4th International Workshop on Space Debris Re-entry

LATEST IMPROVEMENTS ON THE CNES SPACECRAFT-ORIENTED TOOL: PAMPERO

J. ANNALORO[1*], G. PRIGENT[1], S. GALERA[2], C. THIEBAUT[3], P. OMALY[1]

[1]CNES, Toulouse, FRANCE
[2]ALTRAN SO, Toulouse, FRANCE
[3]CNES, Paris, FRANCE

*julien.annaloro@cnes.fr

CONTEXT

- **The French Space Operation Act (2008) enforces the assessment of prospective risks**
  - For every mission launched / operated from French territory
  - In case of launch and satellite reentries

- **The maximum allowable probability to have at least one victim**
  - 10^{-4} for uncontrolled and controlled reentries

- **CNES is in charge of ensuring the right application of the law**

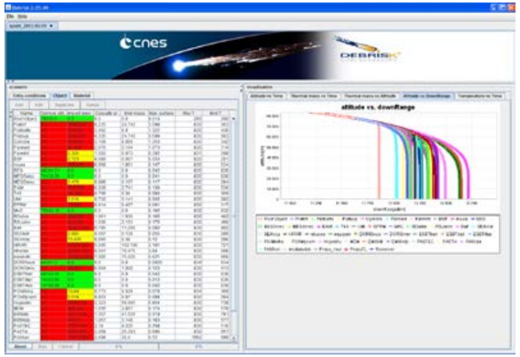
- **CNES develops multidisciplinary tools to predict the casualty area of debris**
  - DEBRISK
  - PAMPERO

© cnes

CNES ATMOSPHERIC REENTRY TOOLS

DEBRISK: certification tool

- Provided to the aerospace companies
- Based on an object-oriented approach
- New version planned for 2019



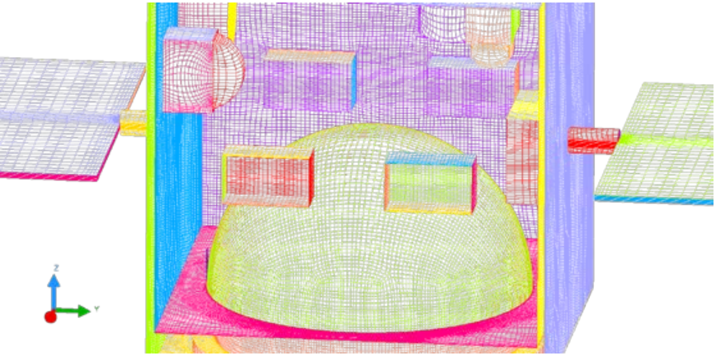
PAMPERO: research code

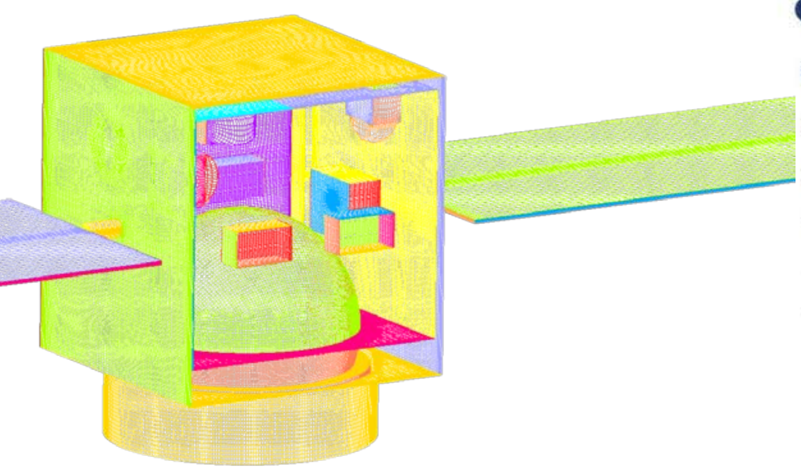
- Based on a spacecraft-oriented approach
- Six degrees-of-freedom flight dynamics
- Aerodynamics and aerothermodynamics analysis
- Heat transfers modeling through a 3D thermal conduction module
- Mechanical stress analysis from the aerodynamic and thermal loads
- Estimate of the destruction phenomena: ablation & fragmentation

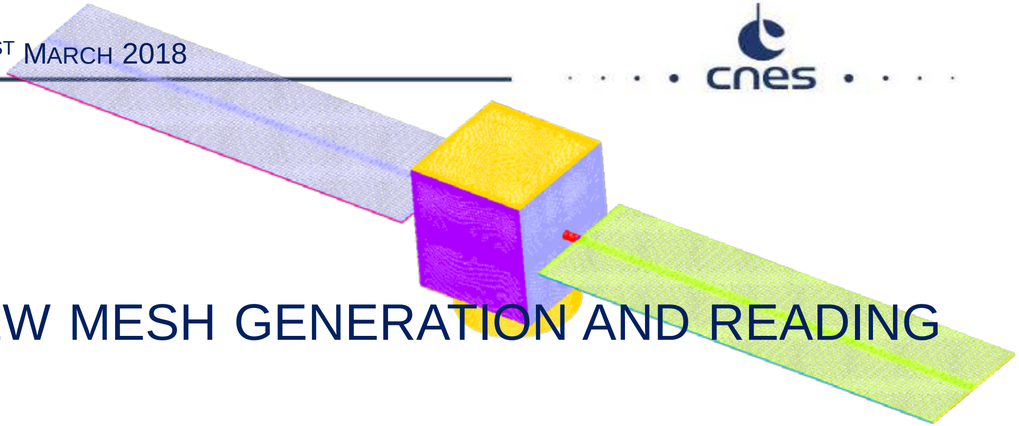
Computation time		Accuracy
5 s /objet/entire trajectory	*Object-oriented tool*	2 to 50% integrated heat flux
10 min – 1day /objet/entire trajectory	*Spacecraft-oriented tool*	1 to 25% integrated heat flux
1 day – 1 week /objet/frozen position	*CFD*	5 to 20% local heat flux

