UNIVERSITY OF PETROLEUM AND ENERGY STUDIES

Study and Fabrication of a Gas Turbine Engine: High Bypass

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FOREWORD

I would like to express my deep appreciation and thanks for my advisor. This work is supported by Prof. Dr. Ugur Guven.

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TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

Study and Fabrication of Scale Model of a Gas Turbine Engine

SUMMARY

A turbofan engine is an internal combustion gas turbine engine. The turbofan engine differs from the other gas turbine engines because of the presence of a fan mounted inside the casing.

In the following chapters, various parameters governing the performance of a Turbofan Engine which are primarly comprised of Range, Endurance, Thrust Specific Fuel Consumption, Propulsive Efficiency, Fan Efficiency, Shaft Horse Power, etc have been discussed. The equations used are the emperical relations which help us compute the above parameters by means of programming.The programs are written in Matlab 7.0 and the various graphs are plotted using plot tool in the Matlab 7.0.

Furhter, flow through the engine has been analysed using CFD tools i.e GAMBIT and FLUENT. Performance of low bypass and high bypass turbofan engines have been compared using the same.

CHAPTER ONE

INTRODUCTION

The Gas Turbine Engines are used in almost every aircraft nowadays. They are basically internal combustion engines which provide essential thrust to move, fly the aircraft efficiently and safely.

1.1 Purpose of the Thesis

The purpose of this thesis is to analyse the working of the Turbofan engine and to study the flow inside the engine.

1.2 Background

Following developments in Turbofan engine have helped to achieve great fuel efficient and less noisy engines. The new engines have great power and thrust. The engines made nowadays are very compact in size and simple in their overall layout.

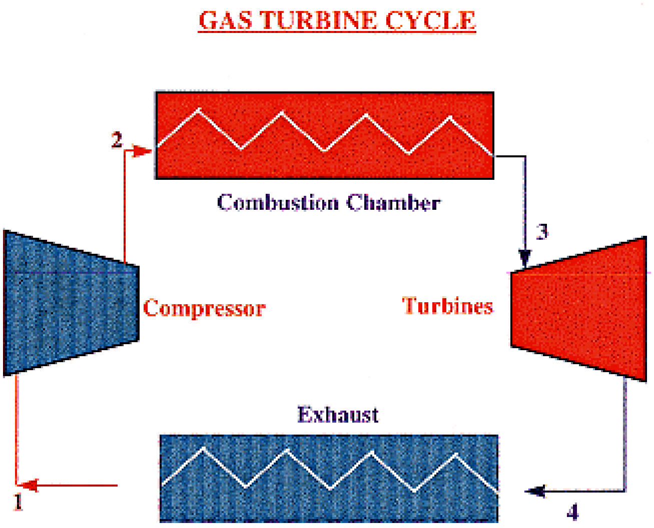


Figure 2.1 : A Simple Gas Turbine Cycle

2. ENGINE

Engine is a machine which is used to convert energy into useful mechanical motion. The engines which convert heat energy into mechanical motion are called as heat engines. Combustion engines (heat engines) are driven by the heat generated by a combustion process.

2.1 External Combustion Engine

In this type of engine, the working fluid is heated by combustion of an external source through the engine wall which acts as a heat exchanger.

2.2 Internal Combustion Engine

In this type of engine, the combustion of a fuel with an oxidizer (usually air) takes place inside a combustion chamber.

2.3 Gas Turbine Engine

Most of the gas turbine engines are internal combustion engines. A gas turbine engine extracts energy from the flow of a combustion gas. There are three main components of a simple a gas turbine engine, namely a compressor, a turbine and a combustion chamber.

2.3.1 Compressor

A compressor compresses incoming air to high pressure. The pressure rise is achieved by converting the high kinetic energy of incoming air into pressure energy.

2.3.2 Combustion Chamber

Inside a combustion chamber, the fuel mixed with oxidiser (air) is burned to produce high- pressure, high-velocity gas.

2.3.3 Turbine

A turbine extracts the energy from the high-pressure, high-velocity gas which is flowing through the combustion chamber.

3. TURBOFAN ENGINE

A turbofan engine, is a gas turbine engine that uses a Gas Generator Core, comprising of a compressor, a combustor and a turbine to generate kinetic energy in the exhaust by means of converting the internal energy in the fuel into kinetic energy. Turbofans are generally more efficient than turbojets at subsonic speeds. This can be understood from the following:

A turbofan engine comprises of a fan, in addition to the gas generator core and nozzle. The fan, just like the compressor is powered by the turbine section of the engine. In a turbofan engine, the exhaust through the nozzle not only comprises of the gas flow through the engine core, but also the flow accelerated by the fan by passing the gas generator core of the engine. So, a turbofan engine gets some of its thrust from the core and some of the thrust from the fan. The by passed flow is at lower velocities than the flow through the gas generator core. But owing to its higher mass, the thrust produced by the fan is more efficient than the thrust produced by the core. Hence, turbofan engine is more efficient than turbojets at subsonic speeds.
The ratio of the air that goes around the engine to the air the air that goes through the engine core is called BYPASS RATIO.

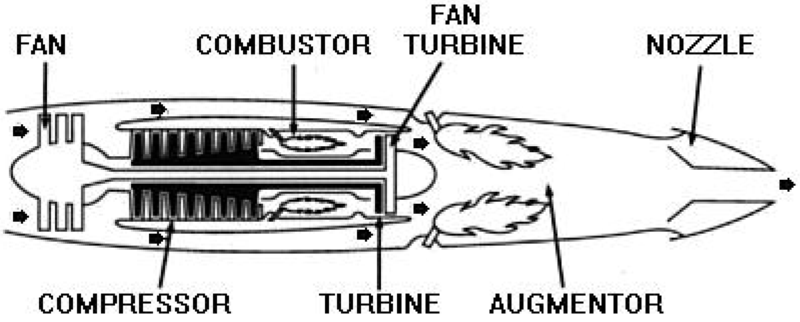


Fig 3.1: A Low Bypass Turbofan Engine

3.1 Low Bypass Turbofan Engine

Low bypass turbofan engines usually have a bypass ratio of 2:1 or even less than that. The bypass flow and the core flow can exit either through the same nozzle or separate nozzles.
Generally, low bypass turbofan engines make use of a mixed exhaust nozzle i.e. the bypass flow and the core flow exit from the same nozzle.

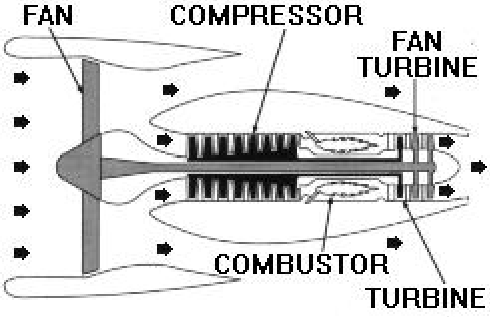


Fig 3.2: A High Bypass Turbofan Engine

3.2 High Bypass Turbofan Engine

High bypass turbofan engines have a bypass ratio of the order of 5:1 or 6:1 which implies, they have larger bypass ratios. Since a large mass of air is accelerated by a fan in high bypass turbofan engines, these are much more fuel efficient and produce much more thrust as compared to a low bypass turbofan engine or a turbojet engine.

3.3 Advantages of a Turbofan Engine

- Since a fan is used, more amount of air is sucked into the engine providing more thrust
- The fan is enclosed by the cowling and is thus protected and its aerodynamics can be easily controlled
- The extra amount of air, which bypasses the core of the engine, produces extra thrust than any the turboprop or turbojet engine.
- Due to presence of fan, the fuel consumption is increased only a little , the turbofan produces more thrust for same amount of fuel and is thus fuel efficient.

3.4 Disadvantages of a Turbofan Engine

- It is the most efficient at subsonic speeds only
- It has a greater complexity due to addition of ducts and multiple shafts
- The engine diameter is increased

3.5 Design of a Turbofan Engine

A turbofan engine essentially consists of an inlet, a fan, a compressor, a combustion chamber (burner or combustor), a turbine, and a nozzle.

3.5.1 Inlet

An inlet is used in all turbine engines for directing the free stream air into the engine. The inlets may be of various shapes and sizes. Depending upon the speed of the aircraft, these are classified as:

- Subsonic inlets
- Supersonic inlets
- Hypersonic inlets

The inlet efficiency has a strong effect on the net thrust produced by the aircraft engine, both at low speeds and high speeds. Hence, an inlet must operate efficiently over the entire flight envelope of the aircraft.

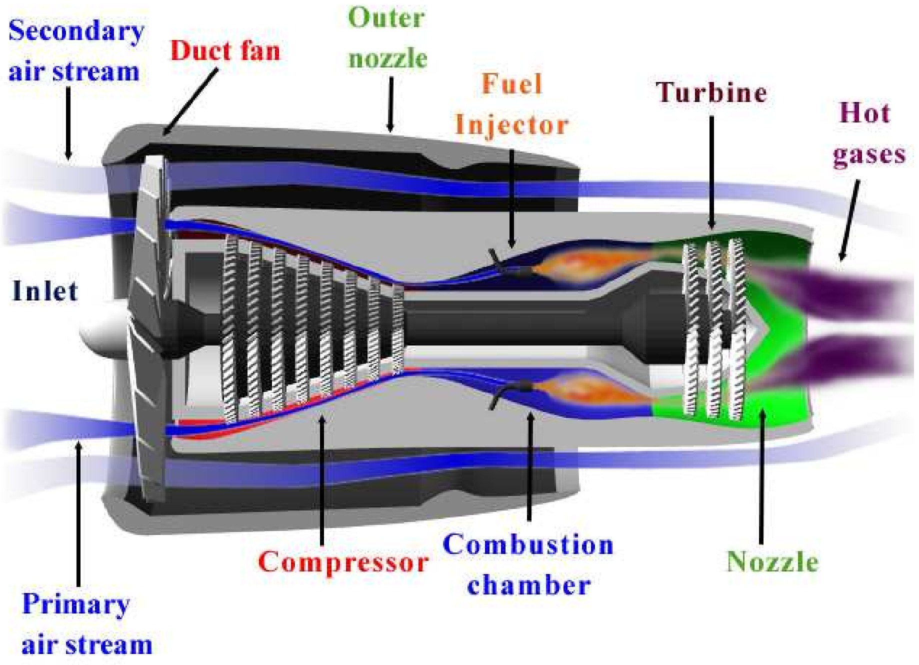


Fig 5.1: A Simple Design of Turbofan Engine

3.5.2 Compressor

A compressor is a part of the engine which increases the pressure of the incoming air before it enters the combustion chamber.

3.5.2.1 Centrifugal Compressor

A centrifugal compressor turns the flow through the compressor perpendicular to the axis of rotation i.e. the air enters axially and is delivered radially. It produces a high pressure ratio of 4:1 or 5:1 in a single stage.

3.5.2.2 Axial Compressor

In an axial compressor, the air enters axially and delivers axially. It is much more fuel efficient than a centrifugal compressor. Moreover, it gives the turbofan engine a long, slim and streamlined appearance. The engine diameter is reduced which results in much low aircraft drag. A multistage axial compressor can develop a pressure ratio as high as 6:1 or more. The air handled by this is more than that handled by a centrifugal compressor of the same diameter. The thrust produced per unit diameter is more. It also ensures 6% to 8% less specific fuel consumption.

A compressor consists of rotating parts called rotors and stationary parts called stators. Rotors are attached to the central shaft rotating at high speed, while the stators remain fixed. Further the rotors may be drum type or disc type rotor. The compressor blades are airfoil shaped and produce pressure variation much like the airfoil of a spinning propeller. A stator increases the pressure and keeps the flow from spiraling around the axis by bringing the flow back parallel to the axis. The rotors and the stators are placed in alternating sequence such that the compressor is composed of several rows of airfoil cascades. One set of a stator and a rotor is called a stage. The number of stages used in a compressor depends upon the pressure ratio required.

3.5.3 Burner

In combustion chamber or burner, the fuel is mixed with high pressure air and burned. These must be designed to ensure stable combustion of the fuel injected and optimum fuel utilization within the limited space available and over a large range of air to fuel ratios. The design of the combustion chamber depends upon the application and requirements in each case.

3.5.3.1 Annular type burner

The liner of the annular combustion chamber consists of a continuous, circular, inner and outer shroud around the outside of the compressor drive shaft. The inner is often called a “burner basket” because of its shape and the many holes that allow cooling air inside. In this type of chamber, fuel is introduced through a series of nozzles. The configuration ensures better mixing of air-fuel, better use of available space and uniform heat distribution.

3.5.3.2 Can type burner

Can type combustion chambers are particularly suitable for engines with centrifugal-flow compressors as the airflow is already divided by the compressor outlet diffusers. The separate flame tubes are all interconnected. The entire combustion system consists of 8 to 12 cans that are arranged around the engine. The disadvantage of this design comprises of the unfavorable inflow/outflow ratios and the associated large size. Ignition problems may also occur at high altitudes. The advantages include low development cost and good accessibility for servicing.

3.5.3.2 Can-Annular type burner

It is a combination of can type and annular type combustion chamber. In this type of combustion chamber, all flame tubes have a common secondary air duct. The aerodynamic properties of this type are inferior to those of annular type combustion chamber. These are suitable for large engines (for mechanical reasons) and the ones with high pressure ratios. Development costs are lower and volume smaller than with a can type combustion chamber.

3.5.4 Turbine

A turbine extracts energy from the hot flow and turns the compressor. The high pressure and temperature gases expand through the turbine to provide enough power output from the turbine. The turbine is directly connected to the compressor and all the power developed by the turbine is absorbed by the compressor and its auxiliaries.

A turbine, just like a compressor consists of rotors and stators. The stators prevent the flow from spiraling. Depending on the engine type, the turbine may be multi staged. A single turbine stage can be used to drive multiple compressor stages effectively. Turbofan engines generally employ a separate turbine and shaft to power the fan and the gear box respectively. This arrangement is called two spool engines.

3.5.5 Nozzle

After the gases leave the turbine they expand further in the exhaust nozzle and are ejected into the atmosphere with a velocity greater than the flight velocity, thereby producing thrust for propulsion. There are two types of nozzles:

3.5.5.1 Convergent nozzle

These nozzles have a fixed geometry.

The convergent nozzle is a simple convergent duct. When the nozzle pressure ratio (p_e /p_o) is low (less than about 4), the convergent nozzle is used. The convergent nozzle has generally been used in engines for subsonic aircrafts.

p_e = pressure at exit

p_o = pressure at entry

3.5.5.2 Convergent – Divergent nozzle

These are used in turbofan engines. It has both Convergent duct and divergent duct. Most convergent-divergent nozzles used in aircrafts are not simple ducts. They incorporate variable geometry and other aerodynamic features. It is used when the nozzle pressure ratio is high (greater than about 6). Variable geometry nozzles are also more efficient over a wider range of airflow, than fixed geometry nozzles. This is because the flow is first converged to a minimum area or throat and then expanded through the divergent section to the exit.

3.6 Working of a Turbofan Engine

In a turbofan engine the air is sucked in by the fan into the inlet. Some of the air enters the core of the engine while the rest bypasses .The air that flows into the core of the engine, enters the compressor first. In the compressor, kinetic energy of the air is converted into raise in the pressure energy. In case of a centrifugal compressor, air is accelerated to the impeller. In the impeller the kinetic energy and static pressure of the air are raised. The diffuser then converts the high kinetic energy into static pressure. While in the case of axial compressor the rotating blades impart kinetic energy to the air which is converted into static pressure. The stators help to recover the kinetic energy of the fluid as well as direct the flow. The temperature of the air is raised in the combustion chamber. The four steps involved in a burner are:

- Formation of the air fuel mixture
- Ignition
- Flame propagation
- Cooling of combustion products.

The uniform mixing of air and fuel mixture is important for complete and stable combustion. The air leaving the combustion chamber must be at a temperature which the turbine blades can tolerate. To ensure this, a primary amount of air is admitted for a stable combustion and a secondary amount of air at a lower temperature is introduced to cool down the gases. The cooled air is expanded in the turbine and thus power is produced. This power is used to drive the fan through the shaft. The exhaust gases then enter the nozzle. The velocity of the gases is increased as it passes out of the nozzle. The thrust obtained is highest when the exit pressure equals the atmospheric pressure. The air that bypasses (just passes through the fan) flows all around the core of the engine and finally leaves through the nozzle at a velocity higher than the initial velocity. So a turbofan engine gets some of it thrust from the core engine and some of it from the fan. The ratio of the air that bypasses to the air that goes into the core of the engine is called the bypass ratio of the engine.

3.7 Thermodynamics of a Turbofan Engine

3.7.1 Inlet

The inlet does no thermodynamic work and the total temperature through out the nozzle remains constant. The total pressure changes across an inlet. The pressure recovery which is defined as the recovery of free stream pressure is given by the ratio of pressure at the inlet exit to the free stream pressure.

$$\text{Pressure Recovery} = \frac{p_2}{p_0} \tag{7.1}$$

Where p_2 is the pressure at the inlet exit and p_0 is the free stream pressure.

3.7.2 Compressor

The air is compressed in the turbine. Since there is no addition or reduction of heat in the system and there are no frictional losses, the process is isentropic. Thus the pressure is raised isentropically in the compressor. Higher the value of compressor pressure ratio higher is the efficiency of the compressor. The relation between the temperatures and the pressures at the entrance and exit of the compressor are as follows:

$$t_3/t_2 = \left(p_3/p_2\right)^{\left(\mu-1/\mu\right)} \tag{7.2}$$

where µ is the ratio of specific heats , p_3 and t_3 are the pressure and temperature at the exit of compressor while p_2 and t_2 are the pressure and temperature at the entrance of the compressor.

The work done by the compressor is equal to the change in enthalpy per unit mass of flow from the entrance to the exit.

$$CW = h_3 - h_2 \tag{7.3}$$

Where CW is the compressor work, h_3 and h_2 are the specific enthalpies at the exit and the entrance.

The enthalpy is related to the temperature as follows

$$h = C_p \times t \tag{7.4}$$

Thus,

$$CW = C_p \times (t_3 - t_2) \tag{7.5}$$

The compressor pressure ratio (CPR) is always greater than 1 and the value of µ is also equal to 1.4 for air. Thus the temperature ratio is greater than 1. We can therefore conclude that air heats up as it passes through the compressor.

3.7.3 Combustor

The air is mixed with fuel and combustion takes place inside the combustion chamber. The burning takes place at a higher pressure than the free stream pressure because of the pressure raise that takes place in the compressor. The pressure in the burner remains constant decreasing only by 1 or 2 percent.
Since heat is produced inside the combustor, energy equation is applied to determine the temperature change.

$$(1+f) \times h_4 = h_3 + f \times \eta \times Q \qquad \textbf{(7.6)}$$

Where, f is the fuel to air mass flow ratio , h_3 and h_4 are enthalpies at the exit and entrance of the burner, η is an efficiency factor considered due to losses during the burning process , and Q refers to the heat released.

3.7.4 Turbine

The air is expanded isentropically in the turbine. Thus, the turbine pressure ratio is always less than 1. Since the process is isentropic the relation between temperature and pressure is given by

$$p_5/p_4 = \left(t_5/t_4\right)^{\left(\mu-1/\mu\right)} \qquad \textbf{(7.7)}$$

Where, p_5 and t_5 are the pressure and temperature at exit of the turbine, p_4 and t_4 are the pressure and temperature at the entrance of the turbine. The turbine work is as follows

$$TW = C_p \times (t_4 - t_5) \qquad \textbf{(7.8)}$$

The turbine blade must be made of a special material which can tolerate the high temperatures.

3.7.5 Nozzle

The temperature and the pressure remain constant through out the nozzle although the velocity increases as air leaves the nozzle.

3.8 THRUST PRODUCED BY A TURBOFAN ENGINE

Thrust is a force produced by accelerating a mass of gas according to Newton’s third law of motion. Also force equals the rate of change of momentum according to Newton’s second law of motion. A gas is accelerated to rear through the engine due to which the aircraft is accelerated in opposite direction.

