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CFD SIMULATION AND FEA ANALYSIS OF A BALLISTIC MISSILE

Abstract: *The ballistic missile model analysed in this paper presents a stringer type fuselage having 10 control surfaces, 8 directional surfaces to execute turns and 2 to execute manoeuvers for changing the angle of attack, but also 4 direction stabilisers. In this paper a CFD simulation was carried out on ballistic missile with a new structure for determining the flight performance and the aerodynamic configuration. It was also performed a finite element analysis of the ballistic missile and the results obtained allowed to precisely determine the areas where the stress is greatest and where is necessary to provide several measures to increase the structure's rigidity, to protect it from temperature and pressure.*

Key words: *ballistic missile, CFD, finite element analysis, pressure, stress.*

INTRODUCTION

The implementation of a new model of aircraft (airplane, helicopter, missile) comprises of a series of calculations, experimental studies, laboratory and operational tests that relate to the manufacturing documentation for the version that best meet the requirements. In this perspective, the design of the aerodynamic configuration and propulsion systems, as well as the pre-dimensioning of the aircraft is an important step, on which depends largely the flight performance of the designed and manufactured model. Designing an aircraft must account for: defining the aerodynamic configuration, sizing of the resistance structure, all of these being done closely related to the designed model's performance of the command and control systems [1].

Missile structures are very diverse in terms of dimensional and form characteristics, as well as the materials they are made of. Construction characteristics depend on the type of missile considered, which may belong to a certain class depending on a number of criteria aimed at its destination and can induce specific structural changes. Some of these criteria are [2]:

- the environment in which it is in service: air, water or outer space;
- the control system: autonomous, remote controlled (through the beam control signals and radio), auto-controlled (active, semi-active or passive), combined;
- aerodynamic configuration: symmetry plane or axial symmetry;
- the position of the shooter and the target: ground-to-air, air-to-ground, ground-to-ground;
- the type of target: anti-tank missile, anti-ship;
- the number of steps.

Despite their diversity, it can be distinguished a common feature of the structures, at least in the case of missiles travelling through atmosphere, namely the requirement imposed on them to withstand given the conditions of having a small weight of the entire missile. Because of this requirement, at the construction of the missile lightweight metallic materials or composite materials are used, and in the case of larger missiles constructive solutions characteristic to aircrafts can be used [2].

In the construction and calculation of missiles can be distinguished a range of aerodynamic configurations, arising in particular from the missile's destination and of the flight regime. Thus, missiles have the following aerodynamic configurations (figure 2):

- plane symmetry: normal (controls behind the wings) or reverse (canard);
- with axial symmetry: normal, without tail, reverse (canard); with mobile wings; fuselage tail (without aerodynamic controls); isolated fuselage (without aerodynamic controls).

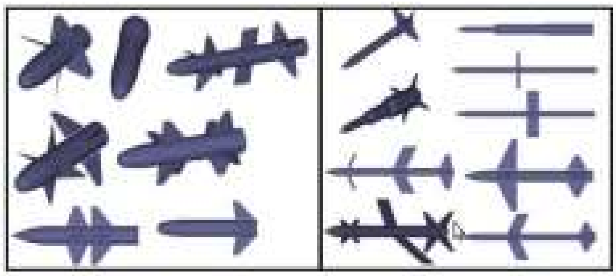

Fig. 1 The main missiles' aerodynamic configurations [3]

2. BALLISTIC MISSILE'S MODEL

In this paper it was analysed a ballistic missile with a new structure, with the following characteristics:

- Length: 3100 mm;
- Body Diameter: 160 mm;
- Missile's weight without fuel and the explosive charge: 721 kgf;
- Missile's weight with fuel and explosive charge: 971 kgf;
- Tank: 15 L;
- The warhead is a mixed type of 11 kg.

As guidance systems of the ballistic missile was used: electro-optical guidance system; infrared guidance system; LOBL system; LOAL system.

The flight performance that can be specified: range of 20-80 km and can reach speeds of Mach 7. The materials used in the structure of this missile are: duralumin - 30%; stainless steel - 8%; titanium - 62%.

The modelling of the missile (figure 2) was performed in CATIA V5 R21 program, in which it was carried out a modelling of the component parts of a missile model based on an existing model. This model of air-air missile has a modified internal structure and much more resistant.

This structure used is an idea that was applied to eliminate loads that appear on the missile skin. The main concept of the analysed missile is a modular missile, the 3 modules being the following starting from the back to the top of the missile: engine module; explosive module (mixed warhead); guidance system and control module.

