The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
ASEE
Paper ID #43045

Curriculum Needs for High Voltage Lithium Batteries in Aviation

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Abstract

As a result of climate change, there is a trend towards replacing petroleum-based engines with electric-based propulsion. Fully electric and hybrid electric vehicles are now frequently seen on the road. Electric propulsion is developing in the aerospace sector as well. Electric propulsion is new in the aviation industry and this recency means there is limited information for aviation programs in engineering and engineering technology programs. There is electricity currently on aircraft, but with the switch to electric propulsion the designers, technicians, and operators will be exposed to new procedures and hardware related to higher voltage and amperage.

One of the primary sources of higher voltage is the battery. Generally, traditional aircraft use lead-acid or nickel-cadmium (Ni-cd) batteries with 10-25 volts and 10-50 Ah values, whereas battery-driven aircraft will use lithium-ion (Li-ion) or lithium-polymer (LiPo) batteries with 200V to 600V or more. The ampere-hour (Ah) rating of these batteries can vary from a few tens to several hundred Ah. The values can vary from one aircraft to another depending on the aircraft's requirements.

This new battery technology in aviation applications has limited publicly-available documentation. This study will use what information is available and existing documentation from other industries, such as ground vehicles and industry standards, to build the foundation for future curriculum. The results will be evaluated against ABET-accredited engineering and engineering technology programs to provide alignment with ABET student outcomes.

Introduction

Since the beginning, aviation has flown on gasoline. It is effective, but not environmentally friendly nor infinitely available. There have been attempts to fuel airplanes with alternate fuels for decades. The first solar-powered airplane took flight in 1974. The first electrically powered airplane model, the "Radio Queen", flew in 1957. In 1957, NACA flew a Martin B-57 on hydrogen. There have even been attempts to power flight with nuclear power in the 1950s. While there have been attempts to power flight by different means, none have endured. Electrical power is trying to be the first alternate form of propulsion to gather a significant portion of the market share.

Currently, aerospace companies are pushing toward for certification with electric-powered aircraft. The eDA40 flight trainer from Diamond Aircraft received FAA certification in July 2023 [1]. The Pipistrel Virus SW 128 was EASA certified in 2020 [2]. Joby Aviation is over 80% complete with its Stage 3 certification and is delivering aircraft to the Air Force [3].

Currently, the effort is generally focused on the design and production of electric aircraft. The aerospace industry has started developing standards to support electric propulsion. A sampling of standards includes those related to specifications [4], electrical systems [5], architecture [6], and light sport aircraft (LSA) batteries [7]. However, once the aircraft is certified, sold, and entered into service, there is another significant amount of effort to support the electric propulsion motors. Repair processes must be developed and engineers and technicians must be trained. Aircraft are maintained by FAA-certified aircraft mechanics with A&P certificates. Currently, regulations do not include electric propulsion in the training curriculum.

This study intends to review existing publicly-available information and documentation on aircraft lithium batteries. Resources will include those from other sources, such as ground vehicles and industry standards, to build the foundation for future curriculum including course outcomes and assessment options. The results will be evaluated against ABET-accredited engineering and engineering technology programs to provide alignment with ABET student outcomes.

The research questions for this study are:

1. What are common potential hazards and handling procedures related to electric propulsion batteries in aircraft and how can they be classified?
2. What are the instructional settings for the electric propulsion batteries course materials?
3. What are some possible course outcomes associated with this new data?
4. Which and where are these outcomes applicable to ABET engineering (EAC) and engineering technology programs (ETAC)?

Limitations

The following are the limitations of this study.

1. There will not be a review or list of every standard or resource.
2. This study is not intended to provide a complete list of all possible procedures and policies that could be included in an environment that is working with high-voltage lithium batteries.
3. Industry standards or reports that are not part of the author's institutional subscriptions will not be reviewed.

