FIU | FLORIDA
INTERNATIONAL
UNIVERSITY

EML 4905 Senior Design Project

A B.S. THESIS
PREPARED IN PARTIAL FULFILLMENT OF THE
REQUIREMENT FOR THE DEGREE OF
BACHELOR OF SCIENCE
IN
MECHANICAL ENGINEERING

SAE Formula Car – Dynamic Spoiler
100% of Final Report – Group 10

Adrian Ortuño Crespo
Brent Alexander Lougheed
Richard Pelaez

Advisor: Dr. Andres Tremante, Igor Tsukanov

April 12, 2013

Ethics Statement and Signatures

The work submitted in this B.S. thesis is solely prepared by a team consisting of Adrian Ortuño Crespo, Brent Alexander Lougheed, and Richard Pelaez and it is original. Excerpts from others' work have been clearly identified, their work acknowledged within the text and listed in the list of references. All of the engineering drawings, computer programs, formulations, design work, prototype development and testing reported in this document are also original and prepared by the same team of students.

Adrian Ortuño Crespo
Team Leader

Brent Alexander Lougheed
Team Member

Richard Pelaez
Team Member

Dr. Andres Tremante
Faculty Advisor

Table of Contents

List of Figures

List of Tables

List of Equations

Abstract

When someone thinks of spoiler the iconic styling of the sixties and seventies comes to mind with the Plymouths Super bird and its extremely high rear wing, and the Porsche 911 turbo or otherwise known as the whale tale. These spoilers were placed on production vehicles for styling and not for performance. The drag created by these spoilers or rear wings decreased the performance of the car. That is not to say that all spoilers inhibit the performance of racecars. The Lotus 49 was one of the first formula one racecars to incorporate a spoiler aimed at increasing performance, primarily by generating down force on the rear wheels and increasing aerodynamic performance.

This project will aim at increasing down force on the rear wheels during braking and cornering and reduce drag during straights, for a formula SAE competition car. By using a dynamic spoiler that will adjust the angle of two separate wings as the car brakes, accelerates, and cornering turns. With the plan of having the spoiler as light as possible, carbon fiber was used for the wing material. The profiles of the wings were optimized using Sold works simulation software. The frame and links was manufactured out of aluminum, with the plan of mounting the spoiler on the rear of the SAE formula racecar. SAE competition rules restrict the size and dimension of the wings. The dynamic spoiler uses two Torxis servomotors that will move each wing. The amount of down force that was expected by the wings dictated the size and strength of the servomotors. The Arduino Uno logic board was chosen to control the Torxis servos, by processing the inputs of sensors that are placed on the braking and steering column of the SAE racecar. The velocity input is supplied from the engine control unit as a digital input.

Introduction

A spoiler is a device designed to spoil turbulent air as it passes over the body of the vehicle. Some spoilers or wings are design to increase the grip or downward force that is applied to the vehicle. Our design is to have a dynamic wing, one that moves or adjust to the conditions that the vehicle faces as it accelerates and changes direction. A split dynamic spoiler allows for the downward forces generated to be applied to the wheels as they are need. This technology is being applied to high performance vehicles such as the Bugatti and Formula 1 race cars most notably the Red Bull team.

Problem Statement

The objective of this project is to design, build and install a dynamic spoiler for the Formula SAE race car team. FIU will compete in the Formula SAE competition that takes place in Michigan in the month of May. The competition events include an endurance race, acceleration, skid pad, design presentation, cost report and sales presentation. We will have to justify that our dynamic spoiler design will benefit the Formula race car in the endurance race and the acceleration and skid pad area of the competition. SAE club has asked our group to design our dynamic spoiler in such a way that it can be removable from the frame of the car. They also asked that we travel with the club to competition in Michigan and explain our design to the judges during the design presentation. SAE has a set of rules regarding the placement and size of wings that are placed on any race car. These rules will have to be satisfied before the race car can compete in any events, the list of applicable rules are in appendix A.

Motivation

A dynamic spoiler's goal is to increase the grip the vehicle has during turns and decrease the drag and add stability on the straights. Dynamic spoilers also aid in braking of the vehicle by increasing the surface area or drag coefficient of the vehicle. Currently Formula SAE race car groups do not implement dynamic spoilers and many SAE groups do not add spoilers in general. Florida international University SAE group wants to be the first group to bring this technology to competition. Not only would a dynamic spoiler help with the endurance race, it also aids the group in the design presentation.

Literature Survey

A spoiler is an aerodynamic device commonly used in racing. The main function is to ‘spoil’ unwanted air motion around the vehicle body, streamlining the air motion around the vehicle body reduces the amount of turbulence, therefore reducing the amount of drag and increase the performance of the vehicle. The other function that a spoiler has is to provide down force to the wheels that are transmitting the power from the engine. By doing this we increase the effective normal force acting on them without increasing the overall inertia of the vehicle, allowing it to turn faster since it has more grip but the same centrifugal force.

An active spoiler is an aerodynamic device that adapts its angle of attack depending on what conditions the vehicle is in. Its main purpose is still the same as that of a static spoiler, to increase the down force while spoiling unwanted air motion. However, since the spoiler can now adapt its position we can minimize the drag when driving on a straight line and maximize the down force when the car is braking. Not all competitions allow dynamic spoilers, for example in Formula 1 they have recently implemented a device known as DRS which stands for Drag Reduction System and essentially what this does is minimize the drag coefficient of the spoiler when the car is driving in a straight line by moving the bottom half of the spoiler to a horizontal position. This concept was first implemented in the Formula 1 world in 2011 to promote overtaking, and it is expected to offer the driver an additional 10-12 km/h when engaged [1]. As with any other Formula 1 technological implementation, there are new rules that come hand to hand with it, for example it can only be activated in certain specified sections of the track or when the car in front of you is a minimum of one second away [2]. Other teams such as RMR Rhys Millen Racing have developed conceptually similar devices to the Formula 1 DRS.

Figure 1 Red Bull Formula 1 DRS Dynamic Spoiler [1]

Our project differs from DRS in the sense that it will not be manually activated by the driver but instead it will be automatically controlled by an on board computer that will detect when the car is driving on a straight path and engage our system to reduce the drag force. This on board computer is an innovative application for this project since it will find the optimum ratio between drag coefficient and down force at all times.

Another big difference between the Formula 1 Drag Reduction System and our project is that the spoiler that we are developing consists of two independently moving wings as oppose to only one. Having two wings allows us a much broader spectrum of possibilities since now, not only can we increase the down force when braking and turning and decrease the drag when driving straight, but we can also distribute the down force to the tires that need it the most when turning. From our research we have found out that there is only one company that manufactures a wing with this concept and it is the S2 model from Aeromotions ™. [3]

Similar technology can also be found in other famous car manufacturers such as Bugatti; in their Veyron model they have implemented a dynamic spoiler that deploys when the car reaches 220 km/h providing an additional 350 kg of down force [4], this is done to increase the traction in the rear tires which are the ones carrying the power to the ground as the speed increases and the revolutions per minute of the rear tires also increase, allowing for a no slip condition to occur.

Design Alternatives

When deciding on different types of design, we first needed to focus on our main objective. We needed down force on the tires to create better traction on the floor, a static spoiler would have worked. With a static spoiler, we would not be able to control the amount of down force needed at specific areas of the race. To have control of the down force, we needed to create a dynamic spoiler. Having a spoiler able to shift its angle of attack during specific sections of a race would have an advantage in speed performance. With this in mind is how we started our design process, two main designs we thought up for a dynamic spoiler. One design was using a 3 pivot piston system, it would be mounted in the middle of the spoiler and be able to pivot in any axis. This proved a problem with stability and control of the amount of force wanted on each rear tire. Our second design was to have a two, 1 axis pivot system on the spoiler. The spoiler would be divided in half, one piston mounted in the middle of the left side spoiler and one piston mounted in the middle of the right side spoiler. This would give us more control of when we want the down force to be applied, which tire we would want it to apply, and with how much intensity we need to be applied.

The actual design used for the dynamic spoiler includes two servo motors that drive the wings by two linkage arms. The decision to use servo motors over linear actuators is due to the limited strength of linear actuators when compared to servo motors. The price for linear actuators with the same comparable lifting force and speed as servo motors was not practical. The wings are made out of carbon fiber, with a profile that aims at decreasing drag at 0 degrees. Carbon fiber allows for high strength and light weight, even though the manufacturing process is difficult and arduous. The body of the Formula SAE car is made out carbon, so to keep a uniform look across the car the wing had to be made out of carbon fiber.

Engineering Design and Analysis

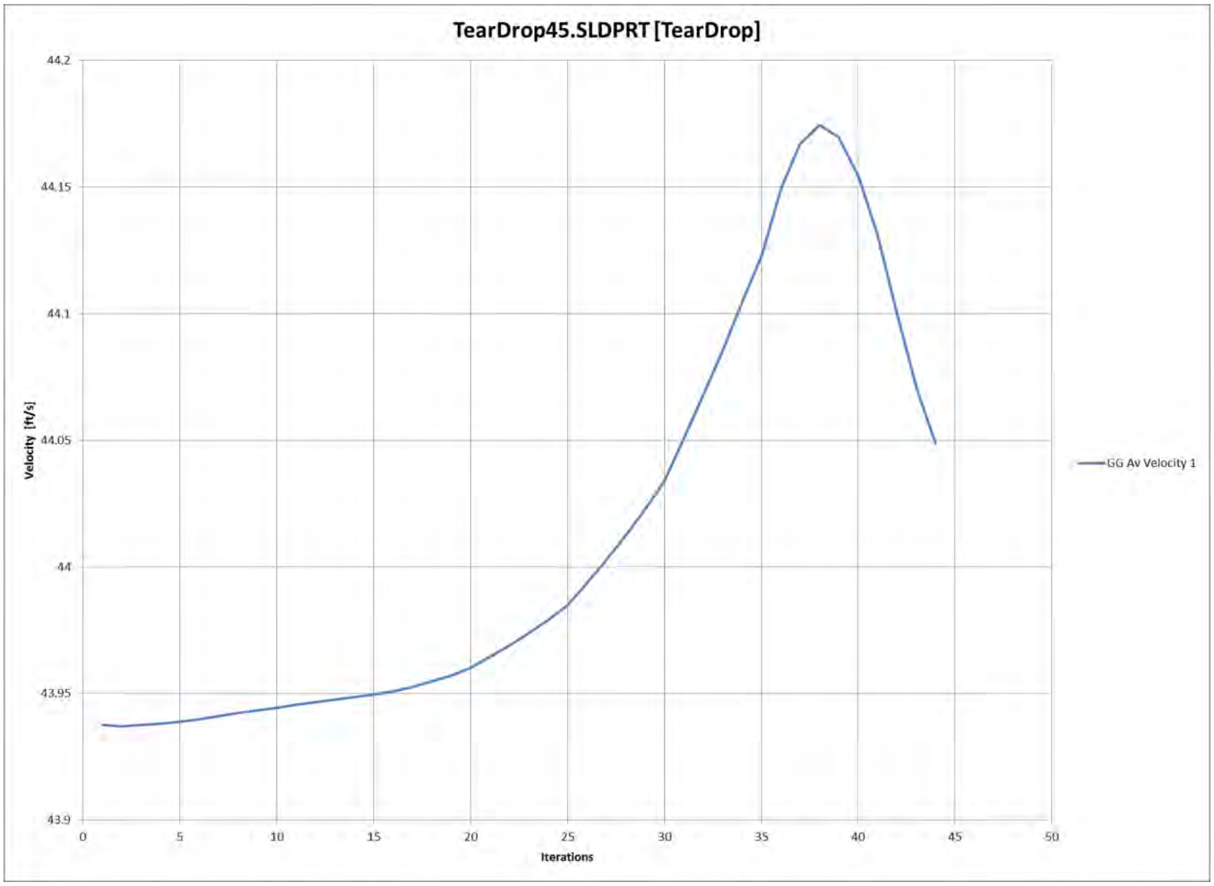


Figure 2 Velocity of Tear Drop Design

Table 1 Values for tear drop profiles

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value
GG Av Total Pressure 1	[lbf/ft^2]	2118.4	2118.4	2118.4	2118.5
GG Av Velocity 1	[ft/s]	44.0	44.0	43.9	44.1
GG Av X - Component of Velocity 1	[ft/s]	42.7	43.5	42.7	43.8
GG X - Component of Force 1	[lbf]	0.866	1.81	0.755	37.7
GG Y - Component of Force 1	[lbf]	-0.898	-1.84	-36.6	-0.822

Table 2 Physics of a car

N_r	Normal force on the rear wheel
N_f	Normal force on the front wheel

F_r	Frictional force on the rear wheel
F_f	Frictional force on the front wheel
W	Gravitational force on Center of Mass
F_w	Drag resistance on Center of Mass

Table 3 Physics of a circle

Linear Velocity	$\boldsymbol{v}$	$\boldsymbol{v = \frac{\omega}{r}}$
Centripetal Force	F	$F = \frac{mv^2}{r}$

To start the analysis of required down force, understanding how forces acted on a vehicle needed to be understood. Once a vehicle starts to turn, the inside and outside radius of the turn are different. If both wheels would be turning at the same speed, the wheels will start slipping. To avoid slipping, the two wheels would need different velocities from the inside tire to the outside tire.

Design

The spoiler is built for easy removal of from the Formula 1 car, this way; different spoilers can be used for different races on the Formula 1 car. In order to achieve this, we would need our design to hold everything needed in order for it to run on its own, independent of the car so testing can still be performed without the need of the Formula 1 car.

Our liner actuator will be powered by a separate 12V battery when it's being tested, but will have a separate connection to the Formula 1 cars battery for when it's mounted. Sensors will be installed in the structure to measure the acceleration and velocity of the system as well as have a separate connection in order to connect to the car when it's mounted on so it can receive data from the Formula 1 car itself. This will help us perform our test to the spoiler and then have easy access to mount it on the Formula 1 car when it's needed to race.

Structural Design

For this dual wing design we have considered several different design alternatives. Each of these designs had one same objective, to be able to lift the wing from horizontal position to an angle of 70 degrees in less than half a second. This condition has made it difficult to come up with a final design since the forces and velocities involved would require us to use a very large motor or actuator which would add too much weight to the vehicle. We also had to be careful that none of the devices added would break the rules established by FSAE. Below we will discuss some of the most important designs that we have considered for this dynamic spoiler.

We can split the design into three major components, the wing design, the electrical components and sensors and the mechanical components and actuators. The first two components have already been decided and will only be slightly affected by the third one. We will discuss them in the first place.

Manufacturing

In this section we are going to discuss how we are planning to manufacture the components that are going to compose our final design. As of right now the final design has not yet been finalized but we have a good idea of what parts are going to be used and what type of loading they are going to receive.

The two servo motors will be attached to a housing that will be made of stainless steel and will then be attached to the connection frame that will be connected to the car. The bottom of the wings will be made of aluminum or some other light material and the servo motors will be connected to this frame by means of two connection rods.

The wings will be made of carbon fiber and adapted in such a way that they will connect to the frame that is laid under them.

Mounting frame for the servos

The servo motors will be connected to a mounting frame that will allow us to easily remove it from the car and test it in a controlled environment. We have decided to manufacture this frame out of steel since it will give us the sturdiness required to minimize the shaking and deflections that might be caused by the forces involved in the operation of the wing.

