TBCC Off-Design Analysis For Mach 6 Civil Aircraft

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The future trend of aviation is to fly faster and higher. The meant by faster is not only to reach or exceed the sonic speed but to reach hypersonic speeds in the range of (4-7 Mach). This hypersonic aircraft have to be driven by an engine that can deliver sufficient thrust for take-off from rest through subsonic climb to hypersonic cruise then through subsonic descent to landing. Such a mission will exceed the limits of current working engines. Combined Cycle Engine (CCE) which is the topic of this study is assumed to drive that hypersonic aircrafts.

CCE is composed of several simple cycles like turbofan, ramjet, scramjet and rocket. These engines are working separately or simultaneously depending on the mission regime and flight conditions. The CCE under study is a Turbine Based Combined Cycle Engine (TBCC) it is composed of a Turbine Based Engine and a Ram Based Engine.

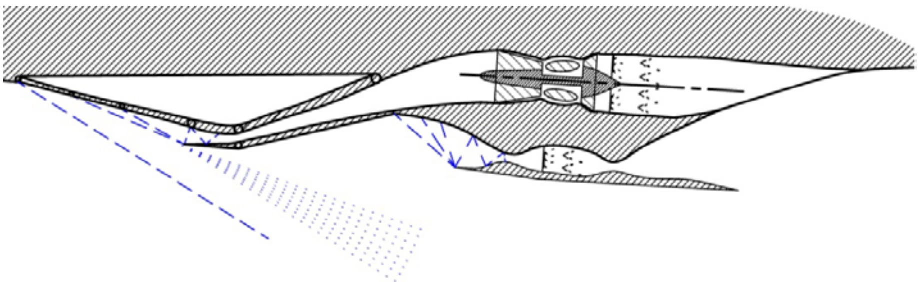

Figure 1: Turbine based Combined Cycle Engine in over-under configuration

Afterburning Turbojet with dual mode combustion Scramjet propulsion system is consideration. System is to be in over under installation with separate intakes and nozzles. The system analyzed and optimized to fit the needs of a selected civil hypersonic transport aircraft. Off design study and fuel consumption calculations are performed.

The selected vehicle HYCAT-1A is a Mach 6 civil hypersonic aircraft capable of caring 200 passengers for 9260 km. liquid hydrogen fuel is used for its high specific energy. The aircraft low speed performance is compatible with the commercial airport aids. The propulsion system must be capable of powering the aircraft through takeoff from a commercial runway. Acceleration from subsonic speed through supersonic to hypersonic speed takes place in climb regime. Cruise at constant speed Mach 6 will start at altitude of 30 km. followed by gliding descent till Mach 0.8 when the turbine Engine starts again.

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The aircraft is powered by turbojet engine alone up to supersonic speed when dual mode combustion scramjet can operate (at low supersonic speeds it operate on a ramjet cycle with subsonic combustion). Ram based engine powers the aircraft in parallel with turbojet engine up to Mach 3+. After Mach 3 the excessive heating in turbojet engine intake and compressor will force it to shut down and leave the scramjet engine to power the vehicle alone tell the end of acceleration and climb then through cruise.

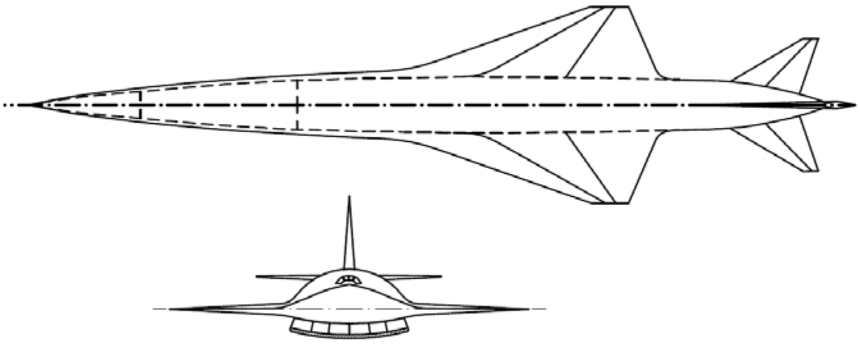

Figure 2: HYCAT-1A Mach 6 civil hypersonic aircraft

Thermal cycle is analyzed and studied. The cycle variables affecting Afterburning Turbojet with dual mode combustion Scramjet system are:

- Compressor pressure ratio.
- Fuel mass flow rate in combustion chamber, afterburner.
- Ratio of air flow through turbine engine to air flow through scramjet.
- Contraction ration in scramjet intake.
- Isolator dimensions for scramjet.
- Fuel mass flow rate in scramjet burner.

