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STRUCTURAL ANALYSES OF BALISTIC MISSILE FIN CONFIGURATION DURING SUPERSONIC FLIGHT CONDITIONS

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Abstract: Attention in this work is focused on aerodynamic heating and aero-thermo-mechanical analysis of fin type structures on the missile at supersonic flight. The modeling of aerodynamic heating of supersonic and hypersonic flights has been under intensive consideration in recent years. At high Mach number the heat due to friction between body and flow, i.e. viscous heating must be taken into account because the velocity field is coupled with the temperature field. The flow field around the fins of the missile and especially the temperature distribution on its surface, as well as aerodynamic-thermal/structural analyses are numerically modeled in ANSYS Workbench environment. The investigation was carried out for two Mach numbers (M = 2.3 and M = 3.7 with same angle of attack of 5°). Available structural experimental results have been used for computational structural mechanics validation and verification, in order to assure credibility of numerical fluid-thermal-structure interaction. In this work a multidisciplinary framework for numerical aerodynamic-thermal/structural analyses, based on only one multi-module software, was used to analyse thermal effects on fin structure during supersonic flights conditions.

Keywords: missile fin, supersonic flight, heating/heat transfer, aerodynamic-thermal/structural analysis

1. INTRODUCTION

In this multidisciplinary study numerical aerodynamic-thermal-structural analyses were carried out on a short range ballistic missile fin model, which was developed for scientific and internal experimental, CFD and CSD testing and calibration purposes. The design process of the ballistic missile fin model in question included primarily static structural experimental analyses, in order to achieve the maximal strength and safeness. Results of those experiments were used for validation and verification of CFD and CSD analyses of the missile fin model. Validation and verification procedures for numerical aerodynamic-structural analyses based on static structural experiments were a part of necessary routine, so that numerical aerodynamic-thermal-structural analyses could be carried out with acceptable accuracy. So, the aim of this paper is to present a numerical aerodynamic-thermal-structural analyses of ballistic missile fin configuration during supersonic flight conditions, within a multipoint and multidisciplinary framework for aerodynamic-thermal-structural analyses, based on one multi-module software, in order to investigate thermal effects on fin structure, regarding safety and reliability in critical exploitation conditions and to improve and quicken the overall design processes with proposed numerical environment.

2. AERODYNAMIC-THERMAL-STRUCTURAL ENVIRONMENT

In this paper complete numerical analysis was performed in ANSYS Workbench environment. This multi-module software enables geometrical modelling, aerodynamic, thermal and structural analysis. The algorithm of multimodular environment [1, 2], for the purposes of computational aerodynamic-structural analysis and aerodynamic-thermal-structural analysis as well, is presented in Figure 1. This algorithm shows data flows and order of activities in given automated framework.