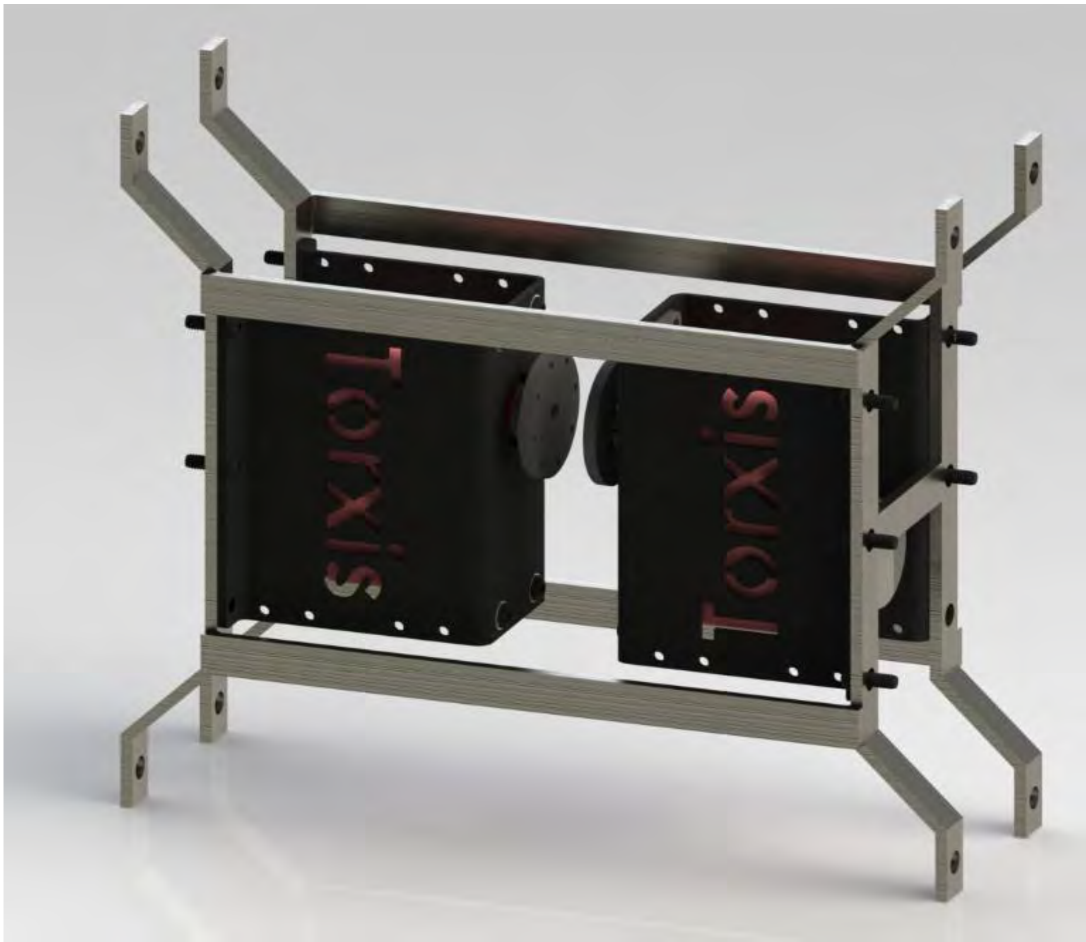


Figure 3 SolidWorks drawing of motor mounts

We will purchase steel rods with a cross section of 1 inch by 0.2 inches, we will then bend it with a steel bar bending machine with a corner pivot. We will weld all the four parts together at a distance of around 1 foot so that we can fit both servo motors inside.

Static analysis of Mounting Frame

In order to analyze the mounting frame, we loaded it in SolidWorks with a load three times higher than what we are expecting the motors to provide. This way we can ensure that we have a good margin of safety in the real application. Below we show a screenshot of the Von Misses stresses associated with such loading. As we can see even when the loading is 300% higher than what we would expect in real life, the stresses are far from the yield stress of steel.

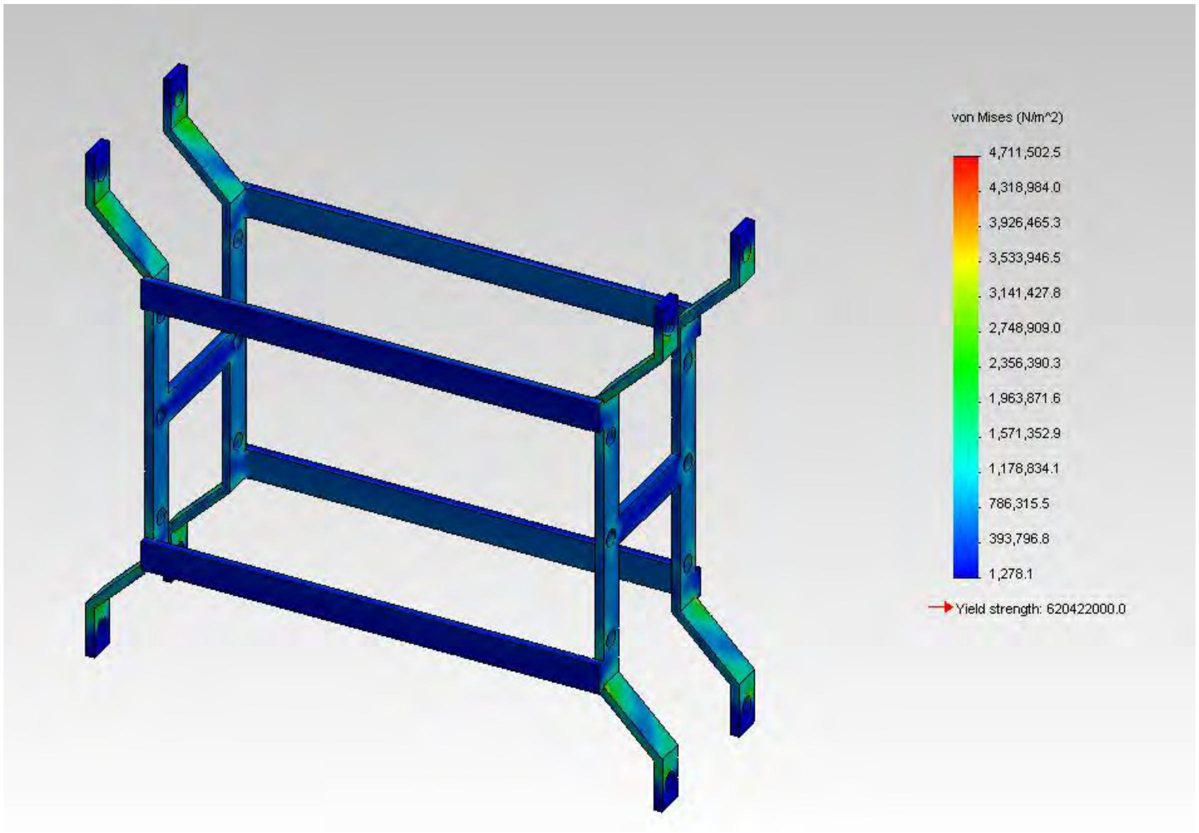


Figure 4 Simulation of Von Mises Stress analysis

We also did a displacement analysis on the same frame since that is the most important value that we are trying to minimize as we want to avoid unwanted deflections and vibrations. As we can see the maximum deflection occurs at the connection links between the bent rods. If vibrations turned out to be a problem we know where we should reinforce our design to solve it.

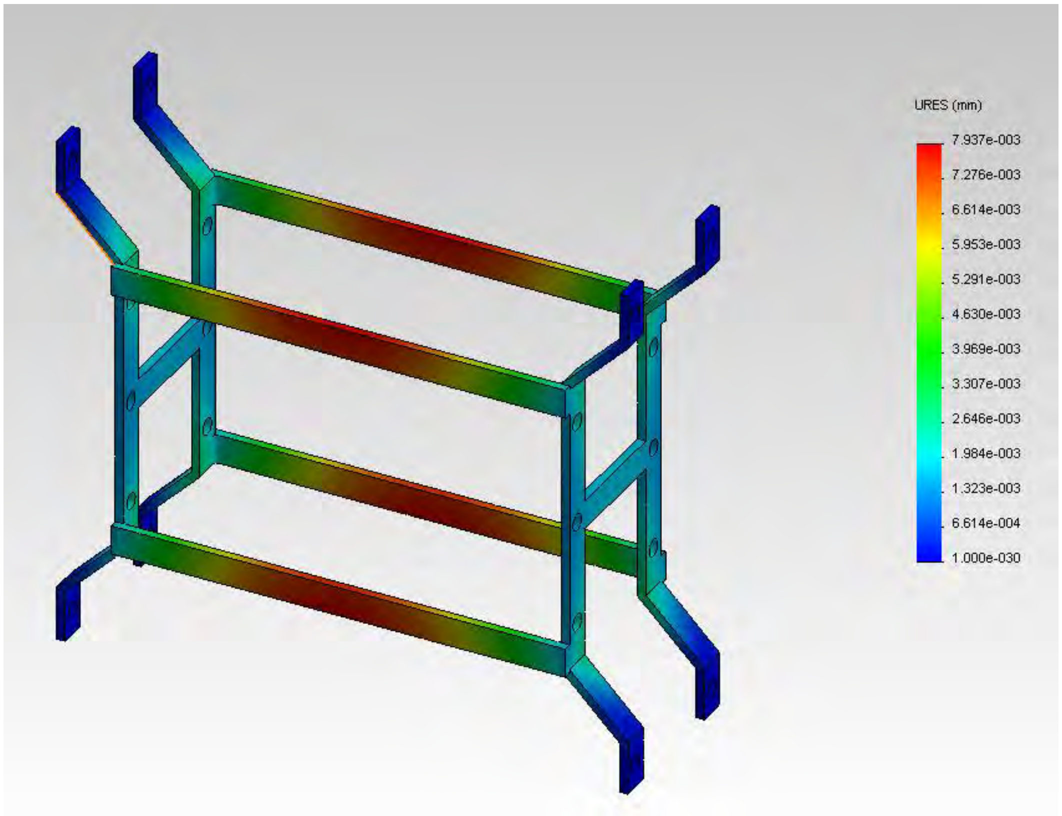


Figure 5 Simulation of Deformation of motor mounts

The Factor of Safety results show where the motor mounts are most likely to fail. According the SAE competition rules all structural components must have a factor of safety exceeding 2. Based on the SolidWorks simulation results the factor safety for the motor mounts is 384.94, which exceeds the required Factor of safety dictated by the SAE competition rules.

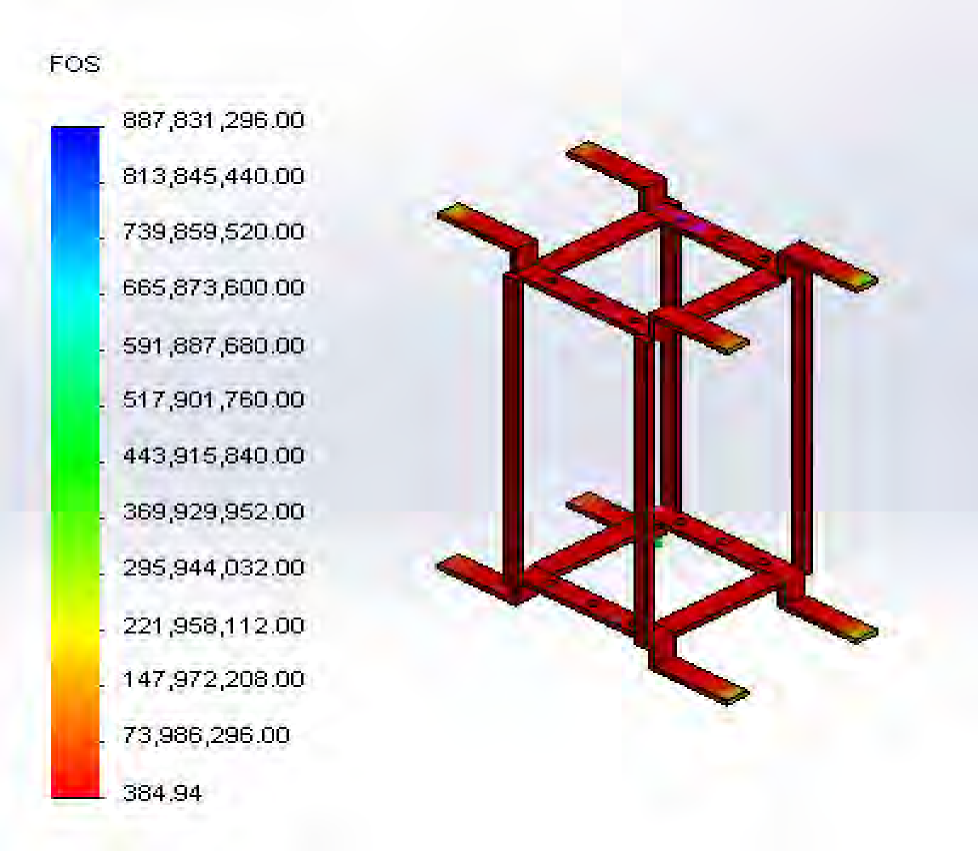


Figure 6 Simulation of Factor of Safety

Connection Frame

The mounted frame for the servos will be connected to a connection frame which will be then connected to the chassis of the car. This connection frame will be made of Cromoly 4130 Steel which is the same 1.5 and 1.3 inches respectively. Having two different connection frames might increase the weight, however it is the best option available to ensure the sturdiness of the design.

The final design for the connection frame with the chassis of the car is yet to be finalized, however an old concept is shown below with the intent to make it easier to understand what we are attempting to accomplish. Note that the design displayed below doesn't include the mounting frame for the servos previously mentioned.

Figure 7 SolidWorks representation of frame location and motor mounts

As we can see in order to mount this frame to the chassis of the car we will have to weld connection brackets on both frames an static analysis of these brackets is yet to be performed however we are not too concerned about this since the geometry of these brackets and the material that we will be using will make it very difficult for the integrity of the design to be jeopardized.

Housing for the servos

From factory, the servo motors come with the connection holes on the same side as the output hub. This makes it difficult for us to attach the servos since the geometry that we would use to hold it in place will most likely interfere with the rotation of the hub. We were planning to manufacture our own way to house the servos and allow us to connect them from the other side, however Torxis already took care of this problem and we decided to purchase their solution. An image of this housing is shown below.

Figure 8 Torxis motor housing for mounting

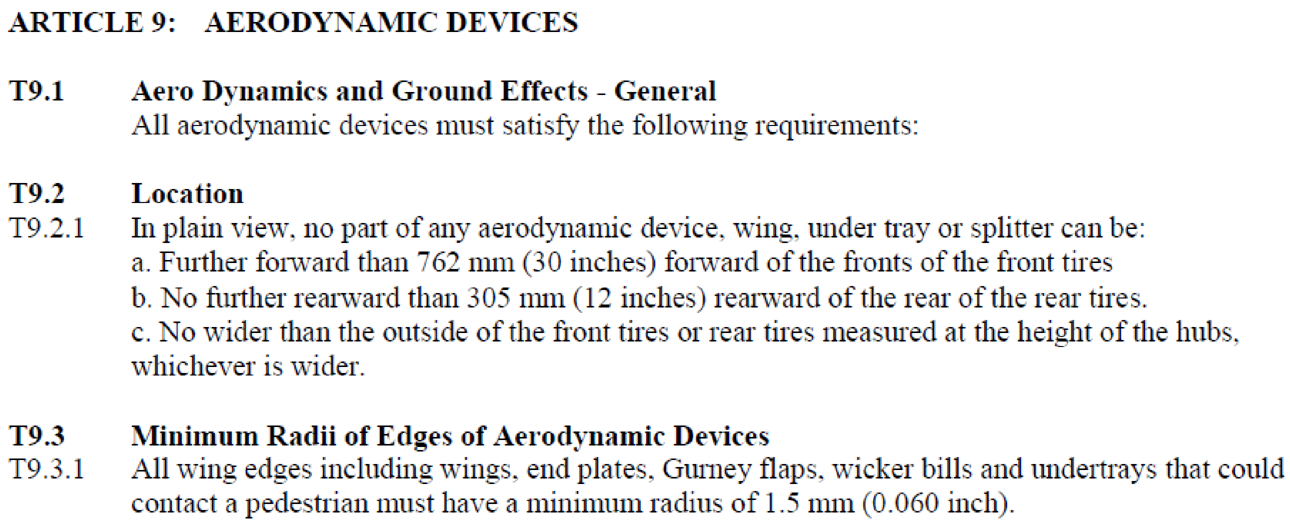
Wing frame

The wing will be pushed and pulled by a connection frame that will cover all the perimeter of its bottom surface. The reason we did this is machining carbon fiber to allow us to attach any sort of connection is a difficult task, and we risk to damage the integrity of the wing by applying any kind of directly to the carbon fiber. By creating a connection frame we can attach the output of the force directly to this frame and not have to worry about damaging the wing in any way. The connection frame will be also connected to spring loaded hinges that will take away some force from the servos by reducing the required torque to lift the wings.

Figure 9 Hinge used to offset the force on motors

Wing

The wing itself will be made of carbon fiber. We have not gone too much in depth in the design specifications of the wing since it will be mounted on the previously mentioned mounting frame and that part of the design will not depend on the material or cross sectional profile of the wing. All we are worrying about right now is to make sure that we follow the rules imposed by the FSAE rulebook. The rules regarding aerodynamic devices that concern our design are listed below.



ARTICLE 9: AERODYNAMIC DEVICES

T9.1 Aero Dynamics and Ground Effects - General
All aerodynamic devices must satisfy the following requirements:

T9.2 Location
T9.2.1 In plain view, no part of any aerodynamic device, wing, under tray or splitter can be:
a. Further forward than 762 mm (30 inches) forward of the fronts of the front tires
b. No further rearward than 305 mm (12 inches) rearward of the rear of the rear tires.
c. No wider than the outside of the front tires or rear tires measured at the height of the hubs, whichever is wider.

