Optimization of Solar-Powered, Sustained, and Autonomous Unmanned Aerial Vehicles for Variable Mission Criteria

Feasibility analysis using Mathematical optimization of solar-powered aircraft using first principles for different mission cases.

~~Feasibility~~ Optimization?

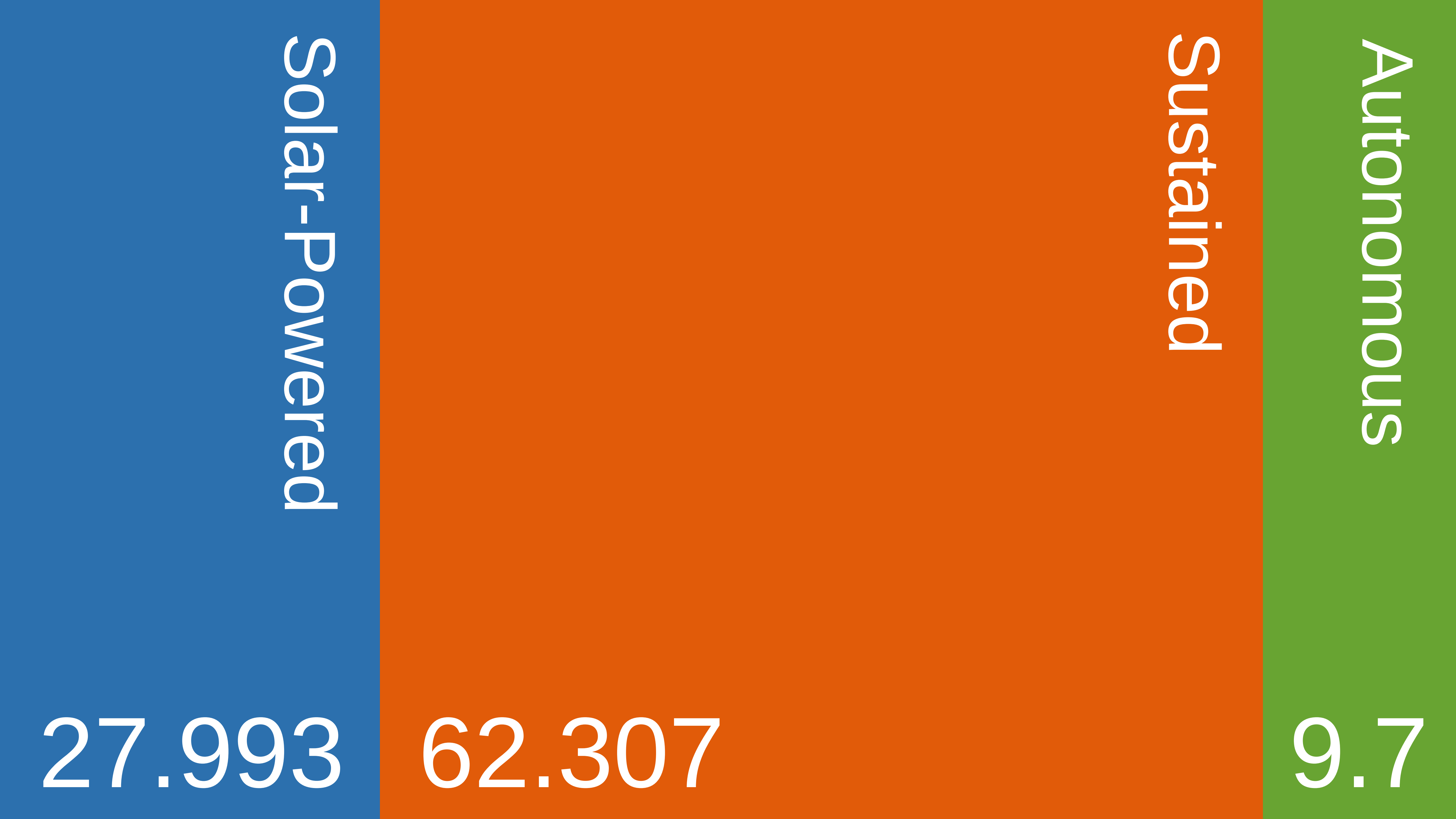
Variable Mission Criteria?

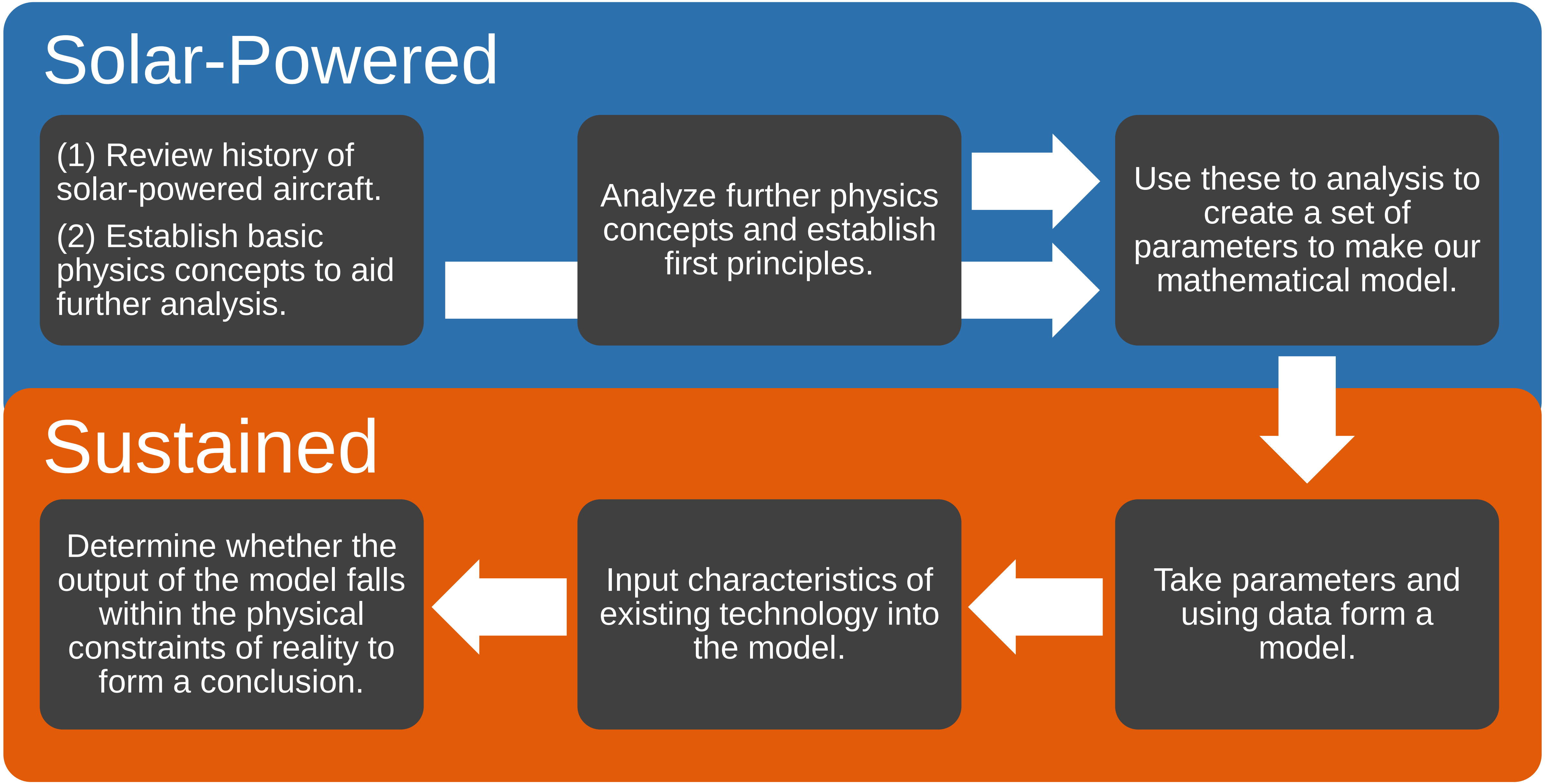
Why?

- Air Travel and Freight
- High Altitude science Experiments
- Search and Rescue Operations
- Industrial Inspection
- Agricultural Irrigation
- Low-cost Telecommunications and Internet
- Medical Supply Delivery
- Meteorology and Imaging

Methodology

Schools of Focus


Solar-Powered
27.993
Sustained
62.307
Autonomous
9.7



Solar-Powered

(1) Review history of solar-powered aircraft.

(2) Establish basic physics concepts to aid further analysis.

Analyze further physics concepts and establish first principles.

Use these to analysis to create a set of parameters to make our mathematical model.

Sustained

Take parameters and using data form a model.

Input characteristics of existing technology into the model.

Determine whether the output of the model falls within the physical constraints of reality to form a conclusion.

The Solar-powered Focus

Chapter

01

Chapter 1: History of Solar-powered Flight

1.1 Early History of Electric Flight and Photovoltaics

The utilization of electric power for the propulsion of flight vehicles is not a recent development. The first instance of this was in 1884 with the hydrogen-filled dirigible France, emerged victorious in a 10 km race around Villacoulbay and Medon. During this period, the electric system was deemed superior to the steam engine. However, with the advent of gasoline engines, research on electrical propulsion for air vehicles was abandoned, and the field remained dormant for 73 years. [13]

On the 30th of June 1957, Colonel H. J. Taplin of the United Kingdom conducted the first officially recorded electric-powered radio-controlled flight with his model "Radio Queen," which utilized a permanent-magnet motor and a silver-zinc battery. Unfortunately, he did not continue with these experiments, but subsequent advancements in the field were made by Fred Militky, who achieved a successful flight with an uncontrolled model in October 1957. Since then, electric flight has continuously evolved with constant improvements in the fields of motors and batteries. [12, 14]

Three years prior to Taplin and Militky's experiments, in 1954, photovoltaic technology was developed at Bell Telephone Laboratories. Daryl Chapin, Calvin Fuller, and Gerald Pearson created the first silicon photovoltaic cell capable of converting enough of the sun's energy into power to run everyday electrical equipment. Initially, the efficiency was at 4%, but it rapidly improved to 11%. [12, 15]

It took two more decades after this to witness the utilization of solar technology for the propulsion of electric model airplanes. [12]

1.2 Introduction

1.2.1 Objectives

The Wright brothers made the first successful powered, controlled and sustained aircraft flight on December 17, 1903. Only a decade later, at the start of World War I, heavier-than-air powered aircraft had become practical for artillery spotting, reconnaissance, and attacks against ground positions. During the Second World War primitive jet technology was developed leading to aircraft that could ferry passengers and freight from place to place in mere hours leading us into a "jet-age". After a sustained period of technological development, we are approaching a stagnation in aviation where we focus on the perfection of fossil-fuel based aircraft rather than the development of solar-powered aircraft that may prove to be the future of air travel, freight carrying, search-and-rescue operations, industrial inspection, agricultural irrigation, telecommunications, internet serviceability in remote regions, delivery of medical supplies, etc.

A theoretically infinite flight-time for solar-powered Unmanned Aerial Vehicles (UAVs) is a lucrative avenue of aircraft development if followed. It would enable a huge range of mission and applications to be rolled out universally where it was previously too economically expensive.

This dissertation therefore assesses whether it is possible to achieve a solar-power based singularity wherein an aircraft is able to fly perpetually and autonomously with today's technology, which in the coming years may perhaps again revolutionize the aerospace industry as once before.

1.2.3 Importance

Sustained solar flight has shown great promise over the last 40 years of continual development, however the singularity in which sustained practical flight which may easily be deployable, affordable and reliable has not come into fruition.

Widespread use of such a technology can completely revolutionize the world in which we live where aircraft can stay in the sky for months –perhaps even years– at a time completing important tasks in the functioning of our society which otherwise would be done using polluting conventional aircraft and UAVs.

1.2.4 Motivation

I have developed a great interest in "practical sustainability" in which our industry and basic necessities are made to be sustainable sustainably, meaning that changes are made in such areas where they result in sustainability without compromising on their original capacity. As such; I have produced a prototype "water catching" system in which water vapour can be "caught" in arid mountain-scapes where ground water and rainwater is inaccessible but low lying fog and clouds carrying a large amount of water can be taped into as part of my GCSE Design and Technology NEA; and a prototype solar powered desalination system which can take water with impurities and distil it using a lens that focuses the sun's energy to purify said water.

This EPQ acts as an extension of my interest in finding practical solutions to the requirement of sustainability in our industrial processes without compromising on scale and practicability.

