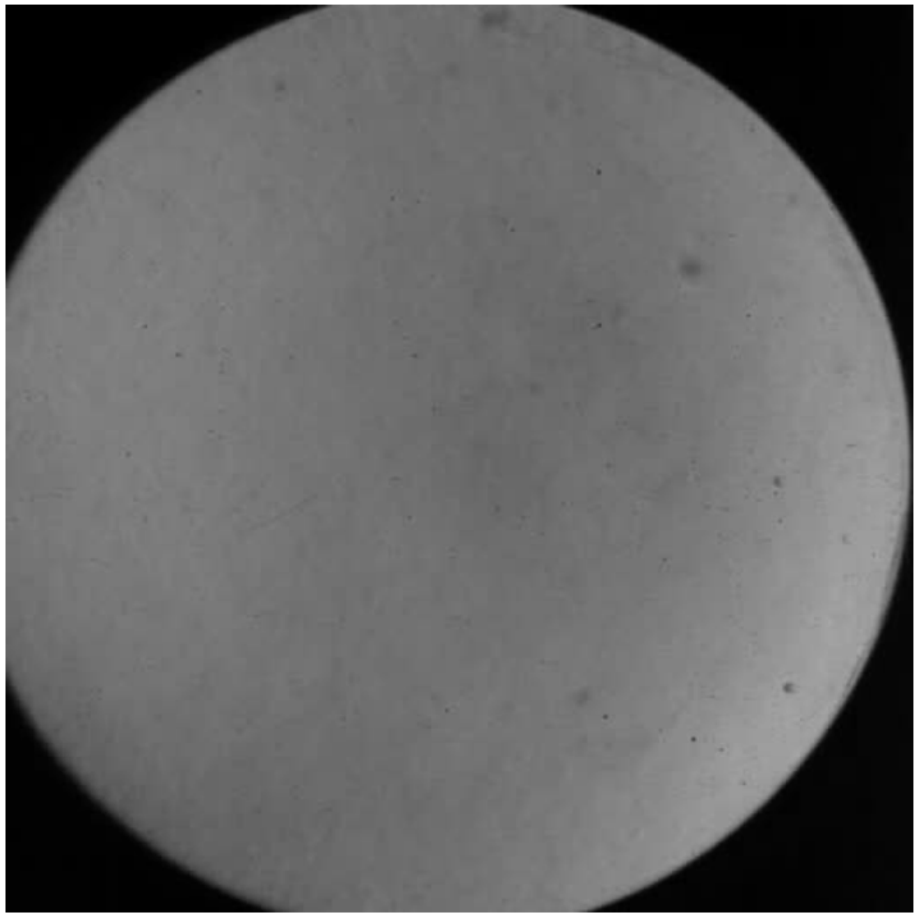
Flow Condition

$T_0 = 600\ °C$

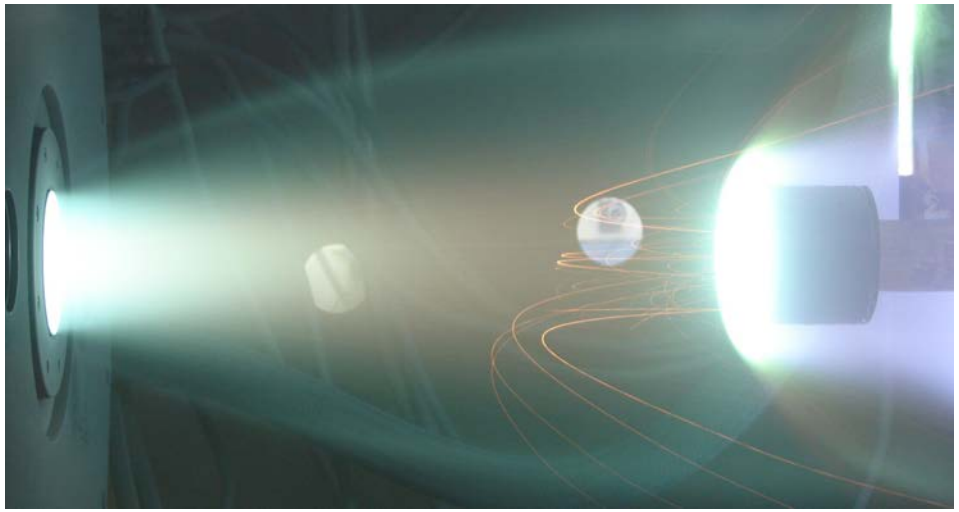
$p_0 = 5{,}2\ bar$

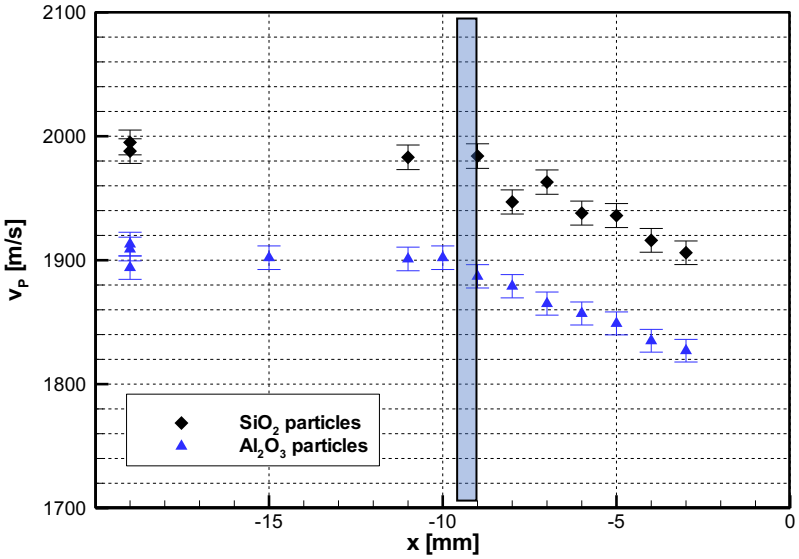
$Re = 2{,}1 \cdot 10^6\ \ 1/m$

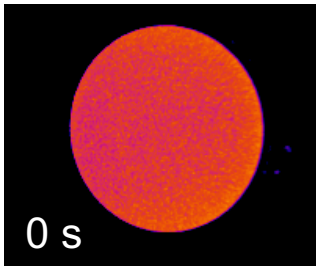
$Ma = 7{,}0$

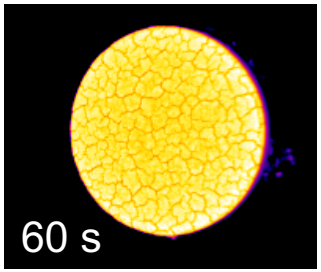


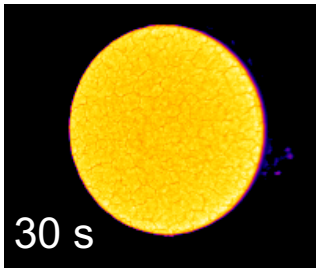
DLR Capabilities: Testing Ablative Materials in Dust-Loaded Flow and Dust Particle Characterization

