Integrating Turbojet Propulsion into Engineering Technology Education: An Independent Study Approach

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Abstract
High-impact, project-based learning experiences are widely recognized as effective approaches for supporting student learning and professional preparation in engineering and engineering technology education. Within engineering technology programs, individualized projects aligned with ABET Engineering Technology Accreditation Commission (ETAC) student outcomes provide a practical pathway for introducing advanced aerospace topics—such as propulsion system design—through applied, simulation-driven approaches. This paper presents a case study of an independent study project conducted by a single undergraduate student, focused on the design and computational analysis of a small-scale turbojet engine for unmanned aerial vehicle (UAV) applications.

The project followed a preliminary aerospace propulsion design workflow based on the Brayton cycle, including centrifugal compressor design, combustion chamber integration, single-stage axial turbine sizing, and exhaust nozzle thrust estimation. Industry-grade turbomachinery software, computer-aided design tools, and computational fluid dynamics (CFD) simulations were used to model component geometries and evaluate key performance indicators such as pressure ratio, mass flow rate, and thrust. Due to limited laboratory access, budget and personnel constraints, restricted manufacturing capabilities, safety considerations, and graduation timelines, physical engine fabrication and experimental testing were not conducted; instead, the project emphasized simulation-driven design and analysis, supported by non-functional 3D-printed components used solely for visualization and design communication.

Educational outcomes were evaluated using a retrospective pre- and post-project survey instrument consisting of 17 items mapped to the five ABET ETAC baccalaureate student outcomes, supplemented by instructor observations and review of student-generated technical artifacts. Paired assessment results suggest perceived improvements across all outcomes, particularly in the application of modern engineering tools, system-level design, and analytical evaluation. Given the single-student scope and reliance on self-reported measures, these findings are exploratory and descriptive rather than generalizable. Nevertheless, the results indicate the potential for simulation-driven independent studies to support the integration of aerospace propulsion content within engineering technology programs, pending further implementation with additional students and expanded assessment approaches.

1. Introduction

Active and project-based learning approaches have been shown to significantly improve student learning outcomes, engagement, and retention in engineering and engineering technology education, particularly when students engage in open-ended, authentic problems [1], [2]. Over time, engineering education has increasingly emphasized experiential learning, system-level design, and the integration of theory with real-world problem solving [3], [4]. These shifts are especially relevant in aerospace education, where multidisciplinary integration of thermodynamics, fluid mechanics, materials, and mechanical design is fundamental.

Design-centered learning has been shown to support deeper conceptual understanding and professional skill development when engineering design thinking is embedded within coursework and project experiences [5]. However, propulsion system design presents unique challenges at the undergraduate level due to the cost, safety considerations, and infrastructure requirements associated with experimental testing of gas turbine engines. Consequently, many aerospace learning experiences rely primarily on theoretical analysis or isolated component studies, offering limited opportunities for integrated system-level design.

Engineering technology programs are well positioned to address this challenge by emphasizing applied design, modeling, and computational analysis using industry-relevant tools while maintaining alignment with accreditation expectations [6]. Independent study courses, in particular, offer a flexible mechanism for introducing advanced aerospace topics—such as turbojet propulsion. This paper presents a case study of a propulsion-focused independent study project designed to support applied learning and ABET-aligned student outcomes through simulation-driven design.

2. Project Context and Educational Motivation

The project was conducted as an independent study within an undergraduate engineering technology program at a regional public university. Prior to enrollment, the student had completed core coursework in applied thermodynamics, mechanical design, and manufacturing processes. Faculty supervision emphasized applied aerospace analysis, system integration, and professional technical documentation consistent with engineering technology program objectives.

The student who undertook this project demonstrated a strong personal interest in aerospace propulsion and independently initiated the topic selection. While this intrinsic motivation contributed positively to engagement, the student's academic preparation was consistent with that of typical upper-division engineering technology students, including foundational coursework in thermodynamics, mechanical design, and manufacturing processes. The project scope and structure were intentionally designed to build upon these fundamentals rather than require specialized prior expertise. As such, the approach is considered adaptable to a broader student cohort, provided appropriate scaffolding is incorporated, including guided instruction in computational tools, structured design milestones, and faculty mentoring.

