INTERNATIONAL JOURNAL OF MATHEMATICAL MODELS AND METHODS IN APPLIED SCIENCES
DOI: 10.46300/9101.2022.16.16 Volume 16, 2022

Study on the effect of two uncertainty parameters on scramjet engine using Monte Carlo simulation

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Received: April 19, 2021. Revised: March 6, 2022. Accepted: April 9, 2022. Published: May 13, 2022.

Abstract: Today, aerospace engines are developing rapidly, these engines are divided into two groups of gas turbines and without gas turbines. In this thesis, the thermodynamic performance of the scramjet engine is examined. This study is carried out with consideration of uncertainty parameters. Two parameters of the combustion chamber efficiency and heating value of fuel are considered as uncertainty parameters. Using Monte Carlo numerical simulation method, the functional curves of the scramjet engine were investigated, and Analysis is done. According to the use of uncertainty parameters, first, a brief explanation of the uncertainty illustrates according to calculate using their functions and the Monte Carlo method. Also, the uncertain effects on the functional charts are analyzed considering the variable taking into account each of the uncertainty parameters. According to the obtained results, it was determined that the uncertain effect of the combustion chamber is negligible compared to the heating value of the fuel, the number of different points of 100,200 and 300 is similar to each other, and according to the extracted functional charts With regard to the uncertainties, it was observed that the least compression efficiency and special fuel consumption would have the greatest effect from the uncertainties.

Keywords: Scramjet, Monte Carlo simulations, the Performance function

I. Introduction

THE concept of airbreathing jet propellant force emanated at the beginning of the 20th century. From a technological viewpoint, the airbreathing jet propellant force can be determined as a particular sort of internal combustion engine that generates its net output power as the rate of alternation in the kinetic energy of the engine's working fluid.

Various patents about airbreathing jet engines had been applied for by variant inventors of several nationalities who worked separately from each other. The working fluid enters as environmental air that is conducted through an inlet diffuser into the engine; the engine outlet fume involves partly of combustion gas and partly of air. The outlet fume is expanded through a thrust nozzle or nozzles to environmental pressure.

In airbreathing propellant force systems, the composed compression by ram and turbo compressor is of great advantage to the thermodynamic propellant force procedure up to flight Mach numbers approximating 3. When the flight Mach number growth, further, the advantages of the turbo compressor start to reduction and the engine starts to operate essentially as a ramjet. When the flight Mach number oversteps about 3.5, any extra compression by a turbo compressor would be a disadvantage. Thus, if the engine functions best as a pure subsonic combustion ramjet, it proportions in a flight Mach number regime from within 3.5 to 5. Beyond flight Mach numbers of about 6, the pressure and temperature proportion would be unfavorably high if the engine continued to function as a subsonic combustion ramjet.

A schematic figure of a ramjet is shown in Fig. 1. The ramjet does not have the turbine and compressor as the turbofan does. In the inlet, section air enters where it is compressed by the inner body and then enters the combustion section that air is mixed with the fuel in the combustion zone and burned. Scramjet schematic looks like a ramjet. (1)

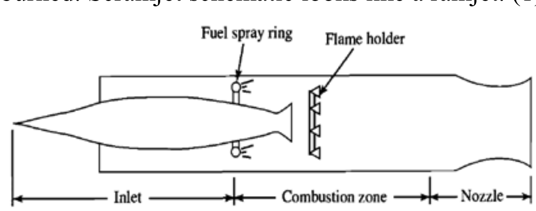

Fig 1 schematic diagram of a ramjet

A ramjet functions by subsonic combustion of fuel in a flow of air compressed by the forward velocity of the aircraft itself, as opposed to an ordinary jet engine, in which the compressor sector (the fan blades) compacts the air. Ramjets function from about Mach 3 to Mach 6. (2)

A scramjet (supersonic-combustion ramjet) is a ramjet engine in which the airstream through the engine leftovers supersonic. Scramjets powered vehicles are envisioned to function at accelerate to at least Mach 15. (2)

In this paper, the impacts of the uncertainty performance functions of scramjet engines using are studied in order to yield a more accurate prediction of values of performance functions. This study is done employing the Monte Carlo Simulation method, which is a probabilistic analysis method.

