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DETERMINATION OF PROPULSIVE THRUST AND SPECIFIC FUEL CONSUMPTION OF A TURBOFAN ENGINE SYSTEM USING SIMULATION METHOD

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ABSTRACT

The study, Determination of propulsive thrust and specific fuel consumption of a turbofan engine system using simulation method was successfully carried out. Researchers achieved the study using simulink in matlab. Simulink in the matlab command window contains gas turbine propulsion block models that were used to model a turbofan engine system to determine propulsive thrust and specific fuel consumption. The initial values of throttle position, Mach number, static pressure and bypass ratio were chosen to be 1, 1.0, 1atm, 0.5 respectively. Initial temperature and pressure were set to 2000k or 2273°C and 1 atm respectively. Simulation was allowed to run for 10seconds using Ode23t solver and results, according to the simulation graphs at the stated conditions showed that the propulsive thrust and specific fuel consumption of turbofan engine system were found to be 0.064N and 0.0000252kg/s while the thrust specific fuel consumption (TSFC) was 0.00039kg/s/N. Similarly, the values of throttle position, Mach number, velocity, bypass ratio, final altitude were adjusted to be 30, 0.2, 20 m/s, 0.5 and 300m respectively. Results at the stated conditions showed that the propulsive thrust and specific fuel consumption of turbofan engine system were found to be 109N and 0.041kg/s while the thrust specific fuel consumption (TSFC) was 0.00038kg/s/N. In addition, the values of throttle position, Mach number, velocity, bypass ratio, final altitude were further adjusted to be 120, 2.0, 45 m/s, 0.5 and 600m respectively. Findings at the stated conditions revealed that the propulsive thrust and specific fuel consumption of turbofan engine system were found to be 164N and 0.06kg/s while the thrust specific fuel consumption (TSFC) was 0.00037kg/s/N. Results suggested that turbofan engine system propulsive thrust and specific fuel consumption are functions of throttle position, mach number, velocity and altitude. Increasing values of the mentioned parameters increases propulsive thrust and specific fuel consumption. Hence, propulsive thrust is a function of specific fuel consumption and optimal value of propulsive thrust that must minimize specific fuel consumption should always be considered in practical designs.

Keywords: Propulsive Thrust, Specific Fuel Consumption, Block Model, Simulink, Turbofan Engine.

I. INTRODUCTION

Engines driven by gas turbine are widely used to power aircraft due to their high power to weight ratio. According to Ahmad (2020), turbofan engine is an air breathing gas turbine and fan engine that is widely used in aircraft propulsion. The turbo portion refers to a gas turbine engine which achieves mechanical energy from combustion and the fan, a ducted fan that uses the mechanical energy from the gas turbine to accelerate air rearwards. Thus, not all the air taken in by a turbofan passes through the turbine combustion chamber; some of that air bypasses the turbine. Therefore, turbofan engine could be described as a turbojet driving a ducted fan, with both of these contributing to the thrust.

In addition, one of the performance influencing parameters, bypass ratio is obtained by dividing the mass flow of air bypassing the combustion chamber core with the mass flow of air passing through the fan nozzle. Thus, we have low-bypass turbofans engines, that use more jet thrust relative to fan thrust and high-bypass turbofan engines with high fan thrust. The components of a practical turbofan engine system includes: low pressure spool, high pressure spool, stationary components, nacelle, fan, low pressure compressor, high pressure compressor, combustion chamber, high pressure turbine, low pressure turbine, core nozzle, fan nozzle, and system auxiliaries (Aria, 2022).

This paper adopted simulink simulation method with block models and the turbofan Engine System block computes the propulsive thrust and the specific fuel consumption (SFC) to the turbofan engine and controller at a specific throttle position, Mach number, and altitude.

Propulsive thrust represents the force that provides the forward motion, acceleration and altitude gain needed to maintain lift and counter drag. Propulsive thrust is a function of throttle position and Mach number. Thrust specific fuel consumption (TSFC), is the amount of fuel consumed by turbofan engine for each unit of thrust output. TSFC is a function of thrust and Mach number, and engine time constant. According to NASA (2023), propulsive thrust of 17,800N and lower value of Thrust specific fuel consumption (TSFC) of 0.5kg/hr/N are appropriate for turbofan engines, as it characterizes high efficiency. Hence, this research paper aimed at studying determination of propulsive thrust and specific fuel consumption of a turbofan engine system using simulation method.

II. METHODOLOGY

Determination of propulsive thrust and specific fuel consumption of a turbofan engine system using simulation method was carried out using simulink in matlab. simulink in the matlab command window contains propulsion block models that were used to represent all the elements of a turbofan engine system model. The block models include: Discrete Pulse Generator, Memory, Actuator, Pressure Altitude, Step, Turbofan Engine System, Block type Count, Model Functions. Block ports were connected as shown in Fig 3 to Fig 5 below. The initial values of throttle position, Mach number, static pressure and bypass ratio were chosen to be 1, 1.0, 1atm, 0.5 respectively. Initial temperature and pressure were set to 2000k or 2273°C and 1 atm respectively. Using Ode23t solver for tight tolerance in fixed step solving, simulation was allowed to run for 10seconds, the turbofan Engine System block computed the propulsive thrust and the specific fuel consumption (SFC) of the turbofan engine and controller at a specific throttle position, Mach number, and altitude.

