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Hybrid – Aero Propulsions

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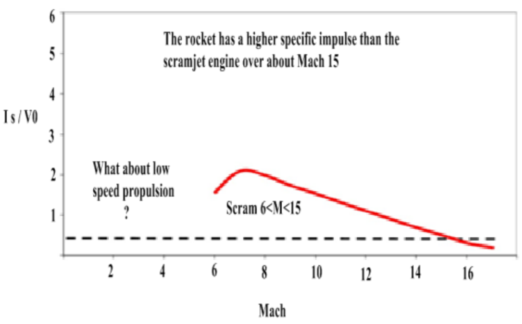
Abstract - **The Aim of this work is to design and develop Hypersonic Aircraft engine. In recent years, large effort are being undertaken around the world, particularly, to improve knowledge on Hypersonic air breathing engine, for potential applications, in the areas of civil, military aviation and space technology such as SSTO-(Single stage to orbit)and TSTO-(two stage to orbit).**

INTRODUCTION

In this study, efforts have been put to design anaircraft thatcombines the established and proven methods of variousaero propulsion systems that can reach hypersonic speed. As we know, scramjet can only be operated in Mach number excess of 5, we need some kind of aero propulsion to reach that Mach number, where the Scramjet is getting operational.

To overcome the limitations, there are various concepts which are being proposed.One of the proposed concept is, when a pre-cooled engine is integrated with the scramjet system, the gap for the low speed propulsion is fulfilled. The design combines a turbo-jet, incorporating a light weight air-pre-cooler, positioned just behind the inlet cone, combined with air-breath mode; using cryogenic fuel.



5. **OMPRESSOR :**

Design considerations:

1. **SHOCK CONE:**

The front of the engine is having a simple translating asymmetric shock cone inlets, slows the air to subsonic speeds using just two shock reflections.

2. BYPASS FLAPS :

There are bypass flaps, located just downstream of the diffuser.

a) During low speed flight, these controllable flaps close the bypass duct and force the air directly towards the compressor section.
b) During high speed flight mode, the flaps block the flow of air into turbojet and operate like a ramjet propulsion, using the aft combustion chamber to produce thrust.

3. **The engine would start out operating as a turbojet during takeoff and while climbing to altitude.**

4. PRE COOLER :

When the engine starts its operation, the air is directed towards the compression section by the by-pass flaps. The air before entering into the compressor passes through a pre-cooler (heat exchanger) section to increase density of intake air, where liquid hydrogen fuel stored on-board are passed or by inserting a gaseous helium cooling loop between air and the cold fuel, avoiding the problems associated with hydrogen embrittlement in the air pre cooler. Care to be taken to prevent blocking the pre-cooler from frozen water vapour and other fractions arising due to dramatic cooling of the air. Presently, thereexist the technologies that overcome this problem.Now, light weight suitable pre-coolers, which reject condensed water before it freezes, have now been experimentally demonstrated. The purpose of introducing pre-cooler is to increase the mass flow rate from the below equation.

$$\dot{m} = \rho A v$$

Where,

ṁ=mass flow rate

ρ=density of air

A=cross section area of the precooler

V=velocity of air

The cooled air from the pre-cooler passes into a reasonably conventional turbo-compressor, similar in design to those used on conventional jet engines, but at unusually high pressure ratio, made possible by lowering the temperature of the inlet air. This feeds the compressed air at very high pressure into the combustion chamber. Whenthe air gets cooled and passes through the compressor, leading to an unusually high pressure ratio within the engine. The below equation is used to find the pressure ratio.

$$P/P_0 = (T/T_0)^{\gamma/(\gamma-1)}$$

6. ENGINES :

It is of paramount important to have a fuel which can burn rapidly and generate an enormous amount of energy to overcome the tremendous drag forces experienced when flying at hypersonic speeds. HYDROGEN meets these criteria. The energy content of a fuel is calculated by a measurement called 'Lower Heating Value' (LHV). For comparison the LHV of the JP-8, which is a fuel commonly used in military aircraft is 43,190 KJ/Kg.; whereas the LHV of the Hydrogen is 1,19,900 KJ/Kg. Hydrogen is highly flammable; it only takes a small amount of energy to ignite it and make it burn. It also has a wide flammability range, meaning that it can burn when it occupies anywhere from 4% to 74 %of the air by volume. In simple, hydrogen provides more "bang" per kilogram, than any other hydrocarbon fuel for that matter.

(Liquid-Hydrogen aircraft would be as safe as modern kerosene aircraft. Liquid Hydrogen has specific handling requirements which must be met, just as kerosene does.The cryogenic temperatures pose additional design requirements, but these have been met in industries, which have been handling liquid hydrogen for over 40 years. Current cryogenic systems would have to be modified for the aricraft environment, such as attainment of a service life of over 40-50 years. Addtionally, liquid-hydrogen storage and support facilities would need to be much larger than any system currently in use, but still be just as safe.

