

Improving Power Conversion Efficiency in an Electric Aircraft

K. Ostalowski, R. Stevenson, D.H. Khan

Northern Illinois University

Department of Mechanical Engineering

DeKalb, IL 60465

Abstract— In the age of climate change caused by the excessive use of fossil fuels, there has been an increase in demand for reducing the use and dependence on fossil fuels. While the shift to other energy sources can already be seen in the automotive industry, the aerospace industry is facing additional challenges. Currently, the limiting factor is the state of battery technologies available, as the specific energy of batteries is much less than the specific energy of jet fuel. Calculating the energy requirements for a flight is vital to estimating the mass of energy storage material required for the flight to succeed. The purpose of this tool is to calculate the energy requirements for a flight and applying it to the gas, electric, and hybrid powertrains to predict the mass of fuel or batteries needed.

I. INTRODUCTION

Over the past few decades, the abundance of carbon dioxide in the atmosphere has been rapidly increasing [1], with transportation industry being responsible for 22% of global greenhouse gas (GHG) emissions [2]. Aircraft, on average, generate about twice as much CO₂ per passenger per kilometer than cars, and about 20 times more than trains [3]. The need for reducing the dependence of the aerospace industry on fossil fuels is clear.

The purpose of this project is to create a tool for engineers to approximate the mass, costs, and GHG emissions of an aircraft with three different powertrain systems: gas, electric, and hybrid. To solve the aircraft dynamics and the power requirements, Aircraft Power Requirement Efficiency Calculator (APREC) has been previously created in Microsoft Excel. Excel was chosen for its simplicity and ease of data presentation. In its original state, the tool was capable of calculating the power requirements for gas powered aircraft, with minor bugs and errors.

The purpose of this project was to expand the functionality to electric aircraft and hybrid aircraft, add optimization functions, and a user interface.

II. METHODS

A. Aircraft Dynamics

The flight profile is split into 7 phases: takeoff, departure, ascent, cruise, descent, approach, and landing. Each phase has a set of specific parameters and conditions which affect the thrust requirements. Forces are solved for from free body diagrams and discretized with respect to time. The forces and kinematics are solved at each timestep, from which power requirements can be derived. Mass flow rate of fuel and

battery discharge characteristics are solved. The data fuel flow and battery discharge data is summed over time intervals to calculate the total fuel mass and battery mass requirements.

Changes were made to the original APREC tool with regards to dynamics calculations. Main improvements include lift coefficient calculation, descent, approach, and landing reformulation, and changes to aircraft parameters and flight profiles.

Several formulas were adjusted to increase the accuracy of derived aircraft and flight parameters. The new parameters are able to reproduce more accurate results.

The reformulation of the descent and approach phases were necessary, as previously the aircraft had negative pitch, equal to the descent angle. The flight profile has been recalculated to keep the aircraft leveled while the flight velocity and thrust are decreased to reduce the altitude.

The modifications to the landing phase added reverse thrust. Previously, the only forces slowing down the aircraft were drag, rolling friction, and braking friction. With the addition of reverse thrust, the calculated landing time is more accurate than previous iterations.

B. Battery and Hybrid Implementation

The main purpose of the APREC tool is to be able to compare the potentials, costs, and GHG emissions of different powertrain types. The aircraft dynamics of the gas, electric, and hybrid models are the same, therefore the only changes needed are power consumption and delivery calculations. The battery pack is composed of individual battery cells arranged in series and parallel. The battery pack had to satisfy voltage, charge, and maximum discharge requirements. The voltage requirement can be satisfied by adding batteries in series arrangement. Charge and discharge current can be increased by adding more batteries in parallel configuration. The product of the number of batteries in series and parallel yields the total number of batteries, which then can be used to calculate the total mass and costs of the battery pack. Energy requirements are used to calculate the GHG emissions from generating electricity to charge the batteries.

The hybrid powertrain is modeled as a combination of gas and electric models. The user has control over the gas-hybrid split for each phase. A 50% electric and 50% gas hybrid model means that half the energy required will be delivered via fuel, and the other half via battery power.

C. Optimization Scripts

Multiple scripts have been added to the Excel tool with the help of Visual Basics for Applications (VBA). The purpose of the main optimization scripts is to adjust the initial fuel mass, battery mass, or battery parameters. A few minor scripts have been added to simplify the tool for the users. Simple scripts such as setting the payload to the maximum allowable, and to reset previously optimized parameters to default values.

