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Comprehensive Analysis of Turboprop Engine Performance Under Diverse Flight Conditions with Pressure Ratio as an Efficiency Parameter Utilizing the Digital Twin Methodology

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Abstract

Traditional mechanical dynamic models and empirical testing methods present inherent limitations in the performance analysis of turboprop engines, particularly regarding scalability, real-time data integration, and high-fidelity three-dimensional modeling. To overcome these constraints, this study presents a comprehensive diagnostic analysis focused on compressor pressure ratio optimization utilizing a digital twin (DT) methodology. The research aims to enhance the multi-objective efficiency of turboprop engines, with a specific focus on short-haul aviation profiles. By utilizing the digital twin paradigm, compressor and turbine performance maps were dynamically characterized to evaluate the coupled effects of operating speed, mass flow rate, and isentropic efficiency under diverse operational envelopes. The developed virtual model enables the high-fidelity simulation of real-time pressure ratio fluctuations across variable flight scenarios and ambient environmental gradients, including altitude, atmospheric temperature, and pressure. Validated under rigorous flight conditions, the empirical findings underscore the critical role of the pressure ratio in maximizing engine efficiency and demonstrate that its optimal values can be precisely determined through this advanced prognostic framework. In contrast to conventional, static approaches, this study provides a highly adaptable and sensitive methodology for evaluating propulsion performance during dynamic flight phases. Ultimately, this research offers a valuable contribution to enhancing the thermal and propulsive efficiency of turboprop configurations while establishing a scalable design framework for next-generation aerospace propulsion systems.

1. Introduction

The increasing need for efficiency and sustainability requirements in the aviation industry necessitates the optimization of gas turbine engines. Alternative fuels have also not been considered an environmental concern for gas turbine engines (Yildiz et al., 2022). These factors have become the dominant criteria for the design of future aircraft engines. The evolution of simple cycle drive gas turbines continues, with the focus now on reducing fuel consumption, lowering emissions, and reducing noise (McDonald & Rodgers, 2009). Turboprop engines are a type of simple cycle propulsion gas turbine engine, and the Turboprop Engine Model Created in the GasTurb Application is shown in Fig. 1. Evaluating the performance of turboprop engines under diverse flight conditions is an important part of aviation propulsion research. These engines offer the advantages of a high power-to-weight ratio at low Mach numbers, low fuel consumption, superior propulsion efficiency, and strong takeoff performance (Han et al., 2025). Providing efficient thrust with high air flow rate and low jet speed, turboprop engines are preferred in regional passenger, military reconnaissance, and short to medium range aircraft due to their fuel economy advantage (Walsh & Fletcher, 2004). Continuous monitoring of critical parameters, such as pressure ratio, is important for high performance, long life, and optimization studies in these engines with a wide range of applications.

Pressure ratio is a design choice used in aerothermodynamic cycle analysis in gas turbine engines. It is a dimensionless parameter that defines the relationship between the inlet and outlet pressures of the engine's compressor, combustion chamber, turbine, or exhaust (Dinc, 2016).

The compressor pressure ratio (CPR) directly affects the performance of gas turbines and combined cycles; increasing this ratio increases the overall thermal efficiency, especially in gas turbine engines, up to an optimum point that can vary depending on the load (Thamir K. Ibrahim1,*, M. M. Rahman1,2, 2012). Higher CPRs also increase the compressor outlet temperature, affecting material limits and emissions (R. von der Bank1, S. Donnerhack2, 2016). Turbine pressure ratio (TPR) is required to run the compressor or generate additional power (English & Silvern, 1952) and an optimum TPR is usually found to maximize overall system performance (Ishii, 2009). Variations in the TPR affect the turbine output and therefore the net power and efficiency of the engine or combined cycle (Ishii, 2009).

The literature on the relationship between engine performance and pressure ratio and optimization studies based on this parameter has evolved with studies from different periods. A study in 1949 stated that the efficiency of ideal turboprop engines is basically a function of the cycle pressure ratio, but that additional components, such as heat exchangers and intercoolers, are difficult to adapt to these engines (Zucrow, 1949). A study published in 1957 showed that a significant reduction in specific fuel consumption (SFC) in turboprop engines with a low CPR was achieved by switching to a higher CPR (Davison, 1957). In cycle studies in 1984, it was found that for pressure ratios between 20 and 40, the minimum fuel consumption difference for the combustion chamber outlet temperature range was much less than for a given total pressure ratio (Golchin et al., 2020). An evaluation in 1986 indicated that the optimum SFC and specific power of recuperative cycle engines are achieved at a lower CPR than simple cycle engines (Hirschkron & Russo, 1986). In 1992, a researcher estimated that a high-pressure ratio intercooled turboprop engine could achieve thermal efficiencies of over 40% with current component efficiencies and a total CPR of 66 (Rodgers, 1992). A 1999 study emphasized that turbine efficiency decreases in single-stage high-pressure turbine (HPT) applications when the high-pressure compressor (HPC) pressure ratio is greater than 9, that the increase in Mach numbers at the blade trailing edge as the HPC pressure ratio increases reduces HPT efficiency, and that the CPR should be increased to reduce SFC (Ahmad & Mirzamoghadam, 1999). In a paper published in 2008, he observed that performance optimization of conventional turboprop engines differs from that of intercooled and recuperated engines in that the maximum specific power of simple engines is low and the minimum SFC is at high pressure ratios (Andriani & Ghezzi, 2008). A 2009 study highlighted the challenges of achieving higher CPRs, noting that the core throughput coefficient tends to increase with CPR and that the optimum CPR in cruise is about 11. They also stated that the increase in CPR leads to a loss in equivalent shaft power (ESHP) while providing a benefit in SFC, and that the optimization focuses on takeoff power at low CPR values (Ghenaiet & Boulekraa, 2009). A study in 2020 found that specific impulse and SFC reached their best values when the compression ratio was between 10 and 15, while overall engine efficiency was better under conditions of low turbine inlet temperature and high compression ratio (Durmuş & Akyüz, 2020). A paper published in 2021 stated that more thrust could be achieved by transferring the extra power to the turbine shaft, but this could result in changes to the aerodynamic characteristics of the aircraft and the design point of the engine (Pateropoulos et al., 2021). Modeling studies on biogas-fueled micro gas turbines have shown that increasing TIT improves thermodynamic efficiency and enhances overall system performance (Oreijah et al., 2025). In contrast,

