Hypersonic Flight

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1 Introduction

Hypersonic flight means reaching speed over Mach 5, that is, flying five times faster than sound speed.

First hypersonic flight was in 1949, when a German V-2 rocket achieved a top speed of 5150 mi/h as it entered the atmosphere [1]. In 1961, the Russian astronaut Yuri Gagarin became the first person to experience hypersonic flight [1]. Since that, reaserchers have been developing this field of study in order to achieve practical hypersonic flight.

In hypersonic flight, the air surrounding the aircraft gets so hot that it is ionized. So, the design of an hypersonic vehicle, does not only consist in reaching hypersonic field, but it must achieve high resistance to thermal efforts that appear in the surface of the aircraft, and capacity of evacuating the heat that it recibes.

Fig. 1 . Aircraft X-15

2 Physic phenomena and aerodynamics.

In this section, the different physics phenomena occurring when the aircraft reaches high Mach number values are going to be explained [1]. Hypersonic flights are placed when Mach number is 5 or greater but it does not mean that these physical consequences appears at this exact point (as it happens when exceed Mach 1). The Mach 5 value is just a convenient rule of thumb, so these phenomena take place at different Mach numbers depending on altitude, vehicle shape or size.

Thin shock layer : During hypersonic flights shock waves lie close to the surface and therefore the shock layer is very thin. Because of that, surface pressure distribution at hypersonic flights can be calculated assuming some aerodynamic simplifications. The thin shock layer can also produce a merging between shock layer and boundary layer which ends with some physical complications[2].

Entropy layer and high temperature effects : When the shock layer is very thin and curved around the nose, it produces high velocity gradients and high thermodynamics changes in the flow. This region is known as entropy layer and it gets bigger on hypersonic flights. The interaction between entropy layer and boundary one produces high temperatures along the whole surface. Also, at elevated Mach number values, the free stream kinetic energy is significantly higher than internal energy. However, when the flow enter a boundary layer it is slowed down because of friction and the kinetic energy decreases rapidly as well as internal grows very fast. This phenomenon produces a notable increase on gas temperature because it is directly proportional to internal energy.

Low density flow : Sometimes, low density flow conditions might be taken into account. At certain altitude, air can't be considered as a continuum medium. Particles collisions distance become bigger and aerodynamic perspective might also change.

Viscous interaction : The laminar boundary layer thickness depends rigidly on the Mach number (d = $M^2/Re^{0.5}$). Therefore, during hypersonic flight, the boundary layer is very thick and it interacts with the outer layer that is call inviscid flow. The interaction between inviscid flow and boundary layer is called viscous interaction and it has some practical consequences such as: increase of surface pressure, increase of skin friction, more drag and more dynamic heating.

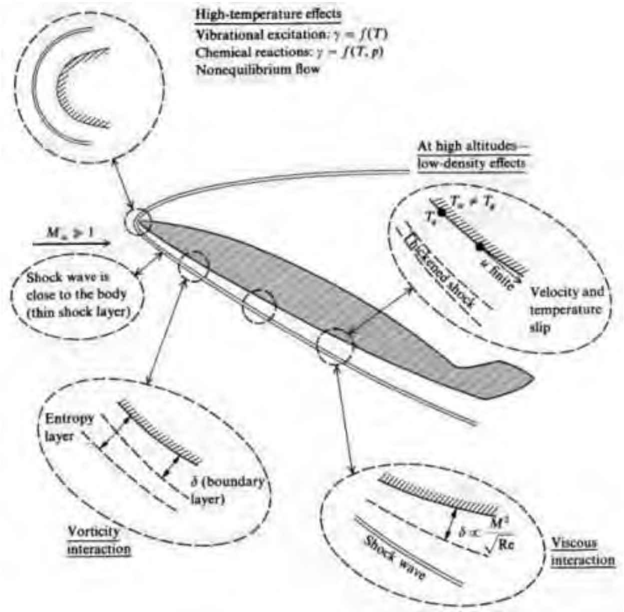

Fig. 2 . Physic phenomena and aerodynamics.

