Development of Aerodynamic Testing Capabilities in an Engineering Technology Program

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My research aims to understand the concepts and mechanisms of lifted jet combustion, electrohydrodynamics, aerodynamics, composite structures, and engineering education . I use advanced techniques and technologies to explore these topics. My students and

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Abstract

Engineering Technology programs, unlike conventional engineering programs focus on the development of practical technical skillsets, rather than mathematical understanding and conceptual framing of conventional engineering problems. As many engineering technology programs have their foundations in existing trade programs or workforce development, these programs do not generally have the same foundational facilities that conventional engineering programs would have. Despite this deficit, many Engineering Technology programs have worked to use existing equipment and knowledgebases, as well as strategic purchases, to develop new capabilities which facilitate the furthering development of clinical undergraduate laboratories and new graduate research programs. The purpose of this paper is to show the progress of an existing Engineering Technology program with limited resources to develop research grade facilities and capabilities for undergraduate and graduate level research.

Introduction

Engineering Technology (ET) programs at the collegiate level exist in a unique area between theoretical engineering curricula and applied technical training. While ET and traditional engineering educational tracks prepare their students for their respective professional fields, because of differing educational doctrines and priorities within their institutions, they diverge greatly [1], [2], [3]. In general, the curriculums of ET programs are centered around applied learning, laboratory-based problem solving, and systems implementation, teaching students the utilization and optimization of existing technologies and design techniques [4], [5]. Conversely, traditional engineering programs focus on theoretical learning, mathematical modeling, and the development of novel technologies. Despite ET programs preparing students for roles in manufacturing, testing, operations, and quality control, there is perceived lack of prestige and recognition when compared to more theory-driven engineering education [4], [5]. Because of these crucial differences, ET programs often face several persistent downstream problems. Firstly, accreditation between ET and traditional engineering curricula are quite different, even falling under two separate accreditation commissions; the Engineering Accreditation Commission (EAC) and the Engineering Technology Accreditation Commission (ETAC) [6]. As a result of this distinction and the perceived lack of mathematical and advanced theory rigor, many licensure boards and graduate engineering programs prefer graduates from undergraduate programs accredited by the EAC [7], [8]. Secondly, flagship engineering department have an existing history of federally and state supported research, and therefore these departments generally appeal to a larger number of federal and industrial research awarding entities. It's typical for these awards to include capital allotted towards the construction of research facilities and the equipment required to conduct the corresponding research [9]. The teaching and applied instruction directives of ET departments usually creates diminished access to these funding sources [8], [10]. Consequently, ET programs and the educational departments in which they operate often function with scarcer institutional resources, budgets reduced in comparison to their engineering counterparts, and reduced access to funding, both from private and federal sources. Thirdly, due to the difference in expertise between engineering and engineering technology in the past, many ET departments did not develop the facilities needed for higher level research that would be seen in engineering programs, and were not supported to develop research programs until recently, which has led to deficits in the ability of said programs to adapt pedagogically with new trends in the industries that they prepare their students for [8], [10]. Because of these previously discussed obstacles, ET departments frequently see their ability to develop advanced laboratories and conduct graduate-level research greatly diminished. These problems affect the ability of ET programs to scale up applied research efforts, recruit graduate students, and retain research-oriented faculty [8], [10]. These impediments further serve the perception that ET programs are mostly vocational in nature and thus inferior to research-intensive engineering programs, in turn contributing to lower enrollment rates of both undergraduate and graduate students, thus tripping the perennial feedback loop of the previously mentioned problems [11]. These challenges aside, ET programs and their graduates occupy a vital space within STEM (Science, Technology, Engineering and Math), possessing advanced understanding at the systems level, hands-on experience, and the practical problem-solving skills necessary to take theory-based engineering concepts and convert them into functioning solutions [12], [9]. Agile ET departments have even utilized some novel means in an effort to contribute graduate-level research to industry and science alike.