the effect of CPR on efficiency follows a parabolic trend: low CPR results in inefficient compression, whereas excessively high CPR increases compression work and losses, reducing overall efficiency. Therefore, each turbine design and operating condition has an optimum CPR that maximizes efficiency (Oreijah et al., 2025). In heavy-duty gas turbines, performance also depends on ambient conditions and load demand. For example, operating below the nominal TIT (under-firing) reduces power output, while compressor fouling decreases both CPR and compressor air mass flow rate, leading to performance deterioration (Park et al., 2024).

According to the literature review, the effect of pressure ratio on the performance of turboprop engines varies depending on the engine type and the specific parameter under investigation. Early studies indicated that higher cycle pressure ratios improve air cycle efficiency and that higher pressure ratios are required for maximum performance as the turbine inlet temperature rises. It has also been observed that moving to higher CPRs results in a significant reduction in fuel economy and an increase in specific power. Some studies have shown that the minimum fuel consumption for the engine is achieved at a given pressure ratio, but as the OPR increases, the engine core becomes smaller, and component efficiencies can vary. It has been emphasized that increasing the HPC pressure ratio can lead to a reduction in HPT efficiency, but in general, the CPR should be increased to reduce SFC. However, more recent assessments reveal that this effect is not always linear or uniform. In particular, increasing the CPR in small turboprop engines has been shown to increase overall efficiency despite a reduction in engine thrust, while increasing the CPR in another cargo aircraft turboprop engine has been observed to reduce overall efficiency. Exergy analysis shows that the exergy efficiency of components such as the compressor and combustion chamber can increase with increasing CPR, but the exergy efficiency of the gas turbine can decrease. It was also noted that for turboprop engine combustion chambers, increasing CPR can positively affect exergy efficiency, but the increase in turbine inlet temperature as the OPR increases can reduce thermal and overall efficiencies while decreasing SFC. Overall, the effect of pressure ratio on turboprop engine performance is a complex interaction with other design and operating parameters, such as propeller efficiency and turbine inlet temperature, and may exhibit different optimum points according to the specific application of the engine and target performance criteria.

Current methods used in optimization studies based on pressure ratio have significant shortcomings. Often based on theoretical assumptions or parametric analyses based on simple assumptions, they may fail to fully reflect the actual operational complexity and dynamic behavior of the engine. The datasets used are often pre-calculated or derived from limited test points, resulting in their inability to cover a wide range of operational or long-term real-time operating modes. Even machine learning models can lack real-time operational feedback mechanisms, as they are often trained on limited or pre-generated data sets. These limitations create a significant gap for critical applications such as real-time detection and proactive maintenance of instantaneous deviations in engine performance or potential failures. The digital twin method, a method that can overcome the shortcomings of this study, is proposed (Tekin & Yildiz, 2026).

Digital twin technology is a technology based on the concept of replicating real-world events in real time in a virtual environment by creating a digital copy of a physical entity (Söderäng et al., 2022). This technology is used in various processes at component, system, and vehicle levels in the aerospace industry (Dişlitaş et al., 2023). While high implementation costs and integration challenges in the early design phase are current barriers in the industry, the digital twin method is expected to significantly improve overall efficiency in this area. Digital twin technology enables the early identification of performance issues and the development of appropriate control approaches through simulations using a virtual representation of the engine without the need for prototype production (Nacak & Yildiz, 2024). Building upon these control strategies, recent studies reported in the literature demonstrate that digital twin systems can serve not only as passive monitoring or fault detection tools but also as active closed-loop control mechanisms. In such frameworks, critical engine parameters, including exhaust gas temperature (EGT) and fuel flow, are regulated in real time to enhance engine thermal safety and operational stability (Tekin et al., 2026).

The applications of digital twin technology in the field of performance control and prediction in internal combustion engines are evolving through various studies. In 2018, they conducted a study on using digital twin technology to simulate various physical processes and operating modes in engine systems for virtual testing and development, intending to reduce testing times and costs (Malozemov et al., 2018). One of the studies on engine performance, especially the effect of compression ratio, using the digital twin method, was carried out in 2021. In this study, the digital twin method is used to optimize the performance of the OPLVCR engine, a variable compression ratio (VCR) internal combustion engine (Guan vd., 2021). Recently, in 2024, they developed a digital twin technology for real-time prediction and control of in-cylinder combustion by integrating machine learning and a data-driven 0-D model (Hu et al., 2024). These studies demonstrate that the digital twin method assumes an increasingly critical role both in virtual testing and development phases and in real-time operational prediction, control, and optimization of engine performance.

The simulation and analysis of the virtual engine model created using the digital twin method is usually based on performance maps revealing the behavior of engine components (Tsoutsanis et al., 2015). Compressor maps generally demonstrate the pressure ratio, corrected mass flow rate, isentropic efficiency and various corrected rotational speeds. Supplementary coordinates are used to resolve ambiguities in the map (Tsoutsanis et al., 2014). The map also includes the surge line, which defines the stability limit of the compressor (Sethi et al., 2013). Turbine maps include similar parameters and often operate in choked conditions. These maps ensure that the virtual model accurately reflects the current performance state of the real engine (Tsoutsanis et al., 2015). Thus, the map based virtual model, refreshed in real time based on real-time or historical data, makes an important contribution to the digital twin modeling process by providing a dependable basis for accurately predicting the future performance of the engine, analyzing current failures, and optimizing maintenance activities (Tsoutsanis et al., 2014). In the methodology section, the previously mentioned compressor and turbine maps are used to analyze the effect of pressure ratio on engine performance.

