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Coupled Fluid and Heat Flow Analysis Around NACA Aerofoil Profiles at Various Mach Numbers

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Abstract

This paper presents the CFD analysis on a symetric aerofoil with estimation of Total surface heat flux, static pressure and static temperature. The fluid pattern is evaluated across standard aerofoil section of NACA 0012 at different mach numbers. The fluid flow coupled with temperature gradients at various mach numbers (0.5 to 4) at an angle of attack of +4 degrees is simulated using commercial CFD code (Ansys 13.0). The satic temperature, pressure coefficients and heat fluxes at various boundaries is presented. Turbulent regions are identified and modifications to aerofoil boundary are suggested.

Introduction

Aerodynamics involves evaluation of drag and lift forces. The estimation of drag and lift at higher altitudes is a critical parameter. For aviation industry estimation of drag and lift coefficient are to in and around an uncertinity of 2%. This crticality demands robust design and estimate of fluid flow pattern over and across the aerofoil. The flow over aerofoil is assumed to beover a flat plate with heat transfer. The present work focus on testing of NACA profile of symmetry namely NACA 0012. The comparitive study on symetric aerfoil is presented. Aerofoils are the cross sectional shapes of the wings as defined by, the intersections with planes parallel to the free stream and normal to the plane of the wing. An aerofoil is any surface, designed to produce lift when air passes over it. Aerofoils are used for two reasons: to create lift or reduce drag. The angle at which an airfoil passes through the air is called angle of attack. Our interest is centered on gases since the atmosphere in which the air craft operate is a gas we know as air. Composed mostly of nitrogen (78%) and oxygen (21%), air is a viscous, compressible fluid, but it is often convenient and reasonably accurate to assume it to be an inviscid, incompressible gas. A gas consists of a large number of molecules in random motion each molecule having a particular velocity, position an energy, varying because of collisions between molecules. The force per unit area created on a surface by the time rate of change of momentum of the rebounding molecules is called the pressure. As long as the molecules are sufficiently far apart so that the intermolecular magnetic forces are negligible, the gas acts as a continuous material in which the properties are determined by a statistical average of the particle effects. Such gas is called a perfect or ideal gas.

Aerodynamics

Forces exerted by a fluid moving past a body such as sphere, a wing, or a streamlined body fall into general classes:

1. Normal or pressure forces
2. Tangential or shearing forces

Consider a small section ΔS of a surface of the body immersed in a moving fluid as shown in the Fig 2.1. The fig represents a plane perpendicular to the surface. The vector ΔF represents the force that the fluid exerts on this section, which is so small that it may be considered to be flat. The force ΔF may be resolved in to two components normal and tangential to the surface element ΔS. these components are indicated by ΔF_n and ΔF_t if these force components are divided by the area of the surface element ΔS, quantities are obtained to have the nature of stresses, or forces per unit area. These stresses are normal stress or pressure acting on the surface, P, and shear stress τ.

