5th International Space Debris Reentry Workshop

Impact of new aerothermodynamics and oxidation modelling on object-oriented codes

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CONTEXT

- **The French Space Operation Act enforces the assessment of prospective risks**
  - LEO satellites need to be removed by re-entering the Earth's atmosphere

- **DEBRISK: French certification tool**
  - Based on an object-oriented approach
  - Since 2015, CNES is working on reducing uncertainties in the physical models

UNCERTAINTIES

Example of Uncertainties	Impact of the survivability with new models
Aerothermodynamics (drag + heat flux)	↑
Oxidation (especially the emissivity)	↑
Break-up	↓
Wake effect	Moderate ↕
Initial wall temperature	Moderate ↓
Random-tumbling assumption	It depends ↕
Low speed drag coefficient	It depends ↕

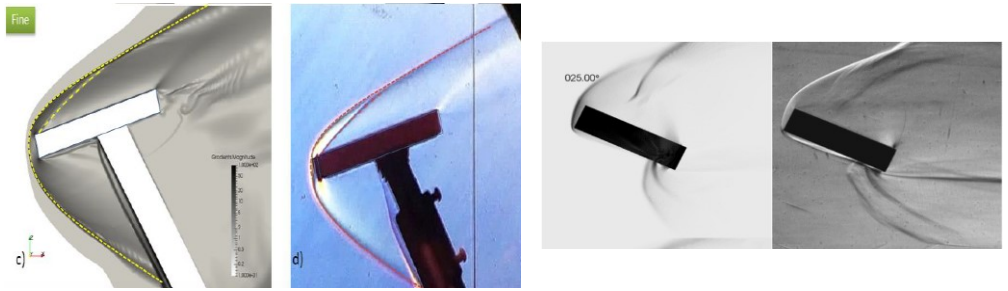
	Aerothermodynamics + Oxidation	
Mass	Old models	New models
200 kg	9 m²	26 m²
600 kg	10 m²	30 m²

The survivability of debris increases with the new aerothermodynamics and oxidation models

AEROTHERMODYNAMICS: KLETT'S METHODOLOGY*

- Methodology extremely valuable from the 60's until today
- Applied for cylinders, generalized by others authors to be applicable to other objects
- Implemented in most certification software such as ORSAT, DRAMA, DEBRISK

- Large CFD/DSMC database built since 2015
- Validated through experimental tests
- Comparisons with the Klett's methodology performed



	Spheres	Cylinders	Boxes	Flat plates
Heat Flux	[-22% -17%]	[-23% -15%]	[-34% -29%]	[-8% -4%]
Drag Coefficient	[-2% +1%]	[+7% +28%]	[-5% +28%]	[+28% +33%]

With new models
Decrease of the heat flux
Increase of the drag coefficient

* "Drag Coefficients and Heating Ratios For Right Circular Cylinders In Free-Molecular and Continuum Flow From Mach 10 To 30."

DRAG COEFFICIENT

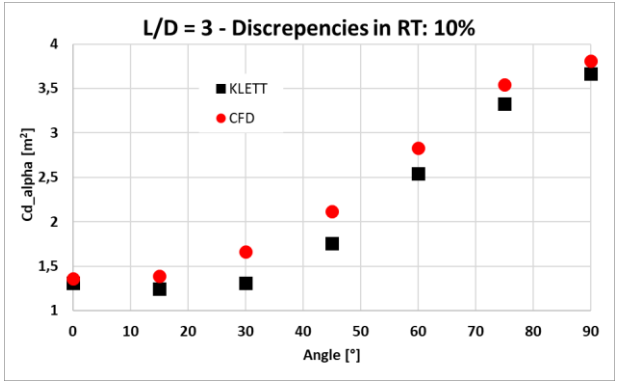
Klett's method

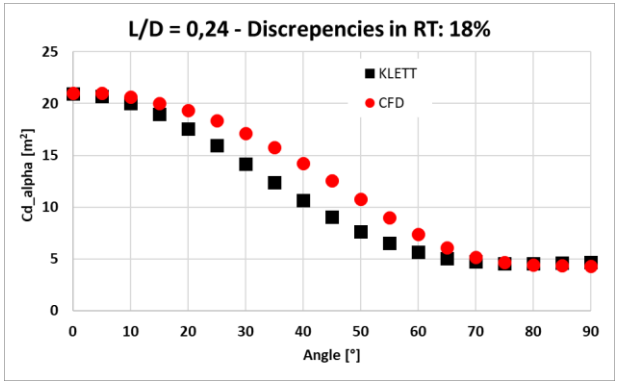
$$C_{D_\alpha} = C_D^{Broadside} \sin^3 \alpha + C_D^{EndOn} \cos^3 \alpha$$

