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Research Article

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Kite Sky Anchor Analysis for Drone Launching System

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Abstract

A system was developed to launch unmanned aerial vehicles (UAV) near cruising altitude by utilizing a kite based system. A kite was flown in the sky asking as an anchor in the sky. A UAV was brought up the tether and released. The tension, tether angles, and other flight characteristics of the kite were simulated and field tested. This data was used to determine the feasibility of the overall project.

Keywords: Field testing; Kite selection; Simulation

Introduction

Unmanned aerial vehicles, also known as UAVs or drones, are becoming favorable assets in multiple fields including, but not limited to, military defense, ecology research, environmental research, aerial photography, agricultural crop surveillance, search and rescue, and small package delivery [1,2]. With this growth comes opportunity for development and improvement. One major issue facing UAVs is flight range. A system was developed to remotely raise small UAVs into the sky then launch them near cruising altitude. Current methods of launching UAVs normally utilize a catapult type system launching the UAV from the ground [3,4]. By rising the UAVs into the sky via this external system onboard energy that would have been require to bring the UAV to cruising altitude would be conserved.

This effectively increases the UAV's range and flight time. This system used a kite flown attached to a tether. The kite would act as an anchor in the sky. A robotic shuttle system would then climb the tether and release the UAV. For this system to properly work a proper kite would have to be selected and its flight properties analyzed.

Kite

Kite requirements

The function of the kite was to act as a sky anchor, creating a fixed point in the sky. This kite was tethered to the ground with a rope. The kite created tension in the rope. This tension allowed the shuttle system to have the ability to climb the rope into the sky in order to release the UAV. The required tension to lift the UAV and shuttle is dependent on the angle of the tether. Once the shuttle was attached onto the tether, two angles in the line were created as shown in Figure 1. The "shuttle angle" is the angle created between the ground and shuttle. The "kite angle" is the angle created between the shuttle and kite. The kite angle is always greater than the shuttle angle.

Since the kite tension is the only controllable design parameter, finding the minimum required kite tension is necessary to select an appropriate kite. The shuttle is acting as a connection point. This creates two separate tensions in the tether: the kite tension and shuttle tension. A free body diagram of the shuttle is shown in Figure 2. The kite tension can be found from a force balance, shown in Equation Set 1. The factors contributing to the kite tension are kite angle, shuttle angle, shuttle weight, and shuttle tension. The shuttle tension is a reacting force that is interdependent with the kite tension. The tether angles themselves are geometrical parameters determined by multiple factors including: length of tether, location of shuttle, and kite tension. With all of these variable codependent factors, creating a practical model for estimation is difficult. There are more variables than governing equations thus creating many possible solutions. To create a design requirement estimation, some reasonable assumptions were made. The mass of the shuttle was estimated to be 6 lbf. The shuttle and kite angles were assumed to be 25 and 40 degrees respectively from our experience of the experiments. The kite tension correlating to these requirements is 21 lbf.

Kite selection

A series of kite styles were researched and tested. The first kite investigated was the "Liquid Force Spectrum II", a double lined dynamic kite.

The "Liquid Force Spectrum II" was originally designed for Kite surfing, a sport in which a kite drags a rider on a board across the water. It could produce reasonable tension, however, had a major drawback: the nature of the kite itself. The kite, by design, continuously moves with a figure "8" pattern in the air. This creates the need for a complicated control system to continuously steer the kite. More importantly, launching the UAV from a moving, non-stable, system would be nearly impossible and lead to many potential issues. Due to this, a static style of kite had to be chosen. After some additional research, the "Flow Form 4.0", was chosen to be the successor to the "Liquid Force Spectrum II". The "Flow Form 4.0" was marketed as a "stable flyer" that is "often used for aerial photography" [5,6]. This made it an ideal choice. This kite was a single line kite with a compact size of 2.2 meters by 2.6 meters.

Field testing

The kite was field tested three times in open field environments. Each time between 100 and 150 feet of tether was let out. The tether angle relative to the ground, tension in tether, and wind speed were observed. The tension was measured using a digital fish scale attached to the end of the tether, while the angle was measured by taking a digital photograph of the tether. The photo was then uploaded to a computer and the angle was found. The wind speed was obtained

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from the National Weather Service's website, which provided current weather data for each location [7].

Due to the nature of wind, wind speed is not truly constant. To obtain a constant wind speed in an ideal open field environment, an altitude of at least 274 m or 900 ft would have to be obtained [8]. This is possible but impractical for most applications. This means the kite cannot be truly static. The average angle of the tether relative to the ground, average tension in the tether, and National Weather Service's wind speeds were recorded to account for these continuous fluctuations. The results of this can be seen in Table 1.