These performance maps are a fundamental reference not only for aerospace applications, but also for the performance analysis of compressors in turbocharging systems used in internal combustion engine automobiles. The compressor, which is part of the turbocharger in cars, works by pumping air into the engine's air intake line. This is a system that compresses the air required for combustion (Kula & ÇiNiViZ, 2020).

Literature studies include the use of digital twin technology in aviation, but the focus of these examples is on different applications rather than directly studying the effect of pressure ratio on engine performance. In this paper, the current potential and future application possibilities of digital twin technology in the field of engine performance control and prediction are investigated. In particular, studies on the contribution of digital twin technology in the management of critical problems, such as engine performance optimization, are mentioned. In addition, within the scope of the mentioned study, a virtual engine model was created with the digital twin method. On this virtual model, it was aimed to reach the optimum simulation values by adjusting the pressure ratio values for the efficiency of the engine performance. In order to compare the performance of engine data under different flight conditions, the “GasTurb” application, a tool specifically designed for the simulation of gas turbines with system modeling, was used. This program can simulate gas turbines widely used in aircraft and power generation and is used to evaluate their performance under both design and off-design conditions (Gao & Huang, 2011).

2. Methodology

2.1. Digital Twin Approach

In this study, a virtual turboprop engine model was created on a Modelica-based application using the digital twin method in order to increase engine efficiency. In order to compare the results of the studies performed on this virtual engine model, GasTurb application, where real engine data is obtained, is utilized. The PT6A-62 turboprop engine was taken as a reference to analyze the turboprop engine performance. The simulated values of the PT6A-62 turboprop engine were extracted from the engine model created on GasTurb and these values were compared with the data of the engine whose pressure ratio value was adjusted on the Modelica-based application. The pressure ratio values were tested with different numbers on the virtual model created in the Modelica-based application and the optimum value obtained in different flight phases was determined for the optimization of engine performance. In order to determine this value accurately, compressor and turbine maps were utilized. While creating the compressor and turbine maps, the corrected operating speed, corrected mass flow rate, pressure ratio, and isentropic efficiency values were entered into the performance map table in accordance with the requirements.

2.2. Digital Engine Modeling

Since there is no direct turboprop engine model in the Modelica-based application, first a 2 spool Turboshaft engine model was created under sea level conditions, and this engine was transformed into a

turboprop engine by adding the propeller model, as shown in Fig. 2.

The developed virtual turboprop engine model was simulated at different pressure ratios and different flight conditions, and the critical parameters such as gas generator speed, gross thrust, output torque, engine airflow, and exhaust gas temperature obtained from the simulation were evaluated with the GasTurb program. While creating the compressor and turbine performance maps on the virtual turboprop engine model, the pressure ratio values were tested proportionally from 10 to 17, which is the ideal pressure ratio value for the compressor, and from 2 to 7 for the turbine, under different flight conditions on the engine. Figure 3 shows the compressor and turbine performance maps of the PT6A-62 turboprop engine operated at sea level conditions generated on the Modelica-based application (Tekin & Yildiz, 2026). At each operating point, the performance of the components is dynamically assessed with data from these maps.

3. Results and Discussion

In this study, firstly, a literature review of the studies investigating the effect of the pressure ratio parameter on engine performance was conducted. It was observed that the methods used in the studies were insufficient to detect instantaneous deviations in engine performance or possible failures in real time, and it was aimed to fill this gap in the literature, and turboprop engine performance was analyzed in detail in a digital twin environment by considering pressure ratio as the main efficiency parameter. The PT6A-62 turboprop engine, which is taken as a reference, was created virtually both on the Modelica-based application and on the GasTurb application using the digital twin method. Gas generator speed, gross thrust, engine airflow, exhaust gas temperature, and output torque values obtained from the simulation of the virtual engine model operated at different pressure ratio values and sea level conditions are shown in Table 1. In order to improve the previous study (Tekin & Yildiz, 2026), it was determined to include the gross thrust value within the scope of the evaluation.

Table 1
Values of Critical Parameters at Different Pressure Ratios

CPR	**TPR**	**10**	**2**	**11**	**3**	**12**	**4**	**13**	**5**	**GasTurb**
Gas Generator Speed (rev/min)		37098		37098		37098		37098.4		36951.6
Output Torque (Nm)		5491.29		5548.61		5577.6		5585.18		5299.42
EGT (K)		875.81		856.19		838.57		822.62		865.59
Engine AirFlow (lb/s)		11.099		11.094		11.089		11.085		10.940
Gross Thrust (lbf)		256.31		253.31		250.58		248.12		235.98
CPR	**TPR**	**14**	**6**	**15**	**7**	**16**	**7**	**17**	**7**	**GasTurb**
Gas Generator Speed (rev/min)		37098.6		37098		37098.5		37098.6		36951.6
Output Torque (Nm)		5575.11		5550.3		5515.32		5470.71		5299.42
EGT (K)		808.07		794.71		782.37		770.92		865.59
Engine AirFlow (lb/s)		11.082		11.077		11.073		11.069		10.940
Gross Thrust (lbf)		245.83		243.67		241.72		239.86		235.98

The engine was modeled under different flight conditions by creating compressor and turbine performance maps on the Modelica-based application. The simulation data obtained as a result of the changes made on the pressure ratio parameter were examined and compared with the engine data in GasTurb. As a result of the comparisons, the margin of error ratios of the parameters that perform a critical role in engine efficiency were obtained, and the impact of the engine on thrust efficiency was prioritized and evaluated by taking the gross thrust parameter with the largest margin of error as a reference. It is aimed at reducing the error rate of the gross thrust parameter by determining the optimum pressure ratio value. It is known that by reducing this error rate, the operating conditions of other parameters will be optimized. At the same time, since the main source of thrust in turboprop engines is the propeller, the gross thrust value generated by the engine gains importance. As the gross thrust value increases, fuel consumption will increase, and engine efficiency will decrease. Table 2 shows the comparison of the gross thrust values obtained from different pressure ratio values on the virtual engine model with the values obtained from the GasTurb application and the margin of error ratios.