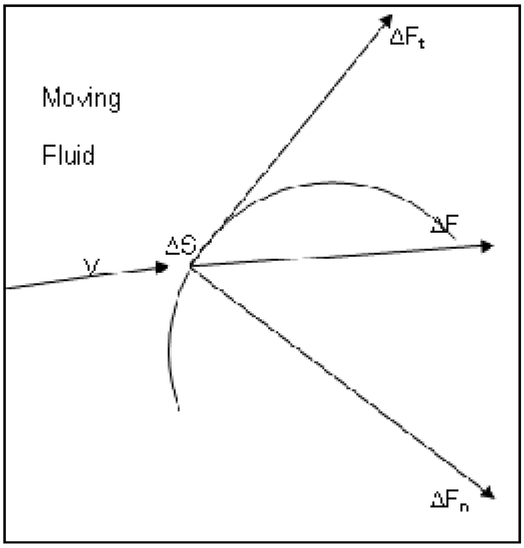

Figure 1: Forces on Aerofoil

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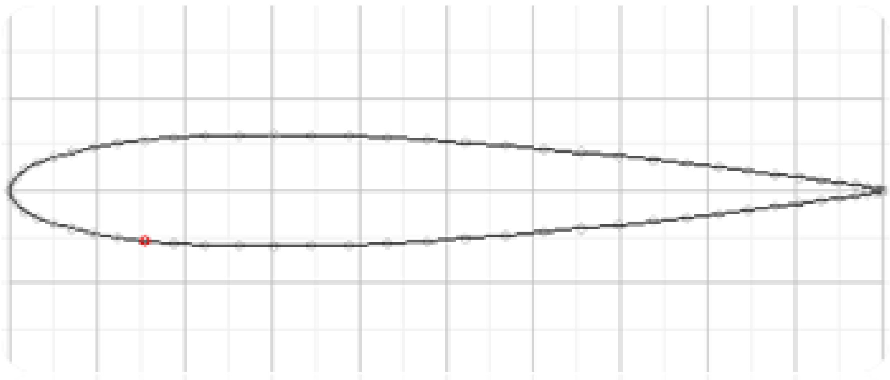
CFD Analysis of Aerofoil

Details of assumed standard aerofoil

NACA specification	:	NACA0012
Chord	:	100mm
Span	:	300mm
Type	:	symmetrical
Maximum camber	:	0mm
Maximum thickness	:	12% of the chord i.e., 12 mm at 30% of the chord



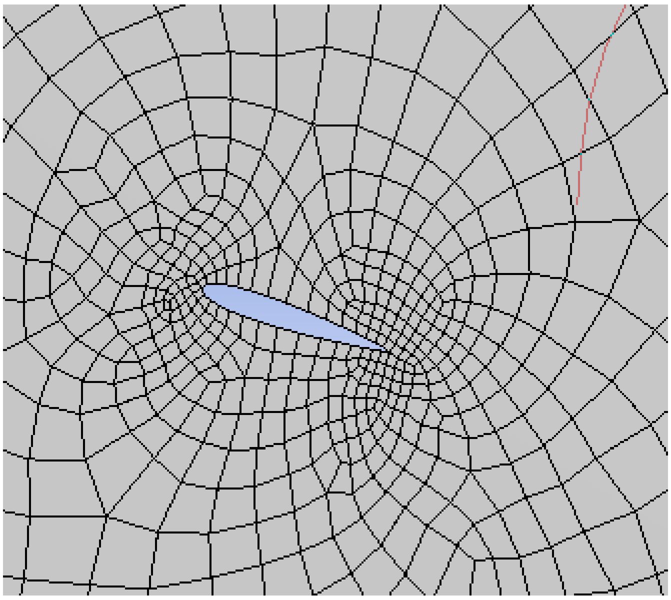
Coordinates of different points on the surface:

X	Y	X	Y	X	Y	X	Y
1.000000	0.001260	0.477568	0.054300	0.002013	-0.007839	0.567117	-0.048243
0.991965	0.002382	0.388739	0.058430	0.018019	-0.022483	0.654508	-0.040917
0.968117	0.005647	0.303487	0.060014	0.049516	-0.035400	0.736934	-0.032952
0.929224	0.010776	0.224551	0.058578	0.095492	-0.046049	0.811745	-0.024921
0.876536	0.017359	0.154469	0.053896	0.154469	-0.053896	0.876536	-0.017359
0.811745	0.024921	0.095492	0.046049	0.224551	-0.058578	0.929224	-0.010776
0.736934	0.032952	0.049516	0.035400	0.224551	-0.060014	0.968117	-0.005647
0.654508	0.040917	0.018019	0.022483	0.388739	-0.058430	0.991965	-0.002382
0.567117	0.048243	0.002013	0.007839	0.477568	-0.054300	1.000000	-0.00126

The problem considers the flow around an symmetric aerofoil at different free stream mach numbers. The flow is supersonic, and has a fairly strong shock near the mid-chord(x/c=0.45) on the upper (suction) side. The chord length is 1m.

