Advancements in demise testing at VKI: Sub- and supersonic experiments and simulations of COPVs, titanium, and glass – a preview

5th International Space Debris Re-entry Workshop

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Cenaero: P. Schrooyen

Technical Officer: L. Walpot (ESA)

02 December 2020

von Karman Institute for Fluid Dynamics

Cenaero

Background GSTP
Validation of Space Debris Demise Tools using Plasma Wind Tunnel Testing and Numerical Tools

ESA GSTP Contract 4000125437/18/NL/RA
Technical Officer: L. Walpot

VKI: High-enthalpy experiments of problematic space debris materials: PLASMATRON
Cenaero: High-fidelity models and numerical simulations: ARGO

Virgili 2017

Many objects have recently demonstrated their non-demisability, posing a **problem for D4D applicability**.

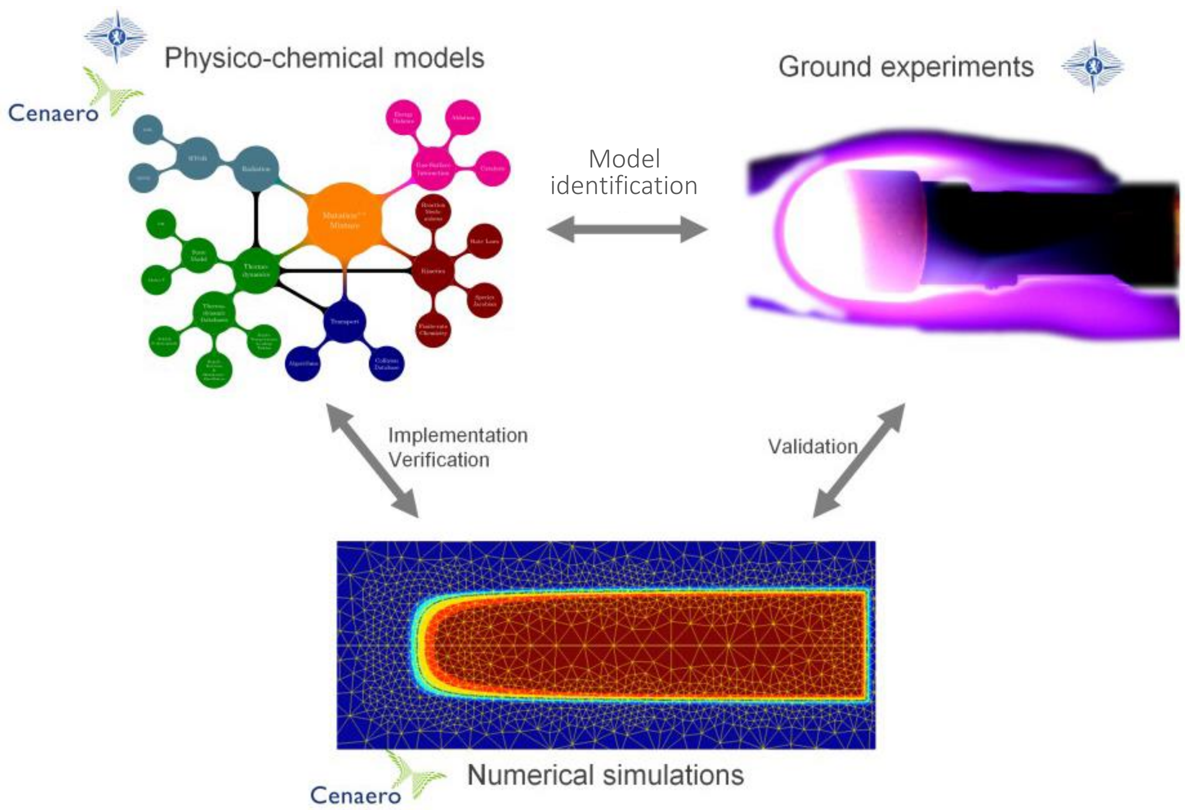
Most problematic are:

- COPV – carbon + epoxy (→ TPS!), titanium (Ti4Al6V)
- Optical payloads – silicates (ZERODUR)

Background GSTP
Validation of Space Debris Demise Tools using Plasma Wind Tunnel Testing and Numerical Tools

Objectives:

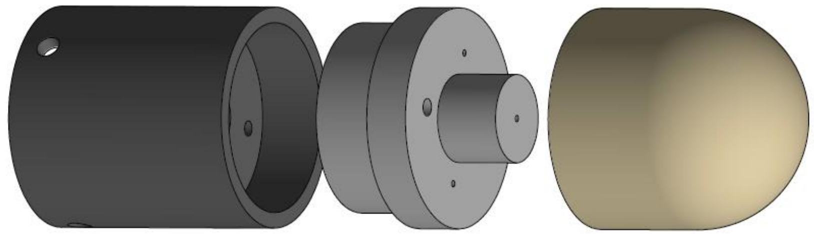
→ strengthening our understanding of demise phenomena
→ produce engineering correlations from high-fidelity simulations



→ engineering correlations for ground casualty risk prediction

Extensive sub- and supersonic experiments

Glass / ZERODUR®
Sub-supersonic stag. pt.



