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Impact of PID Controller on Propulsive Thrust and Specific Fuel Consumption of a Turbofan Engine System Using Simulation Method

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ABSTRACT

The study, Impact of PID controller on propulsive thrust and specific fuel consumption of a turbofan engine system using simulation method was successfully carried out using simulink in matlab. Turbofan engine system was created using gas turbine propulsion block models. With Ode23t solver and the PID controller connected to the throttle position actuator, simulation was allowed to run for 10seconds. Results showed that propulsive thrust increased from 310N to 470N when PID controller was connected and specific fuel consumption of turbofan engine system also increased from 0.098kg/s to 0.131 kg/s when PID controller was connected to throttle position actuator. This suggested that propulsive thrust of a turbofan engine system could be increased by connecting PID controller to the throttle position actuator. But this must be done on expense of specific fuel consumption. Hence, propulsive thrust and specific fuel consumption of turbofan engine system are functions of throttle position and actuator controller accuracy. Also, study showed that the propulsive thrust is inversely proportional to specific fuel consumption without PID controller and directly proportional when PID controller is connected to throttle position actuator. The paper also computed the standard deviations and variances for the two conditions using Matlab.

Keywords ---- *PID controller, Propulsive thrust, Specific fuel consumption, Throttle position, Simulink, Turbofan engine*

INTRODUCTION

The relationship between the thrusting force required and specific fuel consumption in a turbofan engine system during propulsion has been a major concern or interest of researchers over years.

This paper adopted simulink simulation method with block models. The output of the throttle position actuator is controlled using PID controller and optimization block (continuous RMS) to minimize error and improved performance. Turbofan Engine System block computes the propulsive thrust and the specific fuel consumption (SFC) to the turbofan engine system based on throttle position, Mach number, and altitude.

PID (proportional-integral-derivative) controller is a control loop mechanism employing feedback and capable of calculating error based on desired set points and a measured process variable. It also applies a correction based on proportional, integral and derivative terms. PID controller as per the paper was connected to the turbofan engine system throttle position actuator.

It is generally known that turbofan engine is driven by gas turbine and a mechanical ducted fan; is widely used in aircraft propulsion. According to Ahmad (2020) as cited in Okoye et al., (2023) 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.

According to Aria (2022) as cited in Okoye et al., (2023), explained that 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.

According to Okoye, Obaseki, Olagunju and Ewurum (2023) explained that the 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. Reviewed literatures suggested that the performance of turbofan engine system is measured in terms of propulsive thrust and specific fuel consumption and one of the major causes of poor performance has been attributed to throttle positional errors due to slow response controllers. Hence, this research paper aimed at studying the impact of PID controller on propulsive thrust and specific fuel consumption of a turbofan engine system using simulation method.

METHODOLOGY

The paper adopted simulink in the matlab command window that 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, PID controller, optimization block, Step, Turbofan Engine System, Block type Count, Model Functions. Block ports were connected as shown in Fig 1 to Fig 3 below.

Simulation results were obtained when the initial values of throttle position, Mach number, velocity, bypass ratio, final altitude, temperature and pressure were chosen to be 120, 2.0, 45 m/s, 0.5 and 600m, 2000k or 2273℃ and 1 atm respectively; without the connection of PID controller. Similarly, simulation results were also obtained by maintaining the chosen values of throttle position, Mach number, velocity, bypass ratio, final altitude, temperature and pressure with the connection of PID controller and optimization block to the throttle actuator. 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 system.