A 2-D Geometric model is prepared as shown in the figure. The required mesh is generated using quadrilateral cells because they can be stretched easily to account for different flow gradients in different directions.

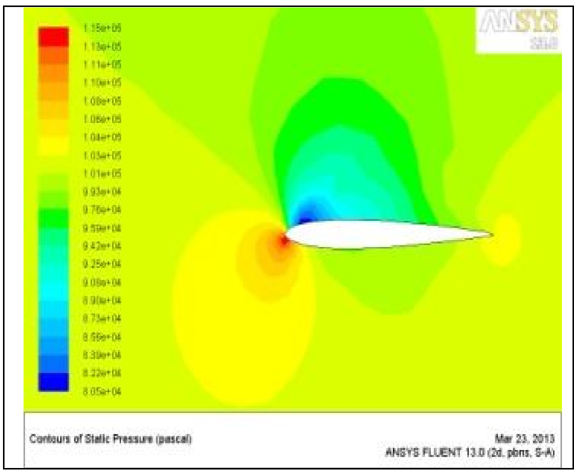
The general settings include pressure-based selection, with k-epsilon(2 eqn) model. The working fluid in this problem is air. The default settings are modified to account for compressibility and variations of the thermophysical properties for temperature. In this problem density and viscosity have been made temperature dependent while specific heat and thermal conductivity have been kept constant. In boundary conditions the particular Mach number is provided as input parameter and suitable turbulent viscosity ratio is limited to 10. Solution parameters are initialized and SIMPLE(semi implicit pressure linked equations) scheme of evaluation is selected. In this current problem hybrid initialization is followed and the solution is obtained in steady state.

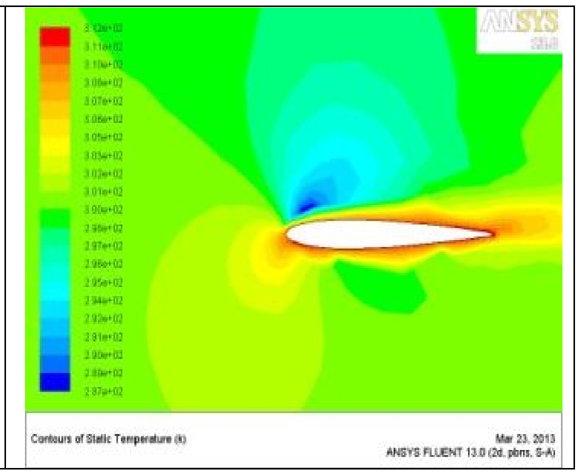


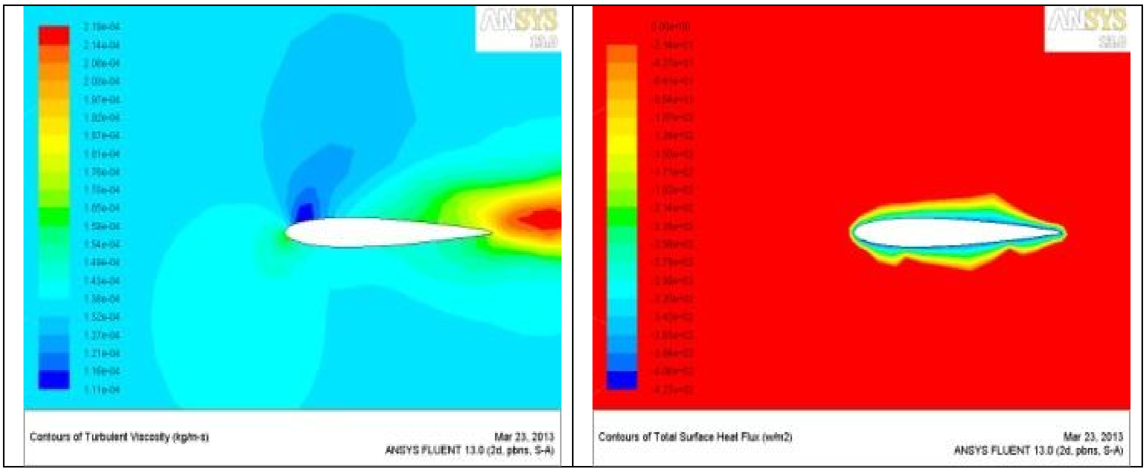
Results

The Aerofoil is tested with different mach numbers at a particular angle of attack.

