Low-Density Ultralight Aircraft

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Chapter 1

Abstract

Possibilities for experimental setup were considered, with particular attention to the method of measuring aerodynamic forces.

Chapter 2

Introduction

From my Spring 2018 report:

> 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.
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> 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

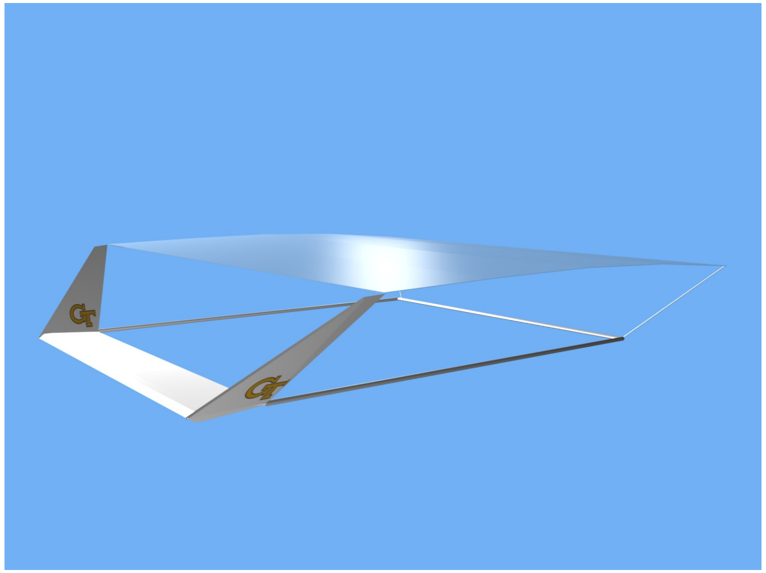

Figure 2.1: An artist's concept of the Flying Carpet

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.

This semester, the project focuses primarily on finding a suitable design for the reflector sheet on the Flying Carpet. In particular, the sheet must be prevented from oscillating or vibrating in a manner that will cause drag or structural failure, and it must be made to produce an acceptable lift-to-drag ratio. The project aims to use wind tunnel experiments to discover which designs will work.

Chapter 3

Define Objectives

In order of importance:

1. Discover what is necessary to obtain a lift-to-drag ratio which will allow the Flying Carpet to meet the mission requirements
2. Reduce flutter even further than in [1].

Chapter 4

Prior Work

During Spring 2018, flutter of a mylar sheet was investigated and several methods of reducing flutter were found. However, flutter was not eliminated entirely, and the lift-to-drag ratio was far too low. [1] Therefore, this semester the project will focus on improving the lift-to-drag ratio. While testing the sheet, we will utilize the flutter-reduction techniques discussed in [1], which are as follows:

1. Produce the sheet with concavely curved edges and attach elastic material under tension to its corners
2. Produce the sheet with concavely parabolic edges and attach a thread under tension to its leading and trailing edges by means of smaller transverse threads
3. Use adhesive to attach the sheet strongly to the support structure along it's lateral edges with negligible room to move

We may modify these methods or devise new ones if it becomes apparent that they are reducing the lift-to-drag ratio.

Chapter 5

Project Schedule

Date	Planned	Accomplished
21-08-2018	Find out where experiments should be performed	Learned that the wind tunnel in MK104 is to be used and obtained access to the schedule on T-Square
22-08-2018	Take measurements of the sting balance for mounting models and obtain baseline lift and drag measurements	Discovered that the sting balance was missing and that we could alternatively construct our own force balance
23-08-2018	Locate the sting balance	Discovered that the balance was under repair in the hands of the manufacturer (Aerolab) and that it is not expected to be returned until the end of September
24-08-2018	Construct a working setup to measure the drag produced by the model	Assembled the electronics necessary to read a voltage from a load cell and proposed ideas for a mount which would transfer either drag or axial force to it
27-08-2018	Evaluate different proposed mount designs and if necessary order materials	Redesigned mount based on advice from Prof. K.
28-08-2018 - 31-08-2018	Construct the mount	Obtained and fabricated all subcomponents
03-09-2018 - 06-08-2018	Finish constructing and testing the mount	Finished constructing the mount and passed basic tests
07-09-2018	Introduce new members to their tasks	prepared the three members who appeared to begin work
10-09-2018	Meet remaining members and ascertain when they are available	NA
11-09-2018	Finish preparing the established mount	NA

