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Technical and Regulatory Factors of Adopting Electric Training Aircraft in a Collegiate Aviation Setting

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Electric-powered aircraft have entered the market. The arrival of the Pipistrel Velis Electro and other developmental efforts by companies such as Bye Aerospace, Piper, and eViation, have signaled to the aviation community that more electric-powered aircraft can be expected in the coming years. But how useful are they for training pilots in a Federal Aviation Administration (FAA) approved Part 141 collegiate aviation environment? To identify candidate flight courses and lessons, the authors examine flight hour distributions of a one-year window of invoiced flights (N = 52,728), including flight hour data cut-points at 60 minutes (n = 6,050) and 90 minutes (n = 25,439). The data distribution suggests that approximately 11.5% of the candidate flights would fall within a 60-minute expected flight duration, whereas 48% of flights would fall within a 90-minute flight duration. These calculations provide realistic targets for designed minimum flight duration (plus the inclusion of required FAA reserve) in order to be determined a feasible trainer in many high-volume FAA Part 141 training environments. Detailed course-level analysis suggests the Instrument Flight Instructor (CFII) flight course as a potential launch point for electric flight due to the relatively lower flight hour per lesson. In addition to minimum flight duration, other feasibility questions are included in this analysis, such as regulatory requirements, battery duration, aircraft turnaround time, multiple charge-discharge cycles per day, environmental factors, airport charging infrastructure, and maintenance factors. Additional research will benefit this developing area of electric aircraft in flight training environments.

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At the time of this writing, significant domestic and global events were and are expected to continue to influence the course of travel and technology. Public education on the relationship between carbon emissions and climate change has contributed to a growing awareness of the risks. According to one survey, well over 90% of adults in Europe and North America were aware of the problems associated with climate change (McSweeney, 2015). Unfortunately, the awareness of the risks of climate change is not uniform around the globe, yet it can be argued that the benefits of decarbonization may be felt by everyone.

In addition to the risks of climate change, the world has significant geopolitical and economic challenges. The war between Russia and Ukraine that began in 2022 has disrupted normal energy markets and contributed to energy and food instability in many parts of the globe (Economist, 2022a). The COVID-19 pandemic continues in selected regions (namely China and certain developing nations), whereas other regions have returned to near pre-pandemic levels, including air travel in the United States. Finally, the combined factors of post-pandemic increase in demand and disrupted supply chains have triggered inflationary pressures in many countries (Economist, 2022a).

One might ask how geopolitical and economic pressures relate to sustainable practices. Well, the uncertainties surrounding energy (oil) markets appear to have strengthened the focus on finding alternative sources of energy, including solar, nuclear, and hydroelectric power. As evidence of growing popularity and ostensibly impacted by this energy uncertainty, battery-powered vehicle availability has continued to grow in many countries, including the availability of electric trucks, such as the Ford F-150 Lightning and Tesla's Cybertruck (Economist, 2022b). According to the Economist (2022b), electric vehicle sales account for one in five cars sold in Europe and one in four vehicles in China.

What about aviation? In summary, the availability of electric-powered aircraft is growing, particularly with the arrival of the European Aviation Safety Agency (EASA)-certified Pipistrel Velis Electro, now owned by Textron (Moore, 2022). Yet, similar to electric cars, battery-powered aircraft will have similar concerns relating to battery endurance and infrastructure. So, what does that mean for potential adopters of this new technology? This research will investigate several considerations for adopting electric-powered aircraft within collegiate aviation.

Literature Review

State of Sustainability in Aviation/Aerospace

The pace of hybrid and electrified aircraft development has accelerated in recent years. Beginning as early as 2010, Airbus, one of the two largest aircraft manufacturers, began the development of the electric aircraft 'Cri-Cri'(Airbus, 2021). From that point, the company embarked upon a series of electric and hybrid aircraft demonstrators, including the E-Fan X, E-Fan 1.0, E-Fan 1.1, and the Airbus City Demonstrator. Solidifying the company's commitment to zero-emission aviation, the company opened the E-Aircraft System House in Germany to serve as a central point for the testing and development of alternative propulsion systems (Airbus, 2021).

In the airline environment, United Airlines recently partnered with Heart Aerospace to bring electric aircraft into U.S. domestic airline operations by 2030 (Thomas, 2022). Heart Aerospace's ES-30 is expected to come to the market in the late 2020s and has also garnered orders from other prominent companies such as Air Canada, Mesa, and Icelandair. The expected range of the ES-30 is expected to be approximately 120 miles (battery-only) to 240 miles (with gas-electric hybrid reserve). Given the expected range of this aircraft, it is expected to fill a short-haul sub-regional type aircraft intended to move passengers from outside metropolitan areas into hub airports.

In the general aviation domain, several aircraft manufacturers are working towards electric-powered aircraft, including Bye Aerospace, Pipistrel, and Diamond Aircraft (Boatman, 2022; Diamond Aircraft, 2022; Moore, 2022). At the time this article was written, the only aircraft with any type of certification from this set of manufacturers was Pipistrel. However, Pipistrel's Velis Electro only held type certification in Europe and currently operates under the experimental category in the United States.

In the light trainer marketspace, other pathways toward electric-powered aircraft exist. In July 2022, Vero Beach, Florida-based aircraft manufacturer Piper, announced it was partnering with the Canadian aerospace firm, Canadian Aviation Electronics (CAE), to generate a retrofit eArcher (Professional Pilot Magazine, 2022). This partnership was expected to produce a supplemental type certificate (STC) to convert existing Piper Archer airframes to electric power with the goal of reducing carbon emissions. The basic airframe, control surfaces, and flight characteristics would remain relatively unchanged; however, the fuel system and powerplant would undergo a renovation, requiring an STC. The STC approval route may be a shorter development and approval timeline compared to the certification of a new electric aircraft. Similar to other electric aircraft developmental efforts, the timeline associated with this effort is currently unclear.