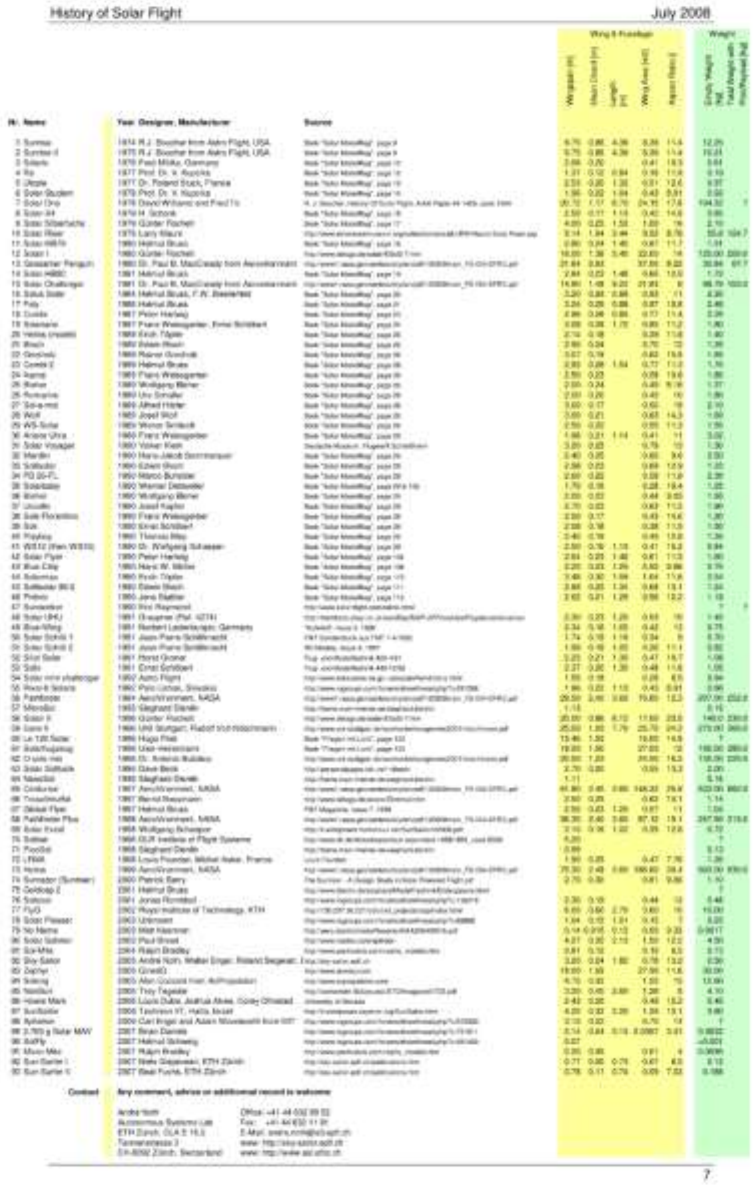
1.2.5 Scope and Goal

The scope of this paper will be limited to:

(1) History of solar-craft leading up to the current position of solar aircraft technology
(2) Relevant explanation of theory so that context analysis is established regarding:
    a. Conventional Flight Technologies (mechanics of flight)
    b. Solar-powered Flight (the electronics of solar-powered flight aircraft)
    c. Autonomous Flight Systems
(3) Discussion around the optimization and choice-weighing through multiple parameters established in the first section of:
    a. Mechanical Design of airframe
    b. Electronic Components regarding solar-flight
    c. Autonomous Algorithms and use of electronic devices
(4) Conclusion of question posed in this dissertation through:
    a. Separate Conclusions for:
        i. Solar-powered
        ii. Sustained
        iii. Autonomous
    b. A "Grand Conclusion" outlining a summary of the above conclusion
    c. A possible prototype using existing or near-future technologies to exemplify a possible solar-aircraft

The overall objective of this dissertation is to examine whether it is feasible for unmanned aircraft called UAVs (unmanned aerial vehicles) to achieve the following with current day technologies:

(1) Be able to be practically solar-powered in the sense it is feasible and affordable
(2) Be able to achieve theoretical infinite flight time in the sense it is feasible and affordable
(3) Be able to adapt autonomously to allow for complex missions and designations in the sense that it is feasible and affordable



History of Solar Flight

July 2008

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Chapter

02

Chapter 2: The Principles of Controlled Flight

2.1 Introduction

To begin weighing the suitability of different electronic technologies, the context of our analysis must first be stated, as such we first must briefly go into detail regarding the way mechanical components work on conventional aircraft.

Only the essential theory required to optimize and deduce whether the proposition of this dissertation is feasible will be analysed.

2.2 The Basic Principles of Flight

2.2.1 The Forces Involved in Level Flight

All aircraft must be designed with the following forces in mind to ensure the craft has optimum flight characteristics: thrust from the engine F_{Thrust}, the lift from the wings of the aircraft F_{Lift}, the weight of the aircraft F_{Weight}, and lastly the drag of the aircraft F_{Drag}. Controlling these values will allow the aircraft to at least become airborne before we need to implement control.

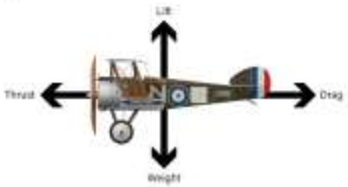


Figure [2.2].1: Forces acting on an aircraft during level flight featuring the Sopwith Camel. This is only a rough simplification as the centre of mass of the aircraft is closer to the bottom wing of the craft and here forces are acting through the visual centre not the centre mass, the next diagram remedies this problem.

Especially for the use case of solar-powered aircraft the parameters that most directly affect F_{Drag} and F_{Weight} must be controlled as much as possible with the remaining two factors falling below them in priority.

The following is during level flight in optimal conditions such as sea-level pressure, air temperature in the range of 10°C to 50°C. The airflow due the relative velocity of the aircraft to the air creates the force of F_{Lift} and F_{Drag}, both which are balanced by F_{Weight} and F_{Thrust}. F_{Lift} is a result of air flowing over the wings creating a pressure difference and is a sort of "manufactured force" in the sense that it a result of the designers of the aircraft adding wings, it allows the aircraft to overcome the F_{Weight} thus allowing us to take flight or remain at a constant altitude during level flight. F_{Drag} is a force due to the inefficiences in our aircraft's design, F_{Drag} can never equal to zero as the drag coefficient (discussed further) is always greater than zero. F_{Thrust} is, in short, a result of the propeller creating a pressure difference and thus a force, this force must exceed F_{Drag} for the aircraft to accelerate, must be the same as F_{Drag} for the aircraft to remain at a constant velocity, and must be less that F_{Drag} for the aircraft to decelerate.

2.2.2 Balancing the Forces in Flight

We can split the 4 forces into the x-plane and y-plane and from there use newton's first law to simple calculate the force required for the aircraft to accelerate, remain at a constant velocity, decelerate in both axis. As represented on a free-body diagram [3]:

Figure [2.2].2: Forces acting on an aircraft in level flight resolved in the x and y axes. Forces are about the approximate centre of mass of the aircraft.

$$\Sigma F_x = ma \qquad \text{Equation [2.2].01}$$

$$\Rightarrow \quad F_{Thrust} - F_{Drag} = ma \qquad \text{Equation [2.2].02}$$

$$\Sigma F_y = ma \qquad \text{Equation [2.2].03}$$

$$\Rightarrow \quad F_{Lift} - F_{Weight} = ma \qquad \text{Equation [2.2].04}$$

Variable	Description	
F_x	Forces in the x axis	Symbol [2.2].01
F_y	Forces in the y axis	Symbol [2.2].02

It should be noted that we subtract place both F_{Drag} and F_{Weight} as being subtracted from their respective forces as we are taking the upwards plan and the leftwards directions as positive as it would be must intuitive as that is both the top and the front of the aircraft.

2.3 Controlling flight

2.3.1 The Importance of Control

For the solar aircraft to be able to fly theoretically infinitely, the craft first must be able to be controlled – autonomously or not, there is a need for control surfaces.

2.3.2 The Control Surfaces Required

Unpowered gliders have existed long before the Wright Flyer, such as George Cayley's full-scale glider published as part of his three-part treatise where it included the world's first (known) manned flight in 1853. [17] Powered aircraft have also existed long before the Wright Flyer such as the first unmanned powered aircraft in 1848 built by John Stringfellow. [19] There have also been manned powered flights such as Ader Avion III built by Clément Ader which achieved "hops" whereby it would take off and then haphazardly land back, flying a few meters. [18] All of these flights did not succeed like the Wright Flyer did as a result of not having one thing: control.

The Wright Flyer succeeded due to the ability to control itself in flight, this allowed it to crash a sustain flight. The Wright brothers had invented three axis flight [2] allowing their aircraft to succeed.

For a solar-powered it must be able to be controlled for it to be able to sustain flight. do this, the craft must use the three axes of control: roll, pitch, and yaw. [20] Small called control surfaces are moved into the flow of air to create a force against the and thus cause it to manoeuvre.

The diagrams below show the axes of movement and their relevant control surfaces allow such movement.

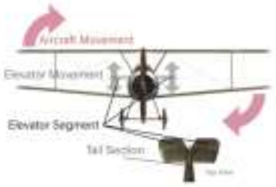


Figure [2.3].1: Axis of roll, control surfaces called ailerons cause this motion.

Figure [2.3].2: Axis of pitch, control surfaces called elevators cause this motion.

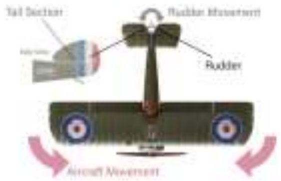


Figure [2.3].3: Axis of yaw, a control surface called the rudder causes this motion.

2.4 Aerodynamics of wings

2.4.1 The Problem

To successfully become airborne, designers must consider the aerodynamics of the wing carefully in the sense that the wing must create lift whilst not creating too much drag and ensuring suitable flight characteristics depending on the average velocity of the craft. Suitable flight characteristic during stalls and high winds should also be taken into consideration for the development of a low-speed solar UAV.

2.4.2 The Forces on an Aerofoil

The figure [2.4].1 shows a cross section of a wing in the optimum condition of laminar flow at a constant velocity of v. The relative airflow over the wing creates a difference in pressure the top of the wing and the bottom wing that once resolved create the two forces of F_{Drag} and F_{Lift}.

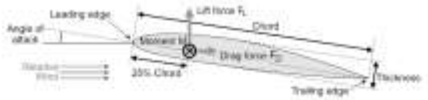
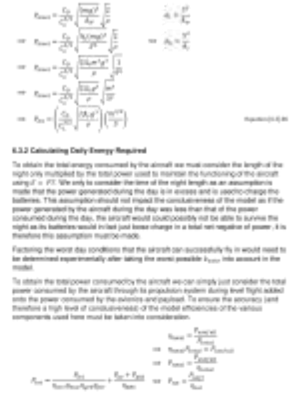
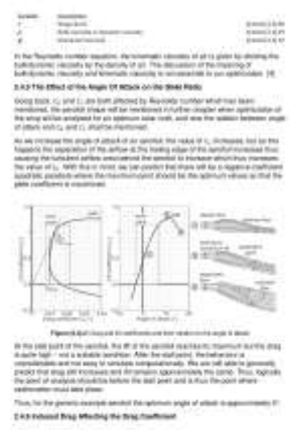
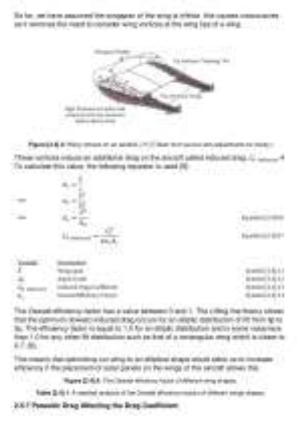


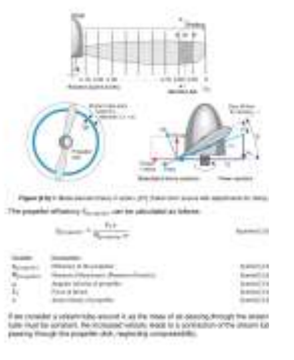
Figure [2.4].1: Cross-section of an aircraft's aerofoil. The cross encased in a circle represents the centre of mass of the wing and that is the place where forces act through. F_{Weight} has been omitted to reduce complexity as we are analysing the wing only and F_{Weight} considers the entire weight of the aircraft.

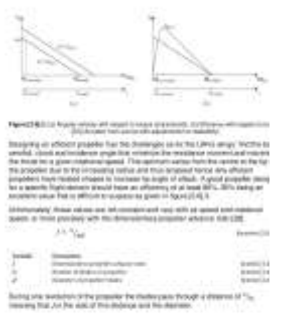
The forces of F_{Drag} and F_{Lift} can be calculated using the following formulas:

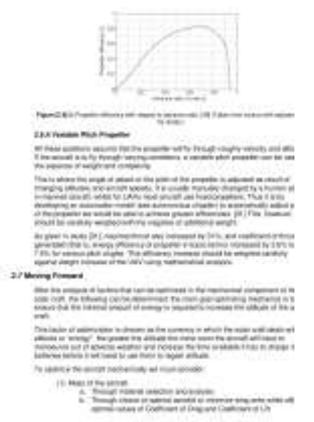












$$\Sigma F_x = ma \qquad \text{Equation [2.2].01}$$

$$\Rightarrow \quad F_{Thrust} - F_{Drag} = ma \qquad \text{Equation [2.2].02}$$

$$\Sigma F_y = ma \qquad \text{Equation [2.2].03}$$

$$\Rightarrow \quad F_{Lift} - F_{Weight} = ma \qquad \text{Equation [2.2].04}$$

Variable	Description	
F_x	Forces in the x axis	Symbol [2.2].01
F_y	Forces in the y axis	Symbol [2.2].02

$$F_D = C_D \frac{\rho}{2} A_W v^2 \qquad \text{Equation [2.4].01}$$

$$F_L = C_L \frac{\rho}{2} A_W v^2 \qquad \text{Equation [2.4].2}$$

Variable	Description	
F_D	Force due to drag, previously F_{Drag}, henceforth F_D.	Symbol [2.4].01
C_D	Coefficient of Drag	Symbol [2.4].02
F_L	Force due to lift, previously F_{Lift}, henceforth F_L.	Symbol [2.4].03
C_L	Coefficient of Lift	Symbol [2.4].04
ρ	Density of air	Symbol [2.4].05
A_W	Area of the wing	Symbol [2.4].06
v	Speed of aerofoil relative to the air (Relative airspeed)	Symbol [2.4].07

$$C_L/_{C_D} = \text{Glide Coefficient} \qquad \text{Equation [2.4].03}$$

$$R_e = \frac{\rho v c}{\mu}$$

$$\Rightarrow \quad R_e = \frac{vc}{\psi} \qquad \text{Equation [2.4].04}$$

$$\psi = \frac{\mu}{\rho}$$

$$\Rightarrow \quad \frac{1}{\psi} = \frac{\rho}{\mu} \qquad \text{Equation [2.4].05}$$

Variable	Description	
c	Wing chord	Symbol [2.4].08
μ	Bulk viscosity or Dynamic viscosity	Symbol [2.4].09
ψ	Kinematic Viscosity	Symbol [2.4].10

$$A_r = \frac{S}{c}$$

$$\Rightarrow \quad A_r = \frac{S^2}{Sc}$$

$$\Rightarrow \quad A_r = \frac{S^2}{A_w} \qquad \text{Equation [2.4].06}$$

$$C_{D\ Induced} = \frac{C_L^2}{\pi e_o A_r} \qquad \text{Equation [2.4].07}$$

Variable	Description	
S	Wing span	Symbol [2.4].11
A_r	Aspect ratio	Symbol [2.4].12
$C_{D\ Induced}$	Induced Drag Coefficient	Symbol [2.4].13
e_o	Oswald Efficiency Factor	Symbol [2.4].14

$$C_{D\ Overall} = C_{D\ Induced} + C_{D\ Parasite} + C_{D\ Aerofoil} \qquad \text{Equation [2.4].08}$$

$$\begin{cases} U = r_a i + k_u \omega_{mot} \\ M_{em} = k_m i \end{cases} \qquad \text{Equation [2.5].01}$$

$$\Rightarrow \quad \omega_{mot} = \frac{U - r_a i}{k_u} \qquad \text{Equation [2.5].02}$$