All these physical variation points are strictly relevant for the understanding of the aerodynamics and the materials used on the aircraft. Even though there is some refrigeration system, titanium or steel is needed due to its high temperature resistance properties. From the aerodynamic point of view, the best shape would be a flat plate because lift to drag ratio at hypersonic speed is the highest possible. However, the flat plate shape is not useful in terms of payload and fuel storage. Therefore, hypersonic airplanes have an even geometry, wing area don't need to be as big because lift coefficient is already created with the high speed[3]. Also, as it will be explained in next section, the type of engine used in hypersonic flights need a bottom part as flat as possible to allow the air flow.

3 Engines

The actual commercial aircrafts use turbofans or turboprops. They get the thrust by a combination among propeller and turbojetm and they reach subsonic velocities ($M \approx 0.8$).

But to go faster, to supersonic velocities (1 < Ma < 5), that types of engines are not the most adequate due to the shock waves can damage the mobile parts. Furthermore, thrust is the result of multiplicate the air mass flow by the difference between flight speed and outlet nozzle speed.

So, the low speed vehicles try to take advantage of increasing the mass flow increasing the bypass ratio, even 1:12 in the new planes. However, for supersonic is used a less ratio than 1.

Both types of engines reduce the air velocity until Mach 0.4-0.5, regardless of flight speed. That jet engines that can fly supersonically include usually an afterburner to increase the nozzle speed. So as to go faster is necessary use ramjet engine, the SR-71 Blackbird was the fastest jet and ramjet hybrid powered plane, reaching Mach 3.35 [4], but above Mach 6 ramjet is inefficient due to the shock waves presents in the inlet [5]. Scramjet resolves this problem operating with supersonic airflow instead of subsonic.

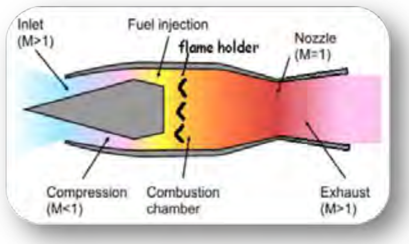

Fig. 3 . Ramjet

Moreover, the problem of these type of engines is that they cannot produce thrust if they are not in moving. Therefore, they need to be assisted to take off. It has been realized in the case of the unmanned X-43A by a B-52. Next, to reach Mach 5, the X-43A used rockets and, then, the scramjet entered in action achieving Mach 9.8. But it is being studied an aircraft (TBCC, [3]) which use turbine engine to accelerate so that ramjet engine can work until Mach 5 and, then, change to scramjet.

Scramjet engines do not need have oxygen reserves since they use the atmospheric air for combustion. This supposes a lower weight and a higher efficiency, ideal for atmospheric hypersonic flights.

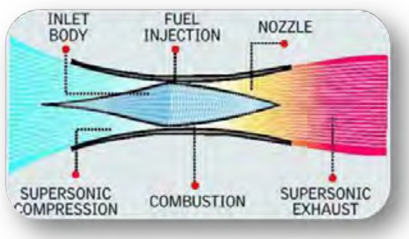

Fig. 4 . Scramjet

4 Challenges and applications

4.1 Challenges

Heat: To withstand the adverse effects of such speeds where the surface temperatures can go up to 1000 °C the materials to be used are special and used to be cooled nickel or titanium. But with advancements in R&D special ceramic materials are coming into the picture. For example, The Falcon HTV-2, recorded surface temperatures of 1.927 °C during its test flight.

Manoeuvring: To attain such speeds and fly effectively it is necessary that our "objects" fly high. Flying high can provide cover, it is also a way for the "object" to avoid the higher pressures present at lower altitudes, which could cause it to burn up. But the problem here is that thinner the air, the more difficult it becomes to steering. Some hypersonic aircraft are manned vehicles, but high altitude's thin air along with the extreme speeds means a human pilot cannot react fast enough to potential issues. This means manned hypersonic crafts have to be controlled by a computerized system that can control it while the pilot can direct the larger manoeuvres.

