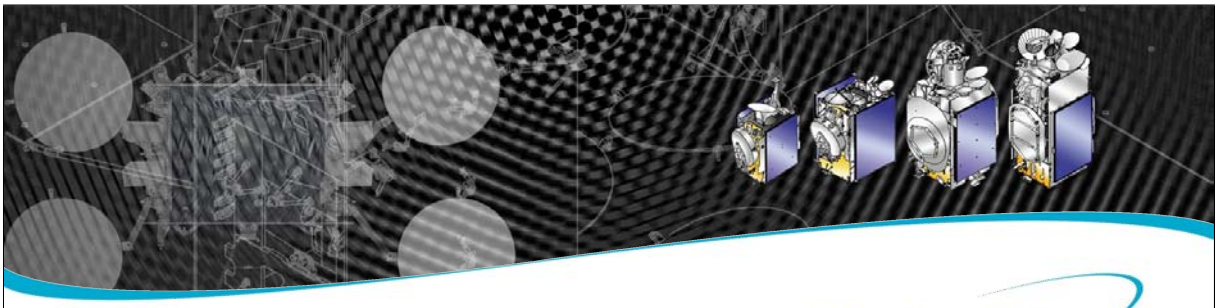
# Appendix N

## Thermal analysis for re-entry vehicles - software needs and expectations

Savino De Palo
(Thales Alenia Space, Italy)



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# Thermal Analysis for Re-Entry Vehicles - S/W Needs and Expectations

Savino De Palo - *Thermal Systems*
Federico Maretto - *Advanced Projects*

Template reference : 100182079N-EN

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## THERMAL ANALYSIS FOR RE-ENTRY VEHICLES

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- STUDY CASE 1 : THERMAL ANALYSIS FOR HMS
- CONCLUSIONS AND PERSPECTIVE
- STUDY CASE 2 : THERMAL ANALYSIS FOR HOT- STRUCTURES
- CONCLUSIONS AND PERSPECTIVE

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# INTRODUCTION

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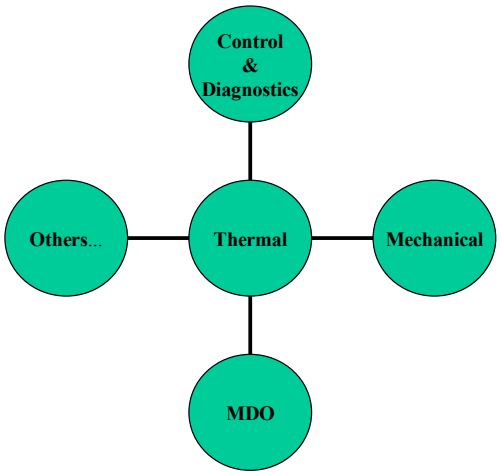
## INTRODUCTION




In the field of Re-Entry Vehicles there is a growing need for Thermal Analysis (TA) not only for Thermal Design needs but also to support other disciplines as Mechanical, Control, etc..

In some cases data exchange and coupling among disciplines are so critical that the TA must be performed with tools different from the standard ones (e.g. ESATAN- ESARAD) even for ESA programs !




# STUDY CASE 1 – TA FOR HMS

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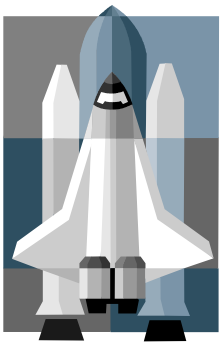
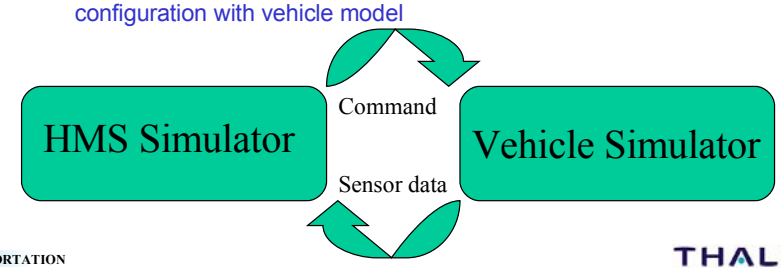
## STUDY CASE 1 : THERMAL ANALYSIS FOR HEALTH MONITORING SYSTEMS