© cnes

OUTLINE



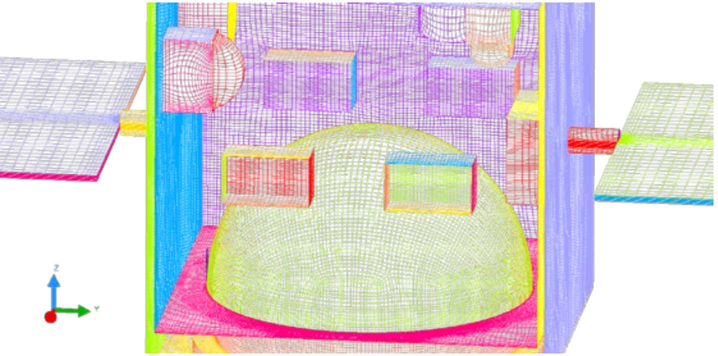


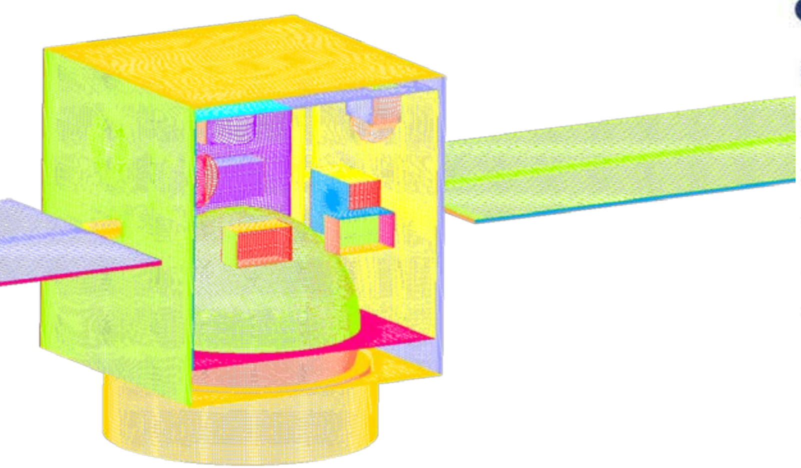


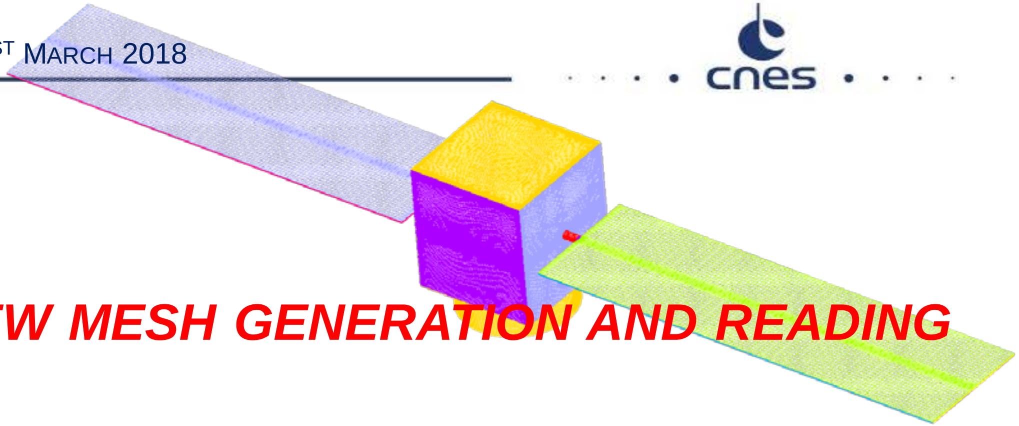
1. NEW MESH GENERATION AND READING
2. FLIGHT DYNAMICS
3. AEROTHERMODYNAMICS
4. HEAT TRANSFERS MODELLING & ABLATION
5. MECHANICAL STRESS ANALYSIS
6. FRAGMENTATION

© cnes

OUTLINE







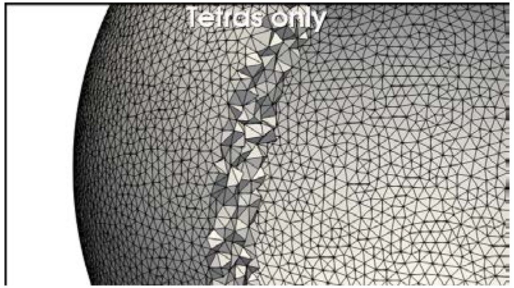
1. **NEW MESH GENERATION AND READING**
2. FLIGHT DYNAMICS
3. AEROTHERMODYNAMICS
4. HEAT TRANSFERS MODELLING & ABLATION
5. MECHANICAL STRESS ANALYSIS
6. FRAGMENTATION

© cnes

NEW MESH GENERATION & READING

Collaboration with R.Tech Research & Technology

- **Since 2013, tetrahedral mesh strategy chosen**
  - Nevertheless, this strategy is not the most relevant
  - Most objects are relatively thin
  - Consequently, either the mesh size is too important or mesh quality is not satisfactory

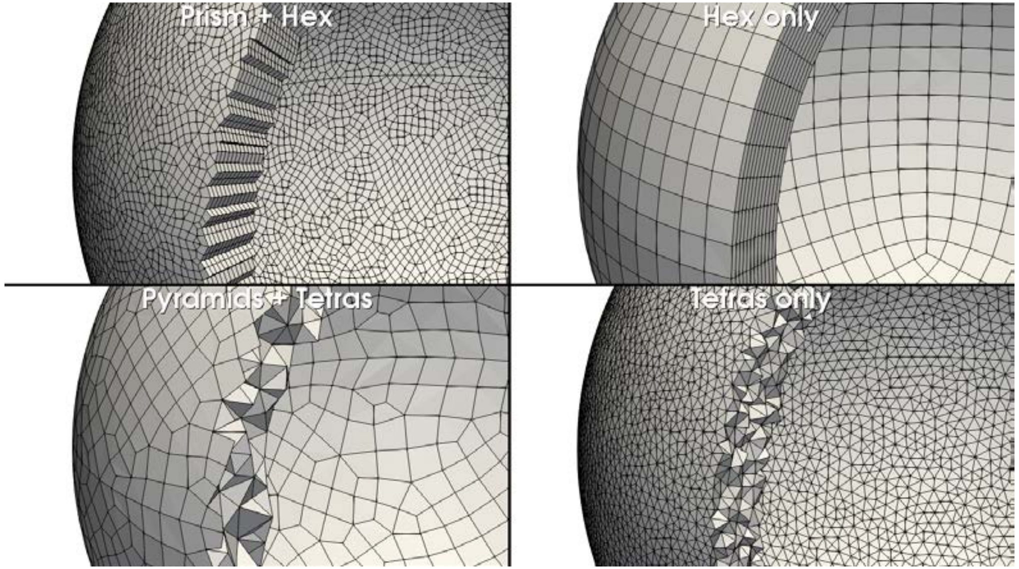


© cnes

NEW MESH GENERATION & READING

Collaboration with R.Tech Research & Technology

- **Since 2013, tetrahedral mesh strategy chosen**
  - Nevertheless, this strategy is not the most relevant
  - Most objects are relatively thin
  - Consequently, either the mesh size is too important or mesh quality is not satisfactory
- **Since 2018, extension of meshes reading by PAMPERO**

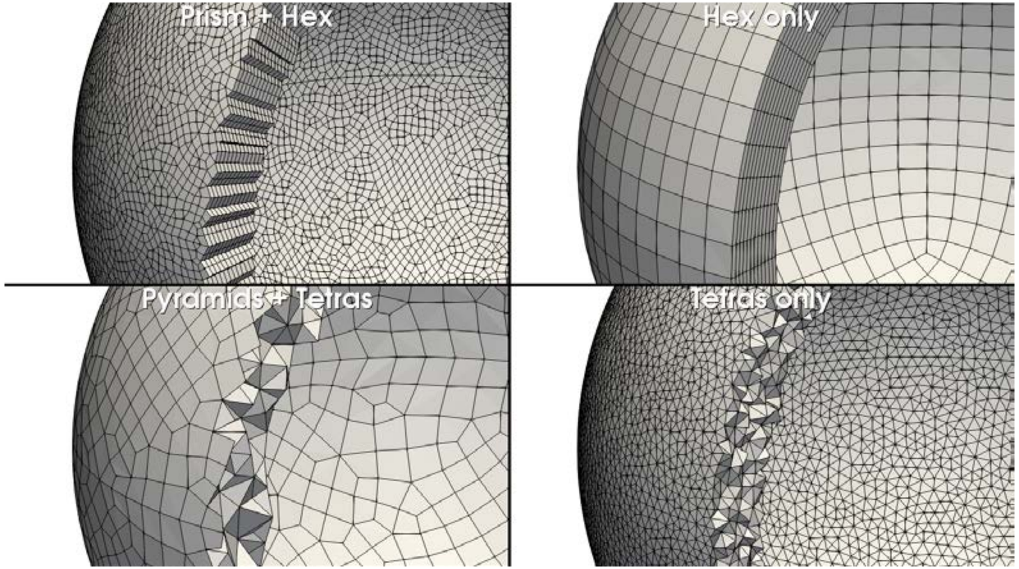


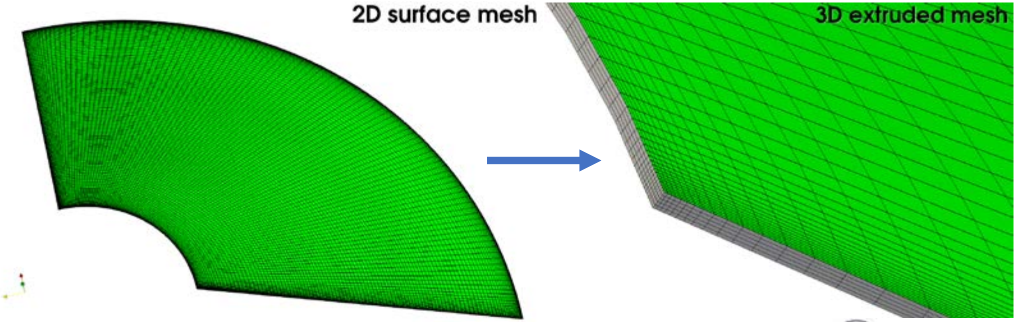
© cnes

NEW MESH GENERATION & READING

Collaboration with R.Tech Research & Technology

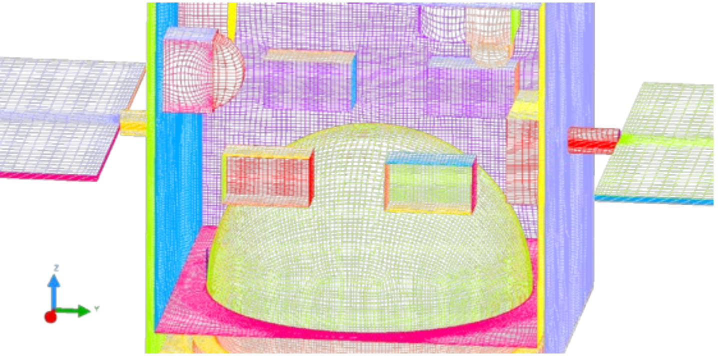
- **Since 2013, tetrahedral mesh strategy chosen**
  - Nevertheless, this strategy is not the most relevant
  - Most objects are relatively thin
  - Consequently, either the mesh size is too important or mesh quality is not satisfactory
- **Since 2018, extension of meshes reading by PAMPERO**
- **Possibility to extrude a 2D mesh to a 3D mesh**

