Appendix D

Advances in AblaTan Ablative Tool development with application to system model analysis

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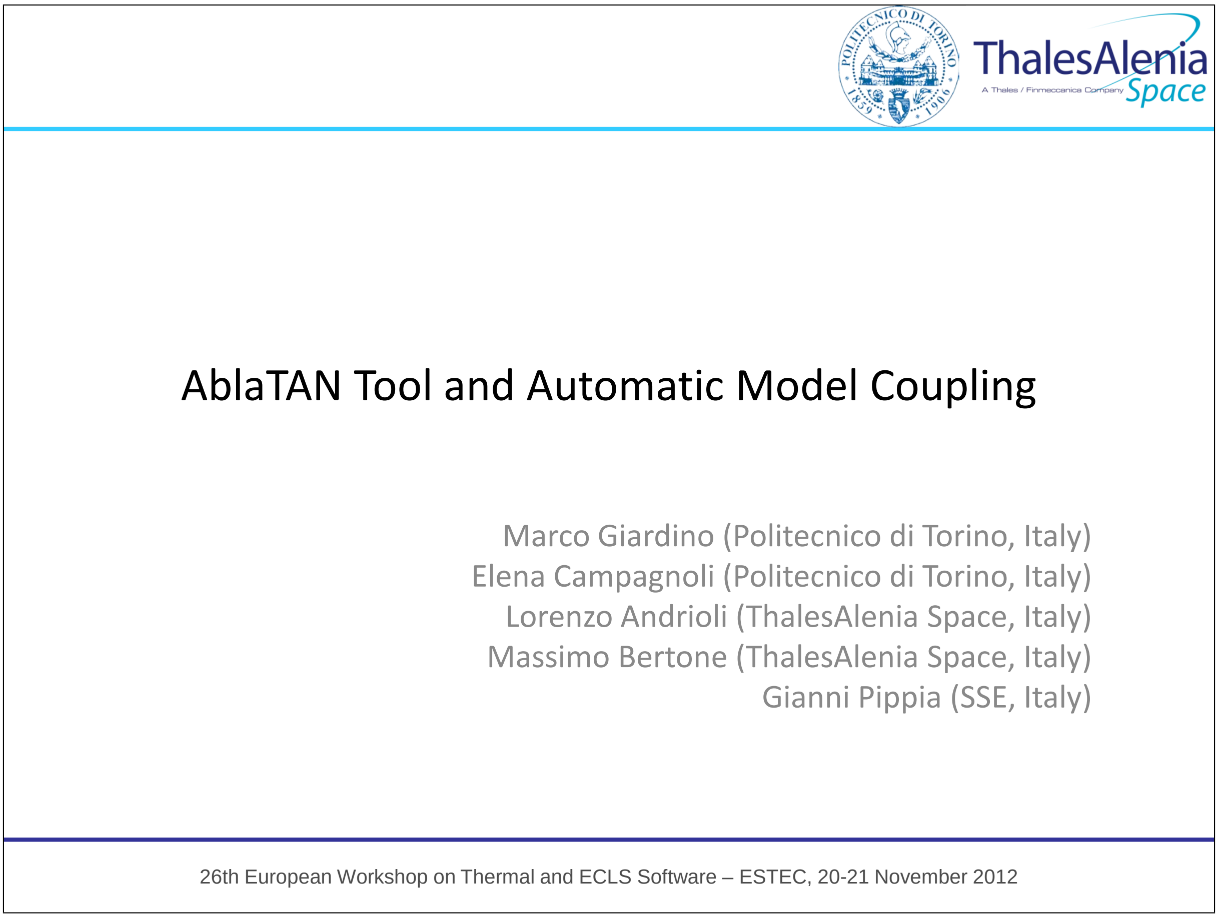
Abstract

AblaTan is the ablative shield analysis tool, developed by ThalesAlenia Space — Italy and Politecnico di Torino, fully compatible with the ESATAN-TMS suite. The tool is currently undergoing first real application on system level analysis to assess the expected advantages of integrated approach analysis versus segregated/iterative method, for which ablative tool and system model TMM are run in a standalone fashion.

First results and discussion are presented together with the tool current development status.



AblaTAN Tool and Automatic Model Coupling

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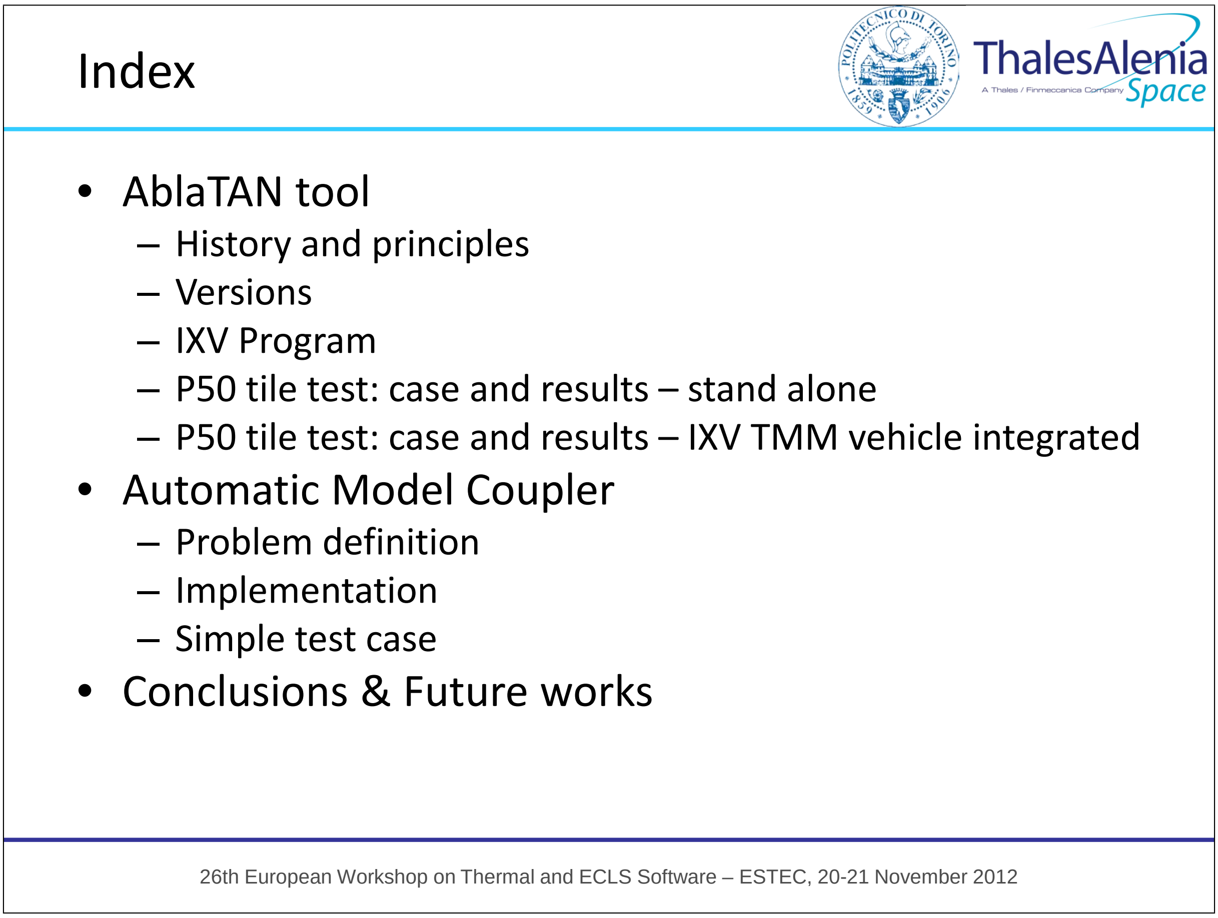

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AblaTAN history and principles

- Development started in 2011
- Simplified state of the art charring ablative material model directly in ESATAN
- Stand alone or system scale integrated simulations capability
- User friendly and reusable
- Minimize input parameters deck
- Options available for physics setting

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AblaTAN versions

- 1.0.0 2011-11-08, base version, Apollo and EXOMARS simulations (presented at 25th Eurpean Workshop on Thermal and ECLS Software);
- 1.1.0 2012-05-09, new evaluation of pyrolysis heat sink term, quadratic evaluation of the all enthalpy values;
- 1.2.0 2012-06-12, bug fixed the corrective terms related to grid motion due to surface recession;
- 1.2.1 2012-06-15, added simplified geometry specification for radial geometries, TACOT test (http://ablation2012.engineering.uky.edu/); results anticipated at 6th European Ablation Working Group (June 2012); presented 42nd ICES, 15-19 July 2012;
- 1.2.2 2012-10-23, bug fix of a error in mass conservation evaluation for multi component material during surface recession;
- 1.2.3 2012-10-26, bug fix of the heat sink term related to material degradation;
- 1.2.4 2012-10-30, updated output format, time dependent external flow type (laminar or turbulent), updated the routine that read the input data to process more generic files;
- 1.2.5 2012-11-06, the tool now automatically check the solver type, and then set the correct properties update procedure, integrated IXV simulation;
- 1.3.0 expected for 2012-12, compatibility with the Automatic Model coupler Tool;
- 1.4.0 expected for 2013-04, thermochemical recession through thermochemical tables;

