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.



| 01 | Contents |
|----------------------------|---|
| 02 03 04 | Title Analysis The Why behind this EPQ The Methodology to Answer the Question Posed by this EPQ |
| 05 06 07 08 09 | Schools of Focus The Solar-powered Focus The Sustained Focus The Model Formed Are the Schools of Focus Connected? |
| 10 | The Autonomous Focus |
| 11 12 | Conclusions So why aren't we seeing this right now? |
| 13 14 15 | Project Management Motivations Source Evaluation |
| 16 17 | Looking Back Looking Ahead |

Feasibility Optimization?

Variable Mission Criteria?

| 01 | Contents |
|----|------------------------------------|
| 02 | Title Analysis |
| 03 | The Why behind this EPQ |
| 04 | The Methodology to Answer |
| | the Question Posed by this EPQ |
| 05 | Schools of Focus |
| 06 | The Solar-powered Focus |
| 07 | The Sustained Focus |
| 80 | The Model Formed |
| 09 | Are the Schools of Focus |
| | Connected? |
| 10 | The Autonomous Focus |
| 11 | Conclusions |
| 12 | So why aren't we seeing this right |
| | now? |
| 13 | Project Management |
| 14 | Motivations |
| 15 | Source Evaluation |
| 40 | Laskina Dask |
| 16 | Looking Back |
| 17 | Looking Ahead |

Mhy?

| 01 | Contents |
|----|---|
| 02 | Title Analysis |
| 03 | The Why behind this EPQ |
| 04 | The Methodology to Answer |
| | the Question Posed by this EPQ |
| 05 | Schools of Focus |
| 06 | The Solar-powered Focus |
| 07 | The Sustained Focus |
| 80 | The Model Formed |
| 09 | Are the Schools of Focus |
| | Connected? |
| 10 | The Autonomous Focus |
| 11 | Conclusions |
| 12 | So why aren't we seeing this right now? |
| 13 | Project Management |
| 14 | Motivations |
| 15 | Source Evaluation |
| 16 | Looking Back |
| 17 | Looking Ahead |

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

| 01 | Contents |
|----------------------------|--|
| 02 03 | Title Analysis The Why behind this EPQ |
| 04 | The Methodology to Answer the Question Posed by this EPQ |
| 05 06 07 08 09 | Schools of Focus The Solar-powered Focus The Sustained Focus The Model Formed Are the Schools of Focus Connected? The Autonomous Focus |
| 11 12 | Conclusions So why aren't we seeing this right now? |
| 13 14 15 | Project Management Motivations Source Evaluation |
| 16 17 | Looking Back Looking Ahead |

Schools of Focus

| 01 | Contents |
|----------------|---|
| 02 03 04 | Title Analysis The Why behind this EPQ The Methodology to Answer the Question Posed by this EPQ |
| 05 | Schools of Focus |
| 06 | The Solar-powered Focus |
| 07 | The Sustained Focus |
| 80 | The Model Formed |
| 09 | Are the Schools of Focus |
| | Connected? |
| 10 | The Autonomous Focus |
| 11 | Conclusions |
| 12 | So why aren't we seeing this right now? |
| 13 | Project Management |
| 14 | Motivations |
| 15 | Source Evaluation |
| 16 | Looking Back |
| 17 | Looking Ahead |

Sustained

27.993 62.307

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

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



Input characteristics of existing technology into the model.



Take parameters and using data form a model.

The Solar-powered Focus

| 01 | Contents |
|----------------|---|
| 02 03 04 | Title Analysis The Why behind this EPQ The Methodology to Answer the Question Posed by this EPQ |
| 05 | Schools of Focus |
| 06 | The Solar-powered Focus |
| 07 08 09 | The Sustained Focus The Model Formed Are the Schools of Focus Connected? |
| 10 | The Autonomous Focus |
| 11 12 | Conclusions So why aren't we seeing this right now? |
| 13 14 15 | Project Management Motivations Source Evaluation |
| 16 17 | Looking Back Looking Ahead |

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 Franco, remeded extortion in a 10 km enser around Villacoubley and Mekelon. During this period, the electric system was deemed superior to the steam engine. However, with the advert of gracultina engines, research on electrical propulation for air vehicles was abandoned, and the field enrealed domant for 73 years. [3]

On the 30th of June 1967, Colonel N. J. Taglin of the United Kingdom conducted the first officially recorded electric-powered radio controlled flight with its model "Radio Queen," which utilized a permanent-magnet motor and a allwer-size battery. Unfortunately, he did not confuse with these experiments, but subsequent advancements in the field were made by freed Milley, 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 betaries. III.2.14

Three years prior to Taglin and Milisty's experiments, in 1954, photovebalc technology was developed at Bell Telephone Laboratories. Daryl Chapin, Calvin Fuller, and Gesald Pearson created the first silicon photovoltaic cell capable of converting enough of the surfs energy into power to run everyday electrical equipment. Initially, the efficiency was at 4%, but if applied improved to 11%, 1[2, 3].

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 austained airorals light on December 17, 1903. Only a decade later, at the start of World War I, heavier-train-air powered airorals had become practical for artillary sporting, recommissiones, and attacks against ground positions. During the Second World War printing by technology and selved pod aboding to airoral that could have present and finight from place to place in mere hours leading us into a "pet-ago", "After a sustained petiod of technological development, we are approaching a stagnistion in window which provides a stagnishm in window when the self-action of the perfection of toxist-fuel based airoral trainer than the development of solin-powered airorals final may provide to the fauture of air brand, fleight carringing, sausch-said-recove appreciations, inclustrial inspection, agricultural impation, telecommunications, internet someiopatility in membra supplies, etc.

A theoretically infinite flight time for solar-powered Unmanned Aerial Vehicles (UAVI) is a fundative internal of aircraft development if belowed. If would enable a huge range of mission and applications to be rolled out universally where it was proviously too occommodity expensive.

This dissertation therefore assesses whether it is possible to achieve a solarpower based singularity wherein an increal to able to fly perpetually and automospies with boday'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 trutton.

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 sustainabily, 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 vapor can be "suspite" in and mountain-scapes where ground water and rainwater is inaccessible but low lying foig and clouds carrying a large amount of water can be taped into as part of my QCSE. Design and Technology NEA: and a prototype solar powered decalination system which can take water with impurities and distil it using a liens 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:

- 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)
 - 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:
 - Mechanical Design of airframe
 - 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:
 - . Solar-powered
 - Sustained
 - iii. Autonomaus

following with oursent day technologies:

- A "Grand Conclusion" outlining a summary of the above conclusion
- c. A possible prototype using existing or near-future technologies

to axemplify a possible solar-aircraft.

The overall objective of this dissertation is to examine whether it is leasible for axiomened arrash called LAVis (unmanned senial vehicles) to achieve the

- de able ro be practically solar-powered in the same it is feasible and affordable.
- (2) the able to scherve theoretical infinite flight time in the sense it is lossible and affordable.
- (3) Be able to adapt autonomously to allow for complex mousions and designations in the sense that it is lessable and effortable.

History of Solar Flight July 2008

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Chapter 2: The Principles of Controlled Flight 2:1 Introduction

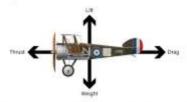
To begin weighing the suitability of different electronic lectrologies, the context of our snalysis must finish a stated, as such we first must briefly go into detail negariting the way mechanical components such on conventional surposit.

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

2.2 The Basic Principles of Flight

2.2.1 The Porces Involved in Level Flight

All alreads must be designed with the following forces in minst to ensure the cost has optimum flight of anabotistics; thread how the engine $F_{\rm manuel}$. The lift from the wings of the alread $F_{\rm min}$, the weight of the alreads $F_{\rm min}$, and lastly the drag of the alread $F_{\rm min}$. Controlling these values will allow the alreads to at least become airbonic before we need to implement control.



Pigare (2.2) if there existing on an around during level fight featuring the Sopwift Carrell. This is only a must importation as in the section of miss of the count and hote factors among of the count and hote factors are reflectly through the valual sectors and the counts make. For madidagen introducts this problem

Especially for the user case of solar powered around the parameters that recall directly affect $f_{\rm pring}$ and $f_{\rm pring}$ 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 see level pressure, as temperature in the range of 10°C to 50°C. The airflow due the relable volacity of the aircraft to the air creates the force of $F_{BB,(p)}$ and $F_{BB,(p)}$, both which are balanced by $F_{BB,(p)}$ and $F_{BB,(p)}$ is a result of air flowing over the wings creating a pressure difference

and is a sort of "manufactured force" in the sense that is a result of the designees of the sense that hadding ellegs, a situate the alorant to overcome the P_{mnjet} that allowing too take flight or remain at a constant offslude during level flight. Person is a force due to the inefficiences in our alread's design, P_{mnje} can rever equal to zero as the chargo coefficient (placeused further) is always prefer than zero. P_{mnjet} is, in short, a result of the projectic creating a pressure difference and thus a through the force must exceed P_{mnjet} for the already to societize, must be the same as P_{mnjet} for the order to remain at a constant velocity, and must be seat that P_{mnjet} for the order to designee.

2.2.2 Balancing the Forces in Flight

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

Figure (2.5): Ponce, acting on an almost in level Right resolved in the x and y avec. Ponces are about the specialized combs of maps of the aircraft.

| 60 | $\Sigma F_p = 1000$ $F_{10 \text{ max}} - F_{20 \text{ mag}} = \pi_{14}$ | Equation (2.7) Fit |
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| Tarodole E _V | Description: Proves to the number Proves to the number | Special (A.17) N |

It should be noted that we subtract place both $F_{\rm crosp}$ and $F_{\rm crosps}$, as being subtracted from their mapsoches forces as we are taking the upwards plan and the lethwards of exections as positive as it would be must intuitive as that to both the top and the front of the archital.

2.3 Controlling flight

2.3.1 The Importance of Control

For the spian aircraft to be able to by theoretically infinitely, the coall 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 thave existed long before the Winght Piyer, such as George Cayley's full-scale glider published as part of his free-port hashes where it included the world's fixer provider manned fight in 1683, [17] Poweed alruralt have also existed large before the Winght Piyer such as the first unnamed powered alruralt have also existed large before the Winght Piyer such as the first unnamed powered disprts such as Ader Aviori. It built by Carrent Ader Aviori. It built by Carrent Ader Aviori. All the such as Ader Aviori. It built by Carrent Ader Aviori. All the such as the world have also dispressed in the such as the world. The such as the world have a such as the world have a such as the world have the such as the world have red as a result of mat having one thing committee.

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

For a solar-powered it must be oble to be controlled for it to be able to sustain flight. I do this, the craft must use the three axes of control, roll, pitch, and yaw, [35] Small we called control surfaces are moved into the flew of air to create a force against the airs and thus cause it to management.

