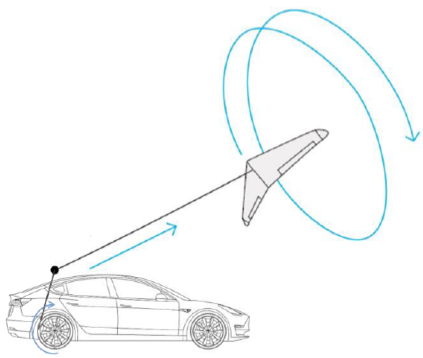
Boston University
Electrical & Computer Engineering
EC463 Capstone Senior Design Project

Problem Definition and Requirements Review

FlyJus Tethered Wind Turbine



Submitted to

Brian MacCleary
brian.maccleary@gmail.com

by
Team 24
Power Drone

Team Members:
Henry Bojanowski henryboj@bu.edu
Jaden Cho choj@bu.edu
Christopher Lemus lemusc@bu.edu
Stephanie Pellicane pellisdp@bu.edu
Brendan Slabe bps123@bu.edu

Submitted: 10/25/2020

Customer Sign-Off ____

Tethered Power Drone Wind Turbine

Table of Contents

(Right click on Table of Contents to update fields and page numbers automatically)

Project Summary

Our project aims to provide a relatively cheaper method of providing renewable energy to those that lack the infrastructure to do so. We will be using a drone tethered to an electric motor to generate electricity. The drone will pull the tether connected to the rim of a wheel that will in turn spin the generator producing 3 phase AC. The internal components such as the motor will be housed in a ground base made out of a shipping container for easy shipping. By doing so, the cost of the whole design will be much cheaper than building a wind turbine along with the required infrastructure needed to keep it running. Our design will generate constant and consistent power independent of an electrical grid.

1 Need for this Project

There are an abundance of locations all throughout the world that are without electricity in an age where electronics can be found in nearly everything.
Locations such as villages in Nigeria are places that lack the needed infrastructure to have consistent power and electricity. By providing a cheaper method of producing electricity, these villages could have a higher quality of life. It would open options such as electric lights and heaters. The need for fire would decrease. This would mean less smoke inhalation, cleaner living conditions, and better visibility at night to name a few. Our project is not just limited to locations that lack infrastructure. It can also be deployed in areas of disaster where the infrastructure was destroyed or made inoperable. It would provide a quick and easy way to access electricity in a zone where it could power medical equipment or lights to find survivors. This more portable wind turbine allows for independence from any electrical grid. As such, this product can be used just about anywhere to help anyone that has an electrical need.

2 Problem Statement and Deliverables

This project is aiming to deliver constant and consistent power to areas that do not have an adequate electric grid to do so. Our project proposes to deliver a relatively inexpensive “wind turbine” that is smaller and easier to maintain than the conventional wind turbine. This is done by using a drone to create the turbine blades. These “blades” will then pull a tether that will spin a generator.

Our ultimate project goal is to modify the open source Ardupilot and Mission Planner flight control software to meet the special needs of Power Drone Tethered Wind Turbine Flight Control. These requirements revolve around the simulation mode for effective flight control software development.

Our first task is to develop a serial interface for the flight computer to support the reading of multiple Analog-to-Digital Converters (ADCs). ADCs will enable strain gauge measurements along the airframe in order to measure lift, drag, and torque on each of the wings during flight. The following task will be to produce simulation models for the power drone aerodynamics, on-board propeller motor-generators, tether line, and ground-based electricity motor-generator using MATLAB/Simulink. These models will be converted to C-code and compiled to run in real time on the flight computer ARM microprocessor. Our third task is to achieve stable and reliable tethered flight while maximizing tether pull force (and thus electricity generation) in a wide range of weather conditions. Ideally, this will be completed while also achieving virtually unlimited flight time by keeping the onboard flight battery pack charged through regenerative braking of the electric motor propellers (by controlling the throttle command signals).