Table 2
Margin of Error Ratios of Gross Thrust Values

CPR	TPR	Gross Thrust Lbf (Model Value)	Gross Thrust Lbf (GasTurb Value)	Error (%)
10	**2**	256.31	235.98	8.611
11	**3**	253.31	235.98	7.339
12	**4**	250.58	235.98	6.183
13	**5**	248.12	235.98	5.139
14	**6**	245.83	235.98	4.169
15	**7**	243.67	235.98	3.253
16	**7**	241.72	235.98	2.426
17	**7**	239.86	235.98	1.642

Since the results of the virtual engine model run at sea level do not accurately represent the actual flying conditions, they are insufficient for optimizing engine performance. To obtain a full range of engine performance in line with the goal of high engine efficiency, the virtual engine model is simulated on the Modelica-based application according to various flight conditions, such as increasing temperature and increasing altitude at different pressure ratio values, as shown in Table 3. The values of the gross thrust parameter taken as reference are compared with the values in the GasTurb application, and the margin of error rates are also calculated.

Table 3
Gross Thrust Values and Margin of Error Ratios for Various Pressure Ratios under Different Flight Conditions

Altitude (ft); Temperature (K)	**Gross Thrust Lbf (GasTurb)**	**Gross Thrust Lbf (Model Value) CPR:10, TPR:2**	**Error (%)**	**Gross Thrust Lbf (Model Value) CPR:11, TPR:3**	**Error (%)**
6000;303.15	240.065	254.245	5.907	252.247	5.074
8000;298.15	246.739	260.722	5.667	258.984	4.963
10000;303.15	227.418	259.481	14.098	258.278	13.569
12000;308.15	209.529	255.268	21.829	253.263	20.872
14000;298.15	236.519	259.508	9.719	258.189	9.162
16000;303.15	216.676	253.391	16.944	252.521	16.543
18000;308.15	197.733	246.941	24.886	246.49	24.658
Altitude (ft); Temperature (K)	**Gross Thrust Lbf (GasTurb)**	**Gross Thrust Lbf (Model Value) CPR:12, TPR:4**	**Error (%)**	**Gross Thrust Lbf (Model Value) CPR:13, TPR:5**	**Error (%)**
6000;303.15	240.065	250.318	4.270	248.58	3.547
8000;298.15	246.739	257.224	4.249	255.585	3.585
10000;303.15	227.418	256.842	12.931	254.684	11.989
12000;308.15	209.529	251.386	19.97	249.641	19.143
14000;298.15	236.519	256.862	8.611	255.563	8.052
16000;303.15	216.676	251.633	16.13	250.736	15.719
18000;308.15	197.733	245.885	24.35	245.114	23.962
Altitude (ft); Temperature (K)	**Gross Thrust Lbf (GasTurb)**	**Gross Thrust Lbf (Model Value) CPR:14, TPR:6**	**Error (%)**	**Gross Thrust Lbf (Model Value) CPR:15, TPR:7**	**Error (%)**
6000;303.15	240.065	246.93	2.859	245.332	2.194
8000;298.15	246.739	254.023	2.952	252.483	2.328

Altitude (ft); Temperature (K)	**Gross Thrust Lbf (GasTurb)**	**Gross Thrust Lbf (Model Value) CPR:10, TPR:2**	**Error (%)**	**Gross Thrust Lbf (Model Value) CPR:11, TPR:3**	**Error (%)**
10000;303.15	227.418	252.676	11.106	250.763	10.265
12000;308.15	209.529	248.002	18.361	246.386	17.590
14000;298.15	236.519	254.272	7.506	252.995	6.966
16000;303.15	216.676	249.626	15.207	246.962	13.977
18000;308.15	197.733	242.079	22.427	244.473	23.637
Altitude (ft); Temperature (K)	**Gross Thrust Lbf (GasTurb)**	**Gross Thrust Lbf (Model Value) CPR:16, TPR:7**	**Error (%)**	**Gross Thrust Lbf (Model Value) CPR:17, TPR:7**	**Error (%)**
6000;303.15	240.065	243.846	1.574	242.389	0.968
8000;298.15	246.739	251.037	1.741	249.565	1.145
10000;303.15	227.418	249.01	9.494	247.335	8.758
12000;308.15	209.529	244.916	16.88	243.45	16.189
14000;298.15	236.519	251.748	6.438	250.012	5.705
16000;303.15	216.676	254.457	17.43	242.445	11.892
18000;308.15	197.733	237.398	20.051	239.581	21.163

When the obtained margin of error values are evaluated, it is observed that as the CPR and TPR values increase, the error rates for gross thrust decrease and become more optimum. Figure 4 shows the changes in the average margin of error values obtained under different flight conditions.

These margins of error rates apply not only to gross thrust but also to other critical parameters affecting engine performance, which were examined at the beginning of the study. This is because engine performance is a multivariable system. Other critical parameters change in parallel with gross thrust in the same way. As can be seen from the analyzed graphs and tables, when the CPR value is tested from 10 to 17, considering different flight conditions, a decrease in the margin of error is observed as the pressure ratio values increase. The pressure ratio value tends to increase with increasing altitude. For this reason, it was thought that it would be more appropriate to create a compressor with a high pressure ratio. Due to the decrease in gross thrust value with increasing pressure ratio values, performance optimization of the engine was realized by obtaining high thrust efficiency and reducing fuel consumption.