Variable	Description	Unit	
U	Terminal voltage from supply to motor		Symbol [2.5].01
r_a	Terminal resistance		Symbol [2.5].02
i	Current		Symbol [2.5].03
k_u	Voltage constant	[$V^1\ s^1\ rad^{-1}$]	Symbol [2.5].04
k_m	Velocity constant	[$rad^1\ V^{-1}\ s^{-1}$]	Symbol [2.5].05
M_{em}	Electromagnetic moment		Symbol [2.5].06
ω_{mot}	Angular speed of motor shaft		Symbol [2.5].07

$$M_{mot} = M_{em} - M_{f_s} \qquad \text{Equation [2.5].03}$$

$$\Rightarrow \quad M_{mot} = k_m i - k_m i_0$$

$$\Rightarrow \quad M_{mot} = k_m (i - i_0) \qquad \text{Equation [2.5].04}$$

Variable	Description	Unit	
i	Current final		Symbol [2.5].08
i_0	Current initial		Symbol [2.5].09
M_{mot}	Moment (Torque) due to motor turn force		Symbol [2.5].10
M_{f_s}	Moment (Torque) due to internal mechanical friction		Symbol [2.5].11

$$M_{mot} = k_m (i - i_0)$$

$$\Rightarrow \quad \frac{M_{mot}}{k_m} + i_0 = i$$

$$U = r_a i + k_u \omega_{mot}$$

$$\Rightarrow \quad U = r_a \left(\frac{M_{mot}}{k_m} + i_0 \right) + k_u \omega_{mot} \qquad \text{Equation [2.5].05}$$

$$k_m = k_u$$

$$\Rightarrow \quad M_{mot} = \frac{k_m^2}{r_a} \omega_{mot} + k_m \left(\frac{U}{r_a} - i_0 \right) \qquad \text{Equation [2.5].06}$$

$$\Rightarrow \quad \omega_{mot} = -\frac{r_a}{k_m^2} M_{mot} + \left(\frac{U - r_a i_0}{k_m} \right) \qquad \text{Equation [2.5].07}$$

$$\eta_{propeller} = \frac{F_T v}{M_{propellor} \omega} \qquad \text{Equation [2.6].01}$$

Variable	Description	
$\eta_{propeller}$	Efficiency of the propeller	Symbol [2.6].01
$M_{propellor}$	Moment of Resistance (Moment of Inertia)	Symbol [2.6].02
ω	Angular velocity of propeller	Symbol [2.6].03
F_T	Force of thrust	Symbol [2.6].04
v	Axial velocity of propeller	Symbol [2.6].05

$$J = {}^{v}/_{nd} \qquad \text{Equation [2.6].02}$$

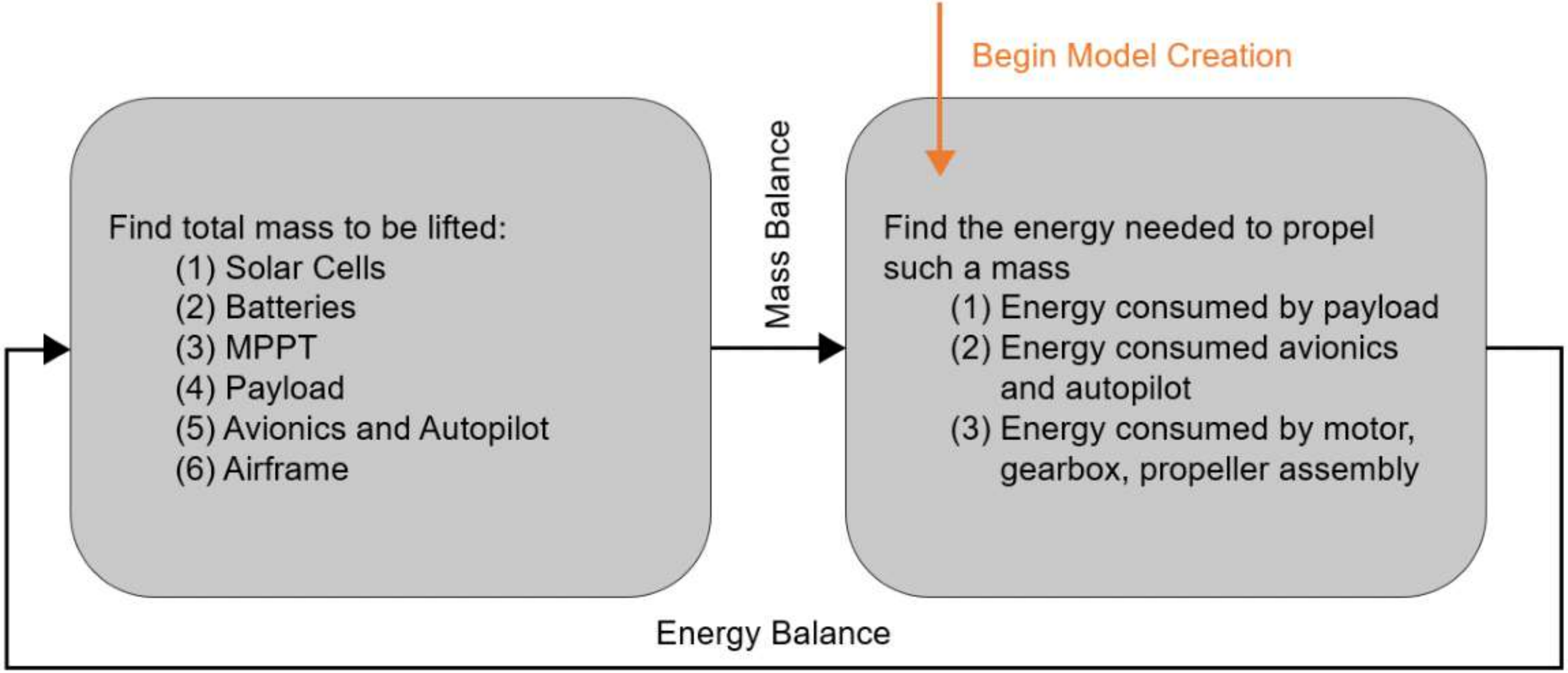
Variable	Description	
J	Dimensionless propeller advance ratio	Symbol [2.6].06
n	Number of blades on propeller	Symbol [2.6].07
d	Diameter of propeller blades	Symbol [2.6].08

M_{mot}	Moment (Torque) due to motor turn force	[N m]	Symbol [2.5].10
M_{f_s}	Moment (Torque) due to internal mechanical friction	[N m]	Symbol [2.5].11
$\eta_{propeller}$	Efficiency of the propeller		Symbol [2.6].01
$M_{propellor}$	Moment of Resistance (Moment of Inertia)		Symbol [2.6].02
ω	Angular velocity of propeller	[rad s^{-1}]	Symbol [2.6].03
F_T	Force of thrust	[N]	Symbol [2.6].04
v	Axial velocity of propeller	[m s^{-1}]	Symbol [2.6].05
J	Dimensionless propeller advance ratio		Symbol [2.6].06
n	Number of blades on propeller		Symbol [2.6].07
d	Diameter of propeller blades	[m]	Symbol [2.6].08
F_T	Force due to thrust, previously F_{Lift}	[N]	Symbol [6.X].01
F_W	Force due to weight, previously F_{Weight}	[N]	Symbol [6.X].02
P_{lvl}	Power consumed during level flight	[W]	Symbol [6.X].03
P_{usfl}	Power spent to create useful work	[W]	Symbol [6.X].04
P_{av}	Power consumed by avionics and autopilot	[W]	Symbol [6.X].05
P_{pld}	Power consumed by payload	[W]	Symbol [6.X].06
P_{tot}	Total power consumed	[W]	Symbol [6.X].07
P_{max}	Maximum Power Output	[W]	Symbol [6.X].08
η_{tot}	Total Efficiency		Symbol [6.X].09
η_{ctrl}	Efficiency of motor controller		Symbol [6.X].10
η_{mot}	Efficiency of motor		Symbol [6.X].11
η_{grb}	Efficiency of gearbox		Symbol [6.X].12
η_{plr}	Efficiency of propeller		Symbol [6.X].13
η_{BEC}	Efficiency of step-down converter		Symbol [6.X].14
η_{chrg}	Efficiency of battery charge		Symbol [6.X].15
η_{dchrg}	Efficiency of battery discharge		Symbol [6.X].16
η	Efficiency		Symbol [6.X].17
η_{sc}	Efficiency of solar cells		Symbol [6.X].18
η_{cbr}	Efficiency of curved solar panels		Symbol [6.X].19
η_{mppt}	Efficiency of MPPT Charge Controller		Symbol [6.X].20
$\eta_{mppt\ conv}$	Efficiency of DC to DC converter of MPPT		Symbol [6.X].21
$\eta_{mppt\ algor}$	Efficiency of tracking algorithm of MPPT		Symbol [6.X].22
k_{wthr}	Arbitrary weather constant		Symbol [6.X].23
k_{mppt}	Mass to power ratio of MPPT	[kg W^{-1}]	Symbol [6.X].24
E_{tot}	Total energy consumed	[J]	Symbol [6.X].25
T_{tot}	Total time elapsed, cumulative time period	[s]	Symbol [6.X].26
T_{day}	Time period of day, time from sunrise to sunset	[s]	Symbol [6.X].27
T_{night}	Time period of night, time from sunset to sunrise	[s]	Symbol [6.X].28
φ	Sunlight Day density		Symbol [6.X].29
I_{max}	Maximum sun irradiance	[W m^{-2}]	Symbol [6.X].30
A_{sc}	Area of solar panels	[m^2]	Symbol [6.X].31
κ	2D Density	[kg m^{-2}]	Symbol [6.X].32
κ_{sc}	Mass density of solar cells	[kg m^{-2}]	Symbol [6.X].33
κ_{add}	Mass density of additional mass around solar panels	[kg m^{-2}]	Symbol [6.X].34
ρ	3D Density	[kg m^{-3}]	Symbol [6.X].35
V	Volume	[m^3]	Symbol [6.X].36
A	Area	[m^2]	Symbol [6.X].37
m	Mass	[kg]	Symbol [6.X].38

The Sustained Focus

Discrete and Iterative Approach

Continuous and Analytical Approach



Begin Model Creation

Find total mass to be lifted:

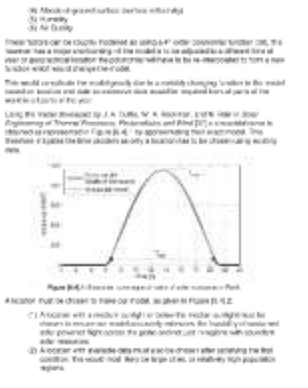
1. Solar Cells
2. Batteries
3. MPPT
4. Payload
5. Avionics and Autopilot
6. Airframe

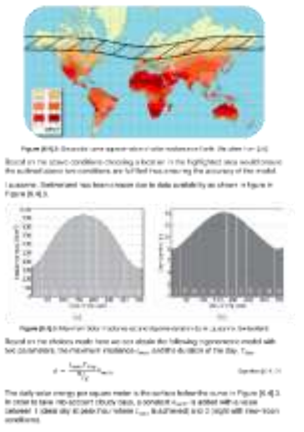
Mass Balance

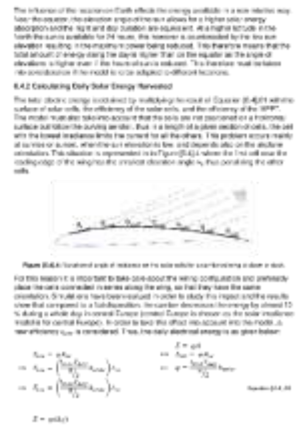
Find the energy needed to propel such a mass

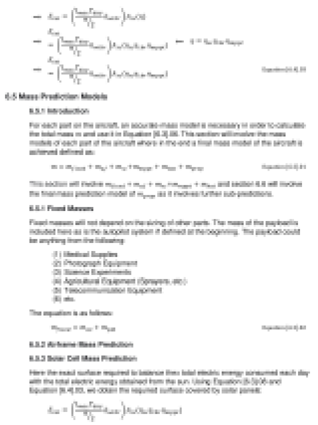
1. Energy consumed by payload
2. Energy consumed avionics and autopilot
3. Energy consumed by motor, gearbox, propeller assembly

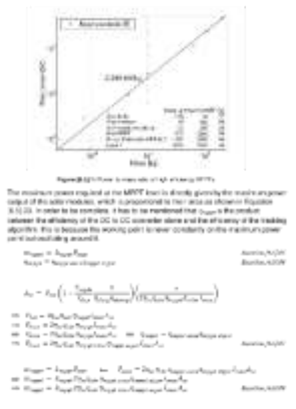
Energy Balance

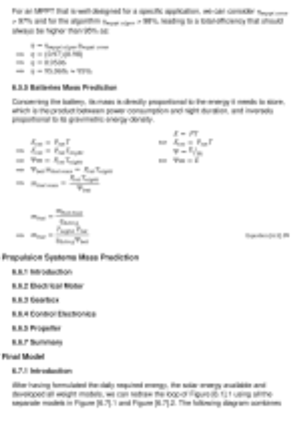


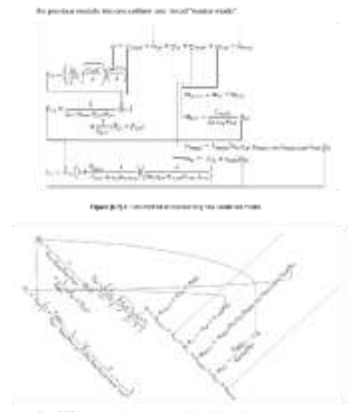


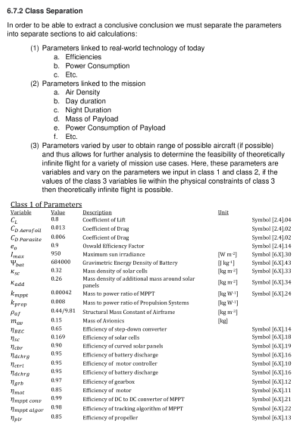












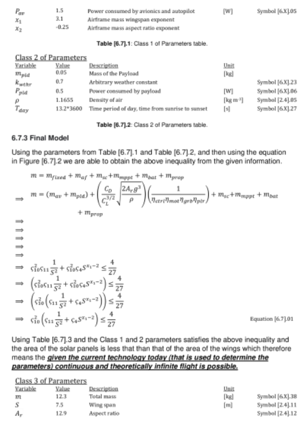
6.7.2 Class Separation

In order to be able to extract a conclusive conclusion we must separate the parameters into separate sections to aid calculations:

(1) Parameters linked to real-world technology of today
    a. Efficiencies
    b. Power Consumption
    c. Etc.
(2) Parameters linked to the mission
    a. Air Density
    b. Day duration
    c. Night Duration
    d. Mass of Payload
    e. Power Consumption of Payload
    f. Etc.
(3) Parameters varied by user to obtain range of possible aircraft (if possible) and thus allows for further analysis to determine the feasibility of theoretically infinite flight for a variety of mission use cases. Here, these parameters are variables and vary on the parameters we input in class 1 and class 2, if the values of the class 3 variables lie within the physical constraints of class 3 then theoretically infinite flight is possible.

