The University of Akron
IdeaExchange@UAkron

Williams Honors College, Honors Research Projects | The Dr. Gary B. and Pamela S. Williams Honors College

Spring 2020

Solar-Powered Exploration of the Venus Atmosphere

Marc Migliozzi
The University of Akron, mjm321@zips.uakron.edu

Cory Everman
The University of Akron, cme80@zips.uakron.edu

Rebecca Buerhle
The University of Akron, rab174@zips.uakron.edu

Umar Muhammed
The University of Akron, um2@zips.uakron.edu

Steven Abbate
The University of Akron, sda40@zips.uakron.edu

Author
Marc Migliozzi, Cory Everman, Rebecca Buerhle, Umar Muhammed, Steven Abbate, and Chase Champagne

NASA Capstone Project

Solar-Powered Exploration of the Venus Atmosphere

Steven Abbate
Rebecca Buehrle
Chase Champagne
Cory Everman
Marc Migliozzi
Umar Muhammed

The University of Akron, Akron, OH, 44325

Dr. Shao Wang

FY20 GRC-Academia Senior Capstone Project Collaboration
Sponsored by
NASA Glenn Research Center
Cleveland, Ohio

NASA Capstone Project

Solar Powered Exploration of Venus

Abstract

The objective of this study was to design a solar powered, unmanned aircraft to orbit in the upper Venus atmosphere and search for signs of alien life. Topics of flight conditions, signs of life, basic mission plan, source of power, design process, instrumentation, and final designs are covered. Solar energy is ideal for this type of mission because it is the only reliable and abundant energy source accessible for long term space travel. The target altitude, being 60 to 70 km, has winds of up to 95 m/s. The aircraft will need to remain stable under such conditions. Due to the high winds that the aircraft must overcome, the mission may be limited to 3 days on exclusively solar power. Other methods are explored to prolong the longevity of the mission.

Contents

I. Introduction and Background

The team was tasked in designing a mission to deploy a solar powered aircraft in the upper Venus atmosphere to perform scientific investigations including a search for life. The first half of this project included understanding the mission conditions and prerequisites for designing. Close collaboration with NASA allowed for the team to conduct preliminary research based off real missions that have been successful in the past. Conditions imperative for this assignment included environmental conditions, planetary orbit, searching for life, correct materials, instrumentation, entry, and deployment. Parameters such as temperature, change in temperature with altitude, pressure, atmospheric composition, and wind velocity were provided by NASA to assist in calculations.

1. Orbital Information

To understand the task at hand, Venus and its unique characteristics must be understood. Venus is the second planet from the Sun. It is one of the only planets in the solar system that does not have a counterclockwise rotation. Due to a 177° rotation from the vertical axis, it rotates in a clockwise fashion. Due to this nearly upright rotation, the planet does not experience noticeable season changes. The planet's rotation period is 243 Earth days, and a day-night cycle takes 117 Earth days. Because of this, the aircraft will be in sunlight during most of its flight. Venus completes one revolution about every 225 Earth days, and the orbit is almost a perfect circle unlike most other planets such as Earth as shown in **Figure 1**. ("Venus")

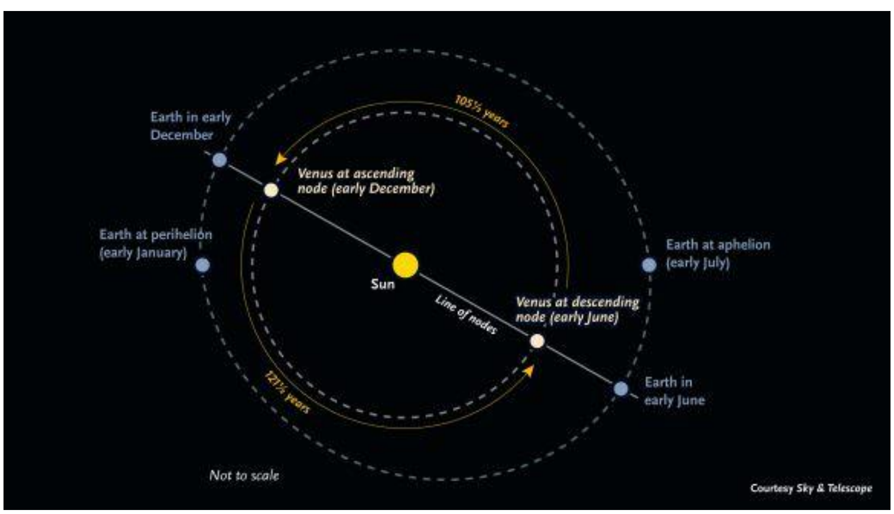

Figure 1: Venus' Orbit compared to Earth's around the Sun (Williams).

II. Methodology and Approach

A. Search for Life

1. Environmental Conditions

In order to identify places that could provide the best possible chance for life to exist, it helps to understand the environments in which life can survive. The surrounding temperatures and atmospheric pressure must be within appropriate ranges for life to exist. Using Earth as a point of reference, most life forms can live and reproduce within a temperature range of -15^oC to115^oC with an atmospheric pressure of around 1 bar (McKay). Looking at the surface of Venus, the pressures and temperatures are both much too large to sustain life. Surface conditions on the planet can reach temperatures over 450^oC and pressures almost one hundred times that on Earth. This harsh environment makes the probability of finding life near the surface very small. However, further up in the atmosphere of Venus, around 60 km, the temperatures and pressure become much more Earth-like at around -10^oC and 0.2 bar respectively. This altitude range should provide the best chance for discovering life.

In addition to pressure and temperature, the chemical composition of atmosphere plays a key role in developing and sustaining life. Certain chemicals, as well as UV light from the sun, provide a source of energy for life to feed on. Three key chemicals that are ideal to help sustain life are Carbon Dioxide (CO_2), Nitrogen (N_2), and water (H_20) (McKay). All three of these can be found in various amounts in the atmosphere of Venus. In fact, $C0_2$ is the most common chemical compound, accounting for 96% of the atmosphere. Nitrogen is the second most common compound at 3.5%. Although not abundantly available in the atmosphere, H_2O can also be found on Venus. Trace amounts of water can be found throughout the sulfur clouds found around 60 km from the surface (Open Stax). This chemical composition in addition to the temperatures and pressures found at altitudes around 60 km suggest that this altitude may provide ideal conditions for life to exist.

2. Signs of Life

Finding the appropriate environment for life to exist is first step in searching for life. The next step is knowing what to look for. One strategy to find microscopic life forms would be to look for traces of either Methane or Nitrous Oxide. These chemical compounds are both very common byproducts of biological processes performed by lifeforms. These presence of either of these could indicate that some form of life is involved in their production ("Signs of Life").

In addition to the existence of Methane or Nitrous Oxide, another method that could be explored when searching for life would be searching for discrepancies in light absorption. When examining the absorption of various wavelengths of light within Venus's atmosphere, there are small patches where UV light in the 330-500 nm range is absorbed. These mysterious dark spots could be a sign of that a microscopic lifeform is absorbing energy from these UV waves. If a drone could explore these dark spots, it may also fight other signs of life present (Limaye).

B. Traversing the Planet

Once deployed on Venus, any drone will need an energy source. In order to remain in operation for an extended time, solar energy is the ideal choice for power. Since Venus is much closer to the Sun than Earth is, the amount of solar energy available is much larger. However, due to the thick layer of clouds covering the planet, barely any of the Sun's energy reaches the surface. Above the cloud layers though, at around the 60 km altitude mark, solar energy is much more prevalent (Landis). This in combination with this altitude's optimum conditions to support life, make this the ideal altitude for this mission. However, extreme winds at these altitudes will need to be taken into consideration if the craft is to sustain flight at these altitudes.

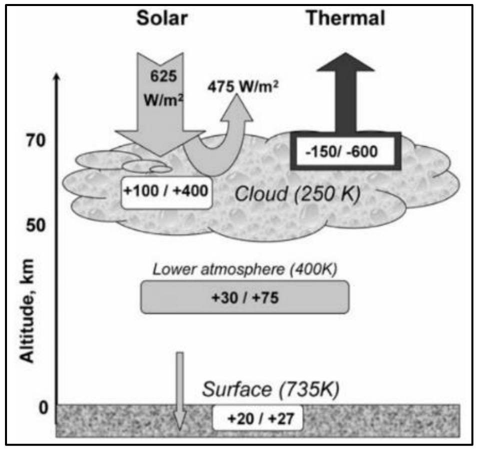

Figure 2: Solar irradiance on Venus (Titov).

C. Mathematical Analysis and Design Process

As previously mentioned, the ideal atmospheric conditions lie in the 60 to 70km range. It was decided that target altitude for the drone would be just on top of the sulfur clouds, at the 66km mark. At these altitudes, however, wind speed is the biggest issue for successful flight. The average wind speed at 66 km being 94 m/s and the crosswind is small at about 1 m/s as shown in **Figure 3**. These do not vary by a large amount and therefore will not cause a stability problem which had been a major concern.

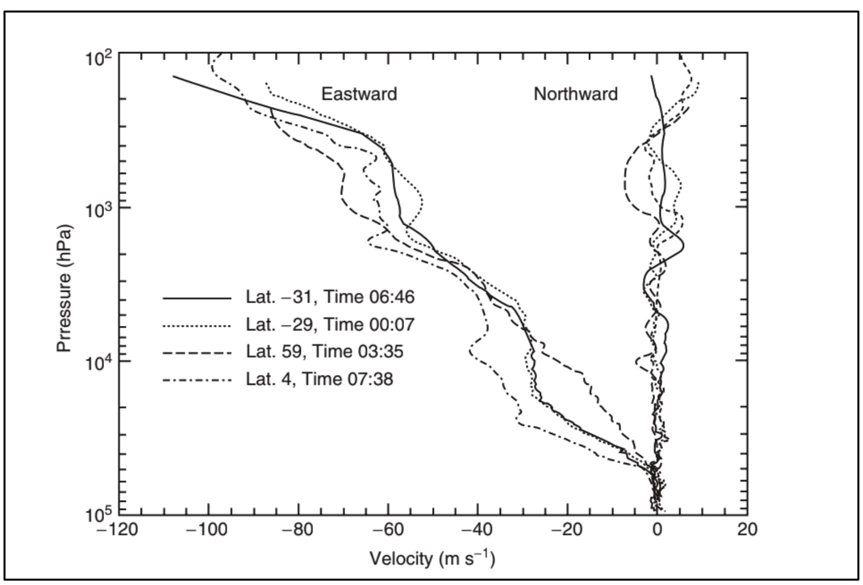

Figure 3: Wind speeds and crosswind by altitude and the amount of variation (Gierasch).

Starting with the entry into Venus a case study done on the Apollo missions was referenced to develop an approximate model starting from a speed of 12 m/s, an entry angle of 10 degrees, and an altitude of 180 km (Tetzman). A low entry angle was chosen in order to decrease the space craft to subsonic speeds at an altitude of 71 km where parachutes could then open and deploy the drone.

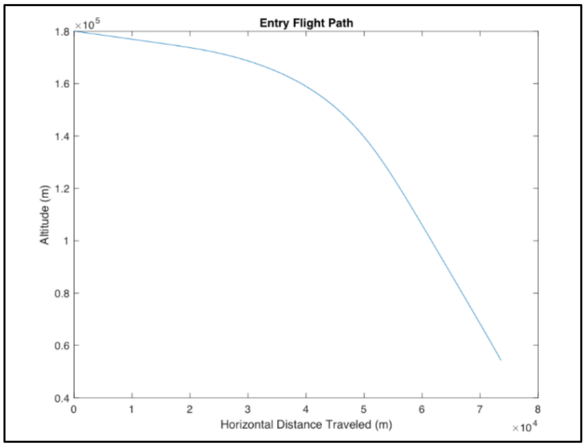

Figure 4: Flight path approximation.

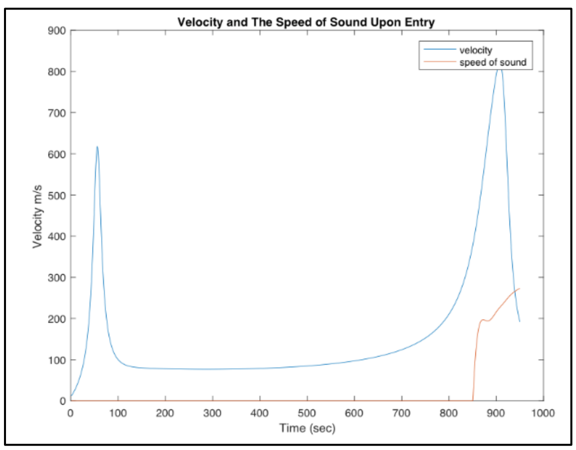

Figure 5: Velocity and speed of sound approximation.

