

Appendix B

Thermal Analysis for Re-entry Vehicles Ablative tool integration in ESATAN

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Abstract

ThalesAlenia Space Italia (TAS-I) works since many years on re-entry vehicle programs and studies like IXV, Expert and ASA (2007) just to mention a few, for which the critical components is represented by the Thermal Protection Systems (TPS).

For the ablative shields analysis and sizing a first stand alone tool was developed and validated together with Politecnico di Torino and named AblaTherm. This cooperation with university has been extended to develop a new tool able to run directly into ESATAN the ablative analysis: this will allow a full integration of ablative shield model with the thermal model of the host vehicle and give a weight reduction through a less conservative heat conduction evaluation. This new tool takes advantage of the AblaTherm heritage, uses a state of the art analytical model and is implemented using a 1D Finite volume discretization with contracting grid. The work is ongoing, and the latest developments and achievements will be illustrated in this presentation.



THERMAL ANALYSIS FOR RE-ENTRY VEHICLES: ABLATIVE TOOL INTEGRATION IN ESATAN

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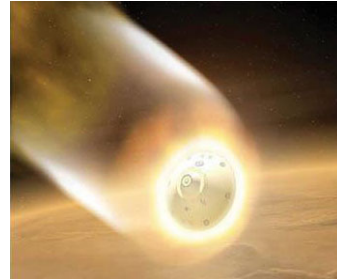
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Introduction



- ThalesAlenia Space – Italy (TAS-I) involved in ESA/ASI re-entry vehicles programs
 - IXV (with ablative)
 - Expert (without ablative)
- Ablative heat shields sizing is a key factor for good vehicle design
- Ablative tools (CMA, AblTherm, Samcef Amaryllis) not integrated with vehicle TMM (ESATAN) ⇒ iterations required



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Introduction

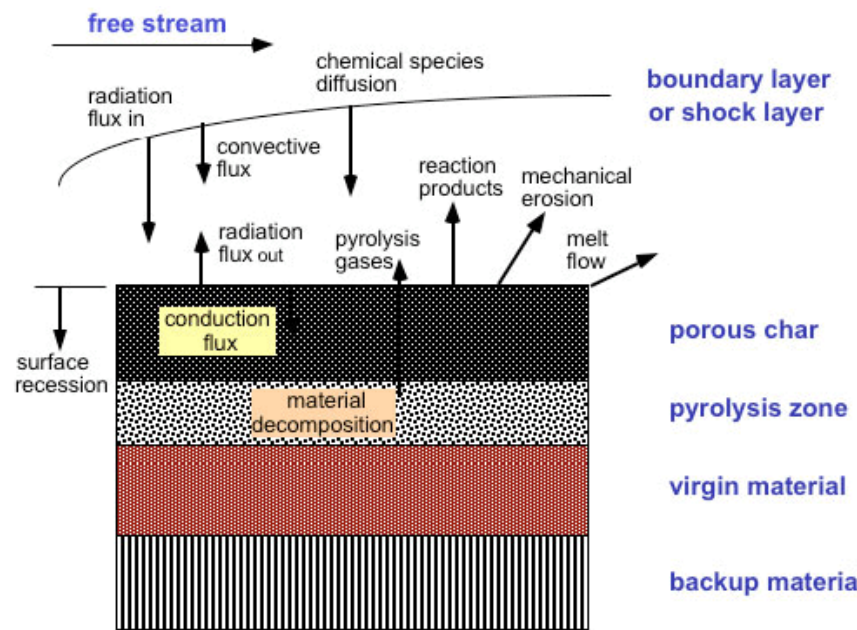


- TAS-I in cooperation with Politecnico di Torino developed a 1-D FEM tool named AblTherm (24th European Workshop Thermal & ECLS S/W)
- Cooperation extended to:
 - develop a new tool able to run directly into ESATAN the ablative analysis
 - full integration of ablative shield model with the thermal model of the host vehicle
 - weight reduction through a less conservative heat conduction evaluation
 - save run time (avoid iterations)
 - take advantage of AblTherm heritage