Regard to R.G.Ghanem and C.Soize study on design optimization of a scramjet under uncertainty using probabilistic learning on manifolds. This paper worked on a scramjet combustion problem. The use of a recent machine learning algorithm to a really great scale LES-based optimization problem associated with scramjet combustion. Three various LES spatial resolutions are explored, each with a various number of instances in the associated training set. (3)

Jie Liu and Ning-fei Wang worked on Optimizing combustion performance in a solid rocket scramjet engine. This study effort a new organization scheme combining cavity and pneumatic slope. The key elements were successfully determined to optimize the suggested system, a series of numerical simulations were performed, and through orthogonal design and single element analysis. The numerical model and Analysis method in this work also provide a valuable guide to study the involved SRS engine. (4)

Obula Reddy Kummitha and K.M. Pandey studied on Numerical investigation of wavy wall strut fuel injector for hydrogen-fueled scramjet combustor. Wavy wall strut has a powerful effect on improving the performance of the scramjet engine with an increase in mixing and combustion efficiency by the development of supplementary oblique shock waves and streamline vortices. In this study, the strut injector has been re-designed, such a way that to generate more oblique shock waves. Numerical Analysis of the scramjet inner flow field has been performed by solving the Reynolds-averaged Navier-Stokes equations. (5)

Qingchun Yang, Juntao Chang studied Thermodynamic Analysis on specific thrust of the hydrocarbon fueled scramjet. The purpose of this study is to supply a higher estimate of the theoretical maximum specific thrust of the hydrocarbon fueled scramjet. An idealized thermodynamic cycle analysis is carried out to appraise the efficiency of scramjet engines at different flight conditions, entry pressure ratio, and fuel equivalence ratio. At cruise conditions, these optimized values are closely related to material temperature limit. (6)

Duo Zhang and Shengbo Yang studied on Thermodynamic Analysis on optimum performance of scramjet engine at high Mach numbers. A thermodynamic model of Brayton cycle was utilized to analyze the influences of inlet pressure ratio, fuel equivalence ratio and the higher limit of gas temperature to the particular thrust and the fuel impulse of the scramjet considering the specifications of non-isentropic compression in the inlet. The inlet efficiency has a significant influence on the overall performances of scramjets. (7)

Kunlin Cheng and Yu Feng paper deals with Thermodynamic Analysis for recuperation in a scramjet nozzle with wall cooling. The expansion process with recuperation was descripted using both diagrams and equations. The conclusions show that the recuperation process attained by wall cooling in the nozzle has the potential to enhance the performance of scramjets efficiently. (8)

II. Parametric Analysis of Scramjet engine

Figure 2 shows a schematic overview of a scramjet engine, with different parts numbered. In this classification, 0 is free to flow, 1 after compression, 3 inlets to combustion chamber, 4 inlet to combustion chamber, 9 outlet nozzle beginning and 10 the end of the nozzle. (9)

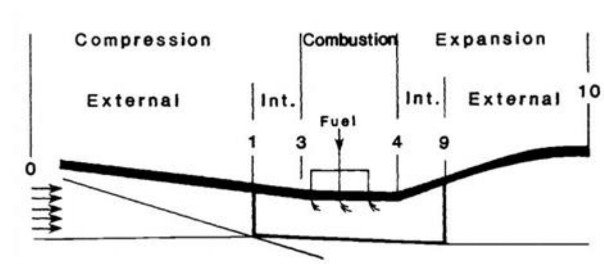

Fig 2 Sections of the Scramjet air breathing Engine

A. Problem assumptions

Parametric cycle analysis examines the thermodynamic changes of the operating fluid when the fluid flows through the engine and expresses the efficiency of the engine under different flight conditions. The assumptions of the problem are as follows: (9)

1) *The flow is considered one-dimensional.*
2) *The flow is stable.*
3) *Thermochemical effects are determined.*
4) *The effects of gravity, velocity, electricity, and magnetic field on the motion or energy of the fluid are ignored.*