Mach No: 0.5

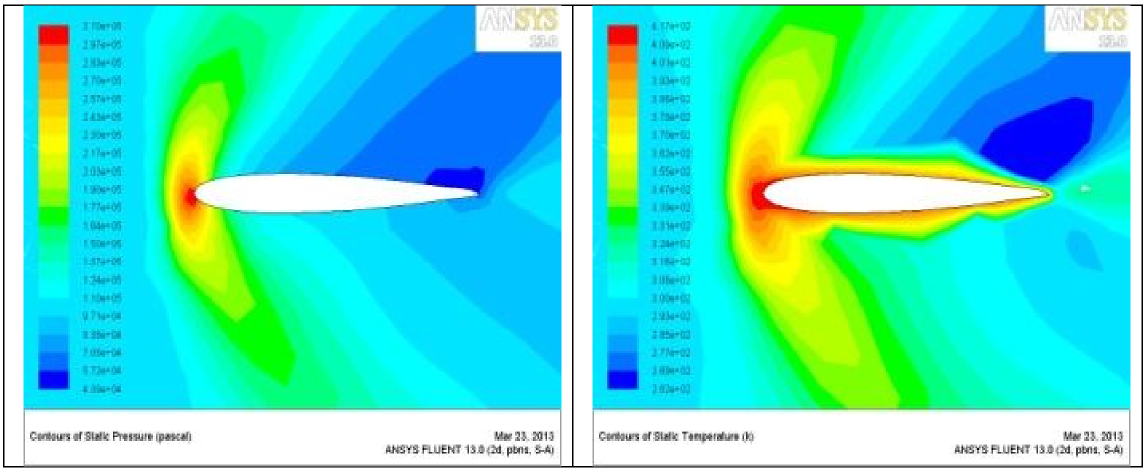


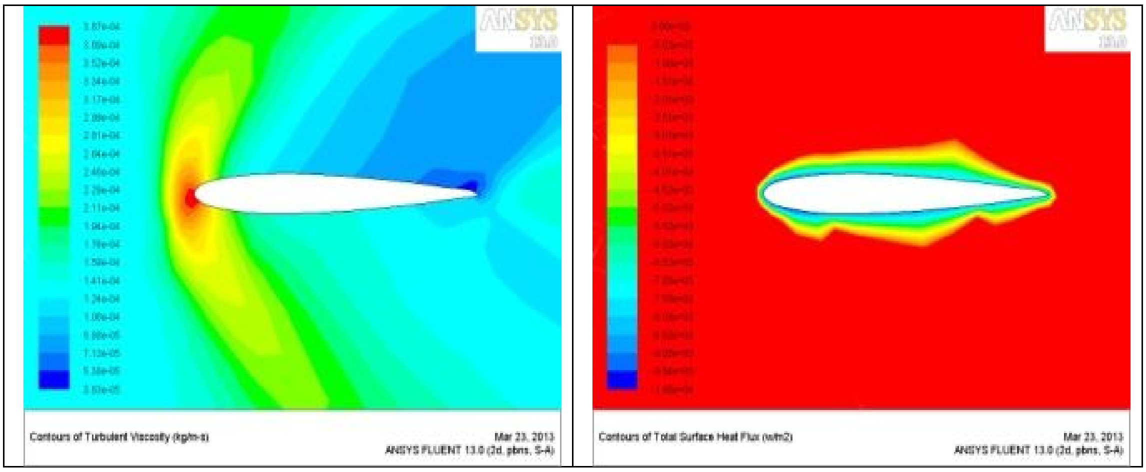




It is observed in the above figure that at a Mach number 0.5 the maximum temperature is 312 K, static pressure is 1.15 bar which is observed stagnating at the tip of the aerofoil as shown in the figure. Maximum generated Heat flux due to aerothermal heating is 427 w/m^2 .