Fig. 2 The ballistic missile's model in Catia V5 R21

In this paper was carried out a CFD simulation (at three angles of attack) and finite element analysis for a ballistic missile with a stringer type fuselage and 10 control surfaces 8 directional surfaces to execute turns and 2 to execute manoeuvers for changing the angle of attack, but also 4 direction stabilisers.

3. CFD SIMULATION OF BALLISTIC MISSILE

Computerized Fluid Dynamics is a branch of fluid mechanics that uses numerical methods, algorithms and hardware and software systems to model and solve problems arising in the fluid flow. Main application of these CFD techniques is modelling turbulent flow at various speeds (subsonic or supersonic) in the aerospace domain [4, 5, 6], but there are many other areas in which it is used, such as vehicles' aerodynamics [7, 8] and construction [9], weather forecasts, geological surveys, pollutants' dispersion, medical or military applications, movies and computer graphics, semiconductor industry, glass industry.

Calculation of ballistic missiles aerodynamic performance is to determine parameters (forces, temperatures, densities). Also, there were represented the air flow paths around the missile, representations of the pressures, stresses on the missile's structure or in a given plane at three angles of attack (0 degrees, 15 degrees, 30 degrees).

To make the CFD simulations of the aerodynamic performances of the missile were set the airspeed and the computational domain in SolidWorks Flow Simulation 2016 software.

3.1 The CFD analysis of ballistic missile at the angle of attack of 0 degrees

The missile flies at a speed of up to 7 Mach and the fluid which meets this body (air) brakes due to drag generated by the missile's body. The return domain at the initial velocity of the fluid is very high due to missile's speed (Mach 7). Due to the control surfaces of the missile body, there is a higher drag. In Figure 3 it can be seen the area as that of light yellow colour, compared to that which occurs along the missile's body, the area shown in green.

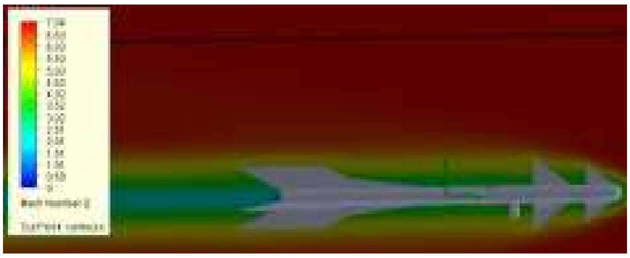

Fig. 3 The speed distributed around the missile (0 degrees angle of attack)

In this case (figure 4) the relationship speed-pressure is accounted for: in the areas with high speed is recorded the lowest pressure values. The area that belongs to the domain describing the drag, observable on the graphic representation of the distribution of pressure by the colour green, has the highest pressure due to the energy exchange between the particles of the fluid (air). This area is represented on the missile's body by the sight dome of the guidance and control system.

Fig. 4 Distribution of pressure around the missile (0 degrees angle of attack)

Due to very high speed (Mach 7) fluid particles present a high energy exchange, which causes intense friction at the surface of the missile and in its close proximity (figure 5), generating very high temperatures of over 1600 K (1400°C).

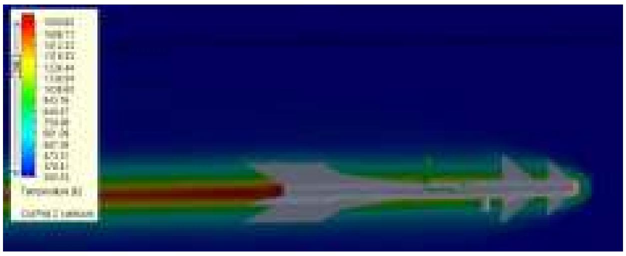

Fig. 5 Distribution of temperatures around the missile (0 degrees angle of attack)

3.2 The CFD analysis of the ballistic missile at the angle of attack of 15 degrees

The return domain to the initial velocity of the fluid is very high due to missile's speed (Mach 6.82). Behind the missile and on its upper surface, is recorded the lowest missile speed value, observable on the graphic representation (figure 6) by the colour light blue.

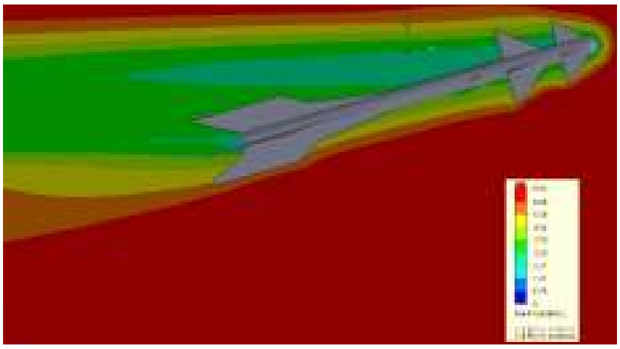

Fig. 6 The speed distributed around the missile (15 degrees angle of attack)

Air layers are deflected uniformly by the missile's body and the control surfaces and fluid pressure tends to revert to its original state before the fluid was disturbed by missile's passing.