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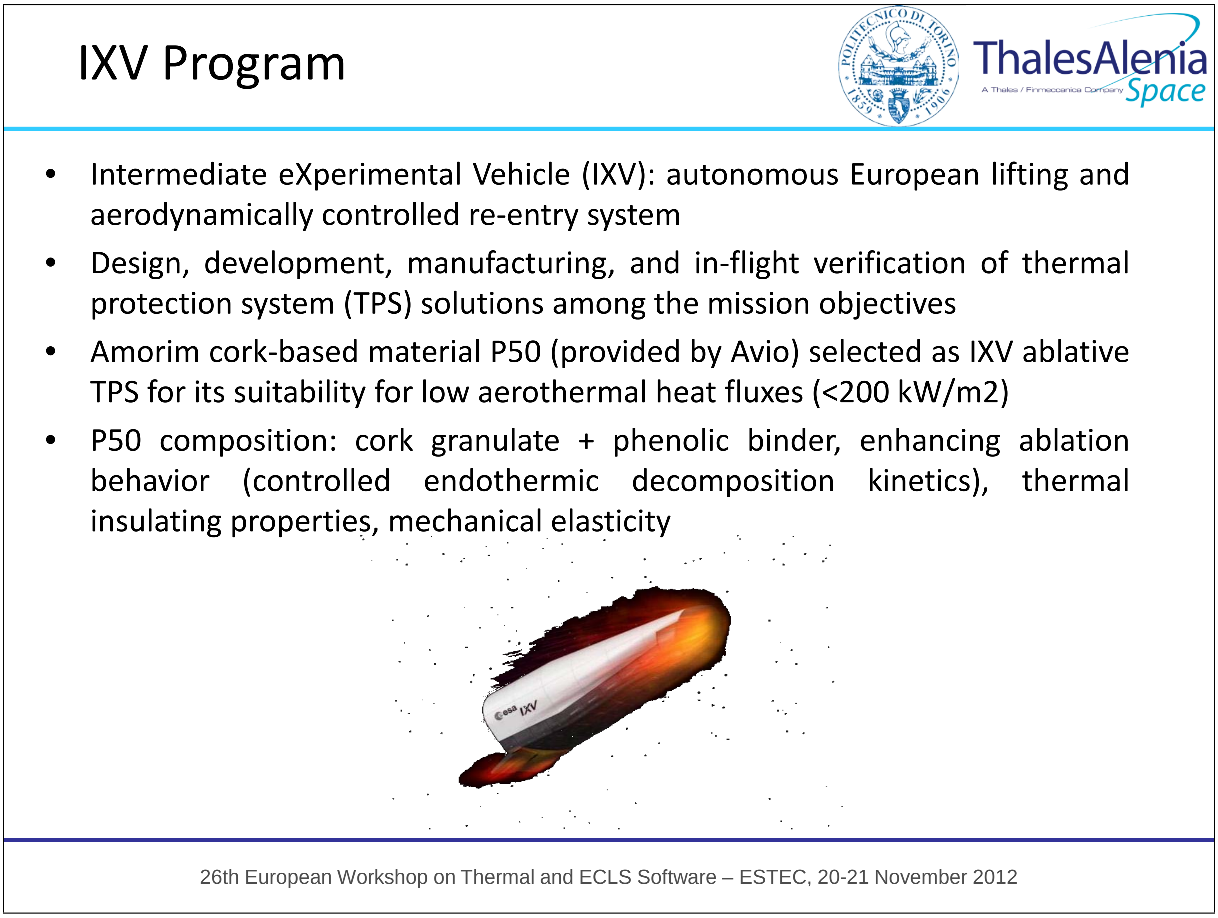

IXV Program

- Intermediate eXperimental Vehicle (IXV): autonomous European lifting and aerodynamically controlled re-entry system
- Design, development, manufacturing, and in-flight verification of thermal protection system (TPS) solutions among the mission objectives
- Amorim cork-based material P50 (provided by Avio) selected as IXV ablative TPS for its suitability for low aerothermal heat fluxes (<200 kW/m2)
- P50 composition: cork granulate + phenolic binder, enhancing ablation behavior (controlled endothermic decomposition kinetics), thermal insulating properties, mechanical elasticity

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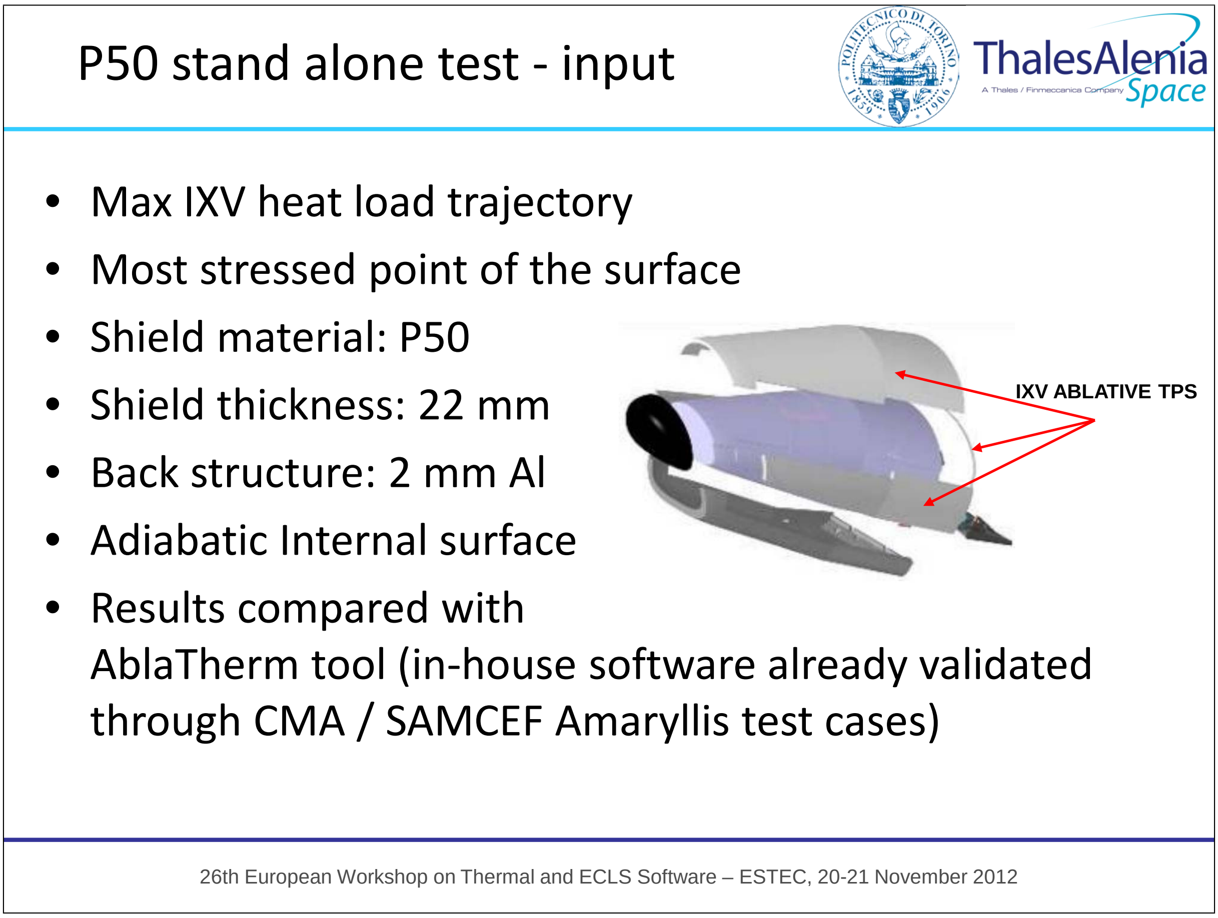

P50 stand alone test - input

- Max IXV heat load trajectory
- Most stressed point of the surface
- Shield material: P50
- Shield thickness: 22 mm
- Back structure: 2 mm Al
- Adiabatic Internal surface
- Results compared with AblaTherm tool (in-house software already validated through CMA / SAMCEF Amaryllis test cases)