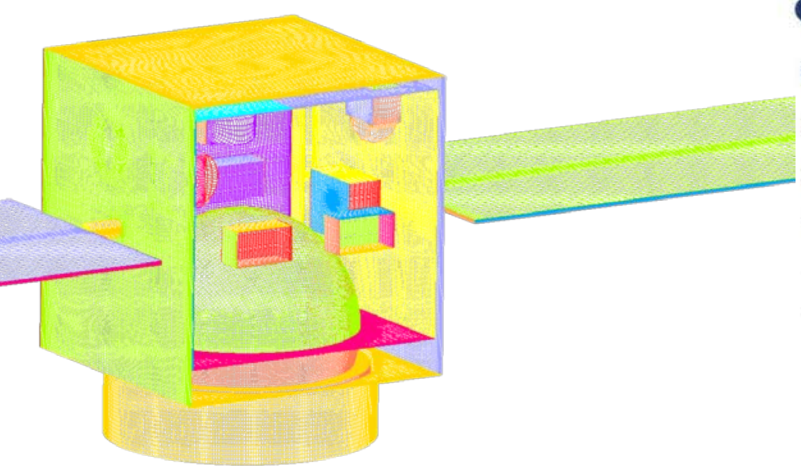


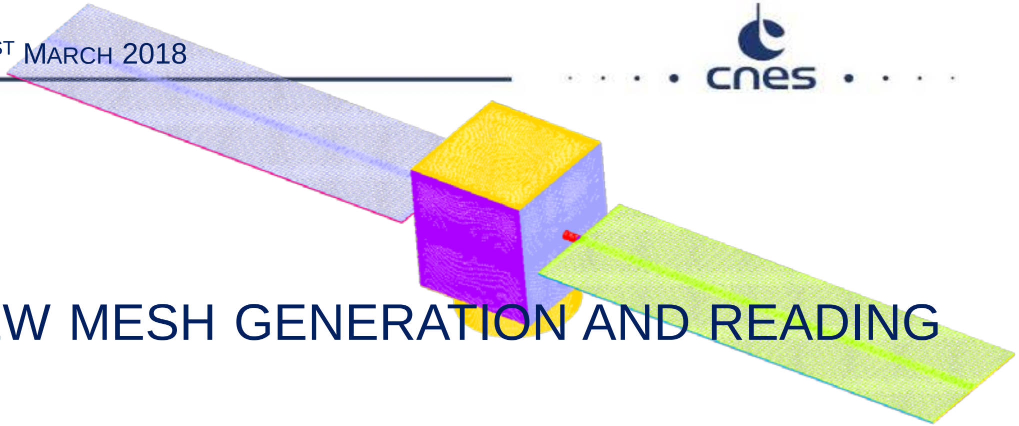


© cnes

Outline







1. New mesh generation and reading
2. ***Flight dynamics***
3. Aerothermodynamics
4. Heat transfers modelling & ablation
5. Mechanical stress analysis
6. Fragmentation

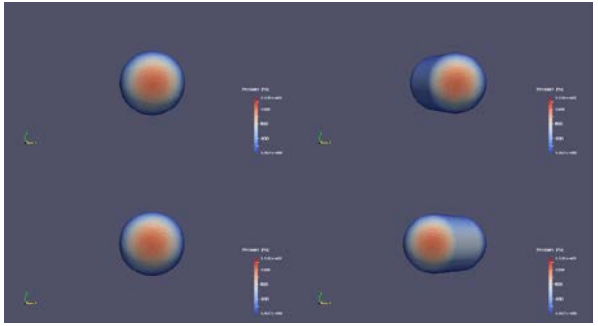
© cnes

FLIGHT DYNAMICS

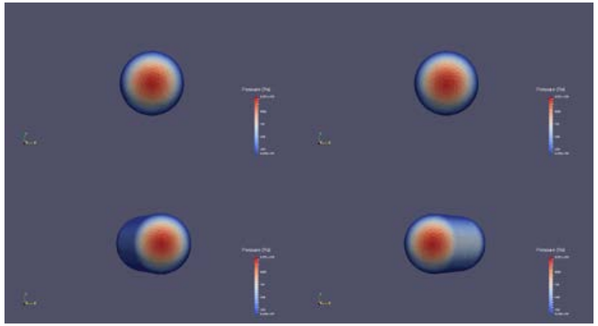
Collaboration with R.Tech Research & Technology

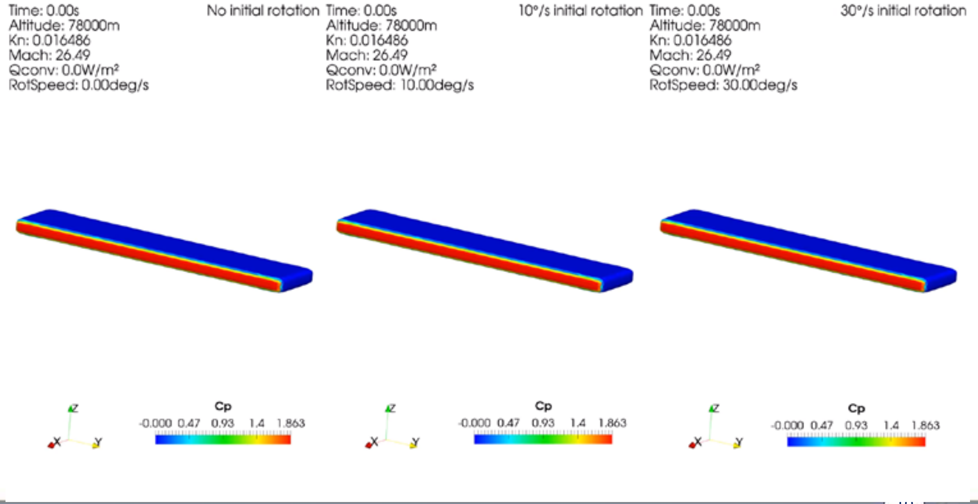
- **Validation on aerodynamics coefficients and moments is relatively easy**
  - Important number of benchmarks in the literature
- **To our knowledge, not enough validation on the flight dynamics**
  - Difficulty finding representative test-cases
  - First, need to make code cross-checks
- **Tank test-case**
  - Our models need to be improved
- **Dumping effects issues are important**
  - Work in progress