The project structure and assessment were aligned with the ABET Criteria for Accrediting Engineering Technology Programs, which emphasize applied knowledge, system and component design, effective communication, analytical evaluation, and professional skills [6]. Industry and professional organizations have highlighted the need for graduates who can apply modern engineering tools, interpret computational results, and perform early-stage system design—particularly in aerospace and unmanned aerial vehicle (UAV) applications [3].

Rather than focusing on fabrication or experimental testing, the project was intentionally structured to mirror preliminary aerospace design workflows commonly used in industry, where modeling, simulation, and iterative analysis precede physical prototyping. The instructor provided initial problem framing and guidance on system architecture, while the student independently carried out detailed modeling, simulation, and design activities. This approach enabled meaningful engagement with propulsion system design while remaining feasible within time and institutional laboratory constraints.

From an implementation perspective, the project was conducted over a single academic term (approximately 15 weeks). The student dedicated an estimated 8–12 hours per week to modeling, simulation, and design activities. Assessment was based on a combination of technical deliverables, including intermediate design reports, final documentation, and demonstration of computational models, as well as faculty evaluation of analytical rigor and design progression. Replication of this approach would require access to standard engineering software tools (e.g., CAD and CFD packages), structured faculty mentorship, and clearly defined project milestones to guide student progress.

3. Engineering Design Approach

The propulsion system was defined around a Brayton-cycle turbojet architecture suitable for unmanned aerial vehicle (UAV) applications. The Brayton cycle forms the theoretical foundation for gas turbine engines and is widely used in preliminary propulsion system analysis and sizing due to its suitability for steady-flow, high-speed propulsion systems [7]–[9]. Target performance parameters were established at the outset of the project to guide subsystem sizing, cycle analysis, and overall system integration.

The project was structured with initial guidance provided by the instructor in defining the overall problem scope, including the selection of a Brayton-cycle turbojet architecture and representative input parameter ranges (Table 1) consistent with small-scale engine design practice. Within this framework, the student independently developed the propulsion model, performed the cycle analysis, and generated the resulting performance metrics (Table 2). The student was responsible for implementing the thermodynamic calculations, conducting CFD simulations, developing the CAD model, and iteratively refining component designs based on analysis results. The instructor's role was primarily advisory, providing periodic feedback on modeling assumptions, design decisions, and interpretation of results.

Table 1 summarizes the primary input parameters used in the Brayton-cycle analysis. These inputs define the operating environment, inlet conditions, and key thermodynamic constraints of the engine. Sea-level International Standard Atmosphere (ISA) conditions were assumed, with a corrected inlet mass flow rate of 0.3 kg/s and a compressor pressure ratio of 3, values representative of small-scale turbojet engines used in UAV and educational applications. The turbine inlet temperature was limited to 1000 K to reflect material and thermal constraints typical of compact turbojet designs and to ensure realistic cycle behavior.

Table 1. Turbojet Brayton Cycle Main Input Parameters

Category	Input Parameter	Unit	Value	Description
Ambient	P_0	kPa	101.325	Ambient Pressure
Ambient	T_0	K	288.15	Ambient temperature
Inlet / Intake	Inlet Corrected Flow (W2Rstd)	kg/s	0.3	Corrected inlet mass flow rate
Compressor	Compressor Pressure Ratio	–	3	Overall compressor pressure ratio
Combustor (Burner)	Burner Exit Temperature (Tt4)	K	1000	Turbine inlet total temperature

Using the inputs presented in Table 1, a preliminary cycle analysis was performed to estimate overall engine performance. The resulting calculated performance metrics are presented in Table 2, including net thrust, fuel flow, and thrust-specific fuel consumption (TSFC). The predicted net thrust of 0.15 kN is consistent with expectations for a compact turbojet operating at static, sea-level conditions. The calculated TSFC reflects the trade-off between thermal efficiency and size constraints inherent in small-scale propulsion systems.