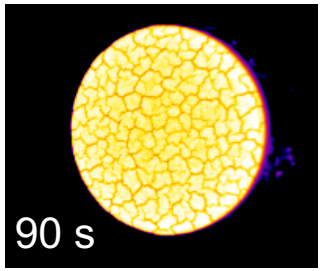






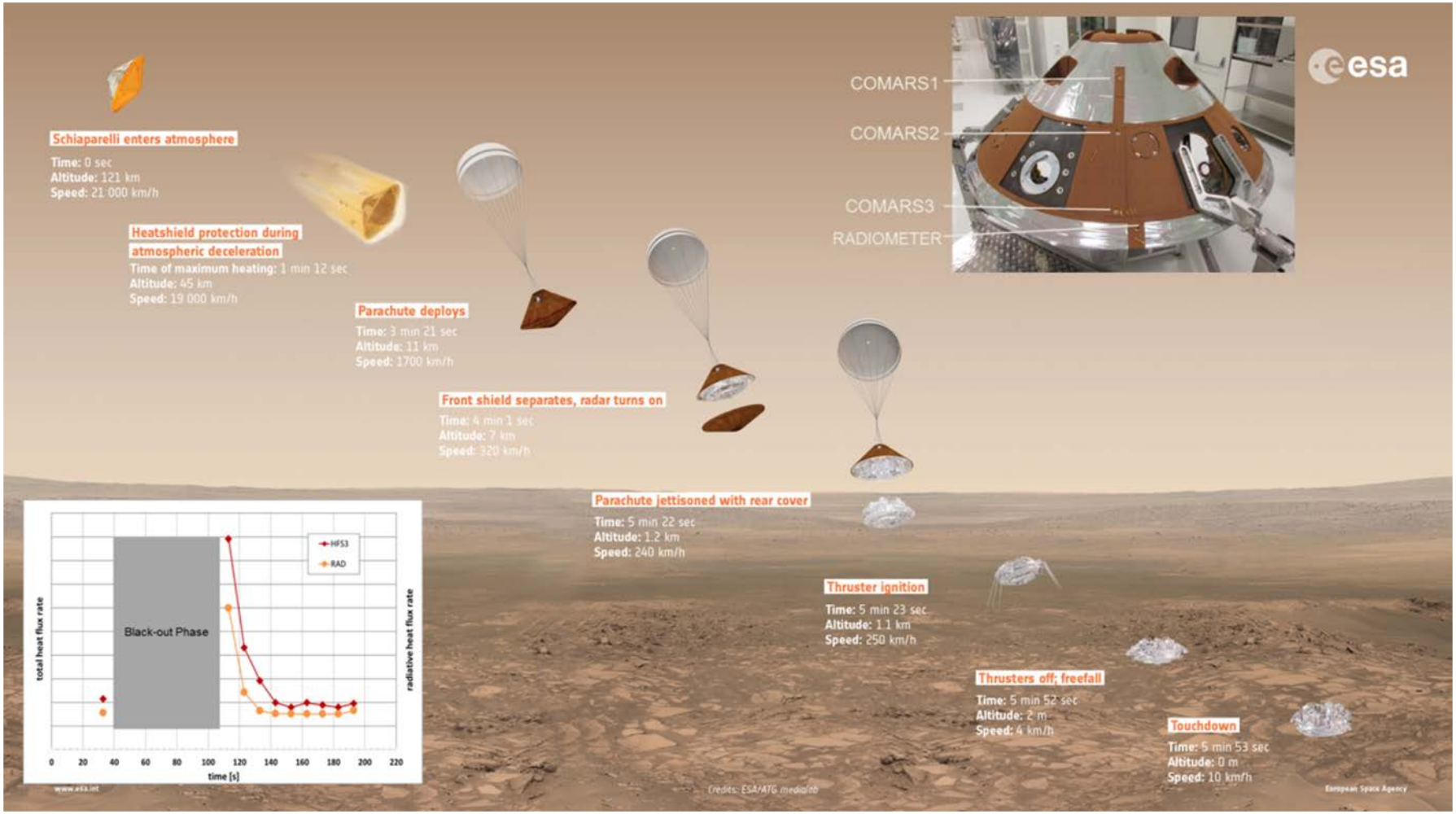






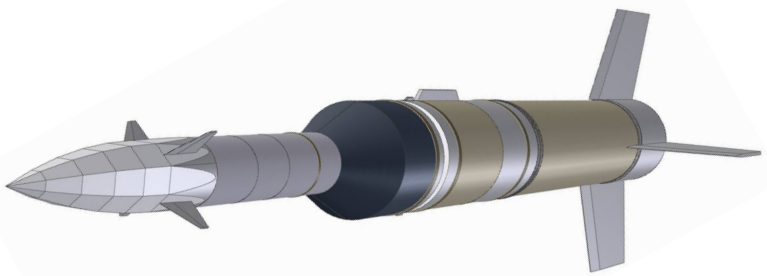
- Freestream velocity
  - 1987 m/s (SiO_2)
  - 1903 m/s (Al_2O_3)
- Deceleration depends on the particle type and size
- Shock stand-off distance: 9-10 mm

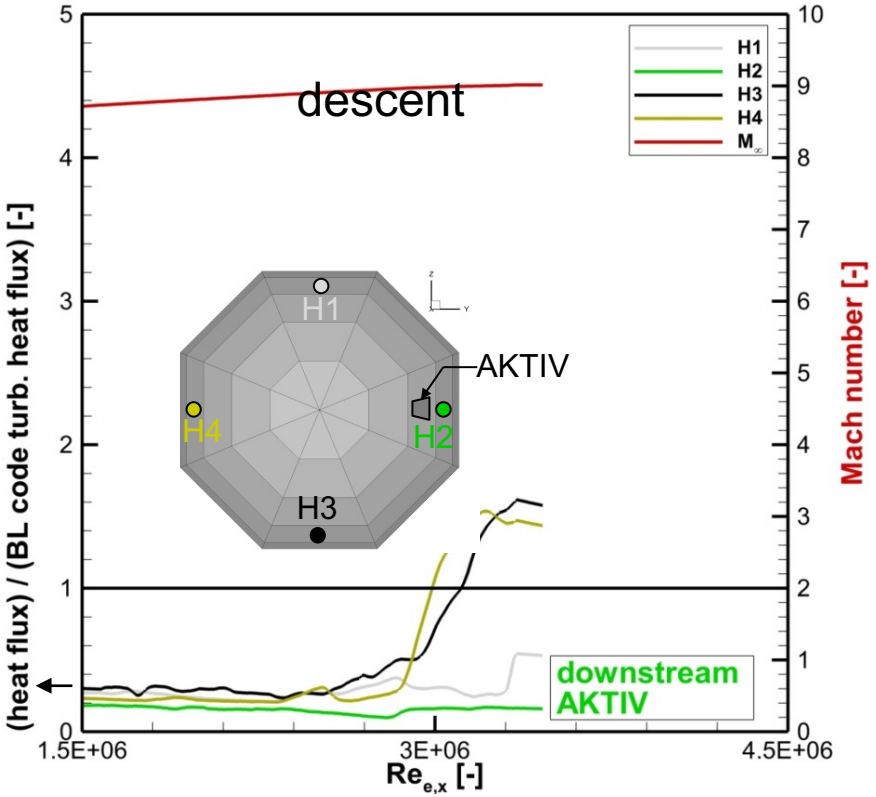
DLR Capabilities:
Flight Instrumentation



DLR Capabilities: Hypersonic Flight Experiments

- DLR has a unique capability performing hypersonic flight experiments using sounding rockets.
- Flight experiments SHEFEX-I, SHEFEX-II and ROTEX-T provided very useful data on TPS and aerothermal heating.
- Coming flight experiments ATEK (2018) and REFEX (2021) will create complementary flight data.