When the exhaust gas temperature value is also considered in Table 4, the fact that this value decreases with increasing pressure ratio values is also an indication that thermal efficiency is achieved. Figure 5 shows a graphical representation of these margin of error values.

Table 4
Comparison of EGT Values at Different Pressure Ratio Values

Compressor PR	Turbine PR	EGT K (Model Value)	EGT K (GasTurb Value)	Error (%)
10	**2**	875.813	865.587	1.181
11	**3**	856.187	865.587	-1.086
12	**4**	838.574	865.587	-3.121
13	**5**	822.621	865.587	-4.964
14	**6**	808.069	865.587	-6.645
15	**7**	794.71	865.587	-8.188
16	**7**	782.368	865.587	-9.614
17	**7**	770.918	865.587	-10.937

4. Conclusions

In this study, the thermodynamic and aerodynamic impacts of Compressor Pressure Ratio (CPR) variations on the performance, efficiency, and operational lifecycle of a virtual turboprop engine were systematically investigated using a high-fidelity Digital Twin (DT) methodology. By executing real-time simulation frameworks and high-approximation optimization algorithms, compressor and turbine performance maps were dynamically updated, demonstrating how the DT paradigm eliminates the necessity for physical prototyping through continuous virtual model synchronization, predictive maintenance scheduling, and multi-scenario flight envelope simulations. The analytical results reveal that the engine's performance behaves as a highly non-linear, multivariable system where critical performance parameters change in tandem with gross thrust. When evaluating CPR scaling from 10 to 17 across diverse flight conditions, a distinct convergence and decrease in the simulation error margins were observed as the pressure ratio values increased, confirming that the digital twin model exhibits higher predictive accuracy and stability at elevated operating pressures.

Furthermore, because ambient atmospheric density drops at high altitudes, the operational requirement for the pressure ratio inherently tends to increase with altitude, justifying the design choice of a compressor with a high pressure ratio to sustain optimal thermodynamic cycles during cruise phases. Although this increase in CPR values results in a nominal reduction in gross thrust, it significantly enhances overall thrust efficiency and reduces specific fuel consumption, thereby yielding a net optimization in fuel economy. This thermodynamic optimization is further substantiated by the behavior of the exhaust gas temperature, which consistently decreases with increasing pressure ratio values,

serving as a direct indicator of enhanced thermal efficiency. This reduction in thermal stress directly contributes to mitigating the degradation rate of high-pressure components, thereby extending the engine's operational lifetime and structural integrity. Ultimately, the multi-objective optimization performed via this virtual model successfully enhanced the engine’s thermal, mechanical, combustion, and propulsive efficiencies, proving that this developed framework provides a robust, scalable infrastructure for design modification and lifecycle optimization across broader aerospace and automotive propulsion systems.

List of abbreviations

CPR Compressor Pressure Ratio

ESHP Equivalent Shaft Power

HPC High Pressure Compressor

HPT High-Pressure Turbine

OPR Overall Pressure Ratio

SFC Specific Fuel Consumption

TIT Turbine Inter Temperature

TPR Turbine Pressure Ratio

VCR Variable Compression Ratio

Declarations

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Author Contribution

E.Z.T. conceived the study, developed the methodology, performed the simulations and analyses, prepared the figures, and wrote the original manuscript. M.Y. contributed to the conceptualization, supervised the research, and reviewed and edited the manuscript. A.K. contributed to the interpretation of the results and critically reviewed the manuscript. U.K. contributed to the technical discussion and reviewed the manuscript. All authors read and approved the final manuscript.

