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Study on the Shock Formation over Transonic Aerofoil

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Abstract

Aerofoil is a primary element to be designed during the initial phase of creating any new aircraft. It is the component that forms the cross-section of the wing. The wing is used to produce lift force that balances the weight which is acting downwards. The lift force is created due to pressure difference over the top and bottom surface which is caused due to velocity variation. At sub-sonic velocities, for a real fluid, we obtain a smooth flow of air over both the surfaces. In this era of high speed travel, commercial aircraft that can travel faster than speed of sound barrier is required. However transonic velocities cause the formation of shock waves which can cause flow separation over the top and bottom surfaces. In the transonic range, shock waves move across the top and bottom surfaces of the aerofoil, until both the shock waves merge into a single shock wave that is formed near the leading edge of theaerofoil. In this paper, a transonic aerofoil is designed and its aerodynamic properties at different velocities in the Transonic range (M = 0.8; 0.9; 1; 1.1; 1.2) are studied with the help of CFD. The Pressure and Velocity distributions over the top and bottom surfaces of aerofoil are studied and the variations of shock patterns, at different velocities, are analyzed. The analysis can be used to determine the effect of drag divergence on the lift created by the aerofoil.

Keywords: Transonic aerofoil; CFD; Drag Divergence; Shock formation; Viscous flow.

1. Introduction

An aerofoil is a shape of an aircraft wing or blade which can produce aerodynamic forces. Force acting perpendicular to the aerofoil is called lift and the force component that acts parallel to the body is called drag. Aerofoil produces lift mainly because of its angle of attack and its cross sectional shape. Most of the aerofoil has positive angle of attack and this turns the air stream,creating a low pressure on upper side and high pressure on the other. This pressure differencecreates lift which is based onBernoulli's principle. According to the air speed, aircrafts are classified into subsonic ($M<0.8$), transonic ($0.8<M<1.2$) and supersonic ($M>1.2$). In transonic type aerofoil, shock initially forms in the mid-section of the aerofoil and gradually moves towards the trailing edge as the speed increases. In this paper, shock formation over a transonic aerofoil is analyzed usingComputerized Fluid Dynamics (CFD) with different transonic speeds.

2. Aerofoil Design

The idea of carefully tailoring the section to obtain supersonic flow without shockwaves (shock-free sections) has been pursued for many years, and such sections have been designed and tested.In a transonic speed aircraft, shock waves are created in the trailing edge which induces wave drag. To overcome this wave drag, specially designed aerofoils are practiced.These aerofoils are called supercritical aerofoils. Supercritical aerofoils are characterized by their flattened upper surface, highly curved aft section and larger radius of the leading edge compared to a traditional aerofoil shapes. Supercritical aerofoils have higher drag divergence Mach number and they greatly reduces shock wave boundary separation. In a typical aerofoil, at some point along the aerofoil, a shock is generated when the local velocity reaches Mach 1 which increases the pressure coefficient to the critical value. A supercritical aerofoil is more efficient because the shockwave is minimized and is originated as far aft as possible thus reducing drag. Compared to a typical aerofoil section, the supercritical aerofoil creates more of its lift at the aft end, due to its even pressure distribution over the upper surface.Formost practical cases with a range of design C_L and Mach number, sections with weak shocks are favored. The aerofoil shape that we have chosen is Grumman K-2 (Fig.1) for its explicit transonic performance.

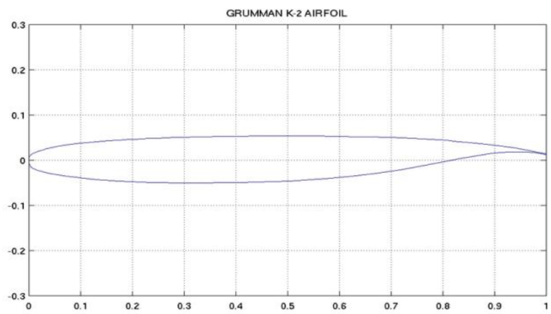

Figure 1: Grumman K-2 aerofoil

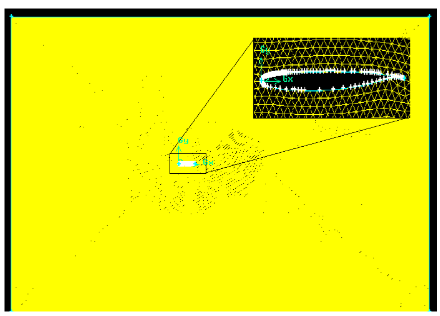

Figure 2: Grumman k-2aerofoilTri-meshed inanalysis software (CFD).

