Extension of ESA's Survival And Risk Analysis tool with hemisphere and lattice shapes

Clean Space Industry Days 2023, ESA-ESTEC, Noordwijk, Netherlands

Context

The *<u>D</u>ebris <u>R</u>isk <u>A</u>ssessment and <u>M</u>itigation <u>A</u>nalysis* (*DRAMA*) tool is the ESA certification tool for the risk assessment of destructive spacecraft re-entry

The *<u>S</u>urvival <u>a</u>nd Risk <u>A</u>nalysis* (SARA) module simulates the re-entry and predicts demise altitude and ground impact information (location, impact energy)

SARA models the spacecraft by a set of user defined primitives

Context

The primitives used in SARA are:

- Box
- Cone
- Sphere
- Cylinder
- Ring

Context

Which of the five primitives to model for example a parabola on a satellite, or a fuel reservoir breaking up?

Context

Or more complex: lattice shapes produced using added manufacturing

3D printed antenna support (courtesy ESA)

Ariane bracket (courtesy ESA)

Objectives

Objectives:

- To implement new concave shape (Hollow Hemisphere) -> user need
- To implement ways to model lattice structures -> experimental prototype
- To provide guidelines for modelling lattice structures -> user need

Objectives:

- To implement new concave shape (Hollow Hemisphere)

-> add sphere cap (hollow hemisphere) primitive

- To implement ways to model lattice structures

-> add a user shape primitive

- To provide guidelines for modelling lattice structures

-> think, think, think

Implementation needs

For each drama shape implementation we need:

- Aerodynamic coefficients as a function of attitude and flow conditions
- Aerothermal heating rates as a function of attitude and flow conditions
- The effect of shading of the shape on another object to simulate ‘blocking’ of the external flow on component based object
- A means to assess the outer surface when ablation occurs

Implementation design

For each drama primitive implementation we need:

1) Aerodynamic coefficients as a function of attitude and flow conditions
2) Aerothermal heating rates as a function of attitude and flow conditions

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Use of existing database capabilities

- For the existing primitives the database is produced with simplified tools
- For the new primitives we perform a CFD matrix in a similar way as has been done since 2016 for the DEBRISK software. One objective is to harmonize the databases of the two tools.

Implementation design

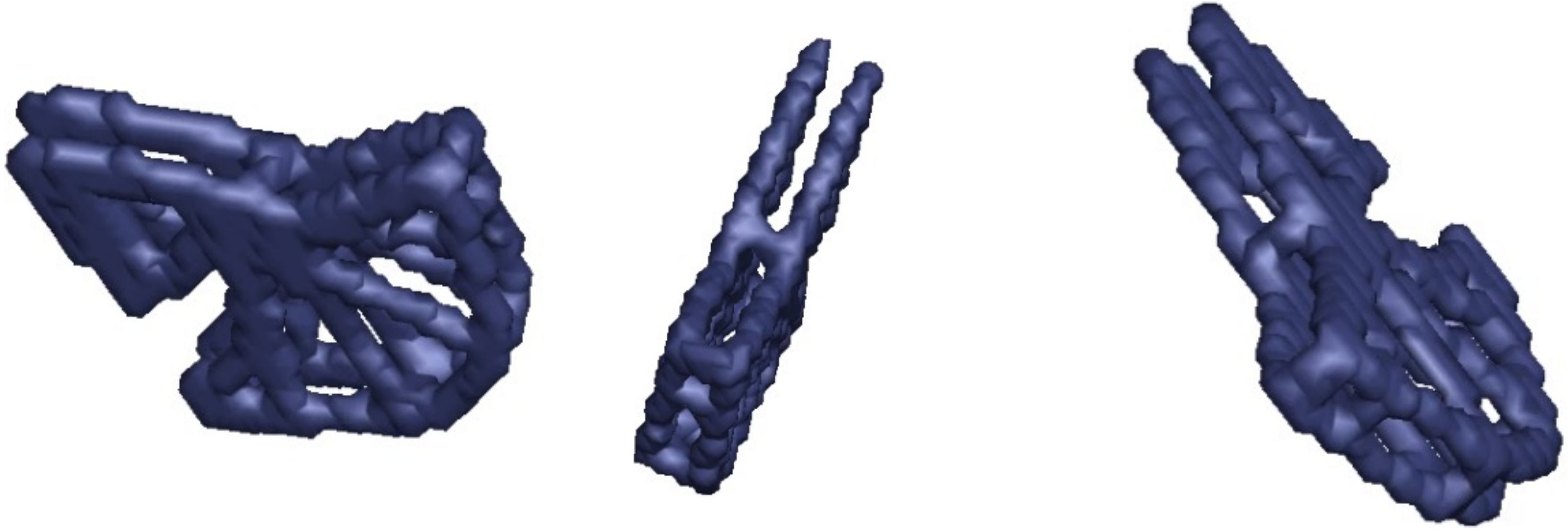
For each drama primitive implementation we need:

3) The effect of shading of the shape on another object to simulate 'blocking' of the external flow on component based objects

Use of existing voxelator tool

- For the existing primitives the voxelation can be performed with analytical relations
- For the sphere cap the voxelation can be performed with analytical relations
- For the User Shapes the voxelation is performed numerically. The primitive needs to be supplied as a discretized shape

Voxelator for User Shapes



-> Voxelator use for arbitrary geometry
-> Objective : Determinate the shading factor for user shapes and projected area
-> Input : Point cloud. The resolution need to be finer than the voxelator resolution. VTP format.