Thus the thrust equation is as follows

$$F = \left(m_2 v_2 - m_1 v_1 \big/ (t_2 - t_1) \right) \tag{8.1}$$

In a turbofan engine some of the air bypasses the engine core and thus the thrust equation is given as follows:

Thrust = thrust of fan + thrust of the core

$$F = \left(\dot{m}_f v_f - \dot{m}_f v_0 \right) + \left(\dot{m}_e v_e - \dot{m}_c v_0 \right) \tag{8.2}$$

Where,

$\dot{m}_f$ = mass flow through fan

$\dot{m}_c$ =mass flow through core

4. CONCLUSION

A higher bypass ratio gives a low (actual) exhaust speed. As a result, the thrust specific fuel consumption is reduced. A lower bypass ratio gives high exhaust speed, which is used to sustain supersonic speeds. Thus, one can conclude that a high bypass turbofan engine gives lower thrust specific fuel consumption.
A high bypass turbofan engine is used at subsonic speeds because of low exhaust speed it produces.

Turbofan engines gain better performance capabilities and better fuel efficiency.

CHAPTER TWO

INTRODUCTION

The jet engine is a device which takes in air at essentially the free stream velocity, heats it by combustion of fuel inside the duct and then blats the hot mixture of air and combustion products out the back end at a much higher velocity. Thrust produced by a turbofan engine is the combination of thrust produced by fan blades and jet from exhaust nozzle.

Turboprop engines and turbofan engines are primarily turbojet engines in which combustion gases are more fully expanded in the turbine section to develop more power than is needed to drive the compressor and its accessories. This excess power is then used to drive either a propeller, in case of a turboprop, or a multi bladed ducted fan, in case of a turbofan, to produce thrust power. Any energy remaining in the gaseous mixture leaving the drive turbines is then expanded in a nozzle to produce what is known as jet thrust. This jet thrust, is considerably less than that produced by a comparable turbojet. Contrary to a turboprop, a turbofan engine is described as though it were a turbojet engine. Its characteristics are determined by the bypass ratio.

2. EQUATION GOVERNING THRUST OF A TURBOFAN ENGINE

A turbofan is a multi flow engine similar in many respects to a turboprop engine except that the additional turbines directly drive a fan that resembles an axial flow compressor. The ratio of the secondary (cold) airflow through the fan to the primary (hot) airflow through the gas generator and the tailpipe is called BYPASS RATIO. The more power that is extracted from the exhaust gases to drive the fan, higher the bypass ratio is and smaller is the jet thrust. Even though with very high bypass ratios the turbofan may produce more power than thrust and perform more like a turboprop than turbojet, it is customary to describe the turbofan as though it was a turbojet, with EQUIVALENT THRUST expressed as

$$T = \left[\frac{375\eta(\text{SHP})}{V} + T_j\right] \tag{1.1}$$

Where,
η = conversion efficiency of fan.
SHP= shaft horse power delivered to the fan.
T_j = jet thrust.
V= airflow velocity.

2.1 Data Assumed in the Program

The following program has been designed to compute the effect of change in velocity of airflow on the equivalent thrust of the turbofan engine. Since turbofan engines work in low supersonic regions, the velocities have been taken in the range of $0.65<M<0.85$. The conversion efficiency of the fan in low bypass turbofan is approximately 20% less than that in a high bypass turbofan engine. The shaft horse power of low bypass turbofan was obtained by lowering the value by 47% of that in case of a high bypass turbofan engine. The various values are assumed on the basis of logical estimation.

2.1.1 Data for High Bypass Turbofan Engine

η= 85%

SHP= 15000 shp

T_j = 17% of the total thrust

V= ranges from 494 to 646 mph

2.1.2 Data for Low Bypass Turbofan Engine

η= 65%

SHP= 7050 shp

T_j = 67% of the total thrust

V= ranges from 494 to 646 mph

2.2 Programs

Two programs, one each corresponding to a high bypass turbofan and a low by pass turbofan were programmed.

2.2.1 Program Computing Thrust for High Bypass (6:1) Turbofan Engine

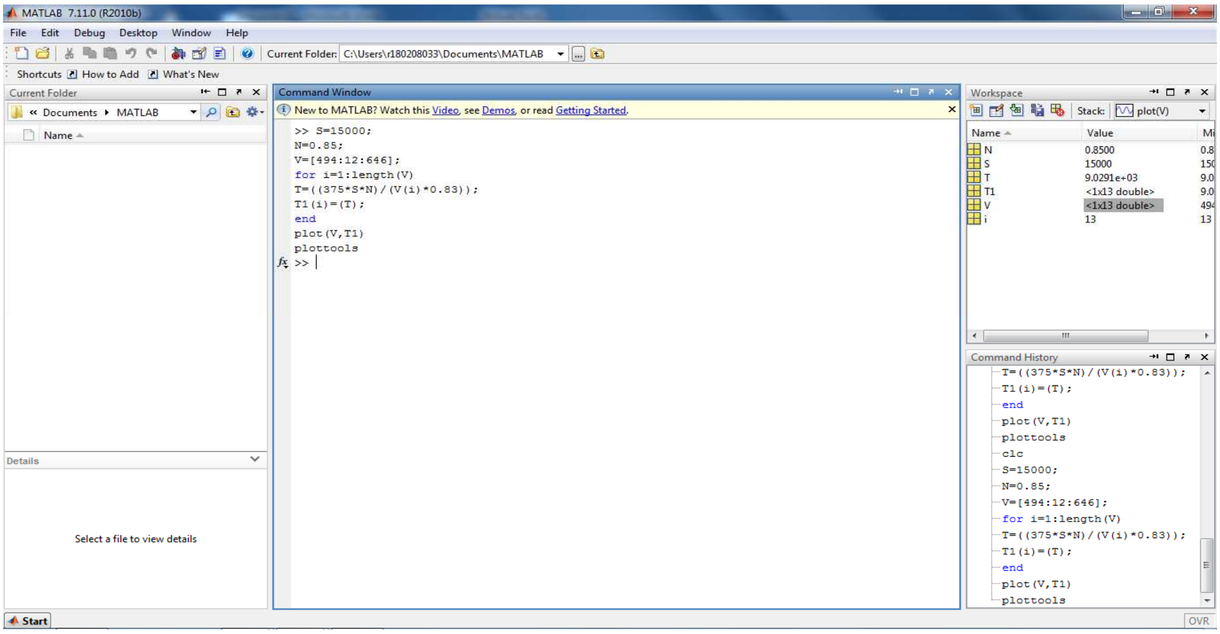
```
S=15000;
N=.85;
V= [494:12:646];
for i=1:length(V)
T= ((375*S*N) / (V(i)*0.83));
T1(i)=T;
end
plot (V,T1)
```

2.2.2 Program Computing Thrust for Low Bypass (2:1) Turbofan Engine

```
S=7050;
N=.65;
V=[494:12:646];
For i=1:length(V)
T=((375*S*N) / V(i)*.33));
T1(i)=T;
end
plot (V,T1)
```

2.3 Results

2.3.1 High Bypass Turbofan Engine



```
>> S=15000;
N=0.85;
V=[494:12:646];
for i=1:length(V)
T=((375*S*N)/(V(i)*0.83));
T1(i)=(T);
end
plot(V,T1)
plottools
>> |
```

Name	Value	Mi
N	0.8500	0.8
S	15000	150
T	9.0291e+03	9.0
T1	<1x13 double>	9.0
V	<1x13 double>	494
i	13	13

```
T=((375*S*N)/(V(i)*0.83));
T1(i)=(T);
end
plot(V,T1)
plottools
clc
S=15000;
N=0.85;
V=[494:12:646];
for i=1:length(V)
T=((375*S*N)/(V(i)*0.83));
T1(i)=(T);
end
plot(V,T1)
plottools
```

Figure 2.1: Matlab Program for Computing Thrust

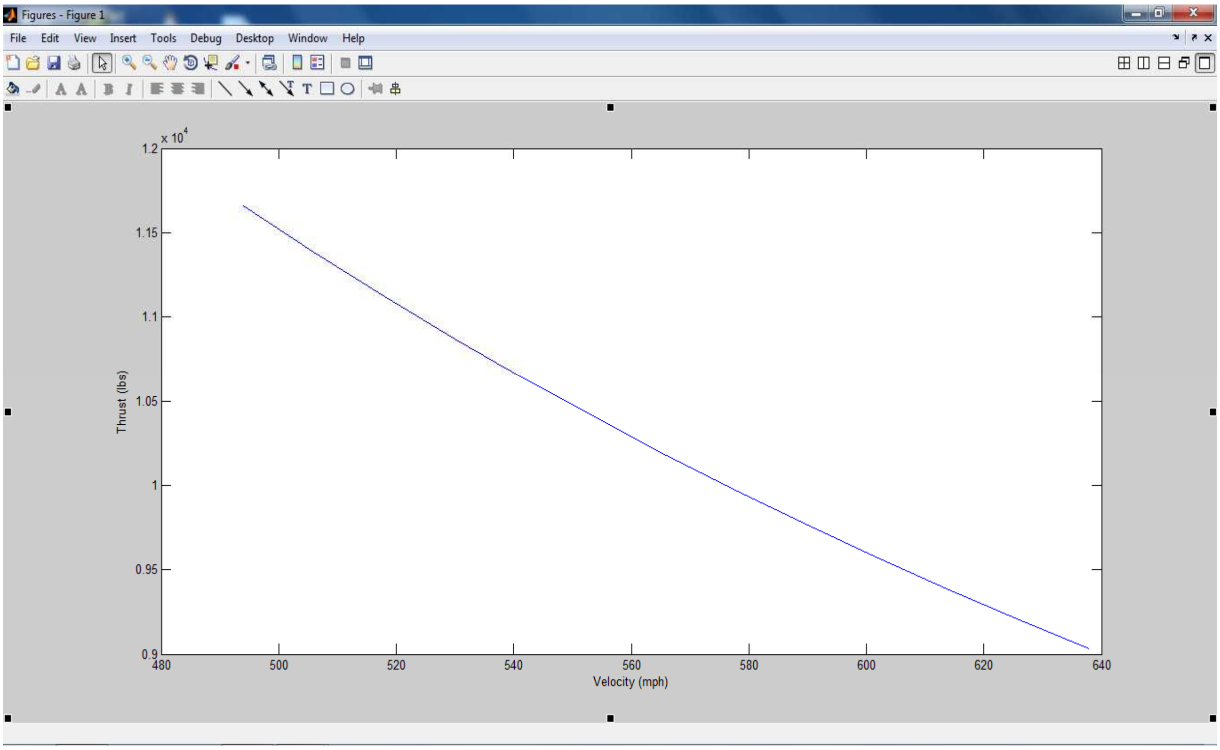
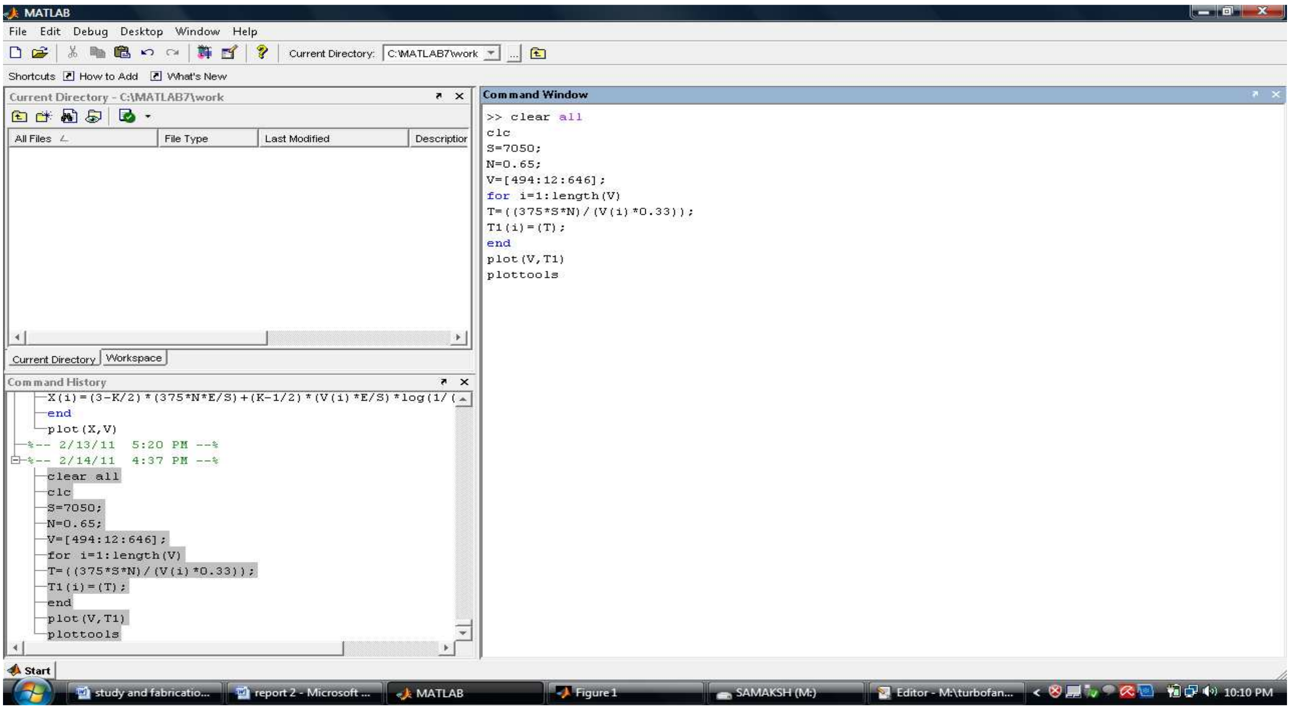


Figure 2.2: Thrust v/s Velocity for High Bypass Turbofan Engine

2.3.2 Low Bypass Turbofan Engine



```
>> clear all
clc
S=7050;
N=0.65;
V=[494:12:646];
for i=1:length(V)
T=((375*S*N)/(V(i)*0.33));
T1(i)=(T);
end
plot(V,T1)
plottools
```

```
X(i)=(3-K/2)*(375*N*E/S)+(K-1/2)*(V(i)*E/S)*log(1/(
end
plot(X,V)
%-- 2/13/11  5:20 PM --%
%-- 2/14/11  4:37 PM --%
clear all
clc
S=7050;
N=0.65;
V=[494:12:646];
for i=1:length(V)
T=((375*S*N)/(V(i)*0.33));
T1(i)=(T);
end
plot(V,T1)
plottools
```

Figure 2.3: Matlab Program For Thrust Calculation

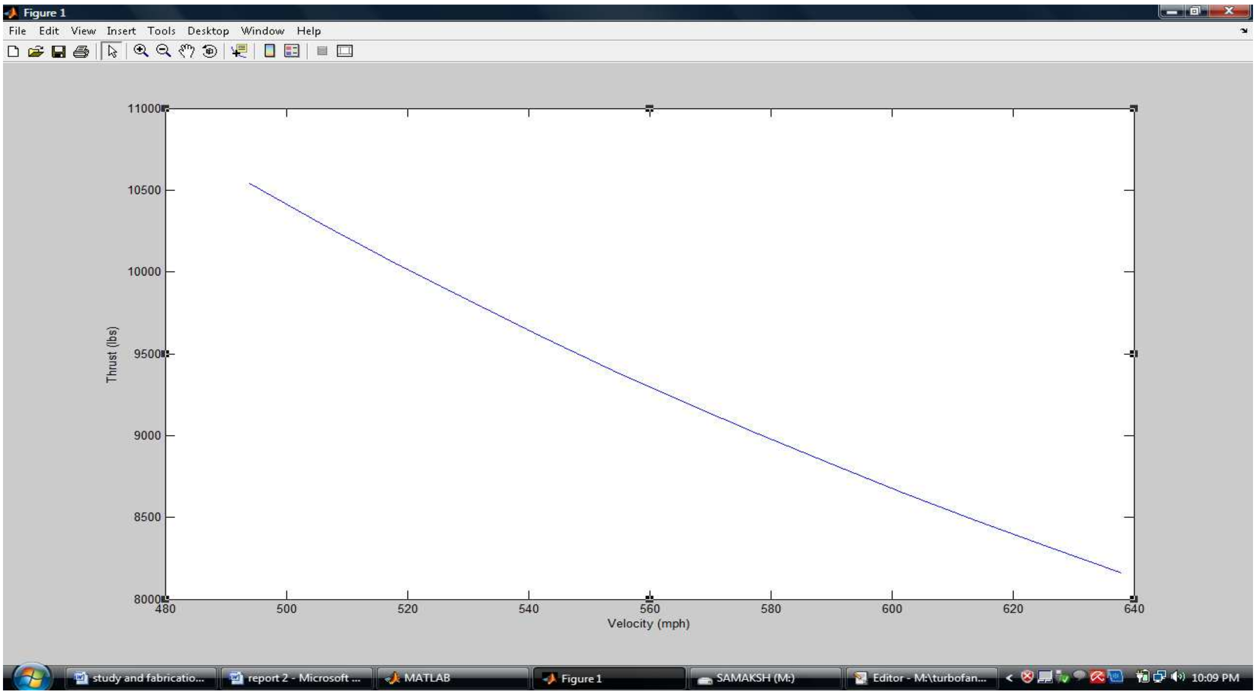


Figure 2.4: Thrust v/s Velocity for Low Bypass Turbofan Engine

2.4 Conclusion

We can conclude from the graph that:

As the true air speed increases, the thrust produced by the engine decreases. This is so because, as the speed increases, the drag between the mass of the air going into the core and the mass of the air going around it increases leading to a overall decrease in the thrust.

3. BREGUET'S EQUATION GOVERNING THE RANGE OF JET ENGINE

Range is defined as the total distance transverse by the airplane on a given tank of fuel. The total range of a turbofan can be represented by the sum of a contribution from a constant-power constituent and one from the constant-thrust constituent, to give the generalized BREGUET'S RANGE EQUATION applicable to all four types of propulsion system.

$$X = \frac{2m^{1/2}E_m}{m+1}\left[\left(\frac{3-k}{2}\right)\frac{375\eta_p}{\hat{c}} + \left(\frac{k-1}{2}\right)\frac{m^{1/4}V_{md}}{c}\right]\ln\left(\frac{1}{1-\zeta}\right) \tag{3.1}$$

Where,
X= range
k = propulsion system designator
c= specific fuel consumption
ĉ = horse power specific fuel consumption
E= l/d ratio
V= velocity
Z = cruise fuel weight ratio
η_p = propeller efficiency
m= air speed parameter

The value of “k” determines the type of propulsion system. For k=1, the turbojet contribution goes to zero, resulting in a pure piston prop engine. For k=3, propeller contribution drops out leaving a pure turbojet engine. For all values of k between 1 and 3, different values of turboprop and turbofan contributions are obtained.

3.1 Data Assumed in the Program

Programs were written to compute the effect of change in air speed parameter (function of velocity) on the relative range of a turbofan. The value of propulsion system designator was taken to be k=2 and k=2.7, in order to obtain results for a turbofan engine.

3.1.1 Case 1: k = 2

A=V md / c= 400
E= l/d = 16.3
Z = 0.3
N= ῃ p / ĉ=2
m= ranges between 0 to 4

3.1.2 Case 2: k = 2.7

A=V md / c=400
E= l/d = 16.3
Z = 0.3
N =ῃ p / ĉ= 2
m= ranges between 0 to 4

3.2 Programs

The trends of how the change in air speed parameter effects the range of a turbofan, was illustrated by means of programming.