A hydrogen aircraft could actually be safer to passengers in a crash, than a kerosene aircraft. Due to the specific chemical characteristics of hydrogen, a liquid hydrogen fire has a much shorter duration than a kerosene fire, about 15-22 sec. for a large hydrogen aircraft. (Ref.12) A kerosene fire lasts long enough to heat the fuselage to the point of collapse, whereas, the hydrogen fire would leave the fuselage intact. Also, the hydrogen aircraft would pose less of threat to the surroundings of a crash site, since the hydrogen would have a much smaller burn radius than kerosene.)

After gaining heat and vaporizing in the heat exchanger system, the fuel (H2) is burnt

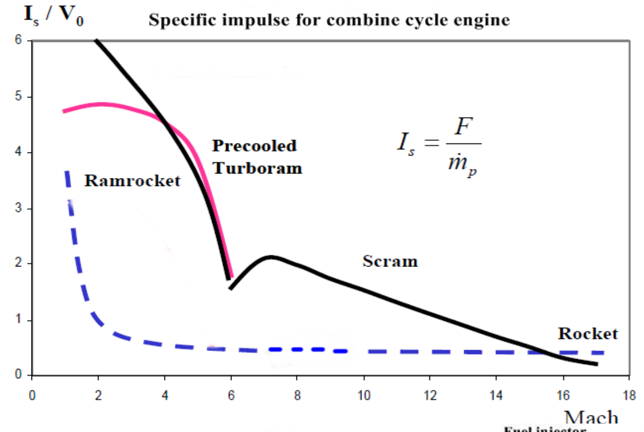
Inthe combustor, along with the compressed pre-cooled air.

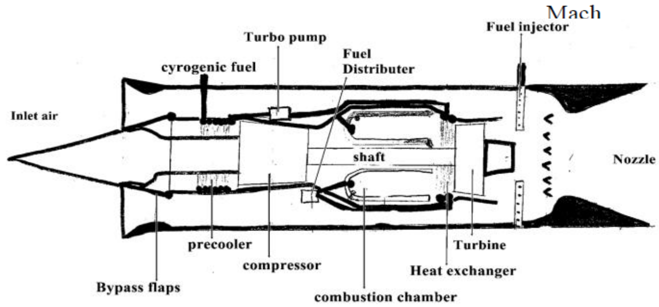
7. Upon reaching high subsonic speed, the portion of the engine downstream of the turbojet, would be used as an afterburner to accelerate the plane, above the speed of the sound.

8. AIR BREATHING MODE:

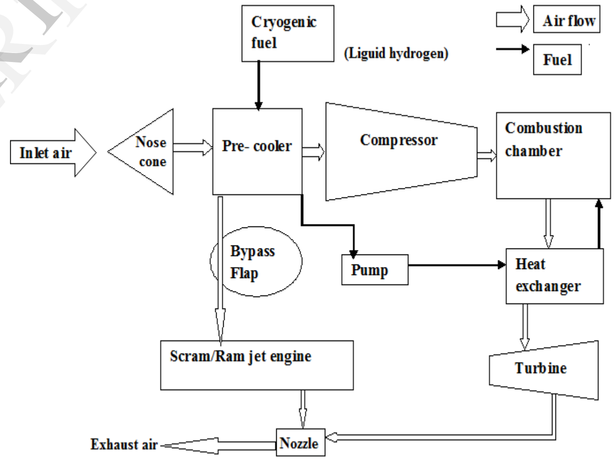
Once the aircraft was travelling fast enough, the bypass flaps would block the flow of air into turbojet and the air is fed directly to another combustion chamber downstream of turbojet; in which, again the cryogenic fuel is mixed and combustion is taking place, resulting in the engine operating on ram jet mode or scramjet mode, attaining the hypersonic speed.

The specific impulse vs. Mach number for a combine engine cycle is given below





This is the diagram of a pre cooled turbo scram jet engine.



This is the schematic diagram of Pre-cooled turbo scram jet engine

ADVANTAGES:

1. The main advantage of using of pre-coolers in this system, is that, for a given overall pressure ratio, there is significant reduction in compressor delivery Temperature (T3) which delays the onset of the T3 limit as flight speed increased. Consequently corrected flow can be maintained after the pre-cooler over a very wide range of flight speeds, thus maximizing net thrust even at high speeds.

2. Another advantage is that, the compressor and ducting after the inlet is subject to much lower and more consistent temperature, and hence may be made of light alloys, which in turn reduces the weight of the engine, that leads to improvement in the thrust/weight ratio.

