Tethered Glider for High Altitude Wind Energy

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1 Abstract

As awareness in environmental concerns has become more widespread, the general population has been demanding more renewable energies that can supply human’s total energy demand while not cause lasting damages to the Earth. Human’s currently rely mainly on fossil fuel type energies for their energy needs, which are rapidly depleting and have been causing drastic changes to Earth’s climate. While there has been a great push to harness renewable energies from wind, water, and other avenues, these energies have not been producing enough power to offset our fossil fuel use. Current wind turbines are limited in size because a large base is needed support the wind turbine blades. Low altitude winds are also not consistent, which causes the wind turbines to have high downtime. Higher altitudes have strong winds from the polar jet streams and constantly flowing. If these winds can be harnessed, large amount of power will be able to be generated, which could seriously offset our fossil fuel use. New methods of harnessing these high altitude winds have recently been created with the use of tether kites. These kites can theoretically reach high altitudes and the tension force in the tether can be used to generate power. Our project seeks to further the research for high altitude kites by creating a small scale system that will measure the tension and orientation of an unpowered RC glider that is tethered to the base station. This system does not vary in tether length nor contain a generator, so our project will not generate power, but this system can be used to gain an understanding of the dynamics of tethered flight.
2 Nomenclature

3 Introduction

Human’s have used fossil fuels to supply our energy needs from the beginning of the Industrial Revolution. Since then, our dependence on this non-renewable resource has only increased despite the drastic changes that have been made to our climate and the ever dwindling supply in the crust of the Earth. In order to curb our consumption of fossil fuels, significant research has been performed on certain methods of harvesting renewable resources. One of the most prominent renewable energies is wind power, which is primarily harvested with wind turbines. Wind turbines, however, are inefficient in harvesting wind energy. They require large bases to support their large blades, limiting the possible altitude to 200 meters with current technology. Because wind turbines can not achieve high altitudes, the wind that is available to harvest energy from is sporadic and slow. A better method of harvest wind energy is with high altitude kites. High altitude kites are method of harvesting energy from the wind that flows kilometers in the air. Higher altitude winds are significantly more consistent than low altitude winds and has higher velocities, especially in the polar jet streams.

High altitude energy was first discovered in the nineteenth century by George Pocock [6] who invented a high altitude kite carriage that he called the charvolant. This charvolant was able to create forces of such magnitude that were not expected at the time. High altitude energy did not become a serious energy harvesting system until Loyd [4] proposed three simple methods in 1980 that were capable of harvesting large amounts of energy from high altitudes. These methods were a simple kite, which harnessed energy by using the lift and drag forces to unreel a drum located at ground level, a cross-wind kite, which is similar to the simple kite but incorporates cross-wind motion to greatly increase the tension forces, and a drag powered kite, which is similar to the cross-wind kite but generates electricity from turbines mounted directly to the kite instead of unreeling a drum. A large amount of research [1, 2, 3, 5] has gone into high altitude energy since Loyd’s paper, but the research has mainly been theoretical. A few corporations, such as Makani Power, Ampyx Power, Sky WindPower, and Altaeros Energies, have taken on the challenge on creating a competitive energy generation company that harnesses high altitude energy, but none have been able to go to market yet.

We seek to further research in this field by building a small scale kite model that can perform experimental research. This model will use an unpowered RC plane, which will fly tethered around a base station. The RC plane will be controlled by a nearby pilot and will use some energy for a propeller assisted take off. Once a stable flight path has been established, power will be cut and the glider will remain in the air solely due to wind energy. The flight path will be a ellipse in the vertical plane. The glider is connected to a base station with a tether. This base station is able to measure the tension in the tether and position of the glider through a data acquisition system. Because our tether length does not change, no power can be generated. We are simply performing research to gain a deeper understanding of the influence of each parameter on the system. Our goal for this project is to maintain maximum tension of the tether while sustaining either a horizontal flight path or a vertical flight path. This project will assist in creating automated controls in future projects.
4 Process

4.1 Overview of Design Process

4.1.1 Customer Requirements

- Tethered glider system (with electric prop assist for launching) that demonstrates at least three minutes of continuous circular flight path with taut tether.
- Clean appearance
- Human controlled plane
- No special flight skills required
- Laptop not required for data collection
- Tether tension is measured and recorded during flights
- Tether direction is measured and recorded during flights
- Videos with accompanying data files of all flight tests (even ones that don’t work)
- Able to survive crashes with minor repairs and short downtimes
- Maximize tether tensions
- Vertical and horizontal flight
- Identify and compile required glider orientation knowledge for set flight paths
4.1.2 Engineering Specifications

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<th>Ideal Value</th>
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Table 1: List of engineering specifications. Marginal value is the value where the project would be declared a success, and ideal value is the desired goal.

