ELECTRIC PLANE BATTERY OPTIMIZATION

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Abstract – *This report discusses the problem of limited battery capacity in the electric aviation industry. It highlights the potential benefits and impacts of optimizing electric plane batteries, including reducing carbon emissions, lowering operation costs, and improving access to remote communities. The report identifies key stakeholders, including Pipistrel, Transport Canada, Waterloo Institute for Sustainable Aeronautics (WISA), and Waterloo Wellington Flight Centre (WWFC). It analyzes the efforts made to address aviation carbon emissions, battery limitations, and decision-making for flight safety. The project objectives of improving data preparation, visualization, and optimizing battery management are outlined, emphasizing the need for accurate models and user-friendly interfaces.*

Keywords: Battery and energy management, machine learning (ML), data pipeline, visualizations, and analysis

1. ELECTRIC AVIATION PROBLEM ANALYSIS

1.1. Key Problems

1.1.1. Aviation Carbon Emissions

The aviation industry annually outputs almost 3% of the world's carbon emissions, which is approximately 1 billion tonnes. Aviation also accounted for 3% of Canada's total emissions in 2019, which is equivalent to 22 megatonnes of CO_2 greenhouse gases (Singh, 2022).

1.1.2. Limitations of Electric Aviation in Canada

Electric aircraft have many restrictions that cause implementation problems and severely limit commercialization. The lack of electric aircraft, specifically in Canada, is due to many factors like battery capacity, weight, and charging infrastructure.

1.2. Key Causes

Battery and energy management: Energy management for e-planes are not well understood. A small e-plane like the Velis Electro (with a useful load of 172 kg) contains 2 batteries totaling 140 kg (Pipistrel, 2023), which adds weight complexity.

Canadian weather conditions: Weather conditions can drastically impact the battery's state of health (SOH). Strong winters can reduce battery efficiency, when optimally, the outside air temperature (OAT) should be in the range –20°C to 35°C (Plevnik, 2020).

Plane operations and range anxiety: Each operation performed by a pilot (takeoff, cruise, tilt, taxi, etc.) utilizes different amounts of energy. With electric aircraft, their flight time is significantly lower than fuel planes, which increases the pilot's range anxiety, a psychological phenomenon where individuals are unsure whether they will reach the destination safely before the energy source runs out (Wardlaw, 2020).

For a deep understanding of the competitors, industry landscape, stakeholder background, and gaps analysis, view Appendix A, B, C, and D.

1.3. Problem (HMW) Statement

How might we analyze plane flight, battery, and weather data for pilots and researchers at the WWFC and WISA to optimize plane operations and enable the users to make flight decisions based on climate conditions, battery SOC, and SOH?

2. PAIN POINTS, NEEDS AND TASKS ANALYSIS ON STAKEHOLDERS

2.1. Impact on Key Stakeholders

Key stakeholders along with their goals and needs are described in Figure 1. Pipistrel, require certifications and government support for increased adoption of electric planes. Transport Canada aims to achieve net-zero emissions by 2050 and seeks sustainable aviation practices. The Waterloo Institute for Sustainable Aeronautics (WISA) focuses on research and technology development in green aviation, while the Waterloo Wellington Flight Centre (WWFC) collaborates with WISA to test the feasibility of electric planes (Appendix C).

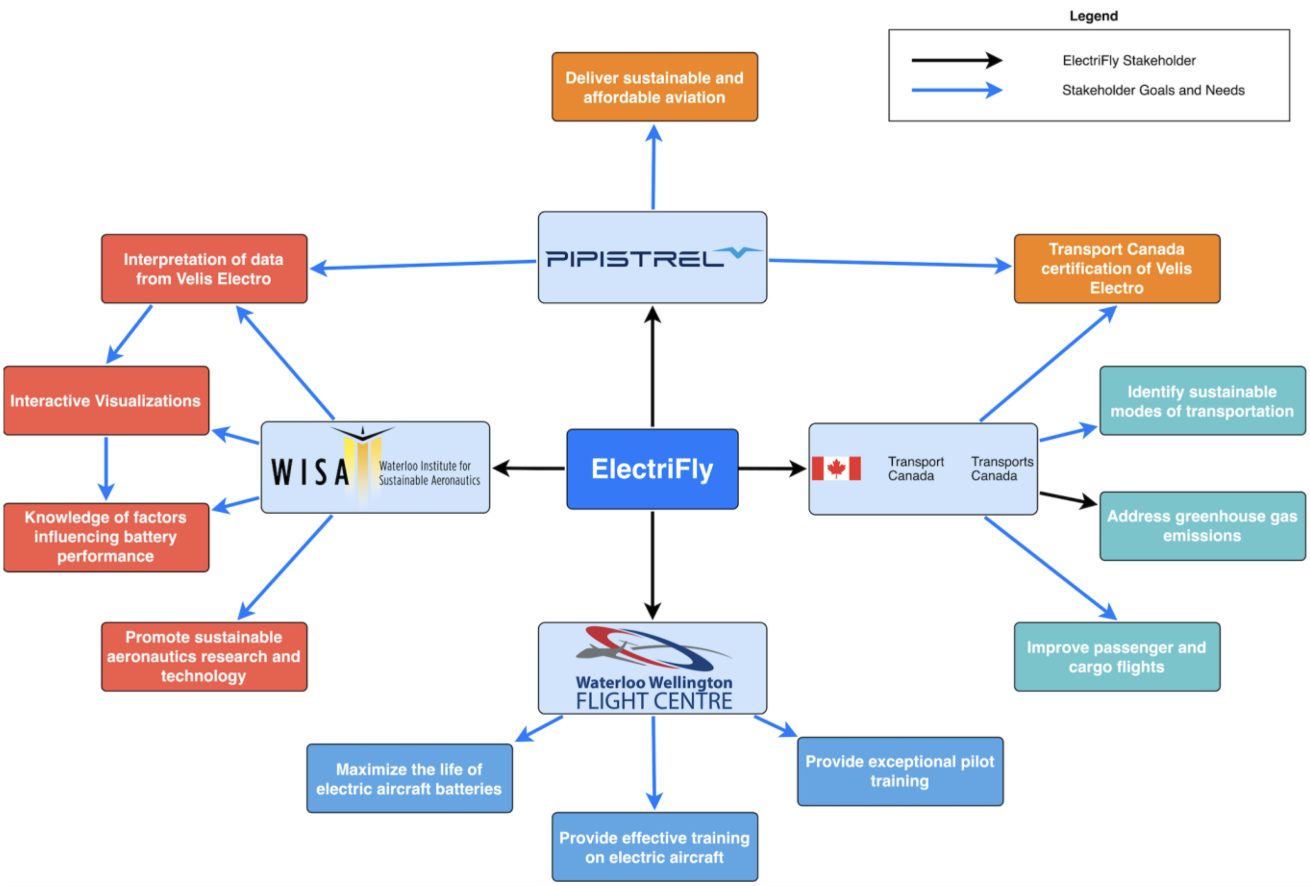


Figure 1: Stakeholder Map of Goals and Needs

2.2. The Problems of Data Overload and Lack of Visualizations

WISA is currently studying the performance of the Velis Electro in Canadian weather conditions. The lead Data Analyst, Fuat Can Beylunioğlu of the University of Waterloo, is analyzing ways of extending flight time, among other tasks. Through a user interview with Fuat (Appendix E), it became apparent that the current workflow of data processing, analysis, and visualizations is manual and time consuming. There are challenges in determining which conditions factor into the discharge rate of the battery, since the battery data is more granular than the general flight data. Redundancy in the data, which can potentially result in multicollinearity in a model is also problematic. Below, as shown in Figure 2, is a high-level flow representing the current process.

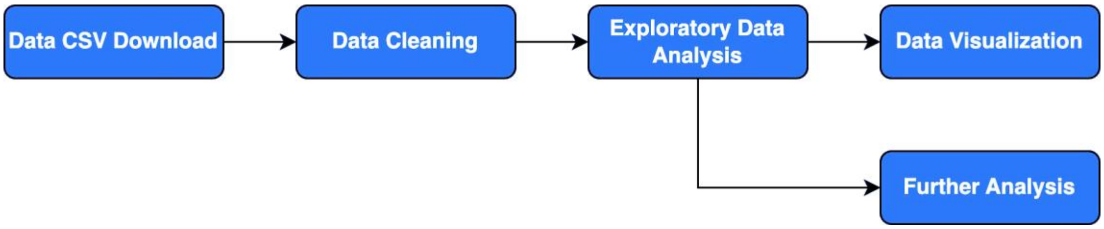


Figure 2: Current Data Workflow

2.3. The Problem of Decision-Making for Flight Operations

There is no systematic process in which the decision is made to determine the feasible plane operations based on environmental conditions. Currently, pilots rely on their intuition to make this decision. Pilots need full confidence in the aircraft, and a lack of understanding of how different flight manoeuvres affect the drainage of the battery forces pilots to fly more conservatively.

3. PROJECT OBJECTIVES

The objective of this project is to analyze flight data and create a battery management system for the optimal usage of the electric plane. Leveraging machine learning (ML), our goal is to determine safe flight operations given current weather conditions, predict flight maneuver strategies to optimize the battery state-of-charge, maximize flight time, and improve the longevity of the batteries. The three main goals of the project are detailed as follows:

3.1. Data Preparation

Flight data is generated and collected every 1/10th of a second when the electric aircraft is in motion. Weather data should be collected and mapped to each flight. Thus, it becomes imperative to have a fully operational data pipeline to transform, clean, and optimize the flight records in a way that will enable valuable insights to be captured more efficiently.

3.2. Visualization of Data Analytics

An interactive user interface (UI) focuses on providing users with a centralized system to evaluate critical factors affecting the operation of electric planes without requiring manual generation of graphs from CSV files, streamlining the data analysis process.

3.3. Prescription of Optimal Operations of Electric Planes

To prescribe the optimal flight patterns and charging sequence of the batteries, a decision support system (DSS) will be built based on a prediction model that considers various factors such as exercises performed during the flight, state of charge (SOC), and weather conditions to provide recommendations. Additionally, a model will be used to create a flight scheduling tool, to output the feasible flights in a day and will guide pilots on how to operate the aircraft in the most efficient manner.

4. REQUIREMENTS

4.1. The Objective of the Design

The objective of the design is to create a system that is user-friendly for not only the technical research team but also non-technical individuals in partnering organizations. Although the separation between functional requirements, non-functional requirements, and constraints can be artificial, for the purpose of this project non-functional requirements are defined as characteristics of the system. Functional requirements are the capabilities/features of the system, and constraints are limitations to the system's behaviors/capabilities.

4.2. Justification of Prioritization

Prioritization of the requirements is grounded in initial discussions with the client on what meets the criteria for a Minimum Viable Product (MVP) for the data pipeline, UI, and ML models. The requirements labelled as “should-have”, “could-have”, and “won’t have” are additional functionality that would supplement client needs as the project continues to evolve.

4.3. Functional Requirements

Based on user interviews the following needs statements and major functional requirements in Table 1 were created. Any should-have, could-have, and would-have requirements are now in Appendix F.

Table 1: Functional Requirements Overview

Priority	Functional Requirements	Description
1	Data pipeline	Utilize a data pipeline to transform plane, battery, weather, and forecast data into features to be used in visualizations, simulations, and ML models.
2	Data visualization UI	Create a UI with data visualization that enables multi-plotting abilities and utilizes multiple variables, all at the command of the individual user. The platform should work seamlessly on both Windows and MacOS.
3	Flight scheduling	Schedule flights on a given day based on weather conditions, classified into levels of safety (green, yellow, red zones).
4	Flight Planning	Based on activity and other factors, predict the SOC with a set of machine learning models.

4.3.1. Requirements: Build Data Pipeline for Data Parsing/Cleaning

Need Statement: A need exists to clean and process raw data while importing existing data in CSV formats. The flow of requirements of the data pipeline is shown in Figure 3. Additionally, Table 2 displays the requirements based on success criteria and validation metrics.

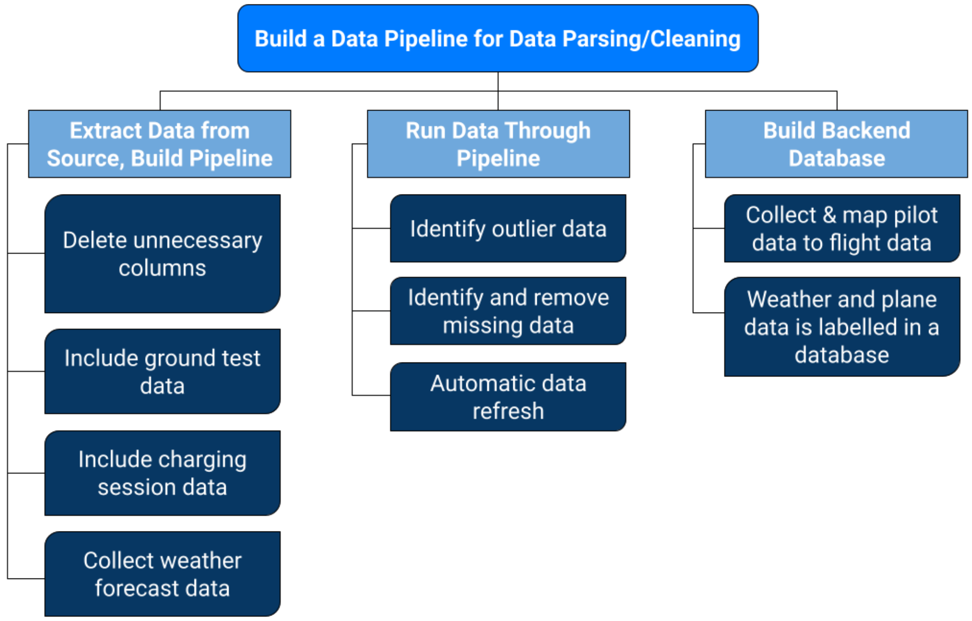


Figure 3: Diagram for both data pipeline

Table 2: Data Pipeline (blue cells are evolved requirements)

No.	MoSCoW Prioritization	Requirement	Characteristic	Relation	Value	Units	Verification	Validation
1	Must-Have	Identify and remove missing data	# and type of filler data point to be added	<<	Previous data cleaning software	Count	Analysis based on historical data	Pilot program
2	Must-Have	Identify outlier data	# of outlier data points based on thresholds	<<	Previous data cleaning software	Count	Analysis based on historical data	Pilot program
3	Must-Have	Delete unnecessary columns	# of columns are reduced to relevant ones	>	Current CSV Format	Count	Qualitative verification from Subject Matter Experts (SMEs)	Pilot program
4	Must-Have	Collect and map pilot data to flight data	Each flight should display pilot's weight	-	N/A since this was not previously done	-	Observe and verify that pilot weights correspond to related flights	Usability testing
5	Must-Have	Weather and plane data is labelled in a database	Labelled data	>=	Manually merging flights with weather	-	User Experience (UX) Testing, Cognitive Walkthrough	Pilot program
6	Must-Have	Include ground test data	Include ground tests in database	>	Manually downloading and	-	UX Testing	Pilot program

					analyzing			
7	Must-Have	Include charging session data	Include charging sessions in database	>	Manually downloading and analyzing	-	UX Testing	Pilot program
8	Must-Have	Collect weather forecast data	Enable flight scheduling through 3-day aviation forecast	-	N/A since this was not previously done	-	UX Testing, verification from SMEs	Pilot program
9	Must-Have	Automatic data refresh	Daily data refresh	>=	Manual download to refresh	-	UX and Usability Validation	Pilot program

4.3.2. Requirements: Build a UI and backend for Data Visualization

Need Statement: A need exists to make better data visualizations for extracting insights on unlabeled data. The flow of requirements of the data visualization is shown in Figure 4. Additionally, Table 3 displays the must-have requirements based on success criteria and validation metrics.

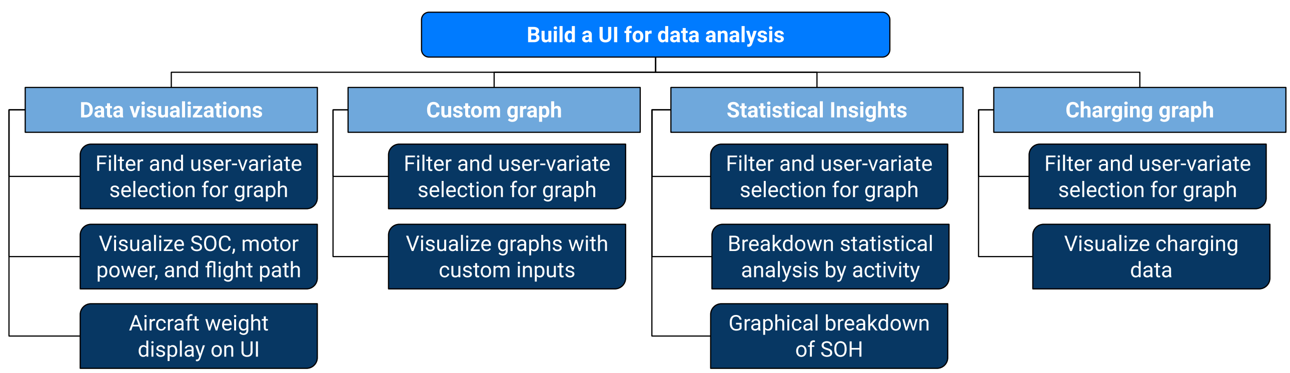


Figure 4: Diagram for Data Analysis

Table 3: UI (blue cells are evolved requirements)

No.	MoSCoW Prioritization	Requirement	Characteristic	Relation	Value	Units	Verification	Validation
1	Must-Have	Filter and variable selection for graphs	User-customized graphs	>=	Manually generated graphs using R	-	Cognitive walkthroughs, heuristic evaluations	Pilot program
2	Must-Have	Breakdown statistical analysis by activity	Users can do statistical analysis based on plane exercise	>=	Statistical analysis for entire flights	-	UX, usability validation	Pilot program

3	Must-Have	Graphical breakdown of SOH	Line graphs showing trends in SOH overtime and scatterplot comparing SOH to SOC rate-of-change	>=	Manual generation of graphs to relay SOH insights	-	UX, usability validation	Pilot program
4	Must-Have	Visualize graphs with custom inputs	Visualizing flight data with options to select various variables	>=	Manual generation of graphs	-	UX, usability validation	Pilot program
5	Must-Have	Visualize SOC, motor power, and flight path	Display most important flight graphs for researchers	>=	Manual generation of graphs		UX, usability validation	Pilot program
6	Must-Have	Aircraft weight display on UI	Numerical value showing the total aircraft weight	>=	Extract aircraft weight manually	-	UX, usability validation	Pilot program
7	Must-Have	Visualize charging data	Visualizing charging data over multiple dates	>=	Manual generation of graphs	-	UX, usability validation	Pilot program

4.3.3. Requirements: Flight Scheduling Simulation

Need Statement: A need exists to make calculated decisions on flight scheduling using a simulation given Canadian weather conditions. The flow of requirements of the ML model is shown in Figure 5. Additionally, Table 4 displays the must-have requirements based on success criteria and validation metrics.