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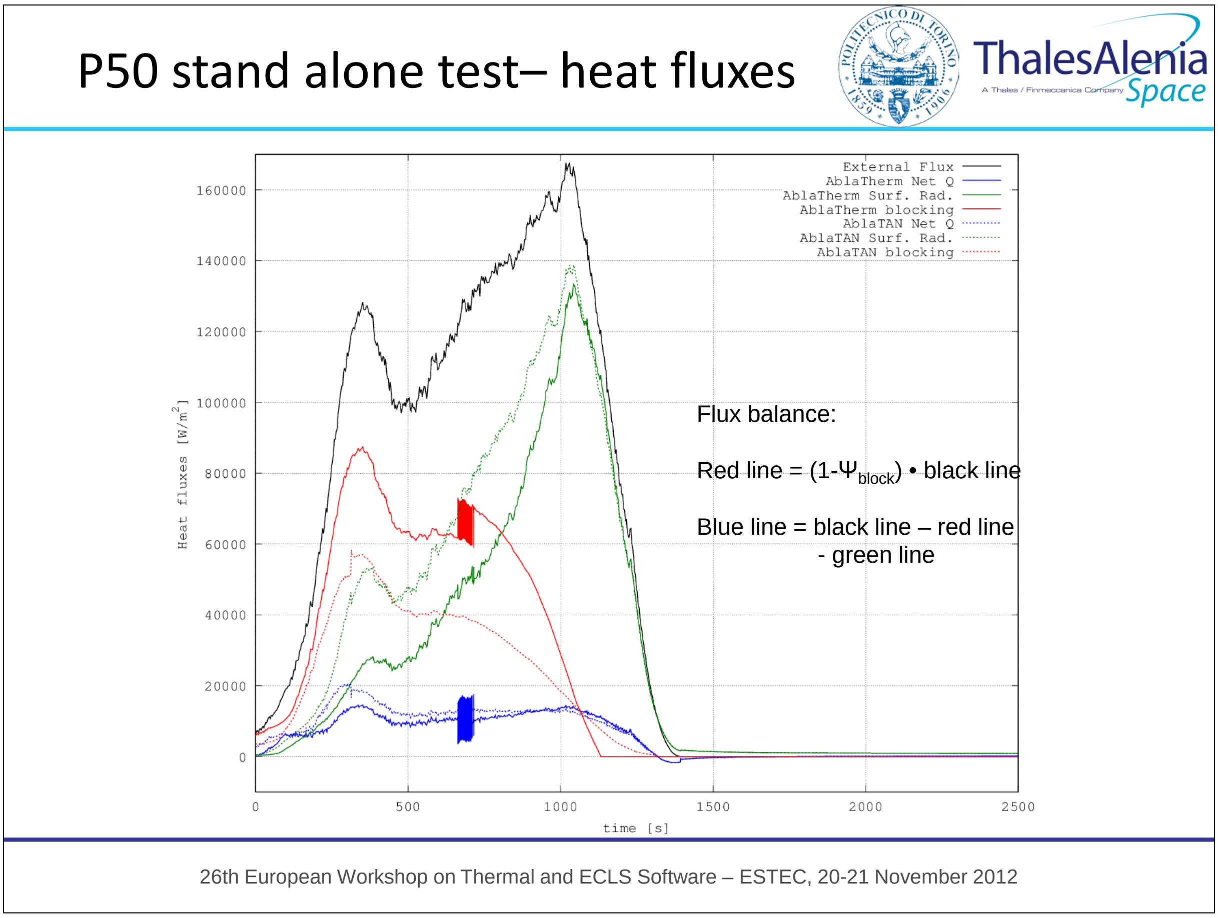

P50 stand alone test– heat fluxes

Flux balance:

Red line = $(1-\Psi_{block})$ • black line

Blue line = black line – red line - green line

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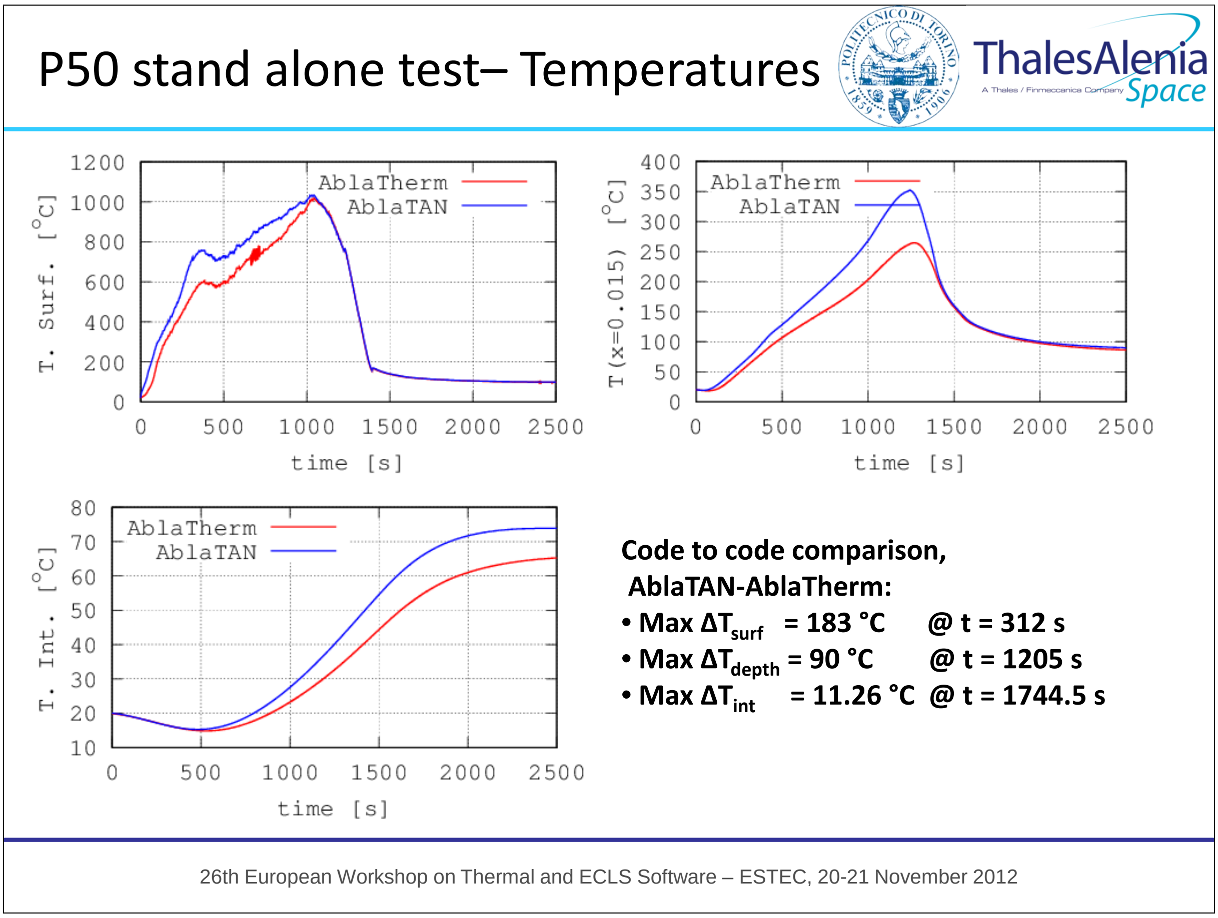

P50 stand alone test– Temperatures

Code to code comparison, AblaTAN-AblaTherm:

- **Max ΔT_{surf} = 183 °C @ t = 312 s**
- **Max ΔT_{depth} = 90 °C @ t = 1205 s**
- **Max ΔT_{int} = 11.26 °C @ t = 1744.5 s**

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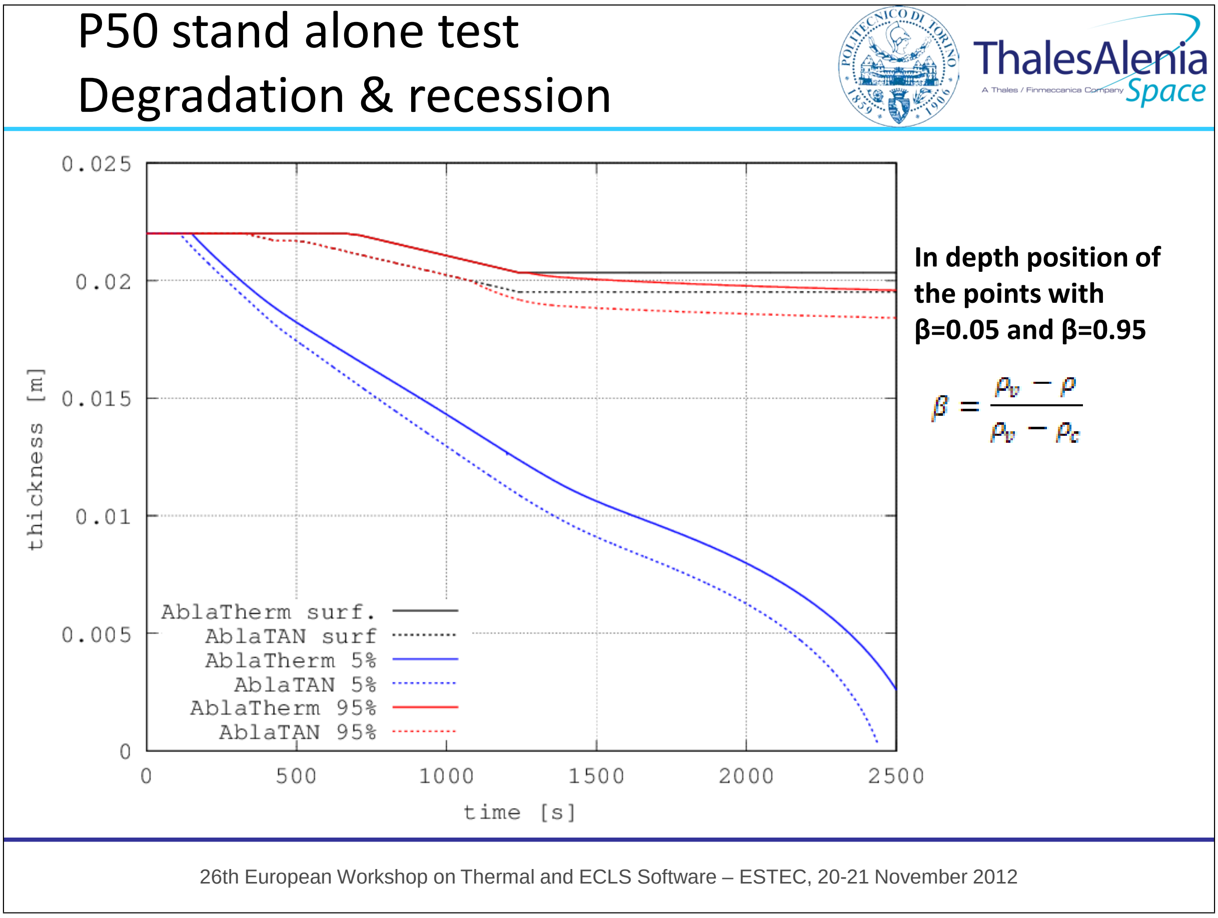