T9.3 Minimum Radii of Edges of Aerodynamic Devices
T9.3.1 All wing edges including wings, end plates, Gurney flaps, wicker bills and undertrays that could contact a pedestrian must have a minimum radius of 1.5 mm (0.060 inch).

As of right now we only have to worry about making sure that the wing will be "*no further rearward than 305 mm rearward of the rear tires*", in order to ensure this we will adjust the connection frame previously mentioned and if needed the cross sectional profile of the wing.

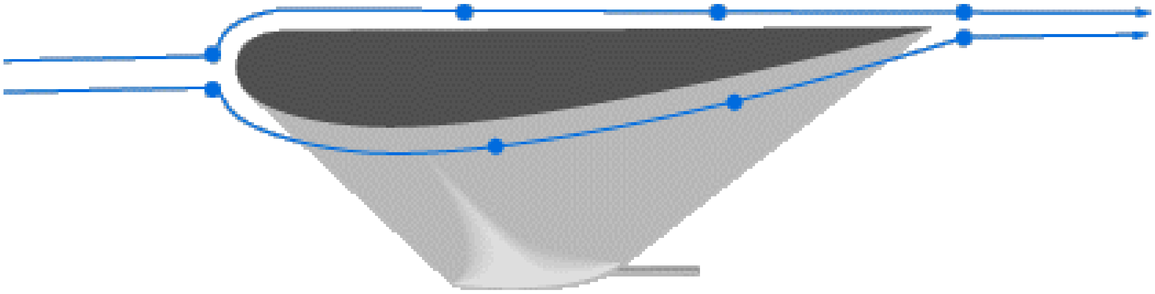


Figure 10 Cross section profile of wing

To manufacture the wing we will create the cross sectional profile of the wing will create the cross sectional profile out of foam and we will lay the carbon fiber sheets on it. We will add the binding agent and heat up in a specially designed oven to ensure that the required hardness is achieved.

Simulated performance

To predict the performance of the profile, SolidWorks simulation was used. The simulation was run for the same profiles, at different angles. The simulation shows that at 0 degrees the drag of the wing would be low, and at 60 degrees the drag is much larger. Along with the forces generated on the wing, the density of the air, pressure and the velocity are also represented. With this data we are able to predict the performance of the wings at different angles.

0 Degrees

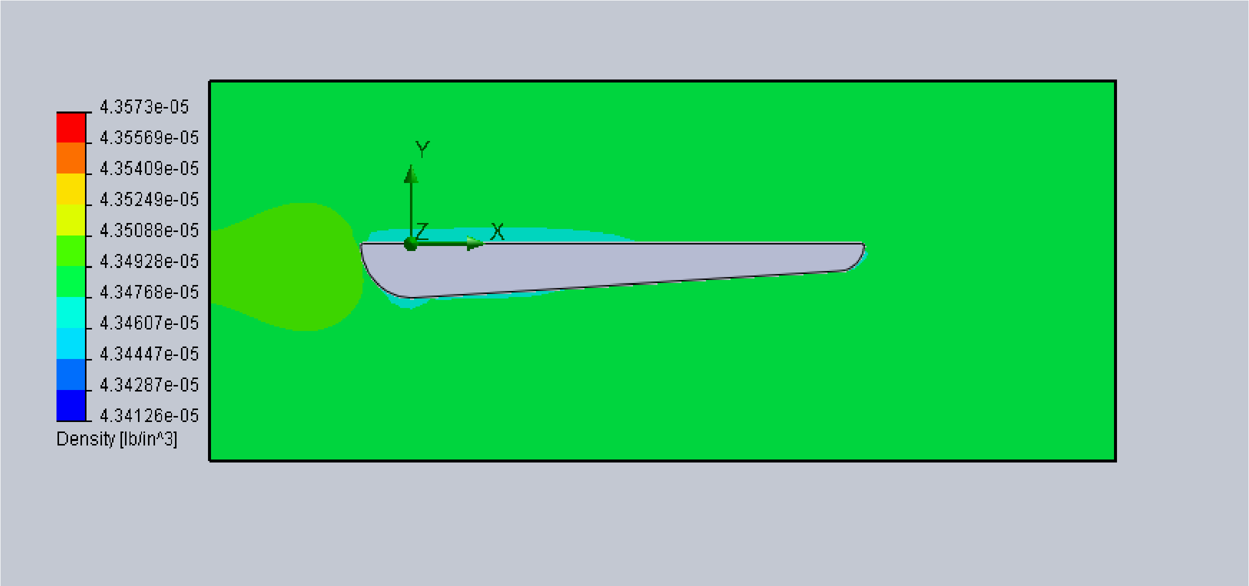


Figure 11 Wing profile at 0 degrees – Density of Air

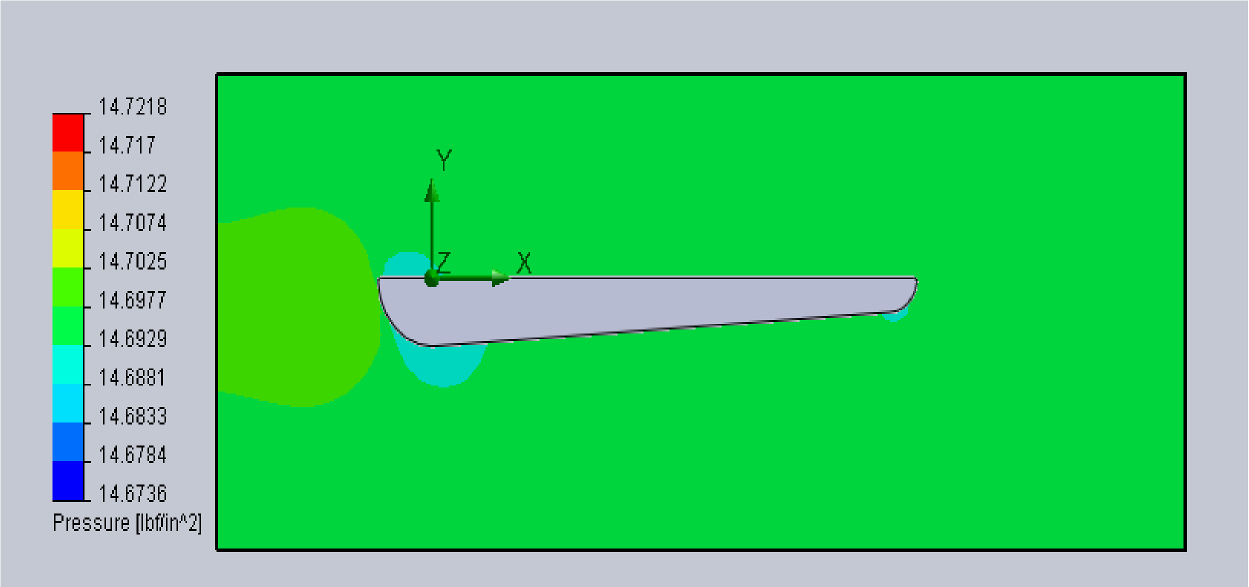


Figure 12 Wing profile at 0 degrees – Pressure

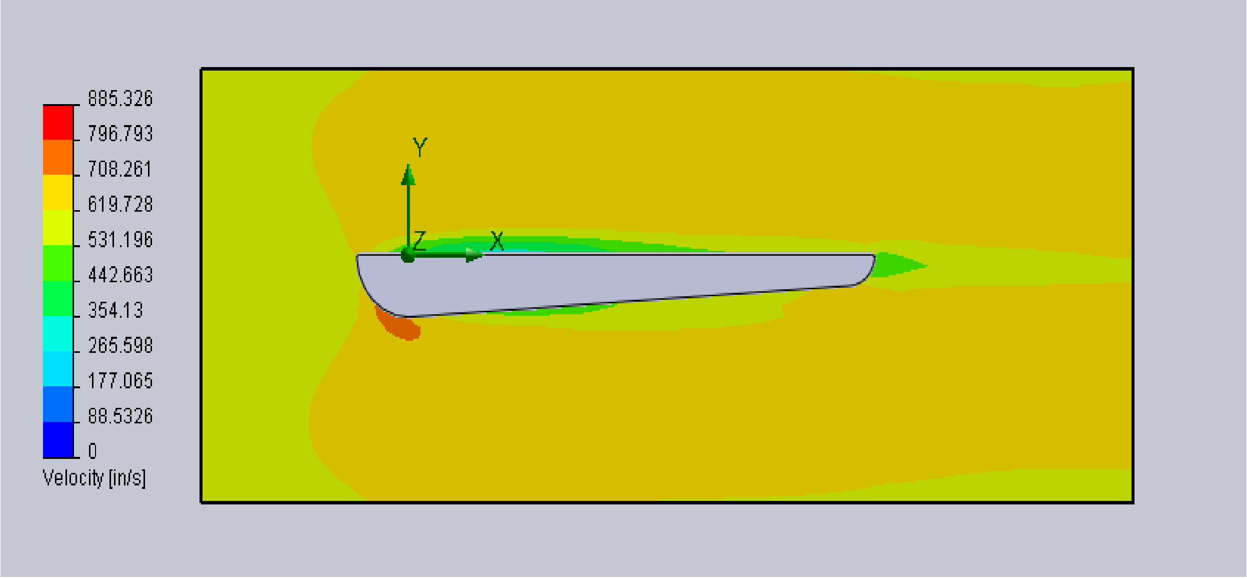


Figure 13 Wing profile at 0 degrees – Velocity of Air

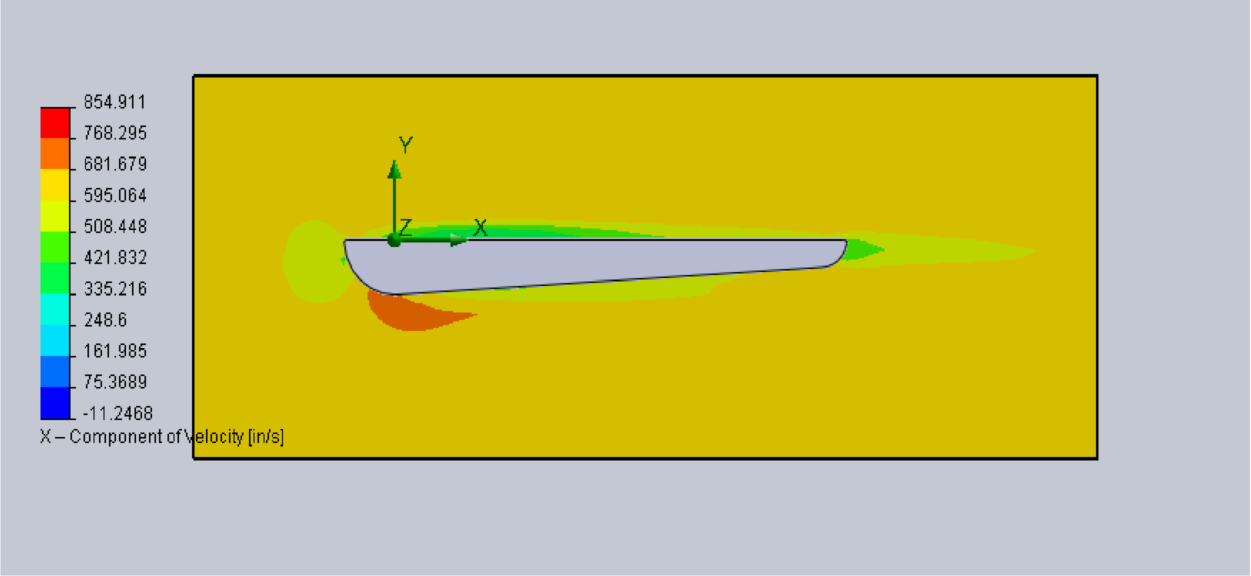


Figure 14 Wing profile at 0 degrees – Velocity of Air in the X direction

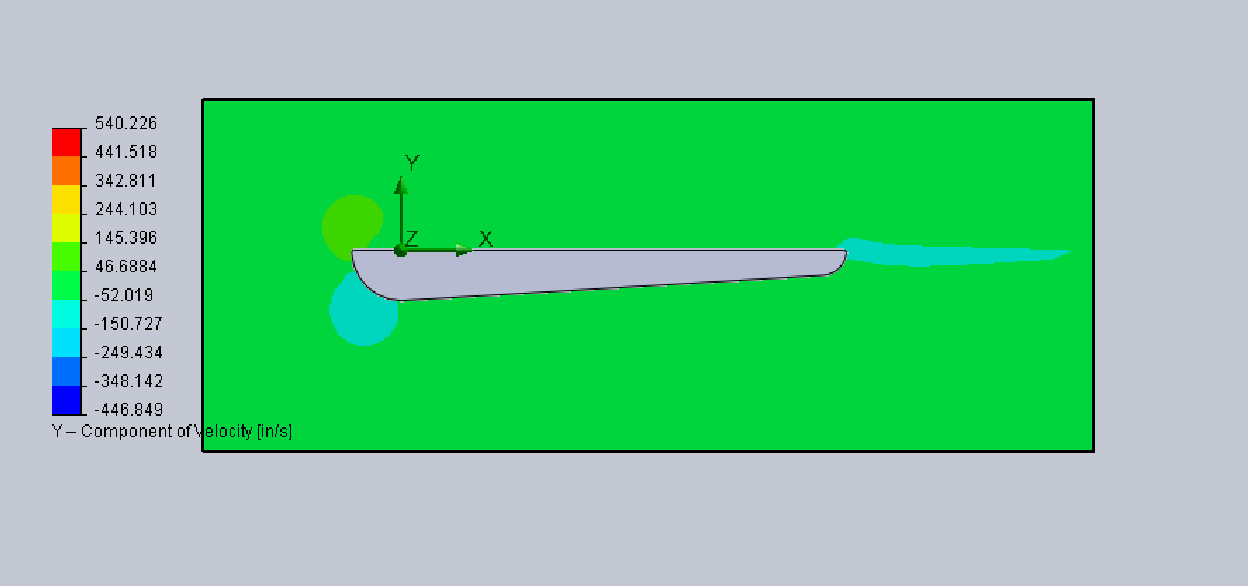


Figure 15 Wing profile at 0 degrees – Velocity of Air in the Y direction

Table 4 Force and pressure generated of Wing profile at 0 degrees

Name	Unit	Value
GG Av Total Pressure 1	lbf/in^2	14.7177
GG Av X - Component of Velocity 1	in/s	613.373
GG X - Component of Force 1	lbf	0.522323
GG Y - Component of Force 1	lbf	-0.423013

Table 5 Min/Max values of the Wing profile at 0 degrees

Name	Minimum	Maximum
Pressure [lbf/in^2]	14.6736	14.7218
Temperature [°F]	67.8298	68.3085
Velocity [in/s]	0	885.326
X – Component of Velocity [in/s]	-11.2468	854.911
Y – Component of Velocity [in/s]	-446.849	540.226
Z – Component of Velocity [in/s]	-443.091	442.898
Fluid Temperature [°F]	67.8298	68.3085
Mach Number [ ]	0	0.0655431
Shear Stress [lbf/in^2]	0	0.000289828
Heat Transfer Coefficient [lbf/s/in/°F]	0	0
Surface Heat Flux [lbf*in/(in^2*s)]	0	0
Density [lb/in^3]	4.34126e-05	4.3573e-05