TABLES AND FIGURES

Table 1. Simulation Parameters

Parameter	Value
Solver	Ode23t
RelTol	1e-3
Refine	1
MaxOrder	5
ZeroCross	on

Table 2. Discrete Pulse Generator Block Properties

Name	Pulse Type	Time Source	Amplitude	Period	Pulse Width	Phase Delay	Sample Time
Pulse Generator	Time based	Use simulation time	2	10	5	0	1
Pulse Generator1	Time based	Use simulation time	2	10	5	0	1

Table 3. Memory Block Properties

Name	X0	Inherit Sample Time	Linearize Memory	Linearize As Delay	State Storage Class
Memory	2	On	Off	off	Auto

Table 4. Nonlinear Actuator Block Properties

Name	Wn fin	Z fin	Fin max	Fin min	Fin maxrate	Fin act 0	Fin act vel
Nonlinear Actuator	1	0.3	20*pi/180	-20*pi/180	500*pi/180	120	20

Table 5. Pressure Altitude Block Properties

Name	Units	Action
Pressure Altitude	Metric (MKS)	Warning

Table 6. Step Block Properties

Name	Time	Before	After	Sample Time	Zero Cross
Step	9	300	600	10	on
Step2	6	0	9	10	on

Table 7. Turbofan Engine System Block Properties

Name	Units	Ic source	Fmax	Tau	SFC	Nt
Turbofan Engine System	Metric (MKS)	External	45000	1	0.35	0.9

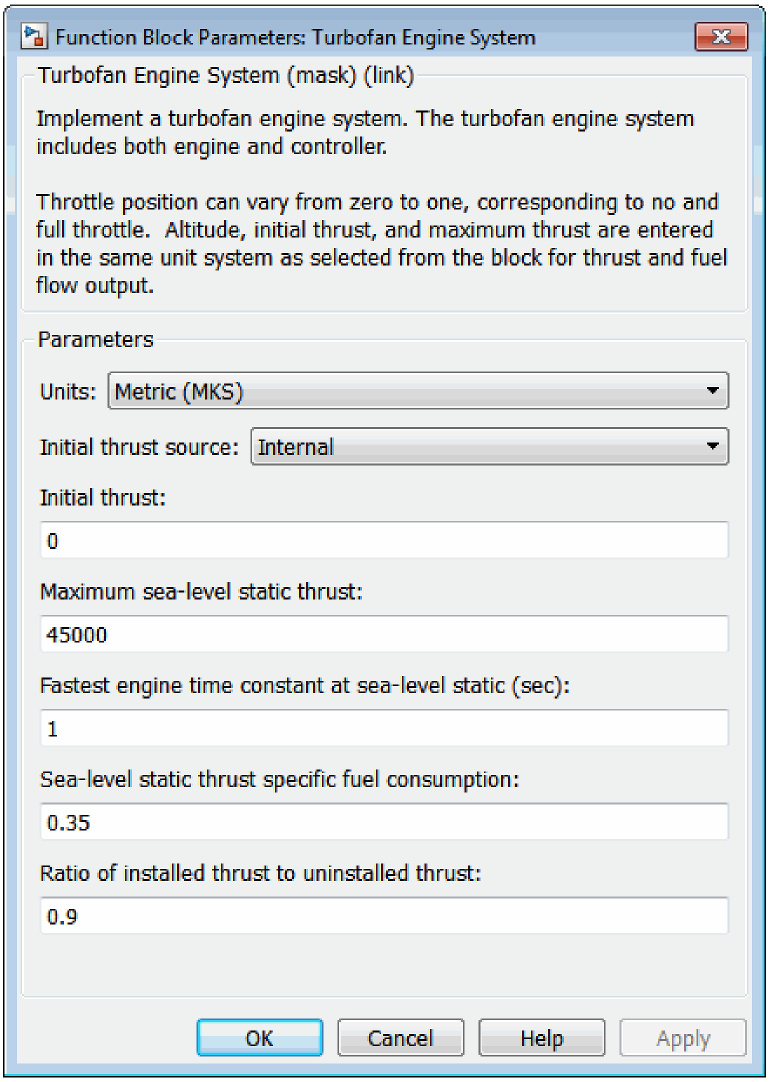

Fig 1. Turbofan Engine System Function Block

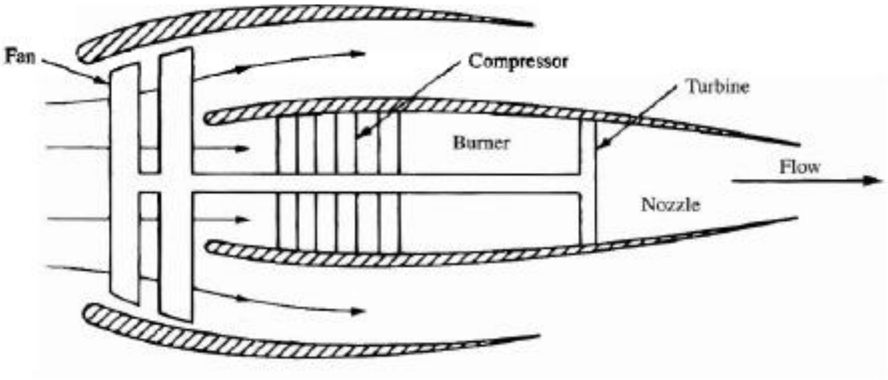

Fig 2. Turbofan Engine (source: Aria, 2022)