3 Visualization

This project contains two aspects in terms of visualization: the physical model and the code model. It's useful to have an idea what the physical model is in order to understand what the code model needs to achieve. Below in figure 1 we have an example of what the setup for this model could look like. The idea is to fly a drone in the air and take the mechanical energy supplied by the wind and convert it into electrical energy when coupled by a tether line via the principle of electromagnetic induction. What is happening is the tether line is wound to the rims of a car motor-generator and when the drone is in the generation phase it will unwind like a spool as the drone is carried away in the wind. When in retraction phase the drone will get reeled in by the motor-generator, due to height limitations by the FAA and tether line length, and will be prepared for the following generation phase. The setup is intended to be in a small shipping container, making it easily deployable and maintainable for those who will oversee them.

The second aspect, which this project proposal is centered around, is the code model. The significance of this code model is for one to be able to control the flight path of the drone, maximize the lift-to-drag ratio, maintain a reasonable magnitude of tension in the tether line all while efficiently producing electricity. The flight computer we are using is by Matek and the model name is F765-Wing and it is programmed using the Ardupilot source code found on GitHub [13] via Eclipse IDE. The principle behind the code model is that by using this flight controller we can have the drone in autopilot mode in both the generation and retraction phase all the while maintaining the efficiency specified earlier. What is desired in code is the ability to have the drone takeoff and immediately enter this vertical circle mode as seen in figure 2. The more perpendicular we can have the wind vector and normal vector of the airfoils, the more force we will have on the tether line, and therefore the more potential there is for electricity generation. The closer we are to achieving vertical takeoff the better because that would mean the drone uses less energy in breaking past the boundary layer where wind moves faster and thus allows us access to the mechanical energy needed to produce electrical energy. For simulation we use X-Plane (to simulate our drone) and Mission Planner (our ground station that controls the aircraft). In theory once we have developed the code we desire that perform the needed tasks we can simulate them first on X-Plane and then once this has worked with successfully with many trials we can program the flight computer and arm the drone for takeoff.

Figure 1 - This is a physical representation of what the finished product will look like. As seen in the figure, the drone is pulling on pulleys that spin the motor of a Tesla Model 3[12]

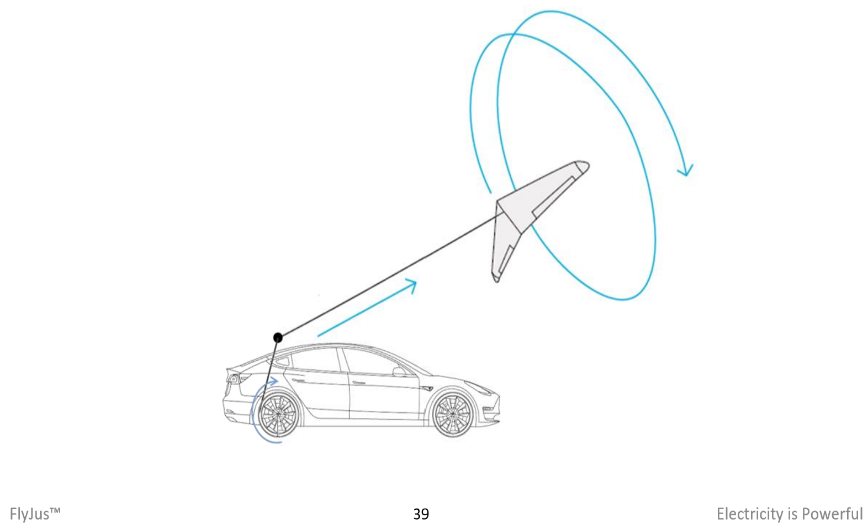


Figure 2 - This is the model representation of the drone's flight path. By flying in a near vertical circle, the power generated is increased. This is acheived by the wind pushing on the "surface" that is created by the drone which in turn causes the drone to fly faster. [12]