$\Delta t = 0{,}1\ s$



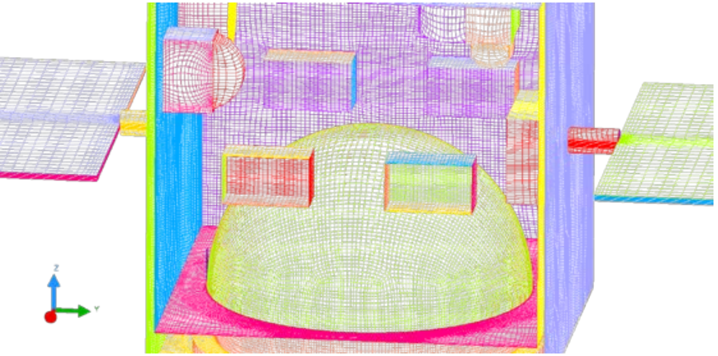
$\Delta t = 0{,}001\ s$

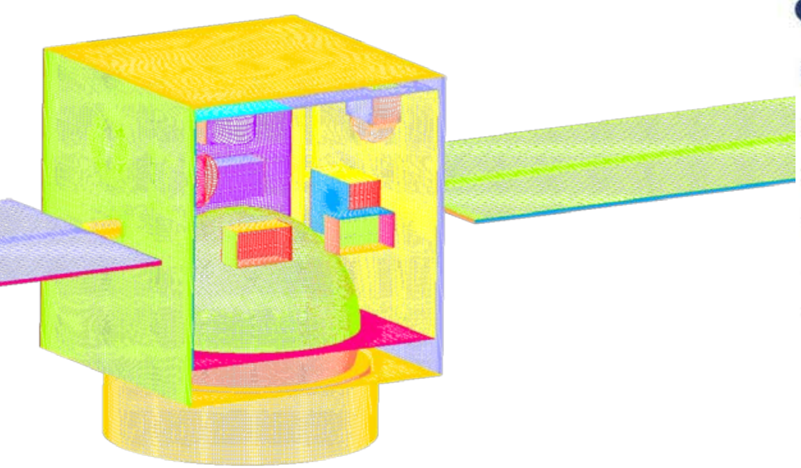


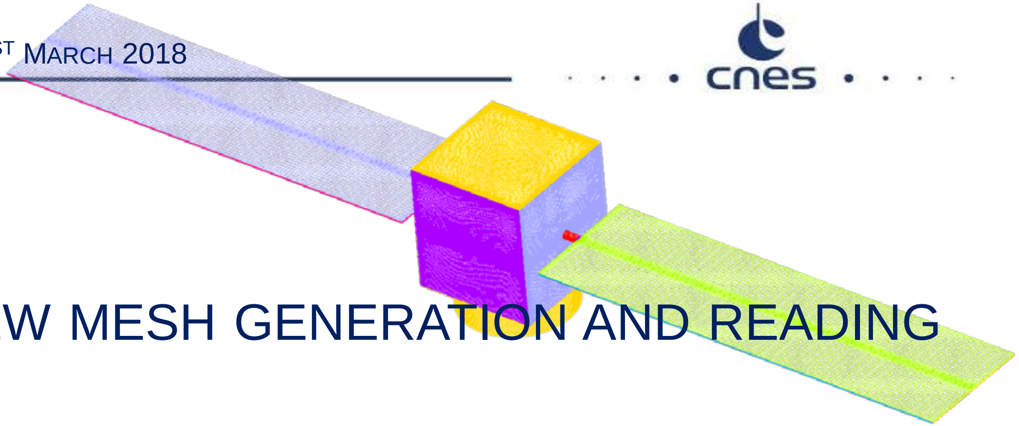


© cnes

OUTLINE







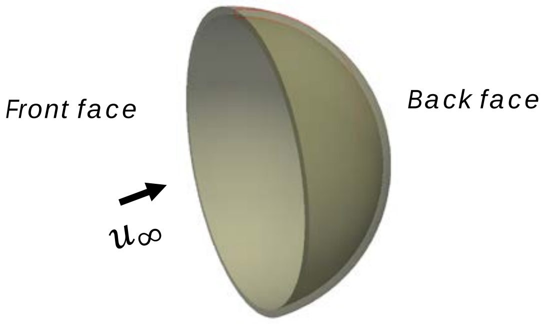
1. NEW MESH GENERATION AND READING
2. FLIGHT DYNAMICS
3. ***AEROTHERMODYNAMICS***
4. HEAT TRANSFERS MODELLING & ABLATION
5. MECHANICAL STRESS ANALYSIS
6. FRAGMENTATION

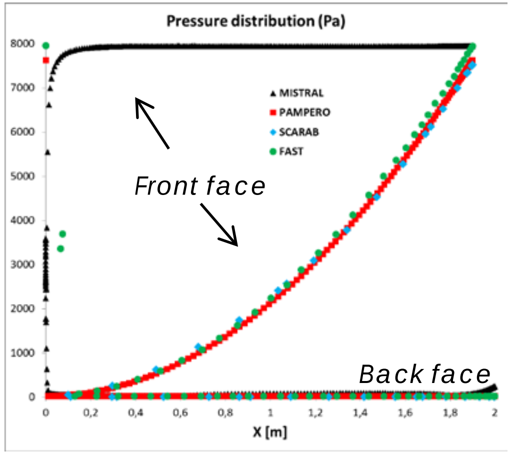
© cnes

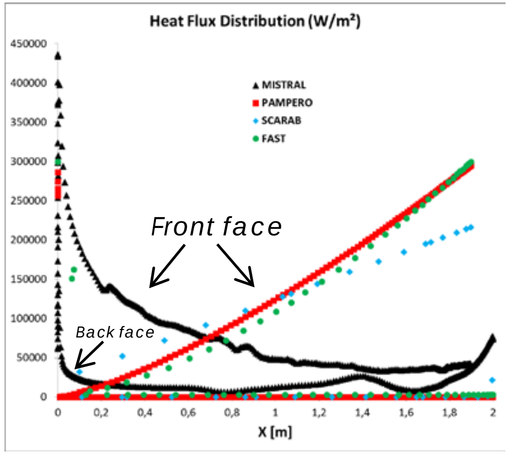
AEROTHERMODYNAMICS

Collaboration with R.Tech Research & Technology, ONERA THE FRENCH AEROSPACE LAB, HTG HYPERSCHALL TECHNOLOGIE GÖTTINGEN GMBH

- **State of the art for the Spacecraft-oriented tools**
  - Pressure: formulas derived from modified Newton assumption
  - Heat fluxes: blunt body experiments or CFD
- **Set up a collaboration with CNES, HTG, RTECH, ONERA**
  - Comparison on different Spacecraft-oriented tools
  - Comparison with high-fidelity codes
  - Perform computations on test-cases, focusing on complex geometries and flow regions







© cnes

AEROTHERMODYNAMICS

Collaboration with ONERA THE FRENCH AEROSPACE LAB

- **Identification of geometries/situations where the modified Newton law is not applicable**

- **Aerothermodynamics improvement in the continuum regime in progress**

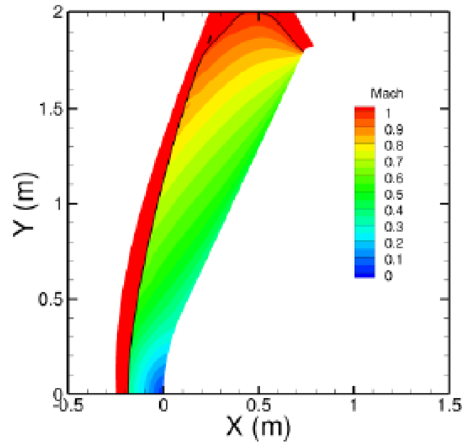
  - Flat faces
  - Concave surfaces
  - Trailing edges
  - Elliptic flows
  - Shock-shock interactions
  - Friction coefficients

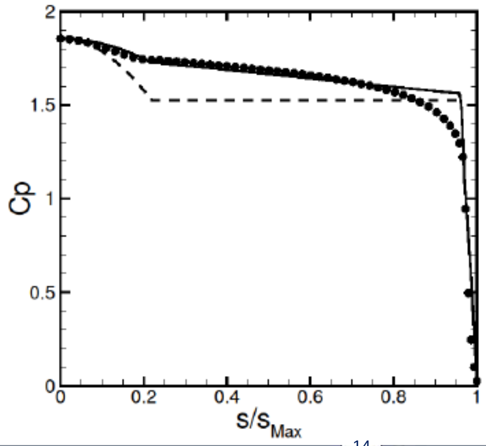
© cnes

AEROTHERMODYNAMICS

Collaboration with ONERA

- **Example 1: elliptic flows over sphere-cone like geometries**
- **More the subsonic region is important, more the elliptical effects are intense**
- **Strategy to obtain new correlations**
  - Important campaign of CFD computations
  - Reduction of the problem
    - Applicable to all dimensions
    - Applicable to all configurations (α, β …)
    - Applicable to all flow conditions