Table 2. Turbojet Brayton Cycle Calculated Performance Metrics

Parameter	Value	Unit	Description
FN	0.15	kN	Engine net thrust
WF	0.00452	kg/s	Fuel Flow
TSFC	30.5672	g/(kN·s)	Thrust specific fuel consumption

A centrifugal compressor was selected to achieve a compact configuration with a moderate pressure ratio, consistent with small-scale turbojet engines used in UAV and model-scale aerospace applications [10], [11]. The combustion chamber was designed to support stable fuel–air mixing and acceptable thermal loading, while a single-stage axial turbine was sized to extract sufficient shaft power to drive the compressor, following classical gas turbine design principles [7]–[9].

A three-dimensional computer model of the engine was developed to support visualization and system understanding. Figure 1 presents a sectional view of the turbojet assembly, illustrating the relative placement of the compressor, combustor, turbine, shaft, and bearing supports. This model was used to communicate component interactions, assembly concepts, and flow path continuity rather than to support detailed mechanical stress or durability analysis.

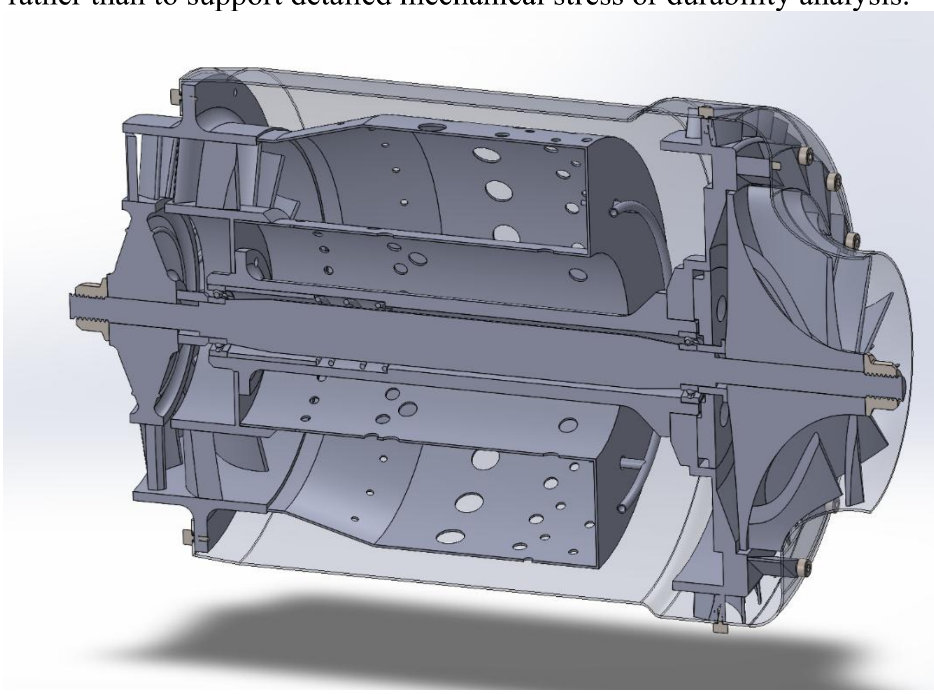

Figure 1. Cross section area of the turbojet engine (3D computer model)

The technical emphasis on analytical and simulation-based propulsion evaluation is consistent with prior research on UAV propulsion systems, where performance, efficiency, and emissions have been extensively studied using thermodynamic modeling, optimization, and exergy analysis rather than full-scale experimental testing [12]–[15]. Comparable educational implementations have demonstrated the effectiveness of small-scale turbojet engines—such as model jet turbines and the SR-30 platform—for teaching propulsion fundamentals and system-level analysis through hands-on laboratory experimentation [16]–[19].

Selected components were fabricated using polymer-based 3D printing to support visualization, design reviews, and technical communication. The project concluded at the conceptual and simulation-driven design stage; therefore, metallic components were not manufactured, and no performance testing was conducted due to time, budget, and laboratory constraints.

Computational fluid dynamics (CFD) simulations were conducted using ANSYS CFX and Fluent to evaluate component-level flow behavior, pressure rise, temperature distribution, and exhaust velocity—key performance indicators in aerospace propulsion analysis [8]. The CFD analyses were performed primarily for educational purposes and as an initial design iteration to support conceptual understanding and comparative evaluation of component performance. All simulations were conducted using established commercial software packages; no custom CFD solver development was undertaken. The student developed and executed CFD analyses for the compressor, combustion chamber, and turbine, including mesh generation, boundary condition definition, and post-processing of results. Simulation results were used to assess component behavior and guide iterative design refinement, including turbine redesign to meet the required shaft power and thermal performance targets.