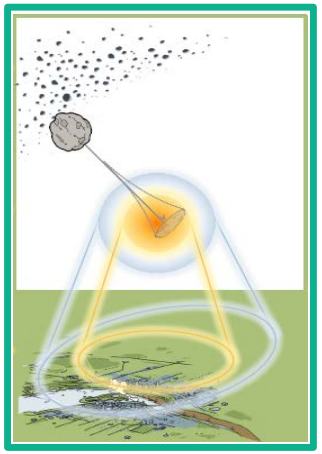




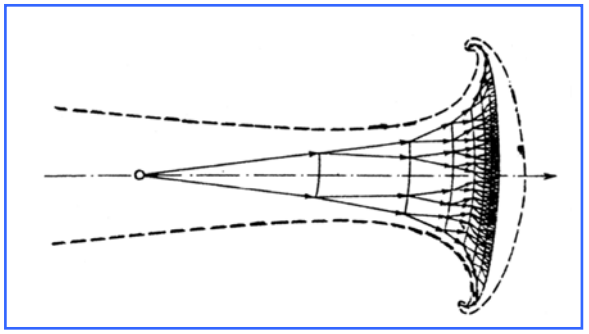
NASA Needs and Collaborations

Ethiraj Venkatapathy

Asteroid Break-up Modeling



Visualization of fragmenting asteroid

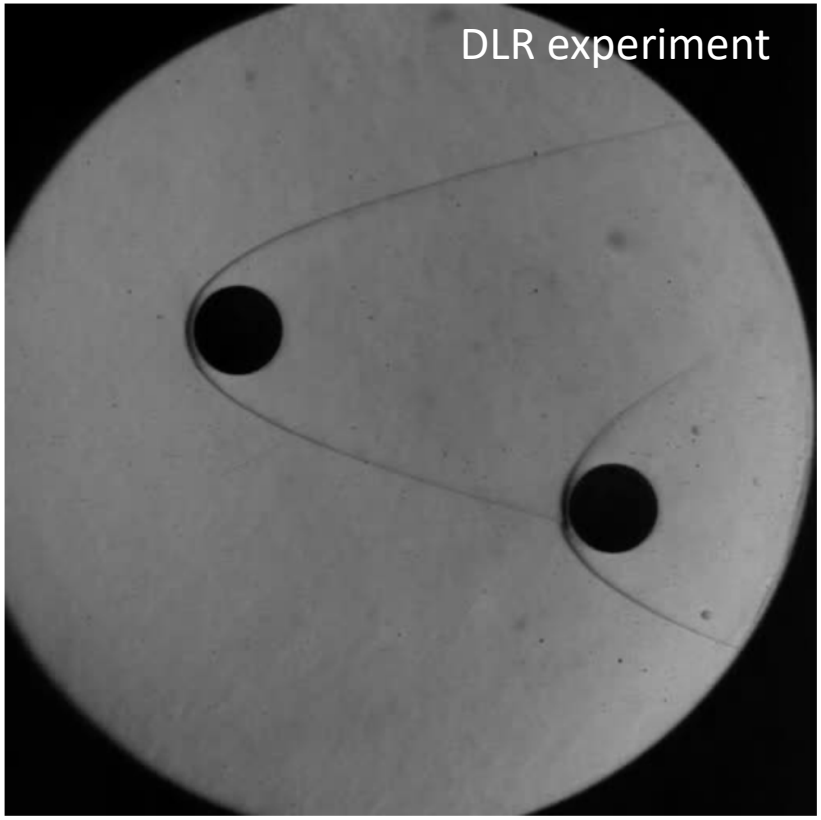


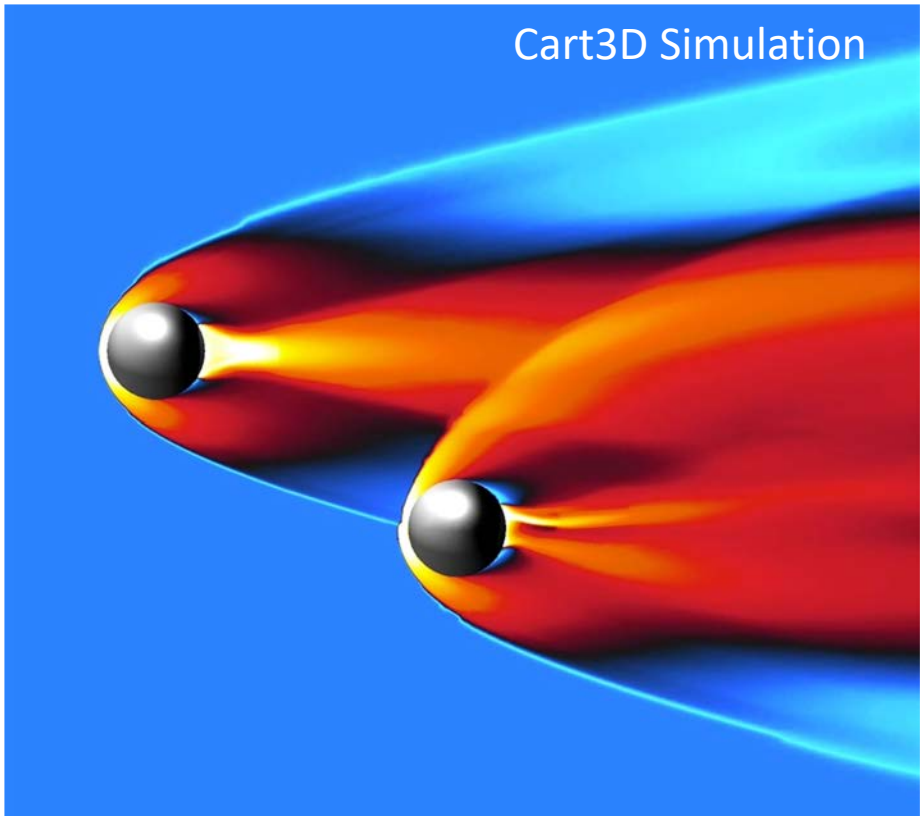
Analytical model for asteroid fragmentation and break-up