3. Analysis of Aerofoil

The Grumman K-2 aerofoil was plotted in Gambit by entering its co-ordinates and was Tri Meshed for improved accuracy in analysis and then the mesh file was imported. The boundary conditions is set for atmospheric pressure and the Spalart-Allmaras viscous condition is chosen. Analysis was carried out for different Mach numbers ranging from 0.8 to 1.2 and corresponding Velocity-Mach plot was obtained. Fluent works on iteration approximation and the model is iterated to n number of times until the result is converged. The plot shows the variation in Mach number along the surface of the aerofoil using different colors. Various other performance variables like pressure coefficient, static and dynamic pressure, density, temperature, absolute pressure, total pressure, velocity magnitude, stream velocity magnitude, etc. can also be obtained.

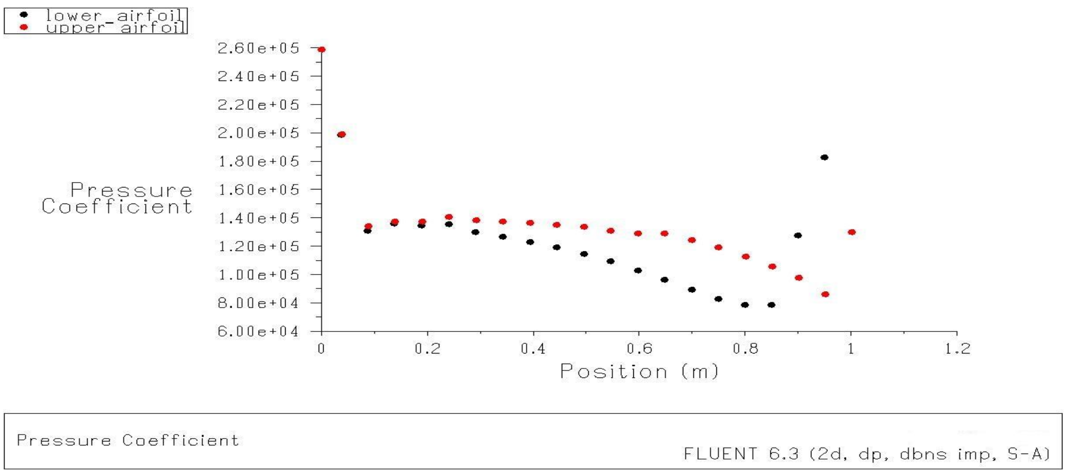

Figure 3: Pressure coefficient at various points over Grumman K-2aerofoil at M=1.

4. Results and Discussion

In Grumman K-2 aerofoil, shock is formed in well aft of the aerofoil. At some free stream Mach number, the local flow becomes sonic at a single point on the upper surface where the flows reaches its highest speed locally. This is called as critical Mach number. As the freestream Mach number increases further, supersonic flow develops. Normally the transonic flow is brought back to subsonic speed by the occurrence of a shock wave. As the Mach number increases, the shock moves aft and becomes stronger.This is shown in Fig.4,5,6,7.When Mach number reaches one, the shock moves all the way to the trailing edge and finally,when the Mach is slightly above one, a bow wave appears just ahead of the aerofoil and shock present in the trailing edge becomes oblique.