Simulation

A 3D Solid Works model of the kite was created, shown in Figure 3. Using Solid Works Flow Simulation the kite model was evaluated using finite element analysis. The kite was simulated at multiple wind speeds with three different angles of attack. The simulations were run using a mesh setting of 4. The resulting forces in the X and Y direction on the kite were determined. From these forces the resulting tension and angle of the tether could be determined using a simple force balance because it is a static system. The forces in balance are X force on kite (Kx), Y force on kite (Ky), tension in tether (T), and weight of tether. Fifty feet of tether used in our system was weighed at 0.16 pounds, correlating to 0.0032 pounds per foot. Three hundred feet of this tether would weigh less than one pound. Since the mass of this tether was minimal, its weight was assumed to be negligible. Therefor we can make the tension in the tether the only reaction force on the kite. This is demonstrated in Figure 4 and Equation Set 2.

$$T = \sqrt{K_x^2 + K_y^2}$$

$$\phi = \tan^{-1}\left(\frac{K_y}{K_x}\right)$$

Equation Set 2: Tether Tension Equation

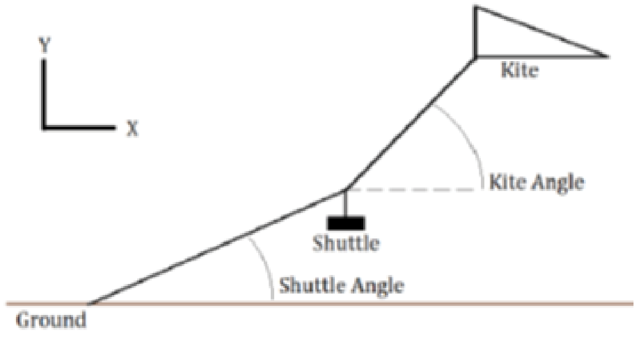

Figure 1: Tether Line Angle diagram.

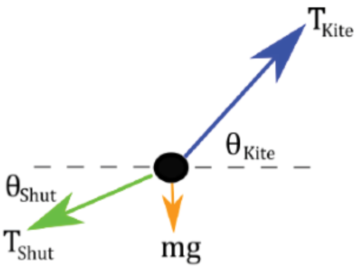

Figure 2: Shuttle on Line free body diagram.

Test date	Wind speed	Avg TetherTension (± 2)	Avg TetherAngle (± 5)
Feb 10, 2015	15 MPH	16 lbf	40 Deg
April 2, 2015	19 MPH	20 lbf	45 Deg
April 4, 2015	16 MPH	16 lbf	45 Deg

Table 1: Kite performance data.

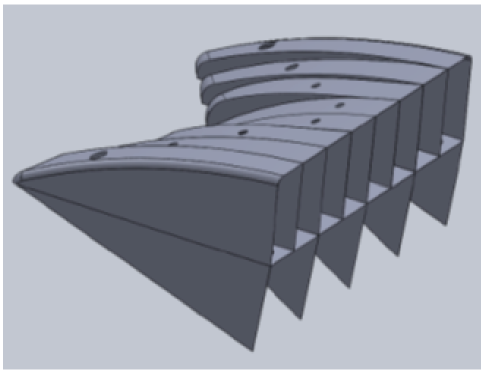

Figure 3: Solid works kite model.

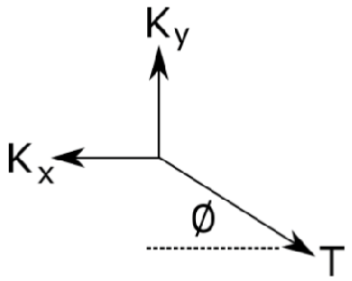

Figure 4: Kite simulation force balance.

The model's default wind attack angle is shown in Figure 5. This angle needed to be altered to simulate real world conditions. As observed during field testing, the orientation of the kite during flight was approximately 20 degrees (± 5 degrees) off of the model's default orientation, shown in Figure 6. To account for this, the simulation was run at angles of attack of 15, 20, and 25 degrees.