In order to fit into a launch capsule and to remain light, the drone itself was designed with limitations not to exceed a length of 5 meters to fit inside the launch capsule and to have a maximum weight of 45 lbs. The airfoil of the wing is an S1223 il NACA airfoil designed for flying at low Reynolds numbers. The fuselage was designed to hold all the instruments near the front of the plane to ensure the proper location of the center of gravity. Using these constraints at the maximum condition it was determined that a thrust of 3.5 N would be required from the propeller in order to obtain a steady flight velocity of 26 m/s in order to keep the drone airborne. This corresponded to a Reynolds number of 230,000. Using JavaProp, a propeller was designed to fit the thrust needs of the drone. Further information on the propeller can be seen in Appendix C. This propeller was assumed to have an 80% efficiency.

Using this data and by summing all the forces, the flight path could be modeled, and the equilibrium point of the drone was determined to occur at 225 seconds.

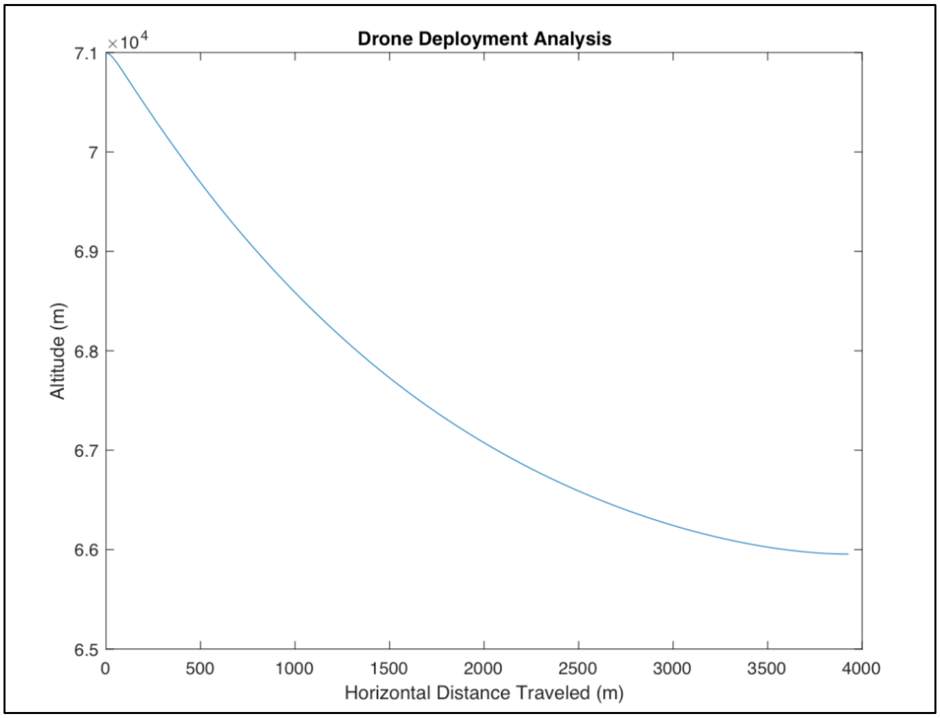

Figure 6: Flight path of drone upon deployment to desired altitude equilibrium point.

By summing all the moments of the aircraft due to the forces acting on the wing a tail, and by using data on the airfoil from the NACA website to find the 3D lift coefficient slope, the drone design was optimized to find the minimum requirements to ensure longitudinal static stability. This resulted in a center of gravity that is located at 29% of the chord of the wing and a static margin of 1%.

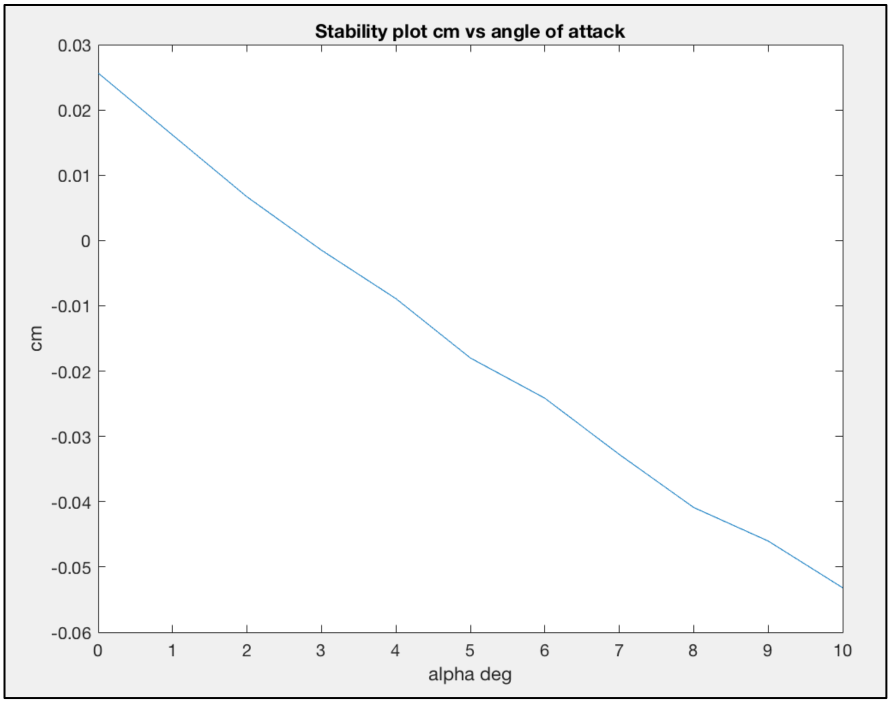

Figure 7: Coefficient of moment versus angle of attack for aircraft.

The winglets on the edge of the wing were trimmed in order to reduce energy loss due to vortices from the wing having a low aspect ratio, and a slight dihedral was added to ensure lateral static stability of the aircraft. MATLAB codes used in this design process can be seen in Appendix D.

III.Discussion of Results and Findings

A. Mission Plan

1. Basic Launch Information

According to NASA, Venus launch opportunities occur about every 19 months. The solar orbit of the launch vehicle will need to be adjusted to take it to Venus. A specific path will need to be taken to minimize the energy needed. To minimize the energy needed by the launch vehicle, it is known that the spacecraft's aphelion (furthest from the sun during orbit) is the distance of Earth's orbit. However, the perihelion (closest to the sun during orbit) will need be on Venus' orbit ("Basics of Spaceflight") (see **Figure 8** below). However, to get to Venus, the spacecraft in trajectory will need to be at the perihelion at the exact same time that Venus will get there. So, the goal is to decrease the periapsis of the spacecraft but also so that the spacecraft as well as the planet reach the target meeting at the same time. The launch vehicle will accelerate opposite the Earth's rotation after rising above the atmosphere to decrease the orbital energy at aphelion, therefore decreasing the periapsis.

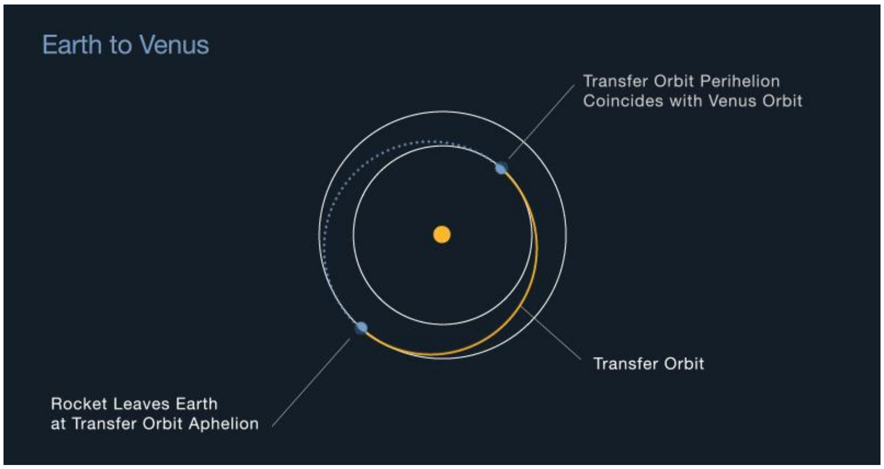

Figure 8: Getting to Venus ("Venus").

2. Launch Vehicle Specifics

A multi-stage launch vehicle will be used to deploy the aircraft. According to guidelines established by NASA, the diameter of the launch vehicle should be at most 5 meters. There are many options for the launch vehicle, but it was decided to base the design off the Atlas V vehicle, which had used been used to launch the Curiosity rover to Mars. The maximum diameter is 3.8 meters, which is less than the maximum allowed. After the first stage has been exhausted of fuel used for the initial launch to get to the upper atmosphere, it will be discarded. From here, the second stage will use its boosters to align itself to be on trajectory to Venus. Once on trajectory, the boosters will separate with only the cruise stage module attached to the probe. From here, the probe will coast all the way to Venus without the use of any further fuel.

3. Drone Deployment

Upon arrival at Venus, an aeroshell containing the designed drone will detach from the probe and begin its decent to the surface. When the aeroshell slows to subsonic speeds, a parachute will be deployed to further slow the decent. Since the 60 to 70 km altitude range appears to be the ideal range to find life, this will be the target altitude for drone deployment. As the aeroshell approaches a height of 70 km, the heat shield will detach from the shell and fall to the surface. Once clear of the heat shield, the drone will deploy from the falling shell and begin its surveying. The drone will move at a speed of 64 m/s and should survive in sunlight for 3 days before hitting night.

B. Final Designs

1. Drone

The final design of the drone will have a 4.5m wingspan with a 0.6m chord and will be 2.3m in length. An assembly of the model can be seen below, with more detailed measurements provided in Appendix A.

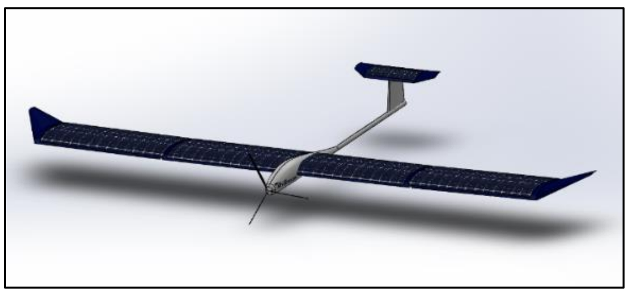

Figure 9: Drone model.

The drone will have foldable wings to allow it to fit into the deployment vessel. A simple compression spring mechanism will allow the wings to fold while being stored and expand once free from the aeroshell. Hinges on the bottom of the wing keep the wing in position for flight.

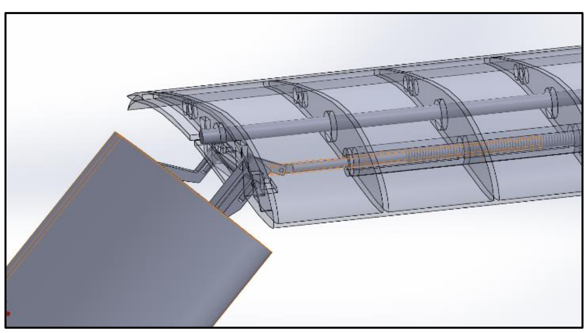

Figure 10: Wing folding mechanism.

2. Aeroshell

Based on recommendations from both NASA and Dr. Wang, in order to simplify the design process, the aeroshell design was based on a preexisting shell. The team decided the design of the of the Apollo command module would meet the necessary requirements. (“Command”). In order to fit the drone and to allow for easy deployment, the Apollo shell was flipped upside down, with the head shield instead on the narrow side. This approach method is like that of the Galileo probe. The shell can be seen below in **Figure 11** and further measurements can be found in Appendix A.

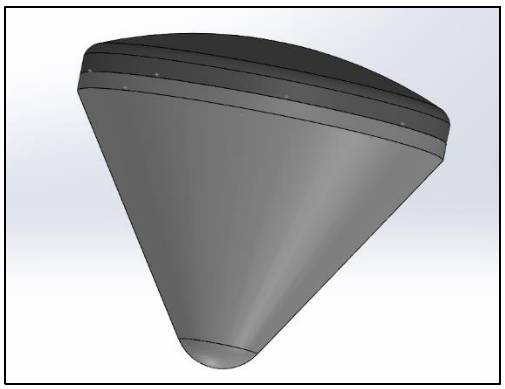

Figure 11: Aeroshell model.