- Fragmentation, and subsequent dispersal of the fragments, results in rapid deposition of energy in the atmosphere. This, in turn given rise the to the "airburst" blast-wave which poses a danger to human populations
- Analytical risk assessment tools capture this phenomenon by modeling the **spread rate** of the fragments after a fragmentation event

Leveraging collaboration between DLR's unique experimental facilities, and NASA's simulation capability is enabling for development of better predictive models for asteroid entry and break-up

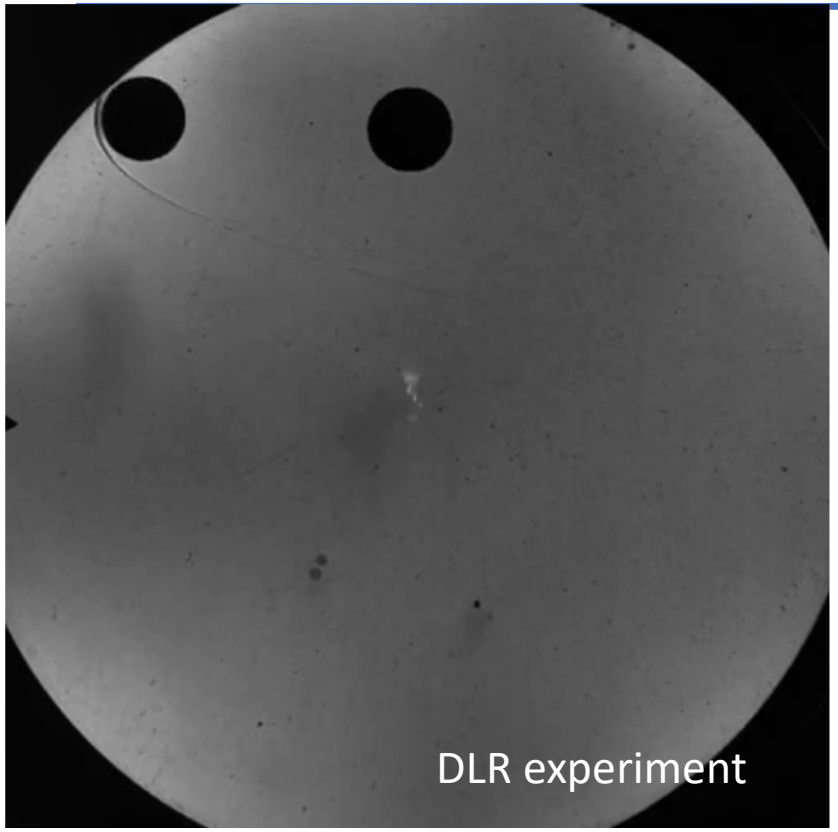
Asteroid Break-up Modeling

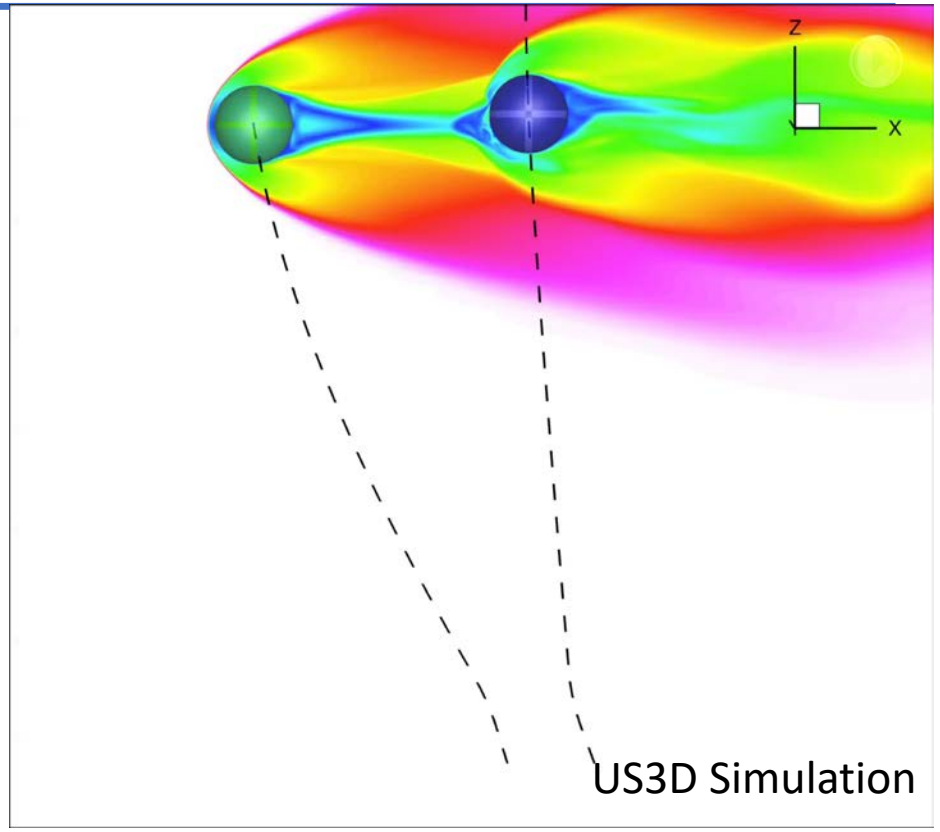




Inviscid flow solver Cart3D has been shown able to accurately predict the trajectories of two spheres in “shock surfing” configurations