The CFD analysis was applied at the component level rather than as a fully coupled engine simulation. For example, compressor performance was evaluated through pressure rise and flow field characteristics obtained from CFD results, while turbine simulations examined temperature drop across the stage and corresponding shaft power estimated using thermodynamic energy balance relations. The combustion chamber CFD focused on flow uniformity, mixing behavior, and thermal distribution within the chamber. Standard turbulence models and steady-state assumptions were employed, and results were interpreted primarily in a qualitative and comparative manner to inform design decisions rather than as validated high-fidelity predictions. This approach is consistent with preliminary propulsion design practice, where component-level analysis supports system-level cycle evaluation. Accordingly, the CFD results should be interpreted as indicative of trends and relative performance rather than definitive or experimentally validated outcomes.

4. Assessment Methodology

Educational outcomes were assessed using a pre- and post-project survey instrument consisting of 17 items mapped to the five ABET ETAC baccalaureate student outcomes (SOs 1–5) [6]. The survey employed a five-point Likert scale ranging from Strongly Disagree (1) to Strongly Agree (5).

The ABET ETAC student outcomes are given below (for baccalaureate degree programs) [6]:

> "(SO-1) an ability to apply knowledge, techniques, skills and modern tools of mathematics, science, engineering, and technology to solve broadly-defined engineering problems appropriate to the discipline;
>
> (SO-2) an ability to design systems, components, or processes meeting specified needs for broadly-defined engineering problems appropriate to the discipline;
>
> (SO-3) an ability to apply written, oral, and graphical communication in broadly-defined technical and non-technical environments; and an ability to identify and use appropriate technical literature;
>
> (SO-4) an ability to conduct standard tests, measurements, and experiments and to analyze and interpret the results to improve processes; and
>
> (SO-5) an ability to function effectively as a member as well as a leader on technical teams."

Given the absence of physical experimentation, survey items related to SO-4 were framed around simulation-based analysis, interpretation of modeled data, and evaluation of system behavior rather than hands-on testing. This framing is consistent with contemporary aerospace design practice and engineering design pedagogy [5].
Table 3 presents the survey instrument used for retrospective pre- and post-project assessment. The student completed the survey at the conclusion of the project by providing paired ratings of perceived competency before and after participation, enabling direct comparison of self-reported changes in competency. Retrospective pre/post assessment has been used in exploratory engineering education studies to capture perceived learning outcomes and student development [1], [2].

Table 3. Pre- and Post-Project Survey Instrument Aligned with ABET ETAC Student Outcomes

Question	Survey Statement	ABET SO
1	Apply thermodynamics and fluid mechanics to analyze aerospace propulsion systems	SO 1
2	Use modern tools (CAD, CFD, simulation) to solve engineering problems	SO 1
3	Integrate math, science, and technology to evaluate performance	SO 1
4	Interpret simulation results for design decisions	SO 1
5	Design components meeting requirements and constraints	SO 2
6	Integrate subsystems into a system-level design	SO 2
7	Evaluate design trade-offs	SO 2
8	Iteratively refine designs using analysis	SO 2
9	Communicate technical concepts in writing	SO 3
10	Present engineering ideas graphically	SO 3
11	Use technical literature and standards	SO 3
12	Develop a test or evaluation plan	SO 4
13	Analyze and interpret modeled data	SO 4
14	Recommend design improvements	SO 4
15	Function as a self-directed contributor	SO 5
16	Collaborate with mentors/advisors	SO 5
17	Demonstrate professionalism and initiative	SO 5

5. Assessment Results

Survey results indicate consistent positive gains across all five ABET Engineering Technology student outcomes. Figure 2 presents the paired pre- and post-project Likert-scale scores for all 17 survey items. As shown in the figure, post-project scores exceed pre-project scores for every item, indicating a uniform upward shift in the student's self-assessed competency following completion of the independent study.