3. *Materials*

Choosing a suitable material is crucial to ensure the aircraft and aeroshell will be able to accomplish its task. The aircraft material must be lightweight, suitable the operating temperatures, withstand sulfuric acid, and cost effective. For these reasons, Aluminum 2024 and Aluminum 7075 were chosen for the aircraft skin and frame. In order to prevent the Aluminum from degrading in the sulfuric acid clouds, a chemLINE784 coating will be used ("784”).

The coating is made of cross links with an ether (carbon-oxygen-carbon) linkage, which allows it to withstand 98% sulfuric acid, is UV resistant, and withstands up to 400 degrees Fahrenheit. The recommended thickness that the coating must be ranges between 12-14 millimeters and can easily be applied. The polymer coating can be force cured or cures with ambient or low temperature. While there are many coating options, this one was decided to be the most suitable for this application, being able to withstand a high concentration of sulfuric acid.

The aeroshell will be made of the same materials as the Apollo command module. It will consist of a back shell and heat shield. These two parts will be made of the same materials, although the heat shield will be thicker. The structure will consist of an aluminum honeycomb structure that is between two graphite epoxy sheets. The outside will be covered with another honeycomb structure made of a phenolic compound (“Mars Exploration”). Honeycomb structures are used because they work well at dissipating heat.

4. Wing Stress Analysis

An Ansys model was created to look at the deformation and stresses occurring on the aircraft wings. A static structural analysis was used on the model. A fixed support, as shown in Appendix B, Figure B.1, was placed on the surface of the wing that connects to the fuselage. On the underside of the wing, a force of 45 pounds was applied. This can be seen in Appendix B, Figure B.2. The wings were assigned the material Aluminum 2024. The properties of Aluminum 2024 used by Ansys are in **Table 1** (“Aluminum”).

Table 1: Aluminum 2024 properties.

Material	Aluminum 2024
Density	0.100 lb/in^3
Modulus of Elasticity	10600 ksi
Poisson's Ratio	0.33

The resulting deformation of the wind is shown in **Figure B-3**. The max deformation is 0.0012ft and occurs at the wing tip. The resulting stress can be seen in **Figure B-4**. The max stress is 20987 psf and occurs at the trailing edge of the airfoil, where the wing connects to the fuselage. This can be seen in **Figure B-5.**

C. Power

Traditional silicon cells are the norm for on Earth applications: they are simple, cheap, have worked for years. Space travel, on the other hand, relies on multijunction photovoltaics. The semiconductors used are not silicon based. Instead, they use III-V compound semiconductors. For the panels, triple-junction cells made up of the following three layers - GaInP/GaInAs/Ge - were chosen. The top layer of GaInP absorbs higher energy (higher frequency) wavelengths while also letting lower energy radiation pass through for absorption into the lower layers.

These cells are more expensive when compared to silicon but give us the characteristics needed for space travel. The first necessary characteristic was flexibility. It is important to have a cell that can match the contour of the wings so that the panels do not inhibit the airfoils characteristic to create lift. The chosen cells can bend to a curve radius of up to 95mm. (King) This allows for coverage of almost the entire wing, leading edge to trailing edge, in solar cells. These cells can achieve this while still maintaining a thin profile, with an actual cell thickness measuring a just small fraction of a centimeter (King). Another necessary characteristic is radiation resistance. These cells have a history of success in space travel. Data shows that these calls can deliver power at a consistent rate for several years despite these harsh conditions (King)(Takamoto). These multijunction solar cells are still a relatively new technology research into improving these resistivity characteristics is only just getting started. The solar cells will be placed above and below the wing. The cells on top of the wing will receive the direct sunlight and provide most of the power. The cells on the bottom will receive extra reflected sunlight from the Venus atmosphere. The cells will have a thin antireflective coating for maximum absorption

To fully understand the capacity of these solar cells, it is important to understand the expected efficiency, as well as the irradiance. As for efficiency, considerations of where the spacecraft will be orbiting must be explored. At the chosen altitude of 60 to 70km above the surface of Venus, thirty percent efficiency is expected, as well as an irradiance value of about 559.2W/m^2.m^2. (Landis). This altitude is a good compromise for power generation as it is an area where the thick clouds that make up the atmosphere begin to break up. It is also preferred when compared to low atmosphere orbits as the solar intensity becomes greater as the altitude increases. With wing hinges, gaps between solar arrays, and intense wing curvature in mind, calculations suggest an allowance of 5.4 square meters of solar panels to cover the wings and tail of the aircraft. While the drone is in the sun, a consistent power generation just over 900 Watts is to be expected. This will be sufficient to power the motor and all the instruments on board.

A battery is also an important part of the power system. While the panels will provide direct power to the plane, it is important to have a backup power supply in case there is a malfunction in any of the solar arrays, or if the craft needs an extra amount of power to overcome an unforeseen obstacle. Lithium Ion batteries are the best option for space applications. The craft will be fitted with a 60-ampere hour space cell from a company called EaglePicher Technologies. This battery can operate anywhere from –20 to 60 degrees Celsius, as well as provide enough power to keep systems running in the event of an emergency.

Lastly, an electric AC motor will be used to power the drone. Calculations account for a motor that can spin a propeller at 3600rpm and can provide a thrust of 3.4N. Moving at 64m/s, a horsepower value of approximately 1/3. An inverter will convert the direct current from the solar cells into the needed alternating current for the motor.

D. Instruments

To perform the scientific investigations and search for potential life, the drone will need to be fitted with many instruments. For this mission, the following instruments were chosen: relay communication package, micro camera, ultraviolet imaging spectrometer, gas chromatograph, and a telescope. Many of the instruments selected were found for comparable applications. Any instruments for a real mission to Venus would call for custom made devices.

The aircraft will use an indirect or relay communication method for communicating back to Earth. This will be like NASA's Mars Reconnaissance Orbiter that was launched in 2005 to provide high data rate communications relay for Mars surface rovers. The Mars Reconnaissance Orbiter uses a relay communication package called Electra ("Mars Reconnaissance"). Electra is an ultra-high-frequency (UHF) radio for relaying commands from Earth to landers on Mars surface and for returning science and engineering data back to Earth using the orbiter's more powerful direct-to-Earth telecommunications system. This same package will be used for the mission to Venus.

The aircraft will also be equipped with two MCAMv3 Digital Space Micro-Cameras. The MCAMv3 camera design is a light and compact radiation-tolerant digital camera for use in harsh environmental conditions ("CAMERAS"). The cameras will allow the aircraft to take images of the atmosphere during its orbit.

The last instrument is a combination of a UV spectrometer, gas chromatograph, and telescope, all in one. This instrument is taken from NASA's New Horizons spacecraft, called *Alice* ("New Horizons"). Alice is an ultraviolet imaging spectrometer that also serves as a telescope and gas chromatograph. It has a special detector with 32 pixels, each with 1024 spectral channels detecting ultraviolet light. It uses an array of potassium bromide and cesium iodide type photocathodes. The instrument will determine the mixing ratios of major atmospheric constituents including water, nitrogen, carbon monoxide, carbon dioxide, methane, hydrogen and noble gases in the ultraviolet. This allows the aircraft to observe the amount of different types of gases and elements in Venus' atmosphere. A more detailed layout of the instruments in this craft can be seen in Appendix A.

E. Possible Mission Addition for Prolonged Drone Life

If it were decided that a mission lasting longer than 3 days was desired, there are some modifications to the mission plan that could be made. For example, if after further testing, it was determined that the drone could sustain flight while holding a larger payload, additional Lithium Ion space cells could be added. These batteries could charge during the day and then be used to power the drone at night.

A more creative solution, although a more complex and more expensive solution, would be the implementation of a satellite equipped with a diffraction laser. With the wind the drone would travel at a speed of 117 m/s and would make a full rotation about Venus about every 4 days. An analysis was done with the help of Dr. Daniel Raible to find the requirements of a satellite orbiting at a height 100 km. Providing just enough power to keep the drone airborne; 111 watts, it was determined that an irradiance of 177 watt/m^2 would be needed over a circular area with a radius of 2.5 m. Therefore, the aspect ratio of the wing was kept low so that this radius would be minimized, backtracking using efficiencies of 40% electrical energy to laser power conversion. 30% solar panel efficiency, 90% storing efficiency and 10% reserved to run the sub systems. It was determined a solar panel area of 19 m^2 would be needed. Calculating the diffraction of the laser, using red light the satellite would need a 2.875 m diameter laser lens.

After running orbital calculations, it is not feasible to have one drone orbit in synchronous with the movement of the drone, due to it being too far away to provide adequate power transfer. However, two satellites in elliptical orbits coming close to the drone during the nighttime at different intervals could provide a solution to this. Without a satellite to keep the plane aloft, going against the wind the drone would have a mission life of approximately 3 days.

IV. Conclusions and Recommendations

Venus is a very intriguing planet when it comes to exploring for life outside of Earth. Some key components for life to thrive exist in the upper atmosphere of the planet. The drone designed in this report should be a good starting point for an unmanned mission to Venus to search for potential signs of life. Before this mission could take place though, it is recommended that substantially more testing and planning take place to ensure proper functionality of the drone. If this research were to be continued, it would almost certainly include wind tunnel testing, multi-physics modeling, further stress analysis, more detailed prototype designs, and finally the construction of physical prototypes. The systems engineering approach to this problem is meant to give an idea about what is required out of every system required for a successful mission.

V. Appendices

A. Drawings and Instrumentation

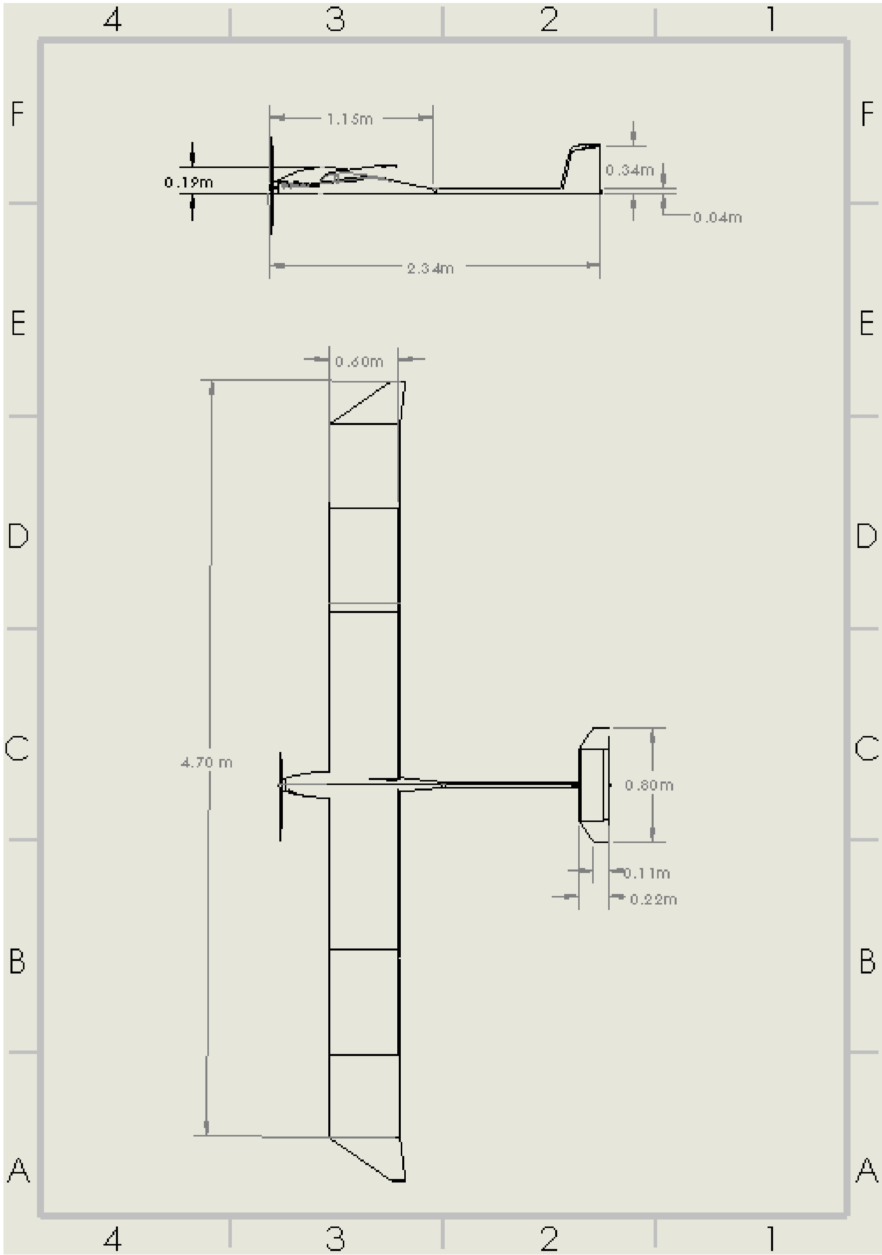

Figure A-1: Drone Dimensions.