**• HMS for RSTS is an ESA Program dedicated to next generation re-usable Re-Entry vehicles:**

- On-board and off-board monitoring systems :
  - healt status check
  - corrective actions during flight
  - maintenance planning / optimization between flights
  - Go/No Go for next flight
- HMS real time simulator to be defined and tested in working configuration with vehicle model



## STUDY CASE 1 – TA FOR HMS

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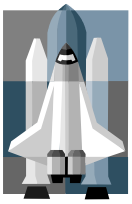
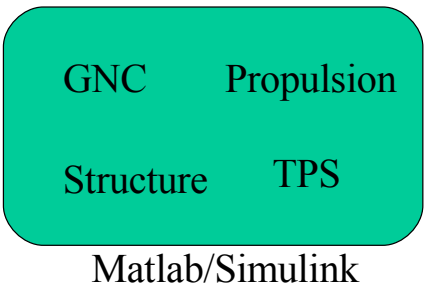
### VEHICLE SIMULATOR

- **Baseline is Hopper vehicle concept (Astrium)**
- **Physical models of the following subsystems:**
  - GNC
  - Propulsion
  - Structure
  - **TPS**
- **Simulator to be developed with Matlab/Simulink**
  - Model-Based Design tool
  - Standard tool for Control System design
  - Able to model any type of Dynamic System
  - Several add-ons available but no one dedicated to Thermal →develop internal models









## STUDY CASE 1 – TA FOR HMS

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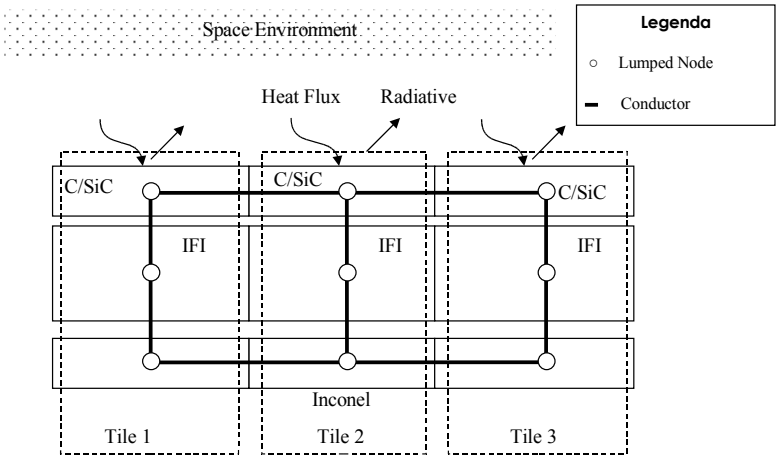
### TPS THERMAL MODEL (1)

- Lumped Parameter approach : physical modelling based on 1° principle
- Full non-linearity implemented (radiative heat exchange, material performance vs T ...)
- Ageing/failure modes/degradations can be switched on/off or tuned on demand



## STUDY CASE 1 – TA FOR HMS

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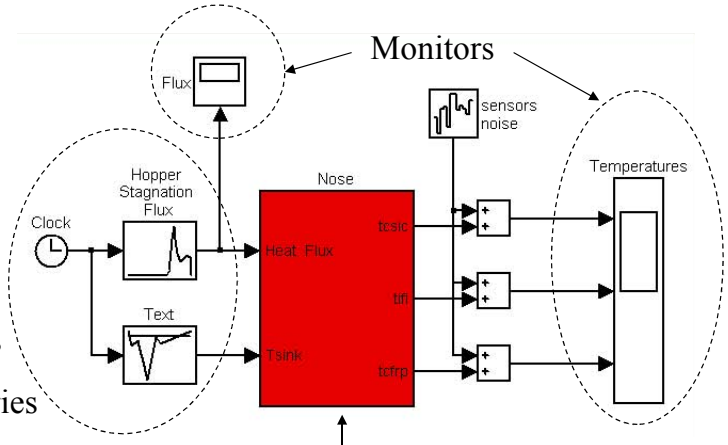
•TPS THERMAL MODEL (2)

• Physical/Geometrical data

Matlab Script

• computation of [C] [GL] [GR] matrixes

model structure variable (.mat)