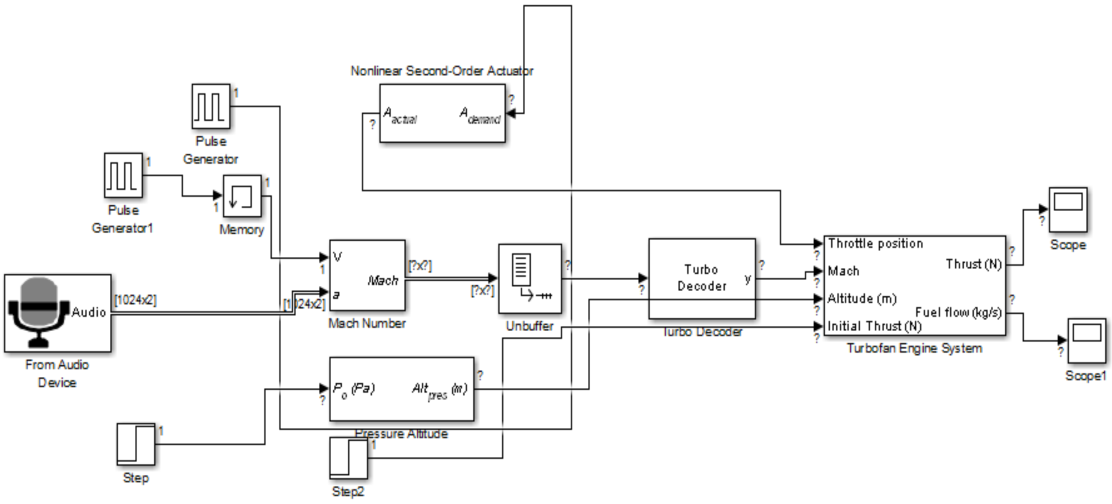

Fig 3. Turbofan Engine System Simulink Model (17-Sep-2023 01:40:23)

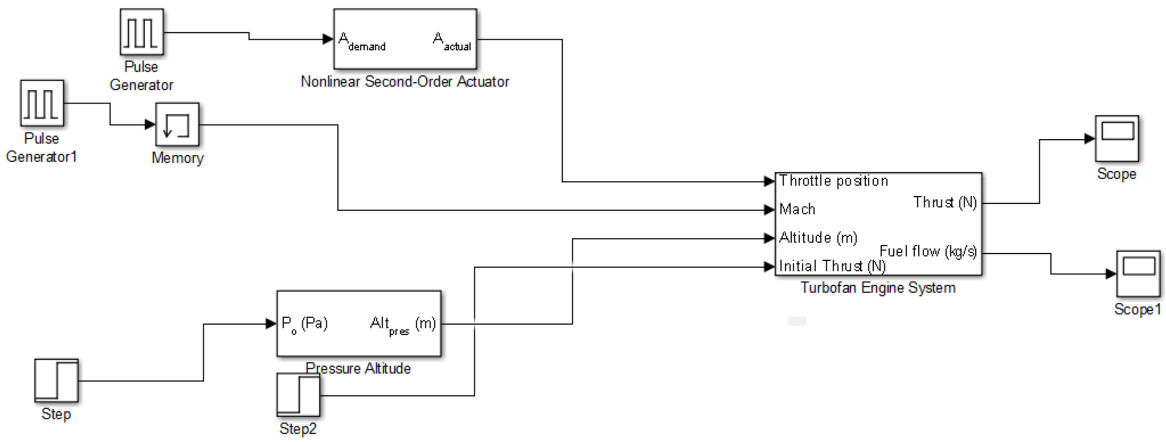

Fig 4. Turbofan Engine System Simulink Model (17-Sep-2023 01:40:23)

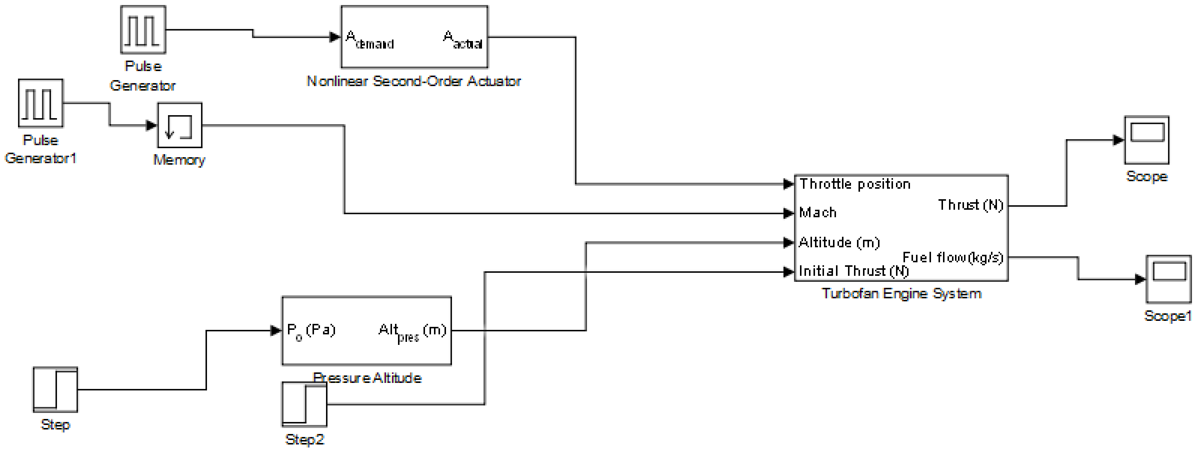

Fig 5. Turbofan Engine System Simulink Model (17-Sep-2023 01:40:23)

III. EQUATIONS

The mathematical equations below could be adopted for calculating the propulsive thrust developed by turbofan engine system.

$$\text{Thrust} = F = M_2V_2 - M_1V_1 \ldots\ldots\ldots\ldots\ldots\ldots.(1)$$

Where m and v are mass flow rate and velocity at exit (2) and inlet (1) of engine

Mass flow rate crossing exhaust area is given below

$$\text{Mass flow} = M_E = \rho_2 V_2 A_E \ldots\ldots\ldots\ldots\ldots\ldots.(2)$$

Mass flow rate inlet area is given below

$$\text{Mass flow} = M_i = \rho_1 V_1 A_i \ldots\ldots\ldots\ldots\ldots\ldots.(3)$$

