Experimental Aerodynamics and Concepts Group

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Contents

Chapter 1

Abstract

1.0.1 The Flying Carpet

The ideation of a set of reflectors floating in the upper atmosphere has the potential to efficiently reflect solar radiation back to space. This 'Flying Carpet' concept can reduce global warming by reducing the radiant forcing into the atmosphere and comes with a cost that is within budget. This is enabled by the design in which the reflective sheets are concentrated within efficient bands rather being uniformly spread over the globe.They are to be propelled by an electric flying wing with the rigidized sheets arranged above and below the flying wing. What increases its efficiency is the ability of the vehicle to rise to 100,000 ft in the daytime due to solar power and remain at 60,000 ft at night due its low wing loading. Any instability that occurs has been studied in initial wind tunnel experiments and later designs aspire to remove the concept of the wing altogether.

Usage of primary energy resources is essential to advancing our economic well-being and standard of living. An obvious way to reduce global warming is to reflect back a part of the sunlight that would otherwise reach the surface. While potential reflectors include bubbles in space, reflective balloons released into the sky or reflective particles released along with industrial exhaust our solution is to float reflective sheets in the upper atmosphere. These sheets are composed of aluminized Mylar and have the ability to reflect 95 percent to 99 percent of broadband sunlight. In effect, 2.72 percent of the Earth's surface must be shaded with reflector sheets oriented normal to sunlight, if we are to achieve a net cooling rate equal to the today's warming rate.

1.0.2 The CSHASR

Another solution to the pressing issue of global warming besides the Glitter Belt concept is a centrifugally stretched high altitude solar reflector or CSHASR. Comprised of a quad-rotor structure, this device initially required the use of a mock flow field in front of a large fan. A stand was built to hold a velocity probe to measure the wind flow. However the idea of testing the rotor in front of the fan was scrapped as it proved to be quite inefficient. If more energy were to be required this would in fact prove to be even less efficient than a flying wing.

1.0.3 The ABR

Finally, an Aerostatically Balanced Reflector sheet held up by hydrogen balloons may also be used. The use of hydrogen in the lab is still under consideration.

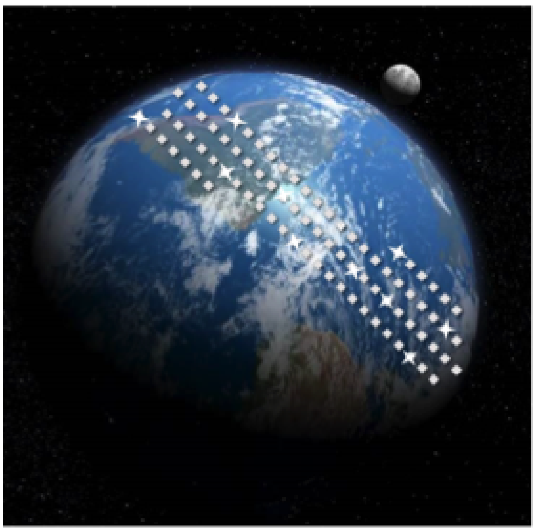


Fig 1.1: The Glitter Belt concept

Chapter 2

Fall 2017: The Glitterbelt Project

The reflective sheets for the Flying Carpet need to be floated permanently at an altitude that is high enough to eliminate absorption of sunlight. For this the sheets need to be ultra- thin and hence were modeled by sheets of paper.

These sheets were rectangular in size and initially were made to be sturdier with supports from drinking straws. These straws were cut and attached in various positions to allow us to eliminate all possible configurations that would lead to failure.

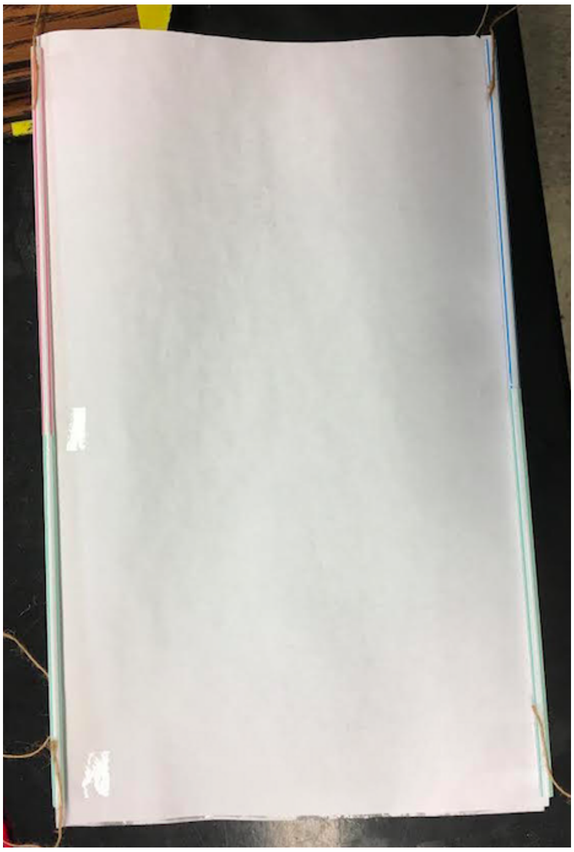


Fig 2.1: Example Straw Configuration

Two of these configurations were eliminated immediately as they were on the horizontal edges and would not be aerodynamically viable. However, after testing all the models in the wind tunnel we realized that the design for the sheet itself had to be remodeled.

To do this we considered coating the sheets of paper in Epoxy. The following type of Epoxy was used:

Fig 2.2: Type of Epoxy Used

The method was as follows:

1. Mix part A and part B of Epoxy coating on a metal sheet with a paint scalpel
2. Use three different sheets of paper
3. For paper 1 coat the full paper in Epoxy
4. For paper 2 coat only the sides in Epoxy
5. For paper 3 create an 'X' with Epoxy

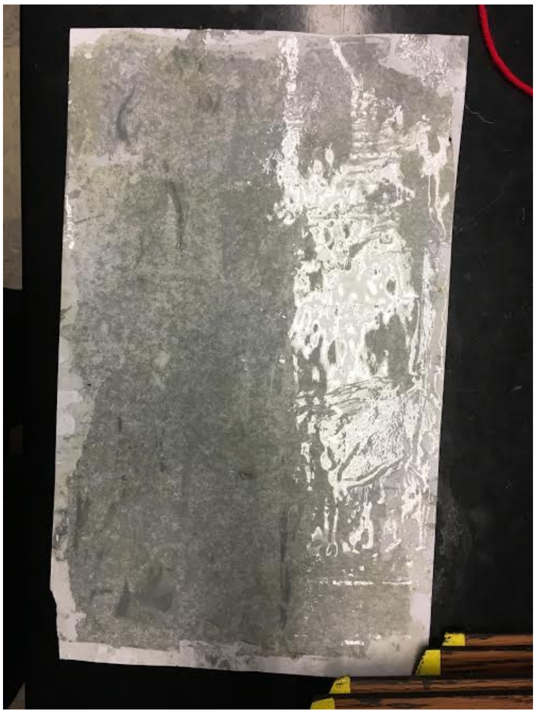


Fig 2.3: Full Sheet Covered in Epoxy

The results of this were disappointing as the epoxy did not have the same effect on paper as we had predicted. Our intentions were to make the sheets of paper more rigid whilst adding the least drag possible. Since our outcome did not reflect this we concluded that the epoxy used was perhaps not appropriate.