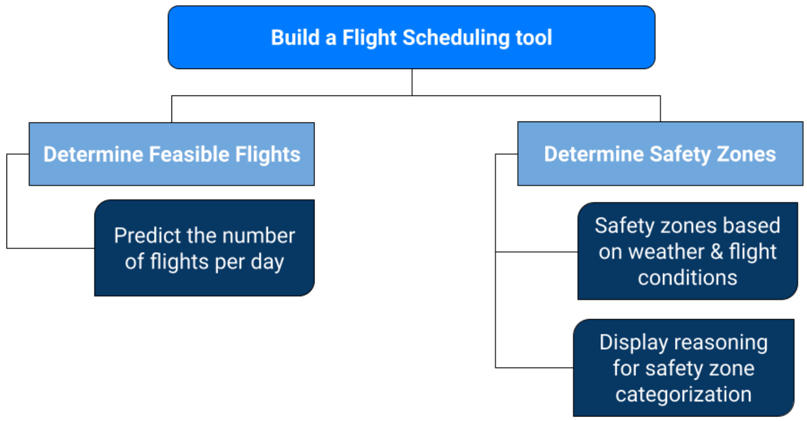


Figure 5: Diagram for Flight Scheduling

Table 4: Flight Scheduling (blue cells are evolved requirements)

No.	MoSCoW Prioritization	Requirement	Characteristic	Relation	Value	Units	Verification	Validation
1	Must-Have	Predict the number of flights per day	Count of flights achievable based on weather conditions	>=	Human decision	Daily	Interviews with pilots, quality validation and flight testing	Pilot program
2	Must-Have	Safety zones based on weather & flight conditions	Green / yellow / red/grey zones and state reasoning	>=	Human Decision	Hourly	Experiments – time it takes for pilots to make decisions *with versus without* the app	Stakeholder walkthrough and usability testing
3	Must-have	Display reasoning for safety zone categorization	Safety reasons should be shown through hover action	>=	Human decision	-	Interviews with pilots, quality validation and flight testing	Pilot program

4.3.3. Requirements: ML Models

Need Statement: A need exists to make calculated decisions on flight operations using a ML model. The flow of requirements of the ML model is shown in Figure 6. Additionally, Table 5 displays the must-have requirements based on success criteria and validation metrics.

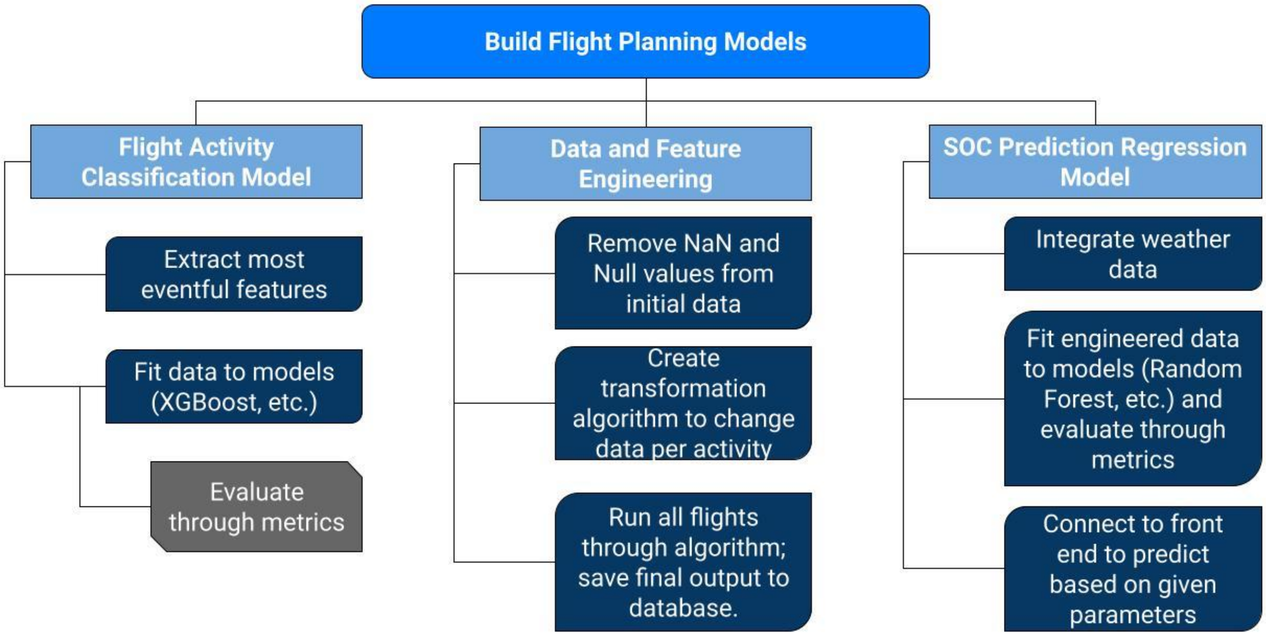


Figure 6: Diagram for both Machine Learning and DSS Model Needs

Table 5: ML Prediction Model for Plane Operations (blue cells are evolved requirements)

No.	MoSCoW Prioritization	Requirement	Characteristic	Relation	Value	Units	Verification	Validation
1	Must-Have	Build classification model for flight activity prediction	# of correct flight activities	>=	Graphical labeling flight activities	-	Statistical metrics (accuracy, recall, precision, and k-fold cross validation)	Pilot – Gabriel
2	Must-Have	Remove unneeded data	Minimize error in modelling with clean data	>=	Biased and unclean data	-	Manual verification and programmatic checks	Advisor - Mehrdad
3	Must-Have	Data transformation algorithm	SOC prediction from models	>=	Prediction of SOC (pilot intuition)	-	Coding checks	Advisor - Mehrdad
4	Must-Have	Integration with weather data	Accurate weather data from updated forecasts	>=	Estimating weather conditions	-	Analysis/simulation using historical data	Pilot – Gabriel
5	Must Have	Fit data to SOC	SOC prediction model output	>=	Manual calculation of SOC	-	Statistical metrics (r-squared, mean	Researcher - Fuat

		prediction models			based on statistical evidence		squared/absolute error, and k-fold cross validation)	
6	Must-Have	Connect to front-end to make SOC predictions based on user input parameters	Faster SOC calculation	<=	Manual calculation	Sec	UX and usability validation	Pilot program

4.4. Non-Functional Requirements

Based on initial user interviews with the research team, the following non-functional requirements in Table 6 have been identified and prioritized.

Table 6: Non-Functional Requirements (blue cells are evolved requirements)

No.	MoSCoW Prioritization	Requirement	Characteristic	Relation	Value	Units	Verification	Validation
1	Must-Have	Intuitive and user-friendly interface	Clean, tidy design with simplicity as a priority	>=	Previous design (Appendix C, Figure C-1)	-	UX	Usability testing with WISA and pilots
2	Must-Have	No back-end operator/maintainer required	System is independent of human maintenance	>=	Staffing personnel	-	UX	Pilot program with WWFC pilots
3	Must-Have	Open access	Software and ML packages should be open access	>=	Having program only on local system	-	Software Testing	Pilot program with WWFC pilots (ensure accessibility to users outside of UW)
4	Must-Have	Quality of Plane Operation Labels	Labels are intuitive to understand for the end user	>=	Human guessing	-	UX and Usability Testing	Pilot program with WWFC pilots

4.5. Design Constraints

As the team moves into the solution development phase and refines the current requirements specifications, the list of system constraints will be re-evaluated and expanded as necessary.

Table 7: Constraints

Constraint	Description
Battery Capacity	Limited battery capacity for the plane must be taken into consideration when designing prediction models, as well as accounting for Canadian weather conditions.
Data Labelling	Our clients have also mentioned that the data may contain some ambiguity due to variables not being clearly labeled, which can pose challenges when trying to extract meaningful insights or make precise interpretations from the data.
Weather Data	The weather data is being collected externally. However, we are constrained by the lack of granularity from the external data source.

5. MEASURING IMPACT AND KEY PERFORMANCE INDICATORS

Optimizing electric aircraft batteries holds tremendous potential for mitigating climate change and driving innovation. Currently, significant hours are dedicated to manual data visualization and analysis. Automating this process enables faster insights and a deeper understanding of battery performance and durability. This optimization can also enhance aircraft efficiency, leading to increased flight times. However, challenges arise due to the absence of a benchmark for validating the effectiveness of potential solutions.

5.1. High Model Accuracy

Pilots and aircraft experts should validate the ML model's accuracy, shown in Table 4, as they understand the potential risks of incorrect decisions. Similar sentiments exist for models helping to maximize the battery's life during flight. The model should be validated, ensuring that any decision made during flight has the same effect on the battery as prescribed by the model, with a very small tolerance for error.

5.2. User Experience (UX) Metrics

UX metrics will be able to judge which features of the interface are beneficial. We will be conducting a pilot program and heuristic evaluations to validate with users. Feedback from subject matter experts with knowledge of the plane will also be able to provide detailed descriptions of what data they want displayed and their desired format.

6. ALTERNATIVE DESIGNS

The alternative database choices are found in Appendix G, Section G.1. and G.2.

6.1. UI Lo-fi Prototypes

Following the conceptual design process, a series of alternative lo-fi designs were developed for the UI. Initially, divergent thinking was applied to generate many potential solutions to the problem, then convergent thinking was utilized to narrow in on the best design given the requirements and constraints. However, given the well-defined nature of the problem and requirements, the divergent perspective in the conceptual design was intentionally kept to a minimum.

6.1.1. Iteration 1: UI Brainstorming

To encourage creative thinking, two team members developed mock-ups based on the requirements to deepen our understanding and further explore the solution space. Figures 7 and 8 were the 2 initial ideas.

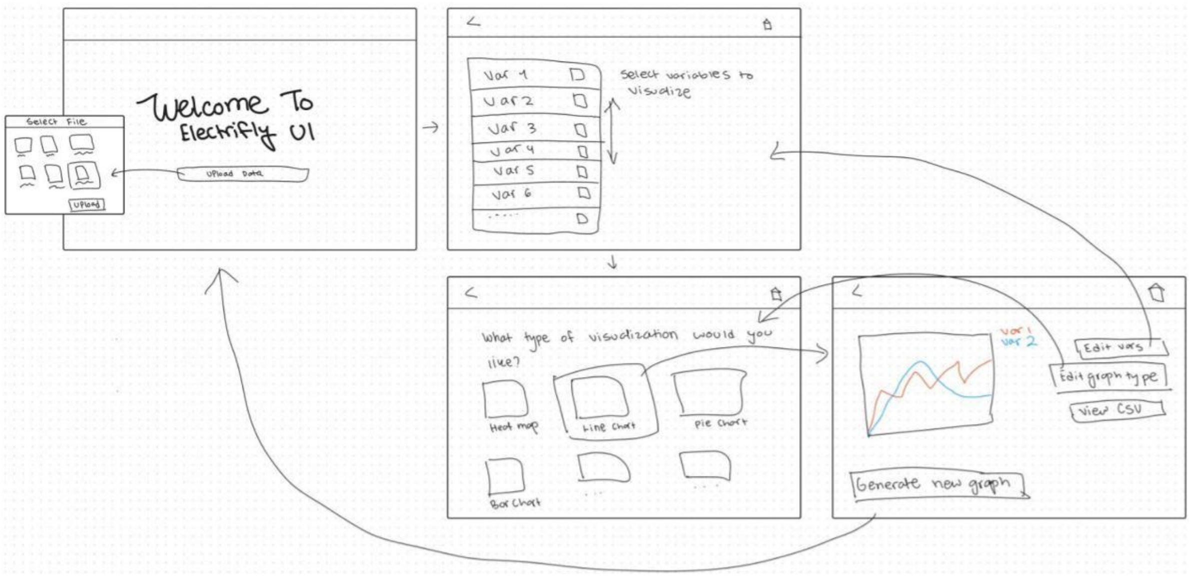


Figure 7: Version A

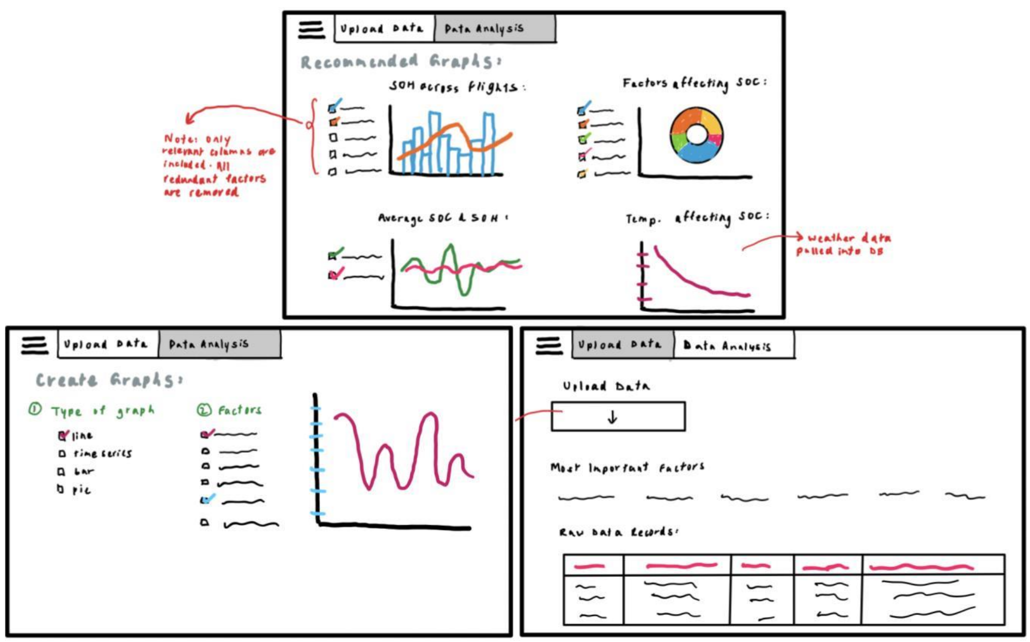


Figure 8: Version B

6.1.2. Iteration 2: Concept Creation

The team evaluated iteration 1 ideas against the requirements, technical feasibility, and project scope, then began to converge to a single idea. The best elements of both designs were chosen and refined in the lo-fi mock-ups as shown in Figure 9.

Figure 9: Combined Version

6.1.3. Iteration 3: Advisor Feedback

The team utilized the design in iteration 2 to develop a shared understanding with the advisor and adjusted both the requirements and UI based on feedback. Figure 10 demonstrates the outcome of the feedback where modifications were made to the ML Recommendations screen. User feedback is shown in Appendix E, Figure E-2.

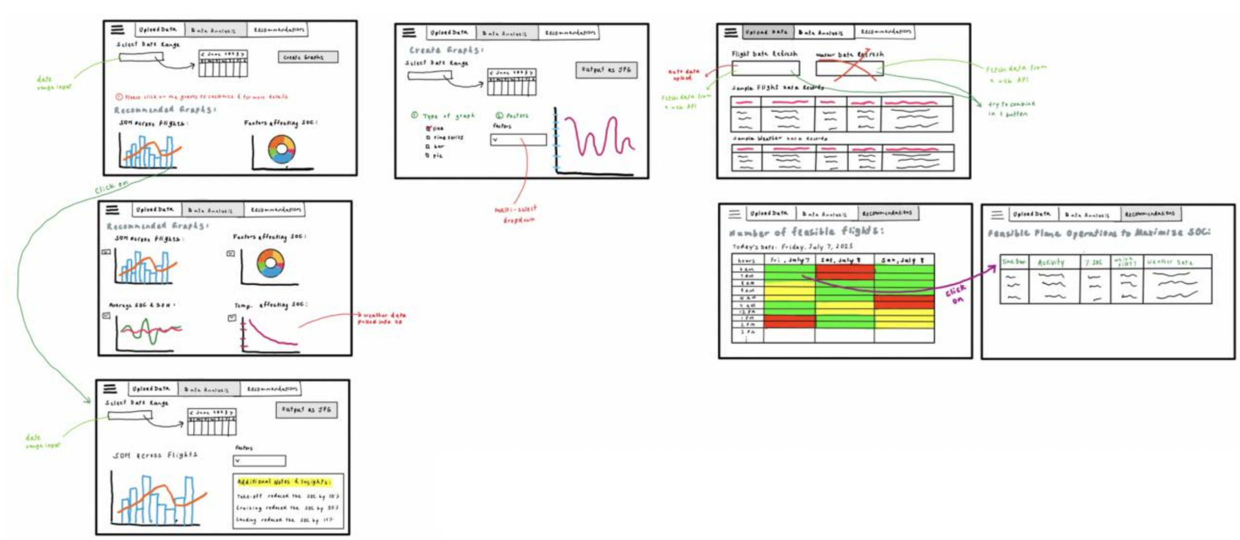


Figure 10: Feedback from Professor Pirnia

6.1.4. Iteration 4: Stakeholder Insights

The pilot/end-user was interviewed using the mock-up from iteration 3 to explore how they would interact with the system and solicit feedback to iteratively improve the design. Figure 11 was the output of these discussions where user feedback is shown in Appendix E, Figure E-3.