The resulting data collected from the simulation can be seen in Table 2. The simulated model data seemed to line up to the field test data at an angle of attack between 15 and 20 degrees. This was close to the orientation angle the kite was observed flying at. An example of this was the Feb 10th, 2015 field test. During that test, a wind speed of 15 MPH resulted in 16 lbf of tension (± 2) at a tether angle of 40 degrees (± 5). According to the simulation, a 15 MPH wind should produce a tension of between 14.14 and 16.02 lbf at a tether angle of between 43.9 and 49.1 degrees. This confirmed that the angle of attack of the kite was between 15 to 20 degrees.

The simulated tether angle was consistent at any given angle of attack regardless of wind speed. This is because the lift to drag ratio at any given angle of attack was dependent on shape and not wind speed, making the lift to drag ratio constant. The tension however increased with wind speed. The tension of the tether was plotted against wind speed for each of the three angles of attack. A second order polynomial trend line was then fitted to each data set. The trend line equation and

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coefficient of determination (R^2) for each was calculated. This data is shown in Figure 7.

This trend line equation can be used reliably to estimate tension in the tether at given wind speeds without the use of complicated and time consuming CFD simulations.

System Integrated Testing

The kite was field tested with the complete system incorporating the shuttle climbing the tether. The kite itself produced enough tension in the tether to support the shuttle however, variation in tension is caused the overall system to fail. The tension in the line would increase or decrease by a few pounds, due to slight changes in the wind. This caused the tether to become either taut or relaxed. These slight decreases in tension caused the shuttle on the tether to drop downwards, while slight increases in tension caused the shuttle to be pulled vertically upwards. This is shown in Figure 8. As the tension increased, the difference between the "kite angle" and "shuttle angle" decreased. This pulled the shuttle vertically up. The same effect occurred in the opposite direction when the tension decreased. This oscillating disturbance caused the shuttle to bounce around on the line. This made it impossible to safely release the UAV with the shuttle flailing around. During one test, the buildup of this disturbance even caused the flailing shuttle to pull the kite down from the sky.

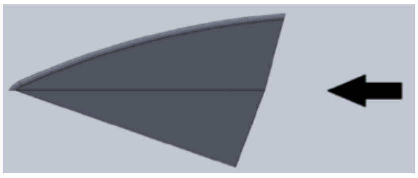

Figure 5: Model default angle of attack orientation.

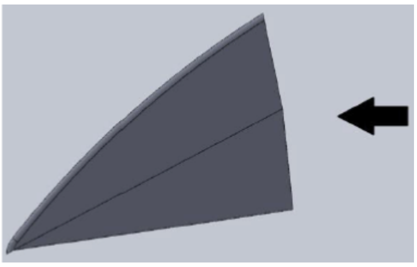

Figure 6: Model modified angle of attack orientation.

Angle (Deg)	Wind Speed (mph)	X (lbf)	Y (lbf)	Tension (lbf)	TetherAngle (Deg)
15	11	5.5	5.3	7.64	43.94
15	15	10.2	9.8	14.14	43.85
15	19	16.3	15.7	22.63	43.93
15	23	23.9	23	33.17	43.9
15	27	33	31.6	45.69	43.76
20	11	56.6	6.5	8.62	48.95
20	15	10.5	12.1	16.02	49.05
20	19	16.87	19.44	25.74	49.05
20	23	24.7	28.5	37.71	49.09
20	27	34.1	39.27	52.01	49.03
25	11	5.67	7.33	9.27	52.28
25	15	10.5	14.05	17.54	53.23
25	19	16.9	22.58	28.2	53.19
25	23	24.89	33.3	41.57	53.22
25	27	34.17	45.54	56.93	53.12

Table 2: Kite simulation data.

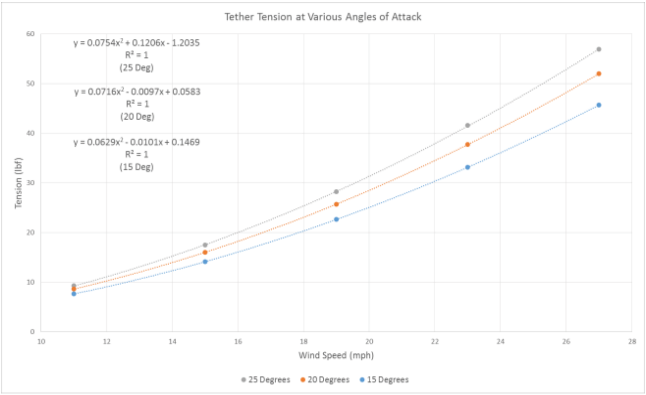

Figure 7: Tether tension simulation data plotted.