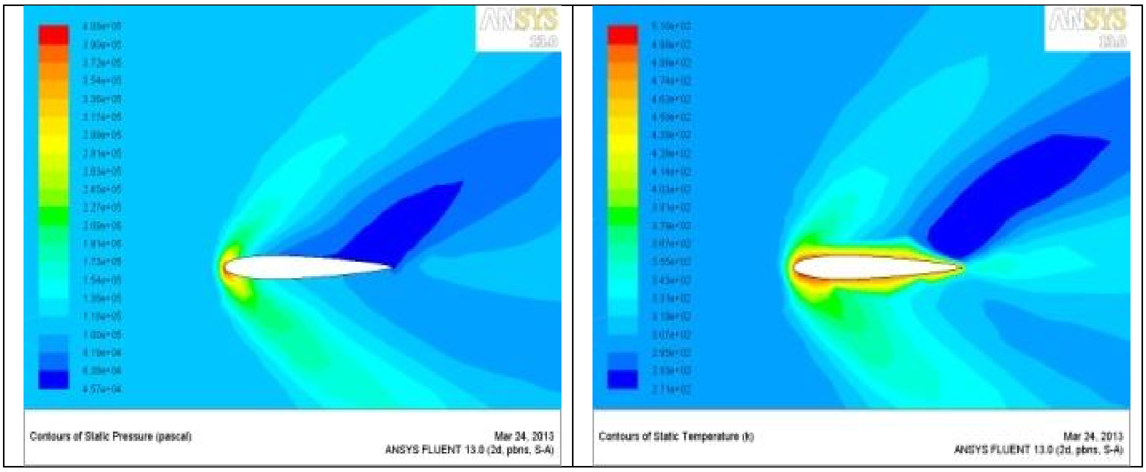
Mach No: 1.5

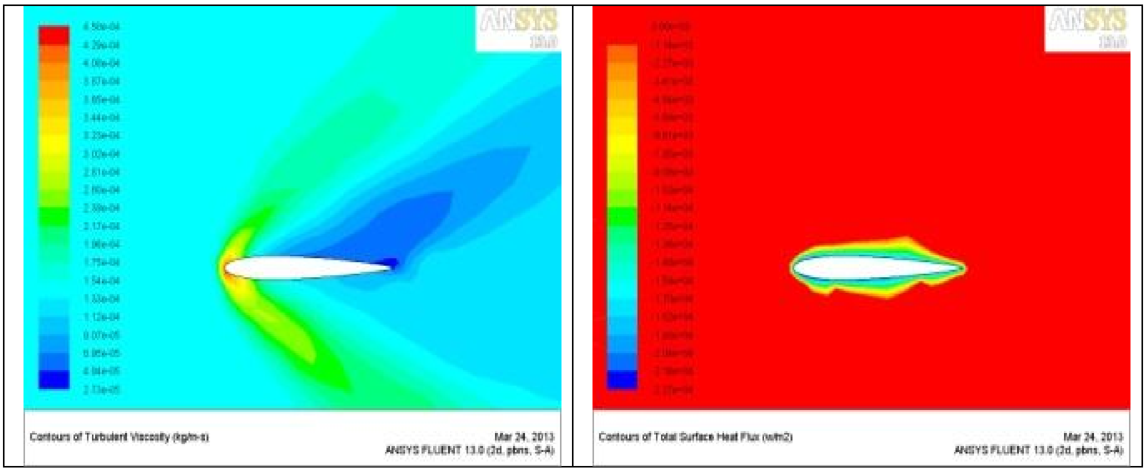




It is observed as shown above in the figure , that at a Mach number 1.5 the maximum temperature is 417 K, static pressure is 3.1 bar which is observed stagnating at the tip of the aerofoil as shown in the figure. Maximum generated Heat flux due to aerothermal heating is 1000 w/m^2 .