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

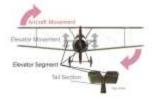


Figure (2.4).1. Annual roll, contain surfaces rathed attention cause the motion.



Figure (3.3).2: Ann. of prich, cardinal numbers called elevation course this matters

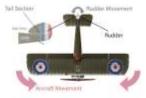


Figure (3.3) 2: Asia of you, a contot surface sated the sudder causes this matter.

2.4 Aerodynamics of wings

2.4.1 The Problem

To accessability become airborne, designess must consider the sendigmentics of the wing country in the cense that the sendigment credit of white set or safety too insuch shap and emanating suitable flight characteristic depending on the average relocity of the cest. Suitable flight characteristic during safet and high write should also be taken into considerable for the development of a five-great safety.

2.4.2 The Forces on an Aerofoli

The figure [I,A], I shows a cross section of a very in the optimum condition of larence flow at a constant velocity of ν . The elitable difflow over the letting creative a difference in pressure the log of the wing and the bottom wing that once resolved create the two layous of $F_{\rm Perm}$ and $F_{\rm LIR}$.



Figure (3.4):1. Consequention of an except's anoded. The consequence of a sincle-regressive of mass of the evirg and that is to be place-where for mass all through, Propage, has been contribute to reduce compressing on one or engineery the lengt only and Propage constains the entire weight of the second.

The forces of Y_{thing} and Y_{tays} can be calculated using the following formulas:

$$\begin{split} E_{col} &= \frac{1}{q_{col} q_{col} q_{col} q_{col}} (P_{col}) \\ &= \frac{1}{q_{col}} (P_{col} + P_{col}) \end{split}$$
 (specimols)

As stated before, using $\ell = \ell T$ the total energy consumacity the abound can be derived

E = 17' can be applied directly but the officiency of the charge and discharge of the

$$\begin{split} f &= f^* \text{ for any tail angle of density cycle the efficiency of the schapes and densitying of the schapes and schapes and schapes and the schapes and schapes are schaped as the schape and schapes are for a finite or for a finite or$$

This energy subject by the dust at a contral point or the Conft Pringings of the day does not write the a light below during pointers and that but state an uniformal and restrictions are sufficient to the subject of the day of the

The time function between the part of spirits and too large and active mode to not identify unity.

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is a for those reasons the continuous data-duple model in biggore for the industribution data recording to the industribution of the data record with one period of the day price as T _{may} and the time period of the input period T _{mayor}, where:

$$T_{\rm tope} + T_{\rm top} = 24 \qquad \rm mponep$$

6.6 Daily Salar Energy Harvested 6.6.1 Impelance Model

The impliance of the sun depends on the following major values:

Figure 2 in account by the leadings of the special flow part of the account, the tending again contains a part of the account of the account

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3.1.6 The Imperiors and Forgons of Epithology Bechanics Columbition on a For the proper featurity coupes their is "Union For two constitution constitutions are setting and setting and setting and the foreign and setting and setting and the setting and properly is American placed against properly in American placed and appropriate and the setting and the set

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U.S. Introduction

The temporary of ISS increases with regional or their inspirational principles will be operational industry from a decimated our tile floors operated that SN choice is placement or significant to the color of the following equations on a point or purple of the decimated and recommend of the purple.

3.8.2 The ten equations

Assets on Advanced to

Moreover, a parametric modernehme parameters can be changed-easily-would allow for ranks leads and onto a technology to be belief and therefore builds to develop a theoretically introducing time solor provide.

6.2 Daily Electrical Energy Required

6.3.1 Power for Level Plight

After harbeing a use care substitute into the following requalities in calculate the power required to maintain-local fight at a constant whichly

$$\begin{aligned} & = \sum_{k=1}^{n} \frac{-k \cdot v \cos(k_k)}{v \cos(k_k)} & \text{Stateback } \\ & = S_{n+1} - k \cdot v_{n+1} \\ & = S_{n+1} - k \cdot v_{n+1} \\ & = S_{n+1} - k \cdot v_{n+1} \\ & = S_{n+1} - v_{n+1} \cdot v_{n+1} \\ & = S_{n+1} - v_{n+1} \cdot v_{n+1} \cdot v_{n+1} \\ & = S_{n+1} - v$$

We can rearged present to level light into the following form to include the wingspan-wing area of the arcost to constrain the power of levertight to the area of the arcost and red Let II's make.

Depotency (C.E. Ph

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has a fixed it. This indicate and tripping provided by the body and strong proportions. For ranging refuges, the form's Figure (2 KL2 is an possible with obsessing stops (2). The this reason that are the beginned the body will be the working part, and the printing part to prepare it the interested of the proper increase these statements to very of the righty with the angular very corpurations of prepare the contract of the co arriving manetice Physics (FS) If we fragation (FS) is the training in alternal

$$\begin{array}{ll} & \frac{\mathbf{R}_{\mathrm{reg}} + \mathbf{R}_{\mathrm{pl}}(t-\mathbf{r}_{\mathrm{pl}})}{\mathbf{R}_{\mathrm{pl}}(t-\mathbf{r}_{\mathrm{pl}})} \\ & = & \frac{\mathbf{R}_{\mathrm{pl}}(t-\mathbf{r}_{\mathrm{pl}})}{\mathbf{R} + \mathbf{r}_{\mathrm{pl}}(t+\mathbf{r}_{\mathrm{pl}})} \\ & = & \mathbf{R} + \mathbf{r}_{\mathrm{pl}}(t-\mathbf{r}_{\mathrm{pl}}) + \mathbf{r}_{\mathrm{pl}}(t-\mathbf{r}_{\mathrm{pl}}) \\ & = & \mathbf{R} + \mathbf{r}_{\mathrm{pl}}(t-\mathbf{r}_{\mathrm{pl}}) + \mathbf{r}_{\mathrm{pl}}(t-\mathbf{r}_{\mathrm{pl}}) \end{array}$$

Binar as per period; and DC means has believed in top 4 of a partiess per reports or 10 miles

$$\begin{split} & = - \delta_{iij} = \left(\frac{-m_i r_{iij}}{r_{ij}} \delta_{iikk}\right) \delta_{ii} \delta_{ij} \delta_{kij} \delta_{kij}$$

In order to obtain a models, the valor rails are intercommented destinate, and their assumption between the constituted to the contract of the

$$\begin{array}{lll} m=nl & m=pl' \\ = m_{cl} = nl_{cl} & m=nl \\ = m_{cl} = (n_{cl} + n_{cl}) nl_{cl} & m=nl \\ = m_{cl} = (n_{cl} + n_{cl}) nl_{cl} & m=nl \\ = m_{cl} = (n_{cl} + n_{cl}) nl_{cl} & m=nl \\ \end{array}$$

8.3.4 Maximum Planer Point Tracker Stees Production

 $= - \left(\frac{16}{4} \left(a_{ab} + b_{a} \right) \frac{1}{4} - a_{b} \right)$

2.8 The Astrophysics of a Projection

24.1 Spec Dancel Transp (817)

T.8.1 Immeloption

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comparisons (see). The following managing is the comparison of community afficiency of the property of the community of the

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6.3.2 Calculating Daily Energy Required

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$$\begin{split} & \eta_{\rm max} = \frac{F_{\rm min}}{f_{\rm min}} = \frac{F_{\rm min}}{f_{\rm min}} \\ & = -\frac{F_{\rm min}}{f_{\rm min}} f_{\rm min} = F_{\rm min}, \\ & = F_{\rm min} = \frac{F_{\rm min}}{f_{\rm min}} \\ F_{\rm min} = \frac{F_{\rm min}}{f_{\rm min}} f_{\rm min} + \frac{F_{\rm min}}{f_{\rm min}} = \frac{F_{\rm min}}{f_{\rm min}} \\ \end{split}$$





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2.4.4 The Papiers Affecting the SMA: Bairs