3.2.1 Program for k=2

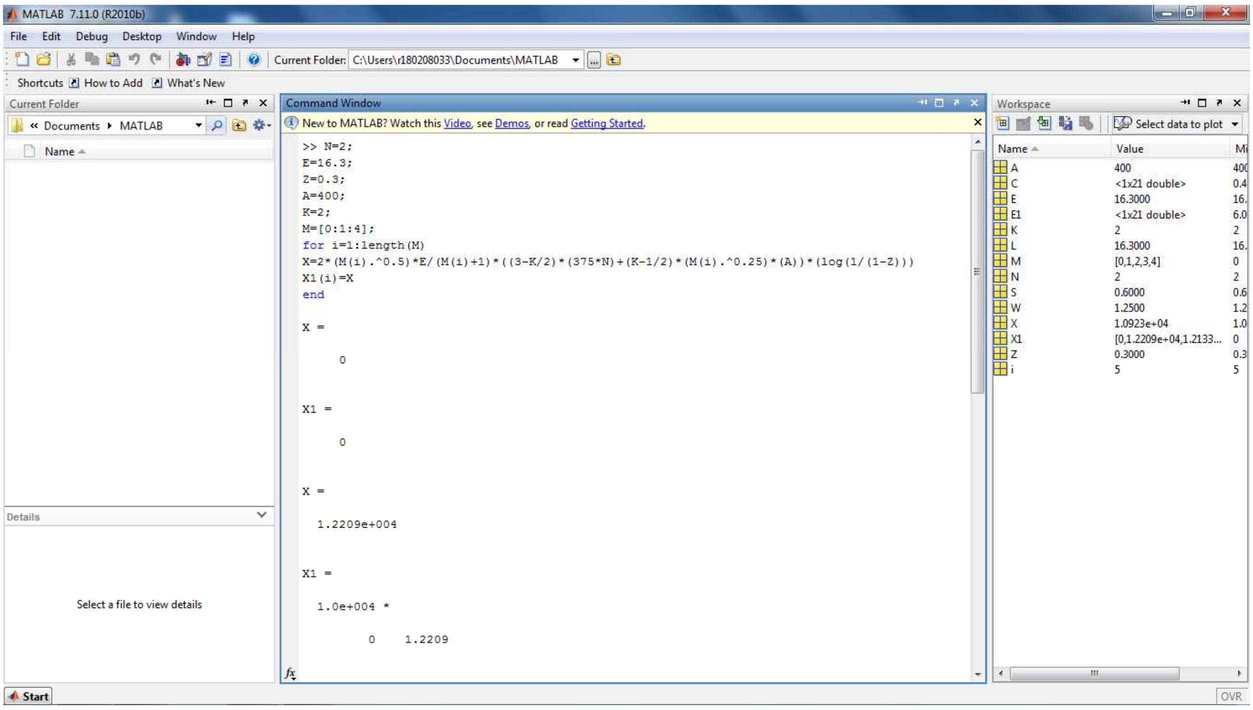
```
N=2;
E=16.3;
Z=0.3;
A=400;
k =2;
M=[0:1:4];
For i=1:length(M)
X= 2* (M(i).^0.5) * E/ (M(i) + 1) * ((3-k/2) * (375*N) + (k-1/2) * (M(i).^0.25) * (A)) * (log(1/(1-Z)));
X1(i)=X;
end
plot (M,X1)
```

3.2.2 Program for k=2.7

```
N=2.7;
E=16.3;
Z=0.3;
A=400;
k =2.7;
M=[0:1:4];
For i=1:length(M)
X= 2* (M(i).^0.5) * E/ (M(i) + 1) * ((3-k/2) * (375*N) + (k-1/2) * (M(i).^0.25) * (A)) * (log(1/(1-Z)));
X1(i)=X;
end
plot (M,X1)
```

3.3 Results

3.3.1 For K=2



```
>> N=2;
E=16.3;
Z=0.3;
A=400;
K=2;
M=[0:1:4];
for i=1:length(M)
X=2*(M(i).^0.5)*E/(M(i)+1)*((3-K/2)*(375*N)+(K-1/2)*(M(i).^0.25)*(A))*(log(1/(1-Z)))
X1(i)=X
end

X =

     0


X1 =

     0


X =

  1.2209e+004


X1 =

  1.0e+004 *

         0    1.2209
```

Name	Value	Mi
A	400	400
C	<1x21 double>	0.4
E	16.3000	16.
E1	<1x21 double>	6.0
K	2	2
L	16.3000	16.
M	[0,1,2,3,4]	0
N	2	2
S	0.6000	0.6
W	1.2500	1.2
X	1.0923e+04	1.0
X1	[0,1.2209e+04,1.2133...	0
Z	0.3000	0.3
i	5	5

Figure 3.1: Matlab Program for Breguet’s Equation of Range

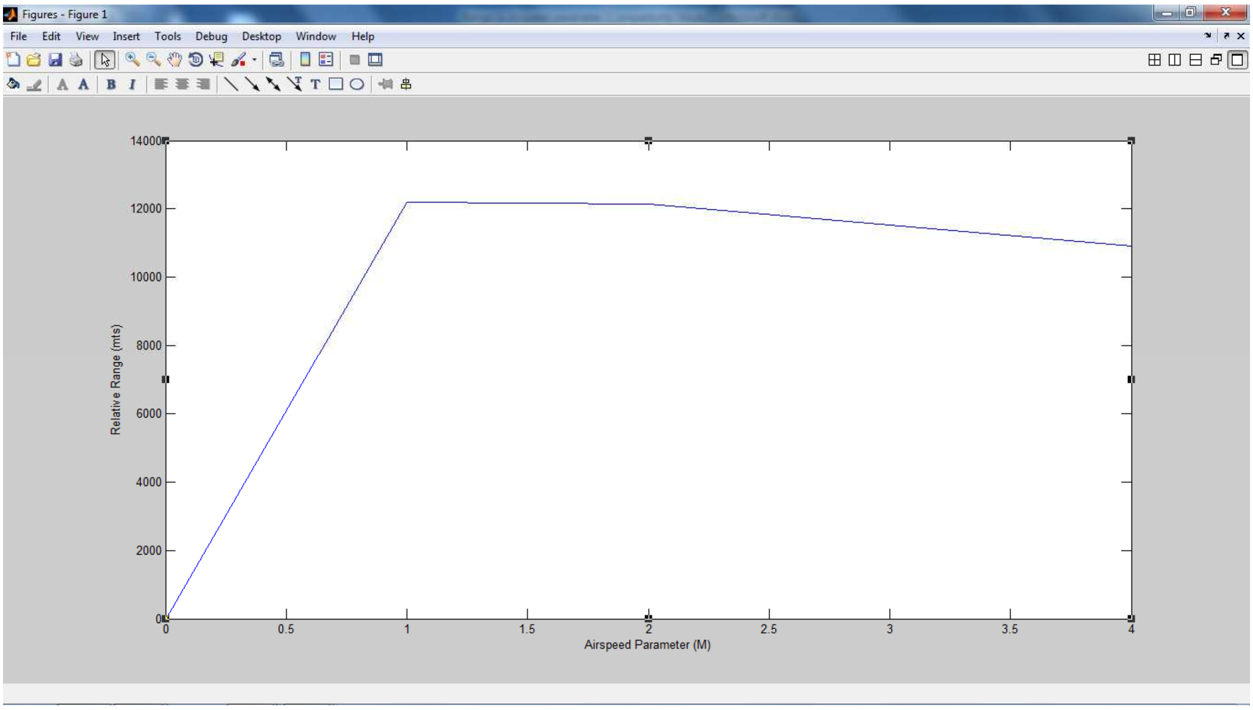
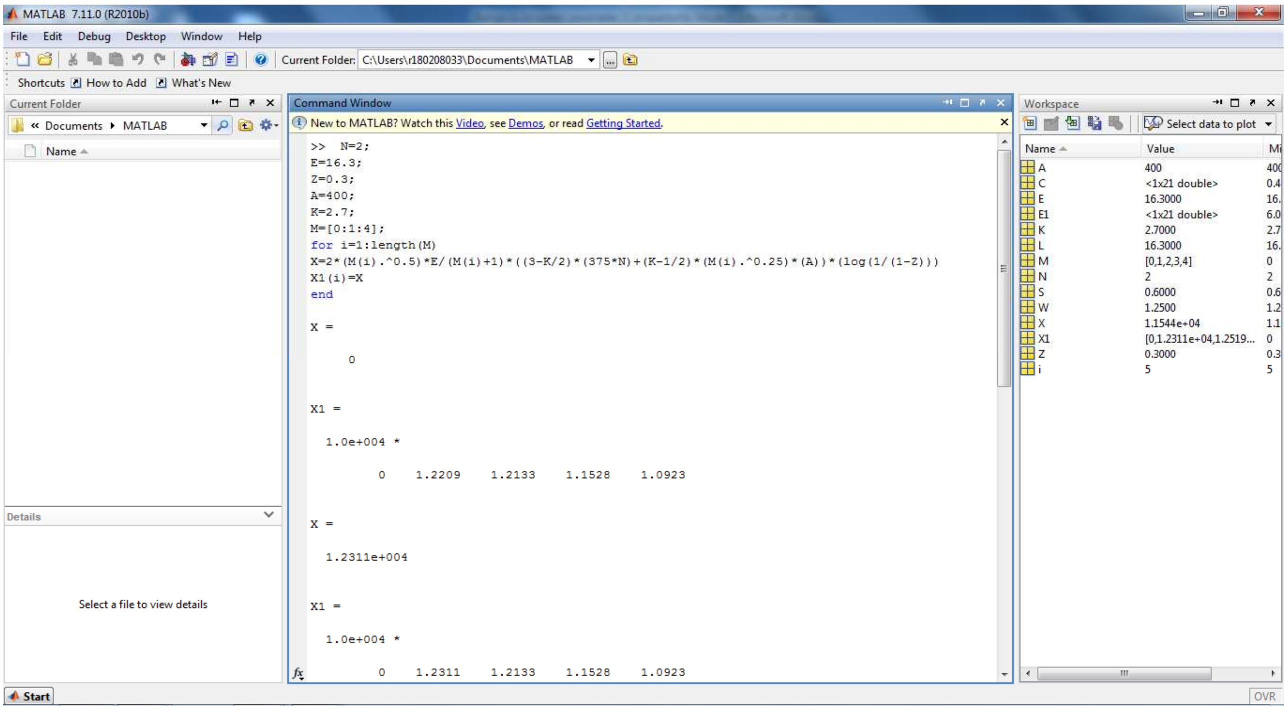


Figure 3.2: Range v/s Airspeed for K=2

3.3.2 For k=2.7



```
>>  N=2;
E=16.3;
Z=0.3;
A=400;
K=2.7;
M=[0:1:4];
for i=1:length(M)
X=2*(M(i).^0.5)*E/(M(i)+1)*((3-K/2)*(375*N)+(K-1/2)*(M(i).^0.25)*(A))*(log(1/(1-Z)))
X1(i)=X
end

X =

     0


X1 =

  1.0e+004 *

         0    1.2209    1.2133    1.1528    1.0923


X =

  1.2311e+004


X1 =

  1.0e+004 *

         0    1.2311    1.2133    1.1528    1.0923
```

Name	Value	Mi
A	400	400
C	<1x21 double>	0.4
E	16.3000	16.
E1	<1x21 double>	6.0
K	2.7000	2.7
L	16.3000	16.
M	[0,1,2,3,4]	0
N	2	2
S	0.6000	0.6
W	1.2500	1.2
X	1.1544e+04	1.1
X1	[0,1.2311e+04,1.2519...	0
Z	0.3000	0.3
i	5	5

Figure 3.3: Matlab Program for Breguet’s Equation of Range

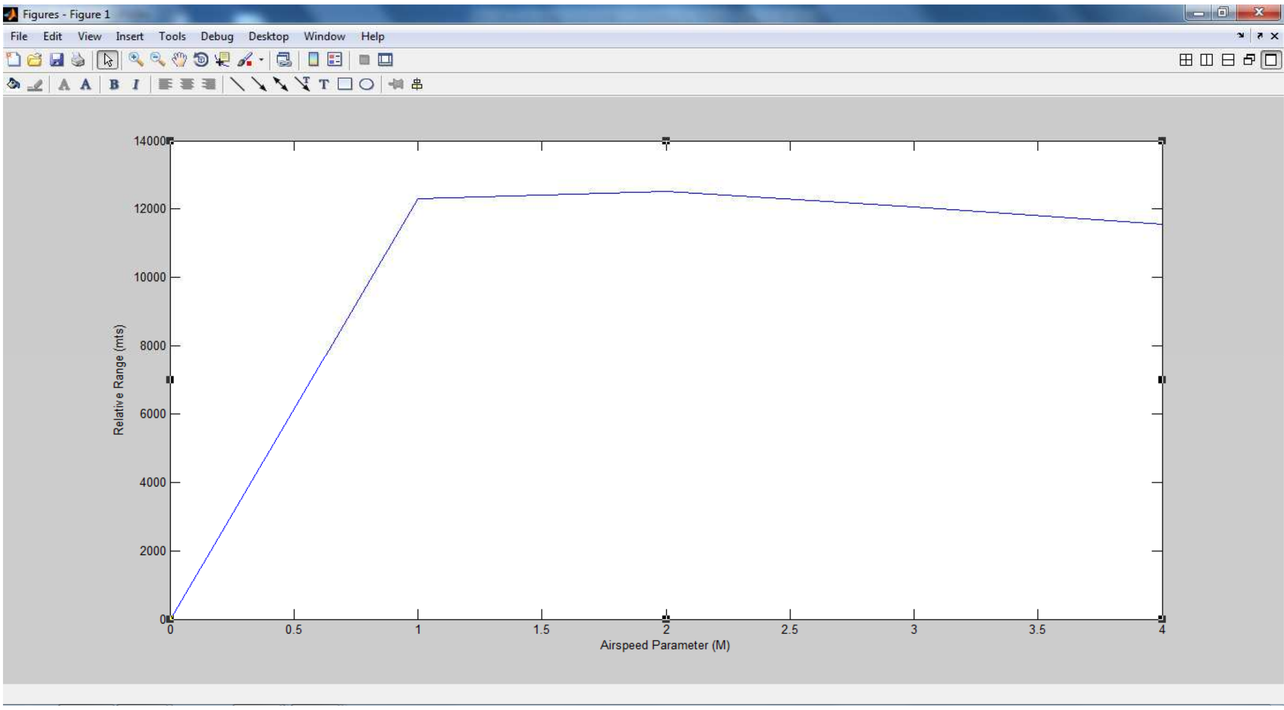


Figure 3.4: Range v/s Airspeed for K=2.7

Theoretically the graph follows the trend as shown in the figure:

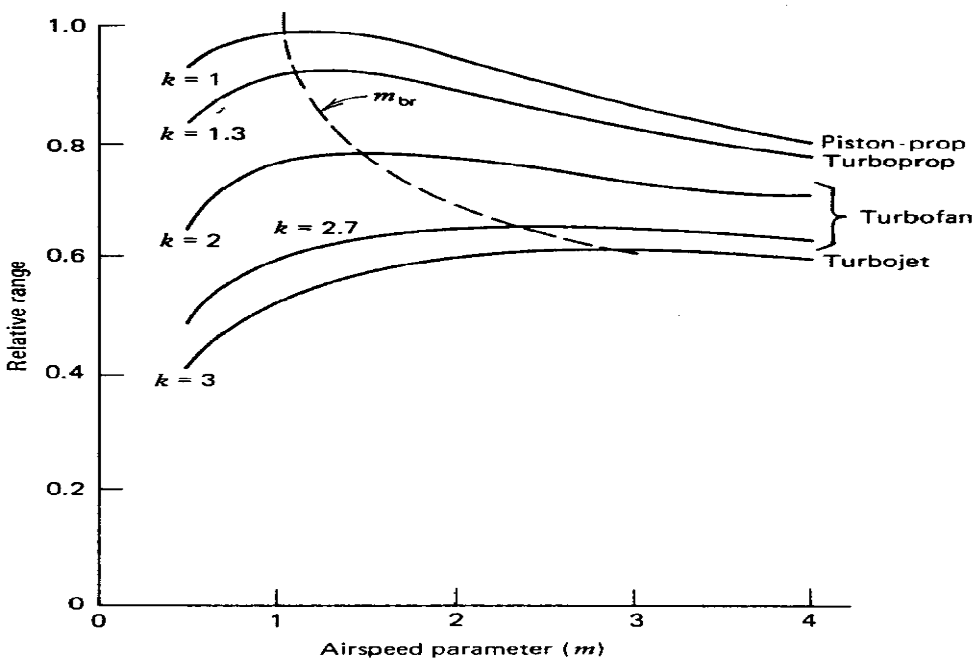


Figure 3.5: Range v/s Airspeed

3.4 Conclusion

The value of the fan contribution and in turn the bypass ratio increases as the propulsion system designator (k) increases from 2 to 2.7. Thus from the graphs we conclude:

- As the bypass ratio of a turbofan engine is increased the value of range decreases. This is so because, as the bypass ratio increases more power is consumed in driving the fan and less thrust is produced to propel the aircraft.

The air speed parameter (m) is given by

$$m = \left(\frac{V}{V_{md}} \right)^4$$

(3.2)

Keeping the value of V_{md} constant , and varying “m” leads to variation in V only. Thus from the graph one can say that:

As the velocity increases, the range increases to a maximum value, and then remains constant after that.

