SELECTION OF THE SURFACEMATERIAL OF A SUPERSONIC SPACE VEHICLE "NASA N+3" BASED ON AERODYNAMIC & STRUCTURAL ANALYSES

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Abstract

Research in the area of Advanced Supersonic Transport (AST has been a focus area for NASA since 1960s, driven by maintaining U.S. leadership in the area of commercial transport.According to a 1980 Open Travel Alliance (OTA) report on the impact of advanced air transport technology, the business case in favor of ASTs results from improved aircraft productivity and its capability to transport twice the number of passengers on long distance flight. Higher cost of operations, concerns over environmental impact due to noise and emissions, and restrictions to fly supersonic on land due to sonic boom are some of the technological issues that need to be addressed for production and deployment of ASTs. NASA's research efforts for the advancement of AST are dedicated to address these technical challenges and the AST technology is being matured under N+1, N+2 and N+3 projects.

The research work is intended to investigate the aerodynamic properties and structural integrity of the NASA N+3 Supersonic Aircraft. The final report of NASA on AST will be used as a reference in our analysis. The aerodynamic results will help us to know the pressure and velocity acting on the aircraft at supersonic flight. Then we may continue the research work further by performing structural analysis. The output of aerodynamic analysis will be used as an input for structural analysis. The parameters obtained will help in knowing the best suited material at those speeds. The research work is performed to increase the knowledge of various requirements in conceptual designing of AST aircraft, as it is one of the needed and upcoming transport for traveling in future. The scaled modelling of the aircraft is performed by utilizing the CAD software Creo 2.0, and the Analysis on the scaled aircraft is performed by using the ANSYS Fluent and Static Structural modules.

Keywords—Flow Analysis, Static Structural Analysis, NASA N+3

1. Introduction

A **supersonic aircraft** [1] is an aerospace vehicle that is able to fly faster than the speed of sound (Mach number 1). Supersonic aircraft were developed in the second half of the twentieth century and have been used almost entirely for research and military purposes. Only two, Concorde and the Tupolev Tu-144, were ever designed airliners. Fighter are the most common example of supersonic aircraft, although they do not always travel at supersonic speed. The aerodynamics of supersonic flight is called compressible flow because of the compression (physics) associated with the shock waves or "sonic boom" created by any object travelling faster than sound. Aircraft flying at speeds above Mach 5 are often referred to as hypersonic aircraft.

1.1 Need for Supersonic Aircraft

NASA's attempts to resuscitate supersonic commercial air travel will involve the use of technology that did not exist in Concorde's day, with the aim of minimizing its negative environmental impact in terms of both emissions and noise. The prospect of once again being able to fly between London and New York in under three hours will no doubt be a boon to frequent flyers, ravaged by the effects of regular long-haul travel on their bodies and minds. [2]

However, with future supersonic passenger jets expected to burn about a quarter more fuel than equivalent subsonic aircraft, does the resurrection of this type of flight make sense at a time when the aviation industry is working hard to reduce its impact on climate change?Unsurprisingly, environmental campaigners believe not – unless the new breed of supersonic aircraft can dramatically reduce the emissions and noise traditionally associated with breaking through the sound barrier.

NASA is well aware of the challenges it faces in developing a supersonic aircraft that is palatable to the public and can comply with ever-stricter noise regulations and emissions reduction targets.

1.2 Literature Review

A Final Report for the Advanced Concept Studies for Supersonic Commercial Transports Entering Service in the 2030 to 2035 Period, N+3 Supersonic Program is the work done at NASA Langley Research Center under prime contract (Lockheed Martin (LM)) NNC08CA84C.