Implementation design

For each drama primitive implementation we need:

4) A means to assess the outer surface when ablation occurs

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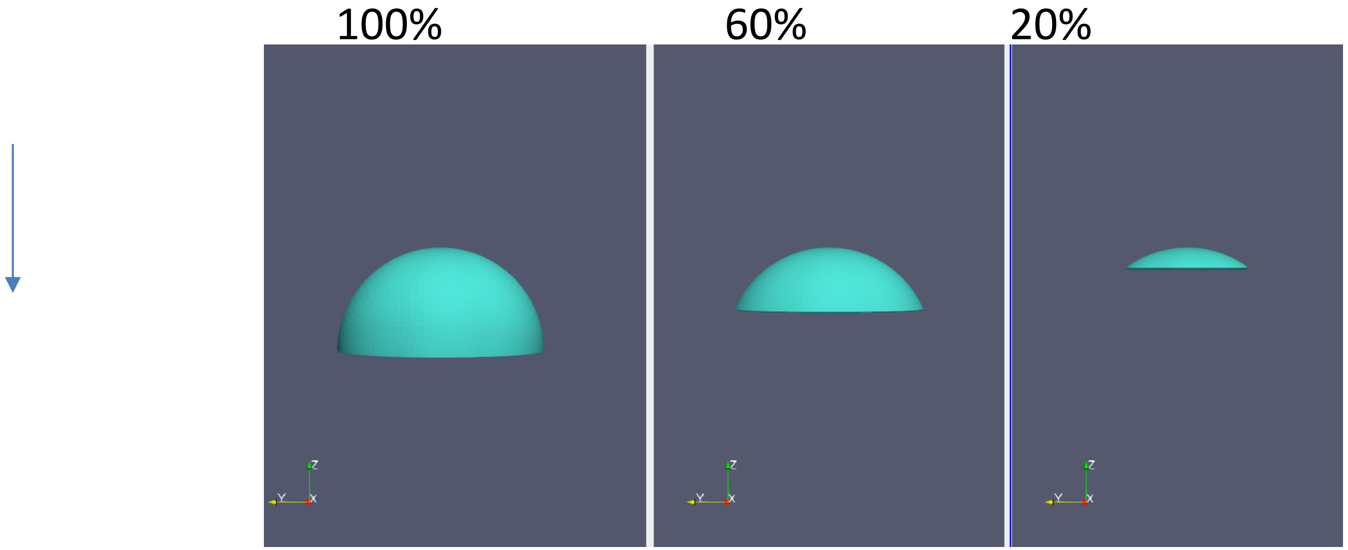
- For the existing primitives the relation between ablated mass and outer surface can be computed analytically
- For the sphere cap the relation between ablated mass and outer surface can be computed analytically
- For the User Shapes the relation between ablated mass and outer surface is performed numerically. The primitive needs to be supplied as a discretized volume mesh.

CFD databases

Ablation by height since highest fluxes ar on the rim (for random tumbling)

Definition percentage of height:

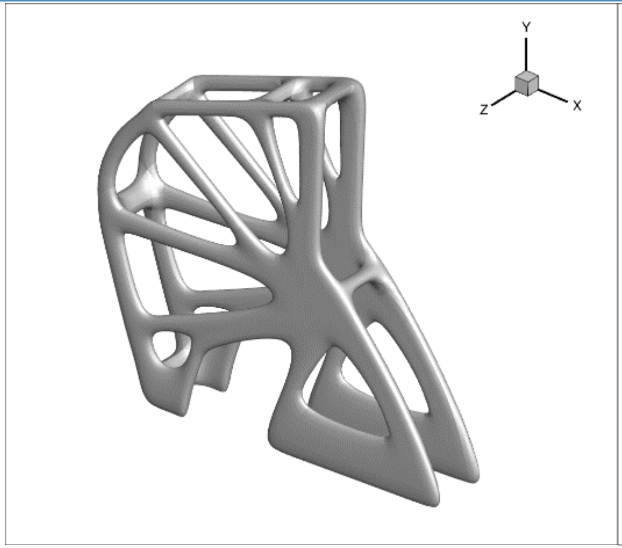
Geometry :

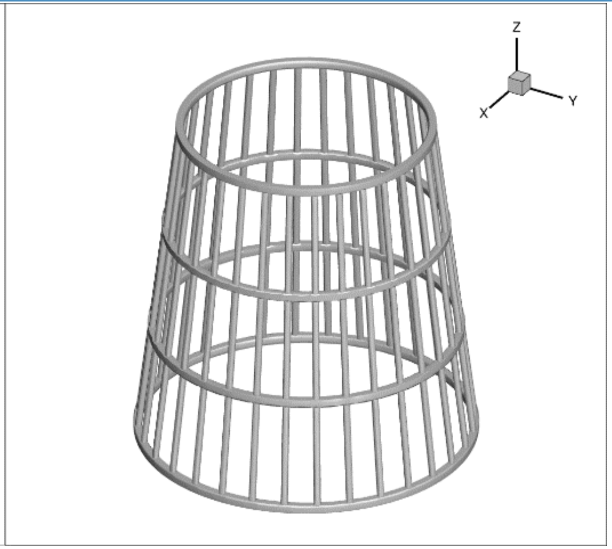


Attitudes:19

CFD databases

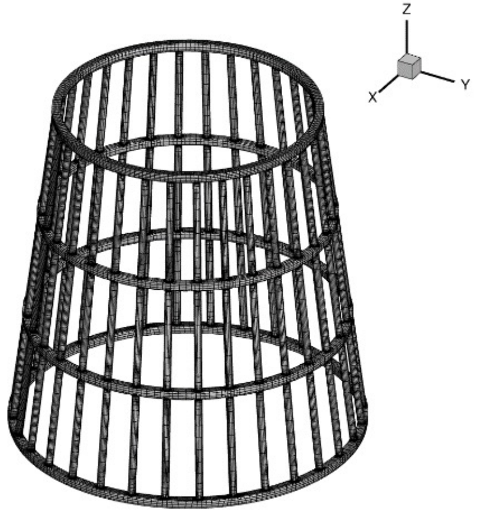
Geometry :