Training Using Experimental Aircraft in the United States

Until recently, pilot training in experimental aircraft in the United States under Part 61 required a Letter of Deviation Authority (LODA) which was required for the individual aircraft and by the instructor (CFI) performing the training (Geil, 2022). The LODA process was recently removed under the FY 2023 National Defense Authorization Act. However, this change for Part 61 operators does not change existing regulations required under Part 141. The regulation 14 CFR Part 141.39(a)(2) precludes the use of experimental aircraft in flight training provided by a Part 141 flight school. Without further FAA airworthiness certification of an aircraft such as the Pipistrel Velis Electro and similar experimental aircraft, the expected utility in high-volume Part 141 training markets is limited. Given the lengthy processes the FAA requires for airworthiness certification and this technology representing a sea-change of sorts, it may be expected that any U.S. operator of new electric aircraft (certified as experimental) may be limited to Part 61 operations. Expansion into Part 141 flight schools will require a newly certified aircraft with a standard airworthiness certificate, a previously certified aircraft operating with a supplemental type certificate (STC), or as per the requirements of 141.39(a)(2).

Electric Training Aircraft Limitations and Operating Considerations

Electric aircraft powered by battery power is subject to the capacity limitations of current battery technology. In effect, this translates to “approximately an hour" (60 minutes) of potential flight duration (plus required reserve) based on current public statements or estimates provided by various manufacturers (CNN, 2017). Additionally, more analysis is required related to charge-discharge cycles, operational considerations of charging, and environmental considerations such as temperature, humidity, and atmospheric salinity (known to accelerate certain types of corrosion). A specific consideration yet to be fully investigated includes the contextual use of battery-powered aircraft within the flight training regime. For example, cycling lithium batteries at high currents, as anticipated in a high-volume flight training environment, combined with very high and very low ambient temperatures, may lead to yet unknown impacts on battery performance and longevity.

The internal combustion engine (ICE) powered training aircraft we fly today emphasize structural integrity, aerodynamic stability, and include more than adequate fuel reserves to complete the typical flight lesson at most any power setting. The electric aircraft we expect to see in the near future must meet the same design safety standards as their ICE predecessors yet, have a substantially new weight (battery) system to consider in place of traditional fuel storage systems. One solution to extend flight lesson duration is to fly these battery-powered aircraft at slower airspeeds (reduced amperage draw). Rarely, however, are training flights designed around these slower, maximum-efficiency flight regimes. Maneuvering lessons often require greater buffer from low-speed flight hazards, such as aerodynamic stall. Lessons focused on runway operation, such as take-off and landing, may place greater strain on battery storage systems due to the fluctuating power demands, including maximum power bursts while initiating the take-off roll or performing a go-around maneuver. Additional research questions and regulatory considerations are explored below.

Regulatory Requirements of Pilot Certification

Flight training in the United States may occur entirely within the realm of 14 CFR Part 61 or within the supplementary context of 14 CFR Part 141. Operations within Part 141, while subject to strict regulatory oversight by the FAA, provides benefits such as reduced aeronautical experience requirements to earn certificates and/or ratings. In both cases, the present technological state of electric aircraft may integrate well within selected aspects of flight training but not others. Within the next section, the focus will be on the following most common airplane single-engine certificates and ratings acquired in a collegiate flight training environment: private pilot certificate – airplane single engine land, instrument rating – airplane, commercial pilot – airplane single engine land, flight instructor – airplane single engine, flight instructor – instrument airplane.

As noted above, two primary limiting factors in the widespread adoption of electric aircraft in the flight training environment are battery endurance and charging infrastructure. While endurance and range have separate definitions, the concepts are closely related. Therefore, the advertised endurance values of electric aircraft can be used to draw basic conclusions about the potential range of the aircraft (assuming a no-wind condition). Range becomes a limiting factor for electric aircraft adoption due to the various cross-country aeronautical experience requirements necessary to obtain certain certificates and ratings. Per 14 CFR 61.1, cross-country time is defined as "a point of landing that was at least a straight-line distance of more than 50 nautical miles from the original point of departure," although, notably, this definition changes to "more than 25 nautical miles" for a sport pilot certificate and "a straight-line distance of more than 50 nautical miles" (without requiring a landing) for an airline transport pilot certificate. Assuming a groundspeed between 100 to 150 knots, a flight of approximately 50 nautical miles would require between 20 to 30 minutes of endurance, well within the advertised capability of existing electric aircraft solutions. Considering a roundtrip will generally be necessary for logistical purposes, the endurance requirements increase to 40 to 60 minutes, approaching or reaching the limit for current battery technology. These assumptions are predicated on the pilot conducting a cross-country flight at the regulatory-minimum distance, eliminating the flexibility to travel further, which may be necessary due to geographic isolation.

Private Pilot Training Considerations

Furthermore, certain certificates and ratings require cross-country flights of greater minimum distances. For a private pilot certificate with an airplane single-engine rating, 14 CFR 61.109(a)(2)(i) requires a night cross-country flight of over 100 nautical miles total distance, similar to the roundtrip demands of the "more than 50 nautical miles" cross-country. However, electric aircraft endurance may be more significantly impacted at night due to exterior and interior electric lighting requirements. Per 14 CFR 61.109(a)(5)(ii), the pilot must conduct a solo cross-country flight with a total distance of 150 nautical miles, equivalent to approximately 60 to 90 minutes of endurance at 100 to 150 knots groundspeed.

Commercial Pilot Training Considerations

For the commercial pilot certificate with an airplane single-engine rating, 14 CFR 61.129(a)(3)(iii) and (a)(3)(iv) both require a "2-hour cross country flight", which must include "a total straight-line distance of more than 100 nautical miles from the original point of departure". Furthermore, 14 CFR 61.129(a)(4)(i) requires a cross-country flight of "not less than 300 nautical miles total distance" with at least one segment consisting of a "straight-line distance of at least 250 nautical miles from the original departure point". If the training is conducted in accordance with Part 141, 14 CFR 141, Appendix D requires a more restrictive cross-country flight consisting of a flight segment of "a straight-line distance of at least 250 nautical miles".

