# Aerodynamic and Structural Analysis of a Land Attack Cruise Missile

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**Abstract**

The objective of the research paper is to perform Aerodynamic and Structural Analysis of the Tomahawk Missile, the outcome of the Analysis is expected us to suggest the best suited Nose Cone for the Missile among the three Nose Cones considered, namely Conical, Elliptical and Von Karman O give. The Aerodynamic Analysis will be carried on three different speed regimes-subsonic supersonic hypersonic. By performing the flow analysis of the missile with different nose cones, the outcome is expected to be the identification of the suitable Nose Cone. Further to continue our research work we shall perform the Structural Analysis on the missile with the best suitable nose cone, the structural analysis shall be performed by considering three different materials namely Aluminum, Titanium and Structural Steel. We shall find out which material is suitable for the missile. Hence our research work is suggesting two vital things, firstly we will find the suitable nose cone for the Tomahawk missile and then for this missile we shall find the suitable material.

The research work shall be performed using CAD/ CAE tools, namely Creo 4.0 for the modelling of missile, nose cone etc., and ANSYS Workbench for performing the Flow and Structural Analysis.

**Keywords:** Missile, Tomahawk Missile, Aerodynamic Analysis, Structural Analysis, Creo, ANSYS

## 1. Introduction

In modern language, a missile is a guided self-propelled system, as opposed to an unguided self-propelled munition, referred to as a rocket (although these too can also be guided). Missiles have four system components: targeting or missile guidance, flight system, engine, and warhead. Missiles come in types adapted for different purposes: surface-to-surface and air-to-surface missiles (ballistic, cruise, anti-ship, anti-tank, etc.), surface-to-air missiles (and anti-ballistic), air-to-air missiles, and anti-satellite weapons. All known existing missiles are designed to be propelled during powered flight by chemical reactions inside a rocket engine, jet engine, or other type of engine. Non-self-propelled airborne explosive devices are generally referred to as shells and usually have a shorter range than missiles.

In ordinary British-English usage predating guided weapons, a missile is such as objects thrown at players by rowdy spectators at a sporting event

Guided missiles have a number of different system components:

- Targeting or missile guidance
- Flight system

- Engine
- Warhead

### 1.1 Tomahawk Missile and Nose Cone

The Tomahawk Land Attack Missile (TLAM) is a long-range, all-weather, subsonic cruise missile that is primarily used by the United States Navy and Royal Navy in ship and submarine-based land-attack operations. Introduced by General Dynamics in the 1970s, it was initially designed as a medium- to long-range, low-altitude missile that could be launched from a surface platform. Since then, it has been upgraded several times with guidance systems for precision navigation. In 1992–1994, McDonnell Douglas Corporation was the sole supplier of Tomahawk Missiles and produced Block II and Block III Tomahawk missiles and remanufactured many Tomahawks to Block III specifications. In 1994, Hughes outbid McDonnell Douglas Aerospace to become the sole supplier of Tomahawk missiles. It is now manufactured by Raytheon. In 2016, the U.S. Department of Defense purchased 149 Tomahawk Block IV missiles for $202.3 million.


**Figure 1. Tomahawk Missile**

The term *nose cone* is used to refer to the forward most section of a rocket, guided missile or aircraft. The cone is shaped to offer minimum aerodynamic drag. Nose cones are also designed for travel in and under water and in high-speed land vehicles.

Given the problem of the aerodynamic design of the nose cone section of any vehicle or body meant to travel through a compressible fluid medium (such as a rocket or aircraft, missile or bullet), an important problem is the determination of the nose cone geometrical shape for optimum performance. For many applications, such a task requires the definition of a solid of revolution shape that experiences minimal resistance to rapid motion through such a fluid medium, which consists of elastic particles.

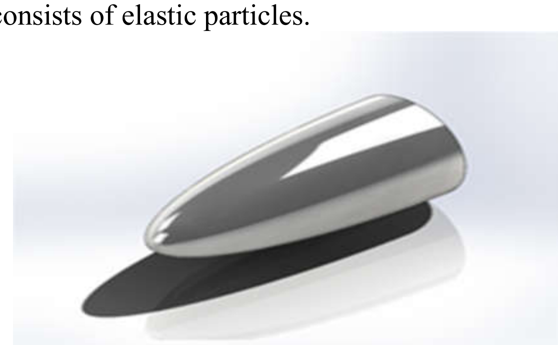

**Figure 2. Nose Cone**

The research work deals with the identification of the suitable nose cone for the Tomahawk Missile by performing Aerodynamic Analysis of the Missile at various Speed Regimes. We shall consider three Nose Cones; Conical, Elliptical and Von Karman. The flow analysis will help us suggest the suitable nose cone for the tomahawk missile, a widely used one. Additionally we shall perform the Structural Analysis on the Missile having the Nose Cone which was suggested as the best one from the Aerodynamic Flow Analysis. The structural analysis will be performed on three materials, Structural Steel, Titanium, and Aluminum. Performing Structural Analysis of the Missile will help us identify the suitable material for the Missile.