Before the reinstatement of the Department of Applied Engineering Technology's (AET) Automotive Engineering Technology B.S. (AUTO) program at North Carolina Agricultural & Technical State University (NC A&T), an alternative vehicle related program existed. Beginning in 2002, the existing Manufacturing Systems Technology (MFG) department began offering classes in Motorsports Technology (MTSP) [13]. This offshoot within the MFG department was an elective based concentration that functioned to mold undergraduates into motorsports professionals familiar with the complexities of motorsports related industries at an organizational level. Eventually, the increased interest and subsequent swell in enrollment justified the establishment of MTSP as its own Bachelor's degree program rather than solely a concentration. This new degree based on the curriculum of MFG, supplemented some secondary manufacturing electives with dedicated MTSP related courses instructed by a veteran automotive engineer and motorsports team owner. Their instruction formed the core of the program and provided undergraduates with courses in high performance engine preparation, vehicle dynamics, data acquisition, and motorsports management. The classes, while immersive, were solely dependent on the presence of the instructor and their equipment which was wholly owned by them. When the instructor vacated their position within the university, expensive racing equipment, materials, and the vehicles themselves, all of which were critical to instruction also left. In the wake of this, a pronounced drop in enrollment followed by a revaluation of the program prompted the transition to a more clinical curriculum. This change saw the rejuvenation of the AUTO Bachelor's degree program. With the adoption of a more clinical instructional doctrine, this revised program aimed to teach undergraduates automotive principles, performance modeling/testing, and mechanical fundamentals with the theoretical and mathematical rigor more closely resembling the curricula of the Department of Mechanical Engineering at NC A&T. The pivot away from the application focused MTSP syllabi to a mathematical and theory driven core curriculum also pulled the AET department more closely in line with the R2 level institutional priorities of NC A&T. Even the "Automotive" nomenclature of the revitalized program obscures the expansion of curriculum emphasis from purely ground-based automotive technology to a comprehensive, vehicular science focused interdisciplinary degree, which includes air, sea, and space-based vehicles. To aid in the transition of instructional principle while maintaining an emphasis on the doctrine of ET, the AET department leveraged experiential teaching aids made available by the vacation of the MTSP laboratory. This equipment included a derelict Learning Labs Inc. Aerodyn low-speed wind tunnel. As part of the expansion of the AUTO program, undergraduate classes like AET 212: Applied Engineering Laboratory, were added to supplement the restructured curriculum. Intended to introduce undergraduates to basic aerodynamic experimental principles, the repurposed equipment aided in the familiarization of students with pitot tubes, manometers, static/dynamic pressure measurements, and airspeed. Additionally, students enrolled in the AET 312: Advanced Engineering Laboratory course were familiarized with experimental aerodynamic testing methods. This includes the calculation of center of lift, pitching moment, coefficient of lift, and coefficient of drag for various small scale vehicle models and aerodynamic surfaces using multi axis load cells and advanced data acquisition software. Subsequently, with the development of graduate level curriculums in adjacence to changes made to the undergraduate serving program and supported by the expanded capabilities afforded by aerodynamic testing equipment and the department's additive manufacturing laboratory, new graduate research opportunities in aerodynamics and aerospace systems were realized.

Cost Barriers to Research-Grade Test Facilities

Research-grade wind tunnel facilities represent a substantial capital investment that often exceeds the financial capacity of ET programs. These facilities require significant infrastructure investment and continuing maintenance requirements [14], [15], [16], [17], [18], [19]. NASA facility sustainment studies and university infrastructure disclosures indicate that even modest low-speed research tunnels typically require multi-million-dollar capital expenditures, with additional recurring operating costs driven by electrical power, calibration, and maintenance requirements [20], [21], [19]. Instrumentation and data acquisition systems alone frequently represent a significant fraction of total facility cost, particularly when multi-axis force balances and automated traversing systems are required [22], [23]. An analysis conducted by NASA of its 23 wind tunnel facilities across four research sites illustrates that sustainment and operations costs alone amount to hundreds of millions of dollars [20]. Strategic assessments conducted for NASA and the Department of Defense further emphasize the importance of long-term planning and consistent funding to preserve national wind tunnel test capability and address facility management issues [24].