Instrument Rating Training Considerations

The instrument rating is applied to either a private pilot certificate or commercial pilot certificate, granting a pilot the privilege of operating an aircraft under instrument flight rules (IFR), permitting operations such as flight in instrument meteorological conditions (IMC) or flight in Class A airspace. Among other requirements, 14 CFR 61.65(d) requires 50 hours of cross-country flight time as pilot-in-command, 40 hours of actual or simulated instrument time, and an IFR cross-country flight of 250 nautical miles. Per 14 CFR 61.1, the provision requiring a landing of more than 50 nautical miles from the original point of departure applies to the 50 hours of cross-country time for the instrument rating, suggesting the same limitations (and potential solutions) for most of the cross-country aeronautical experience required for other certificates and ratings.

While the 40 hours of instrument time is not required to be paired with the 50 hours of cross-country pilot-in-command time, an instructor and student may choose to design the training in this manner to produce maximum efficiency and lowest cost, impacting the ability to integrate an electric aircraft into this training. Additionally, the 250 nautical mile cross-country flight poses a substantial challenge for an electric aircraft to achieve within existing capabilities, although multiple stops to allow for recharging could mitigate this.

Appendix C of 14 CFR Part 141 outlines the requirements for an instrument rating course at a pilot school (14 CFR 141). A significant difference is the exclusion of any cross-country flight time requirement, requiring only 35 hours of actual or simulated instrument time. However, the 250 nautical mile cross-country remains a requirement, with a more restrictive element of one segment of at least 100 nautical miles between airports. While the incorporation of an electric aircraft in a 14 CFR 141 instrument rating course may be simpler than incorporating it in instrument training outside the provisions of 14 CFR 141, the 250 nautical mile cross-country continues to pose a significant hurdle.

Electric Aircraft – Airport Charging Infrastructure

The installation of charging infrastructure at designated cross-country “outstations” could mitigate endurance concerns for most cross-country requirements. Of course, this would require significant investment to provide the infrastructure, especially if “fast charging” is desired. Additionally, airports and fixed base operators would likely need to reconsider their service fee model to account for electrical utility usage and potential reduction of fuel distribution revenue. Even if those barriers were overcome, this solution would currently be insufficient to achieve a single 250 nautical mile cross-country flight segment; a groundspeed of 100 to 150 knots would require approximately 1 hour 40 minutes to 2 hours 30 minutes of endurance, well beyond the current advertised capabilities of electric training aircraft operating on a single charge.

Precedents to overcome these minimum distance (endurance) hurdles may exist within the context of flight training on small islands. Due to the geographic limitations of locations such as Hawaii, many of the cross-country requirements for various certificates and ratings are impractical or impossible to achieve. 14 CFR 61.111 allows for a waiver of the cross-country distance provisions of 14 CFR 61.109 (aeronautical experience for a private pilot certificate) for applicants located on islands in which the cross-country requirements would necessitate flying over water more than ten nautical miles from the nearest shoreline. Conducting training using the provisions of 14 CFR 61.111 mandates the issuance of a limitation on the pilot certificate prohibiting the carrying of passengers on flights of more than ten nautical miles from the respective island (and all other islands) in which the training was conducted. The limitation may be removed upon meeting the cross-country requirements of 14 CFR 61.109.

For the commercial pilot certificate, 14 CFR 61.129(a)(4)(i), requiring a 300 nautical mile cross-country flight (with one segment of at least 250 nautical miles), permits a reduction for applicants conducting the training in Hawaii. These applicants can instead conduct the longest segment at only 150 nautical miles rather than 250 nautical miles. The same substitution is permitted in 14 CFR Appendix D (Commercial Pilot Certification Course) (5)(a)(1).

Flight Instructor (CFI) Training Considerations

Notably, per 14 CFR 61 Subpart H, the flight instructor certificate has no explicit aeronautical experience requirements beyond 15 hours of pilot in command time in the category and class of aircraft for the rating sought, which the trainee is likely to already possess upon commencement of their flight instructor training. The same subpart also governs the requirements to earn an instrument rating for the flight instructor certificate, again with no explicit aeronautical experience requirements. Flight instructor training under 14 CFR 141 is arguably more stringent. 14 CFR 141 Appendix F requires 25 hours of total aeronautical experience in an approved flight instructor training course with no specific requirements regarding the type of flying (ex., cross-country flights). Similarly, 14 CFR 141 Appendix G simply requires 15 hours of total aeronautical experience in an approved flight instructor instrument course. Additional flight-hour/flight-course analysis and adoption considerations are explored below.

Purpose of the Study

The purpose of this study is to address questions related to the technical and regulatory factors of using electric-powered general aviation training aircraft in a collegiate flight training environment. The first two questions intend to identify how many potential flights would fall within the expected flight duration of an example electric-powered aircraft at two different potential battery capacities; 60 minutes and 90 minutes (plus required reserve). Another purpose of the study was to perform an analysis of the flight lesson curricula by flight course to identify flight courses that may serve as suitable launch points for electric aircraft based on their composition of flight lessons and average flight lesson durations. The final purpose of this study was to identify sets of additional technical and operational factors which may need to be considered if a collegiate aviation institution were to adopt electric training aircraft.