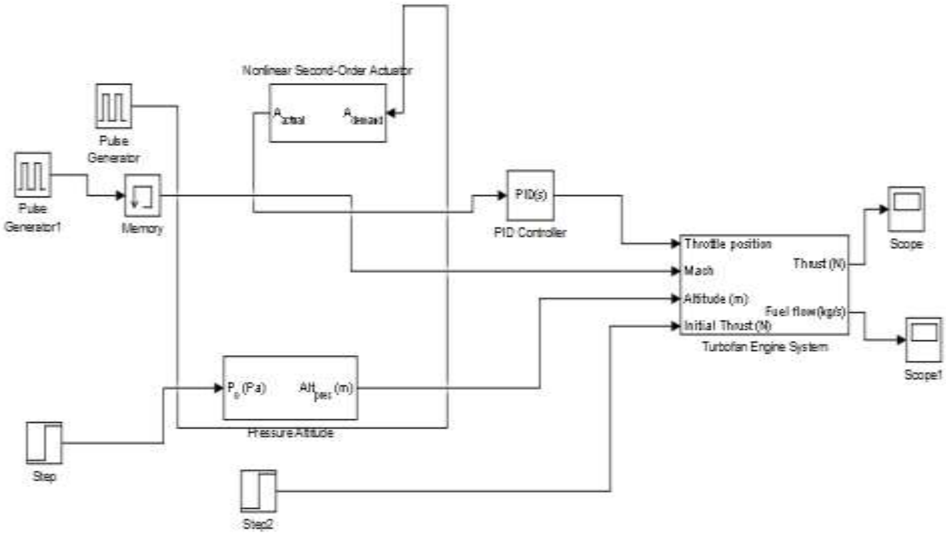

Fig 1: Turbofan Engine System with PID Controller Simulink Model (14-Oct-2023 04:40:23)

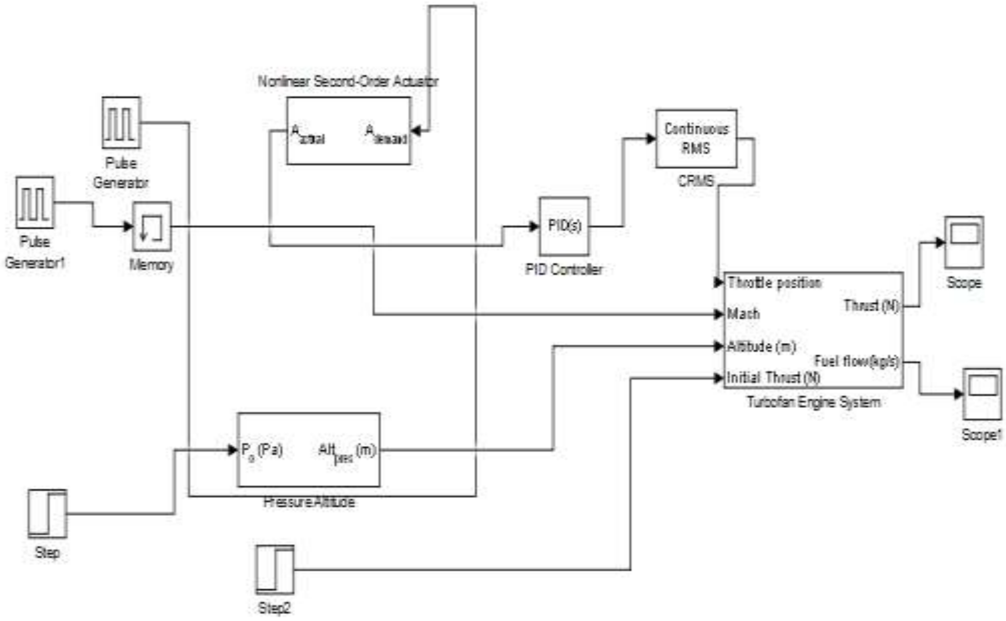

Fig 2: Turbofan Engine System Simulink Model with optimization block (14-Oct-2023 04:20:23)