Lockheed Martin Aeronautics Company (LM Aero), working in conjunction with seven industry and academia sub-contracting teammates, executed an 18 month program responsive to the NASA sponsored "N+3 NRA Advanced Concept Studies for Supersonic Commercial Transports Entering Service in the 2030 to 2035 Period" contract. The key technical objective of this effort was to generate promising supersonic concepts for the 2030 to 2035 timeframe and to develop plans for maturing the technologies required to make those concepts a reality. The N+3 program is aligned with NASA's Supersonic Project and is focused on providing alternative system-level solutions capable of overcoming the efficiency, environmental, and performance barriers to practical supersonic flight. [3]

The goal of the N+3 project is to explore a conceptual design for multi-Mach aircraft in 2030 timeframe that has low sonic boom, is environmentally acceptable, fuel efficient, and able to fly at supersonic speed above land. Other, integrated design concerns include

- Sonic Boom Reduction
- Cruise Efficiency
- Aero-Propulsion-Servo-Elasticity
- Airport Noise
- Light Weight Structure for Airframe/Propulsion Systems
- High Altitude Emissions

Sizing and mission performance drove the final configuration loft. The drooped nose in the initial configuration reduced the vehicle length, but this was not enough to overcome the added complexity of the shape. A straighter nose may cause difficulties with pilot visibility, but this will be solved with the use of Synthetic Vision as the design moves closer to reality. As a result, the final configuration is shown with a reduction in the drooped nose. [4]

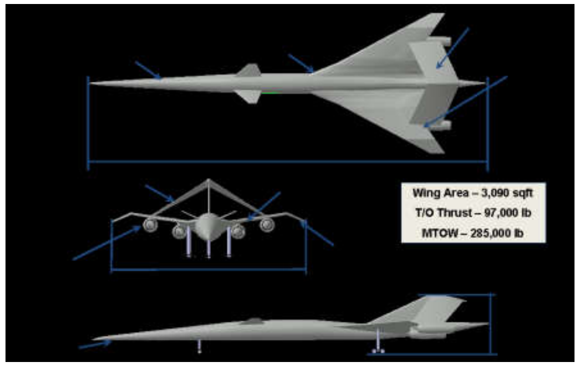

Fig 1 Final Configuration of the NASA N+3

The above final configuration would be used for our research work, where in we will be analyzing the various flow properties and flow parameters on the supersonic vehicle. We will use Creo 2.0 [5] for modelling the geometry and will utilize the existing CAE software i.e., ANSYS Workbench-Fluent for performing the aerodynamic analysis.

2. Modelling the Geometry

For our research work we will be utilizing the CAD tool Creo 2.0 , wherein we perform the modelling of the geometry of the NASA N+3 Supersonic Aircraft and use the CAD file for further analysis, to investigate the best suited material. The first step towards modelling the geometry is to import the scaled image of the NASA N+3 Supersonic Aircraft into the Sketch Module of the Creo Parametric, through the imported image we may sketch and model the Aircraft. We are using the scaled figure of the Aircraft as the aircraft is still under research and there are no existing dimensions of the Aircraft, Hence using the scaled image of the Aircraft will help us model and the create the scaled geometry.

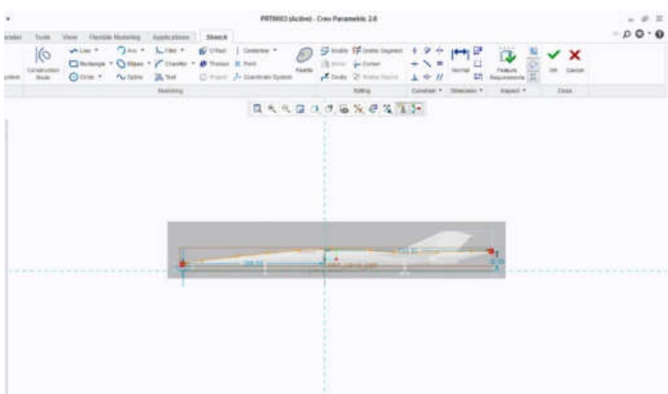

Fig 2 Scaled Image of NASA N+3 in the Sketch Module

Then the next step towards modelling is to create the geometry chronologically and make the final model, at first, we initiate the modelling of the Fuselage which is then assembled by the wings, the aircraft is having a canard configuration. Then the Horizontal and Vertical Stabilizers are modelled. It is seen that the structure of the NASA N+3 Supersonic Aircraft is different from the conventional aircraft.