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Analytical model





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Analytical model



- Modified CMA material model
- Local 1D assumption
- One equation model (energy conservation), without gas effects + BC:

$$\left\{ \begin{aligned} (\rho c_v(\rho, T)) \frac{\partial T}{\partial t} + \frac{\partial}{\partial x} \left(-\lambda(\rho, T) \frac{\partial T}{\partial x} \right) + \frac{\rho_v h_v(T) - \rho_c h_c(T)}{\rho_v - \rho_c} \frac{\partial \rho}{\partial t} &= 0 \\ T(t=0) &= T_0(x) \\ \lambda \frac{\partial T}{\partial x}(x=0, t) &= q_c(t) \\ \lambda \frac{\partial T}{\partial x}(x=s(t), t) &= q_w(t) \end{aligned} \right.$$

- Charring material (Arrhenius equation with different material constituents).

$$\rho = \sum_{i=1}^N c_i \rho_i \quad \frac{\partial \rho}{\partial t} = \sum_{i=1}^N c_i \frac{\partial \rho_i}{\partial t} \quad \frac{\partial \rho_i}{\partial t} = k_i \left(\frac{\rho_i - \rho_{i_c}}{\rho_{i_v} - \rho_{i_c}} \right)^{n_i} e^{-B_i/T}$$

- Surface heat flux boundary condition:

$$\underbrace{q_w}_{\text{Net wall heat flux}} = \underbrace{\left(\underbrace{\psi}_{\text{Blocking}} q_{conv_0} + q_{rad_0} \right)}_{\text{External flux}} - \underbrace{q_{rad}}_{\text{Surface radiative heat flux}} - \underbrace{Q_{recc} \rho_{carb} \Delta s}_{\text{Recession heat}}$$

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Numerical implementation



- Implementation through ESATAN global file system: local parameters set through “\$SUBSTITUTIONS”
- Material properties and environmental data read from file at runtime
- Automatic grid generation (uniform or with defined height ratio)
- Contracting grid implementation (to account for surface recession)

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Numerical implementation



- Different simplified geometries: plate, circular section, spherical cap, pyramid
- Finite Volume Method (FVM) discretization is translated in a lumped parameter network
- Nodes capacitances, thermal resistances and local heat fluxes updated at each time step
- Blocking evaluation at run time (simplified gas model)
- Coupled with ESATAN solver set-up (\$EXECUTION)

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Material and environmental data



Following input data are required:

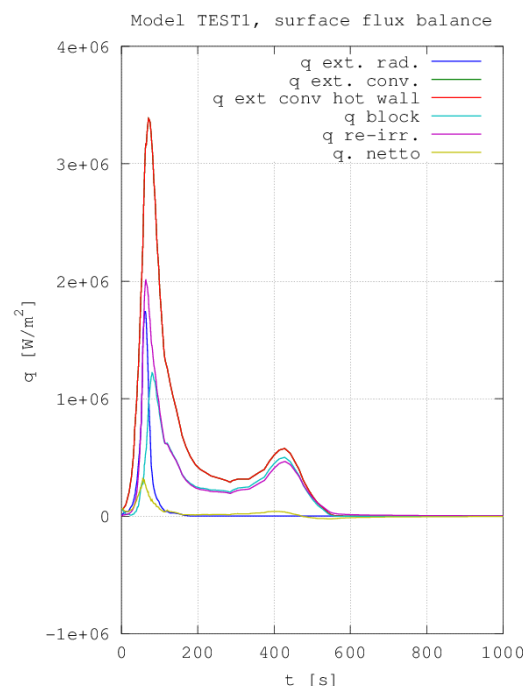
- Material properties (in a dedicated file):
 - Number of components
 - Virgin and charred sub-densities
 - Arrhenius coefficients for each material component
 - Pyrolysis reaction enthalpy at a provided temperature
 - Temperature dependence of specific heat, thermal conductivity, surface emissivity, both for virgin and charred material.
 - Surface recession model data (different models available)
- Heat flux data (external convective and radiative fluxes) and recovery enthalpy (1 file each)

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Apollo 4 test - Definition



- Entry fluxes from Apollo 4 capsule (see the flux balance graph on the right) near front shield's stagnation point
- Shield's material: Avcoat
- Shield thickness: 5.3 cm.