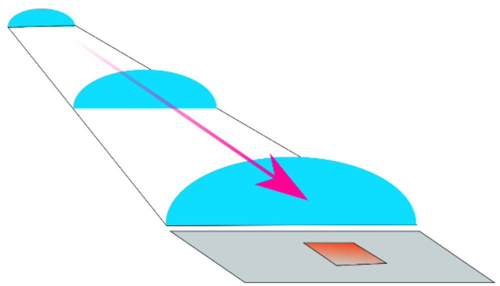
Titanium grade-2 and 5
Sub-supersonic stag. pt.

Composite Overwrapped Pressure Vessels
supersonic

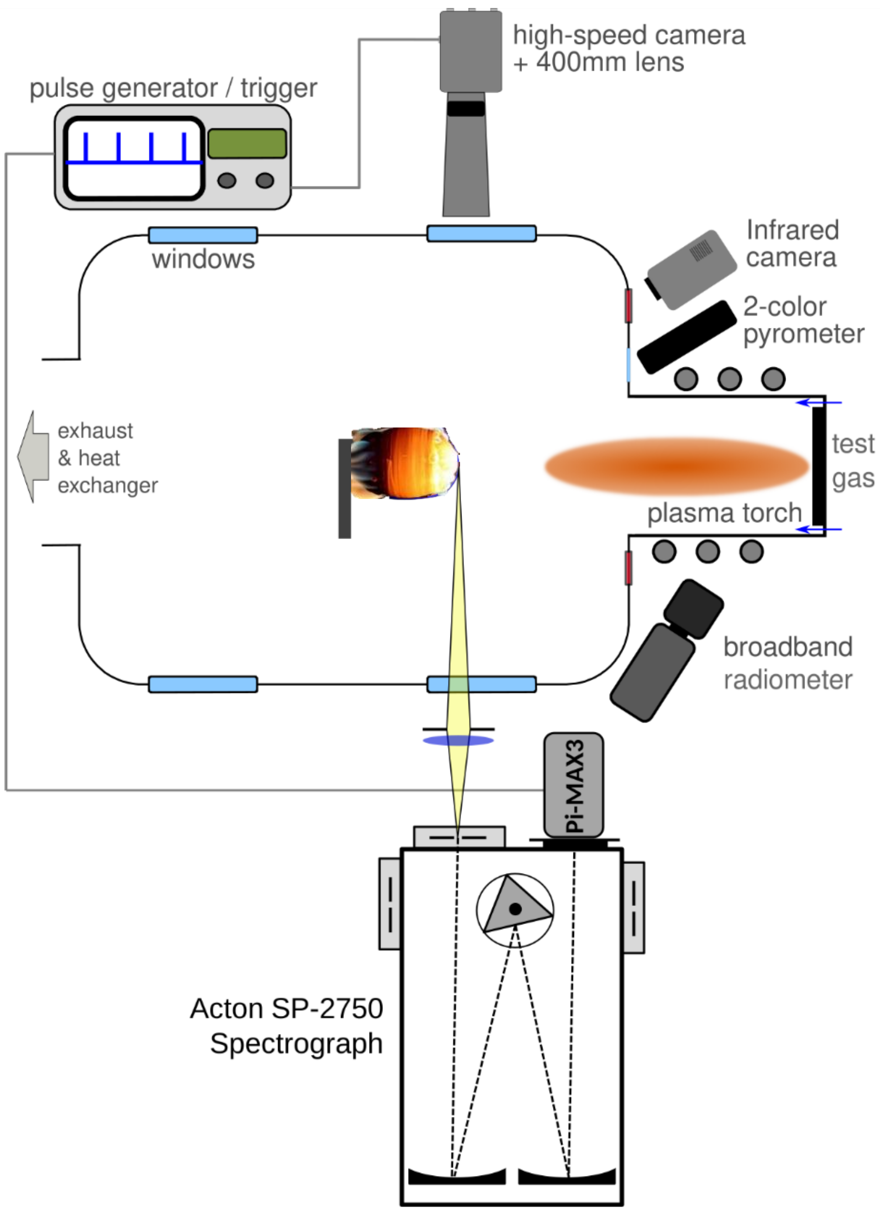
sideways

stagnation point

Glass/Ti/CFRP flat plate testing
supersonic



First experiments on quartz and titanium



FLIR A6750sc MWIR (3-5µm)
250 – 3000°C calibrated (FLIR)

2-colour pyrometer MRS1B & C (0.75-1.1µm)
1000 – 3000°C calibrated (NPL London)

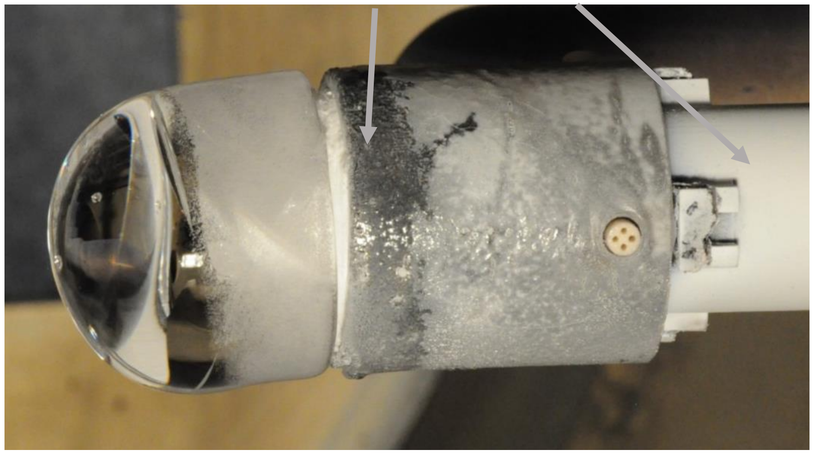
Broadband radiometer KT19 HEITRONICS (0.65-39µm)
RT – 3000°C calibrated (NPL London)