Asteroid Break-up Modeling



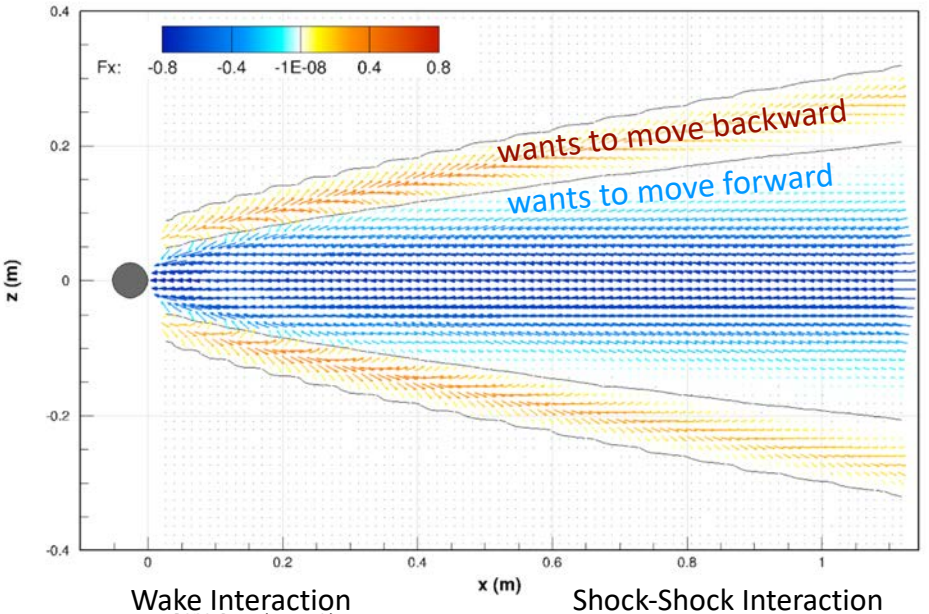


Simulations of two-sphere experiments performed by DLR have shown that a Navier-Stokes solver is required to accurately predict trajectories when trailing body is in the wake of the leading body

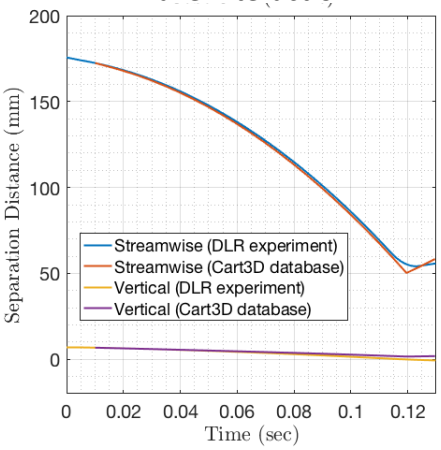
Toward a New Model for Asteroid Break-up...

- ATAP is developing a fast-running database approach to fragmentation break-up modeling for asteroid risk assessments
  - Database is comprised of several thousands of Cart3D and US3D (in the wake) simulations of two sphere configurations
  - Trajectories for arbitrary configurations of spheres ("fragments") may then be integrated analytically to obtain fragment spread rates
- Comparisons between database approach and data from experiments performed at DLR show *very* good agreement for both wake interaction and shock-shock interaction cases

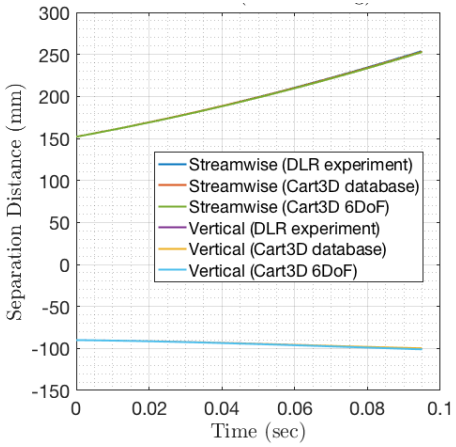
The ATAP — thanks to the synergy between the unique, high-quality experimental techniques at DLR and the state-of-the-art computation capabilities at NASA Ames — are poised to deliver a first of its kind physics-based model for asteroid energy deposition and threat assessment



Wake Interaction



Shock-Shock Interaction



Publications

- Venkatapathy, E., Gülhan, A., Aftosmis, M. J., Brock, J. M., Mathias, D. L., Neeb, D., et al. (2017). IN PURSUIT OF IMPROVING AIRBURST AND GROUND DAMAGE PREDICTIONS. Presented at the Planetary Defense Conference, Tokyo, Japan.