4. BREGUET’S EQUATION FOR EFFECT OF TSFC ON RANGE OF TURBOFAN ENGINE

Range of a jet engine is the distance transverse by an airplane on a given tank of fuel. Turbofan engine is the combination of turbojet engine and piston prop engine. Thus to determine the effects of various parameters on the range of a turbofan engine, Breguet’s equation for these two engines has been combined .The generalized Breguet’s equation has been used for showing the effect of change in thrust specific fuel consumption (TSFC) on the range of a turbofan, which is given as:

$$X=\left[\left(\frac{3-k}{2}\right)\frac{375\eta_p E}{\hat{c}}+\left(\frac{k-1}{2}\right)\frac{VE}{c}\right]\ln\left(\frac{1}{1-\zeta}\right) \qquad \textbf{(4.1)}$$

Where,

X= range

k = propulsion system designator

c= specific fuel consumption

ĉ = horse power specific fuel consumption

E= l/d ratio

V= velocity

Z = cruise fuel weight ratio

η_p = propeller efficiency

4.1 Data Assumed for the Program

k = 2

E= l/d = 16.3

Z=Zeta = 0.3

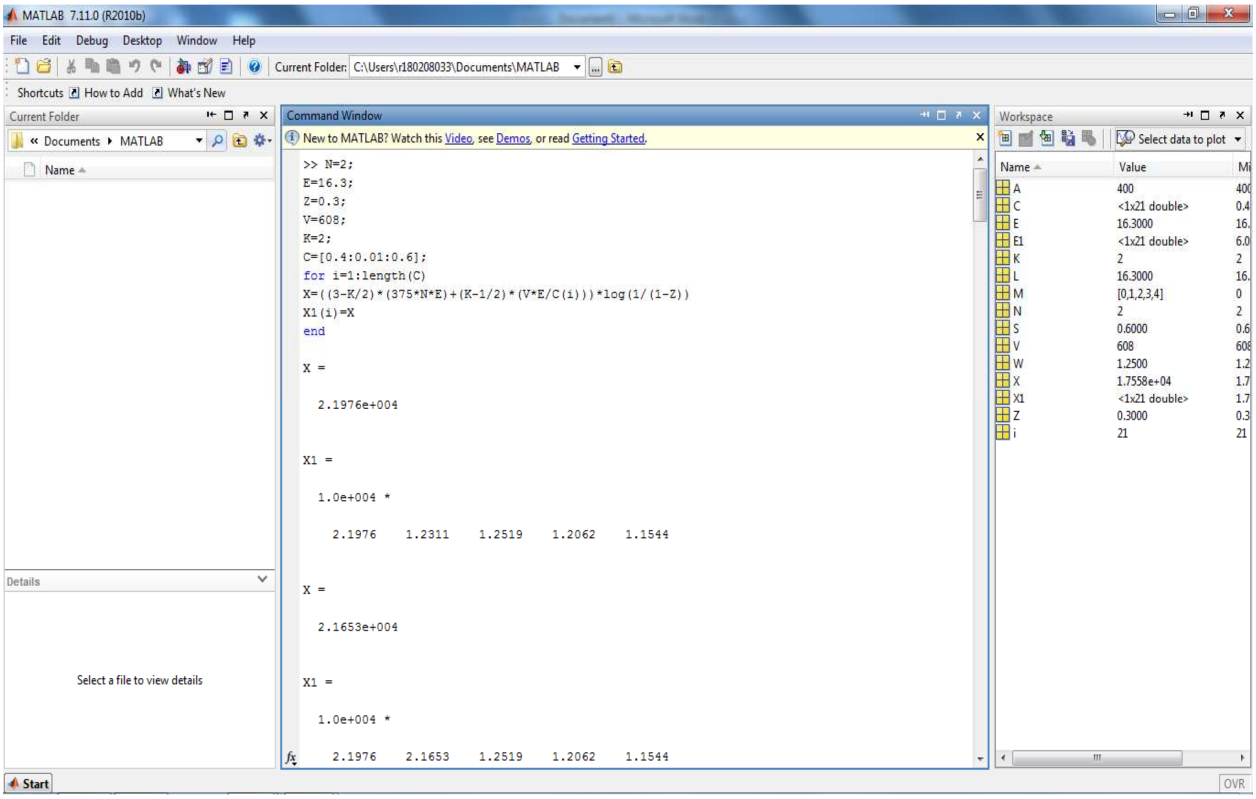
N= (η_p / ĉ) =2

V= 608 mph

4.2 Programs

```
N=2;
E=16.3;
Z=0.3;
V=608;
k =2;
C=[0.4:.01:0.6];
For i=1:length(C)
X= ((3-k/2) * (375*N) + (k-1/2) * (V*E/ C(i))) * (log(1/(1-Z)));
X1(i)=X;
end
plot (C,X1)
```

4.3 Results



```
>> N=2;
E=16.3;
Z=0.3;
V=608;
K=2;
C=[0.4:0.01:0.6];
for i=1:length(C)
X=((3-K/2)*(375*N*E)+(K-1/2)*(V*E/C(i)))*log(1/(1-Z))
X1(i)=X
end

X =

  2.1976e+004


X1 =

  1.0e+004 *

    2.1976    1.2311    1.2519    1.2062    1.1544


X =

  2.1653e+004


X1 =

  1.0e+004 *

    2.1976    2.1653    1.2519    1.2062    1.1544
```

Name	Value	Mi
A	400	400
C	<1x21 double>	0.4
E	16.3000	16.
E1	<1x21 double>	6.0
K	2	2
L	16.3000	16.
M	[0,1,2,3,4]	0
N	2	2
S	0.6000	0.6
V	608	608
W	1.2500	1.2
X	1.7558e+04	1.7
X1	<1x21 double>	1.7
Z	0.3000	0.3
i	21	21

Figure 4.1: Matlab Program for Breguet’s Equation of Range v/s TFSC

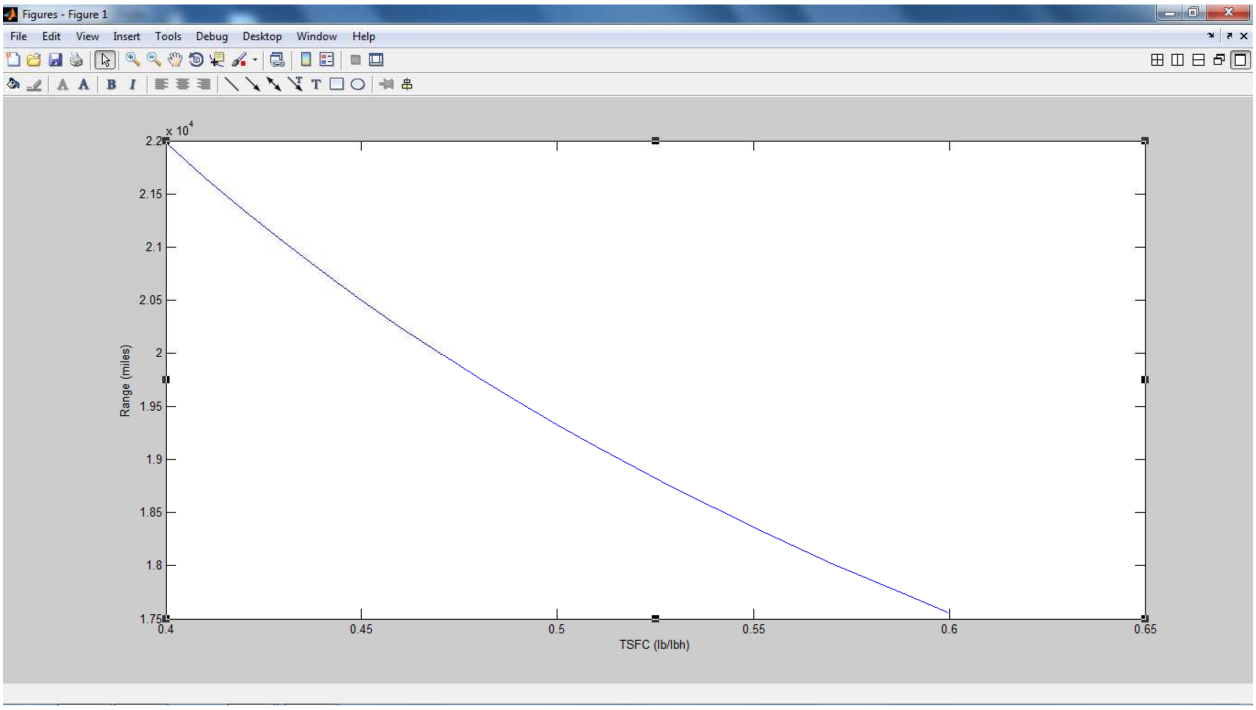


Figure 4.2: Range v/s TSFC

4.4 Conclusion

The graph shows that:
As the thrust specific fuel consumption of the turbofan engine increases, the range decreases. Thus we may say that if the rate of fuel consumption increases, then the distance travelled by the airplane with a turbofan engine decreases.

5. EQUATION FOR ENDURANCE OF TURBOFAN ENGINE

Endurance is the total time that an airplane stays in the air on a tank of fuel. One of the critical factors affecting range and endurance is the specific fuel consumption, a characteristic of the engine. For a jet engine it is defined as the weight of fuel consumed per unit thrust per unit time. Specific fuel consumption depends on the thrust produced by the engine in case of the jet engines and is thus called thrust

$$TSFC = \frac{lb\ of\ fuel}{lb\ of\ thrust} \tag{5.1}$$

Let dW be the change in weight of the airplane due to fuel consumption over a time increment dT. Then,

$$dW = -C_T \times T_A \times dt \tag{5.2}$$

where, C_T is the thrust specific fuel consumption and T_A is the thrust available .
For a steady and level flight, thrust available is equal to the thrust required.
Thus integrating from W_O to W_1, we get

$$E = (\frac{1}{C_T}) \times \frac{C_L}{C_D} \times \log\frac{W_O}{W_1} \tag{5.3}$$

Where,
W_O is the initial weight of the airplane
W_1 is the weight of the airplane after fuel consumption during time dT.

5.1 Data Assumed in the Program

$C=C_T$ = ranges between 0.4 to 0.6

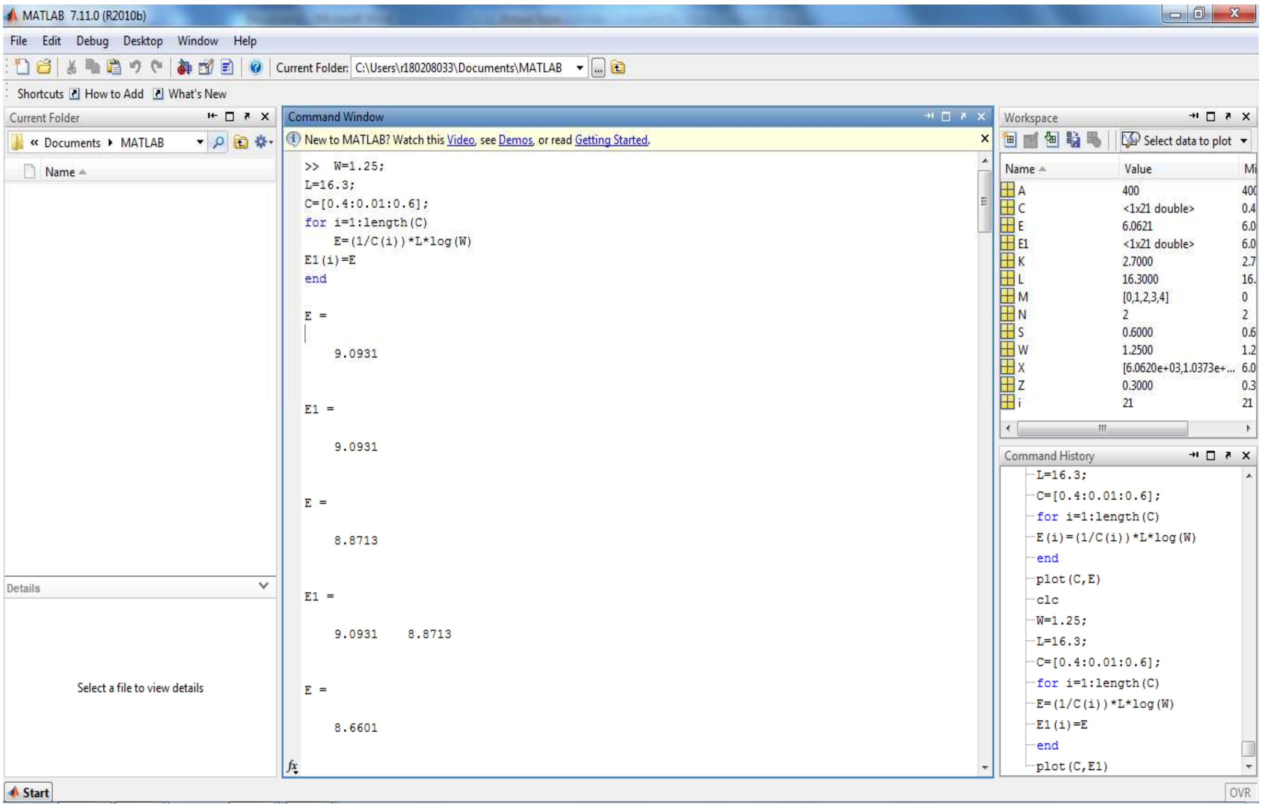
$L=(C_L/C_D) = 16.3$

$W=(W_0/W_1) = 1.25$

5.2 Program

```
W=1.25
L=16.3;
C=[0.4:0.01:0.5];
for i=1:length(C)
E=(1/C(i))*L*log(W)
E1(i)=E
end
Plot(C,E1)
```

5.3 Results



```
>>  W=1.25;
L=16.3;
C=[0.4:0.01:0.6];
for i=1:length(C)
    E=(1/C(i))*L*log(W)
E1(i)=E
end

E =

    9.0931


E1 =

    9.0931


E =

    8.8713


E1 =

    9.0931    8.8713


E =

    8.6601
```

Name	Value	Mi
A	400	400
C	<1x21 double>	0.4
E	6.0621	6.0
E1	<1x21 double>	6.0
K	2.7000	2.7
L	16.3000	16.
M	[0,1,2,3,4]	0
N	2	2
S	0.6000	0.6
W	1.2500	1.2
X	[6.0620e+03,1.0373e+...	6.0
Z	0.3000	0.3
i	21	21

```
L=16.3;
C=[0.4:0.01:0.6];
for i=1:length(C)
E(i)=(1/C(i))*L*log(W)
end
plot(C,E)
clc
W=1.25;
L=16.3;
C=[0.4:0.01:0.6];
for i=1:length(C)
E=(1/C(i))*L*log(W)
E1(i)=E
end
plot(C,E1)
```

Figure 5.1: Matlab Program for Endurance Equation

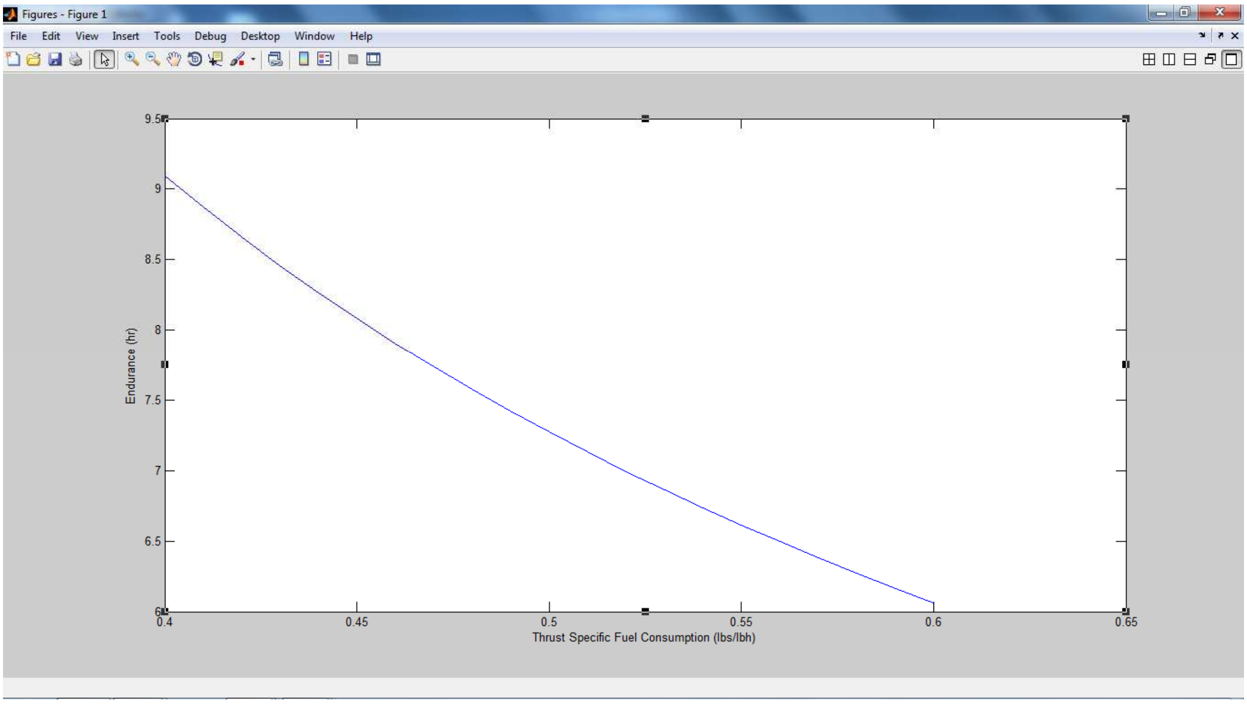


Figure 5.2: Endurance v/s TSFC

5.4 Conclusion

As the thrust specific fuel consumption of the turbofan engine increases, the endurance decreases. It shows that if the rate at which fuel is consumed increased, then the time for which an airplane with a turbofan engine can stay in air decreases.

CHAPTER THREE

INTRODUCTION

To study the flow through the engine, CFD simulations were developed. CFD simulations are developed using two software’s: GAMBIT and FLUENT.

1.1 Gambit

It is the CFD software where the model is built (designed) and developed for analysis. The model is built using the standard co-ordinate axis. Once the geometry is made it is meshed using different meshing schemes, which in turn are dependent on the shape of the model being developed. After this, various boundary conditions are set like wall, velocity_inlet, velocity_outlet, etc. along with the continuum. Thereafter, the mesh file is exported to be solved in FLUENT.

1.2 Fluent

Fluent is the software in which the developed model (in gambit) is solved and analyzed. Fluent software contains physical modeling capabilities needed to model flow, heat transfer reactions and turbulence which have many industrial applications. In fluent, all the necessary parameters are specified and the model is iterated whereby all the transport equations i.e momentum, mass and energy balance are solved across each point using various numerical methods. The flow across the engine can be analyzed from the results obtained in the form of contours, vectors and plots.

2. DEVELOPMENT OF GAMBIT MODEL

For working on the final model and performing analysis, the effect on flow conditions inside the turbofan engine was considered in two cases:

1. Low bypass turbofan engine (2:1)
2. High bypass turbofan engine (6:1)

2.1 DEVELPOMENT OF LOW BYPASS (2:1) TURBOFAN ENGINE MODEL

The first attempt to any CFD model is to try and develop a 2-D model of the same as per the given dimensions. The model failed to produce the desired results as the velocity- inlet boundary conditions and the like, could not be specified for a 2-D model. This was necessary as the primary objective of the project is to study the flow trend across the engine which is a 3-D flow.

The next approach was thus, to develop a 3-D model. This model was generated using the following steps:

STEP 1

The first step is to create an engine casing.

i) For this, select volume command button from geometry.

ii) Select cylinder from the list of geometries available:

- height= 90mm
- radius1= 6mm
- radius2= 6mm

iii) Name this entire geometry centred around z-axis as CASING.

iv) Click apply.

STEP 2

The next step is to draw an extension to the casing which technically surrounds the fan. This is done by following the given steps.

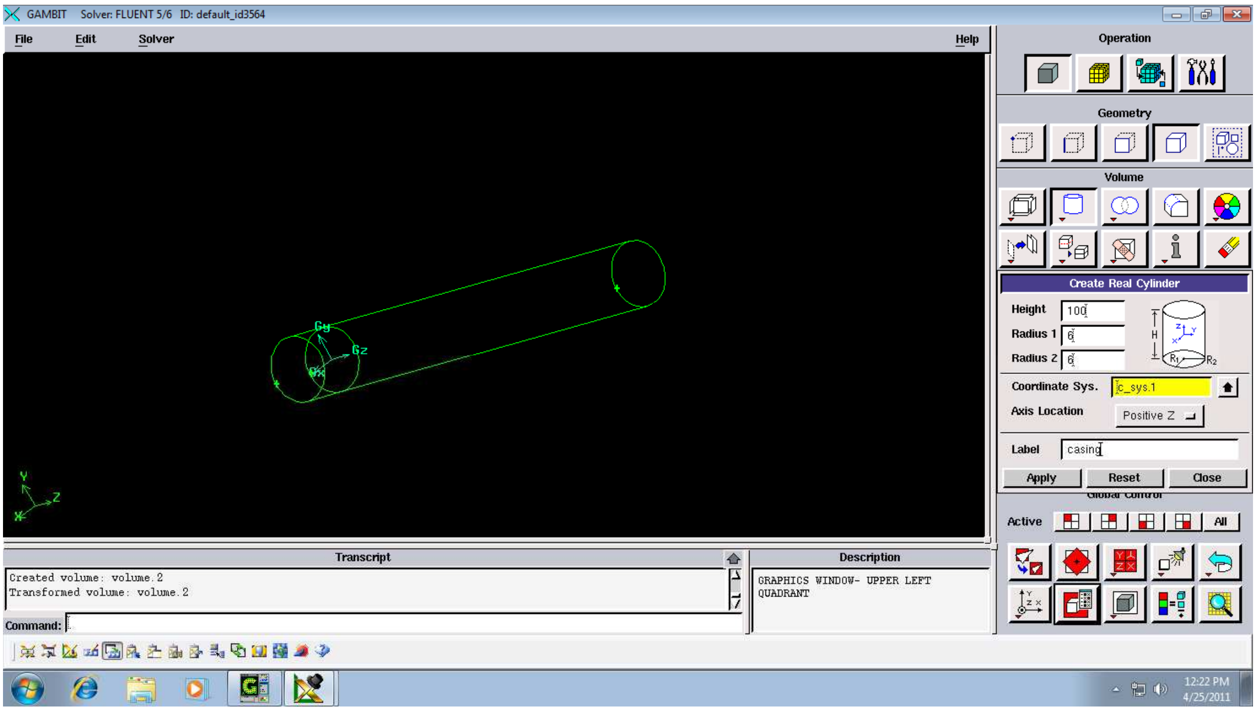
i) From the operations command button, select geometry command button. Thereafter, select volume command button.

ii) Select cylinder from the list of geometries available.

iii) Draw the cylinder in negative z direction with the following dimensions:

- height= 10mm
- radius1= 6mm
- radius2= 6mm

iv) Click apply.



