**Mobius Solar Plane Sizing Methodology**

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This document is intended to provide a brief overview of the sizing methodology used on the Mobius Solar Powered Aircraft. The first section will provide an overview of the code. The second section will provide detailed description about each function used in the sizing code.

**Overview**

This program aims to estimate the initial weight of the solar powered aircraft, as well as run a sensitives study on certain sizing inputs. Additionally, the aspect ratio and wing loading can be optimized to minimize the takeoff weight. This will be explained further later in the description.

There are 3 main models used in the sizing code, which will be explained further later. The first is the drag polar model. It is used to find the minimum thrust power required. Next is the solar array mode. It takes sun elevation data and estimates the power available from the solar array. This model has matched well with test results, therefore it can be used with fairly high confidence. The last model is a weight model. The weight model estimates the empty weight fraction of the aircraft. This model still needs to be validated against test articles, therefore it is being used with relatively low confidence.

The sizing code must use an iterative process to solve for the TOGW of the aircraft. The iterative sizing process is as follows: first, the battery of the solar plane is sized to allow flight throughout the duration of the night. Both the total energy and weight of the battery are calculated. Next, energy required to fly during the day is found using thrust power required times length of day. Then the solar array is sized based on the total energy required to fly for 24 hours. Solar array weight and area are calculated during this step. Next, the weight model is used to estimate the aircraft empty weight. Finally, the battery weight, solar array weight, empty weight, and payload weight are added to find the new TOGW. The function then checks to see if the solution has converged.

**Script/Function Description**

This section will descript in detail each of the scripts and functions in the order that they are called on.

“Main Script”

All sizing inputs are entered into the main script. Structures are relied on to pass variables in and out of functions. The structures are broken into specific categories. The structure “aero.” Contains all the aerodynamic parameters used for sizing. Many of these inputs are only educated guesses based on prior experience. Certain parameters that involve airfoil performance are based on available numeric low Reynold’s number data. The structure “PT” contains all Power Train sizing inputs. This includes solar array parameters. The other structures (“geom.”,”loads.”,”sys.”, and “design.”) only contain a few variables. However, they are present to maintain flexibility in the code as more variables/refinement is added.

“Main \_Script” also asks the user to provide several inputs. The first input is the option to run the optimization procedure (this procedure will be explained further later). The second input is the option to graphically visualize power in versus power out of the system. This can be a useful sanity check for the results. The last input is the sensitivities analysis, which will again be discussed later.

“Constant\_Weight\_Sizing”

This is the function that actually sizes the aircraft. First, the solar array model is loaded. A “While” loop then runs the iterative solver (as described above). When the TOGW has converged to within the specified tolerance, the while loop is exited. The results are then placed in a “results.” structure and sent out to the “Main\_Script”.

“Solar Array Model”

This model is based off a model in NASA CR3699 research paper. The inputs to this function are the string of the text file of the sun position data used, as well as the solar array characteristics. This model then calculates the energy *per meter squared* from the solar array. This value is used in the iterative solver in “Constant\_Weight\_Sizing”. This model accounts for the atmospheric attenuation that will diminish power from the solar cells, especially at low sun elevation angles (dawn and dusk). The other outputs from this function are not extremely significant, as they are used by other functions for plotting purposes, or are information about the sun data text file.

“Size\_Batt”

This function sized the battery to fly the aircraft through the night. First the total energy to fly through the night is found by calculating the thrust power required (plus systems power) and then multiplying by the length of night. Then the characteristics of the batteries (Panasonic 18650 cells) are used to find the battery weight, volume and capacity. It should be noted that the battery efficiency and useable range (~80%) are taken into account when sizing the battery. Additionally, the efficiency of the Max Power Point Tracker (MPPT), which controls the solar array power output, is used in case power will be fed back through the MPPT during the night. The battery characteristics are currently based on information available on line, but will be updated with test results shortly.

“Thrust\_Power\_Req”

This function finds the thrust power required for the aircraft (in Watts). It uses the drag polar for the aircraft, as well as Weight and Wing area. It should be noted that the thrust power is divided by the propulsive efficiency as well as the assumed thrust lapse of the propeller. These trends are just estimates for now, but will be updated after propeller wind tunnel testing this week.

“Drag Polar”

The drag polar uses a simple parabolic approximation for the induced drag. However, the parasitic drag estimate consists of the Reynolds-dependent Cd,min drag of the airfoil (follows a logarithmic approximation ), the lift dependent viscous drag of the wing, and a miscellaneous term to account for pods, sensors, antennas, etc

This function calculates the Reynolds-dependent drag polar of the solar powered aircraft. The function also finds the maximum ratio of CL1.5/CD to find the minimum power required for the aircraft. The outputs are the C\_L required for minimum thrust power, C\_D required for minimum thrust power, the velocity at which minimum power required occurs. It should be noted that for the joined wing configuration, the Mean Geometric Chord is divided by two, increasing the Re # and therefore parasitic drag.

“Weight Model”

This function estimates the empty weight (and empty weight fraction) based on TOGW, aspect ratio, t/c, and several other parameters. Constant weights (such as servos, MPPT, receiver, etc) are also entered in this function. The weight of certain components, such as ribs, covering, and spar, are estimated based off simple geometric parameters of the aircraft (such as wing area, span, etc.) These equations are then multiplied by a constant to predict a reasonable component weight. These constants MUST BE UPDATED with actual test articles in the future.

“Power Visualization”

This function uses the results from “Constant\_Weight\_Sizing” to graphically show power available vs power required.

“Fitness\_fcn”

This function is used if the wing loading and aspect ratio are to be optimized. It sets TOGW as the fitness parameter for the Genetic Algorithm Optimizer and converts the inputs and outputs of the GA into useable variables for “Constant Weight Sizing”

**Optimization Procedure**

As the sizing model gained refinement, it was noted that there was a complex interaction between Aspect Ratio, Wing Loading, and TOGW. For example, as aspect ratio was increased, induced drag would decrease, parasitic drag would increase (for a given wing area, due to Reynolds dependency) and empty weight fraction would increase. Would the gain in efficiency be worth it? Similarly with wing loading, a higher wing loading would result in a smaller wing (lower EW fraction), but increased cruising speed (more thrust power required). After the author blindly guessed at finding an optimal combination that would minimize the TOGW, it was decided that the Genetic Algorithm would be implemented to find this combination. The effectiveness of the GA is apparent in the sensitivities study. If the optimizer is run, any change in Optimized Wing Loading or Aspect ratio shows and increase in TOGW.

**Sensitivities Study**

In order to evaluate the risk of the design, a sensitivities analysis was added. Key sizing inputs such as propulsive efficiency, wing loading, aspect ratio, payload weight, etc. are iterated through. All other variables are held constant, and the new TOGW is calculated. In order to have a true comparison of the sensitivity to certain variables, all parameters are normalized by a *percent change from original value* rather than the variables actual value. Interestingly, TOGW appears to be most sensitive to changes in propulsive efficiency. This necessitates immediate and effective testing to determine this parameter with more confidence.