2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
Paper ID #39605

Identification of Student Outcomes for the Electric Propulsion Aircraft Industry Based on Industry-Developed Consensus Standards

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Introduction

Electric-drive cars are becoming more common on the roads, so it is imaginable to foresee a time when electric propulsion aircraft and air mobility vehicles are in the airspace. With over 200 electric aircraft in development in 2023, the market size for electric propulsion aircraft is expected to exceed $25 billion by 2030 [1]. With regulations and international consensus driving the aerospace industry away from its dependence on fossil fuels, the future of electric propulsion is strong with a positive outlook. As the employment market increasingly demands more graduates with electric vehicle skills, there may be Industrial Advisory Board members that advocate for inclusion of this knowledge, skills, and abilities to be included in undergraduate programs. These programs include aerospace engineering, engineering technology, technologists, and certificated mechanics. Undergraduate engineering student project teams have participated in design-build courses where hybrid-electric race cars compete in national competitions [2]. Problem-based learning is widely used in aerospace education using electric aircraft [3]. As standards are being developed to establish electric aircraft propulsion practices, knowledge required, vocabulary, and techniques for requirements and testing, it may be time for collegiate education programs to consider how and where to incorporate these technologies and associated standards.

For casual observers of the aircraft industry, electric propulsion may be more closely associated with electric-powered unoccupied aircraft that are remotely piloted, sometimes known as drones or unmanned aircraft. As the light sport aircraft to transport category aircraft designs advance in electric propulsion development, more aircraft are seeking aviation authority certification. For instance, Pipistrel's Velis Electro is EASA type certified for pilot training in daylight VFR operations [4]. Joby Aviation has completed the second stage required by the FAA to obtain certification for their electric vertical take-off and landing (eVTOL) aircraft with a goal to start passenger service by 2025 [5]. Other aircraft are being developed and seeking certification as engineering developments continue to break design, manufacturing, operational, and sustainment barriers by companies across the globe.

Electric aircraft, while in development, are not currently flying passengers to destinations. That day is coming soon and so is the need for people that are trained to design, build, and maintain these systems. At this time, there is a lack of curriculum in aviation-related programs focused on electric propulsion aircraft. To begin to meet this need, the authors explored the intersection of six industry standards and ABET EAC and ETAC student outcomes. Then, an industry standard on electric aircraft propulsion is mapped to a series of undergraduate engineering technology courses in electrical systems. The research questions for this study are:

1. What are the major ABET EAC and ETAC student outcomes in aviation electric propulsion related industry standards?
2. How do course outcomes developed from an electric propulsion standard align with ABET student outcomes?
3. Which and where are these outcomes applicable to engineering and engineering technology programs?

Electric Propulsion Standards

Industry or consensus standards may identify specific vocabulary, techniques, depiction methods, composition requirements, performance requirements, and/or testing methods. In this way, some may view standards as restrictive and not allowing creativity. However, standards have already established consensus vocabulary, techniques, depiction methods, composition requirements, performance requirements, and/or testing methods. These standards may be referred to when developing new standards, or even determining if new or modified standards are needed. In this way, standards are freeing and focus creativity efforts in potentially productive directions. How would it be if every time we needed to represent the mass of an item, we would have to define a vocabulary, depiction method, techniques to identify and test it, and so on? It is more convenient to represent mass in kilograms as kg, and have scales developed and calibrated to kilograms. The same is true for electrical resistance measured in ohms and depicted by Omega. Industry standards also bring interchangeability to systems. One example is the use of a USB cable used to charge cell phones from multiple companies. This effect is already happening in aircraft using electric propulsion. A recently EASA-certified electric aircraft uses an SAE standard charging plug [4]. By using an SAE standard plug, compatibility, interchangeability, and replaceability are more likely, and there is a potential savings of design hours. When standards are used it is more likely that results are repeatable and that the definitions are consistent worldwide.

For electric propulsion standards for aircraft, there are standards that are directly related to electric motors. ASTM F3239-22 Standard Specification for Aircraft Electric Propulsion Systems [6] and addresses airworthiness requirements for the design and installation of aircraft electric motors. Other standards such as ASTM F3316 Standard Specification for Electrical Systems for Aircraft with Electric or Hybrid-Electric Propulsion are tangentially related to aircraft electric propulsion standards [7]. A sample of electric propulsion standards is listed in Table 1. This study focuses on standard ASTM F3239, directly related to the electric motor itself and not all those related to connected systems.

ABET Criteria

Using the ABET criteria for 2023-2024 for Engineering Accreditation Commission [12] baccalaureate programs and for Engineering Technology Accreditation Commission [13] baccalaureate programs, this study focuses on aerospace engineering and aerospace engineering technology (or similarly named) programs. For aerospace engineering, section III. Program Criteria identify that propulsion must be covered. In section I. General Criteria for Baccalaureate Level Programs, Criterion 3 addresses Student Outcomes. There are seven student outcomes identified by ABET. Student Outcomes 2 and 7 may be of particular interest for electric propulsion. Outcome 2 identifies “an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, social, cultural, social, environmental, and economic factors [13, p. 8].” Outcome 7 states “an ability to acquire and apply new knowledge as needed, using appropriate learning strategies [13, p. 9].” Outcome 4 is also a possibility.