Upon instruction I even attempted to allow the sheets to dry on this cambered surface to determine whether the sheet would curve according to the shape of the surface. The following surface was used:

Fig 2.4: Cambered Surface

Once again, the results were disappointing. Not only did the sheets of paper not take the shape of the surface, they remained limp. It was concluded that the epoxy had had not effect on the rigidity of the sheets of paper. Hence, the experimental design was remodeled to the following structure:

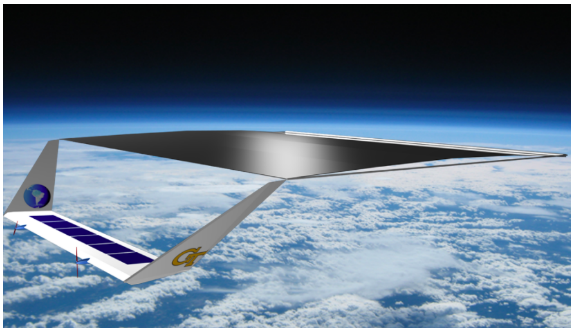


Fig 2.5: Remodeled Design

To determine whether any improvements were made to the results we had to test it in the wind tunnel. To do this we built a model out of the sheets of paper and cardboard. The sheets of paper mimicked the horizontal surface and the cardboard mimicked the structure below. Something that we initially struggled with was determining how to attach the sheet of paper to the cardboard and keeping the vertical sides of the cardboard at a 45 degree angle.

To solve this problem we tried to cut a slit at the edge of the paper and attach it to the edge of the cardboard.

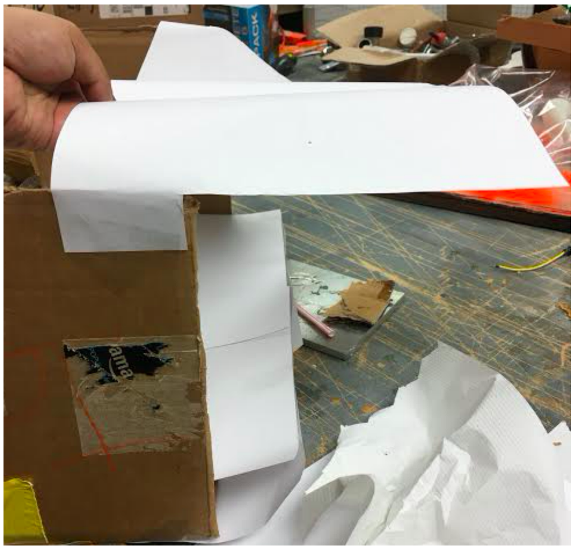


Fig 2.6: Cardboard and Paper Structure

We then sheared off the remaining section of the paper that jutted out along that line of reference. This gave us a sheet of paper that was held above the tabletop which stood horizontal to the surface.

To keep the cardboard at a 45 degree angle we used pieces of metal as follows:

Fig 2.7: Form of Support Used

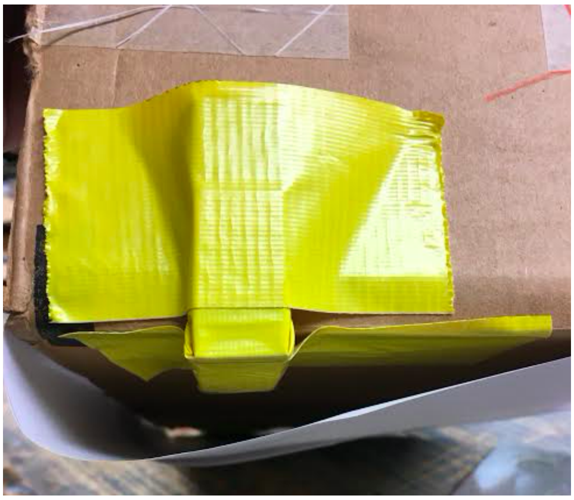


Fig 2.8: Metal Attached to Structure

Unfortunately, the metal pieces were only useful in keeping the sides of the structure at a 90 degree angle. This meant that the initial model built was of extremely poor and unreliable quality. Furthermore, it was modeled wrongly and aspects of our design became redundant. Examples of such additions were implementing straws to the horizontal cardboard base to keep the structure at the specified angle.

Hence the following improvements were needed to be made:

1. Reconfigure the metal strips to attain the specified 45 degree angle
2. Bend the sides to this angle and keep in place using duct tape as the preferred choice of adhesive
3. According to the reconfigured position of the sides of the cardboard, attach straws to the bottom section of the cardboard end-to-end in a line
4. Fold the sheet of paper and create slits on the side with greater precision
5. Attach a larger portion of the sheet of paper to the cardboard to increase its ability to remain horizontal and above the surface of the table top

Fig 2.9: Initial Assembly

This idea then evolved to using SolidWorks to model a surface that can hold the pieces of cardboard. It would have slots that would allow the pieces of cardboard to be inserted at the 45 degree angle. After this is modeled this will be 3D printed and then attached to a wooden wing surface to carry out tests in the wind tunnel. The remainder of the design stays the same. It was hypothesized at the time that perhaps the 45 degree itself might not be the best choice of angle. Since this was hypothesized due to the trial and error nature of the experiment we left the angle open to be changed on the 3D modeled part.

To model this part, an initial trapezoid was drawn on the Front Plane and extruded. The fillet feature was then used to create the rounded edge on the right side. Similarly, the fillet feature was used to curve the inner corners. Finally, to create the inner slots, the cut extrude feature was used on two rectangular sketches.

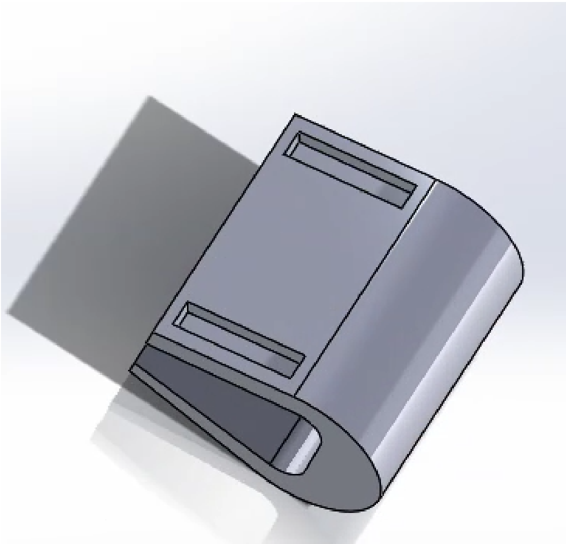


Fig 2.10: Part

The wooden wing that this will be attached to is as follows:

Fig 2.11: Wooden Wing

The only issue that remains is the floppy nature of the paper as pictured:

Fig 2.12: Wooden Wing

To tackle this issue perhaps the material of the paper can be altered. This ideation can occur in the next stage as we rework this design for Mars exploration.