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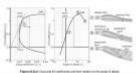
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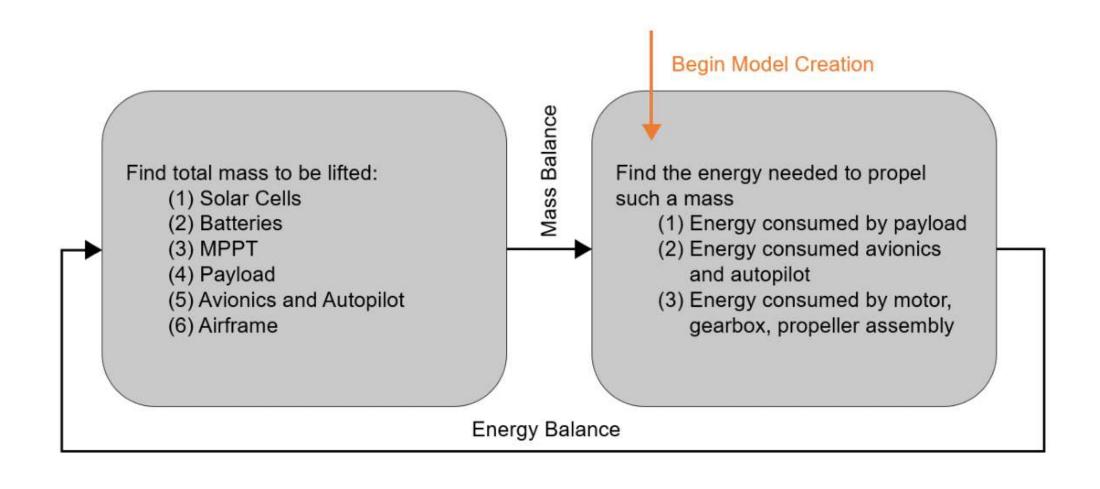
| | $\Sigma F_a = m_{t\bar{t}}$ | Equation (2.2) 01 | | | | | | | | |
|----------------------------------|--|--|--------------------------|---|---------------|------------------------------------|----------------------|---|------------------------|-----------------|
| *** | $F_{Thrust} - F_{Drug} = ma$ | Equation [2.2] 02 | | $C_{D \text{ Overall}} = C_{D \text{ Induced}} + C_{D \text{ Parasite}} + C_{D}$ | Aero/ail | Equation [2.4].08 | M_{mot} | Moment (Torque) due to motor turn force | [N m] | Symbol [2.5].10 |
| | $\Sigma F_{\nu} = ma$ | A | | 111 = n 1 + h | | | M_{f_S} | Moment (Torque) due to internal mechanical friction | [N m] | Symbol [2.5].11 |
| | $E_{IJIT} - F_{Weight} = ma$ | Equation (2.2) 85 | | $\begin{cases} U = r_0 i + k_u \omega_{mot} \\ M_{vm} = k_m i \end{cases}$ | | Equation [2.5].01 | $\eta_{propeller}$ | Efficiency of the propeller | | Symbol [2.6].01 |
| | Fills - rweight - min | Equation [2.2],04 | | r com - com | | | $M_{propellor}$ | Moment of Resistance (Moment of Inertia) | | Symbol [2.6].02 |
| | | | | $\omega_{mot} = \frac{U - r_a t}{k}$ | | Equation (2.5) 02 | ω | Angular velocity of propeller | [rad s ⁻¹] | Symbol [2.6].03 |
| Yacutife | Description | 12-12-22-22-2 | 1.7.2 | K _w | | | F_T | Force of thrust | [N] | Symbol [2.6].04 |
| 5 | Forces in the n asis | Symbol (2.2) 01. | 55555550 | | | | v | Axial velocity of propeller | [m s-1] | Symbol [2.6].05 |
| Fy | Forces in the y axis | Symbol [2.2] #2 | Vaciable | Description | Uon | 15 c catalil | J | Dimensionless propeller advance ratio | | Symbol [2.6].06 |
| | | | U | Terminal voltage from supply to motor | | Symbol [2.5].01 | n | Number of blades on propeller | | Symbol [2.6].07 |
| | $F_B = C_B \frac{\rho}{2} A_W \sigma^2$ | Equation (2.4) If L | ra . | Terminal resistance Current | | Symbol [2.5].02 Symbol [2.5].03 | d | Diameter of propeller blades | [m] | Symbol [2.6].08 |
| | $F_L = C_L \frac{\partial}{\partial} A_W \pi^2$ | | k _a | Voltage constant | [Vi at rad-1] | Symbol [2.5].04 | F_T | Force due to thrust, previously F_{Lift} | [N] | Symbol [6.X].01 |
| | $F_1 = C_1 \frac{\rho}{-} A_W v^2$ | Equation (2.4).II | km | Velocity constant | [rod(V) w)] | Symbol [2,5],05 | F_W | Force due to weight, previously Fweight | [N] | Symbol [6.X].02 |
| | | | Mon | Electromagnetic monwrit | Descending A | Symbol [2.5].06 | P_{lvl} | Power consumed during level flight | [W] | Symbol [6.X].03 |
| | | | Officer | Angular speed of motor shuft | | Symbol [2,5],07 | P_{usfl} | Power spent to create useful work | [W] | Symbol [6.X].04 |
| Variable | Description | | | | | | P_{av} | Power consumed by avionics and autopilot | [W] | Symbol [6.X].05 |
| F ₀ | Force due to drag, previously F_{Bridge} , henceforth, F_{D} . | Symbol [Z.4].#1 | 827 | $M_{\rm max} = M_{\rm em} - M_{\rm f_0}$ | | Equation [2.5],03 | P_{pld}^{av} | Power consumed by payload | [W] | Symbol [6.X].06 |
| Co | Goefficient of Drug Force due to lift, previously F_{LDL} , horsewherth F_L . | Symbol [2.4] 62 Symbol [2.4] 63 | = | $M_{max} = k_m i - k_m i_0$ $M_{max} = k_m (i - i_0)$ | | Equation (2.5),04 | | Total power consumed | [W] | Symbol [6.X].07 |
| F _L C _L | Coefficient of Life | Symbol [2-4] 04 | - | minut - with - 40% | | Edmine (makes | P_{tot} | Maximum Power Output | [W] | Symbol [6,X].08 |
| 0 | Density of air | Symbol (2.4) 05 | 500000016 | A20074135-0 | 1000 | | P_{max} | Total Efficiency | [11] | |
| A_{W} | Area of the wing | Symbol [2,4],06 | Vaciable | Description Current final | Unit | Symbol [2.5].08 | η_{tot} | | | Symbol [6.X].09 |
| | Speed of acrobal relative to the sir (Relative airspeed) | Symbol [2.4],87 | (a | Current initial | | Symbol [2.5].09 | η_{ctrl} | Efficiency of motor controller | | Symbol [6.X].10 |
| | | | M _{mot} | Moment (Torque) due to motor turn force | | Symbol [2.5]:10 | η_{mot} | Efficiency of motor | | Symbol [6.X].11 |
| | C ₁ / _{C₂} = Glide Coefficient | Equation [2.4],03 | M_{f_n} | Moment (Torque) due to internal mechanical friction | | Symbol [2.5].11 | η_{grb} | Efficiency of gearbox | | Symbol [6.X].12 |
| | 177 | | 100000 | | | | η_{ptr} | Efficiency of propeller | | Symbol [6.X].13 |
| | $R_{\phi} = \frac{\rho wc}{B}$ | | | $M_{mot} = k_m(i - i_0)$ | | | η_{BEC} | Efficiency of step-down converter | | Symbol [6.X].14 |
| | μ. | | 120 | $\begin{aligned} &\frac{M_{max}}{k_m} + i_0 = i \\ &U = r_{st}i + k_{st}\omega_{mot} \\ &U = r_{\sigma}\left(\frac{M_{mot}}{k_{st}} + i_0\right) + k_{st}\omega_{mot} \end{aligned}$ | | | η_{chrg} | Efficiency of battery charge | | Symbol [6.X].15 |
| | w | | - | $k_m + \epsilon_0 = 1$ | | | η_{ackrg} | Efficiency of battery discharge | | Symbol [6.X].16 |
| === | $R_{\sigma} = \frac{vc}{\psi}$ | Equation [2.4].04 | | $U = r_x i + k_w \omega_{mot}$ | | | η | Efficiency | | Symbol [6.X].17 |
| | | | | $U = r_a \left(\frac{M_{mot}}{h} + t_0 \right) + k_u \omega_{mot}$ | | Equation (2.5) 05 | η_{sc} | Efficiency of solar cells | | Symbol [6.X].18 |
| | $\psi = \frac{\mu}{}$ | | | K _{SH} | | | η_{cbr} | Efficiency of curved solar panels | | Symbol [6.X].19 |
| | 1 0 | | | 14-11-4-11 | | | η_{mppt} | Efficiency of MPPT Charge Controller | | Symbol [6.X].20 |
| 100 | $\frac{\dot{\omega}}{\psi} = \frac{\nu}{\mu}$ | Equation [2.4],05 | | $\begin{aligned} k_{in} &= k_{ii} \\ M_{mat} &= \frac{k_{iii}^2}{\tau_{ii}} \omega_{mat} + k_{in} \left(\frac{U}{\tau_{i}} - t_{i} \right) \\ \omega_{mat} &= -\frac{\tau_{i}}{k_{in}^2} M_{mot} + \left(\frac{U - \tau_{i} t_{i}}{k_{in}} \right) \end{aligned}$ | | | | Efficiency of DC to DC converter of MPPT | | Symbol [6.X].21 |
| | Y . F | | | $M_{max} = \frac{\kappa_{in}}{\omega_{max}} \omega_{max} + k_{sc} \left(\frac{\omega}{\omega} - t_0 \right)$ | | Equation (2.5).06 | $\eta_{mppt\ conv}$ | | | |
| | | | | r_0 r_0 r_0 r_0 r_0 r_0 | | | $\eta_{mppt\ algor}$ | Efficiency of tracking algorithm of MPPT | | Symbol [6.X].22 |
| Variable | Description | | - | $\omega_{\text{mod}} = -\frac{\alpha}{k^2} M_{\text{mod}} + \left(\frac{\alpha}{k_m}\right)$ | | Equation [2.5].07 | k_{wehr} | Arbitrary weather constant | | Symbol [6.X].23 |
| 10 | Wing chord | Symbol [Z.4].08 | | | | | k_{mppt} | Mass to power ratio of MPPT | [kg W-1] | Symbol [6.X].24 |
| y v | Bulk stocosity or Dynamic viscosity Kinematic Viscosity | Symbol [2.4].09 Symbol [2.4].10 | | $F_T v$ | | 12-01-02-02-02-02 | E_{tot} | Total energy consumed | [7] | Symbol [6.X].25 |
| | Homestan, Francisco | special 2.43.10 | | $\eta_{propetter} = \frac{F_T v}{M_{propetter} \cdot 0}$ | | Equation [2.6].01 | T_{tot} | Total time elapsed, cumulative time period | [s] | Symbol [6.X].26 |
| | $A_{\star} = \frac{S}{-}$ | | | N: 70 | | | T_{day} | Time period of day, time from sunrise to sunset | [s] | Symbol [6.X].27 |
| | A; - c 52 | | Variable | Description | | | T_{night} | Time period of night, time from sunset to sunrise | [s] | Symbol [6.X].28 |
| 339 | $A_r = \frac{S^+}{2}$ | | | Efficiency of the propeller | | Symbol (2.6).01 | φ | Sunlight Day density | | Symbol [6.X].29 |
| | $A_r = \frac{S}{Sc}$ S^2 | | Upropetter Mpropetter | Moment of Resistance (Moment of Inertia) | | Symbol [2.6].02 | I_{max} | Maximum sun irradiance | [W m-2] | Symbol [6,X].30 |
| 100 | $A_{\tau} = \frac{\alpha}{A_{\omega}}$ | Equation [2.4].06 | to propertor | Angular velocity of propeller | | Symbol [2.6].03 | A_{sc} | Area of solar panels | [m ²] | Symbol [6.X].31 |
| | | | F_T | Force of thrust | | Symbol [2:6].04 | K | 2D Density | [kg m-2] | Symbol [6.X].32 |
| | $C_{D\ Instructed} = \frac{C_{L}^{p}}{\pi v_{\phi} A_{r}}$ | Equation [2.4] 07 | tr. | Axial velocity of propeller | | Symbol [2:6].05 | K_{SC} | Mass density of solar cells | [kg m·2] | Symbol [6.X].33 |
| | argarit. | | | J = v/nd | | Equation (2.6) 02 | Kadd | Mass density of additional mass around solar panels | [kg m·2] | Symbol [6.X].34 |
| | | | | r - rnd | | reference frozens | ρ O | 3D Density | [kg m·1] | Symbol [6.X].35 |
| Vaciable | Description | Bunkate ass | | | | | v | Volume | [m ³] | Symbol [6,X],36 |
| S A _r | Wing span Aspect ratio | Symbol [2.4].11 Symbol [2.4].12 | Vaciable | Description | | 0.000.00.000.000 | A | Area | [m ²] | Symbol [6.X].37 |
| Co required | Induced Drag Coefficient | Symbol [2.4].13 | 1 | Dimensionless propeller advance ratio | | Symbol [2:6]:06 | m | Mass | [kg] | Symbol [6.X].38 |
| Co reduced | Oowald Efficiency Factor | Symbol [2,4].14 | n d | Number of blades on propeller Diameter of propeller blades | | Symbol [2.6].07 Symbol [2.6].00 | *** | | [61 | ayanaa (unjab |
| 1.71 | The September of September 1999 (1999) | 5-14-11-15-6-2-7-6-5-5-5-5-5-5-5-5-5-5-5-5-5-5-5-5-5-5 | 1076.0 | waste with the business continue | | existen feralum | | | | |

The Sustained Focus

| 01 | Contents |
|----|------------------------------------|
| 02 | Title Analysis |
| 03 | The Why behind this EPQ |
| 04 | The Methodology to Answer |
| | the Question Posed by this EPQ |
| 05 | Schools of Focus |
| 06 | The Solar-powered Focus |
| 07 | The Sustained Focus |
| 08 | The Model Formed |
| 09 | Are the Schools of Focus |
| | Connected? |
| 10 | The Autonomous Focus |
| 11 | Conclusions |
| 12 | So why aren't we seeing this right |
| | now? |
| 13 | Project Management |
| 14 | Motivations |
| 15 | Source Evaluation |
| 16 | Looking Back |
| 17 | Looking Ahead |

Discrete and Iterative Approach

Continuous and Analytical Approach





From this figure we are able to see those an end model to model the baseloing of a objective of an end to e

To material auch a model we can use the technologies protect methods.