The following table depicts the cost estimates (unadjusted for inflation) for the construction of several purpose built, research-grade wind tunnels owned and operated by universities in the United States. The values are consistent with publicly available financial information reported from the university wind tunnel facilities [14], [15], [16], [17], [18], [19]. Costs related to such facilities may easily exceed $10 million as the sophistication of them increases [20], [21], [19], [16],[25].

Table 1: Cost estimates for purpose-built, research-grade wind tunnel facilities run by universities.

Wind Tunnel	**Estimated Cost (USD)**
Kirsten Wind Tunnel – University of Washington [14]	~$0.12M (1936)
Glenn L. Martin Wind Tunnel – University of Maryland [15]	$2.3M (1949)
SuperSonic/TranSonic/WindTunnel – University of Alabama Huntsville [16]	$2M (2016)
Hardaway Supersonic Wind Tunnel (proposal for modern replacement) [17]	~$2.3M (2023)
University of Tennessee – Tickle College of Engineering (Hypersonic) [19]	$17.8M (2024)
Tennessee Tech University (Large-scale, low-speed) [18]	$50M (2024)

The most crucial piece of equipment to the AET department's aerodynamic testing capability is made possible by an Aerodyn/Learning Labs Inc, open-circuit wind tunnel. This commercially available wind tunnel was produced as a teaching aid, providing students with practical learning when studying the fundamentals of fluid dynamics. With a test section of $0.018m^3$ [0.45m × 0.20m × 0.20m], the tunnel permits the experimentation of small-scale models and aerodynamic devices. After decades of use, its retirement and subsequent abandonment saw the deterioration of much of the wind tunnel's original equipment. Fortunately, much of the restoration was facilitated by readily available off the shelf components.

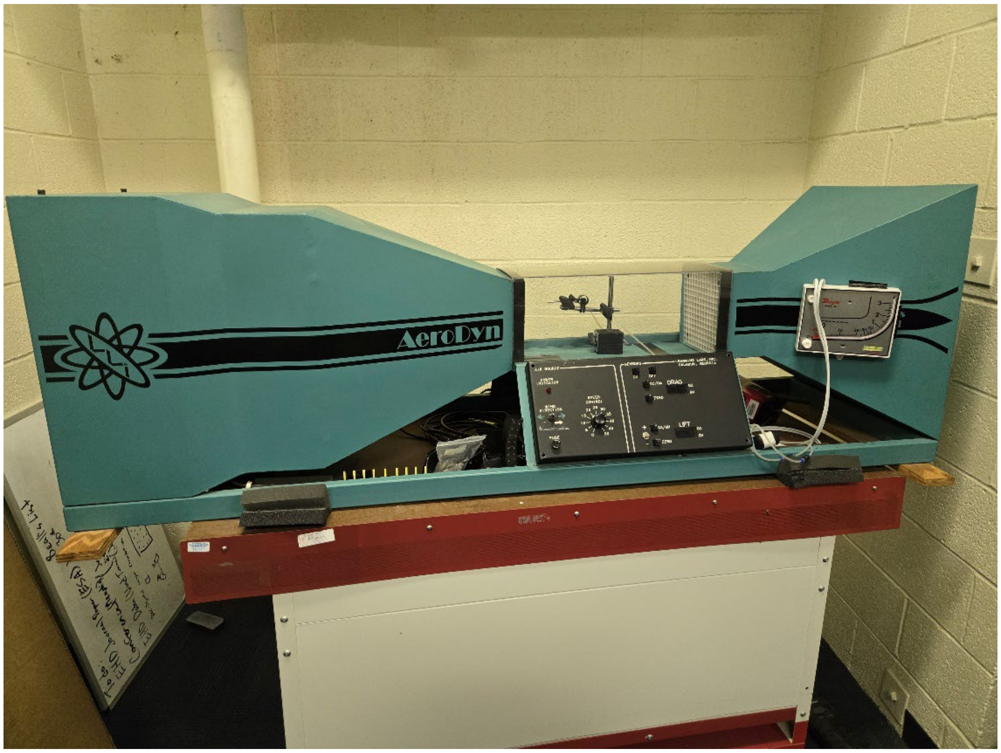

Figure 1: Derelict Learning Labs Inc. Aerodyn low-speed instructional wind tunnel shown before retrofit.