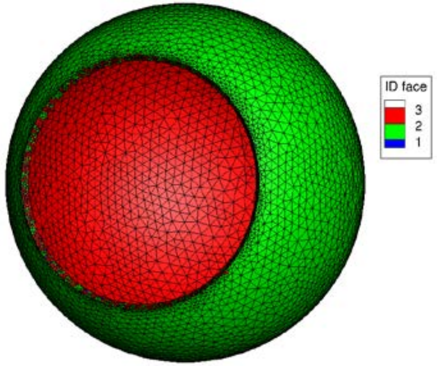


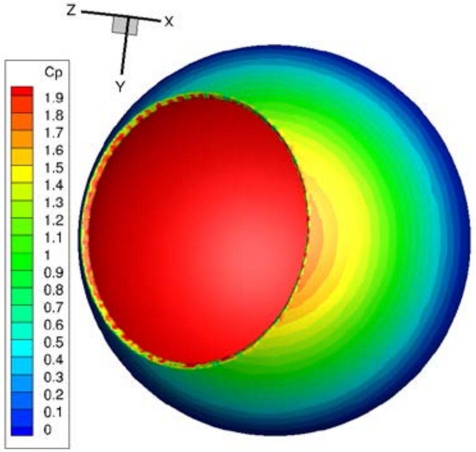
© cnes

AEROTHERMODYNAMICS

Collaboration with ONERA THE FRENCH AEROSPACE LAB

- **Example 2: concave sphere**
- **Concave surface recognition algorithm in progress**
- **Same strategy to obtain new correlations**
- **Correlations applied according to the region (concave versus convex)**





© cnes

AEROTHERMODYNAMICS

- **Usual strategy for calculating the parietal heat flux**

$$Q_{conv} = Q_{conv,stag}\, f(r, P)$$

© cnes

AEROTHERMODYNAMICS

Usual strategy for calculating the parietal heat flux

$$Q_{conv} = Q_{conv,stag}\, f(r, P)$$

already improved (P)

© cnes

AEROTHERMODYNAMICS

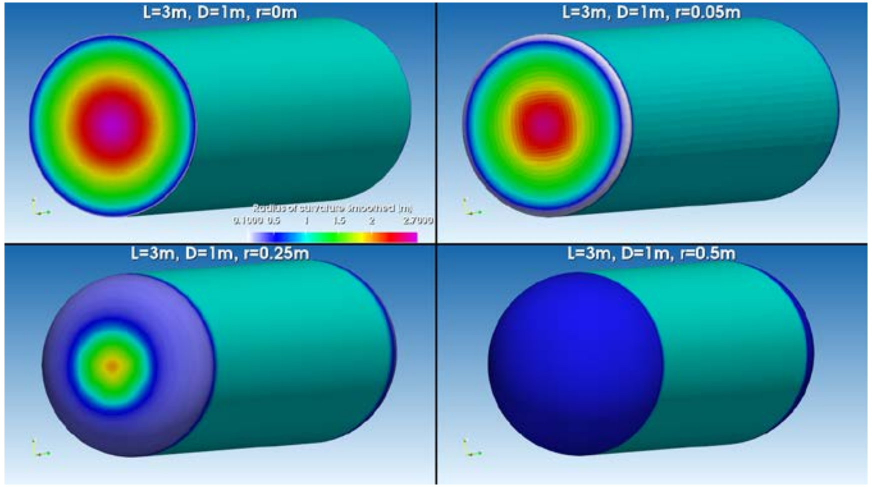
Collaboration with R.Tech Research & Technology

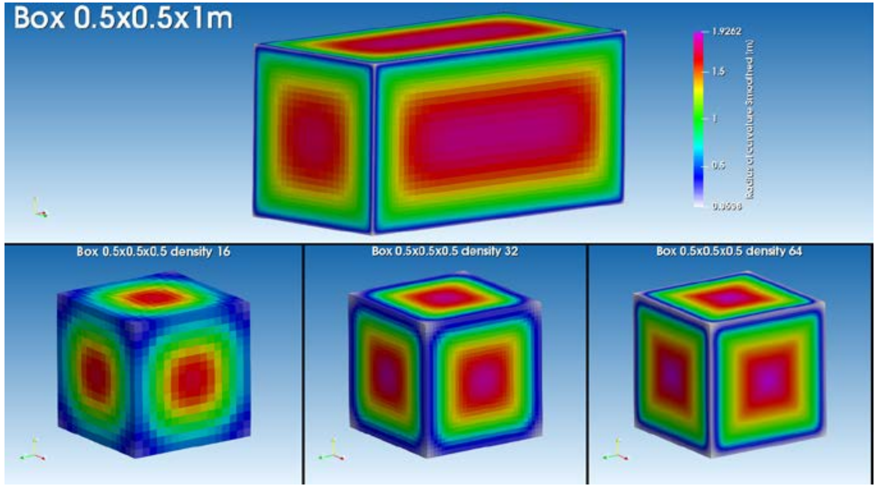
❖ Usual strategy for calculating the parietal heat flux

$$Q_{conv} = Q_{conv,stag}\, f(r, P)$$

❖ First way of improvement: the curvature radius

➢ Not calculate a mathematical curvature radius, but based on the physics involved





© cnes

Aerothermodynamics

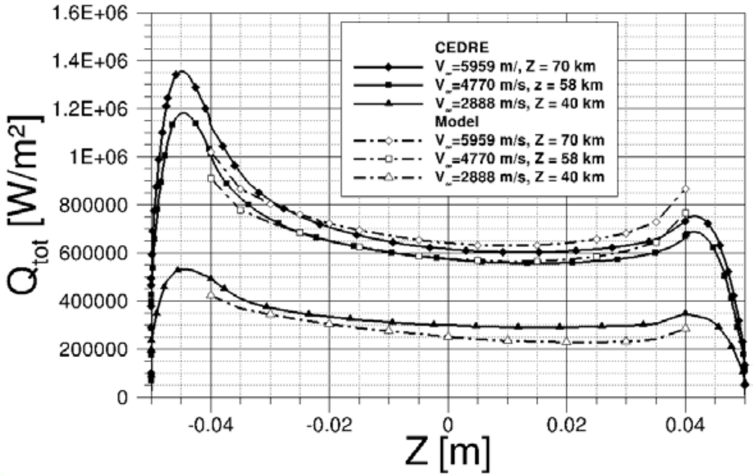
Collaboration with ONERA

❖ Usual strategy for calculating the parietal heat flux

$$Q_{conv} = Q_{conv,stag}\, f(r, P)$$

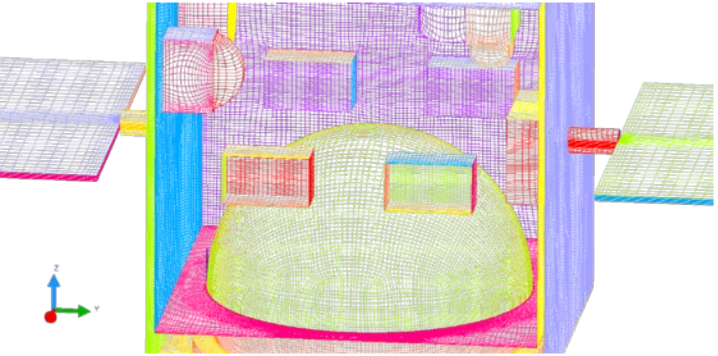
❖ Second way of improvement: no dependence of the curvature radius (e.g. planar surface)

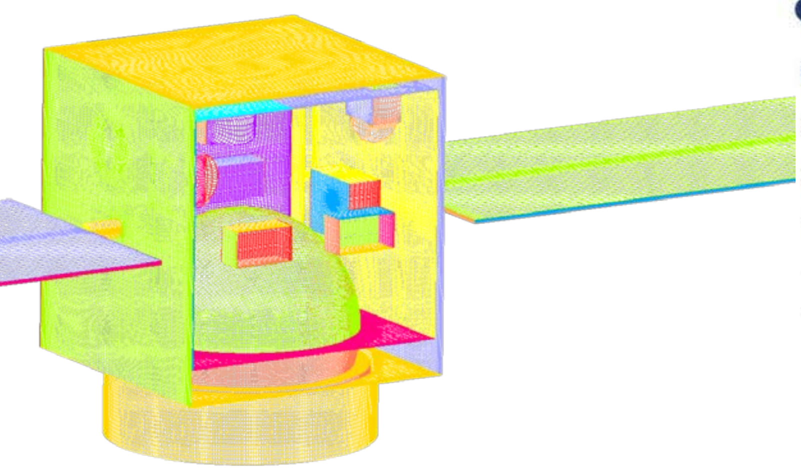
- Important campaign of CFD computations