6.2 Melhomatical Sourcementers

6.2.1 Discrete and Bureline Sources.

This discrete and heatine against conduct in covering an initial set of companies such as fedirates, and careful, which will, therefore an effective or the first required page later companies and careful. A price control or grows or people of or page later companies and careful. A price control or grows or people and a control or page in the control of the control of the control or people and interaction and it form business a dering the price are resided to bot flight. This while a third or power performance are settled for the properties better bot flight. This while a flight or power people are people and the properties are proposed for design converging at a sufficient selection global to a generation affirm.

6.2.2 Continuous and Analytical Approach

This side is expressed have an algorithmic remain use approach that consider of contributing of the extension-bowers has component with contribute operations using which show they the observation of man in these. This contributes have the size of strengt providing is a visual and applicated design, for any virtue very good matter makes.

4.3.3 Choice Researing

White hore sociate mathematical nodes are record the colleges and energic opposeds would seem to be more authors to the study once twee, in the present once, as incoming other with the mode for time models as according to according to the present of the support of the along the study of the support of the study that th Moreover, a parametric modernehme parameters can be charged-searly-would allow for revious lessels and could be freely by the tested and therefore featible to develop a theoretically intrinsing fight time solar aircraft.

6.2 Daily Electrical Energy Required

6.3.1 Power for Level Plints

To authore been light at a constant whoshy in the sense as described in Chapter 2, the sum of the layers in both the x-axis and p-axis must be equivalent.

$$\begin{array}{ll} \{f_i = ng \\ & 12_i = 0 \\ & 13_i = 0 \\ & 11_{i+1} = 1 \\ & = 1_i = r_j \\ & = 1_i = r_j \\ & = 1_i = r_j \\ & = r_i = r_j \cdot \frac{r_i}{r_i} A_{ij} r^i \end{array}$$
 superscope of

$$\begin{split} & = & \sum_{k_{B}=1}^{N_{B}} \sum_{k_{B}=1}^{N_{$$

$$\begin{split} & G_{\text{max}} = \frac{e_{\text{pr}}^{-1}}{e_{\text{pr}}^{-1}} & \qquad G_{\text{pr}} \in \frac{e_{\text{pr}}^{-1}}{e_{\text{pr}}^{-1}} \\ & = G_{\text{max}} = \frac{e_{\text{pr}}^{-1}}{e_{\text{pr}}^{-1}} & \qquad G_{\text{pr}} \in \frac{e_{\text{pr}}^{-1}}{e_{\text{pr}}^{-1}} \\ & = G_{\text{max}} = \frac{e_{\text{pr}}^{-1}}{e_{\text{pr}}^{-1}} & \qquad G_{\text{pr}}^{-1} \in \frac{e_{\text{pr}}^{-1}}{e_{\text{pr}}^{-1}} \\ & = G_{\text{max}} = \frac{e_{\text{pr}}^{-1}}{e_{\text{pr}}^{-1}} & \qquad G_{\text{pr}}^{-1} \in \frac{e_{\text{pr}}^{-1}}{e_{\text{pr}}^{-1}} \\ & = G_{\text{pr}}^{-1} = \frac{e_{\text{pr}}^{-1}}{e_{\text{pr}}^{-1}} & \qquad G_{\text{pr}}^{-1} \in \frac{e_{\text{pr}}^{-1}}{e_{\text{pr}}^{-1}} & \qquad G_{\text{pr}}^{-1} = \frac{e_{\text{pr}}^{-1}}{e_{\text{pr}}^{-1}} \\ & = G_{\text{pr}}^{-1} = \frac{e_{\text{pr}}^{-1}}{e_{\text{pr}}^{-1}} & \qquad G_{\text{pr}}^{-1} = \frac{e$$

6.3.2 Calculating Daily Energy Required

6.3.2 Calculating Carly Energy Responsed.
7. So deside the behalving resourced by the oldered are mudi consoler fine largely of the option of models for the statistic own source and the market for the charges of the design of the market fine the charges of the design of the market fine the part of the charges of the statistic order of the charge of the statistic order of the model of the charge of the charge of the model on Energy agreement by the whole the fine of the charge of the model on Energy agreement by the whole of the charge of the char

Factoring the worst day conditions that the sknotch can auccessfully their would need to e determined experiencially after lating the exect complice have into account in the

To attain the total power consumption the sincesh we can already just sometime the tot purser is minimized by the size all Through is proposition replace studies given fifty intended to the purser consumed by the advisors and populated. The streams the accounts just timetime a triple twin of constitutionable of the model efficiencies of the various comprometic used from model to be inferred to considerable of the comprometic used from model to be inferred to considerable or proposable used from model to be inferred to considerable or the constitution of the constitution of the constitution of the constitution of the comprometic used from model to be inferred to considerable or the constitution of the

$$\begin{split} & = \frac{I_{\rm col}}{I_{\rm col} e_{\rm col} I_{\rm col} I_{\rm col}} (P_{\rm col}) \\ & + \frac{1}{I_{\rm col}} (P_{\rm col} + P_{\rm col}) \end{split} \tag{Specime O(I)}$$

As stated before, $samp_i \mathcal{E} = PT$ the total energy consumed by the pricual can be derived which would their silver use to splinkly how much very the alread needs spained how much leads to be trained by without the legit architect to the reaction has been such as the production of the splinkly of t reserver has a major unarisonary of the resided in to be adjusted to a different time of year or percentational decident the options are within as to be re-intercontent to home a man-teriation which was of prompt be mode.

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žu.

 $\Gamma=P\Gamma$ can be used at shortly but the afficiency of the change and discharge of the batteries must be taken into account to maintain the accuracy of the model

belows that the time mile account in number the account of the following of the modes:
$$\begin{split} & I_{cos} = F_{cos} \Gamma_{cos} \\ & I_{cos} = F_{cos} \Gamma_{cos} \\ & = I_{cos} \Gamma_{cos} + \frac{\Gamma_{cos}}{4\pi_{cos} + 4\pi_{cos}} \\ & = I_{cos} = F_{cos} \Gamma_{cos} + \frac{\Gamma_{cos}}{4\pi_{cos} + 4\pi_{cos}} \\ & = I_{cos} = \Gamma_{cos} + \Gamma_{cos} \\ & = I_{cos} + \Gamma_{cos} \\ \end{split}$$

The energy suggest by the sun at a contain point on the Confi throughout the day does not The energy indust for the old of a content person for Carth Presigned the day odos is which the a light industrate prise and shad but deliver a continuous action proports from new copilipse id, progress areas contented to the day deliver for place of the day depending or the group personal and contents, that demokrategories in the mobile reduced the accountry of the model in the true reduce, this between is not region completed to the flago completion you doubt me the model and the confidence of the flago completion you doubt me the model and the confidence of the day completion you doubt me the model and the confidence of the day completion you doubt me the model and the confidence of the day completion you doubt me the model and the confidence of the day completion of the confidence and the confidence of the day completion of the confidence and the confidence of the confidence and the confidence of the

(f.) The time transition between day and regions red too large and so the mode is net shareout greatly.
Its Since power is districted from the batteries in the aircraft rather than disease.

a may present excellented from the labelment of the except (BHO THE descript from the value practic the labels in our administration is approximately to the charge cycle of the lithurinos between reporting that over it a progressive sittle and dust incolleration used. The difference between a progressive and an instant model would be since to negligible. It is for these research the continuous deam-dusk model in trageneritor the instant deam dusk model with time penult of the day-prior as $\Gamma_{\rm extr}$ and the time penult of the right

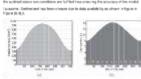
$T_{\rm right}+T_{\rm top}=24$

6.4 Date Saler Energy Harvested 6.4.1 Irradiance Model

The impliance of the sun depends on the following major values:

Page 8953 (secretificate appointment of the solutions of the Depth Co. 195).

Digitating of Theres Protests. Posterofales and Rhid [17] a consolidation in the node a representation Figure 8. 4. It is approximating that exact role line. Twentile if Signate the time proteins associate and not that is a storenous re-search. Board on the stand-conditions-choosing a boarier in the highlighted seas moulticonsist. The authoritations has conditions are fulfilled tractional region accuracy of the model.



Type (II.4): North City Tables or performance in a province behalfer

Recall on the choices must have we can obtain the following regovernments must distinct commences the materials
$$a_{min}$$
 and the distinct of the stay, T_{min} :
$$d = \frac{\lambda_{min}T_{min}}{K_{min}} \lambda_{min}, \qquad (a_{min} a_{min} a_{min})$$

The dely-solar energy per square mater is the surface before the curve in Figure (6.4) 3. In other to taken improposed of body have, a compact v_{ector} is added with a vector between 1 classes day at page of the vector vector v_{ector}, is addressed, and 2 pages with reso-most appropriate vector This influence of the recommend flash official the coming confliction is a risk relation may been the context of the desiration registration as about the inflyed as one enterpy described on the context of the context

6.4.2 Calculating Early Solar Energy Renyested

This start above coming contributed to well-play the count of Equative (E-4) for white surface of index could, the efficiency of the state could, and the efficiency of the SPT.

White the effect of the efficiency of the state could could be efficiency of the SPT.

White the efficiency of the efficiency of the efficiency of the SPT.