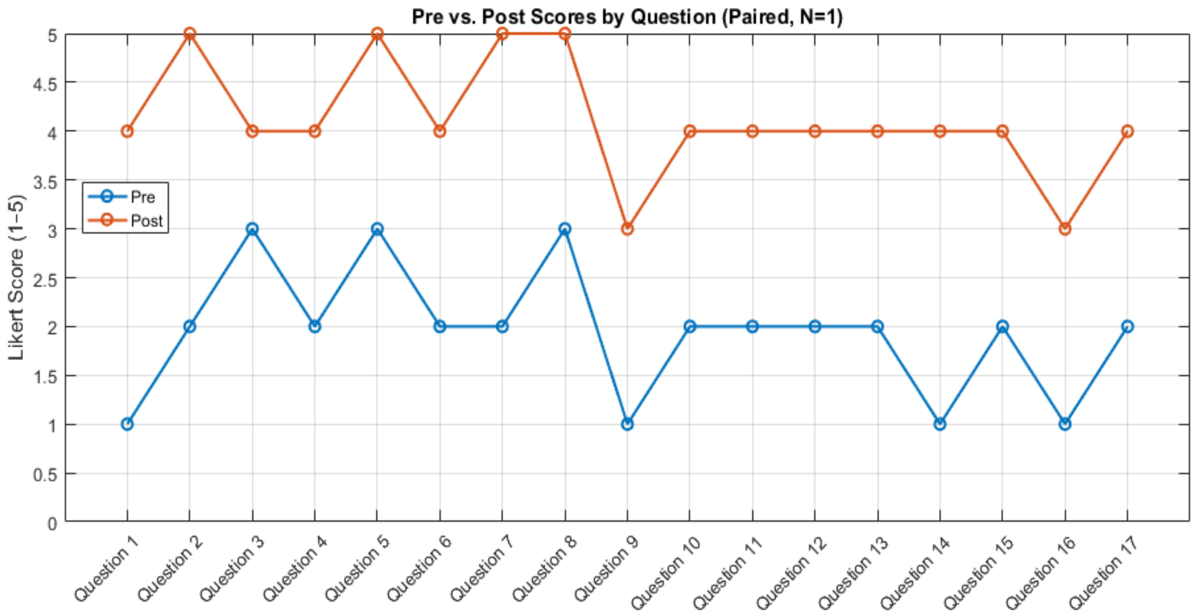

Figure 2. Survey assessment results

For ABET SO-1 (Questions 1-4), the largest increases were observed in the use of modern engineering tools (Question 2: score 2 → 5) and application of thermodynamics and fluid mechanics to propulsion analysis (Question 1: score 1 → 4). All SO-1–related items increased by at least one Likert point.

For ABET SO-2 (Questions 5-8), design-related items exhibited increases of two to three Likert points. Notable gains were observed in evaluating design trade-offs (Question 7: score 2 → 5) and iterative design refinement (Question 8: score 3 → 5). Post-project scores for all SO-2 items were 4 or higher.

For ABET SO-3 (Questions 9-11), increases were observed in written communication (Question 9: score 1 → 3), graphical communication (Question 10: score 2 → 4), and use of technical literature and standards (Question 11: score 2 → 4).

For ABET SO-4 (Questions 12-14), which focused on simulation-based evaluation rather than physical testing, all items increased by two to three Likert points, including recommending design improvements (Question 14: score 1 → 4).

For ABET SO-5 (Questions 15-17), gains of two Likert points were observed in self-directed contribution and professional responsibility, while the ability to communicate and collaborate with faculty mentors increased from 1 to 3 (Score of Question 16).

6. Discussion

The assessment results suggest perceived improvements in the student's technical, analytical, and professional competencies within a simulation-driven, propulsion-focused independent study, even in the absence of physical prototype fabrication or experimental testing. The consistent upward trends observed across all ABET student outcomes indicate that the project structure supported engagement in system-level aerospace problem solving. The strongest gains occurred in areas related to modern engineering tools, system-level design, and analytical evaluation, which align closely with early-stage aerospace industry workflows. These outcomes reflect the project's emphasis on computational modeling, iterative design, and performance assessment—core competencies in contemporary aerospace practice.