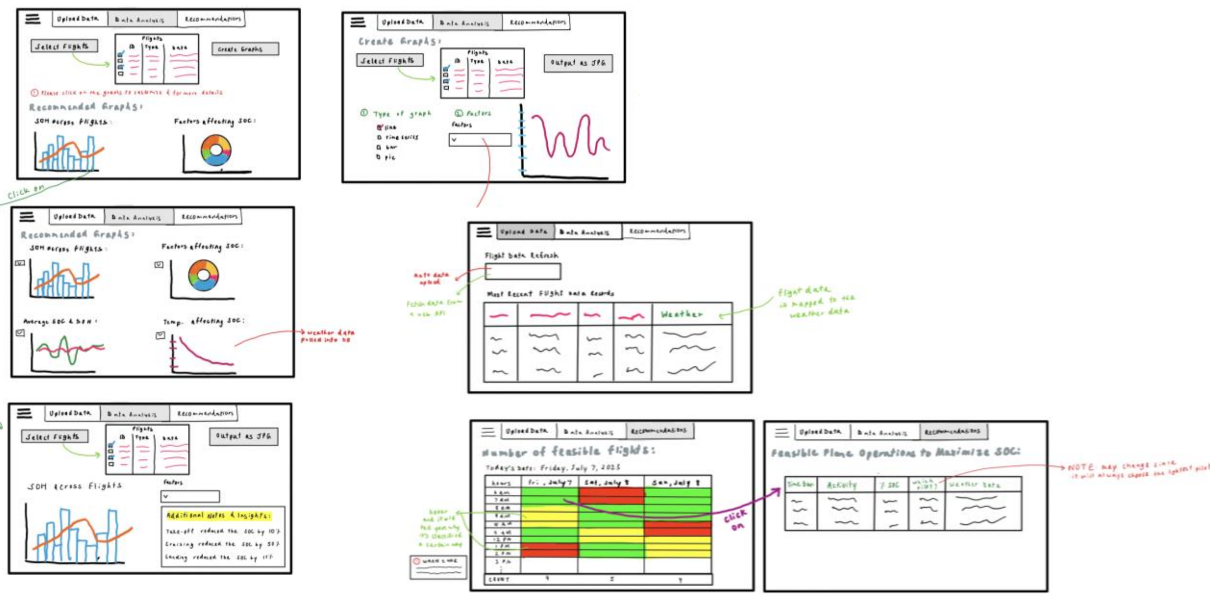


Figure 11: Feedback from Gabriel Song, Pilot

7. SOLUTION DEVELOPMENT

7.1. System Diagram

The system diagram in Figure 12 details the entire technical system at a high-level. It includes the data pipeline, UI, server, and how they interact with each other.

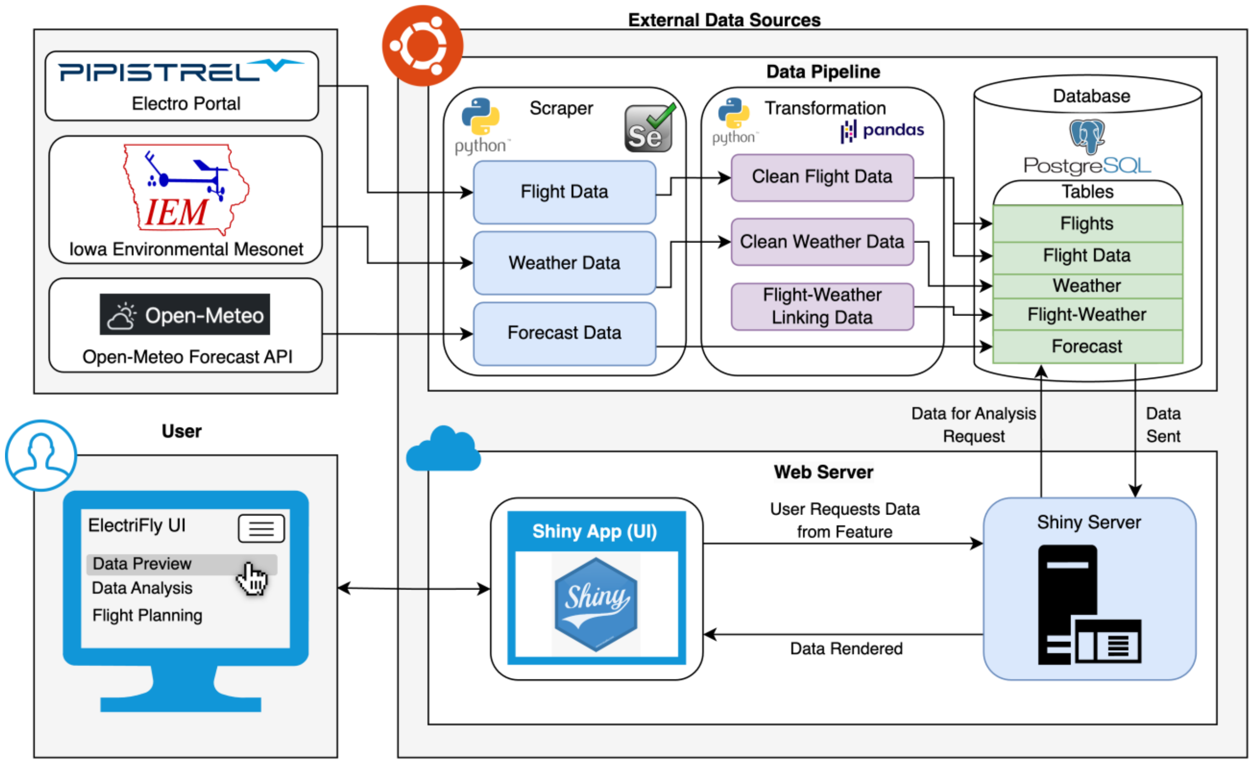


Figure 12: System Diagram

7.2. Machine Learning Pipeline Diagram

Figure 13 depicts the three main sections of the machine learning pipeline. Flight data is utilized to classify flight activities (e.g., takeoff, climb) at specific times. This data is stored in the "Flight Activities" table in the database (Figure 14). Following this, the data undergoes transformation to reflect changes in state of charge (SOC) and time based on the activity, necessary for predicting SOC requirements per activity. The SOC-prediction regression model is trained using labeled activities from the classification model. Model performance is then evaluated, with XGBoost and Random Forest identified as top performers for classification and regression respectively. The best models are selected for deployment.

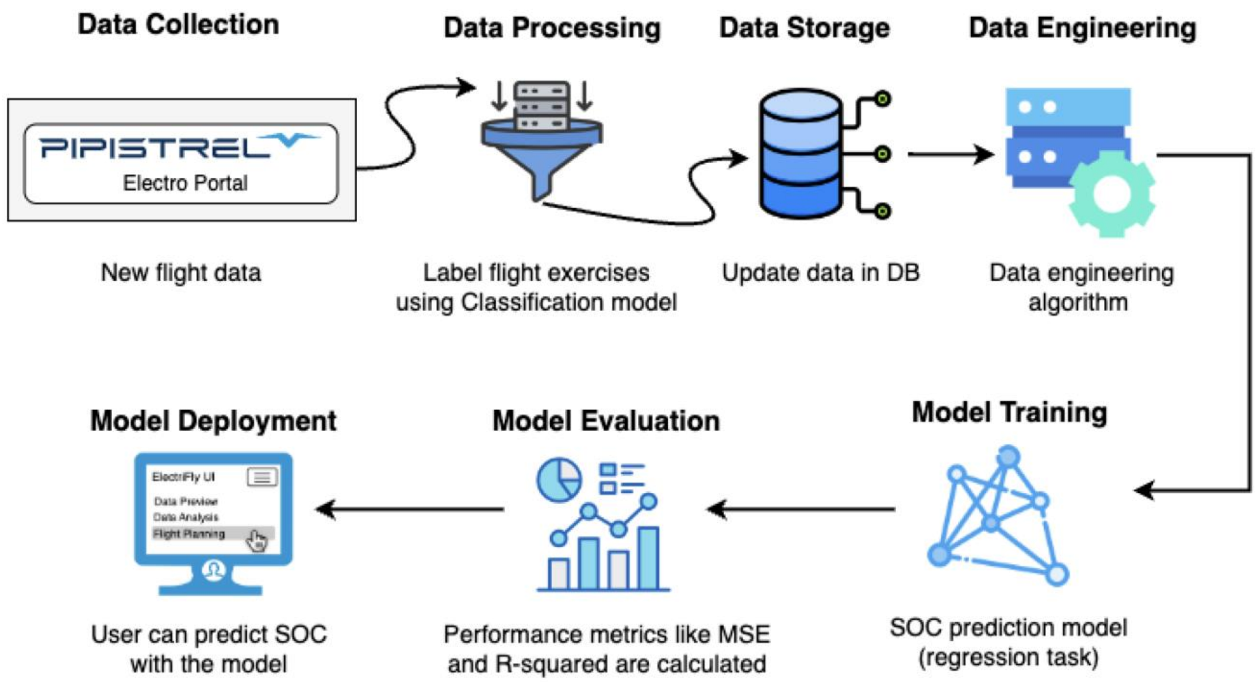


Figure 13: ML Pipeline Diagram

7.3. Data Pipeline

The data pipeline extracts flight and weather data, transforms it by cleaning and formatting, then loads it into a database for plotting and machine learning. Flight data comes from Pipistrel's Electro Portal (Pipistrel, n.d.), weather data from the Iowa Environmental Mesonet (Iowa State University, n.d.), and forecasts from Open-Meteo API (Open-Meteo.com, n.d.). The database schema includes tables for flights, flight data, weather, flight activities, and forecasts. Figure 14 details the database schema. Flight identification details go in the *Flights* table, aircraft-gathered data is stored in the *FlightData_FlightID table*, and its corresponding weather data in the *Weather* table. Weather events are linked to flights through the *flight_weather* table. *Flight Activities* table contains the labelled timestamps of all flights by ID. Forecast table contains the weather forecast data for the next 72 hours, including temperature, visibility, and wind gusts.

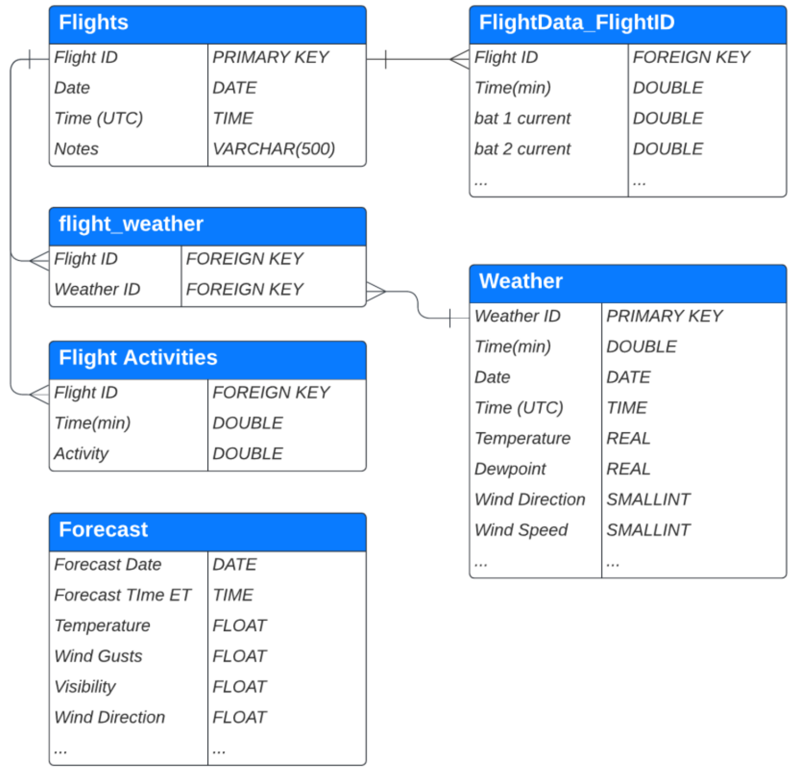


Figure 14: Database Schema

Manual evaluation was completed, with the highest potential risks in the data collection process. Web scraping may fail or be compromised if changes occur to source data format.

7.4. User Interface (UI)

The UI is a valuable tool for researchers and pilots, offering e-plane performance insights based on weather conditions. Divided into three sections: data preview, data analysis, and flight planning.

7.4.1. Data Preview

Implemented using Python Shiny, the data preview screen allows users to swiftly access and view flight and weather data through a series of filters. Iteration 1 (Appendix H, Figure H-1) was a preview of the top 10 rows of the latest flight; however, users requested the ability to download and filter to retain the granularity of data. Hence, for iteration 2 a download feature was added as well as filtering options for data granularity, type, and date, shown in Figure 15.

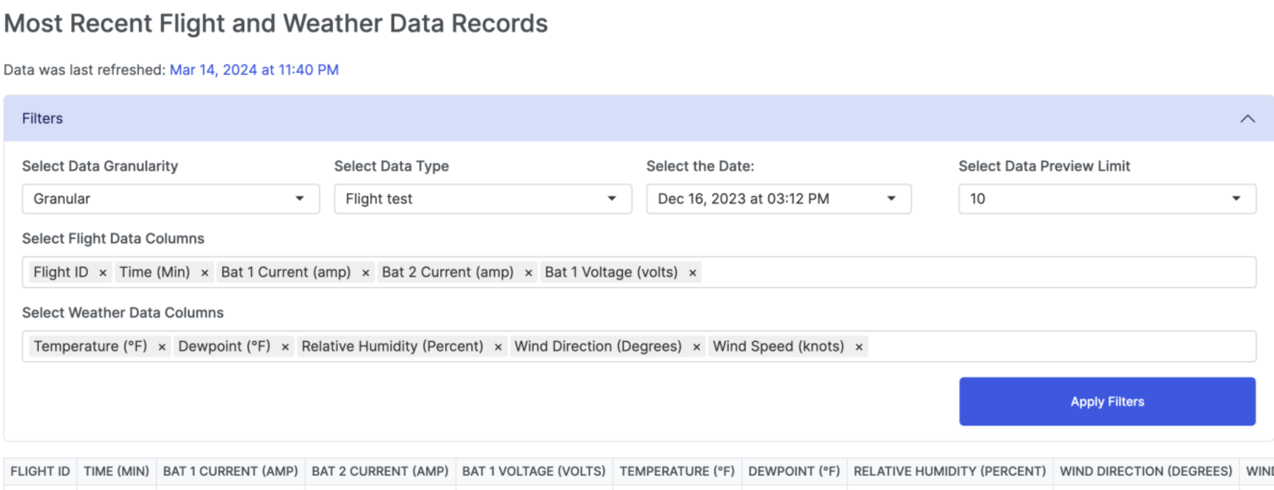


Figure 15: Data Preview Implementation

7.4.2. Data Analysis

7.4.2.1. Data Visualization

Data visualizations allow researchers to track battery behavior over time. Initially, the platform featured time-based graphs for SOC, motor power, weather data tables, and a flight path map, providing an overview of plane performance (Appendix H, Figure H-2). In the second iteration, similar filters were consolidated, organizing graphs into "Flight Graphs" (Figure 16) and "Time Graphs" (Figure 17) to streamline filtering. The third iteration introduced an aircraft weight visual to address researcher preferences and battery performance analysis. The final iteration improved UI visibility for graph components and implemented error handling to prompt user input when filters are deselected.