Electric battery standards and documentation (RQ1)

A foundational skill when working with any system is a common understanding of terms and definitions. There are several sources to establish common definitions. The FAA has a website of definitions [8]. SAE has a standard on basic terminology, SAE J1715 hybrid vehicle and electric vehicle terminology [9]. ASTM F3060 is an industry standard for standard terminology pertaining to aircraft [10].

Working with lithium batteries may be new for aviation, but it is not in other fields such as electric cars. Aviation personnel can learn from how auto mechanics work with high-voltage lithium batteries. Aviation engineers and technicians typically work with lead-acid or nickel-cadmium (Ni-cd) batteries which have values in the range of 10-25 volts and 10-50 Ah values. However, lithium-ion (Li-ion) or lithium-polymer (LiPo) batteries can have values of 200V to 600V or more. The ampere-hour (Ah) rating of these batteries can vary from a few tens to several hundred Ah. The values can vary from one aircraft to another depending on the aircraft's requirements. These higher voltages require additional personal protection equipment to handle the equipment. OSHA 1910 includes requirements for those working with high voltages [11]. These requirements include the following:

a. 1910.269: If the voltage is more than 600v there should be at least two employees present.
b. 1910.269: The technician should be wearing rubber-insulated gloves.
c. 1910.137: Protective gloves must be worn over the insulated gloves.

High-voltage environments also require boundaries to ensure that people are not near active high voltage. For instance, according to NFPA 70E [12], if a technician is working with a cover removed with direct exposure to a fixed voltage between 50V and 750V there must be a boundary established that is at least 3.5 feet.

In addition to the established standards for working with lithium batteries, organizations have also begun to publish standards on both electric propulsion and electric propulsion batteries in aviation as whole, including references to lithium batteries. ASTM F2840, the design and manufacture of electric propulsion units for light sport aircraft (LSA), includes direction on the design and use of electric batteries [13]. ASTM F3239, the standard for the specification of aircraft electric propulsion systems, also includes design and operation criteria for batteries or energy storage systems [14]. Standards shown in Table 1 include directives for the maintenance and operation of batteries or storage systems.

A review of standards from the Society of Automotive Engineers (SAE) found SAE J3235 best practices for the storage of lithium-ion batteries [15]. This standard includes hazards, safety risks, and mitigation strategies. For instance, the standard identifies chemical energy as a chemical hazard where the concern or safety risk is thermal runaway, high heat generation, or even open flames. There are four mitigation strategies related to the storage of lithium batteries: 1) physical containment, 2) control of the state of charge as part of the storage plan, 3) the use of detection equipment, and 4) storage temperature such as cold storage [15]. SAE J3235 also includes different types of fire suppression and monitoring and detection technologies. The American Institute of Aeronautics and Astronautics (AIAA) AIAA G-136-2022 is a guide to lithium battery safety for space applications, however, the author was not able to access the full text.

Table 1. Examples of Maintenance and Operation Specific Directives from Standards

Standard	Directive
ASTM F2840 Design and manufacture of electric propulsion units for LSA	6.12 The EPU charging system shall be designed to safely enable ground personnel to recharge the energy storage device. 6.12.1 Be designed to prevent improper (reverse polarity) connections. 6.12.3 Incorporate features such that ground personnel can determine the state of charge of the energy storage device (ESD) before disconnecting the charger system from the charge source.
ASTM F3239 Standard specification for aircraft electric propulsion systems	5.3.2.2 Each energy storage system shall have access provisions for maintenance. 5.3.2.3 Design precautions shall be taken to minimize the hazards to the aircraft in the event of a fire or sudden discharge which could result in damage to components, structure, or flight controls near the storage area.
SAE J3235 Best practices for storage of lithium-ion batteries	5.1.2.1 Use physical containment to limit propagation. 5.1.2.2 Limit state of charge during storage and transport. 5.1.2.3 Maintain cool storage temperature. 5.1.2.4 Detect the release of chemical energy. 5.2.2.2 Minimize the voltage exposure for serviceable components or sub-assemblies by keeping them less than 60VDC 5.2.2.3 Battery and/or cell terminals are protected. 5.2.2.5 Signage and labelling should be utilized to inform and protect both personnel and emergency responders. High voltage battery packs should be labeled with an ISO high voltage warning icon or similar icon often dictated by regulations. 5.3.2.3 Facilities may have trenching or absorbent socks along the perimeter to mitigate the runoff of electrolyte when water or other fire suppression techniques are used.