Persistent electromechanical resonance required that the original 90V, ¾ horsepower DC motor be replaced with a brand-new unit provided by Dayton Electrical. In addition, the aluminum, five-bladed clover-type OEM fan blade was substituted with a composite high-output axial type equipped with six blades. This modified configuration provided some level of vibration damping via the reduction of rotating mass, while improving laminar airflow generation. To ensure reliable control of the new motor and the higher CFM rating of the composite fan blade, a new Dayton DC speed controller was also installed.

Figure 2: New Dayton DC permanent magnet motor and composite 6-bladed axial fan.

Following the installation of the Aerodyn's new DC motor, fan blade assembly, and DC speed controller several test runs were conducted to benchmark the performance of the newly retrofitted wind tunnel. Installed in the tunnel, a pitot-static tube connected to a Risepro digital manometer was utilized to establish correlation between the new DC motor controller and the actual windspeed conditions generated in the test section. For cross-correlational redundancy, the pitot-static system was additionally connected to a Dwyer analog (water to air) type manometer. Airflow visualization of the new test section conditions were provided by way of Professional Haze Fantasy FX fogging spray and multiple Viltrox RB10 LED video lights. These tests indicated improvements to flow conditioning, maximum windspeed generation (from 22.4 to 28.2 m/s), vibration generated noise, and precision of control over the motor/fan during operation of the wind tunnel.

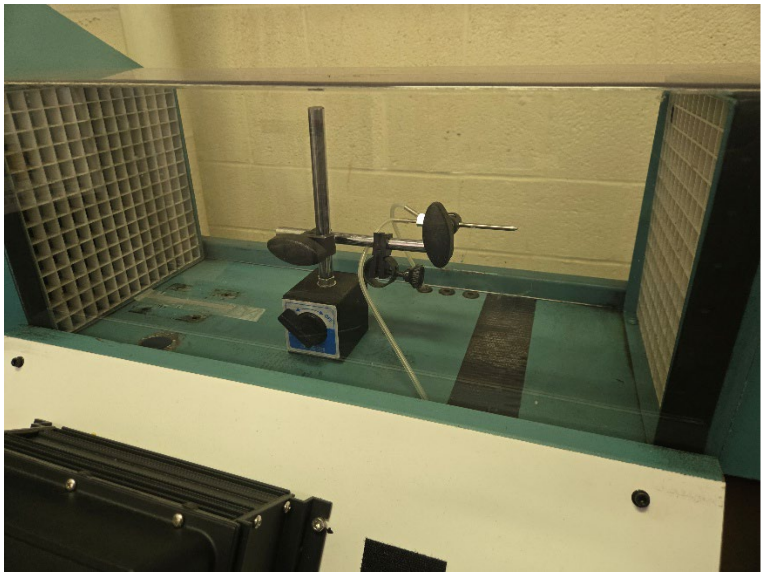

Figure 3: Pitot-static system installed in the test section of the Aerodyn wind tunnel.