Type-K thermocouples
(Nickel-Chromium/Nickel-Alumel)
RT – 1260°C

Quartz in air plasma 200s

100 hPa, 2.6 MW/m^2

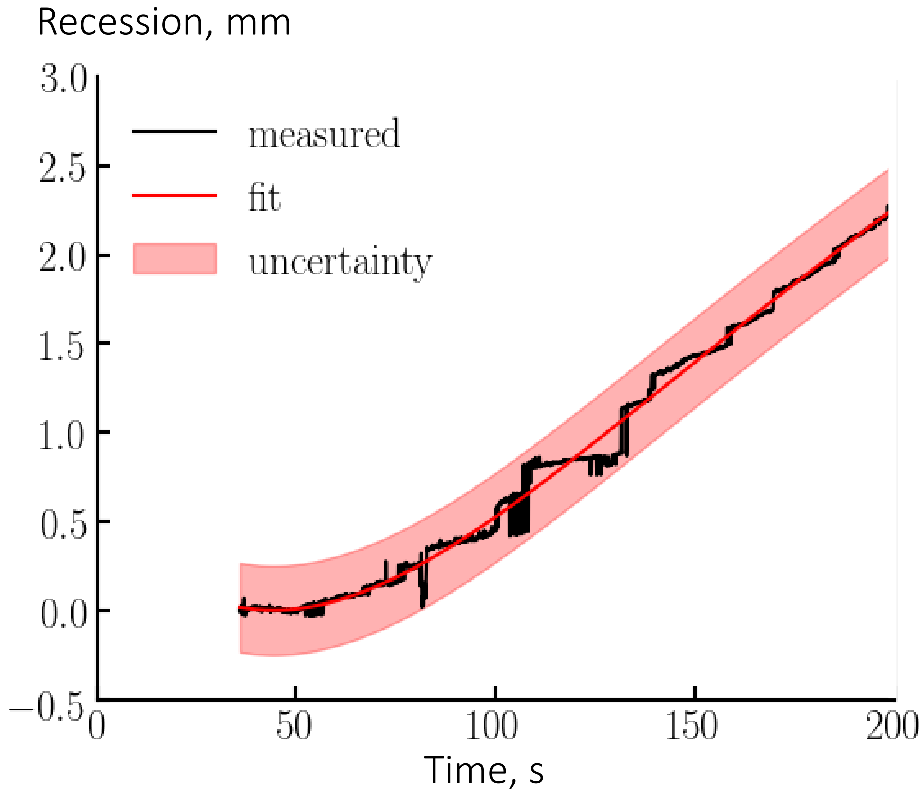
ablated material condensed
on graphite and brass support



Natural quartz glass -class 2

OH-Content 150 ppm

Impurity Content 20-40 ppm



RESULTS

- significant ablation
- symmetry respected
- increased HF possible
- (exploit low thermal conductivity)
- ~2.5 mm recession during ~200 s
- bent after ~215s

Quartz surface pyrometry: Problems with transmissivity

100 hPa, 2.6 MW/m^2

Pyrometer (0.75-1.1 µm)

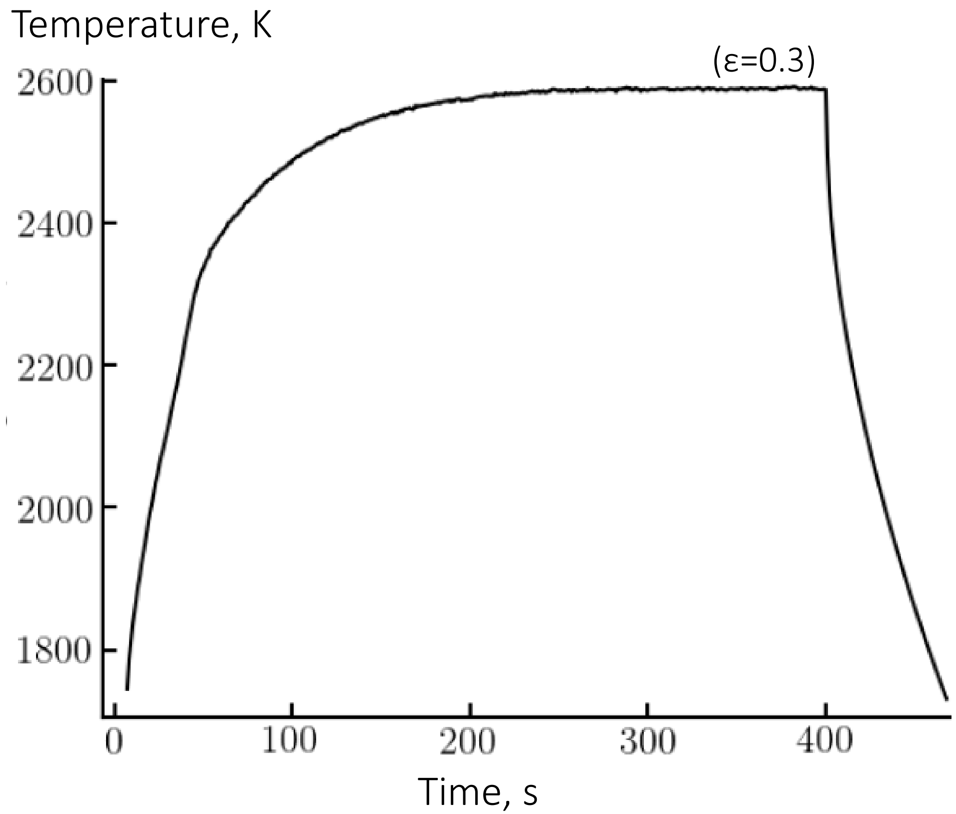
- T2C reading only in the cool down phase
- transmissivity issue to be addressed
- T1C reading ok (not displayed)
- transmissivity issue to be addressed