White the efficiency of the efficienc



Place E.A.A. Supplied and of relations on the sale values assert and one in date For this reason it is important to take one-appoint the winner configuration and preferable similation, 5 multi-one transformers and muscle to study the import and the results have that compared to a fairbidge-office. The combine decreased the energy by alread 15 is during a whole by in commit forces promote forces to show on the social muscless results to commit fundow. In commit too the other than the account into the mode, as

$$\begin{split} &- \delta_{cd} = \left(\frac{1}{100} \frac{T_{cd}}{\delta_{cd}} \delta_{cd} \delta_{cd} \right) \delta_{cd} / 3 \\ &- \delta_{cd} = \frac{1}{100} \frac{T_{cd}}{V_{cd}} \delta_{cd} \delta_{cd} \delta_{cd} \delta_{cd} \delta_{cd} \\ &- \delta_{cd} = \frac{1}{100} \frac{T_{cd}}{V_{cd}} \delta_{cd} \delta_{cd$$

6.5.1 Introduction

For each part or the unuset, an advance-mass model is reconstany in order to outside the facilities are and was to flaqueties (E.S.) All. This sentime all immigration mass models of each of the sincest whore in the order is four mass model of the sincest was a shown of their mass model of the sincest was some order of their mass model of the sincest is softened defined as:

$$m + m_{ijink} + m_{ij} + m_{ij} + m_{ijink} + m_{ini} + m_{inin}$$
 . Appendix of the social of the many $m_{ijink} + m_{ij} + m_{inink} = 0$. The social of the social of

E.S. I Front Manager Fixed masses will not departed on the surings of other parts. The mass of the psychoptic

included here as in the autoprist system it defined at the beginning. The payload could be anything from the following:

(1) Illestrad Eupples c) Proopspe Equipment (3) Stenor Esperiment (4) Agricultural Equipment (Sprayers, etc.) of Tenocommunication Equipment (6) etc. The equation is as belown:

Thomas I Have S House 5.5.2 Al-hame State Production

8.3.3 Solar Del Mass Prediction Here the exact confuse required to batterine their balat ethnics energy some, with the total sector energy obtained from the pur-Voling Equation (5-5) of Equation (6-4) 20, we obtain the required confuse covered by some parent.

$$d_{\rm cut} = \left(\frac{t_{\rm min} T_{\rm may}}{T_{\rm pl}} d_{\rm sate}\right) d_{\rm min} \eta_{\rm min} \eta_{\rm mapp} +$$



In order to obtain a module. For order calls are interconnected startically and then In state is station in mission for the station shall are informationable about year the committed behavior from the efficient of integrated layers. This subditional reviews in the station of the final region properties on early someoned as a separate separative from the wing structure. Thus, the first discussions of the self-speciments have been discussed in the station of stations of the station of the self-speciments are subject to come and the station of stations of the station of the station of the self-speciments are subject to the station of stations are the station of station of the station of the station of the station of stations are stationary to the station of the station of the station of the station of stations are stationary to the station of stationary to stationary the station of stationary to the stationary to the station of stationary to the stationary to the stationary to the stationary to stationary to the stationary to the stationary to the stationary to stationary to

n = pl'

managed in the

$$\begin{array}{lll} & \text{in } n_{ij} = A d_{ij} \\ & \text{in } n_{ij} = (n_{ij} + n_{ijk}) d_{ij} \\ & \text{in } n_{ij} = (n_{ij} + n_{ijk}) d_{ij} \\ & \text{in } n_{ij} = (n_{ij} + n_{ijk}) d_{ij} \end{array} \qquad \text{degenerates } \\ & \text{E.3.4 Maximum Power Point Fractor Mass Freedom} \end{array}$$

An immilised personals, the MPT is required to adopt the richage of the solds parents on their they provide the highest power provide. MPT's are specifiedly sprinned for Soldcott (and-colors and on a finality, power provides, MPT's are specifiedly sprinned for Soldcott (and-colors and on a finality of the sold provides and the sold selection may find they writted specified to find or simply, and their algorithms are not designed to the cost colors of the sold provides of the find of the color provides of the color distribution, stacks, sharpers are graph in solders, thus, long data from 11 solders MPT's to selec-rations. Figure and provides are colored to the colors of the colors of provides. The sold provides are colored to the colors of provides and the sold provides are colored to the colors of provides and the sold provides are colored to the color of the color of provides and the color of provides are colored to provide the color of provides and provides ratio of $k_{\rm apper} = 1/_{\rm 2DBH} k_{\rm B} m^{\prime\prime}$

Equipment of the second of the straining of the

consistent passering and in the form that is a strategy permitting the training and in passering at the size reviews, which is proportional to the real and influential filling allow (3.5) (3.1) in patient to be consistent in that to be a residenced that the consistent of the artifaction contained the artifaction of the CEO LOS convention allows on a fill and invaring the training adjournity. This is because the second point to review conducting on the interior strategy participation and are according to according to the contract of the contract of

$$A_{12} = E_{12} \left(1 - \frac{v_{\rm coph}}{V_{\rm top}} \frac{1}{V_{\rm cop}V_{\rm total}}\right) \left(\frac{v}{\sqrt{2 V_{\rm coph} V_{\rm coph}} V_{\rm coph}} + \frac{v}{V_{\rm coph}}\right)$$

$$\begin{split} & = \sup_{t \in \mathcal{T}} - \lambda_{top} \lambda_{top} \quad \text{in} \quad \lambda_{top} - \lambda_{top} \lambda_{$$

The maximum power required at the MPVT level in already given by the maximum power

$$A_{12} = S_{12} \bigg(1 + \frac{\eta_{\rm equil}}{\eta_{\rm tot}} \frac{1}{\eta_{\rm tot} \eta_{\rm dates}} \bigg) \bigg(\frac{s}{(2\eta_{\rm e} \eta_{\rm tot} \eta_{\rm tot} \eta_{\rm tot} \eta_{\rm tot})} \bigg).$$

For an MPPT that is well-designed for a specific application, we can consider
$$\tau_{\rm depotency}$$
 . If the algorithm $\tau_{\rm depotency}$ will be adding to a bosoft-densy that allowed sheaps to export than 10% only

which is the product between power consumption and right duration, and inversignational to its gravimetric energy-density.

$$\mathcal{K}_{m} = \mathcal{F}_{m}\Gamma$$
 $\mathcal{K}_{m} = \mathcal{F}_{m}\Gamma$
 $\mathcal{K}_{m} = \mathcal{F}_{m}\Gamma$

$$= \begin{array}{ccc} \Psi u = I_{co} T_{ciget} \\ = & \Psi_{bol} H_{boloma} = I_{co} T_{ciget} \\ = & H_{boloma} = \frac{I_{co} T_{ciget}}{\Psi_{bol}} \end{array}$$

$$\begin{split} m_{\rm tot} &= \frac{m_{\rm tot}}{r_{\rm tot}} \\ &\approx \frac{m_{\rm tot}}{r_{\rm tot}} \frac{r_{\rm tot}}{r_{\rm tot}} \\ \end{split} \label{eq:mass_mass_sol}$$

6.3.2 Batteries Mass Predictor

Concerning the ballery, demans indirectly proportional to the energy it needs to store which is the product features power consumption and right duration, and inversels projectional to its gravimetric energy-density.

6.6 Preputation Systems Mass Prediction 8.8.1 Mitroduction

proportional to its generators energy density:
$$\begin{aligned} \mathcal{L}_{col} &= P_{col} \Gamma \\ &= \mathcal{L}_{col} &= P_{col} \Gamma_{col} \\ &= \mathcal{L}_{col} &= P_{col} \Gamma_{col} \\ &= \nabla m = P_{col} \Gamma_{col} \\ &= \nabla m = P_{col} \Gamma_{col} \end{aligned}$$

Tree

$$m_{\rm red} = \frac{m_{\rm biline}}{g_{\rm birth}}$$
 $g_{\rm birth}$
 $g_{\rm birth}$
 $g_{\rm birth}$

S.S. & Control Electronics B. B. S. Browner, B.B.P Summers

6.T Final Model 6.7.1 Introduction

After fraction formulated the state required process. The polar process analysis as developed all weight models, we can redraw the loop of Figure 6.1) I using all the separate models in Figure (6.7). I and Figure (6.7).2. The following diagram continues:

the province records incorrectables and incodifferance model."

1 1 2 1 1 1 1 2 2

Place \$14,1 directly coverage of rate of alle nationals Red.

C) Arconter ett a redovr sorligt ir boter tip redor sorlightmus tip strans til resuer som mateliassundig mitrates til fossillig rifraskrind ader poverat fightsores de gode andred jet inneglere sett soundere alle reseates.

O Accessor after purisde data must ano be chosen after parathing the florid control. This round most they be targe of each or enablery trip population regions.

Alexander must be chosen to make our model, as given in Figure (II. 4, Z.

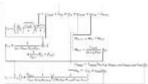


Figure (A.S.). Concerns of concerning the contract model.



Equivaji. (3.1) International valued regional product model. The families carrie decrease obtains the product of the officer of part.

6.7.2 Class Separation

| Variable | Value | Description | Unit | |
|-------------------------|-----------|--|-----------------------|-----------|
| C_L | 0.8 | Coefficient of Lift | | Symbol [|
| C _{D Acrufoll} | 0.013 | Coefficient of Drag | | Symbol [: |
| C _{p Parasite} | 0.006 | Coefficient of Drag | | Symbol [|
| e_o | 0.9 | Oswald Efficiency Factor | | Symbol [|
| Imax | 950 | Maximum sun irradiance | [W m ⁻²] | Symbol [6 |
| Ψ_{bat} | 684000 | Gravimetric Energy Density of Battery | [[kg+] | Symbol [6 |
| Knc | 0.32 | Mass density of solar cells | [log m ⁺] | Symbol [|
| $\kappa_{\rm edd}$ | 0.26 | Mass density of additional mass around solar punels | $[\log m^{+}]$ | Symbol [|
| k_{mppt} | 0.00042 | Mass to power ratio of MPPT | [log W-1] | Symbol [|
| k_{prep} | 0.008 | Mass to power ratio of Propulsion Systems | [log W-1] | |
| ρ_{af} | 0.44/9.81 | Structural Mass Constant of Airframe | [log m ⁺] | |
| ITL _{OR} | 0.15 | Mass of Avionics | (kg) | |
| Truc | 0.65 | Efficiency of step-down converter | | Symbol [|
| η_{sc} | 0.169 | Efficiency of solar cells | | Symbol [|
| 13ctor | 0.90 | Efficiency of curved solar panels | | Symbol [|
| Backey | 0.95 | Efficiency of battery discharge | | Symbol |
| Nove | 0.95 | Efficiency of motor controller | | Symbol [|
| Sachra | 0.95 | Efficiency of battery discharge | | Symbol [|
| North | 0.97 | Efficiency of gearbox | | Symbol [|
| Treat | 0.85 | Efficiency of motor | | Symbol [t |
| Truppt cour | 0.99 | Efficiency of DC to DC convertor of MPPT | | Symbol [6 |

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

Table (6.7).2: Class 2 of Parameters table

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.

$$\begin{split} & m = y_{\text{true}} + m_{\text{true}} + m_{\text{eff}} + m_{\text{eff}} + m_{\text{true}} + m_{\text{true}} \\ & = m = (m_{\text{true}} + m_{\text{true}}) + \left(\frac{C_{\text{true}}}{\rho_{\text{true}}} \left[\frac{1}{\rho_{\text{true}}} \right] + m_{\text{true}} + m_{true} + m_{\text{true}} + m_{\text{true}} + m_{\text{true}} + m_{\text{true}} + m$$

 $\Rightarrow \varsigma_{10}^2 \left(\varsigma_{11} \frac{1}{S^2} + \varsigma_4 S^{\kappa_1 - 2} \right) \le \frac{4}{27}$ 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.