As it can be seen on the graphic representation (figure 7), on the underside of the missile is imprinted a drag much larger than that on the upper surface of the missile, this is observable on the graphic representation (figure 7) as follows: on the underside is observed a higher pressure by the presence of light green colour, so a higher drag and friction between the missile's body and the fluid around it.

On the upper side, the friction and drag are very low, observable on the graphic representation (figure 7) by the light blue and dark blue colours.

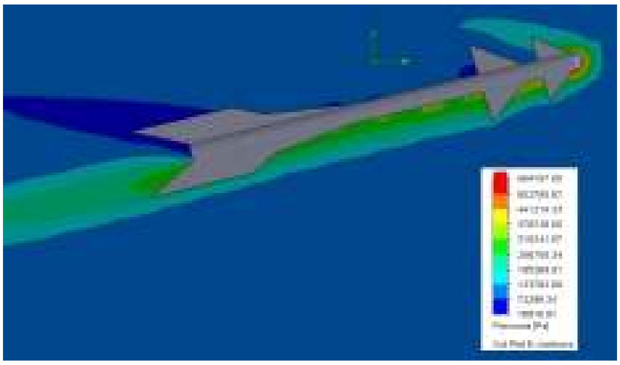

Fig. 7 Distribution of pressure around the missile (15 degrees angle of attack)

The highest temperature is recorded in the rear of the engine, because in that area is recorded the highest thermal values due to missile's reaction jet engine, implicitly the lowest values for pressures.

The return to baseline temperature is not accounted for in this analysis (figure 8), as this chart analysis determines only the temperature distribution during the evolution of the missile.

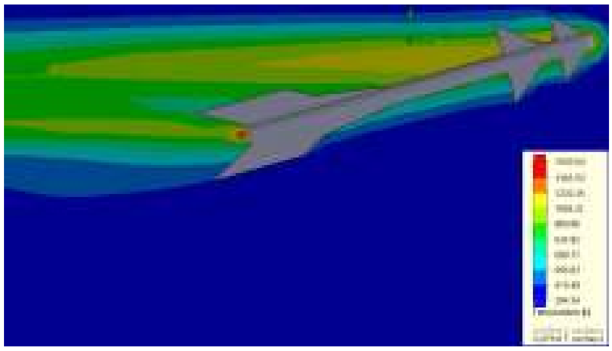

Fig. 8 Distribution of temperatures around the missile (15 degrees angle of attack)

3.3 The CFD analysis of ballistic missile at the angle of attack of 30 degrees

In this analysis (figure 9) are not recorded separation of air layers because there are no major differences of pressure (is taken account of the relationship between speed and pressure, namely, a high speed generates low pressure).

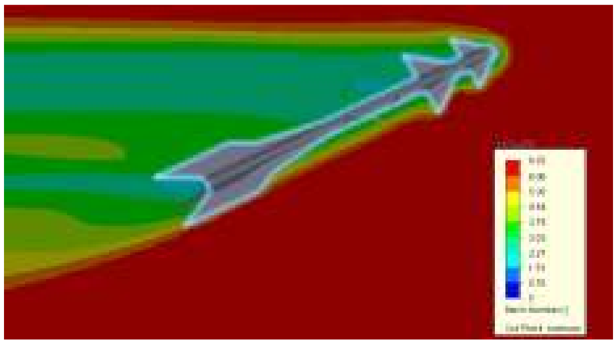

Fig. 9 The speed distributed around the missile (30 degrees angle of attack)

Due to the aerodynamic profile, since from the missile's body there is a reversion to the initial pressure of air fillets, observable on the graphic representation (figure 10) of the pressure distribution in the colour light blue.

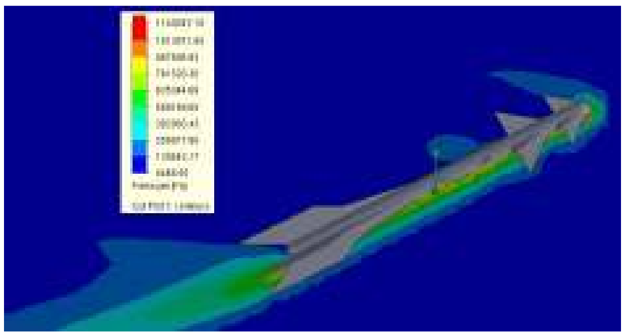

Fig. 10 The distribution of pressure around the missile (30 degrees angle of attack)

Due to drag that occurs with the increasing of the attack angle, the missile cannot fly at the same speed of Mach 7, being broken, but not very much, as can be seen braking is worth Mach 0.18.