Attitudes: 50

3D volume Mesh :



CFD Database defition

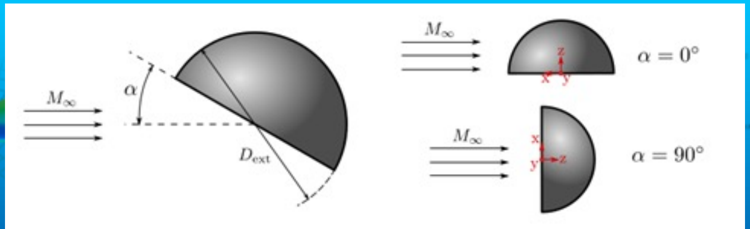
CFD/DSMC Simulations

Geometry	Mach	Height/Radius ratio	Simulation/Condition	Total simulations
BRACKET	5, 20, 22.85	X	50	150
LATTICE	5, 20, 22.85	X	50	150
HOLLOW HEMISPHERE	5, 20, 22.85	1(0.5/0.5), 0.6(0.3/0.5), 0.2(0.1/0.5)	19	171

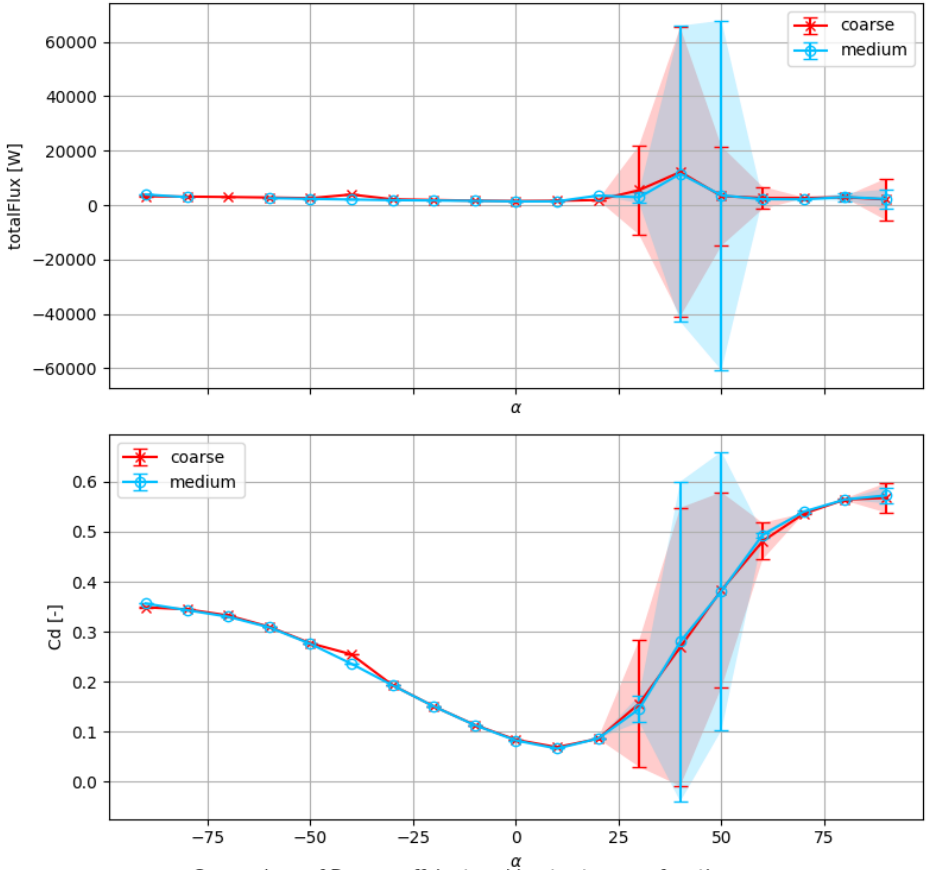
-> Unsteady cases for some Hollow Hemisphere simulation cases.

Conditions have been chosen based on preliminary Pampero trajectories in the continuum and rarefied regime.
2x CFD matrix, 1x DSMC matrix