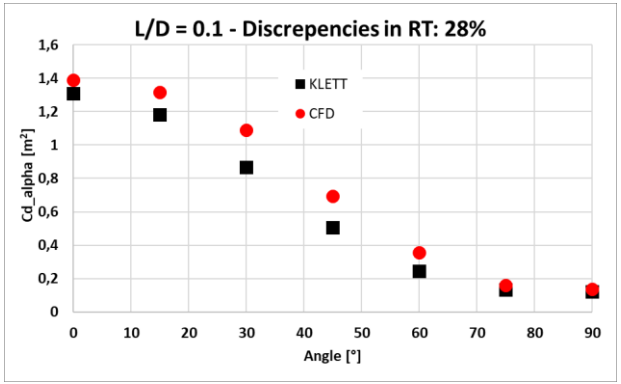
$$C_D = \frac{\int_0^{2\pi} \int_0^{\frac{\pi}{2}} C_{D_\alpha} \sin \alpha \, d\alpha \, d\psi}{\int_0^{2\pi} \int_0^{\frac{\pi}{2}} \sin \alpha \, d\alpha \, d\psi}$$

CFD computation

$$C_{D_\alpha} = CFD\ computation\ at\ each\ angle$$

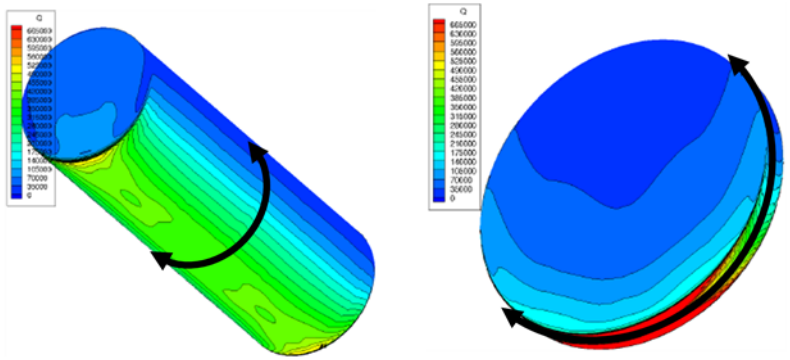


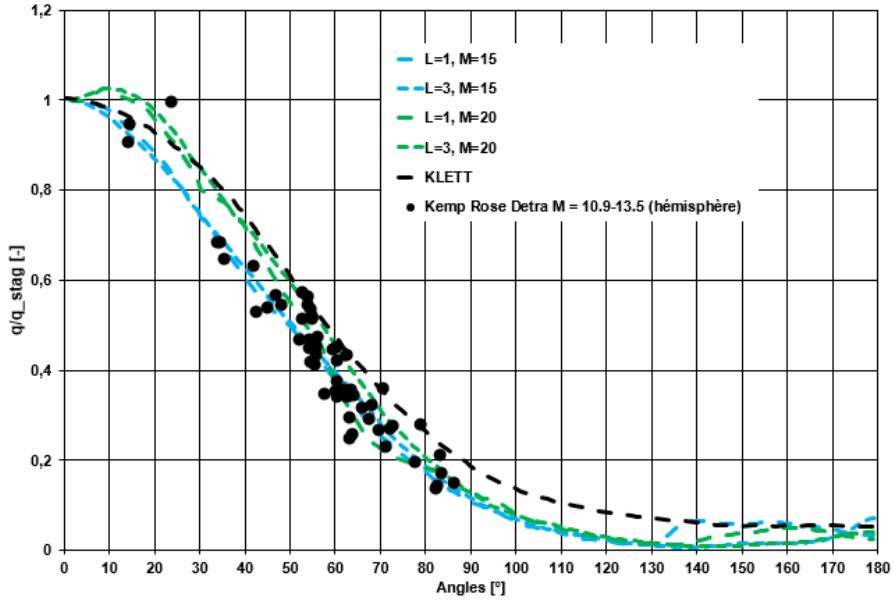




HEAT FLUX: SIDE PART

- The interpolation profile from Klett overestimates the experimental data
- Same profile whatever the length of the cylinder
  - 3D effects are more and more important as the length decreases