Chapter 3

Divergence Code

I have now had a certain amount of experience coding equations for the divergence of a pendulum. The divergence code has been heavily modified from a physics standpoint, as well as the simulation method. All the kinematics and the dynamics for the compound pendulum have been calculated in the inertial frame to avoid non-inertial forces and moments.

The equations I have coded are as follows:

$$x = \mathcal{L} sin\theta cos\phi$$

$$y = \mathcal{L} sin\theta sin\phi$$

$$z = -\mathcal{L} cos\theta$$

$$Lagrange\ L = U - K.E$$

$$U = -mg\mathcal{L}cos\theta$$

$$K.E = \frac{1}{2}mV^2 = \frac{1}{2}Iw^2$$

$$V^2 = (xt)^2 + (yt)^2 + (zt)^2$$

$$xt = \mathcal{L}\left[\sin\theta\left(-\sin\phi\right)\phi t + \cos\phi\cos\theta\theta t\right]$$

$$(xt)^2 = \mathcal{L}^2\left[\sin^2\theta\sin^2\phi\left(\phi t\right)^2 + \cos^2\phi\cos^2\theta\left(\theta t\right)^2 - 2\sin\theta\sin\phi\cos\theta\cos\phi\phi t\theta t\right]$$

$$(yt)^2 = \mathcal{L}^2\left[\sin^2\theta\cos^2\phi\left(\phi t\right)^2 + \sin^2\phi\cos^2\theta\left(\theta t\right)^2 + 2\sin\theta\sin\phi\cos\theta\cos\phi\phi t\theta t\right]$$

$$(zt)^2 = \mathcal{L}^2\left[\sin^2\theta\left(\theta t\right)^2\right]$$

$$\begin{aligned}(xt)^2 + (yt)^2 + (zt)^2 &= \mathcal{L}^2\left[\sin^2\theta\left(\phi t\right)^2 + \cos^2\theta\left(\theta t\right)^2 + \sin^2\theta\left(\theta t\right)^2\right] \\ &= \mathcal{L}^2\left[\sin^2\theta\left(\phi t\right)^2 + \left(\theta t\right)^2\right]\end{aligned}$$

$$K.E = \frac{1}{2}\left(m\mathcal{L}^2\right)\left[\sin^2\theta\,(\phi t)^2 + (\theta t)^2\right]$$

$$\mathcal{L} = \frac{1}{2}m\mathcal{L}^2\left[\sin^2\theta\,(\phi t)^2 + (\theta t)^2\right]$$

$$t\,(\mathcal{L}\theta) = \mathcal{L}\theta$$

$$\mathcal{L}\theta = \frac{1}{2}m\mathcal{L}^2\left[2\sin\theta\cos\theta\,(\phi t)^2\right] + mg\mathcal{L}\,(-\sin\theta)$$

$$\mathcal{L}\theta = \frac{1}{2}m\mathcal{L}^2\,[2\,(\theta t)]$$

$$t\,(\mathcal{L}\theta) = \frac{1}{2}m\mathcal{L}^2\left[2\,(\theta t)^2\right] = m\mathcal{L}^2\,(\theta t)^2$$

$$m\mathcal{L}^2\,(\theta t)^2 = \frac{1}{2}m\mathcal{L}^2\left[2\sin\theta\cos\theta\,(\phi t)^2\right] - mg\mathcal{L}\sin\theta$$

$$m\mathcal{L}^2\,(\theta t)^2 = m\mathcal{L}^2\left[\sin\theta\cos\theta\,(\phi t)^2\right] - mg\mathcal{L}\sin\theta$$

$$m\mathcal{L}^2\left[(\theta t)^2 - \sin\theta\cos\theta - (\phi t)^2\right] + mg\mathcal{L}\sin\theta = 0$$

$$\mathcal{L} = \frac{1}{2}m\mathcal{L}^2\left[\sin^2\theta\,(\phi t)^2 + (\theta t)^2\right] + mg\mathcal{L}\cos\theta$$

$$(\mathcal{L}\phi) = 0$$

$$\left(\mathcal{L}\dot{\phi}\right) = \frac{1}{2}m\mathcal{L}^2\left[2\sin^2\theta\,(\phi t)\right]$$

$$t\left(\mathcal{L}\dot{\phi}\right) = \mathcal{L}\phi = 0$$

$\mathcal{L}\dot{\phi}$ = constant independent of time

$$\mathcal{L}\dot{\phi} = H\,(\theta) = m\mathcal{L}^2\sin^2\theta\,(\phi t) = m\mathcal{L}^2 H$$

Solve equations I and II simultaneously for θ and ϕ or substitute II in I.

$$m\mathcal{L}^2\left[(\theta t)^2 - \sin\theta\cos\theta\,(\phi t)^2\,\frac{\sin^3\theta}{\sin^3\theta}\right] + mg\mathcal{L}\sin\theta = 0$$

$$m\mathcal{L}^2\left[(\theta t)^2 - \sin^4\theta\,(\phi t)^2\,\frac{\cos\theta}{\sin^3\theta}\right] + mg\mathcal{L}\sin\theta = 0$$

$$m\mathcal{L}^2\left[(\theta t)^2 - h^2\frac{\cos\theta}{\sin^3\theta}\right] + mg\mathcal{L}\sin\theta = 0$$

$$m\mathcal{L}\left(\theta t\right)^2 + mg\mathcal{L}\sin\theta - m\mathcal{L}^2h^2\frac{\cos\theta}{\sin^3\theta} = 0$$

$m\mathcal{L}^2 =$ I, for a bob mass

$$I\left(\theta t\right)^2 + mg\mathcal{L}\sin\theta - Ih^2\frac{\cos\theta}{\sin^3\theta} = 0$$

$$\dot{\theta} + \frac{g}{\mathcal{L}}\sin\theta - h^2\frac{\cos}{\theta}\sin^3\theta = 0$$

$$h = \left(\sin^2\theta\right)\dot{\phi}$$

$$m\mathcal{L}^2$$

$$I\dot{\theta} + m\mathcal{L}g\sin\theta - Ih^2\frac{\cos\theta}{\sin^3\theta} = 0$$

$$I\left(I - h^2\frac{\cos\theta}{\sin^3\theta}\right)\dot{\theta} + mg\mathcal{L}\sin\theta = 0$$

Chapter 4

Final Report - Fall 2017

The steps I would take to allow easy transmittal of knowledge about work done this semester to a successor team would be to primarily show them how to code on Latex and create effective reports. The creation of this report gives a sense of pride to any student engaging in research. All other aspects or learning within this particular lab are trial and error oriented. One has to do to learn. It is also important to familiarize them with the lab so they can come in and work at their convenience. For this the cleanup and storage of items within the lab is important. Things must be organized effectively to be taken back out when required. Hence all items must and return of items to inventory. The glitter belt project has massive potential in changing how we perceive the changing global climate and its calamities. If effective, this can reduce these emissions by a significant amount and help match the pace at which fossil fuels are being burnt.