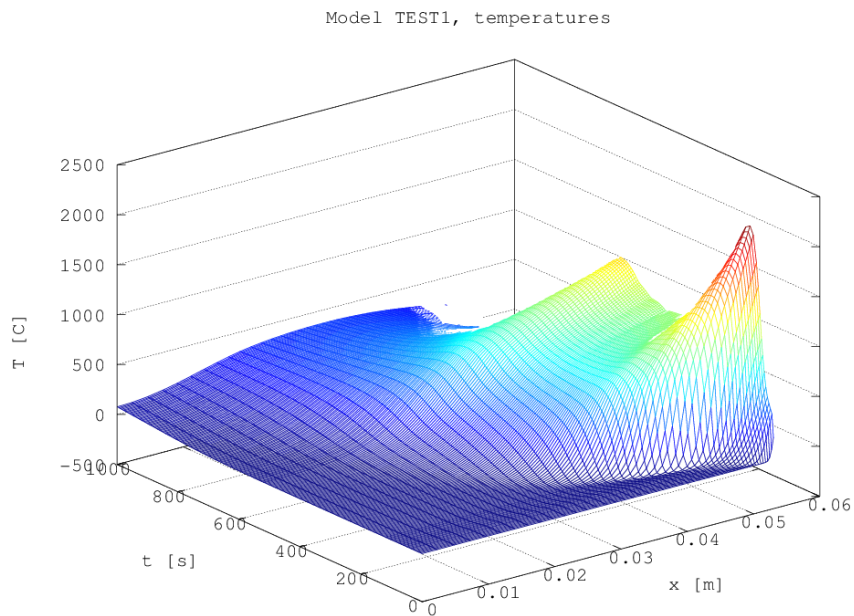


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Apollo 4 test – Results 1 Temperatures



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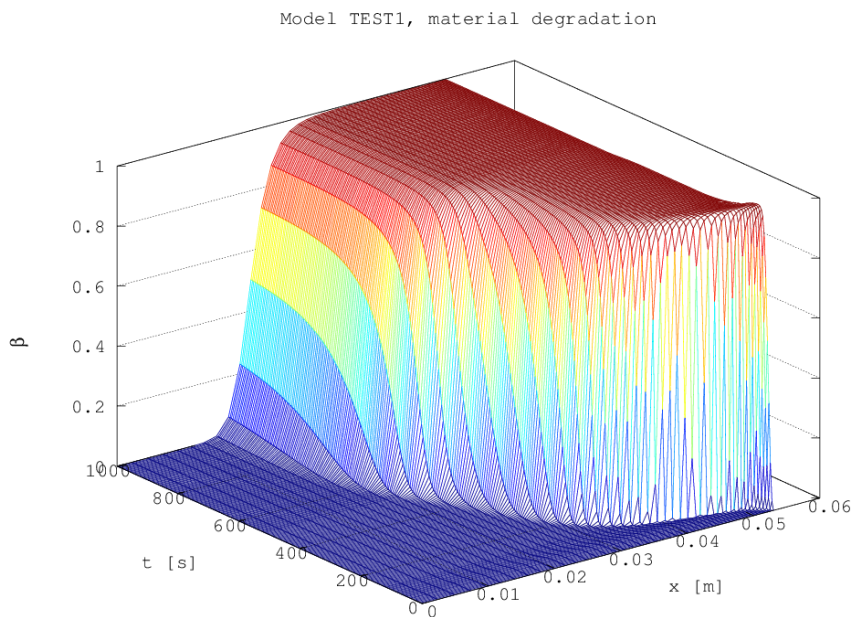