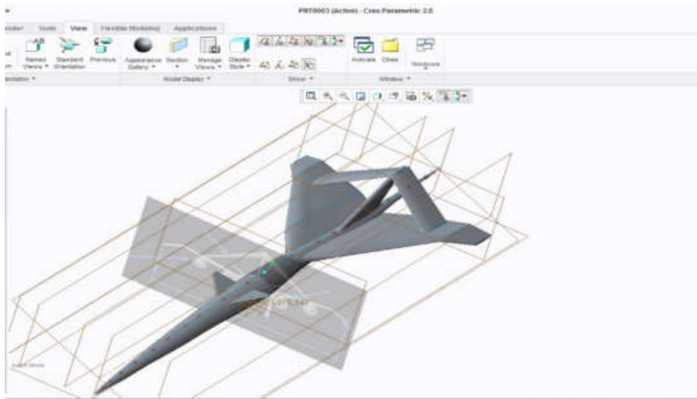

Fig 3 Modelling of the Inverted-V Structural Member on the Aircraft

The final step toward modelling would be the creation of the Engine Geometry, as our research work is not focussed on the engine analysis, we will make the engine a hollow object which is attached to the Wing of the Aircaft. One engine is modelled on the wing of the engine and using the Pattern option we will generate the other three engines.

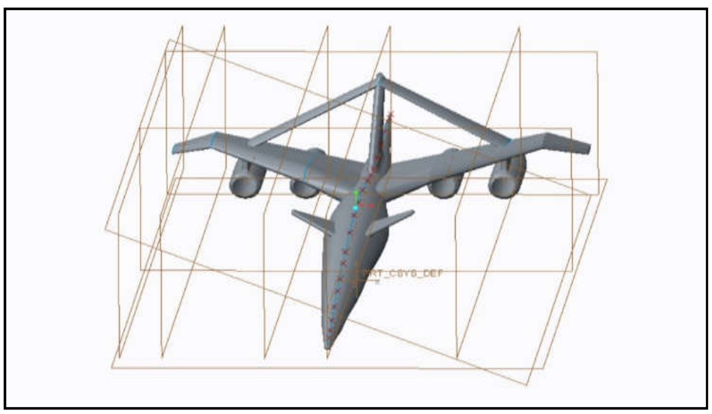

Fig 4 Final CAD Model of the NASA N+3 Supersonic Aircraft

The Final configuration of the Aircraft is saved in the IGES format, which then will be imported into the ANSYS software for analysis. the aim of the research work is to investigate the material which suitable to sustain the loads of deformation at a pressure generated during supersonic speeds, hence at first we will perform an aerodynamic analysis on the body of the above aircraft for Supersonic Flow conditions, the results of the flow analysis will help us know what amount of pressure is acting on the aircraft. Then this Pressure will be taken as an input to the Static Structural Analysis, wherein we compare three different materials and infer the suitable among them.

3. Analysis using ANSYS-Workbench

The aim of the research work is to investigate the material which suitable to sustain the loads of deformation at a pressure generated during supersonic speeds, in order to know thepressure acting in supersonic speed over the body, first we will perform an aerodynamic analysis on the body of the above aircraft for Supersonic Flow conditions, the results of the flow analysis will help us know what amount of pressure is acting on the aircraft. Then this Pressure will be taken as an input to the Static Structural Analysis, wherein we compare three different materials and infer the suitable among them.

3.1 Aerodynamic Analysis

The CAD model which is saved in the IGES file is imported in the Fluent Flow module of the Workbench. [6]