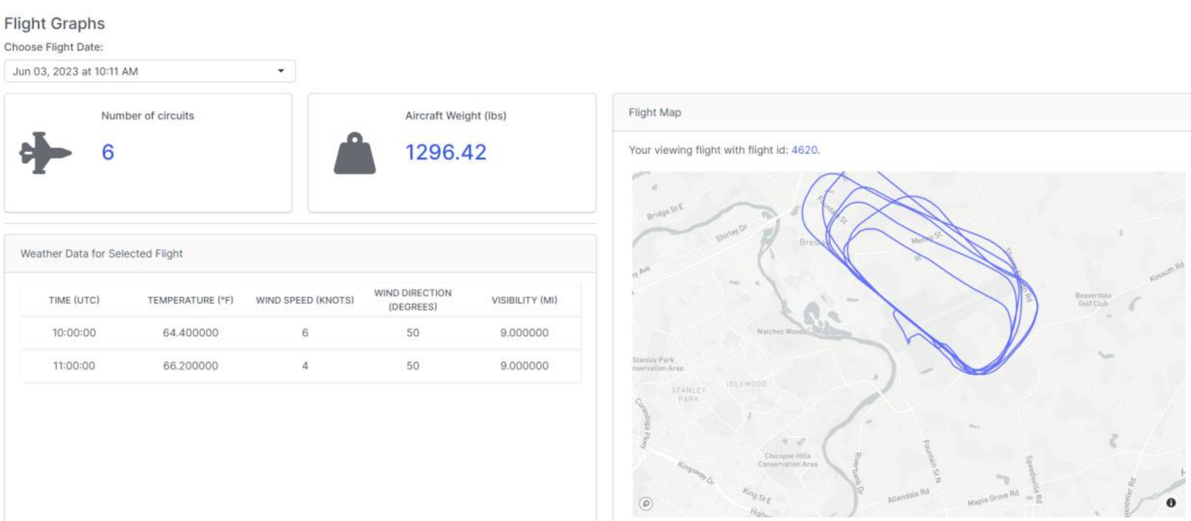


Figure 16: Data Visualization – Flight Graphs Section

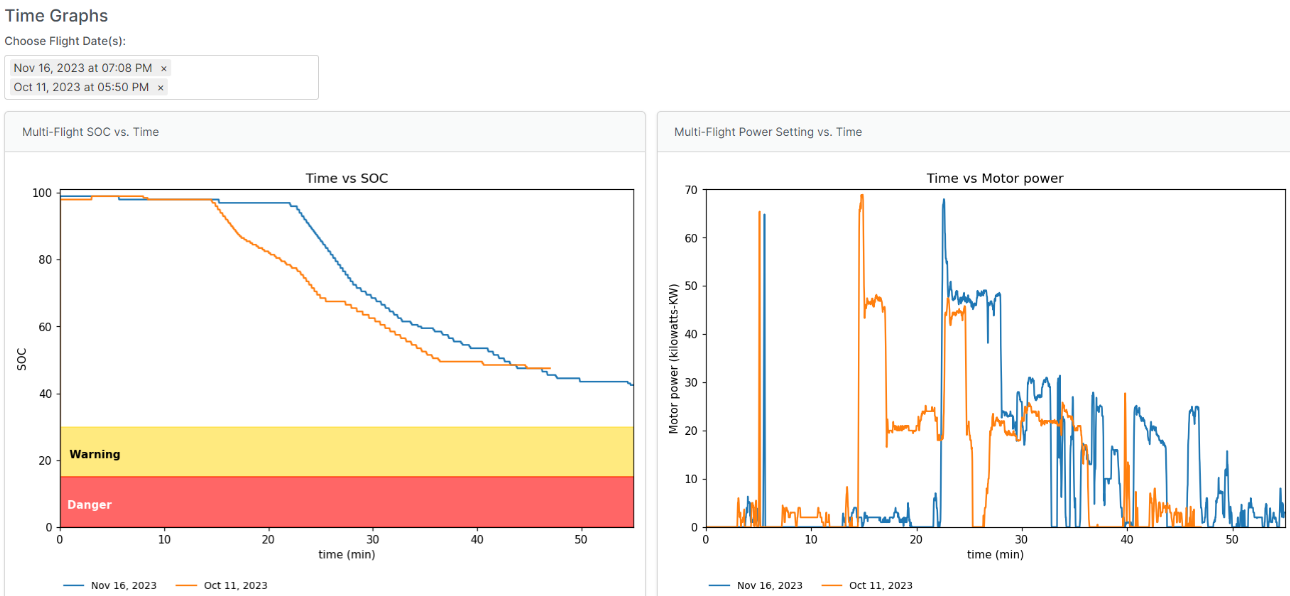


Figure 17: Data Visualization – Time Graphs Section

7.4.2.2. Custom Graphs

Custom graphs offer researchers the ability to choose the variables they wish to explore graphically so they can draw more insights. The first iteration satisfied initial requirements with selections for variables, plots, and dates. The final iteration improved this feature by adding units to the variable dropdowns, enhancing user comprehension (Figure 18).

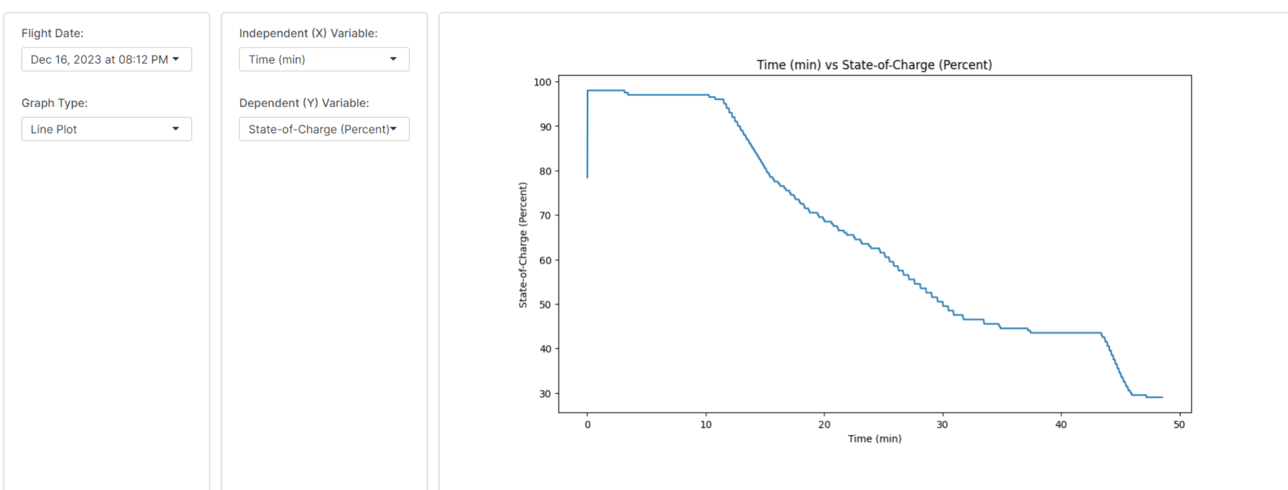
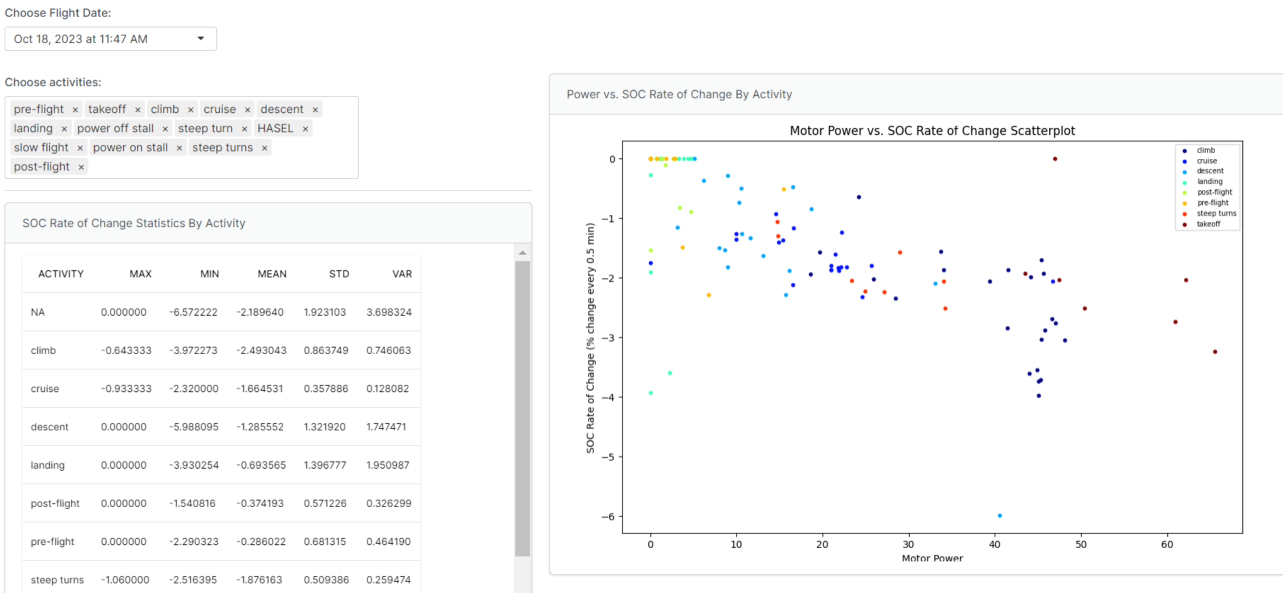


Figure 18: Custom Graphs

7.4.2.3. Statistical Insights

Statistical insights provide insights into SOC and SOH. The initial iteration includes statistics on the SOC rate-of-change by activity and incorporates a plot comparing this rate to motor power, analyzing how motor power affects SOC depletion and whether certain activities accelerate SOC reduction (Appendix H, Figure H-3). In iteration 2, an average SOH per month line plot was introduced to show monthly battery health trends, alongside a SOH vs. SOC rate-of-change plot to investigate SOH's influence on SOC depletion. The final iteration focused on UI enhancements, ensuring graph titles, axes, and legends are always visible (Figure 19 and 20).



ACTIVITY	MAX	MIN	MEAN	STD	VAR
NA	0.000000	-6.572222	-2.189640	1.923103	3.698324
climb	-0.643333	-3.972273	-2.493043	0.863749	0.746063
cruise	-0.933333	-2.320000	-1.664531	0.357886	0.128082
descent	0.000000	-5.988095	-1.285552	1.321920	1.747471
landing	0.000000	-3.930254	-0.693565	1.396777	1.950987
post-flight	0.000000	-1.540816	-0.374193	0.571226	0.326299
pre-flight	0.000000	-2.290323	-0.286022	0.681315	0.464190
steep turns	-1.060000	-2.516395	-1.876163	0.509386	0.259474

Figure 19: Statistical Insights – SOC Rate-of-Change by Activity

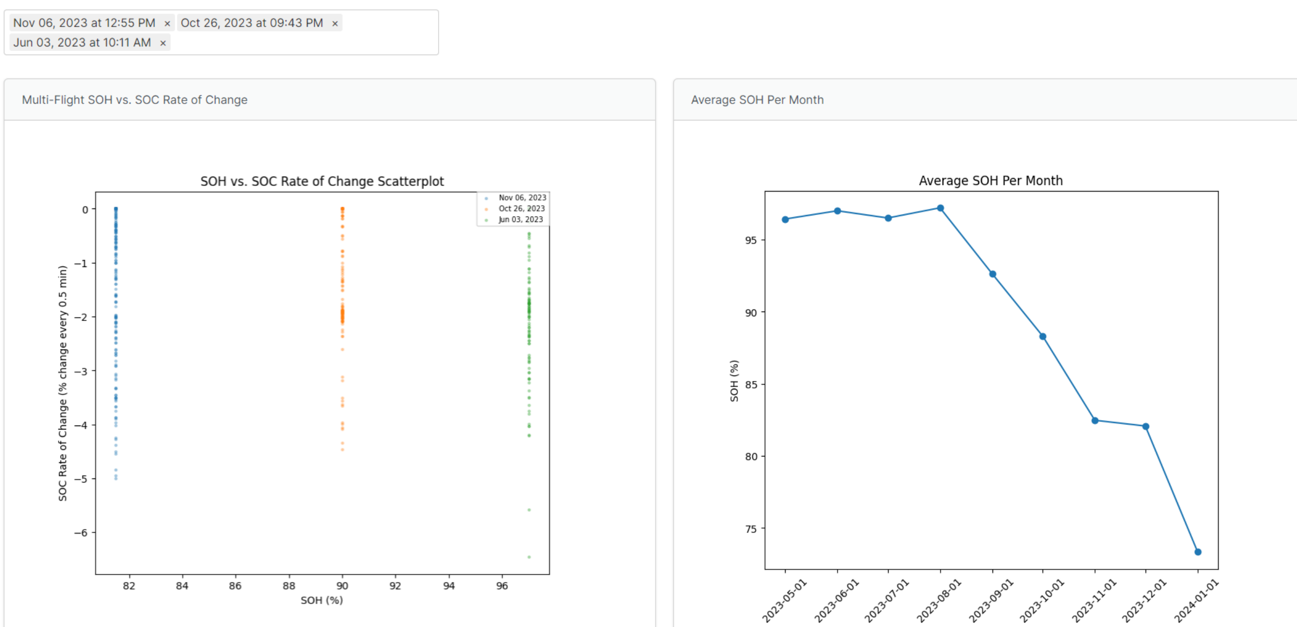


Figure 20: Statistical Insights – SOH

7.4.2.4. Charging Data Visualizations

Recently, the project added charging data visualizations. In iteration 1, it featured a single graph comparing SOC to temperature. To enhance analysis for charging data, the final iteration introduced custom graph functionality, allowing for filtering by multiple dates and variable selection, such as temperature, SOC, and SOH (Figure 21). This feature had the least number of iterations because this requirement was introduced through feedback from the pilot program.

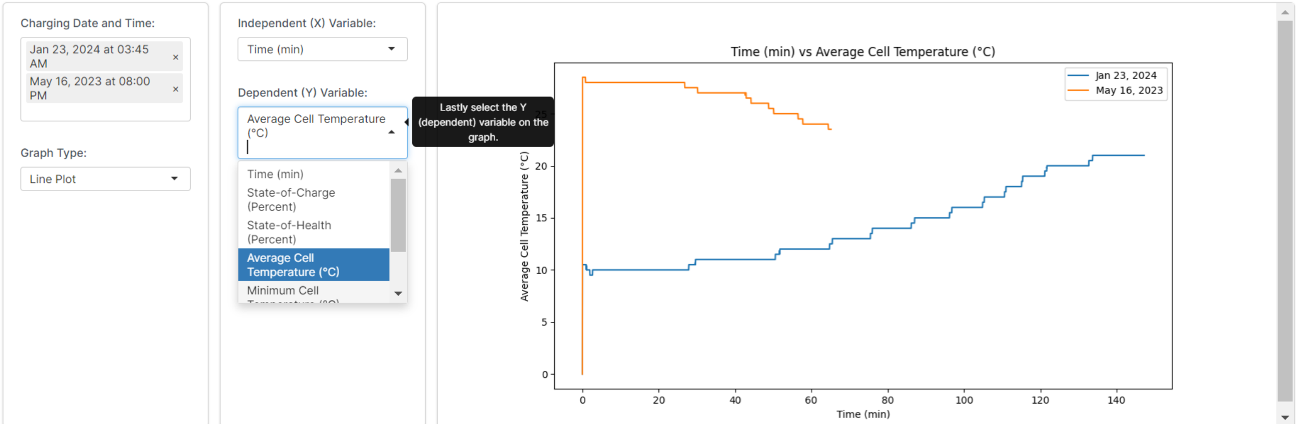


Figure 21: Charging Data Graph

7.4.3. Flight Planning

7.4.3.1. Scheduling

The flight scheduling tool recommends optimal flying times for pilots in the next 72 hours based on forecasted weather data. It categorizes each timeslot into green, yellow, and red zones to indicate flight safety levels. Iterations refined the zone categorization logic, validated by a pilot. The initial design followed requirements discussions (Appendix H, Figure H-4), while the second iteration (Appendix H, Figure H-5) incorporated hover logic to provide safety explanations for informed flight planning decisions. The final design (Figure 22) integrated a table listing possible flight timings to enhance tool usability.

FLIGHT NO.	START TIME	FINISH TIME
1	07:45	08:15
2	08:00	08:30
3	08:15	08:45
4	08:30	09:00
5	08:45	09:15
6	09:00	09:30
7	09:15	09:45
8	09:30	10:00
9	09:45	10:15
10	10:00	10:30
11	10:15	10:45
12	11:15	11:45
13	12:15	12:45
14	12:30	13:00
15	12:45	13:15
16	13:00	13:30
17	13:15	13:45
18	13:30	14:00
19	13:45	14:15
20	14:00	14:30
21	14:15	14:45
22	14:30	15:00

Figure 22: Flight scheduling tool – Iteration 3 (Final design)

7.4.3.2. Flight Exercise Planning

The flight exercise planning screen (Figure 23) utilizes the ML pipeline from Figure 13 to determine the state-of-charge (SOC) based on various parameters such as total time, altitude, and outside temperature. Originally, a drag-and-drop interface with a visual battery indicator was considered, but due to technical limitations, individual parameter selections with a table were implemented. Feedback from pilots led to the inclusion of additional parameters in the third iteration (Appendix H, Figure H-6). Additionally, for iteration 3, the "Delete Activity" button was added for pilots to delete specific activities. The fourth iteration includes sliders for each parameter, toggleable through a switch, for easier selection. All filters are located under the "Flight Activity Selection" section.