Currently efforts might be redirected to a concept that is more vital for Mars exploration. However in effect it carries out the same function. Our methods will still remain the same to reduce the combined weight of the object and the technique to do this also correspond to our previous efforts.

Chapter 5

Spring 2018: The Glitterbelt Project

Progress has been made in remeasuring the wooden wing that is to be used to attach the base of the Flying Carpet model. This was done using vernier calipers. These measurements were then transferred onto SolidWorks to alter the 3D model that was designed last semester. Next the NACA database was used to generate airfoil shapes within SolidWorks to refine the design of the 3D modeled part.

Besides these efforts, more ideation took place as to how to conduct these experiments. The following ideas had been proposed:

1. Use 3D printed or laser cut airfoil frames to build a skeleton, wrap paper, tape or cardboard around it, and then fiberglass the entirety of it.

2. Build aircraft wings out of Styrofoam. The wing and tails could be joined seamlessly, and made with any airfoil shape, accurate to perhaps += 2mm. A wooden spar could be inserted into the wing and each tail, reinforcing the joint with a gusset, without interfering with the airflow.

The following engineering drawing was drawn by my peers to explain the Styrofoam method along with its dimensions:

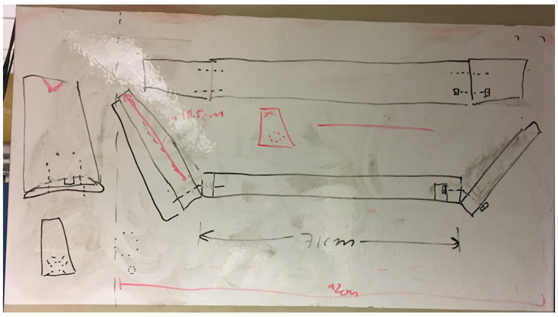


Fig 5.1: Engineering Drawing

Further ideation was extremely useful in making progress as we were finding it difficult to construct a 3-D printed model which could allow the wings of the structure to be at variable angles. Hence we decided to start constructing the model using the Styrofoam method.

The first a long section of Styrofoam was cut using a hot tool such that it were 71 cm long and 10.5 cm wide. Using SolidWorks a sketch was created of the wings that were to be laser cut at the Aero Maker Space.

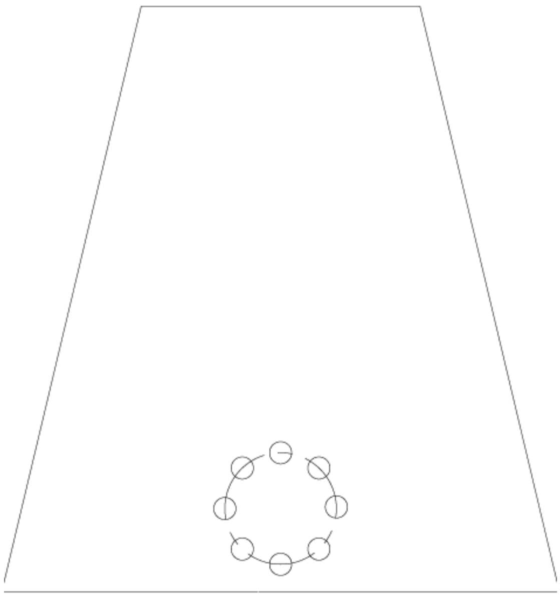


Fig 5.2: Wing Sketch

Indents were then made on the sides of the Styrofoam to slot two pieces of plastic. These pieces of plastic were used to strengthen the sides and prevent the wires from damaging the soft Styrofoam during testing. Holes were created within the plastic using the hot tool to allow bent wires through the wings and the plastic.

Fig 5.3: Styrofoam Indent

Slots were also created within these indents for these pieces to sit within the sides of the Styrofoam base. A hot glue gun was then used to secure these pieces in their slots.

Fig 5.4: Attachment of Plastic

The idea was that the different holes could be used to create variable angles for the wings. Hence the wires were inserted in the following position:

Fig 5.5: Wire Attachment

Fig 5.6: Wire Attachment

This allowed us to create the following structure:

Fig 5.7: Structure

The next steps would be to finish attaching the sheet on top of the wings and be ready to test this model. Additionally, we have to have the mylar sheet itself be deployable in the atmosphere.

To do this we first created a small airfoil that was to be stuck at the back edge of the mylar sheet. This was created out of Styrofoam and sanded down. Poles were already attached onto the top of vertical tail and parallel to the styrofoam piece. The idea was to have the Mylar sheet rolled up and then 'pulled out' along the direction of the poles that are stuck on the vertical tail. This is akin to pulling out a drawer but having the Mylar sheet appear. A pipe was stuck along the span of the styrofoam piece to make a rounder leading edge and pieces of paper were attached along the styrofoam piece to form a sharper trailing edge. After these modifications were made informal tests were conducted in the wind tunnel.

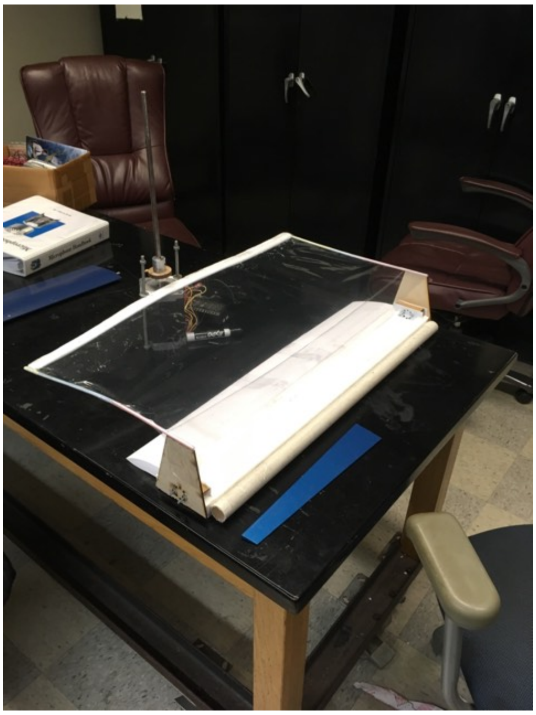


Fig 5.8: Updated Structure

These tests initially led us to believe that the sheet on top was fluttering relentlessly based off of our current model. Hence we planned to take an audio recording of the fluttering noise to allow Nandeesh to analyse the amplitudes of the sound waves. Our intentions were to make modifications based on the data gathered by Nandeesh regarding these amplitudes. To take the audio recording we needed to ensure that that angle of attack with which we held the model was consisted. Hence we stuck strips of paper on the side of the door frame to create a consistent angle.