Research Questions

> *RQ1.Assuming no changes to the current FAA-approved Part-141 training curriculum, what percentage of the flights would be considered candidate flights for electric-powered aircraft with a 60-minute flight hour duration plus reserve?*
>
> *RQ2. Assuming no changes to the current FAA-approved Part-141 training curriculum, what percentage of the flights would be considered candidate flights for electric-powered aircraft with a 90-minute flight hour duration plus reserve?*

> *RQ3. What are the mean flight hours by flight course, and what percentage of each flight course's training flights would be covered by aircraft flight durations of 60 minutes (1.0 Hobbs meter) and 90 minutes (1.5 Hobbs meter)?*

Method

Sample

The master dataset includes invoiced training flights (*N* = 52,728) from all flight courses at a collegiate aviation institution during the fiscal year 2022 (FY22) (July 1, 2021, through June 30, 2022). For the purposes of the study, only invoices generated through the use of internal combustion engine (ICE) powered single-engine aircraft (e.g., the Piper Archer) were included in the study. To facilitate a more detailed analysis relevant to the study purpose, two subsets of the master dataset were created; a dataset with flight lessons of 1.5 hours Hobbs meter or less (*n* = 25,439) and a dataset with flight records of 1.0 hours Hobbs meter or less (*n* = 6,050). To determine invoiced flight lessons that may not represent "normal" training flights, the researchers also identified lessons with an invoice of 0.4 or fewer hours. These low-time lessons were limited to 316 flights and represented only a small fraction of the operation (0.59%) and, as such, did not represent a meaningful portion of the training requirements of a pilot candidate. Finally, a small number of flight records (*n* = 29) were removed from the analysis as they represented *legacy* courses of the approved Part 141 (*n* = 23) curriculum or were non-standard database entries (*n* = 6).

Data Collection

After each training flight, the student and/or flight instructor completes an invoice and submits it for processing into the flight records system. Included on the invoice are pertinent details about the flight, including the date, flight course, flight lesson, and billable flight hours. The billable flight hours are recorded from an analog gauge in the aircraft (referred to as the Hobbs meter). A report was generated from this dataset for FY22, and the data was cleaned of any identifiable student information and non-pertinent records. Additionally, the dataset included a small number of records (<1%), which represented flight courses either no longer a part of active training course outlines (TCOs) or non-standard database entries. Those records were also removed from the dataset. After cleaning the data, researchers rank-ordered the flight records by the duration of the flight (0.1 to 8.0 hours) and compiled a master (all flight records) and two subset (nested) datasets representing flight records 60 minutes and less (≤1.0 Hobbs meter) and 90 minutes (≤1.5 Hobbs meter). As the study focused only on flight duration analysis without any identifiable student information, no IRB approval was sought for the study.

Results

Using the master and two nested datasets, researchers first noted the record count within each dataset and calculated the lesson mean flight hour durations for each of the three related datasets using the *=average(cellrange)* function within Microsoft Excel. The result of this initial analysis of the master and two subset datasets is included in Table 1. To aid in the feasibility analysis of battery-powered flight, additional analyses were performed using the two nested datasets with lesson durations up to and including 60 minutes (1.0 Hobbs meter) and up to and including 90 minutes (1.5 Hobbs meter). These values were chosen as they represent the currently forecasted flight durations of electric aircraft in-service or proposed for development at the time of this writing.

Using these datasets, researchers then created pivot tables to assess the data by flight hour duration using incremental Hobbs hour records (0.1, 0.2, 0.3, etc.) and, separately, by flight course. The pivot table of the flight hour records was used to create the distribution shown in Figure 1. Flight lessons of 60 minutes or less represented 11.5% of the dataset, whereas a notable increase in candidate flights was noted when expanding the analysis to include 90-minute (1.5 Hobbs meter) flight durations, representing 48.2% of the dataset. The pivot table of the flight course records was used to calculate mean flight hours per flight course, as shown in Table 2.

Table 1
Master Dataset and Nested Datasets, Flight Record Counts and Means

Datasets	**Flight Count (N/n)**	**% of Master Dataset**	**Lesson Duration Mean (hrs)**
All Training Flights (Master)	52728	100.0	1.68
Flights ≤ 90 min (0.1-1.5)	25439	48.2	1.22
Flights ≤60 min (0.1-1.0))	6050	11.5	0.79
Flights ≤ 0.4 (≤ 24 min)	316	0.6	0.36

Note. The master dataset includes all flight records within the assessment period, whereas the 90- and 60-minute datasets are proportionately smaller. Flight records less than or equal to 0.4 hours Hobbs were included in the Master, 60-min, and 90-min datasets but had negligible impact on analysis.

In addition to the 60- and 90-minute subset analysis, the researchers analyzed the individual flight courses which currently employ ICE-powered aircraft and which may use electric aircraft in the future. Six (6) flight courses included in the FAA Part 141 curriculum using a single-engine aircraft (e.g., the Piper Archer) were analyzed. The results of the flight lesson count, mean flight lesson length, standard deviation (SD), and percentage of flight lessons within each flight course at and below the 60- and 90-minute cut points are included in Table 2. The first commercial “time-building” course (CP1) and instrument training (IR) courses include several longer cross-country flights, which increases the lesson mean above other courses such as Private Pilot (PVT) and the two fixed-wing airplane instructor courses (CFI and CFII). For consideration purposes, only 8.5% of flights would be covered within the existing CP1 curriculum with battery durations of 60 minutes, whereas over 80% of the flights in the CFII course would be covered at a battery duration of 90 minutes.

Table 2

Course Flight Counts, Means, SD, and Percentage of Lessons at or Below 60 and 90 Mins

Course	Flight Count (*n*)	Lesson Duration Mean (hrs)	SD	% Flight ≤ 60 min	% Flight ≤ 90 min
Private (PVT)	18,732	1.54	0.49	14.2	48.9
Commercial – Basic (CP1)	10,058	1.97	1.07	8.5	38.6
Instrument (IR)	8,035	1.89	0.97	10.6	49.2
Commercial - Advanced (CP2)	7,388	1.68	0.88	11.5	43.4
Flight Instructor (CFI)	5,480	1.48	0.35	15.5	50.9
Instrument Flight Instructor (CFII)	3,035	1.42	0.47	28.1	80.2
Total	**52,728**				

Note. Invoices from students who entered the university with an FAA private pilot certificate were grouped under the PVT course, along with traditional student pilots enrolled in the FAA PVT course.