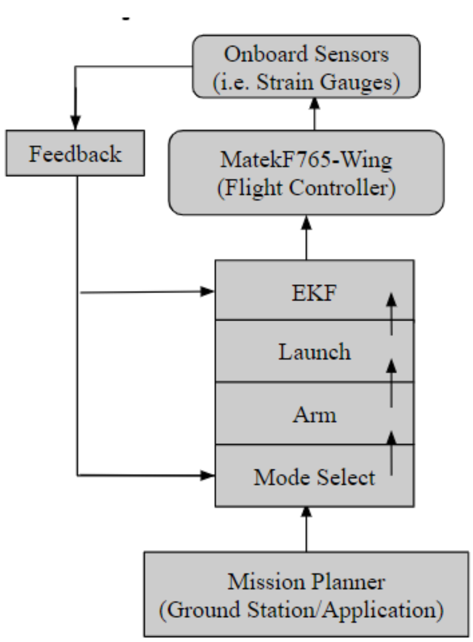


Figure 3 - This figure shows the general methodology of the modified Ardupilot code. The ground station will use Mission Planner to select a mode, arm the program, launch the mode, and send the signal through an EKF. This signal is then received by the flight controller to adjust the necessary components. The controller will also take inputs from onboard sensors and feed them back into Mission Planner and loops through continuously.

4 Competing Technologies

The competing technologies for tethered drones are essentially all power generation technologies that are independent from the grid. What this means is the power generation must happen locally, rather than from a direct grid connection through the grid operator.

The biggest competing technology is residential solar. According to David Heinz of Stanford "Peak solar irradiated power is greater than $1kW/m^2$…it is still possible to harness considerable energy with this solid state technology" [1]. Solar requires sunshine, but won't "provide around the clock power" without battery technology [2]. With battery technology, solar energy captured during the day (when the sun shines) can be available at night. Solar technology also requires space either on a roof or area on the ground [9]. In Honolulu, Hawaii, there is an average of "271 days of bright sunshine per year" [3] making it an ideal place for panels. Other locations don't get nearly as much sunshine, and therefore wouldn't benefit from solar nearly as much [4]. Advantages of solar include that there's no need for fuel [1], it costs between $0.25/kWh-$1.09/kWh [1] which is cheap, and the system can last "over 20 years" [1].

Small scale wind turbines are another competing technology in environments where there's no grid connection. Wind turbines, like solar, require space. Since "Wind speed typically increases with altitude…" [5] optimal power generation would occur with turbines built higher since the power generation is related to the cube of wind velocity $P \alpha v^3$ [8]. Wind turbine requirements would include a significant amount of wind at the building site, about "…9 miles per hour (4.0 meters per second)" according to energy.gov

[6]. In addition, wind speed changes throughout the day [7]. In general “higher winds are …at night” [7]. Like with solar, battery storage may be necessary or potentially having a system with solar and wind to solve the issue of less wind during the day and no solar power output at night.

Micro/pico hydro is another competing technology in environments without a direct grid connection. Micro hydro requires “…a rapidly moving stream, or possibly a simple pope to build additional water pressure with a controlled descent”[1]. The configuration requires a water source. “…a consistent flow of water” [1] is necessary, in times of drought this technology could be rendered useless. Like solar and wind though, no fuel is required. Other benefits include low cost of energy at “USD $0.15kWh” [1].

There are also competing technologies that are relatively similar to the FlyJus™ model. Makani Power worked on “harnessing wind energy with kites to create renewable energy” [10]. Makani looked to avoid the more expensive and tall wind turbines with a tethered kite. The generation occurs on board the kite through rotation of the plane via wind forces. The electricity generated in the generator on the kite is then sent to the ground through a conducting tether. Makani Power’s journey “came to an end…in 2020” [10] despite getting funding from google, but other companies like Sky WindPower, Kite Gen, and are building technologies similar to Makani [11] so the technology will undoubtedly be relevant, especially given the low LCOE for the technology as suggested by [12].