P50 stand alone test Degradation & recession

In depth position of the points with β=0.05 and β=0.95

$$\beta = \frac{\rho_v - \rho}{\rho_v - \rho_c}$$

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P50 stand alone test Results comparison

- Different surface temperatures due to wall enthalpy evaluation methods used in the blocking models
- AblaTAN results (which relies on ESATAN solvers) show a higher stability (no oscillations in the results and a larger time step) and forecasts a deeper pyrolysis depth
- AblaTAN provides higher temperature (caused by the lower blocking effect)
- Temperature differences at the end of the trajectory, structure to ablative interface : 8.6 °C

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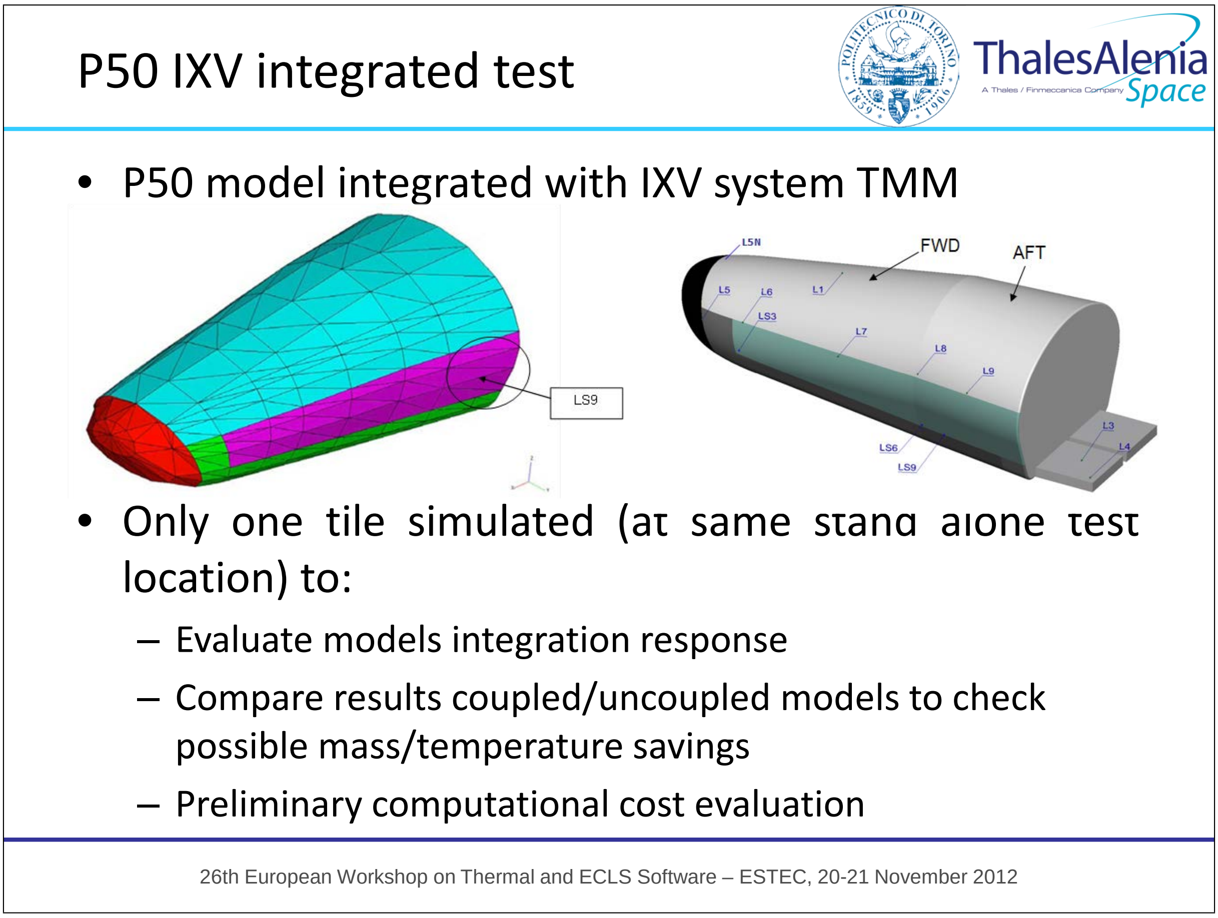

P50 IXV integrated test

- P50 model integrated with IXV system TMM

- Only one tile simulated (at same stand alone test location) to:
  - Evaluate models integration response
  - Compare results coupled/uncoupled models to check possible mass/temperature savings
  - Preliminary computational cost evaluation

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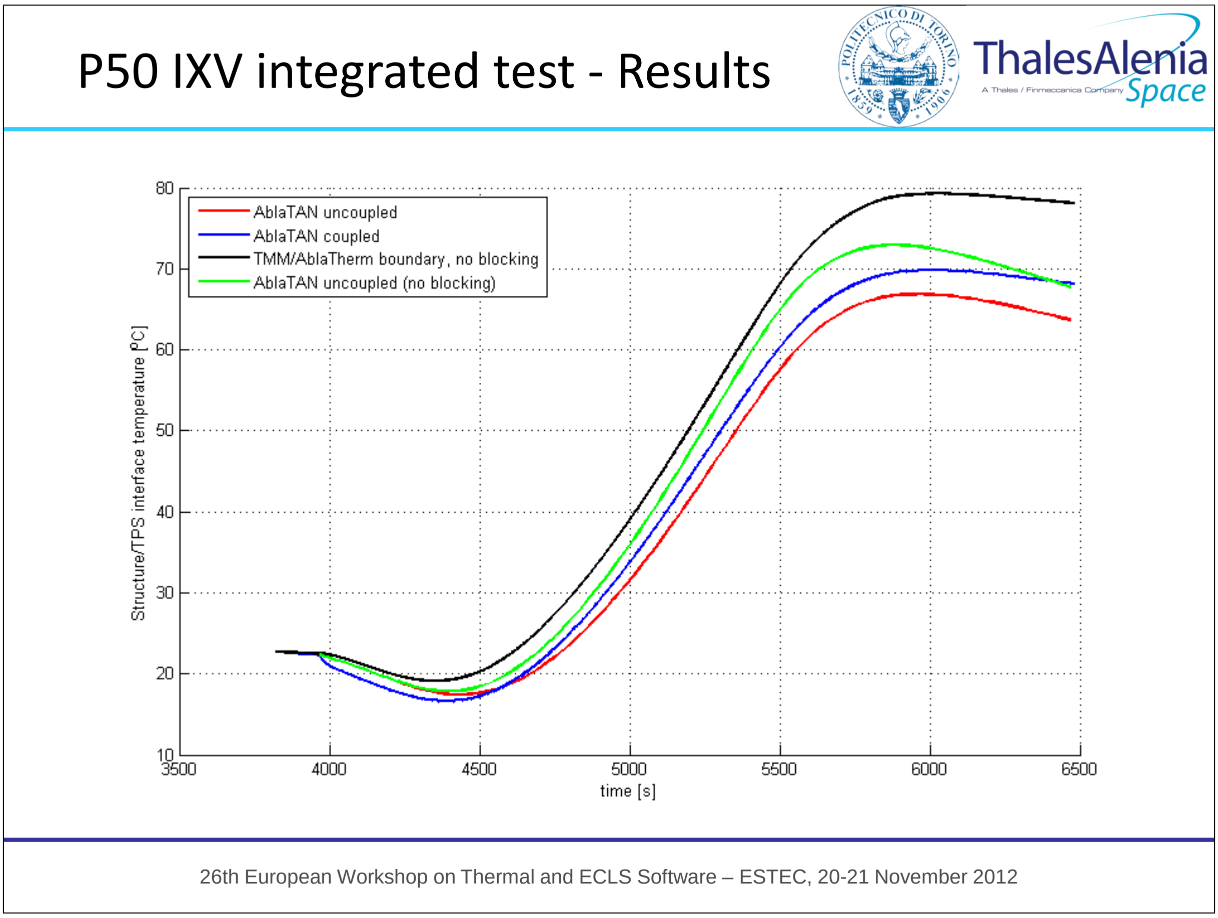

