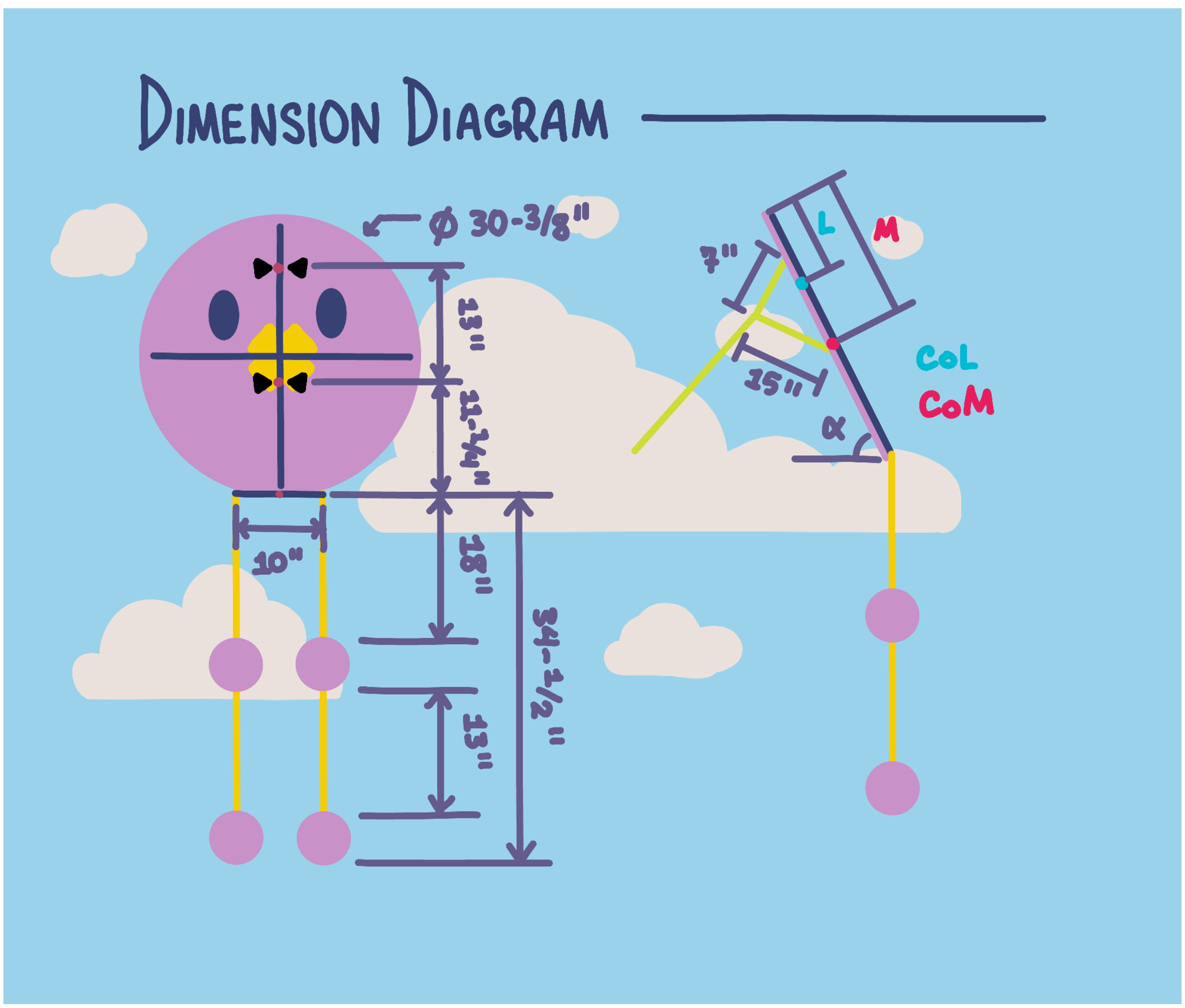
Kite Project Documentation

Kite Project | Transport Phenomena 2022 | Andrew C., Sofia G.

Design

Our team wanted to try designing a circular kite, and realized that we could aesthetically match a *Pokemon* called *Drifloon* for our kite design. This motivated us because we thought the creature was cute and appropriate for a kite design; as can be seen from the reference picture, it has a large frontal surface area and a pair of tails.



We planned for the kite to have the same diameter as the provided bamboo spars, which was ~29”. Spars were inserted perpendicular to each other, tied at the center with a string knot and fastened using rectangular sleeves of paper taped onto the main circular kite cutout.

An additional cut spar taped at the bottom functioned as the kite tail mounting point. Tails were composed of string, with crumpled squares of ~7”x7” paper with equidistant tape stoppers below each crumpled tail “tie,” and mounted on either end of the bottom spar.

String for the top and bottom bridle mounts was tied around the vertical spar at 11-¼” and 24-¼” from the bottom spar, respectively, with a pair of triangular holes cut out to allow a string wraparound. The string was tied so that it pulled the spars into the back surface of the kite plane rather than pulling the spars out from the kite plane; this was done to prevent potential ripping of the spars from the main kite body.