III. Monte Carlo Method

For the Analysis of continuous systems, integrals from Equations 1 and 2 must be derived, but because integrals of these equations are involved, they cannot be computed.

$$\mu = E[X] = \int_{-\infty}^{\infty} x f_X(x) dx \tag{1}$$

DOI: 10.46300/9101.2022.16.16

$$\sigma^2 = V[X] = \int_{-\infty}^{\infty} (x-\mu)^2 f_X(x)dx = \int_{-\infty}^{\infty} x^2 f_X(x)dx - \mu^2 \tag{2}$$

One of the most useful methods in numerical simulation is the Monte Carlo method. This is a simulation method in which random numbers are generated between zero and one, random samples that have been generated from uncertain parameters, and then the system is simulated as per each randomly generated sample. In the Monte Carlo numerical simulation method, the sampling order of an n-dimensional vector like . N indicates the number of uncertain parameters. Figure 3 illustrates the simulation process for the parameters x1 and x2 using the random generation of numbers (10)

The process of the Monte Carlo method is summarized in three points: (fig 3)

1. Generate random numbers in n-dimensional unit space uniformly
2. Equalize any of the numbers produced by the probability of a random variable event.
3. Mapping the numbers generated on the horizontal axis according to the population distribution curve of each random variable to produce the desired sample.

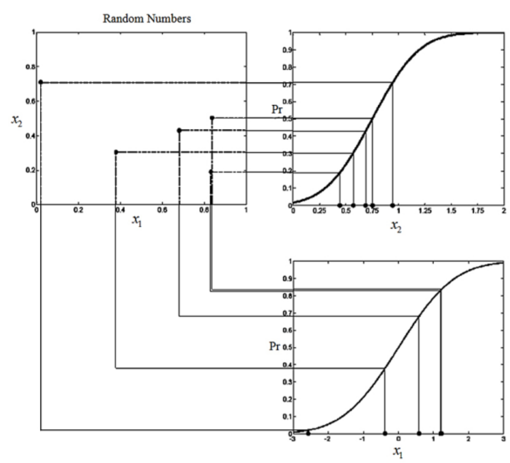

Fig 3 Simulation process of Monte Carlo

IV. Scramjet Engine Performance Graphs with Uncertainties

The assumed constant values in the Analysis can be divided into two categories: certain or uncertain. In fact, the actual value of some certain parameters can be different from the assumed nominal value. In this section, changes to some of these uncertain parameters on performance graphs are studied. The effects of combustion chamber efficiency changes and thermal fuel values (hpr) are examined as uncertain parameters. The assumption is that the efficiency of the combustion chamber is uncertain due to the relative loss of this efficiency during operation resulting from the combustion process in the engine. (11). Also, according to Table 1 (12), this parameter cannot be quantified due to the different range of thermal fuel value.

Section: Appendix A

Lower and Higher Heating Values of Gas, Liquid and Solid Fuels

Fuels	Lower Heating Value (LHV) [1]			Higher Heating Value (HHV) [1]			Density
Gaseous Fuels @ 32 F and 1 atm	Btu/ft3 [2]	Btu/lb [3]	MJ/kg [4]	Btu/ft3 [2]	Btu/lb [3]	MJ/kg [4]	grams/ft3
Natural gas	983	20,267	47.141	1089	22,453	52.225	22.0
Hydrogen	290	51,682	120.21	343	61,127	142.18	2.55
Still gas (in refineries)	1458	20,163	46.898	1,584	21,905	50.951	32.8

Table 1 (12)

B. Inputs parameters for the current study

These parameters have been used as fixed inputs in the study.

