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On prediction of non-uniform temperature fields in heat analysis of aero engines using machine learning approach

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1. Introduction

A fundamental task in the development process of modern aircraft engines is to ensure the effective cooling of highly thermal stressed engine components. The lifetime of components, and therefore the lifetime of the entire engine, is strongly dependent on material cyclic warming up and therefore it is required a reliable temperatures prediction in materials for specific operation conditions. Conjugated heat transfer, first formulated by Perelman [8], considers the interaction between a solid and fluid. Flow conditions strongly influence material temperatures and thermal interactions. Thus, secondary flows can occur in the concentric annular cavities of compressors and turbines. For an optimal design, transient processes and the solid-fluid interaction as well as the thermal time mismatch for the solid and the fluid must be considered.

In transient analyses of temperature and stress distributions in turbine components, the finite element method (FEM) is usually used. The resulting thermal loads are described by simplified boundary condition models from empirical correlations using advective one-dimensional models as presented by Fiedler et al. [3]. Heselhaus and Vogel [5] have shown that by using transient simulations, conjugate flow and heat transfer that account for three-dimensional effects, a significant improvement in accuracy can be achieved without relying on empirical correlations. This can significantly improve the prediction of component temperatures. Conversely, inappropriate modelling of transients during flight changes can lead to critical clearances or thermal stresses, as reported by Sun et al. [9]. Thermal differences in time make conjugate simulations of the heat transfer with respect to all time scales extremely expensive, as convective heat transfer in a fluid is up to $104\times$ faster than heat conduction through a solid body.

In order to reduce the computational complexity, Errera and Baqué [1] and Sun et al. [9] introduced coupled aerothermal and mechanical methods where optimized programs are used to independently simulate heat transfer in a fluid and in a solid. This so-called weak coupling allows the thermal behaviour of the solid to be calculated using a FEM code, while the adjacent flow is calculated using computational fluid dynamics (CFD). To ensure a physical, accurate and stable solution of the conjugate system, the FEM and CFD codes must exchange information on a common interface. Different strategies exist in the literature for this purpose. Errera and Duchaine [2] investigated different coupling coefficients and continuity of the exchange variables for aerothermal simulations. They showed that if a criterion based on the ratio of thermal resistances at the interface is satisfied, the Dirichlet-Robin transfer procedure leads to stable and fast convergence. Gimenez et al. [4] presented approaches updating the boundary conditions between the coupling points. They showed that the quasi-dynamic coupling method with transient calculations for solids and steady-state calculations for fluids is the most promising in terms of accuracy and efficiency. Gimenez et al. [4] further showed that a value of the relaxation parameter close to the heat transfer coefficient is advantageous.

This paper is devoted to the study of novel numerical coupling approach between CFD and FEM in conjugated heat transfer for steady-state and possibly transient analysis of aero-engine applications and similar applications in turbomachinery. The coupling is made using a correlation based on CFD data postprocessed by a novel artificial higher order neural network approach. Temperature field prediction can be prescribed on the boundary nodes of the FEM mesh and the observed overall deformation in time can be determined.

2. An approach

The problem is solved on the single annular geometry, which is key geometry in turbomachinery, specifically in compressors and turbines section. The considered geometry is shown in Fig. 1.

Initial conditions entering the CFD analysis are based on the thermodynamic cycle of an aircraft engine in *CRUISE* flight mode that is discussed in detail by Pařez et al. [7]. Temperature field distribution on outer tube is calculated by CFD and the correlation is determined using artificial neural network. This temperature distribution is non-uniform on the outer annular tube due to ongoing natural convection caused by the steady-state homogeneous heating of the inner tube, which is representing hot gases flowing through the turbine. Since the outer tube represents the case of the gas turbine, this temperature distribution is important for the electronic components placement or the overall engine deformation, that can be calculated by FEM.