P50 IXV integrated test - Results

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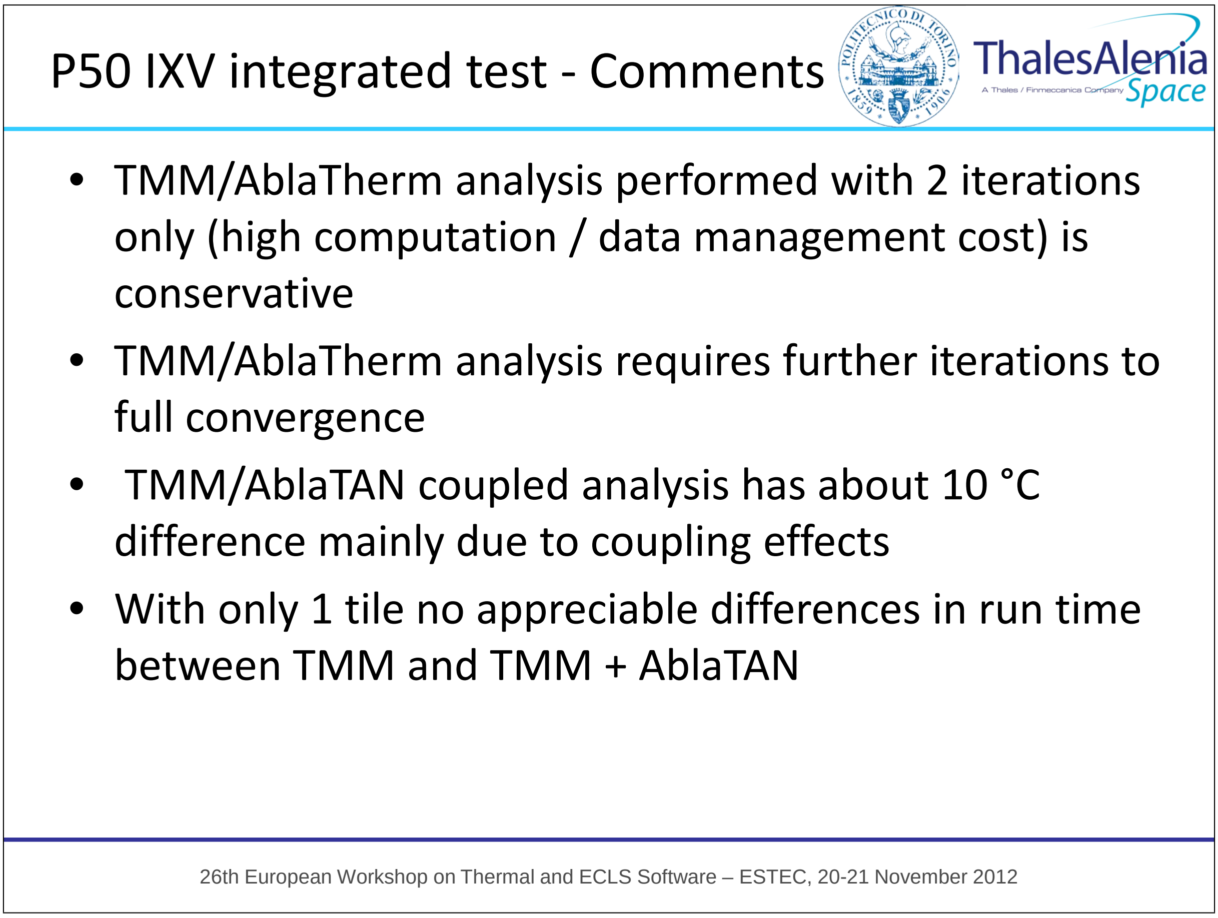

P50 IXV integrated test - Comments

- TMM/AblaTherm analysis performed with 2 iterations only (high computation / data management cost) is conservative
- TMM/AblaTherm analysis requires further iterations to full convergence
- TMM/AblaTAN coupled analysis has about 10 °C difference mainly due to coupling effects
- With only 1 tile no appreciable differences in run time between TMM and TMM + AblaTAN

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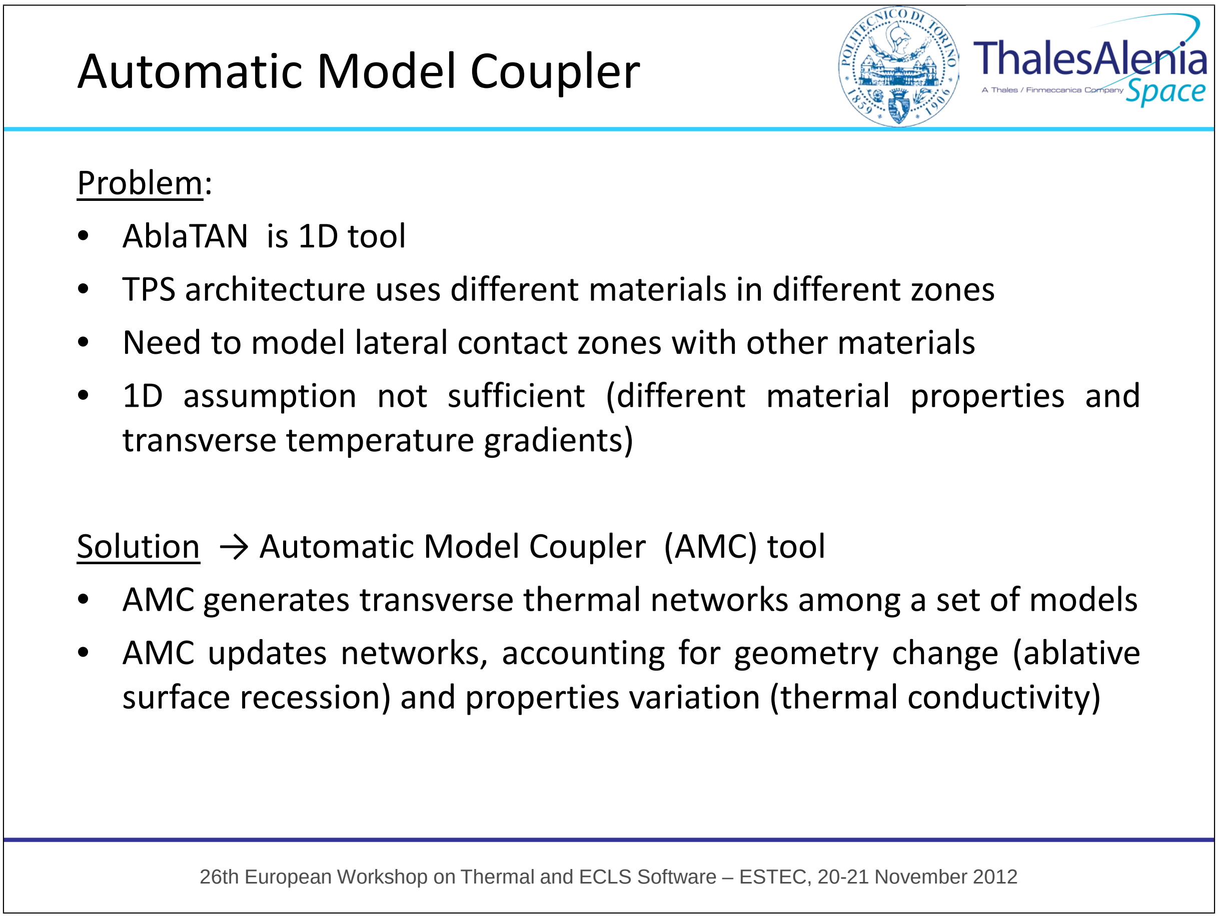

Automatic Model Coupler

Problem:

- AblaTAN is 1D tool
- TPS architecture uses different materials in different zones
- Need to model lateral contact zones with other materials
- 1D assumption not sufficient (different material properties and transverse temperature gradients)

Solution → Automatic Model Coupler (AMC) tool

- AMC generates transverse thermal networks among a set of models
- AMC updates networks, accounting for geometry change (ablative surface recession) and properties variation (thermal conductivity)