The surfaces most affected by temperature (figure 11) arising from the friction of fluid particles during the evolution, are the areas of control surfaces and the sight dome due to high drag that appears on the missile and in the immediate vicinity due to swirling of the fluid on the missile's profile.

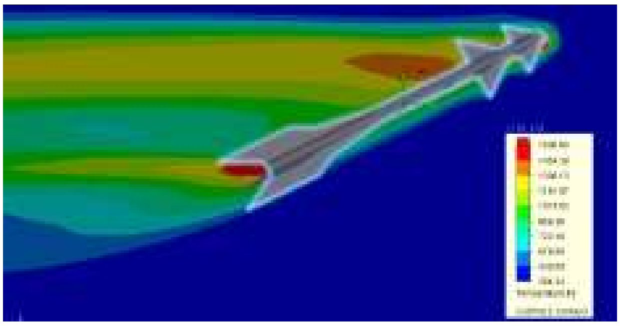

Fig. 11 Distribution of temperatures around the missile (30 degrees angle of attack)

4. THE FINITE ELEMENT ANALISYS OF THE BALLISTIC MISSILE'S STRUCTURE

The resistance calculation of the missile's fuselage can be made based on simplifying assumptions about the type of structure and loads. The structure is approximated on portions with either a bar having constant rigidity, or are analysed the components approximated as a thick-walled and thin-walled tubes. Loads are considered axially symmetrical, applied on substructures [2].

Consequently, the problem of resistance calculation of the missile's fuselage and its component structures should be studied as a whole, using methods other than the classic ones. Classical methods for calculating the resistance requires a complex algorithm and it does not always show the correct results. In this regard, using the finite element method allows to fairly configuring the geometry and loads for the ballistic missile analysed.

Linear static analysis of the stress state in the case of missile bodies, deformable, which are in accelerated motion, is possible if it is imposed that external forces and inertia to be in balance. For this reason it was necessary before the strength calculation to determine the precise mass of the main components of the missile. Then the finite element meshing was conducted, of ballistic missile model, which previously was modelled on computer, based on nominal dimensions from documentation.

The mechanical characteristics of the materials necessary for the finite element calculation of the ballistic missile are: modulus of elasticity in tension-compression, Poisson's coefficient, density, thermal expansion coefficient and thermal conductivity coefficient. In addition, it is necessary the value of elastic limit tension for determining areas of maximum stress by comparing this value with maximum equivalent stresses obtained from finite elements analysis.

Finite element analysis was performed in ANSYS 15 Workbench software, the Static Structural module. The steps to perform finite element analysis of ballistic missile are described in Figure 12.

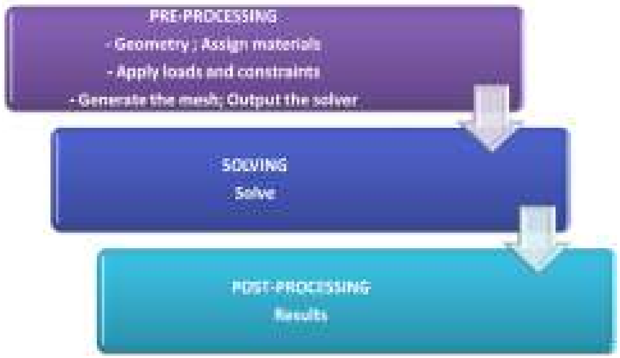

Fig. 12 Flow chart for finite element analysis of the ballistic missile

The input data for this finite element analysis are the pressures resulted from the CFD simulation of the aerodynamic performance for the angle of attack 0 degrees. To verify the structure and to determine its resistance for analysis was used the highest pressure that appears on ballistic missile, so it was used a pressure of 650000 Pa. The missile was embedded at the back and the pressure was evenly distributed over the surface of the racket. The three materials (duralumin - 30%; stainless steel - 8%; titanium - 62%) were distributed to the components of the ballistic missile.

In Figure 13 is represented the Von-Misses equivalent stress state of the structure for the ballistic missile, pointing out that the stress peaks occur in the junction area of the four direction stabilizers for the missile's body, and at the junction between the missile's body and the two winglets. It can be seen that most of the maximum stresses occurring on the missile's structure are in the assembly area between the various components which have radiuses determining the appearance of stress concentrators.