HOLLOW HEMISPHERE CFD

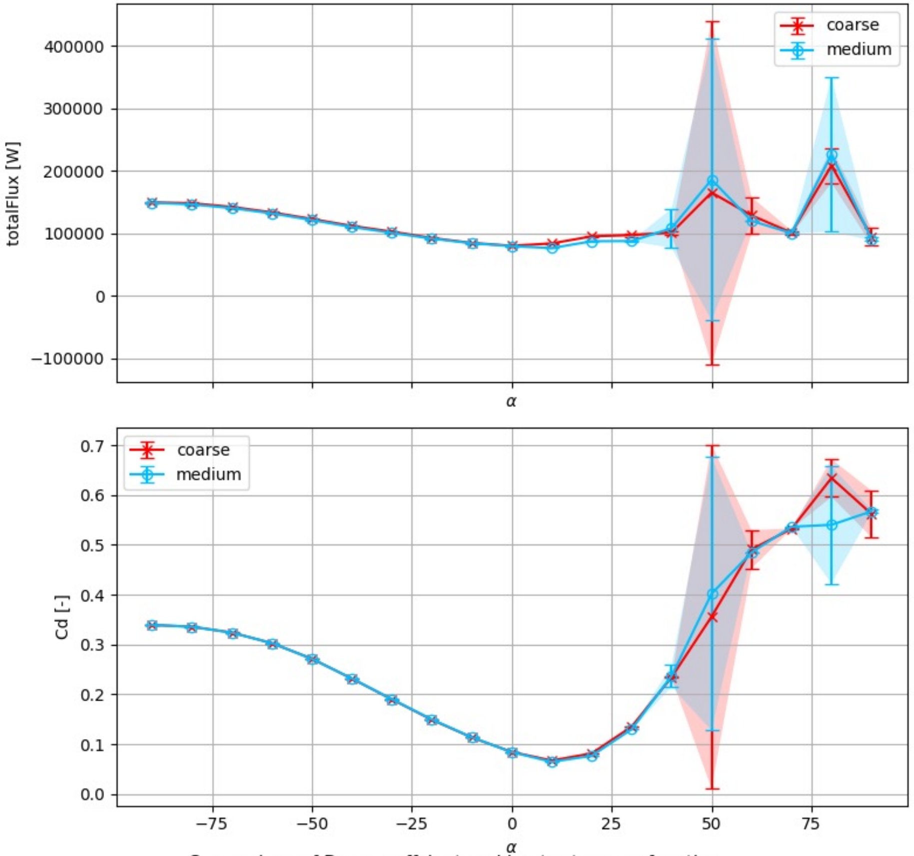


60 % MACH 5



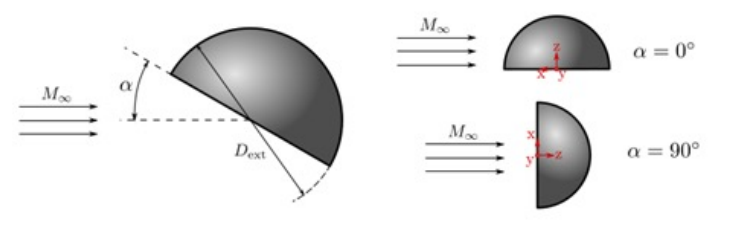
Comparison of Drag coeffcient and heat rates as a function of the angle or attack α for different mesh refinements Hollow hemisphere 60% of height M5

60 % MACH 20

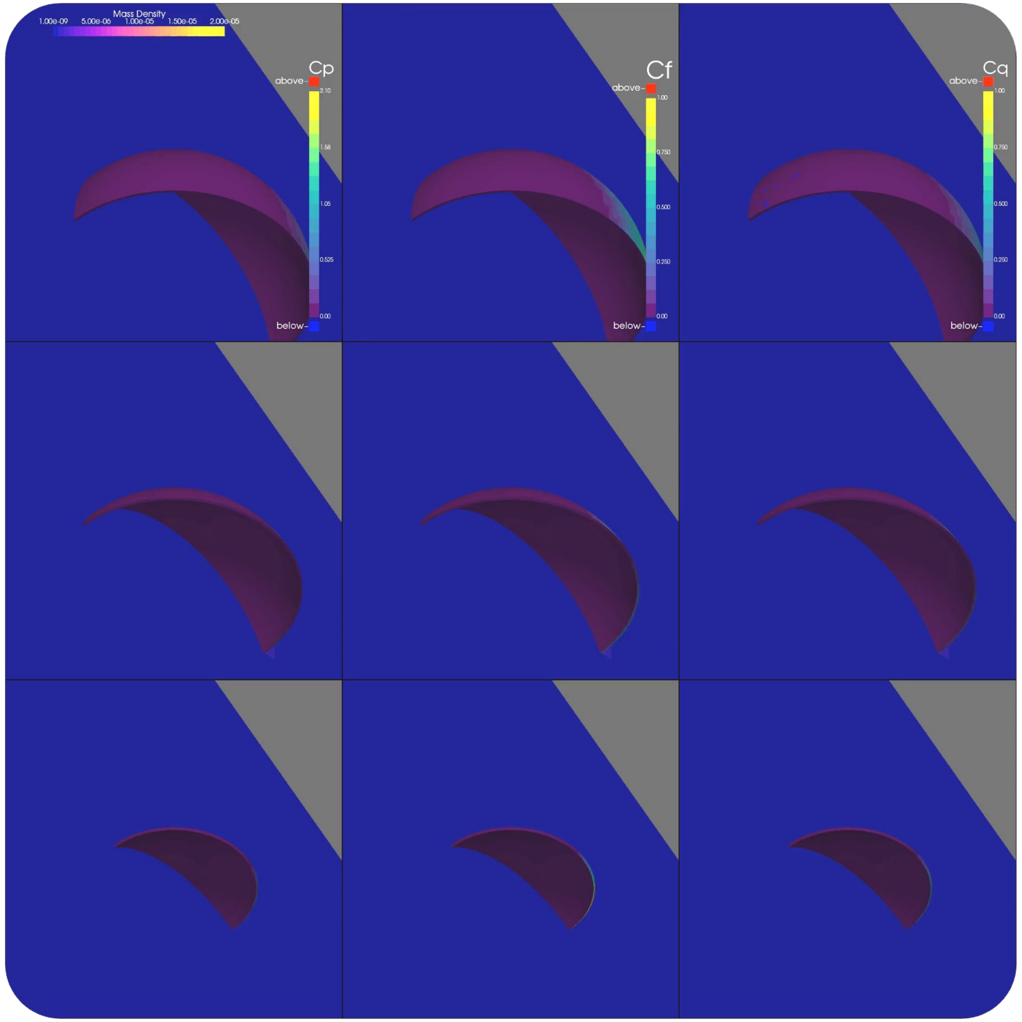


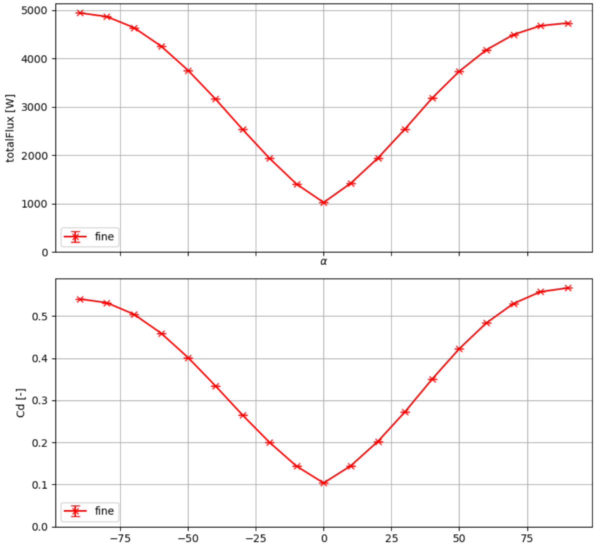
Comparison of Drag coeffcient and heat rates as a function of the angle or attack α for different mesh refinements Hollow hemisphere 60% of height M20

