Visual C++프로그램을 이용한 Ramjet Simulation Code의 생성방법

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Use of Visual C++ program to generate Ramjet Simulation code

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ABSTRACT

This paper presents on research findings of how Visual C++ program can be used to generate codes capable of performing ramjet engine simulation an arbitrary ramjet model will be considered for which generated output values will be compared with those from a commercial program GASTURB 9

Several governing thermodynamic equations will first be discussed in order that we understand the fundamental idea behind values printed out on the GUI. The program is designed that it generates its station input value. Similar results were realized compared to those produced by gasturb 9.

초 록

본 연구에서는 Visual C++프로그램을 이용하여 램젯엔진시뮬레이션을 위한 코드를 생성하였다. 연구에 사용되어진 램젯엔진은 이상적인모델로 가정하였다. 우선, Visual C++에의해 만들어진 GUI프로그램을 이해하기위해 기초이론을 설명하였다. 주변에서 흔히 구할수 있고, 사용이 용이하며, 빠른계산이 가능한 Visual C++프로그램은 특히 GUI프로그램을 DOS Mode에서도 사용할 수 있게 해준다. GUI프로그램은 엔진흡입구의 초기입력값만 넣어주면, 나머지 스테이션의 초기입력값은 이 프로그램에 의하여 자동으로 계산되어진다. 이 프로그램의 결과는 널리사용되어지고 있는 상형툴인 GASTURB9의 결과와 비교하여 타당성을 검증하였다.

Key Word: Ramjet, Performance Simulation, Simulation code, Visual C++,

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1. Introduction

It is a necessity in the design of a ramjet engine to know pressures, temperature, velocities and flow areas at each point along the gas path as they are used to estimate stage performance of the given engine.

Various analytical methods of varying degree of accuracy are in common usage for these calculations. It is of general practice to assume that the flow we will consider here is one-dimensional across the passage to avoid complex flow patterns in actual flow regimes. We will consider the average specific heat method of calculation to try and limit errors most prevalent in other simpler methods like arbitrary and constant specific methods.

It would be more easy and accurate to evaluate defined dynamic model with given known values of K (pressure loss coefficient) C_d (nozzle discharge coefficient) and other parameters only determined after research. However though we shall assume ideal conditions where such values are needed.

II. Model geometry

2.1 station numbering

A convergent-divergent ramjet model with station numbering as used in this paper is represented in figure 1 below it should be noted that intake ramp were not considered.

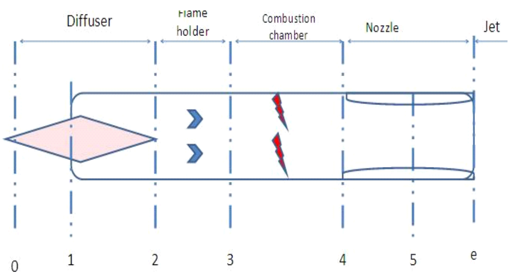

Fig. 1 Ramjet model station numbering

Respective model areas of interest necessary for calculating air mass flow and nozzle area ratio are given in the following table 1 below.

Table 1 (Area of relevance)

Area	1 (Inlet)	5 (Nozzle throat)	e (nozzle exit)
M^2	0.0257	0.033	0.0615

2.2 Operational condition

Flight and environmental conditions at 50000ft was selected to be the operational altitude which gives us the environmental ISA conditions values of pressure, temperature, and density P, T, ρ respectively.

Table 2 (Ambient conditions at 50000ft)

Parameter	Temperature	Pressure	Mach no
	216.65 (K)	12112 (N/M^3)	3

2.3 Theory

We calculate total pressure, temperature and inlet air mass flow rate for Mach number 3 taken to be our flight mach number. These valuesare used to calculate different states of stage 1.

$$\frac{T_t}{T} = 1 + \frac{\gamma - 1}{2} M^2 \quad \text{and} \quad \frac{P_t}{P} = \left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{\gamma}{\gamma - 1}} \tag{1}$$

$$\dot{M} = M \rho A \tag{2}$$

Similarly stage 2 diffuser downstream conditions calculated for static, total temperature and pressures. Diffuser pressure ratio and burner entry Mach number may also be determined at this stage.

$$P_t = P \left(\frac{T_t}{T}\right)^{\frac{\gamma}{\gamma - 1}} \quad , \quad T_{t2} = \frac{T_t}{(1 + 0.2 M_2^2)} \tag{3}$$

$$M_2 = \sqrt{\frac{1 + \frac{\gamma - 1}{2} M_1^2}{\gamma M_1^2 - \frac{\gamma - 1}{2}}} \tag{4}$$

