INVESTIGATION OF BALISTIC MISSILE FIN CONFIGURATION DURING SUPERSONIC FLIGHT

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ABSTRACT

The investigation was carried out for two Mach numbers (M = 2.5 and M = 3.0 With Alpha 0, 2,5,10 at an Altitude of 5km). And the data are compared with own available Thermal and structural experimental results have been used for computational structural mechanics validation and verification, in order to assure credibility of numerical fluid-thermal-structure interaction. Conducted simulations were carried out to better understand the fluid-thermal-structure interaction of the missile fin during supersonic flight. The fin is modeled in SOLID WORKS and then it is imported in POINTWISE for meshing and then the meshed file is imported to ANSYS FLUENT for solution and Microsoft Excel used for post processing. To this end, a procedure is adopted in which shock-expansion theory is used to predict the flow properties over the fin, with the Eckert reference temperature method then being used to predict the heat transfer into the surface.

Keyword: - *Missile Fins1, Supersonic Flight2, Thermodynamic Heating3, Fluid-Thermal-Surface Interaction4,.*

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1. INTRODUCTION

When a missile travels into the air, the surface of the missile gets heated due to the friction with the air. Therefore at microscopic level the air molecules will be restarted by the surface (because of roughness of the surface) and hence heat is generated due to temperature differences thought the small particles that hits the missile fin un elastically, therefore the kinetic energy of the fluid particles are converted to heat. This aerodynamic heating is not in any way the realistic model of the actual phenomena for 3 reasons:

1. The air flows around the missile, and the temperature of the air-flow depends upon local conditions. The surface of the missile does not reach absolute temperature rather than a temperature distribution.
2. The aerodynamic heating does not necessarily originate from friction, but from heat transfer from heated air-flow to the missile surfaces, and this heat transfer from the air-flow to the surface of the missile is not perfectly smooth.
3. The surface heating is the dynamic process due to motion of the flow, where the capacity of heated surface raises a lag in the temperature on the surfaces with respect to the flow.

2. OBJECTIVE

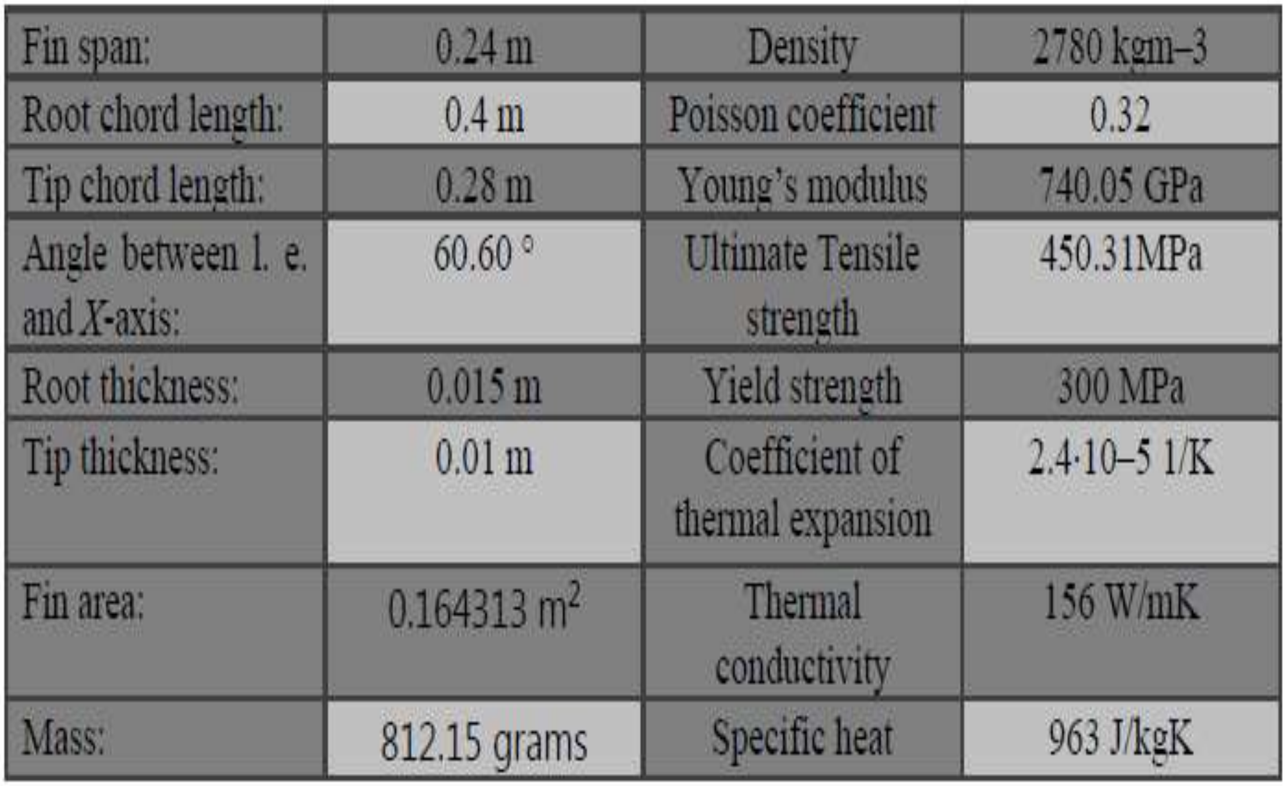
The main objective of this paper is to Design a missile fin in such a way that it must sustain the higher load and higher thermal properties to avoid damages and melting of fin at high speed such as supersonic and hypersonic.
The high temperatures directly impact the installed sensors on the fins, which may affect the missile calibrations. With respect to the missile survivability during the operation requirement, the objectives of the fins are :