20 Degrees

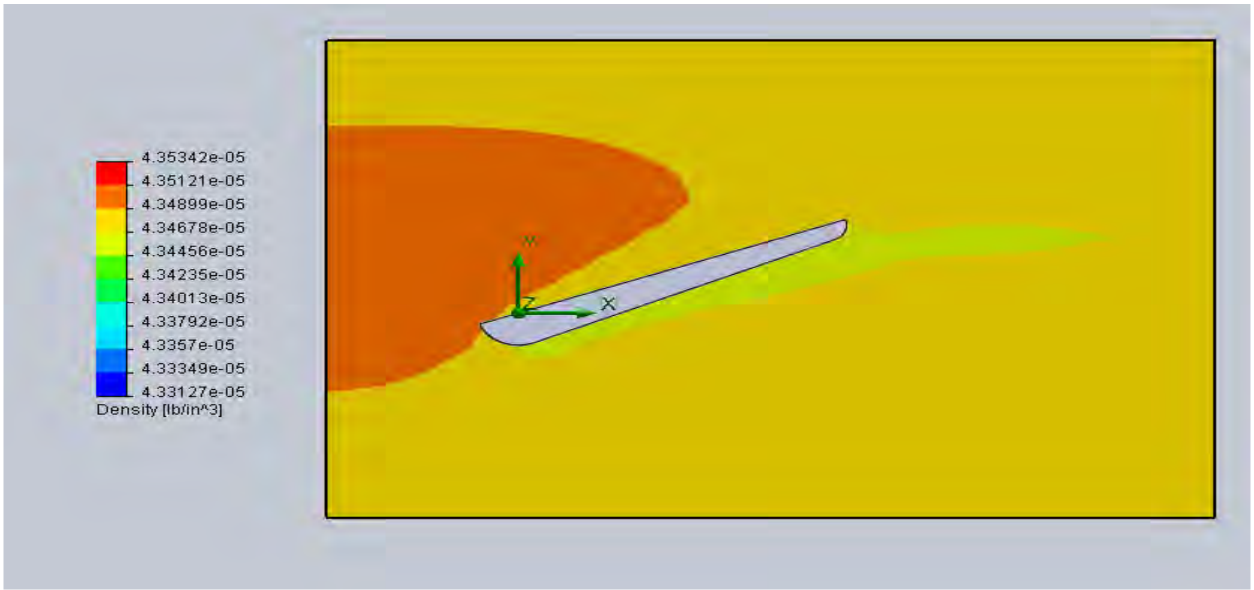


Figure 16 Wing profile at 20 degrees – Density

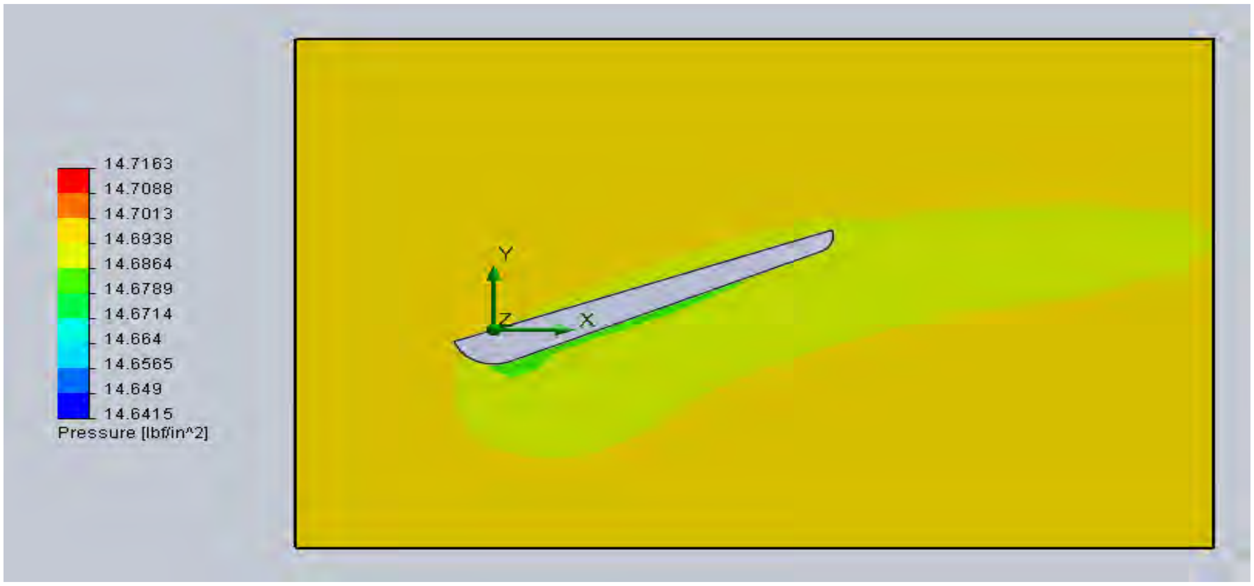


Figure 17 Wing profile at 20 degrees – Pressure

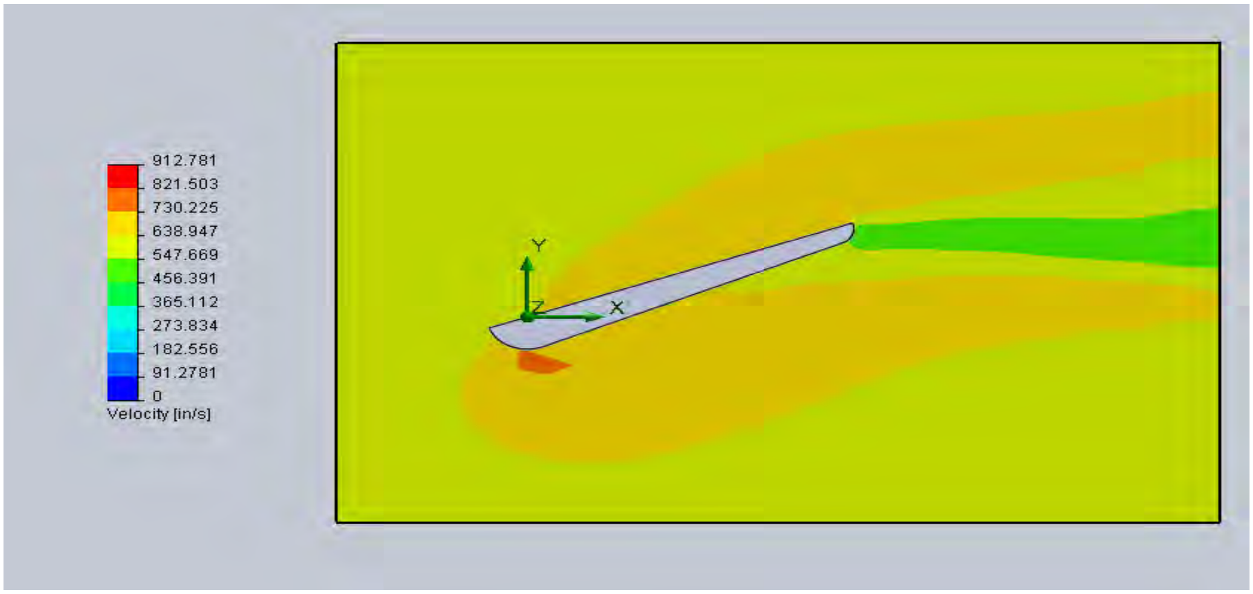


Figure 18 Wing profile at 20 degrees – Velocity of Air

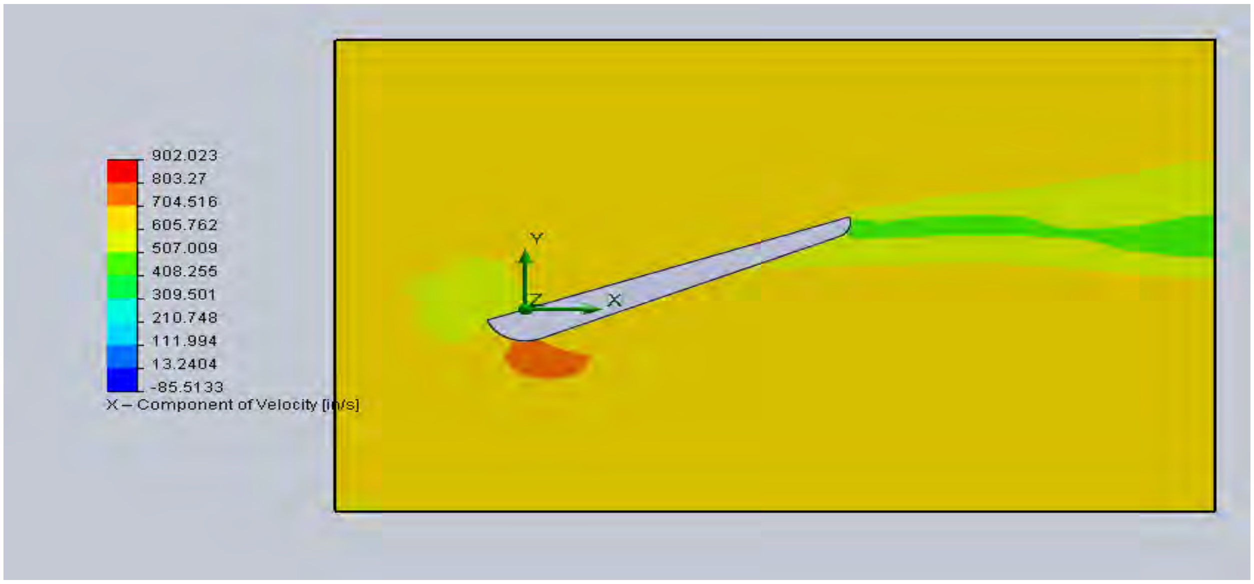


Figure 19 Wing profile at 20 degrees – Velocity of Air in the X direction

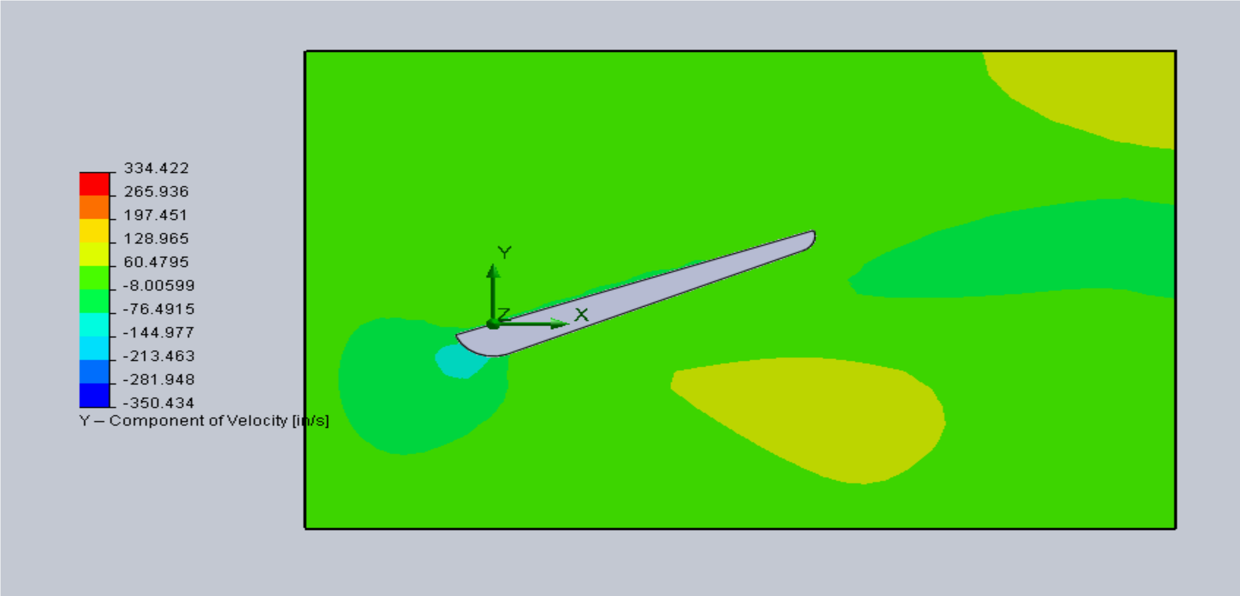


Figure 20 Wing profile at 20 degrees – Velocity of Air in the Y direction

Table 6 Force and pressure generated of Wing profile at 20 degrees

Name	Unit	Value
GG Av Total Pressure 1	lbf/in^2	14.7177
GG Av X - Component of Velocity 1	in/s	616.984
GG Av Y - Component of Velocity 1	in/s	26.0016
GG X - Component of Force 1	lbf	1.75817
GG Y - Component of Force 1	lbf	-4.77635

Table 7 Min/Max values of the Wing profile at 20 degrees

Name	Minimum	Maximum
Pressure [lbf/in^2]	14.6415	14.7163
Temperature [°F]	67.7991	68.307
Velocity [in/s]	0	912.781
X – Component of Velocity [in/s]	-85.5133	902.023
Y – Component of Velocity [in/s]	-350.434	334.422
Z – Component of Velocity [in/s]	-421.061	422.06
Fluid Temperature [°F]	67.7991	68.307
Mach Number [ ]	0	0.067579
Shear Stress [lbf/in^2]	0	0.000318645
Heat Transfer Coefficient [lbf/s/in/°F]	0	0
Surface Heat Flux [lbf*in/(in^2*s)]	0	0
Density [lb/in^3]	4.33127e-05	4.35342e-05