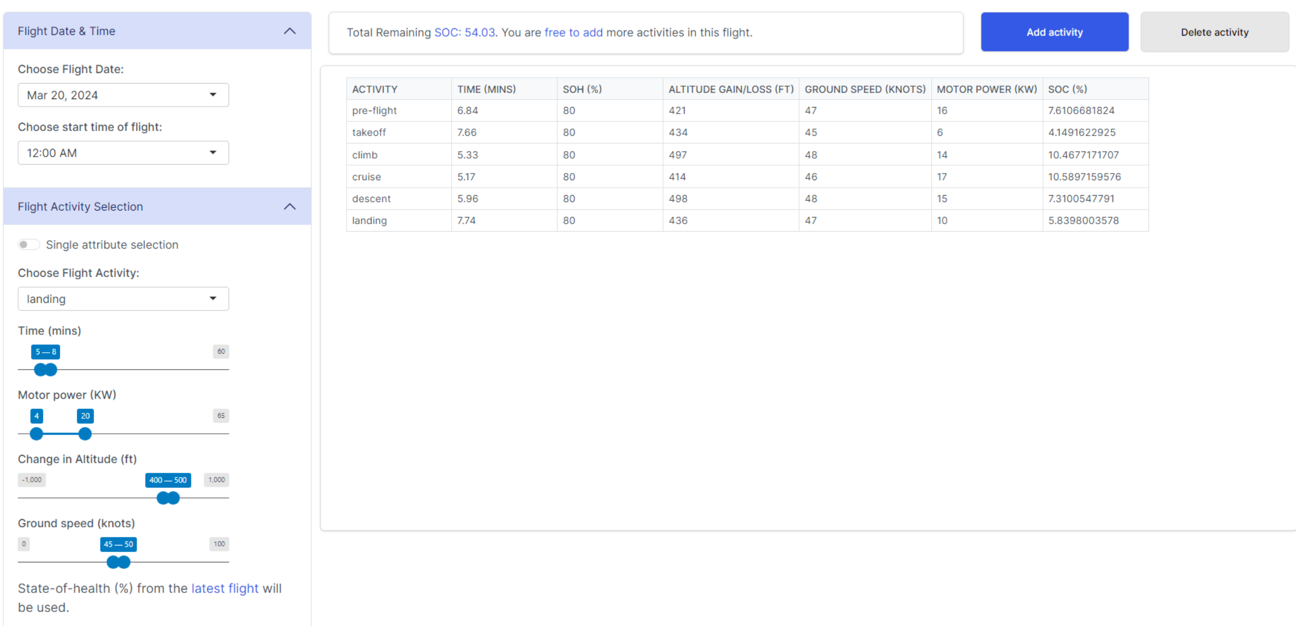


Figure 23: Flight Exercise Planning Implementation

8. VERIFICATION AND VALIDATION

8.1. ML Model Verification

8.1.1. Classification Model

The final classification model was validated by domain experts, who were impressed by our model's accuracy and interpretability. Performance was assessed against train, test, and cross-validation accuracy as outlined in Figure 24, with XGBoost being the top-performing model. Additionally, general classification metrics were examined for each exercise, as detailed in (Appendix I, Table I-1). Our advisor guided the selection of these metrics to ensure optimal model choice.

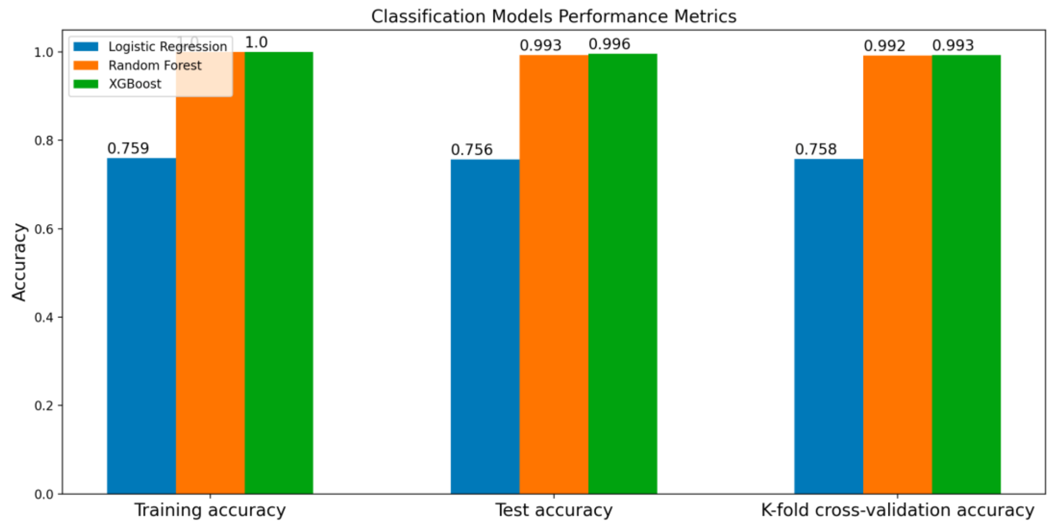


Figure 24: Classification Model Performance Metrics

8.1.2. Regression Model

The final SOC prediction regression model was validated by domain experts and users through the pilot program who reported high interpretability and accuracy of results. Four models were considered for this task as shown in Figure 25, where random forest had the highest accuracy. Here a lower mean squared error, and a higher coefficient of determination and cross-validation score indicates better performance.

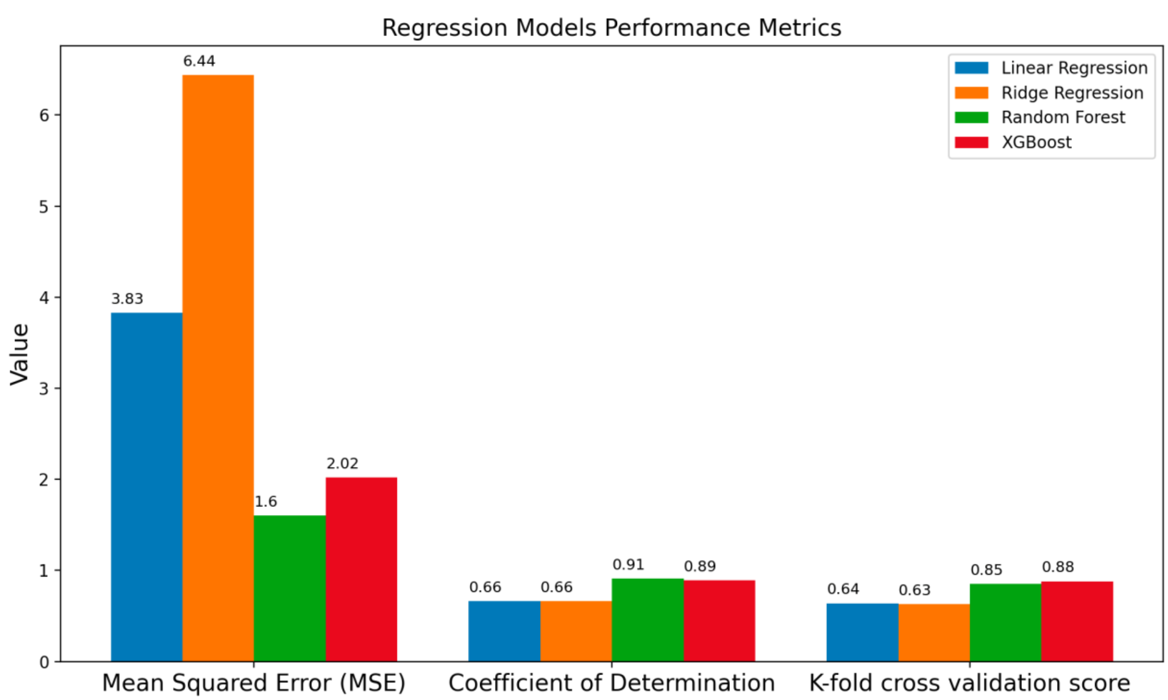


Figure 25: SOC Prediction Model Performance Metrics

8.2. Heuristic Evaluation

Heuristic evaluations were chosen as a suitable verification method to validate if we met user requirements, refine the interface, and drive iterative improvements from an initial MVP to a polished product. We conducted two rounds following Neilson Norman's 10 usability heuristics, involving a domain expert in human-computer interaction for iteration 1 and fifteen additional users for iteration 2. A total of 54 issues were identified, categorized, and prioritized based on severity, with 49 deemed relevant for fixing within project requirements. Example prioritized issues and solutions are detailed in Figure 26. [Appendix I, Section I.3](). describes the sample tasks and template used for the evaluations.

Team Heuristic Evaluation Results

Done	PM Priority	Heuristic	Description of Problem	Severity Rating	Potential Solution	UI Page	Sprint
☑	Must do	H2-2: match between system an...	Dates are all disorganized to select	2	Make the most recent at the top and less recent at the bottom	Upload Data Page Data Analysis – Recomm... Data Analysis – Custom ... Data Analysis – Statistic... Simulation – Forecasting Simulation – Flight Ops ...	21
☑	Urgent	H2-1: visibility of system status	Change the menu headers to something more meaningful	2	- Upload Data → "Data Preview" - Data Analysis - Simulation → Flight Planning - Data Analysis > Recommended Graphs → Data Visualization - Simulation > Forecasting → Flight Scheduling - Simulation > Flight Operations Modeling → Flight Exercise Planning	Menu Data Analysis – Recomm... Simulation – Forecasting	16
☑	Urgent	H2-4: consistency and standards	All graphs titles and legends are cut off	4	Fix the sizing. Make the graphs fit onto Shiny cards.	Data Analysis – Recomm... Data Analysis – Custom ...	16
☑	Must do	H2-7: flexibility and efficiency of...	Be able to edit and delete each exercise	1	For each flight activity chosen, you should be able to edit the mins selected (and potentially the exercise selected), you should be able to delete any row	Simulation – Flight Ops ...	18
☑	Must do	H2-4: consistency and standards	Date/time is wrong format	1	• For date: Dec 16, 2023 • For date AND time (if multiple flights): Dec 16	Upload Data Page Data Analysis – Statistic...	16, 17

Figure 26: Combined Heuristic Evaluation Results

8.3. Pilot Program

A 1.5-week pilot program engaged 10 users in a usability study, supplemented by pre- and post-program interviews to explore user experience and expectations. An onboarding resource ([Appendix J]()) was developed for user alignment. Survey results ([Appendix I, Table I-2]()) revealed a system usability score (SUS) of 79 and indicated that 75% of users intend to use the tool in the future. Interview feedback led to the identification of 20 potential improvements ([Appendix I, Figure I-1]()), with 10 prioritized and implemented within a week. These enhancements included the addition of three new features: a charging data graph, pilot weight data, and filtering options on the data preview page. Notable user quotes are provided in Figures 27, with further quotes available in [Appendix I, Table I-3]().

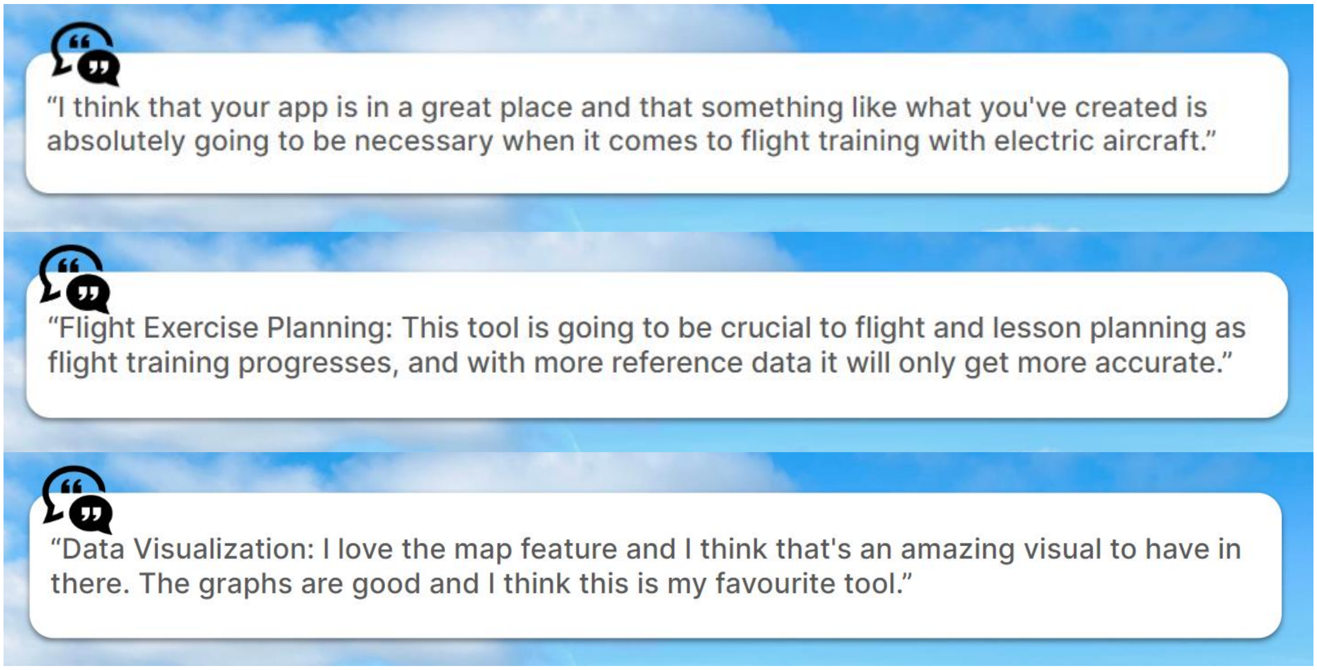


Figure 27: User Feedback Quotes

9. FEASIBILITY ASSESSMENT

9.1. Solution Feasibility

Through verification and validation, most features were determined to be feasible with the workflows of our users. 75% of our pilot program participants would use our solution in the future.

9.2. Integration with Existing Interfaces

While the application is feasible for our users, it does not integrate with their existing tools. The scraper uses data from the Pipistrel UI, and we improve on the original graphs with our graphing features. There are internal discussions to integrate our application with Pipistrel's interface. The flight scheduling feature does not integrate with the existing scheduling tool, Wingman, being used by WWFC. Wingman schedules flights but does not integrate weather data directly as in our tool. This is because the Flight Centre has the authority to veto a decision to fly if the weather is too harsh.

10. DESIGN IMPACT

10.1. Safety and Regulations

Safety is a very important factor to consider in electric planes. That is why the design interface provides clear visualizations for researchers to conduct accurate analysis of flights. For instance, in Figure 17, the warning zone (between 15% and 30% SOC) and danger zone (below 15% SOC) are highlighted in yellow and red, respectively. Such visualizations prevent researchers from drawing inaccurate conclusions.

10.2. Technological Sustainability

The proposed design will predominantly be self-sufficient. The system will require minimal maintenance, enabling seamless data uploading and storage. In the event of a server crash, the scraper can re-upload the lost data from the Pipistrel UI. Additionally, our advisor is familiar with Shiny, providing the flexibility for him to make desired changes after the project handoff.

An area of unsustainability arises if Pipistrel makes changes to its UI, which would cause the scraper to malfunction and prevent new data uploads to the interface. Since the team lacks control over Pipistrel's UI decisions, this poses a risk that will be communicated to stakeholders.

10.3. Social and Economic Impact

WISA researchers will benefit from our platform because it will improve their understanding of electric plane usage in Canadian climate conditions. The goal is to determine the feasibility of electric aircraft for pilot trainings which will result in numerous societal and economic impacts.

10.4. Propagating Project Impacts

WWFC and pilot trainees will benefit from the cost reduction offered by electric planes, addressing the pilot shortage and improving utilization rates. Electric planes can also have a secondary impact by reducing emissions from short-haul flights and connecting remote communities and improving access to essential services (Appendix D).

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Word Count: 4990

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APPENDIX A: INDUSTRY OVERVIEW

A.1. About the Industry

Planes are an astounding innovation that has revolutionized the way we think of travel. They allow humanity to travel long distances in short times, provide quick/reliable transportation of goods, and provide connectivity to off-road isolated Indigenous communities. The aviation industry in Canada is the third largest sector (with regards to aviation) in the world. It generates $29.8 billion in annual revenue, and is linked to 211,000 jobs (Kearns, 2018).

Electric planes are a great solution to the carbon emission problem that petroleum aircraft have caused and are the great choice to reach Canada's net zero carbon emission goal by 2050. Additionally, 50% of all airlines operating costs are linked to fuel (Hanano, 2019), which could practically be eliminated by electric planes, leading to an expansion of affordable domestic air-travel for tourism (Hanano, 2019).

The industry market size for electric planes was $8.5 billion in 2021 and is expected to grow to $23.5 billion by 2031, but currently it is restricted to short regional flights because of limitations in battery capacity, weight, and insufficient charging infrastructure (Correa, 2023).

A.2. About the Plane

The Pipistrel Velis Electro (introduced in 2020) is the world's first and only electric plane to obtain Type Certification (achieved similar safety standards to a conventional plane) (Pipistrel, 2023). The aircraft has been flown and tested in Europe numerous times but is the first electric plane that has been flown in Canada.

The Velis Electro produces zero carbon emissions and flies at a sound level comparable to a normal conversation; approximately 60 decibels (CDC, 2022). Maintenance costs for the plane are insignificant and charging/re-fueling costs are low compared to similar petroleum aircrafts (Pipistrel, 2023).

The plane is powered by a 345 Volts Direct Current (VDC) electric system which consists of two Pipistrel PB345V124E-L batteries located in the nose and cabin. The batteries are liquid-cooled and fan-operated to ensure no overheating. The state of charge (SOC) of the batteries must be at least 30% at time of landing, which gives the Velis Electro a flight time of around 50 minutes. This makes it possible for pilot training, which is why the plane is approved for training in more than 30 countries (Pipistrel, 2023).

APPENDIX B: COMPETITOR ANALYSIS

There are two main classifications for competitors: conventional aerospace companies and specialized firms focused on electric aviation.

B.1. Conventional Aerospace Companies

Boeing and Airbus, prominent players in the aerospace sector, have primarily concentrated on commercial planes powered by fuel. However, these companies are now expanding their interests into electric aviation, such as automated flying taxis as a futuristic means of connecting communities (Hanano, 2019).

B.2. Gap Analysis of Conventional Aerospace Companies

The primary challenge faced by aerospace companies lies in the sustainability of their planes. For instance, a Boeing 737 traveling at a speed of 780 km/hr, generates 90 kg of CO_2 emissions per person per hour (Carbon Independent, 2021). Electric planes address this gap by being emission-free, resulting in a 100% reduction in emissions.