HOLLOW HEMISPHERE CFD

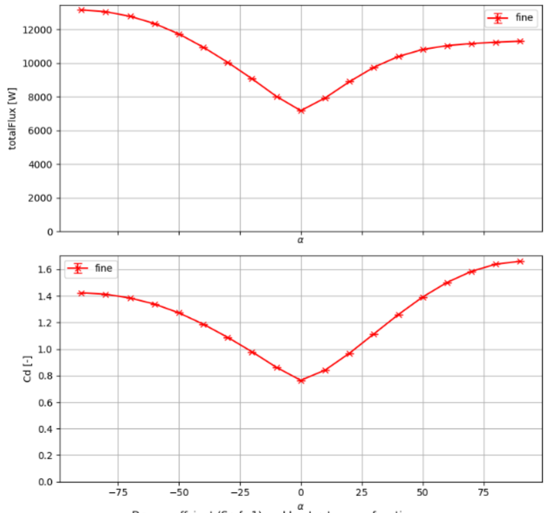


DMSC results
Hollow sphere

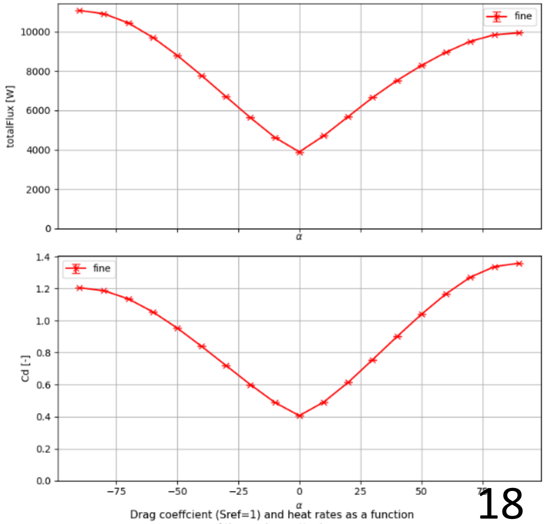




Drag coeffcient (Sref=1) and heat rates as a function of the angle or attack α
SPHCAP DG0.6 DP0 E0.01 H0.1 theta360

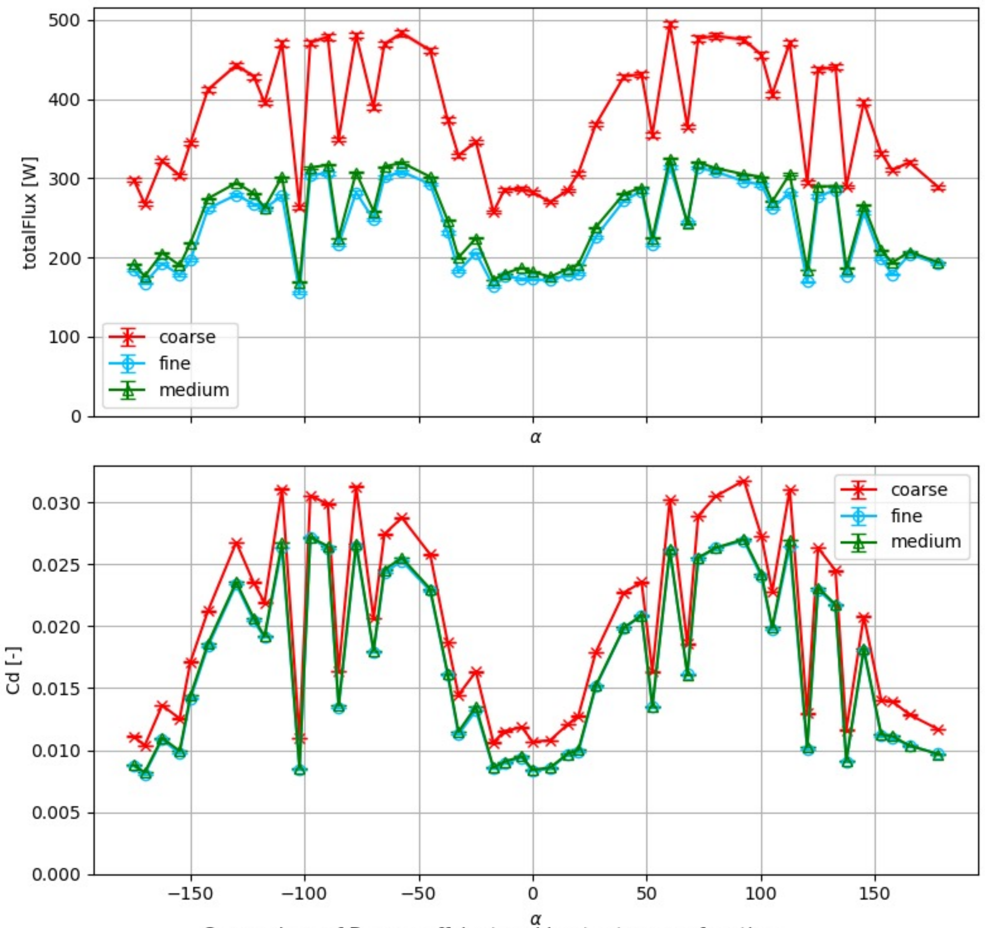


Drag coeffcient (Sref=1) and heat rates as a function of the angle or attack α
SPHCAP DG1 DP0 E0.01 H0.5 theta360