1. Determine the durability of the missile fin structure w.r.t. to its required survivability by the analytically modeling of the fin due to the aerodynamic loading as well as heating problems to evaluate the structural integrity of the missile fins.
2. The measurements of temperatures of the fin made by aluminum under computational testing to compare to analytical predictions of the missile fin skin friction performance used to validate the fin model for thermal capabilities.
3.. The e.g. balanced for the easy and quick operation of missile fins at supersonic and hypersonic speeds

3. STRUCTURAL MODELING AND ANALYSIS

The structural model was generated in the SOLIDWORKS based on the geometrical information's for understanding and analysis of the wall shear stresses that the material will developed under the given operating condition. The model was developed to simple fin structural model which is used to understand the boundary-conditions of the fin structure. This model allowed us to fully understand the all types of aero-thermal loading conditions.
Missile fin is Modeled in the Modeling Software "SOLIDWORKS " 2017 version , the missile fin configuration is :

Table 1: Represents the geometrical information and material properties for fin



Fin span:	0.24 m	Density	2780 kgm–3
Root chord length:	0.4 m	Poisson coefficient	0.32
Tip chord length:	0.28 m	Young's modulus	740.05 GPa
Angle between l. e. and X-axis:	60.60 °	Ultimate Tensile strength	450.31MPa
Root thickness:	0.015 m	Yield strength	300 MPa
Tip thickness:	0.01 m	Coefficient of thermal expansion	2.4·10–5 1/K
Fin area:	0.164313 m^2	Thermal conductivity	156 W/mK
Mass:	812.15 grams	Specific heat	963 J/kgK