Presented approach allows a quick estimation of the temperature distribution with no need to perform time demanding CFD simulations that can rapidly accelerate design and development

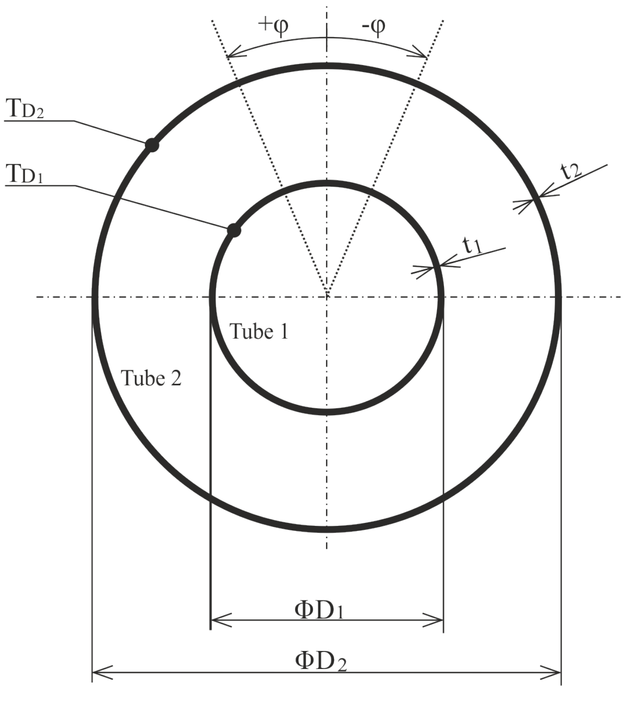

Fig. 1. Sketch of the computational domain

Table 1. Input parameters for CFD analysis

Parameter	Values	Unit
D_1/D_2	$\{0.5, 0.6, 0.7, 0.8, 0.9\}$	[1]
t_2	$\{1, 2, 3\}$	[mm]
T_{D_1}	$\{500, 600, 700\}$	[°C]
φ	$\{0, 1, \dots, 358, 359\}$	[°]

of the device. This is essential for transient FEM analysis where deformation is determined in every time step with time-depend parameters change. The goal is to determine a limited number of the most important parameters that affect the outer tube temperature distribution. The values of the dependent parameters are listed in Table 1. The influencing angular position parameter φ is considered to be equally spaced around the tube wall.

The correlation function is obtained using an extensive set of CFD simulations under different operational conditions and geometrical setups as it is shown in Fig. 2. A machine learning approach is applied to results of the CFD simulation and the only correlation function is obtained for a range of input variable parameters. The correlation function can be expressed as

$$T_{D_2} = \mathcal{N}(\bullet) = f(D_1/D_2, t_2, T_{D_1}, \varphi). \tag{1}$$

The calculation of deformations is then carried out using the standard FEM calculation, which has been presented, for example, in the paper by Pařez and Kovář [6], where a computational tool developed in the MATLAB environment was presented.

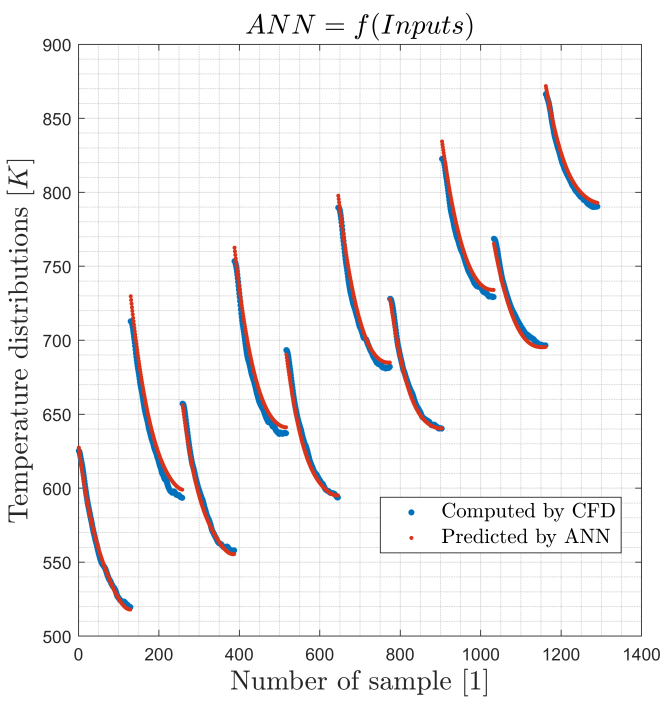

Fig. 2. Resulting correlation function: Comparison of the ANN prediction and CFD simulations

3. Summary

An approach how the temperature field on the case of the aircraft engine can be modelled based on the neural networks has been presented. This approach can make deformation analysis using FEM much faster due to no need to compute time demanding CFD. Instead of the simulation, boundary conditions can be obtained by learned neural network.

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