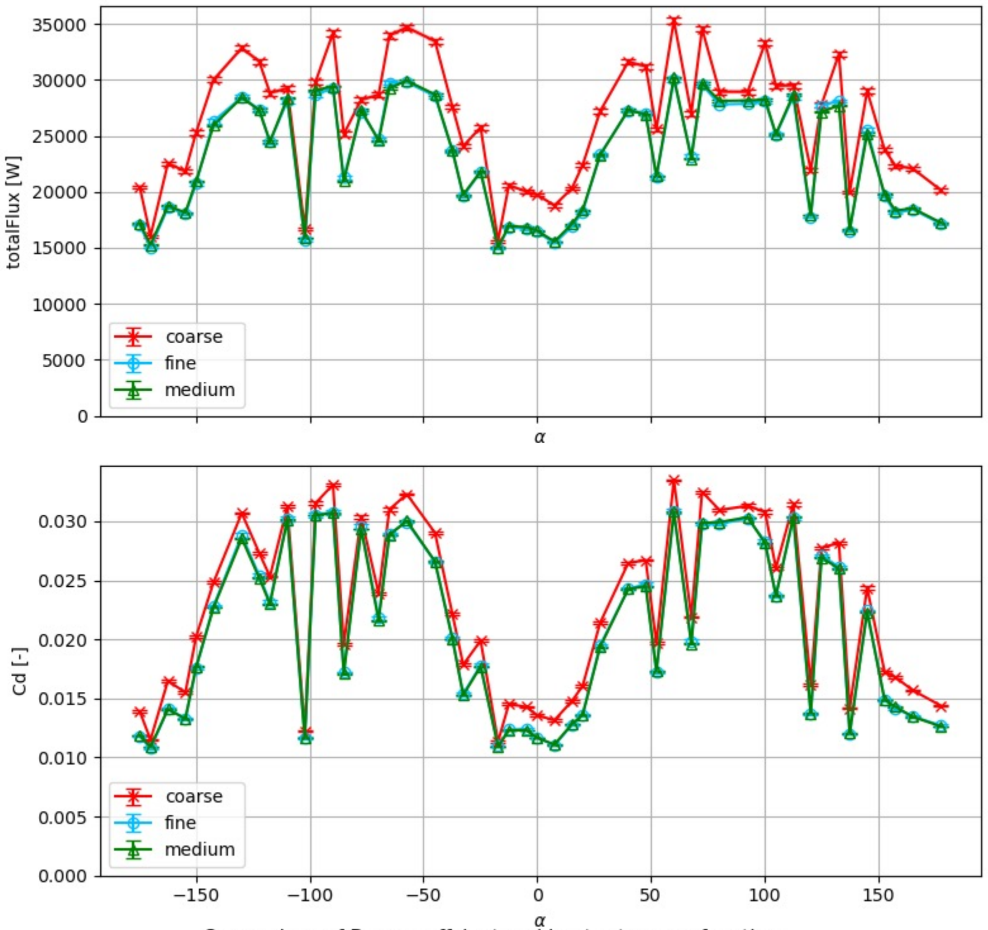
Drag coeffcient (Sref=1) and heat rates as a function of the angle or attack α
SPHCAP DG0.916515 DP0 E0.01 H0.3 theta360

BRACKET MACH 5



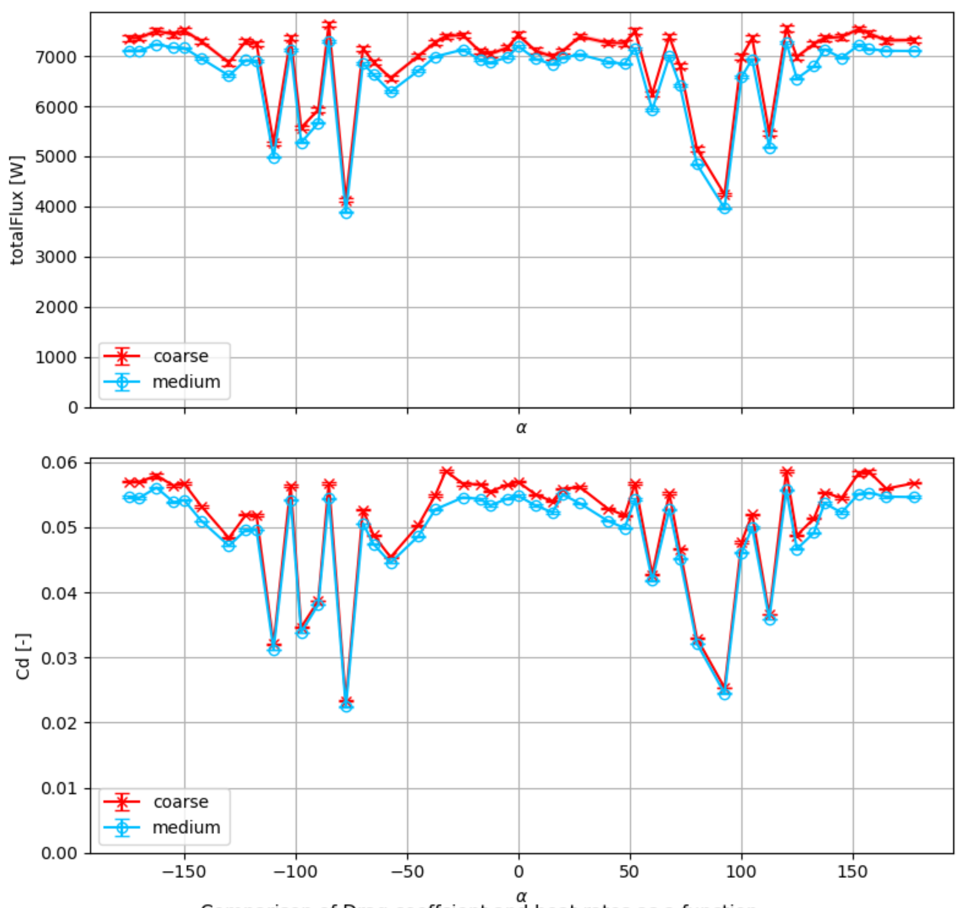
Comparison of Drag coeffcient and heat rates as a function of the angle or attack α for different mesh refinements bracket