Initially, the aircraft's fuel mass is set to its maximum value. The script reduces the initial value by a small percentage until the fuel life at the end of the flight is near a desired value. The fuel life is calculated as a ratio of current fuel mass to the maximum fuel mass.

The battery mass optimization adjusts the initial battery mass of an electric aircraft. The initial battery mass is set equal to the maximum fuel mass. The tool then calculates the battery mass required for the flight. The calculated battery mass is then substituted as the initial battery mass of the next iteration. The loop ends once the difference in battery mass between two consecutive iterations is less than 1%. Since no more battery mass needs to be added, the aircraft can complete its flight with the calculated battery mass.

Another script was added to optimize the battery properties. Certain flight profiles are not possible to be completed with batteries, as the battery mass never converges to a value. For these cases, a script was added to increase battery cell properties like voltage, charge, and maximum discharge current. The battery mass is set to the maximum fuel mass for the aircraft and fixed through the optimization process. The optimized battery parameters are displayed to the user for comparison against the initial parameters.

D. User Interface

A user interface has been added to the tool using VBA. The interface simplifies the tool for the user to limit the necessary inputs and outputs, with selected outputs shown in Table 1. All inputs but the Aircraft Type and Trip Distance can be different for System A and System B to compare different flight profiles. The addition of the interface reduces the amount of unnecessary data displayed. Navigating the spreadsheet is no longer necessary to use the tool and to see the results.

A plotting function has also been added to allow the user to view trends in variables as functions of other variables, as seen in Figure 1. The plotting function generates plots of variables and display a table of datapoints below the table for more precise analysis. Both System A and System B are plotted at the same time to show the differences between the two systems.

III. CONCLUSION

The APREC tool has the functionality of comparing different powertrain options between gas, electric, and

hybrid. The aircraft dynamics have been corrected and improved over the previous version. Battery calculations have been implemented to design appropriate battery packs from battery cells for different flight profiles. A hybrid model is also implemented to split the power requirements between gas and batteries.

Table 1: Interface inputs and selected outputs.

Inputs	Outputs
Aircraft Type	Mass of plane
Trip Distance	Velocity
Battery	Fuel/Battery Mass
Motor Voltage	Fuel Burn
Payload	Fuel Life
Electrical Efficiency	Fuel/Battery Cost
Engine Efficiency	CO ₂ Emissions (Fuel/Electricity)

VBA scripts have been added to optimize the flight profiles. The initial mass of fuel and batteries can be calculated through an iterative process. In case the battery mass cannot be optimized due to divergence, the battery cell properties can be optimized to satisfy flight parameters.

A user interface was added to simplify the user experience by limiting the displayed inputs and outputs. A plotting function has also been added to simplify the analysis of trends.

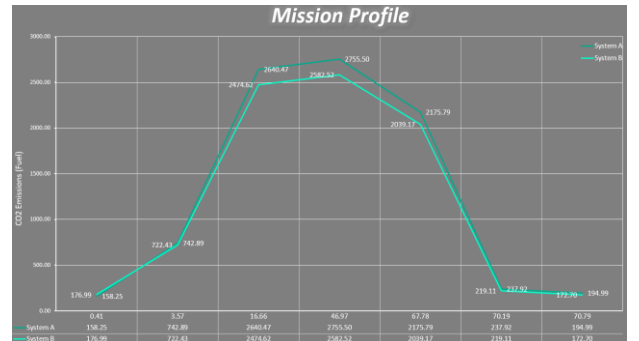


Fig 1: Data plotter

ACKNOWLEDGMENT

The authors would like to acknowledge Dr Nicholas Pohlman and Collins Aerospace.

REFERENCES

- [1] R. Lindsey, "Climate Change: Atmospheric Carbon Dioxide | NOAA Climate.gov," 2020. <https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide> (accessed Apr. 20, 2020).
- [2] J.-P. Rodrigue, "Transportation and the Environment | The Geography of Transport Systems," *The Geography of Transport Systems*, 2017. https://transportgeography.org/?page_id=5711 (accessed Apr. 20, 2020).
- [3] EEA, *Focusing on environmental pressures from long-distance transport*, no. 7. Publications Office of the European Union, 2014.