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Figures

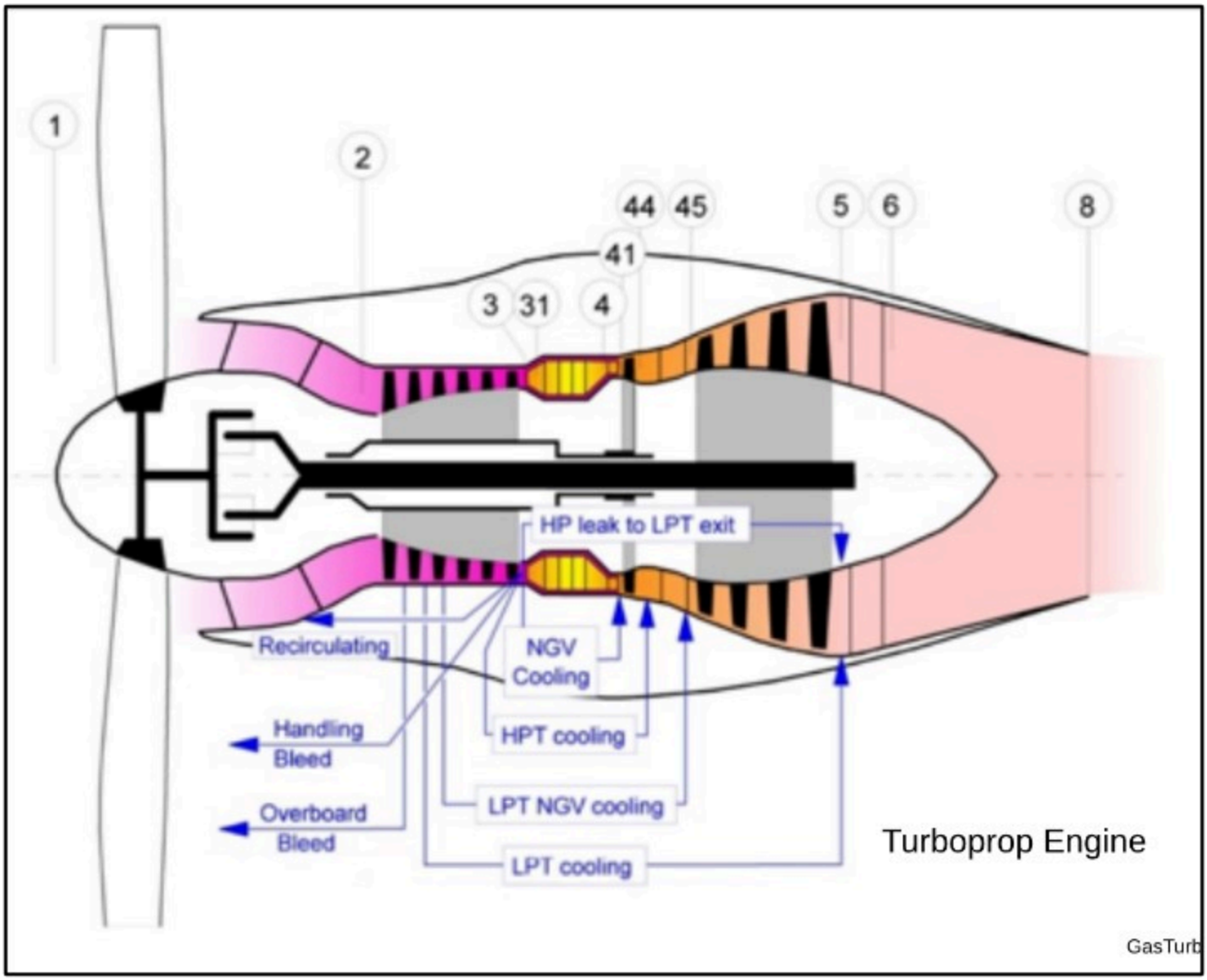


Figure 1

Turboprop Engine Model Created in GasTurb Application

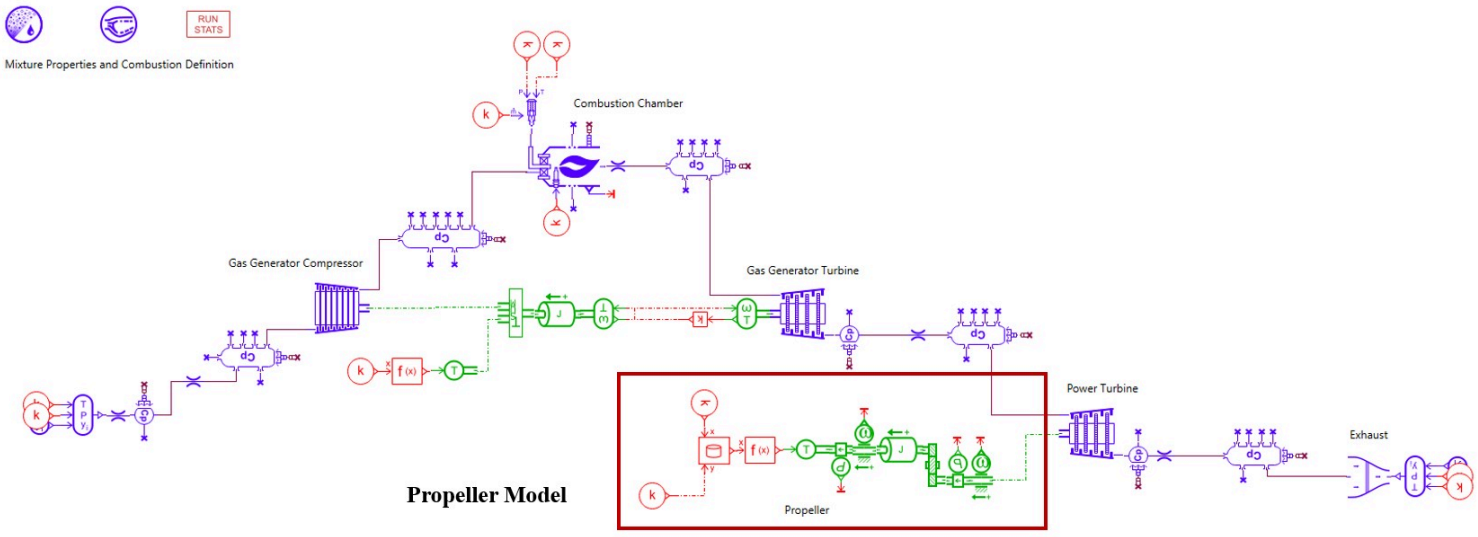
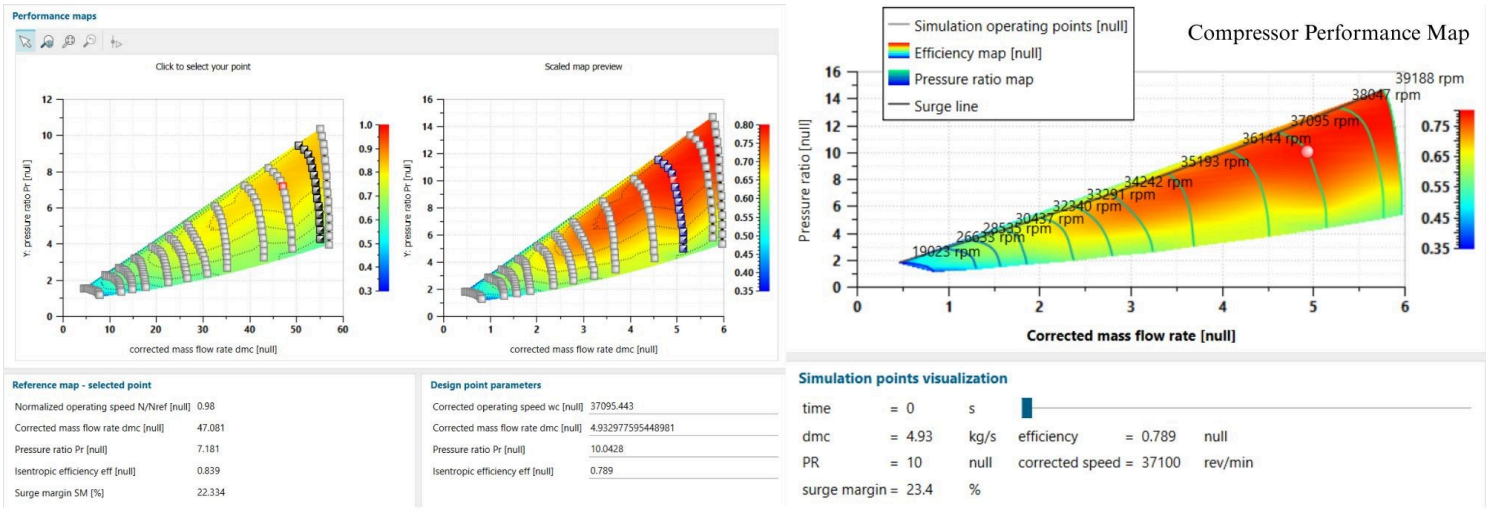