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Apollo 4 test – Results 2 Material degradation



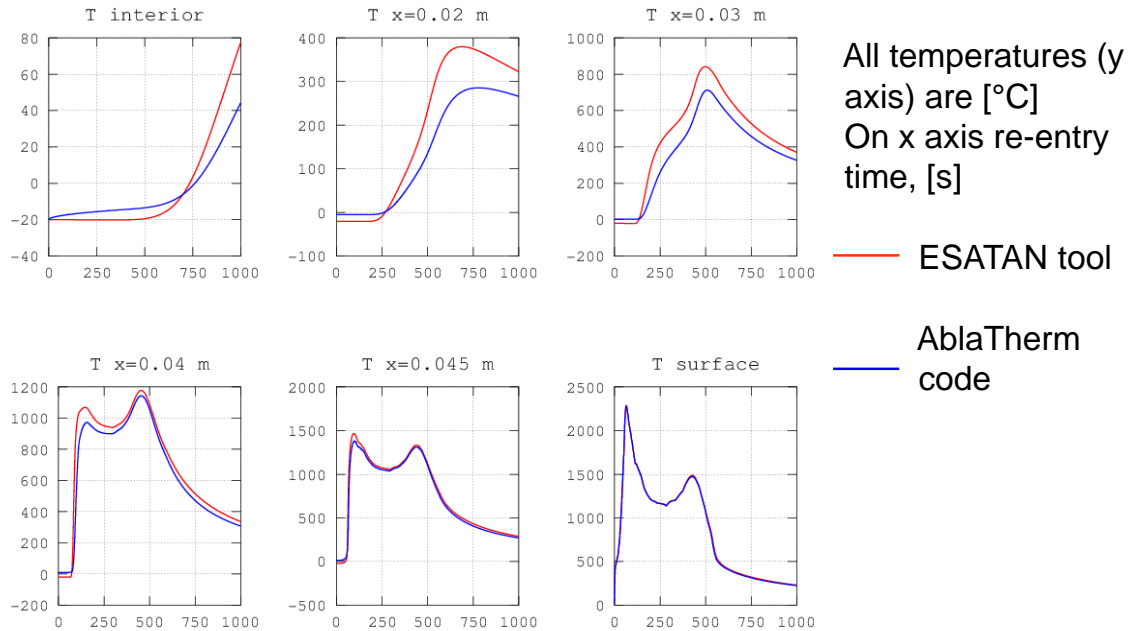
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Apollo 4 test – Results 3