HEAT FLUX: DISK PART

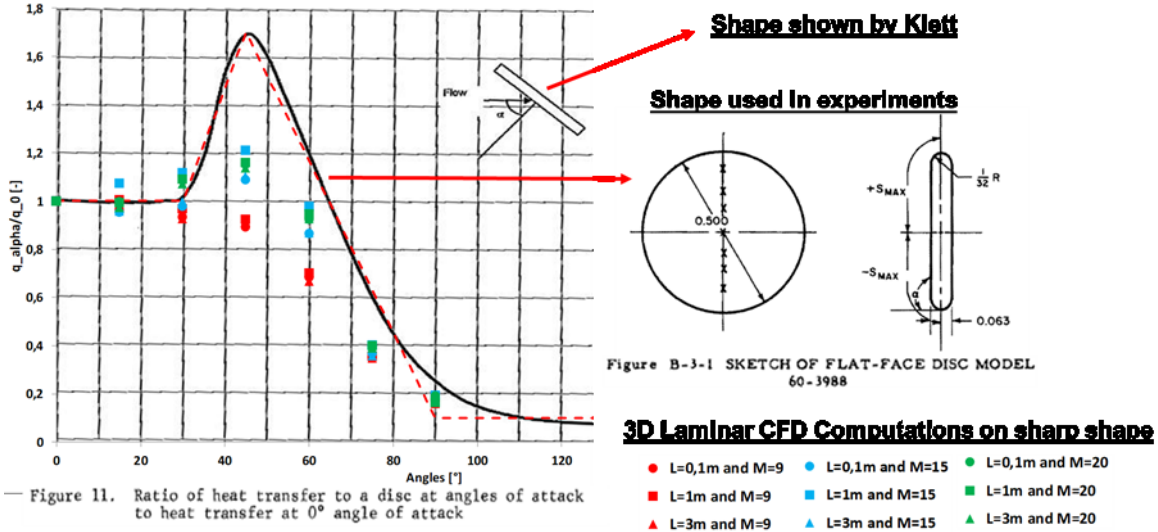
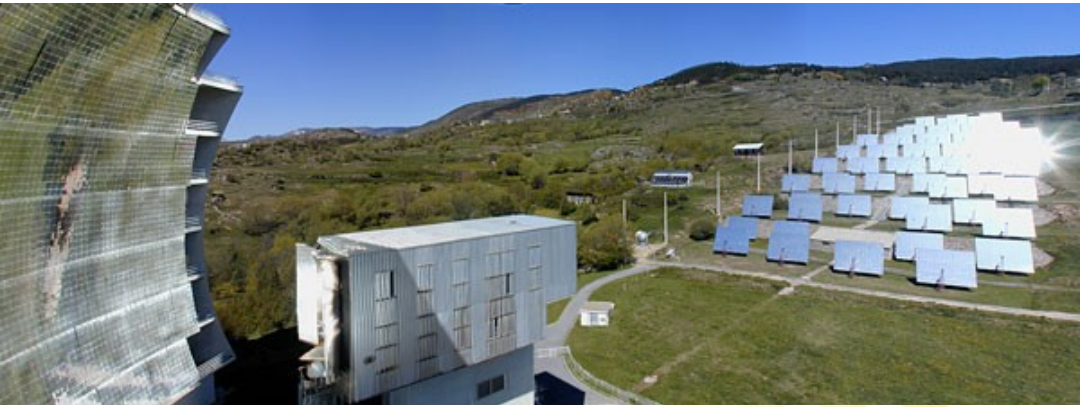


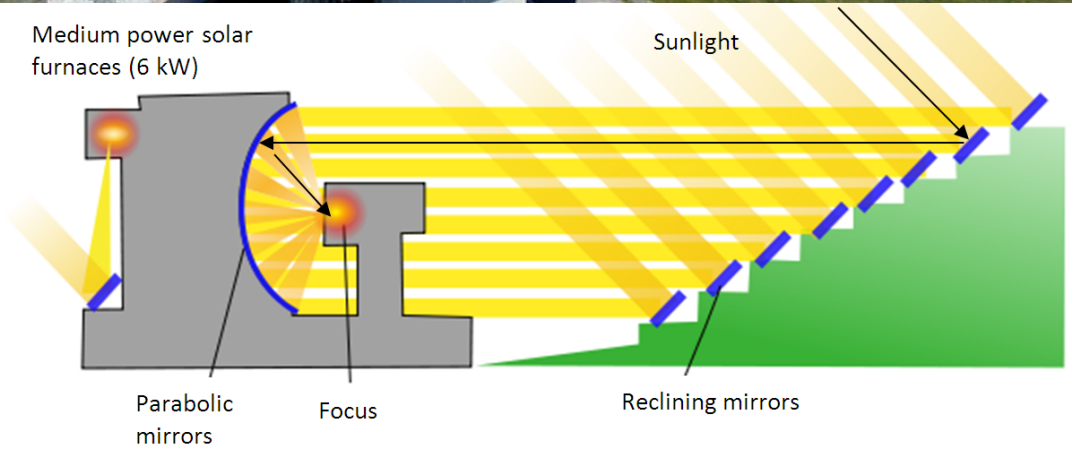
Figure 11. Ratio of heat transfer to a disc at angles of attack to heat transfer at 0° angle of attack

- Shape used in experiments is a cylinder with rounded edges
- Reynolds number are representative of a turbulent flow for the experiments
- The profile does not depend on the length of the cylinder