3. Using the Cryogenic fuel, eliminates the harmful pollutants like CO and CO2 or particulate matter, during the combustion process – that is an ideal environment clean fuel.
4. The performance of this engine will be very high, because of the application of pre-cooler. The combination of cooled air being denser and hence require less, but more importantly, of the low air temperature permitting lighter alloy to be used in much of the engine, leading to high thrust/weight ratio.
5. Using cryogenic fuel to pre-cool the incoming air, thus allowing a normal turbo- compressor to work up to Mach 5.5+ without melting, achieve fuel and air densities that blurs jet engine with rocket engine (and thus the thrust to weight far greater then a jet engine). This would allow an aircraft to take off from a speed of 0 to Mach 5.5 or greater, then the engine could switch over to air breathing mode using the same cryogenic fuel, make the craft to even travel faster.
6. As the liquid hydrogen fuelled engine can operate with a lower turbine entry temperature, which results in longer engine life & lower maintenance cost. And has a high specific impulse and thrust to weight ratio(see ref.13)

TABLE 1: *Engine Performance Envelopes, Quoted I_{sp}s are Fully Expanded Values.*

Engine	Mach Number Range	Specific impulse I_{sp} (s)	T/W (N/kg)
LH/LOX			
Rocket (vac)	0 – 27	450 – 475	60-80
Ramjet (LH)	1 - 6	1500 – 3000	1 - 3.5
Scramjet	4 – 15	1000 – 3000	0.5- 2
Turbojet	0 - 2.5	2000 – 6000	1 – 4
Precooled Engine:			
- LACE	0 - 6	600 – 1000	6 – 14
- SABRE	0 - 5.5	1500 – 3200	6 – 14

TECHNOLOGICAL CHALLANGES:

1. The low density of the liquid hydrogen has negative effects on the rest of the vehicle. Storing of the liquid hydrogen needs a tank twice the size of that required for conventional hydrocarbon fuel.
2. Another aspect is the cost and safety issue involved in manufacturing and storing cryogenically-cooled fuel.

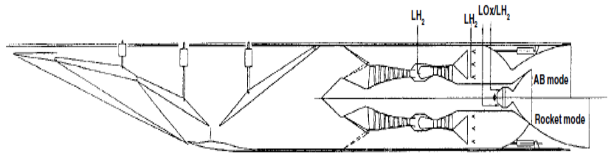


Fig. 1 Turbo-ramjet Engine (with integrated rocket engine).

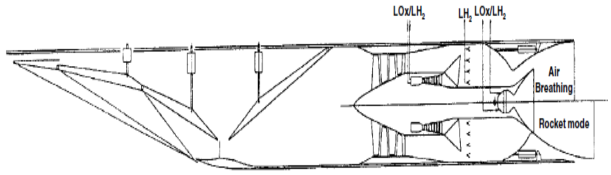


Fig. 2 Turborocket.

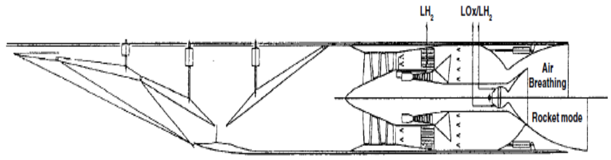


Fig. 3 Turbo-expander engine.

TECHNOLOGICAL VALIDATION:

1. Despite the drawbacks of liquid hydrogen, it is been the clear choice for researchers due to its versatility and performance. On March 2004, first hydrogen fuelled hypersonic flight –X43A- NASA's Hyper-X programme – was launched, attained a positive acceleration at Mach 7.
2. A Hybrid jet like SABRE, uses the advanced light weight pre-cooler to reach low hypersonic speed, of 5.5 Mach at air-breathing mode.
3. Atrix is a combined cycle engine with same pre-cooler and a fan boosted ramjet concept for TSTO vehicle.

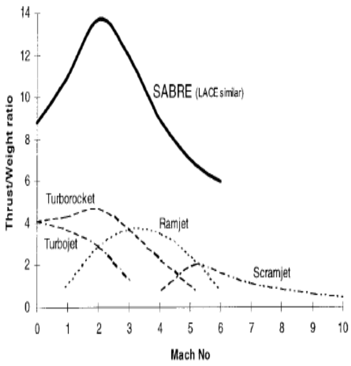
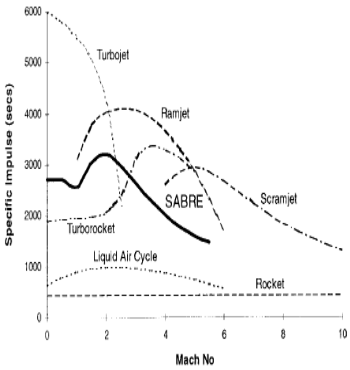


Fig. Installed thrust/weight ratio of the combined SSTO propulsion installation in airbreathing mode.

Fig. Installed specific impulse of SSTO propulsion systems



IN SUMMERY:

Today the aeronautical and aerospace industries are obsessed with the high performance engines having characteristics of using clean fuel, reducing the dependence of hydrocarbons. This proposed engine, may meet the criteria, as the pre-cooled engine is virtually here, with the usage of cryogenic fuel. It may be adequate to have comfortable low Hypersonic speed at 5-6 Mach, at which, we can do a very great deal, to safeguard our atmosphere and the quality of life, through improved high speed transportation. – It is an attempt by a humble student to achieve the above goal.

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