BRACKET MACH 20



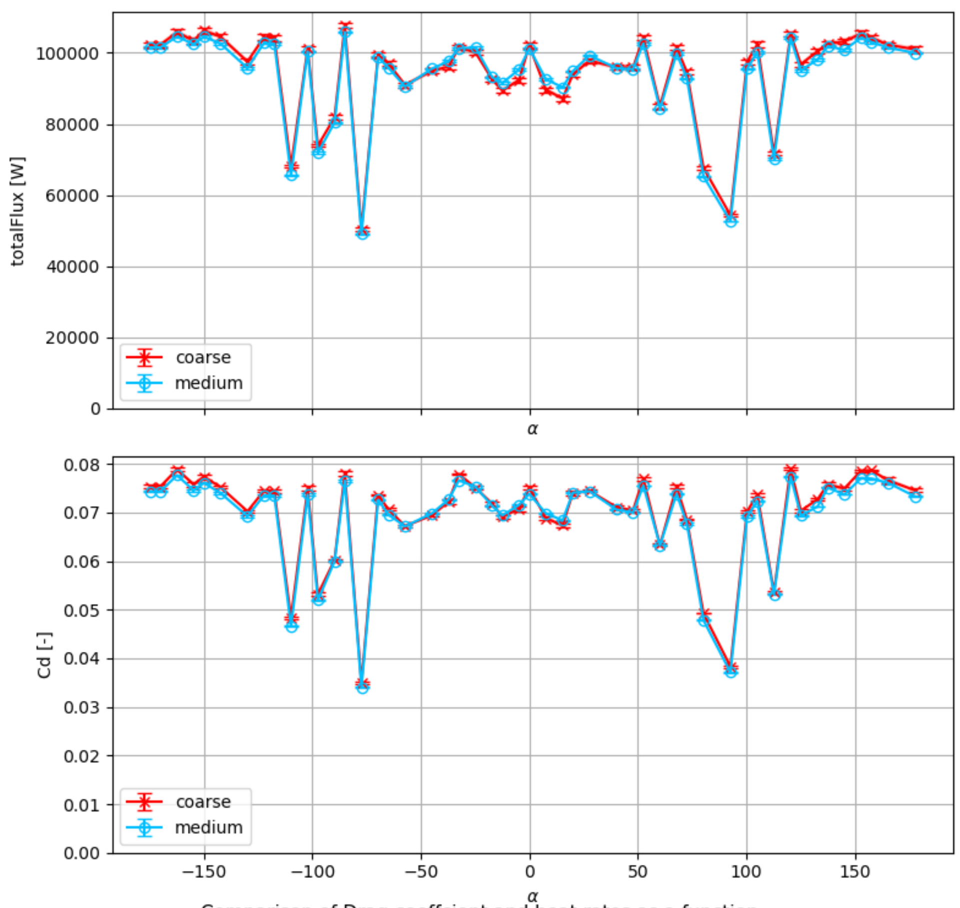
Comparison of Drag coeffcient and heat rates as a function of the angle or attack α for different mesh refinements bracket

LATTICE MACH 5



Comparison of Drag coeffcient and heat rates as a function of the angle or attack α for different mesh refinements lattice

LATTICE MACH 20



Comparison of Drag coeffcient and heat rates as a function of the angle or attack α for different mesh refinements lattice