The next pressure force acting on the turbofan engine is given below

$$P_f = (P_i - P_e)A_E \ldots\ldots\ldots\ldots\ldots\ldots.(4)$$

The mass flow rate of fuel is given as below

$$\text{Mass flow of fuel} = M_f = \rho_2 V_2 A_E - \rho_1 V_1 A_i \ldots\ldots\ldots\ldots\ldots\ldots.(5)$$

Thrust specific fuel consumption (TSFC) = $\frac{M_f}{F}$ .... (6)

Where A, P and ρ are area, pressure and density at exit (2) and inlet (1) of engine

IV. RESULTS AND DISCUSSION

The following results were obtained when initial values of throttle position, Mach number, static pressure, thrust, specific fuel flow rate and bypass ratio were chosen to be 1, 1.0, 1atm, 0, 0, 0.5 respectively. Initial temperature and pressure were set to 2000k or 2273°C and 1 atm respectively.

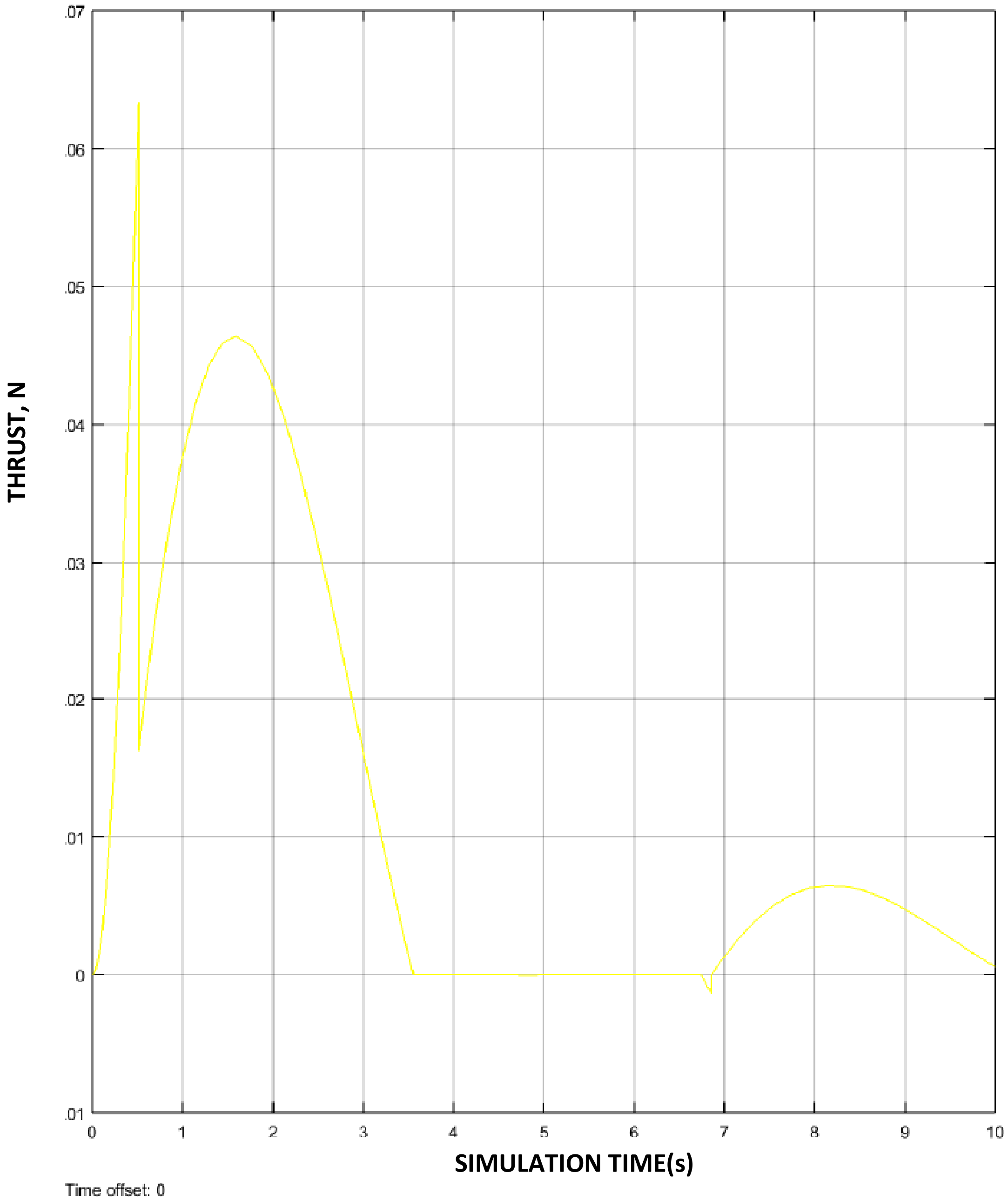

Fig 6. Turbofan Engine Thrust

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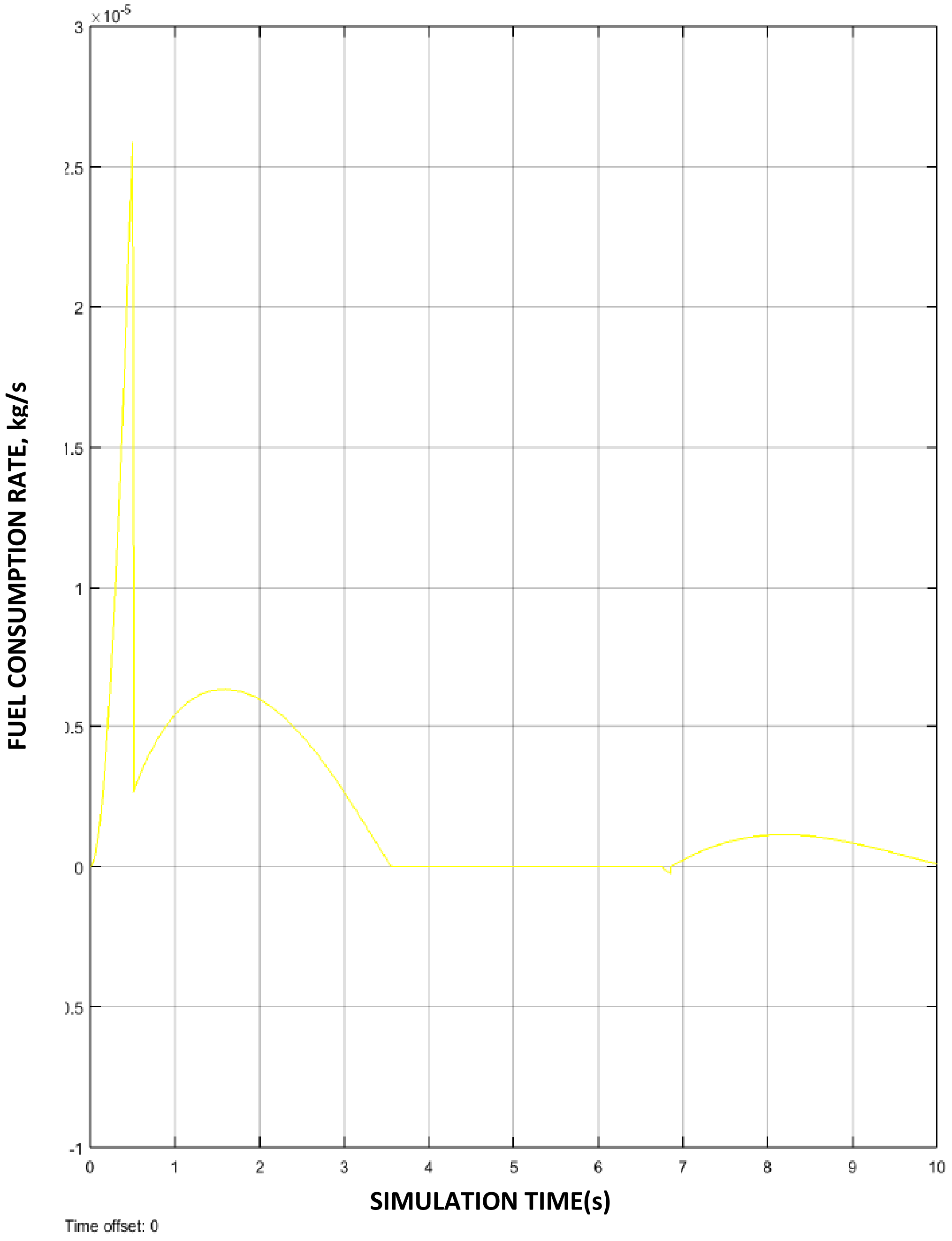

Fig 7. Turbofan Engine Specific Fuel Consumption

Thrust specific fuel consumption (TSFC) = $\frac{M_f}{F} = \frac{2.52\times10^{-5}}{0.064}$ = 0.00039kg/s/N

The following results were obtained when values of throttle position, Mach number, velocity, bypass ratio, final altitude were chosen to be 30, 0.2, 20 m/s, 0.5 and 300m respectively. Initial temperature and pressure were set to 2000k or 2273°C and 1 atm respectively.

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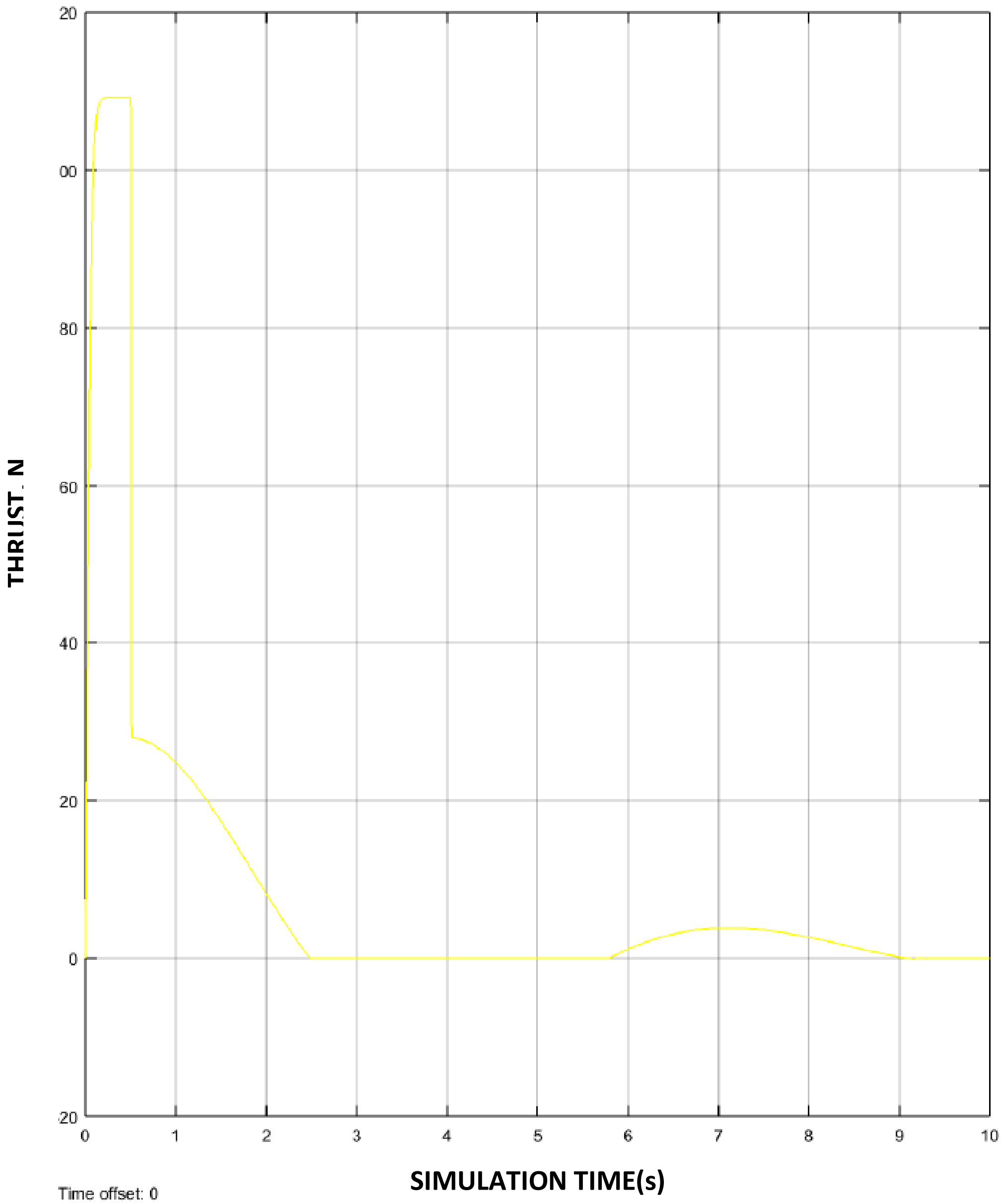