•Lumped Parameter Heat Equation

•Ageing/degradation/failure effects




## STUDY CASE 1 – TA FOR HMS

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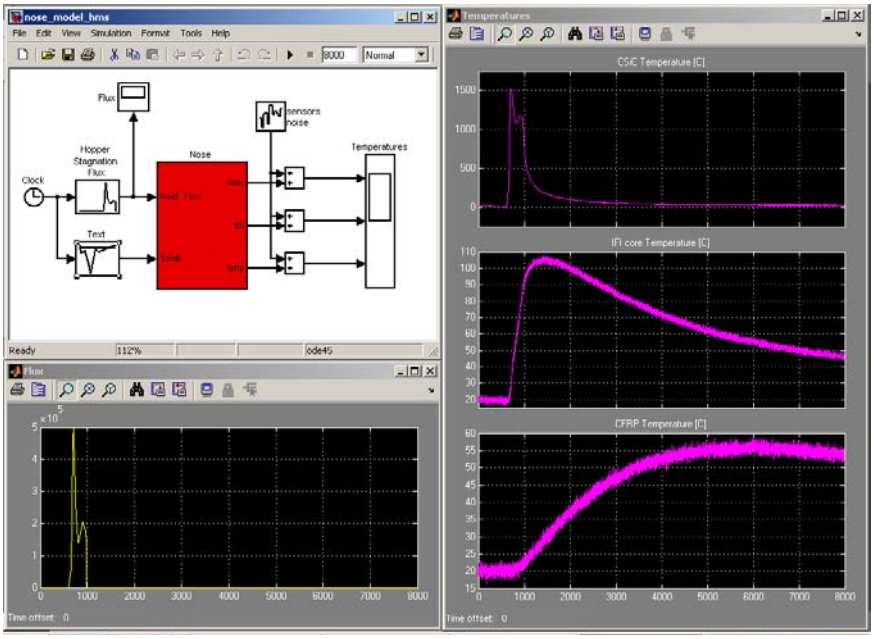
•TPS THERMAL MODEL (3)



## STUDY CASE 1 – TA FOR HMS

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### CONCLUSIONS ON STUDY CASE 1 (1)

**WHY SIMULINK THERMAL MODELS ?**

***Thermal models in MATLAB / SIMULINK can be useful for the following tasks (other than Re-Entry vehicles applications...)***

- Control Systems developement (e.g., PID), providing also a clear link between Thermal Dept. & Avionic Dept.
- Real Time simulator for real time applications (flight operations, tests ...)
- Integrated analysis with any type of system (HMS like, multiphysics)




## STUDY CASE 1 – TA FOR HMS

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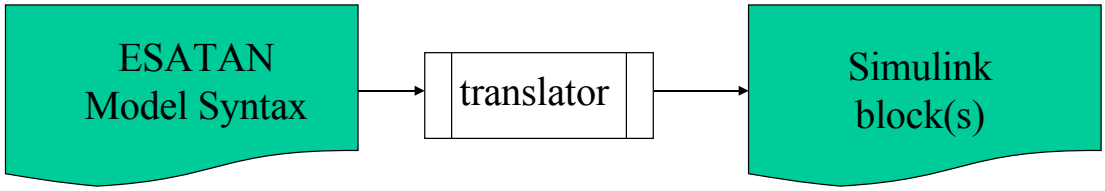
### CONCLUSIONS ON STUDY CASE 1 (2)

**THERMAL S/W INTERFACING WITH MATLAB / SIMULINK ?**

- Comsol MultiPhysics (export FEM models to S-functions)
- SINDA models can be run/stop from Matlab command lines

***Need for automatic translator from Lumped Parameter model (e.g. ESATAN like syntax) to Simulink model (e.g. S-function)***



## STUDY CASE 2 – TA FOR HOT-STRUCTURES

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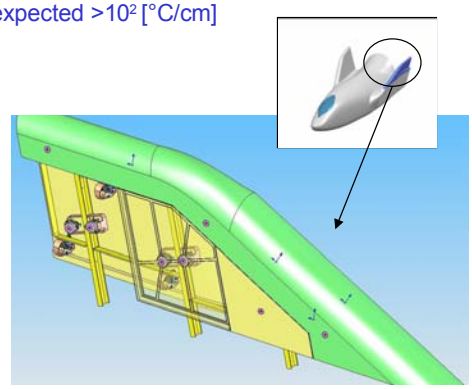
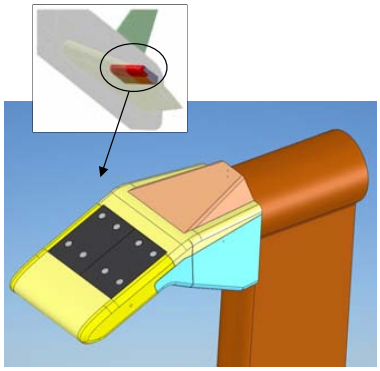
### STUDY CASE 2 : THERMAL ANALYSIS FOR HOT-STRUCTURES