Mathematical models relating these variables to system performance parameters (specific thrust, thrust specific fuel consumption) are built. Constrains imposed on propulsion system are divided into four types: thermo-fluid constrains, chemical constrains, performance constrains, and size constrains. Thrust specific fuel consumption is selected as an evaluation parameter. Thrust specific fuel consumption represents the system profit (thrust), and cost (fuel consumption). Specific thrust is employed to obtain the air mass flow through the system which is constrained by size constrain.

Genetic optimization technique based on Darwin’s theory of evaluation and natural selection is employed to optimize propulsion system. Minimum thrust specific fuel consumption is used as fitness function. 1500 individuals are the size of population at each generation. Each individual is built from 80 binary digit representing the cycle variables affecting the system. Fifty percent of the population is replaced in each new generation, a mutation probability of one percent take place on ten percent randomly selected individuals. Roulette wheel selection process is used for a weighted random pairing in multi point crossover. Matlab 2010b (Math works) is employed to build Genetic optimization codes and mathematical models of propulsion system.

Optimum values of cycle variables are obtained and plotted versus Mach number. Design point for the system is selected. Off design study is performed to obtain the system performance and estimate the fuel consumption through a typical mission then compared with HYCAT-1A data.

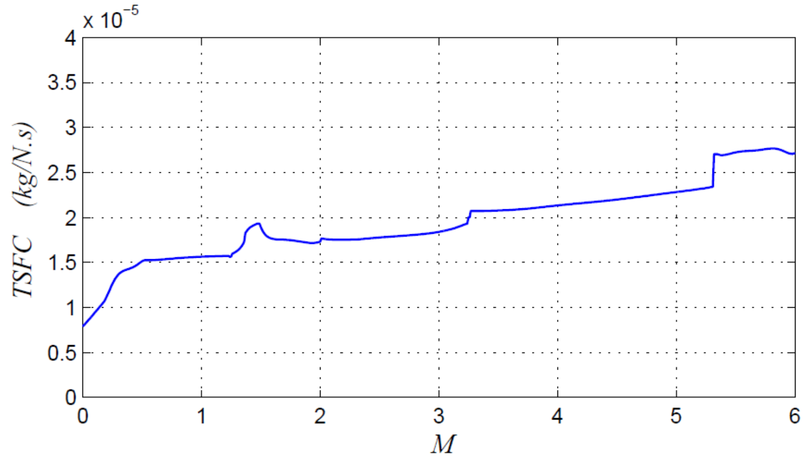

Figure 3: TSFC for turbojet/dual combustion scramjet system

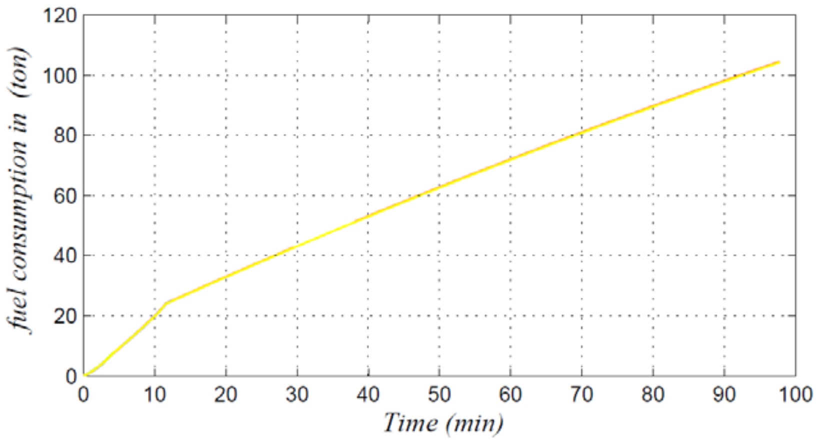

Figure 4: fuel consumption in turbojet/dual combustion scramjet system

Conclusion:

Liquid Hydrogen is accepted theoretically as a turbine engine propellant. 120 ton of Liquid Hydrogen will be enough to power the aircraft through the whole mission with 5-7% reserve fuel. Compressor with maximum pressure ratio of 20 and 250 kg/s is required. Increasing the thermal constrain of turbine inlet temperature will reduce the air mass flow rate and size of system.

This thesis achieved the following objectives:

- *Study and analysis of Turbine Based Combined Cycle (TBCC) Engine*
- *Study of system constrains: thermal, chemical, and performance constrains*
- *Genetic optimization technique for the propulsion systems*
- *System sizing and off design calculations*

Key Words:

Hypersonic, Propulsion, TBCC, Dual combustion scramjet, Civil, Genetic optimization