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Hypersonic Aerodynamics of Aerospace Vehicle Design: Basic Approach and Study

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Abstract

Motion of any object in air , be it a car, bird, kite ,building, bridges (exhibiting simple harmonic motion), aircraft and of course why not us, have to cut through or withstand the resistance of wall of air for the existence. Aerospace, Civil, Automobile and Structural Engineers, Town Planners have to study aerodynamics as an important engineering subject, because we all are surrounded by the blanket of air which exerts pressure or wind load on the objects.

Aerodynamics is the branch of engineering which deals with the motion of object in air or up to atmosphere. It is a subset of fluid dynamics and gas dynamics where we study the forces such as lift, thrust, drag and weight and the resulting motion of object through air. Therefore these forces must be thoroughly taken up into consideration. But before calculating and quantifying these forces for any specific body or object we need to go through the basic assumptions and conservation laws of aerodynamics, which are being discussed in this paper. In Aerodynamics we study the flow properties such as flow speed, compressibility and viscosity, and whenever we take the flow speed as one of our parameters of classification, we compare the speed of the object with respect to the speed of sound commonly referred to as Mach number. Up to date the vehicle which has acquired the five times speed of sound or above are the aircrafts, ballistic missiles etc. since early 1950's. Here we are going to discuss various designing parameters of hypersonic aerodynamics which are very important from safety point of view. The hypersonic objects create disturbance in the path through which they move. Sometimes disturbances are so large in magnitude, that window panes of large buildings crack due to exposure to such high velocities on the earth surface. The properties which influence the motion of air in such flow regimes are called hypersonic aerodynamics. These properties are thin shock layers, entropy layers, and aerodynamic heating due to these layers, low density flow and viscous effects. To estimate the form of pressure distribution around the bodies undergoing such flows, Newtonian sine- squared law which mostly focuses on the hypersonic vehicles moving through air are also discussed in the subsequent sections of the paper.

Keywords: Hypersonic Aerodynamics, Airflow, Pressure distribution, Ballistic missiles.

1. Introduction

Any object present on the earth surface interacts with its atmosphere up to a certain height till where this blanket of air exists. We study this interaction of air and the body deeply in a branch of dynamics called Aerodynamics, which is a hybrid of fluid and gas dynamics . much of the theories of aerodynamics are shared between the two.

Aerodynamics basically is concerned with the motion of air mostly when it interacts with a moving object. Objects on ground like buildings, bridges etc. also interact with air as they exhibit simple harmonic motion. Besides, them the moving bodies in air be it jets, cars, airplanes have to push through the mass of air in front of them, which takes energy and is very exhausting for a particular body. In case of moving bodies it is termed as wind resistance while the bodies which are stationary with respect to the ground the civil, structural engineers and the town planners term it as wind loading. Understanding this flow field around the object with the help of concepts dealt in aerodynamics enables the calculation of forces and moments acting on the object. Aerodynamics appeared in early 20th century with advent of aircraft construction, as it was the first invention whose motion was solely in air. The aerodynamics of aircraft and in general of flying vehicle deals with definition of aerodynamic forces and moments acting on the entire vehicle and on its parts, wing, fuselage and tail. The use of aerodynamics through mathematical model analysis, empirical approximation and wind tunnel experiment form the scientific basis for idea of heavier- than-air flight. Typical properties which we calculate for a flow field around a dynamic body includes velocity, pressure , density and temperature as a function of unsteady air flow. By defining a control volume around the flow field, equations for the conservation of mass, momentum, and energy can be defined and used to study such type of interaction.

2. Classification of Flows

Of all the ways of classifying, subdividing and describing different aerodynamic flows , the distinction based on the Mach number is probably the most prevelant. Mach number is defined as the ratio of speed of the flow to speed of the sound.