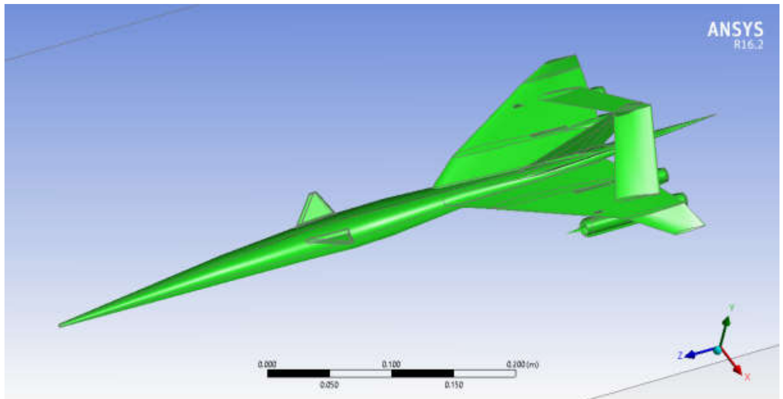

Fig 5 CAD model imported into ANSYS-Workbench-Fluent

The Analysis involves the creation of domain onto the body, then the meshing of the Body and the Domain, and after which we will need to create mesh on it, then the meshed file will be sent to the Setup, wherein we will enter the properties of air (Density, and Dynamic Viscosity) and other flow solving Parameters.

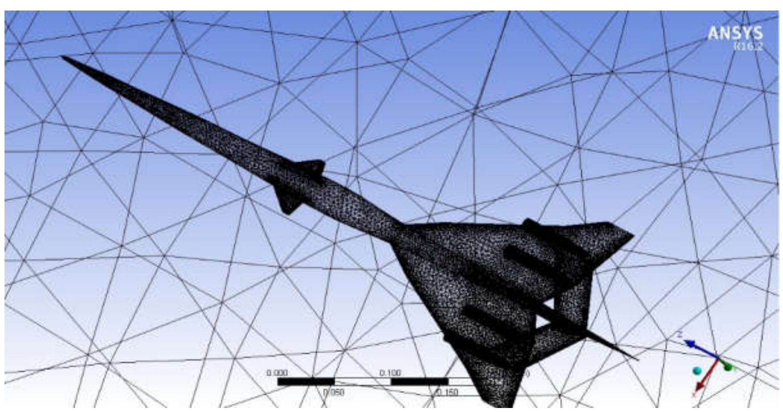

Fig 6 generation of the Mesh on the aircraft and the domain

The velocity at the inlet of the domain is considered to be Supersonic as the aircraft is intended to achieve Supersonic Flight. The Supersonic Velocity taken for this flow is **800m/s,** whereas the Pressure at the Outlet is considered as. The flow is solved with Coupled initialisationkeeping the Pressure and Momentum as Second Order. On initiating the Solver the iterations are initiated, waiting till the residuals get converged, the Pressure over the body could be extracted from the CFD-POST, as shown in the below figure.

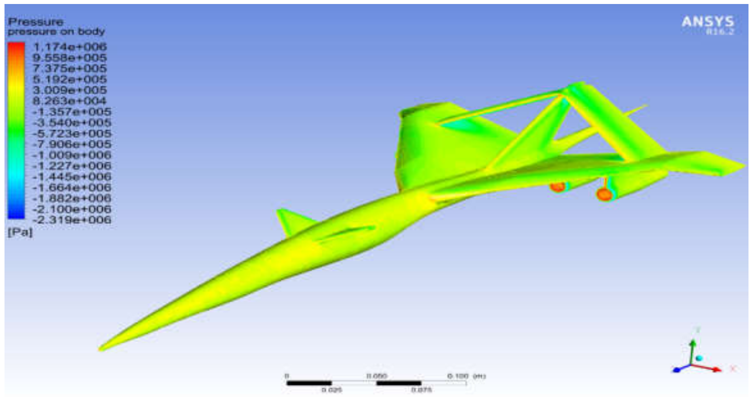

Fig 7 Pressure Contour on the Aircraft by performing Supersonic Flow Analysis

The Maximum and the Minimum values of the Pressure in Pascal's could be sighted in a tabular form as follows.