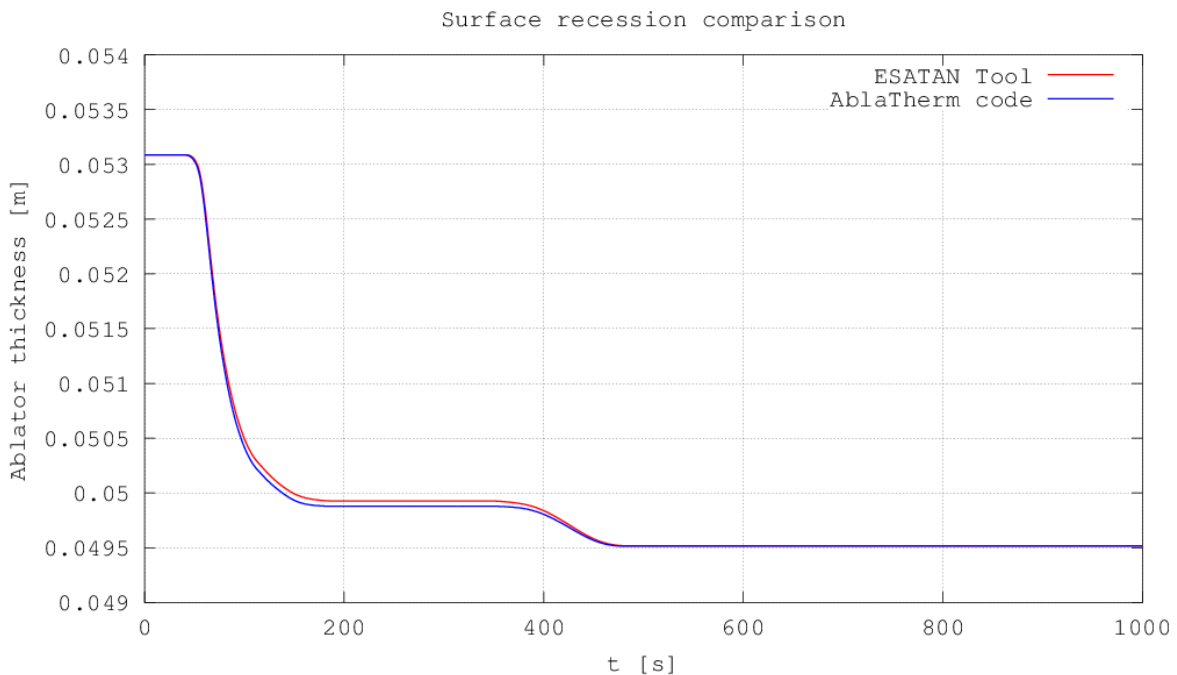
Codes comparison - Temperatures



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Apollo 4 test – Results 4

Codes comparison - Recession



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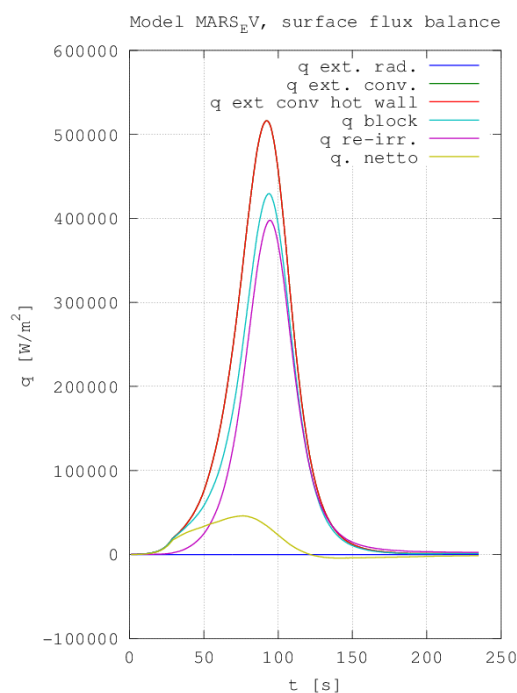
Mars entry capsule test case Definition



- Entry fluxes from MER trajectory.
- Material: Norcoat Liege.
- Shield layers (from Exomars EV):