Tables 3 through 8 below represent a summarized format of the current FAA Part 141 curriculum at the collegiate aviation institution separated by flight course. The tables are presented to allow the reader to further understand what portion of the curriculum would be covered by electric-powered aircraft of varying battery durations, assuming (1) no changes in the curriculum, and (2) assuming improvements to the battery longevity as technology improves. It is acknowledged that both of these factors – curriculum design and battery duration – will change over time, so a nearly infinite combination of curriculum designs would not be prudent to include in this manuscript. Collegiate aviation institutions have the option to include ground training devices (FTDs/ATDs/simulators) in their flight courses and determine to what scale they are used. Training time in the ground training devices does count towards pilot training requirements. The tables below do not include the TCO-approved use of ground training devices and focus primarily on single-engine airplane training time. These tables do include the additional practice and training typically observed at the collegiate aviation institutions dataset and not just the training required to meet FAA pilot training minimums.

Table 3

Part 141 PVT Curriculum – Breakdown by Expected Flight Lesson Duration and Count

Flight Lesson Type	Flight Lesson Duration - in TCO	Expected Lesson Count
Local Dual	1.5	30
Local Solo	1.3	2
X Country Dual	3	2
X Country Solo	3	1

Note. Students may witness differences in lesson times and numbers of lessons due to a variety of factors, including practice, weather, proficiency, prior experience, and others.

Table 4

Part 141 CP1 Curriculum – Breakdown by Expected Flight Lesson Duration and Count

Flight Lesson Type	Flight Lesson Duration - in TCO	Expected Lesson Count
Local Dual	1.5	15
Local Solo	1.5	5
X Country Dual	3	5
X Country Solo	3	5

Note. Students may witness differences in lesson times and numbers of lessons due to a variety of factors, including practice, weather, proficiency, prior experience, and others.

Table 5

Part 141 IR Curriculum – Breakdown by Expected Flight Lesson Duration and Count

Flight Lesson Type	Flight Lesson Duration - in TCO	Expected Lesson Count
Local Dual	1.5	13
Local Solo	NA	NA
X Country Dual	3	3
X Country Solo	NA	NA

Note. Students may witness differences in lesson times and numbers of lessons due to a variety of factors, including practice, weather, proficiency, prior experience, and others.

Table 6

Part 141 CP2 Curriculum – Breakdown by Expected Flight Lesson Duration and Count

Flight Lesson Type	Flight Lesson Duration - in TCO	Expected Lesson Count
Local Dual	1.5	17
Local Solo	NA	NA
X Country Dual	NA	NA
X Country Solo	NA	NA

Note. Students may witness differences in lesson times and numbers of lessons due to a variety of factors, including practice, weather, proficiency, prior experience, and others.

Table 7

Part 141 CFI Curriculum – Breakdown by Expected Flight Lesson Duration and Count

Flight Lesson Type	Flight Lesson Duration - in TCO	Expected Lesson Count
Local Dual	1.5	20
Local Solo	NA	NA
X Country Dual	NA	NA
X Country Solo	NA	NA

Note. Students may witness differences in lesson times and numbers of lessons due to a variety of factors, including practice, weather, proficiency, prior experience, and others.

Table 8

Part 141 CFII Curriculum – Breakdown by Expected Flight Lesson Duration and Count

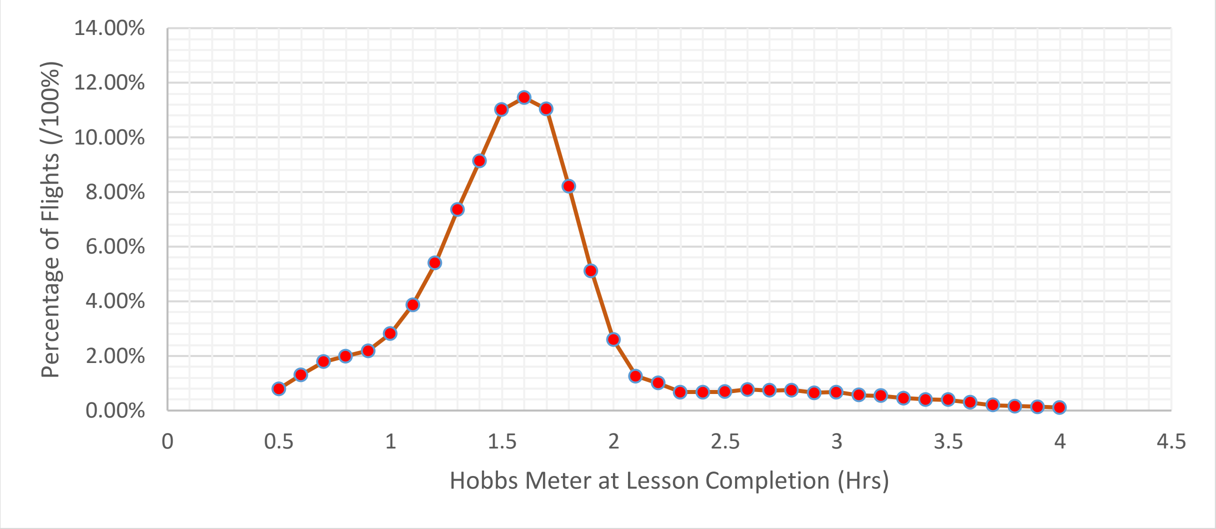
Flight Lesson Type	Flight Lesson Duration - in TCO	Expected Lesson Count
Local Dual	1.5	9
Local Solo	NA	NA
X Country Dual	2.5	1
X Country Solo	NA	NA

Note. Students may witness differences in lesson times and numbers of lessons due to a variety of factors, including practice, weather, proficiency, prior experience, and others.