Table 1.Pressure acting on NASA N+3 Supersonic Aircraft

	Maximum	Minimum
Pressure (Pa)	1.174e+006 Pa	-2.319e+006 Pa

3.2 Static Structural Analysis

Static analysis is used to determine the displacement, stress, strains and forces in structures or components due to loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed. The kinds of loading that can be applied in static analysis include externally applied forces and pressures, steady-state inertia forces such as gravity of rotational velocity imposed (non-zero) displacements, temperatures (for thermal strain).[8]

For performing structural analysis we use ANSYS Workbench Mechanical APDL. First we import the initially designed White Knight Aircraft model into Workbench. Here we consider three different metals created by using different material combinations which are as follows

1. Aluminum 6061alloy
2. Carbon epoxy
3. Titanium alloy (TI-6AL-2NB-1TA10.80MO)

Table 2. Material Properties

Material name	Density (kg/m^3)	Young's modulus(Pa)	Poisson's ratio
Aluminum 6061	2700	6.9E+10	0.33
Carbon epoxy	1470	7E+11	0.342
Titanium alloy	4430	1.138E+11	0.342

The initial procedure for the Structural Analysis is similar to the Flow Analysis; we wil import the IGES file of the Aircraft into the Design Module of the Fluent, mesh the body of the aircraft, and then send it to the setup module, where we apply load on the aircraft in terms of the pressure. Hence after meshing we need to apply loads as we are performing structural analysis in skin of White Knight Aircraft so we need to consider pressure loads. He we only a concentrated force at the centre at symmetric and done the analysis by varying the skin material. As we have considered three new materials we have created using different metal properties combinations and test for best results

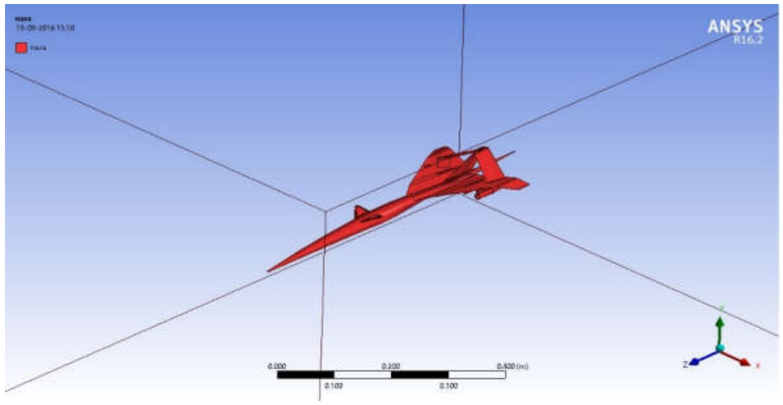

Fig 8 Application of Load in terms of Pressure (obtained from Flow Analysis)

The objective here is to perform Structural Analysis on the Aircraft for the Pressure obtained on the Aircraft, on the three material as mentioned in the Table 1.

a) Structural Analysis on the Aircraft using Aluminium Alloy

Applying the above loads on the aircraft by choosing the material as Aluminium will give us different results with respect to Deformation, Equivalent Stress and Equivalent Strain.