Class 1 of Parameters

Variable	Value	Description	Unit	
C_L	0.8	Coefficient of Lift		Symbol [2.4].04
$C_{D\,Aerofoil}$	0.013	Coefficient of Drag		Symbol [2.4].02
$C_{D\,Parasite}$	0.006	Coefficient of Drag		Symbol [2.4].02
e_o	0.9	Oswald Efficiency Factor		Symbol [2.4].14
I_{max}	950	Maximum sun irradiance	[W m^{-2}]	Symbol [6.X].30
Ψ_{bat}	684000	Gravimetric Energy Density of Battery	[J kg^{-1}]	Symbol [6.X].43
κ_{sc}	0.32	Mass density of solar cells	[kg m^{-2}]	Symbol [6.X].33
κ_{add}	0.26	Mass density of additional mass around solar panels	[kg m^{-2}]	Symbol [6.X].34
k_{mppt}	0.00042	Mass to power ratio of MPPT	[kg W^{-1}]	Symbol [6.X].24
k_{prop}	0.008	Mass to power ratio of Propulsion Systems	[kg W^{-1}]	
ρ_{af}	0.44/9.81	Structural Mass Constant of Airframe	[kg m^{-3}]	
m_{av}	0.15	Mass of Avionics	[kg]	
η_{BEC}	0.65	Efficiency of step-down converter		Symbol [6.X].14
η_{sc}	0.169	Efficiency of solar cells		Symbol [6.X].18
η_{cbr}	0.90	Efficiency of curved solar panels		Symbol [6.X].19
η_{dchrg}	0.95	Efficiency of battery discharge		Symbol [6.X].16
η_{ctrl}	0.95	Efficiency of motor controller		Symbol [6.X].10
η_{dchrg}	0.95	Efficiency of battery discharge		Symbol [6.X].16
η_{grb}	0.97	Efficiency of gearbox		Symbol [6.X].12
η_{mot}	0.85	Efficiency of motor		Symbol [6.X].11
$\eta_{mppt\,conv}$	0.99	Efficiency of DC to DC converter of MPPT		Symbol [6.X].21
$\eta_{mppt\,algor}$	0.98	Efficiency of tracking algorithm of MPPT		Symbol [6.X].22
η_{plr}	0.85	Efficiency of propeller		Symbol [6.X].13



P_{av}	1.5	Power consumed by avionics and autopilot	[W]	Symbol [6.X].05
x_1	3.1	Airframe mass wingspan exponent		
x_2	-0.25	Airframe mass aspect ratio exponent		

Table [6.7].1: Class 1 of Parameters table.

Class 2 of Parameters

Variable	Value	Description	Unit	
m_{pld}	0.05	Mass of the Payload	[kg]	
k_{wthr}	0.7	Arbitrary weather constant		Symbol [6.X].23
P_{pld}	0.5	Power consumed by payload	[W]	Symbol [6.X].06
ρ	1.1655	Density of air	[kg m^{-3}]	Symbol [2.4].05
T_{day}	13.2*3600	Time period of day, time from sunrise to sunset	[s]	Symbol [6.X].27

Table [6.7].2: Class 2 of Parameters table.

6.7.3 Final Model

Using the parameters from Table [6.7].1 and Table [6.7].2, and then using the equation in Figure [6.7].2 we are able to obtain the above inequality from the given information.

$$
\begin{aligned}
& m = m_{fixed} + m_{af} + m_{sc} + m_{mppt} + m_{bat} + m_{prop} \\
\Rightarrow\; & m = (m_{av} + m_{pld}) + \left(\frac{C_D}{C_L^{3/2}}\sqrt{\frac{2A_r g^3}{\rho}}\right)\left(\frac{1}{\eta_{ctrl}\eta_{mot}\eta_{grb}\eta_{plr}}\right) + m_{sc} + m_{mppt} + m_{bat} \\
& \qquad + m_{prop} \\
\Rightarrow\; & \\
\Rightarrow\; & \\
\Rightarrow\; & \\
\Rightarrow\; & \\
\Rightarrow\; & \\
\Rightarrow\; & \varsigma_{10}^2\varsigma_{11}\frac{1}{S^2} + \varsigma_{10}^2\varsigma_4 S^{x_1-2} \le \frac{4}{27} \\
\Rightarrow\; & \left(\varsigma_{10}^2\varsigma_{11}\frac{1}{S^2} + \varsigma_{10}^2\varsigma_4 S^{x_1-2}\right) \le \frac{4}{27} \\
\Rightarrow\; & \left(\varsigma_{10}^2\left(\varsigma_{11}\frac{1}{S^2} + \varsigma_4 S^{x_1-2}\right)\right) \le \frac{4}{27} \\
\Rightarrow\; & \varsigma_{10}^2\left(\varsigma_{11}\frac{1}{S^2} + \varsigma_4 S^{x_1-2}\right) \le \frac{4}{27} \qquad \text{Equation [6.7].01}
\end{aligned}
$$

Using Table [6.7].3 and the Class 1 and 2 parameters satisfies the above inequality and the area of the solar panels is less that than that of the area of the wings which therefore means the ***given the current technology today (that is used to determine the parameters) continuous and theoretically infinite flight is possible.***

Class 3 of Parameters

Variable	Value	Description	Unit	
m	12.3	Total mass	[kg]	Symbol [6.X].38
S	7.5	Wing span	[m]	Symbol [2.4].11
A_r	12.9	Aspect ratio		Symbol [2.4].12

$$\begin{aligned} & \Sigma F_x = ma \\ \Longrightarrow\ & \Sigma F_x = 0 \\ \Longrightarrow\ & F_{Thrust} - F_{Drag} = 0 \\ \Longrightarrow\ & F_T = F_D && \Longleftarrow\ F_D = C_D \frac{\rho}{2} A_W v^2 \\ \Longrightarrow\ & F_T = C_D \frac{\rho}{2} A_W v^2 \end{aligned}$$

Equation [6.3].01

$$\begin{aligned} & \Sigma F_y = ma \\ \Longrightarrow\ & \Sigma F_y = m(0) \\ \Longrightarrow\ & F_{Lift} - F_{Weight} = 0 \\ \Longrightarrow\ & F_L = F_W \\ \Longrightarrow\ & C_L \frac{\rho}{2} A_W v^2 = F_W && \Longleftarrow\ F_L = C_L \frac{\rho}{2} A_W v^2 \\ \Longrightarrow\ & C_L \frac{\rho}{2} A_W v^2 = mg && \Longleftarrow\ F_W = mg \end{aligned}$$

Equation [6.3].02

$$\Longrightarrow\ v = \sqrt{\frac{2mg}{C_L \rho A_W}}$$

Equation [6.3].03

$$P_{level} = F_T v \cos(\theta_{Fv})$$

Equation [6.3].04

$$\begin{aligned} \Longrightarrow\ & P_{level} = F_T v \cos(0) \\ \Longrightarrow\ & P_{level} = F_T v(1) \\ \Longrightarrow\ & P_{level} = F_T \sqrt{\frac{2mg}{C_L \rho A_W}} \\ \Longrightarrow\ & P_{level} = \left(C_D \frac{\rho}{2} A_W v^2\right)\left(\sqrt{\frac{2mg}{C_L \rho A_W}}\right) \\ \Longrightarrow\ & P_{level} = \frac{C_D}{C_L^{3/2}} \sqrt{\frac{2(mg)^3}{A_W \rho}} \end{aligned}$$

Equation [6.3].05

$$\begin{aligned} & && E = PT \\ & E_{tot} = P_{tot} T_{tot} && \Longleftrightarrow\ E_{tot} = P_{tot} T_{tot} \\ \Longrightarrow\ & E_{tot} = P_{tot}\left(T_{day} + \frac{T_{night}}{\eta_{chrg}\eta_{dchrg}}\right) && \Longleftarrow\ T_{tot} = (T_{day} + T_{night}) \\ \Longrightarrow\ & E_{tot} = P_{tot}\left(T_{day} + \frac{T_{night}}{\eta_{chrg}\eta_{dchrg}}\right) \end{aligned}$$

Equation [6.3].08

$$\begin{aligned} & && E = PT \\ & E_{tot} = P_{tot} T && \Longleftrightarrow\ E_{tot} = P_{tot} T \\ \Longrightarrow\ & E_{tot} = P_{tot} T_{night} && \Psi = {}^{E}/_{m} \\ \Longrightarrow\ & \Psi m = P_{tot} T_{night} && \Longleftrightarrow\ \Psi m = E \\ \Longrightarrow\ & \Psi_{bat} m_{bat\ max} = P_{tot} T_{night} \\ \Longrightarrow\ & m_{bat\ max} = \frac{P_{tot} T_{night}}{\Psi_{bat}} \end{aligned}$$

$$m_{bat} = \frac{m_{bat\ max}}{\eta_{dchrg}}$$

$$m_{mppt} = k_{mppt} P_{max}$$

Equation [6.5].05

$$\eta_{mppt} = \eta_{mppt\ conv} \eta_{mppt\ algor}$$

Equation [6.5].06

$$A_{sc} = P_{tot}\left(1 + \frac{T_{night}}{T_{day}} \frac{1}{\eta_{chrg}\eta_{dchrg}}\right)\left(\frac{\pi}{2\eta_{sc}\eta_{cbr}\eta_{mppt} k_{wthr} I_{max}}\right)$$

$$\begin{aligned} \Longrightarrow\ & P_{tot} = 2\eta_{sc}\eta_{cbr}\eta_{mppt} I_{max} A_{sc} \\ \Longrightarrow\ & P_{max} = 2\eta_{sc}\eta_{cbr}\eta_{mppt} I_{max} A_{sc} \\ \Longrightarrow\ & P_{max} = 2\eta_{sc}\eta_{cbr}\eta_{mppt} I_{max} A_{sc} \quad \Longleftarrow\ \eta_{mppt} = \eta_{mppt\ conv}\eta_{mppt\ algor} \\ \Longrightarrow\ & P_{max} = 2\eta_{sc}\eta_{cbr}\eta_{mppt\ conv}\eta_{mppt\ algor} I_{max} A_{sc} \end{aligned}$$

Equation [6.5].07

$$\begin{aligned} & m_{mppt} = k_{mppt} P_{max} \quad \Longleftarrow\ P_{max} = 2\eta_{sc}\eta_{cbr}\eta_{mppt\ conv}\eta_{mppt\ algor} I_{max} A_{sc} \\ \Longrightarrow\ & m_{mppt} = k_{mppt} 2\eta_{sc}\eta_{cbr}\eta_{mppt\ conv}\eta_{mppt\ algor} I_{max} A_{sc} \\ \Longrightarrow\ & m_{mppt} = k_{mppt} 2\eta_{sc}\eta_{cbr}\eta_{mppt\ conv}\eta_{mppt\ algor} I_{max} A_{sc} \end{aligned}$$

Equation [6.5].08

$$\begin{aligned} & && \eta_{total} = \frac{P_{usefull}}{P_{total}} \\ & && \Longrightarrow\ \eta_{total} P_{total} = P_{usefull} \\ & && \Longrightarrow\ P_{total} = \frac{P_{usefull}}{\eta_{total}} \\ & P_{tot} = \frac{P_{lvl}}{\eta_{ctrl}\eta_{mot}\eta_{grb}\eta_{plr}} + \frac{P_{av} + P_{pld}}{\eta_{BEC}} && \Longleftrightarrow\ P_{tot} = \frac{P_{usfl}}{\eta_{tot}} \end{aligned}$$

$$T_{night} + T_{day} = 24$$

Equation [6.4].09

$$\Longrightarrow\ \begin{aligned} P_{tot} = & \frac{1}{\eta_{ctrl}\eta_{mot}\eta_{grb}\eta_{plr}}(P_{lvl}) \\ & + \frac{1}{\eta_{BEC}}(P_{av} + P_{pld}) \end{aligned}$$

Equation [6.3].07

$$\varphi = \frac{I_{max} T_{day}}{{}^{\pi}/_{2}} k_{wthr}$$

Equation [6.4].01

$$\begin{aligned} \Longrightarrow\ & \left(\frac{I_{max} T_{day}}{{}^{\pi}/_{2}} k_{wthr}\right) A_{sc}(\eta_{sc}\eta_{cbr}\eta_{mppt}) = P_{tot}\left(T_{day} + \frac{T_{night}}{\eta_{chrg}\eta_{dchrg}}\right) \\ \Longrightarrow\ & A_{sc} = P_{tot}\left(T_{day} + \frac{T_{night}}{\eta_{chrg}\eta_{dchrg}}\right)\left(\frac{\pi}{2\eta_{sc}\eta_{cbr}\eta_{mppt} k_{wthr} I_{max} T_{day}}\right) \\ \Longrightarrow\ & A_{sc} = P_{tot}\left(1 + \frac{T_{night}}{T_{day}} \frac{1}{\eta_{chrg}\eta_{dchrg}}\right)\left(\frac{\pi}{2\eta_{sc}\eta_{cbr}\eta_{mppt} k_{wthr} I_{max}}\right) \end{aligned}$$

