Expert Conference: Hypersonic flights

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1 Introduction

Throughout the history, human being has always dreamt with the idea of going faster, as depicted from the evolution of means of transport. Supersonic flights have been so far the fastest transports that humanity has achieved inside the atmosphere, but there is one further step, hypersonic flights, which speed goes beyond Mach 5. It requires huge technical development, since the aerodynamics have to be specifically modified and the structure of the object has to overcome temperatures above 1273 K. The border between supersonic and hypersonic is set arbitrarily because there is not a huge physical difference among them.

2 History

After the WW2, due to the technical achievements obtained during this time, there was an astounding need of applying that new knowledge and improve it. After achieving supersonic speeds in 1947 with the Bell X-1, American scientist continued researching in enlarge the speed of aircraft with V-2 German rockets. Finally, a modified German V-2 was achieved in February 1949 with maximum speed of 8,288 kph, which means that flew above Mach 5 becoming the first hypersonic flight ever. Afterwards, the first satellites were thrown to the atmosphere and the need of studying hypersonic conditions was mandatory. In 1956 the studies of hypersonic conditions started in NACA's Langley laboratories ending in the X-2 (Mach 3) and in the X-15 unmanned prototype which reached Mach 8. This research was incredibly helpful for the development of the nuclear missiles which heads reach supersonic speeds and even for the Discovery program (Mach 24 in reentry). [1] [2] [3]

3 Physics

It is necessary to define the hypersonic flow regime as the speed of Mach Number 5 and above. Nevertheless, it can also be defined as speeds where sramjets do not produce net thrust. While the definition of hypersonic flow can be quite vague and is generally debatable (especially due to the absence of discontinuity between supersonic and hypersonic flows), a hypersonic flow may be characterized by certain physical phenomena that can no longer be analytically discounted as in supersonic flow. The peculiarity in hypersonic flows are Shock layer, Aerodynamic heating, Entropy layer, Real gas effects, Low density effects and Independence of aerodynamic coefficients with Mach number.[4]

Once it is known what the hypersonic flow and its main characteristics are, it is time to start talking about hypersonic aerodynamics. The main characteristic of hypersonic aerodynamics is that the temperature of the flow around the aircraft is so great that the chemistry of the gas must be considered. When an object moves through the air at greater Mach Number, the production of electrons in the shocked layer of air which surrounds the object has a significant effect on some of the properties of the shocked air. It occurs especially in the ionosphere where the ambient electron density is no longer negligible. The influence of electrons is felt not only on aerodynamic quantities such as heat transfer, drag and flow field, but also on physical quantities such as transport properties, radiative emission and absorption, and electromagnetic signal interaction.

At hypersonic speeds, the molecules break apart producing an electrically charged plasma around the aircraft. Plasma physics then are simply the physics of a gas. Large variations in air density and pressure occur because of shock waves, and expansions. At hypersonic velocities a detached shock surrounds a blunt nosed object as it travels through the atmosphere.[5]

We can observe an schematic diagram of the flow of air around a hemisphere cylinder in Figure (1).

The shock front is a non-equilibrium region in which energy is being transferred from the translational degrees of freedom of the air molecules to various internal degrees of freedom. Immediately adjacent to the surface of the missile is the boundary layer (a narrow region in which the tangential gas velocity increases from zero at the surface to the local flow ve-

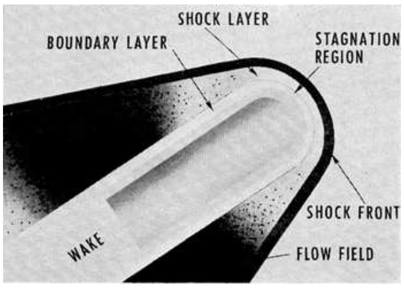

Fig. 1 . Flow about a hemisphere cylinder moving through the atmosphere at hypersonic speeds.

locity in the shock layer). In between the shock front and the boundary layer is the shock layer (a region of thermodynamic equilibrium). Finally, the wake (or afterflow region) is a region of low density, high temperature and turbulent flow.[6]

4 Problems and Solutions

4.1 Temperature

Kinetic Energy becomes heat. For hypersonic flights, where very great speeds are reached, aircraft surfaces get temperatures over 1,000ºC. This might lead to overheating problems and, in some cases, the aircraft might burn. That happened, for example, to the V-2 rocket in 1949, which burned up when reentering into the atmosphere [7]. In order to avoid burning, aircraft surfaces must be covered with a thermal protection system [8].

4.2 Mach cone

Hypersonic flights are the ones above Mach = 5, and for those speeds the angle of the Mach cone is lower than 12º [9].

$$\mu = sin^{-1}(\frac{1}{M}) \quad (1)$$

If M=5 then μ=11.54º.

If the nose shock-wave intersects any part of the aircraft (wing, tail. . .), this might produce great structural problems due to the vibrations produced. So that, aircraft must be very slender and wing must be perfectly designed in order to avoid collisions with the shock-wave. In most cases, a delta wing is used in order to avoid those collisions.
Instead of facing Mach cone as a problem, it can be used to generate lift in wave-riders, for example, Boeing X-51 A scramjet, which uses shock-waves to generate lift.

4.3 Drag

For hypersonic flights, the most important component of the Drag is the pressure-wave drag. This drag is about the 80% of the total drag, with values of the drag coefficient near to 0.04 [10]. This fact must be taken into account when designing the propulsion system in order to achieve the thrust enough to equal the drag increase.

5 Future

To sum up, engineers from all over the world have been doing their research in order to accomplish their purpose: making hypersonic flights possible lowering all (or at least most) of the "problems" that they carry.

As an example, we must point out the X-60A, a GOLauncher1 (GO1) Hypersonic flight research vehicle designated by the U.S Air Force [11]. Its main purpose is to increase the frequency of flight testing while lowering the cost of maturing technologies including scramjet propulsion, high temperatures and autonomous control. Its propulsion system is the Hadley liquid rocket engine, which uses liquid oxygen and kerosene propellants in order to be able to acces high dynamic pressure flight condition between Mach 5 and Mach 8.

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