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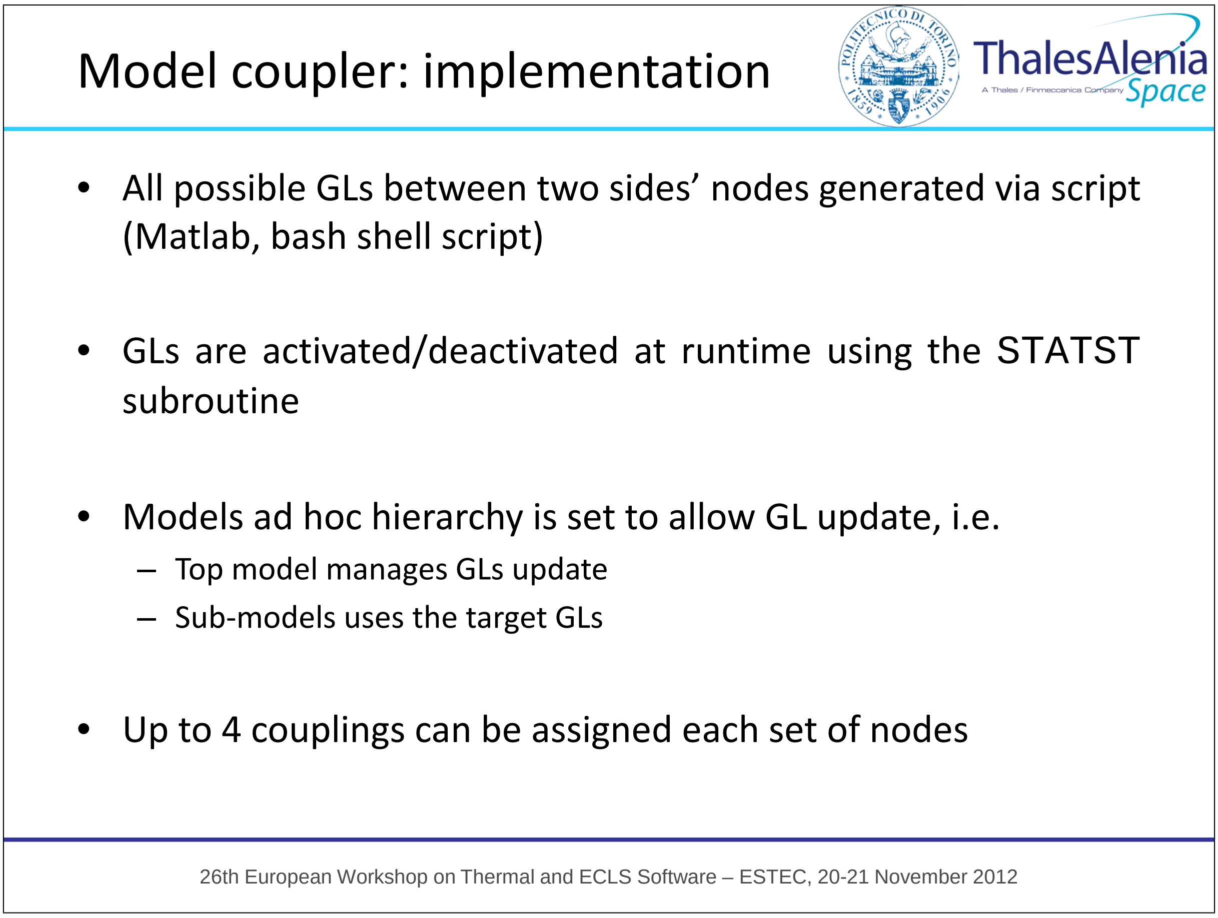

Model coupler: implementation

- All possible GLs between two sides' nodes generated via script (Matlab, bash shell script)
- GLs are activated/deactivated at runtime using the STATST subroutine
- Models ad hoc hierarchy is set to allow GL update, i.e.
  - Top model manages GLs update
  - Sub-models uses the target GLs
- Up to 4 couplings can be assigned each set of nodes

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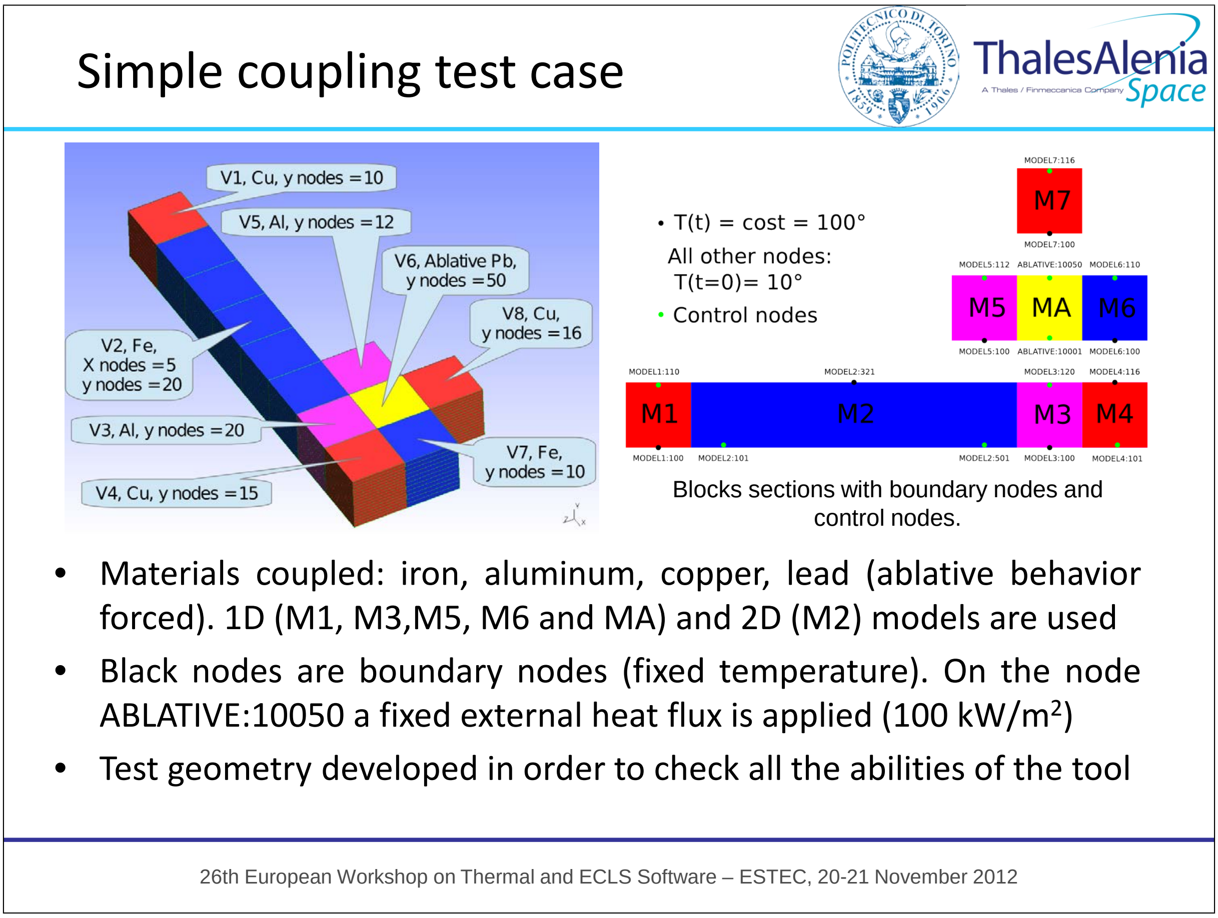

Simple coupling test case

- T(t) = cost = 100°

All other nodes:
T(t=0)= 10°

- Control nodes

Blocks sections with boundary nodes and control nodes.