Equation [6.5].03

$$\begin{aligned} & && m = \rho V \\ & m = \kappa A && \Longleftrightarrow\ m = \kappa A \\ \Longrightarrow\ & m_{sc} = \kappa A_{sc} \\ \Longrightarrow\ & m_{sc} = (\kappa_{sc} + \kappa_{add}) A_{sc} && \Longleftarrow\ \kappa = \kappa_{sc} + \kappa_{add} \\ \Longrightarrow\ & m_{sc} = (\kappa_{sc} + \kappa_{add}) A_{sc} \end{aligned}$$

Equation [6.5].04

$$m = m_{fixed} + m_{af} + m_{sc} + m_{mppt} + m_{bat} + m_{prop}$$

Equation [6.5].01

$$\begin{aligned} \Longrightarrow\ & E_{tot} = \left(\frac{I_{max} T_{day}}{{}^{\pi}/_{2}} k_{wthr}\right) A_{sc}(\eta) \\ \Longrightarrow\ & E_{tot} = \left(\frac{I_{max} T_{day}}{{}^{\pi}/_{2}} k_{wthr}\right) A_{sc}(\eta_{sc}\eta_{cbr}\eta_{mppt}) && \Longleftarrow\ \eta = \eta_{sc}\eta_{cbr}\eta_{mppt} \\ \Longrightarrow\ & E_{tot} = \left(\frac{I_{max} T_{day}}{{}^{\pi}/_{2}} k_{wthr}\right) A_{sc}(\eta_{sc}\eta_{cbr}\eta_{mppt}) \end{aligned}$$

Equation [6.4].03

$$\begin{aligned} & P_{level} = \frac{C_D}{C_L^{3/2}} \sqrt{\frac{(mg)^3}{A_W}} \sqrt{\frac{2}{\rho}} && A_r = \frac{S^2}{A_w} \\ \Longrightarrow\ & P_{level} = \frac{C_D}{C_L^{3/2}} \sqrt{\frac{A_r (mg)^3}{S^2}} \sqrt{\frac{2}{\rho}} && \Longleftrightarrow\ A_w = \frac{S^2}{A_r} \\ \Longrightarrow\ & P_{level} = \frac{C_D}{C_L^{3/2}} \sqrt{\frac{2 A_r m^3 g^3}{\rho}} \sqrt{\frac{1}{S^2}} \\ \Longrightarrow\ & P_{level} = \frac{C_D}{C_L^{3/2}} \sqrt{\frac{2 A_r g^3}{\rho}} \sqrt{\frac{m^3}{S^2}} \\ \Longrightarrow\ & P_{lvl} = \left(\frac{C_D}{C_L^{3/2}} \sqrt{\frac{2 A_r g^3}{\rho}}\right)\left(\frac{m^{3/2}}{S}\right) \end{aligned}$$

Equation [6.3].06

$$\begin{aligned} & && E = \varphi A \\ & E_{tot} = \varphi A_{sc} && \Longleftrightarrow\ E_{tot} = \varphi A_{sc} \\ \Longrightarrow\ & E_{tot} = \left(\frac{I_{max} T_{day}}{{}^{\pi}/_{2}} k_{wthr}\right) A_{sc} && \Longleftarrow\ \varphi = \frac{I_{max} T_{day}}{{}^{\pi}/_{2}} k_{wthr} \\ \Longrightarrow\ & E_{tot} = \left(\frac{I_{max} T_{day}}{{}^{\pi}/_{2}} k_{wthr}\right) A_{sc} \end{aligned}$$

Equation [6.4].02

$$E = \varphi A(\eta)$$

$$\begin{aligned} & E_{tot} = \left(\frac{I_{max} T_{day}}{{}^{\pi}/_{2}} k_{wthr}\right) A_{sc}(\eta_{sc}\eta_{cbr}\eta_{mppt}) \\ \Longrightarrow\ & E_{tot} = \left(\frac{I_{max} T_{day}}{{}^{\pi}/_{2}} k_{wthr}\right) A_{sc}(\eta_{sc}\eta_{cbr}\eta_{mppt}) \quad \Longleftarrow\ E_{tot} = P_{tot}\left(T_{day} + \frac{T_{night}}{\eta_{chrg}\eta_{dchrg}}\right) \end{aligned}$$

$$m_{fixed} = m_{av} + m_{pld}$$

Equation [6.5].02

The Model Formed

$$A_{sc} = P_{tot}\left(1+\frac{T_{night}}{T_{day}}\frac{1}{\eta_{chrg}\eta_{dchrg}}\right)\left(\frac{\pi}{2\eta_{sc}\eta_{cbr}\eta_{mppt}k_{wthr}}\right)$$

$$P_{lvl} = \left(\frac{C_D}{C_L^{3/2}}\sqrt{\frac{2A_r g^3}{\rho}}\right)\left(\frac{m^{3/2}}{S}\right)$$

$$P_{tot} = \frac{1}{\eta_{ctrl}\eta_{mot}\eta_{grb}\eta_{plr}}(P_{lvl}) + \frac{1}{\eta_{BEC}}(P_{av}+P_{pld})$$

$$m = m_{fixed} + m_{af} + m_{sc} + m_{mppt} + m_{bat} + m_{prop}$$

$$P_{lvl} = \left(\frac{C_D}{C_L^{3/2}}\sqrt{\frac{2A_r g^3}{\rho}}\right)\left(\frac{m^{3/2}}{S}\right)$$

$$m_{fixed} = m_{av} + m_{pld}$$

$$m_{sc} = (\kappa_{sc}+\kappa_{add})A_{sc}$$

$$m_{bat} = \frac{T_{night}}{\eta_{dchrg}\kappa_{bat}}P_{tot}$$

$$P_{tot} = \frac{1}{\eta_{ctrl}\eta_{mot}\eta_{grb}\eta_{plr}}(P_{lvl}) + \frac{1}{\eta_{BEC}}(P_{av}+P_{pld})$$

$$A_{sc} = P_{tot}\left(1+\frac{T_{night}}{T_{day}}\frac{1}{\eta_{chrg}\eta_{dchrg}}\right)\left(\frac{\pi}{2\eta_{sc}\eta_{cbr}\eta_{mppt}k_{wthr}I_{max}}\right)$$

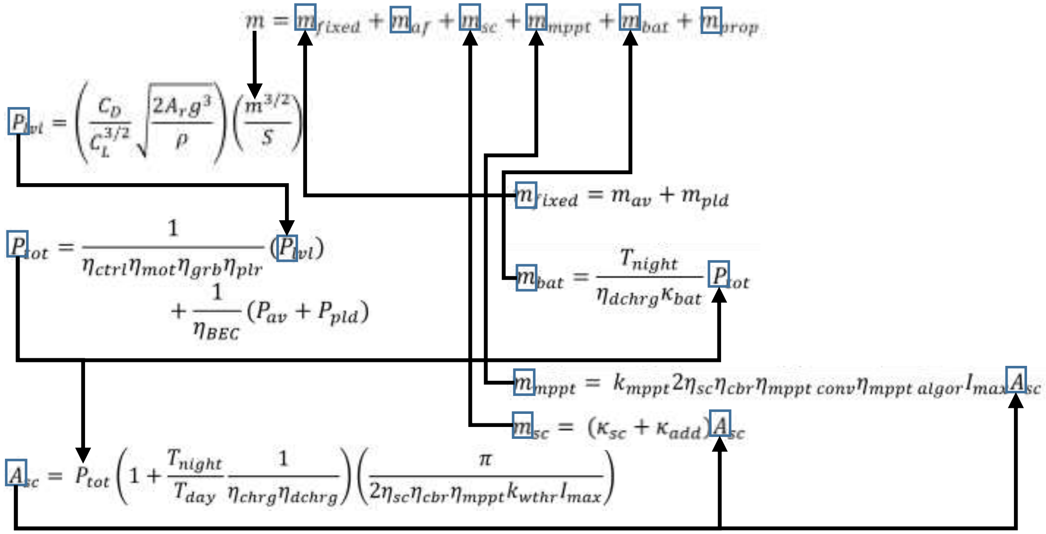
$$\Longrightarrow\ m = k_{mppt}2\eta_{sc}\eta_{cbr}\eta_{mppt\ conv}\eta_{mppt\ algor}I_{max}A_{sc}$$

$$m_{fixed} = m_{av} + m_{pld}$$

$$m_{sc} = (\kappa_{sc}+\kappa_{add})A_{sc}$$

$$m_{bat} = \frac{T_{night}}{\eta_{dchrg}\kappa_{bat}}P_{tot}$$

$$m = m_{fixed} + m_{af} + m_{sc} + m_{mppt} + m_{bat} + m_{prop}$$



$$m = m_{fixed} + m_{af} + m_{sc} + m_{mppt} + m_{bat} + m_{prop}$$

$$P_{lvl} = \left(\frac{C_D}{C_L^{3/2}}\sqrt{\frac{2A_r g^3}{\rho}}\right)\left(\frac{m^{3/2}}{S}\right)$$

$$m_{fixed} = m_{av} + m_{pld}$$

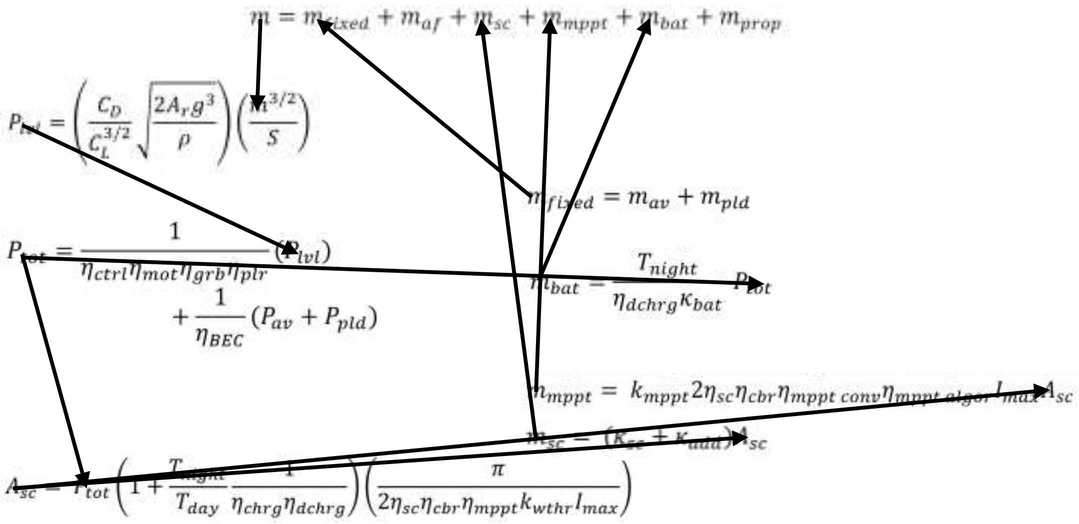
$$P_{tot} = \frac{1}{\eta_{ctrl}\eta_{mot}\eta_{grb}\eta_{plr}}(P_{lvl}) + \frac{1}{\eta_{BEC}}(P_{av}+P_{pld})$$

$$m_{bat} = \frac{T_{night}}{\eta_{dchrg}\kappa_{bat}}P_{tot}$$

$$m_{mppt} = k_{mppt}2\eta_{sc}\eta_{cbr}\eta_{mppt\ conv}\eta_{mppt\ algor}I_{max}A_{sc}$$

$$m_{sc} = (\kappa_{sc}+\kappa_{add})A_{sc}$$

$$A_{sc} = P_{tot}\left(1+\frac{T_{night}}{T_{day}}\frac{1}{\eta_{chrg}\eta_{dchrg}}\right)\left(\frac{\pi}{2\eta_{sc}\eta_{cbr}\eta_{mppt}k_{wthr}I_{max}}\right)$$



$$m = m_{fixed} + m_{af} + m_{sc} + m_{mppt} + m_{bat} + m_{prop}$$

$$P_{lvl} = \left(\frac{C_D}{C_L^{3/2}}\sqrt{\frac{2A_r g^3}{\rho}}\right)\left(\frac{m^{3/2}}{S}\right)$$

$$m_{fixed} = m_{av} + m_{pld}$$

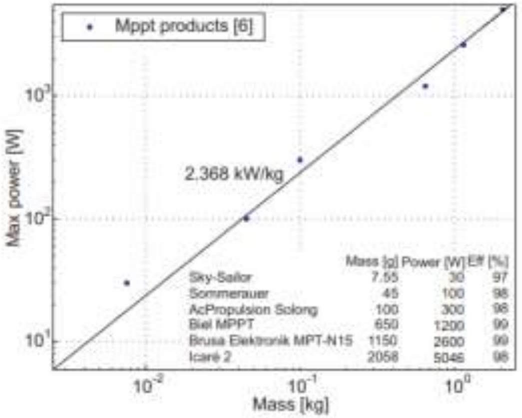
$$P_{tot} = \frac{1}{\eta_{ctrl}\eta_{mot}\eta_{grb}\eta_{plr}}(P_{lvl}) + \frac{1}{\eta_{BEC}}(P_{av}+P_{pld})$$

$$m_{bat} = \frac{T_{night}}{\eta_{dchrg}\kappa_{bat}}P_{tot}$$

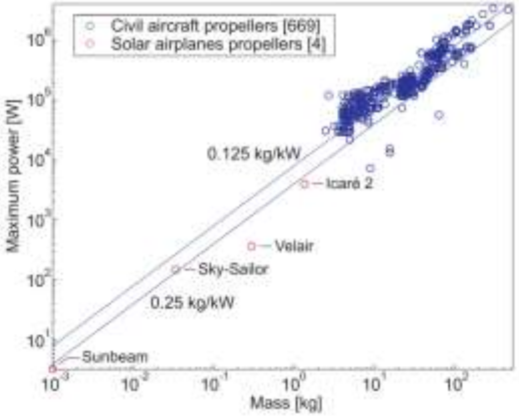
$$m_{mppt} = k_{mppt}2\eta_{sc}\eta_{cbr}\eta_{mppt\ conv}\eta_{mppt\ algor}I_{max}A_{sc}$$