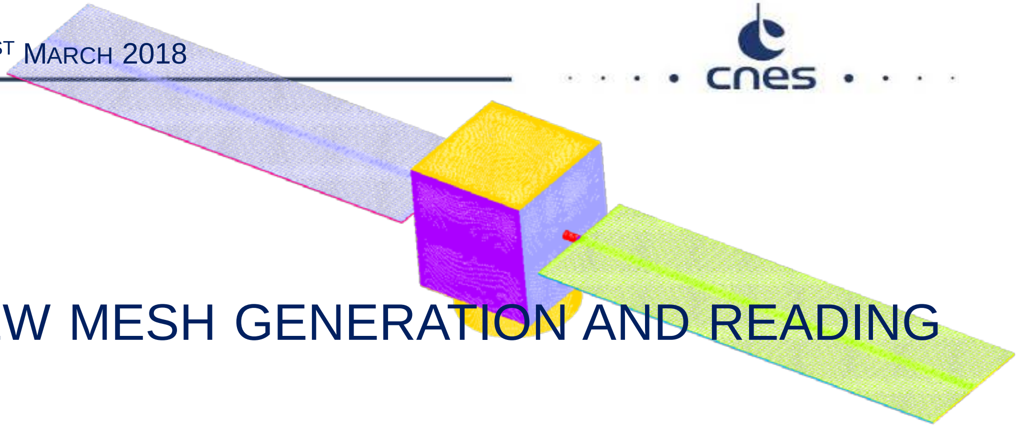


© cnes

OUTLINE





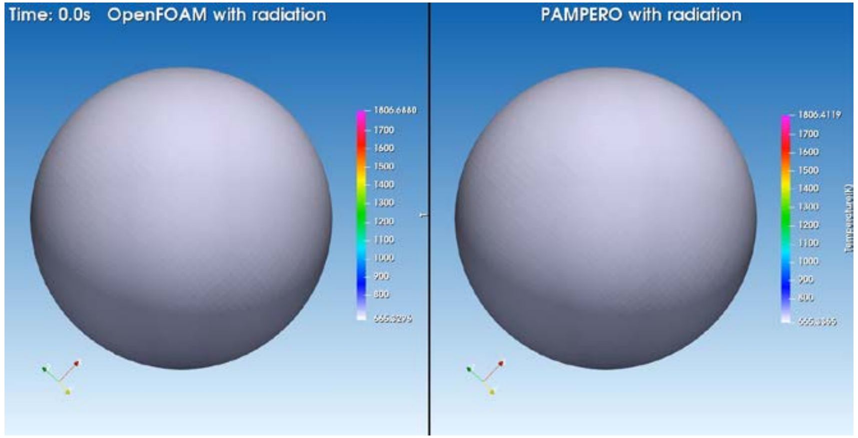


1. NEW MESH GENERATION AND READING
2. FLIGHT DYNAMICS
3. AEROTHERMODYNAMICS
4. ***HEAT TRANSFERS MODELLING & ABLATION***
5. MECHANICAL STRESS ANALYSIS
6. FRAGMENTATION

© cnes

HEAT TRANSFERS MODELLING & ABLATION

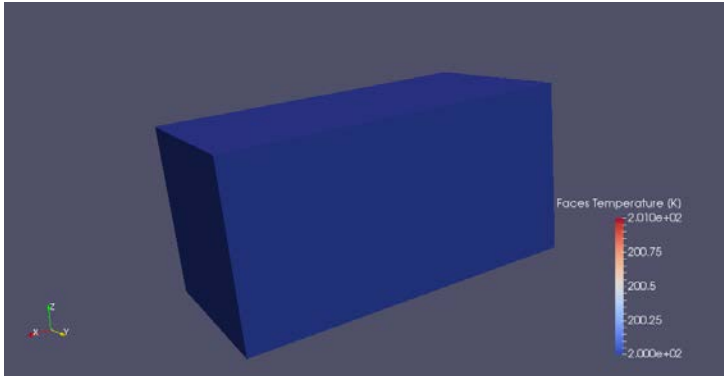
Collaboration with R.Tech Research & Technology

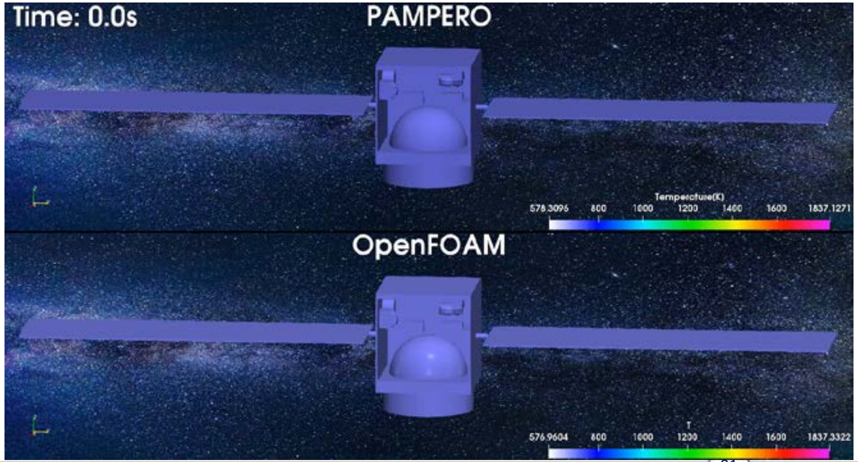


❖ Heat transfers modelling validation

- For simple objects via comparisons with analytical results and cross-check with Openfoam
- For a complex satellite with Openfoam (in progress)
- Taking into account multi-material objects is now possible. Validation planned in 2018.