Electric propulsion battery training settings (RQ 2)

In educational institutions, it is essential to provide students with hands-on experience and highly engaging learning environments. Institutional access to equipment or facilities may direct instructors to a particular learning environment. From a review of current educational training settings, the electric battery curriculum can be set up through three instruction settings. Instructors can choose from the following depending on which option works best for their program.

1. Physical instruction setting: This is a conventional instruction setting, where institutions equip all resources and provide students with the most realistic practical instruction. While this setting can provide students with high interaction and hand-on experience, but it can challenge institutions to prepare all required resources due to the limits of the budget and other administrative hurdles. Also, the learners need to be in educational instruction setting, which generates cost of relocation.
2. Computer based instruction setting: The form of learning process is two-dimensional based, uses a computer or video. The instruction material can be delivered online, which provides high learning flexibility and a low-cost learning tool. However, it has limits in providing a realistic practice and holistic view of objects [16].
3. Virtual based instruction setting: Using virtual reality (VR), augmented reality (AR), and mixed reality (MR) technologies, the course materials can be delivered in a virtual environment. This technology is proposed to overcome the limits of computer-based instruction setting [16] and physical instruction setting. In recent years, virtual based instruction is actively developed and implemented as a training strategy for pilots and maintenance technicians [17]. Jiang et al. [17] points out challenges of virtual setting is the cost of equipping hardware and compatible with other devices.

Curriculum and ABET expectations (RQ3 & 4)

Working with high-voltage lithium batteries will be new for aviation engineers and technicians, and there is minimal existing documentation sourced directly from the aviation industry. However, there is a large body of existing knowledge outside of the aviation industry, primarily from industries that build/use ground vehicles. After a review of the existing body of knowledge, the author has identified four major categories of knowledge that aviation engineers and technicians should become familiar with before working with high-voltage lithium batteries commonly found in electric aircraft. Possible course outcomes (CO) are shown below

a. Terminology

CO1 Students will be able to accurately define and differentiate between key terminology related to lithium and hydrogen electric high voltage batteries, including terms such as voltage, current, capacity, energy density, cycle life, charging efficiency, and state of charge.

CO2 Students will demonstrate an understanding of how these terms are interconnected and their significance in the context of battery technology and applications.

b. Personal protection equipment

CO3 Students will demonstrate an understanding of personal safety protocols and protection measures related to aviation electric batteries. This includes knowledge of proper handling procedures, storage requirements, and the use of protective equipment such as insulated gloves and eye protection.

c. Handling and operating procedures

CO4 Students will be proficient in handling and operating aviation electric batteries in compliance with industry standards and safety regulations.

CO5 Students will demonstrate the ability to safely connect and disconnect batteries, perform routine inspections for damage or anomalies, troubleshoot basic operational issues, and implement proper storage and transportation procedures.

CO6 Students will understand the importance of following manufacturer guidelines and regulatory requirements to ensure the reliable and safe operation of aviation electric batteries.

d. Common risks, hazards, and mitigation strategies

CO7 Students will be able to identify common risks and hazards associated with aviation electric batteries, such as thermal runaway, short circuits, overcharging, and exposure to hazardous materials.

CO8 Students will demonstrate an understanding of the factors contributing to these risks, including battery design, operation conditions, and maintenance practices.

CO9 Students will develop skills in risk assessment and mitigation strategies, including proper storage and handling, use of protective equipment, implementation of safety protocols, and emergency response procedures in the event of battery-related incidents.