## 2. Modelling of the geometry using Creo 4.0 CAD Software

The modelling of the Tom Hawk Cruise Missile, will be performed using the above CAD software, firstly we should identify the basic specifications of the vehicle. The height, diameter and the width of the vehicle is listed in the below table.

**Table 1: Specifications of Tomahawk Missile**

| | |
|---|---|
| Length | 20.3 feet; with booster: 20 feet 6 inches (6.25 meters) |
| Diameter | 21 inches |
| Wingspan | 8 feet 9 inches (2.67 meters). |

Apart from the basic specifications we have the detailed dimension image of the Tom Hawk Missile, we shall consider this image and start the modelling of the geometry. The below image represents the detailed dimensions of the missile.

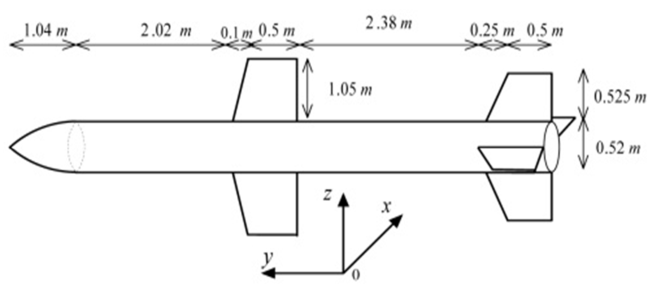


**Figure 3. Detailed dimensions of the Tom Hawk Cruise Missile**

The objective of the research work is to perform aerodynamic analysis of the missile having different Nose Cones at different Mach regimes. Hence for our research work we are considering the three used nose cones, which are

1. Conical Nose Cone
2. Elliptical Nose Cone
3. Von Korman O Give Nose Cone

Firstly, we shall initiate the analysis by performing the geometric modelling of the Tom Hawk Missile which is installed with conical missile by the manufacturer. Latter for the same missile we shall create different front Missile.

For the ease of geometric modelling we shall consider the above scaled image of the Tom Hawk Cruise Missile and resize it. We shall scale the dimensions sighted in the table 1. The scaling is required as we are performing the research work using the computational tools, and as we aren't working with any super-computer, working with the same dimensions will hand our desktop. Hence scaling is mandatory. After scaling the image, we shall import the image in the software i.e. Creo 4.0.