The correlations obtained overestimate the heat fluxes

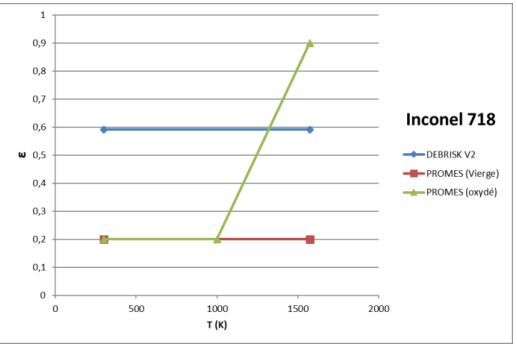
EMISSIVITY ESTIMATE

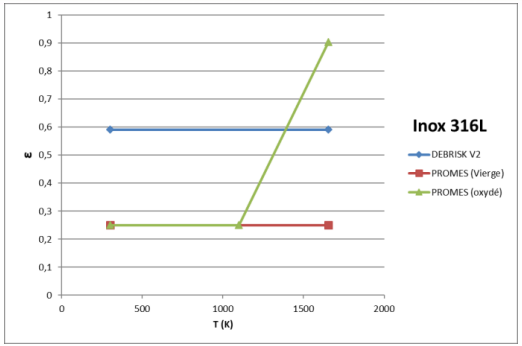


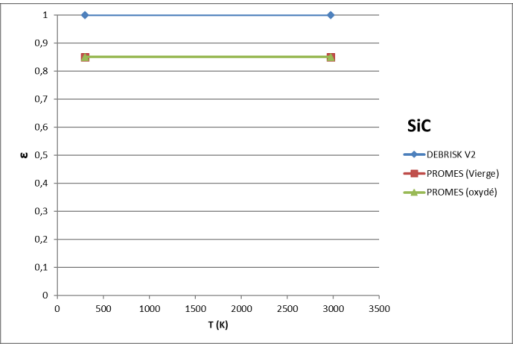


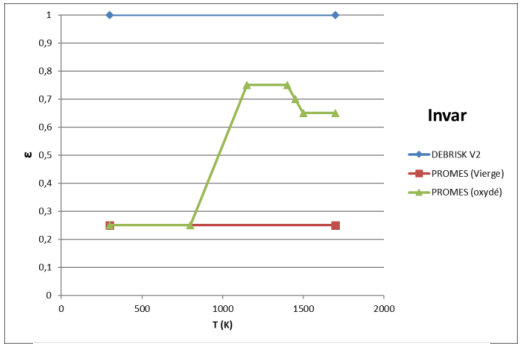
- High vacuum: 10^{-4} Pa or controlled pressure (standard atmosphere or plasma conditions)
- Emissivity estimate using a direct method
- Temperature from 1000 up to 2500 K, measured using a pyro-reflectometer (1.3 and 1.55 µm)
- Measurement of the radiance from 0 to 80° and from **0.6-40** µm

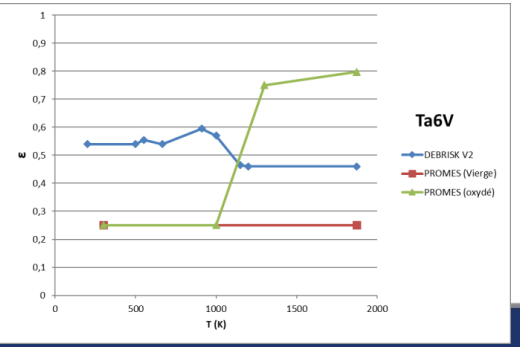
DATABASE

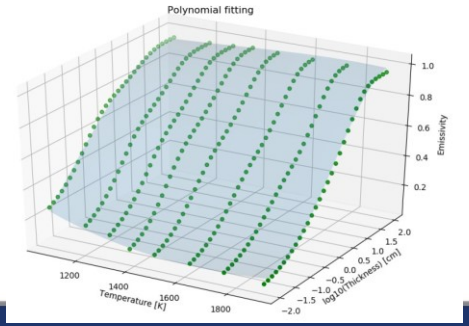












	Emissivity value (melting temperature)	
Material	Old models	New models
Inconel	0.6	0.9
Inox	0.6	0.9
SiC	1	0.85
Invar	1	0.65
TA6V	0.45	0.8
Zerodur	1	0.85 (for thick pieces)

Higher emissivity values for Inconel, Steel and TA6V

Consistent the ESTIMATE Database

	Emissivity value (melting temperature)	
Material	ESTIMATE	DEBRISK
Inconel	0.8	0.9
Inox	0.8	0.9
Invar	0.8	0.65
TA6V	0.77	0.8

Conclusion

- Rather confident about the relevance of the new aerothermodynamics and oxidation models (emissivity)
- The impact of the survivability is huge

Question: do you have the same analyzes through your activities on this topic?