Calculations for stage 3 commences with the assumption that momentum is conserved, although not practical, pressure and friction losses are assumed so small to be ignored

Flame holder drag K was taken as 1. It should however be determined experimentally

$$\frac{P_{t3}}{P_{t2}} = 1 - \frac{K}{2}\frac{\gamma M_2^2}{(1 + \frac{\gamma - 1}{2} M_2^2)^{\frac{\gamma}{\gamma - 1}}} \tag{5}$$

This formula opens a way to calculate stage 3 total temperature. Further assumptions made at stage 4 (combustor) are that the combustor is of constant area passage and supplied with liquid fuel.

Given combustor total exit temperature, Mach number M_4 is calculated, that also servers as reheat entry Mach number, although gamma value for air is ($\gamma = 1.4$) we will consider it to be $\gamma = 1.3$ due to temperature effect from the combustor inlet onwards

Nozzle calculations for stage 5 start with the assumption that the nozzle is choked $M_5 = 1$

$$T_5 = \frac{T_{t4}}{1 + \frac{\gamma - 1}{2} M_5^2}, \quad V_5 = M_5 \sqrt{\gamma R T_5} \tag{6}$$

Using the area-mach relation exit Mach number is calculated

$$\frac{A_e}{A_t} = \left(\frac{\gamma + 1}{\gamma}\right)^{\frac{\gamma + 1}{2(\gamma - 1)}} \frac{M_e}{(1 + \frac{\gamma - 1}{2} M_e^2)^{\frac{\gamma + 1}{2(\gamma - 1)}}} \tag{7}$$

$$T_e = \frac{T_{te}}{1 + \frac{\gamma - 1}{2} M_e} \tag{8}$$

Once all stage 5 is done the final stage 6 calculations start with pressure at exit taken to be equal to ambient pressure $P_e = P_{ambient}$ Different performance parameters are then determined.

All the above calculations and more form the fundamental backbone idea behind the programs working. It is at this stage that the constants and governing equations are edited into visual c++ compiler

```
double T=216.65;
double Gamma=1.4;
double Gamma_4=1.3;
double C_p=1005;
double R=287;
double Rho=0.19476;
double V=M*sqrt(Gamma*R*T);
double a=V/M;
double H_f=43.124;
double T_t=T*(1+0.2*(M*M));
double Pt=P*pow((T_t/T),(1.4/(1.4-1)));
double Rho_t=Rho*   pow((1+(Gamma-1)/2*M*M),(1/(Gamma-1)));
double U=M*a;
double M_2=0.2;
double T_t2=T_t/(1+0.2*M_2*M_2);
// double T_t2=606.620/(1+0.2*0.2*0.2);
```

Fig. 2 Visual C++ compiler inputting constants and formulae

It is easily noticeable from figure 2 the ease in which formulae is edited in this compiler. Traditional form of the formulas is maintained and does not need special editing knowledge or style to input data.

The important thing to keep in mind is the progressive order from the ambient to exit stage. it should be maintained to ensure flow as each preceding stage forms input values to the successive stage

Printing output command should be run after each formula edit to cross check its output closeness to the expected value.

Once all is finished a GUI is made to allow edit ability of input values.

III. Input values

Table 3 input condition

ITEM	Altitude	Mach no	Temperature	Pressure
GASTURB 9	50000ft	3	216.65	12.045
C++ GUI	50000ft	3	216.65	12.045

Similar inputs were maintained for both cases to ensure output value comparison derived using the same preceding conditions

3.1 GASTURB 9

This is a GUI type commercial program capable of performing steady state ramjet simulation; it involves entering the above table

3 inputs to produce thermodynamic calculation results of each stage

Altitude	m	15000
Delta T from ISA	K	0
Relative Humidity [%]		0
Mach Number		3

Inlet Corr. Flow W2Rstd	kg/s	4.604
Intake Pressure Ratio P2/P1		1
Diffusor Pressure Ratio P6/P2		0.97
Burner Exit Temperature	K	1800
Burner Efficiency		0.999
Fuel Heating Value	MJ/kg	43.124
Nozzle Cooling Air Wcl/W6		0.04
Burner Inlet Mach Number		0.2
Nozzle Thrust Coefficient		1