5 Engineering Requirements

The project requirements are heavily geared towards software development due to the circumstances of the course. However, the one piece of hardware able to be tested is the flight controller. By flashing our software to the flight controller we will be able to test certain limited aspects of our design. As for requirements, our overall goal is to have at the bare minimum a piece of software branched from the original ardupilot repo capable of controlling the glider. The core requirement of the project is to be able to algorithmically control the glider such that it can produce a net positive amount of power when accounting for the fact that it has general inefficiencies as well as the power draw of a thruster. The core requirement for the hardware component is to be able to translate software signals into hardware signals to be outputted by the flight controller. Other requirements for this project can be considered stretch goals. For example, general optimizations to the control algorithm and the ability to convert the flight controllers digital output signals to analog signals for the various motors and servos fall under this category.

6 Appendix A References.

[1] D. Heinz. “Small Scale Generation for Electrification of Rural and Remote Areas” Stanford.edu. http://large.stanford.edu/courses/2014/ph240/heinz1/ (Accessed Oct. 23, 2020).

[2] “Residential Solar Panels Useful in Remote Areas” intermtnwindandsolar.com https://www.intermtnwindandsolar.com/residential-solar-panels-useful-in-remote-areas/#:~:text=Remote%20Applications%20of%20Solar%20Energy&text=Solar%20powered%20systems%20have%20the,photovoltaic%20panels%20for%20electrical%20power. (Accessed Oct. 25, 2020).

[3] “Best Places In The US To Have Solar Panels” umasolar.com https://www.umasolar.com/blog/best-places-in-the-us-to-have-solar-panels/ (Accessed Oct. 25, 2020).

[4] S. De Jong, W. L. Auping, W. T. Oosterveld, A. Usanov, M. Abdalla, A. van de Bovenkamp, C. F. della Frattina. “Energy Choices in Sub-Saharan Africa” in *The Geopolitical Impact of Climate Mitigation Policies, 1st edition,* The Hague, the Netherlands. Hague Center for Strategic Studies 2017. Ch. 5 pp. 69-75. https://www.researchgate.net/publication/316308189_The_Geopolitical_Impact_of_Climate_Mitigation_Policies

[5] “Wind turbine heights and capacities have increased over the past decade” eia.gov https://www.eia.gov/todayinenergy/detail.php?id=33912#:~:text=Since%202012%2C%20the%20average%20height,such%20as%20trees%20or%20buildings. (Accessed Oct. 25th 2020).

[6] “Installing and Maintaining a Small Wind Electric System” energy.gov https://www.energy.gov/energysaver/installing-and-maintaining-small-wind-electric-system (Accessed Oct. 25th 2020).

[7] J. Halblaub, “Daily Wind Changes in the Lower Levels of the Atmosphere”, *The Front: NOAA Weather Service,* pp 1-4, Feb. 2014. https://www.weather.gov/media/publications/front/14feb-front.pdf (Accessed Oct. 25th 2020).

[8] Mohamed A. El-Sharkawi, “Renewable Energy” in *Electric Energy an Introduction*, 3rd edition, Boca Raton, FL, USA: CRC Press 2013. Ch. 6, Sec 6.2, pp 133-202.

[9] Mohamed A. El-Sharkawi, “Renewable Energy” in *Electric Energy an Introduction*, 3rd edition, Boca Raton, FL, USA: CRC Press 2013. Ch. 6, Sec 6.1, pp 99-133.

[10] “Harnessing wind energy with kites to create renewable electricity” x.company https://www.x.company/projects/makani/ (Accessed Oct. 25th 2020).

[11] C. Blackman, “High-altitude winds: The greatest source of concentrated energy on Earth” *Stanford: Report, Jun. 2009.* https://news.stanford.edu/news/2009/june24/high-altitude-winds-062309.html (Accessed Oct. 25th 2020).

[12] B. MacCleary, "Electricity Generation for Challenging Environments: Report and Proposal" forums.ni.com https://forums.ni.com/t5/Power-Electronics-Development/Electric-Vehicle-Tethered-Wind-Turbine-Electricity-Generator/gpm-p/4001147?profile.language=en (Accessed Oct. 19th 2020).

[13] Ardupilot Source Code, https://github.com/ardupilot/ardupilot (Accessed Oct. 19th)