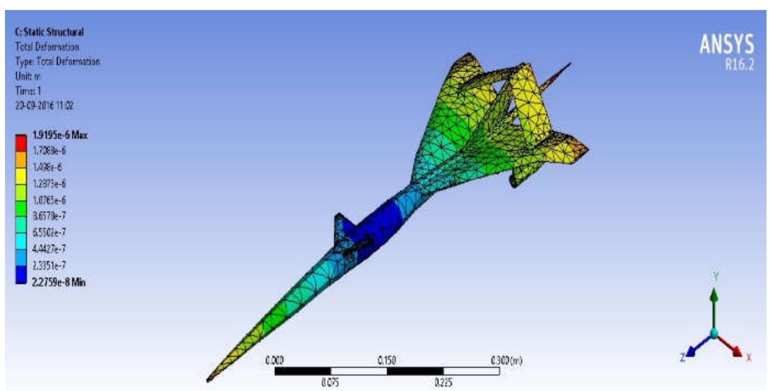

Fig 9: Total Deformation on the Aircraft for Aluminium material

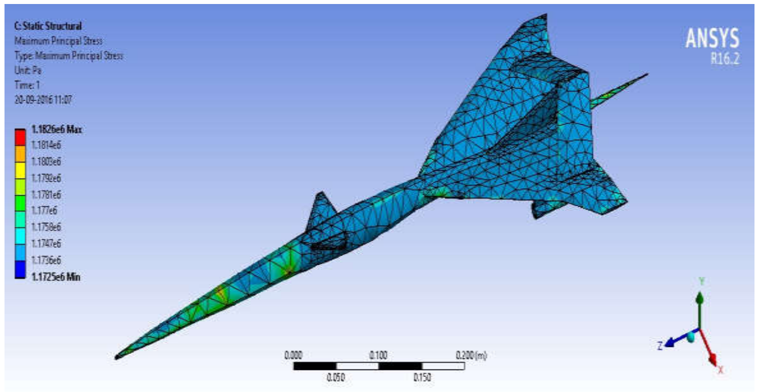

Fig 10: Maximum Principal Stress

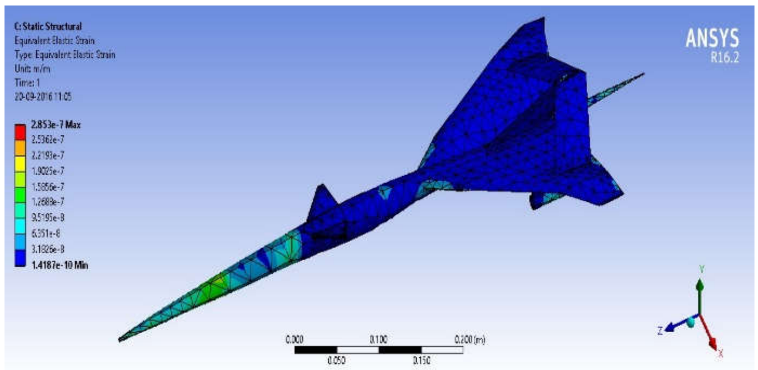

Fig 11: Equvivalent Elastic Strain

The above figures represents the variation of the Deformation, Equivalent Stress and Equivalent Strain on the Aircraft.

