

Modeling and Performance Simulation of a Micro Turbojet Engine Using Flownex

G. Jims John Wessley^{1*} and Swati Chauhan²

¹Aerospace Engineering, Karunya Institute of Technology and Sciences, Karunya Nagar – 641114, Coimbatore, Tamil Nadu, India; jims_john@karunya.edu

²Alpine Institute of Aeronautics, Prem Nagar – 248007, Dehradun, Uttarakhand, India; alpine.swati2011@gmail.com

Abstract

Objectives: The study presents the results of modelling and analysis of a micro turbojet engine that can develop thrust in the range of 4 kN, that is sufficient to propel small UAVs and Drones. The modelling and simulation is carried out in Flownex simulation environment which is a powerful one-dimensional tool commercially available to analyze the performance of engine components by establishing network linkages between the components. **Methods/Findings:** This study also uses the “Turbo power match” module for matching of power produced between the turbine and compressor components in the engine assembly as well as “Adiabatic flame element” module to estimate the combustion parameters in the engine. The results show that the analyzed system produces a thrust of 3.79 kN at an inlet air pressure of 1.01 bar. The burnt gases in the combustor are found to reach a maximum of 556.17 K which permits the use of existing materials in the construction of this engine. The one-dimensional eliminates the time needed for analysis and hence enables quick implementation of design parameters resulting in cost reduction and time delay in manufacturing of engines. **Application:** This performance analysis provides vital information needed for micro turbine engine manufacturers and drone designers and hence plays a vital role in the future propulsion of UAVs and Drones.

Keywords: Adiabatic Flame Temperature, Drone Propulsion, Flownex, Modeling and simulation, Turbojet Engine, Turbo Power Match

1. Introduction

Modelling and simulation of the dynamic behaviour of aircraft engine to optimize its performance, even manufacturing a prototype for actual testing leads to better results, cost cutting and time saving. In this process it is essential to consider the complex dynamic behaviour of the interactions between engine stages like and low pressure compressors, turbines, nozzle exit etc.,. In addition, this analysis results in obtaining first-hand information on the parameters that affects the optimal working of the engine and enables precise modelling of materials and complex blade shapes. The dynamic behaviour analysis of these engine mechanisms enables increase in jet engine performance through detailed analysis of systems in the engine and fine-tuning, resulting in more power with

less fuel. It also helps to enhance the design by taking more phenomena into account, which can be important to assure safety as well as simulate the global jet engine system coupled to detailed component analysis. The comprehensive modelling and detailed outcomes on the performance of a turbojet engine suitable to propel future UAVs and Drones that necessitates thrust in the range of 4 kN is presented in this study.

For more than a decade, the manufacturing and assembling of complex systems like engines has been made more simple by the use of modelling and simulation software that gives enormous freedom to the designer to make changes and analyze the performance beforehand. Similarly, the use of software in Micro turbine engine design and analysis applied to drone propulsion has been extensively used by the researchers. However, there is a

*Author for correspondence

handful of reported work available in the open literature on the modeling and analysis of turbojet engine assembly. Some of the relevant works carried out by researchers related to the present work is given below.

In¹ carried out research on the analysis of the performance of a Titanium alloy-based turbine and compressor in a jet engine by estimating the maximum stress experienced in the components and the total deformation undergone under the test conditions. From the study, it is seen that the maximum compressive and tensile strengths of the turbine and compressor were found to be 930 MPa and 1070 MPa. In² carried out the performance analysis of a single-spool and two-spool engine and compared their performances. From the study, it is evident that the cooling of turbine causes huge impact on the net load which is found to be highly nonlinear. It is also observed that the overall efficiency is nearly 5% for a Turbine Inlet Temperature (TIT) of 1600K while the optimum efficiency is obtained when the reheat combustor is placed at nearly 10%-20% of the expansion section. He also configured various types of engines and proposed numerical models for the analysis of Jet engines. In³ performed study on a turbocharger with a newly developed combustion chamber obtained from an automobile. It is evident from the study that equivalence ratio and the quality of mixing of primary and secondary air influence the combustion quality and the speed of the engine. In⁴ used Siemens NX 8.0 to design and analyze an annular combustion chamber with low bypass flow in a turbofan engine while simulating the aerodynamic flow characteristics using ANSYS 14.5. The simulation study shows that the Specific Fuel Consumption (SFC) can be reduced with a marginal reduction in the size of the combustor and regulation of temperature and pressure loss in the combustor. In⁵ developed a cost-effective micro jet engine that is capable of generating 60 kN to 70 kN needed for powering helicopters. The speed of the engine in the analysis was assumed to be around 50,000 rpm to 70,000 rpm. The novelty of the engine was the use of a bigger compressor and turbine than the normal engines of this category. In⁶ used CATIA and ANSYS to design and analyze a turbojet engine. The impeller of the compressor was designed to develop 2.9 bar at 8000 rpm with a combustion chamber of 320 mm outer diameter and 240 mm inner diameter.