Figure 2

Turboprop Model Created on a Modelica-Based Application



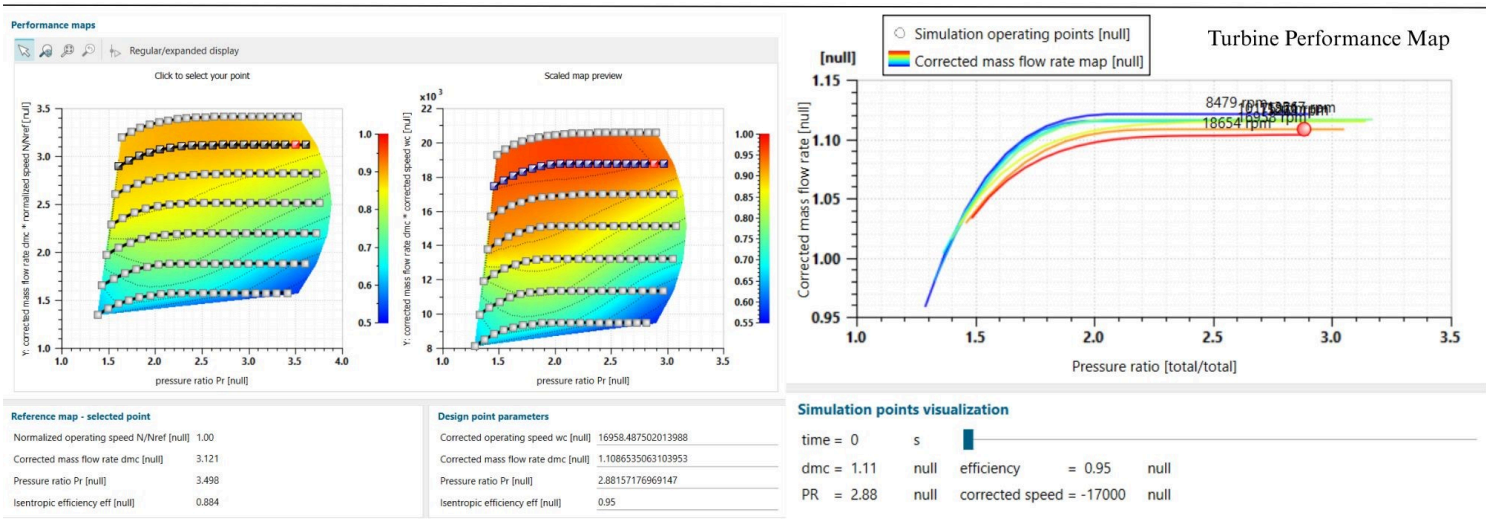


Figure 3

Compressor and Turbine Performance Maps

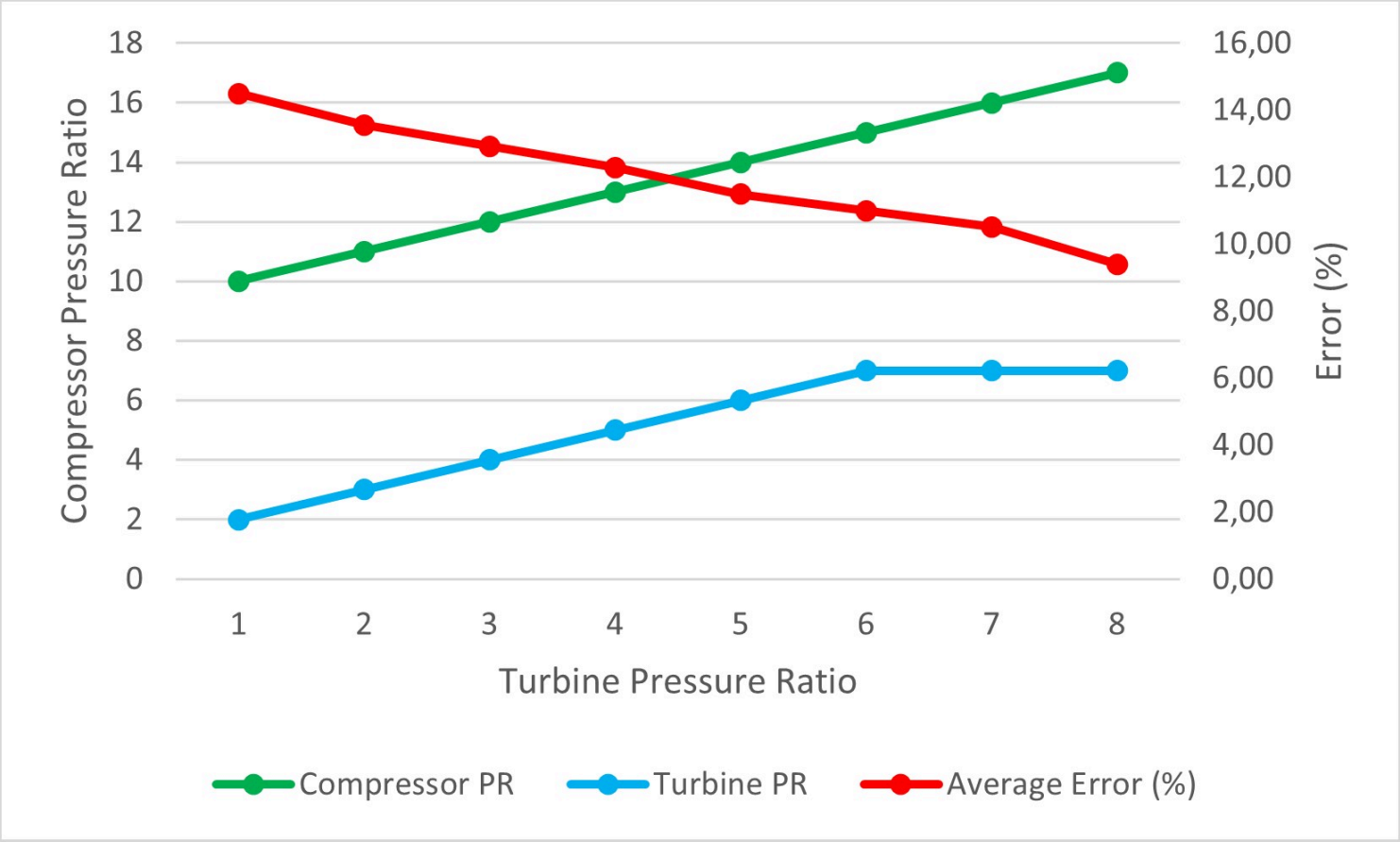


Figure 4