Chapter 6

Experimental Setup

6.1 Model Details

6.2 Load Cell Details

6.2.1 Load Balance

The experimntal setup from Spring 2018 cannot be reused because the force balance is under repair away from Georgia Tech. Therefore, an alternative force balance system must be developed. Another force balance exists, but we doubt the accuracy of its drag measurements based on previous experience. So, to measure drag, we have constructed an axial force balance. The axial force balance uses a mechanical structure involving ball bearings to transfer load in only one direction. The affects of moments, other components of force, and friction are minimal. It uses a 100g load cell to measure force. The model will be attached to the axial force balance, and will rotate together with it as the angle of attack is changed. The lift will be measured by the existing force balance, and when combined with the axial force measurements from the axial force balance, the drag can be calculated.

There is some concern that the drag force on the axial force balance itself will interfere with measurements of the model's drag. In order to take the drag of the balance into acount, tests will be performed on the balance without a model on it. The drag measured in these baseline tests will be subtracted from the drag measured in model experiments. However, if the drag on the axial force balance is too high, then it may be difficult to resolve the drag of the model. For that reason, the axial force balance was designed to be as small as possible in order to minimize its drag.

6.3 Prediction of Expected Forces and Moments

6.3.1 From Boundary Layer Equations

The drag on the sheet was predicted using a standard, well tested technique based on Blasius' equation. This technique assumes laminar flow, the accuracy of which in our wind tunnel experiments is uncertain. Based on these assumptions, the following equation from [2] gives the drag on each side of the sheet.

$$C_f = \frac{1.328}{\sqrt{Re_c}}$$

Where C_f is the drag coefficient and Re_c is the chord-based Reynolds number. For a $60cm \times 30cm$ sheet at $9.8m/s$ in the wind tunnel, this predicts a drag of $0.063N$.

6.3.2 From CFD

CFD in ANSYS Fluent was used to predict the lift and drag at nonzero angle of attack. A 2D, laminar, transient simulation was performed. Since it is impractical to attempt to create a mesh fine enough to resolve the thickness of the sheet, a needle-like shape with sharp leading and trailing edges was used. The maximum thickness was 1simulation ought to be done with a thinner sheet. In any case, it should accurately capture the phenomena at the leading and trailing edge, although it may overpredict the drag by a small amount.

At zero angle of attack, the drag predictions match that described in the previous section with 3% error. However, at nonzero angle of attack, the drag is remarkable high. Also, the drag polar (Fig. 6.1) does not have the shape which is expected for airfoils. In order to investigate the cause of the drag, a the magnitude of the flow velocity near the leading edge was rendered (Fig. 6.3). There appears to be a standing vortex near the leading edge on the downwind side of the sheet. This is probably related to the phenomenon known as "vortex lift" which occurs for wings with sharp leading edges.

It may be possible to avoid the vortex which is causing extra drag. Another simulation was done using a cambered sheet. The camber line is an arc which subtends a $10°$ angle. This significantly improved the lift-to-drag ratio (Fig. 6.1), since the sheet was able to avoid the leading edge vortex while simultaneously generating lift (Fig. 6.2). The lift-to-drag ratio is still not very impressive, but this can probably be improved by designing the camber line less naively.