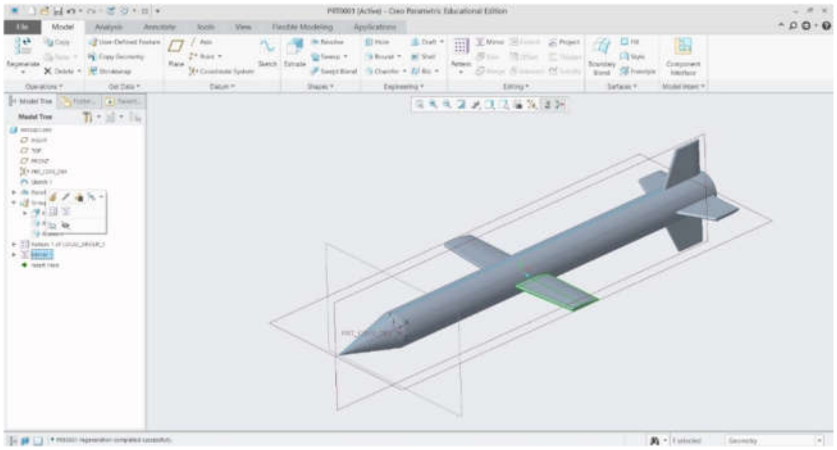

**Figure 4. CAD model of the TOM HAWK MISSILE with CONICAL NOSE CONE**

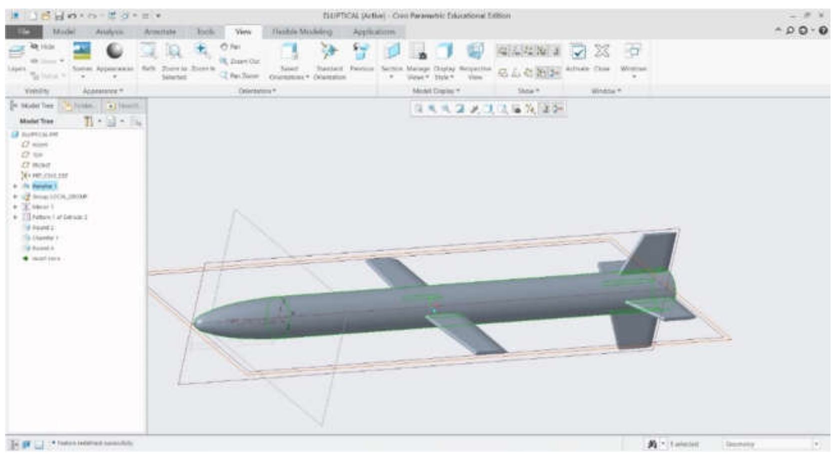

**Figure 5. Final CAD model of the Elliptical Nose Cone Missile**

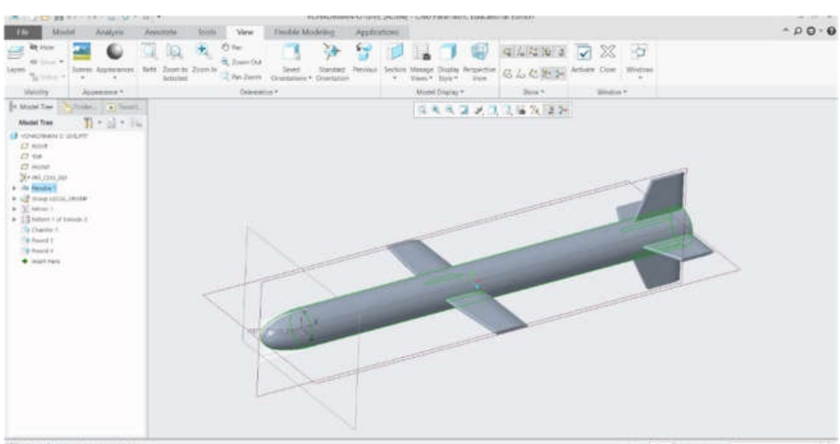

**Figure 6. Final CAD model of the Von Korman O-Give Nose Cone Missile**

The above figure represents the three CAD models of the Tomahawk missile having three different Nose Cone, the CAD files are saved in the IGES format and exported into the ANSYS Software.

## 3. Aerodynamic Analysis of the Missiles

We have simulated the CAD models of the three missiles in the ANSYS-Fluent. The simulation was initiated by importing the CAD file in the ANSYS-Fluent Module, creating an enclosure, meshing the geometry with suitable mesh properties, assigning the boundary conditions and solving the case.

We have chosen K-Epsilon Turbulence Model for the Flow Analysis having Non Equilibrium wall functions with Viscous Heating Engaged. The inlet velocity is set at 275 m/s and the outlet pressure is set at 5.408 pa for subsonic flow analysis, Velocity of 800m/s, Pressure of 2.65 pa for supersonic flow analysis and Velocity of 2000m/s, Pressure of 1.2 pa for hypersonic flow analysis. The solution was initialized with 500 iterations and stopped on convergence. Post-Convergence we have extracted the contours representing the pressure variations over the three CAD models.

Following are the images corresponding to the Pressure Contours of each missile solved individually using ANSYS-Fluent.