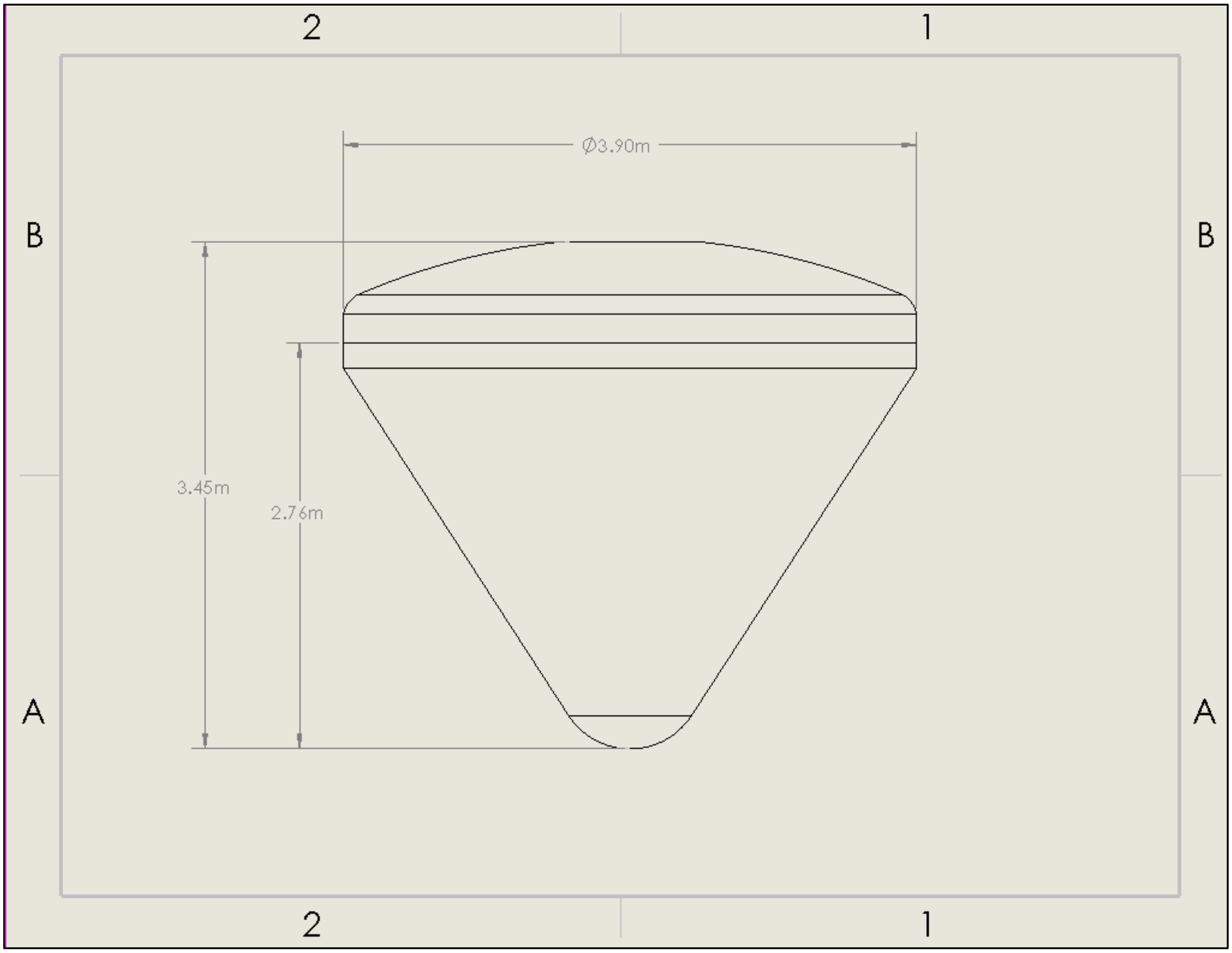

Figure A-2: Aeroshell Dimensions.

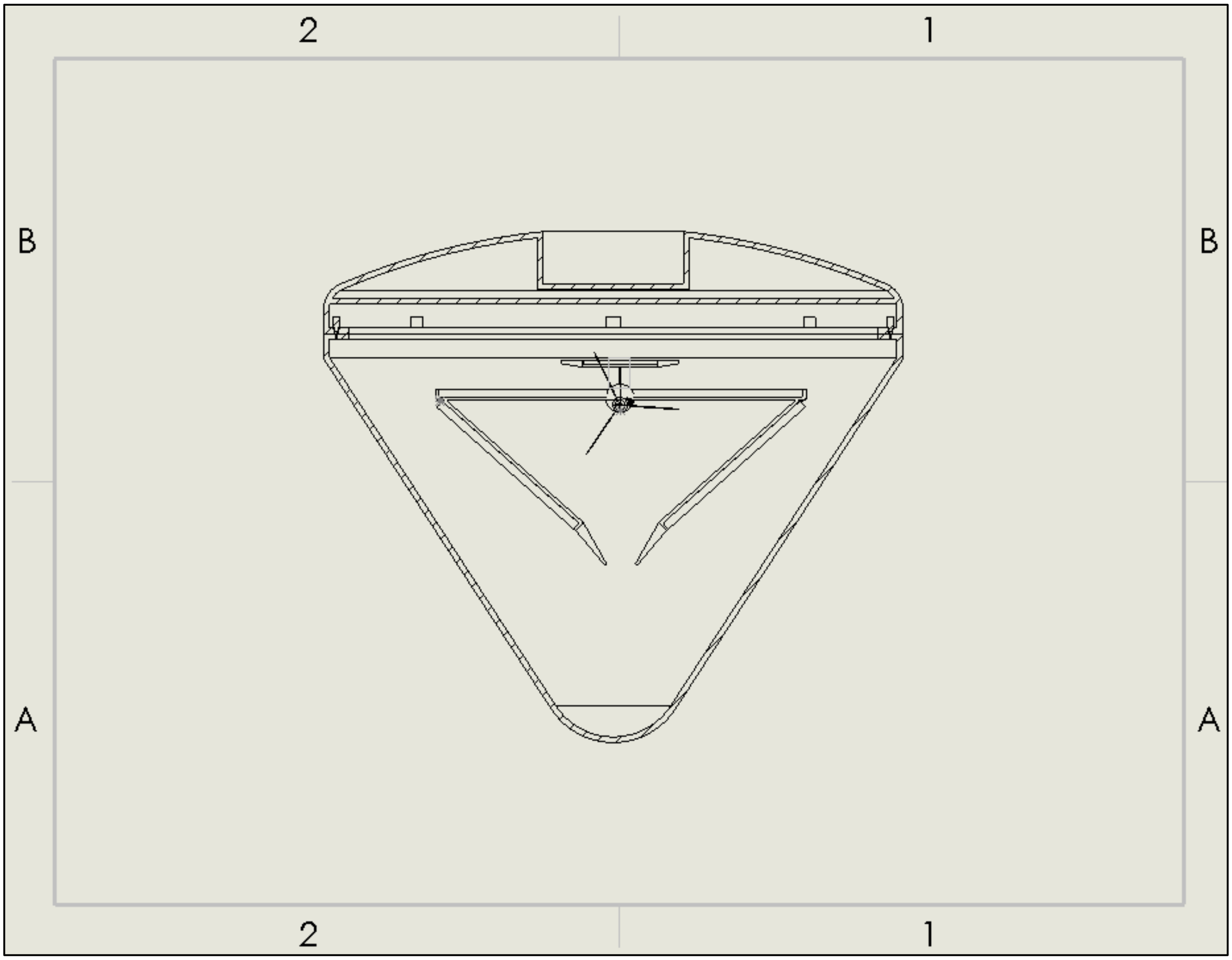

Figure A-3: Drone Mounted in Aeroshell.

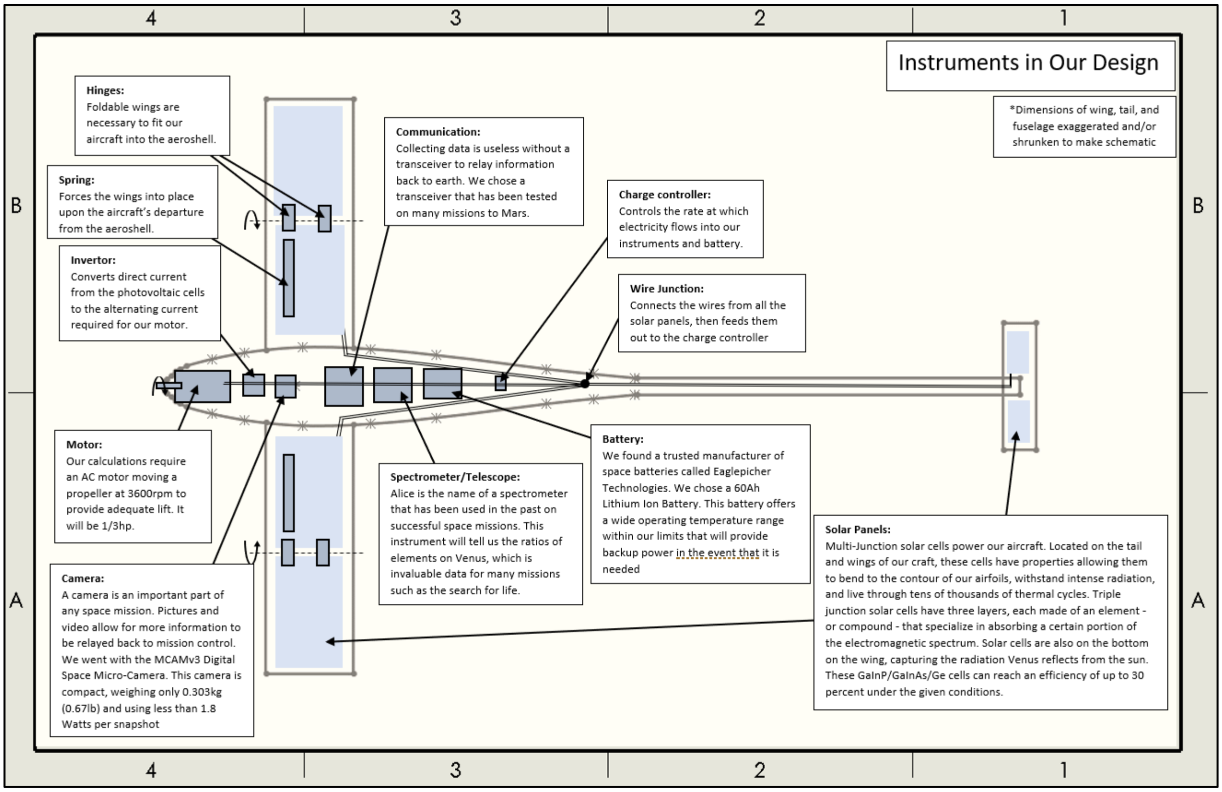

Figure A-4: Map of Instruments.

B. Ansys Analysis

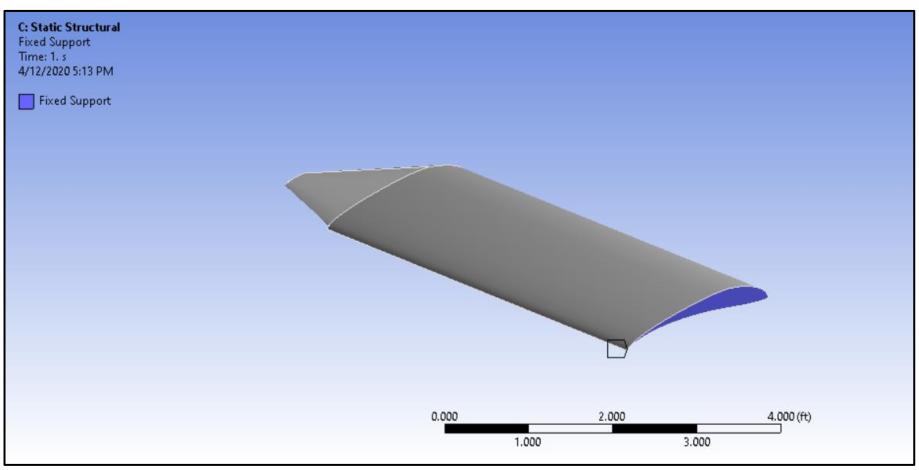

Figure B-1: Fixed support.