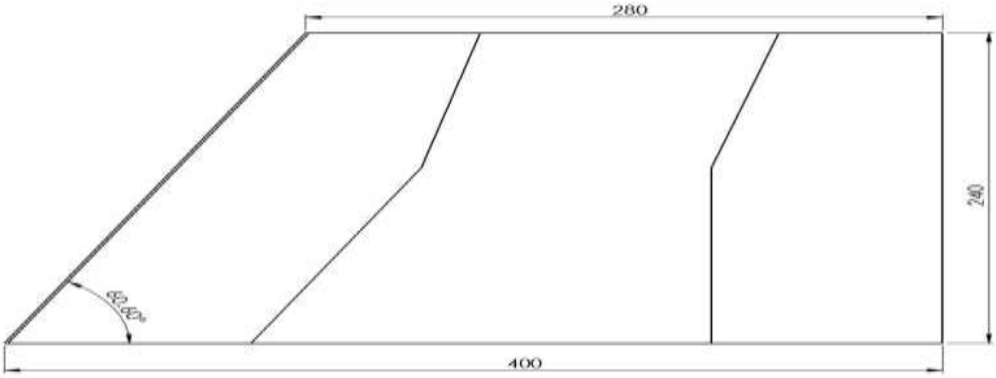


Fig-1: Represents the geometrical information for fin

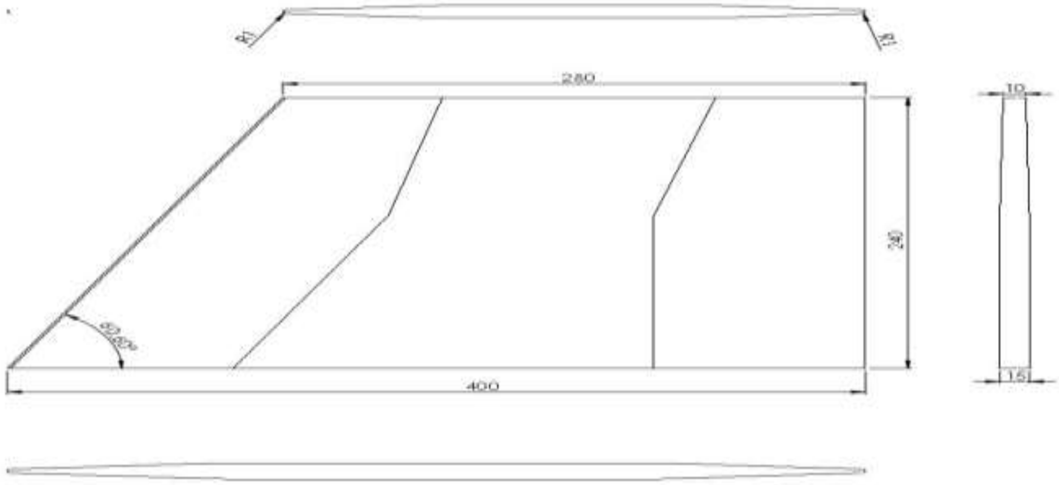


Fig-2: Represents the geometrical views of fin

4. RESEARCH METHODOLOGY

For the best air flow phenomenon and prediction, the Navier-Stokes (N-S) equations must have to be solved. And the 3-D, real time-dependent, discretized Reynolds-averaged-Navier-Stokes equations have to be used for centric-cell finite volume approaches. However the governing equations has been used for entire fluid flow system in conservation form as given in the flow solver, i.e. pressure based and density based which is based on the method of finite volume, used in this study is the ANSYS FLUENT(2017 version)

In this work the solution for complete modeling and numerical & computational analysis was performed in SOLIDWORKS, POINTWISE and ANSYS FLUENT environment. These softwares enable the geometrical modeling and simulation of aerodynamics, thermal-structural analysis**.**

The algorithm of ANSYS modular environment used for the purposes of the computational- aero-thermal-structural analysis which is presented in figure below. However this algorithm was design and developed by ANSYS which shows data calculations and order of activities as input/output in given automated framework.