Burned out wiring and an inoperative telemetry display necessitated the replacement of the Aerodyn's original metrological instrumentation panel. The rudimentary balance affixed with strain gauges provided only lift and drag data measured in ounces (oz) or grams (g) of force. To circumvent the lack of accurate force sensing, data collection, and sensor control, an ATI Mini40 load cell was selected for incorporation. This compact device provides precise six-axis force and torque sensing within 1/200 lbf (x,y-axis), 1/100 lbf (z-axis), and 1/200lbf-in (Tx,Ty) respectively, while maintaining an adaptable design that can be easily integrated into a number of applications. Time-averaged values derived from large datasets were used in order to cut through unwanted variability (noise) during data collection caused by structural vibrations present during powered operation of the wind tunnel. Power and signal conditioning for the Mini40 are provided by an ATI DAQ Interface Power Supply (model # 9105-IFPS-1) and a National Instruments USB-6210 multifunction data acquisition device providing analog to digital signal conversion and high incidence data logging. Control of the data acquisition system is managed via ATI's proprietary data acquisition software.

Figure 4: ATI Mini40 load cell shown with semi-traversable test stand head and sting holding assembly.

While much of the electrical, control, and data collection retrofit of the Aerodyn was made possible by way of off the shelf components, the prohibitive expense of automated traversing balance systems demanded the development of a simpler, more cost-effective alternative. Instead, a "semi-traversable" stand was designed permitting the positioning of the fixture's head and sting at angles of attack varying from 0 to 15 degrees in fixed 5-degree increments. This system secures the test sample aloft in the wind stream by sandwiching the ATI Mini40 load cell between the head of the "semi-traversable" stand and the tapered sting holding assembly. The components that comprise this design were rendered in Autodesk Fusion and manufactured from ABS using a Stratasys F370 FDM industrial 3D printer provided by the AET department's Additive Manufacturing Laboratory.

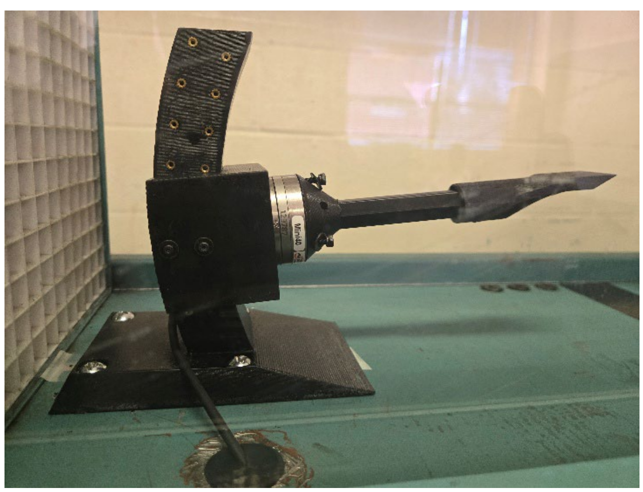

Figure 5: 3D printed (ABS) semi-traversable test stand assembly shown with ATI Mini40 loadcell and sting installed in wind tunnel test section.

The application of additive manufacturing with ABS permitted the rapid development of durable, lightweight subassemblies required to integrate the ATI Mini40 into the test fixtures and existing wind tunnel hardware without the costly expenditures of raw materials and CNC machine time associated with traditional subtractive manufacturing. Additionally, minor design changes, the production of spare or modified components, and even the fabrication of scale model test samples were made effortless by the additive manufacturing capabilities of AET. Additionally, the work of undergraduate students enrolled in senior capstone courses have seen the continued development of a honeycomb smoothing grate designed to smooth the inflow of air at the Aerodyn's inlet. Due to its size, the initial iterations of this flow conditioning device were manufactured from PLA in four separate assemblies using a Flashforge Creator 4 Professional 3D printer, it too made available by the AET department's Additive Manufacturing Laboratory.