Furthermore, conventional plane manufacturers are relatively new in the domain of electric planes. For instance, Boeing and Airbus are currently in the early stages of exploring automated flying taxis, with concepts and prototypes being developed (Hanano, 2019). The viability and safety of this form of electric transportation remains uncertain. In contrast, the Velis Electro addresses this gap as it is the world's first certified electric plane (Pipistrel, 2023).

B.3. Electric Aviation Companies

In addition to Pipistrel, several other electric aviation companies are actively working on the development of electric planes. Among them is Eviation, known for manufacturing the Eviation Alice. Notably, the Eviation Alice is the largest electric plane capable of accommodating 9 passengers and covering distances of up to 400 km, as well as being a quiet plane and producing zero emissions.

B.4. Gap Analysis of Electric Aviation Companies

The official introduction of the Eviation Alice has experienced multiple delays and is currently slated for 2027 release (Korn, 2022). With no certification in place, there are potential risks involved. In contrast, the Velis Electro stands as the sole electric plane that has obtained certification and approval for pilot training in numerous countries, affirming its reliability. Other electric planes, either being in the conceptual phase or lacking certification, present uncertainties and are yet to be established.

B.5. Overall Competitors and Gap Analysis

All businesses involved in electric aviation, including Pipistrel, face limitations due to battery capacity. Within the industry, there exists a gap with regards to battery capacity optimization, as the technology for increasing battery performance is not fully developed. This project aims to fill that gap by leveraging existing e-plane battery data and creating a novel system that maximizes the efficiency of electric planes for each flight. By optimizing battery usage, pilots can make the most of their flight time while ensuring their safety and peace of mind. As well, this project will bridge the gap between current battery capabilities and future improvements in battery capacity.

APPENDIX C: STAKEHOLDER BACKGROUND & NEEDS ANALYSIS

C.1. Pipistrel

Pipistrel is on the forefront of revolutionizing the future of aviation through the development of electric planes. Specifically, it has created the Velis Electro, the world’s first and only type-certified and commercially available electric plane. Their mission is to advance pilot training and deliver the future of affordable travel with an emphasis on sustainability, safety, and cost-effective approach to flying.

C.1.1 Need Analysis of Pipistrel

Pipistrel is working towards having the Velis Electro certified by Transport Canada in Fall 2023 (Fedy-Macdonald, 2023). They require two licenses to fly their planes in Canada: Certificate of Airworthiness and Certificate of Transportation (Transport Canada, 2020). Partnering with WISA and WWFC to embark on this mission of testing viability of electric planes and optimizing range in Canadian weather conditions is key to their company’s growth. A need exists to encourage the Government of Canada to invest in electric planes and increase adoption of their product.

C.2. Transport Canada

The Government of Canada has been collaborating closely with industry leaders in the aviation sector to identify sustainable modes of transportation to address the growing concerns of greenhouse emissions in this industry. Canada’s Aviation Climate Action Plans has set a target of net-zero emissions by 2050 (Transport Canada, 2022).

C.2.1 Need Analysis of Transport Canada

A need exists to develop sustainable aviation practices within Canada that offer the benefit of accommodating additional tourism, leisure flights and commodity flights to remote communities.

C.3. Waterloo Institute for Sustainable Aeronautics (WISA)

WISA is the world’s leading centre for research, education, and technology in the sustainable aeronautics space. Their mission is to promote lasting social, environmental, and economic change through interdisciplinary research and innovating solutions to foster propagating global impacts (Waterloo Institute for Sustainable Aeronautics, 2022). In Fall of 2022, the organization was awarded $9.2M in funding to explore the green aviation space (Federal Economic Development Agency for Southern Ontario, 2023) and additionally purchased Canada's first electric plane from Pipistrel to test the feasibility of battery powered flights in Canadian weather conditions.

C.3.1. Need Analysis of WISA

Currently all the flight data is housed in the Pipistrel interface, without any data pre-processing. Graphs need to be created manually and across external platforms including the use of R and Excel which has been time-consuming and frustrating from an analytics perspective. Additionally, the interface stores the data files but does not provide information about what the collected variables mean. Thus, valuable insights are missed due to the difficulty in deciphering important factors. A need exists to transform the data and provide meaningful visualizations from the CSV files through a method that increases the efficiency and effectiveness of data cleaning, parsing, and interpretations.

Figure C-1: Diagram for ML model needs

C.4. Waterloo Wellington Flight Centre (WWFC)

Founded in 1932, WWFC is one of Canada's largest flight centres located in Breslau, Ontario at the Region of Waterloo's International Airport. Their mission is to provide pilot training for commercial, recreational, and post-secondary programs for the University of Waterloo and Conestoga College (Waterloo Wellington Flight Centre, 2022). WWFC has partnered with the University of Waterloo to research and collaborate on testing the viability of electric planes in Canada using the Velis Electro, which is currently stationed on-site at their centre.

C.4.1. Need Analysis of WWFC

Shifting from jet fuel to electric batteries means that trained pilots need to be more conscious of their flight maneuvers since different behaviours affect the state of charge and state of health of the batteries at varying rates. As a result, pilots begin to develop range anxiety while flying e-planes due to the added stress of considering various calculations/factors while operating the aircraft (Sergeant, 2022). Therefore, a need exists to help pilots become trained in understanding how to manage their flight skills so that they can optimize the effectiveness of the battery, maximize the overall range, and arrive safely at their destination.

APPENDIX D: IMPACT PROPAGATION

D.1. Primary Impact

D.1.1. WWFC and Pilot Shortage Mitigation

The primary group of stakeholders who are impacted by the problem are pilot training students, the aviation industry and flight training institutions, namely WWFC. To become a pilot, students in Canada must spend approximately $75,000-$150,000 in tuition fees and flight time (Kearns, 2018). The high cost of acquiring a pilot's license has been a major barrier of entry into the pilot industry causing several issues as a by-product, including but not limited to, flight delays, cancellations, and low utilization rate of airplanes. Canada will require 7,000 to 10,000 new pilots in the next two years. Additionally, it is projected that Air Canada alone will be short 3000 pilots by 2025 (Kearns, 2018).

By commercializing the use of electric airplanes for flight training schools such as WWFC, they will be able to significantly reduce the cost of operating airplanes, and as a result offer cheaper and more sustainable flight training programs for students. The commonly used Lycoming Engine Cessna 152 utilizes approximately $50-$60 worth of fuel per hour of flight, whereas the Pipistrel Velis Electro only requires around $6 worth of electrical energy for the same flight duration (Bleakly, 2023).

D.2. Secondary Impact

D.2.1. Short-Haul Flights Impact on Global Climate Change

The use of electric planes in Canada will also result in socio-economic development in many areas. A common use of electric airplanes in the next few years will be for smaller-point-to-point regional air travel. Approximately 45% of global flights are under 800 km, which means that almost half are within the range that electric aircrafts operate in (Schwab et al., 2021). In addition, short haul flights are up to 50% less efficient than long-haul flights based on emissions (Baumeister, Leung, and Ryley 2020). Therefore, this is a huge factor in global sustainability goals.

D.2.2. Connecting to Remote Indigenous Communities

Another way of impact through using electric planes is to connect to remote Indigenous communities. In Canada, there are 250 or so remote communities, home to around 185,000 people, who can often only be reached by boat or plane which isolates these communities (United Nations, 2021). Isolation presents a number of issues including food insecurity, poor health care, and essential services since hospitals are usually too far from home and under-equipped/under-staffed. Introducing electric airplanes as a way of connecting with these communities is a clean alternative for cheaper and faster travel, as well as contributing to economic development of those regions. It could also open opportunities for critical cargo delivery such as organ delivery to help those in remote areas who need urgent care.

APPENDIX E: USER INTERVIEW AND USER INTERFACE

E.1. Fuat Task Analysis Meeting Notes

Q: What is the specific process you go through in getting the data, parsing the data, then visualization of data? Tell us step-by-step and point out any parts that might be frustrating. From the data collection to the final results?

A:

1. Data is on the uploaded page we gave you.
2. Go to the page and download the CSV file.
3. Usually, there are quick notes in the data to see what we are looking at. Paul/Gabriel might say that we tested certain things that we might want to look at.
4. Data is cleaned. Types of data are 1. flight, 2. the two batteries – focus is on the flight data.
5. Visualize the trip, starting from the hangar and coming back, etc., to understand times.

6. Plot x-SOC vs y-time. Note these time points, at what minute takeoff occurred, cruising, etc.
7. Visualizes power, comparing battery power used to motor power, and the same times are also put. Overlaps between this graph and others show when the SOC sharply changes pattern.
8. Battery voltage and current are used to calculate power in watts, then divided by 1000 to convert it to kW. The sum of the two battery powers becomes the full power of the plane. Manually calculated.
9. Analysis is then conducted, comparing battery power vs. motor power to identify when they match. Efficiency losses, cooling energy usage, and total energy losses are analyzed. Plot inefficiencies and aims to understand factors contributing to inefficiency percentages.
10. Looking for a regression model to determine the reduction in battery power if a specific action is taken.

Q: How long does the process usually take?

A: It takes a long time.

Q: What are your biggest pain points in the process/topic space?

A:

- The manual process is tiring and time-consuming:
- It takes time to perform analysis and visualizations, particularly determining the x and y limits of graphs.
- Still extracting insights and doesn't know where else to look and there is no standardized way to easily visualize the data.
- Analysis of data is challenging:
  - Battery data is more detailed and requires combining and granularity compared to plane data.
  - Identifying factors affecting discharge is difficult.
  - Redundancy in data leads to the need for figuring out similar variables.
  - Some variables are hard to understand their meaning, but it is possible to learn about them based on their mechanical or electrical nature.

Q: How do you envision the ideal workflow or process for parsing, cleaning, and processing airplane flight data?

A:

1. It would be beneficial to have a folder with all the data instead of making an API call.
2. Selecting the flights to visualize from a list would be useful.
3. Clicking on "discharge" would display one SOC on the y-axis and time on the x-axis, allowing comparisons of flights.
4. The interface should allow selecting which data to visualize.
5. Considerations should be made for efficient handling of large amounts of data, potentially in a two-step process due to limitations of RShiny.

Q: Are there any limitations or issues with RShiny and your current data visualization tools?

A: R is used for visuals because it is fast, and RShiny allows for interactive plots. By plotting everything and then filtering by the period of flight, losses and other relevant information can be observed.

E.2. Mehrdad UI Additional Feedback & Comments

- Put it in the manual about user .env files → instructions on how to change username and password in .env file
- Pick columns in data upload screen to be shown in table → dropdown

- Average and statistical information on flight (UPDATE REQUIREMENT TABLE TO MUST HAVE)
    - e.g. how much SOC drainage per circuit
    - deviations among the flights (standard deviation)
        - Comparing May to July - std dev would be bigger
        - Only July - standard deviations would be smaller
    - Show number of circuits somehow - nice-to-have
    - all the statistical information can be shown in visualizations as well (pie chart, bar chart)
    - Looking at data in a season and have a sentence of how every degree of weather change causes SOC to deplete faster by this much - partial derivative, rate of SOC change with respect to temperature - really helpful because looking at graphs you can't make conclusions like this
        - User can select a few days or a whole season or a month
        - how much hotter and how much colder and the impact on SOC
        - maybe have insights tab??? or under data analysis
- Wants us to use seaborn
- Paul laid out all activities
- give Mehrdad access to server
- Include Paul in usability testing

E.3. Gabriel's UI Insights (07/14/23)

Data upload screen

- Change "Sample" to "Most Recent"
- Put weather data under a specific flight instead of a separate table

Data analysis screen

- Will the graphs be for a range of flights or a single flight?
- Depends on the date range selected
- Suggestion: Add a button for single flight
    - pick 1 flight
- Suggestion: Add button for multiple flights
    - select date range
- If you have a list of flights, select a range of flights instead of date range
- Types of graphs
    - Avg. power setting vs. flight duration
    - Ask the researchers as well
    - Temperature and air density affect on endurance

Recommendation Screen

- Suggestion: If you hover over the zone it will tell you why it's yellow or red or some way to show why it's yellow or red
- Try and see if count of flights works, he doesn't know how scheduling will work for e-plane
- He thinks it's good but the which pilot column might always pick the lightest one

Data

- get rid of stall-calibrated unless it does anything other than 0.

- Stall-warn is what pilot sees so likely most useful
- for heading 140 and 320 they'll be making right turns rather than left (which they do for normal circuits)
- June 9 - only did 2 circuits. taxi to runway
- first higher bit 79 knots is climbing, 60 knots is descent and approach for landing

APPENDIX F: Functional Requirements Should-Haves, Could-Haves and Won't-Haves

Table F-1: User Interface (Should-Haves, Could-Haves, Won't-Haves)

No.	MoSCoW Prioritization	Requirement	Characteristic	Relation	Value	Units	Verification
1	Should-Have	User input for initial SOC	Should be flexible enough to input the initial SOC (i.e. was it charged to 90 or 100%)?	<=	Being limited to the SOC data collected by the plane		Analysis based on historical data and programs
2	Should-Have	Automatic Generation of Box Plots	Box plot showing max and min	>=	Manual generation of box plots		Task completion time and completion rate
3	Should-Have	Aggregated statistical analysis	Show aggregated statistical analysis across all flights when no flight is selected	>=	Empty space on UI when no flights are selected		UX and Usability Validation
4	Could-Have	Users can create accounts and login for security management	User management and login	>=	Single user functionality without passwords for multiple users	-	Sensitive data is password protected
5	Could-Have	Being able to save user input history for visualizations	Users can see history of generated graphs	>=	Users save past visualizations through screenshot	-	Number of inputs saved successfully
10	Could-Have	Statistical comparison with manufacturer baseline	Compare rates and performance of plane with manufacturer guidelines	>=	Guessing if the plane is performing as it should	•	Statistical Significance Analysis
11	Won't-Have	3-D Plotting of Graphs	Visualizing factors of plane operations interacting in a 3D space	>=	2D version of graphs	-	N/A
12	Won't-Have	Button	Button for manual data pipeline trigger	>=	Restricted to hourly refresh	•	User Experience Analysis

					to get new data		

Table F-2: ML Model and DSS for Flight Predictions (Old must-haves, Could-Haves, and Won't-Haves)

No.	MoSCoW Prioritization	Requirement	Characteristic	Relation	Value	Units	Verification
1	Must-Have	Making prediction of flight maneuvers and range of activities that can be accommodated	# of correct plane operations given battery status	>=	Pilots perform real-time calculations manually	-	Analysis/simulation using historical data
2	Must-Have	Integration with weather data	Accurate weather data from updated forecasts	>=	Estimating weather conditions in real-time	-	Analysis/simulation using historical data
3	Must-Have	Continuous (online) predictions in real-time	# of accurate real time predictions based on current weather conditions	>=	Guessing which operations are feasible in current weather	-	Analysis/simulation using historical data
4	Must Have	Extract clean and labeled data	Clean and labeled data that minimizes bias of seasonal plane data	>=	Manual cleaning and labeling of bias data	-	Analysis/simulation using historical data
5	Could-Have	Predict the best times of day to fly within the week	Apply weather forecast data	>=	Human Decision	Weekly	Simulation Analysis
~~6~~	~~Could-Have~~	~~Range circle~~	~~Map showing a range circle of how far you can go from airport~~	~~>=~~	~~Human Decision~~	-	~~Simulation Analysis~~
7	Nice-to-have	Historical Records of Simulation vs. Reality	How many flights have been done in each day? Did we fly in every green zone or wasted time?	>=	Manually going through records	•	User Experience Analysis
8	Won't-Have	Predict the number of planes to	Number of electric planes to buy	>=	Human Decision	Yearly	Simulation Analysis

		purchase to electrify the entire training program					
9	Won't-Have	Scheduling decisions of planes based on inspection, charging and flying times	Automated scheduling decisions	>=	Manual schedules	Daily	Simulation Analysis
10	~~Must-Have~~	~~Include total flight time in determining feasible flights per day~~	~~Consider time for charging, safety and maintenance inspection, and actual flight time~~	~~>=~~	~~Human estimating feasibility of flights~~	~~Hourly~~	~~Quality validation and Flight Testing~~
11	Won't-Have	Interactive UI to change default simulation constraints	Settings panel to change the variable thresholds (e.g. temperature) for simulation decisions	>=	Static default rules (no flexibility to change simulation model)	-	Cognitive Walkthrough

Table F-3: Data Pipeline (Could-Haves and Won't-Haves)

No.	MoSCoW Prioritization	Requirement	Characteristic	Relation	Value	Units	Verification
1	Could-Have	System diagnostic data format	Convert all data format to	>=	Risk of pipeline breakdown due to changes in source data	-	Tests with various data formats

Table F-4: Plane Operations Requirements

No.	MoSCoW Prioritization	Requirement	Characteristic	Relation	Value	Units	Verification	Validation
1	Should-Have	Connect to flight scheduler simulation	Get forecasted weather data for feasible flight times from simulation to make predictions	>=	Making predictions for arbitrary times instead of actually feasible flight times.	-	Analysis/simulation using historical data	Pilot program with WWFC pilots

APPENDIX G: ALTERNATIVE DATABASE CHOICES

G.1. Database Choices

Due to the abundance of flight data, there exists a need for a database. The team investigated two database options to implement in this project: PostgreSQL and InfluxDB. The team is more familiar with PostgreSQL, but InfluxDB fits the use case better given it is a time-series database. Furthermore, PostgreSQL utilizes SQL to query data while InfluxDB uses Flux (Figure G-1).

```
SQL

SELECT flight_data.battery_health, flight_data.windspeed FROM flights JOIN flight_data
ON flights.flight_id = flight_data.flight_id WHERE flights.flight_number =
'june-23-flight' AND flight_data.timestamp > NOW() - INTERVAL '1 hour'

FLUX

data = from(bucket: "june-23-flight")
  |> range(start: -1h)
  |> filter(fn: (r) => r["_measurement"] == "flight_data")

batteryHealth = data
  |> filter(fn: (r) => r["_field"] == "battery_health")
  |> last()

windspeed = data
  |> filter(fn: (r) => r["_field"] == "windspeed")
  |> last()

batteryHealth
  |> join(tables: {windspeed: windspeed}, on: ["_time"])
```

Figure G-1: SQL vs. Flux Query Example

As shown in Figure G-2, the number of pros and cons were similar. However, after team conversations and discussions with our advisor, it was determined that learning a different querying language would be time-consuming and comes with learnability issues. Furthermore, familiarity and faster development took precedence over scalability and execution time considerations, leading to the selection of PostgreSQL.