- Hot-Structures are key components for next generation Re-Entry vehicles
  - 5°European WorkShop on TPS & Hot Structures
- Thermal-Mechanical interactions is the core problem
  - Reduce deformations to the minimum (plasma injection must be avoided)
  - Thermal gradients expected >$10^2$ [°C/cm]
  - Bolts pre-loading
  - Contact
- Thermal analysis must be :
  - Accurate
  - Detailed
  - Good interpolation with FEM
- Other aspects
  - CAD I/F



Hybrid Structures



ASA experiment




## STUDY CASE 2 – TA FOR HOT-STRUCTURES

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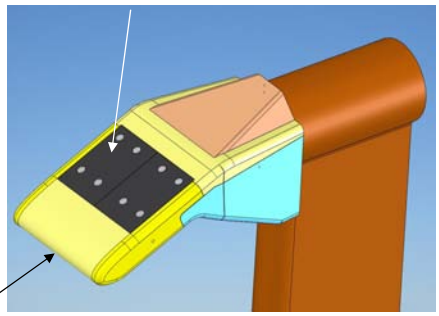
### ADVANCED STRUCTURE ASSEMBLY (ASA)

- **Research financed by the Italian Space Agency (ASI)**
- **Goal: use new technologies, test at material and wing assembly levels (Scirocco PWT)**
- **Wing Leading Edge**
  - Actively Cooled (Thales Alenia Space)
  - UHTC (CIRA)
- **Closure Panels**
  - Hybrid Panels (Univ. La Sapienza)
  - Metal Matrix Composite (CSM)
- **Thermal- Mechanical design developed with MultiPhysics approach by using Ansys 10**
- **ESATAN-FHTS used for hydraulic elements only**

Closure Panel



Wing Leading Edge

## STUDY CASE 2 – TA FOR HOT-STRUCTURES

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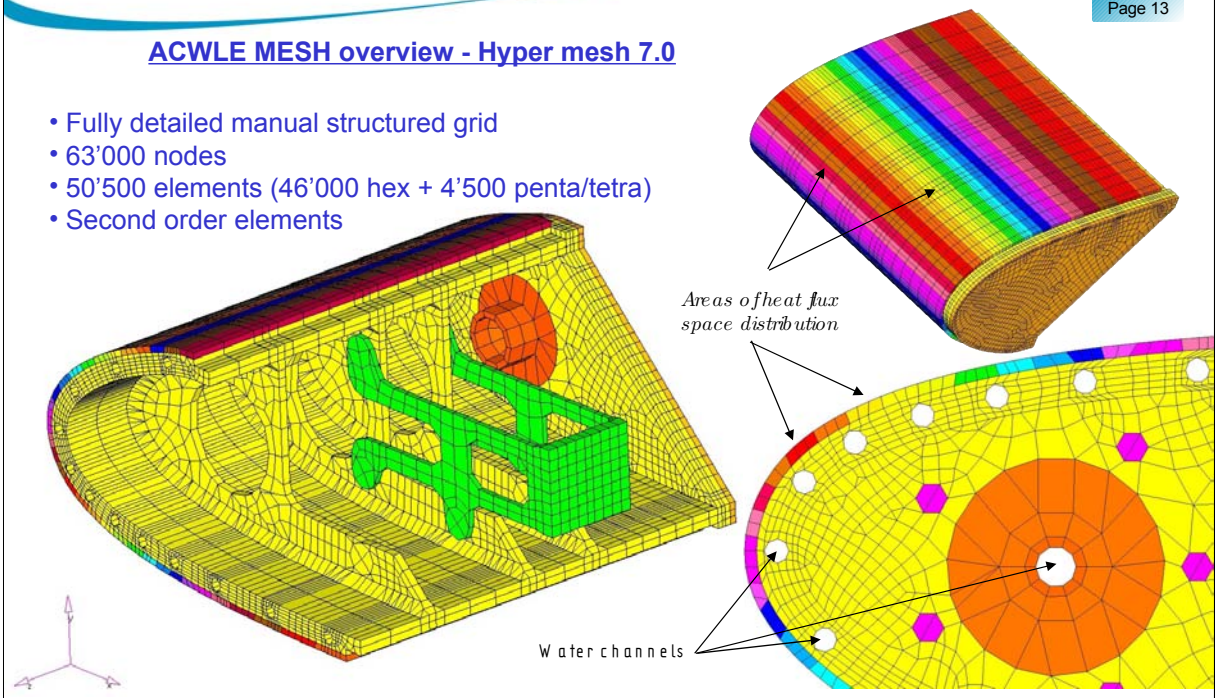
### ACWLE MESH overview - Hyper mesh 7.0

