INVERSE METHOD FOR PYROLYSABLE AND ABLATIVE MATERIALS

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S. Alestra , Simulation Information Technology and Systems Engineering, EADS IW Suresnes, France
J.Collinet, Re-entry Systems & Technologies, EADS ASTRIUM ST, Les Mureaux, France
F.Dubois, Professor of Applied Mathematics, Conservatoire National des Arts et Métiers Paris, France

Stephane.alestra@eads.net; jean.collinet@astrium.eads.net; fdubois@cnam.fr

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In the framework of aerospace vehicles design, the thermal protection system is one of the most critical parts of the spacecraft. Atmospheric re-entry missions often rely on its robustness. For such missions, the mass balance is also a challenge and an optimal sizing of the heat shield is of great interest. Therefore, the high level of aerothermal heat fluxes encountered during the descent has to be well known but is in flight only available by indirect methods based on temperature measurements.
ASTRIUM Space Transportation has developped for many years a transient one-dimensional thermal model with one moving boundary (ablative surface). This "direct" simulation tool has been used to model complex chemical processes such as pyrolysis or ablation on thermal protection materials.
The present work deals with inverse analyses used to evaluate highly evolutive heat fluxes. This restitution is based on temperature measurements on thermal protection along a flight trajectory or during ground tests. An inverse problem has been formulated, developped and applied to estimate transient surface heat fluxes (convection coefficient), which are input data parameters for the direct code.
The inverse problem is formulated as a minimization problem involving an objective functional, through an optimization loop. An optimal control formulation (Lagrangian, adjoint and gradient steepest descent method combined with quasi-Newton method computations) has been used, resulting in MONOPYRO inverse code, derived from the already existing and operational direct thermal solver.
To compute numerically the adjoint and gradient quantities, both an analytical manual differentiation and an Automatic Differentiation (AD) engine tool (TAPENADE, developed at INRIA Sophia-Antipolis by the TROPICS team) have been used. Automatic differentiation is a family of techniques for computing the derivatives of a function defined instruction by instruction in a computer program, for sensitivity and gradient analysis applications.
Several validation test cases, using synthetic temperatures measurements are carried out, by applying the results of the inverse method with minimization algorithm.
Accurate results of identification on high fluxes test cases and good agreement for temperatures restitutions are obtained, without and with ablation and pyrolysis, using bad values of fluxes as initial guesses. First encouraging results with an automatic differentiation procedure are also presented.

KEYWORDS : Inverse Problem, Ablation, Pyrolysis, Thermal Protection, Re-Entry, Optimal Control, Adjoint, Gradients, Optimization, Automatic Differentiation