4.2 Glider Design

In order to gain a rough estimate of the magnitudes of the tether tension that will be created from our system, a three-dimensional numerical simulation was created in MATLAB. The acceleration of the glider was solved using the momentum balance equations, and a fourth order Runge-Kutta numerical integrator was used to solve for the position and velocities at any time. Once these values were known, the tension, lift, and drag forces were able to be solved. We assumed that the airfoil was a NACA0015 airfoil [7] and that the simulation started in the flight path. Tab. 2 shows the major flight simulation assumptions and how they will effect our predictions.

The simulation shows that a 1.4 meter wingspan plane created 1000 pounds of tension force under certain conditions once steady state has been achieved. We found a similar airplane from HobbyKing called the Bixler, Fig 1. Once steady state has been achieved, the tension force is equal to the addition of the aerodynamic forces. We assumed that the aerodynamic forces are distributed evenly across the projected wing area and in the opposite direction of the tether. In order to find an orientation of the tether bridle that allow the glider to support the extremely large forces that are applied, brute force optimization was performed on the tether attachment locations and bridle angle to minimize the largest stress applied on the wings. The tether that was chosen to support the tension was a Dyneema line. This material was chosen because it can support the high stresses, has high visibility, and a small diameter. The line is also designed to break just after 1000 pounds, so it will break before more important components, such as the base station or the glider.
Assumption | Effects of assumption
--- | ---
Side slip negligible | Neglecting side slip assumes that all the flow is going ideally across the wing of the glider, that is perpendicular to the chord. This means the forces that in reality are being generated through side slip are instead being modelled as lift forces. The coefficient of lift is inherently larger than the coefficient of side slip thus the predicted model will yield a greater performance than the non-ideal scenario.
Glider is a point mass | Assuming a point mass neglects inertial moments. Instability of the aircraft, which would decrease the gliders performance, is not factored in.
Aerodynamic forces calculated based on 3-D glider | Using 3-D lift and drag forces is a more accurate representation of the forces acting on the glider than the simplified 2-D method because it takes into account the surface area of the wing instead of just the chord length.
Tether is rigid and mass-less | Without this assumption, tether slack and drag would have to be integrated into the simulation. These components act against the performance glider thus the predicted model will yield a greater performance.
Constant flight conditions | We cannot predict the slight variation in environmental conditions such as density and wind turbulence. Moderate variations in wind velocity during a run can be built in but have been neglected for this simulation as multiple simulation runs at different wind speeds have been conducted.
Glider is orthogonal to the tether line | We cannot predict the slight variations in glider orientation. It is simplest to assume that the glider is fixed with respect to the tether line vector.
Wind is always horizontal (parallel to the ground) | We cannot predict the slight variation in environmental conditions wind turbulence and velocity changes.

Table 2: List of all major flight simulation assumptions and their effects.

Fig. 1: Fully Assembled HobbyKing Bixler
4.3 Base Station Design

The glider is attached to a base station for the purpose of anchoring the glider, as well as gathering position and tether tension data during flight. The simulation results for tension were used as the basis for the design of the base station components. Using structural analysis, the base station components were designed using a maximum force of 1000 pounds applied from the tip of the load cell. The following figures depict the progression of the base station design from the initial concept phase to the final construction.

Fig. 2: Base Station Concept
Fig. 3: CAD Model
Fig. 4: Actual Construction

Two tapered roller bearings were used to support the vertical shaft loading (axial and radial) and still allow rotation. Two radial ball bearings were used to support the radial loading on the horizontal shaft. Two potentiometers were connected to the base station, one to the horizontal shaft and one to the vertical shaft to capture the sweep angles. By knowing the length of the tether and these angles at any time instance, the position of the glider can be determined as a function of time. Additionally, a load cell was attached to the horizontal shaft in order to obtain the tether tension which can be compared to the theoretical model.