- Fully detailed manual structured grid
- 63'000 nodes
- 50'500 elements (46'000 hex + 4'500 penta/tetra)
- Second order elements

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## STUDY CASE 2 – TA FOR HOT-STRUCTURES

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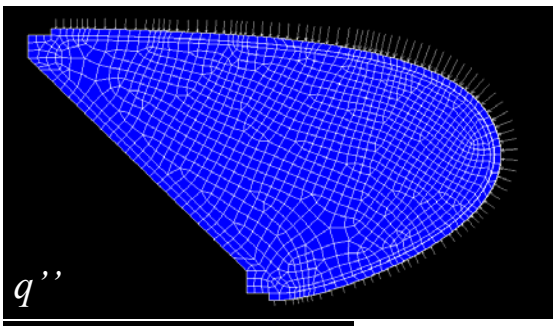
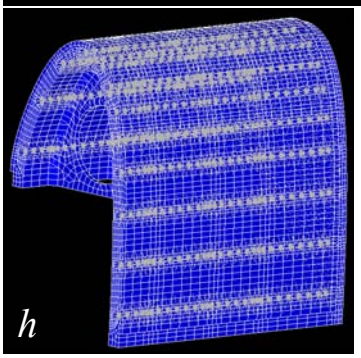
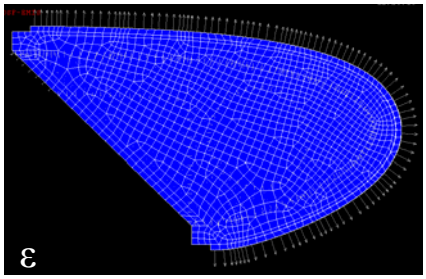
### THERMAL ANALYSIS overview Ansys 10.0

- Transient non-linear thermal analysis, 4000s
- Material properties temperature dependent
- Heat fluxes distributed in time and space
- Convection distributed along ACWLE channels lenght and manifolds computed with FHTS
- External radiation

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## STUDY CASE 2 – TA FOR HOT-STRUCTURES

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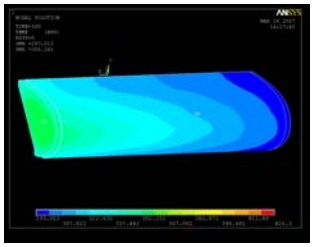
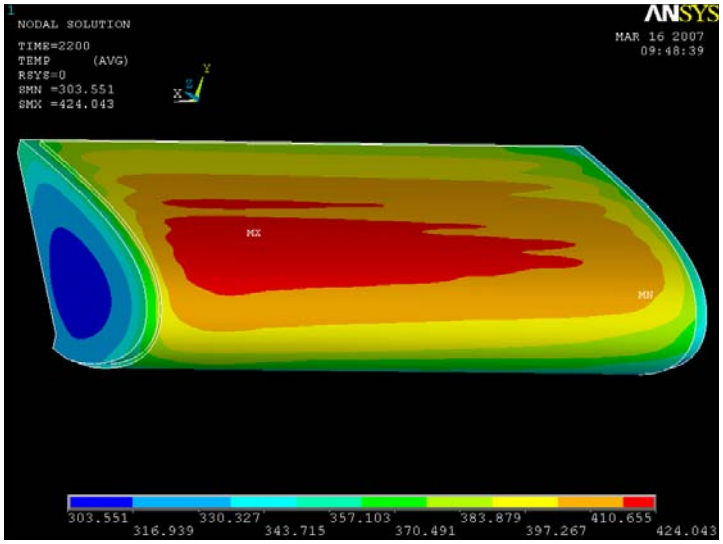
### THERMAL ANALYSIS - Temperature

Max Temperature raised :
@ 2400s → 426°K (153°C)