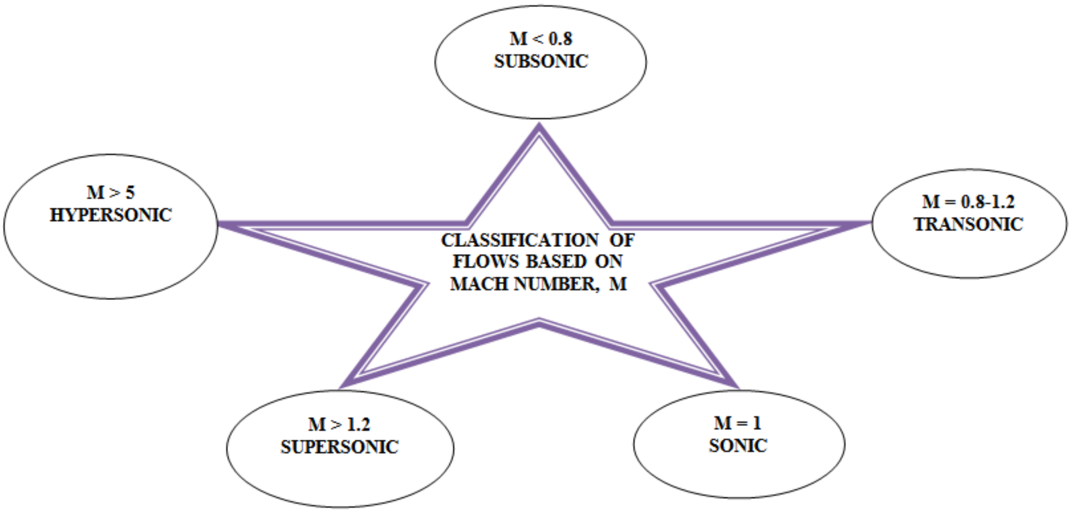

Figure 1: Classification of Flows

3. Hypersonic Aerodynamics

Hypersonic aerodynamics is a special branch of aerodynamics where we study the property of the flow at mach number greater than the value of 5. The term " hypersonic" in a way means highly supersonic, but hypersonic aerodynamics is the study of the distinguish flow fields , phenomenon, and problems appearing at flight speeds greater than speed of sound counterparts from those appearing at flight speeds which are at most moderately supersonic. When the Mach number in a fluid approaches 5, the behavior of the fluid depends more upon the Reynolds number than the Mach number. There exist various criteria which must be satisfied to declare a certain flow to be hypersonic flow which is very high supersonic flow. Depending upon the Mach number (M), we have criteria by which the physical flow doesn't change. Moreover, the dependence of Mach number with same parameter may vary with the body shape. Temperature is very important parameter for the dependence of hypersonic flow. For high speed such as in case of hypersonic flow, temperature rises very fast and hence temperature distribution plays an important role, thus thermodynamics also comes to picture thus adding a concept of aerothermodynamics.

4. Physical Aspects of Hypersonic Flows

The different factors which enables us to differentiate hypersonic flow from the other mach flows include:

4.1 Thin shock layers

A characteristic of hypersonic flow is that shock waves lie close to the surface, thus creating thin shock layers, which, in turn , can cause physical complications . At low Reynolds number, boundary layer on the surface can grow quite thick , on the same order as the thickness of shock layer itself . This leads to merging of shock wave with boundary layer, constituting a 'fully viscous shock layer'. Shock wave angle is very small in this case. Hence large change in pressure density and velocity is experienced across this shock layer.

4.2 Entropy layer

In this flow regime, the thin shock waves curves downstream of the vehicle and wraps itself around the nose of the body. The shock layer is thin and is highly curved. Due to this strong curvature large velocity gradients are induced in the flow behind the shock wave in the nose region. These large velocity gradients are accompanied by strong thermodynamic changes in the flow. This entropy layer interacts with the boundary layer growing along the surface which causes an increase in aerodynamic heating to the surface. Since the strength of the entropy layer is related to shock curvature, entropy layer effect is primarily a hypersonic phenomenon.

4.3 Viscous interaction

Results for compressible flow boundary layer show that thickness (δ) is inversely proportional to square root of the Reynolds number and square of the mach number. As a result, at high mach numbers associated with hypersonic flows δ is so large that it affects the outer inviscid flow , and the changes in the inviscid flow feedback influencing the boundary layer growth, which increases the surface pressure and the skin friction, leading to increase in drag and aerodynamic heating. Hence, induced pressure increment is seen at the leading edge .

4.4 High temperature effects

The ratio of kinetic energy to internal energy of a system increases as the square of M. Hypersonic flow when enters a boundary layer, is slowed by the effects of friction, Hence the kinetic energy decreases rapidly and transforms to internal energy which results in rise in temperature rapidly and such high temperature results in dissociation of gases like O_2 ($T > 2000$ K) & N_2 ($T > 4000$ K) , the molecules break apart producing an electrically charged plasma around the aircraft. Hence the flow properties change & aerodynamic heating occurs.

4.5 Low density flow

Instead of exhibiting continnum properties, free molecular flow is observed at such high mach numbers. Body perceives individual molecular impacts. A parameter called Knudsen number , ratio of λ/l is used in low density flows.whenever $\lambda >> l$ we have a free molecular flow. The thick shock waves lose their identity in such type of flows . Drag coefficient (C_D), heat transfer coefficients increases with increase in mach number. $C_D = 2$ for free molecular flows.

5. Newton's Impact Theory

For estimation of pressure distribution on the surface of hypersonic objects Newton gave a law which allows us to calculate the pressure coefficient at a point on a surface where the angle between a tangent to the surface at that point and free stream direction is α.

Mathematically,

$$C_p = 2\sin^2\alpha \quad (1)$$

where,

C_p = the coefficient of pressure,

α = the angle between the flow and aircraft's surface element.

6. Conclusion and Future Aspect

Current research is going on to break this barrier and to decrease the affects of the different aspects discussed above. A class of vehicles called "wave rider" are designed to have shock wave attached along their complete leading edge so that it appears as if vehicle were riding on top of its shock wave. Its shape is just an academic result today predicting high L/D values. An important aspect of hypersonic airplane design, i.e. necessity to integrate the propulsion system fully with the airplane is implemented in this. Secondly, care is taken that shock waves from one portion of the plane , including propulsion system ,do not impinge upon and interact , with other portions of the airplane. Thirdly, the flow goes through one or more shock wave systems before passing through the scramjet engine of the hypersonic plane so as to tailor the aerodynamic properties of air so as to encourage most efficient performance of the engine. Moreover, the vehicle has a more fully integrated propulsion system where the rear part of airframe acts as largest part of engine nozzle expansion. Also, wings and fuselage are more fully integrated and wings become less distinct i.e. blended wing body configuration. Spanwise flow would be stopped by the shockwave being generated by the aircraft, and that if the wing was positioned to deliberately approach the shock, the spanwise flow would be trapped under wing, increasing pressure, and thus increasing lift. Therefore, waverider design is more of like a " lifting body" than a wing body combination.

References

[1] G.G.Cherni: *Introduction to Hypersonic Flow*, Academic Press, New York, 1961.

[2] H.W. Dorrance: *Viscous Hypersonic Flow*, McGraw-Hill Company, New York 1962.

[3] R.W. Truitt: *Hypersonic Aerodynamics*, the Ronald Press Company, New York, 1962.