Equation [6.7].01

 $\Longrightarrow E_{tot} \equiv \left(\frac{l_{max}T_{day}}{2t/2}k_{wthr}\right)A_{vt}(\eta)$ $\Rightarrow = \left(\frac{l_{max}T_{day}}{\pi f_{2}}k_{wthr}\right)A_{ic}(\eta_{zz}\eta_{chr}\eta_{inppr}) \iff \eta = \eta_{zc}\eta_{chr}\eta_{mppt}$ $\Rightarrow = \left(\frac{l_{sig}}{\pi_{f_a}}k_{sethr}\right)A_{sr}(\eta_{sr}\eta_{chr}\eta_{sepps})$ Equation [6.4]:03 $P_{level} = \frac{c_B}{C_L^{3/2}} \sqrt{\frac{(mg)^*}{A_W}} \sqrt{\frac{\epsilon}{\rho}}$ $A_v = \frac{\delta^*}{A_w}$ $\Rightarrow P_{level} = \frac{C_0}{C^{3/2}} \sqrt{\frac{A_r(mg)^3}{S^2}} \sqrt{\frac{2}{p}} \Leftrightarrow A_w = \frac{S^2}{A_r}$ $\Rightarrow P_{brevi} = \frac{C_0}{C^{3/2}} \sqrt{\frac{2A_r m^3 g^3}{\rho}} \sqrt{\frac{1}{S^2}}$ $\Rightarrow P_{largel} = \frac{C_D}{C^{3/2}} \left[\frac{2A_r g^3}{R} \right] \frac{m^3}{S^2}$ $\Rightarrow P_{tot} = \left(\frac{C_D}{C_L^{1/2}} \sqrt{\frac{2A_r g^3}{\rho}}\right) \left(\frac{m^{3/2}}{S}\right)$ Equation [6.3].06 $H_{tot} = \varphi A_{sr}$ $\Rightarrow E_{tot} = \left(\frac{I_{min}T_{day}}{R/2}k_{sethr}\right)A_{sr}$ Equation | 6.4|.02 $E = \phi A(\eta)$
$$\begin{split} E_{cor} &= \left(\frac{t_{max}T_{day}}{\pi/2}k_{sotar}\right)A_{cc}(\eta_{sc}\eta_{cbr}\eta_{soppt}) \\ \Rightarrow &\quad E_{tor} &= \left(\frac{t_{max}T_{day}}{\pi/2}k_{sotar}\right)A_{cc}(\eta_{rc}\eta_{cbr}\eta_{soppt}) \quad \Longleftrightarrow \quad E_{cor} &= P_{tot}\left(T_{day} + \frac{T_{night}}{\eta_{cory}\eta_{sorarg}}\right) \end{split}$$

Equation [6:5].01

Equation [6.5].02

 $m = m_{fixed} + m_{ef} + m_{ec} + m_{supel} + m_{bot} + m_{sense}$

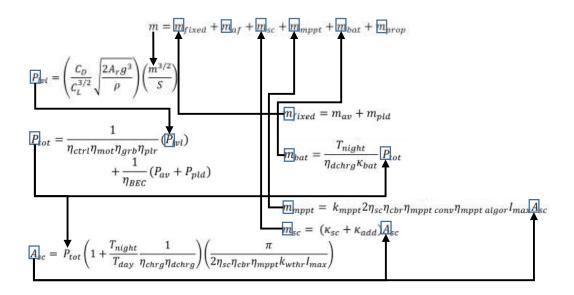
 $m_{fixed} = m_{av} + m_{pid}$

The Model Formed

| 01 | Contents |
|----------------|---|
| 02 03 04 | Title Analysis The Why behind this EPQ The Methodology to Answer the Question Posed by this EPQ |
| 05 | Schools of Focus |
| 06 | The Solar-powered Focus |
| 07 | The Sustained Focus |
| 08 | The Model Formed |
| 09 | Are the Schools of Focus |
| 40 | Connected? |
| 10 | The Autonomous Focus |
| 11 | Conclusions |
| 12 | So why aren't we seeing this right now? |
| 13 | Project Management |
| 14 | Motivations |
| 15 | Source Evaluation |
| 16 | Looking Back |
| 17 | Looking Ahead |
| | |

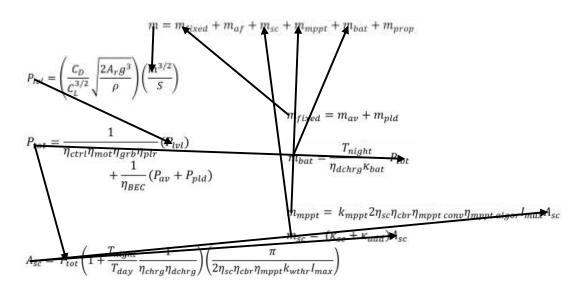
$$\begin{split} A_{sc} &= P_{tot} \left(1 + \frac{T_{night}}{T_{day}} \frac{1}{\eta_{chrg} \eta_{dchrg}} \right) \left(\frac{\pi}{2 \eta_{sc} \eta_{cbr} \eta_{mppt} k_{wthr}} \right) \\ P_{lvl} &= \left(\frac{C_D}{C_L^{3/2}} \sqrt{\frac{2 A_r g^3}{\rho}} \right) \left(\frac{m^{3/2}}{S} \right) \\ P_{tot} &= \frac{1}{\eta_{ctrl} \eta_{mot} \eta_{grb} \eta_{plr}} (P_{lvl}) \\ &+ \frac{1}{\eta_{BEC}} (P_{av} + P_{pld}) \end{split}$$

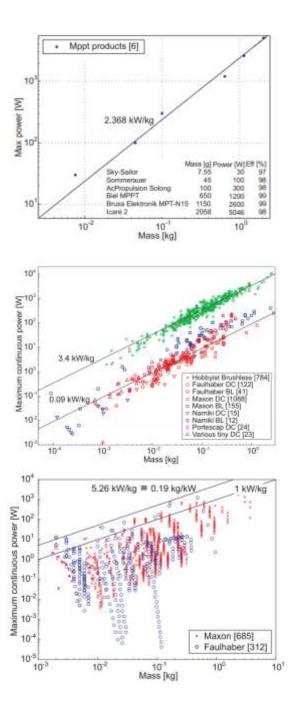
$$\begin{split} & m_{fixed} = m_{av} + m_{pld} \\ & m_{sc} = \left(\kappa_{sc} + \kappa_{add}\right) A_{sc} \\ & m_{bat} = \frac{T_{night}}{\eta_{dchro} \kappa_{hat}} P_{tot} \\ & m = m_{fixed} + m_{af} + m_{sc} + m_{mppt} + m_{bat} + m_{prop} \end{split}$$

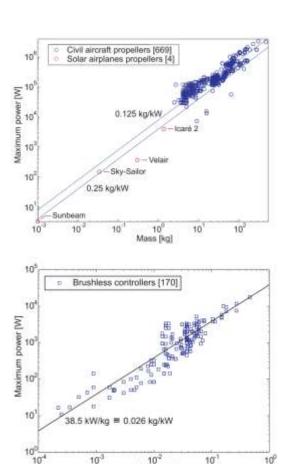


$$P_{lvl} = \begin{pmatrix} C_D \\ C_L^{3/2} \\ \end{pmatrix} \sqrt{\frac{2A_r g^3}{\rho}} \begin{pmatrix} \frac{1}{m^{3/2}} \\ \frac{1}{S} \\ \end{pmatrix} \begin{pmatrix} \frac{1}{m^{3/2}} \\ \frac{1}{\eta_{ctrl} \eta_{mot} \eta_{grb} \eta_{plr}} \\ \eta_{ctrl} \eta_{mot} \eta_{grb} \eta_{plr} \end{pmatrix} \begin{pmatrix} \frac{1}{\eta_{ctrl} \eta_{dchrg}} \\ \frac{1}{\eta_{ctrl} \eta_{mot} \eta_{grb} \eta_{dchrg}} \end{pmatrix} \begin{pmatrix} \frac{\pi}{2\eta_{sc} \eta_{cbr} \eta_{mppt} k_{wthr} l_{max}} \end{pmatrix}$$

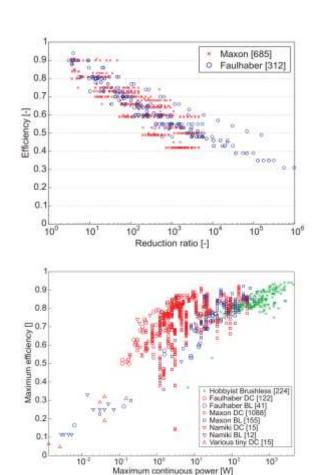
 $\Rightarrow m = k_{mppt} 2\eta_{sc}\eta_{cbr}\eta_{mppt\ conv}\eta_{mppt\ algor}I_{max}A_{sc}$