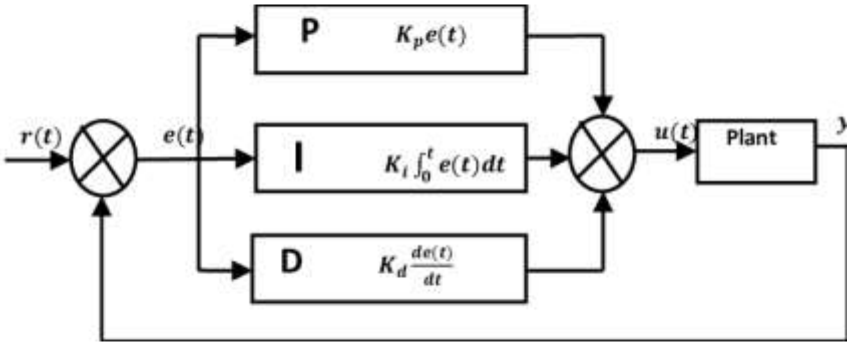

Fig 3: Turbofan Engine System with PID Controller Simulink Model (14-Oct-2023 04:40:2)

The paper adopted a continuous time domain PID controller, having one degree of freedom with forward Euler as the integrator. The filter method is forward Euler.

RESULTS

The following results were obtained when simulation was run without PID controller and Optimization blocks connections.

Table 1: Throttle Position, Mach number, Velocity, Bypass ratio, Altitude, Temperature, Pressure, Propulsive Thrust and Specific Fuel Consumption of Turbofan Engine System without PID Connection.

Throttle Position(degrees)	**Mach Number**	**Velocity(m/s)**	**Bypass Ratio**	**Final Altitude(m)**	**Temperature (℃)**	**Pressure(atm)**	**Propulsive Thrust (N)**	**Specific Fuel Consumption (kg/s)**
120	2.0	45	0.5	600	2273	1	310	0.098

The following results were obtained when simulation was run with PID controller and Optimization blocks connections.

Table 2: Throttle Position, Mach number, Velocity, Bypass ratio, Altitude, Temperature, Pressure, Propulsive Thrust and Specific Fuel Consumption of Turbofan Engine System with PID and Optimization block Connections

Throttle Position(degrees)	**Mach Number**	**Velocity(m/s)**	**Bypass Ratio**	**Final Altitude(m)**	**Temperature (℃)**	**Pressure(atm)**	**Propulsive Thrust (N)**	**Specific Fuel Consumption (kg/s)**
120	2.0	45	0.5	600	2273	1	470	0.131

The standard deviation and variance in propulsive thrust for the turbofan engine system due to PID controller connection were observed using matlab as shown below.

>> STD (A, B)

ans = 79.9579

>> var (A,B)

ans = 6.3933e+03

The standard deviation and variance in specific fuel consumption for the turbofan engine system due to PID controller connection were observed using matlab as shown below.

>> std (A,B)

ans =   0.0318

>> var (A,B)

ans = 0.0010

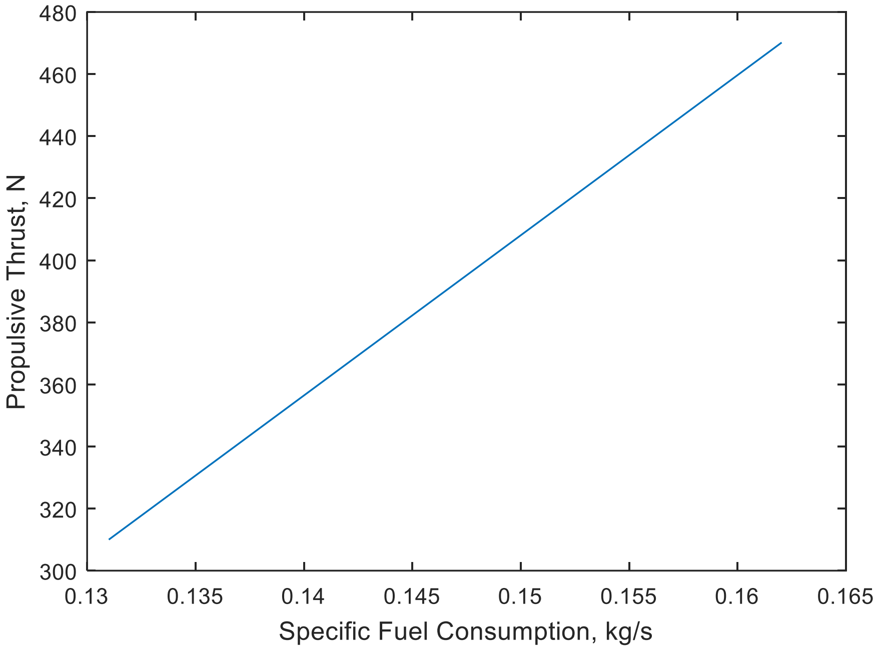

Fig 4: Matlab Graph of Propulsive Thrust against Specific Fuel Consumption with PID Connection