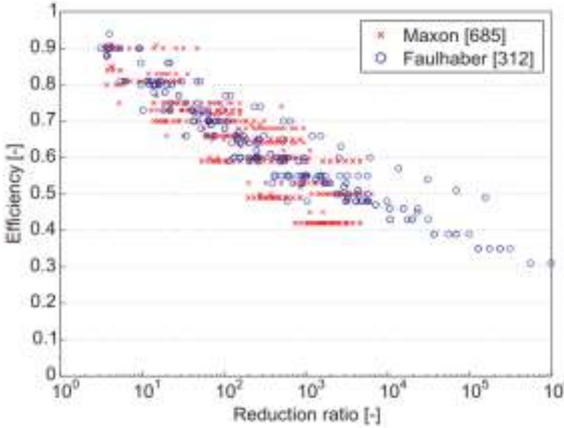
$$m_{sc} = (\kappa_{sc}+\kappa_{add})A_{sc}$$

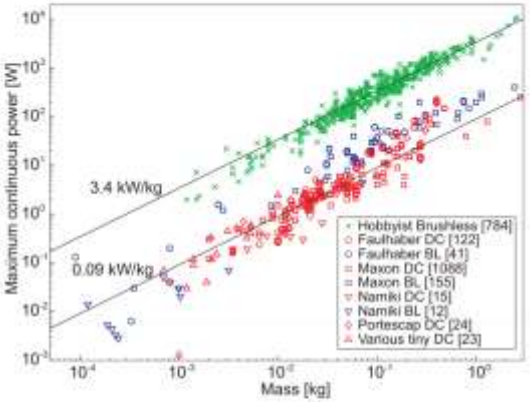
$$A_{sc} = P_{tot}\left(1+\frac{T_{night}}{T_{day}}\frac{1}{\eta_{chrg}\eta_{dchrg}}\right)\left(\frac{\pi}{2\eta_{sc}\eta_{cbr}\eta_{mppt}k_{wthr}I_{max}}\right)$$

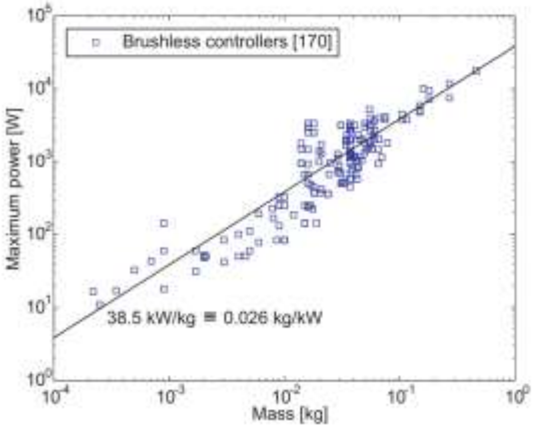


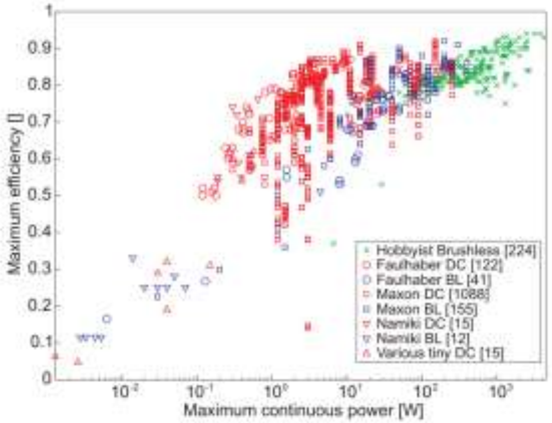
	Mass [g]	Power [W]	Eff [%]
Sky-Sailor	7.55	30	97
Sommerauer	45	100	98
AcPropulsion Solong	100	300	98
Biel MPPT	650	1200	99
Brusa Elektronik MPT-N15	1150	2600	99
Icaré 2	2058	5046	98

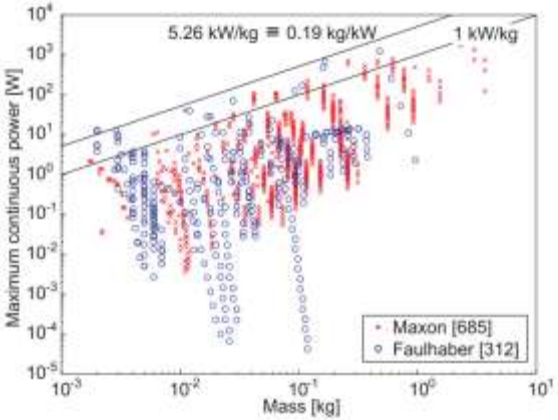


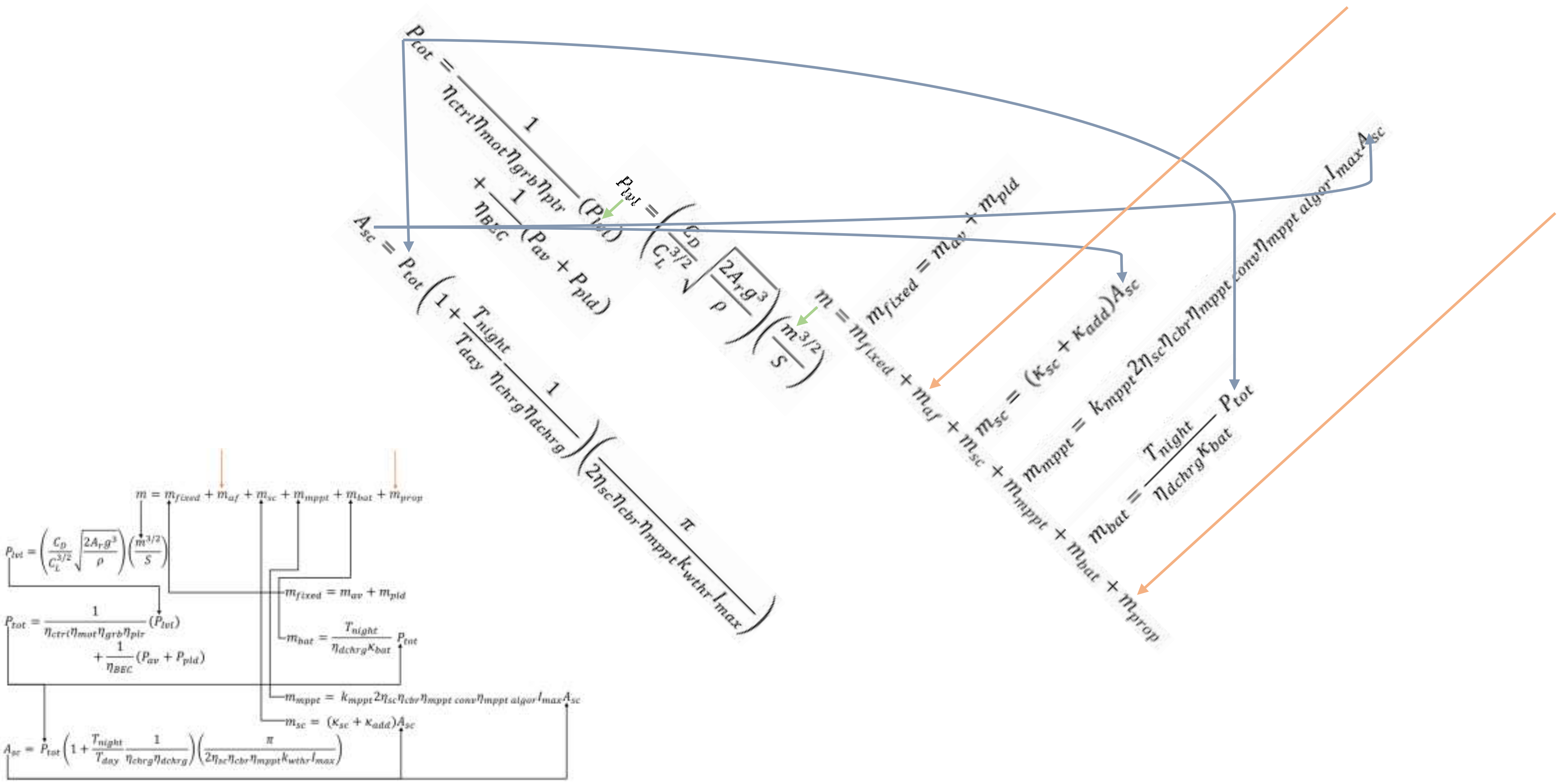












$$m = m_{fixed} + m_{af} + m_{sc} + m_{mppt} + m_{bat} + m_{prop}$$

$$P_{lvl} = \left(\frac{C_D}{C_L^{3/2}}\sqrt{\frac{2A_r g^3}{\rho}}\right)\left(\frac{m^{3/2}}{S}\right)$$

$$m_{fixed} = m_{av} + m_{pld}$$

$$P_{tot} = \frac{1}{\eta_{ctrl}\eta_{mot}\eta_{grb}\eta_{plr}}(P_{lvl}) + \frac{1}{\eta_{BEC}}(P_{av} + P_{pld})$$

$$m_{bat} = \frac{T_{night}}{\eta_{dchrg}\kappa_{bat}} P_{tot}$$

$$m_{mppt} = k_{mppt} 2\eta_{sc}\eta_{cbr}\eta_{mppt\ conv}\eta_{mppt\ algor} I_{max} A_{sc}$$

$$m_{sc} = (\kappa_{sc} + \kappa_{add})A_{sc}$$

$$A_{sc} = P_{tot}\left(1 + \frac{T_{night}}{T_{day}}\frac{1}{\eta_{chrg}\eta_{dchrg}}\right)\left(\frac{\pi}{2\eta_{sc}\eta_{cbr}\eta_{mppt}k_{wthr}I_{max}}\right)$$

$$P_{tot} = \frac{1}{\eta_{ctrl}\eta_{mot}\eta_{grb}\eta_{plr}}(P_{lvl}) + \frac{1}{\eta_{BEC}}(P_{av} + P_{pld})$$

$$P_{lvl} = \left(\frac{C_D}{C_L^{3/2}}\sqrt{\frac{2A_r g^3}{\rho}}\right)\left(\frac{m^{3/2}}{S}\right)$$

$$A_{sc} = P_{tot}\left(1 + \frac{T_{night}}{T_{day}}\frac{1}{\eta_{chrg}\eta_{dchrg}}\right)\left(\frac{\pi}{2\eta_{sc}\eta_{cbr}\eta_{mppt}k_{wthr}I_{max}}\right)$$

$$m = m_{fixed} + m_{af} + m_{sc} + m_{mppt} + m_{bat} + m_{prop}$$

$$m_{fixed} = m_{av} + m_{pld}$$

$$m_{sc} = (\kappa_{sc} + \kappa_{add})A_{sc}$$

$$m_{mppt} = k_{mppt} 2\eta_{sc}\eta_{cbr}\eta_{mppt\ conv}\eta_{mppt\ algor} I_{max} A_{sc}$$

$$m_{bat} = \frac{T_{night}}{\eta_{dchrg}\kappa_{bat}} P_{tot}$$

P_{av}	1.5	Power consumed by avionics and autopilot	[W]	Symbol [6.X].05
x_1	3.1	Airframe mass wingspan exponent		
x_2	-0.25	Airframe mass aspect ratio exponent		

Table [6.7].1: Class 1 of Parameters table.

Class 2 of Parameters

Variable	Value	Description	Unit	
m_{pld}	0.05	Mass of the Payload	[kg]	
k_{wthr}	0.7	Arbitrary weather constant		Symbol [6.X].23
P_{pld}	0.5	Power consumed by payload	[W]	Symbol [6.X].06
ρ	1.1655	Density of air	[kg m^{-3}]	Symbol [2.4].05
T_{day}	13.2*3600	Time period of day, time from sunrise to sunset	[s]	Symbol [6.X].27

Table [6.7].2: Class 2 of Parameters table.

6.7.3 Final Model

Using the parameters from Table [6.7].1 and Table [6.7].2, and then using the equation in Figure [6.7].2 we are able to obtain the above inequality from the given information.

$$
\begin{aligned}
& m = m_{fixed} + m_{af} + m_{sc} + m_{mppt} + m_{bat} + m_{prop} \\
\Rightarrow \quad & m = (m_{av} + m_{pld}) + \left(\frac{C_D}{C_L^{3/2}}\sqrt{\frac{2A_r g^3}{\rho}}\right)\left(\frac{1}{\eta_{ctrl}\eta_{mot}\eta_{grb}\eta_{plr}}\right) + m_{sc} + m_{mppt} + m_{bat} \\
& \qquad\qquad + m_{prop} \\
\Rightarrow \quad & \\
\Rightarrow \quad & \\
\Rightarrow \quad & \\
\Rightarrow \quad & \\
\Rightarrow \quad & \\
\Rightarrow \quad & \varsigma_{10}^2\varsigma_{11}\frac{1}{S^2} + \varsigma_{10}^2\varsigma_4 S^{x_1-2} \leq \frac{4}{27} \\
\Rightarrow \quad & \left(\varsigma_{10}^2\varsigma_{11}\frac{1}{S^2} + \varsigma_{10}^2\varsigma_4 S^{x_1-2}\right) \leq \frac{4}{27} \\
\Rightarrow \quad & \left(\varsigma_{10}^2\left(\varsigma_{11}\frac{1}{S^2} + \varsigma_4 S^{x_1-2}\right)\right) \leq \frac{4}{27} \\
\Rightarrow \quad & \varsigma_{10}^2\left(\varsigma_{11}\frac{1}{S^2} + \varsigma_4 S^{x_1-2}\right) \leq \frac{4}{27}
\end{aligned}
$$

Equation [6.7].01

Using Table [6.7].3 and the Class 1 and 2 parameters satisfies the above inequality and the area of the solar panels is less that than that of the area of the wings which therefore means the ***given the current technology today (that is used to determine the parameters) continuous and theoretically infinite flight is possible.***

Class 3 of Parameters

Variable	Value	Description	Unit	
m	12.3	Total mass	[kg]	Symbol [6.X].38
S	7.5	Wing span	[m]	Symbol [2.4].11
A_r	12.9	Aspect ratio		Symbol [2.4].12

6.7.2 Class Separation

In order to be able to extract a conclusive conclusion we must separate the parameters into separate sections to aid calculations:

(1) Parameters linked to real-world technology of today
    a. Efficiencies
    b. Power Consumption
    c. Etc.
(2) Parameters linked to the mission
    a. Air Density
    b. Day duration
    c. Night Duration
    d. Mass of Payload
    e. Power Consumption of Payload
    f. Etc.
(3) Parameters varied by user to obtain range of possible aircraft (if possible) and thus allows for further analysis to determine the feasibility of theoretically infinite flight for a variety of mission use cases. Here, these parameters are variables and vary on the parameters we input in class 1 and class 2, if the values of the class 3 variables lie within the physical constraints of class 3 then theoretically infinite flight is possible.