Structural Analysis on the Aircraft using Carbon Epoxy

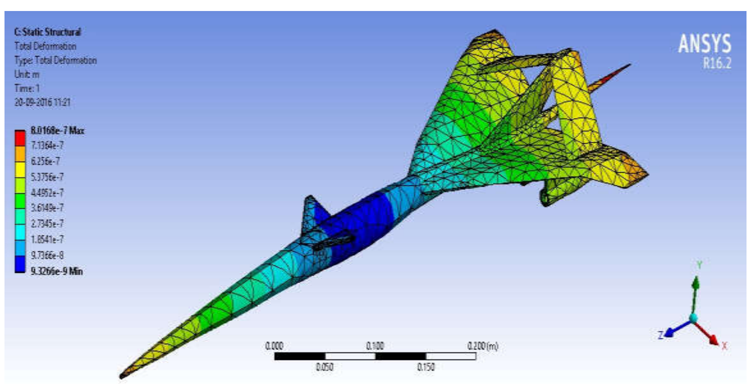

Fig 12: Total Deformation on Aircraft using Carbon Epoxy

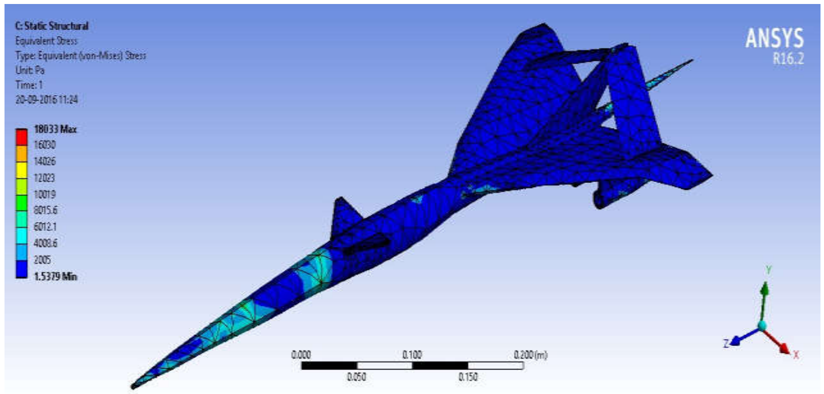

Fig 13: Equivalent Stress

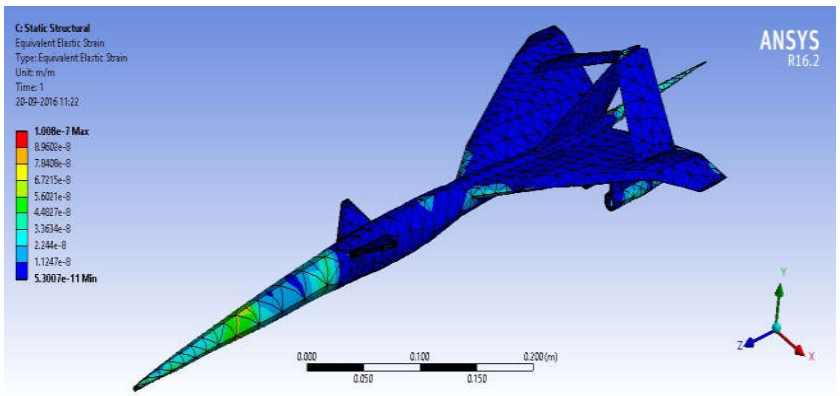

Fig 14: Equivalent Strain

c) Structural Analysis on the Aircraft using Titanium Alloy

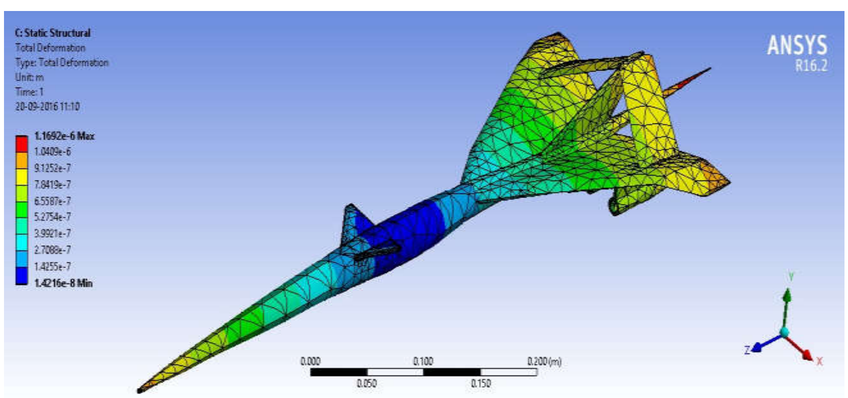

Fig 15: Deformation on the Aircraft using Titanium Alloy

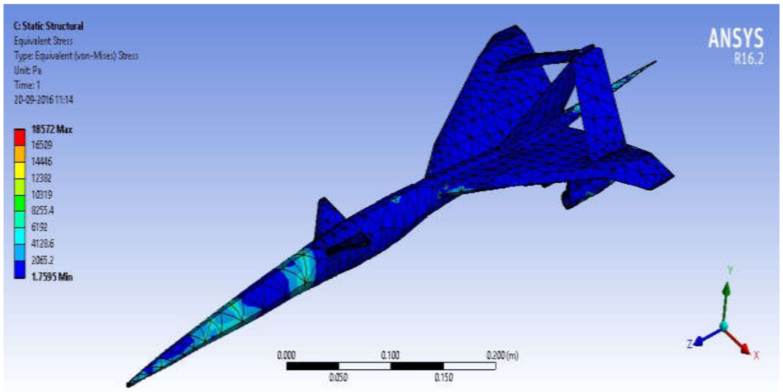

Fig 16: Equivalent Stress

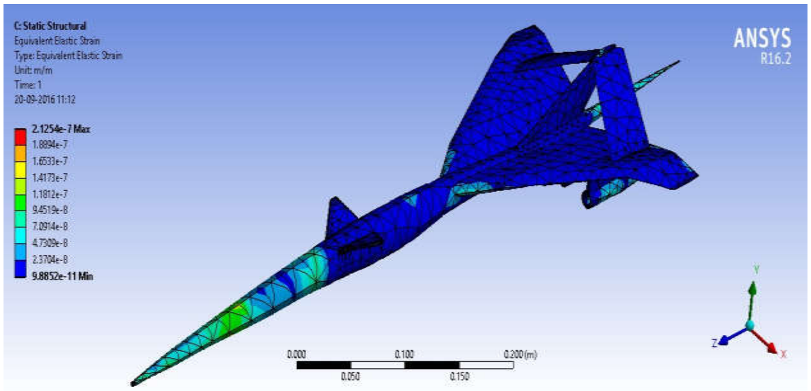

Fig 17: Equivalent Strain

The above figures represents the variation of the Deformation, Equivalent Stress and Equivalent Strain on the Aircraft.

The corresponding values of the above figures will be sighted in the form of tables for comparisons,

Table 3. Deformation on the vehicle

Material	**Pressure Applied**	**Maximum in Meters**	**Minimum in Meters**
AA6016	$1.174e^{6}$ Pa	$1.9195e^{-6}$	$2.2759e^{-8}$
Carbon epoxy	$1.174e^{6}$ Pa	$8.0168e^{-7}$	$9.3266e^{-9}$
Titanium alloy	$1.174e^{6}$ Pa	$1.1692e^{-6}$	$1.4216e^{-8}$

Table 4. Equivalent Stress in Pa

Material	Pressure Applied	Maximum in pascals	Minimum in pascals
AA6016	$1.174e^6$ Pa	$1.1826e^6$	$1.1725e^6$
Carbon epoxy	$1.174e^6$ Pa	18033	1.5379
Titanium alloy	$1.174e^6$ Pa	18572	1.6028

Table 4. Equivalent Strain in Pa

Material	Pressure Applied	Maximum in pascals	Minimum in pascals
AA6016	$1.174e^6$ Pa	2.853e-7	1.1418e-10
Carbon epoxy	$1.174e^6$ Pa	1.008e-7	5.3007e-11
Titanium alloy	$1.174e^6$ Pa	2.1254e-7	9.8852e-11

CONCLUSION

The Future Supersonic Aircraft i.e., NASA N+3 Supersonic Aircraft has been modelled in creo-2.0. Considering the “Final Report for the Advanced Concept Studies for Supersonic Commercial Transports Entering Service in the 2030 to 2035 Period, N+3 Supersonic Program” we have chosen the final configuration and modelled the scaled geometry. After the modelling, we have performed the Aerodynamic analysis on the aircraft, which help us analyze the flow parameters during a supersonic flight. The aerodynamic results indicate