Fig 8. Turbofan Engine Thrust

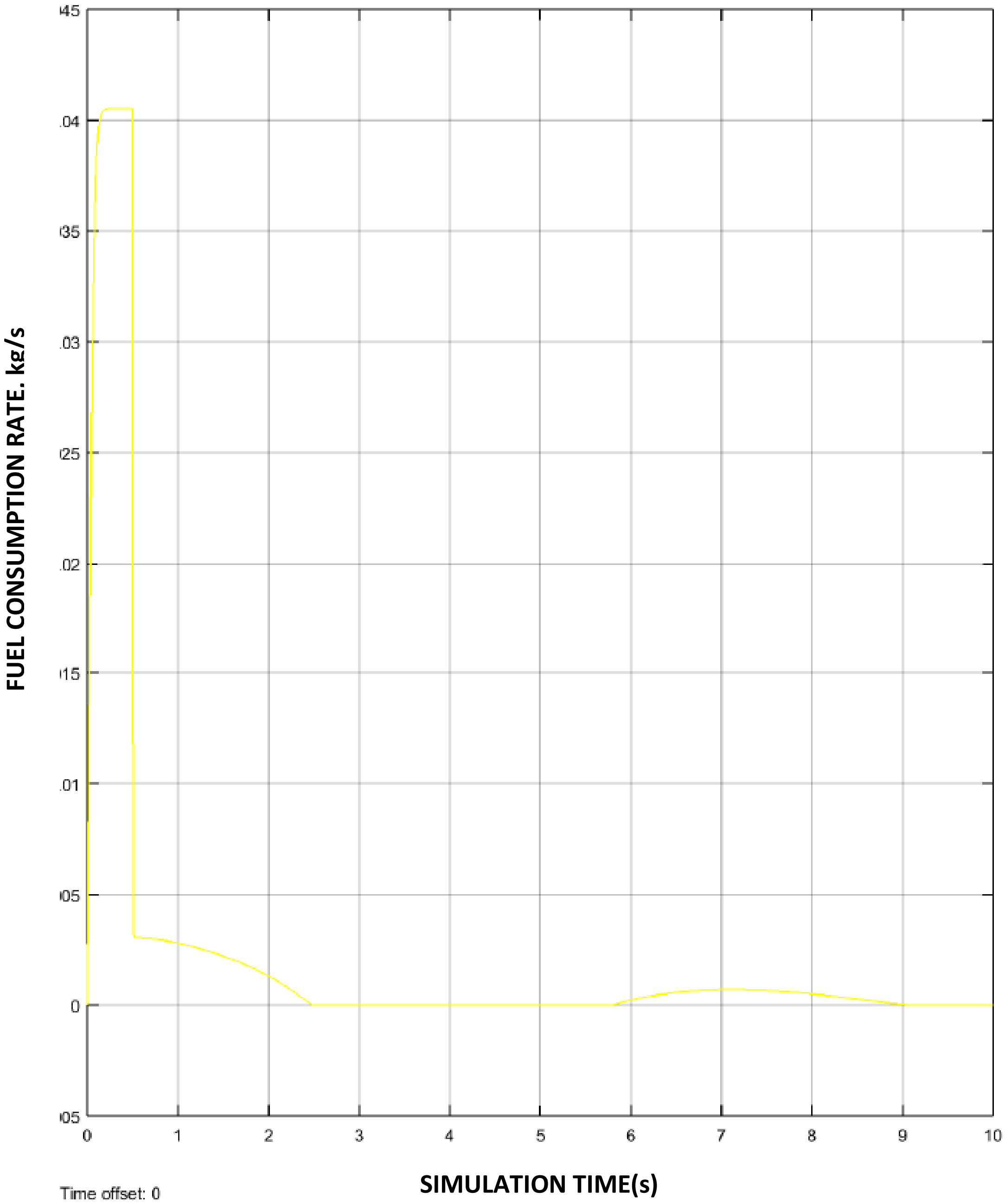

Fig 9. Turbofan Engine Specific Fuel Consumption, Maximum is 0.041kg/s

Thrust specific fuel consumption (TSFC) = $\frac{M_f}{F} = \frac{0.041}{109}$ = 0.00038kg/s/N

The following results were obtained when values of throttle position, Mach number, velocity, bypass ratio, final altitude were chosen to be 120, 2.0, 45 m/s, 0.5 and 600m respectively. Initial temperature and pressure were set to 2000k or 2273°C and 1 atm respectively.