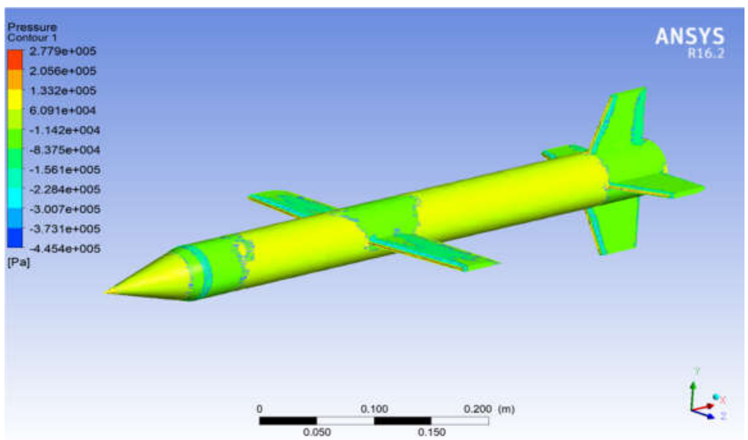


**Figure 7. Pressure on Missile with conical nose at subsonic speed**

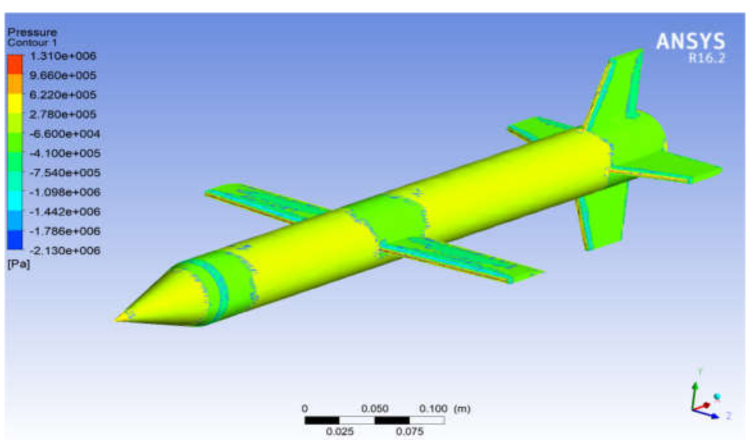


**Figure 8. Pressure on Missile with conical nose at supersonic speed**

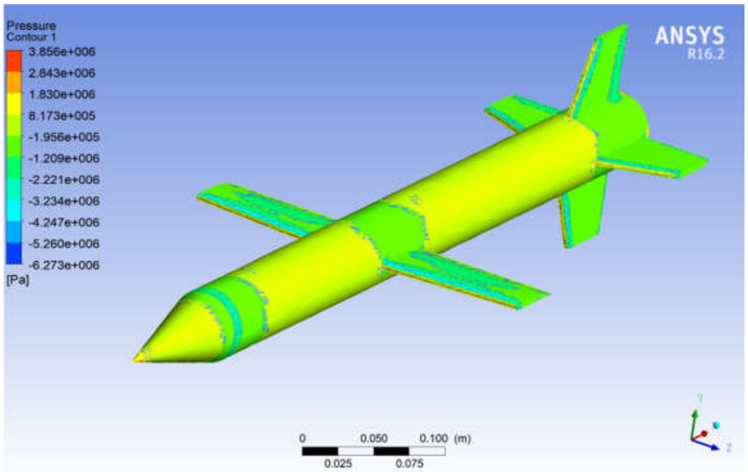


**Figure 9. Pressure on Missile with conical nose at hypersonic speed**

Similarly following the above procedure we have performed three flow analysis of the missile with other two types of nose cones and the following figures represents the pressure variation over them