Inputs:

$$\psi = 7.0 \quad f = 0.0291 \quad h_f = 0.0$$

$$q_0 = 1000 lbf / ft^2 \left(47.88 kN/m^2\right)$$

$$fh_{PR} = 1780 BTU/lbm \left(4137.5 kJ/kg\right)$$

$$T^\circ = 400^\circ R\left(222K\right) \quad C_{ev} = 0.99$$

$$R = 1730\left(ft/s\right)^2 / ^\circ R \quad \left(289.3\left(m/s\right)^2/K\right)$$

$$\frac{V_{fx}}{V_3} = 0.5 \quad \frac{V_f}{V_3} = 0.5 \quad C_{ea} = 1.00$$

$$\frac{P_{10}}{P_0} = 1.0 \quad \eta_1 = 0.95 \quad \eta_b = 0.90$$

$$\left(\frac{C_f}{2} \cdot \frac{A_W}{A_a}\right)_c = 0.01 \quad \left(C_f \cdot \frac{A_W}{A_a}\right)_b = 0.10$$

$$C_{pe} = 0.38\ BTU/lbm.^\circ R\ (1.59 kJ/kg\ .K) \quad \gamma_e = 1.222$$

$$C_{pc} = 0.260 BTU/lbm.^\circ R\left(1.09 kJ/kg\ .K\right) \quad \gamma_c = 1.362$$

$$C_{pb} = 0.360 BTU/lbm.^\circ R\left(1.51 kJ/kg\ .K\right) \quad \gamma_b = 1.238$$

C. Equations

Here we have the equations that used in this work.

$$\eta_c = \eta_1 \left(\frac{1-\frac{1}{\psi_1}}{1-\frac{1}{\psi}}\right) \qquad \eta_e = \frac{C_{ev}^2 - \left(\frac{V_4}{V_y}\right)^2}{1-\left(\frac{V_4}{V_y}\right)^2}$$

$$\frac{F}{\dot{m}_0} = (1+f)Sa_{10} - Sa_0 - \frac{R_0 T_0}{V_0}\left(\frac{A_{10}}{A_0} - 1\right)$$

$$S = \frac{f}{F/\dot{m}_o} \qquad I_{sp} = \frac{1}{g_0 f} \cdot \frac{F}{\dot{m}_0}$$

$$\eta_p = \frac{Thrust\,Power}{Engine\,mechanical\ power} = \frac{FV_0}{\dot{m}_0\left\{(1+f)\frac{V_{10}^2}{2} - \frac{V_0^2}{2}\right\}}$$

$$\eta_{th} = \frac{Engine\,mechanical\ power}{Chemical\,energy\,rate} = \frac{(1+f)\frac{V_{10}^2}{2} - \frac{V_0^2}{2}}{fh_{PR}}$$

$$\eta_O = \frac{Thrust\ Power}{Chemical\,energy\,rate} = \frac{FV_0}{\dot{m}_f h_{PR}}$$

D. Study of the Uncertain Impact of Both Parameters on performance Functions for 100, 200 and 300 Random Samples

In this section, the curves are examined for the number of random samples of 100, 200, and 300, and the uncertainties of both parameters and the figures of mean and variance of the functional functions are obtained.

In Figures 4 to 13, the mean and standard deviation curves, each of the special thrust functions, the specific fuel consumption, total efficiency, expansion, and compression are plotted for inlet Mach number in the range of 5 to 25, and they have been analyzed. These figures are calculated and plotted for N random points for each of the uncertain parameters. The values of these points are in the range of zero and one. For example, 100 = N, that is, in the range of 0 to 1, 100 random points are generated and uncertain parameters are obtained for them. Figures 4 and 5 show the mean and variance of the specific thrust function, respectively. The mean and variance of the special thrust function are reduced. Figures 6 and 7 show the changes in the mean and variance of the specific fuel consumption, respectively. As shown in the figure, the curves of different values of the number of samples overlap. On the other hand, in the range of Mach number 5 to 15, the variance is negligible. Figures 8 and 9 show the mean and variance of the total efficiency function, the difference between the nominal values, and the curve obtained by considering the uncertainties in the above 20 Mach (Fig. 8). On the other hand, it can be seen in Figure 9 that the amount of variance in the whole flight range is very low. Similar results are observed for the uncertain effects on the mean expansion and compression efficiency (Figures 10 and 12), and the variance diagrams of these two functions are close to zero in all flight ranges (Figures 11 and 13).