Class 1 of Parameters

Variable	Value	Description	Unit	
C_L	0.8	Coefficient of Lift		Symbol [2.4].04
$C_{D\ Aerofoil}$	0.013	Coefficient of Drag		Symbol [2.4].02
$C_{D\ Parasite}$	0.006	Coefficient of Drag		Symbol [2.4].02
e_o	0.9	Oswald Efficiency Factor		Symbol [2.4].14
I_{max}	950	Maximum sun irradiance	[W m^{-2}]	Symbol [6.X].30
Ψ_{bat}	684000	Gravimetric Energy Density of Battery	[J kg^{-1}]	Symbol [6.X].43
κ_{sc}	0.32	Mass density of solar cells	[kg m^{-2}]	Symbol [6.X].33
κ_{add}	0.26	Mass density of additional mass around solar panels	[kg m^{-2}]	Symbol [6.X].34
k_{mppt}	0.00042	Mass to power ratio of MPPT	[kg W^{-1}]	Symbol [6.X].24
k_{prop}	0.008	Mass to power ratio of Propulsion Systems	[kg W^{-1}]	
ρ_{af}	0.44/9.81	Structural Mass Constant of Airframe	[kg m^{-3}]	
m_{av}	0.15	Mass of Avionics	[kg]	
η_{BEC}	0.65	Efficiency of step-down converter		Symbol [6.X].14
η_{sc}	0.169	Efficiency of solar cells		Symbol [6.X].18
η_{cbr}	0.90	Efficiency of curved solar panels		Symbol [6.X].19
η_{dchrg}	0.95	Efficiency of battery discharge		Symbol [6.X].16
η_{ctrl}	0.95	Efficiency of motor controller		Symbol [6.X].10
η_{dchrg}	0.95	Efficiency of battery discharge		Symbol [6.X].16
η_{grb}	0.97	Efficiency of gearbox		Symbol [6.X].12
η_{mot}	0.85	Efficiency of motor		Symbol [6.X].11
$\eta_{mppt\ conv}$	0.99	Efficiency of DC to DC converter of MPPT		Symbol [6.X].21
$\eta_{mppt\ algor}$	0.98	Efficiency of tracking algorithm of MPPT		Symbol [6.X].22
η_{plr}	0.85	Efficiency of propeller		Symbol [6.X].13

$$\Longrightarrow \quad \varsigma_{10}^{2}\left(\varsigma_{11}\frac{1}{S^{2}}+\varsigma_{4}S^{x_{1}-2}\right)\leq\frac{4}{27}$$ Equation [6.7].01

Class 3 of Parameters

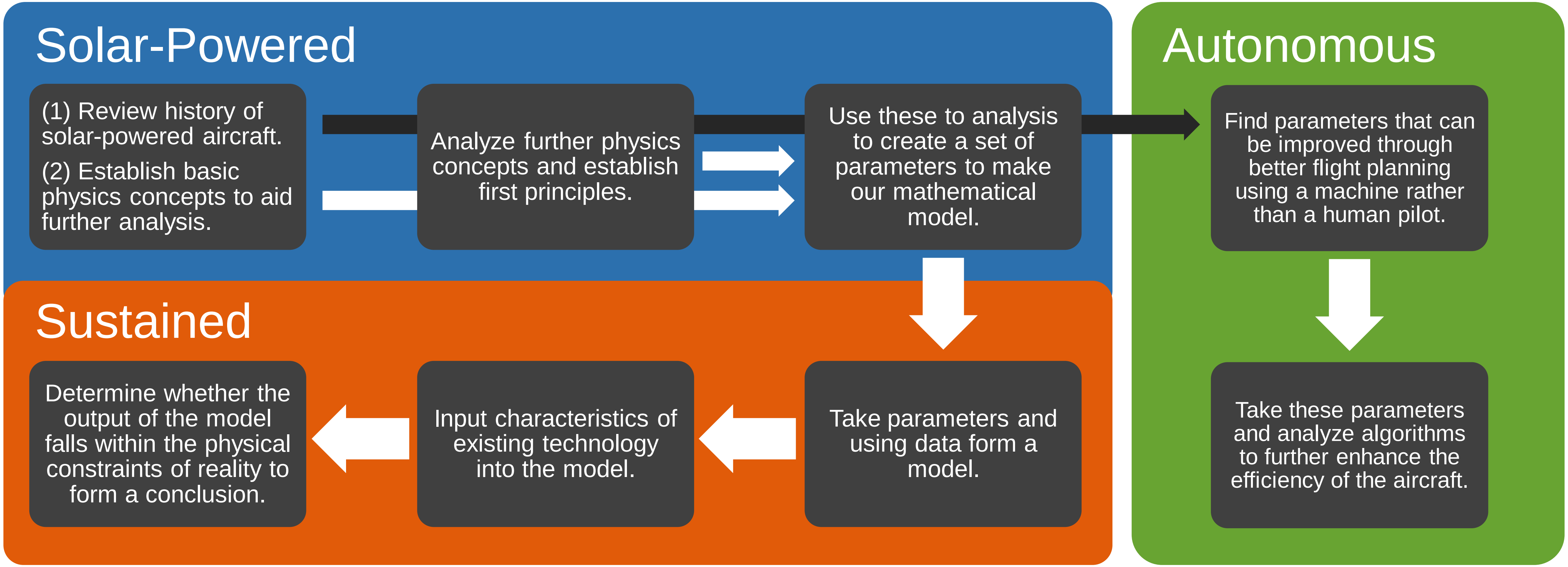
Variable	Value	Description	Unit	
m	12.3	Total mass	[kg]	Symbol [6.X].38
S	7.5	Wing span	[m]	Symbol [2.4].11
A_r	12.9	Aspect ratio		Symbol [2.4].12

Using Table [6.7].3 and the Class 1 and 2 parameters satisfies the above inequality and the area of the solar panels is less that than that of the area of the wings which therefore means the ***given the current technology today (that is used to determine the parameters) continuous and theoretically infinite flight is possible.***

Interconnectedness?

First Study

Second Study



Solar-Powered

(1) Review history of solar-powered aircraft.

(2) Establish basic physics concepts to aid further analysis.

Analyze further physics concepts and establish first principles.

Use these to analysis to create a set of parameters to make our mathematical model.

Sustained

Take parameters and using data form a model.

Input characteristics of existing technology into the model.

Determine whether the output of the model falls within the physical constraints of reality to form a conclusion.

Autonomous

Find parameters that can be improved through better flight planning using a machine rather than a human pilot.

Take these parameters and analyze algorithms to further enhance the efficiency of the aircraft.

The Autonomous Focus

Storm and high winds prediction and avoidance.

Hot air updrafts and cold air downdrafts riding.

Altitude planning and course planning to increase solar efficiency.

Conclusions

Solar-powered flight is feasible and has been done before at low-costs and complexity.

Given the current technology today, continuous and theoretically infinite flight is possible at this very moment.

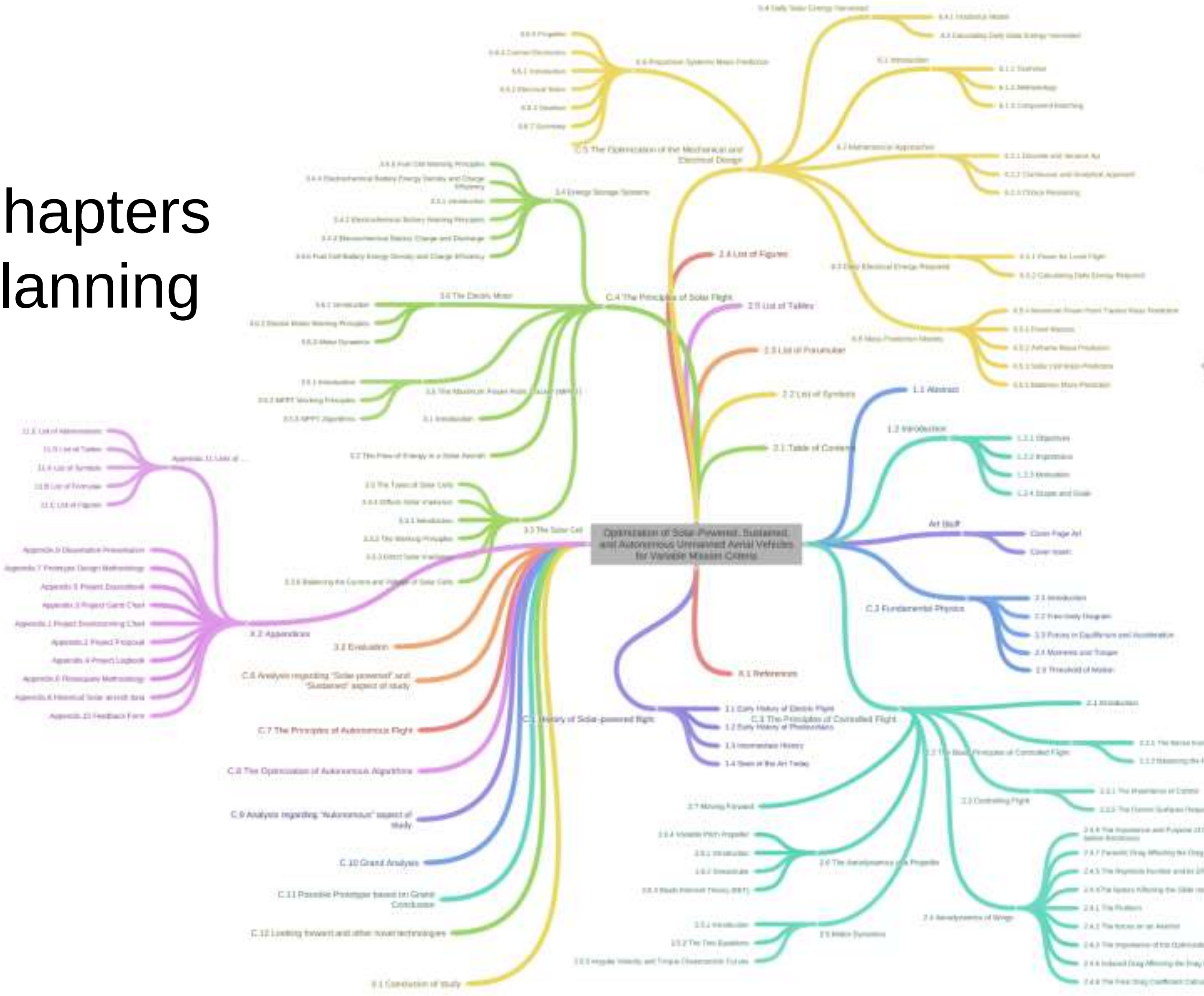
Autonomous flight is entirely possible as commercial grade solutions already exist and algorithms for meteorological avoidance whilst not open-source are available. Machine learning is also on the rise.

So why aren’t we seeing this right now?

- Lack of specific constraints set in designs.
- Lack of commercial viability.
- Lack of incentive to switch due to existing aviation industry.
- Scalability.

Project Management

Chapters Planning



Title Planning

Section Three: Activities and timescales	
Activities to be carried out during the project:	How long this will take:
(1) Initial planning a. Brainstorm EPQ choices and settle for one EPQ project b. Brainstorm possible titles and settle on a "working title"	2 Weeks
(2) Project planning a. Find existing research papers for gathering information on existing craft and data b. Prepare Gantt chart for overall structure of project delivery c. Submit Project proposal form	1 Week
(3) Research a. Gather information on existing aircraft for brief history b. Gather information on the working principles of solar flight and general flight	6 Weeks
(4) Write-up of objectives (3), (4), (5), (6), and (7)	3 Weeks
(5) Carry out objectives (8), (9), and (10)	8 Weeks
(6) Write-up of objectives (8), (9), (10), (11), and (12)	3 Weeks
(7) Write-up objectives (1), (2), (13), and (14)	2 Weeks
(8) Editing	1 week
(9) Presentation a. Produce the presentation b. Prepare for oral presentation c. Carry-out oral presentation	2 Week 28 Weeks ← Total Time

(1) *Milestone: Finish Filling in project proposal*
Target date (set by tutor assessor): 30th January

(2) *Milestone: Finish Mid Project review*
Target date (set by tutor-assessor): 17th April

(3) *Milestone: Finish First draft of project*
Target date (set by tutor-assessor): 1st September

(4) *Milestone: Final Project submission*
Target date (set by tutor-assessor): 1st November

(5) *Milestone: Final Oral Presentation*
Target date (set by tutor-assessor): Approx. End of November

(6) *Milestone: All Paperwork Submission*
Target date (set by tutor-assessor): 10th December