- Materials coupled: iron, aluminum, copper, lead (ablative behavior forced). 1D (M1, M3,M5, M6 and MA) and 2D (M2) models are used
- Black nodes are boundary nodes (fixed temperature). On the node ABLATIVE:10050 a fixed external heat flux is applied (100 kW/m^2)
- Test geometry developed in order to check all the abilities of the tool

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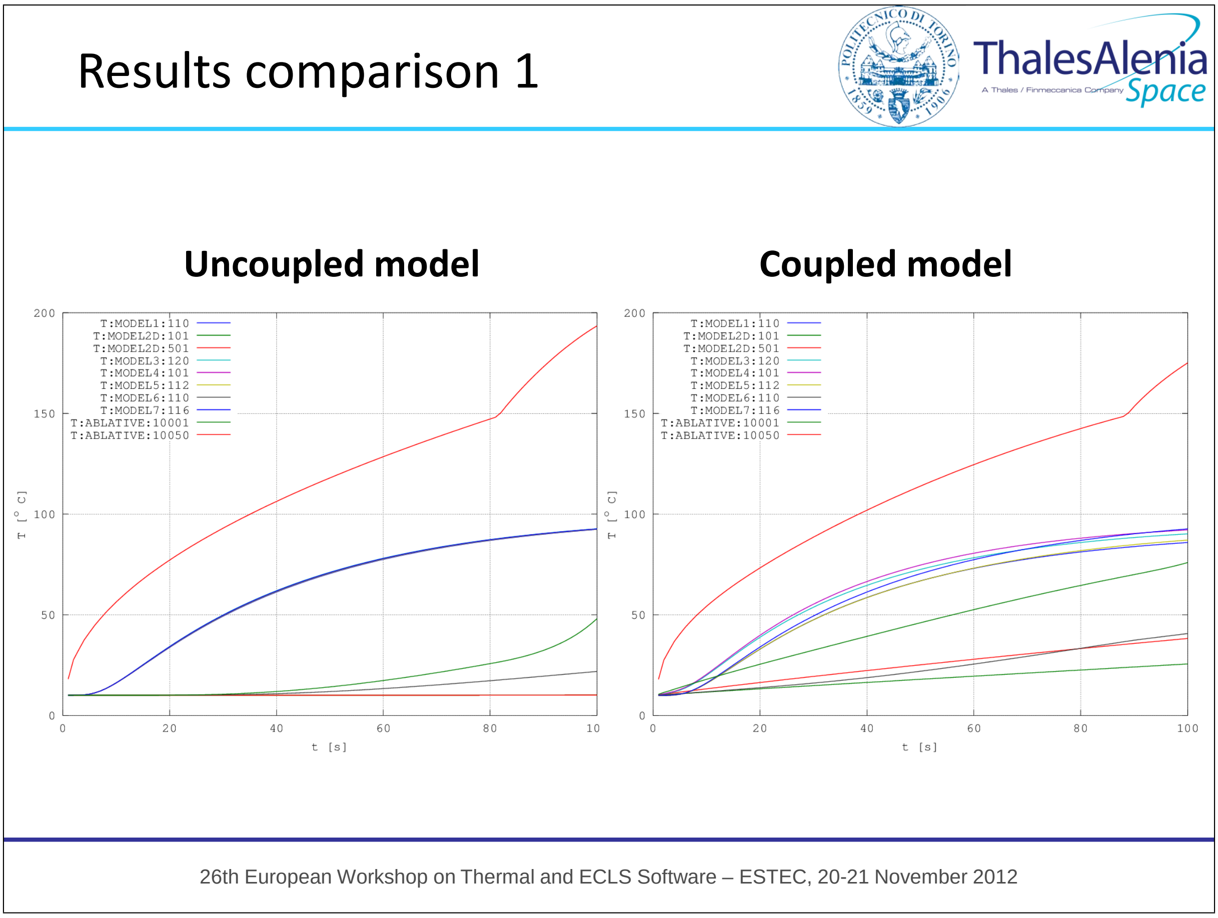

Results comparison 1

Uncoupled model

Coupled model

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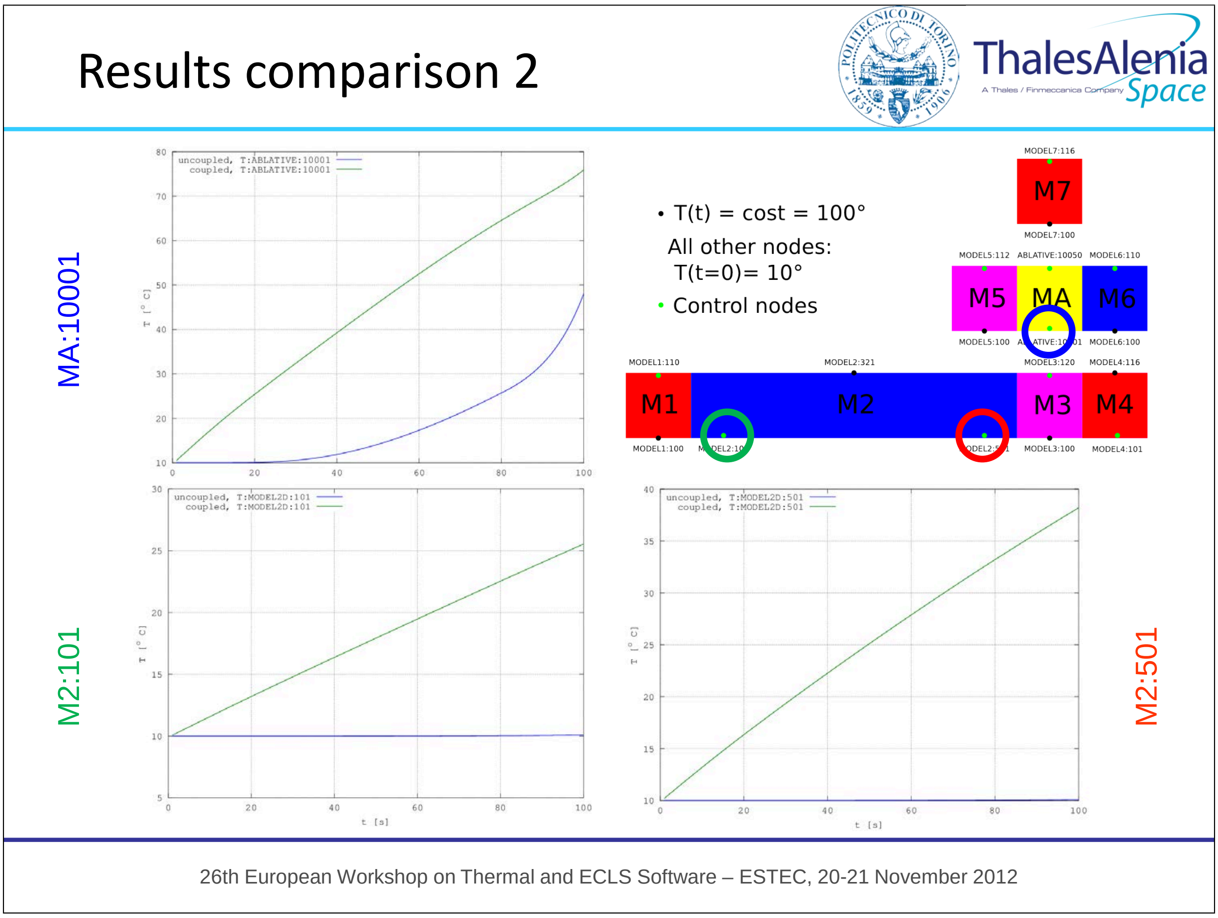

Results comparison 2

- T(t) = cost = 100°

All other nodes:
T(t=0)= 10°

- Control nodes

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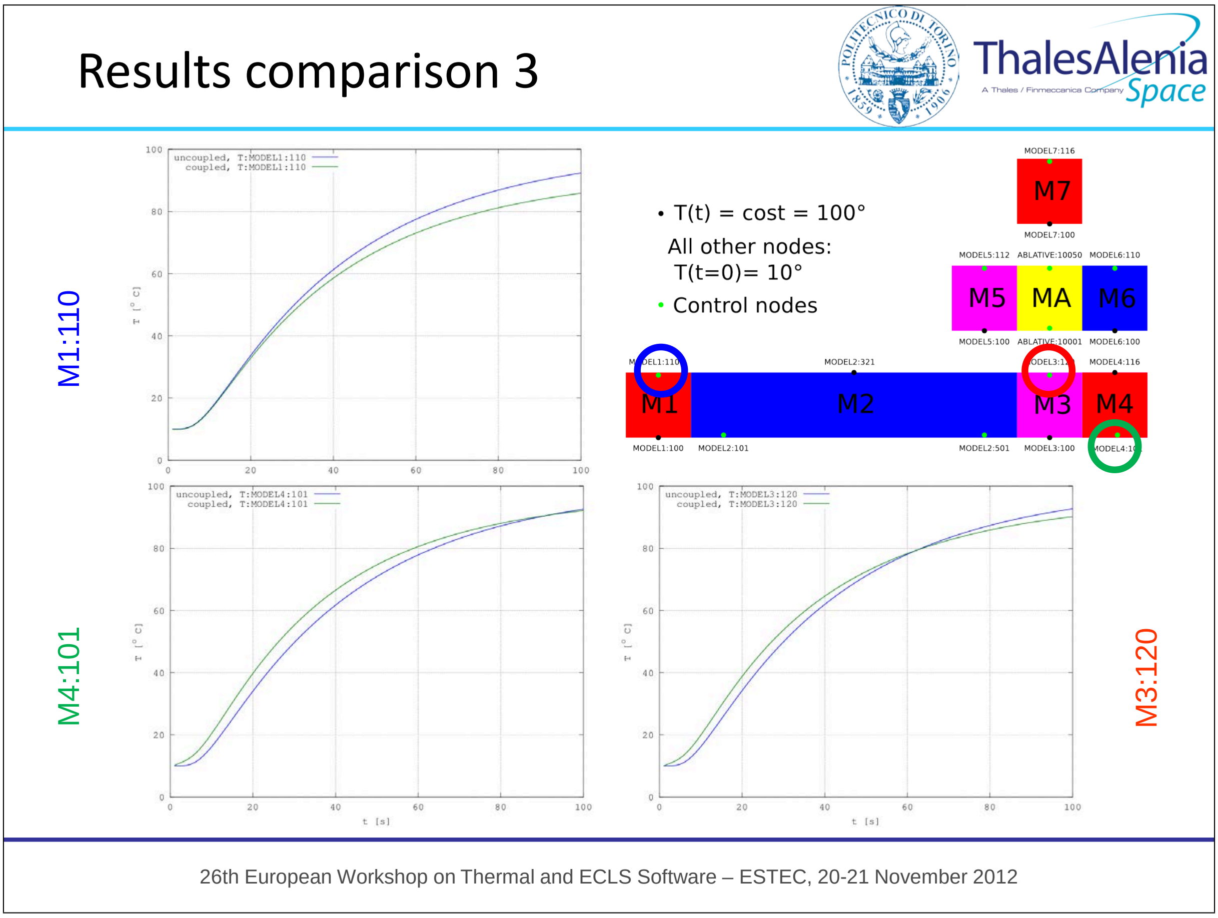