Collaboration with gmv INNOVATING SOLUTIONS



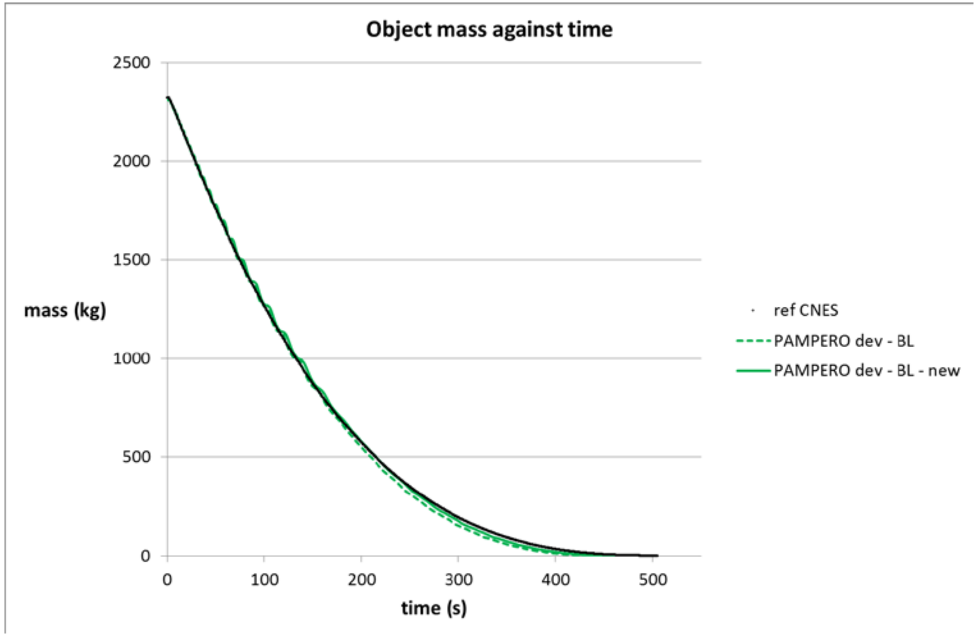


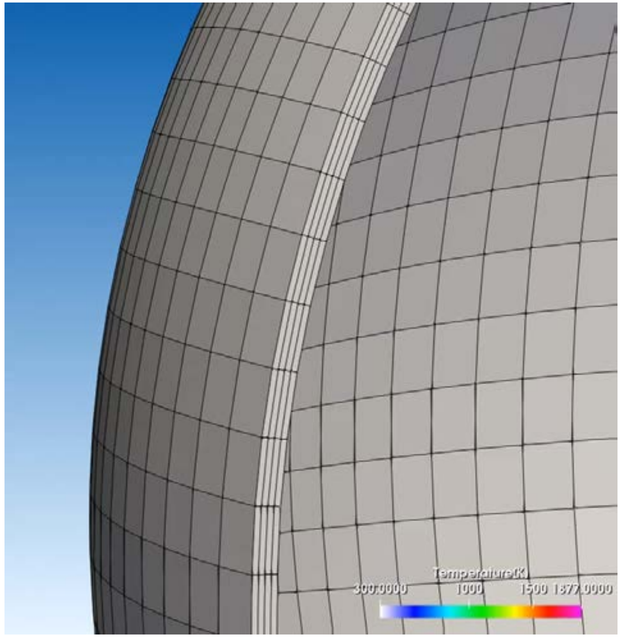
HEAT TRANSFERS MODELLING & ABLATION

Collaboration with R.Tech Research & Technology

Ablation validation

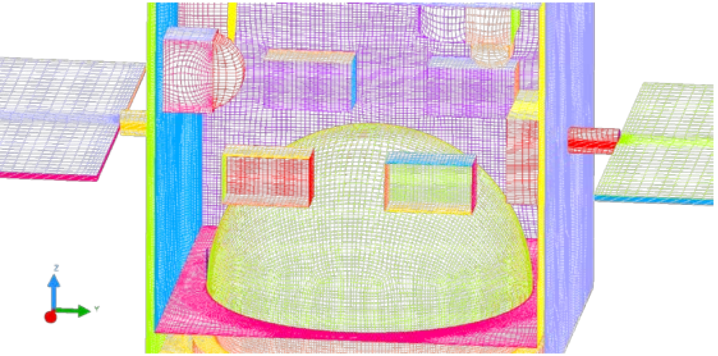
- For simple objects via comparison with analytical results

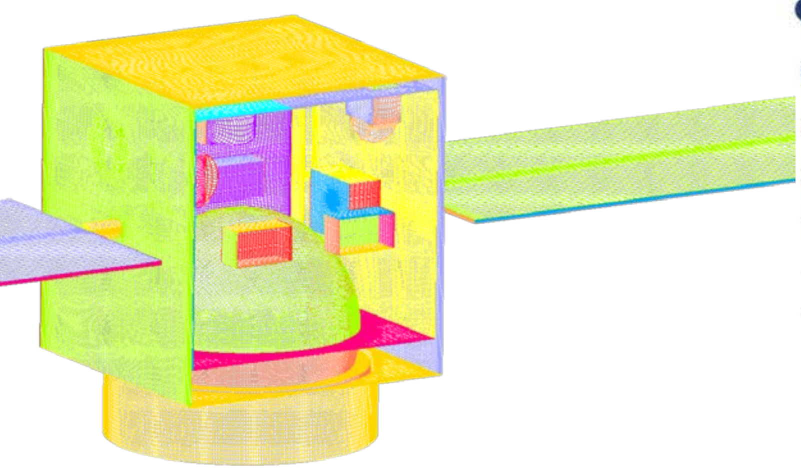


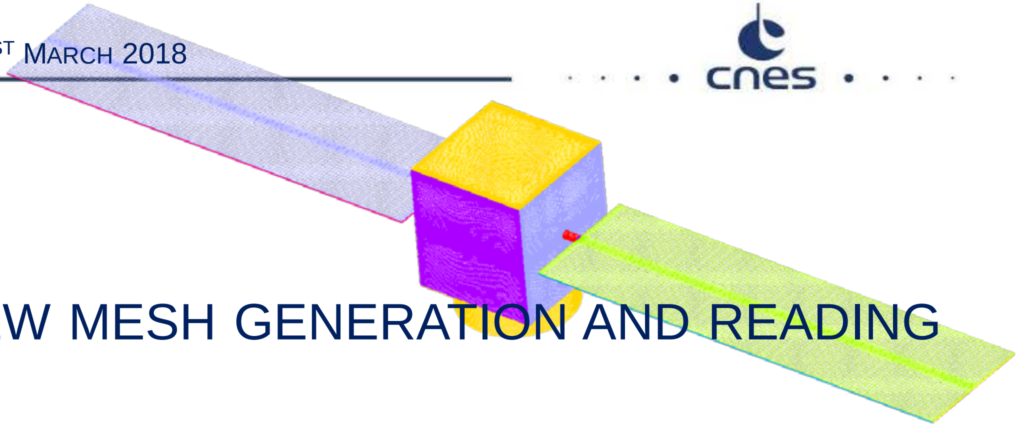


© cnes

OUTLINE







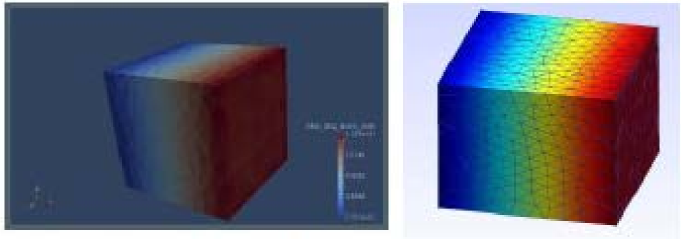
1. NEW MESH GENERATION AND READING
2. FLIGHT DYNAMICS
3. AEROTHERMODYNAMICS
4. HEAT TRANSFERS MODELLING & ABLATION
5. ***MECHANICAL STRESS ANALYSIS***
6. FRAGMENTATION

© cnes

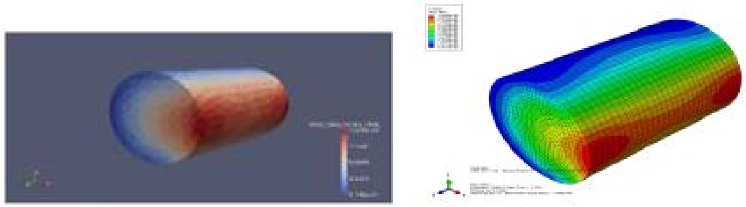
MECHANICAL STRESS ANALYSIS

Collaboration with

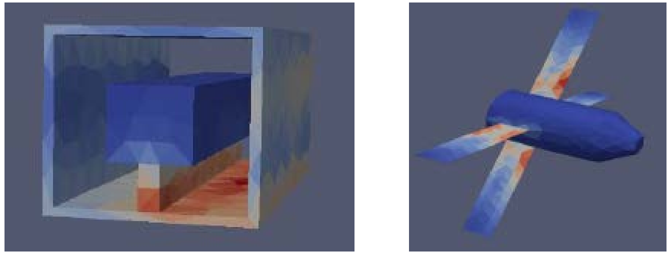
- Trade-off to take into account the mechanics
  - Coupling with an existing mechanical code
  - Selection of Code_Aster from EDF
- Assumptions
  - Rigid body motion (PAMPERO)
  - Quasi-static local displacements
    - Linear-elastic behavior assumption (small deformations)
    - Negligible impact of the deformation on aerodynamic and inertial forces computation
- Validity of the mechanical stress computations is ensure by Code_ASTER own validation
- Verification is focused on the coupling