- Marwege, A., Willems, S., Gülhan, A., Aftosmis, M. J., & Stern, E. C.. Superposition method for force estimations on interacting bodies in supersonic and hypersonic flows. Journal of Spacecraft and Rockets (accepted, January 2018)

- Register, P., Stern, E., Mathias, D., Aftosmis, M., Seltner, P., Gülhan, A., "Fragment-Wake Interaction: A New Approach to Asteroid Fragmentation Modeling," Planetary and Space Science (in process)

- Seltner, P., Willems, S., Gülhan, A., Brock, J., Stern, E., "Aerodynamics of cylindrical bodies free-flying in hypersonic flow." AIAA Journal (in process)

Aeothermal-Mechanical Erosion of TPS Due to Dust

- **Martian dust storms can augment TPS recession through mechanical erosion and greater heating. Global dust storms have been observed to occur every 3-4 years.**

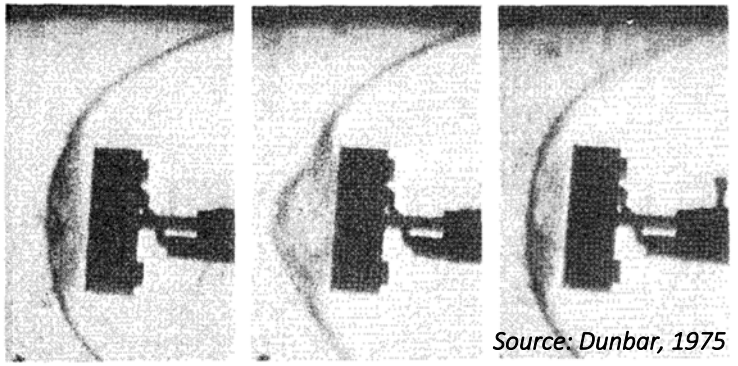
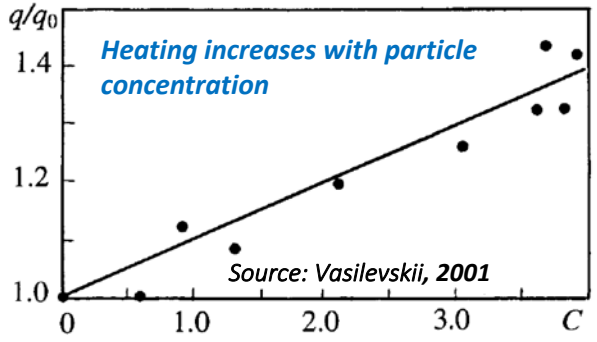
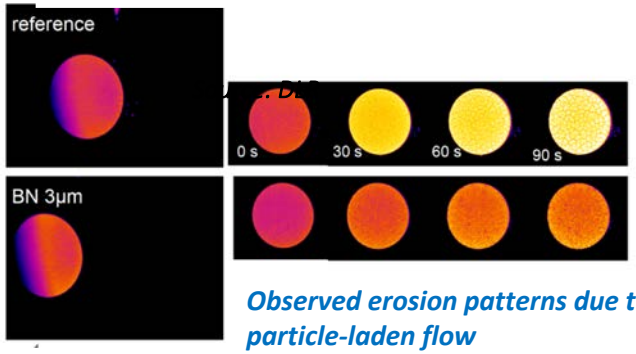


Fig. 1 Particle-induced flowfield distortion for a disk in the BHWT.

- **State of the art traces back to mid-90s studies for Mars Pathfinder**
  - Decoupled CFD-material response
  - Phenomenological models of erosion based on scant experimental data
  - Applied as recession augmentation to material response model



- **Risks carried for**
  - Mars InSight
  - ExoMars Schiaparelli



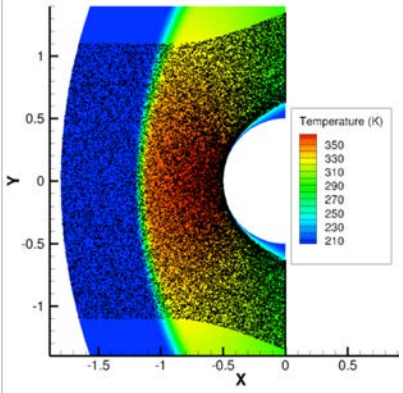
Observed erosion patterns due to particle-laden flow

NASA-DLR Implementing Arrangement:
Fundamental Studies of Combined Aerothermal-Mechanical Erosion

Scope: Perform fundamental studies on mechanical erosion of materials due to atmospheric dust at Mars during entry

Objectives:

- Design and conduct experiments to quantify the material erosion caused by particle-laden flows
- Use experimental data to develop and validate models and simulation techniques
- Disseminate data and methods to mission designers and the broader modeling community



Coupled particle-based simulation techniques under development will accurately capture multiphase transport and surface interaction. This will then be coupled to improved material response models for a complete, integrated analysis.

Dust erosion tests in DLR L2K tunnel provide fundamental data for model construction and validation.

Improvements in dusty flow modeling will address important concerns in Safety and Mission Assurance for Mars and Human Exploration Programs

Engineering Science Investigation (ESI) - NASA Missions

- NASA's is committed to obtaining EDL engineering science data and have instrumented
  - MSL, Mars 2020, Orion EFT1 and EM1 missions
- DLR has flight qualified sensors
  - COMARS Sensors on ESA's Schiaparelli EDM aeroshell.
- NASA and DLR proposed COMARS Sensors in response to ESI requirements on four NF-4 proposals.
- COMARS Sensor is currently part of the Dragonfly Phase-A Study
  - Dragonfly is a cool mission. If you have not heard about Dragonfly, Tuesday you will hear about it.
- If Dragonfly is selected, NASA and DLR is likely to collaborate on instrumenting the TPS with COMARS derived Sensors suitable for Titan.