40 Degrees

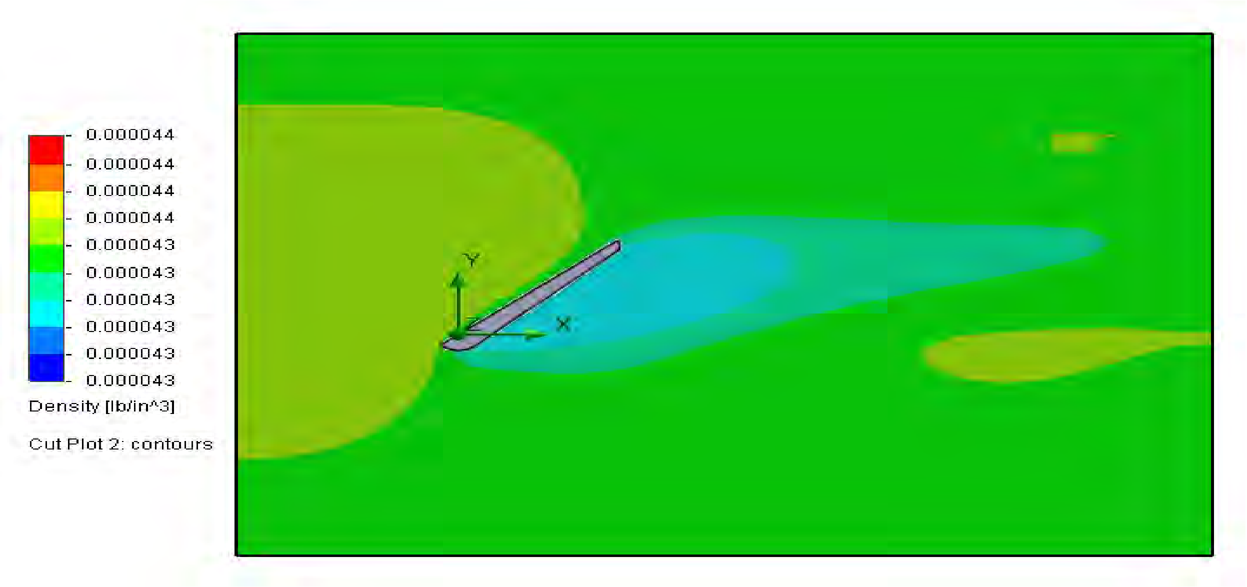


Figure 21 Wing profile at 40 degrees – Density

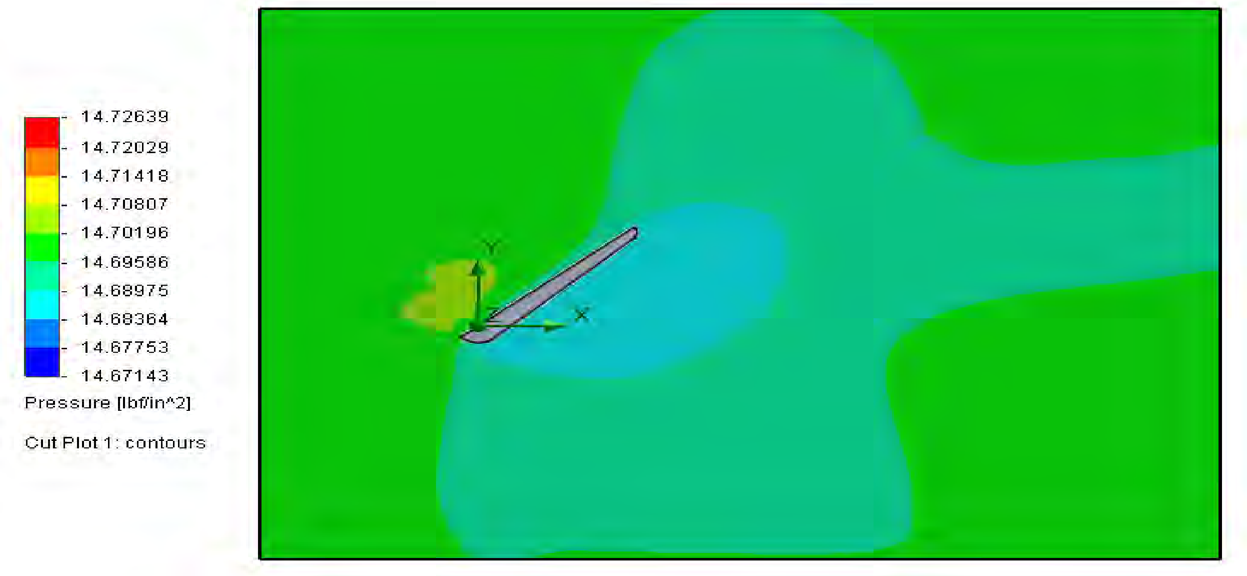


Figure 22 Wing profile at 40 degrees – Pressure

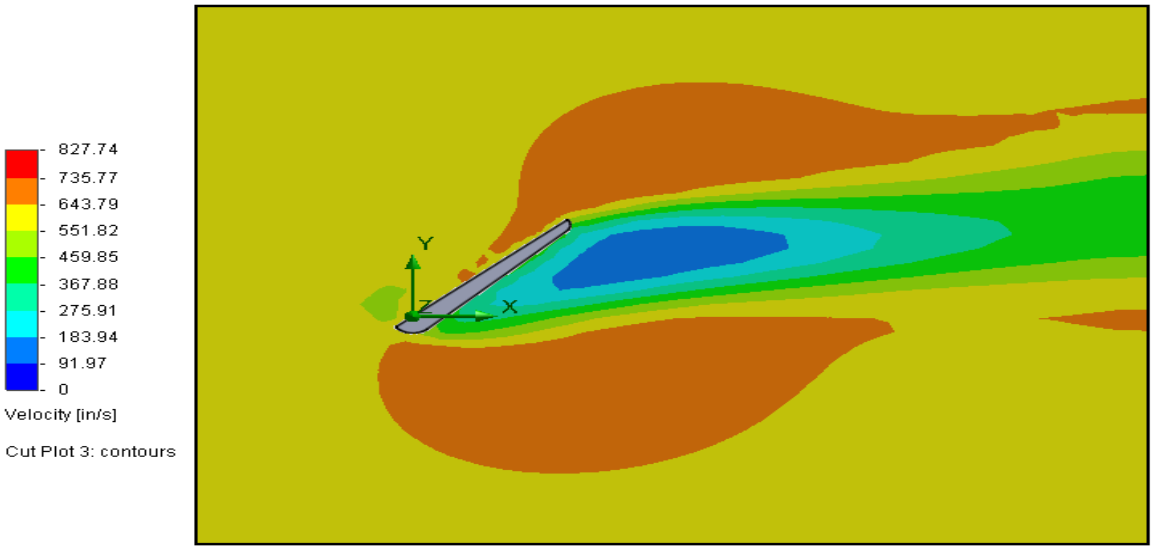


Figure 23 Wing profile at 40 degrees – Velocity

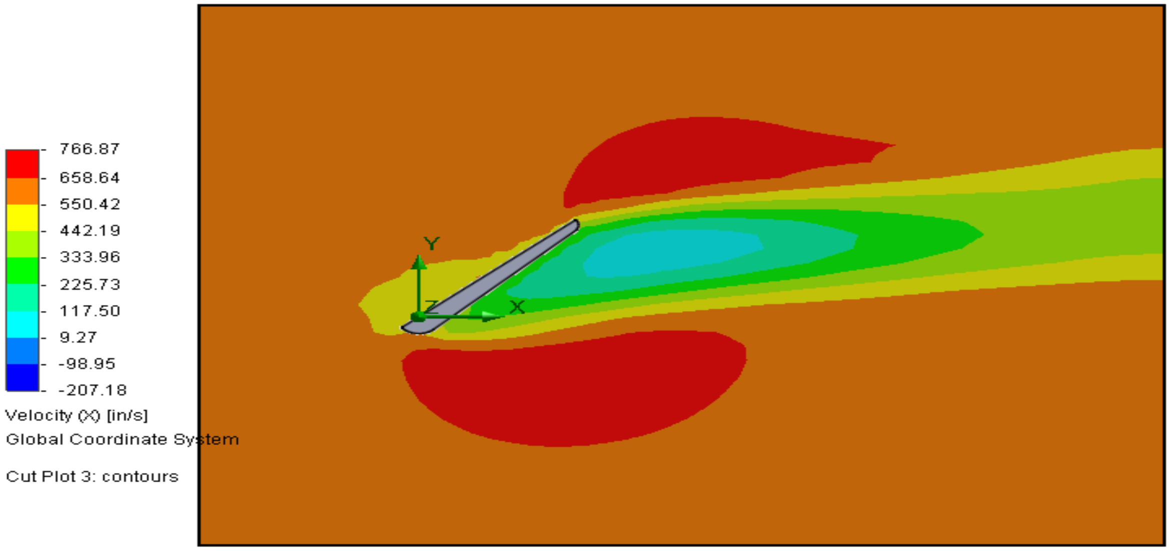


Figure 24 Wing profile at 40 degrees – Velocity in the X direction

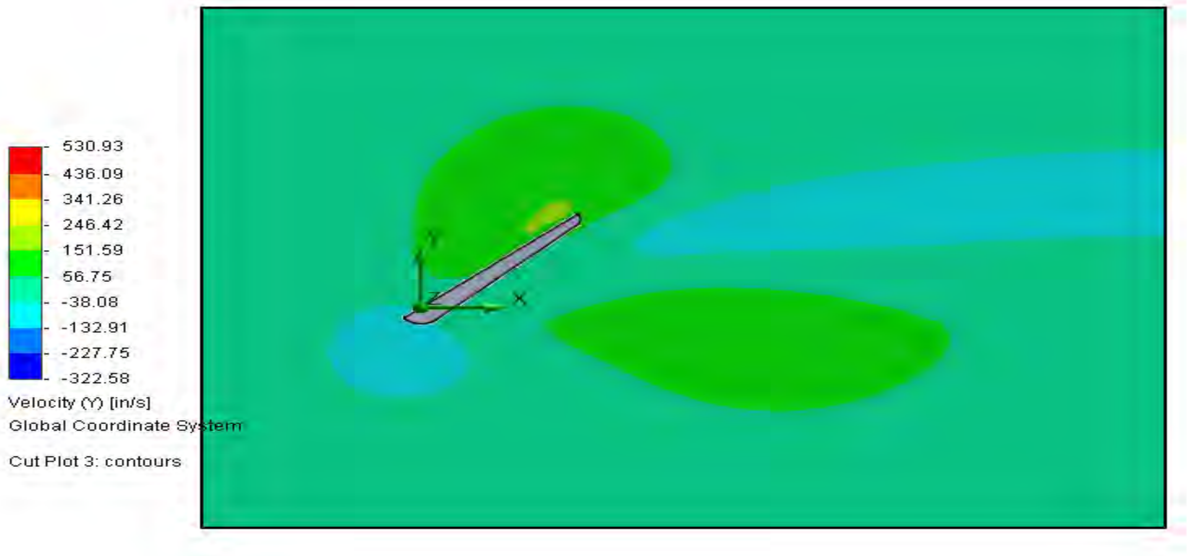


Figure 25 Wing profile at 40 degrees – Velocity in the Y direction

Table 8 Force and pressure generated of Wing profile at 40 degrees

Name	Unit	Value
GG Av Total Pressure 1	lbf/in^2	14.71731
GG Av Density 1	lb/in^3	0.000043
GG Av Velocity (X) 1	in/s	610.17
GG Av Velocity (Y) 1	in/s	11.12
GG Force (X) 1	lbf	5.534
GG Force (Y) 1	lbf	-5.953

Table 9 Min/Max values of the Wing profile at 40 degrees

Name	Minimum	Maximum
Pressure [lbf/in^2]	14.67143	14.72639
Temperature [°F]	67.87	68.30
Density [lb/in^3]	0.000043	0.000044
Velocity [in/s]	0	827.74
Velocity (X) [in/s]	-207.18	766.87
Velocity (Y) [in/s]	-322.58	530.93
Velocity (Z) [in/s]	-428.93	437.44
Temperature (Fluid) [°F]	67.87	68.30
Mach Number [ ]	0	0.06
Vorticity [1/s]	0.032	342.440
Shear Stress [lbf/in^2]	0	0.00018
Relative Pressure [lbf/in^2]	-0.02452	0.03045
Heat Transfer Coefficient [lbf/s/in/°F]	0	0
Surface Heat Flux [lbf*in/(in^2*s)]	0	0