Ablation management method for « UserShape » primitives

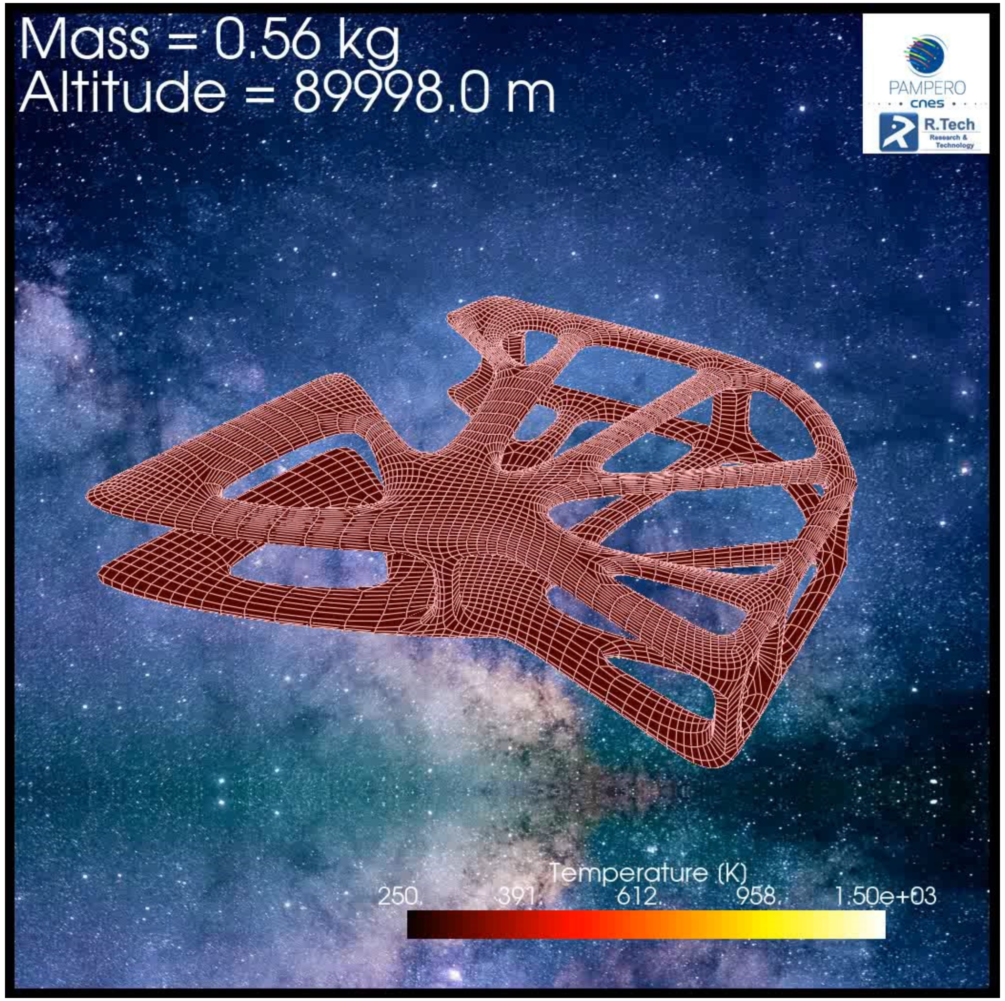
$$\frac{dS}{dV}_{netCDFfile} = Cst \qquad S_{current} = Cst(V_{current} - V_{init}) + S_{init}$$

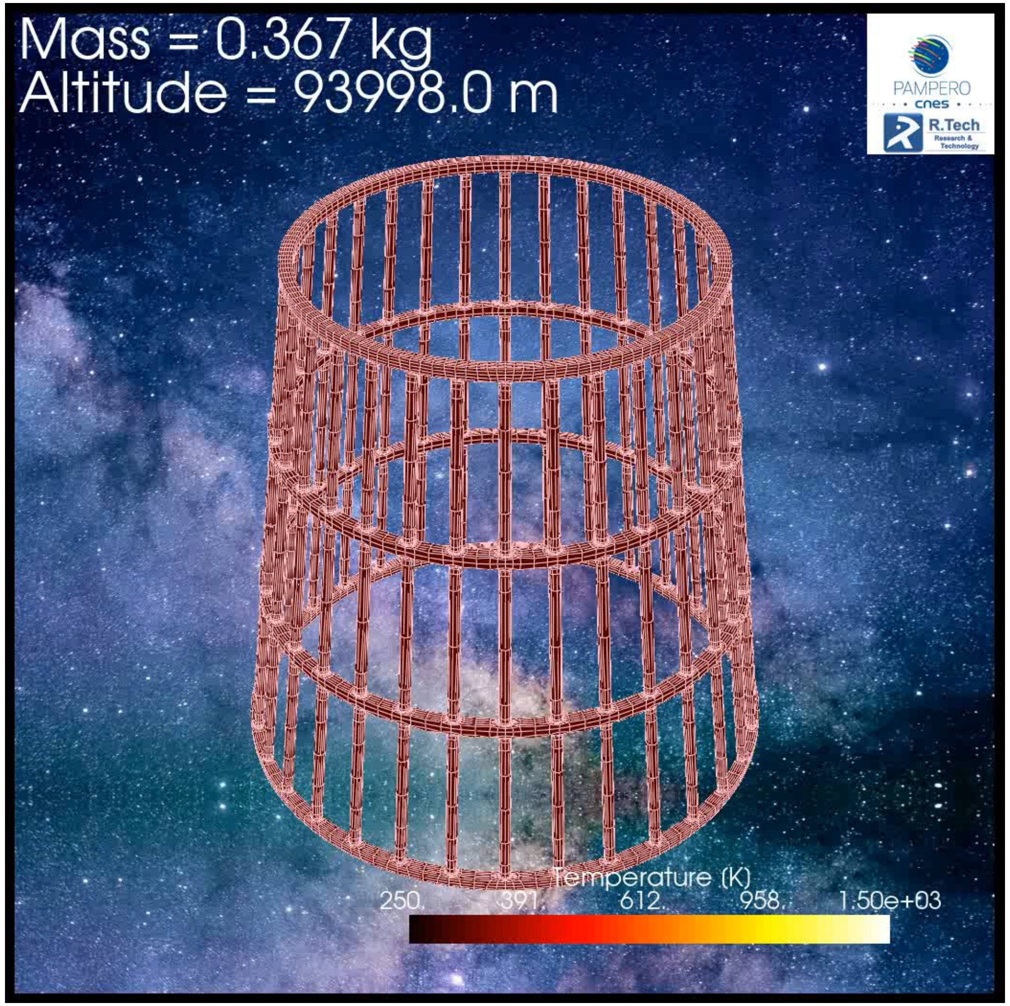
TEST VALIDATION

- Initial surface : 0.11156654 m²
- Initial Volume : 0.00017112769 m^3
- Volume clipped : 7.563024E-5 m^3
- Surface clipped : 0.0542456 m²

The surface calculated by DRAMA is 0.0552916 m², with an error of 1.8% with the surface calculated with Python.

Fragmentation of lattice shapes (Pampero)





Conclusions

- Succesfully implemented a sphere-cap primitive (HollowHemiSphere) with a CFD database
- Succesfully implemented a new user shape primitive demonstrated with two lattice shapes
- Care should be taken with lattice shapes when ablation is occuring: the likelyhood of fragmentation is high. If fragmentation occurs the use of higher fidelity tools is recommended.