Additional graphical analyses of candidate flight lessons are included in Figure 1 and Figure 2 below. Figure 1 shows invoiced flight lessons between 0.5 and 4.0 flight hours and a concentration of candidate flight lessons between 1.0 and 2.0 hours, with fewer flights occurring above and below those values. Figure 2 shows greater detail on flight lesson counts, specifically focusing on flights that could be substituted from an internal combustion engine (ICE) powered aircraft to an electric-powered aircraft given current electric aircraft capabilities. The data in Figure 2 is color-coded by the flight hour duration with data up to 60 minutes (1.0 Hobbs meter) (blue) and data greater than 60 minutes and less than or equal to 90 minutes (between 1.1 and 1.5 Hobbs meter) (red). The data is colored to emphasize the difference in the nominal count of candidate flights which could benefit from an aircraft with a 60-minute flight duration plus reserve or an aircraft with a 90-minute flight duration plus reserve battery. Considering the data in Figure 2, flight lessons with a Hobbs reading of 0.1 to 0.4 total of 316 flights, lessons with a length of 0.5 to 1.0 hours total of 5,734 flights, and the records ranging from 1.1 to 1.5 represent *an additional* 19,073 flights.

Figure 1.

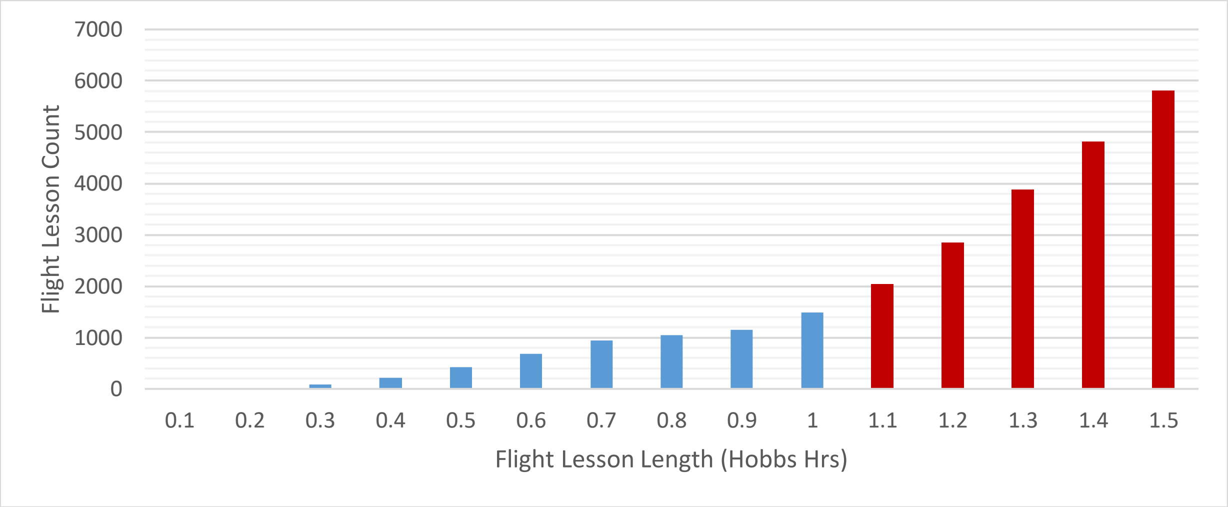
Fixed-Wing Flight Lesson Distribution by Percentage of Flights 0.5 – 4.0 Hours FY22 (n = 51,243)



Note. Training flights under 0.4 or over 4.0 recorded Hobbs time were excluded from the graph above to simplify graph interpretation. Flights over 4.0 recorded duration represent a small portion of cross-country training and will ostensibly require aircraft with internal combustion engines until battery technology continues to mature.

Figure 2.

Piper Archer Flight Lesson Count by Hobbs Meter Subset Data (≤60 and ≤90 Mins) – FY22 (n = 25,439)



The next portion of this research effort was to identify a set of additional factors flight schools must consider when assessing technical and operational considerations of electric aircraft. The research team generated this list through their extensive experience in Part 141 training environments and as a natural consequence of considering the logistical requirements of adopting electric aircraft into the training environment. It should be noted that the research team is all Federal Aviation Administration (FAA) certified pilots and flight instructors, each with extensive management, instructional experience, or both. Although this dataset includes many important factors, additional research and analysis by other teams may generate additional regulatory, infrastructure, or human factors considerations not included below. The factors and proposed research, training, or operational questions are listed below in Table 9.

Table 9

Operational and Training Factors of Electric Aircraft for Further Research

Factor	Operational Impact	Proposed Question(s)
Battery duration	If flight time available per charge is less than what is expected today using fuel, curriculum, training schedules, and/or flight lesson content must be modified.	What is the expected or typical amount of flight time available per charge? What is the projected development timeline for battery capacity increases?
Battery charging – Aircraft Turnaround Time	Fueling a general aviation airplane takes minutes. Longer times to charge the battery may extend the time between flights and may result in less aircraft utilization and/or increased operational costs.	What is the expected or typical time to charge the battery? What R&D is being done today to reduce this factor?
Battery charging – Multiple Cycles per Day	Airplanes used for flight training are used multiple times per day. The time needed to cool the battery after charging may extend the time between flights.	Will the battery need cooling time when charged multiple times per day? Does the frequency of the charge cycle impact battery health/longevity?
Battery Charging – Environmental Factors	Ambient temperature. Atmospheric Salinity (corrosion). Effects on airplane turnaround times and utilization.	What effects does ambient temperature (high or low) have on battery charging and the time to reach a full charge? Does atmospheric salinity increase the risk of corrosion on power components?
Base Airport Infrastructure – Charging Stations	The number of charging stations available will impact aircraft turnaround times. Large fleets may require dozens of available charging stations. Smaller operators may be able to operate with a single charging station.	Are airports prepared to construct and provide multiple charging stations? In ground installation? Above ground installation? What other power storage solutions can facilitate charging requirements?