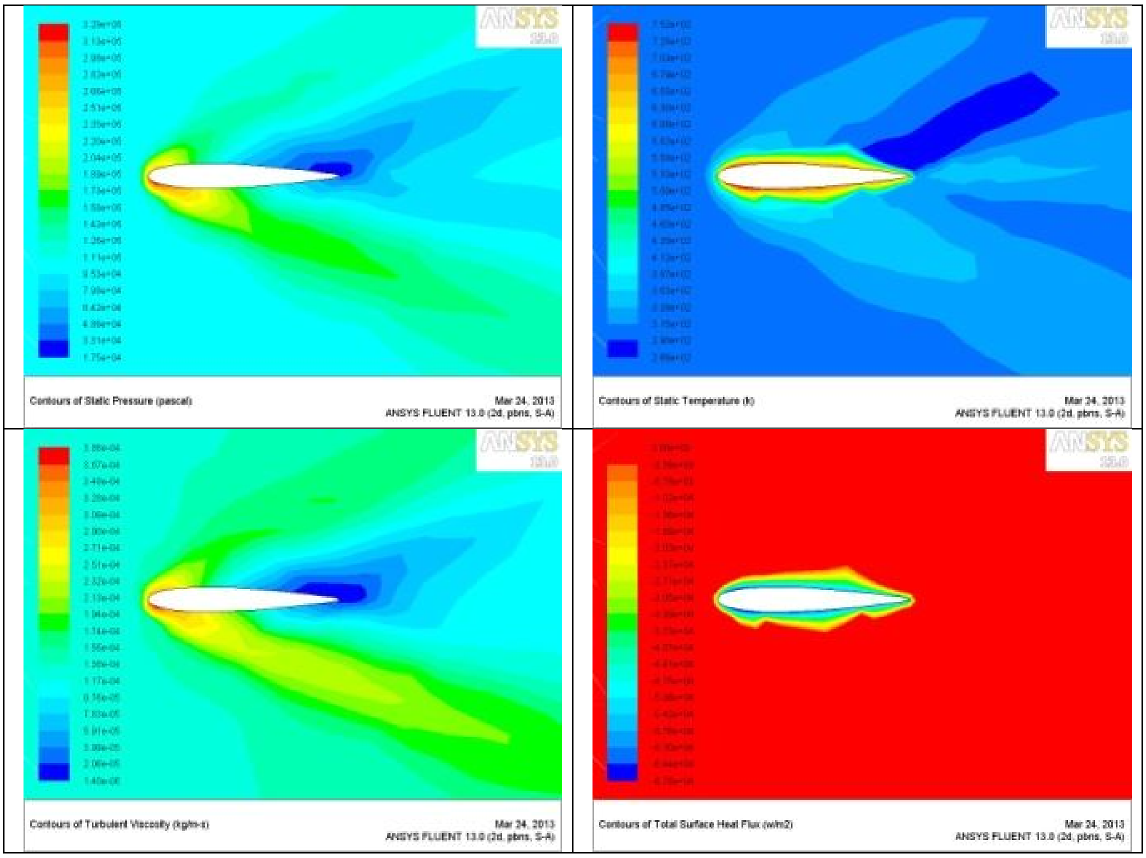
Mach No: 2





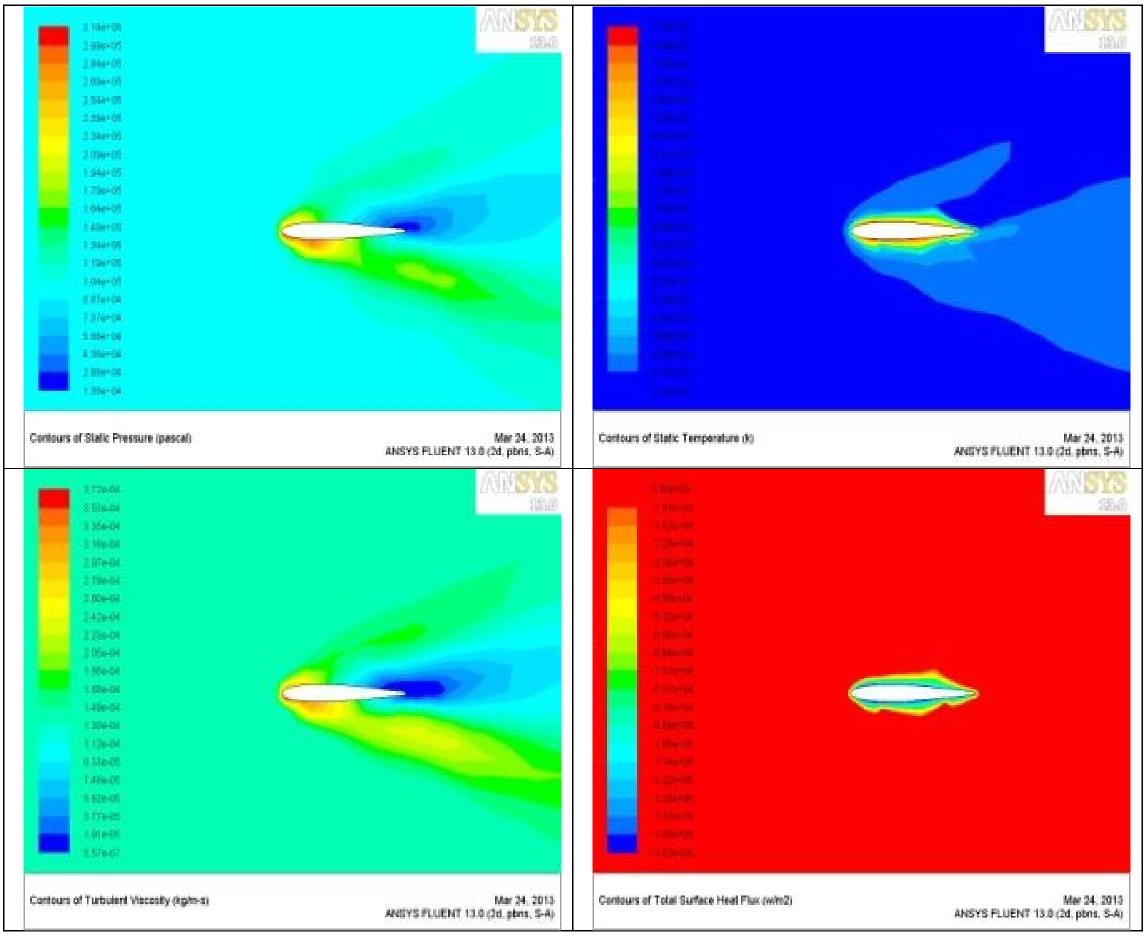
It is observed in the above figure , that at a Mach number 2.0 the maximum temperature is 510 K, static pressure is 40.5 bar which is observed stagnating at the tip of the aerofoil as shown in the figure. Maximum generated Heat flux due to aerothermal heating is 2.27e+4 w/m^2 .