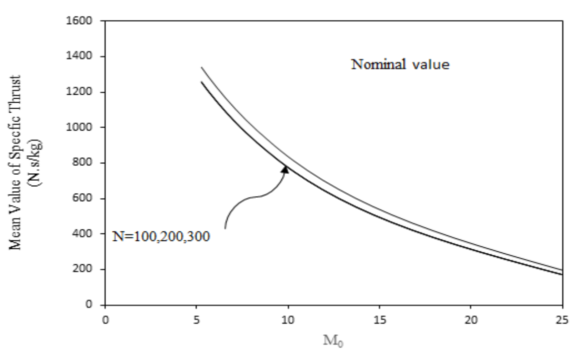

Fig 4 Mean Special Thrust Force for N different points of each of the uncertain parameters Changes with Fly Mach

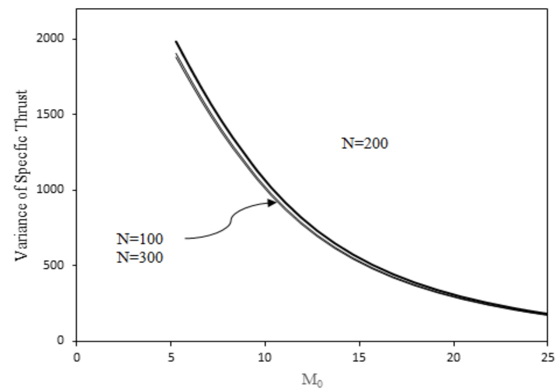

Fig 5 Variance of the special thrust force for N different points of each of the uncertain parameters Changes with Fly Mach

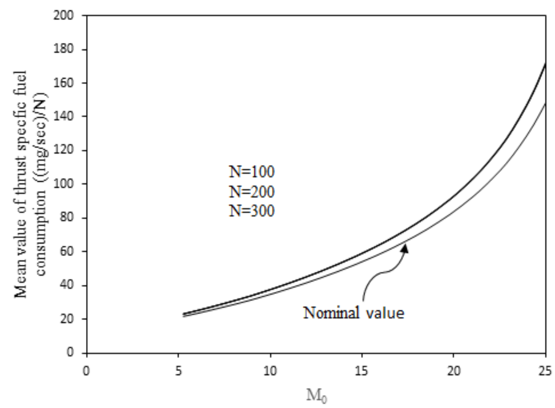

Fig 6 Mean specific fuel consumption for N different points of each of the uncertain parameters Changes with Fly Mach

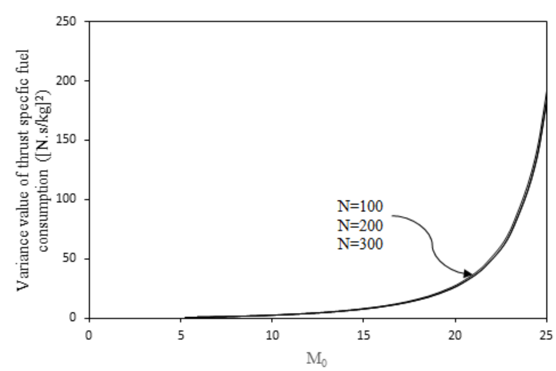

Fig 7 Variance of specific fuel consumption for N different points of each of the uncertain parameters Changes with Fly Mach

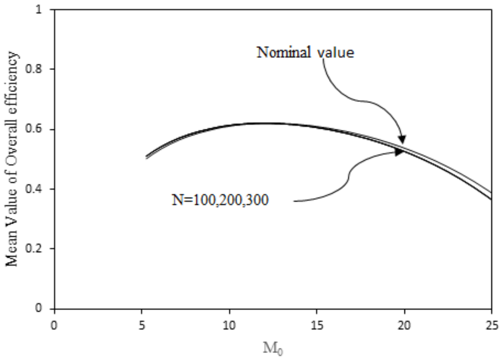

Fig 8 Mean overall efficiency for N different points of each of the uncertain parameters Changes with Fly Mach