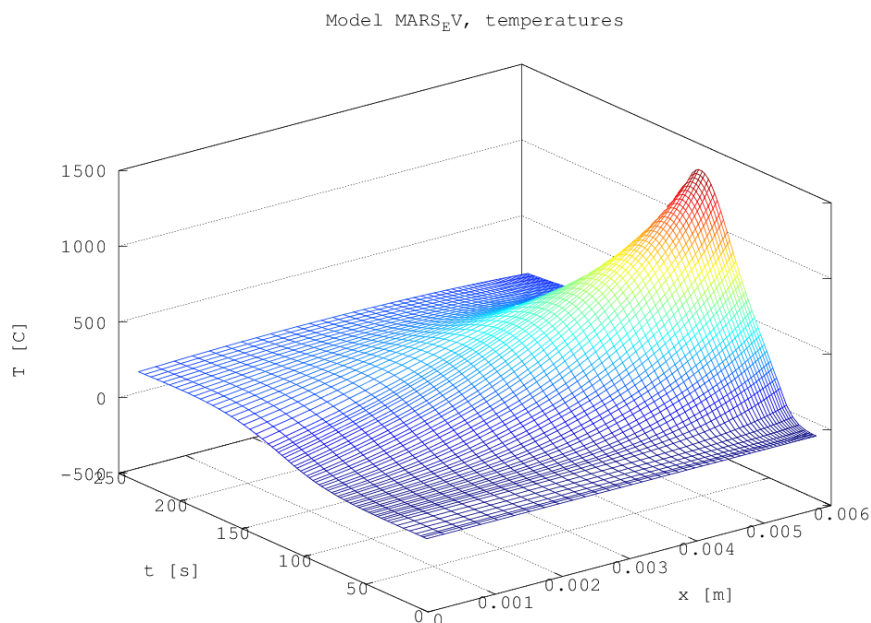
Layer material	Thickness
Saffil Insulator	1 cm
CFRP	0.03 cm
Alluminium Honeycomb	4 cm
CFRP	0.03 cm
Norcoat Liege	0.58 cm
Total thickness	5.64 cm

- The ablative tool simulates the ablative layer: the underlying structure is simulated through a normal ESATAN model.



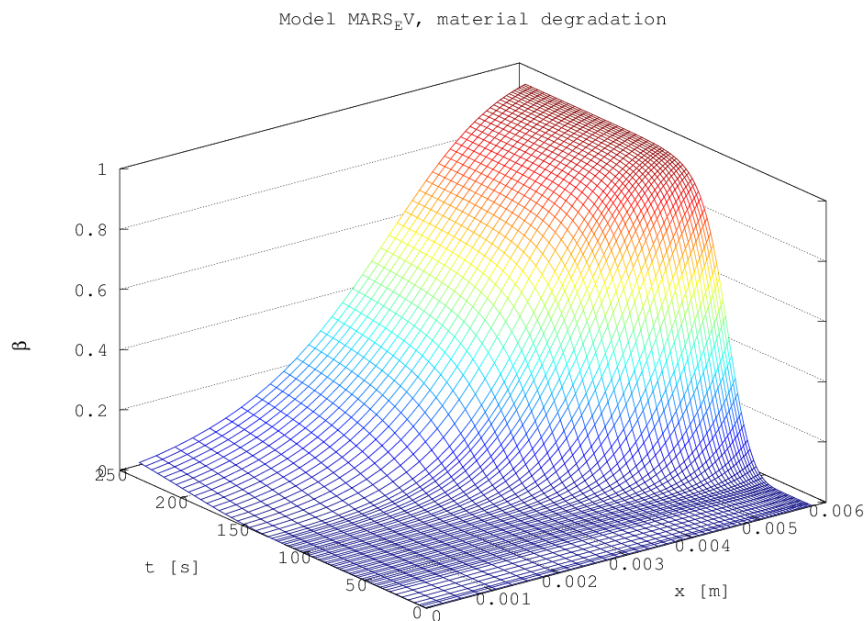
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Mars entry capsule test case Results 1 - Temperatures



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Mars entry capsule test case Results 2 - Degradation



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Conclusions



- New ablative tool has been implemented in ESATAN
- Verification (numerical checks) & validation (vs CMA, Samcef Amaryllis & test data) is undergoing but first results gave positive feedback
- Use advanced numerical methods and user friendly
- ESATAN TMM + Ablative shield in one shot !!

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What's next ?



- Implementation of pyrolysis gas effects through gas mass conservation equation: evaluation of the energy transfer through gas convection (blowing) and the external convective heat flux reduction (blocking)
- Activation/deactivation of the ablative behavior at runtime (memory and execution time reduction)
- Complex surface recession model implementation

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THANKS FOR YOUR ATTENTION

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