Results comparison 3

- T(t) = cost = 100°

All other nodes:
T(t=0)= 10°

- Control nodes

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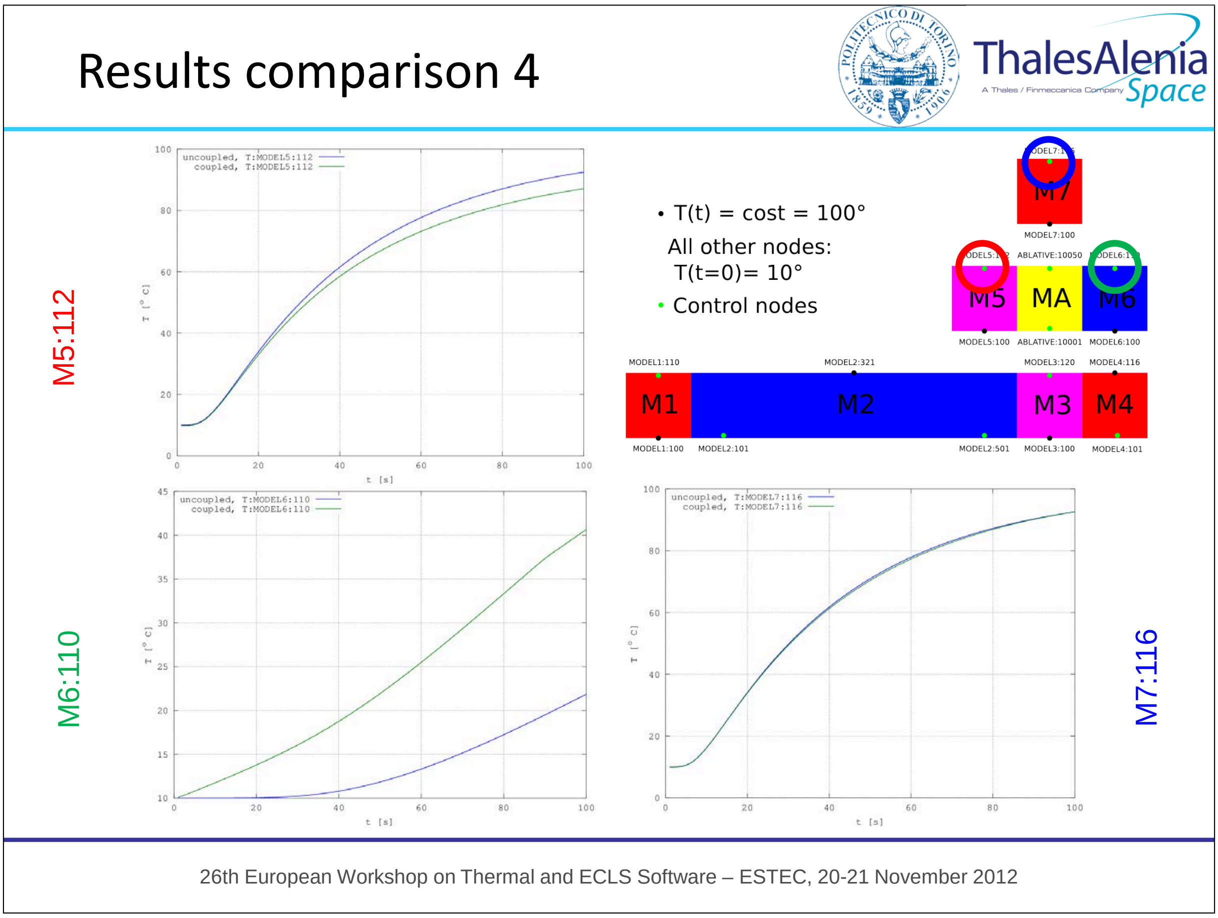

Results comparison 4

- T(t) = cost = 100°

All other nodes:
T(t=0)= 10°

- Control nodes

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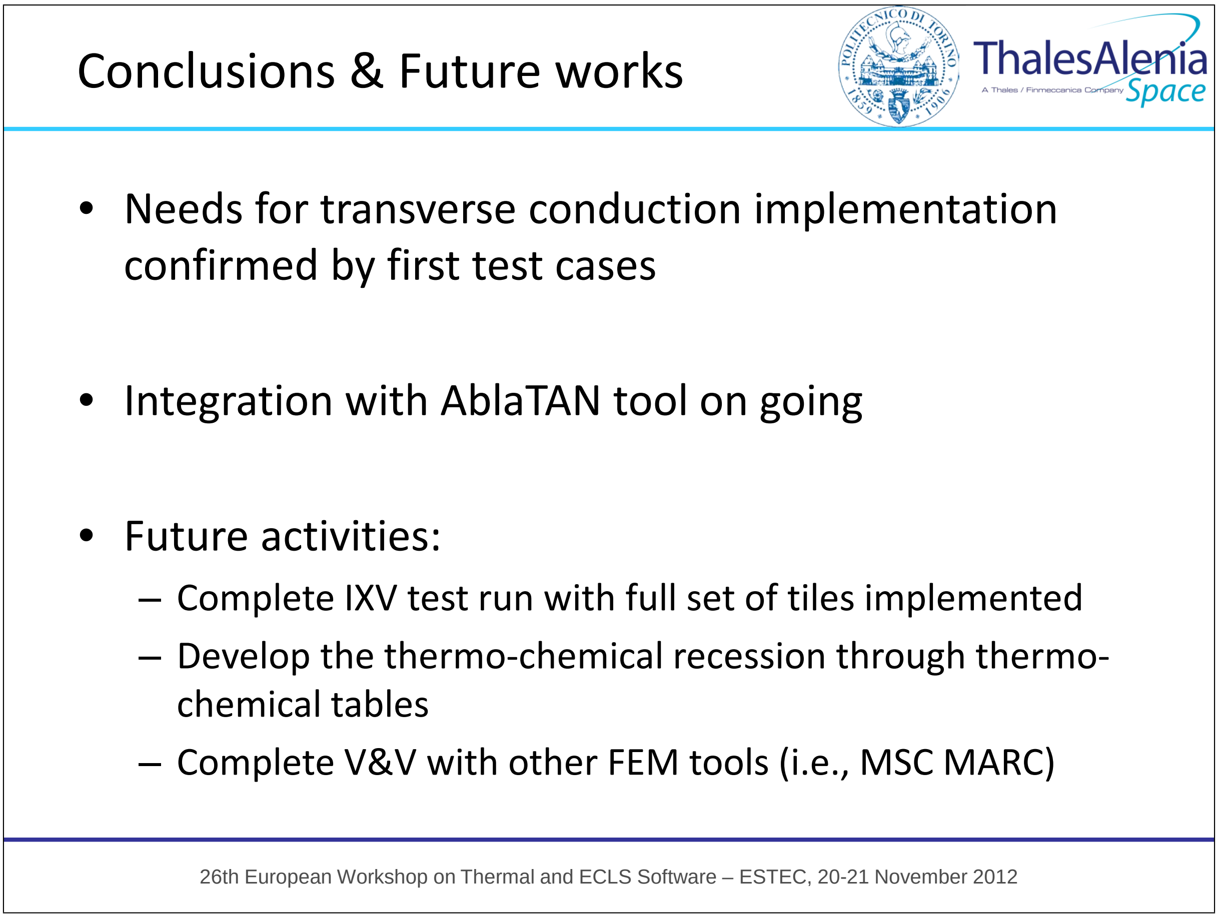

Conclusions & Future works

- Needs for transverse conduction implementation confirmed by first test cases
- Integration with AblaTAN tool on going
- Future activities:
  - Complete IXV test run with full set of tiles implemented
  - Develop the thermo-chemical recession through thermo-chemical tables
  - Complete V&V with other FEM tools (i.e., MSC MARC)

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ANY QUESTIONS?

THANKS FOR YOUR ATTENTION.

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