60 Degrees

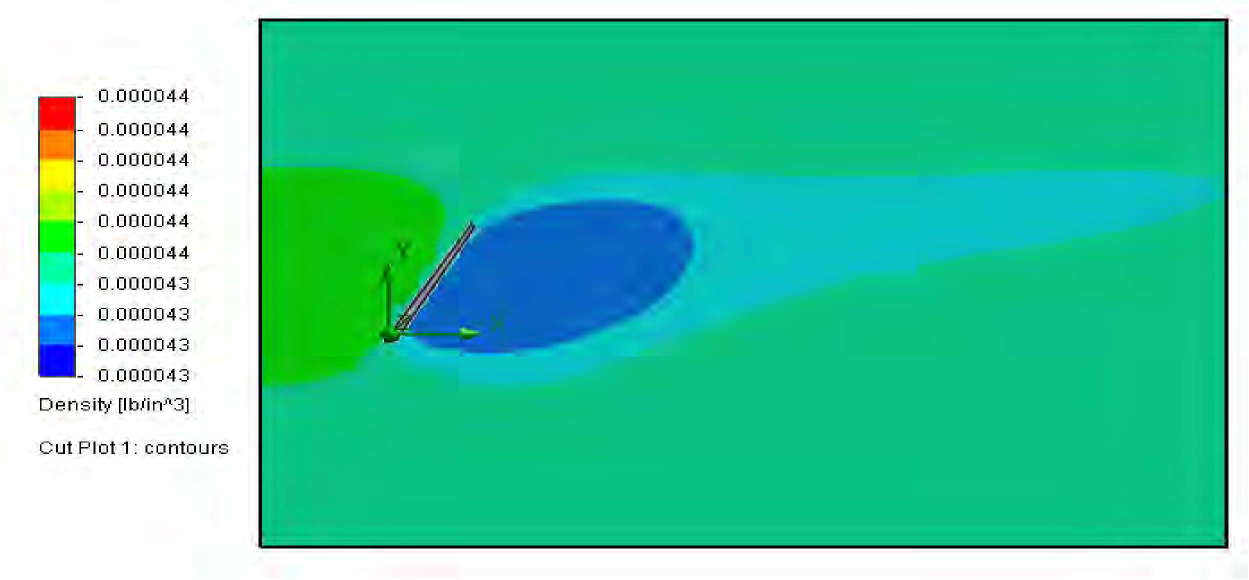


Figure 26 Wing profile at 60 degrees – Density

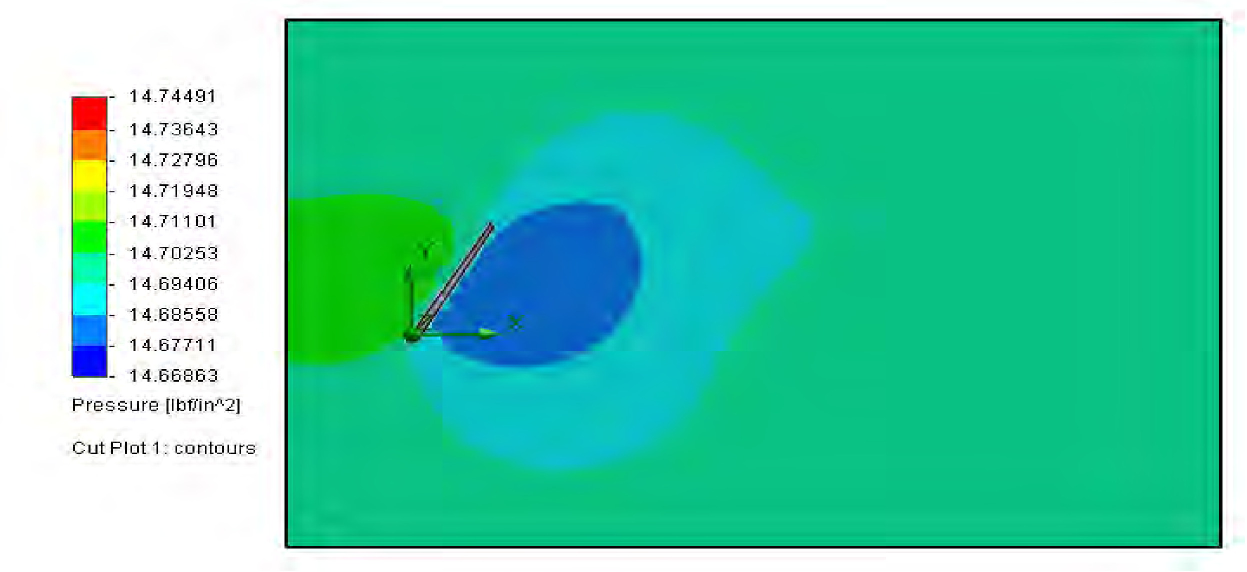


Figure 27 Wing profile at 60 degrees – Pressure

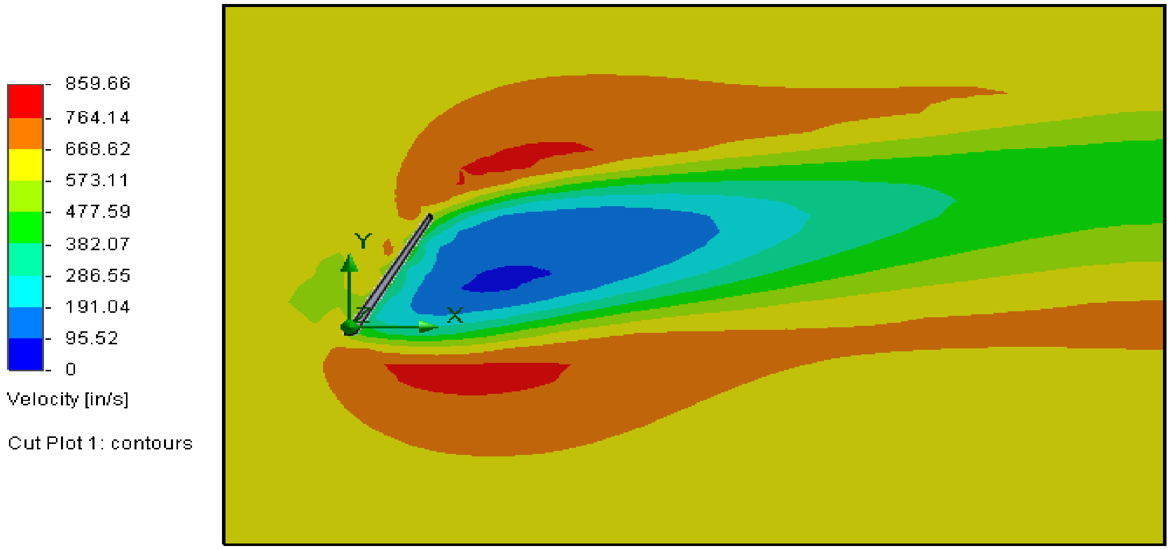


Figure 28 Wing profile at 60 degrees – Velocity

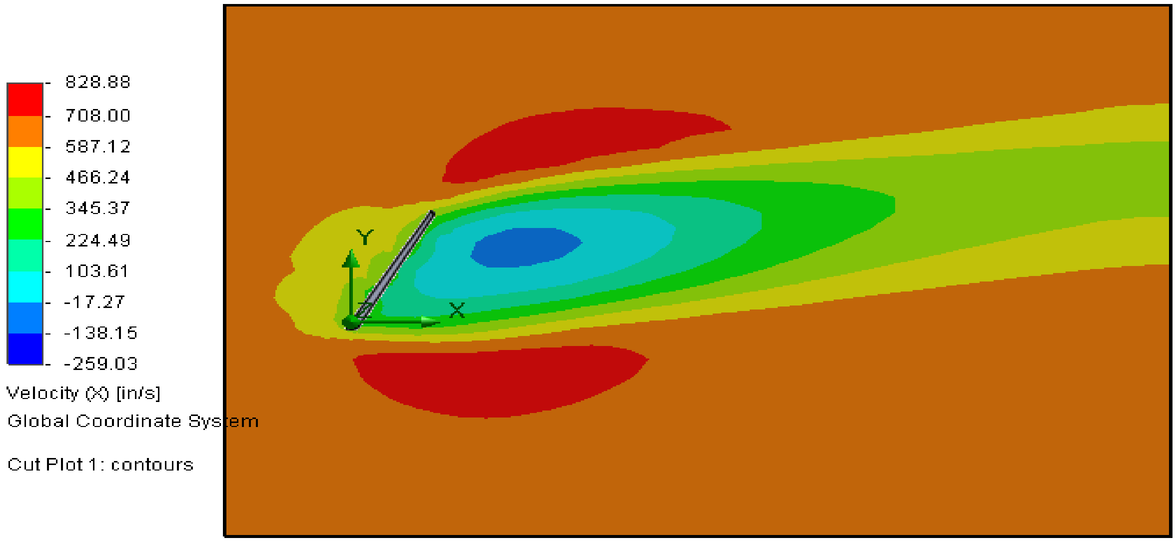


Figure 29 Wing profile at 60 degrees – Velocity in the X direction

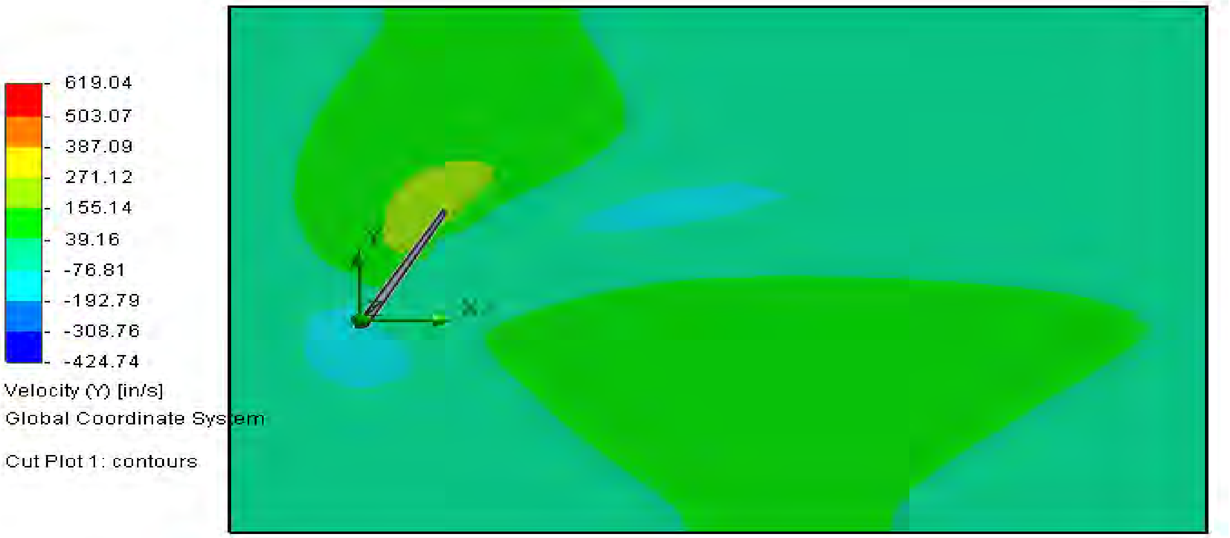


Figure 30 Wing profile at 60 degrees – Velocity in the Y direction

Table 10 Force and pressure generated of Wing profile at 60 degrees

Name	Unit	Value
GG Av Total Pressure 1	lbf/in^2	14.71763
GG Av Velocity 1	in/s	617.98
GG Av Velocity (X) 1	in/s	612.70
GG Av Velocity (Y) 1	in/s	10.74
GG Force (X) 1	lbf	11.147
GG Force (Y) 1	lbf	-6.636

Table 11 Min/Max values of the Wing profile at 60 degrees

Name	Minimum	Maximum
Pressure [lbf/in^2]	14.66863	14.74491
Temperature [°F]	67.88	68.31
Density [lb/in^3]	0.000043	0.000044
Velocity [in/s]	0	859.66
Velocity (X) [in/s]	-259.03	828.88
Velocity (Y) [in/s]	-424.74	619.04
Velocity (Z) [in/s]	-664.48	660.63
Temperature (Fluid) [°F]	67.88	68.31
Mach Number [ ]	0	0.06
Vorticity [1/s]	0.028	306.225
Shear Stress [lbf/in^2]	0	0.00017
Relative Pressure [lbf/in^2]	-0.02731	0.04896
Heat Transfer Coefficient [lbf/s/in/°F]	0	0
Surface Heat Flux [lbf*in/(in^2*s)]	0	0

Sensors

Force- sensing resistor

The force – sensor will be used to measure the pressure generated between the brakes pad and brake disc. This data will then be plotted against the displacement of the brake pedal. The pressure generated between the brake pad and the brake disc will allow for us to calculate the braking force that the car will have without a dynamic spoiler. This data will give a better idea of the angle the dynamic spoiler will need at different displacement of the brake pedal. With the aim of increasing the efficiency of the brakes of the SAE formula car, the position the dynamic spoiler in relation to the braking force being requested from the driver is important.

A few requirements of the force- sensor are that, it can handle the max load of the brakes and accurately record the pressure generated. The sensor also has to also be able to fit in between the brake pad and the brake disc and connect with the Arduino Uno logic board. The sensor chosen for the task is the Flexi force Pressure Sensor - 100lbs. This sensor is a piezoresistive force sensor with dimensions of .208mm thick, 197mm long, and a sensing area of 9.53mm. This sensor has three pins that can connect directly into a breadboard allowing for easy access from the Arduino board. With a cost of $19.95 and a max force-reading load of 100Ibs this is the prefect sensor for the job.

Figure 31 Force Sensor

Piezoresistors are resistors that are usually used for measuring of mechanical stress. Taking advantage of the piezoresistive effect of the change in the electrical resistivity of a semiconductor when mechanical stress or load is applied, make for great sensors. Piezoresistors are commonly used as strain gages or pressure sensors, when connected to a Wheatstone bridge they can become very accurate. The Flexi force pressure sensor changes resistance from infinite to around 300k, only changing resistance when pressure is applied.

This sensor will not be permanently attached the SAE formula car, instead it will be only used for calibration of the dynamic spoiler. With calibrating the dynamic spoiler expected to be the most challenging task of this project it is important to include calibrating sensors in to the build and design of the dynamic spoiler.

Flex sensor

The flex sensor will be used to measure the displacement of the brake pedal as the driver applies pressure. This sensor will be used to control the angle of the dynamic spoiler. The flex sensor will also be used in the calibration of the dynamic spoiler, by plotting the displacement of the brake pedal and the pressure generated between the brake pad and brake disc. This data will give a clear picture of the performance of the brakes and allow for the dynamic spoiler to increase the efficiency of the braking required from the driver.

The sensor that will be placed on the brake pedal cannot interfere with the braking mechanism, or hinder the performance of the brakes in any such way. The brake pedal is mounted to a cylinder or pipe and rotates on a bearing with the throttle limiting the space of the enclosure. This limits the options for placing sensors on the pedal. The idea of using a potentiometer to measure the brake pedal displacement was first suggested; this was quickly rejected for the bearing would not allow for an easy installation. The second idea was to us a linear potentiometer to measure the pedal displacement; this was also rejected for fear that the sensor would cause the brake pedal to stick in an upright position, interfering with the breaking mechanism. A flex sensor was chosen for its small size and the ability to measure the angle at which the pedal is displaced.

A flex sensor measures the angle displacement, bending and flexing physically with motion of the device. The flex sensor chosen is from Spectra Symbol. The dimensions of this sensor are about 4.5 inches long and .25 inches wide, with a sensing area of 3.75 inches. The sensor has a flat resistance of 10k ohms and as the sensor bends the resistance is increased to a max resistance of 110k ohms.

The sensor will be attached to the brake pedal in a simple method. Either with electrical tape or super glue, the only concern is the sensor may slip or move out of position during competition leading the dynamic spoiler to fail or receive incorrect input values. Securely attaching the flex sensor into position is an important endeavor. The sensor will also have to be attached to a reference location, preferably the floor of the SAE formula car. This gives the sensor a surface as to which bend against as the brake pedal undergoes an angular displacement. To prevent a catastrophic failure of the wing in the unlikely event that this senor fails or slips out of place, programming counter measures will be taken. The counter measures will still allow for the steering sensor and the velocity inputs to control the wing.

Steering Sensor

A small ring potentiometer of 5 kΩ will be placed on the steering column to measure the angle of turn the SAE formula car is experiencing as the car goes around the track. Ring potentiometers are a rare device only manufactured by ALPS. ALPS developed ring potentiometers for use in automotive industry, primarily with throttle control of motorcycles. The ring potentiometer will be mounted in such a way as to take advantage of its precision and size. With an outer diameter of no larger than 45 mm they could prove to be idea for mounting on the steering column in such a way that will not interfere with driver or the functionality of the steering. The problem with the ring potentiometer is the size, with such a small size it will require a mounting bracket. The mounting bracket will have to be manufactured with high tolerances; this is to reduce the risk of the sensor coming lose and malfunction.

Figure 32 45 mm Size LED Illuminated Type RK45B/RK45C Series - Ring Potentiometer

The ring potentiometer chosen has a total of six pins that will send information to the Arduino Uno, using an analog signal. The pins of the ring potentiometer are short on the magnitude of 3.5 mm and are designed to plug directly into a control unit. The idea of designing a mounting bracket could be a suitable solution to the pins obstacle. By integrating the connection of the pins directly into the mounting bracket can resolve two complications with one fix.

ALPS are the only manufacture that sells ring potentiometer. They only come in two sizes based on the inner diameter of the ring, 20.2mm and 25mm. This is causing a problem coordinating with SAE design team, primarily with the diameter of the outer diameter of the steering column. As of date the designs for the steering column are not available. This is concern, because the tolerances between the steering shaft and the ring potentiometer should be very small. The original goal of having an accurate fit may not be achievable with the limited options of ring potentiometers and the designs for the steering column not available.

A mounting bracket will be used to securely fit the ring potentiometer to the steering column and a non-moving plate. The mounting bracket will have two halves, one that attaches the ring potentiometer to the steering column and the other half that attaches the potentiometer to the floor of the car.

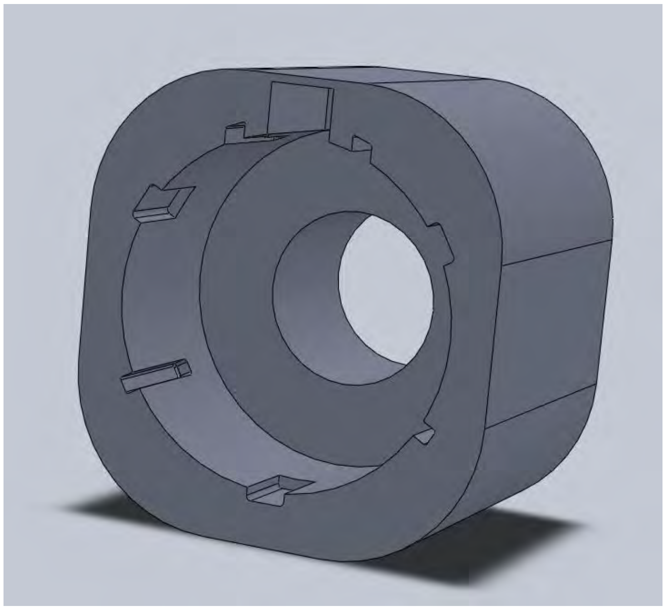


Figure 33 Top Mount for the Ring Potentiometer

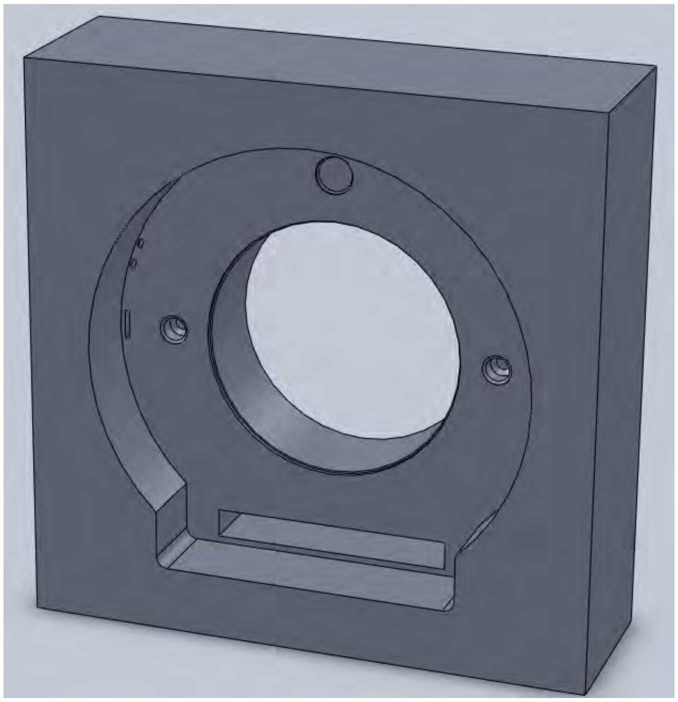


Figure 34 Bottom Mount for Ring Potentiometer

The mounts have to incorporate a space for the pins, this allows for the ring potentiometer to be connected to the proto board, this can be seen on the bottom mounts as a slot that is cut out. The tolerances of the mounts have to be accurate, and the shape of the mounts follows the contours of the ring potentiometer. This was done so that the mounts have faces of the ring potentiometer to grip.

Circuitry setup

The Arduino Uno is the main focus of the electrical components, where the sensors are connected to the analog inputs and the motors and motor controller are connected to the digital outputs. The logic board is the brains of the dynamic spoiler controlling the wings position based on the inputs of the sensors and communicating to the motors the precise specified position. The motors are updated every 20 milliseconds; this is the limit that the motor controller can handle. If the Arduino were to update any faster this would cause the motors to jitter, which could have potential damaging effects on the life of the motors.

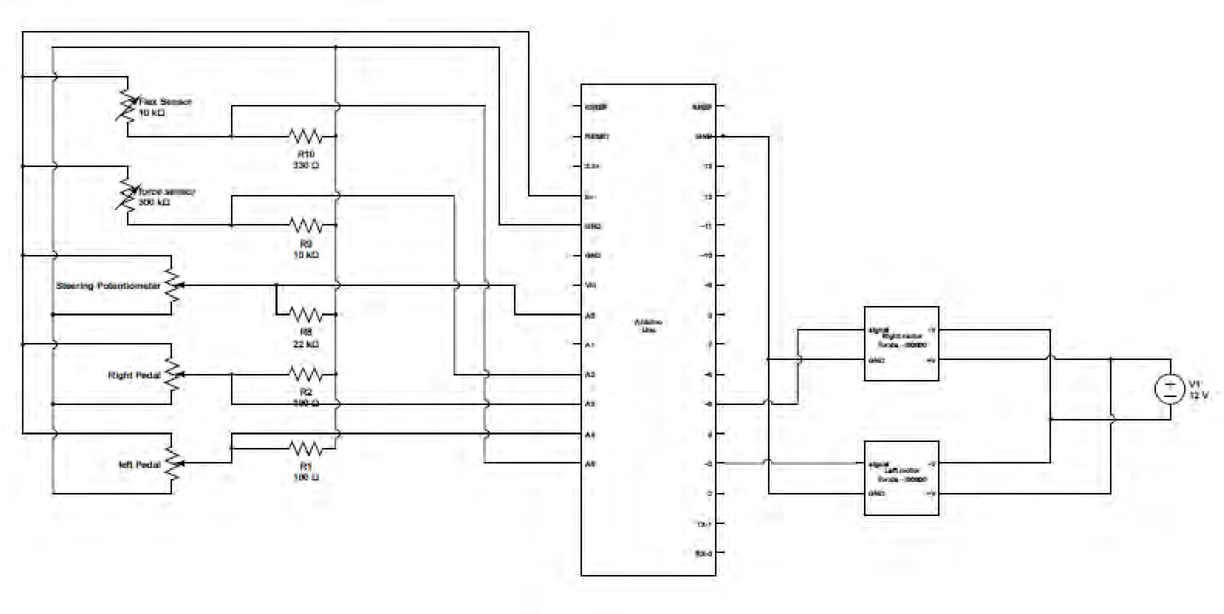


Figure 35 Electrical Schematic

Proto board

A proto board allows for the circuitry to be organized and tested without requiring soldering. Allowing for easy creation of temporary prototypes, in our case the sensors, resistors and motors are connected directly to the proto board.

The power and the ground lines of the proto board are connected to the Arduino Uno’s 5v output and the GND ports respectively. This is done to supply power to the sensors and the JRK 21v3 motor controller, which required the ground connection from the Arduino Uno. The proto board also aided in the construction of the electronics case, allowing for organized plug-in ports for each sensor, and with space available if more sensors are required. Each sensor required a circuitry consisting of one resistor. The name of the circuitry used for each resistor is called a voltage divider.

Voltage divider

A voltage divider was used with each sensor to allow for the Arduino to compare the resistant changes of the sensors. A voltage divider is a linear circuit that produces an output voltage, which can be used as a reference voltage or to get a low voltage signal proportional to the voltage to be measured. The flex and the force sensors are variable resistors; because of this they only required one pin to power and the other pin is the signal. From the signal connection a resistor was connected and went to ground on the proto board. The resistance of the resistor depended on how many analog signal points were needed and the sensors resistance. The flex sensor was 23 analog signal points and the force sensor has over 900 analog signal points.