Radiometer (0.65-39 µm)

reading ok

Can we get total emissivity if we knew surface temperature?

Correcting for ε=0.3 [1] provides T_w≈2600K

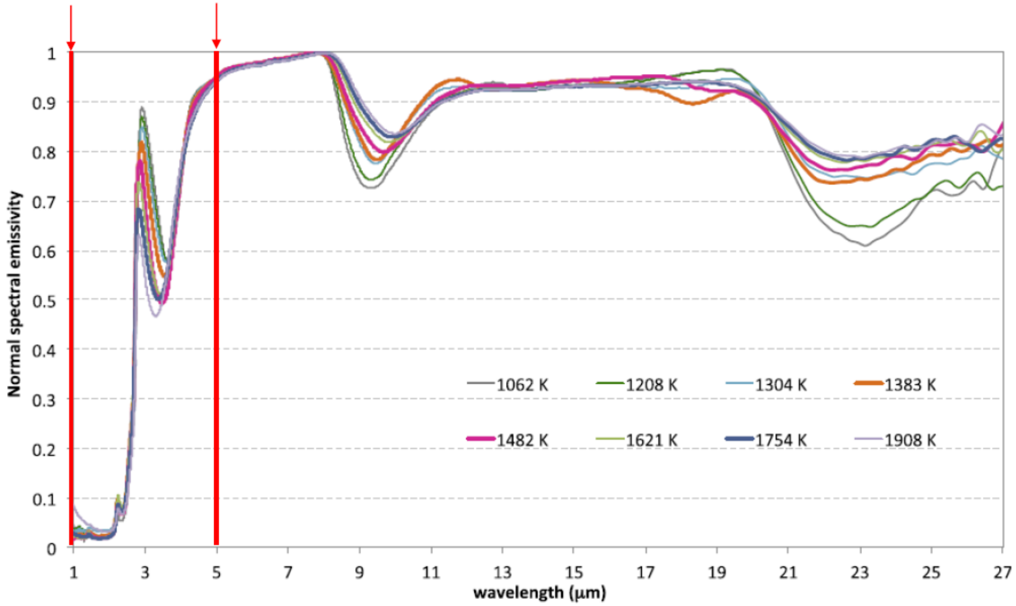


[1] Chen, Y. K., Stern, E. C., and Agrawal, P. JSR, 56:3, 2019 (865–874)