It is seen from the above literatures that the modeling and simulation of a complete engine as a whole is not available. Hence, this study aims at filling the gap by carrying out the performance analysis of a micro turbojet

engine assembly using Flownex software. The outcomes of this study will be very much useful for drone manufacturers and engine assemblers for drone propulsion

2. Modelling of Turbojet Engine Subsystems

Flownex SE is developed in order to facilitate design and one-dimensional analysis of aerospace propulsion engines. This modelling and analysis tool can be used to perform modelling as well as on-design and off-design and simulation of gas turbine engine and its networks. The main parts of a gas turbine engine are the air inlet, impeller and Compressor, the combustion chamber, single spool turbine, exit nozzle, pipes, and heat transfer elements are chosen based on the analysis from a library in the software. The model developed using the various engine components from the library and the network developed to analyze the engine performance is shown in Figure 1. The boundary conditions for all the subsystems in the inlet and exit conditions are connected through nodes to ensure smooth and essential connectivity and flow between the subsystems.

Table 1. Input parameters used in the Flownex analysis

Parameters	Name of the Parameters	Values	Unit
Ambient conditions	Ambient Temperature	288.15	K
	Ambient Pressure	101.325	kPa
Model Parameters	Combustor Length	250	mm
	Combustor Diameter	250	mm
	Combustor Thickness	1	mm
	Nozzle area	0.039722	m ²
	Mechanical Efficiency	98	%
	Combustor Pressure drop	10	%

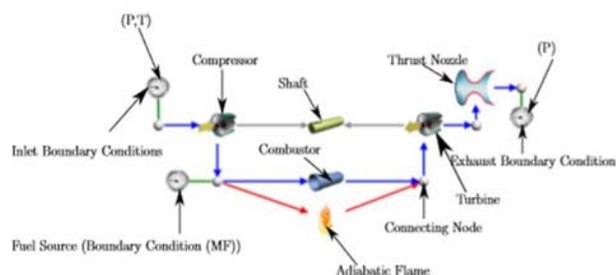


Figure 1. Engine components modeling using Flownex.

2.1 Setting up Parameters for Analysis

The input parameters used in the Flownex simulation for analyzing the micro turbojet engine is shown in Table 1. The combustor thickness was assumed to be 1 mm as the geometry of the combustor is not considered for estimation of adiabatic flame temperature in this one-dimensional analysis. All the simulations were assumed to be conducted in the ground conditions only⁷.

2.1.1 Matching of Components in Flownex Model

The next important step in the analysis is that the components and other systems in the engine need to be matched^{8,9}. Flownex direct design function and the turbo power match tools are used for doing the same. The function tool in Flownex with “SE design” performs automatic computation on the sizing and matching of the subsystems to obtain system conditions. The component matching is done by the tool with equal number of constrains and independent variables by using matrix iteration method. The equality constraints are set as shaft excess power and turbine flow rate whereas the turbine geometry and the rotational speed are chosen as independent variables.

Turbo Power Match (TPM) is another tool used for matching the engine components which can be done both in the steady state and transient mode. The execution of matching tool to match the power obtained from the engine in the present study is shown in Figure 2.

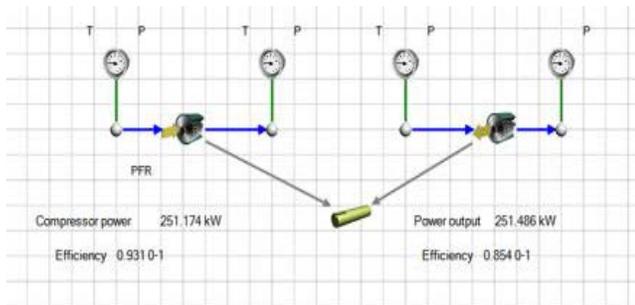


Figure 2. Matching of turbo power in Flownex simulation.

