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Design and Analysis Variable Cycle Engine for Supersonic Jet Propulsion by Using Compressible Fluid Dynamics

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***Abstract*— It is a very sophisticated technology that to combine the different gas turbine engines to a single unit to make the aircraft to be suitable to operate under different operating or flying conditions. In that, the turbo ramjet engine plays a vital role in the military fighter aircrafts. In this project we designed an innovative turbo-ramjet engine conceptually which can operate efficiently in the various operating conditions and it is analyzed using CFD. The main problem for the design is in the mechanism development for changing the operating thermodynamic cycle. A Computational Fluid Dynamics model of the flow through the shrouded turbojet engine was developed and successfully used to assist in predicting the primary intent for research and design of Variable Cycle Engine has been for the use in supersonic aircrafts.**

***Index Terms*— CFD, Supersonic Jet Propulsion, Variable Cycle Engine.**

I. INTRODUCTION

Three type engines which are commonly used in aircraft are the reciprocating engine, the turbojet and the ramjet. Of the three the the reciprocating engine is the best at lower speeds of the order of 0 to 350 miles per hour. The turbojet is efficient in the ranges of Mach number 0.8 to 2 (Perkins, 1995). Above Mach 2, the ramjet is most efficient of the three types of engines. For medium speed operation, the turbojet has been. A variable cycle engine is an engine that is designed to operate efficiently under mixed flight conditions, such as subsonic, transonic and supersonic. The next generation of Supersonic transport (SST) may require some form of VCE. SST engines require a high Specific Thrust (net thrust/airflow) at propulsion to keep the cross-sectional area of the power plant to a minimum, so as to reduce aircraft. Unfortunately, this implies a high jet velocity not only at supersonic cruise, but at takeoff, which makes the aircraft noisy.

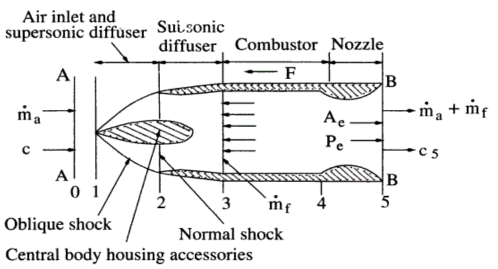

Figure1: Ramjet

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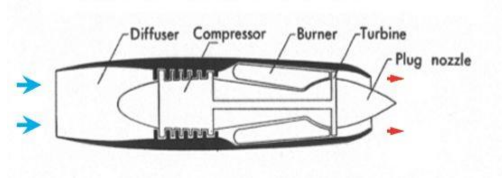

Figure2: Turbo Jet Engine

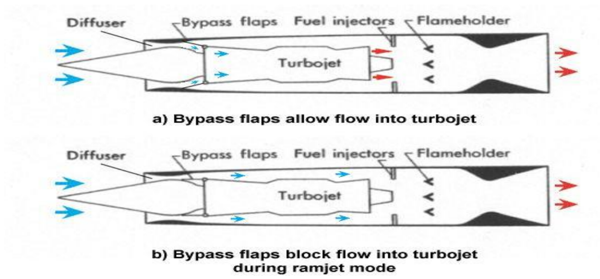

Figure3: Turboram Jet engine

The engine used on the SR-71 Blackbird is called a turbo-ramjet because it is a combination of a basic turbojet engine and a ramjet. How the J58 engines on the Blackbird change do from normal jets to ramjets as the plane accelerates? The term ramjet is short for ram-air compression. The ramjet is the simplest form of a jet engine because it has no moving parts.

The advantages of the ramjet are its simplicity and its ability to accelerate a vehicle to high speeds over Mach 3. However, we have already pointed out that the engine must already be in motion before it can work, so there is a minimum Mach number that must be reached before a ramjet can be turned on and start producing thrust.

That is the advantage of the turbojet, which is a member of the gas turbine family of engines. A turbojet operates much like a ramjet except that it does not rely purely on the motion of the engine to compress the incoming air flow. Instead, the turbojet contains some additional rotating machinery that compresses incoming air and allows the engine to function during takeoff and at slow speeds. The turboramjet is a hybrid engine that essentially consists of a turbojet mounted inside a ramjet. The turbojet core is mounted inside a duct that contains a combustion chamber downstream of the turbojet nozzle. The turboramjet can be run in turbojet mode at takeoff and during low speed flight but then switch to ramjet mode to accelerate to high Mach numbers.