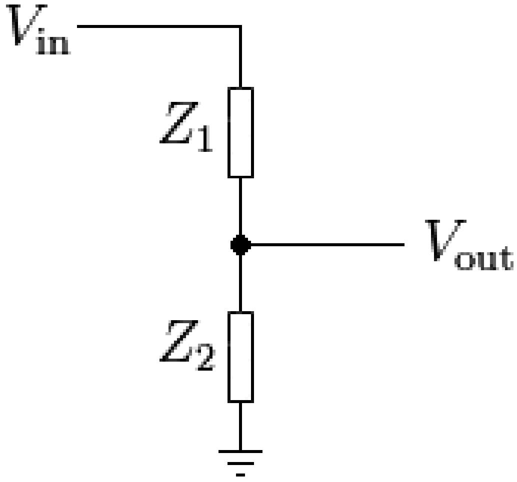


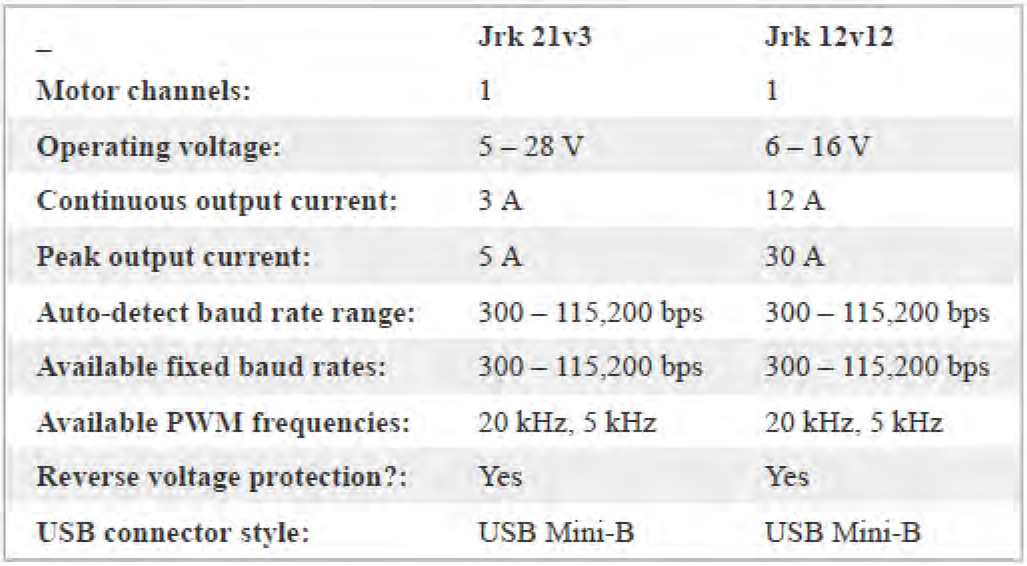
Figure 36 Voltage divider

The circuitry setup for the ring potentiometer and the presentation pedals is a little different, but uses the same concept. The potentiometer has one port plugged into ground and one plugged into power (5V) usually the outer ports and the center port is plugged into the signal. From the signal connection a resistor was connected and went to ground on the proto board.

JRK motor controllers

The Torxis motors have installed JRK motor controllers for control of the servos. JRK motor controllers have broad operating range from 5v to 28v, and continuous output current of 3A for controlling dc brushed motors. JRK motor controllers allow for simple bidirectional control of one DC brush motor, and hobby radio control (RC) pulse width (PWM) interface for direct connection to an RC receiver. From the Arduino board the JRK 21v3 motors controller is connected to the digital output port. These ports are pulse width modulation (PWM). On the Arduino Uno board the ports that support PWM have a (~) next to the port number.

The circuitry setup for the motors controller is simple; one port that goes to signal and the other connects to ground of the Arduino. The motors require a separate power supply of 12v and a max 3A. This can also be observed from the electrical schematic.



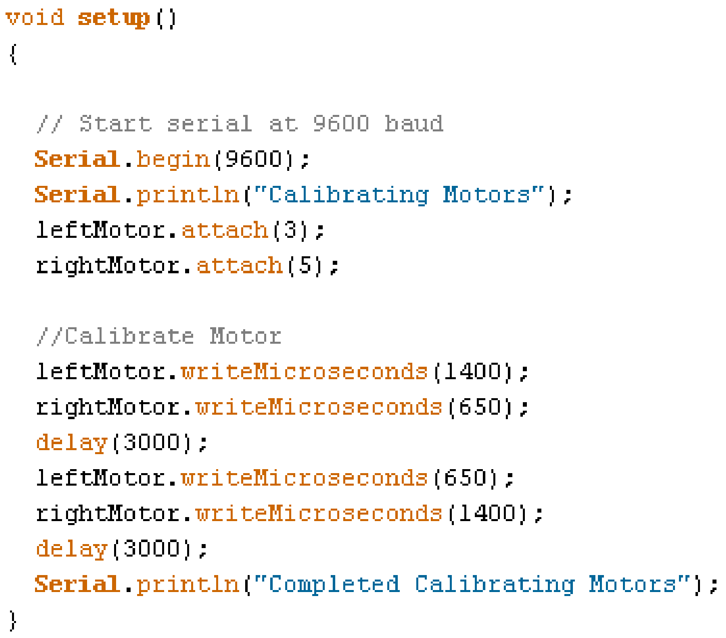
_	Jrk 21v3	Jrk 12v12
Motor channels:	1	1
Operating voltage:	5 – 28 V	6 – 16 V
Continuous output current:	3 A	12 A
Peak output current:	5 A	30 A
Auto-detect baud rate range:	300 – 115,200 bps	300 – 115,200 bps
Available fixed baud rates:	300 – 115,200 bps	300 – 115,200 bps
Available PWM frequencies:	20 kHz, 5 kHz	20 kHz, 5 kHz
Reverse voltage protection?:	Yes	Yes
USB connector style:	USB Mini-B	USB Mini-B

Figure 37 JRK 21v3 Specifications

Programming

The Arduino programming language is based on Wiring an open source-programming framework for microcontrollers. Wiring allows for software writing controlling devices attached to a wide range of microcontroller boards. The coding written in the Arduino environment is called sketches. The Arduino environment is very similar to C++ in how commands are called.

The first set of coding for our dynamic spoiler is the calibrating motors. This is essential for the dynamic spoiler. If the wings are moved out of start position, or the Arduino is powered off before the wings are set back to the resting position this set of coding returns the motors and wings back to rest or starting position.

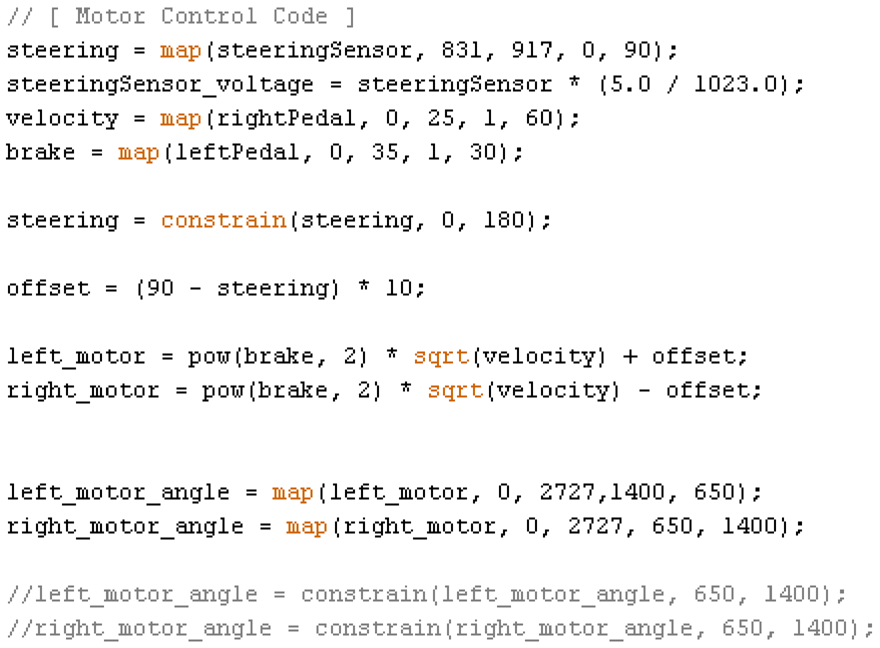


```
void setup()
{

  // Start serial at 9600 baud
  Serial.begin(9600);
  Serial.println("Calibrating Motors");
  leftMotor.attach(3);
  rightMotor.attach(5);

  //Calibrate Motor
  leftMotor.writeMicroseconds(1400);
  rightMotor.writeMicroseconds(650);
  delay(3000);
  leftMotor.writeMicroseconds(650);
  rightMotor.writeMicroseconds(1400);
  delay(3000);
  Serial.println("Completed Calibrating Motors");
}
```

Figure 38 Setup coding used written in the Arduino environment

This piece of coding also sets up the location of the two servos from the Arduino Uno digital ports 3 and 5. These ports are the PWM output ports, and the {.attach ()} coding calls the location. The coding that tells the motors where to move is the {.writeMicroseconds ()}, this piece of coding controls the strength of the PWM pulse. {.writeMicroseconds ()} sends commands to the servo on its position, the servo will travel to that position at max speed. To control the speed on the motor, with the {.writeMicroseconds ()} function, sets or increments have to be used example (1500, 1510, 1520, …) all the way to the required position.

The set of coding that controls the motors position is a combination of the {map ()} function; {constrain} function, and three equations that use the three sensors as inputs. The analog signals from the sensors are mapped to represent what they are doing, or supposed to be measuring. The {constrain ()} function keeps the values in the required range, some sensors for example the steering sensor can give analog signals outside the mapped values. The three equations that control the angle of the wings based on the sensors mapped values, one is for the offset of the steering sensor, and the other two are for each motor.

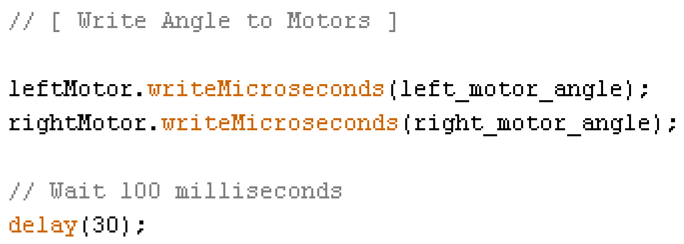


```
// [ Motor Control Code ]
steering = map(steeringSensor, 831, 917, 0, 90);
steeringSensor_voltage = steeringSensor * (5.0 / 1023.0);
velocity = map(rightPedal, 0, 25, 1, 60);
brake = map(leftPedal, 0, 35, 1, 30);

steering = constrain(steering, 0, 180);

offset = (90 - steering) * 10;

left_motor = pow(brake, 2) * sqrt(velocity) + offset;
right_motor = pow(brake, 2) * sqrt(velocity) - offset;


left_motor_angle = map(left_motor, 0, 2727,1400, 650);
right_motor_angle = map(right_motor, 0, 2727, 650, 1400);

//left_motor_angle = constrain(left_motor_angle, 650, 1400);
//right_motor_angle = constrain(right_motor_angle, 650, 1400);
```

Figure 39 Motor Control Code

The offset equation takes the mapped values and the constrain values and gives either a positive or negative value. The intensity of offset is related to the constant in the equation. The offset is than either added or subtracted to the equation of the square of the brake-mapped value multiplied by the square root of the velocity-mapped value. The reason to square the brake value and square root the velocity value is that at high speeds the braking force of the spoiler is intense and at low speeds the braking force is less intense.

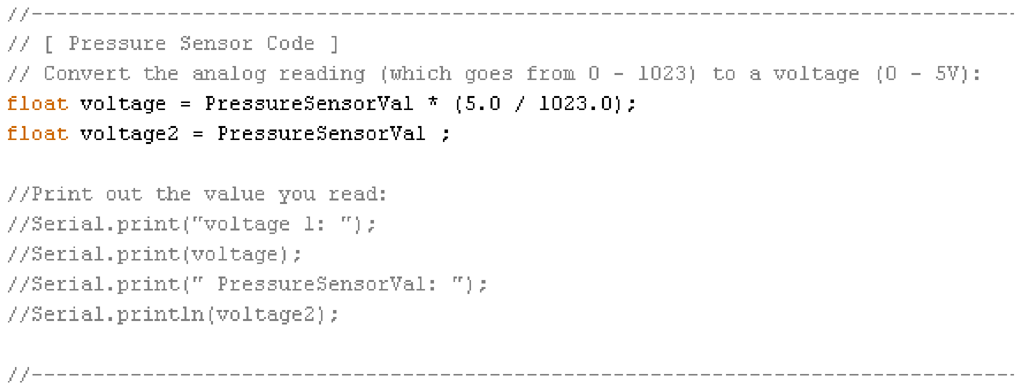
The value of the left_motor and right_motor is than mapped to the range of the motor mounts. The motor mounts have a max range of 55 degrees, the value is then finally sent to the {.writeMicroseconds} command.



```
// [ Write Angle to Motors ]

leftMotor.writeMicroseconds(left_motor_angle);
rightMotor.writeMicroseconds(right_motor_angle);

// Wait 100 milliseconds
delay(30);
```

Figure 40 Command code used to control the angle of the motors

For calibrating the motors to maximize the down force applied to the rear wheels, we plan on using a force sensor to map the angle of the wing to the amount of down force applied by the wing. The coding for the force sensor takes the analog value received from the circuit and maps that value to ibs force. To calibrate the force sensor we measure the capacitance of a known mass that is placed on the sensors measuring surface. This step is repeated two more times, allowing for a linear relation of the force that is applied to the force sensor to the resistance change applied. The force sensor will also be used in measuring the brakes pads internal pressure. This will be plotted against the angle of the brake pedal. This allows for the wing to be in sync with the braking force being applied and the amount of down force and drag generated.



```
//------------------------------------------------------------------------------
// [ Pressure Sensor Code ]
// Convert the analog reading (which goes from 0 - 1023) to a voltage (0 - 5V):
float voltage = PressureSensorVal * (5.0 / 1023.0);
float voltage2 = PressureSensorVal ;

//Print out the value you read:
//Serial.print("voltage 1: ");
//Serial.print(voltage);
//Serial.print(" PressureSensorVal: ");
//Serial.println(voltage2);

//------------------------------------------------------------------------------
```

Figure 41 Force Sensor Coding

Design option 1: Linear actuator driven

The first design that we thought of involved using a linear actuator to control each wing. This seemed like the most logical question since the actuator would apply the force directly to the wing and it would be easily controlled by a logic board.

Proposed Design

Our choice for our dynamic spoiler contains a bracket to hold the spoiler, pistons, springs, motherboard, Pitot tube, etc. From *Figure 43 Flat Face Airfoil* to *Figure 64 Teardrop Airfoil 0 degree Incline* shows the types of airfoils we decided to test out for our spoiler. We will calculate which out of the three causes the least amount of drag with the most amount of down force.

Figure 42 Bracket shows a rough sketch in SolidWorks of what we intend our mechanism to be. The mechanism that will hold the wings and tilt them forward will most likely be made of aluminum rods or carbon fiber, and it will consist of two assemblies as the one shown above. Each of the assemblies will be driven by an independent pneumatic piston which will be attached to the center bar; the actuator will have to be strong enough not only to lift the entire wing but to also hold it in place as the drag force pushes it down. When retracting the wing back to its original position, we were first considering to install a spring that will pull down, so that when the pneumatic actuator wasn't engaged it would automatically come back to its original position, there are three main reasons that we have chosen not to do this, the first reason is that by having a spring pulling down, the actuator would have to be able to hold not only the force due to the aerodynamic resistance of the wing but the additional spring, also it would be hard for us to control the speed at which the spring will retract the wing and this would potentially end up in damaging the mechanism, finally having only one actuator per wing will make the assembly, tuning and maintenance of the wing much easier.

The mechanism will later be mounted on a plane that we will have to adapt to the geometry of the car, since the car frame has not been built yet we cannot come up with the complete design of the mechanism, and we are forced to approach it in this manner.

The wings will most likely be screwed to the frame with through screws and nuts. We are currently still learning how to work with carbon fiber and we are realizing that punching or drilling holes in carbon fiber is a difficult task. Attempting to drill holes in carbon fiber results in separation of the fibers and weakening of the material in the local area.

