Flying Carpet Testing and ROTCFD Analysis

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Chapter 1

Abstract

The author was introduced to the EACG, its projects, and standard practices. He acquired the proper safety training and was assigned to work on Glitter Belt (particularly the Flying Carpet concept) and ROTCFD projects. He was made familiar with the nature of CFD while awaiting of licence renewal for the necessary software. He was informed of the prior work on the Flying Carpet and the need for demonstration and testing models. A Flying Carpet wind tunnel model was designed and constructed, and preliminary testing was conducted. The flutter instability of the sheet was moderately reduced by constraining the sheet using wires under tension.

Chapter 2

Introduction

The Glitter belt project aims to reverse climate change by reflecting solar radiation out to space. The reflection will be accomplished by solar-powered aicraft carrying ultralight mylar sheets at approximately 100,000 feet of altitude. Cost analysis shows that this is feasible to do using government funding. The name ”Glitter Belt” refers to the appearance the reflectors may have when viewed from space.

There are three different concepts for implementing the Glitter Belt: The Flying Carpet, the Quadrotor, and the Baloon Beanie. The author's work concerns primarily the first, which includes more challenging aerdynamic questions, appropros of this lab group's title and purpose. In the Flying Carpet, the first, the mylar sheet is supported by aerodynamic lift. During the day, it is towed through the air by propellers, driven by electric motors. The propellers are mounted on a flying wing, and the motors are powered by solar cells on the wing. During the night, the aircraft maintains forward flight by gliding downward, using gravitatational potential energy, staying above the upper limit of controlled airspace, 60,000 feet. Incidentally, this concept may also be useful for transportation on Mars, since the martian atmosphere at lower altitude is similar to that of earth at 100,000 feet.

The second concept is the Quadrotor. This involves supporting the sheets using four rotary wings. Thus far no feasible way has been found to keep such an aircraft above 60,000 feet at night, so the author's work is not concerned with it.

The third and final concept is the Balloon Beanie. In this concept, a flat reflector sheet is supported by hydrogen balloons. Some solar powered rotors are included to provide trim and propulsion. (It will be necessary under certain conditions to move the aircraft, although most of the time it will drift in the wind.) This may be particularly useful near the poles, where due to the low angle of elevation of the sun, a horizontal reflector such as the Flying Carpet will be less effective. and the later nearer to the equator.

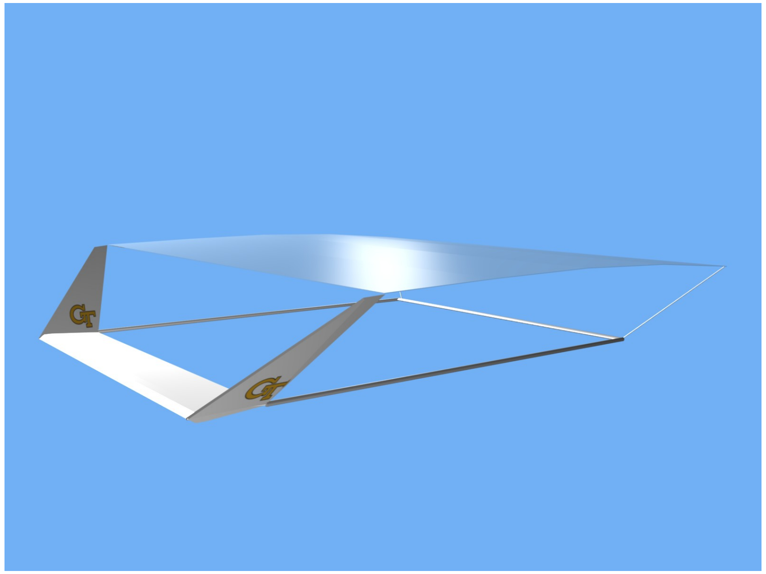

Figure 2.1: An artist's concept of the Flying Carpet

Chapter 3

Define Objectives

Objectives: Build a model of the Flying Carpet, approximately 70cm in span,which can:

- carry a reflector sheet internally, as in the climb phase of the mission
- deploy the sheet
- hold the sheet steady (without significant flutter) during a wind tunnel test

Chapter 4

Prior Work

Cost analysis shows that the Glitter Belt project can be implimented using government expenditures. It also shows that the flying carpet will probably be cheaper to produce per unit reflector area than the Balloon Beanie. However, the Balloon Beanie has the unique property of being capable of orienting to be normal to the Sun's rays no matter the angle. This eliminates the need to place them on the part of the Earth directly beneath the Sun, near the poles in particular (for the purpose of stopping ice melting). The author suggests that both concepts may be manufactured, and the Flying Carpet may be deployed beneath the Sun and the Balloon Beanie may be deployed near the poles.

The primary challenge of the Flying Carpet concept is keeping the reflector sheet smooth and flat. Present design calls for a sheet of reflective mylar trailing behind the wing. However, wind tunnel testing has shown that the sheet oscillates in a self-excited manner. When the aspect ratio is high, the oscillations propagate spanwise. When the aspect ratio is low (i.e. less than 1) the oscillations are longitudinal. Moving the sheet away from the wing, or making spanwise slits in it does not help. Limited success has been achieved by introducing rigid structures made of drinking straws into the sheet. The oscillations are detrimental in that they increase drag and reduce the effective area of the sheet.

Another design calls for stretching the sheet by its four corners which will be connected to a rigid frame. This causes a problem because the sheet bends upward like a parachute, which has inferior aerodynamic and reflective characteristics.

Chapter 5

Project Schedule

- Friday 1-19-17: Discussed concepts for a Glitter Belt model
- Monday 1-22-17: Designed a base for the Glitter Belt model, consisting of a wing, (where the engines and solar cells would reside, and two winglets which could be installed at different dihedral and sweepback angles.
- Friday 1-26-17: Constructed base of model
- Monday 1-29-17:
  - installed PVC pipe and paper to form respectively the leading and trailing edge of the base wing
  - installed sheet tail booms
  - began construction of trailing edge airfoil
- Friday 2-2-17:
  - Finished construction of trailing edge airfoil.
  - Installed sheet and trailing edge airfoil
  - discussed concepts for a deployable sheet
- Monday morning 2-5-17: Show existing model to Prof. Komerath and obtain directives for further development/testing

- Monday afternoon 2-5-17:
  - test Prof. Komerath's idea to dampen flutter using holes in the sheet
  - construct proof of concept for wire-constraint idea
- Friday 2-9-17:
  - build and test wire-constrained model
- Monday 2-12-17:
  - obtain next goal from Prof. K.

Chapter 6

Experimental Setup

An experiment has yet to be formally designed. It will involve attempting to float the model using the wind generated by the wind tunnel's ventilation fan, and running wind tunnel tests on the model to see which configurations minimize sheet oscillations.

6.0.1 Model Details

The model consists of a base wing, winglets, a sheet, and a trailing edge airfoil. The wing is made out of a styrofoam block. It has a PVC pipe taped to the leading edge and two sheets of paper which are attatched to the rear face of the styrofoam block and join together to form a sharp trailing edge. Two winglets were laser cut out of plywood. There are two holes in the end of the base wing and a ring of holes in each winglet. A threaded pin fits through the holes in the base wing and through a pair of holes in each winglet. The each connection is secured by a total of four nuts. By using pins which are bent at different angles, any dihedral can be achieved, and by selecting a different pair of holes in the winglets, any sweepback angle can be achieved.

The sheet and trailing edge airfoil have gone through several iterations, described below.

Simple (Original) Version

The sheet is supported by two tail booms, constructed from drinking straws, which are attatched to the tips of the winglets using hot glue. The sheet, made of heat-shrink plastic, is taped to the tail booms. A high aspect ratio wing, made by sanding styrofoam until its cross section resembled an airfoil, was glued to the rear end of the tail booms. This is referred to tas the trailing edge airfoil. The trailing edge of the sheet is taped to the upper surface of the trailing edge airfoil.