To ensure the integrity of the missile's structure some measures shall be taken to protect and strengthen these areas with thermal insulating materials that confer the missile as resistant a structure as possible. It can be seen that the maximum stress of 117 MPa is less than the allowable stress of any material composition in the ballistic missile.

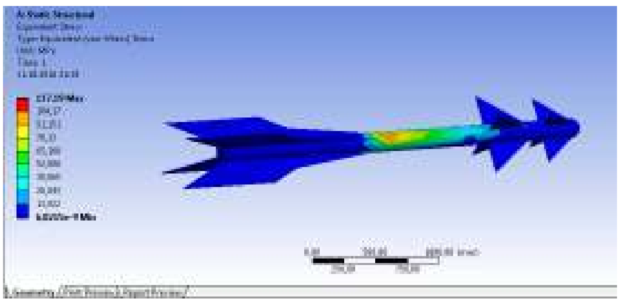

Fig. 13 Distribution of equivalent Von- Misses stresses on ballistic missiles structure

Areas that are necessary for the determination of the stresses are shown in Figure 14. As it can be seen the maximum values of total deformations are obtained at the top of the missile and are 12 mm.

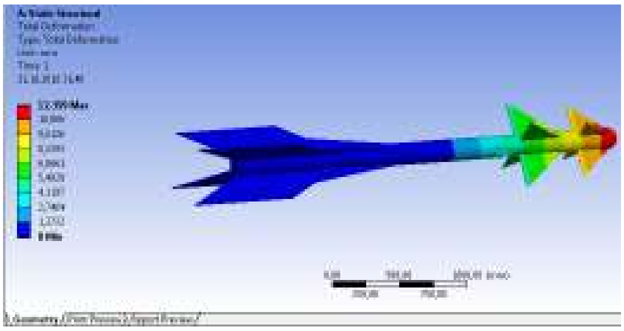

Fig. 14 The total deformations occurring on the ballistic missiles structure

The equivalent elastic strain of ballistic missile is obtained in the assembly area of the missile's body and steering stabilizers (figure 15).

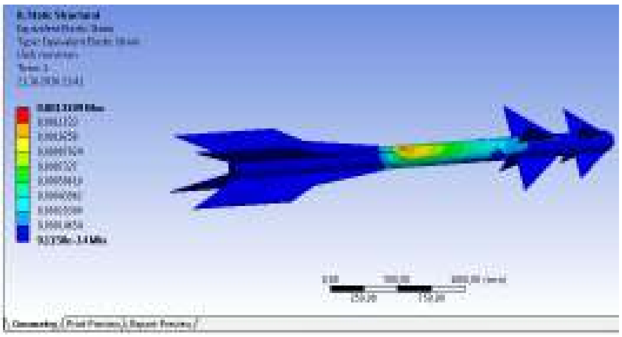

Fig. 15 Equivalent elastic strain of ballistic missile

The maximum directional deformation (X axis) values of ballistic missile is obtained in the assembly (fuselage missiles and steering stabilizers) and on the two directional surfaces to execute manoeuvers for changing the angle of attack (figure 16).

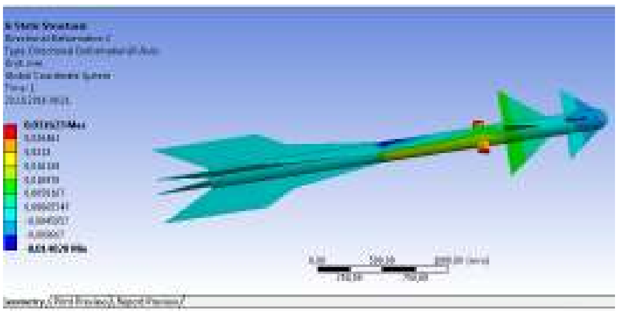

Fig. 16 Directional deformation (X axis) contours

5. CONCLUSIONS

The inner structure of the analysed ballistic missile is a new structure that gives better resistance to bending and torsion stresses. Stringer type outer surface adds aerodynamics to the missile and allows better handling, work also achieved by the two types of control surfaces.

By eliminating external fasteners, it was created a laminar boundary layer flow on the missile's aerodynamic profile, evidenced well by the aerodynamic analysis using CFD techniques.

At the same time the missile skin made up of a double envelope of titanium, gives it a very good resistance to elastic deformation, as can be seen from the finite element analysis, the maximum deformation was 12 mm from the tip of the missile, having regarded the overall length of 3100 mm.

The double skin acts as resistance casing (the casing made of profiled sheet serving as a longitudinal resistance element) and the outer shell as laminar casing to achieve laminar flow.

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