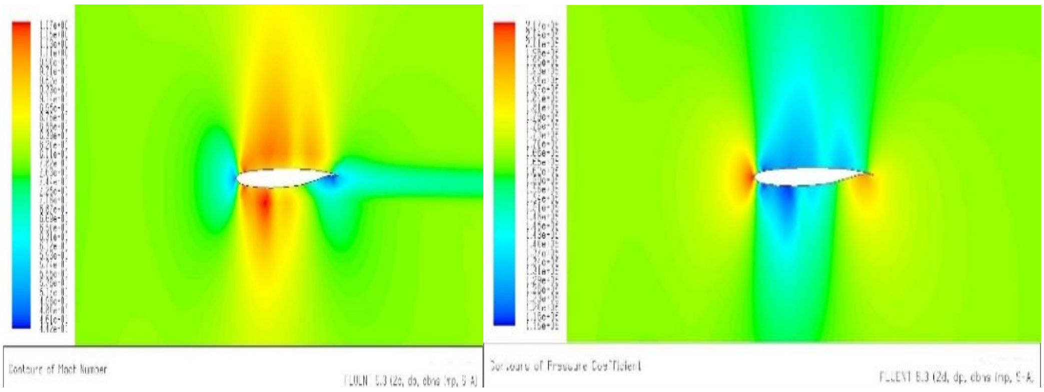

Figure 4: Mach number and Pressure co-efficient contour plot for Grumman K2 aerofoil at M=0.8

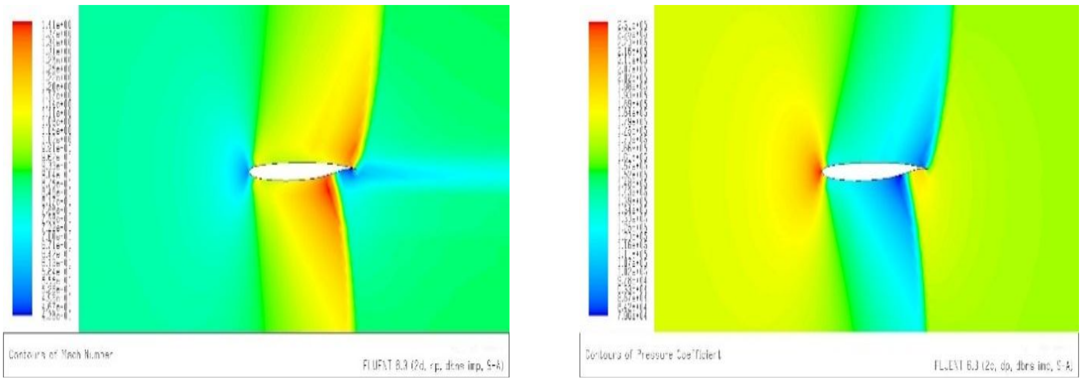

Figure 5: Mach number and Pressure co-efficient contour plot for Grumman K2 aerofoil at M=0.9.

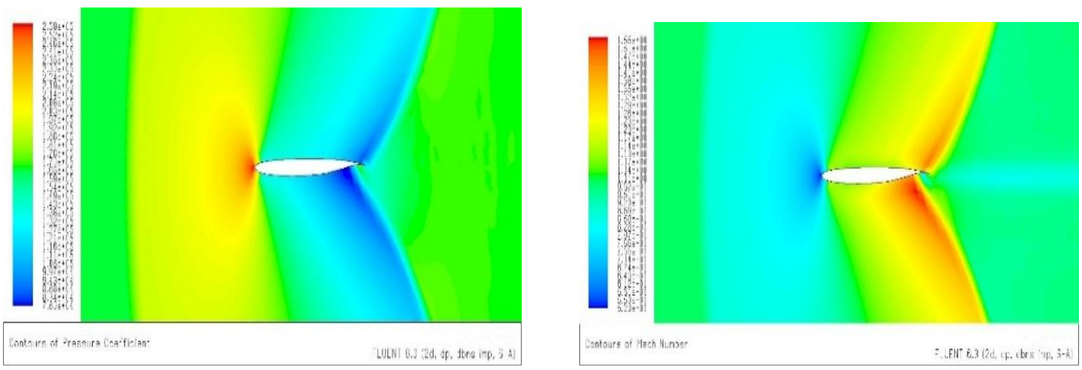

Figure 6: Mach number and Pressure co-efficient contour plot for Grumman K2 aerofoil at M=1