*Animation 0>4000s*







## STUDY CASE 2 – TA FOR HOT-STRUCTURES

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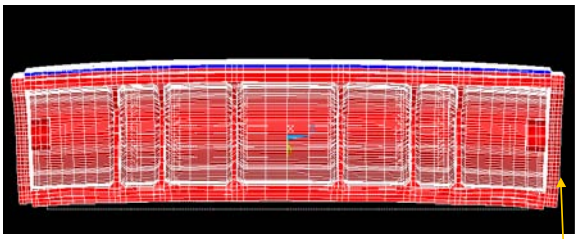
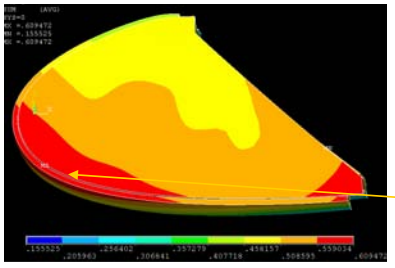
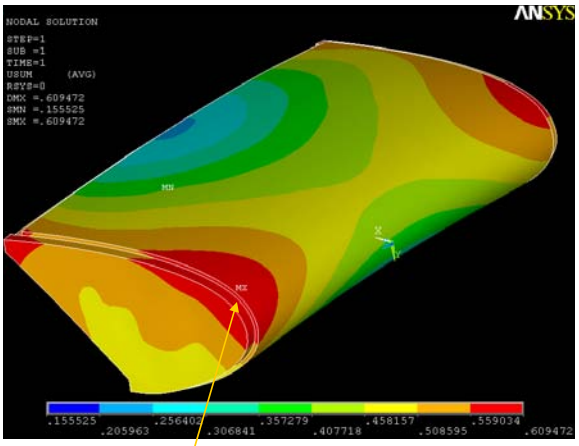
### MECHANICAL ANALYSIS - temperature effects (1)

Displacement



Max temperature:153°C






Max displacement: 0.61mm

## STUDY CASE 2 – TA FOR HOT-STRUCTURES

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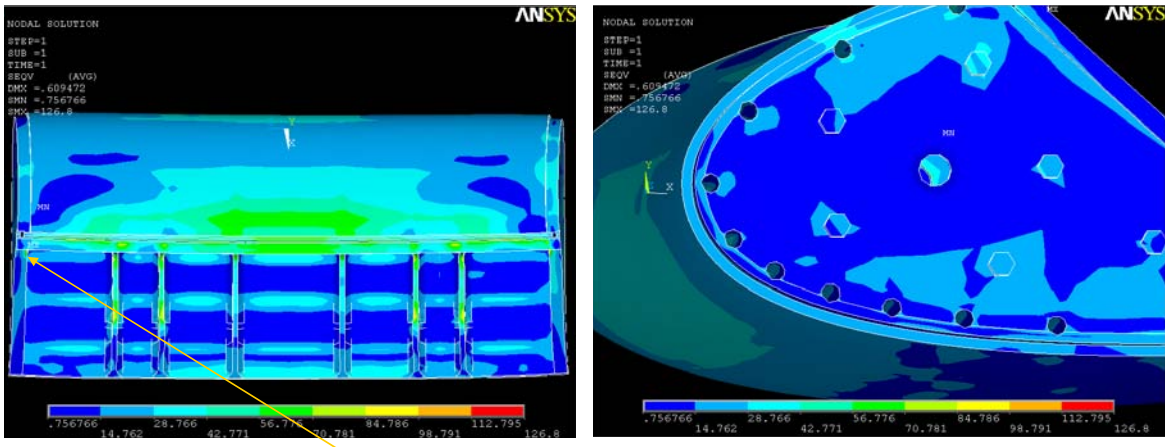
### MECHANICAL ANALYSIS - Temperature Effects (1)

Von Mises stress




Max: 140MPa@117°C




## STUDY CASE 2 – TA FOR HOT-STRUCTURES

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### CONCLUSIONS ON STUDY CASE 2

- Hot-Structures is one of the “natural” application of Multiphysics analysis
- Huge FEM models → System size limitations (not for complete vehicle models!)
- Several COTS S/W are available for MultiPhysics analysis (Ansys, Abaqus ...) which allow:
  - direct coupling with Mechanical (and not only) FEM models
  - rapid implementation of design modifications with CAD models
- These tools are already the standard S/W for Re-Entry vehicle applications
- Interfaces with CFD codes is another key point. Also in this case COTS tools (e.g. MpCCI) are already the standard

**To have a clear idea of the market status, COTS MultiPhysics FEM tools developers should be invited at the WorkShop to discuss / present / make demonstrations on thermal applications**