	PostgreSQL	InfluxDB
Team Familiarity	✓ Familiar	✗ Not Familiar
Execution	✗ Slow	✓ Fast
Scalability	✗ Performance loss with volume	✓ Good
Integration with Python	✓ Yes	✓ Yes
Amount of Overhead Work	✓ Low	✗ High

Figure G-2: Competitive Analysis of Database Options

G.2. Technical Software Design Choices

After thorough research, the team evaluated four potential software options for our UI: Shiny, Streamlit, Grafana, and Dash. The competitive analysis criteria in Figure 9 were created with our requirements in mind. Among these choices, Shiny was the most suitable. While Grafana, offered time-series visualizations, it was dropped due to longer setup time and a steeper learning curve. Streamlit and Dash were eliminated due to concerns about limited customization in Streamlit and the slower prototyping capabilities in Dash.

Shiny, as depicted in Figure G-3, met 4 of 5 of our key criteria, making it a confident choice for our project. Our advisor also supported this decision due to Shiny's excellent visualization and customization options. Additionally, its quick learning curve, attributed to our team's familiarity with Python, was a decisive factor, since it allowed us to concentrate on the project's core aspects rather than spending excessive time learning a new framework.

	Fast Prototyping User Interfaces		Interactive Dashboard Interfaces	
	Shiny	Streamlit	Grafana	Dash
Rapid Prototyping	✓	✓	✗	✗
Easy Customization	✓	✓	✓	✓
Integration with Plotting Libraries	✓	✓	✗	✓
Native Database Connection	✗	✗	✓	✗
Many customization options	✓	✗	✓	✓

Figure G-3: Competitive Analysis of UI Software Options

APPENDIX H: Solution Development Iteration

H.1. Data Preview

Most Recent Flight and Weather Data Records

Select Columns to Preview

Flight Date × Flight ID × Time (Min) × Bat 1 SOC × Bat 1 SOH ×
Bat 1 Max Cell Temp × Temperature × Visibility ×

FLIGHT DATE	FLIGHT ID	TIME (MIN)	BAT 1 SOC	BAT 1 SOH	BAT 1 MAX CELL TEMP	TEMPERATURE	VISIBILITY
2023-12-16	5367	0				42.8	9
2023-12-16	5367	0.02	78.4	65.6	3.6	42.8	9
2023-12-16	5367	0.04	98	82	18	42.8	9
2023-12-16	5367	0.06	98	82	18	42.8	9
2023-12-16	5367	0.08	98	82	18	42.8	9
2023-12-16	5367	0.1	98	82	18	42.8	9
2023-12-16	5367	0.12	98	82	18	42.8	9
2023-12-16	5367	0.14	98	82	18	42.8	9
2023-12-16	5367	0.16	98	82	18	42.8	9
2023-12-16	5367	0.18	98	82	18	42.8	9

Data was last refreshed at: 2024-02-17 15:35:54

Figure H-1: Old Data Preview Implementation

H.2. Data Analysis

H.2.1 Data Visualization

Figure H-2: Data Analysis First Iteration

H.2.2 Statistical Insights

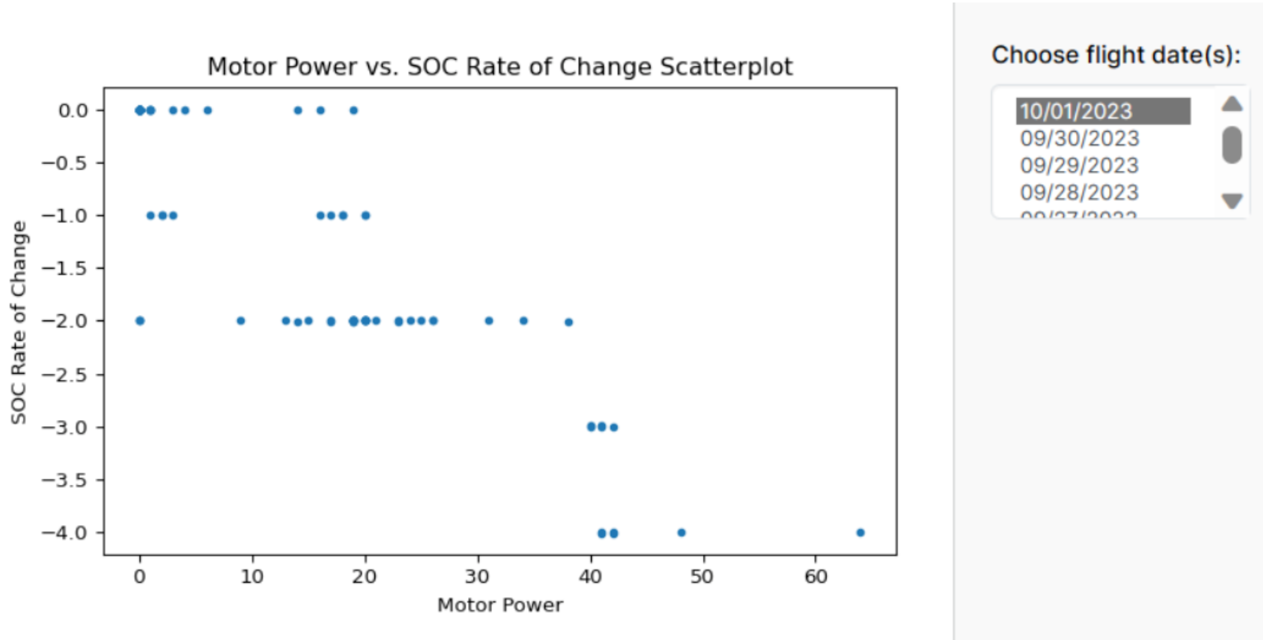


Figure H-3: Statistical Insights First Iteration

H.3. Flight Planning

H.3.1 Scheduling

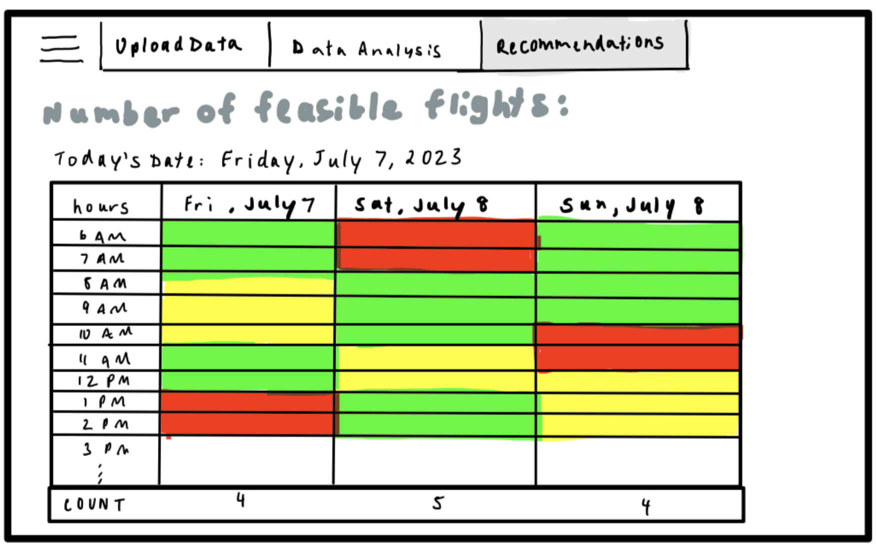


Figure H-4: Flight scheduling tool – Iteration 1

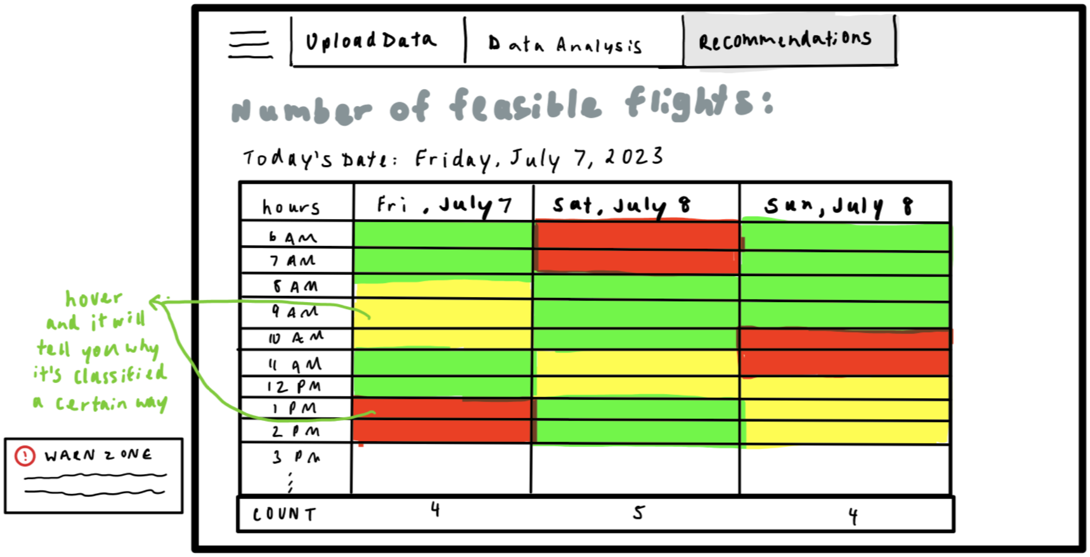


Figure H-5: Flight scheduling tool – Iteration 2

H.3.2 Exercise Planning

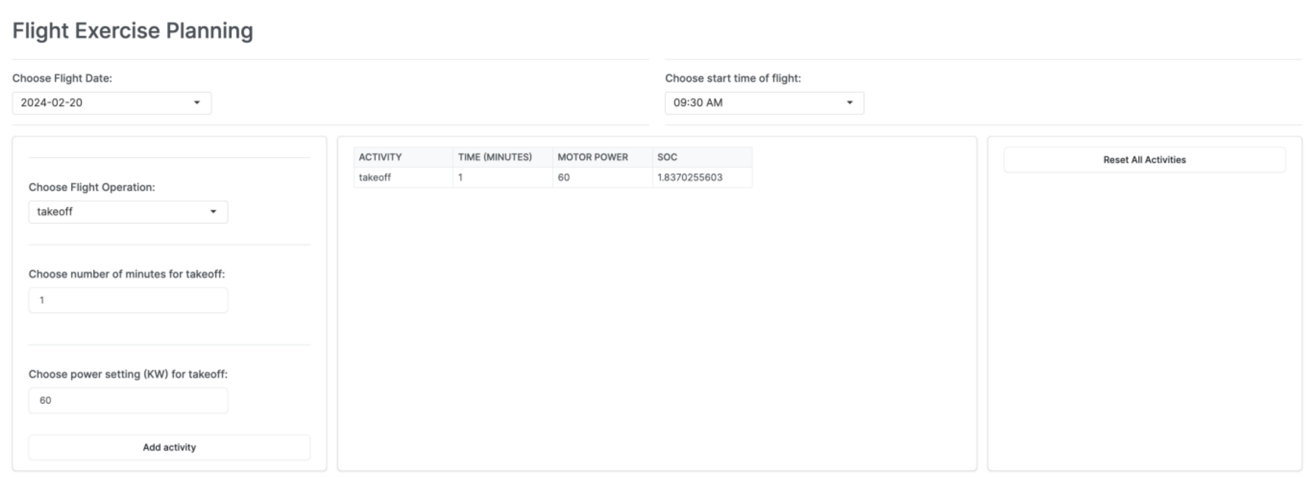


Figure H-6: Old Flight Exercise Planning Implementation

APPENDIX I: Verification and Validation

I.1. Machine Learning Verification

Table I-1: Classification Report for XGBoost

Exercise	Precision	Recall	F1-Score	Support
HASEL	1	0.98	0.99	112
climb	1	1	1	1758
cruise	1	1	1	3901

descent	0.99	0.99	0.99	793
landing	1	1	1	2613
post-flight	1	1	1	742
power off stall	0.96	0.99	0.97	116
power on stall	1	1	1	29
pre-flight	1	1	1	2216
slow flight	1	0.99	0.99	378
steep turn	1	1	1	14
steep turns	1	0.99	0.99	355
takeoff	0.99	0.99	0.99	1009

I.2. Pilot Program Verification

Combined Pilot Program Feedback

Table

Filter Sort New

Pilot Program Results

UI Page + Add filter

Done	PM Priority	Description of Problem	Potential Solution	UI Page	Sprint
☐	Could do	Not clear about the purpose of feature	Include last SOH and SOC after a flight or charge	Data Preview	20
☑	Urgent	Bug: Flight map - Datapoint ends up in ocean	Fix bug, can we just get rid of the last point. Making it a nice-to-do since no one will likely notice in symposium	Data Visualization	
☑	Must do	The scatter plot type graphs appear illegible to me as compared to the very clear line graphs	Make the points much thicker	Custom Graph	
☑	Urgent	No units listed in independent and dependent dropdowns or on graphs axis	Include units in dropdowns and on the axis of graphs	Custom Graph	21
☐	Must do	On the graphs, pressure altitude should be in feet not meters	Make feet, change axis	Custom Graph	
☑	Urgent	Inconsistent spacing and padding, things cut off	Fix spacing and height	Statistical Insights	20, 21
☐	Must do	Page is too long	Shrink the page a bit by just starting at 5AM or so and running until 11PM year round	Flight Scheduling	
☐	Nice to do	Too tedious to input and makes the tool harder to use	Make default values for the input features (i.e., 64 kW and 60-90 seconds for takeoff)	Flight Exercise Planning	
☐	Nice to do	Move “Add activity” button to bottom of flight activity	Move “Add activity” button to bottom of flight	Flight Exercise Planning	

Figure I-1: Pilot Program Feedback from Survey and User Interviews

I.2.1. User Interview 1 – UX Interview [Tim]

Background Information

- Name of Interviewee: Peter
- Name of User: Timothy Doak
- Role of User: Pilot?
- Interview Date: Feb 29, 2024 - 2:00 pm

Can you briefly describe your experience using the app so far?

- Useful tool, data analysis more useful than flight planning, can see it used in future.

Which features did you find most useful?

- Custom graphs, allow to pinpoint what i want to see, especially figuring out how battery and temp have relationship. Data visualization, some bugs with it.

Were there any features that were difficult to understand or use?

- Everything was pretty good, didn't try exercise planning. Scatterplot in custom graphs, changing colour to dots in scatter to make it.

Did you find the content provided helpful and relevant?
- Yes, read through was useful, researchers and pilots and explained what to do with app. Each section had a description which was useful to help.

Was there any information missing that you expected to see? If so, what might be helpful to add?
- Flight data was comprehensive. Charging data consideration/visualizations, plot charging time and how the charge works versus temperature outside, building off of that calculator to estimate charging time how long it would take based on outside temperature and battery temp

Do you have any suggestions for new features or improvements to existing ones?
- Flight route is correct, but there's an extra point where its off. Charging the aircraft

What value do you think this app provides to pilots and instructors?
- In the data analysis, very useful, don't have to pull data from the website. Saves researchers a lot of time. Flight scheduling might not be the most valuable because they can check their app themselves where they schedule flights → some backup. Flight exercise planning seems it will be useful to calculate SOC.

How much time did it take to make flight planning decisions before this tool existed?
- Separate app WingMan, flight school owns the app, we pick a time. Weather under discretion of pilot in command, flight centre has authority. They output what you can do. Usually boils down to what pilot is comfortable with. 10 knot wind you could fly, some pilots would not be comfortable because its flimsy.

How much time does it take now [to do the activity outlined above]?
- General sense of what time would be good to fly, would still have to look at flight status anyway. So it adds extra time on top, but is useful for future planning.

Do you have any final comments or feedback you would like to share?
- Fairly useful, minor bugs few additions.

I.2.2. User Interview 2 – UX Interview [Alex]

Background Information
- Name of Interviewer: Nayeema
- Name of User: Alex
- Role of User: Researcher
- Interview Date: Wednesday, Feb 28, 2024

Can you briefly describe your experience using the app so far?
- He is research assistant with Velis, maintains and get aircraft ready and gets to sit with pilot and help them but doesn't fly. It isn't useful for him because he isn't flying but he thinks it will be useful for pilots.

Which features did you find most useful?
- The weather section is innovative.

Were there any features that were difficult to understand or use?
- It would be useful to know how the weather section is implemented, also linking the flight status to the twitter account will be nice.

Did you find the content provided helpful and relevant?
- He ignored me.

Do you have any suggestions for new features or improvements to existing ones?
- He doesn't know since he is not flying. Under data preview: rows are like in very little time intervals, it's not very useful, but it would be useful to have it longer eg. per second, all the rows are pretty much constant right now in data preview which isn't useful.