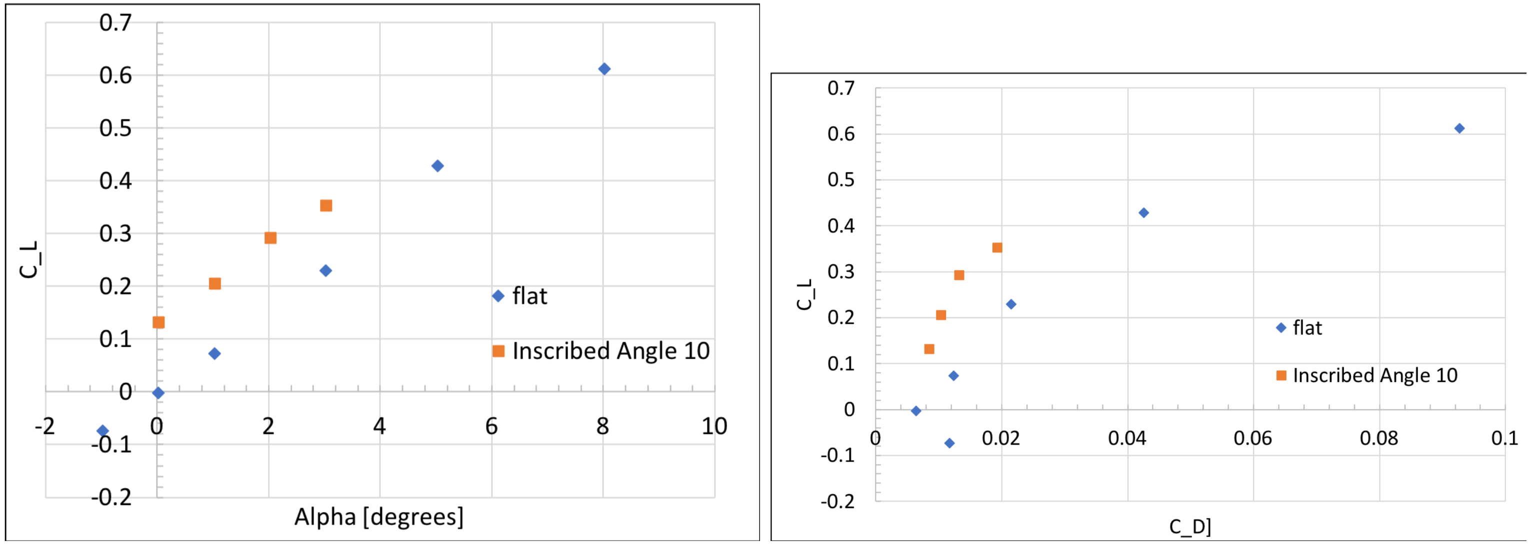

Figure 6.1: Lift and drag data from CFD simulations of both sheets

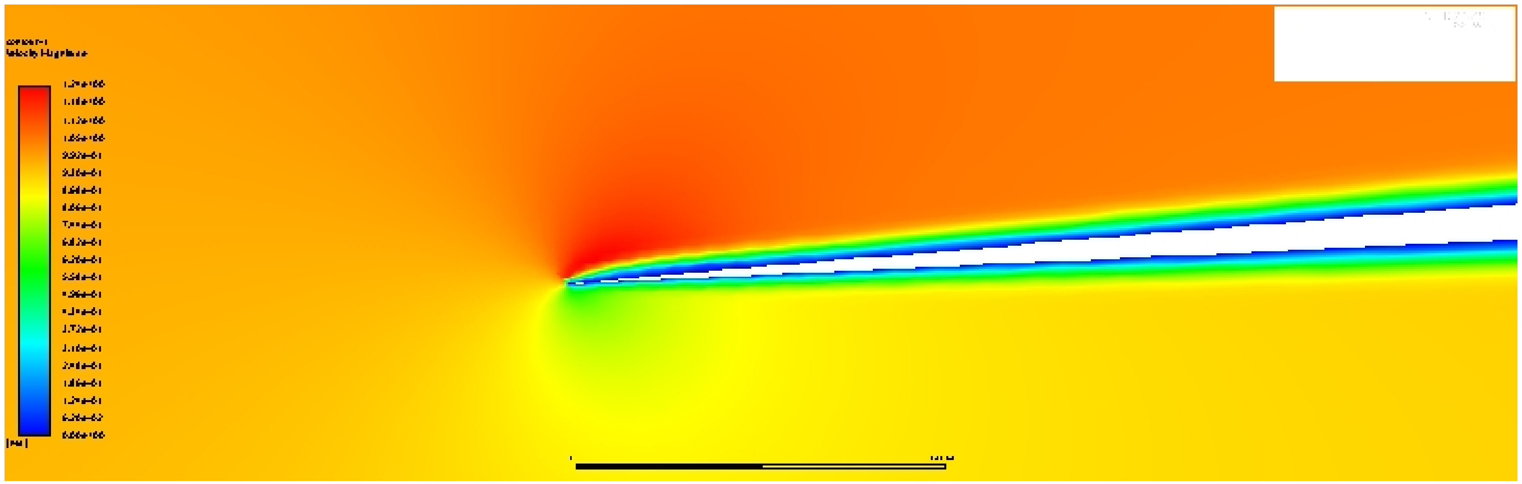

Figure 6.2: The cambered sheet at $\alpha = 2°$

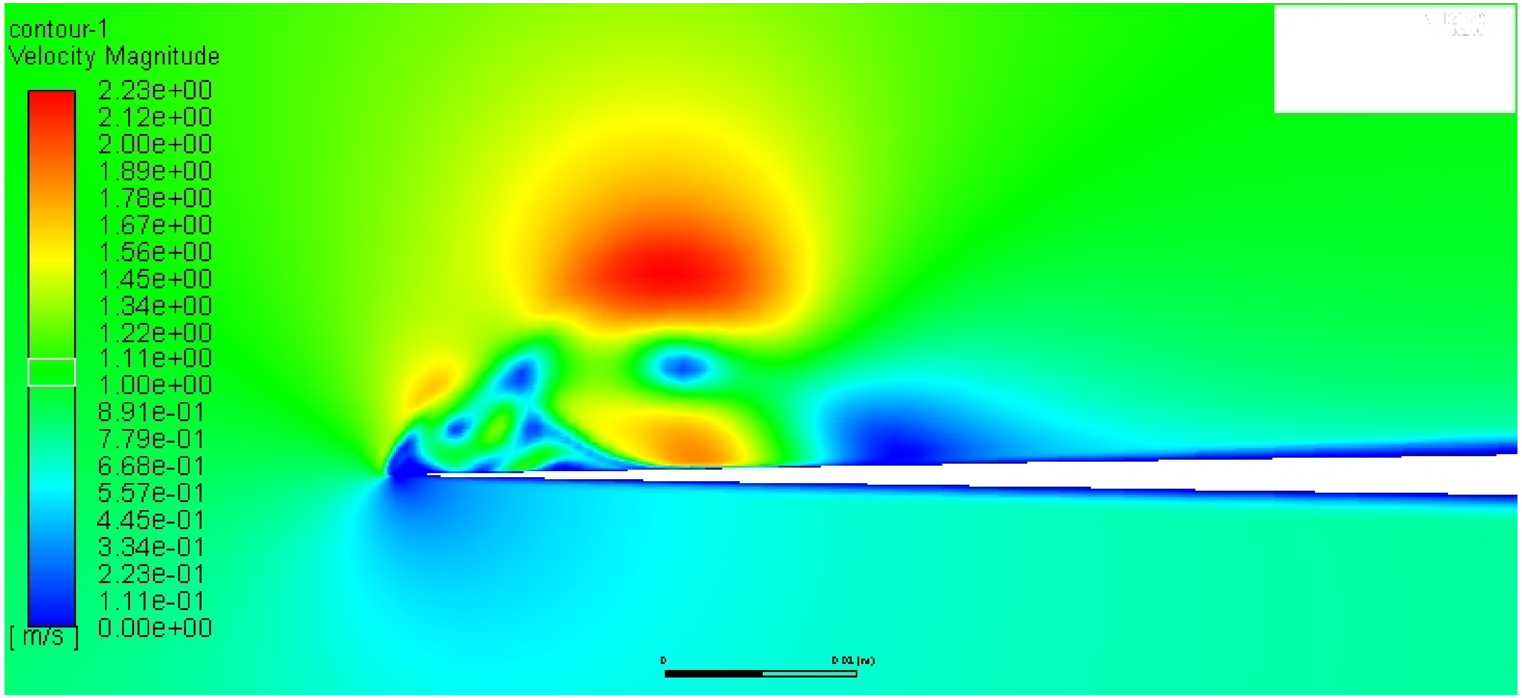

Figure 6.3: The flat sheet at $\alpha = 5°$

Bibliography

[1] Micaiah C. Smith-Pierce, Yana Charoenboonvivat, Dhwanil Shukla, and Narayanan M. Komerath. "High Altitude Aerodynamic Reflectors To Counter Climate Change", 2018 Applied Aerodynamics Conference, AIAA AVIATION Forum, (AIAA 2018-3963) `https://doi.org/10.2514/6.2018-3962`

[2] John Anderson, *Fundamentals of Aerodynamics*, 6th edition