There is an opportunity to align the anticipated curriculum with both engineering (EAC) and engineering technology (ETAC) ABET accredited programs, see Table 2. Terminology is foundational and the learning of common terms is already firmly established in both engineering and engineering technology programs. The use of personal protection equipment is needed to develop and share technical data and processes. If an engineer or technician intends to develop processes, repairs, or any other technical documentation for lithium batteries, then they must understand how the batteries work and how they should be properly handled to avoid risk.

Table 2. Alignment between course outcomes and ABET ETAC and EAC student outcomes

ABET ETAC and EAC Outcomes	Course Outcomes
ETAC 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. EAC 1: An ability to communicate effectively with a range of audiences.	CO1: Students will be able to accurately define and differentiate between key terminology related to lithium and hydrogen electric high voltage batteries, including terms such as voltage, current, capacity, energy density, cycle life, charging efficiency, and state of charge. CO 2: Students will demonstrate an understanding of how these terms are interconnected and their significance in the context of battery technology and applications.
ETAC 4: 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. EAC 2: 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, cultural, social, environmental, and economic factors.	CO3: Students will demonstrate an understanding of personal safety protocols and protection measures related to aviation electric batteries. This includes knowledge of proper handling procedures, storage requirements, and the use of protective equipment such as insulated gloves and eye protection.
ETAC 1: 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. EAC 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.	CO4: Students will be proficient in handling and operating aviation electric batteries in compliance with industry standards and safety regulations. CO5: Students will demonstrate the ability to safely connect and disconnect batteries, perform routine inspections for damage or anomalies, troubleshoot basic operational issues, and implement proper storage and transportation procedures. CO6: Students will understand the importance of following manufacturer guidelines and regulatory requirements to ensure the reliable and safe operation of aviation electric batteries.

ABET ETAC and EAC Student Outcomes	Course Outcomes
ETAC 2: An ability to design systems, components, or processes meeting specified needs for broadly- defined engineering problems appropriate to the discipline. EAC 2: 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, cultural, social, environmental, and economic factors.	CO7: Students will be able to identify common risks and hazards associated with aviation electric batteries, such as thermal runaway, short circuits, overcharging, and exposure to hazardous materials. CO8: Students will demonstrate an understanding of the factors contributing to these risks, including battery design, operation conditions, and maintenance practices. CO9: Students will develop skills in risk assessment and mitigation strategies, including proper storage and handling, use of protective equipment, implementation of safety protocols, and emergency response procedures in the event of battery-related incidents.

Discussion

A review of the existing documentation on the design, use, and maintenance of high voltage lithium batteries found information and opportunity to use for building curriculum to support electric aircraft. Much of the information found was from existing documentation from the ground vehicle sector that can be easily transferred to aviation. Additional information was found from industry standards specific to aviation. This study found four major curriculum categories to use as the basis for inclusion into existing courses or new courses: terminology, personal protection equipment, handling and operating procedures, and common risks, hazards, and mitigation strategies. All four categories support ABET student outcomes from both engineering and engineering technology programs.

Future directions

According to IATA [18] and ATAG [19], the plan is to introduce electric aircraft into the market. Starting with small-range aircraft (eVTOL) and gradually increasing the size and range, with the goal of long-distance flights with larger aircraft. Future studies can lead to conducting failure and safety assessments using different parameters such as range, payload, and seats of electric aircraft. Additionally, this study can be used as a baseline for developing student outcomes and building curriculum in electric propulsion aircraft.

Conclusion

The rising visibility and use of electric propulsion in aviation are bringing new opportunities for those who are responsible for the design and maintenance of airplanes. With this new opportunity brings uncertainty due to the lack of published technical data from the manufacturers. To bridge the gap until specific technical data becomes available, data from other industries where the data can be easily transferred is one way to support electric aircraft.

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