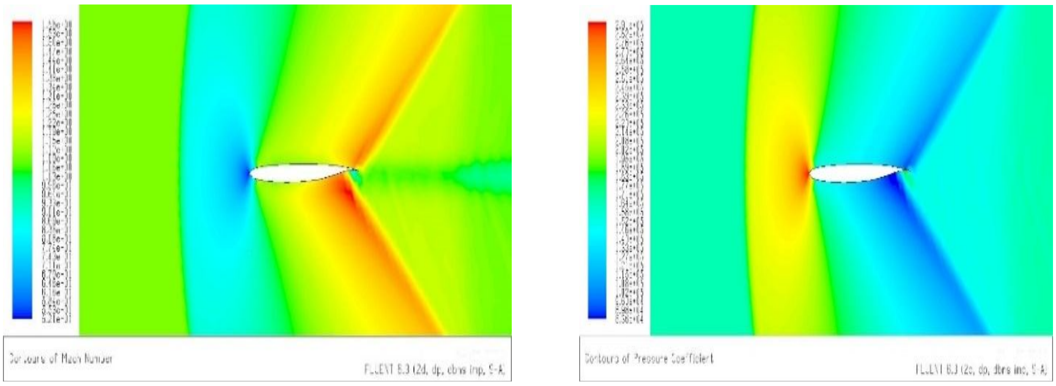

Figure 7: Mach number and Pressure co-efficient contour plot for Grumman K2 aerofoil at M=1.1

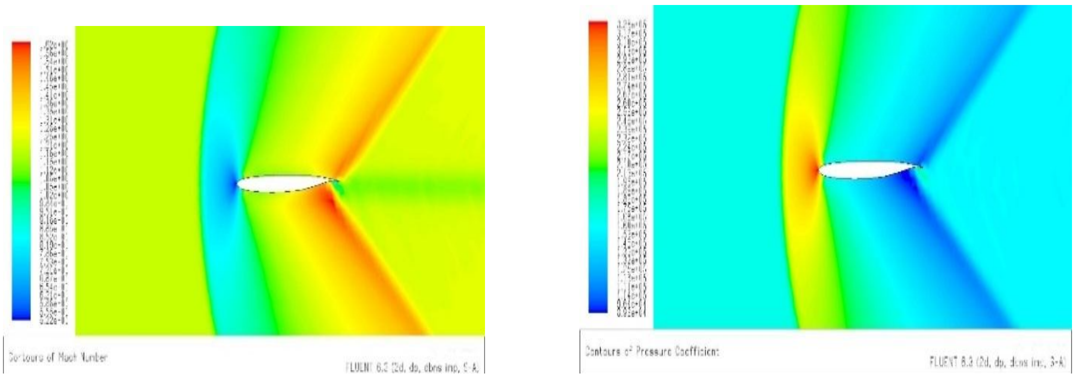

Figure 8: Mach number and Pressure co-efficient contour plot for Grumman K2 aerofoil at M=1.2.

The pressure coefficient of an aerofoil gives the dynamic relative pressures throughout the flow field. Every point in the flow field around the aerofoil has its own pressure coefficient. Generally pressure will be low if there is a shock present. In Grumman K2 aerofoil, at different flow velocities change in pressure coefficient can be seen. At M=0.9 (Fig.4), where the shock waves are about to produce, the atmospheric pressure is maintained around the flow field. When the free stream Mach number reaches M=1, the shock waves are produced at the leading edge, decreasing the pressure coefficient to greater extent and when further the velocity is increased pressure is drastically decreased. This leads to formation of bow shock, where the pressure is high compared to other region.

5. Conclusion

In a preliminary design of a transonic aerofoil, it is necessary to design geometry model with hundreds of shape parameters, particularly when searching for subtle performance. As a general when an aircraft speed is above Mach 1, the aerofoil designed for that speed must be optimized to reduce the wave drag produced due to shock. Thus the results obtained from this analysisindicates that shock is produced aft the wing than a traditional wing,reducing wave drag which increases the performance of a transonic aerofoil.

Reference

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