Variation Graph of Average Margin of Error Ratios According to Pressure Ratio Values

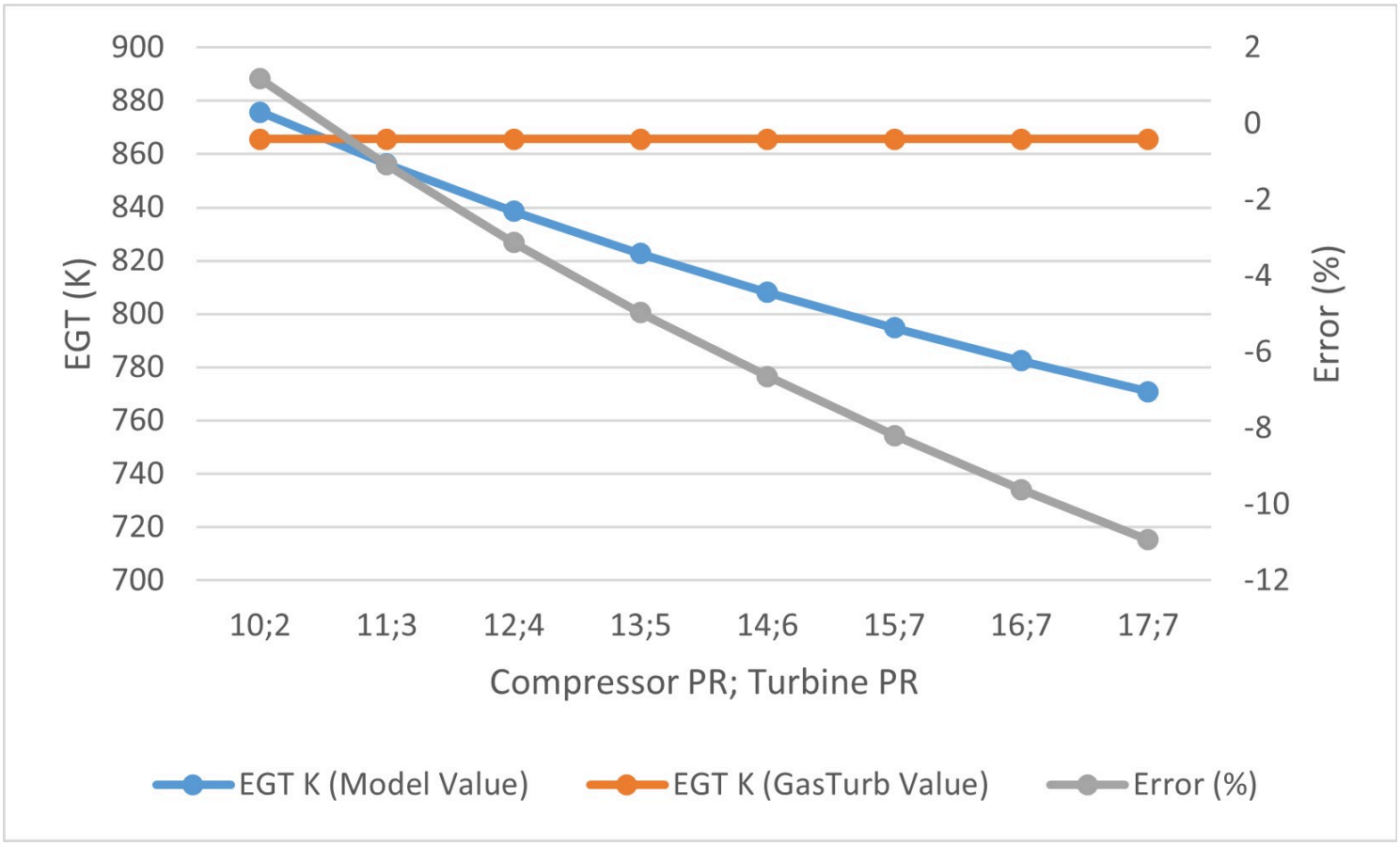


Figure 5

Error Margin Ratio Graph of EGT Values at Different Pressure Ratio Values