Table 1. Sample of Electric Propulsion Standards

Organization	Number	Title
ASTM	F3239-22 [6]	Standard Specification for Aircraft Electric Propulsion Systems
ASTM	F3338-21 [8]	Design of Electric Engines for General Aviation Aircraft
SAE	ARP8676 [9]	Nomenclature and Definitions for Electrified Propulsion Aircraft
SAE	AS6502 [10]	Aircraft Propulsion System Performance Nomenclature
EASA	NPA 2021-15 [11]	New Air Mobility Continuing Airworthiness (CAW) Rules for Electric and Hybrid Propulsion Aircraft and Other Non-Conventional Aircraft (Draft)¶

For aerospace engineering technology baccalaureate programs, in section II. Program Criteria, applied propulsion is a mandatory requirement [13]. In section I. General Criteria, there are five student outcomes for baccalaureate programs listed under Criterion 3. While a valid assertion that all five student outcomes are applicable to electric propulsion, we focused on Outcome 2, "an ability to design systems, components, or processes meeting specified needs for broadly-defined engineering problems appropriate to the discipline;", Outcome 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", and Outcome 5 "an ability to function effectively as a member as well as a leader on technical teams [13, p. 8]."

ABET Student Outcomes are then mapped to specific course outcomes. In this way, the specific course outcomes build upon previous courses so that the overall program student outcomes may be met at the end of the baccalaureate program. An accredited ABET program must document that there are course syllabi and materials that support specific student outcomes that in turn support the program educational objectives [12], [13].

Methodology

In this study, the authors attempt to identify course outcomes from an electric propulsion aviation standard and their applicability to student outcomes from ABET ETAC and EAC baccalaureate accreditation rules. To answer these questions the authors engaged in a process that reviews electric propulsion standards in aviation, the development of course outcomes, a review of the most recent ABET student outcomes, and the alignment of those electric propulsion course outcomes with ABET student outcomes and ABET-accredited engineering and engineering technology programs, see Table 2.

This study discusses two ways of incorporating electric-propulsion course outcomes into aviation maintenance programs. One is the development of a completely new and unique course that can be included in an existing program. If the course is to be considered part of the program, then additional credit hours may be needed to fit the new course into the program. Otherwise, the new course could be included as an elective. An elective course leaves the decision to take the class up to the student and their ability to take an additional course. The other way is to split the material into smaller modules that can be incorporated into existing courses. This approach does not require additional credit hours; it does require that an existing course is related enough to the material and there is extra room in the course for additional material.

Table 2. Examples of Student Outcomes related to Electric Propulsion in Aviation Standards

Organization	Number	Title	Student Outcomes
ASTM	F3239-22	Standard Specification for Aircraft Electric Propulsion Systems	ETAC Outcome 3 EAC Outcome 2
ASTM	F3338-21	Minimum Design Requirements for Electric Propulsion	ETAC Outcome 2 EAC Outcome 2, 7
SAE	ARP8676	Nomenclature and Definitions for Electrified Propulsion Aircraft	ETAC Outcome 3, Outcome 5 EAC Outcome 7
SAE	AS6502	Aircraft Propulsion System Performance Nomenclature	ETAC Outcome 3, Outcome 5 EAC Outcome 7
EASA	NPA 2021-15	New Air Mobility Continuing Airworthiness (CAW) Rules for Electric and Hybrid Propulsion Aircraft and Other Non-Conventional Aircraft (Draft)	ETAC Outcome 2, Outcome 5 EAC Outcome 7

In the Purdue University ABET ETAC accredited aeronautical engineering technology program, there are faculty that are exploring the inclusion of electric propulsion technology in smaller modules to be incorporated into an existing course. While electric propulsion technology may be applicable to other ABET ETAC outcomes, in this paper the focus is on electric powerplant knowledge as it may be developed across a bachelor of science program as a way to support the development of Outcome 3. There are many applicable standards and laws. For this study, the application of ASTM F3239-22 is explored. For a student to gain knowledge of electric propulsion operational characteristics, installation, operation, and safety mitigation, the development of this knowledge and abilities may intersect with three required courses in BS Aeronautical Engineering Technology: AT 11600 (freshman), AT 26200 (sophomore), and AT 44502 (senior). These courses and their potential relationship to the ASTM F3239-22 standards are summarized in Table 3. Each course is discussed:

a) In AT 11600 Aircraft Science for Engineering Technology, “This course is an introduction to theory of flight, aircraft nomenclature, aircraft configurations, high-speed flight, and helicopter configurations and rotor dynamics. Covers lift/drag and concepts for flight at an engineering technology level beyond that of flight ground school. Federal regulatory systems for aircraft design and persons other than flight personnel and associated technical documents are covered. Introduces center of gravity theory, defines how to locate centers of gravity, and introduces weight and balance procedures for engineering technology, not covered by flight ground school [14].”