Quartz surface pyrometry: Problems with transmissivity

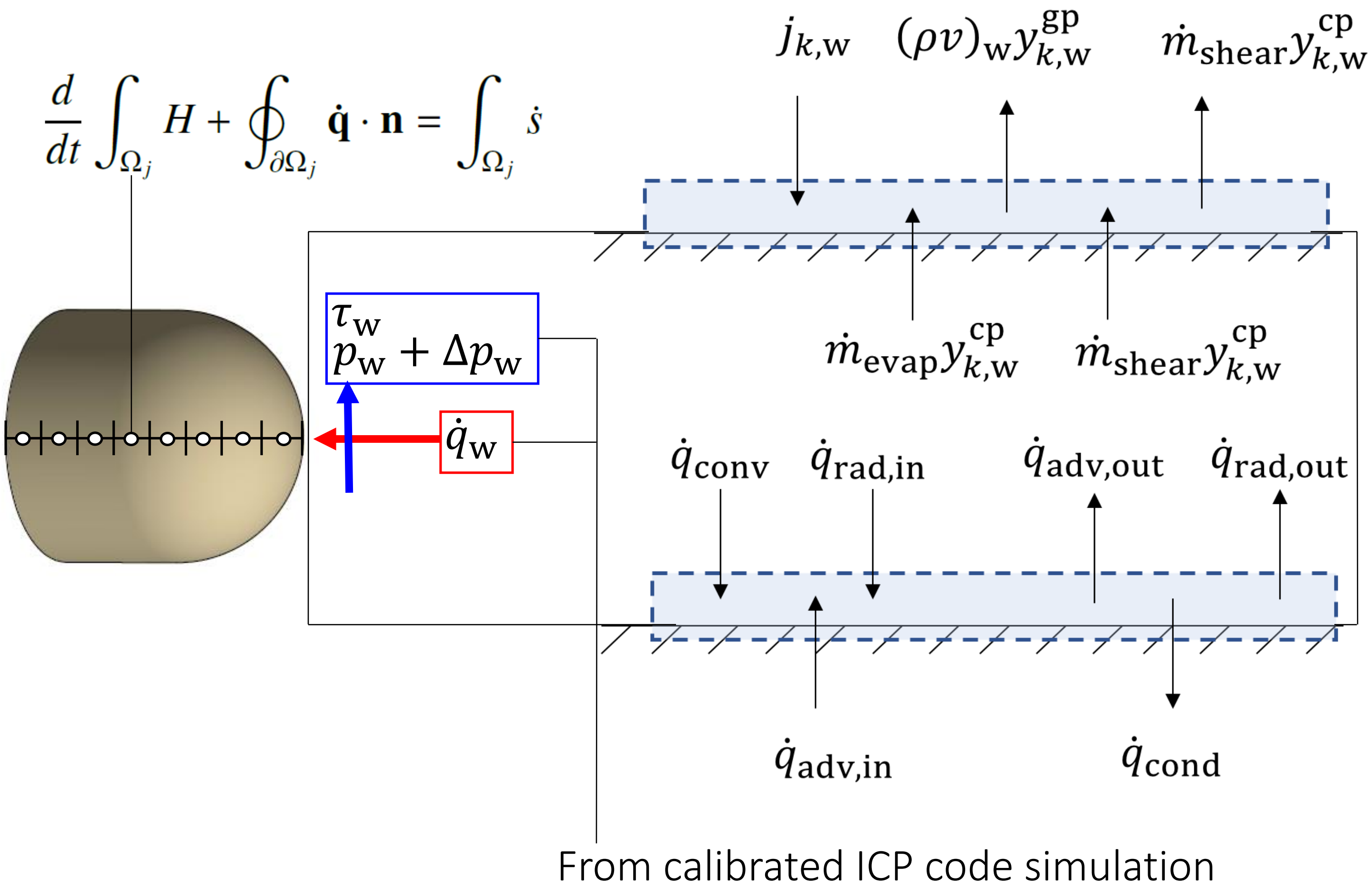
New glass pyrometer:
- OptrisCTlaserG5
- spectral range 5µm

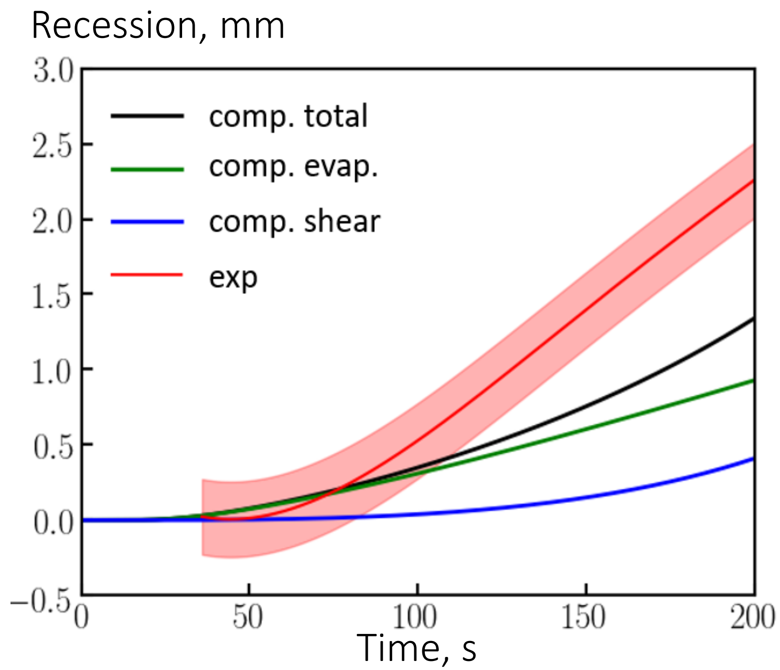
to be calibrated at VKI
emissivity required, e.g., from [2]



[2] Balat-Pichelin, M., De Sousa Meneses, D., and Annaloro, J. *Infrared Phys. Technol.*, 101, 2019 (68–77)

Preliminary quartz response simulations at VKI

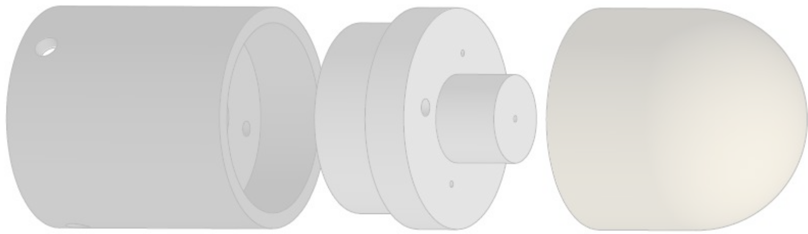




*Fagnani A., Dias B. et al. Ablation Workshop 2019
AVIATION 2021 (submitted)

Extensive sub- and supersonic experiments

Glass / ZERODUR®
Sub-supersonic stag. pt.