certain magnitude of pressure and velocity of air acting on the aircraft. The amount of pressure would help us know the total load an aircraft had to face during a supersonic flight. The pressure would also help us to choose a material which could sustain that amount of pressure. Hence the second part of the research work is to perform a structural analysis on the NASA N+3 Supersonic Aircraft.

The output of the aerodynamic analysis is used as the input of the structural analysis. The magnitude of pressure attained during Aerodynamic analysis is entered as the input in structural analysis. The Structural analysis is performed on three materials that are Aluminum, Titanium Alloy, and Carbon Epoxy. The research work is now aimed to investigate the best suitable material among the mentioned at a pressure attained during supersonic flight. Therefore on performing the structural analysis on the three materials and checking their respective deformations, Equivalent stresses and Equivalent strains we can predict the suitable material.

The set of results obtained are the maximum and minimum values of deformations, stress and strains, the material can withstand at the chosen location, upon the application of uniform load (Pressure) thereby helping us to recognize which material is suitable for the model.

Now approaching to the material selection, we need to compromise on various factors, based on the application of the aircraft. In this research work we are considering the deformation, equivalent stress & equivalent strain as the factors for material selection. Neglecting the availability, cost, weight, Carbon Epoxy is well suited if we consider deformation as the major factor in material selection. As can be seen from the results that the carbon epoxy has less deformation. Now coming to the next benchmarks the equivalent stress and strain, again the Carbon Epoxy is suitable. Therefore we conclude that the best suited material for the NASA N+3 Supersonic Aircraft is Carbon Epoxy, neglecting the cost and availability.

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