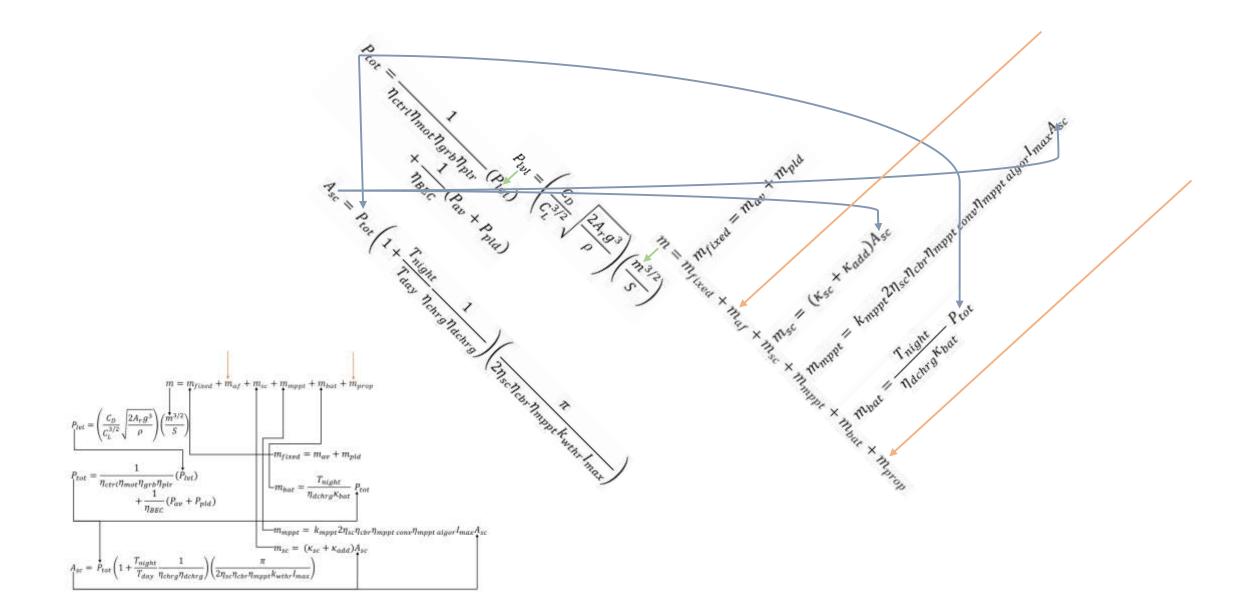






Mass [kg]





| 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_{pid} | 0.05 | Mass of the Payload | [kg] | |
| k_{wtkr} | 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 | [8] | 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.

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

| 34 1 5 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 | THE RESERVE OF THE PARTY. | | | |
|--|---------------------------|--|-----------------------|-----------------|
| Variable | Value | Description | Unit | |
| C_L | 0.8 | Coefficient of Lift | | Symbol [2.4].04 |
| $C_{DAerofoil}$ | 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 |
| Kadd | 0.26 | Mass density of additional mass around solar panels | $[kg\ m^{\cdot 2}]$ | 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_{achrg} | 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_{pir} | 0.85 | Efficiency of propeller | | Symbol [6.X].13 |
| | | | | |

$$\Rightarrow \zeta_{10}^2 \left(\zeta_{11} \frac{1}{S^2} + \zeta_4 S^{x_1 - 2} \right) \le \frac{4}{27}$$
 Equation [6.7].01

Class 3 of Parameters

| <u>Variable</u> | <u>Value</u> | Description | <u>Unit</u> | |
|-----------------|--------------|--------------------|-------------|-----------------|
| 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 <u>given the current technology today (that is used to determine the parameters) continuous and theoretically infinite flight is possible.</u>

Interconnectedness?

| 01 | Contents |
|----------------------|---|
| 02 03 04 | Title Analysis The Why behind this EPQ The Methodology to Answer the Question Posed by this EPQ |
| 05 06 07 08 | Schools of Focus The Solar-powered Focus The Sustained Focus The Model Formed |
| 09 | Are the Schools of Focus Connected? |
| 10 | The Autonomous Focus |
| 11 12 | Conclusions So why aren't we seeing this right now? |
| 13 14 15 | Project Management Motivations Source Evaluation |
| 16 17 | Looking Back Looking Ahead |

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

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

Input characteristics of existing technology into the model.

Take parameters and using data form a model.

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

| 01 | Contents |
|----------------------------|---|
| 02 03 04 | Title Analysis The Why behind this EPQ The Methodology to Answer the Question Posed by this EPQ |
| 05 06 07 08 09 | Schools of Focus The Solar-powered Focus The Sustained Focus The Model Formed Are the Schools of Focus Connected? |
| 10 | The Autonomous Focus |
| 11 12 | Conclusions So why aren't we seeing this right now? |
| 13 14 15 | Project Management Motivations Source Evaluation |
| 16 17 | Looking Back Looking Ahead |

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

| 01 | Contents |
|----------------------------|---|
| 02 03 04 | Title Analysis The Why behind this EPQ The Methodology to Answer the Question Posed by this EPQ |
| 05 06 07 08 09 | Schools of Focus The Solar-powered Focus The Sustained Focus The Model Formed Are the Schools of Focus Connected? |
| 10 | The Autonomous Focus |
| 11 | Conclusions |
| 12 | So why aren't we seeing this right now? |
| 13 14 15 | Project Management Motivations Source Evaluation |
| 16 17 | Looking Back Looking Ahead |

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?

| 01 | Contents |
|----------------------------|---|
| 02 03 04 | Title Analysis The Why behind this EPQ The Methodology to Answer the Question Posed by this EPQ |
| 05 06 07 08 09 | Schools of Focus The Solar-powered Focus The Sustained Focus The Model Formed Are the Schools of Focus Connected? |
| 10 | The Autonomous Focus |
| 11 | Conclusions |
| 12 | So why aren't we seeing this right now? |
| 13 14 15 | Project Management Motivations Source Evaluation |
| 16 17 | Looking Back Looking Ahead |

Lack of specific constraints set in designs.

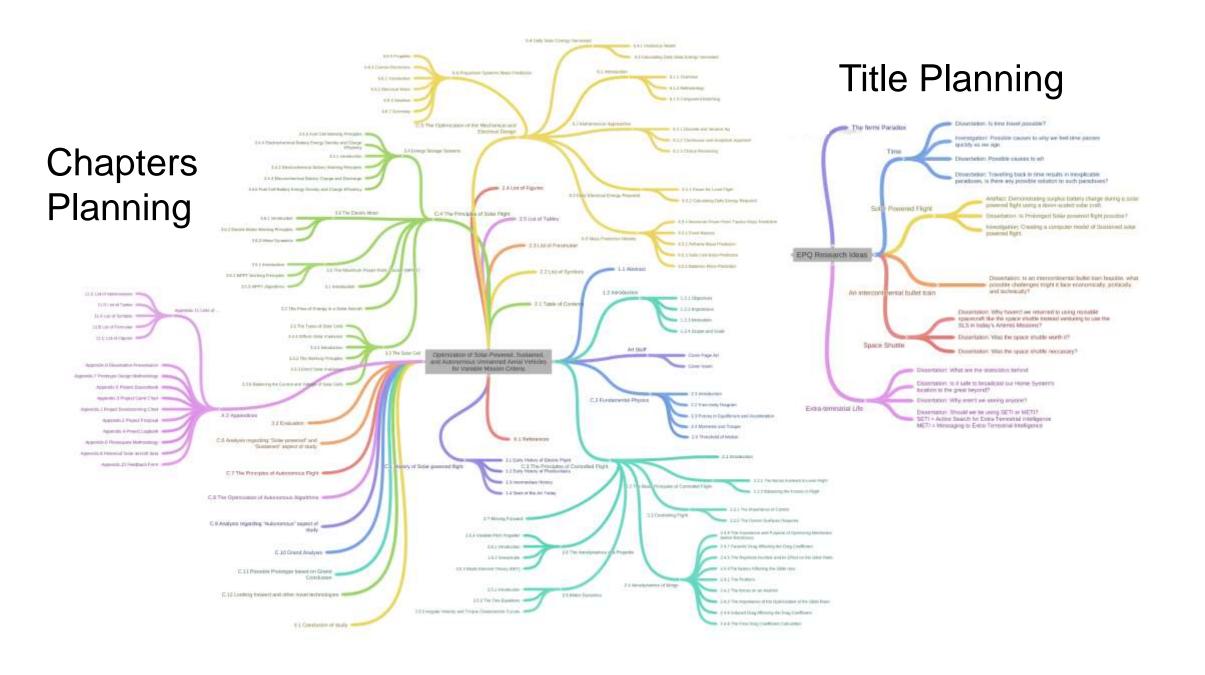
Lack of commercial viability.

Lack of incentive to switch due to existing aviation industry.

Scalability.

Project Management

| 01 | Contents |
|----------------|---|
| 02 03 04 | Title Analysis The Why behind this EPQ The Methodology to Answer the Question Posed by this EPQ |
| 05 06 07 | Schools of Focus The Solar-powered Focus The Sustained Focus |
| 08 | The Model Formed |
| 09 | Are the Schools of Focus Connected? |
| 10 | The Autonomous Focus |
| 11 | Conclusions |
| 12 | So why aren't we seeing this right now? |
| 13 | Project Management |
| 14 | Motivations |
| 15 | Source Evaluation |
| 16 17 | Looking Back Looking Ahead |



| Section Thre | re: Activities and timescales | Commence of the contract of |
|--------------|---|-----------------------------|
| | be carried out during the project: | How long this will take: |
| (1) | Initiat 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 | 1 Week |
| | Prepare Gantt chart for overall structure of project delivery Submit Project proposal form | |
| (3) | Gather information on existing aircraft fur brief history Gather information on the working principles of solar flight and general flight | 6 Wooks |
| (4) | Write-up of objectives (3), (4), (5), (6), and (7) | 3 Weeks |
| (5) | Carry out objectives (8), (9), and (10) | 8 Weeks |
| [6] | | 3 Weeks |
| (7) | | 2 Weeks |
| | Editing | 1 week |
| [9] | Presentation | 2 Week |
| | a. Produce the presentation | - meen |
| | b. Prepare for ural presentation | SERVICE SERVICES |
| | c. Carry-out gral presentation | 28 Weeks 4- Total Time |