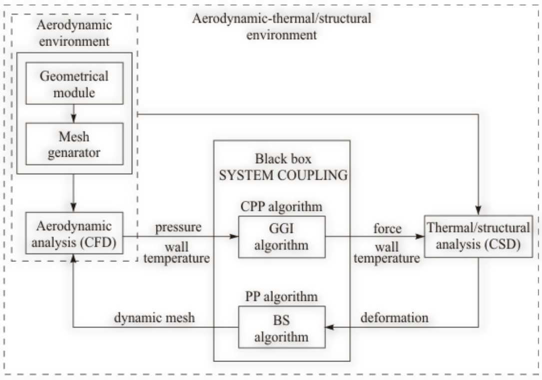


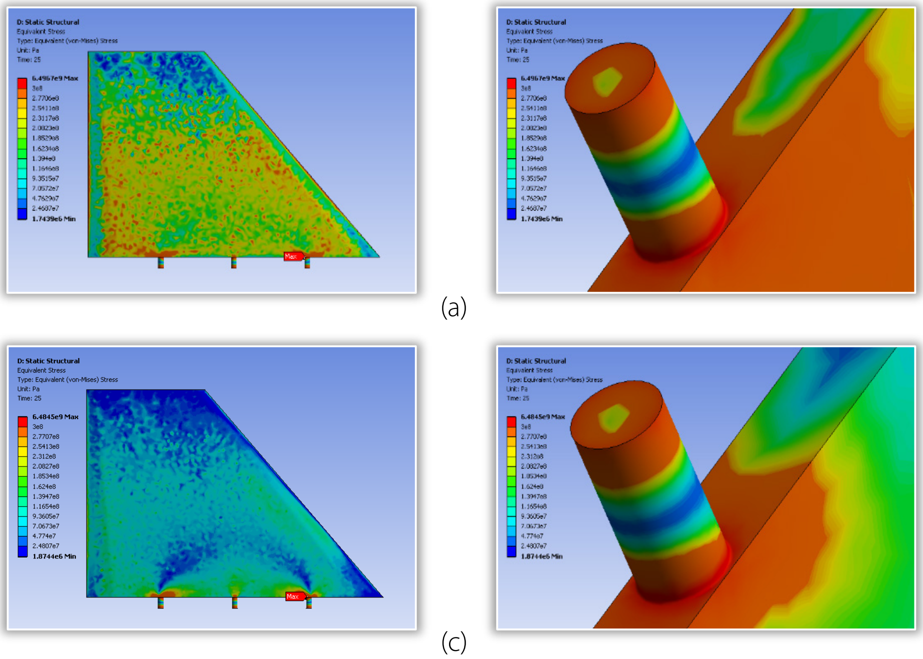
Figure 1. Multimodular environment dataflow algorithm

The 3D parametric fin configuration and appropriate computational fluid domain were created in the DESIGN MODELER environment. These geometries delivered by DESIGN MODELER are discretized by MESH module. The flow solver, based on finite volume method, used in this study was the ANSYS FLUENT. Pressure-based type solver with coupled scheme was used to compute the flow field. Menter's [3-6] Shear Stress Transport *k-ω* model was selected for the numerical calculation of the turbulent flow in the computational domain. The entire system of governing equations in conservation form is given as in [6]. The structural solver, based on finite element method, used in this study was the ANSYS MECHANICAL (STATIC STRUCTURAL). Equilibrium equation for three dimensional static analysis problem was derived from the minimum potential energy principle [6]. Data transfer algorithms are combinations of mapping and interpolation algorithms that are used by the SYSTEM COUPLING module. Two mapping algorithms are in use for executing data transfer procedures (Figure 1). Data transfer procedure could be executed by *profile preserving* algorithm, when transferring non-conserved quantities (displacements or temperatures), and by *conservative profile preserving*, when transferring conserved quantities (mass, momentum, forces or energy flows). Within *profile preserving* algorithm the *Bucket Surface* mapping algorithm is used to generate mapping weights [7], while within *conservative profile preserving* algorithm the *General Grid Interface* mapping algorithm is used to generate mapping weights [8].

3. AERODYNAMIC-THERMAL-STRUCTURAL ANALYSES

Verification procedure is the assessment of the accuracy of the solution to a computational model by comparison with known solutions (benchmark/standard, analytical, panel), or black-box testing, or a grid-independent solution ensuring, and validation procedure is the assessment of the accuracy of a computational simulation by comparison with experimental data. Experimental installation, properties and test results, as well as procedures of verification, validation and numerical efficiency of CFD and CSD were in detaild published in [1, 6, 9, 10].

Based on conducted studies, the optimal settings of numerical calculations have been adopted. The strategy is based on the assumption that if the validation/verification of aerodynamic-structural model (static aeroelastic) was very good, the aerodynamic-thermal-structural results of the analysed fin model are credible as well. So, the settings for aerodynamic-thermal-structural model are the same as the ones of static aeroelastic numerical model [1] and with the same dicretizations of fluid and structural domain. This locally conducted multidisciplinary study for fin geometry clearly suggests that in case when fluid domain was discretized with 368634 elements, and structural domain with 110267 nodes, time needed for static aeroelastic numerical calculations is optimal, with well-established numerical calculations accuracy with acceptable discrepancies. For the purpose of aerodynamic-thermal-structural simulations, structural domain was modelled with SOLID227 coupled field element, which takes significantly longer to solve. The results of aerodynamic-thermal-structural analysis of fin for M = 2.3 and M = 3.7 are shown in Table 1 (locations 3 and 7 correspond to leading and trailing points of tip airfoil).