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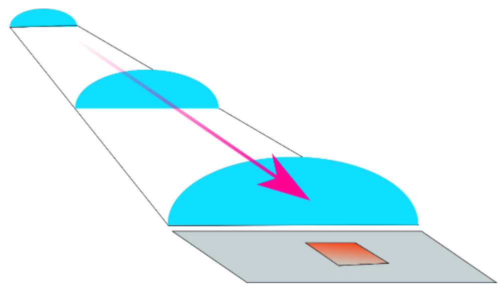
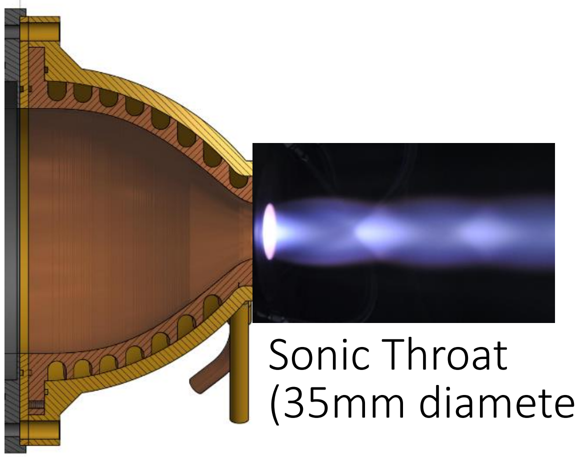


Design of conical and semi-elliptical nozzles

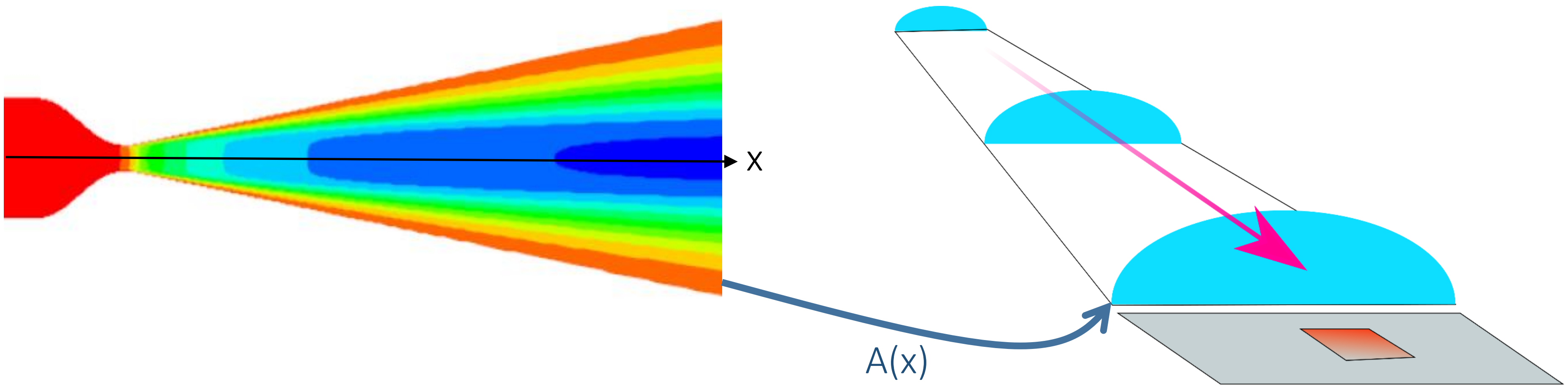
Aerothermal and aeromechanical testing

Start from existing design



Sonic Throat
(35mm diameter)

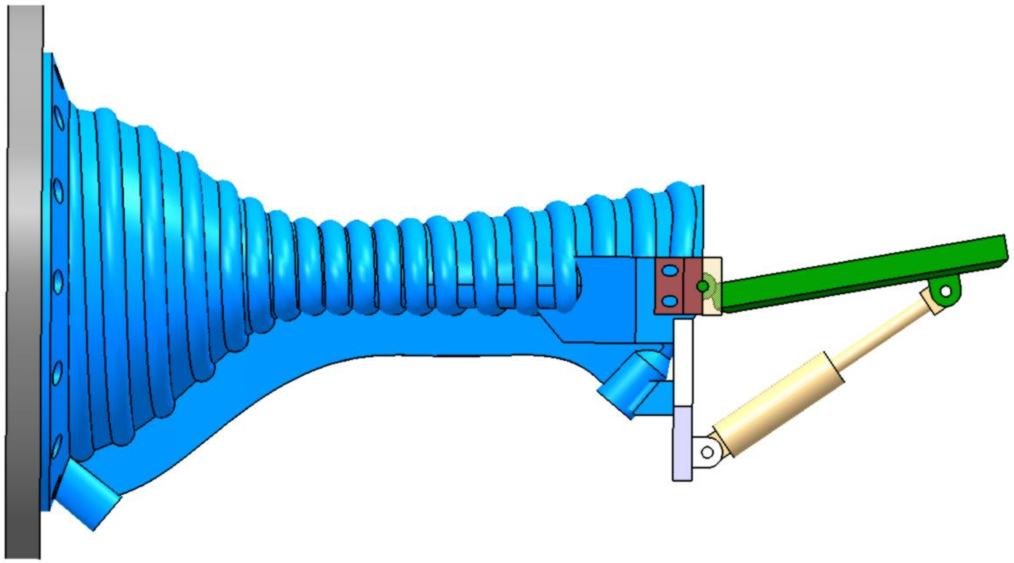
Conical nozzle **Semi-elliptical nozzle**