In addition to survey-based assessment, student-generated technical artifacts—including CAD models, CFD simulation results, and thermodynamic cycle analyses—provided qualitative evidence of competency development. The progression and refinement of these deliverables over the course of the project support the interpretation of improved technical understanding and design capability. Improvements in communication and professional skills, while more modest than those observed in technical design areas, are consistent with the independent-study format, which emphasized individual technical work and mentor interaction rather than formal team-based activities. Similarly, gains in ABET SO-4 demonstrate that simulation-based evaluation can support analytical reasoning and design improvement skills when physical testing is not feasible.

Given the single-student scope and reliance on self-reported measures, these findings should be interpreted as exploratory and descriptive rather than generalizable evidence of effectiveness. While this study focuses on an individual case, the project structure is adaptable to broader implementation. Scaling this approach to a larger cohort would require structured scaffolding, including staged instruction in thermodynamic modeling, guided use of CAD and CFD tools, and clearly defined project milestones. A modular implementation—where students focus on specific propulsion subsystems—may further support scalability while maintaining technical depth. With appropriate instructional design and resource support, such projects could be integrated into upper-division courses or capstone design experiences.

Beyond the independent study format, similar propulsion-focused learning experiences could be implemented through alternative instructional models, including structured laboratory courses, capstone design projects, or modular project-based courses embedded within the curriculum. Each approach presents trade-offs in terms of scalability, depth of engagement, and faculty involvement. For example, laboratory courses can accommodate larger cohorts through standardized activities, while capstone projects emphasize team-based system integration. Independent studies, by contrast, offer greater flexibility and depth for individualized exploration but require more intensive faculty mentorship.

Direct comparison of learning outcomes across these instructional formats was not conducted in this study. Future work should investigate differences in ABET-aligned outcome development across modalities—such as independent study, capstone design, and laboratory-based courses—to better understand the relative effectiveness of simulation-driven approaches. Such studies would also help evaluate applicability across students with diverse academic backgrounds and preparation levels.

In summary, this study adopts a simulation-driven approach motivated by limited laboratory access, budget and personnel constraints, restricted manufacturing capabilities, safety considerations, and graduation timelines. The findings highlight the role of computational analysis in understanding propulsion system behavior across mission profiles, operating conditions, and design trade spaces, and suggest that such experiences may support the development of skills relevant to industry practice and advanced academic study.

7. Limitations

Several limitations should be acknowledged. The study involved a single student participant, which substantially limits the generalizability of the findings and precludes statistical inference. Assessment relied primarily on retrospective self-reported survey data, supplemented by instructor observations and review of project artifacts (e.g., CAD models, simulation outputs, and technical documentation), and may therefore be influenced by perception and recall bias. As such, the results should be interpreted as exploratory and descriptive rather than conclusive evidence of effectiveness. These limitations motivate future implementations involving multiple students, longitudinal tracking, and the incorporation of objective performance measures.

8. Conclusions and Future Directions

This paper presents a simulation-driven independent study approach for integrating aerospace propulsion design into engineering technology education. The case study illustrates that ABET-aligned learning outcomes can be addressed through computational analysis, system-level design, and professional technical documentation without reliance on physical testing. The results suggest perceived improvements across technical, analytical, and professional skill areas, indicating that simulation-centered propulsion projects can support meaningful engagement with complex aerospace systems.

Given the single-student scope and reliance on self-reported measures, the findings should be interpreted as exploratory rather than generalizable. Nevertheless, the study highlights the potential of simulation-driven independent studies as a complementary pathway for introducing advanced aerospace topics—such as turbojet propulsion—within engineering technology programs. Such approaches may serve as practical alternatives or precursors to laboratory-intensive experiences, enabling students to develop transferable skills aligned with early-stage aerospace industry workflows and professional expectations.

From an implementation perspective, broader adoption would require structured scaffolding, including guided instruction in computational tools, clearly defined project milestones, and access to appropriate software resources. Time commitment, faculty mentorship, and assessment strategies based on technical deliverables are also important considerations for effective integration into existing curricula.

Future work will focus on extending this approach to multiple students, incorporating more objective and direct assessment measures, and integrating the project framework into upper-division courses or capstone design experiences. Additional studies comparing outcomes across instructional formats (e.g., independent study, laboratory-based courses, and capstone projects) would further support evaluation of scalability, reproducibility, and broader educational impact.

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