Breaking the barrier: A sonic boom can generate a 160-decibel noise that travels to the ground and can potentially damage human ears. The retired Concorde airplane used to produce noise up to 135-decibel on the ground which is way too much than the average commercial plane today. Another problem is that of the 'superboom' which develops when a supersonic airplane changes its speed, turns or manoeuvres. In a superboom the ground noise of a sonic boom can be two or three times louder than compared to one at the plane's altitude. Thus, with increasing altitude of the plane's flight, its ground shock waves can spread out and produce smaller shock waves.

Fuel: Going with the usually used aviation kerosene fuel is not feasible for going hypersonic. Hence, the liquefied oxygen/nitrogen/hydrogen comes into place. But hydrogen being able to give the highest specific impulse (a measure of the efficiency of rocket and jet engines) and its ability to un-pollute the air when oxidized with liquid oxygen (as its by product is only water) has become one of the preferred choice of fuel. Also, in case of mishaps, hydrogen burns 20% less hotter than its kerosene counter-part.

If the hydrogen can be sourced from natural gas, instead of from the electrolysis of water, the airfare tickets of a hypersonic trip could drop to about half the price of a business-class ticket. Based on current projections the ticket price will be about three times more expensive on average than current business-class subsonic tickets. Even though hydrogen-fuelled airliners would not emit gases such as carbon dioxide, sulphur oxides etc like today's subsonic airplanes, which increases the greenhouse effect. But there is another concern, water vapour produced by the combustion of hydrogen remains in the stratosphere for a long time, and could be a major contributing factor to global warming. Studies earlier have shown that the lifetime of water vapour decreases exponentially, taking from 30 years at 25 kilometres altitude to less than one year above 32 to 34 kilometres. An alternative fuel which could seem promising could be liquefied natural gas such as super-cooled liquid methane. It also occupies far less space than other gases when stored as liquid.

4.2 Applications

Development of hypersonic technologies came up mainly for/through military purposes and space programs like the development of X-15, X-51, Spaceship one and two by NASA along with the US Air Force and manufacturers like Boeing and Lockheed Martin. In space programs, USA started off with space shuttles and the Soviets followed with their Buran Project which is now on hold. India recently developed and tested RLV-TD all aimed to develop a reusable launch vehicle. There are countries that have developed and currently using hypersonic missiles/warheads also like Zircon (Russia), Shaurya (India) and Brahmos (India and Russia).

Within the recent/upcoming projects, The Defence Research & Development Organization of India has developed an unmanned scramjet demonstration aircraft for hypersonic speed flight aimed to develop for both civil purposes (low cost satellite launchings) as well as military purposes (long range cruise missiles). The project is called HSTDV (Hypersonic Technology Demonstrator Vehicle). There are many projects and research undergoing currently as well like the WU-14 hypersonic glide vehicle (China), Falcon HTV-2 (USA), AVATAR (India), SHEFEX (Germany), LAPCAT (EU) to name a few. For civil purposes there is a huge research and extensive testing going on mainly focused on human transportation within the globe as well as to outer space. Virgin Galactic and Space-X are such private firms into this.

Fig. 5 . Sharuya Missile

5 Conclusions

Human beings have always been curious about airspace and aviation. The improvements since the beginning of XIX century are astonishing but there is still some room for progression. Probably, the next main challenge is dominating the hypersonic flight. The aim is to develop an aircraft able to fly longer periods of time at hypersonic speed.

However, this is a hard challange. Aerodynamics, propulsion and structure demands on hypersonic flights are significantly more complex than in subsonic airplanes. Here lies the biggest problem and the technical issues that have to be solved before hypersonic flight becomes a reality.

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