Heat-shield for Extreme Entry Environment Technology: ESA-NASA Potential Collaboration and Common Probe

- Heat-shield for Extreme Entry Environment Technology
  - NASA effort to enable Venus, High-speed Sample Return Missions, and Saturn, Uranus and Neptune Probe Missions
  - Efficient, robust and will be ready at TRL 6 (D. Ellerby's presentation on Tuesday)
- Hera, Saturn Probe mission proposal to ESA-M5 call
  - Proposed by jointly European and US Space Science community
  - NASA as potential partner, if selected and supported by NASA
    - NASA to provide Aeroshell with HEEET.
  - Hera was a strong candidate but not selected in 2nd step.
- Ice-Giant Probes
  - Science community is advocating for NASA/ESA collaboration
    - Sending multiple probes to multiple Ice-Giant destination in the coming decades with ESA leading one probe science and NASA the other.
    - HEEET will be an enabler for both NASA and ESA missions.
- Common Probe Study
  - Potential to Enable Collaboration (H. Hwang's presentation on Common Probe and Gary Allen's poster)

Concluding Remarks

- Collaboration in EDL can range from
  - Fundamental physics that allows for better understanding, to
  - Mission enabling hardware elements
- Requires careful evaluation; involved processes
  - Export Control laws and regulations have to be carefully considered and assessed by the institutional processes.
  - Takes time and effort.
- International Planetary Probe Workshops - catalyst for initiating collaborations in EDL

- If you interested and need help from us, please contact us:
  - Ali and I will be available at this workshop.

Ethiraj.Venkatapathy-1@nasa.gov or Ali.Guelhan@dlr.de

Backup

Technical Data vs Technology

Dept. of State Definition under the ITAR "Technical Data"

Technical data is information that is required for the design, development, production, manufacture, assembly, operation, repair, testing, maintenance or modification of an export-controlled item.

Dept. of Commerce Definition under the EAR "Technology"

Technology refers to specific information necessary for the "development," "production," or "use" of a product. The information takes the form of "technical data" or "technical assistance."

Definitions: Publicly Available Information & Fundamental Research

- *Publicly Available Information*: Information that is published or will be published and can include the results of fundamental research, educational info, or patent information (e.g. general system descriptions, marketing materials)
- *Fundamental Research:* Basic & applied research in science and engineering where the resulting info is ordinarily published and shared broadly within the scientific community
- **"Publicly available information" and "fundamental research" are NOT subject to export controls**
- Center Export Administrator (CEA) will make the determination on fundamental research and public information

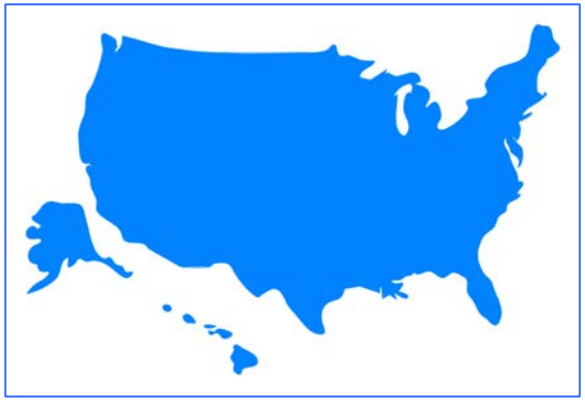
DLR Capabilities Available for future collaboration

- Upgraded combined aerothermal sensors for high surface temperatures above 1000 K.
- Qualification of of the sensor package for different atmospheric conditions like Mars, Titan and Earth.
- Simultaneous velocity and shape measurements of dust particles in hypersonic Martian flow of the arc heated facility L2K.
- Improvement of accuracy of aerodynamic coefficients of three body free flight configuration.
- Creation an experimental link between demise test results and flight trajectory prediction of spacecraft fragments.

Export Control: International and National Concern & Response

- *Export Controls are guided by the United Nations Resolution 1540 to prevent the proliferation of weapons, in particular WMD or the means of their delivery. Those last few words are particularly important here at NASA:* ***"the means of their delivery."*** *This concern is specifically addressing rocket technologies. With the UN's mandate and guidance, each nation has developed their own series of rules and regulations to control the flow of their exports.*

- The U.S. has enacted specific laws and regulations to ensure that all entities within our jurisdiction comply with export control
- NASA must abide by U.S. export control laws and regulations
  - Individuals can be indicted for violations, whether these are caused by willfulness or ignorance
  - The penalty for violation can be very severe



What is an "Export"? What are Export Controls?

- An "export" is the transfer, or transmission of anything to a foreign person or a foreign destination by any means, anywhere, anytime
  - An export can involve a commodity, software, technical data, technology, and/or providing a defense service
- **Export controls are not intended to restrict legitimate trade**
- Military defense articles and services are controlled by State Department under the auspices of the International Traffic in Arms Regulations (ITAR)
- Commercial items with "Dual Use" and Less-Sensitive Military capability are controlled by the Department of Commerce according to the Export Administration Regulations (EAR)
- **Local Export Administrator and Export Control Staff are there to help**