Create Real Cylinder

Height 100

Radius 1 6

Radius 2 6

Coordinate Sys. c_sys.1

Axis Location Positive Z

Label casing

Apply Reset Close

Transcript

```
Created volume: volume.2
Transformed volume: volume.2
```

Command:

Description

```
GRAPHICS WINDOW- UPPER LEFT
QUADRANT
```

Figure 2.1: Step 1 and Step 2.

STEP 3

Keeping in mind, the basic geometry of a turbofan engine, the next step is to create an engine core.

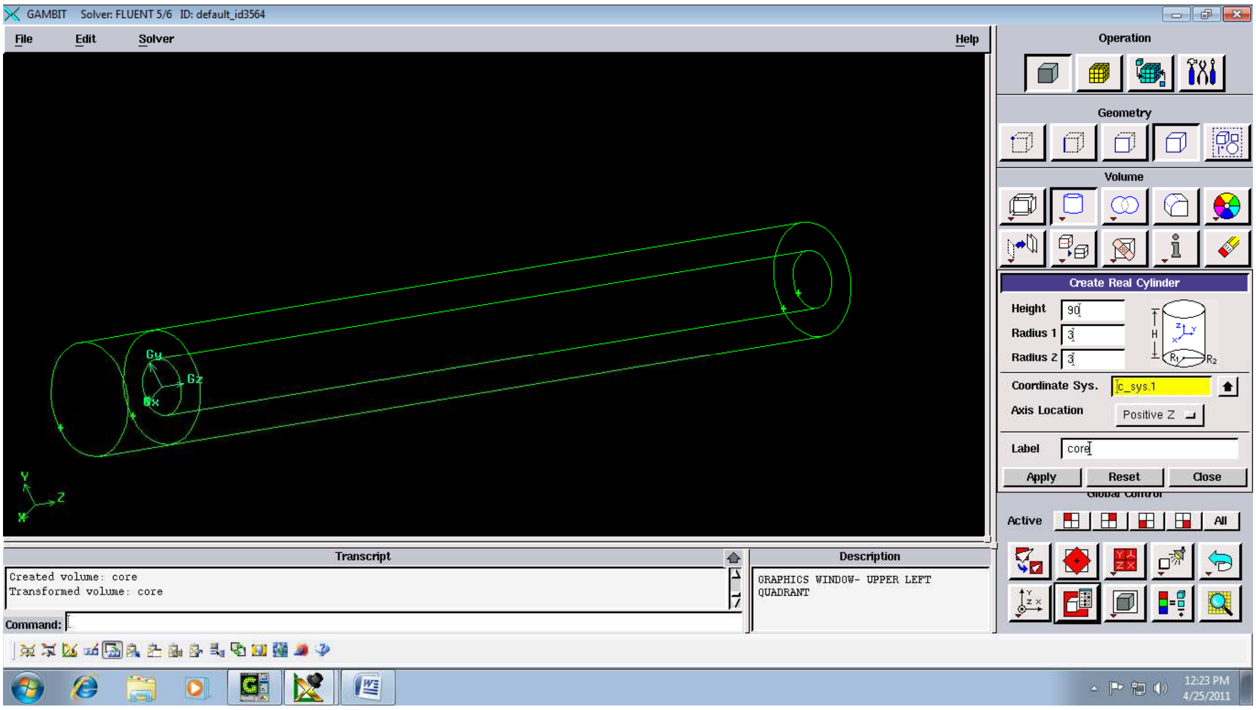
i) For this, select volume command button from geometry.

ii) Select cylinder from the list of geometries available:

- height = 90 mm
- radius1 =3 mm
- radius2 =3 mm

iii) Name this entire geometry centred around z-axis as CORE.

iv) Click apply.



Height 90

Radius 1 3

Radius 2 3

Coordinate Sys. c_sys.1

Axis Location Positive Z

Label core

Transcript

```
Created volume: core
Transformed volume: core
```

Command:

Description

```
GRAPHICS WINDOW- UPPER LEFT
QUADRANT
```

Figure 2.2: Step 3.

STEP 4

Then create a nozzle following the casing of the engine. In order to do so, following steps were followed:

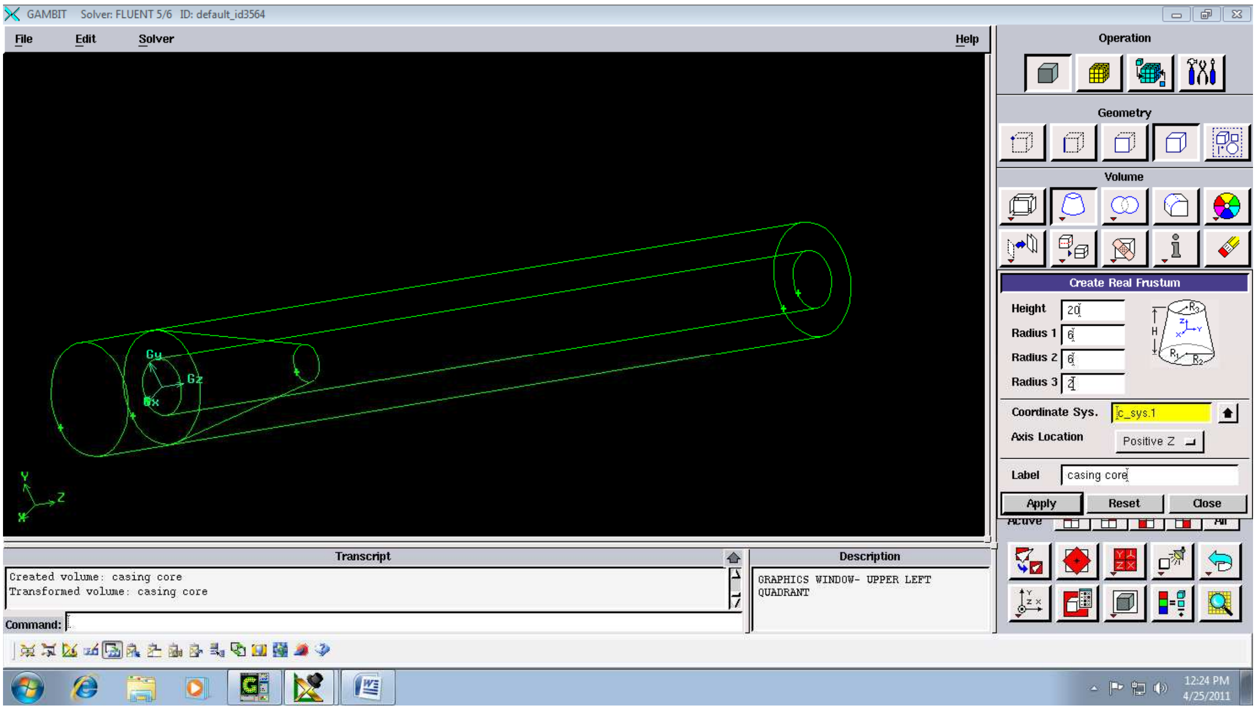
i) Select the volume command button from geometry.

ii) Select frustum from the list of geometries available:

- height= 20mm
- radius1= 6mm
- radius2= 6mm
- radius3= 2mm

iii) Name this geometry centred around z-axis as OUTER NOZZLE.

iv) Click apply.



Create Real Frustum

Height 20

Radius 1 6

Radius 2 6

Radius 3 2

Coordinate Sys. c_sys.1

Axis Location Positive Z

Label casing core

Apply Reset Close

Transcript

```
Created volume: casing core
Transformed volume: casing core
```

Command:

Description

```
GRAPHICS WINDOW- UPPER LEFT
QUADRANT
```

Figure 2.3: Step 4.

STEP 5

The next step is to create a nozzle following the core of the engine. In order to do so, following steps were followed:

i) Select the volume command button from geometry.

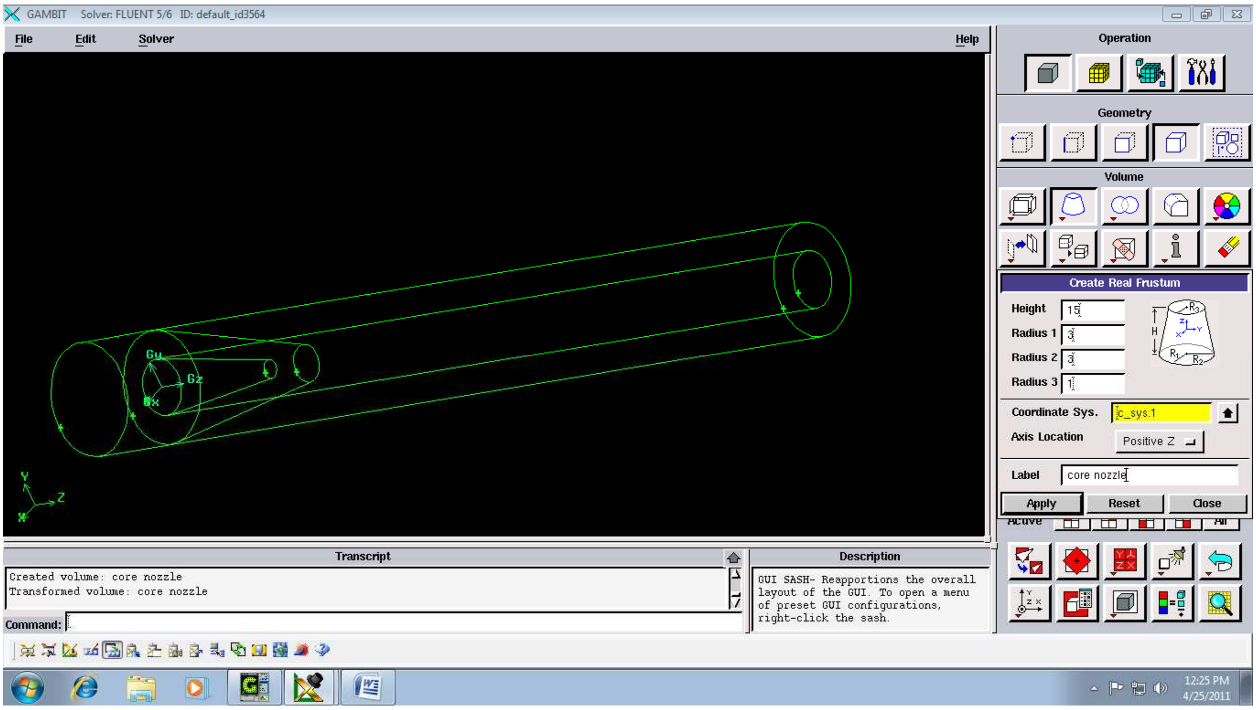
ii) Select frustum from the list of geometries available:

- height = 15mm
- radius1= 3mm
- radius2= 3mm

radius3= 1mm

iii) Name this geometry centred around z-axis as INNER NOZZLE.

iv) Click apply.



Height 15

Radius 1 3

Radius 2 3

Radius 3 1

Coordinate Sys. c_sys.1

Axis Location Positive Z

Label core nozzle

Apply Reset Close

```
Created volume: core nozzle
Transformed volume: core nozzle
```

```
GUI SASH- Reapportions the overall
layout of the GUI. To open a menu
of preset GUI configurations,
right-click the sash.
```

Figure 2.4: Step 5.

STEP 6

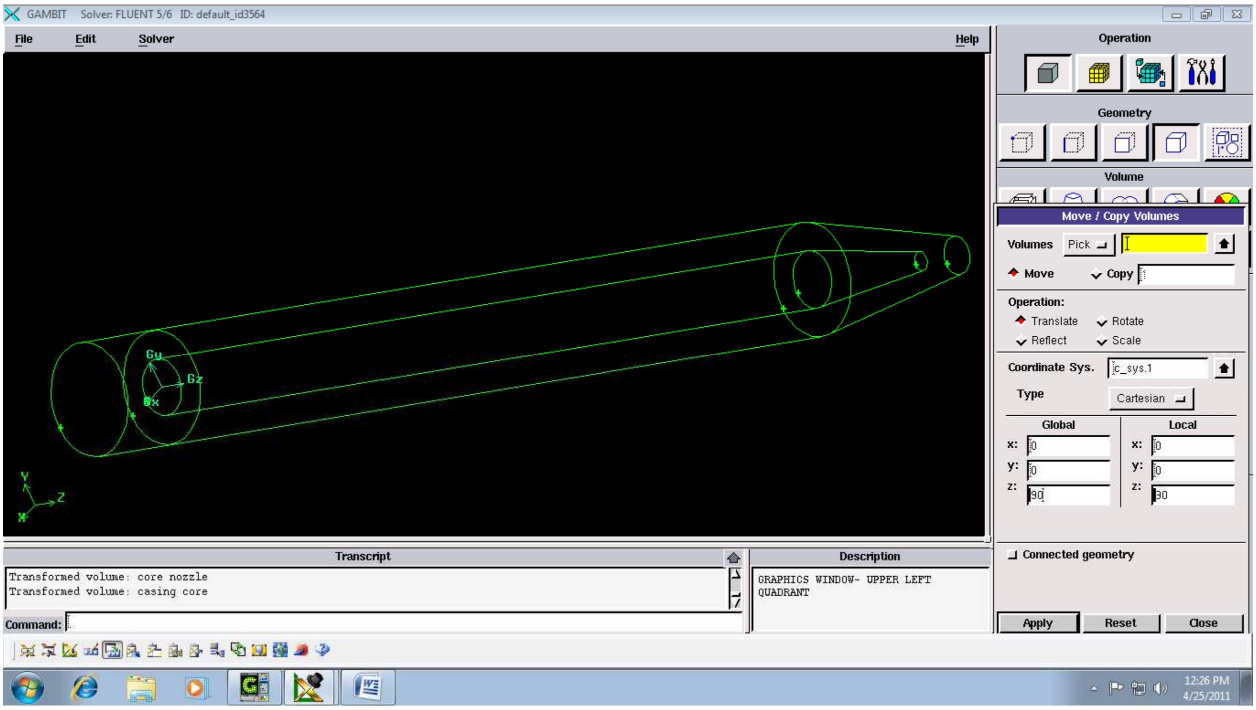
Move the geometries made in step 4 and step 5. This is done as follows:

i) From operations command button, select volume command button.

ii) Select move options.

iii) Select the nozzles made in step 4 and step 5 and move them to a distance of 90mm along positive z-axis.

iv) Click apply.



Move / Copy Volumes

Volumes: Pick

◆ Move ◇ Copy 1

Operation:
◆ Translate ◇ Rotate
◇ Reflect ◇ Scale

Coordinate Sys.: c_sys.1

Type: Cartesian

	Global	Local
x:	0	0
y:	0	0
z:	90	90

☐ Connected geometry

Apply Reset Close

```
Transformed volume: core nozzle
Transformed volume: casing core
```

```
GRAPHICS WINDOW- UPPER LEFT
QUADRANT
```

Figure 2.5: Step 6.

STEP 7

Unite the geometries by performing the following steps.

i) From the operations command button, select volume command button.

ii) Select the unite option.

iii) Pick up the following volumes: casing, extension and casing nozzle.

iv) Click apply.

Similarly, follow the same process for core volume and core nozzle to unite them.

By doing so, the volumes united become a single entity.

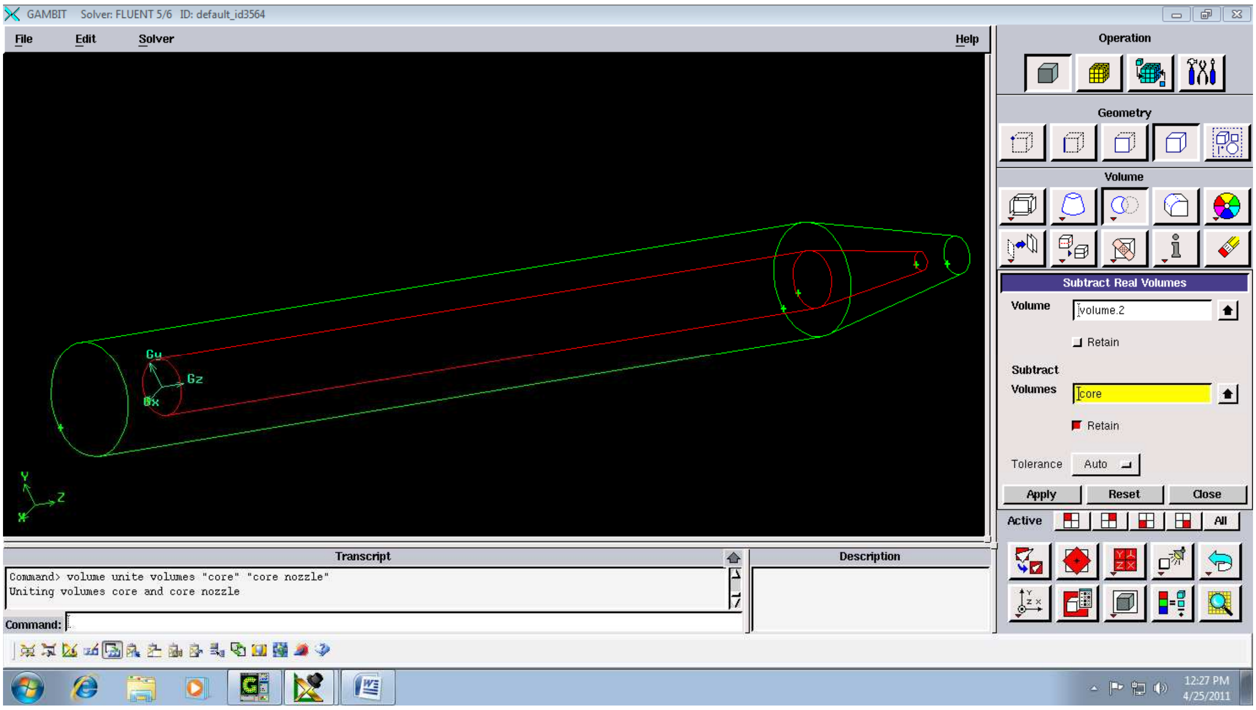
STEP 8

The next step is to subtract the core volume from the casing volume but retaining the core volume.

i) From the geometry command button, select volume. Then select subtract volume options. First, select the larger volume i.e. the casing and in subtract option, select the core volume.

ii) Select retain to retain the core volume.

iii) Click apply.



Subtract Real Volumes

Volume: volume.2

☐ Retain

Subtract Volumes: core

☑ Retain

Tolerance: Auto

```
Command> volume unite volumes "core" "core nozzle"
Uniting volumes core and core nozzle
```

Command:

Figure 2.6: Step 7 and Step 8.

STEP 9

After completion of creation of geometry, one has to specify the continuum conditions.

i) Go to operations command button, select zones and then from zones select continuum.

ii) Now select both the core and the casing and define them as fluid under continuum (because the fluid flows through them i.e this is where the fluid flow actually occurs).