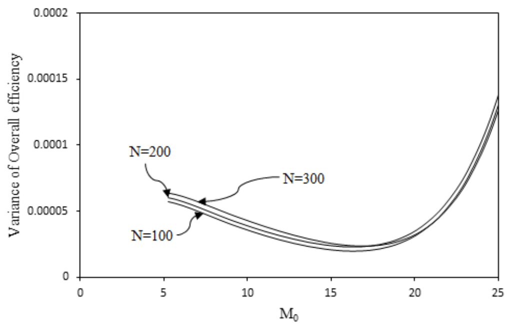

Fig 9 Variance of overall efficiency for N different points of each of the uncertain parameters Changes with Fly Mach

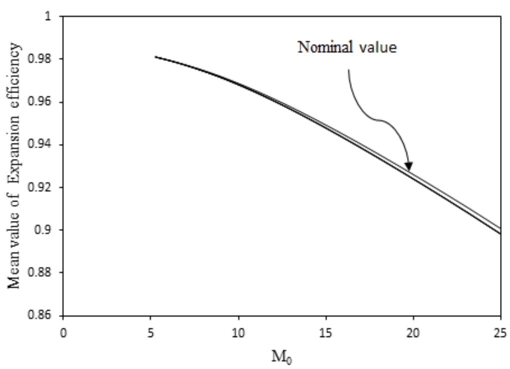

Fig 10 Mean Expansion Efficiency for N different points of each of the uncertain parameters Changes with Fly Mach

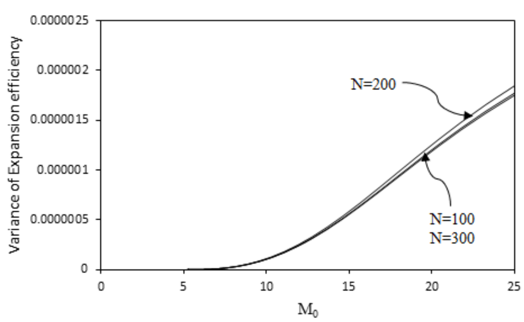

Fig 11 Variance of expansion efficiency for N different points of each of the uncertain parameters Changes with Fly Mach

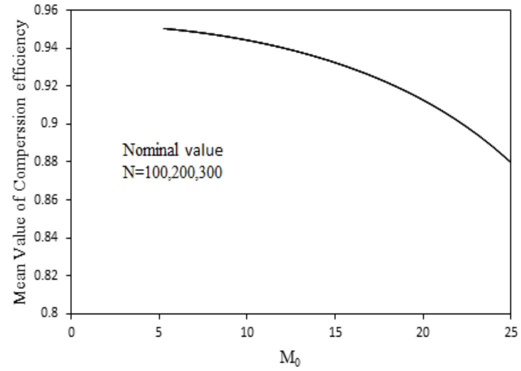

Fig 12 Mean compression efficiency for N different points of each of the uncertain parameters Changes with Fly Mach

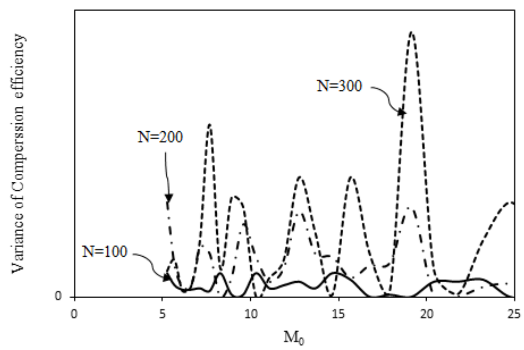

Fig 13 Variance of compression efficiency for N different points of each of the uncertain parameters Changes with Fly Mache.

V. Conclusions

In uncertain studies with different numbers of 100, 200, and 300 points, the results were similar. The plots illustrate the effects of combustion chamber efficiency changes and fuel thermal values (hpr) as uncertain parameters, and they are negligible and special fuel consumption would have a huge efficacy from the uncertainties of a manuscript is not required for participation in a conference.

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