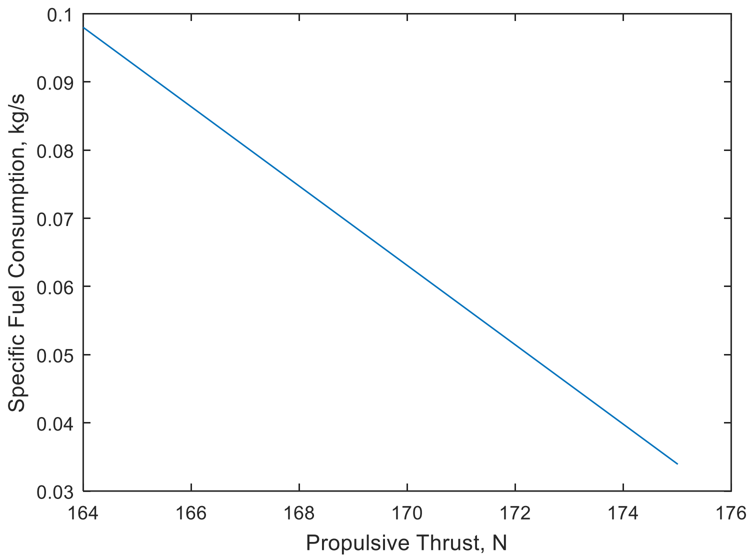

Fig 5: Matlab Graph of Specific Fuel Consumption against Propulsive Thrust without PID Connection

MATLAB Script for the Graph above on 28-Oct-2023 10:23:28

```
function createfigure1(X1, Y1)

%CREATEFIGURE1(X1, Y1)

%  X1:  vector of x data

%  Y1:  vector of y data

% Create figure

figure1 = figure;

% Create axes

axes1 = axes('Parent',figure1);
```

```
box(axes1,'on');
hold(axes1,'on');
% Create plot
plot(X1,Y1);
% Create xlabel
xlabel({'Propulsive Thrust, N'});
% Create ylabel
ylabel({'Specific Fuel Consumption, kg/s'});
```

DISCUSSION

Impact of PID controller on propulsive thrust and specific fuel consumption of a turbofan engine system using simulation method was successfully investigated. 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 1 to Fig 3**. Results showed that propulsive thrust increased from 310N to 470N when PID controller was connected. Specific fuel consumption of turbofan engine system also increased from 0.098kg/s to 0.131 kg/s when PID controller was connected to throttle position actuator according to **table 1 and table 2**. Results suggested that propulsive thrust of a turbofan engine system could be increased by connecting PID controller to the throttle position actuator. But this must be done on expense of specific fuel consumption. Therefore, optimal value of propulsive thrust that must minimize specific fuel consumption should be modulated with PID controller.

According to **Fig 4 and Fig 5**, propulsive thrust is inversely proportional to specific fuel consumption without PID controller and directly proportional when PID controller is connected to throttle position actuator. The paper also computed the standard deviations and variances for the two conditions.

CONCLUSION

Impact of PID controller on propulsive thrust and specific fuel consumption of a turbofan engine system using simulation method was obviously achieved. Propulsive thrust is inversely proportional to specific fuel consumption without PID controller and directly proportional when PID controller is connected to throttle position actuator. Hence, optimal value of propulsive thrust that must minimize specific fuel consumption should be modulated with PID controller.

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 modulated with PID controller.

2) This research could also be done in future using different block design models, effective PID tuning and other advanced software for generalization.

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