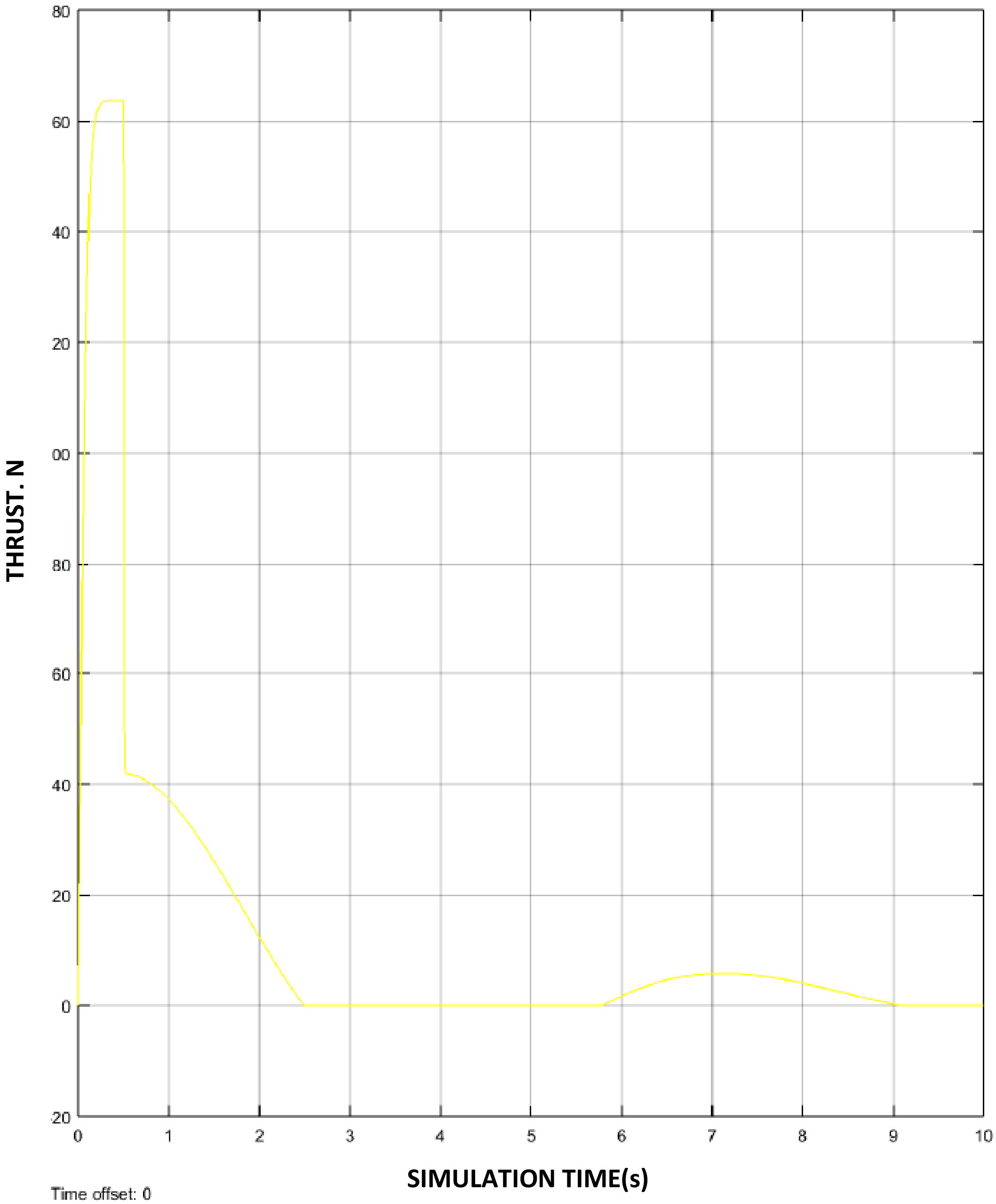

Fig 10. Turbofan Engine Thrust, Maximum 162N

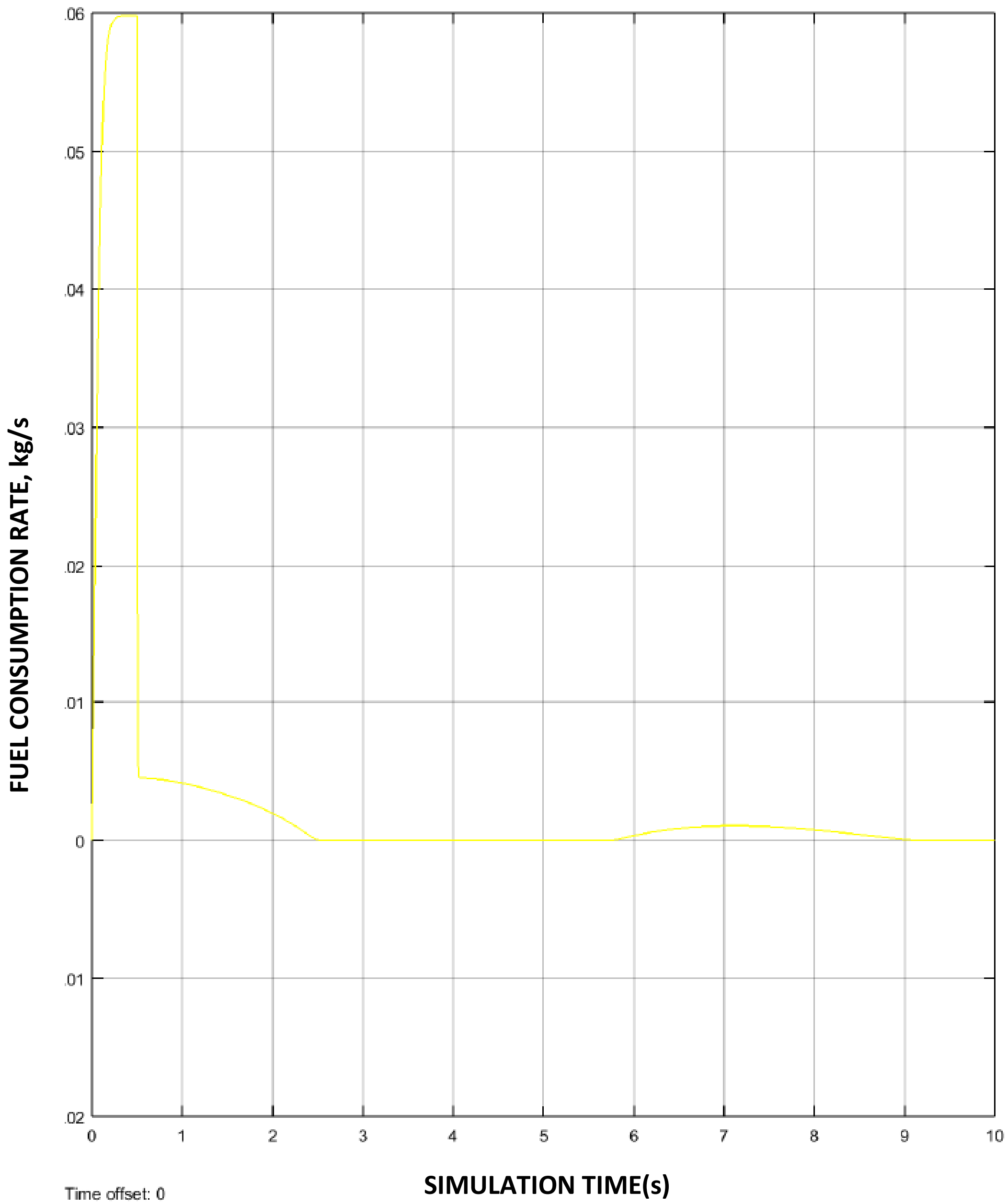

Fig 11. Turbofan Engine Specific Fuel Consumption, Maximum is 0.06kg/s

Thrust specific fuel consumption (TSFC) = $\frac{M_f}{F} = \frac{0.06}{164}$ = 0.00037kg/s/N

V. DISCUSSION

Determination of propulsive thrust and specific fuel consumption of a turbofan engine system using simulation method was investigated using simulink in matlab. simulink in the matlab command window contains propulsion block models that were used to represent all the elements of a turbofan engine system model according to Fig 3 to Fig 5 and Table 2 to Table 7. The initial values of throttle position, Mach number, static pressure and bypass ratio were chosen to be 1, 1.0, 1atm, 0.5 respectively. Initial temperature and pressure were set to 2000k or 2273°C and 1 atm respectively. Using Ode23t solver, simulation was allowed to run for 10seconds, according to Table1.0. According to Fig 6 and Fig 7, results at the stated condition showed that propulsive thrust and specific fuel consumption of turbofan engine system were found to be 0.064N and 0.0000252kg/s while the thrust specific fuel consumption (TSFC) was 0.00039kg/s/N.

Furthermore, the values of throttle position, Mach number, velocity, bypass ratio, final altitude were adjusted to be 30, 0.2, 20 m/s, 0.5 and 300m respectively. According to Fig 8 and Fig 9, results at the stated condition showed that the propulsive thrust and specific fuel consumption of turbofan engine system were found to be 109N and 0.041kg/s while the thrust specific fuel consumption (TSFC) was 0.00038kg/s/N. Similarly, the values of throttle position, Mach number, velocity, bypass ratio, final altitude were further adjusted to be 120, 2.0, 45 m/s, 0.5 and 600m respectively. According to Fig 10 and Fig 11, findings at the stated condition revealed that the propulsive thrust and specific fuel