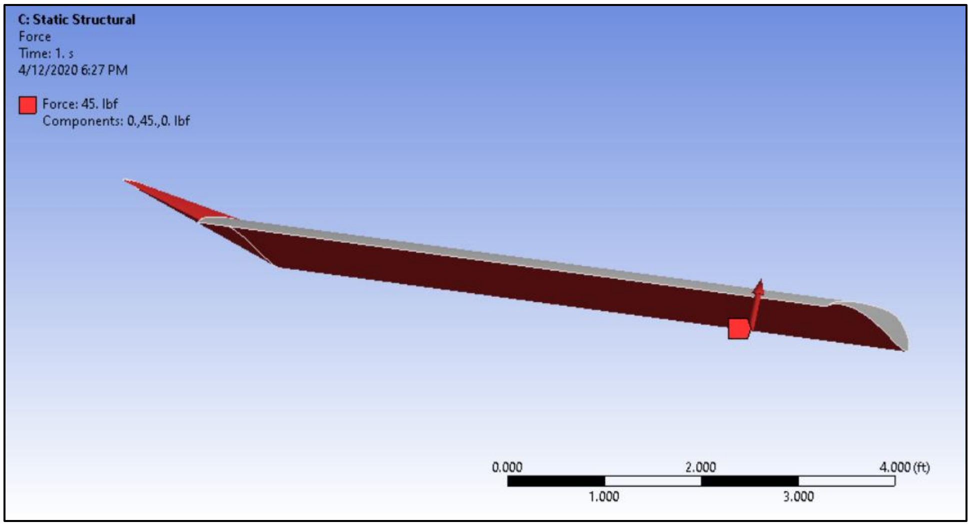

Figure B-2: Applied Load.

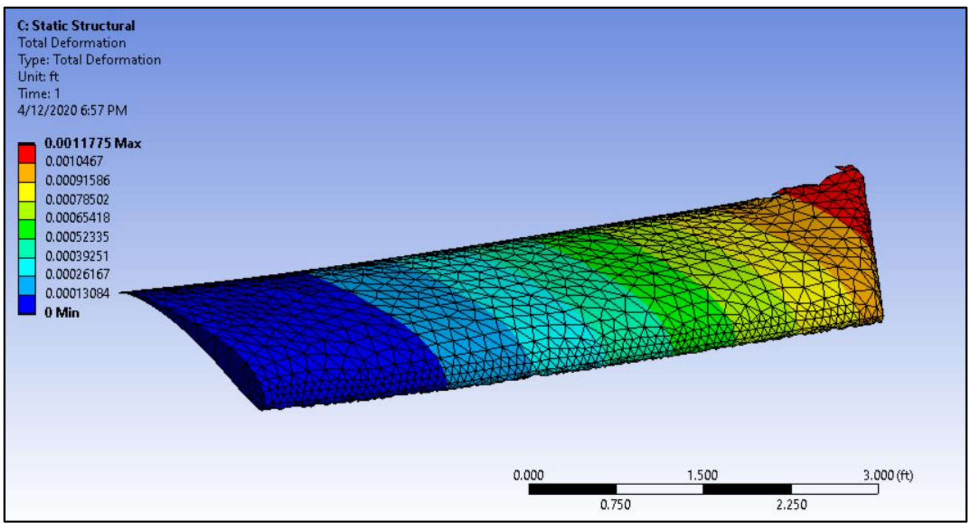

Figure B-3: Deformation.

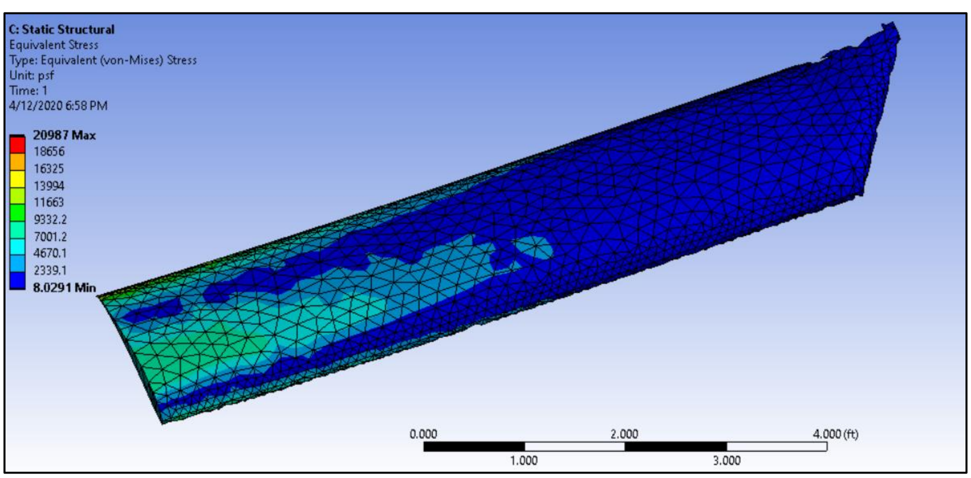

Figure B-4: Stress.

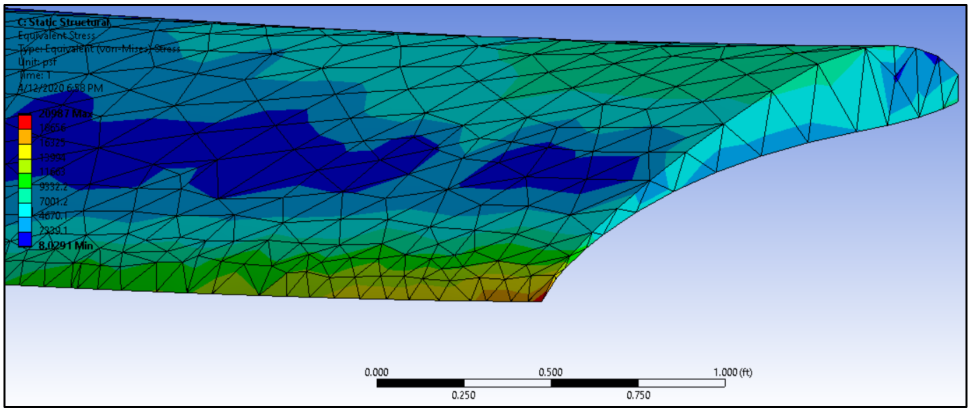

Figure B-5: Max stress.

C. JavaProp Propeller Analysis

Propeller			
v/(nD)	0.533	v/(ΩR)	0.17
Efficiency η	88.083 %	loading	low
Thrust T	3.51 N	Ct	0.0025
Power P	95.63 W	Cp	0.0015
Torque Q	0.25 Nm	Cs	1.9506
β at 75%R	15.8°	Pitch H	501 mm

Figure C-1: JavaProp design outputs.

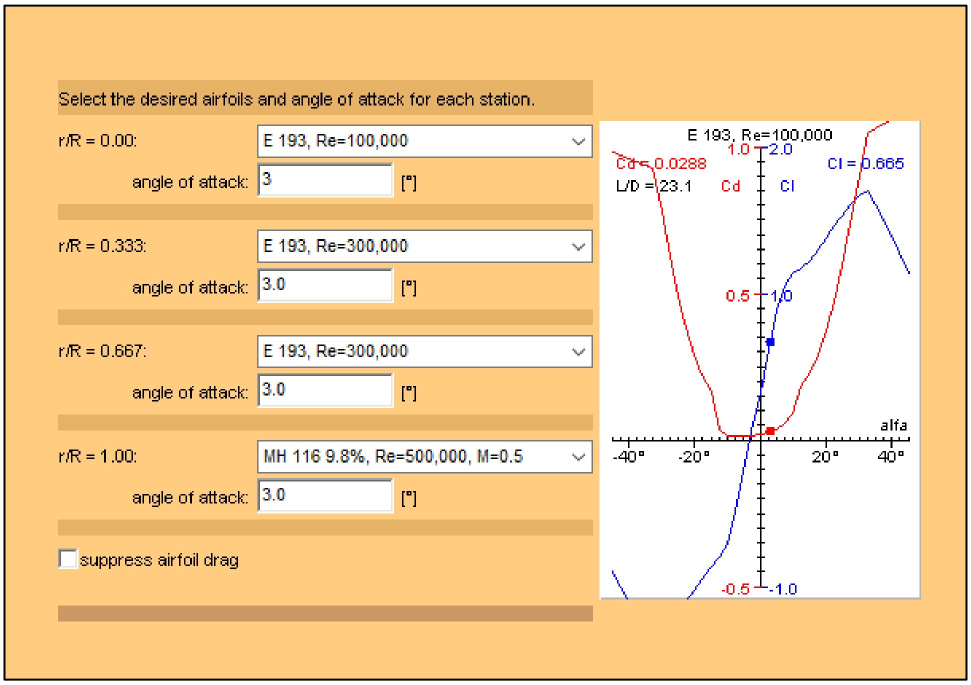

Figure C-2: Propeller airfoil layout.