II. METHODOLOGY

Availability of Tools

The tools required for this work are mainly design and analysis softwares. They are mainly the following;

1. CATIA V5
2. GAMBIT
3. FLUENT
4. GASTURB

These softwares were available at Jetwings Technologies, Bangalore, where we sought assistance for doing this project.

List of Experiments

The following are the experiments that are going to be done in our work.

1. Ramjet Shroud with Nose Cone.

2Turbo-Ramjet Geometry with Inflow and Outflow through the Turbojet.

3Turbo-Ramjet Geometry with Flow through the Turbojet with an Actuator Disk and Heatin.

Procedure of Experiments

These experiments are conducted from the designs done using CATIA V5. Each experiment is to be conducted by separate designs done. They are done in one by one manner.

1. The designs are done using CATIA
2. These designs are imported to the grid generation package.

III. GAMBIT AND IT IS DESCRETIZED.

Proper editing works are done FLUENT softwares.

Then these are analyzed using FLUENT software by specifying necessary boundary conditions.

Duration

The total duration of our project work is 3 months. This is excluding preliminary surveys. The analysis works took almost 2 months. We have been doing the analysis where the industrial and academical CFD analysis works are done.

IV. IV DESCRIPTION

Computational Fluid Dynamics (CFD) is widely used in aeronautics as a modern engineering design tool. The purpose of using CFD was to obtain solutions to the internal flow field of the turbo-ramjet and to compare these results to experimental and analytical results.

Modeling of the internal flow of the turbo-ramjet engine was accomplished using FLUENT. A two-dimensional planar grid was generated using the grid generation software GAMBIT. Four computational grids were created for use in FLUENT. All grids were C-type axi-symmetric grids. Simple test cases of a ramjet with nose-cone shroud and a cylindrical pipe were run to ensure no difference in the solutions between internal only and internal/external solutions.change of an internal only flow solution, convergence of solutions for a free stream Mach number below 0.6 were unattainable.

V. GAMBIT

GAMBIT is software for the generation of 3D, multiple block, and structured grids. The code may also be used to generate single block structured grids, single surface structured grids, and overset structured grids. FLUENT

FLUENT is a Navier-Stokes flow solver for structured grids. First-order implicit time stepping was used. FLUENT is a software environment for analyzing Computational Fluid Dynamics data. Calculations could be performed on the solution for flow visualization which may be animated and recorded.

VI. RESULT AND DISCUSSIONS

Proposed Engine Design

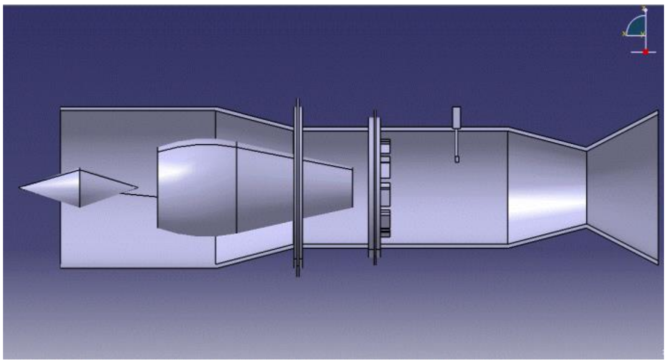

Figure4: Proposed Engine Design

This is axi-symmetric design. This design has been done after a stringent effort from the articles we have gone through and this design is maintained dimensionally valid in each part of its design. The works on CFD software are done by taking the flow area of one single cross-section and its upper half.

Final Flame Holder Design

Since it is a turbo-ramjet, it has to hold the flame for high subsonic conditions. So design should be done by keeping these requirements in the mind.

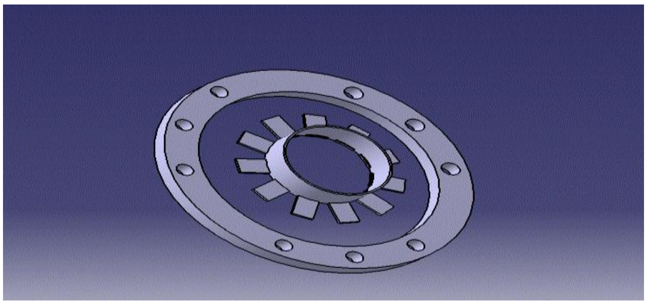

Figure5: Flame Holder Design

The large swirl caused by the turbojet exhaust made flame stabilization difficult. In order to minimize the effect, a new flame holder was designed and implemented. The final flame holder inner radius was circumferentially continuous. The final flame holder was also more uniformin appearance and eliminated asymmetries in the afterburner duct.