STEP 10

The next step is to define the boundary conditions. To do this,

i) From operations command button, select zones. From zones, select boundaries.

ii) Now define the boundary conditions as:

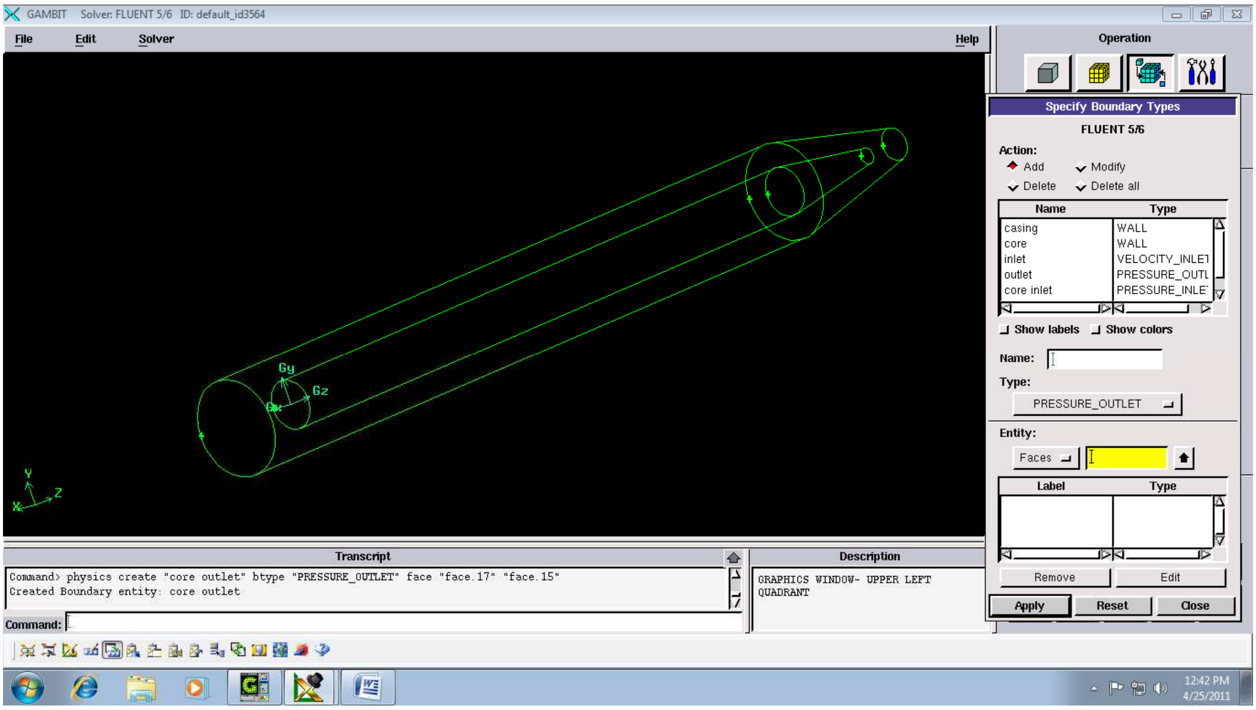
casing: wall

core: wall

casing inlet: velocity_inlet

casing outlet: pressure_outlet

- core inlet: pressure_inlet
- core outlet: pressure_outlet



```
Command> physics create "core outlet" btype "PRESSURE_OUTLET" face "face.17" "face.15"
Created Boundary entity: core outlet
```

GRAPHICS WINDOW- UPPER LEFT QUADRANT

Action: ● Add ○ Modify ○ Delete ○ Delete all

Name	Type
casing	WALL
core	WALL
inlet	VELOCITY_INLET
outlet	PRESSURE_OUTL
core inlet	PRESSURE_INLE

☐ Show labels ☐ Show colors

Name:

Type: PRESSURE_OUTLET

Entity: Faces

Label	Type

Figure 2.7: Step 9 and Step 10.

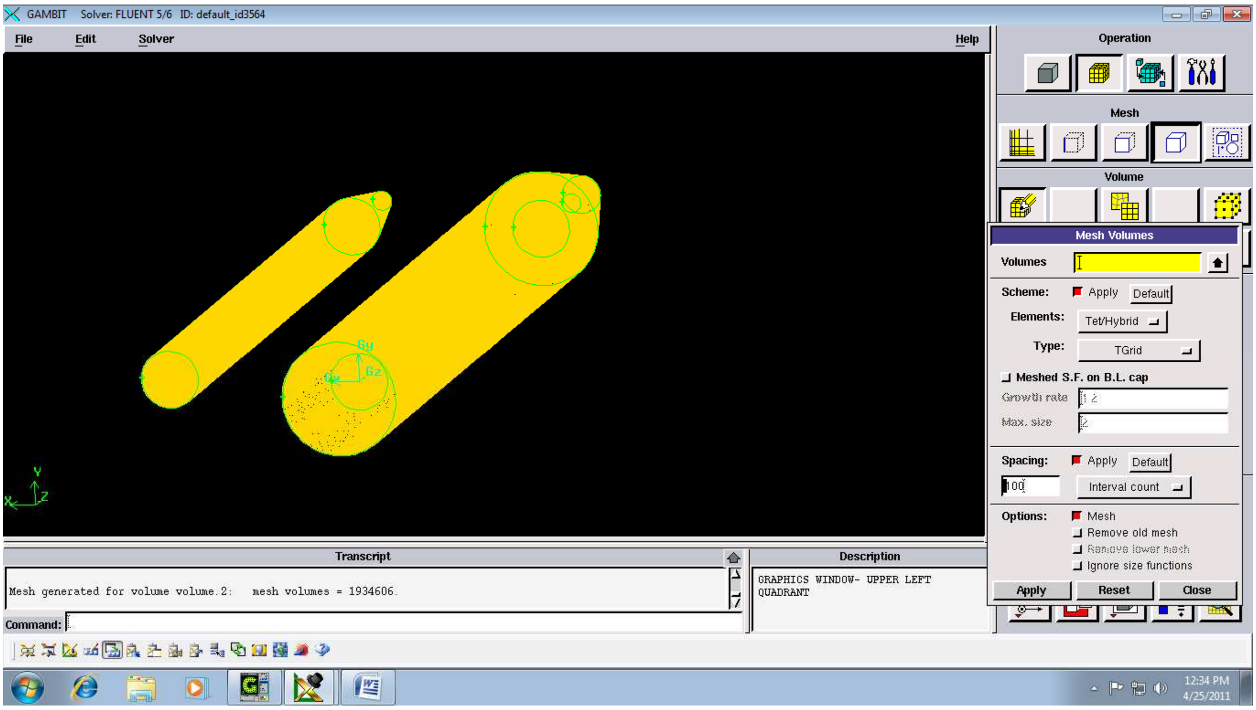
STEP 11

The final step is to mesh the geometry.

i) From operations command button, select mesh. Select all the volumes one by one for meshing. Change the interval size to interval count and take it equal to 100.

ii) In meshing type, select tet/hyb.

iii) Once the meshing is done, save and export the mesh for analysis in Fluent.



Scheme: ☑ Apply Default
Elements: Tet/Hybrid
Type: TGrid
☐ Meshed S.F. on B.L. cap
Growth rate 1.2
Max. size 2
Spacing: ☑ Apply Default
100 Interval count
Options: ☑ Mesh
☐ Remove old mesh
☐ Remove lower mesh
☐ Ignore size functions

```
Mesh generated for volume volume.2:   mesh volumes = 1934606.
```

```
GRAPHICS WINDOW- UPPER LEFT
QUADRANT
```

Figure 2.8: Step 11.

2.2 DEVELOPMENT OF HIGH BYPASS (6:1) TURBOFAN ENGINE MODEL

Following the procedure described above, similar model has been developed for a high bypass turbofan engine using the following specifications.

List of specifications for the high bypass turbofan engine:

CORE:

- Height= 90mm
- Radius1= 3mm
- Radius2= 3mm

INNER NOZZLE

- Height= 15mm
- Radius1= 3mm
- Radius2= 3mm
- Radius3= 1mm

CASING

- Height= 90mm
- Radius1= 18mm
- Radius2= 18mm

OUTER NOZZLE

- Height= 20mm
- Radius1= 18mm
- Radius2= 18mm
- Radius3= 6mm

3. ANALYSIS OF TURBOFAN ENGINE IN FLUENT

Before starting analysis in fluent, the complete grid that was meshed in gambit is displayed in fluent with all necessary boundary conditions.

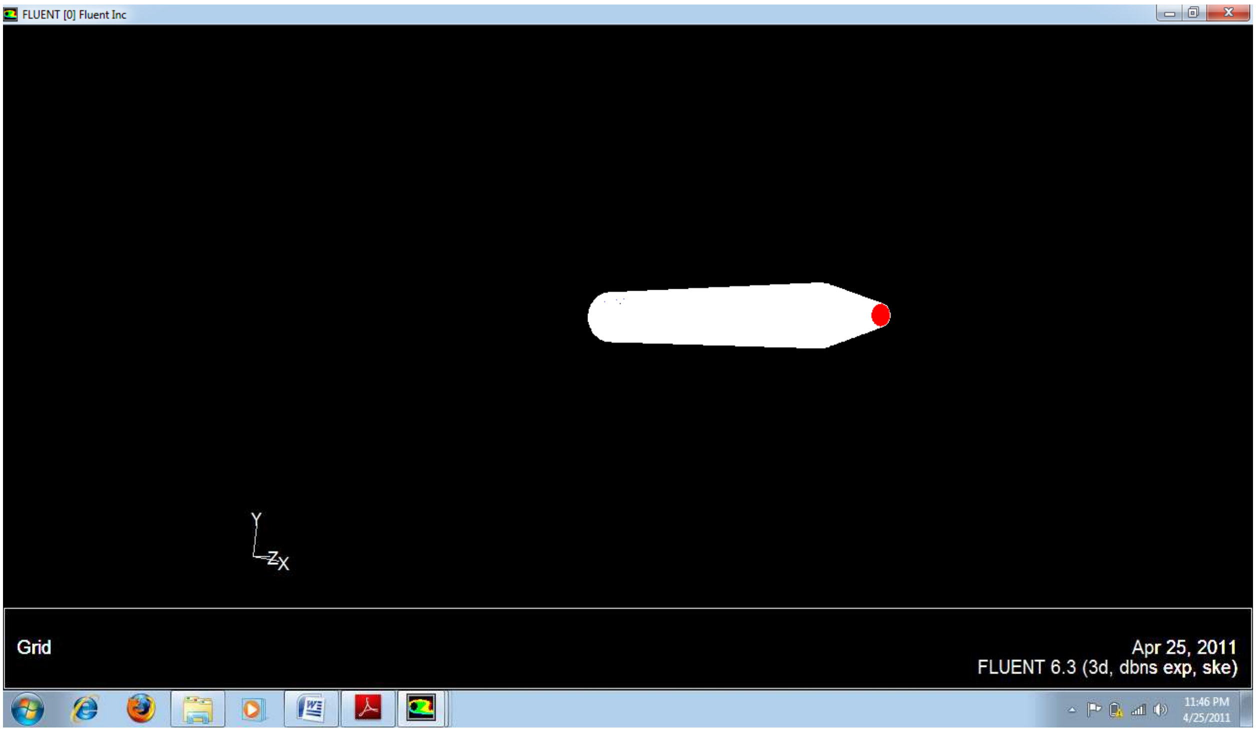


Figure 3.1: Grid for low bypass turbofan engine.

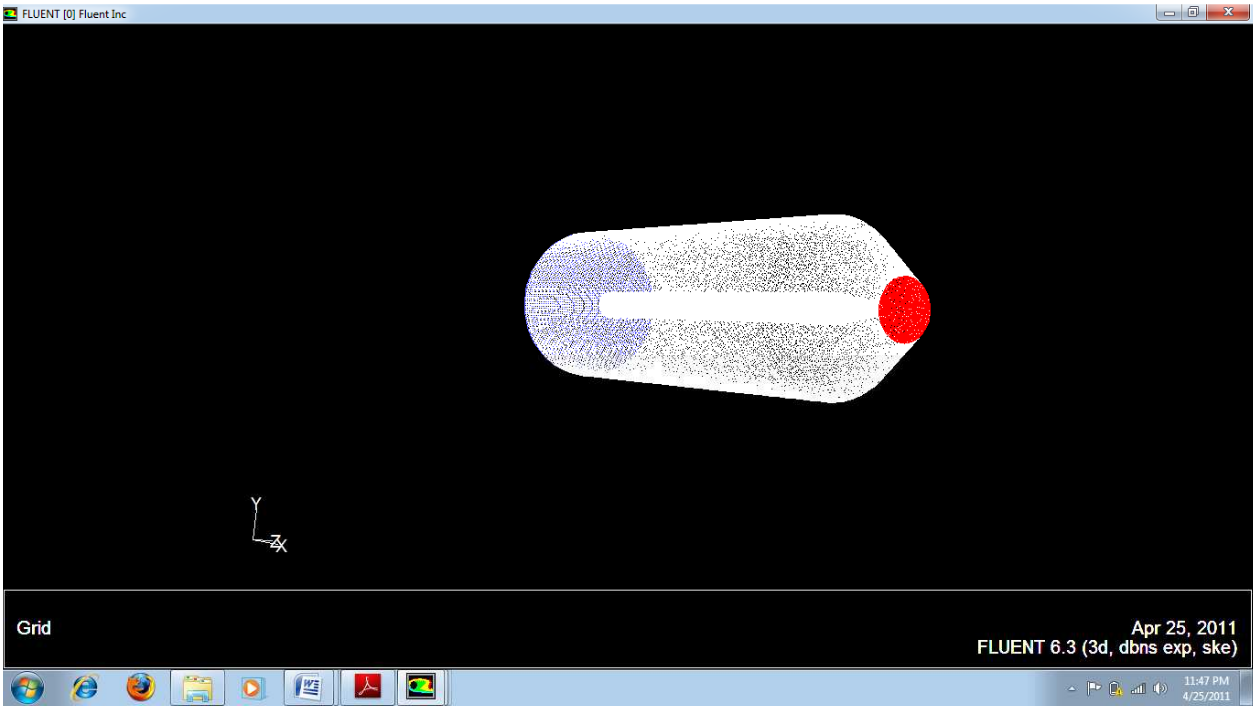


Figure 3.2: Grid for high bypass turbofan engine.

For analysis in fluent, since the flow is governed by low Reynold’s number i.e towards the low subsonic range, density based solver was chosen in order to increase the accuracy with the available mesh. From the list of materials available in the fluent database, the fluid passing through the engine was selected to be air. For the engine casing and core assembly, steel was selected because it can withstand centrifugal and thermal stresses.

Practically, the fluid is in motion and the casing of the engine is stationary. But for simplicity, motion was imparted to the casing of the engine with the fluid remaining stationary. Therefore, the outer casing wall was rotated at a speed of 15 rad/s. An initial flow velocity of 1000m/s was imparted to the fluid (air). The core of the engine remains stationary.An initial pressure of 3 atm was set in operating conditions.

In boundary conditions in fluent, convection was taken into consideration as heat is transferred from the core to the casing through air as a medium. The casing was set at a temperature of 300K and core at a temperature of 1073K as the core is always hotter than the casing.

About 4000 iterations were performed for the low bypass turbofan engine and about 1000 iterations for the high bypass turbofan engine.

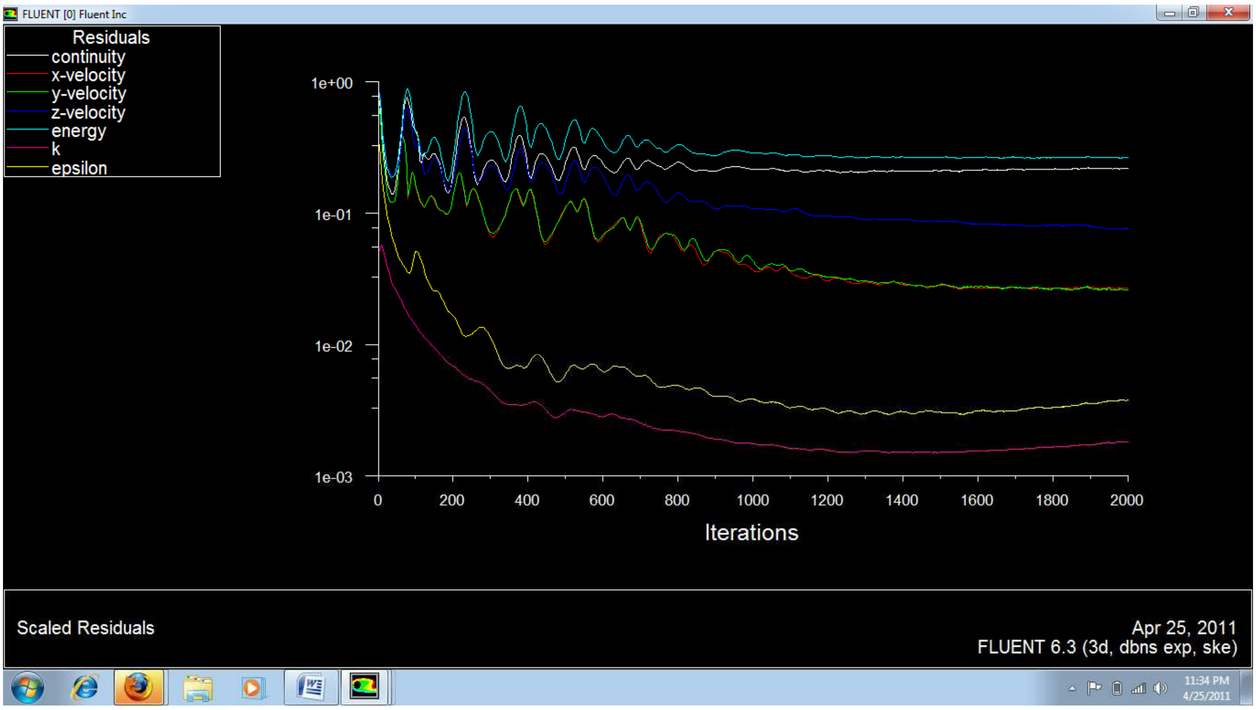


Figure 3.3: Error residuals plot for low bypass turbofan engine.

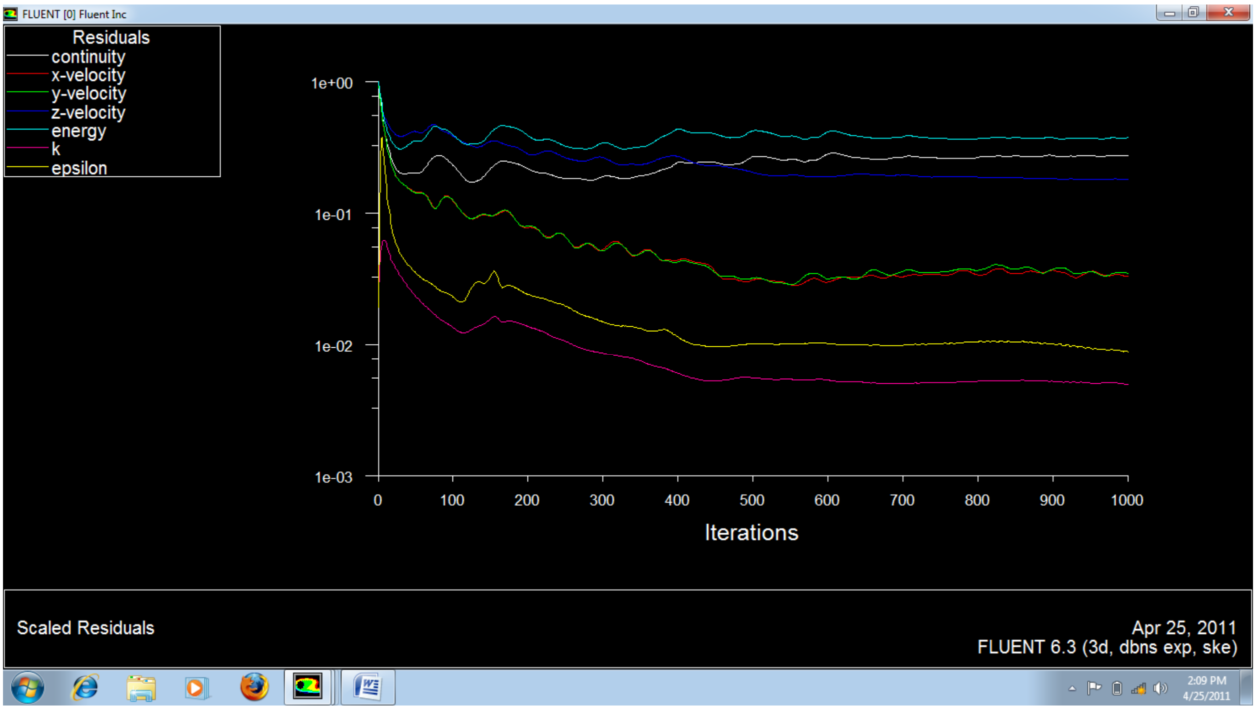


Figure 3.4: Error residuals plot for high bypass turbofan engine.