Charging Station Availability at Other Airports	Flight training requires cross-country training. Charging station availability affects route selection. When paired with weather conditions, cross-country training could result in extended training timelines or limited route selection.	Are airports prepared to construct and provide multiple charging stations? In ground installation? Above ground installation? In the event of a diversion to an airport not equipped with charge, what solutions exist to recharge that aircraft after landing?
Aircraft Systems	The aircraft systems in an electric airplane are different from a standard combustion engine (E.g., fuel level vs. battery capacity, engine start/stop controls, emergency procedures, environmental system usage, etc.).	Will pilots in training be required to train in both electric and internal combustion engines, or will there be separate training similar to what is expected for complex, high-performance, and tailwheel airplanes?
Emergency and Operating Procedures	The aircraft systems and operating procedures in an electric airplane are different from an aircraft with a standard combustion engine.	Will pilots in training be required to train in both electric and combustion engines, or will there be separate training similar to what is expected for complex, high-performance, and tailwheel airplanes?
Insurance	Do insurers have adequate data to make informed decisions related to insurance rates? Aircraft with a standard combustion engine typically have fuel endurance of 4 to 6 hours.	Will individual aircraft or fleet insurance be higher or lower than ICE-powered aircraft? Will less flight time available because of lower battery endurance increase the per-hour cost of insurance?
Aircraft maintenance	The differences between electric and internal combustion engines.	Will aircraft mechanics be required to have additional training to be authorized to work on electric aircraft engines and systems in an environment where there is already a mechanic shortage?
Airport Rescue Fire Fighting (ARFF) Training and Capability	Electric batteries and liquid fuel tanks are different methods of storing chemical energy. They also present different challenges with respect to the containment of any reactions.	Do local ARFF teams need new equipment or training to support battery-powered aircraft?

Human Factors Decision Making	Pilots of common ICE-powered training aircraft can expect several hours of flight duration.	How does pilot decision-making change with different battery durations or remaining capacity display representations?

Discussion

Flight Course/Lesson Candidates – Course Type and Lesson Duration

Numerous factors influence the feasibility of adopting electric aircraft, given their current operating considerations and limitations. First, if we consider the nominal flight time for any set of candidate flight lessons (without respect to flight course, flight lesson content, or regulatory requirements), approximately 11.5% of the flights would be considered candidates at 60 minutes or less duration (plus reserve). If battery technology increases to allow for up to 90-minute battery duration (plus reserve), the amount of candidate flight lessons increases substantially to around 48.2% of possible flights. Most providers of flight training understand that sequential flight lessons may be of varying lengths. For example, a normal maneuvers lesson (~1.2-1.5 hours) may be followed by a night-cross country (~2.5 hours). Should students and instructors be expected to routinely switch aircraft types (or, at minimum, engine types) from one lesson to the next on a regular basis? On an isolated basis or if the aircraft type remains constant, it may not have a substantial negative impact assuming the instructors are adequately proficient in both aircraft types (electric or ICE). However, switching regularly between ICE and electric-powered aircraft simply to maximize utilization of electric aircraft may have secondary effects on student progress, human factors, and/or proficiency with normal and emergency procedures. These questions are not yet fully understood. Yet, we know that as battery technology improves to allow longer flights with operationally necessary payloads, the amount of *switching* between ICE and electric-powered aircraft is expected to diminish.

If we consider the alignment between the flight course curriculum and current electric aircraft capabilities, more specific solutions become evident. Considering Table 2, the flight instructor courses (CFI and CFII) and instrument training (IR) courses may be candidates for early adoption of electric flight. The instrument flight instructor course (CFII) with lower average flight times and no cross-country requirements may yield up to 80% of flight lessons as candidates for electric aircraft, assuming a 90-minute plus reserve capacity. Follow-on conditions may be placed on lessons such as “simulated instrument conditions only” to ensure compliance with regulatory factors such as filing of the alternate airport(s), etc. An additional breakdown of individual flight course curriculum structures was presented in Tables 3 – 8.

Flight Course/Lesson Candidates - Regulatory Considerations

For rapid adoption of electric aircraft in flight training, governing agencies must consider either regulatory exceptions or a review of existing regulations to better accommodate electric aviation. Regulatory carveouts similar in style to the carveouts provided for flight training on small islands could provide precedent. For the private pilot certificate, a new regulation could permit a waiver of the minimum cross-country distance requirements when training is conducted in an electric aircraft, with a limitation prohibiting passengers carrying on flights more than 50 nautical miles from the original point of departure. For the commercial pilot certificate, 14 CFR 141 Appendix D (5)(a)(1) should also apply to electric aircraft, allowing the "straight-line distance of at least 250 nautical miles" to be substituted for a "straight-line distance of at least 150 nautical miles". For commercial pilot training conducted under Part 61, the "Hawaii carveout" within 14 CFR 61.129(a)(4)(i) should also apply to electric aircraft, permitting a straight-line distance from the original point of departure of 150 nautical miles versus 250 nautical miles. There currently exists no "Hawaii carveout" for the 2-hour cross-country requirements, requiring a new, unprecedented regulation, perhaps reducing the requirement to 1-hour for electric aircraft.

There currently exists no regulatory exception for instrument training on small islands, providing no precedent to overcome the 250 nautical mile cross-country flight requirement for the instrument rating. The 40 hours (or 35 hours under 14 CFR 141) of instrument experience could be more achievable with the current state of electric aircraft technology, assuming these hours are acquired during local flights. Summarily, an electric aircraft (assuming current technology) could only be utilized to earn an instrument rating if supplemented by an aircraft powered by an internal combustion engine. Furthermore, while not necessarily required for most instrument training (with the exception of the 250 nautical mile cross-country), if the instructor and/or trainee wish to operate under instrument flight rules (IFR), the aircraft must be IFR-certified.

Training for flight instructor certificates may present the greatest opportunity to practically integrate electric aircraft immediately, without the need for any regulatory relief. No cross-country aeronautical experience requirements are mandated for the certificate in both Part 61 and Part 141. The same is true for the training required for a flight instructor instrument airplane rating. Assuming lesson profiles are designed to accommodate the endurance of an electric aircraft, the entirety of this training can be accomplished with an electric aircraft. Certainly, flight instructors and flight schools would need to consider the implications of the non-exposure of flight instructor applicants to aircraft with internal combustion engines. For example, an internal combustion engine malfunction or failure may be handled much differently, with different instructional considerations, from malfunction or failure of the electric propulsion system in an electric aircraft.