Deployable Sheet Concept

In the full scale prototype, the trailing edge airfoil is intended to be used to maintain the trim of the sheet. There will be actuators which manipulate its AOA. Also in the full scale prototype, the sheet must be contained internally during takeoff and the climb to 100000 feet and be deployed at said alititde. Our model must simulate this, and several concepts have been discussed:

- The sheet may start out rolled up inside the base wing and be dragged into position by means of a pulley system, operated by a pair of servo motors inside the wing.
- The sheet may start out rolled up inside the trailing edge airfoil. The trailing edge airfoil would be connected to the tail booms which would be mounded on a pair of servo actuators mounted on the winglets. The sheet would be attatched to the winglets, such that at cruise altitude, the sevos would move the tail booms and trailing edge airfoil back, and the sheet would unroll.
- The tail booms may be ”telescoping”, i.e. made of multiple subsections, which may fit inside one another to dramatically decrease the overal lengeth. At altitude, the trailing edge airfoil would increase its AOA past stall, and the aerodynamic drag would pull the trailing edge airfoil back into position, extending the tail booms and unrolling the sheet.

This concept has not yet been built

Dampening Holes

In hopes of dampening the oscillations, six holes were cut in the sheet, each approximately 1cm in diameter (Figure 6.1). The rationale behind these holes is as follows: Assume the sheet is oscillating in a pattern that can be modeled by the 2D wave equation. Allowing air to flow through holes in the sheet should either reduce the forcing due to aerodynamic forces or provide a damping force in the form of drag. Thus, the holes were cut at the locations where the greatest amplitude of oscillation was observed, presumably the antinodes.

Wire Constraints

See figure 6.2. Cardboard strips were glued on top of the tail booms (so far made of straws) and trailing edge airfoil to stiffen them. Four pieces of thin electrical wire were tied to a piece of a rubber band at each end using a triple overhand knot. The rubber bands were glued to the winglets and the ends of the trailing edge airfoil so that the wires formed a rectangle. The wire-rubber band assemblies are of such a length that when in place on the model they are under a small amount of tension.

A 71cm by 35.5cm rectangular sheet was cut as before. However, four additional cuts were made. Each cut was in the shape of a parabola. The parabolic cuts on the two long edges had a vertex 5cm behind (toward the center of the sheet) the corners of the sheet, and

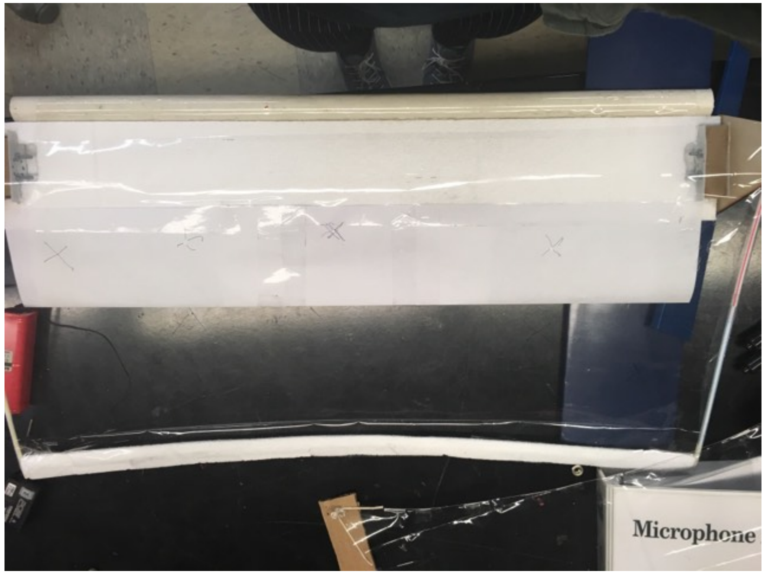

Figure 6.1: The dampening holes model. A hole is located at the center of each "X" drawn on the sheet.