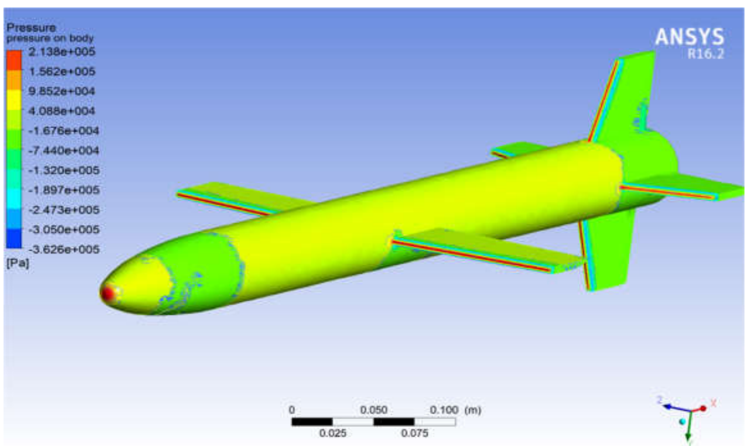


**Figure 10. Pressure on Missile with elliptical nose at subsonic speed**

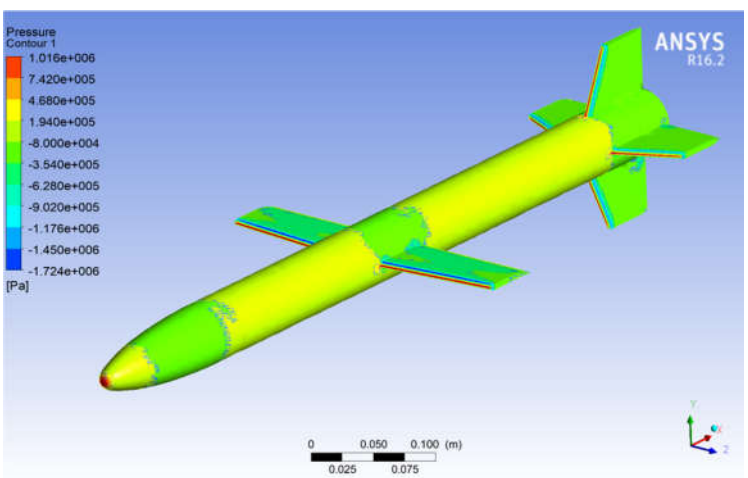


**Figure 11. Pressure on Missile with elliptical nose at supersonic speed**

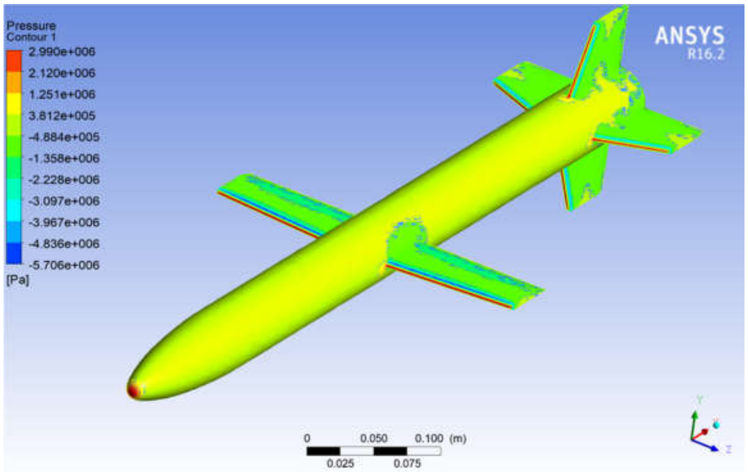


Figure 12. Pressure on Missile with elliptical nose at hypersonic speed

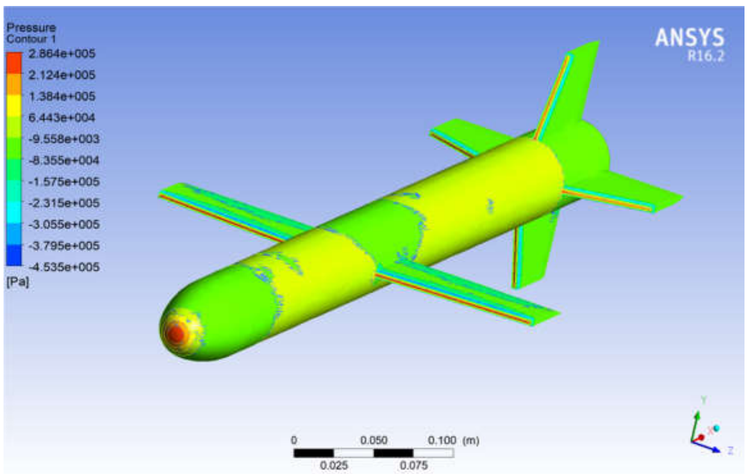


Figure 13. Pressure on Missile with Vonkorman nose at subsonic speed

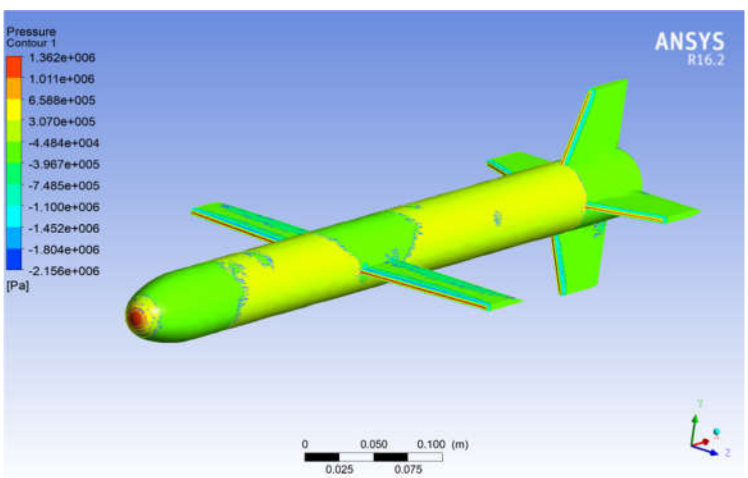


Figure 14. Pressure on Missile with Vonkorman nose at supersonic speed

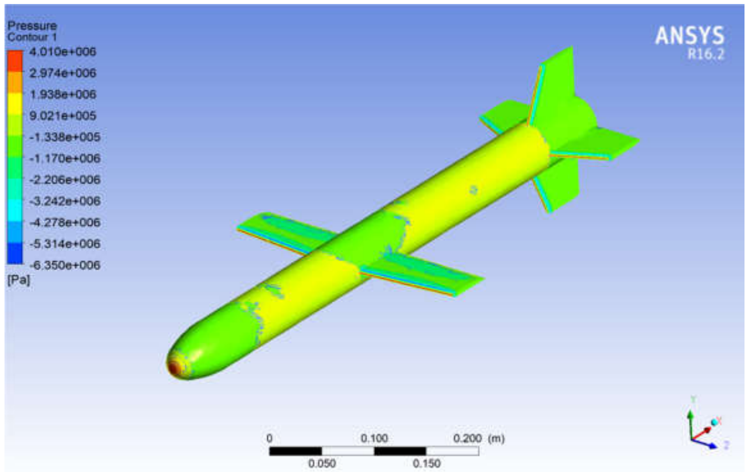


**Figure 15. Pressure on Missile with Vonkorman nose at hypersonic speed**

The flow analysis of the missile with three different Nose Cone will help us identify and suggest in our research work that which nose cone among the three can be used for the missile in order to have improved aerodynamics. From the above figures (Post Results) on observing, we conclude that the missile having Elliptical Nose Cone has smoother air flow as it has less pressure acting in all the three speed regimes. Hence now we shall perform structural analysis of the missile with Elliptical Nose Cone to extend our research in finding the suitable material for the missile.

## 4. Structural Analysis of the Missile

For performing structural analysis we've used ANSYS Workbench Static-Structural Module. Following are the three different metals to be applied as the material of the missile body that shall undergo stress analysis for the pressure acting over the body.

1. Aluminum alloy
2. Stainless steel
3. Titanium alloy

The CAD file was imported and meshed with fine mesh properties, then we have assigned each of the material mentioned above to the geometry. The missile is then applied with a pressure load of $2.99e^{006}$ Pa acting over the entire body of the missile, this value of pressure c was obtained from previous flow analysis (Hypersonic) of the missile. After solving the boundary model for the three materials, we have extracted the variations of Total Deformation, Equivalent Strain and Equivalent Stress.