With the aforementioned regulatory limitations and suggestions, training for the private pilot certificate using electric aircraft can be considered to be feasible. All requirements for the certificate could theoretically be met with an electric aircraft today, though regulatory relief would make the integration much more practical without the need to either install additional infrastructure or supplement the training with an aircraft powered by an internal combustion engine for the purposes of meeting the cross-country requirements. Commercial training could be made more possible with the suggested regulatory relief but remains a significant practical challenge without supplement from an aircraft powered by an internal combustion engine.

An additional application of electric aircraft could be as a "time-building" solution towards the aeronautical experience requirements for an airline transport pilot (ATP) certificate required to serve as a required crewmember in a 14 CFR 121 operation (scheduled airlines). 14

CFR 61.159 requires 1500 hours of total pilot time for the ATP, although pilots may qualify for a restricted ATP certificate at 750 hours, 1000 hours, or 1250 hours depending on the type of previous experience and/or whether flight training was conducted in a collegiate setting. Without additional aeronautical experience beyond that acquired during flight training, an instrument, and multi-engine rated commercial pilot is likely to have approximately 200 to 300 hours upon completion of training, leaving a deficit of approximately 800 to 1300 hours of pilot time. Some may choose to gain this experience through traditional "experience-building" jobs such as pipeline patrol, aerial survey, or flight instructor, all of which allow the pilot to receive compensation while time-building. Electric aircraft could, however, provide a modern, alternate, and low cost means of gaining this experience.

The Mesa Airlines Pilot Development Program utilizes a fleet of Pipistrel Alphas, the internal combustion version of the Pipistrel Velis Electro (*Mesa Pilot Development*, n.d.). The program allows cadets to build time, up to 40 hours per week at $25/hour, all financed by Mesa Airlines. The cadet would then repay this loan after employment by the carrier. Flight schools could adopt similar programs, offering an electric aircraft such as the Velis Electro to conduct low-cost time-building.

Required Airport Infrastructure

The change from internal combustion engines (ICE) to electric-powered aircraft requires a paradigm shift in the required airport infrastructure. For example, a *theoretical* airport with a 100% electric fleet would no longer require in-ground or above-ground liquid fuel tanks for local tenants, yet would need some electric power-grid replacement. Additionally, the risk of fuel spillage, environmental damage, or unintended combustion of flammable liquids would be mitigated. Although these longer-term benefits may serve as a vision of sorts towards decarbonizing aviation, it is expected that significant investment (expense) in airport infrastructure will be required to facilitate electric aircraft in the near term as well as the ongoing support needs of legacy ICE aircraft whether based locally or transient.

Limitations

This study was conducted using flight lesson data at a collegiate flight institution in the midwestern United States. The flight hour dataset and its associated analysis are influenced by the current-state curriculum in place at the institution as approved by the Federal Aviation Administration (FAA). In addition to the impact of the current-state curriculum, the analysis may be impacted by the airport, airspace, and environment. For example, a flight school at a smaller airport with fewer flight operations may require less ground taxi time and less flight time to transit to and from a 'practice area' if a practice area has even been designated. Conversely, a flight school or institution based at a larger airport may require more time for ground taxi and transit to and from any practice areas. An additional consideration that may impact some analyses are weather conditions. Significant weather variations such as high cross-winds, low ceilings, thunderstorms, winter weather, and icing may have a nominal impact on any dataset and could influence an individual training provider's experience depending on their local climate. Consumers of this dataset should understand that curriculum, airport, flight operations, and weather may change how you interpret the data included in this study as well as how similarly or differently another collegiate aviation organization or flight school may witness similar analysis.

One final limitation of this study relates to the method by which the researchers generated the operational and training factors listed in Table 9. Although the authors are all FAA-certified pilots and instructors and have a variety of management or instructional backgrounds, this portion of the manuscript did not include input from a broader audience and could be improved through additional research. In fact, the purpose of this table was to assist future researchers in identifying potential research topics, adoption considerations, and/or performing research to further the knowledge in the aviation discipline.

Conclusions and Future Implications

Flight training is expensive, and Universities have a responsibility to explore green initiatives. Today's collegiate aviation students are building high levels of debt to pay for their flight training. Universities and training providers are doing what they can to keep costs as low as possible while remaining competitive. At the time of writing, the average price of 100LL nationally is just under $7 per gallon (*100LL - Aviation Fuel Prices*, n.d.). That means a training aircraft with a 180 HP combustion engine requires over $50 an hour for fuel alone. Utilizing electric aircraft is an option that could lower fleet operating costs, lower the cost burden to the student, and enable Universities and training providers to adapt to greener alternatives. However, the authors of this paper have identified many considerations for adopting electric flight in a collegiate environment.

If a battery-powered aircraft can sustain flight for 60 minutes plus reserve, a simplified analysis suggests that approximately 11.5 percent of training flights at a given Part 141 collegiate flight program could benefit from such aircraft without respect to flight curriculum. If the battery duration plus reserve expands to 90 minutes, nearly half of all candidate flights within the curriculum could benefit from an electric aircraft. Although battery duration is one important factor, many other factors must be considered. Regulatory requirements suggest that charging infrastructure at the base and remote airports must be developed across our nation to facilitate cross-country length requirements, or conversely, the regulations must be changed. Additionally, any potential flight school may need to consider environmental factors (e.g., temperature), maintenance, and charge-discharge cycles with any adoption decision. In addition to the questions we have raised in this research, there are additional human factors considerations such as potential time pressures, changes (improvement) in pilot fatigue, and others yet to consider. More work remains within this developing field to understand the long-term implications of electric flight. Two questions remain. When will electric-powered aircraft become commonplace at collegiate aviation institutions? Will converting a fleet of aircraft from ICE to electric-powered and training its associated support personnel and facility updates result in lower or higher costs over time?

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