After these iterations, the results were analyzed and a comparison between the high bypass and low bypass turbofan engines was made. This is evident from some contours obtained from the solution shown in the following figures.

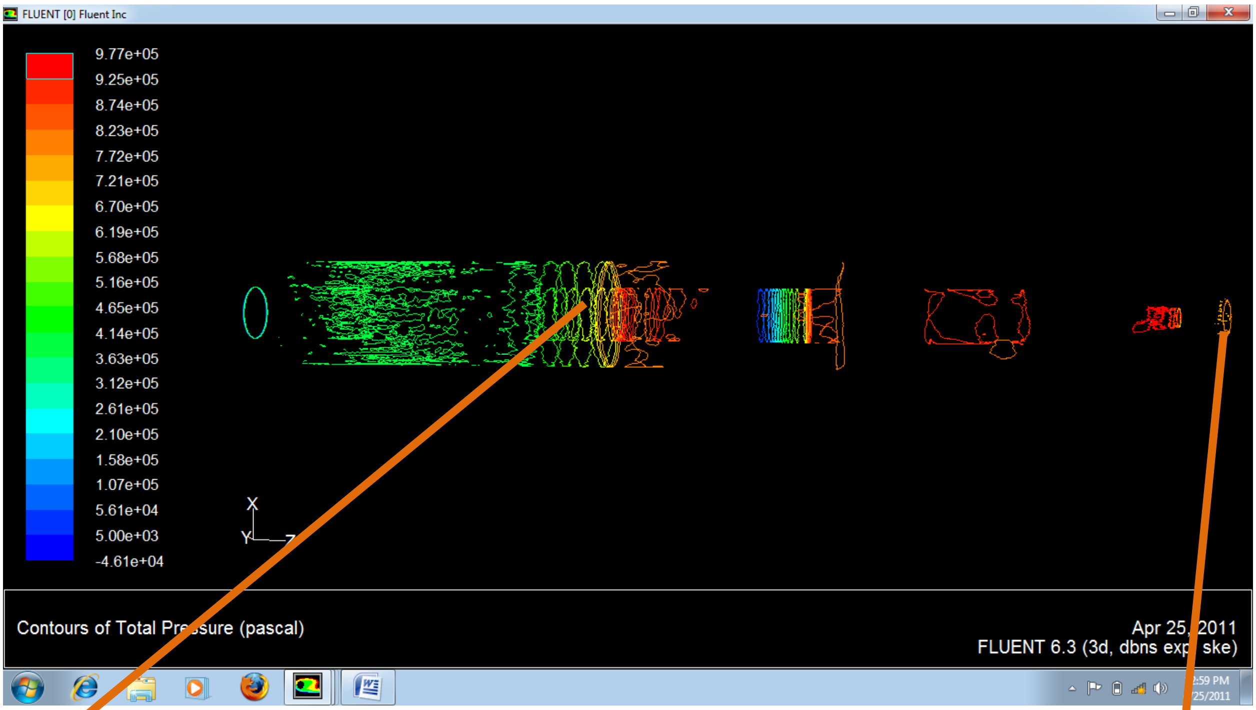


Figure 3.5: Total pressure contours for low bypass turbofan engine.

The total pressure is in a lower

The total pressure is in a higher

The pressure is lower in lower in the low bypass turbofan

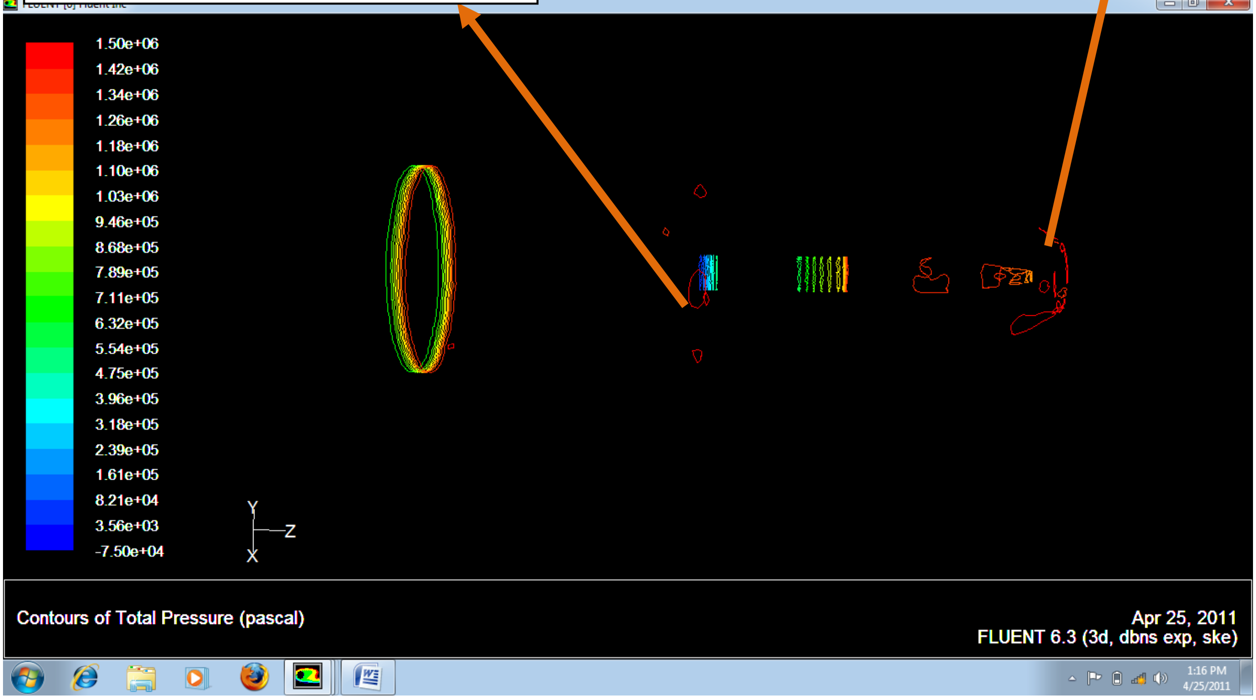


Figure 3.6: Total pressure contours of high bypass turbofan engine.

3.1CONCLUSIONS DRAWN FROM PRESSURE CONTOURS

From the figure and figure contours, it is observed that the value of pressure is higher in case of high bypass turbofan engines as compared to the low bypass turbofan engine at the nozzle outlet (exhaust). Since pressure is directly proportional to the mass of fluid flowing through the engine, we can say that the mass of fluid accelerated by the fan is higher in case of a high bypass turbofan engine resulting in higher thrust.

The kinetic energy of the fluid is converted into the pressure energy in a turbofan engine. As observed from the figure figure, the pressure energy at the end of the nozzle is lower in case of a low bypass turbofan engine and thus, the kinetic energy and hence, the velocity (exhaust) is higher than in a high bypass turbofan engine. Therefore, it is concluded that a high bypass turbofan engine produces a lower exhaust velocity.

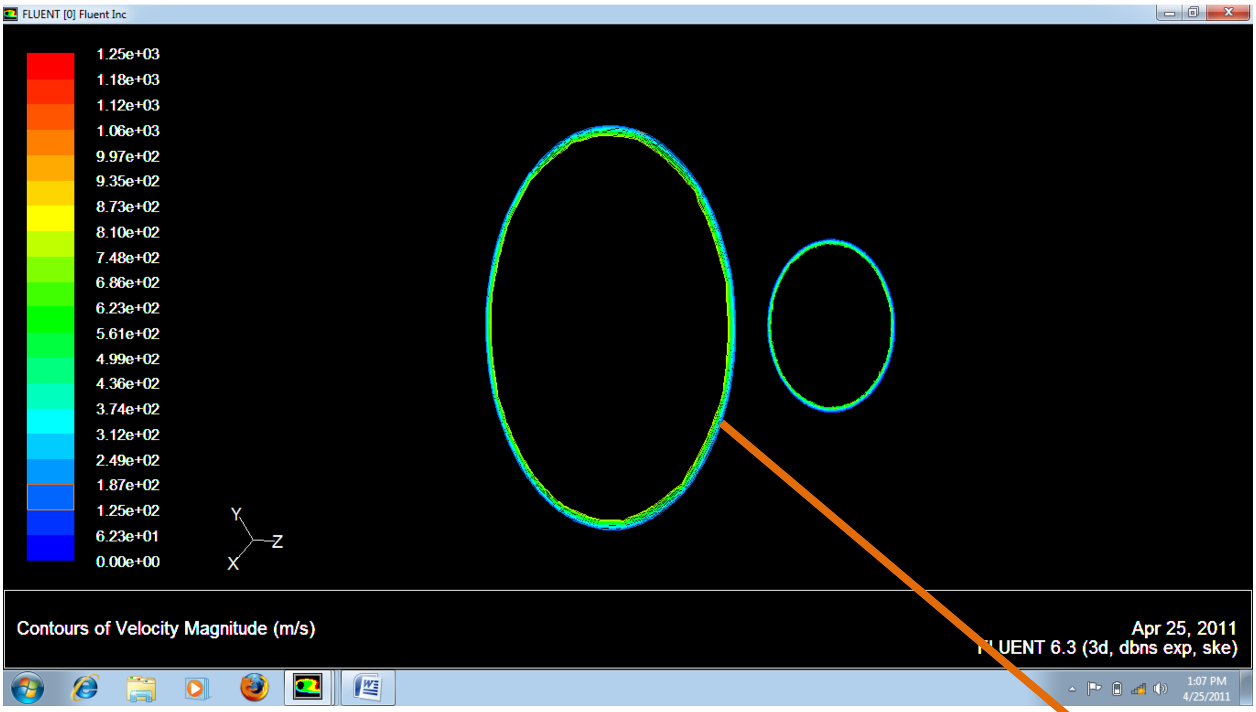


Figure 3.7: Inlet velocity contours for low bypass turbofan engine.

The flow velocity at inlet is in a lower range.

The flow velocity at the inlet is in a higher

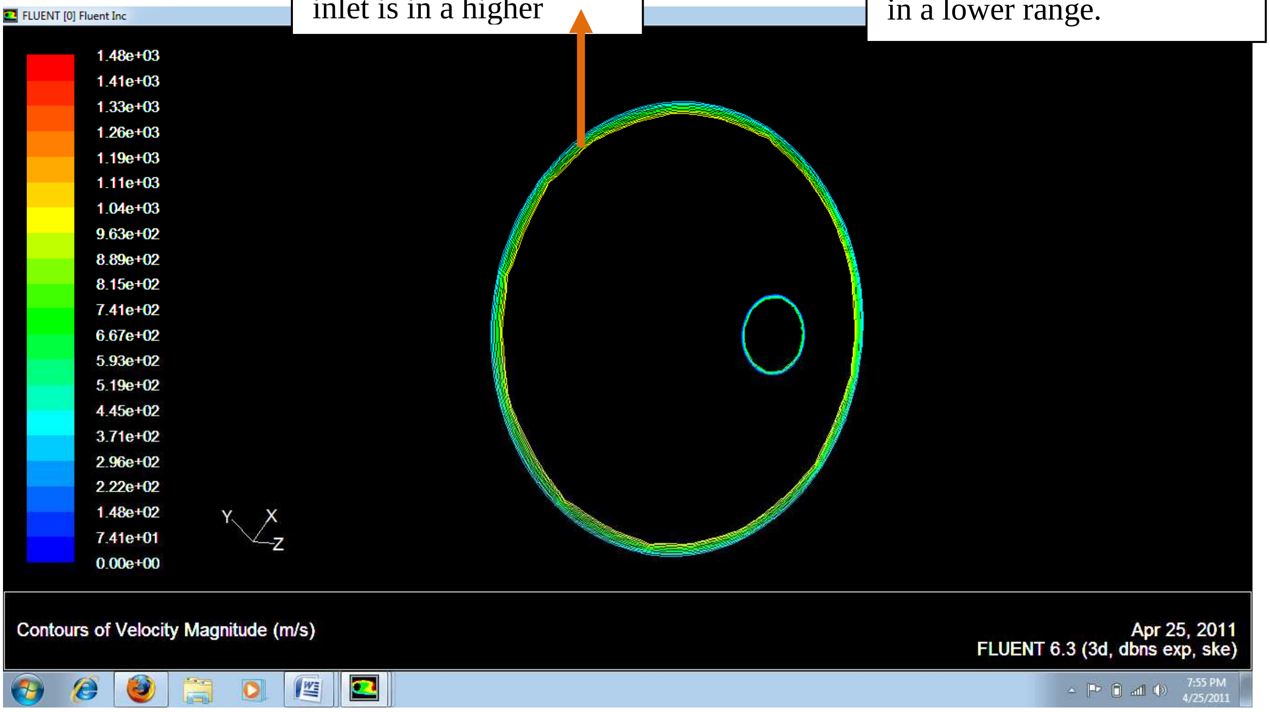


Figure 3.8: Inlet velocity contours for high bypass turbofan engine.

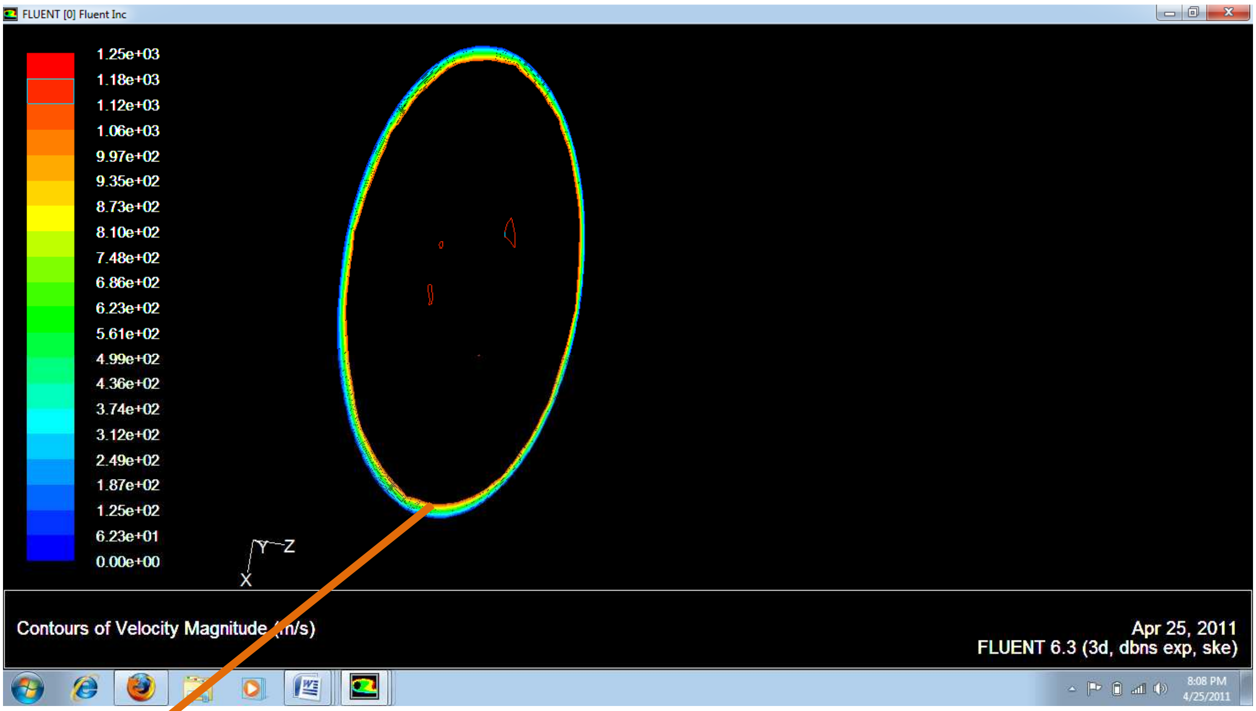


Figure 3.9: Outlet velocity contours for low bypass turbofan engine.

The flow velocity is in a higher range.

The flow velocity is in a lower range.

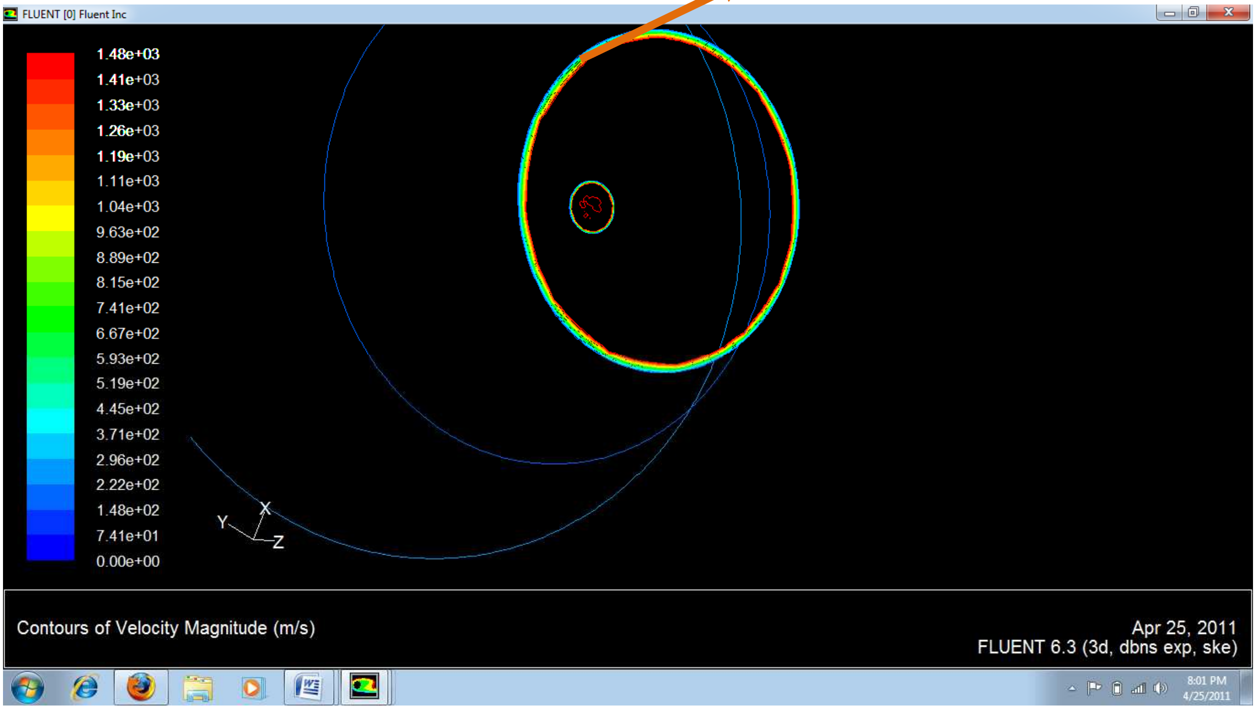


Figure 3.10: Outlet velocity contours for a high bypass turbofan engine.

3.2 CONCLUSIONS DRAWN FROM THE VELOCITY CONTOURS

The thrust of a turbofan engine is the sum of the jet thrust and the thrust produced by the fan

$$F = \left(\dot{m}_f v_f - \dot{m}_f v_0\right) + (\dot{m}_e v_e - \dot{m}_c v_0) \qquad \textbf{(3.1)}$$

As seen from figure figure figure figure, the velocity at the inlet and outlet of the core is almost same for the high and low bypass engines, whereas the inlet velocity of the fan is higher in case of a high bypass turbofan engine. Also, though the velocity at the exit is lower in case of the high bypass turbofan engine, the difference between the inlet and exit velocities of the fan in a high bypass turbofan engine is higher. Thus the thrust of the fan is higher in the case of a high bypass turbofan engine and so is the net thrust.