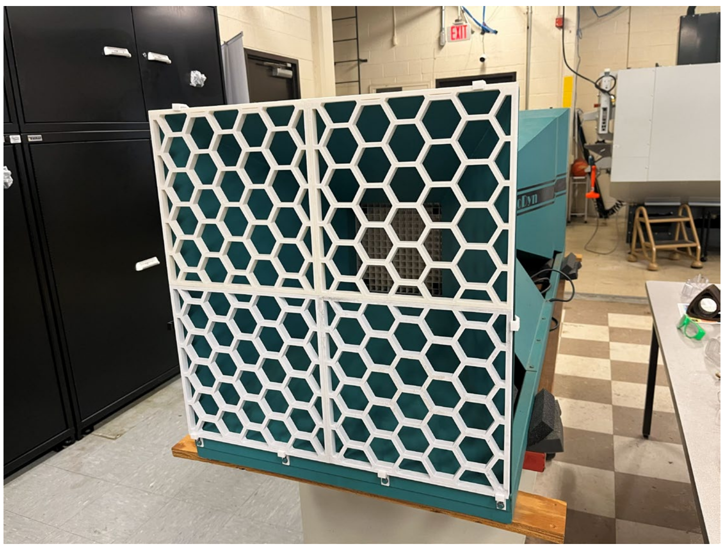

Figure 6: Learning Labs Inc. Aerodyn wind tunnel shown with 3D printed (PLA) honeycomb inlet grate.

Table 2: Breakdown of cost estimate for Aerodyn retrofit.

Category	**Estimated Cost (USD)**	**Notes**
Existing wind tunnel (sunk cost)	—	Undergraduate teaching equipment
Minor mechanical refurbishment	< $2k	New DC motor, DC motor controller, control panel
Flow conditioning enhancements	< $200	Composite 6-bladed axial fan assembly
Additive-manufactured fixtures	$300 – $500	ABS-printed stands/mounts, adapters, sting

Pressure measurement hardware	< $800	Pitot-static tubes, digital/analog manometers, tubing
Data acquisition system	$7k – $10k	ATI Mini40 load cell, ATI data interface/power supply, NI DAQ/data logger
Visualization & diagnostics	< $400	Smoke/fog, LED lighting
Electrical materials & tooling	< $400	Soldering iron, solder, wiring, shrink tubing, fuses, wire strippers/cutter
Total retrofit cost	**≈ $12k – $16k**	
Annual operating cost	<$2k	Power + consumables

Figure 7: Learning Labs Inc. Aerodyn wind tunnel shown with small-scale airfoil model after retrofit.

Conclusion

In addition to the research expectations required of most ET faculty, the importance of graduate-level research derived from ET departments remains relatively nuanced. While most ET departments are still required by their respective institutions to contribute to the scholarly output of their universities, empirical research conducted by these departments beneficially contributes to the experiential learning of undergraduates [26]. Moreover, ET graduate students, like their engineering counterparts are required to participate in the research process in order to generate their manuscripts, satisfy their program requirements, and contribute to the scholarly output of their colleges.

When compared with the $2.0M–$50M capital costs of university operated research-grade wind tunnels (Table 1), the aerodynamic research capacity of NC A&T's AET department was created using an outdated instructional wind tunnel with an estimated additional investment of less than $16k (Table 2). This represents a cost reduction exceeding two and a half orders magnitude, achieved through the retrofitting of derelict undergraduate teaching equipment, additive manufacturing of testing hardware, and the adaptation of commercially available low-cost instrumentation. While such an approach imposes limitations on achievable Reynolds number, flow quality, and measurement resolution, the results demonstrate that aerodynamic phenomena and applied aerospace technologies can be experimentally investigated within the financial constraints typical of Engineering Technology programs. Evidence for the effectuation of the retrofitted laboratory equipment is supported by the ongoing experimental research of a PhD student attached to the AET department. Their investigation into the influence of surface type dielectric barrier discharge actuators on the performance of small-scale airfoils at low Reynolds numbers has resulted in noteworthy findings. Statistically significant changes to the coefficients of lift/drag, as well as measured changes in pitching moment were identified and analyzed with reports presently being prepared for peer-review and eventual publication.

Future improvements to the research capabilities and current infrastructure of the AET department should include but not be limited to automated traversing systems for the wind tunnel's balance hardware, aero rakes for improved pressure distribution measurements, a smoke generating rake system, and particle imaging velocimetry equipment for the improvement of visualized data.

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