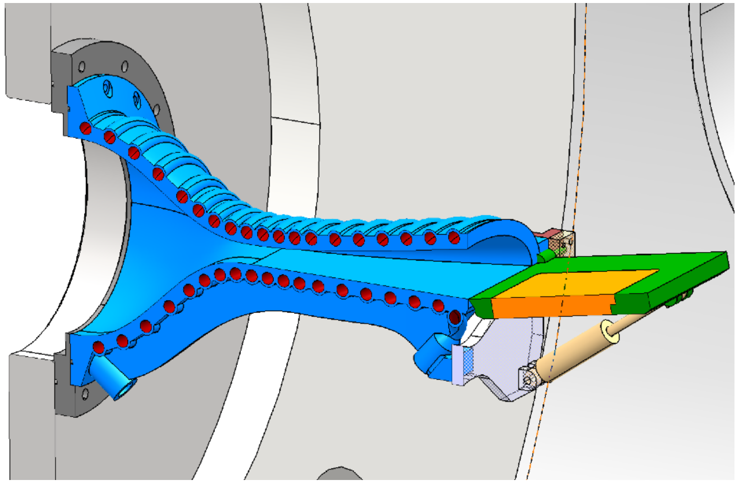


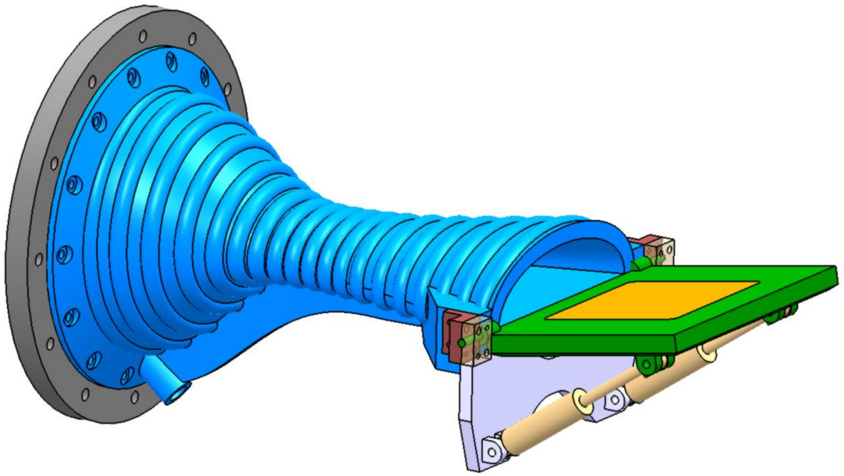
Same Mach and Pressure ratio

Design of conical and semi-elliptical nozzles

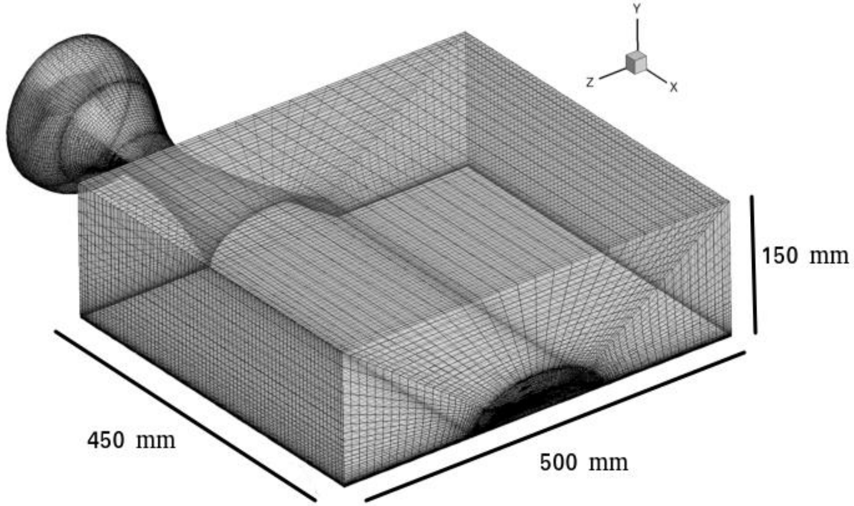
Aerothermal and aeromechanical testing

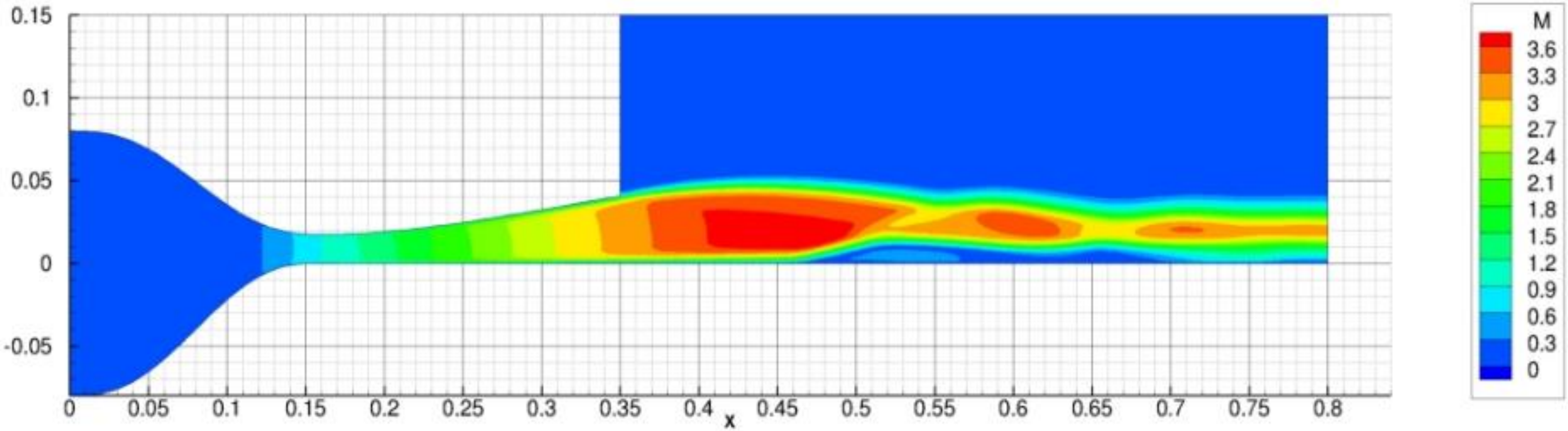






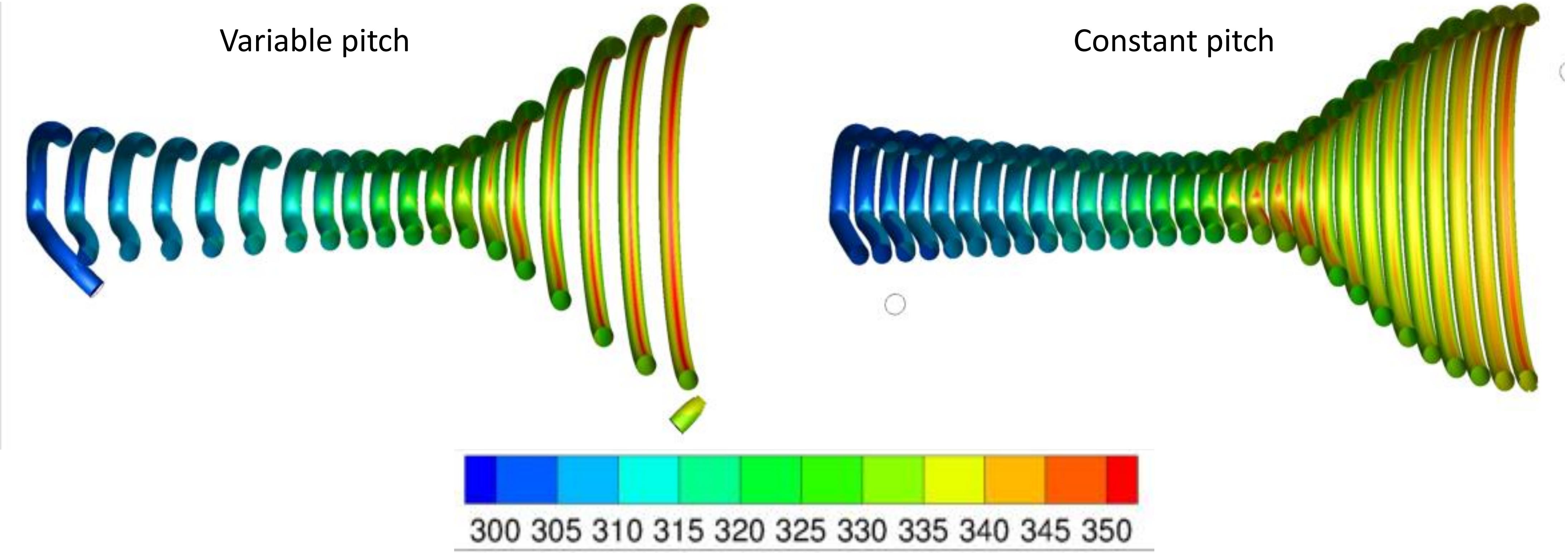
CFD flow field characterization (*CFD++*)





Design of conical and semi-elliptical nozzles

weight and p_{loss} reduction without compromising overall cooling



Design of conical and semi-elliptical nozzles

1:1 section pre-print, cut open

Material: AlSi10Mg

Summary and outlook

Subsonic experiments on quartz, ZERODUR®, Titanium ongoing (finalization early 2021)

→ high-fidelity modelling of subsonic experiments by ARGO (Titanium)

→ 1D-modelling of subsonic experiments by VKI (quartz)

Semi-elliptical nozzle in manufacturing

→ first tests and characterization during spring 2021

→ followed by design of conical nozzle

Supersonic experiments (semi-elliptical and conical)

→ after nozzle characterization

Cenaero's ARGO platform extended

→ to treat supersonic flow

→ models to treat melting of metallic materials

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