Tables of Dimensions

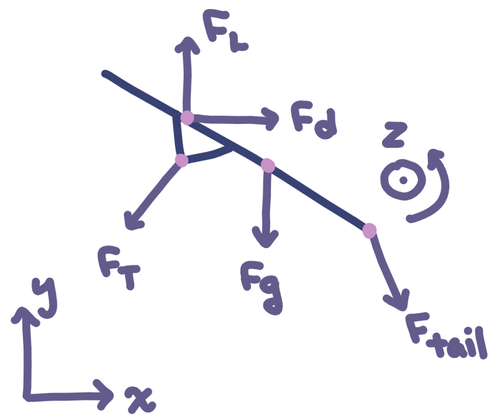
Name	Dimension (in)
Diameter of Kite	30 3/8
Bottom Bridle Mount	11 1/4
Top Bridle Mount	24 1/4
Bottom Bridle	15
Top Bridle	7

Name	Dimension (in)
Lower Spar	10
Width Between Tails	9 1/2
First Crumple to Spar	18
Second Crumple to First	13
Total Tail Length	34.5

Goals

- Have a kite that flies
- Have the kite be circular in shape
- Utilize tails for stabilization
- Aesthetically mimic *Drifloon* from *Pokemon*

Theory of Operation



Our kite was modeled using the simple free body diagram above. Please refer to the Desmos (Link above References) and MATLAB files (submitted alongside this paper) for more complete documentation of the following calculations.The forces of lift and drag originate from the center of pressure, and the force of gravity from the center of mass. We calculated the location of these two points, which can be seen on the plot in our Desmos. Effects of the tails were not included when finding the center of pressure, since we were unsure how to incorporate them, as the equation we used was geometry based, and for model simplicity.

Finding center of pressure (Y position):

$$y = \sqrt{\left(\frac{D}{2}\right)^2 - x^2} \qquad Y_{COP} = \frac{\int_{-\frac{D}{2}}^{\frac{D}{2}} y\left(\frac{3}{4}y\right) dx}{\int_{-\frac{D}{2}}^{\frac{D}{2}} y \, dx}$$

Where D=Diameter.

We then determined what force equations we needed for the kite. The same equations were used to find the forces on the tails.

Force Equations:

Lift Force: $F_L = \frac{1}{2} C_L \rho v^2 A$ Drag Force: $F_D = \frac{1}{2} C_D \rho v^2 A_F$

Where C_L=Coefficient of lift, C_D=Coefficient of drag, ρ=Density of air, v=Air velocity, A=Area, and A_F=Frontal area.

We could then balance the force equations. These need to be separated into the x and y components of the forces.

Force Sums:

$$\sum F_x = F_{Tx} - F_D \qquad \sum F_y = F_L - F_G - F_{Ty}$$

Torque also needed to be calculated and balanced.

Torque Equation:

$$\Sigma\tau = (r_{CP} \times F_P) + (r_{CG} \times F_g) + (r_{T1} \times F_g) + (r_{T2} \times F_g)$$

Where r is the distance from the force F to the center of rotation. We are using the bridle point as our center of rotation. T1 and T1 are the tail masses, with T1 being the sum of the top masses and T2 being the sum of the bottom masses.

To solve for the angle of attack, we started by modeling our kite in MATLAB at a zero angle for simplicity in determining our distance vectors needed to calculate moments. We set up a rotation matrix that rotates by an abstract attack angle alpha. All our force equations are listed as 3D matrices, as are their respective r values due to MATLAB functions being optimized for 3D space. The r values are multiplied by the rotation matrix, which rotates the kite model by the attack angle. We used the Torque Equation along with the vpasolve function to then solve for the angle alpha, which came out to be 5.416°.

Results

Our kite flew successfully! Although the circular kite shape did not lend itself to stability, this was heavily compensated for by our tail drag and weight. This led to an oscillating fishtail movement in the kite's flight path. We estimate that the wind speed on the day we flew the kite to be around 7 m/s after checking the weather report, which is a good speed for kite flying. The kite was stable in steady, strong wind, so you could stand still and it would stay in the air. In lower wind, moving into the breeze was necessary to keep it up, and with no wind a sprint was necessary. However this is expected behavior for a kite, and ours was an undeniable success.

Reflection

Designing the kite was straightforward, since a circular kite only needs its diameter determined to be ready to build. Construction was interesting, especially for the tails, since we weren't sure how much weight or drag we needed. We started with an estimate based on our initial modeling that turned out well. We learned a new knot when stringing the kite to fasten the bridle point. Flying the kite was a ton of fun, and it was so rewarding to see it working. Seeing our own kite fly alongside our peers' really helped us understand the effects of kite shape, size, and tail composition. Our observations of our class kites allowed us to determine what features of kites made each flightworthy or not (useful insight for novice kite-flyers such as ourselves.)We also learned how to effectively estimate the attack angle of the kite (after some trial and error). Were we to continue improving this kite, we would strengthen the frame since the kite sometimes crumples or rides up, making it less effective. For modeling improvements, we would also figure out how to incorporate the tails into our center of pressure calculation.

Desmos Calculator
Note that there are some calculations here that we ended up not using.

References

Oh, Braden. “Primer: Lift and Kites.” 2022.
https://drive.google.com/open?id=1ta1pKvN4QFuJQiNQorIQgmEmFCuqP_KB&authuser=emily.w.tow%40gmail.com&usp=drive_fs