Analytical verification



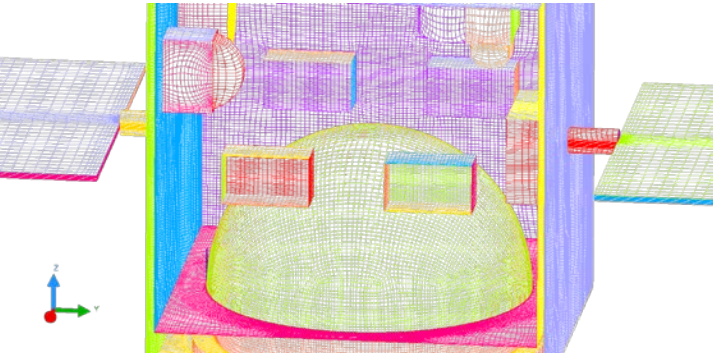
Code cross-check

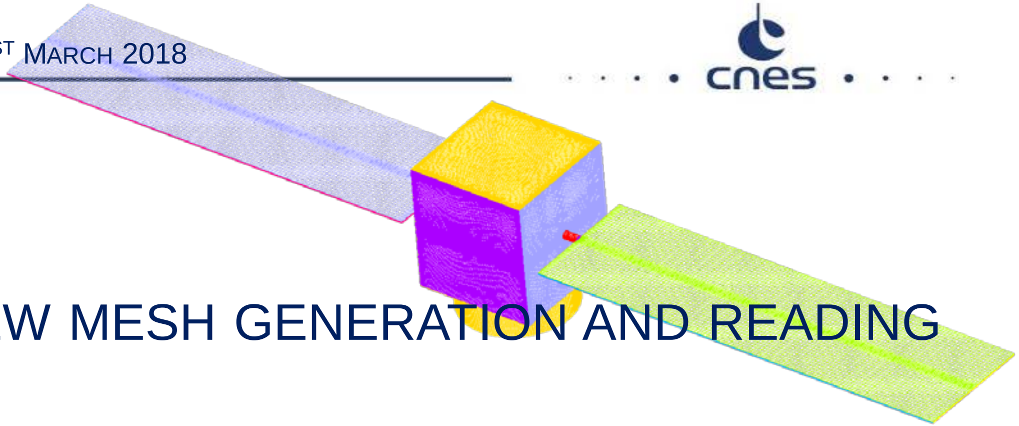


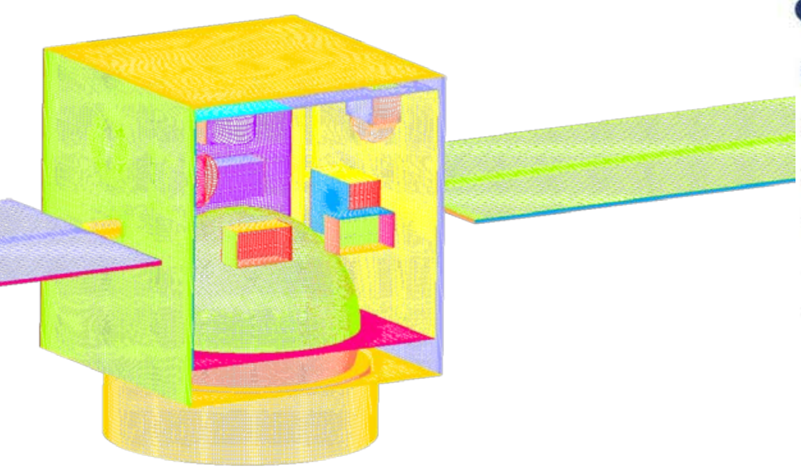
Qualitative verification

© cnes

OUTLINE





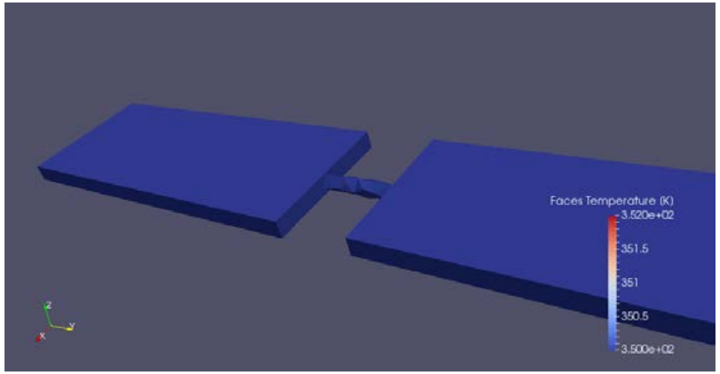


1. NEW MESH GENERATION AND READING
2. FLIGHT DYNAMICS
3. AEROTHERMODYNAMICS
4. HEAT TRANSFERS MODELLING & ABLATION
5. MECHANICAL STRESS ANALYSIS
6. ***FRAGMENTATION***

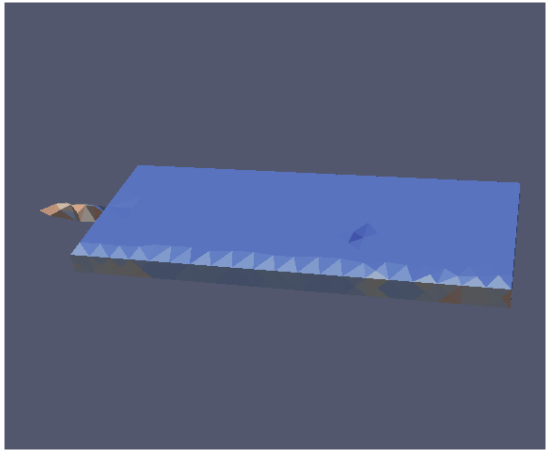
© cnes

FRAGMENTATION

Collaboration with gmv INNOVATING SOLUTIONS, CENTRALE NANTES



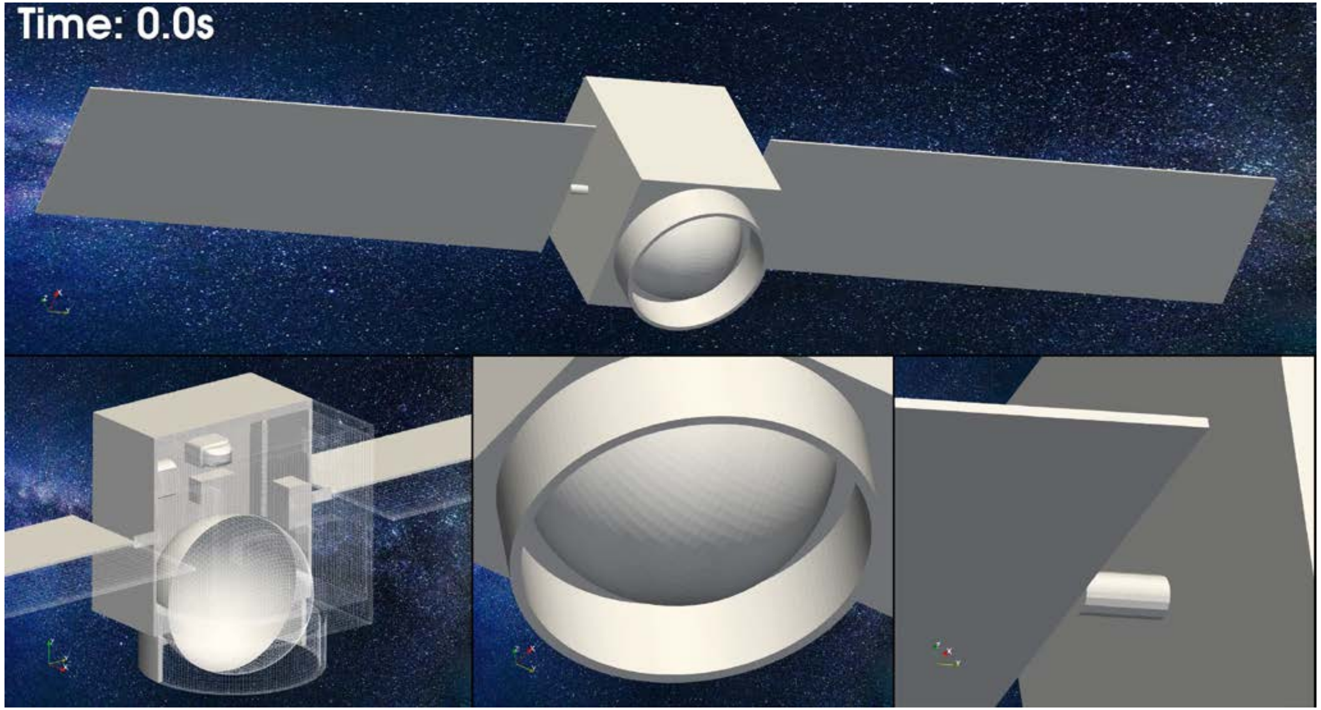
- **Possibility to demise cells through thermo mechanical criteria**
  - Melting temperature and fusion enthalpy
  - Maximal pressure
- **We consider the fragmentation when several pieces are no longer connected**
- **The fragments (mesh and configuration file) are saved and calculated separately**
- **Validation planned in 2018**



© cnes

CONCLUSIONS

- **PAMPERO is currently in an important phase of improvement and validation**
- **Our short-team goal is to perform complete computations on whole satellites along trajectories**



© cnes

Thank you to all the CNES team

Thank you to all our partners

R.Tech Research & Technology

Vincent Rivola
Martin Spel
Christophe Vasse

ONERA THE FRENCH AEROSPACE LAB

Ysolde Prévereaud
Jean-Luc Vérant
Fernando de la Puerte Cerezo

gmv INNOVATING SOLUTIONS

Javier Carro
Morgane Jouisse
Baptiste Crusson

Special thanks to Vincent Rivola for your help and all the movies/pictures generated for this presentation

© cnes