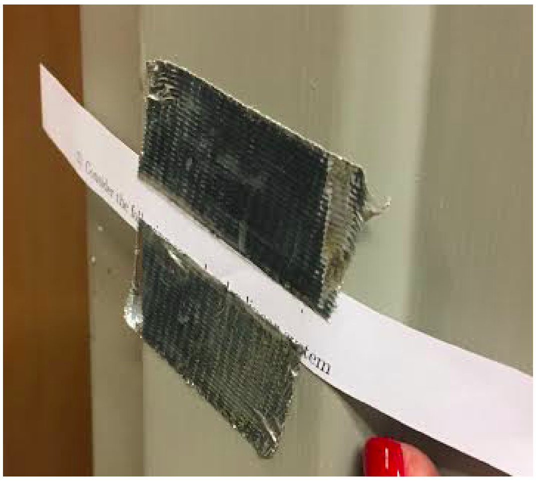


Fig 5.9: Adjusting the Angle of Attack

However, the faults lay in the sheet used and a specific crease at one end of the material. Hence we resolved to changing the entirety of the sheet. Essentially, the material of the sheet was replaced with one that did not have creases solely at the edge. When fixing this model the edges were made parabolic and constrained with thread and elastic bands. This was to ensure that the sheet was held taunt and minimize the effects of the creases.

Fig 5.10: Updated Structure

We then began practicing using SolidWorks to create a mount for the model. The model would be placed on the mount in the wind tunnel and used to attach the model to the stand. The top section of the stand was irregularly shaped and to create the mount we had to account for this. To do this we first took measurements of the top section of the stand. These measurements were taken with a vernier caliper in inches. This task was initially difficult as we had to determine how we wanted to construct the model to avoid the ridges in the middle of the top section of the stand.

Fig 5.11: Top Section of the Stand

We initially considered creating the mount such that it would run along the two sides of the top of the stand instead of covering the middle section. However we decided to construct the mount such that it sat on top of the ridges with attachments at the four corners that had holes in them. Hence the following measurements were taken:

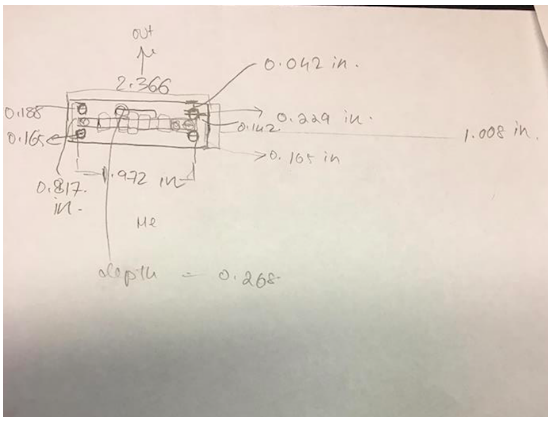


Fig 5.12: Measurements

Since this was a practice, we were told to create the mount for a blade that was to be used in AE1601 projects. Hence we also had to take measurements and CAD the blade itself. When creating the sketch on SolidWorks the following dimensions were used:

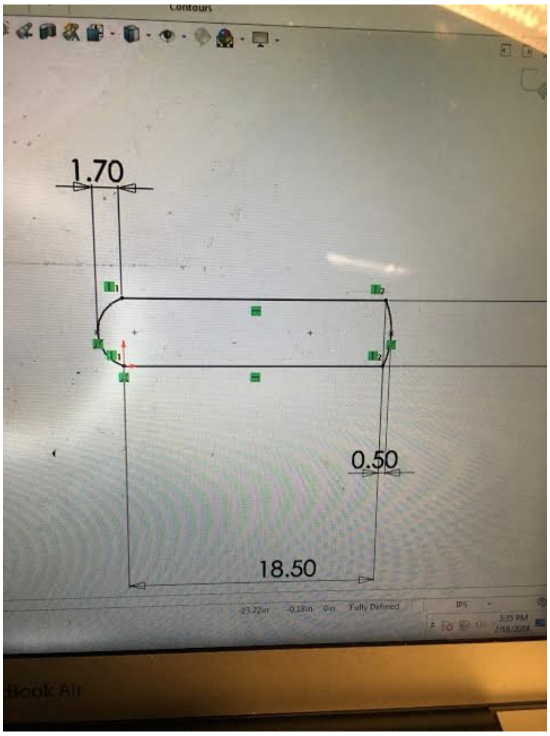


Fig 5.13: Blade Sketch

This translated to the following engineering drawing:

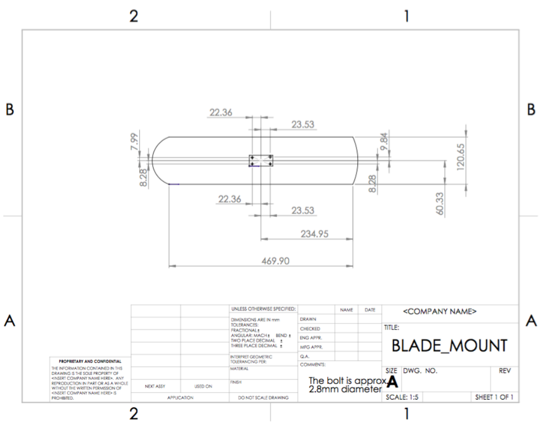


Fig 5.14: Blade-Mount Drawing

Our efforts after this were directed towards understanding the software, LabVIEW, that was to be used to take the data measurements in the low turbulence wind tunnel. Since the software itself was not working as per the requirements for the practical exercise that was to help us prepare for testing the model it was difficult to proceed. Hence, anticipating its use in the near future, I familiarized myself with the general concept of LabVIEW - a software used to create virtual instruments. Code is added using the virtual instruments and front panel objects (or the user interface). LabVIEW is then used to communicate with hardware.

I also familiarized myself with the practical exercise that we were practicing with. Here the rectangular wing used is fitted with end plates. This inhibits the flow of air from the lower side of the lifting wing around the tips to the upper side. If the end plates are removed from the model, the behavior of the wing changes from one of infinite span to one of finite span. This gave me a greater understanding of the exercise before conducting it and prepared me for the upcoming week.

Once the LabVIEW software was accessible, we could finally begin working in the low turbulence wind tunnel. We initially calibrated the values for the lift and the drag of the stand without the flat plate. We then added the flat plate and calibrated values for both the lift and the drag at 16 mps which is the highest speed. These gave us different sets of data for different angles of attack that we then had to work with. Essentially, we took the average values and the standard deviation of the lift and drag of the plate.