Mach No.3

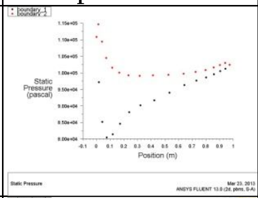
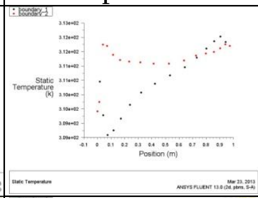
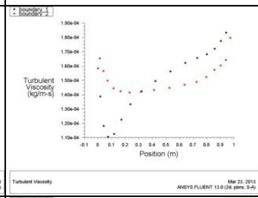
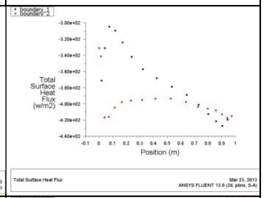
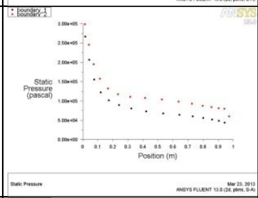
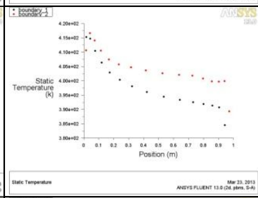
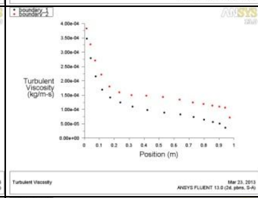
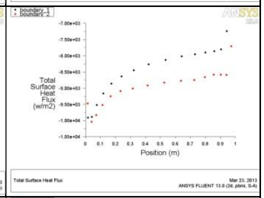
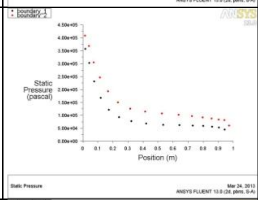
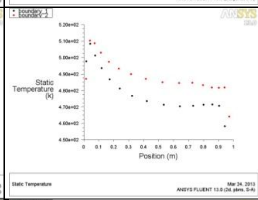
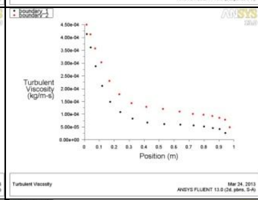
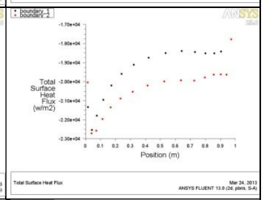
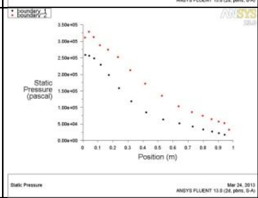
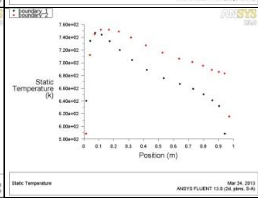
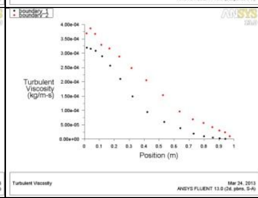
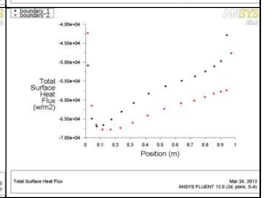
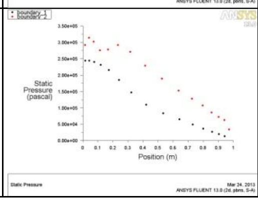
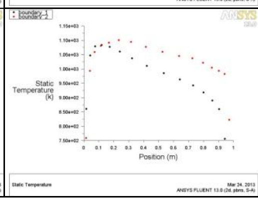
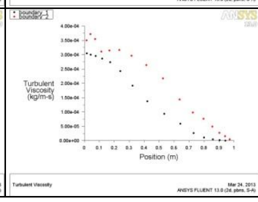
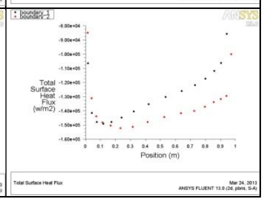


It is observed in the above figure that at a Mach number 3.0 the maximum static temperature is 752 K, static pressure is 32.5 bar which is observed stagnating at the tip of the aerofoil as shown in the figure. Maximum generated Heat flux due to aerothermal heating is 6.2e+4 w/m^2.

Mach No.4



It is observed in the above figure that at a Mach number 4.0 the maximum temperature is 1022 K, static pressure is 31.3 bar which is observed stagnating at the tip of the aerofoil as shown in the figure. Maximum generated Heat flux due to aerothermal heating is 1.52e+6 w/m^2 . The value of heat flux is negative because refrence is taken as the fluid and there is heat transfer from fluid to the aerofiol due viscous heating.

Mach No	Static pressure	Static temperature	Turbulence	Heat flux
0.5				
1.5				
2.0				
3.0				
4.0				

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