The three-dimensional fin configuration and approximations for computational-fluid-domain which created in the DESIGNING SOFTWARE environment. And the fluid domain was initialized in the FLUENT to be a part of spherical with 2 times of root fin chord lengths upstream & downstream of the missile fin was created for inlet

boundary conditions for CFD analysis are defined as pressure far field, and the initial input conditions are given in ANSYS FLUENT to solve the Navier Stroke equation to established the flow field condition are defined.
The methodology used to determine the missile fin durability is described below:

1. Determine the mechanisms that could endanger the missile fin structural integrity. This includes the thermal-radiation, aerodynamic-heating, melting, and thermal expansion.
2. Performance of the aerodynamic and thermal heating analysis using the POINTWISE and Fluent, the finite element codes are designed to model the software for fluid flow and heat transfer analysis. Just by creating an external flow field domain around the fin model in meshing software. The results of this fin model analysis are to be compared with analytical calculations or by a more specific code to verify the aerodynamic and thermal results.
3. Performing an aero-thermal analysis done by incorporating the aerodynamics-heating and simulating the high energy heat transfer phenomenon between fluid and fin structures.
4. Evaluating the structural and thermal integrity of the missile fin via coupled aero-thermal and structural analysis.
5. Evaluating the results of the thermal and structural data using output data from FLUENT which is used to determine the missile fin strength and thermal capacity as well as durability during the flight.

5. RESULT AND DISCUSSION

In the result section, the results of numerical aero-thermal and structural analyses has been presented. The results of the conducted numerical and computational verification as well as validation process based on the static fin structural experiment for M = 2.5 , AOA = 0°,2°,5°,10°, and M = 3.0 , AOA = 0°,2°,5°,10°, at an altitude of 0.5 km, and here the identical settings has been made for the structural analyses of the fin.
There is all the data taken during this test and analysis of fin parts including the L.E blunted shape. So that we can see the effect of fin L.E due to shock waves i.e. the L.E. experiences a large amount of aerodynamic loading and thermal dissipation rate. Since in our analysis a limited aerodynamic load data on fin have been taken during the analysis however only the co-efficient of normal force variation over the all part of the have been shown in figure 6.2, from the figure it is very clear that fin L.E experiencing the highest aerodynamic load.
In both of these Mach test i.e. M=2.5 and M=3.0 test programs at a different angle of attack, there is a huge effect of L.E. bluntness on the induced heating it can be seen easily in figure6.3 and figure 6.7. We also observed that there is a relatively large amount of heating increases occur due to L.E. bluntness at a higher Mach number than a lower Mach number i.e. Tm3.0> Tm2.5. However, most of the thermal heating increases could not be responsible only for the corresponding rise in the pressure due to bluntness but as well as surface roughness is also responsible. As we know that the variation of pressure due to sharp L.E and Blunt L.E. used the pressure correlation that has been used to transform the sharp fin L.E. heating correlation into the blunt fin heating correlation just multiplying by the blunt to the sharp ratio of the peak pressure to the power of 0.8. This blunt L.E. of the fin correlation still falls under the well below the blunt fin data. This relation can be used to design the different fin shape configurations for the supersonic and hypersonic speeds.

The wall shear stress distribution is also presented for M = 2.5 and M 3.0 in fiure6.10 and figure 6.11. In this case, the wall shear stress change on the whole fin surface and is slightly above 400 N/m2. Again, the wall shear stresses are higher at the lower of the fin surface, where the value of the wall ***shear stresses is recorded 2380 N/m2 ,*** which occurs at the fin leading edge at M3.0 and Alpha 100, can be seen from table 6.5 and figure 6.10, while the wall shear stress distribution is slightly lower at the top of the fin surface. However, the wall shear stress distributions are nearly greater than the M3.0 than the M2.5, as well as the influence of thermal heat flux is greater for M = 3.0 than for M = 2.5. In case of, without the influence of an aerodynamic heating, the distribution of the equivalent wall shear stress are different. We have observed that thermal heating is much more on the fin L.E as compare to the other portion of the fin surfaces and of course, the normal forces are very important parameter for the designers to design any high speed vehicles and hence we must design a fin in such a way that it should sustain the higher load or normal forces, keep in mind that it should have less projected area and high strength and low weight. Therefore geometrical properties of the initial design phase must be carefully selected by the designer to avoid excess wall shear stress which may cause the failure of the fin structures.