D	E	F	G	H
Lw(LBF)	Dw(LBF)		Lw(N)	Dw(N)
0.9895209	0.5706814		4.40160666	2.53851642
std				
0.16276262	0.08765409		0.72400393	0.38990466

Fig 5.15: Data Manipulation

To do this we used excel. We then changed these values from lbf to N by multiplying the constant 4.44822. Once we had values for all data sets we put them together on a shared document and also calculated the lift and drag average and standard deviation values for the flat plate. To calculate the actual value for lift and drag we would have to subtract the value of the stand from the ones of the plate and the stand. To then calculate the values of the coefficient of drag and lift we needed these values calculated for lift and drag, the total area of the flat plate, the highest speed at which the wind tunnel operated and the density of the plate.

flat plate area (m^2)	
0.06153	
density of air (kg/m^3)	
1.167	
velocity (m/s)	
16	
b(m)	
0.5258	
c(m)	
0.1207	

Fig 5.16: Data Substitutions

These produced the following graphs with the following values.

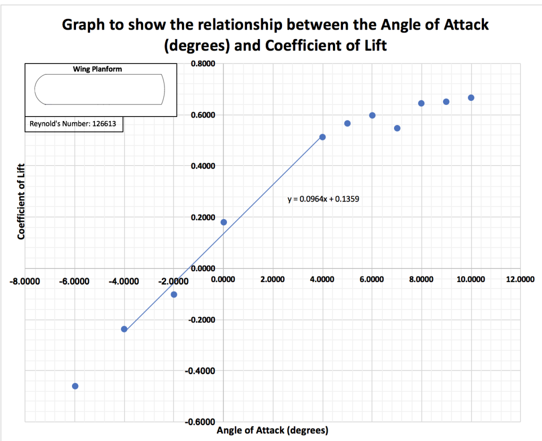


Fig 5.17: Graph 1

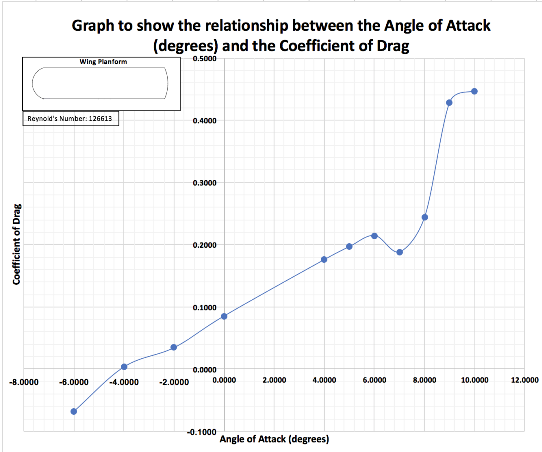


Fig 5.18: Graph 2

K	L	M
Stand Average Lift	Stand Average Drag	Linear Fit coefficients
-0.6304	0.809	CL = mx + b
		m (/rad):
		5.6061
		b:
		0.1343
		m (2π)
		6.283185307
		%error of m
		10.77614735

Fig 5.19: Data Values

After conducting these tests we had a good understanding of the software and got a feel of how the experiment would pan out. Hence this week we began testing with the actual flying carpet model. We created a mount for the model using wood and the dimensions that were taken earlier to create the mount for the plate. We attached this mount to the model by using screws from the Aerospace shop.

Fig 5.20: Model Ready for Testing

First we used an X-Acto knife to create insertions in the Styrofoam and scooped out the material to put the wooden mount into it. We then secured the screws through the holes in the mount. We were worried about the stability of the model on the base stand. However it withstood the air flow, both with and without the sheet attached. Our first set of tests were conducted across a range of 0 - 2 for the angle of attack with no sheet attached. These were the values collected:

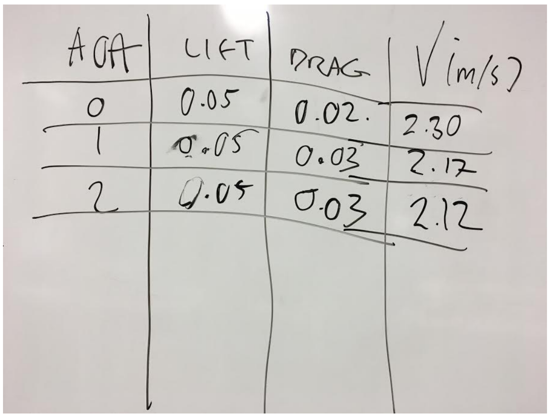


Fig 5.21: Data without Sheet

We then conducted these tests with the sheet on for the same range for the angle of attack. The following are the values:

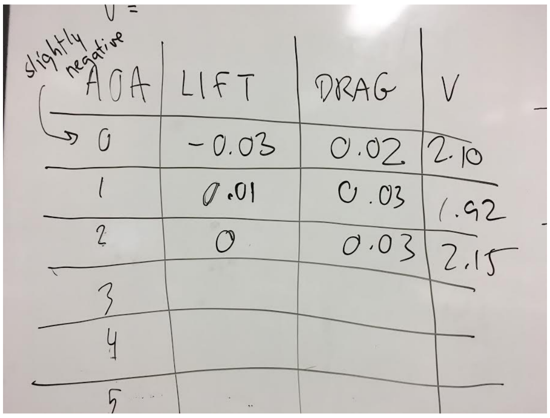


Fig 5.22: Data with Sheet

As one can tell the slightly negative values needed to be retaken and we needed to proceed to take the trials for the remaining angles of attack.

For this, data was collected at 4m/s at AOAs between 3 degrees to 12 degrees. The general results can be seen in the following graphs:

However after this, further measurements could not be taken as having accurate measurements of the drag were needed to make any further conclusions about the the trends in the lift that were seen.

Hence we started working on making the research poster. To do this we began with taking a photo of an exemplar as follows:

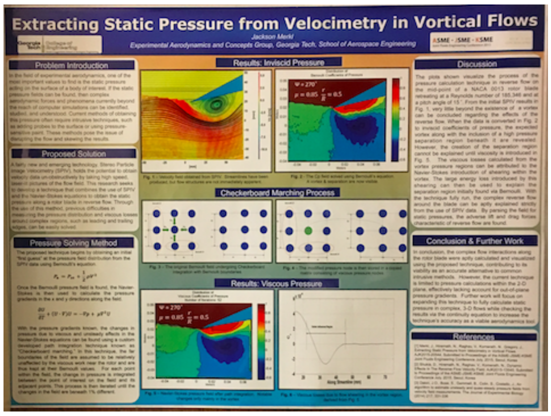


Fig 5.23: Example for Research Poster

We noted that there was a certain format for these research posters and we tried to emulate this for our own poster. We also noted how there was a lot of text in blocks. We wanted to ensure that for our own poster we would have text that was more accessible to students and faculty alike. Although our content was to be technical it was going to be broken down on the poster itself. Hence we decided on the following format for the poster:

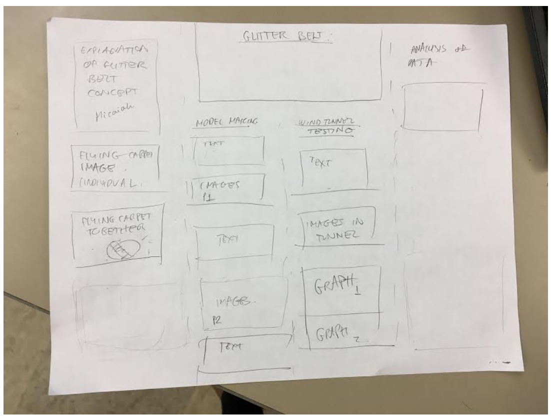


Fig 5.24: Plan for Research Poster

We began by editing the abstracts and making it more accessible to a common reader. We also worked on power-point to make technical images. We produced some of these following photos:

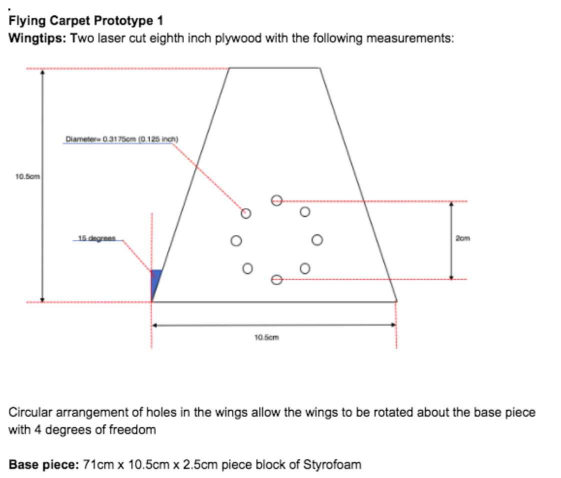


Fig 5.25: Plan for Research Poster

It was extremely exciting putting the poster together and I felt this especially when I was printing it out and it was coming out of the large machine. Yana, Micaiah and I set up the poster so that the background would be that of stars and the main content would be divided into three subsections. We began with the problem introduction, and then progressed to the proposed solution. From here we went into the model building process, wind tunnel testing and the subsequent steps we would be taking. I edited the content on our shared document and then sized and re-sized the words on the poster.

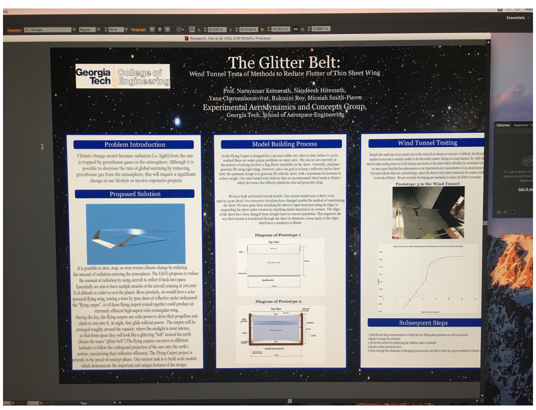


Fig 5.26: Research Fair Poster

Nandeesh also gave many editing suggestions that I then followed through with. The fair itself was also extremely fun and eye-opening. It was really interesting to see the different things students were working on on campus. The best part about doing this was that we finally got to take a step back and reflect on what we'd done and what we needed to do. Over the course of the two semesters working on this project I have learnt how to talk about the work that we've been doing 'technically'. With time I have understood things that I have yet to learn in class and grasped a lot of the 'basics' that were touched upon in AE 1601.

Amongst these things was the setup of the low speed wind tunnel itself. For the longest time I felt as though I knew only the basics of operating the controls to make the wind tunnel run. I did not have enough depth in terms of my knowledge in this. Nandeesh's report on the experimental investigations on the ceiling fan blade were helpful in reiterating the concepts I've been exposed to these past two semesters.

On the last day of research Micaiah and I cleaned up our parts that we used to test the lift and drag values for the different angles of attack with the mylar sheet.We took multiple videos of the model with the sheet attached in two different configurations. One included string on the parabolic edges attached on the corners with duct tape and rubber bands. The rubber bands were problematic in the sense that they easily popped open. We readjusted them multiple times. However layering the duct tape and attaching it in a triangular manner allowed us to take all the tests we needed without the sheet snapping out of the model.

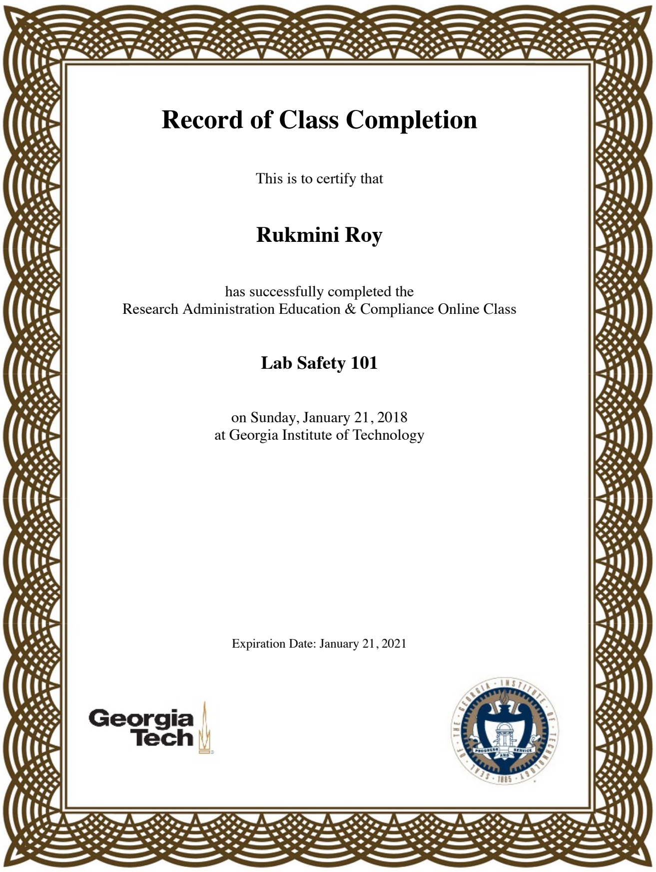
Chapter 6

Final Report - Spring 2018

The semester began with me transmitting knowledge to my team members about the Glitter Belt Project. It was exciting as they were new and had a multitude of ideas. We worked with a lot of tools that were purchased by team members from the outside to make the project faster. An example of this is the hot tool purchased by my team member Micaiah with which we made holes in our styrofoam and pieces of wood. This project was exciting this semester because of the number of prototypes we made and how we continued to build on our previous ideas. It truly felt experimental. A lot of the items that we used this semester were brought from external sources such as the arts and supply shop in Midtown hence I would advise people taking on the project next semester to not be afraid of branching out and thinking outside the box as to what materials to use.