4.4 Flight Experiments

Due to the complexity of the experiments and the difficulty to fly an RC plane in windy conditions, multiple practice experiments were performed during the course of the design process. Originally, we flew the planes untethered in both windy and low wind days, and eventually tethered the glider during second phase of our practices. The tethered flights added a new challenge to flying the plane, because the glider would lose control and crash when the tether became taut. After attempting to enter a flight path in different methods, we discovered ways to retain stability when the tether became taut. When there was minimal wind, the glider was flown in increasingly large circles until the tether just became taut. The glider would smoothly reorient itself into the flight path. When there was large amounts of wind, it became too difficult to fly the plane smoothly into a flight path. We discovered that it was more beneficial to enter the flight path as soon as possible. We would try to gain altitude and become taut quickly. The plane would lose stability when the tether becomes...
taut, but with enough altitude, the pilot may regain control before crashing. Another challenge we encountered after entering the flight path was that the glider would not gain altitude with any control surface inputs. We first thought that this would be fixed by increasing the rudder area. While this did increase the controls entering the flight path, we still did not gain altitude after the tether became taut. After viewing our flight videos, we realized with a symmetric bridle caused the lift forces to be horizontal to the ground. In order to make our glider gain altitude, we reoriented the bridle so that the lift force would be pointed towards the center of our flight radius.

4.5 Data Acquisition

The data acquisition (DAQ) system used consists of three major stages: the sensor stage, the amplification stage, and the recording stage.

4.5.1 Sensor Stage

This stage consists of three sensors (one load cell and 2 potentiometers) that record all the required data. The load cell is a Phidgets Micro Load Cell (0-50kg). This device uses precisely mounted strain gauges to measure deformation. The signal change is measured in volts and through a calibration constant, is converted to pounds (lbs). Two aluminum blocks are attached to the sensor to help center the load the sensor will see. On block connects to a steel shaft collar with a welded on thread. This allows integration to the base station. The other block has a threaded bolt with two washers that clamp the tether together. Refer to Fig 5.

The potentiometers used are three turn potentiometers from a high resolution plotter. They are used to measure the vertical and horizontal swept angle of the attached aircraft. These work as variable resistors and a change in voltage is measured as the shaft rotates. The voltage change is then converted to degrees with a calibration constant. The potentiometers are mounted with aluminum L-brackets and coupled to the main shafts via flexible couplings to avoid binding. Refer to Fig 6.
4.5.2 Amplification Stage

Due to the nature of the sensors on the load cell, the output signals are too small to read by the DAQ device. The amplification stage amplifies this signal so it may then be recorded by the system. The device used is a Logos Electromechanical Bridge Amplifier v2. It is a system that uses different resistor and other electrical components to provide a certain gain to the input signal. This bridge also enables the ability to choose between excitation voltages of 1.27V, 2.5V, 5V, or 10V. The load cell is wired into the bridge and the resulting output is connected to the DAQ device for measuring and recording. Refer to Fig 7.

4.5.3 Recording Stage

This stage consists of the DAQ device, the computer, and the LabVIEW code. The DAQ device used is a NI USB-6210 module. It has 16 analog inputs, 4 digital inputs, 4 digital outputs, and two 32-bit counters. It is a 16-bit device capable of 250 kS/s. Refer to Fig 5. This translates to a load cell resolution of 0.008 N and a potentiometer resolution of 0.016 degrees. Each sensor has a noise range that must be taken into account when recording, however this range has yet to be measured as of this writing. All three sensors are wired to the DAQ device which is connected to the computer via USB. The computer is responsible for supplying the DAQ device with power, which then supplies +5V to each sensor. The computer used for testing is a Dell Inspiron mini 910 laptop provided by Dr. Gomes. LabVIEW 2013 was used to develop the code for measuring
and the resulting save file includes input parameters, weather conditions, date and time, and the recorded data both in volts and the corresponding conversion units. LabVIEW 2010 is installed on the Dell laptop so the code must be saved as a previous version to be usable on this device. The device itself is slow to operate and the small screen and old version affect the way the code displays on the screen. For this reason the laptop is not ideal for displaying the system to the public. The battery of the laptop (after a new battery was purchased) only lasts less than 30 minutes while running LabVIEW which becomes another limitation while testing outdoors.

4.6 Design of Experiments

5 Results and Discussion

6 Conclusions and Recommendations

References


[6] George Pocock. A treatise on the æropleustic art, or Navigation in the air, by means of kites, or buoyant sails: with a description of the charvolant, or kite carriage, and containing numerous
most amusing and interesting anecdotes connected with several extraordinary excursions both by sea and land. 1851.