Is there anything else you would like to see changed or added to the app?

- It would be helpful to know how long it took to charge the battery (when it's cold it takes a long time to charge) he oversees maintenance, so he wants to see how long to charge with weather temp.

What value do you think this app provides [insert their role]? Would you see yourself using this tool now or in the future? How might it help your day-to-day activities?

- Isn't useful for him now, but in the future, he will be trained to fly it then it might be useful for him. It will be useful if we added how long it took to charge vs the outside air temp that day, but he isn't sure if he have access to the "how long it took to charge" data, but they do track it and send it to Velis.

How much time did it take to [insert responsibility → analyze graphs or make flight planning decisions] before this tool existed?

- He doesn't rly use the app.

How much time does it take now [to do the activity outlined above]?

- Input time started to charge and when charge finished, and this info is sent to Velis but, maybe we can setup something on our end to track how long it took to charge.

I.2.3. User Interview 3 - UX Interview [Dahui]

Background Information

- Name of Interviewee: Joanna Yang
- Name of User: Dahui Kang
- Role of User: Researcher
- Interview Date: Feb 28, 2024

Can you briefly describe your experience using the app so far?

Really good on data analysis part. Data analysis custom graph - she really likes it. Flight exercise planning takes long - it was not loading at all. Clear, the structure makes sense.

Which features did you find most useful?

Custom graphs and SOH insights. Flight exercise planning when it was working.

Were there any features that were difficult to understand or use?

No, everything straight-forward.

Did you find the content provided helpful and relevant?

yes

Was there any information missing that you expected to see? If so, what might be helpful to add?

no

Do you have any suggestions for new features or improvements to existing ones?

activities potentially add to data analysis graphs.

Is there anything else you would like to see changed or added to the app?

a functionality to download the graph. Custom graph scatter plot: add additional colour category.

What value do you think this app provides [insert their role]?

customize graphs quickly flight exercise planning - quick to get results data preview - nice quick overview of data.

Would you see yourself using this tool now or in the future? How might it help your day-to-day activities?

yes!!

How much time did it take to [insert responsibility → analyze graphs or make flight planning decisions] before this tool existed?

generating graphs → did not change much. Getting an overview of the data → 2 hours because downloading the data is a pain in the ass.

How much time does it take now [to do the activity outlined above]?

generating graphs → did not change much she uses our graphs to create graphs across different days getting an overview of the data → 1 minute now.

I.2.4. User Interview 4 - UX Interview [Gabriel]

Background Information

- Name of Interviewee: Meenakshi
- Name of User: Gabriel Song
- Role of User: Pilot
- Interview Date: Feb 29th

Introduction and Warm-up:

Can you briefly describe your experience using the app so far?
It's pretty good, any issues he found was logged.

Which features did you find most useful?
Exercise planning was useful. It could be improved, like when you perform a descent with power off, the model shows a SOC, but in theory it shouldn't. Also, manual is better than the ranges.

Were there any features that were difficult to understand or use?
Flight scheduling. The cloud height is important. Cloud cover could be overcast, but you can still go flying.

Did you find the content provided helpful and relevant?
Stat insights, data viz, custom graphs not as important for pilots
Data preview: not too sure if it's useful.
could be last 10 flights and choose some columns: SOH, TIME, AND WEATHER COLUMNS
Limitation is the data source

Was there any information missing that you expected to see? If so, what might be helpful to add?
Nice to scrape data from METAR from flight scheduling
Most advanced is Toronto Airport → 24 hours in advance

What value do you think this app provides [insert their role]?
Useful tool to play around with to see how much can get done in a flight
Likes that it porovides a layer on top of pipistrel website to look at all flights in a less tedious way

Would you see yourself using this tool now or in the future? How might it help your day-to-day activities?
Yes, once learning gets better and can trust it need real life validation.

How much time did it take to [insert responsibility → analyze graphs or make flight planning decisions] before this tool existed?
Didn't involve soc analysis for exercise planning they would check the weather they would call center and say want plane out it was always fully charged but going forward its gonna be ina. low charge state then they would go up and do the exercises and monitor the soc while theyre flying and then when it drops below 50% you know u need to go back.

How much time does it take now [to do the activity outlined above]?
Squeeze in more exercises. Might be able to make better use of the battery they have won't save time because now i must use the tool before I fly.

I.2.5. User Interview 5 - UX Interview [Paul]

Background Information:

- Name of Interviewee: Vikram Bhatt

- Name of User: Paul Parker
- Role of User: Pilot and Researcher
- Interview Date: March 5th, 2024

Questions:

Can you briefly describe your experience using the app so far?

Very accurate statements rather than incorrect states. Statements on the first page that were not accurate. Statement about the Velis not accurate, its the first type certified and commercially produced

Were there any features that were difficult to understand or use?

30 minutes are not long enough, in practice the flight school' booking system is better.

Table I-2: System Usability Survey Results

Users	SUS 1	SUS 2	SUS 3	SUS 4	SUS 5	SUS 6	SUS 7	SUS 8	SUS 9	SUS 10	SUS
1	3	2	3	1	3	1	4	1	2	1	72.5
2	4	2	3	1	4	2	4	2	3	3	70
3	4	3	4	1	4	3	4	2	4	3	70
4	5	4	4	4	4	5	4	4	4	3	52.5
5	5	1	4	1	5	1	4	2	5	2	90
6	4	1	4	1	4	1	5	2	5	2	87.5
7	5	1	4	2	5	1	5	2	5	1	92.5
8	4	1	4	1	4	2	5	1	5	1	90
9	4	1	4	1	5	2	4	1	5	1	90
10	4	2	5	2	4	2	5	1	4	2	82.5
											79.75

Table I-3: User Quotes

Name	Feedback
Zachary Taylor	"I wanted to outline my feedback here for your six tools and also wanted to congratulate you and your team on your work. **I think that your app is in a great place and that something like what you've created is absolutely going to be necessary when it comes to flight training with electric aircraft. "
Zachary Taylor	"Data Visualization: I love the map feature and I think that's an amazing visual to have in there. The graphs are good and I think this is my favourite tool."
Zachary Taylor	"Custom Graph: These custom graphs are great because it allows us to see many more combinations of data than the pipistrel website allows"
Zachary Taylor	"Flight Exercise Planning: This tool is going to be crucial to flight and lesson planning as flight training progresses
Anonymous	"I like the idea of having a central location for scheduled flights to be listed. Previously we have been using a mix of the flight centre's schedule software and a spreadsheet. I also like that it shows when flights cannot occur based on time of day."

Anonymous	"I think it is useful to have a better understanding of how much power each flight exercise requires. The single attribute selection was a useful function and easier to use than the sliders to get a specific number."

I.3. Heuristic Evaluation Verification

Table I-4: Neilson's 10 Usability Heuristics Reference Sheet

Heuristic	Description	Example
H2-1: Visibility of system status	The user should always know what the current state of the system is by the feedback given by the system with a fast response time.	Pop-up that indicates a password has been successfully reset
H2-2: Match between system and the real world	The language used in the app should be clear and concise. There is no technical jargon used, and information appears in a logical order.	Any messages and pop-ups use clear and concise language, no technical language is used
H2-3: User control and freedom	Users are given the ability to rectify their mistakes and undo the action without starting over.	Back, cancel and undo buttons
H2-4: Consistency and standards	Platform and industry conventions are followed so that users don't have to wonder if different words, situations, or actions have the same meaning.	Buttons and pages are consistent (e.g., the settings button on the menu bar will always take you to the settings page)
H2-5: Error prevention	Error prevention is important. Errors are prevented through eliminating situations for errors or checking with the user first before they complete the action.	Confirmation pop-up when user is deleting a review
H2-6: Recognition rather than recall	The user's memory load should be minimized as much as possible by making options, elements, and actions visible. Going from one section of the interface to another, the user shouldn't have to memorize the information. The information needed to use the design (e.g., field labels and menu items) should be retrievable effortlessly.	Prompts to enter email and password

H2-7: Flexibility and efficiency of use	Shortcuts should be available for expert users but hidden from novice users so that the design can accommodate different experience levels.	Autofill options for previously entered information
H2-8: Aesthetic and minimalist design	The interfaces shouldn't contain irrelevant information. Extra information will compete with other components of the interface and reduce their visibility.	The design of the app isn't overcrowded with colour and information
H2-9: Help users recognize, diagnose, and recover from errors	Error messages should clearly indicate the problem and suggest a solution in a constructive way.	An error message "fill in email and password" indicates the problem clearly
H2-10: Help and documentation	Help and documentation should be available close to where the user is completing the task. The language should be concise, and steps clearly laid out.	Help page, information popups that help explain functionality

Source: https://www.nngroup.com/articles/ten-usability-heuristics/ and Professor Oliver Schneider's Slides

Table I-5: Severity Ratings

Severity Rating	Description
0	Not a usability problem
1	Cosmetic problem, could fix but low priority
2	Minor usability problem, would be nice to fix
3	Major usability problem, should be fixed
4	Usability catastrophe, absolutely must be fixed

Source: Professor Oliver Schneider's Slides

I.3.1 Heuristic Evaluation Tasks

Task 1: Data Upload
You are a user (WISA researcher or WWFC pilot) and would like to quickly preview the data columns that exist

1. Select the upload data page
2. Select the columns to preview
3. View the values and type of data available

Task 2: Recommended Graphs
You are a researcher, and you would like to analyze the SOC versus time across multiple flights

1. Select the data analysis page
2. Select the "Recommended Graphs" tab

3. Select multiple flights (ex. Nov 06, 2023 at 7:55 AM and Oct 27, 2023 at 7:05 AM)
4. View the graph and make interpretations

Task 3: Custom Graphs
You are a researcher and a new user of the “ElectriFly” platform, and you would like to create a custom scatterplot graph comparing SOC vs time for the flight on October 18th 2023 at 2:48 PM

1. Select the data analysis page
2. Select the “Custom Graph” tab
3. Choose flight date of “October 19, 2023 at 8:53 AM”
4. Select the type of graph as “**scatterplot**”
5. Select “**Motor Power**” as the independent variable
6. Select “**state-of-charge**” as the dependent variable
7. View the graph and make interpretations

Task 4: Statistical Insights
You are a researcher and a new user of the “ElectriFly” platform, and you would like to understand statistical insights regarding motor power vs SOC rate of change for the flight on October 18th, 2023

1. Select the data analysis page
2. Select the “Statistical Insights” tab
3. Choose the flight date of “October 18, 2023”
4. View the graph and make interpretations

Task 5: Simulation - Flight Scheduling Tool
You are a pilot and want a flight scheduling tool to easily understand which dates and times you can schedule the flights for

1. Select the simulation page
2. View the colour zones
3. Understand the explanation for why there is a red zone listed for today at 4:45 am

Task 6: Simulation - ML Flight Exercise Planning
You are a pilot and want to understand how much SOC is consumed for future activities you choose

1. Select a future flight date (ex. January 31, 2024)
2. Select a time of flight (ex. 12:15 PM)
3. Choose an activity (landing)
4. Choose how long the activity lasts for (ex. 10 mins)
5. Choose the motor power
6. Choose the altitude to fly at
7. Choose the ground speed in knots
8. Click “Add activity”
9. View the SOC consumed
10. Repeat the process again for another activity (ex. cruise) and repeat steps 3-5
11. Click reset all activities

APPENDIX J: Pilot Program Onboarding Resource

J.1. Onboarding Resource

Introduction

At ElectriFly, we are proud to introduce a pioneering initiative in collaboration with Pipistrel Velis Electro, the world's first fully operational electric plane. Our platform serves as the nexus where cutting-edge technology meets the skies, empowering researchers to analyze intricate flight data and develop a robust battery management system. This system is tailored for the optimal operation of the electric plane, ensuring efficiency, safety, and sustainability.

As we embark on this electrifying journey, we invite you to be part of a community dedicated to shaping the future of aviation. Together, we are not just analyzing data; we are propelling the evolution of electric flight and contributing to a greener, more sustainable future for the skies.

About our team

ElectriFly emerges from the visionary collaboration of five driven Management Engineering Students, whose shared passion for aviation fuels their pursuit of excellence in electric flight. With a profound belief in the transformative potential of electric aviation within Canadian airspace, this dynamic team combines their diverse expertise and unwavering dedication to shape the future of flight.

Getting Started

Our application is hosted on the website (https://electrifly.uwaterloo.ca/). Please click the link to get started.

Our goals with the pilot program

Our goal of the pilot program is to collaborate closely with participants to pinpoint any usability issues or challenges they encounter during their use of the app. We will then utilize the feedback gathered to implement timely and targeted updates to the app, addressing any identified issues and enhancing overall user experience. We will host a symposium on March 20th with the finalized product at the University of Waterloo.

Your Responsibilities during the Program

Your role in this program is essential for its success. Here are your key responsibilities:

1. **App Utilization:**
   - Familiarize yourself with the app.
   - Explore all features and tools.
   - Regularly use the app for your daily use cases (e.g. data visualization, statistical analysis, flight planning).
2. **Feedback Provision:**
   - Share your valuable insights and experiences.
   - Provide feedback regularly, share your thoughts throughout the program.
3. **Bug Reporting:**
   - Report technical issues promptly.
   - Contribute to app improvement.

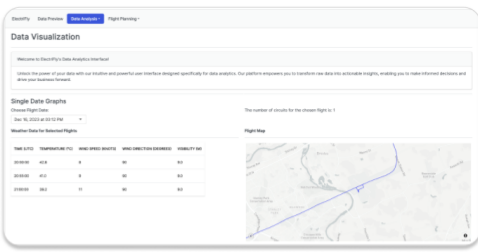
Your commitment is vital. Together, let's make ElectriFly soar. Thank you for being a crucial part of this journey!

App Navigation

In this section, we outline the primary tabs within our application that offer the most utility for two distinct user groups: researchers and pilots. Please feel free to explore all tabs and specifically focus on the ones that are used for your daily use cases.

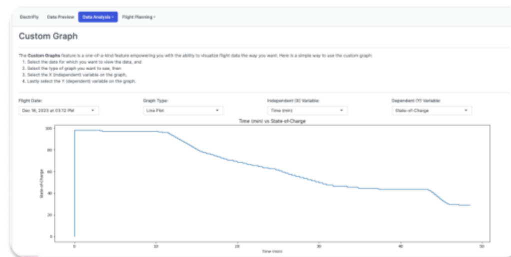
For sample tasks to guide WISA researchers and WWFC pilots through completing various tasks efficiently on the ElectriFly platform. Please comment on any areas of difficulty in the survey and randomly selected individuals will be asked to comment on their experience with the tasks below.

Researchers



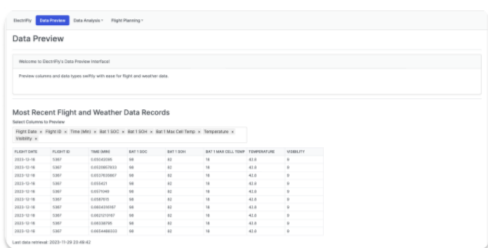
Data Visualizations

Gain comprehensive insights into plane and battery behaviours



Custom Graphs

Develop your own graphs and plot any variable including flight and weather data



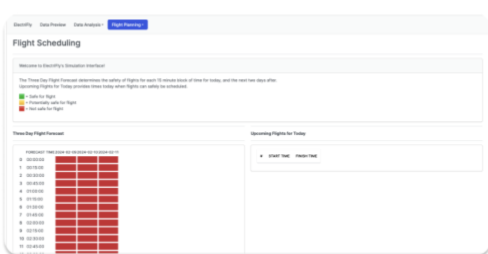
Data Preview

Preview data at a glance of the most recent flight to ensure all data was uploaded correctly

Statistical Insights

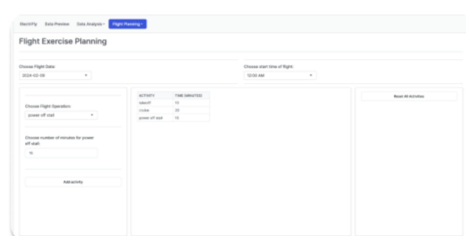
Unlock valuable statistical insights to enhance flight operations efficiency

Pilots



Flight Schedule

Determine the optimal flight times based on a simulation model derived from local weather forecasts



Flight Exercise Planning

Empower pilots' confidence during flight by planning what exercises can be performed in the air

Feedback Mechanism

Your thoughts are invaluable in shaping the success of ElectriFly. We've crafted a thoughtful feedback mechanism to ensure your insights are heard and acted upon:

During the Program

- Feel free to share your regular feedback and concerns directly with us by filling out this Google Form.
- For critical issues including the inability to connect to our app, please email vikram.bhatt@uwaterloo.ca and your message will be given prompt attention.

Post-Program Feedback

- At the culmination of the program, we invite you to participate in a comprehensive survey designed to capture your overall experience. Your responses will help us understand what worked well and where we can make enhancements.
- To delve deeper into your experiences, select users will have the opportunity to partake in interviews. This personalized approach allows us to gather more nuanced feedback and better tailor our improvements.

Troubleshooting

If you face any issues, challenges or have questions, please email our Communication Manager, vikram.bhatt@uwaterloo.ca.

Conclusion

In closing, we sincerely thank every participant in our pilot program. Your feedback, dedication, and commitment have shaped the future of our electric aviation project. Together, we've advanced innovation and collaboration, laying the foundation for a sustainable aviation landscape. Your contributions are invaluable, propelling our project and fostering a brighter, greener future. We deeply appreciate your support and look forward to continuing this journey together.