D. MATLAB Codes

```
%flight simulation

clc

clear

format short g

% function T = Propellar[v,h]

%kg/m^3 density

pp =    [64.79  61.56   58.45   55.47   52.62   49.87   47.24   44.71   42.26   39.95   37.72   35.58
33.54   31.6    29.74   27.95   26.27   24.68   23.18   21.74   20.39   19.11   17.88   16.71   15.62
14.57   13.59   12.65   11.77   10.93   10.15   9.406   8.704   8.041   7.42    6.831   6.274   5.762
5.276   4.823   4.404   4.015   3.646   3.303   2.985   2.693   2.426   2.186   1.967   1.769   1.594
1.432   1.284   1.153   1.032   0.9207  0.8183  0.7212  0.6289  0.5448  0.4694  0.40525 0.3411  0.2927
0.2443  0.2086  0.1729  0.14695 0.121   0.102465    0.08393 0.07084 0.05775 0.04854 0.03933 0.03298
0.02663 0.022235    0.01784 0.01485 0.01186 0.0097925   0.007725    0.0063255   0.004926    0.004007
0.003088    0.002493    0.001898    0.0015245   0.001151    0.0009173   0.0006836   0.00054155
0.0003995   0.00031545  0.0002314   0.00018305  0.0001347   0.0001068   0.0000789 ];

%fuild bulk elasticity mod N/m^2

Kk =    [2594.536194    2704.093567 2820.11976  2942.419326 3071.151653 3208.341688 3349.806097
3500.321181 3662.176053 3830.724406 4011.69141  4209.359191 4419.35003  4642.056962 4881.002017
5139.21288  5398.841264 5673.648298 5963.556514 6276.74149  6605.64002  6956.209314 7337.183445
7747.219629 8177.641485 8649.622512 9138.025018 9672.730435 10241.95752 10864.51601 11523.5468
12246.68935 13032.42647 13890.01865 14819.21294 15845.55702 16980.70768 18196.18882 19554.48067
21046.22849 22673.93279 24494.38605 26562.10642 28869.94853 31450.90787 34317.11846 37494.87222
40951.80238 44784.05694 48994.55059 53490.58971 58002.26257 62993.27103 68288.25672 74242.48062
80948.19159 88823.36551 98256.29506 109816.8866 123510.2056 139616.5317 159827.884  187654.6467
216099.2484 255832.9922 296031.8792 352857.1429 410141.2045 492033.0579 573915.4833 692017.1572
809039.5257 979200.6926 1149370.416 1399368.421 1646118.86  2010738.265 2374996.177 2919015.695
3457748.148 4268549.747 5096508.552 6368315.858 7665487.313 9700763.297 11751684.55 15024987.05
18335515.44 23724362.49 29093053.46 37950477.85 47801548.02 64388589.82 81588108.21 111019674.6
141134886.7 193128608.5 245065501.2 334289829.3 423209363.3 575019011.4];

%kinematic viscocity m^2/s

uu =    [5.17055E-07    5.07147E-07 4.95124E-07 4.8062E-07  4.63322E-07 4.43152E-07 4.6232E-07
4.82666E-07 5.04496E-07 5.27159E-07 5.51432E-07 6.3294E-07  7.22719E-07 8.21519E-07 9.30733E-07
1.05188E-06 1.10697E-06 1.16532E-06 1.22692E-06 1.29347E-06 1.36341E-06 1.44322E-06 1.5302E-06
1.62418E-06 1.72343E-06 1.83253E-06 1.9426E-06  2.06324E-06 2.19201E-06 2.33303E-06 2.48276E-06
2.64937E-06 2.83088E-06 3.02947E-06 3.24528E-06 3.48412E-06 3.75199E-06 4.04026E-06 4.36315E-06
4.71905E-06 5.10899E-06 5.54919E-06 6.05047E-06 6.61217E-06 7.24288E-06 7.94653E-06 8.71393E-06
9.55169E-06 1.0483E-05  1.15093E-05 1.26098E-05 1.37849E-05 1.50935E-05 1.64961E-05 1.80814E-05
1.98762E-05 2.19724E-05 2.4487E-05  2.7572E-05  3.12408E-05 3.55773E-05 4.08883E-05 4.8197E-05
5.57226E-05 6.623E-05   7.69415E-05 9.20763E-05 0.000107452 0.000129421 0.000151564 0.000183486
0.000215274 0.000261472 0.000307993 0.000376303 0.000444209 0.000544499 0.000645379 0.000795964
0.000946128 0.001172007 0.001406178 0.001765696 0.0021358   0.0027162   0.003306713 0.004248705
0.00521059  0.006775553 0.008350279 0.010947003 0.013768669 0.018519602 0.023432739 0.0318398
0.04041845  0.055229041 0.06998088  0.09532294  0.120505618 0.163498099 ];

%wind velocity m/s

vv = [  0.6 0.7 0.8 0.9 1   1.2 1.3 1.9 2.4 3.4 4.5 6.3 8.2 10.8    13.4    16.1    19.6    22  24.5
26  27.6    28.8    29.9    30.6    31.3    32.3    33.3    34  34.6    35  35.5    36  36.4    36.7
36.9    37.3    37.6    38.2    38.7    39.7    40.7    42.6    44.5    47.4    50.3    54.2    57.4
59.4    61  61.2    60.9    60.2    59.4    59.3    59.2    59.9    60.5    62.7    65  71.1    77.2
85.4    92  94  94.5    95  94.4    93.8    93.2    92.6    92  89.4    86.8    84.2    81.6    79
74.6    70.2    65.8    61.4    57  52.4    47.8    43.2    38.6    34  30.4    26.8    23.2    19.6
16  15  14  13  12  11  10.8    10.6    10.4    10.2    10];
```

```
%height m

H = [   0   1000    2000    3000    4000    5000    6000    7000    8000    9000    10000   11000
12000   13000   14000   15000   16000   17000   18000   19000   20000   21000   22000   23000   24000
25000   26000   27000   28000   29000   30000   31000   32000   33000   34000   35000   36000   37000
38000   39000   40000   41000   42000   43000   44000   45000   46000   47000   48000   49000   50000
51000   52000   53000   54000   55000   56000   57000   58000   59000   60000   61000   62000   63000
64000   65000   66000   67000   68000   69000   70000   71000   72000   73000   74000   75000   76000
77000   78000   79000   80000   81000   82000   83000   84000   85000   86000   87000   88000   89000
90000   91000   92000   93000   94000   95000   96000   97000   98000   99000   100000];

% plot(H,vv)

m = 15; % mass kg

sr = 560; %solar radiance at 70 km W/m^2

ns = .3; %solar panel efficieny

nm = .98; %electric motor efficiency of EE to ME

sa = 5.4; %solar panel area m

alpha = 15; %propellar angle

d = .3; %prop diameter m

A = .25*pi*d^2; % prop area m^2

Q = 1; %torque N*m

p = 1; %density kg/m^3

r = 60; %revoluyions per second 1/s

%ct = 1; %thrust coefficient

%cp = 1; % power coefficient

Pin = sa*sr*nm*ns*.7; %mechanical power in watts

n = .8; %propellar efficiency

lc = .8; % chracteristic length m

uc = .94; %ultimatum coefficeint determines when the airplane turns around

ha = 66000; % height of interest m

rv = 6051800; %radius of venus in m

cir = 2*pi*(ha+rv); %circumference at airplane height m

g = 8.87; %m/s^2 gravity of venus

t = 1; %time increment sec

S = 2; %wing area m^2
```

```
cl = 1.25; %coefficient of lift

cd = .02; %coefficient of drag

i = 1;

k = 1;

j = 1;

h(i) = 71000; % initital height m

vd(i) = 0;

cdt = .03;

clt = 2;

St = .15*.4;

vyrel(i) = 0;

vxrel(i) = .6;

vrel(i) = sqrt((vxrel(i)^2) + (vyrel(i)^2)); %relative velocity m/s

theta = 0; %climb angle degrees

aa = cir/2;

Pin = 120;

for i = [1:225]

l = 1;

if i < 2

  hh = h(1);

else

hh = h(i); %m

end

    while hh > H(l)

        l = l+1;

    if hh < H(l)

           % K(i) = (hh-H(l-1))/(H(l) - H(l-1)) * (Kk(l)-Kk(l-1)) +Kk(l-1)

            u(i) = (hh-H(l-1))/(H(l) - H(l-1)) * (uu(l)-uu(l-1)) +uu(l-1) ;

            p(i) = (hh-H(l-1))/(H(l) - H(l-1)) * (pp(l)-pp(l-1)) +pp(l-1) ;
```

```
            wv(i) = (hh-H(l-1))/(H(l) - H(l-1)) * (vv(l)-vv(l-1)) +vv(l-1);

         elseif hh == H(l);

                 %K = Kk(l)

                 u(i) = uu(l);

                 p(i) = pp(l)

                 wv(i) = vv(l);

    end

    end

cp = Pin/(p(i)*(r^3)*(d^5));

ct = (n*r*d*cp)/vrel(i);

if i<1900

T(i) = ct*(r^2)*p(i)*(d^4);

% Re(i) = (vrel(i)*lc)/u(i);

else

    T(i) = 3.4;

end

L(i) =  .5*cl*p(i)*(vrel(i)^2)*S-.5*p(i)*(vrel(i)^2)*St;

D(i) = .5*cd*p(i)*(vrel(i)^2)*S + .5*cdt*p(i)*(vrel(i)^2)*St;

%Acceleration in sunlight

% ax(i) = (T(i)*cosd(theta(i)) - L(i)*sind(theta(i)) -D(i)*cosd(theta(i)))/m

% ay(i) = (T(i)*sind(theta(i)) + L(i)*cosd(theta(i)) -D(i)*sind(theta(i)) - m*g)/m

ax(i) =  (T(i)*cosd(theta) -L(i)*sind(theta) -D(i)*cosd(theta))/m   ;

ay(i) = (T(i)*sind(theta)  + L(i)*cosd(theta) -D(i)*sind(theta) - m*g)/m;

vxrel(i+1) = ax(i)*t + vxrel(i);

vyrel(i+1) = ay(i)*t + vyrel(i);

h(i+1) = h(i) + vyrel(i+1)*t;%

vd(i+1) = vd(i) + vxrel(i+1)*t;%

vrel(i+1) = vpa(sqrt((vxrel(i+1)^2) + (vyrel(i+1)^2)));

tt(i+1) = i;
```

```
i = i+1;

end

plot(vd,h)

%calculations for power and velocity

%by Steven Abbate

clc

clear

%kg/m^3 density

pp =    [64.79  61.56   58.45   55.47   52.62   49.87   47.24   44.71   42.26   39.95   37.72   35.58
33.54   31.6    29.74   27.95   26.27   24.68   23.18   21.74   20.39   19.11   17.88   16.71   15.62
14.57   13.59   12.65   11.77   10.93   10.15   9.406   8.704   8.041   7.42    6.831   6.274   5.762
5.276   4.823   4.404   4.015   3.646   3.303   2.985   2.693   2.426   2.186   1.967   1.769   1.594
1.432   1.284   1.153   1.032   0.9207  0.8183  0.7212  0.6289  0.5448  0.4694  0.40525 0.3411  0.2927
0.2443  0.2086  0.1729  0.14695 0.121   0.102465    0.08393 0.07084 0.05775 0.04854 0.03933 0.03298
0.02663 0.022235    0.01784 0.01485 0.01186 0.0097925   0.007725    0.0063255   0.004926    0.004007
0.003088    0.002493    0.001898    0.0015245   0.001151    0.0009173   0.0006836   0.00054155
0.0003995   0.00031545  0.0002314   0.00018305  0.0001347   0.0001068   0.0000789 ];

%fuild bulk elasticity mod N/m^2

Kk =    [2594.536194    2704.093567 2820.11976  2942.419326 3071.151653 3208.341688 3349.806097
3500.321181 3662.176053 3830.724406 4011.69141  4209.359191 4419.35003  4642.056962 4881.002017
5139.21288  5398.841264 5673.648298 5963.556514 6276.74149  6605.64002  6956.209314 7337.183445
7747.219629 8177.641485 8649.622512 9138.025018 9672.730435 10241.95752 10864.51601 11523.5468
12246.68935 13032.42647 13890.01865 14819.21294 15845.55702 16980.70768 18196.18882 19554.48067
21046.22849 22673.93279 24494.38605 26562.10642 28869.94853 31450.90787 34317.11846 37494.87222
40951.80238 44784.05694 48994.55059 53490.58971 58002.26257 62993.27103 68288.25672 74242.48062
80948.19159 88823.36551 98256.29506 109816.8866 123510.2056 139616.5317 159827.884  187654.6467
216099.2484 255832.9922 296031.8792 352857.1429 410141.2045 492033.0579 573915.4833 692017.1572
809039.5257 979200.6926 1149370.416 1399368.421 1646118.86  2010738.265 2374996.177 2919015.695
3457748.148 4268549.747 5096508.552 6368315.858 7665487.313 9700763.297 11751684.55 15024987.05
18335515.44 23724362.49 29093053.46 37950477.85 47801548.02 64388589.82 81588108.21 111019674.6
141134886.7 193128608.5 245065501.2 334289829.3 423209363.3 575019011.4];

%kinematic viscocity m^2/s

uu =    [5.17055E-07    5.07147E-07 4.95124E-07 4.8062E-07  4.63322E-07 4.43152E-07 4.6232E-07
4.82666E-07 5.04496E-07 5.27159E-07 5.51432E-07 6.3294E-07  7.22719E-07 8.21519E-07 9.30733E-07
1.05188E-06 1.10697E-06 1.16532E-06 1.22692E-06 1.29347E-06 1.36341E-06 1.44322E-06 1.5302E-06
1.62418E-06 1.72343E-06 1.83253E-06 1.9426E-06  2.06324E-06 2.19201E-06 2.33303E-06 2.48276E-06
2.64937E-06 2.83088E-06 3.02947E-06 3.24528E-06 3.48412E-06 3.75199E-06 4.04026E-06 4.36315E-06
4.71905E-06 5.10899E-06 5.54919E-06 6.05047E-06 6.61217E-06 7.24288E-06 7.94653E-06 8.71393E-06
9.55169E-06 1.0483E-05  1.15093E-05 1.26098E-05 1.37849E-05 1.50935E-05 1.64961E-05 1.80814E-05
1.98762E-05 2.19724E-05 2.4487E-05  2.7572E-05  3.12408E-05 3.55773E-05 4.08883E-05 4.8197E-05
5.57226E-05 6.623E-05   7.69415E-05 9.20763E-05 0.000107452 0.000129421 0.000151564 0.000183486
0.000215274 0.000261472 0.000307993 0.000376303 0.000444209 0.000544499 0.000645379 0.000795964
0.000946128 0.001172007 0.001406178 0.001765696 0.0021358   0.0027162   0.003306713 0.004248705
0.00521059  0.006775553 0.008350279 0.010947003 0.013768669 0.018519602 0.023432739 0.0318398
0.04041845  0.055229041 0.06998088  0.09532294  0.120505618 0.163498099 ];

%wind velocity m/s

vv = [  0.6 0.7 0.8 0.9 1   1.2 1.3 1.9 2.4 3.4 4.5 6.3 8.2 10.8    13.4    16.1    19.6    22  24.5
26  27.6    28.8    29.9    30.6    31.3    32.3    33.3    34  34.6    35  35.5    36  36.4    36.7
36.9    37.3    37.6    38.2    38.7    39.7    40.7    42.6    44.5    47.4    50.3    54.2    57.4
59.4    61  61.2    60.9    60.2    59.4    59.3    59.2    59.9    60.5    62.7    65  71.1    77.2
85.4    92  94  94.5    95  94.4    93.8    93.2    92.6    92  89.4    86.8    84.2    81.6    79
74.6    70.2    65.8    61.4    57  52.4    47.8    43.2    38.6    34  30.4    26.8    23.2    19.6
16  15  14  13  12  11  10.8    10.6    10.4    10.2    10];
```

```
%height m

H = [    0   1000    2000    3000    4000    5000    6000    7000    8000    9000    10000   11000
12000   13000   14000   15000   16000   17000   18000   19000   20000   21000   22000   23000   24000
25000   26000   27000   28000   29000   30000   31000   32000   33000   34000   35000   36000   37000
38000   39000   40000   41000   42000   43000   44000   45000   46000   47000   48000   49000   50000
51000   52000   53000   54000   55000   56000   57000   58000   59000   60000   61000   62000   63000
64000   65000   66000   67000   68000   69000   70000   71000   72000   73000   74000   75000   76000
77000   78000   79000   80000   81000   82000   83000   84000   85000   86000   87000   88000   89000
90000   91000   92000   93000   94000   95000   96000   97000   98000   99000   100000];

% plot(H,vv)

m = 20; % mass kg

sr = 1100; %solar radiance of venus at 66 km W/m^2

ns = .3; %solar panel efficieny

nm = .98; %electric motor efficiency of EE to ME

sa = 2.7; %solar panel area m

alpha = 15; %propellar angle

d = .3; %prop diameter m

A = .25*pi*d^2; % prop area m^2

Q = 1; %torque N*m

p = 1; %density kg/m^3

r = 60; %revoluyions per second 1/s

%ct = 1; %thrust coefficient

%cp = 1; % power coefficient

Pin = sa*sr*nm*ns*.7 %mechanical power in watts

n = .8; %propellar efficiency

lc = .8; % chracteristic length m