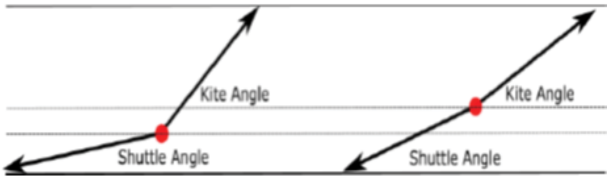

Figure 8: Shuttle vertical position with alternating tension.

The disturbance can be quantified by the change in height of the shuttle. The height of the shuttle can be determined from the shuttle angle and length of tether from the ground to the shuttle. The largest deflection occurs when the shuttle is located in the center of the tether. To account for the worst case, the length of tether to shuttle can be considered half the total tether length. This is shown in Equation Set 3.

$$h = \frac{L_{total}}{2} * \sin(\theta_{shut})$$

$$\Delta h = h_{t+1} - h_t$$

Equation Set 3: Disturbance Shuttle Height

The shuttle angle can be found either by field test; or calculated from a known kite tension, shuttle weight, and kite angle. This equation was found by rearranging the previous equation for kite tension and solving for the shuttle angle. This is shown in Equation Set 4.

$$\theta_{shut} = \tan^{-1}\left(\tan\theta_{kite} - \frac{mg}{T} * \frac{1}{\cos\theta_{kite}}\right)$$

Equation Set 4: Shuttle Angle Formula

Conclusion and Future Work

The disturbance in the line caused by the changing wind speed made it impossible to keep the shuttle stable enough to safely release a UAV. To minimize disturbance, the tension in the kite tether would have to be increased. The same amount of change in tension would create a lesser disturbance with a higher kite tension. This means a tension drop from 25 lbf to 20 lbf in the line would create more of a disturbance than a tension drop from 40 lbf to 35 lbf. To obtain this higher tension, the kite would have to be flown higher. This would require adding an anchoring system and possibly upgrading to a higher tension rope to account for the stronger winds.

This brings up the question of how this system is stable enough for aerial photography. During kite aerial photography, the camera is attached to a stabilizing rig with pan and tilt. This rig is then attached to the tether close to the kite itself [9]. Since the rig is always close to the kite, which is acting as an anchor point, it sees minimal deflection as the tension varies. This is unlike the UAV system which climbs up the entire tether experiencing the worst deflection in the middle of the line between the kite and ground. This can be thought of as a beam supported by a fixed point at both ends. The most deflection would be caused by adding a weight in the center of the beam while the minimal amount of deflection would be caused by adding that same weight on the end of the beam directly above the anchor point. Future research would focus on overcoming the disturbance issue. Flying the kite at higher altitudes should be the first option to test. Another possibility is to modify the project to incorporate a blimp or balloon style of sky anchor instead of a kite. These, while still affected by wind, would be less sensitive to wind changes. This could assist in minimizing the disturbance. This style of system would be simpler overall and easier to launch compared to the kite system. Similar technology is already being used to gather weather data using weather balloons [10]. If the kite aspect is retained instead of investigating a balloon style sky anchor, the system could be integrated with an autonomous flight control system to fly the kite. There is current researching into developing these types of systems [11,12]. Research into damping the motion of the tether or adding damping to the counterweight stability system are other possible areas of future development. A possibly solution is developing an active tether tension control system. This additional mechanism would pull or release tether to maintain constant tension in the tether line to minimize disturbance.

References

1. Ogden LE (2013) Drone Ecology BioScience 63: 776-776.
2. Cook M (2015) The 10 Most Innovative Drone Applications Today.
3. Fahlstrom P, Gleason T (2012) Introduction to UAV Systems. Hoboken Wiley.
4. Hindle P (2015) UAVs Unleashed. Microwave Journal 56: 18-22.
5. (2015) Flow Form 4.0 Lifter Sled.
6. (2015) Great selection of sutton flow form kites ideal for power to haul your favorite line laundry FunWithWind Kites.
7. (2015) National Weather Service.
8. Chen W (1997) Handbook of Structural Engineering. Boca Raton Fla CRC Press.
9. Aber JS, Marzolff I, Ries JB (2010) Small-format aerial photography. Amsterdam Elsevier Science.
10. Crane R (1990) Sampling the Weather in the Upper Atmosphere by Ballon American Association of Physics Teachers 28: 182.
11. McGarey P, Saripalli S (2013) Auto kite. Journal of Intelligent & Robotic Systems 74: 363-370.
12. Erhard M, Strauch H (2013) Control of Towing Kites for Seagoing Vessels IEEE Transactions on Control Systems Technology 21: 1629-1640.