Chapter 7

Certificates



Record of Class Completion

This is to certify that

Rukmini Roy

has successfully completed the
Research Administration Education & Compliance Online Class

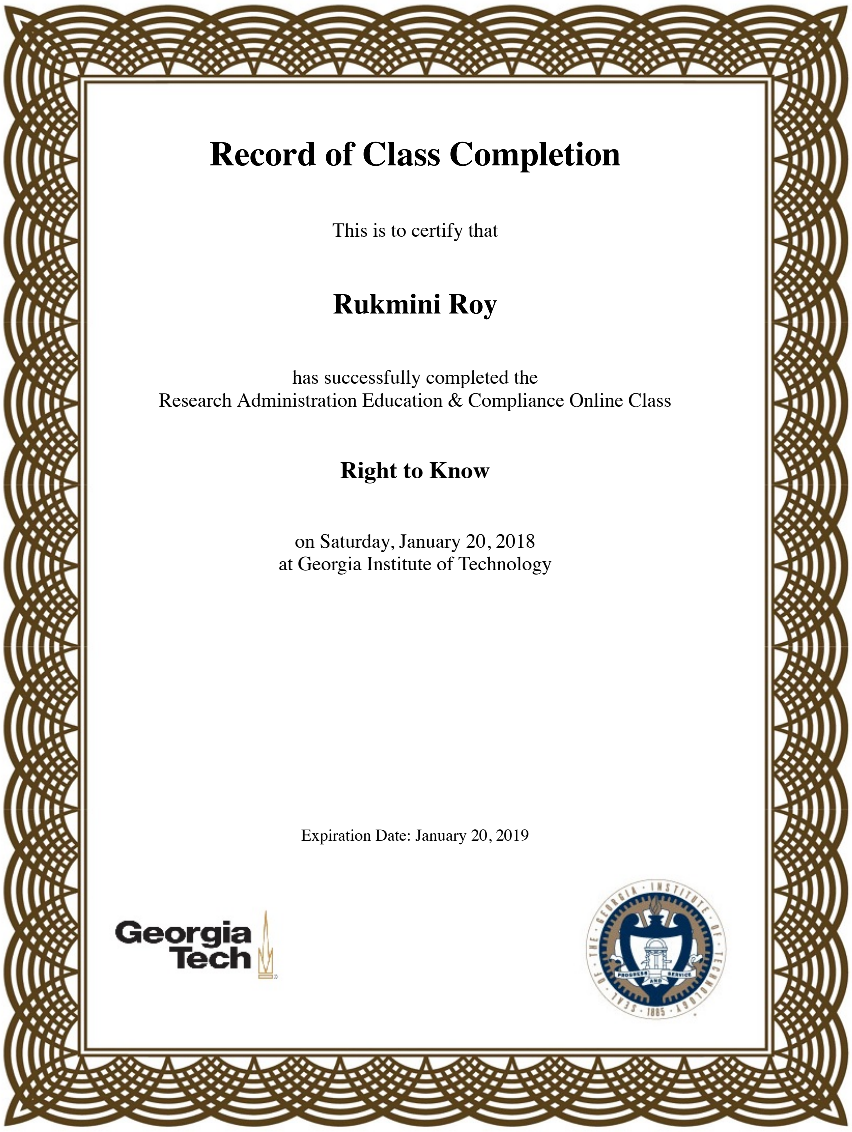
Lab Safety 101

on Sunday, January 21, 2018
at Georgia Institute of Technology

Expiration Date: January 21, 2021

Georgia Tech

Fig 7.1: Lab Safety 101 Certificate



Record of Class Completion

This is to certify that

Rukmini Roy

has successfully completed the
Research Administration Education & Compliance Online Class

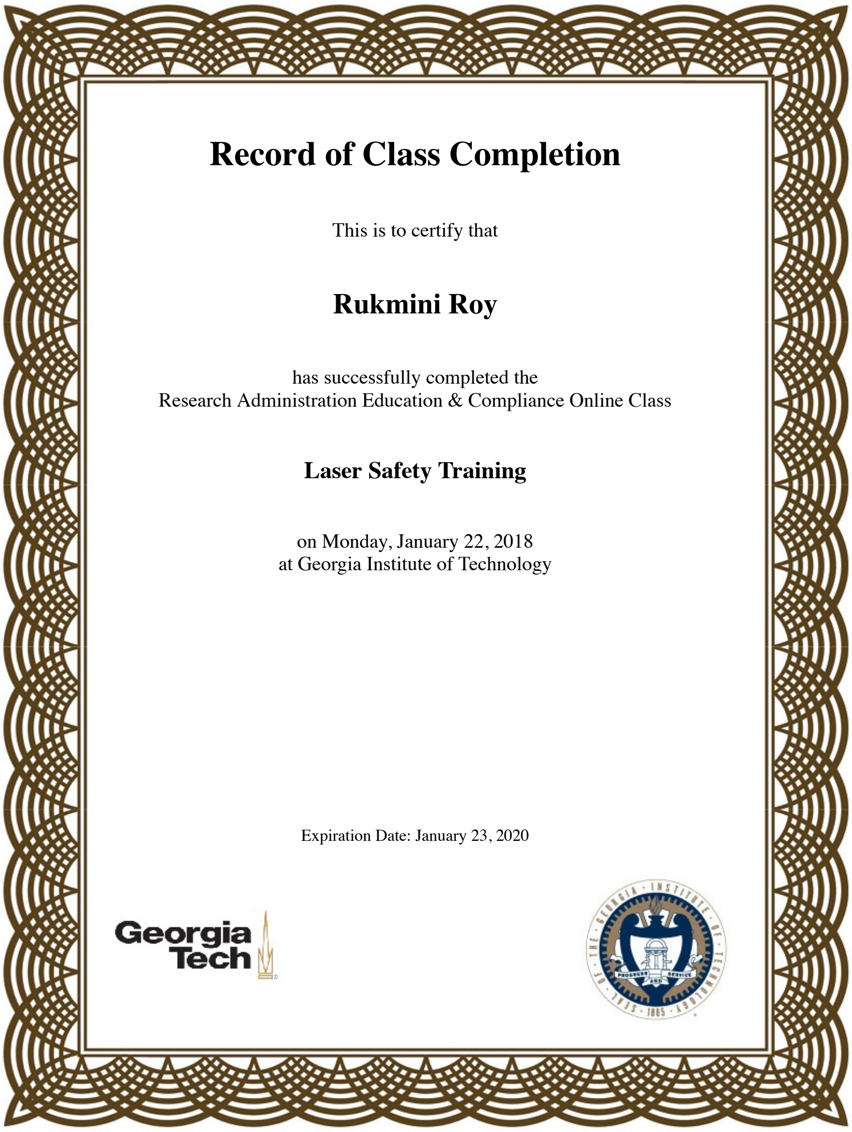
Right to Know

on Saturday, January 20, 2018
at Georgia Institute of Technology

Expiration Date: January 20, 2019

Georgia Tech

Fig 7.2: Right To Know Certificate



Record of Class Completion

This is to certify that

Rukmini Roy

has successfully completed the
Research Administration Education & Compliance Online Class

Laser Safety Training

on Monday, January 22, 2018
at Georgia Institute of Technology

Expiration Date: January 23, 2020

Georgia Tech

Fig 7.3: Laser Safety Certificate