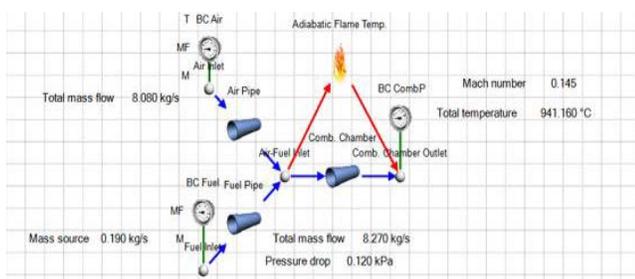


Figure 3. Adiabatic flame simulation of the engine assembly.

The excess shaft power is expressed by the relation⁹

$$PE_{\text{excess}} = \eta_m * \Sigma P_{\text{positive}} - \Sigma P_{\text{Negative}}$$

where η_m is the mechanical efficiency, $\Sigma P_{\text{Positive}}$ is the power supplied by turbine and $\Sigma P_{\text{Negative}}$ is the power required by the compressor.

2.1.2 Simulation of Engine Assembly Performance

The Adiabatic Flame element in the module, estimates the composition of the fuel-air mixture and the maximum temperature arrived at by the chemical mixture based on chemical reaction. Since the combustion chamber dimensions are not considered in this analysis, the program does not calculate the mass balance or pressure drop across the chamber. However, the mass balance and pressure drop calculation is done by Flownex SE. This can be achieved by placing any Flownex fluid flow component along with the Adiabatic Flame element as shown below in Figure 3.

Table 2. Performance analysis of micro turbojet engine at various inlet pressures

Inlet Pressure (Bar)	Max Temperature (°C)	Exit Mach	Mass Source (kg/s)	Thrust (kN)
0.98	554.82	0.290	8.444	3.579
0.99	555.27	0.837	8.535	3.651
1.00	555.72	0.845	8.625	3.722
1.01	556.17	0.853	8.715	3.794
1.02	556.61	0.861	8.805	3.866
1.03	557.05	0.869	8.894	3.938
1.10	561.34	0.917	9.417	4.379
1.20	565.26	0.991	10.272	5.121
1.30	568.92	1.000	11.106	5.871
1.40	572.32	1.000	11.938	6.621
1.50	575.49	1.000	12.770	7.372

3. Results and Discussion

The complete assembly with dimensions, performance chart and mixed fluid is drawn in Flownex SE Drawing page and system performance is analyzed by changing ambient conditions of the system as shown in Figure 4.

The system analysis is carried out for different inlet conditions of pressure and the results are tabulated in Table 2. It is observed that, as ambient pressure decreased below 1 bar, the maximum temperature; mass source, exit Mach and thrust also decreased but increase in ambi-

Table 3. Power output of turbine and compressor for various ambient pressure

Inlet Pressure (Bar)	Exit Temperature (°C)	Compressor Power (kW)	Power Output (kW)	Mach	Thrust (kN)	Total Temperature (°C)
1	397.841	697.684	699.940	0.839	3.672	557.09
1.01	396.698	704.883	708.177	0.847	3.743	557.52
1.02	395.659	712.077	716.314	0.855	3.814	557.95
1.03	394.423	719.253	724.452	0.863	3.886	558.38
1.1	386.495	769.198	779.880	0.918	4.394	561.29

ent pressure above 1 bar the maximum temperature, mass source, exit Mach and thrust also increases. In this study, the analysis is performed for inlet pressure 0.98 to 1.5 bars to check the response of the system. The highest temperature reached during the analysis is found to be within 1000°C for a thrust range of 3.579 kN to 7.372 kN, which indicates that our design requirement is met and the design is safe.

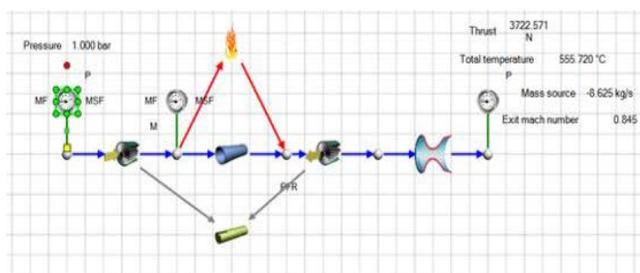


Figure 4. Turbojet system performance analyses for 1 bar.