For the **Aluminum Material** following are the results obtained:

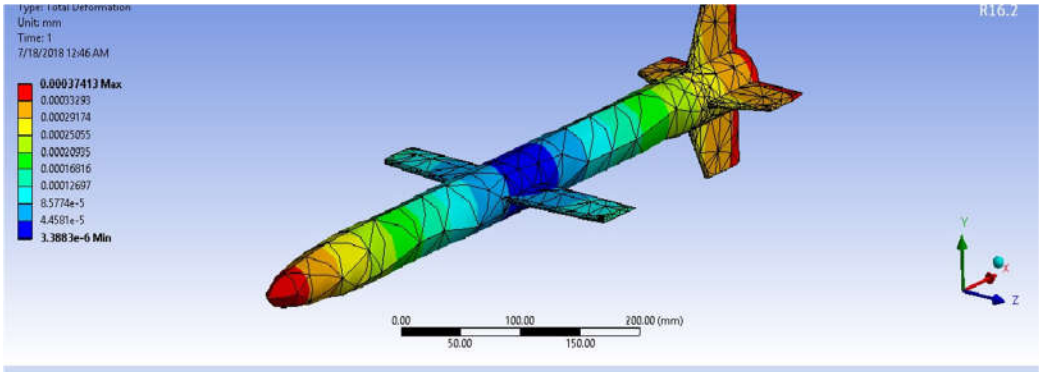


**Figure 16. Total deformation of Missile**

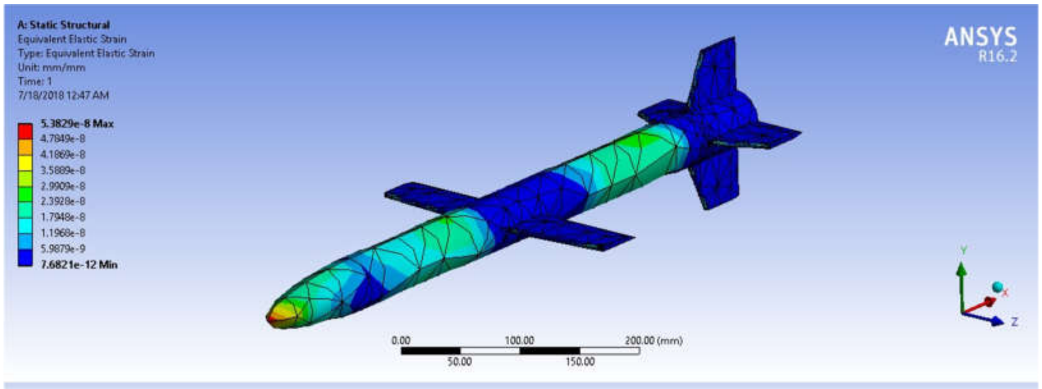


**Figure 17. Equivalent elastic strain of missile**

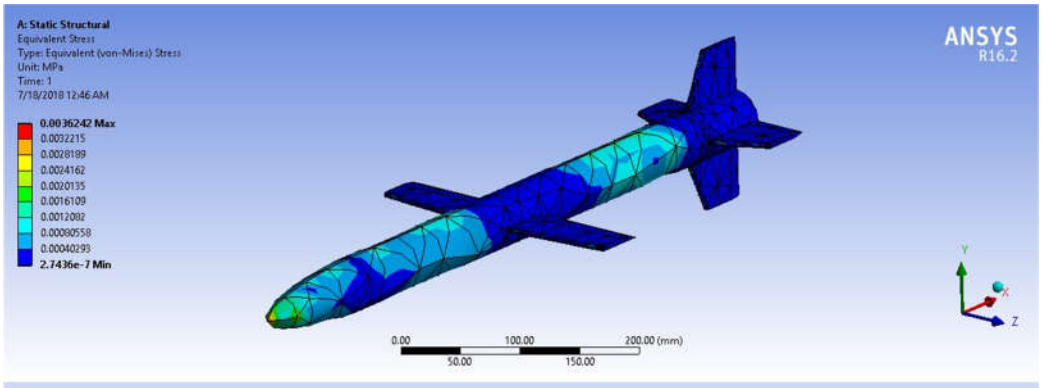


**Figure 18. Equivalent stress of missile**

For the **Structural Steel** Material following are the results obtained:

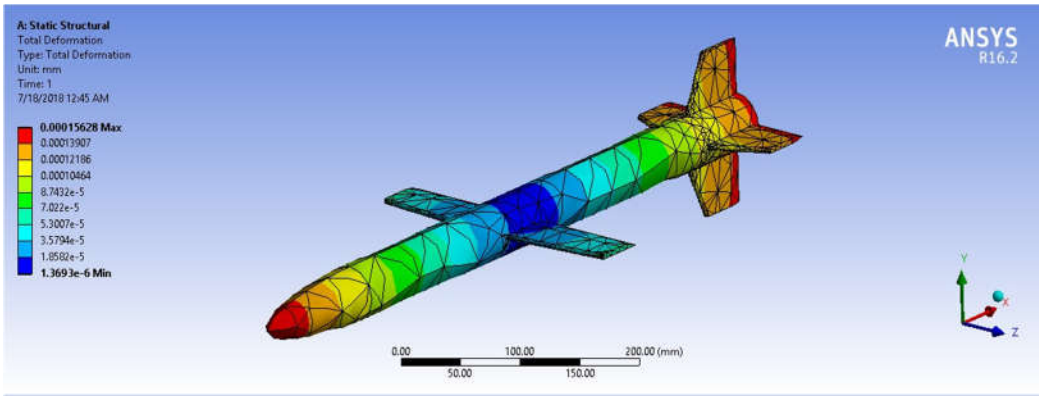


**Figure 19. Total deformation of Missile**

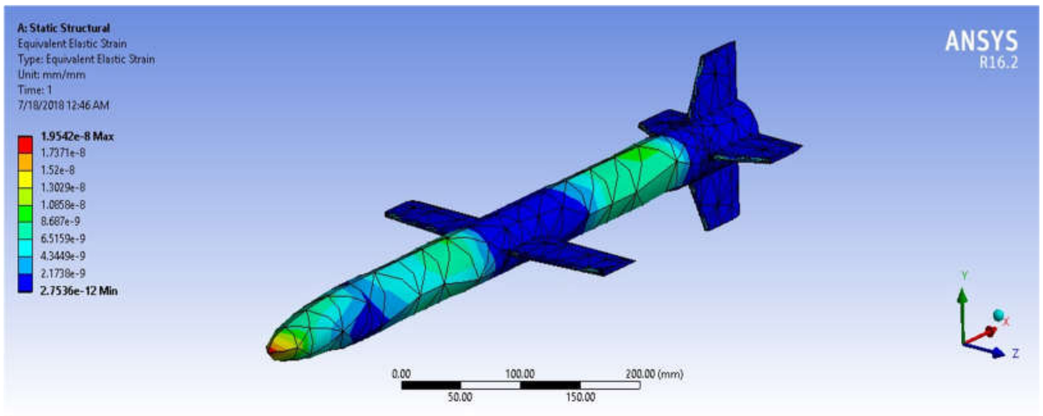


**Figure 20. Equivalent elastic strain of missile**

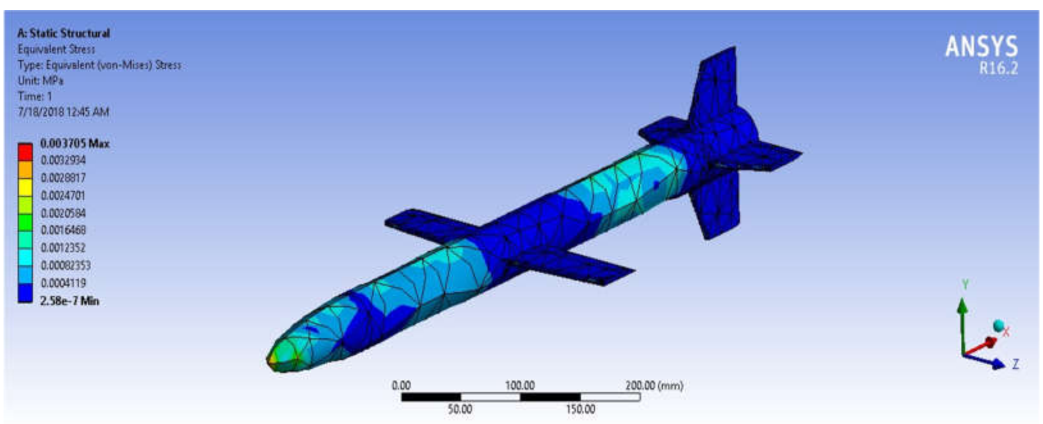


**Figure 21. Equivalent stress of missile**

For the **Titanium Material** following are the results obtained:

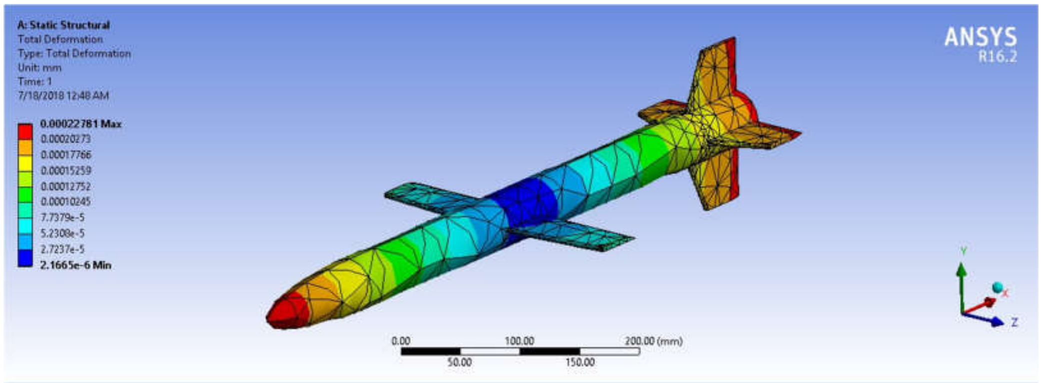


**Figure 22. Total deformation of Missile**

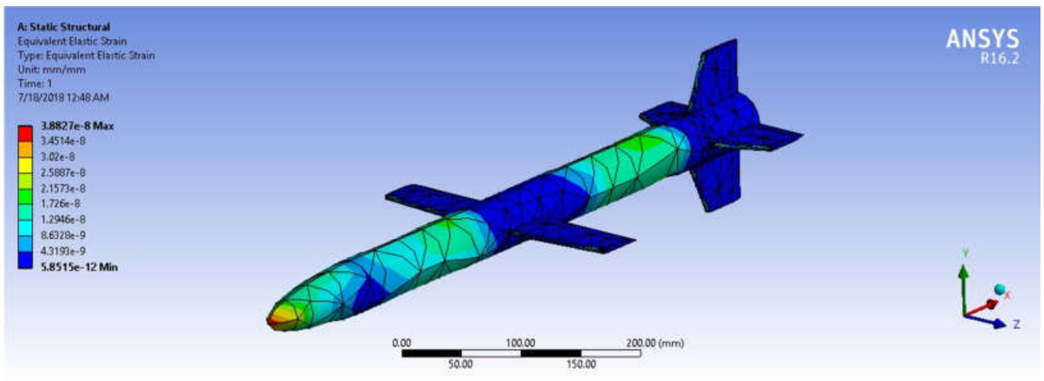


**Figure 23: Equivalent elastic strain of missile**

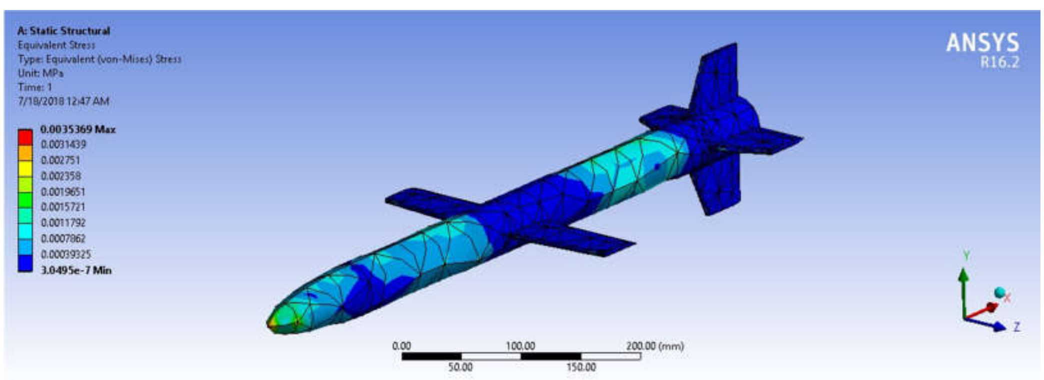


**Figure 24: Equivalent stress of missile**

In order to find out the best suited material for the missile having Elliptical Nose Cone, the extracted deformations, stresses and strains need to have desired conditions, the deformations should be less for a material under the action of load, similarly the strain induced should be less and concerning the stress, the material should be capable of sustaining higher amount of stresses. Therefore considering the above conditions we may observe that values of structural steel are desirable, hence the structural steel is the best suited material for the elliptical nose cone missile

## 5. Conclusion

The Tomahawk Missile is one of the mostly used and preferred military aircraft missile by many countries, it has the ability to aid the combat on different conditions, with ultimate turns and maneuvers. The objective of the research work is to find the suitable Nose Cone for the Missile among the three Nose Cones. Thus we have performed Flow Analysis of the Missile equipped with the three nose cones, namely, Conical, Elliptical and the Von Karman O give Nose Cones, the three Flow Analysis were carried over the different speed regimes that are Sub-Sonic, Super-Sonic and Hyper-Sonic. The analysis was performed after the creation of the three dimensional CAD model of the Missile using CAD software CREO 4.0.

The Flow Analysis of the CAD model of the Tomahawk Missile has helped us to attain the pressure acting on the body of the Missile at different speeds. The values of the pressure are sighted in the tables of the previous section, analyzing the values we may see that there is a decrease in the pressure on the missile when it is equipped with the Elliptical Nose Cone on comparison with the other two. The material of the skin of the missile shall be able to withstand the loads generated by the air pressure, therefore in order to identify the Structural Variations of the Elliptical Nose Cone missile’s skin caused by the pressure induced on the skin, hence we have performed the structural analysis of the missile with different skin materials to find out the best suited material for the missile. We have considered Aluminum, Titanium and Structural Steel as the material for performing the analysis, and from the structural analysis we have taken out the variations of the deformation, Stresses and Strains aroused on each material for the given pressure load. On analyzing the values of Total Deformation and Elastic Strains, the Structural Steel stands first and Titanium Second in the preferences as they have less deformations as desired, whereas if we consider the Stress, we need a material that should withstand more stress, on analyzing the values we could predict the Structural Steel and then Aluminum could be the well suited material.

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