consumption of turbofan engine system were found to be 164N and 0.06kg/s while the thrust specific fuel consumption (TSFC) was 0.00037kg/s/N. Results suggested that turbofan engine system propulsive thrust and specific fuel consumption are functions of throttle position, mach number, velocity and altitude. Increasing values of the mentioned parameters increases propulsive thrust and specific fuel consumption.

VI. CONCLUSION

Determination of propulsive thrust and specific fuel consumption of a turbofan engine system using simulation method was obviously achieved. Undoubtedly, results revealed that the maximum propulsive thrust and specific fuel consumption of a turbofan engine system were determined to be 164N and 0.06 kg/s respectively.

VII. RECOMMENDATIONS

The following recommendations are suggested based on the study:

1) Since propulsive thrust is a function of specific fuel consumption, optimal value of propulsive thrust that must minimize specific fuel consumption should be chosen.
2) This research could also be done in future using different block design models and other advanced software for generalization.

VIII. LIMITATION OF THE STUDY

In the course of carrying out this research, Determination of propulsive thrust and specific fuel consumption of a turbofan engine system using simulation method, the researchers encountered many hindrances which might cause deviations from actual results. Some of the hindrances includes: modeling and simulation difficulties, lack of electricity, material sourcing, etc.

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DISCLOSURE OF CONFLICT OF INTEREST

This research article is original and the corresponding author hereby confirms that co-authors participated actively in the development of the paper and had read and approved the manuscript with no ethical issues and with declaration of no conflict of interest.

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