Fig. 3 GASTURB 9 input window

It should be noted that geometric area cannot be edited in this program.

```
Station    W          T          P        WRstd      FN       =      9.12
 amb                216.65     12.045               TSFC     =   53.6331
  1                 601.44    445.512               WF       =   0.48928
  2     14.012      601.44    445.512     4.604     FN/W2    =  651.0762
 61     13.451      601.44    432.147               P2/P1    =    1.0000
  7     13.940     1800.00    402.717               A8       =    0.0385
  8     14.501     1756.29    402.717               P8/Pamb  =   33.4356
Burner Efficiency             0.9990                A61      =   0.05645
 Jetpipe Diam.                0.2681                XM61     =   0.00000
 Pressure Loss [%]              6.81                XM7      =   0.43310
Con-Di Nozzle:                                      A9/A8    =   1.86200
 A9*(Ps9-Pamb)                 2.611                XM9      =   2.04041
                                                    CFGid    =   0.95005

  Fuel            FHV     humidity    war2
Generic         43.124      0.0      0.0000
```

Fig. 4 GASTURB 9 output window

3.2 Visual C++ GUI

This GUI is designed with the left hand side having editable input window with the out put on the right side

The reset button sets the default values at that pre chosen altitude and also used to clear the output window for an alternate command simulation

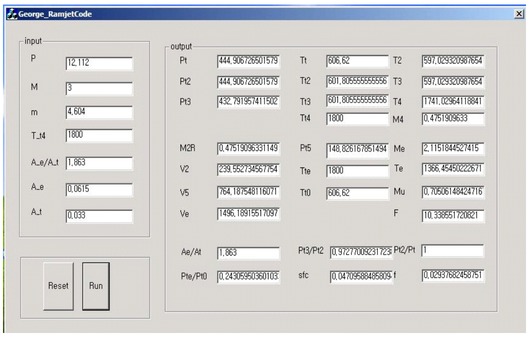

Fig. 5 Visual C++ Output GUI

The run button allows the program to start computing the given inputs through governing equations to generate the output values printed on the right hand side.

3.3 Output results

Table 4 below shows simulation results that were generated by both programs using environmental conditions at 50000ft and Mach number 3 as input

Reference should be made to figure 1 for station numbering, although similar, different numbering method are used in Gasturb 9 from station 4

Table 4 Thermodynamic station outputs

Item	Temp Gasturb	Temp Visual c	(T) Pressure Gasturb	(T) Pressure Visual c
Station 1	216.65	216.65	12.045	12.112
2	601.44	601.805	445.512	444.906
3, or 61	601.44	601.805	445.512	444.906
5 or 8	601.44	601.805	432.147	432.791
e or 9	1756.29	1741.02	-	148.826

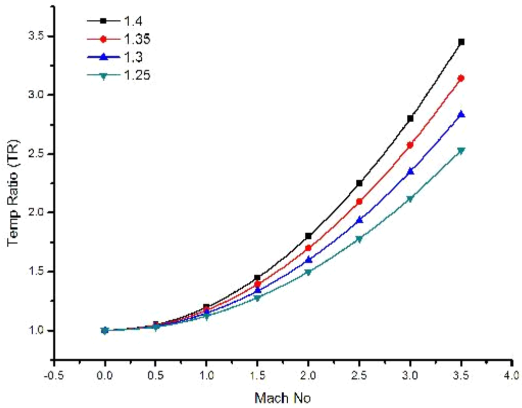

Fig. 6 Temperature Ratio against Mach number

Respective values of temperature ratio at station two were generated by changing Mach number in the visual C++ GUI then plotted for values of gamma between 1.25 to 1.4

It can be concluded from the graphs that constant increase in temperature occurs with increasing Mach number

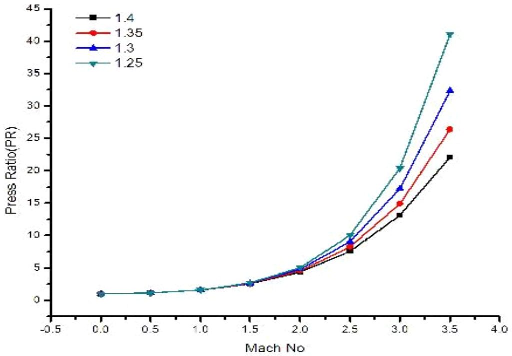

Fig. 7 Pressure Ratio against Mach number

Pressure ratio value for mach numbers between 0.5 to 4.0, plotted at varying values of gamma constant pressure is observed up to mach one where rapid increase is noted

Table 5 Performance output data

Item	Thrust (kN)	Inlet Press Ratio	Reheat Mach no	Nozzle Exit Mach	Nozzle Area Ratio
Gasturb	9.12	1	0.433	2.029	1.862
C++	10.33	1	0.475	2.115	1.862

The difference in thrust may be attributed to the fact that Gasturb 9 considered pressure loss of 6.81% whereas we assumed ideal conditions and losses were ignored.