In this course, students are introduced to electric propulsion nomenclature, applicable aircraft configurations, and applicable standards and federal laws for aircraft design.

b) In AT 26200 Basic Aircraft Powerplant Technology, this course is "A study of the design, construction, and operating practices of aircraft reciprocating and small gas turbine engines. Laboratory exercises emphasize airworthiness evaluation, fault-isolation techniques, and standard service/maintenance practices [14]."

This course would be expanded to include exposure and experience with electric propulsion designs. As the course materials are already designed and implemented, the redesign would be necessary to judiciously reallocate course time to the topics.

c) In AT 44502 Aircraft Electronics, this course is "A study of the computer-based electronic systems used to control both flight and engine parameters on modern aircraft. The course examines the various systems with an emphasis on how each component integrates into the electronic structure of the aircraft [14]."

The course would build upon AT 11600, AT 26200, and other courses in the program to examine the use of engine control parameters and integration into the aircraft system. In this way, students would be able to use appropriate technical literature to discuss electric propulsion control, and indication that demonstrates their understanding of electric propulsion controls and indications within the electrical system to also include energy storage, powerplant installation and operations, and hazard identification and mitigation.

Discussion

Incorporation of new technologies into educational programs is challenging. There are philosophical and practical dilemmas. Questions such as: What material stays? What material goes? What materials are reduced in coverage or depth? What materials are increased in coverage or depth? What kinds of laboratory experiences are to be included or removed? Where to place new materials in an already packed curriculum? These issues may be met with support, opposition, or sometimes apathy among educators, administrators, and industry advisory boards. This paper does not address these challenges. This paper does acknowledge that the incorporation of new materials for electric propulsion means that some course material might have to be removed from classes in order to include this new material. This paper is meant as an initial step for incorporating electric propulsion into existing aerospace programs. The authors assert that a potential way to begin the process is to discuss where and how these materials may be incorporated throughout the program.

Table 3. Course outcomes with notional use of ASTM F3239-22 in an ABET ETAC aerospace program.

AT 11600 Aircraft Science for Engineering Technology	AT 26200 Basic Aircraft Powerplant Technology	AT 44502 Aircraft Electronics
The student shall be able to define and distinguish terminology for electric propulsion such as the following: capacity, electric engine, energy distribution system, energy storage system (ESS), usable energy capacity, and electric propulsion system (EPS)	The student shall be able to use electric propulsion terminology in technical communications. The student shall be able to identify two electric propulsion design technical literature and use it appropriately in technical communication.	The student shall be able to identify and use appropriate technical literature related to electric propulsion control and indication for use in technical communication.
The student shall be able to identify and distinguish applicable electric aircraft configurations and operational characteristics.	The student shall be able to describe electric powerplant controls and operational characteristics, and its relationship to energy storage.	The student shall understand energy storage, controls, powerplant operational characteristics, and installation.
The student shall be able to identify and distinguish electric propulsion hazards and mitigation methods.	The student shall be able to use standards to develop plans and procedures for hazard mitigation for at least one known hazard of electric propulsion.	The student shall be to develop plans and procedures for hazard mitigation that includes fire detection, lightning, and high-energy rotors

In this paper, the authors developed course outcomes from ASTM F3239-22 and connected them to ABET student outcomes from EAC and ETAC. Additionally, the authors illustrated how these course outcomes could be incorporated into a three-course structure in an existing aeronautical engineering technology program. There are many methods for curriculum development. Many of them focus on a multi-stage process that typically begins with developing goals or gathering existing resources and ends with implementation, assessment, evaluation, and revision. With the scarcity of existing resources, much of the curriculum development should be focused on the location, identification, and development of resources that can be used to develop course outcomes that lead to ABET student outcomes. This study used industry standards that will need to be supplemented with technical data from the actual hardware to become part of a full course.

Conclusion

Standards for electric propulsion for aircraft are beginning to expand upon the minimal existing support documentation. Standards are a publicly available source of data that can be used to identify the needs of the industry at large. This study reviewed five existing industry-developed consensus standards related to electric propulsion for their applicability to ABET EAC and ETAC student outcomes. Specific course outcomes were developed for one standard, ASTM F3239-22. For an ABET ETAC aerospace engineering technology program, a series of courses were identified and connected to both specific ASTM F3239-22 requirements and specific course outcomes. This information may be used by collegiate engineering or engineering technology programs to meet the future needs of the electric propulsion-based aircraft industry. While these course outcomes are focused on undergraduate education, there may be applicability to introductory courses at the graduate level. This paper is proposed as the beginning stage of the conversation leading to a future, more seamless inclusion of electric propulsion.

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