- Wilestone: Finish Filling in project proposal Target date (set by tutor assessor): 30th January
- (2) Mikastone: Finish Mid Project review Target date (set by tutor-assessor): 17th April
- (3) Milestone: Finish First draft of project Target date (set by futor assessor): 1st September
- (4) Milestone: Final Project submission Target date (set by futor assessor): 1st Hovember
- (5) Wildstone: Final Oral Presentation Target date (set by tutor assessor): Approx. End of Hovember
- [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 provise 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 raid 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
 - How power delivery works during the day and during the night (Solar Panel → Charge Controller → Satteries → etc.)
 - 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
- (b) 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.)
 - Energy constraints (Batteries, Solar Panels, Battery Charge Controllers, Accompanying flight electronics)
 - Metrological constraints (High winds, cold/hot air updrafts/downdrafts)
- (7) Frovide 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 Fission 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. Staff to be able. Staff to be done concurrently | | Optimization of the Glide Ration | PAGE | | 3.6.2 Electric Motor Working Principles | PAGE | | | PAG |
|----------|---|----------|--|------|-------|--|------|-------------------|--|-----|
| | | | 2.4.4 The Factors Affecting the Glide Ratio | PAGE | | 3.6.3 Motor Dynamics | PAGE | X.2 Appendices | | PAG |
| | Trave missing diagnama | | 2.4.5 The Reynolds Number and its Effect on the | | 200 | | mane | Appendix.1 | Project Brainstorming Chart | PAG |
| | Toucke phoce ait sources ared properly | | Gilde Ratio | PAGE | C.5 | The Optimization of the Mechanical and Electrical Design | PAGE | Appendix.2 | Project Proposal | PAG |
| | Add proper endence to the yellow sections of fest | | 2.4.6 Induced Drag Affecting the Drag Coefficient | PAGE | | 6.1 Introduction | PAGE | Appendix.3 | Project Gantt Chart | PAG |
| | Jodain Project Logbook | | 2.4.7 Parasitic Drag Affecting the Drag Coefficient | PAGE | | 6.1.1 Overview | PAGE | Appendix.4 | Project Logbook | PAG |
| | Andrew Project Styrephood | | 2.48 The Final Drag Coefficient Calculation | PAGE | | 6.1.2 Methodology | | Appendix.5 | Project Sourcebook | PAG |
| | Security of the self three children of the security dusts | | 2.4.9 The Importance and Purpose of Optimizing | | | 6.1.3. Component Matching | PAGE | Appendix fi | Flowsquare Methodology | PAG |
| | CONTRACTOR OF THE PARTY OF THE | | Mechanics before Electronics | PAGE | | 6.2 Mathematical Approaches | PAGE | Appendix 7 | Promtype Design Methodology | PAG |
| 2.1 Ta | ble of Contents | | 2.5 Motor Dynamics | PAGE | | 6.2.1 Discrete and Iterative Approach | PAGE | Appendix 8 | Historical Solar sinzaft data | PAG |
| | A LONG TO CONTROL OF THE CONTROL OF | | 2.5.1 Introduction | PAGE | | 6.2.2 Continuous and Analytical Approach | PAGE | Appendix 9 | Historical Solar aircraft data Dissertation Presentation | PAG |
| | Cover Page | 01 | 2.5.2 The Two Equations | PAGE | | 6.2.3 Choice Reasoning | PAGE | Appeinds: 10 | Faceback Form | PAG |
| | Cover Insert | 0.2 | 2.5.3 Angular Velocity and Torque Characteristic Curve | PAGE | | 6.3 Daily Electrical Energy Required | PAGE | Appendix.11 | Lists of | PAG |
| 1.1 | WENNER | No. | 2.6 The Aerodynamics of a Propeller | PAGE | | 6.3.1 Power for Level Flight | PAGE | 11.A | List of Symbols | PAG |
| 1.2 | Introduction | PAGE | 2.6.1 Introduction | PAGE | | 6.3.2 Calculating Daily Energy Required | PAGE | 11.B | List of Formulae | PAG |
| 1.00 | 1.2.1 Objectives | PAGE | 2.6.2 Streamtube | PAGE | | 6,4 Daily Solar Energy Harvested | PAGE | 11.C | List of Figures | PAG |
| | 1.2.2 Importance | PAGE | 2.6.3 Blade Element Theory (BET) | PAGE | | 6.4.1 Irradiance Model | PAGE | 11.D | List of Tables | PAG |
| | 1.2.3 Motivation | PAGE | 2.8.4 Variable Pitch Propeller | PAGE | | 6.4.2 Calculating Daily Solar Energy Harvested | PAGE | 11.E | List of Abbreviations | PAG |
| | 1.2.4 Scope and Goal | PAGE | 2.7 Moving Forward | PAGE | | 6.5 Mass Prediction Models | PAGE | | | |
| | 1.2.4 Scope and Goal | | | | | 6.5.1 Fixed Masses | PAGE | Back-cover Insert | | PAG |
| 2.1 | Table of Contents | PAGE C.4 | The Principles of Solar Flight | PAGE | | 6.5.2 Airframe Mass Prediction | PAGE | Back-cover | | PAG |
| 2.2 | List of Symposis | PAGE | 3.1 Introduction | PAGE | | 6.5.3 Solar Cell Mass Prediction | PAGE | | | |
| 2.3 | List of Formulae | PAGE | 3.2 The Flow of Energy in a Solar Aircraft | PAGE | | 6.5.4 Maximum Power Point Tracker Mass Prediction | PAGE | | | |
| 2.4 | List of Figures | PAGE | 3.3 The Solar Cell | PAGE | | 6.5.5 Batteries Mass Prediction | PAGE | | | |
| 2.5 | List of Tables | PAGE | 3.3.1 Introduction | PAGE | | 6.6 Propulsion Systems Mass Prediction | PAGE | | | |
| 4 | | | 3.3.2 The Working Principles | PAGE | | 6.6.1 Introduction | PAGE | | | |
| C.1 | History of Bolar-powered Flight | PAGE | 3.3.3 Direct Solar Irradiance | PAGE | | 6.6.2 Electrical Motor | PAGE | | | |
| | 1.1 Early History of Electric Flight and Photovoltaics | PAGE | 3.3.4 Diffuse Solar irradiance | PAGE | | 6.6.3 Gearbox | PAGE | | | |
| 0.2 | Fundamental Physics | PAGE | 3.3.5 The Types of Solar Cells | PAGE | | 6.6.4 Control Electronics | PAGE | | | |
| - | 2.1 Introduction | PAGE | 3.3.6 Balancing the Current and Voltage of Solar | | | 6.6.5 Propeller | PAGE | | | |
| | 2.2 Free-body Diagram | PAGE | Cells | PAGE | | 6.6.7 Summary | PAGE | | | |
| | 2.3 Forces in Equilibrium and Acceleration | PAGE | 3.4 Energy Storage Systems | PAGE | | 6.7 Final Model | PAGE | | | |
| | 2.4 Moments and Torque | PAGE | 3.4.1 Introduction | PAGE | 0.6 | Ansiya's regarding "Sour-covered" and "Sustained" espect | | | | |
| | 2.5 Threshold of Mation | PAGE | 3.4.2 Electrochemical Battery Working Principles | PAGE | 40.00 | of shafe | PAGE | | | |
| | | | 3.4.3 Electrochemical Battery Charge and | | | of surviva | | | | |
| 0.3 | The Principles of Controlled flight | PAGE | Discharge | PAGE | 0.7 | The Principles of Autonomous Flight | PAGE | | | |
| | 2.1 Introduction | PAGE | 3.4.4 Electrochemical Battery Energy Density and | | 20.0 | WEST TO SELECT A SECURITY OF THE SECURITY OF T | PAGE | | | |
| | 2.2 The Basic Principles of Flight | PAGE | Charge Efficiency | PAGE | C.8 | The Optimization of Autonomous Algorithms | PAGE | | | |
| | 2.2.1 The Forces Involved in Level Flight | PAGE | 3.4.5 Fuel Cell Working Principles | PAGE | 0.9 | Analysis regarding "Autonomous" aspect of study | PAGE | | | |
| | 2.2.2 Balancing the Forces in Flight | PAGE | 3.4.6 Fuel Cell Battery Energy Density and Charge | | | | | | | |
| | 2.3 Controlling Flight | PAGE | Efficiency | PAGE | C.10 | Gland Analysis | PAGE | | | |
| | 2.3.1 The Importance of Control | PAGE | 3.5 The Maximum Power Point Tracker (MPPT) | PAGE | C.11 | Possitive Prototype based on Grand Concusion | PAGE | | | |
| | 2.3.2 The Control Surfaces Required | PAGE | 3.5.1 Introduction | PAGE | | | | | | |
| | 2.4 Aerodynamics of Wings | PAGE | 3.5.2 MPPT Working Principles | PAGE | C.12 | Looking forward and other navie technologies | PAGE | | | |
| | 2.4.1 The Problem | PAGE | 3.5.3 MPPT Algorithms | PAGE | 3.1 | | PAGE | | | |
| | 2.4.2 The Forces on an Aerofoli | PAGE | 3.6 The Electric Motor | PAGE | 3.2 | Conclusion of study | PAGE | | | |
| | 2.4.3 The Importance of the Optimization of the | | 3.6.1 Introduction | PAGE | 3.6 | The state of the s | PAGE | | | |

Motivations

| 01 | Contents |
|----------------------------|---|
| 02 03 04 | Title Analysis The Why behind this EPQ The Methodology to Answer the Question Posed by this EPQ |
| 05 06 07 08 09 | Schools of Focus The Solar-powered Focus The Sustained Focus The Model Formed Are the Schools of Focus Connected? |
| 10 | The Autonomous Focus |
| 11 12 | Conclusions So why aren't we seeing this right now? |
| 13 | Project Management |
| 14 | Motivations |
| 15 | Source Evaluation |
| 16 | Looking Back |
| 17 | Looking Ahead |
| | |

The promise of solving world-problems.

The proximity to my chosen field of studies.

Continuation of Practical Sustainability.

Source Evaluation

| 01 | Contents |
|----------------------------|---|
| 02 03 04 | Title Analysis The Why behind this EPQ The Methodology to Answer the Question Posed by this EPQ |
| 05 06 07 08 09 | Schools of Focus The Solar-powered Focus The Sustained Focus The Model Formed Are the Schools of Focus Connected? |
| 10 | The Autonomous Focus |
| 11 12 | Conclusions So why aren't we seeing this right now? |
| 13 14 | Project Management Motivations |
| 15 | Source Evaluation |
| 16 17 | Looking Back Looking Ahead |
| | |

X.1 References

[16]

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Looking back

| 01 | Contents |
|----------------------------|---|
| 02 03 04 | Title Analysis The Why behind this EPQ The Methodology to Answer the Question Posed by this EPQ |
| 05 06 07 08 09 | Schools of Focus The Solar-powered Focus The Sustained Focus The Model Formed Are the Schools of Focus Connected? |
| 10 | The Autonomous Focus |
| 11 12 | Conclusions So why aren't we seeing this right now? |
| 13 14 15 | Project Management Motivations Source Evaluation |
| 16 | Looking Back |
| 17 | Looking Ahead |

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

| 01 | Contents |
|----------------------------|---|
| 02 03 04 | Title Analysis The Why behind this EPQ The Methodology to Answer the Question Posed by this EPQ |
| 05 06 07 08 09 | Schools of Focus The Solar-powered Focus The Sustained Focus The Model Formed Are the Schools of Focus Connected? |
| 10 | The Autonomous Focus |
| 11 12 | Conclusions So why aren't we seeing this right now? |
| 13 14 15 | Project Management Motivations Source Evaluation |
| 16 | Looking Back |
| 17 | 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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