Table 6 Performance with varying Mach no

Mach no	1.5	2	2.5	3
Units	(KN)	(KN)	(KN)	(KN)
(Gasturb 9)	error	3.12	5.41	9.12
(Visual C)	3.42	4.788	6.97	10.33

Since Gasturb 9 has no input provision for intake area which was considered in Visual C++ we may assume that they used the theory that the frontal area equals exit area. Hence explains great difference in thrust at low Mach numbers

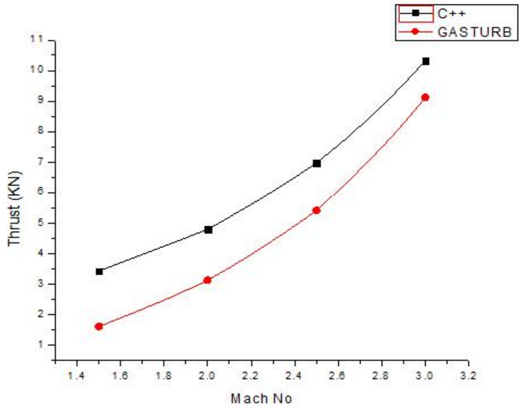

Fig. 8 Thrust and against Mach number

3.4 Performance

One amongst the most importance performance defining parameters is the fuel flow rate.

Calculated herein as

$$f = \frac{\left(\frac{T_{t4}}{T_{t3}} - 1\right)}{\frac{h_f}{C_p T_{t3}} - \frac{T_{t4}}{T_{t3}}} = 0.029166 \qquad (9)$$

$$M_f = 3600 f M_a \qquad (10)$$

$$sfc = \frac{M_f}{F} = 0.0467967340 \qquad (11)$$

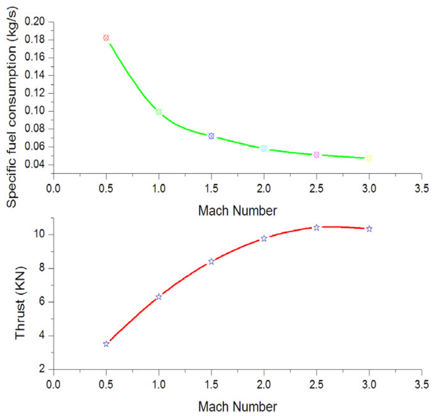

Fig. 9 Thrust and specific fuel consumption against Mach number

This graphs were plotted from performance results output of the simulation code program developed using visual C++ both graphs show expected trend

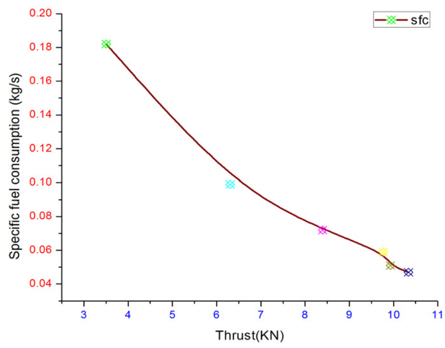

Fig. 10 Specific fuel consumption against thrust

The graph indicate that specific fuel consumption reduces with increasing thrust, this is so because specific fuel consumption is inversely related to thrust as defined in equation (11).

Ⅳ. Conclusion

From the analysis results we experienced close or similar values of temperature and pressure for the stations considered; it would be adequate hence to conclude that Visual C++ program is accurate as may be verified by the commercial program used.

Net thrust also reflects closeness the difference of which may be attributed to frictional pressure losses considered in Gasturb 9.

This code generated by C++ compiler may be suitable to simulate defined dynamic model as it allows editing of geometric data like intake area, combustor temperatures to match desired values

Visual compiler being readily available would be a suitable tool for making simulation codes at intellectual level with additional advantage of being used for commercial purposes due to its numerous interface capabilities with other programs.

References

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