Figure 6.2: The wire-constrained model

the cuts on the short edges were correspondingly 2.5cm deep. Thus the sheet has edges which bow inward, so that it vaguely resembles a star. In order to attatch the sheet to the model, the sheet was taped to the wires at roughly 5cm intervals. Because the wires are under tension, the sheet is now under tension.

There is a reason behind the parabolic shape of the cuts. The sheet is to be under uniform tension, so the wire must support a uniformly distributed load. Consider the wire on the leading edge of the sheet, using standard vehicle-centered aeronautical coordinated (i.e. the x-axis is roughly parallel to the chord line, the y-axis is roughly parallel to the leading edge, and the z-axis points toward the ground). Let the contour followed by the wire be given by

$$x = f(y)$$

and the tension be $T(y)$, which may be resolved into components $T_x(y)$ and $T_y(y)$. Clearly,

$$\frac{T_x}{T_y} = \frac{\partial f}{\partial y}$$

Now, consider the small segment of the wire at y_1 with lenth dy. In order for it to be in equilibrium, we have

$$T_y(y_1) - T_y(y_1 + dy) = 0$$

, i.e. T_y is constant throughout the wire. Furthermore, since the sheet is under uniform tension, there will be some uniform distributed load λ on the wire, i.e. for any points y_a and y_b, the sheet exerts a force on the segment ofwire between y_a and y_b equal to

$$\lambda * |y_a - y_b|$$

in the negative x direction. The upward force due to the tension in the wire must equal this force, so we have

$$T_x(y_1) - T_x(y1 + dy) = \lambda * dy$$

$$\frac{T_x(y_1) - T_x(y1 + dy)}{dy} = \lambda$$

$$\frac{\partial T_x}{\partial y}(y1) = \lambda$$

$$\frac{\partial^2 f}{\partial y^2} = \frac{\lambda}{T_y}$$

. Integrating,

$$f(y) = \lambda y^2 + Cy + D$$

for some constants C and D. This shows that f is quadratic, so a parabola is the correct shape for a wire to hold up a sheet under uniform tension. The same shape can be observed in some suspension bridges.

Furthermore, because the fluttering appeared to occur in spots where the sheet was loose, one may speculate that putting the sheet under uniform tension may eliminate all loose places ad thus eliminate the flutter instability.

6.0.2 Static testing of the model

Testing procedures are TBD.

Chapter 7

Flow and Test Conditions

The ventilation fan in the wind tunnel was run and the doors to the lab were opened, forming a gentle breeze in the doorway to the wind tunnel. The model was held in this wind at various angles of attack.

Chapter 8

Results

8.0.1 Simple Version

The sheet was unstable. The leading edge had a tendency to fold up, but could be induced to fold down by changing the AOA. It was observed that there was a prominent crease in the sheet near the leading edge, caused by the manner in which it was stored prior to being used as a construction material. The spot in which the sheet bent due to the instability coincided with the crease, leading the experimenters to conclude that the crease caused the instability. The amount of flutter was small at negative AOA, moderate at very high AOA, and extreme at AOA close to zero.

8.0.2 Dampening Holes

The holes caused no difference which was visually apparent.

8.0.3 Wire Constraint

The amplitude of the flutter was reduced to a fraction of its original value, however it was still present. Similar to the former two test cases, the flutter was smallest at negative AOA, and highest at small AOA, and moderate at high positive AOA.

Chapter 9

Conclusions

Thus far, constraining the sheet with a wire under tension appears to be the most effective way of reducing the flutter. Perhaps increasing the number of dampening holes may make that method more effective. On a separate note, presumably the increased stability at low angle of attack is due to the fact that gravity and lift act in the same direction, which reduces the sheet's freedom to move. One may speculate that the increased stability at high angle of attack occurs along with and is caused by flow separation.

Bibliography