uc = .94; %ultimatum coefficeint determines when the airplane turns around

ha = 65000; % height of interest m

rv = 6051800; %radius of venus in m

cir = 2*pi*(ha+rv) %circumference at airplane height m

g = 8.87; %m/s^2 gravity of venus

t = 1; %time increment sec

S = 2.7; %wing area m^2
```

```
cl = 1.2; %coefficient of lift

cd = .02; %coefficient of drag

cdt = .03;

clt = 2;

St = .22*.55;

i = 1;

k = 1;

j = 1;

h(i) = 66000; % initital height m

vy(i) = 0; %initial vertical velocity m/s

vx(i) = 0; %initial horizontal velocity m/s

vd(i) = 0; %vertical distance traveled m

%vrel(i) = .2; %relative velocity m/s

%theta(i) = 0; %climb angle degrees

aa = cir/2;

l= 1

hh = 66000

   while hh > H(l)

        l = l+1;

    if hh < H(l)

           % K(i) = (hh-H(l-1))/(H(l) - H(l-1)) * (Kk(l)-Kk(l-1)) +Kk(l-1)

            u = (hh-H(l-1))/(H(l) - H(l-1)) * (uu(l)-uu(l-1)) +uu(l-1) ;

            p = (hh-H(l-1))/(H(l) - H(l-1)) * (pp(l)-pp(l-1)) +pp(l-1)

            wv = (hh-H(l-1))/(H(l) - H(l-1)) * (vv(l)-vv(l-1)) +vv(l-1);

        elseif hh == H(l);

                %K = Kk(l)

                u = uu(l);

                p = pp(l)

                wv = vv(l);
```

```
    end

   end


%calculations stable angled flight not taking into account the lift and

%drag of the tail

%

% Tt = 20;

%

% o = [0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20];   %different angles

%

% v = sqrt((m*g-Tt*sind(o))./(.5*p*cl*S*cosd(o)-.5*p*cd*S*sind(o)));

%

% T = (.5*p*cd*S*(v.^2).*cosd(o) + .5*p*cl*S*(v.^2).*sind(o))./cosd(o);

%

%   plot(o,T)

%

% pin = (v.*T)./n;

%

%  plot(o,pin)

%

% vvv = sqrt(m*g./(.5*cl*p*S*(tand(o).*sind(o)+cosd(o))));

%plot(o,vvv)


%calculations for stable unaccelerated flight including the tail

v = sqrt(m*g/(.5*p*cl*S-.5*p*clt*St)) %required velocity

T = .5*p*(v^2)*cd*S+.5*p*(v^2)*cdt*St %required thrust

ct = T/((r^2)*p*(d^4));

cp = (ct*v)/(n*r*d);
```

```
pin = cp*p*(r^3)*(d^5)

Re = (v.*lc)./u %reynolds number



%s1223 il airfoil stability equations

%by Steven Abbate

%for cog equations look to end of stability slide

clear

clc

H   =[  -6.5    -6.25   -6  -5.75   -5.5    -5.25   -5  -4.75   -4.5    -4.25   -4  -3.75   -3.5    -
3.25   -3  -2.75   -2.5    -2.25   -2  -1.75   -1.5    -1  -0.75   -0.5    -0.25   0   0.25    0.5 0.75
1   1.25    1.5 1.75    2   2.25    2.5 2.75    3   3.25    3.5 3.75    4   4.25    4.5 4.75    5
5.25    5.5 5.75    6   6.25    6.5 6.75    7   7.25    7.5 7.75    8   8.25    8.5 8.75    9   9.25
9.5 9.75    10  10.25   10.5    10.75   11  11.25   11.5    11.75   12  12.25   12.5    12.75   13
13.25   13.5    13.75   14  14.25   14.5    14.75   15  15.25   15.5    15.75   16  16.25   16.5];

CL  =[  0.0364  0.0469  0.0508  0.0806  0.1067  0.1164  0.1245  0.1269  0.1391  0.1638  0.1856  0.2183
0.2671  0.3591  0.4521  0.4529  0.5218  0.5219  0.7757  0.9027  0.9431  1.0263  1.0687  1.1086  1.1554
1.1864  1.2135  1.242   1.2746  1.3047  1.3344  1.365   1.3971  1.4305  1.4588  1.4884  1.519   1.5503
1.5826  1.6008  1.6172  1.6448  1.673   1.7018  1.7319  1.7614  1.7847  1.8093  1.8348  1.8609  1.8886
1.9197  1.9392  1.9602  1.9826  2.0067  2.0339  2.0592  2.0753  2.0938  2.1151  2.14    2.1647  2.1738
2.1881  2.2074  2.2356  2.2334  2.2372  2.2491  2.2719  2.2654  2.2678  2.2764  2.2901  2.2823  2.2837
2.2919  2.2866  2.2836  2.2883  2.2781  2.2747  2.2675  2.2602  2.2502  2.2389  2.2241  2.2082  2.1887
2.1686  2.1474];

CD  =[  0.10133 0.09868 0.09669 0.09179 0.08822 0.08572 0.08324 0.081   0.0773  0.07385 0.07076 0.06637
0.06098 0.05325 0.04675 0.04601 0.04093 0.04093 0.02427 0.0189  0.01846 0.01778 0.01778 0.01768 0.01758
0.01804 0.01838 0.01874 0.01909 0.01928 0.01947 0.01971 0.02001 0.02039 0.02059 0.02083 0.0211  0.0214
0.02183 0.02189 0.02196 0.02235 0.02276 0.02319 0.02371 0.02435 0.02474 0.02518 0.02563 0.02606 0.02652
0.02729 0.02771 0.02819 0.02863 0.02903 0.02946 0.03015 0.03067 0.03118 0.03159 0.03193 0.03255 0.03312
0.03358 0.03388 0.03427 0.03499 0.03556 0.03592 0.03633 0.03739 0.03827 0.0389  0.03956 0.04106 0.04222
0.04308 0.0449  0.04662 0.04791 0.05052 0.05267 0.05551 0.05848 0.06209 0.066   0.07075 0.0758  0.08179
0.08806 0.09474];

CDp =[  0.09809 0.09546 0.09349 0.08861 0.08503 0.08257 0.08011 0.07789 0.07421 0.07075 0.06763 0.06318
0.05766 0.04961 0.0426  0.04165 0.03616 0.03605 0.01766 0.01064 0.01006 0.00904 0.00887 0.00875 0.00895
0.00925 0.00963 0.00993 0.01014 0.01035 0.01053 0.01072 0.01095 0.01132 0.01164 0.01197 0.01232 0.01269
0.01318 0.01352 0.01369 0.01404 0.0144  0.01477 0.01522 0.01581 0.0163  0.0168  0.0173  0.01772 0.01812
0.0188  0.0194  0.02    0.02052 0.02093 0.0213  0.02202 0.02275 0.02338 0.02385 0.02415 0.02477 0.02558
0.02617 0.02649 0.02675 0.02779 0.02851 0.0289  0.02923 0.0306  0.03165 0.03234 0.03299 0.03479 0.0361
0.03696 0.03903 0.04092 0.04219 0.0451  0.04732 0.05034 0.05337 0.05715 0.06107 0.066   0.07108 0.07721
0.08356 0.09029];

CM  =[  -0.068  -0.0718 -0.0763 -0.0765 -0.08   -0.0804 -0.0809 -0.0827 -0.0888 -0.0875 -0.0892 -0.0983
-0.1085 -0.1352 -0.1598 -0.1524 -0.1705 -0.1634 -0.2308 -0.253  -0.2557 -0.2611 -0.2641 -0.2666 -0.2707
-0.2712 -0.2708 -0.2708 -0.2717 -0.272  -0.2723 -0.2728 -0.2736 -0.2747 -0.2747 -0.275  -0.2755 -0.2761
-0.2769 -0.2746 -0.2721 -0.272  -0.2721 -0.2723 -0.2728 -0.2732 -0.2723 -0.2716 -0.2712 -0.2708 -0.2708
-0.2717 -0.27   -0.2687 -0.2676 -0.2669 -0.2669 -0.2666 -0.2643 -0.2626 -0.2614 -0.2609 -0.2605 -0.2569
-0.2543 -0.2527 -0.253  -0.2473 -0.2428 -0.2399 -0.2392 -0.2331 -0.2287 -0.2256 -0.2234 -0.2178 -0.2139
-0.2111 -0.2067 -0.2029 -0.2001 -0.1961 -0.1931 -0.1902 -0.1876 -0.1854 -0.1835 -0.1821 -0.1811 -0.1807
-0.1809 -0.1815];

wl=  4.6; %wing length m

ww =  .6; %wing width m

tl = .55;%tail length m
```

```
tw = .22; %tail width m

l =  1.7; %length between the LE of wing and LE of tail m

DSM = .01; %desired static margin

e = .9;

ARw = wl/ww;

ARt = tl/tw;

%Wing

alo = -13;% deg angle of attack where L = 0 for the wing

cLa = .11/(1+((57.3*.11)/(pi*e*ARw)));  %3D slope for wing

ang = [0:1:10];

clw = cLa*(ang-alo) %3D CL equantion for the wing

%Tail

% alot = 10;%angle of atk where L = 0 for the tail deg

% cLat = .11/(1+((57.3*.11)/(pi*e*ARt)));%3D slope for tail

% clt = cLat*(ang-alot)%3D CL equantion for the ;

anga = [9 8 7 6 5 4 3 2 1 0 -1];

i = 1;

while i<12

    ll= 1;

hh(i) = anga(i); %m

    while hh(i) > H(ll)

        ll = ll+1;

    if hh(i) < H(ll)

            clt(i) = (hh(i)-H(ll-1))/(H(ll) - H(ll-1)) * (CL(ll)-CL(ll-1)) +CL(ll-1) ;

            cdt(i) = (hh(i)-H(ll-1))/(H(ll) - H(ll-1)) * (CD(ll)-CD(ll-1)) +CD(ll-1) ;

            cmt(i) = (hh(i)-H(ll-1))/(H(ll) - H(ll-1)) * (CM(ll)-CM(ll-1)) +CM(ll-1) ;

        elseif hh(i) == H(ll);

                %K = Kk(l)

                clt(i) = CL(ll);
```

```
                cdt(i) = CD(ll);

                cmt(i) = CM(ll);

    end

    end

    i = i+1;

end

       x = ang;

  p1 = 1.1723e-09;

  p2 = -6.1708e-08;

  p3 = 1.1985e-06;

  p4 = -1.1179e-05;

  p5 = 6.5047e-05;

  p6 = -0.00034525;

  p7 = 0.0018168;

  p8 = -0.0050508;

  p9 = -0.26954;

  cmw = p1*x.^8 + p2*x.^7 + p3*x.^6 + p4*x.^5 + p5*x.^4 + p6*x.^3 + p7*x.^2 + p8*x + p9;

C = wl;

WMAC = ww; %wing MAC

TMAC = tw; %tail MAC

d = wl/2;

WA = wl*ww;%wing area

TA = tl*tw;%tail area

WAR = wl/ww; %wing aspect ratio

TAR = tl/tw; %tail aspect ratio

WAC = .25*ww;

TAC = .25*tw;

TARM = (l -WAC) + TAC;

Vbar = (TA/WA)*(TARM/WMAC)
```

```
NP  = 0.25 + (0.25 * sqrt(sqrt(WAR)) * Vbar)% neutral point

cg = NP - DSM

if cg < .25

xw = .25*ww - ww*cg ;

yt = .3;

xt = l - cg*ww+.25*tw;

sw = ww*wl;

cw = ww;

st = tw*tl;

ct = tw;

%   wcm = cmw

%   wcl = -clw*(xw)/cw

%   tcl = clt*st*xt/(sw*cw)

%   tcm = - cmt*st*ct/(sw*cw)

%   tcd = cdt*st*yt/(sw*cw)

% a = clt

% b = -cmt

% c = cdt

cmcg =   cmw -clw*(xw)/cw +clt*st*xt/(sw*cw) -cmt*st*ct/(sw*cw) + cdt*st*yt/(sw*cw); %coefficient of
moment about the center of gravity

%plot(ang,cmcg)

else

xw = ww*cg -.25*ww  ;

yt = .3;

xt = l - cg*ww+.25*tw;

sw = ww*wl;

cw = ww;

st = tw*tl;

ct = tw;

%   wcm = cmw
```

```
%   wcl = clw*(xw)/cw

%   tcl = clt*st*xt/(sw*cw)

%   tcm = -cmt*st*ct/(sw*cw)

%   tcd = cdt*st*yt/(sw*cw)

cmcg = cmw +clw*(xw)/cw  +clt*st*xt/(sw*cw) -cmt*st*ct/(sw*cw) + cdt*st*yt/(sw*cw);

end

plot(ang,cmcg)

title('Stability plot cm vs angle of attack')

xlabel('alpha deg')

ylabel('cm')

clear

clc

% H = [ 0   1000    2000    3000    4000    5000    6000    7000    8000    9000    10000   11000
12000   13000   14000   15000   16000   17000   18000   19000   20000   21000   22000   23000   24000
25000   26000   27000   28000   29000   30000   31000   32000   33000   34000   35000   36000   37000
38000   39000   40000   41000   42000   43000   44000   45000   46000   47000   48000   49000   50000
51000   52000   53000   54000   55000   56000   57000   58000   59000   60000   61000   62000   63000
64000   65000   66000   67000   68000   69000   70000   71000   72000   73000   74000   75000   76000
77000   78000   79000   80000   81000   82000   83000   84000   85000   86000   87000   88000   89000
90000   91000   92000   93000   94000   95000   96000   97000   98000   99000   100000];

% pp = [    64.79   61.56   58.45   55.47   52.62   49.87   47.24   44.71   42.26   39.95   37.72
35.58   33.54   31.6    29.74   27.95   26.27   24.68   23.18   21.74   20.39   19.11   17.88   16.71
15.62   14.57   13.59   12.65   11.77   10.93   10.15   9.406   8.704   8.041   7.42    6.831   6.274
5.762   5.276   4.823   4.404   4.015   3.646   3.303   2.985   2.693   2.426   2.186   1.967   1.769
1.594   1.432   1.284   1.153   1.032   0.9207  0.8183  0.7212  0.6289  0.5448  0.4694  0.40525 0.3411
0.2927  0.2443  0.2086  0.1729  0.14695 0.121   0.102465    0.08393 0.07084 0.05775 0.04854 0.03933
0.03298 0.02663 0.022235    0.01784 0.01485 0.01186 0.0097925   0.007725    0.0063255   0.004926
0.004007    0.003088    0.002493    0.001898    0.0015245   0.001151    0.0009173   0.0006836
0.00054155  0.0003995   0.00031545  0.0002314   0.00018305  0.0001347   0.0001068   0.0000789];

% vv = [0.6 0.7 0.8 0.9 1   1.2 1.3 1.9 2.4 3.4 4.5 6.3 8.2 10.8    13.4    16.1    19.6    22  24.5
26  27.6    28.8    29.9    30.6    31.3    32.3    33.3    34  34.6    35  35.5    36  36.4    36.7
36.9    37.3    37.6    38.2    38.7    39.7    40.7    42.6    44.5    47.4    50.3    54.2    57.4
59.4    61  61.2    60.9    60.2    59.4    59.3    59.2    59.9    60.5    62.7    65  71.1    77.2
85.4    92  94  94.5    95  94.4    93.8    93.2    92.6    92  89.4    86.8    84.2    81.6    79
74.6    70.2    65.8    61.4    57  52.4    47.8    43.2    38.6    34  30.4    26.8    23.2    19.6
16  15  14  13  12  11  10.8    10.6    10.4    10.2    10];

% aa = [    410 408 406 404 402 400 397.8   395.6   393.4   391.2   389 387 385 383 381 379 376.6
374.2   371.8   369.4   367 364.6   362.2   359.8   357.4   355 352.4   349.8   347.2   344.6   342
339.4   336.8   334.2   331.6   329 326.4   323.8   321.2   318.6   316 313.6   311.2   308.8   306.4
304 301.6   299.2   296.8   294.4   292 288.2   284.4   280.6   276.8   273 269.6   266.2   262.8
259.4   256 254.5   253 251.5   250 248.5   247 245.5   244 242.5   241 239.4   237.8   236.2   234.6
233 231.4   229.8   228.2   226.6   225 223.4   221.8   220.2   218.6   217 215.4   213.8   212.2
210.6   209 209.4   209.8   210.2   210.6   211 211.4   211.8   212.2   212.6   213];

y(1) =  10; %initial entry angle  degrees

v(1) = 12; %initial velocity m/s

vx(1) = v(1)*cosd(y(1));
```

```
vy(1) = v(1)*sind(y(1));

B = 1400; %ballistic coeff

LD = .3; %lift over drag assumed const

h(1) = 180000; % initial height

xv(1) = 0; %m

t = 1; %sec

g0 = 8.87 ; %m/s^2

R = 6051800; %m radius of venus

a(1) = 0;

x = h(1);

for i = [2:950]

  p1 = -6.2387e-24;

  p2 = 3.2886e-18;

  p3 = -6.7324e-13;

  p4 = 6.7457e-08;

  p5 = -0.0033266;

  p6 = 64.852;

p = p1*x.^5 + p2*x.^4 +p3*x.^3 + p4*x.^2 +p5*x + p6;

p1 = -1.25e-45;

  p2 = 4.1369e-40;

  p3 = -4.9989e-35;

  p4 = 2.4508e-30;

  p5 = -1.5531e-27;

  p6 = -6.3093e-21;

  p7 = 4.5973e-16;

  p8 = -1.9084e-11;

  p9 = 4.0926e-07;

  p10 = -0.0021758;

  p11 = 2.5896;
```

```
w = p1*x.^10 + p2*x.^9 + p3*x.^8 + p4*x.^7 +p5*x.^6 + p6*x.^5 + p7*x.^4 + p8*x.^3 +p9*x.^2 + p10*x
+p11;

if w < 0

    w = 0;

end

 p1 = -6.7787e-45;

  p2 = 3.22e-39;

  p3 = -6.4363e-34;

  p4 = 7.0373e-29;

  p5 = -4.5825e-24;

  p6 = 1.8148e-19;

  p7 = -4.2829e-15;

  p8 = 5.6501e-11;

  p9 = -3.7458e-07;

  p10 = -0.0010968;

  p11 = 409.67;

a(i) = p1*x.^10 + p2*x.^9 +p3*x.^8 + p4*x.^7 +p5*x.^6 + p6*x.^5 +p7*x.^4 + p8*x.^3 +p9*x.^2 + p10*x +
p11;

if a(i) < 0

    a(i) = 0;

end

g = g0*((R/(R+h(i-1)))^2);

ydot = (p*v(i-1)*LD)/(2*B) + (g*cosd(y(i-1))/v(i-1)) - (v(i-1)*cosd(y(i-1)))/R ;

y(i) = y(i-1) + ydot*t;

ac = -p*(v(i-1)^2)/(2*B) + g*sind(y(i));

v(i) = v(i-1) + ac*t;

vx(i) = v(i)*cosd(y(i));

vy(i) = v(i)*sind(y(i));

xv (i) = xv(i-1) + vx(i)*t;

h(i) = h(i-1) - vy(i)+t;
```

```
x = h(i);

end

figure

plot(xv,h)

y = [1:950];

figure

plot(y,v)

hold on

plot(y,a)

legend('velocity','speed of sound')

figure

plot(y,h)

%yp(i) = arctand(sind(y(i))/(cosd(y(i))+w/v));
```