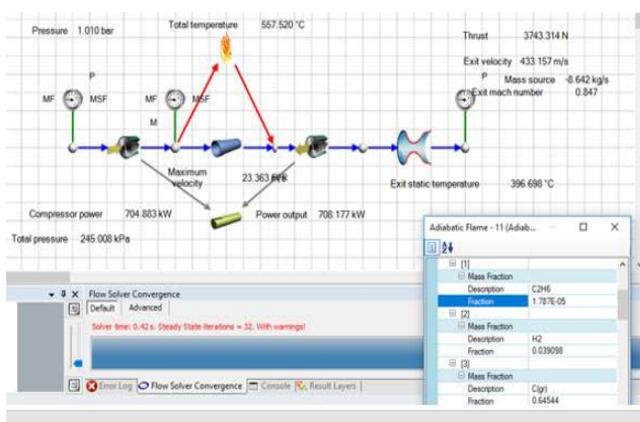


Figure 5. Power estimation in compressor and turbine.

In the single spool turbojet engine, the compressor is run by the power developed in the turbine. Hence, to sustain the compression process and engine operation, the turbine is expected to produce more power than the compressor requirement at all inlet conditions. The power generated in

the turbine and the energy used by the compressor for various ambient conditions is shown in Figure 5.

It is observed that as ambient pressure increases, the power generated by the turbine also increases, thereby providing the work required by the compressor. The maximum velocity of flow in the combustor is found to be 23.363 m/s, while the exit velocity is 433.157 m/s which is around 0.847 Mach (Subsonic Exit). The results of power output from Turbine and Thrust compressor as computed by the simulation in Flownex is summarized in Table 3.

4. Conclusions

In this study, Flownex simulation programme has been used for component matching and investigation of the engine. The simulation results show that, Flownex can be effectively used to design and simulate the working of a gas turbine engine. The results from this study will be used to further investigate the successful integration of modified compressor and turbine stages into the turbojet engines.

- The output thrust of the engine analyzed in this study is found to be 3.79 kN at an inlet air pressure of 1.01 bar at an inlet flow rate of 8.71 kg/s.
- The maximum temperature experienced during the performance analysis is found to be 556.17 K, which implies that the available materials in market can be used for the construction of these engines.

This study provides a one dimensional analysis of a micro turbojet engine that will be used to propel future UAVs having a thrust requirement in the range of 4 kN.

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6. References

1. Peruri S, Murty KLN, Jayananda Kumar T. Design and Analysis of Micro Gas Turbine, *International Journal of Advances in Engineering Research*. 2015; 10(3):88–105.
2. Nada T. Performance characterization of different configuration of Gas Turbine Engines, *Propulsion and Power Research*. 2014; 3:121–32. <https://doi.org/10.1016/j.jprr.2014.07.005>.
3. Abdulkarim Jaff JM, Tahir MH, Tahir YF, Sleman SS, Abdullah HB. Contribution in development of design and performance of turbine jet engine, *ISOR Journal of Mechanical and Civil Engineering*. 2015; 12(6):14–23.
4. Priyant Mark C, Selwyn A. Design and analysis of annular combustion chamber of a low bypass turbofan engine in a jet trainer aircraft, *Propulsion and Power Research*. 2016; 5(2):97–107. <https://doi.org/10.1016/j.jprr.2016.04.001>.
5. Raviteja V, Kashivishwanath T, Ashok kumar V, Venugopal N, Pavan Kumar R. Design and fabrication of model jet engine (Sivani 150), *International Journal of Modern Engineering Research*. 2015; 5(12):25–33.
6. Virdi PS, Khan MS, Nelroy Pereira, Suresh KV, D'Silva RS. Design and fabrication of major components of turbojet engine, *Energy and Power*. 2017; 7(5):130–35.
7. Farokhi S. *Aircraft Propulsion*. Second Edition, John Wiley & Sons, Ltd.; 2014.
8. Treager IE. *Aircraft Gas Turbine Engine Technology*. Third Edition, Tata McGraw-Hill Publishing Company Limited, New Delhi; 2009.
9. Saravanamuttoo H. Cohen, GFC Rogers. *Gas Turbine Theory*. Fifth Edition, Pearson; 2014.
10. Mattingly JD. *Elements of Gas Turbine Propulsion*. Indian Edition, Tata McGraw-Hill Publishing Company Limited, New Delhi; 2014.