CFD Experimental Results

Ramjet Shroud with Nose Cone

A test case was run with free stream Mach, $M\infty = 0.6$. The grid size was a 411x51x3 grid and the extent of the shroud.

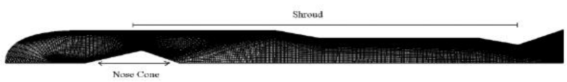

Figure 6: Ramjet Grid (411x51x3**)**

The present full shroud simulation allowed for the pportunity to analyze the flow through the duct and determine the amount of spillage caused by the nosecone and shroud back pressure at subsonic speeds.

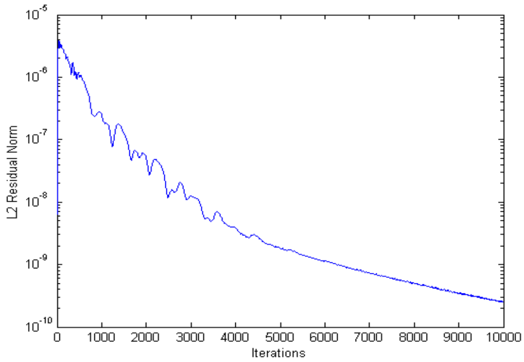

Figure7: L2 Residual Norm for Turbo-Ramjet Shroud at M∞=0.6

The Mach 0.6 results from FLUENT showed a large amount of spillage caused by the nose cone and a large area of recirculation developed downstream of the conical inlet.

Analysis of Design and Prediction Tools

The CFD results of the turbo-ramjet modeling of the turbojet engine flow gave qualitative and quantitative data of the flow through the turbo-ramjet. Figure shows the pressure distribution through the turbo-ramjet at M∞= 0.6.

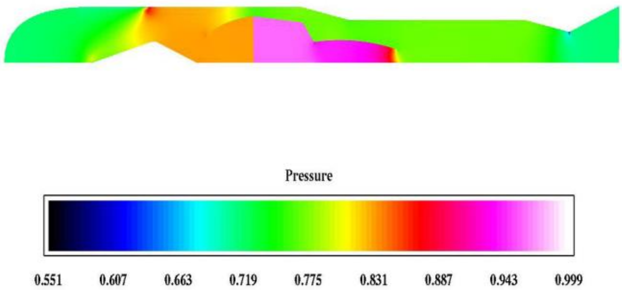

Figure 8: Pressure Distribution of Flow through Turbo-Ramjet at M∞=0.6

The density solution from FLUENT depicted almost constant density radially over the profile of the mixed exhaust flow. Hence, the CFD model of the shrouded engine closely simulated the actual flow through the engine with the bypass duct.

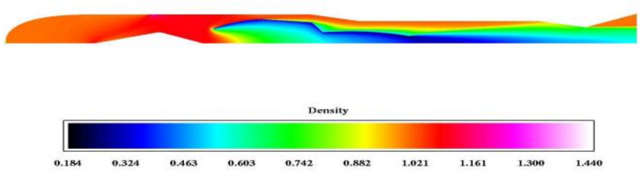

Figure 9: Density Distribution of Flow through Turbo-Ramjet at M∞=0.6

The angle of the nozzle pressure port would cause a stagnation point that would cause a larger than actual measurement. At static conditions this was a result of the correct pressure not being "sensed" by the transducer as a result of the expanding exhaust from the turbojet not yet reaching the shroud wall.

VII. CONCLUSION

- Testing of the shrouded turbojet engine was extended from Mach 0.45 to Mach 0.6.
- Static pressures in the shrouded engine were analysed to determine a cold-flow bypass ratio of 0.4 at Mach 0.2 and 4.75 at Mach 0.54.
- The combustor was successfully simulated to a Mach number of 0.2 with stable operation during increased and decreased free stream velocities.
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- The increase in bypass flow rate from Mach 0.2 to Mach 0.54 should result in a further increase in thrust due to the combustion of the cold bypass flow.
- The large increase in total mass flow rate calculated using the shrouded turbojet static pressure measurements demonstrate the large fuel rates needed at higher Ma numbers.

VIII. FUTURE SCOPE

- This provided optimism for future testing at higher speeds in conjunction with optimization of the flame holder.
- One idea for future testing is to use the turbojet compressor bleed air as the power source for the afterburner fuel pump.
- The ramjet shroud should be redesigned from its present convergent shape aft of the turbojet to a constant diameter duct followed by a convergent nozzle.

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