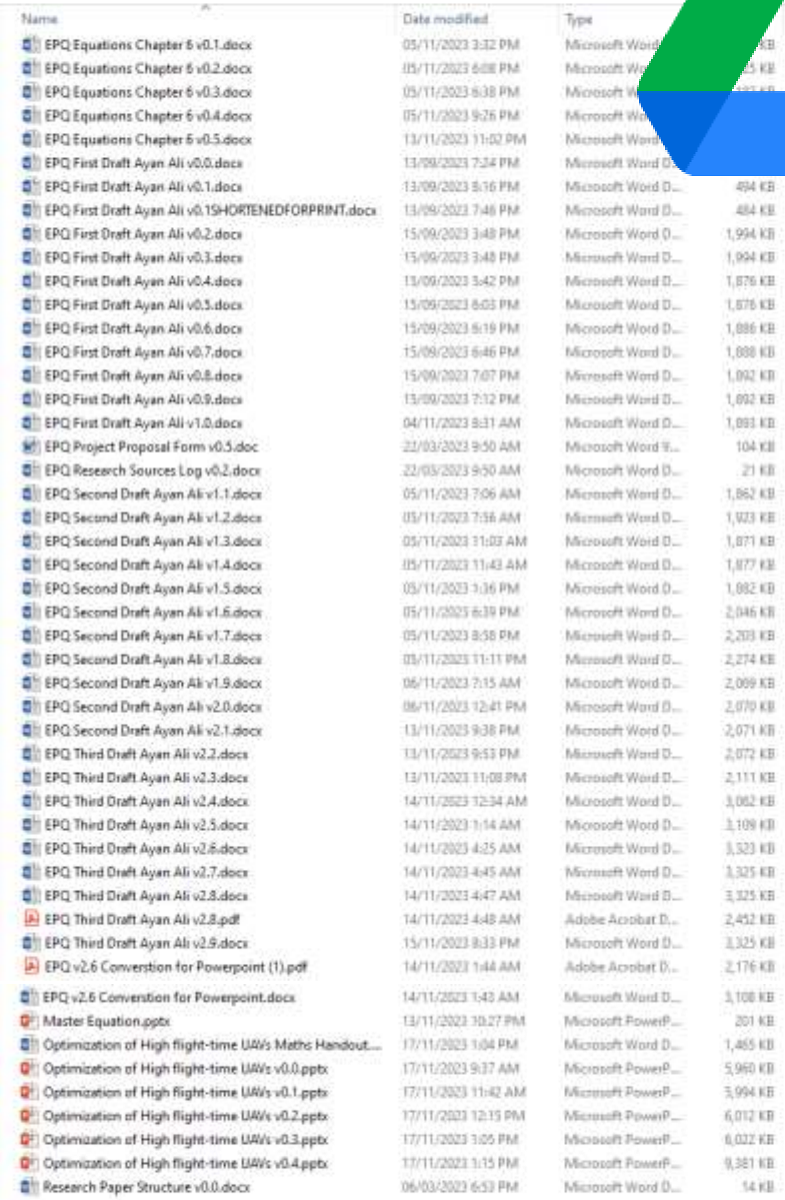
Project objectives:

The main object of such a dissertation is to:

(1) Provide an abstract detailing the promise of how solar flight could revolutionize the industry of search and rescue, agriculture, military surveillance, weather prediction, photography, etc.
(2) Provide an introduction to my motivations behind such a project.

(3) Provide a brief overview / account of previous solar flight and accompanying relevant data.
(4) Provide analysis on what has been done so far in the world of solar flight, compare craft, analyse strengths and deficiencies of said craft.
(5) Provide a summary of the basic principles behind solar based flight, and flight in general:
   a. Principles of controlled flight
   b. Principles of solar flight
      i. How power delivery works during the day and during the night (Solar Panel → Charge Controller → Batteries → etc.)
      ii. Metrological factors that must be considered with lightweight aircraft (Such as updrafts, wind, low temperatures, cloudy days, etc.)
   c. Principles of Solar Panels
   d. Principles of Batteries
   e. Principles of RC flight
(6) Provide the challenges faced that prevent prolonged solar flight. (The below is a rough preliminary outline of what majors factors prevent said flight)
   a. Airframe constraints (Aerodynamics, weightiness, flexibility, etc.)
   b. Energy constraints (Batteries, Solar Panels, Battery Charge Controllers, Accompanying flight electronics)
   c. Metrological constraints (High winds, cold/hot air updrafts/downdrafts)
(7) Provide possible solutions to said challenges
(8) Provide a mathematical model that addresses such constraints using available data from previous studies
(9) Provide a fluid model in Flowsquare that verifies such models
(10) Provide a prototype design in Fusion 360 that addresses such challenges
(11) Provide an evaluation of said design
(12) Provide a short overview of emerging technologies that may perhaps aid addressing the aforementioned challenges.

(13) Provide Data evaluation of the data used to build the aforementioned mathematical model.
(14) Provide Source evaluation of sources used in this project



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Stuff to do, *Stuff to be done*, *Stuff to be done concurrently*

- *Draw missing diagrams*
- *Double check all sources cited properly*
- *Add proper evidence to the yellow sections of text*
- *Update Project Logbook*
- *Update Project Sourcebook*
- *Add stuff to all the different lists*

2.1 Table of Contents

Motivations

The promise of solving world-problems.

The proximity to my chosen field of studies.

Continuation of Practical Sustainability.

Source Evaluation

X.1 References

[1] A. Sawale, D. Archana, and C. Seshank, "Design and analysis of propeller", *IOP Conf. Series: Mater. Sci. Eng.*, vol. 455, p. 012018, Dec. 2018. Accessed: Sep. 12, 2023. [Online]. Available:

[2] G. D. Padfield and B. Lawrence, "The birth of flight control: An engineering analysis of the Wright brothers' 1902 glider", *Aeronautical J.*, vol. 107, no. 1078, pp. 697–718, Dec. 2003. Accessed: Sep. 12, 2023. [Online]. Available: https://doi.org/10.1017/s0001924000013464

[3] D. Kleppner and R. Kolenkow, *Introduction to Mechanics*. Second Edition Cambridge Univ. Press, 2013.

[4] "Reynolds number." NASA Glenn Research Centre. Accessed: Sep. 13, 2023. [Online]. Available: https://www.grc.nasa.gov/www/k-12/airplane/reynolds.html

[5] "The lift coefficient." NASA Glenn Research Centre. Accessed: Sep. 13, 2023. [Online]. Available: https://www.grc.nasa.gov/www/k-12/rocket/liftco.html

[6] "Induced drag coefficient." NASA Glenn Research Centre. Accessed: Sep. 13, 2023. [Online]. Available: https://www.grc.nasa.gov/www/k-12/VirtualAero/BottleRocket/airplane/induced.html

[7] Robotics for rehabilitation | MIT - Massachusetts Institute of Technology. Accessed: Sep. 13, 2023. [Online]. Available: http://web.mit.edu/16.unified/www/SPRING/fluids/Spring2008/LectureNotes/f10.pdf

[8] "NASA - NASA Dryden technology facts - winglets." NASA. Accessed: Sep. 15, 2023. [Online]. Available: https://www.nasa.gov/centers/dryden/about/Organizations/Technology/Facts/TF-2004-15-DFRC.html#:~:text=Winglets%20are%20vertical%20extensions%20of,airplane%20moves%20through%20the%20air.

[9] "Turbulators." Willkommen / Welcome. Accessed: Sep. 15, 2023. [Online]. Available: https://www.mh-aerotools.de/airfoils/turbulat.htm

[10] L. W. Traub, "Experimental investigation of annular wing aerodynamics", *J. Aircr.*, vol. 46, no. 3, pp. 988–996, May 2009. Accessed: Sep. 15, 2023. [Online]. Available: https://doi.org/10.2514/1.39822

[11] "Aerodynamics of wing vortices." pilot resources aviation resources aviation weather flight training for general aviation. Accessed: Sep. 15, 2023. [Online]. Available: http://www.pilotfriend.com/training/flight_training/aero/wng_vort.htm

[12] A. Noth, "History of Solar flight", *Robot. Intell. Syst.*, p. 7, Jul. 2008. Accessed: Sep. 15, 2023. [Online]. Available: https://ethz.ch/content/dam/ethz/special-interest/mavt/robotics-n-intelligent-systems/asl-dam/documents/projects/History_of_Solar_Flight_Skysailor.pdf

[13] R. Boucher, "History of solar flight", in *20th Joint Propulsion Conf.*, Cincinnati, OH, U.S.A. Reston, Virigina: Amer. Inst. Aeronaut. Astronaut. 1984. Accessed: Sep. 15, 2023. [Online]. Available: https://doi.org/10.2514/6.1984-1429

[14] "History of electric flight." Accessed: Sep. 15, 2023. [Online]. Available: http://www.vrhc.co.uk/dave/hist.htm

[15] "This month in physics history." APS Physics | American Physical Society. Accessed: Sep. 15, 2023. [Online]. Available: https://www.aps.org/publications/apsnews/200904/physicshistory.cfm

[16]

[17] T. D. Crouch. "Sir George Cayley | Aviation pioneer, aeronautics, aerodynamics." Encyclopaedia Britannica. Accessed: Sep. 15, 2023. [Online]. Available: https://www.britannica.com/biography/Sir-George-Cayley

[18] T. D. Crouch. "Ader Avion III | WWI fighter, biplane, reconnaissance." Encyclopaedia Britannica. Accessed: Sep. 15, 2023. [Online]. Available: https://www.britannica.com/topic/Ader-Avion-III

[19] "John Stringfellow | chard museum." Chard Museum. Accessed: Sep. 15, 2023. [Online]. Available: https://www.chardmuseum.co.uk/john-stringfellow

[20] "Dynamics of flight." NASA Glenn Research Centre. Accessed: Sep. 15, 2023. [Online]. Available: https://www.grc.nasa.gov/www/k-12/UEET/StudentSite/dynamicsofflight.html

[21] "Propeller analysis." NASA Glenn Research Center. Accessed: Nov. 4, 2023. [Online]. Available: https://www.grc.nasa.gov/www/k-12/airplane/propanl.html

[22] "Propeller propulsion." NASA Glenn Research Center. Accessed: Nov. 4, 2023. [Online]. Available: https://www.grc.nasa.gov/www/k-12/airplane/propeller.html

[23] "Streamlines and streamtubes." University of Virginia, USA Physics Lecture Notes. Accessed: Nov. 4, 2023. [Online]. Available: https://galileo.phys.virginia.edu/classes/311/notes/fluids1/node7.html#:~:text=A%20streamtube%20is%20a%20tubular,(see%20Fig.

[24] H. Winfield, *The Art of Electronics*. Cambridge: Cambridge Univ. Press, 2017.

[25] H. Winfield, *The Art of Electronics: The X Chapters*. Cambridge Univ. Press, 2020.

[26] C. E. W, *Numerical Mathematics and Computing*, 4th ed. Pacific Grove, CA: Brooks/Cole Pub. Co., 1999.

[27] "Aerodynamics for students." Cambridge-MIT Multidisciplinary Design Project. Accessed: Nov. 4, 2023. [Online]. Available: http://www-mdp.eng.cam.ac.uk/web/library/enginfo/aerothermal_dvd_only/aero/propeller/prop1.html

[28] "11.7 performance of propellers." MIT - Massachusetts Institute of Technology. Accessed: Nov. 4, 2023. [Online]. Available: https://web.mit.edu/16.unified/www/FALL/thermodynamics/notes/node86.html

[29] B. M. Simmons, "Efficient variable-pitch propeller aerodynamic model development for vectored-thrust E-VTOL aircraft", in AIAA AVIAT. 2022 Forum, Chicago, IL & Virtual. Reston, Virginia: Amer. Inst. Aeronaut. Astronaut. 2022. Accessed: Nov. 4, 2023. [Online]. Available: https://doi.org/10.2514/6.2022-3817 [30]

[31] M. Podsędkowski, R. Konopiński, D. Obidowski, and K. Koter, "Variable pitch propeller for UAV-experimental tests", Energies, vol. 13, no. 20, p. 5264, Oct. 2020. Accessed: Nov. 4, 2023. [Online]. Available: https://doi.org/10.3390/en13205264

[32] L. Zaccarian, "DC motors: Dynamic model and control techniques." Accessed: Nov. 5, 2023. [Online]. Available: https://homepages.laas.fr/lzaccari/seminars/DCmotors.pdf

[33] "Maxon motor dynamics." Maxon Motor group. Accessed: Nov. 5, 2023. [Online]. Available: https://www.maxongroup.com/medias/sys_master/8815460712478.pdf?attachment=true

[34] R. Sharmin, S. S. Chowdhury, F. Abedin, and K. M. Rahman, "Implementation of an MPPT technique of a solar module with supervised machine learning", *Frontiers Energy Res.*, vol. 10, Aug. 2022. Accessed: Nov. 5, 2023. [Online]. Available: https://doi.org/10.3389/fenrg.2022.932653

[35] M. Hassanzadeh, M. Etezadi-Amoli, and M. S. Fadali, "Practical approach for sub-hourly and hourly prediction of PV power output", in *2010 North Amer. Power Symp. (NAPS 2010)*, Arlington, TX, USA, Sep. 26–28, 2010. IEEE, 2010. Accessed: Nov. 5, 2023. [Online]. Available: https://doi.org/10.1109/naps.2010.5618944

[36] "Module 54: The terminology and concepts used to determine the magnitude and direction of incident solar radiation - CIBSE Journal." CIBSE Journal. Accessed: Nov. 5, 2023. [Online]. Available: https://www.cibsejournal.com/cpd/modules/2013-07/x`

[37] J. A. Duffie, W. A. Beckman, and N. Blair, *Solar Engineering of Thermal Processes, Photovoltaics and Wind*, 5th ed. 2020. Accessed: Nov. 13, 2023. [Online]. Available: https://www.eng.uc.edu/~beaucag/Classes/SolarPowerForAfrica/Solar%20Engineering%20of%20Thermal%20Processes,%20Photovoltaics%20and%20Wind.pdf

[39] B. S. Richards and A. Iris Schaefer, "Renewable energy powered water treatment systems", in *Sustainable Water for the Future – Water Recycling Versus Desalination*. Elsevier Sci., 2009, pp. 353–374. Accessed: Nov. 14, 2023. [Online]. Available: https://www.researchgate.net/publication/244478324_Renewable_Energy_Powered_Water_Treatment_Systems

Looking back

Greater appreciation and knowledge of continuous mathematical models.

Finding the answer to a multi-faceted complex question from start to finish.

Fitting this in with school-work is tricky.

Looking ahead

Optimization of Solar-Powered, Sustained, and Autonomous Unmanned Aerial Vehicles for Variable Mission Criteria

Feasibility analysis using Mathematical optimization of solar-powered aircraft using first principles for different mission cases.

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