VI.References

784: Lining for Acids, Alkalis, Solvents, Methanol." *ChemLINE*, www.adv-polymer.com/chemline-coatings/784.

"Aluminum 2024-T4." *MatWeb*, www.matweb.com/search/datasheet_print.aspx?matguid=67d8cd7c00a04ba29b618484f7ff7524.

"Basics of Space Flight - Solar System Exploration: NASA Science." *NASA*, NASA, solarsystem.nasa.gov/basics/chapter4-1/.

"CAMERAS: Micro-Cameras & Space Exploration." *Microcameras.Space*, microcameras.space/cameras/.

"Command Module." *NASA*, www.hq.nasa.gov/alsj/CSM06_Command_Module_Overview_pp39-52.pdf .

Gierash, P J. "Venus" *Elsevier Science, Cornell University ,* 2003

King, Richard R., et al. "Advanced II-V Multijuncation ." *Presented at the 4th World Conference on Photovoltaic Energy Conversion*, 7 May 2006.

Landis, Geoffrey A., and Emily Haag. "Analysis of Solar Cell Efficiency for Venus Atmosphere and Surface Missions." *AiAA 11th International Energy Conversion Engineering Conference*, 15 July 2013.

Limaye, Sanjae S. "Venus' Spectral Signatures and the Potential for Life in the Clouds." *Astrobiology*, vol. 18, no. 9, 30 Mar. 2018, https://www.liebertpub.com/doi/10.1089/ast.2017.1783.

"Mars Exploration Rover Mission: The Mission." *NASA*, mars.nasa.gov/mer/mission/spacecraft_edl_aeroshell.html.

"Mars Reconnaissance Orbiter Arrival Press Kit - NASA." *NASA*, mars.nasa.gov/files/mro/mro-arrival.pdf.

McKay, Christopher P. "Requirements and Limits for Life in the Context of Exoplanets." *Proceedings of the National Academy of Sciences of the United States of America*, National Academy of Sciences, 2 Sept. 2014, www.ncbi.nlm.nih.gov/pmc/articles/PMC4156692/.

"New Horizons - Instrument Overview." *Spaceflight 101*, spaceflight101.com/newhorizons/instrument-overview/.

OpenStax. "Astronomy." *The Massive Atmosphere of Venus | Astronomy*, courses.lumenlearning.com/suny-astronomy/chapter/the-massive-atmosphere-of-venus/.

"Signs of Life." *StarDate*, stardate.org/astro-guide/signs-life.

Takamoto, Tatsuya, et al. "InGaP/GaAs-Based Multijunction Solar Cells." *Progress in*

Photovoltaics: Rsesearch and Applications, 26 Mar. 2005, https://onlinelibrary.wiley.com/doi/epdf/10.1002/pip.642 .

Tetzman, Derrick G. "Simulation and Optimization of Spacecraft Re-entry Trajectiores" *University of Minnesotta,* May 2010 https://conservancy.umn.edu/bitstream /handle/11299/93005/Tetzman_Derrick_May2010.pdf?sequence=1

Titov, Dimitri V. "Radiation in the Atmosphere of Venus" *American Geophysical Union* 2007 http://lasp.colorado.edu/~espoclass/ASTR_5835_2015_Readings_Notes/Titov_EtAl-EVTP.pdf

"Venus." *NASA*, NASA, solarsystem.nasa.gov/planets/venus/in-depth/.

Williams, Matt. "What Is the Closest Planet to Earth?" *Universe Today*, 19 May 2016, www.universetoday.com/14447/what-is-the-closest-planet-to-earth/.

Yastrebova, Natalya V. "High-Efficiency Multi-Junction Solar Cells: Current Status and Future Potential." *Research in Photonics, University of Ottawa*, Apr. 2007, https://pdfs.semanticscholar.org/2a4d/ce1dd62aba60fb2fe2a8f3f11241b2f325a0.pdf?_ ga=2.175115042.1204106992.1586709008-1601137268.1586709008.