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Finite element transient modelling for whole engine-secondary air system thermomechanical analysis

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Abstract

This paper presents a new procedure developed in cooperation with Ansaldo Energia and aimed to predict metal temperatures in a gas turbine whole engine with an axisymmetric transient finite element approach. The 2D model includes a dedicated thermal fluid network where mass flow rates and pressure distributions are provided by external fluid network solvers in terms of time serie, while fluid-metal temperatures are computed through a customized version of CalculiX®. This work represents a first insight about a fully integrated WEM (*Whole Engine Modelling*) procedure currently under development. The future implementation steps will be oriented to the usage of a customized version of the native CalculiX®fluid network solver and the implementation of a system of monitoring and updating of the secondary air system (SAS) geometry. The aim is to progress from the current partly coupled approach with previously assessed mass flow and pressure distributions, to a fully integrated procedure able to take into account the interaction between the SAS fluid properties and the modifications in the geometry caused by mechanical and thermal loads.

In this paper, the methodology will be presented introducing some details about the main modelling aspects and illustrating some preliminary results from the test of the procedure applied to a simplified model representative of a real engine geometry under transient conditions.

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Keywords: whole engine modelling; gas turbine; heat transfer; partly coupled procedure; fully coupled procedure; CHT; fluid network solver

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1. Introduction

Due to changes in power market in recent years, operation conditions of large heavy duty power generation turbines have been deeply modified. In order to manage the thermal and mechanical stresses encountered in their repeated transient operations, the investigation of the heat transfer between secondary air systems and structural components represents a decisive point in the design process.

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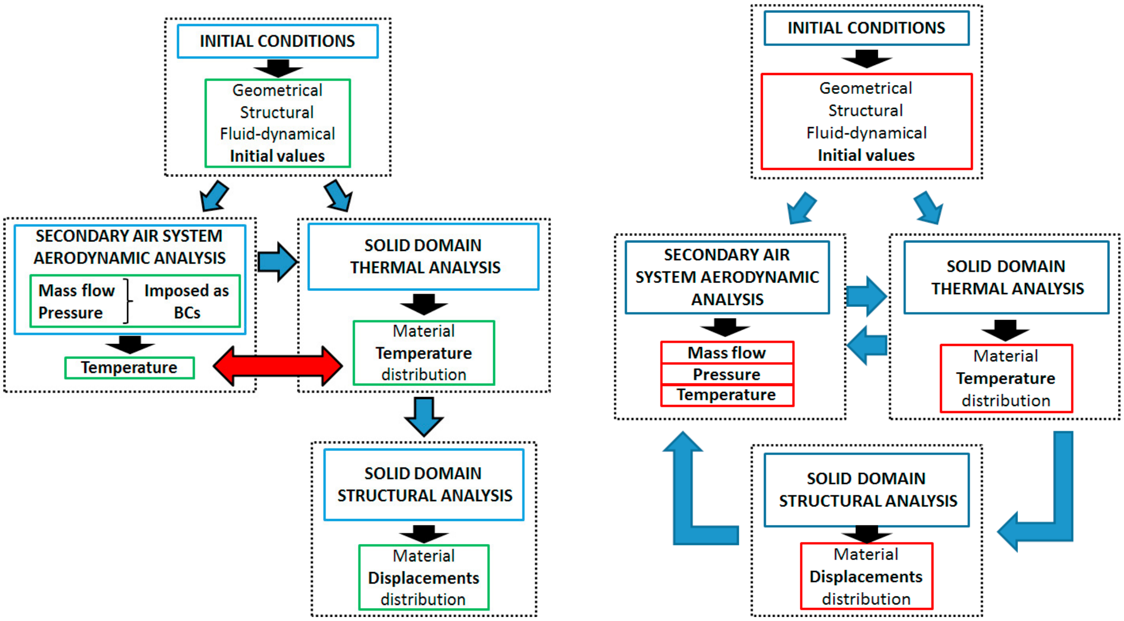

(a) Partly coupled *WEM* approach. (b) Coupled Fully Integrated *WEM* approach.

Fig. 1. Coupling approaches.

In literature, despite sub-classifications sometimes not univocal, primarily two approaches are presented for the solution of the solid-fluid heat transfer problem. One is the fully conjugate, based on the solution of a unique domain through the application of one solver for the Navier Stokes and Fourier equations. A number of works show the application of the conjugate analysis to engine components, such as blades and vanes [1], [2], and rotor-stator systems [3]. The other main approach is based on the distinction of the different convective and conductive problems solved separately in a monolithic or partitioned manner [4] according to the method adopted for the integration of the solution of one domain in the other. In industries such kind of methodologies are generally chosen for their reduced computational costs and the possibility to carry out *whole engine modelling* (WEM) analyses in reasonable time. A coupling scheme example is the FEM-CFD application. It has been adopted for various analyses of components subjected to thermal transient cycle, such as pre-swirl systems [5], [6] and cavities [7], [8]. However the typical limitation of using CFD application is the computational cost. Consequently CFD tools find a collocation in a WEM process only as support to 1D simulations (which generally substitute the CFD analyses) for the investigation of those phenomena that one-dimensional models cannot catch. Besides containing computational costs, the other crucial point in the WEM process is accounting the strong coupling and non linearity in the heat transfer process during transient operations. During transient cycles indeed, components geometries can vary significantly according to the thermal gradients, modifying pressure losses and mass flow rates in the air system, affecting in turn flow and material temperatures [9]. In the aero-thermal FEM-CFD analyses the general approach is to account the effects of seal deformation by switching mass flow inlet and static pressure outlet boundary conditions between discrete levels of corresponding ramp points of the engine cycle [10], [11]. In [10] a fully integrated FEM-CFD aero-thermomechanical transient analysis through a flight cycle on an engine is presented. Anyhow due to the reduced computational costs, the WEM process is mostly oriented on iterative decoupled methods based on dimensionally heterogeneous models applying 1D fluid network solvers providing coolant flow rates and pressures to a 2D/3D finite element code for the solid domain [12], [4]. Industrial practices generally carry out the performance of fluid network solution, thermal analysis and solid deformation evaluation in an iterative separated way [9, 13]. Being based on a sequential approach this methodologies cannot catch the coupling nature of the phenomena. Nevertheless recently, procedures have been oriented towards coupling approach such as that presented in [4].

This paper presents a partially coupled procedure (Fig. 1a) aimed to predict heat loads on a gas turbine engine, developed in collaboration with Ansaldo Energia. The present work represents a first step of a procedure, still under development, aimed to carry out calculations on a whole engine model with a fully integrated approach (Fig. 1b). The