(a) (b)

(c) (d)

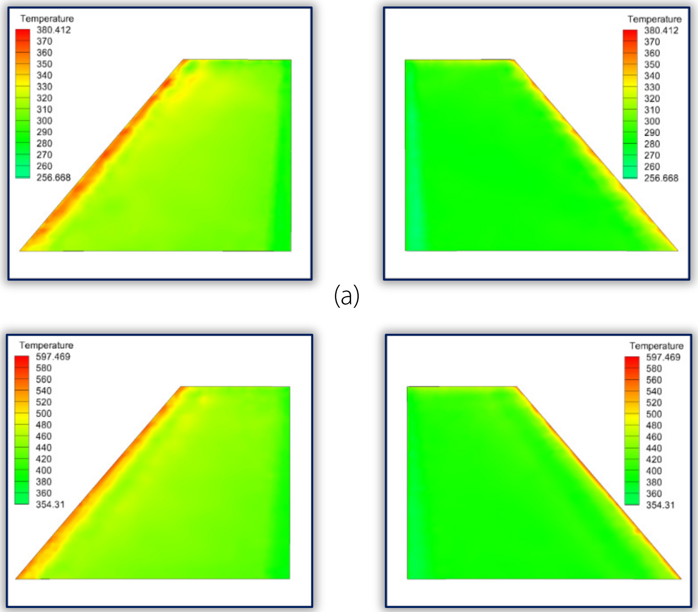
Figure 2. Stress distribution with thermal influence for M = 2.3 ((a) and (b)) and for M = 3.7 ((c) and (d))

For aerodynamic-thermal-structural analysis, equivalent von-Mises (averaged) stress distributions for both exploitation regimes are shown in Figure 2. As it can be seen (Figure 2 (a) and (c)), region of maximal stress was occurred on the first support. Numerical calculations of aerodynamic-thermal-structural behaviour consumed up to 8.43 GB RAM.

Table 1. Aerodynamic-thermal-structural numerical responses for M = 2.3 and M = 3.7 exploitation regimes

M	AoA [°]	Calculated lift force [N]	Calculated location of aerodynamic force (X/Z) [m]	Calculated displacement on locations 3 and 7 (u_3/u_7) [mm]	Duration of conducted simulation [min]
2.3	5	3581.4	0.4151/0.2199	20.78/24.09	31
3.7	5	1501.5	0.4125/0.2125	14.17/17.46	26

The static temperature distribution for M = 2.3 on fin surface is represent in Figure 3 (a) and (b). The temperature change on whole fin surface is almost 124 K. As expected, temperatures are higher at the lower fin surface where is recorded the highest temperature of 380.412 K, which occurs directly beside the leading edge (Figure 3 (a)). The temperatures are slightly lower at the upper fin surface (Figure 3 (b)). Obviously, this temperature difference emanates from AoA, which is 5°, because the flow travels faster over the upper fin surface and the less heat is generated.



(a) (b)

(c) (d)

Figure 3. Static temperature distribution for M = 2.3 on lower (a) and upper (b) fin surface and static temperature distribution for M = 3.7 on lower (c) and upper (d) fin surface

The static temperature distribution is also presented for M = 3.7 in Figure 3 (c) and (d). In this case, the temperature change on whole fin surface is slightly above 243 K. Again, temperatures are higher at the lower fin surface, where is recorded the highest temperature of 597.469 K which occurs at the leading edge (Figure 3 (c)), while the temperatures are slightly lower at the upper fin surface (Figure 3 (d)), for the same reason as in previous case. The maximum displacements caused by aerodynamic heating occur at location 7 (Table 1), where is evident that increase in Mach number largely affects the increase in displacements. The equivalent stress distributions are nearly the same for both Mach numbers, but the influence of thermal stresses is greater for M = 3.7 than for M = 2.3. The maximum equivalent stresses appear on the first support from leading edge.

It has to be noted, that due to coarse approximation of fin-body attachment, obtained equivalent stress values must be taken with great reserve. Never the less, these results can give the general picture of stress distributions in conducted analyses.

4. CONCLUSIONS

In this paper the analysis of thermal effects on fin structure during supersonic flight conditions were carried out, using multidisciplinary framework for numerical aerodynamic-thermal-structural analyses, which was based on only one multi-module software. The analysis was conducted for two Mach numbers. As expected, all obtained results were higher for the higher Mach number. In both cases the maximum temperatures were concentrated near leading edges i.e. in the stagnation regions, and the temperatures were slightly higher at the lower fin surface, which is the consequence of AoA.

In order to achieve as accurate results as possible, this analysis included independently conducted static structural experiments of the analysed missile fin model, which were used for validation and verification purposes. These validation and verification procedures enabled that the use of this numerical environment makes a significant upgrade of the overall fluid-thermal-structure interaction modelling and in quickening of the overall conceptual design process. The proposed well-established environment represents powerful tool for numerical aerotermoelastic prediction in aerospace science and demonstrates high quality of modelled responses with acceptable calculation times.

Acknowledgments

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Note

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