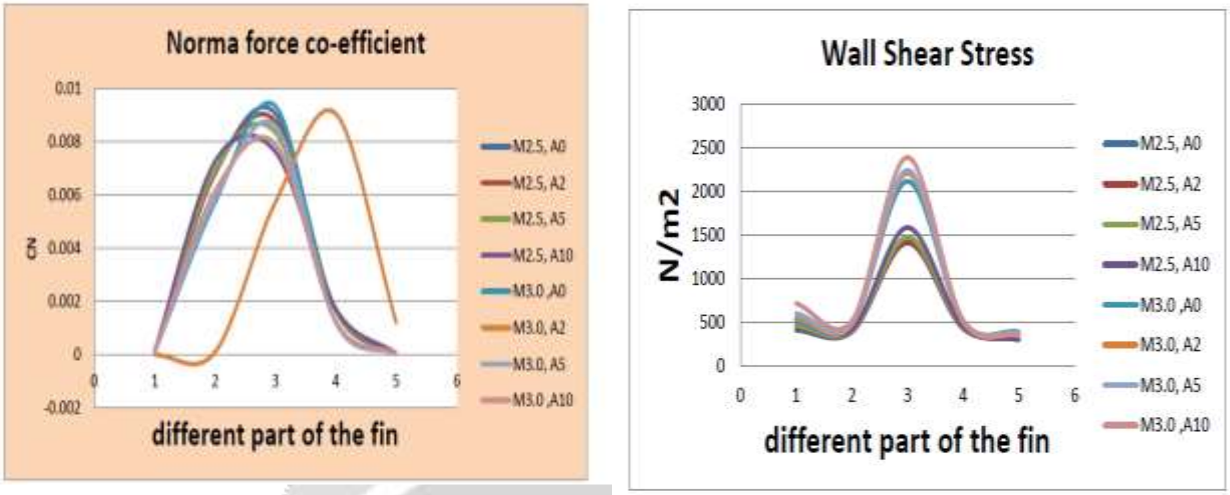


Fig:-3 Normal Force component and wall shear stress along the Fin

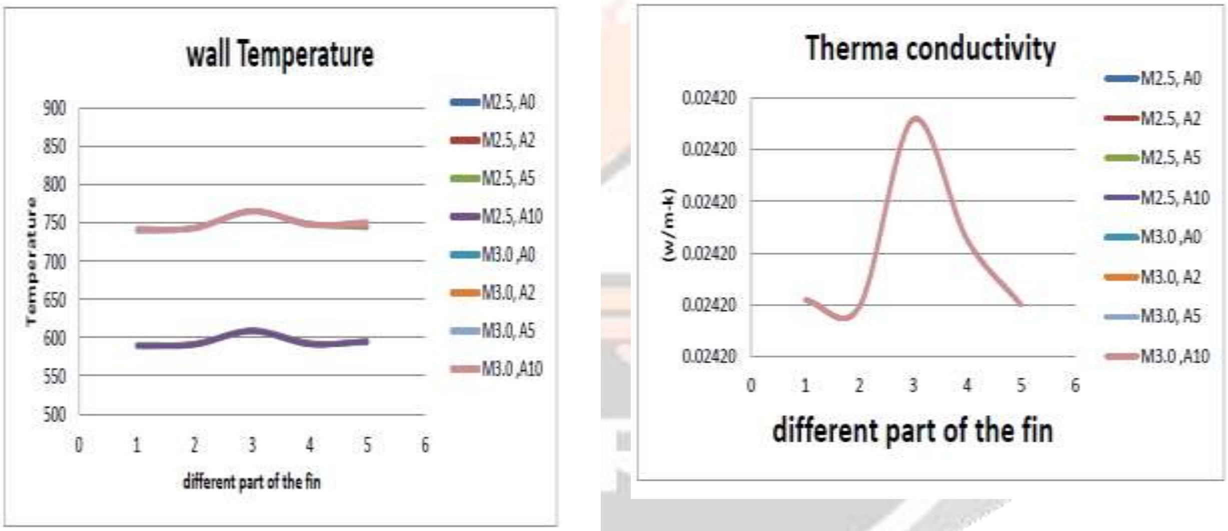


Fig:-4 Wall Temperature and Thermal Conductivity along the Fin

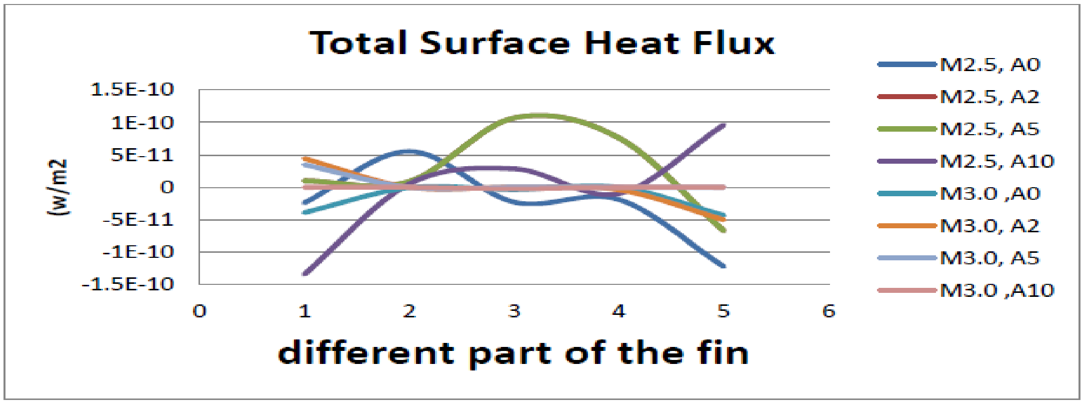


Fig:-4 Total Surface Heat Flux along the Fin

In this work a multiphase framework for numerical aero-thermal and structural analysis, based modeling, meshing and simulation software's, was used for predicting the surface temperature rise on the fin structure due to aerodynamic loading at a high speed. Thermal effects over fin structure during operation of supersonic flights was conducted for two Mach numbers mainly M = 2.5 and M = 3.0. The results we obtained showed us an evident influence for the two different Mach numbers on aerodynamic heating and wall shear stresses. However, the stresses due to presence of aerodynamic heating were increased as the speed increases that have been shown in figure 6.10 and figure 6.11 in the result section. And also, it can be clearly seen from wall temperature plots those plots, and table represents how the temperature gets affected as increase in speed of a flight vehicle. Furthermore, the analysis which we conducted delivered a more qualitative result that can be used for material selection for the fin as well as to decide the shape of fin which can produce a minimum aerodynamic load and structurally very strong.

The conduction of static missile fin numerical experiments was a necessary step to start with creating a well-established numerical environment for aero-thermal and structural study and simulation, as they were frequently used for verification and validation of CFD and structural analyses of the missile fin model or full missile model and analysis or any supersonic and hypersonic vehicle design and analysis.

6. CONCLUSION

The verification and validation enabled us the use of numerical environments which makes a significant approach for the overall aero-thermal-structure analysis and great helps in quickening of the complete conceptual designing process of aero vehicles. The proposed and well-established numerical environment integrated and validated with existing experimentally generated database shows some powerful tools for numerical aero-thermo-elastic prediction in the aerospace sciences and demonstrates the high quality of results and data which will be used to design an aero-vehicle with acceptable calculation of times.

So that this work is well describes the approach for adopting to estimate the aerodynamic loading and heating effects of any aerodynamic configuration in high speed vehicle design and analysis. Hence to provide the better and general understanding of aero-thermo-elastic behavior during the supersonic and hypersonic flight conditions.

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