The propulsive efficiency of a turbofan engine is given by:

$$\eta = \frac{2}{1+\frac{c}{v}} \qquad \textbf{(3.2)}$$

Where ‘c’ is the exhaust velocity and ‘v’ is the velocity of the air vehicle. As seen from the velocity contours at the exit of the engine, the exhaust velocity is low in case of high bypass turbofan engine as compared to the low bypass turbofan engine. Thus, propulsive efficiency of a high bypass turbofan engine is higher than a low bypass turbofan engine.

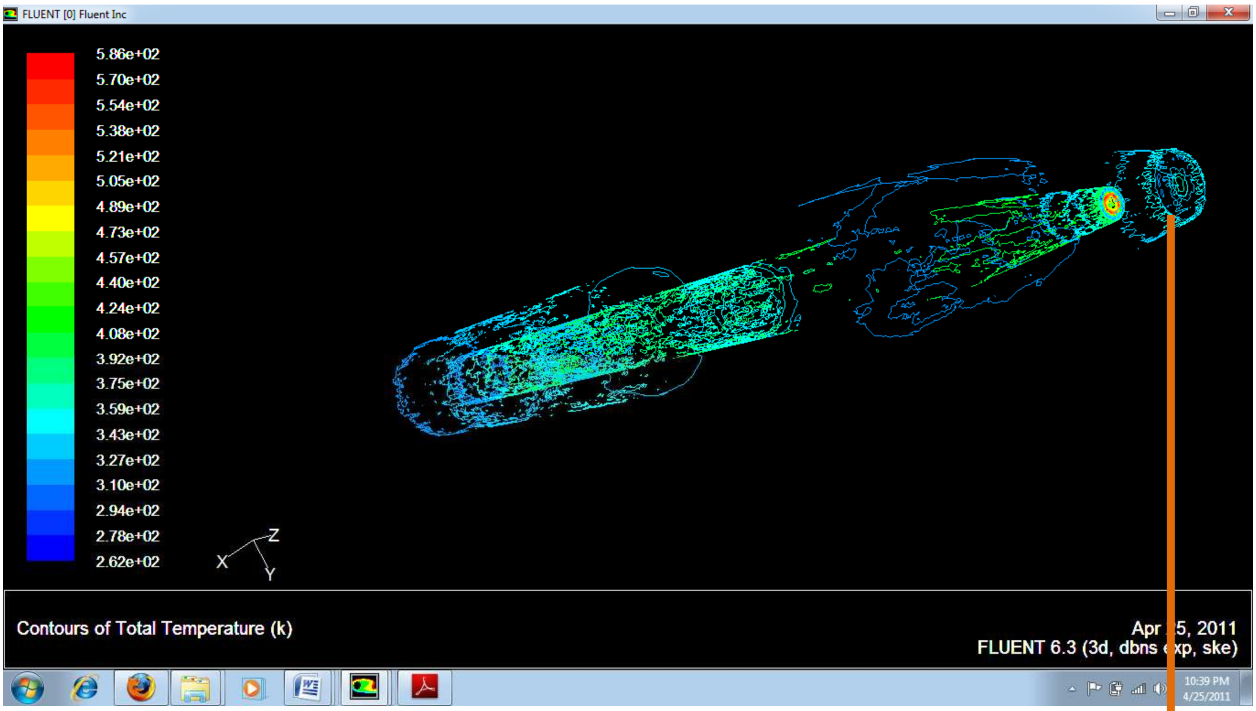


Figure 3.11: Temperature contours for a low bypass turbofan engine.

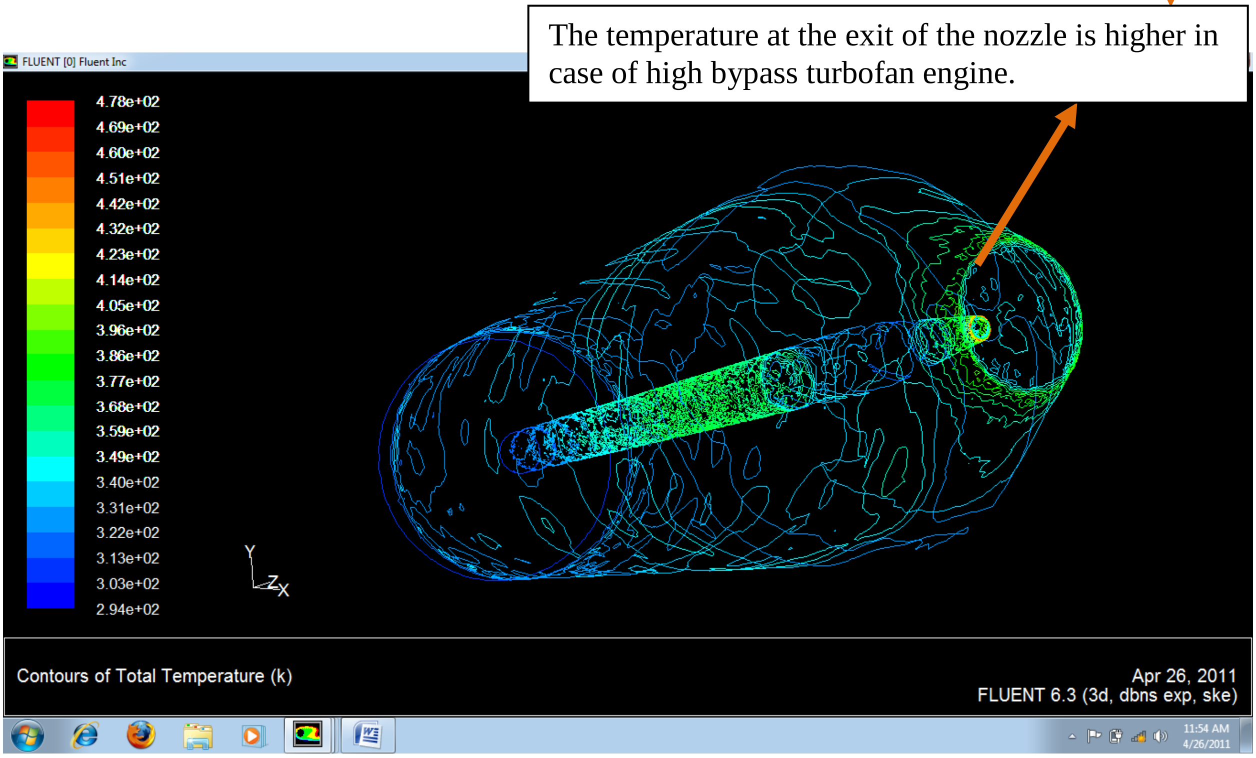

The temperature at the exit of the nozzle is higher in case of high bypass turbofan engine.

Figure 3.12: Temperature contours for a high bypass turbofan engine.

3.3CONCUSIONS DRAWN FROM THE TEMPERATURE CONTOURS

From the figure figure it is observed that temperature at the exit of the nozzle in case of a high bypass turbofan engine is higher.

One of the major functions of an exhaust nozzle is to convert the gas thermal energy into kinetic energy. Work done by the nozzle and nozzle efficiency depend on the temperatures at the exit of the turbine and that at the exit of the nozzle.

$$\eta_{noz} = \frac{h_{04}-h_{05}}{h_{04}-h_{05}^{'}} \qquad \textbf{(3.3)}$$

h_{04} and h_{05} , denote the enthalpies at the exit of turbine and nozzle respectively.

Higher the temperature difference higher will be the work done. Thus, greater thrust is produced by a high bypass turbofan engine.

CHAPTER FOUR

INTRODUCTION

A turbofan engine is an internal combustion gas turbine engine. Like most of the propulsive systems, it produces thrust by accelerating a mass of gas through it. The main components of the engine are a fan, a compressor, a combustion chamber, a turbine and a nozzle. Air is taken in by the fan which is then compressed in the compressor and heated in the combustion chamber. The turbine expands the heated and pressurized gas to obtain power. This power is used to drive the compressor. The exhaust gases leave the nozzle with a higher velocity thus giving a thrust to the engine.

The turbofan engine differs from the other gas turbine engines because of the presence of a fan mounted inside the casing. Due to this arrangement, some of air bypasses the engine core and just flows across the fan. Since this mass of air has a higher velocity while leaving the engine through the nozzle, it contributes in generating thrust. Thus a turbofan engine produces more thrust for almost same amount of fuel. Ratio of mass of air that bypasses the engine to mass of air that passes through the core is called the bypass ratio.

1.1 Material Used

Wood: To construct the shaft.

Aluminium sheets: To construct rotor and stator blades.

Cardboard: To show the combustion chamber.

Plastic sheets: To show the casing.

2.VARIOUS PARTS OF THE SCALE MODEL

2.1 Shaft

The shaft of the engine has been made out of wood. Its dimensions are as follows:

Diameter= 2.5 cm, Length= 45 cm

Figure 1.1: Shaft of scale model.

2.2 Compressor

The model makes use of an axial compressor. An axial compressor consists of rotating parts called rotors and stationary parts called stators. Rotors are attached to the central shaft rotating at high speed, while the stators remain fixed. The rotor and stator blades have been made out of aluminium sheets with the following dimensions:

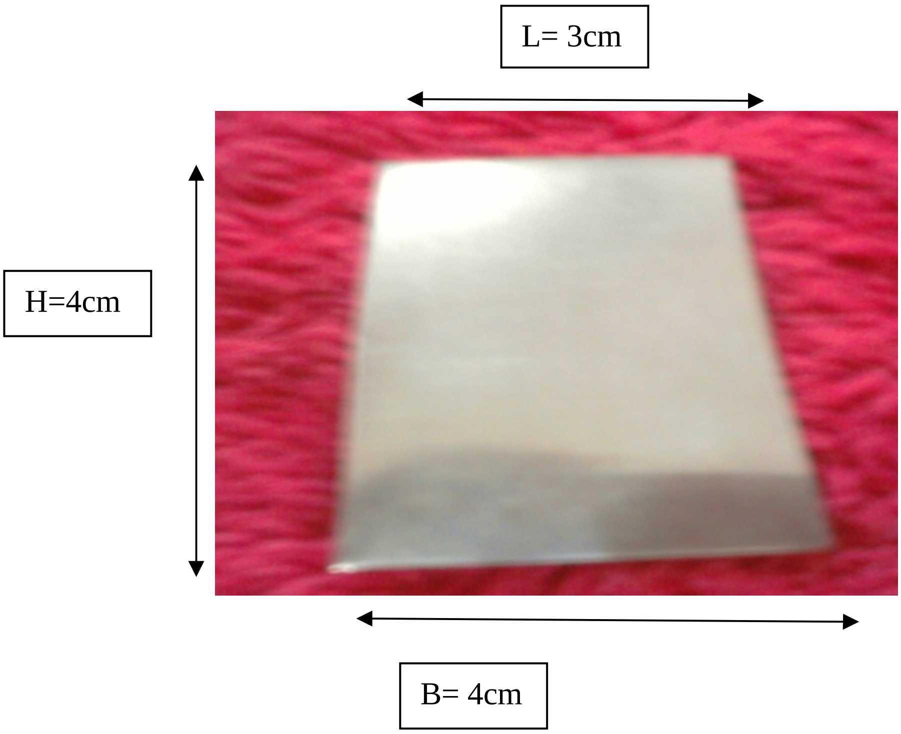


Figure 1.2: Compressor Blade of the scale model.

2.3 Combustion Chamber

The combustion chamber has been made out of cardboard.

2.4 Turbine

A turbine, just like a compressor consists of rotors and stators. The stators prevent the flow from spiraling. A single turbine stage can be used to drive multiple compressor stages effectively. It has the same dimensions as rotor and stator blades of the compressors shown above in Figure 1.2.

2.5 Nozzle

After the gases leave the turbine they expand further in the exhaust nozzle and are ejected into the atmosphere with a velocity greater than the flight velocity, thereby, producing thrust for propulsion. The model incorporates the use of a convergent nozzle.

2.6 Fan

The blades of the fan of the turbofan engine are made out of aluminium sheets. The dimensions of the same are as follows:

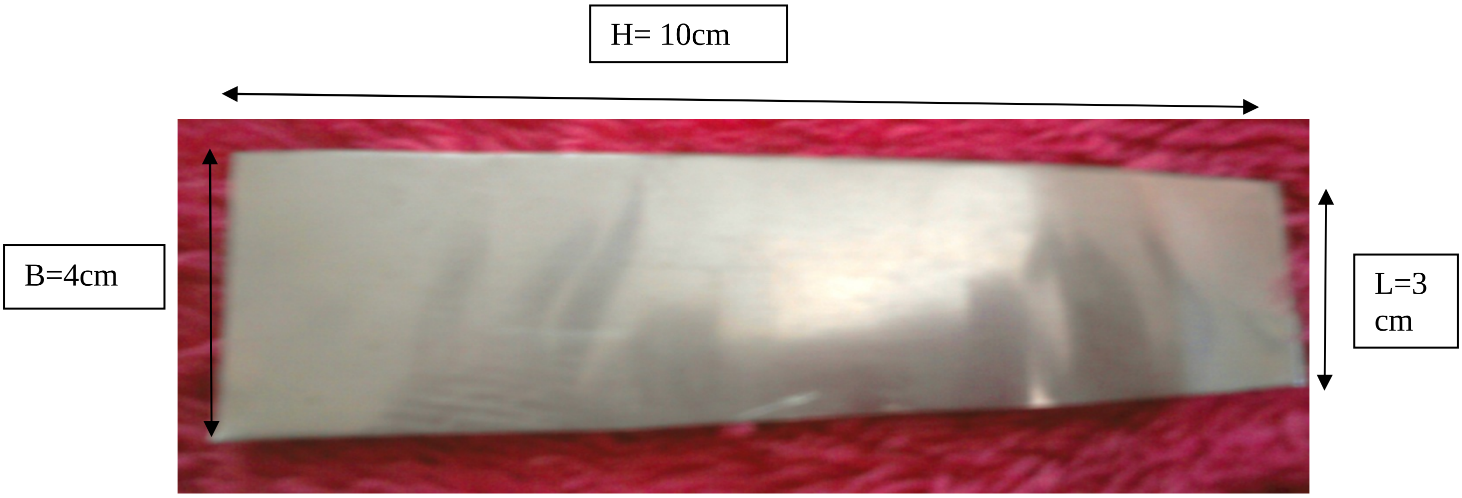
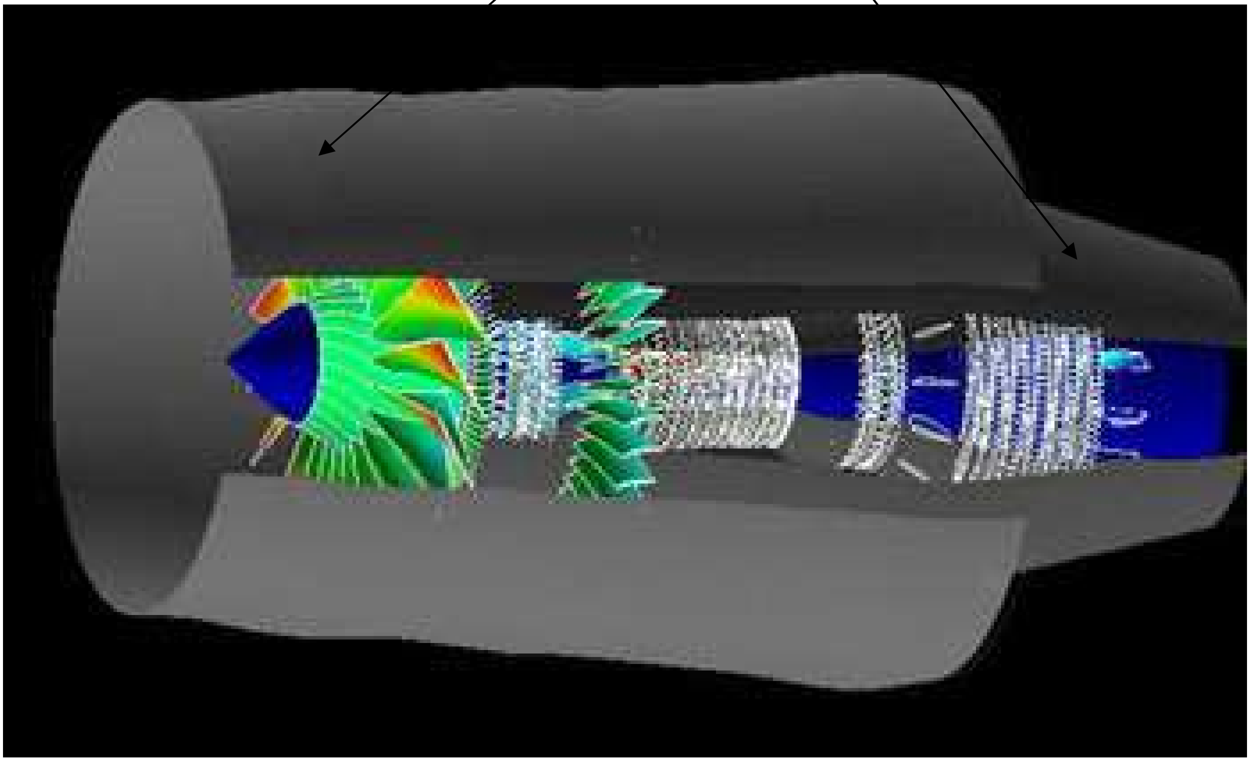


Figure 1.3: Fan Blade of the model.

2.7 Cowling

The cowling is made out of thin transparent plastic sheets to help understand the concept of bypass ratio. This transparency all ensures visibility of every part of the model. This can be seen as shown in the Figure 1.4.



Casing made out of transparent plastic sheet. Bypass ratio is approximately 3:2.

Figure 1.4: Cowling of the model.

CONCLUSIONS

After observing the results from all the preceding chapters the following conclusions can be drawn:

- A higher bypass ratio gives a low (actual) exhaust speed. As a result, the thrust specific fuel consumption is reduced. A lower bypass ratio gives high exhaust speed, which is used to sustain supersonic speeds. Thus, a high bypass turbofan engine gives lower thrust specific fuel consumption.

- As the true air speed increases, the thrust produced by the engine decreases. This is so because, as the speed increases, the drag between the mass of the air going into the core and the mass of the air going around it increases leading to a overall decrease in the thrust.

- As the bypass ratio of a turbofan engine is increased the value of range decreases. This is so because, as the bypass ratio increases more power is consumed in driving the fan and less thrust is produced to propel the aircraft.

- As the thrust specific fuel consumption of the turbofan engine increases, the range decreases. Thus, one can conclude that if the rate of fuel consumption increases, then the distance travelled by the airplane with a turbofan engine decreases.

- As the thrust specific fuel consumption of the turbofan engine increases, the endurance decreases. It shows that if the rate at which fuel is consumed is increased, then the time for which an airplane with a turbofan engine can stay in air decreases.

- A high bypass turbofan engine generates greater thrust due to various reasons, some of which are as follows:
  - Larger the fan in case of a high bypass turbofan engine resulting in higher thrust accelerates mass of fluid produced.
  - The change in velocities between the inlet of the fan and the engine exit is higher in case of a high bypass turbofan engine, thereby, generating higher thrust.
  - The temperatures at the inlet and exit of a nozzle are higher in a high bypass turbofan engine and thus larger work is done.

- A high bypass turbofan engine produces low exhaust speed. Thus, it has a higher propulsive efficiency as compared to a low bypass turbofan engine. In addition, high bypass turbofan engine is used at subsonic speeds because of low exhaust speed it produces.

This report justifies the importance and use of high bypass turbofan engine owing to its larger thrust, high propulsive efficiency and low thrust specific fuel consumption.

FUTURE WORK

With greater number of iterations performed on these engine models in CFD, a much-advanced flow can be developed. This project enables one to understand the significance and need of turbofan engines with respect commercial aircrafts.

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