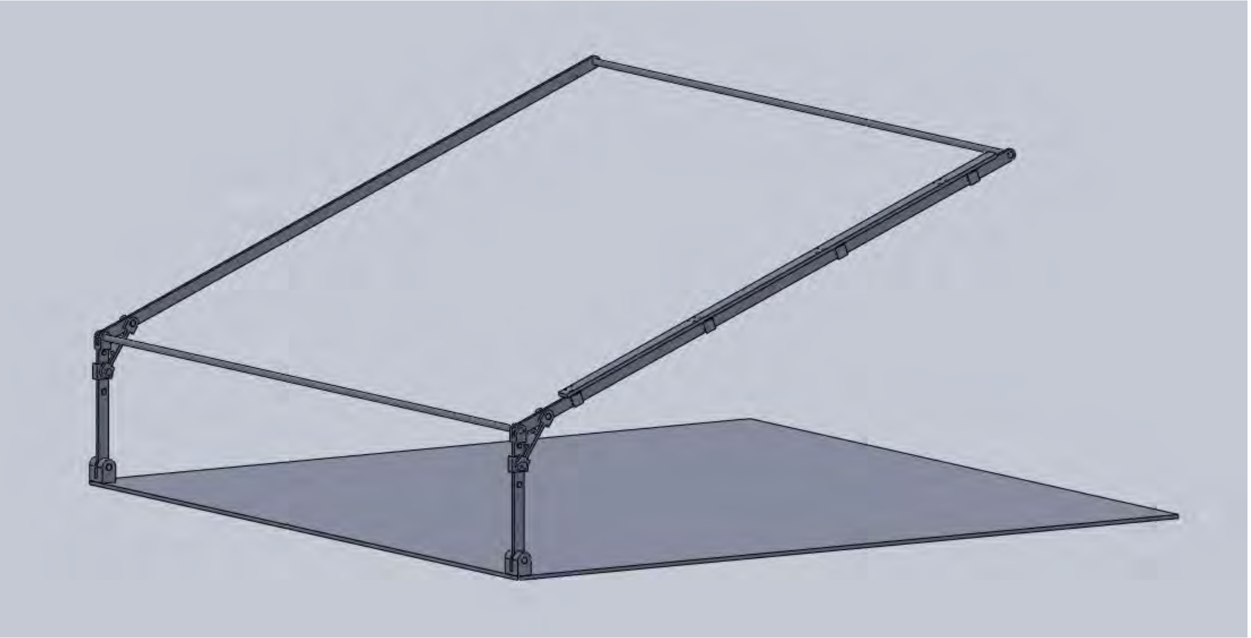


Figure 42 Bracket

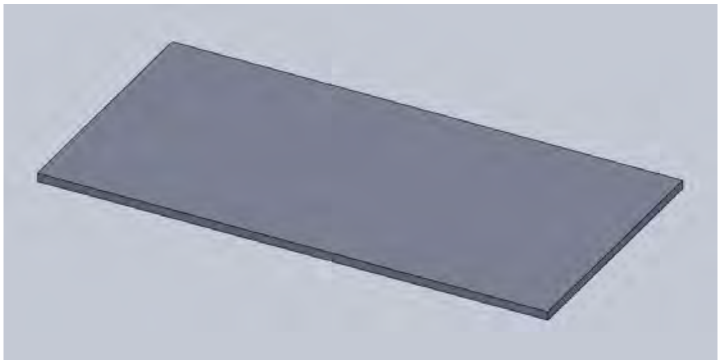


Figure 43 Flat Face Airfoil

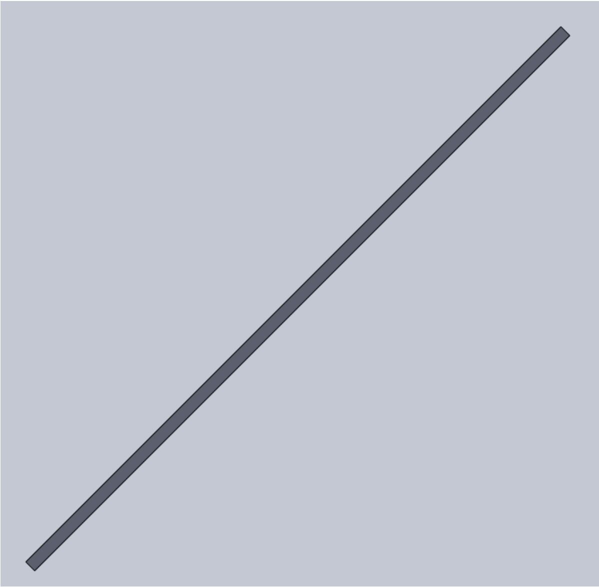


Figure 44 Flat Face Airfoil 45 degree Incline

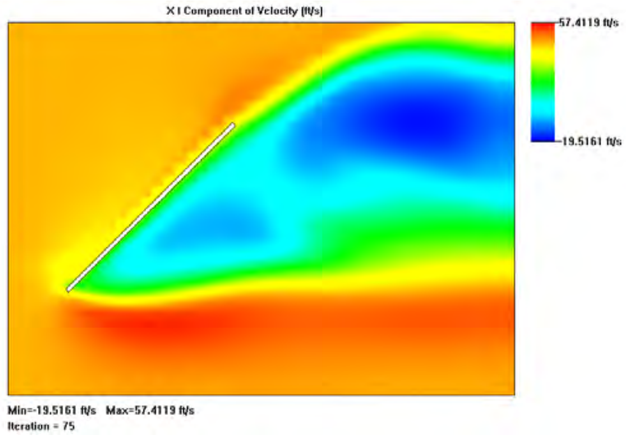


Figure 45 X component of velocity for Flat Face

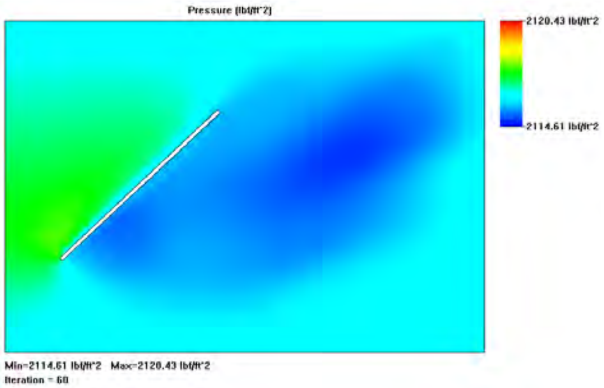


Figure 46 Pressure for Flat face Airfoil 45 degree Incline

Airfoil 45 degree Incline

Table 12 Numerical Data for flat face Airfoil 45 degree Incline

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value
Av Total Pressure	[lbf/ft^2]	2118.4	2118.5	2118.4	2118.5
Av Velocity	[ft/s]	43.9	43.1	42.2	43.9
X Component of Force	[lbf]	1.1	0.9	0.8	1.1
Y Component of Force	[lbf]	-1.0	-0.8	-1.0	-0.7

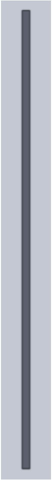


Figure 47 Flat face Airfoil 90 degree Incline

Figure 48 Flat Face Airfoil 0 degree Incline

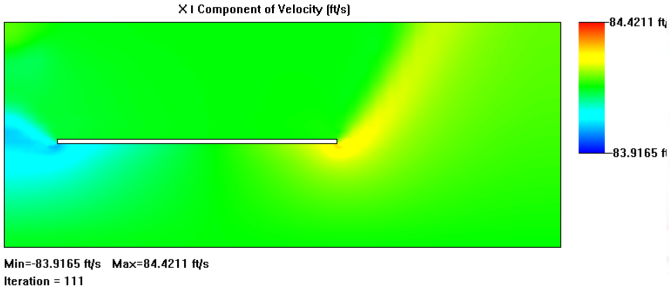


Figure 49 X component of velocity for Flat Face Airfoil 0 degree Incline

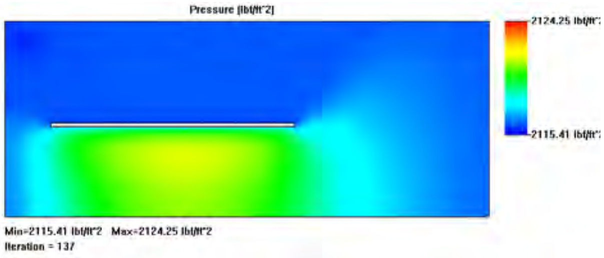


Figure 50 Pressure for Flat face Airfoil 0 degree Incline

Table 13 Numerical Data for flat face Airfoil 0 degree Incline

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value
Av Total Pressure	[lbf/ft^2]	2119.3	2119.3	2119.3	2119.3
Av Velocity	[ft/s]	0.7	0.7	0.7	0.7
X Component of Force	[lbf]	0.0	0.0	0.0	0.0
Y Component of Force	[lbf]	3.1	3.1	3.1	3.1

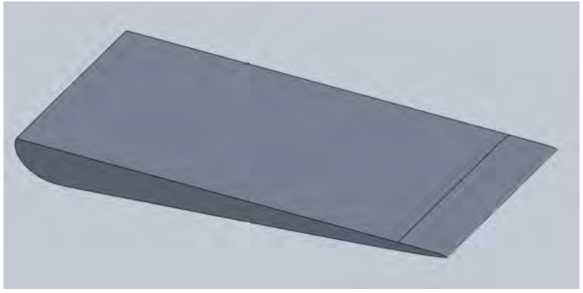


Figure 51 Half Teardrop Airfoil

Figure 52 Half Teardrop Airfoil 45 degree Incline

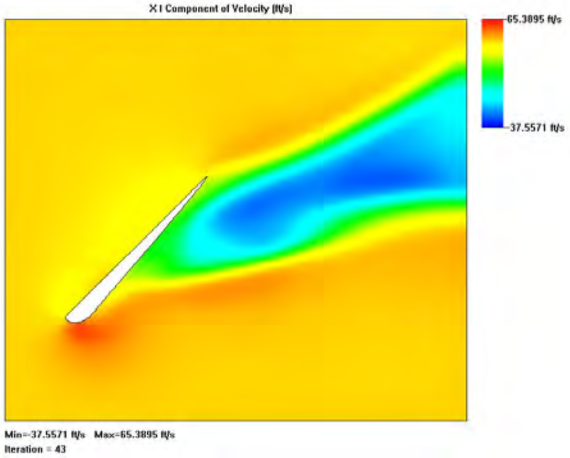


Figure 53 X Component of Velocity for Flat Top

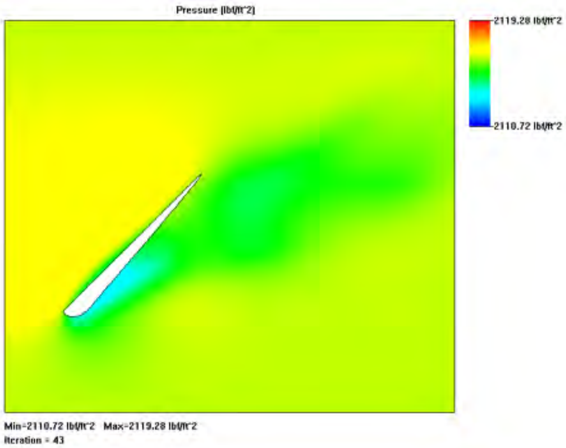


Figure 54 Pressure for flat top Airfoil 45 degree

Airfoil 45 degree Incline

Incline

Table 14 Numerical data for flat Top Airfoil 45 degree Incline

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value
Av Total Pressure	[lbf/ft^2]	2118.5	2118.5	2118.5	2118.8
Av Velocity	[ft/s]	44.1	44.1	44.0	44.4
X Component of Force	[lbf]	1.0	2.0	0.9	39.8
Y Component of Force	[lbf]	-1.1	-2.3	-36.5	-1.0

Figure 55 Half Teardrop Airfoil 90 degree Incline

Figure 56 Half Teardrop Airfoil 0 degree Incline

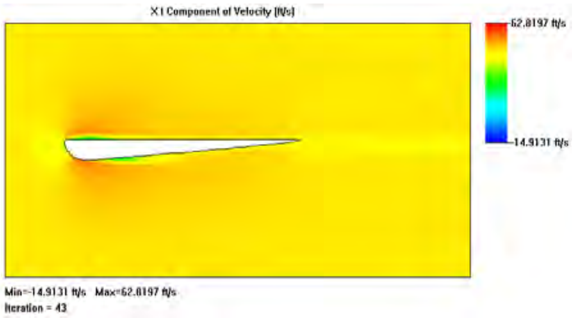


Figure 57 X Component of Velocity for Flat Top Airfoil 0 degree Incline

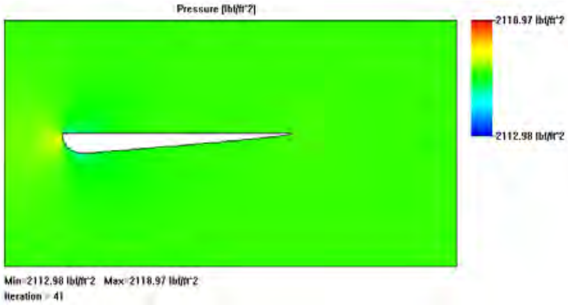


Figure 58 Pressure for flat top Airfoil 0 degree Incline

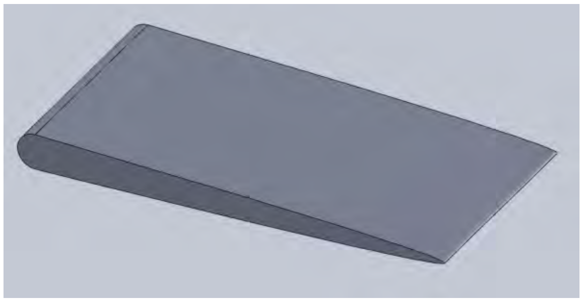


Figure 59 Teardrop Airfoil

Figure 60 Teardrop Airfoil 45 degree Incline

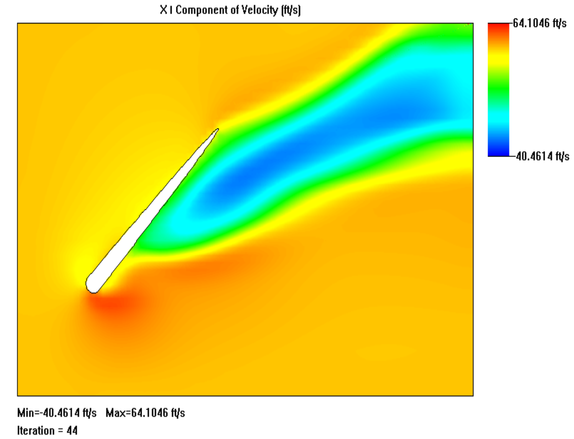


Figure 61 X Component of Velocity for Teardrop Airfoil 45 degree Incline

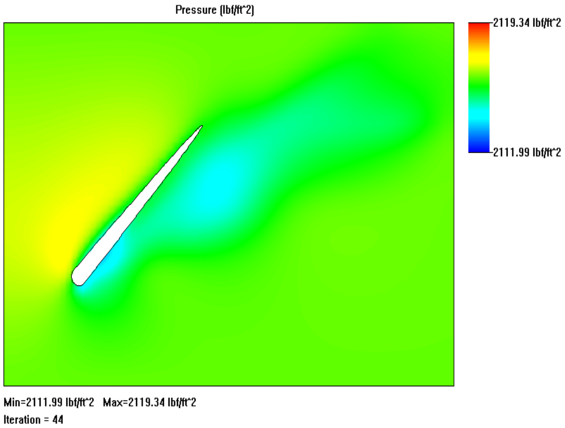


Figure 62 Pressure for Teardrop Airfoil 45 degree Incline

Table 15 Numerical Data for Teardrop Airfoil 45 degree Incline

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value
Av Total Pressure	[lbf/ft^2]	2118.5	2118.5	2118.5	2118.6
Av Velocity	[ft/s]	44.0	44.0	43.9	44.2
X Component of Force	[lbf]	0.9	1.8	0.8	37.7
Y Component of Force	[lbf]	-0.9	-1.8	-36.6	-0.8

Figure 63 Teardrop Airfoil 90 degree Incline

Figure 64 Teardrop Airfoil 0 degree Incline

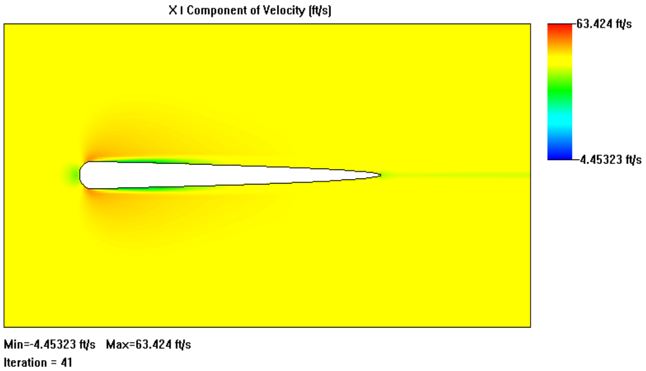


Figure 65 X Component of Velocity for Teardrop

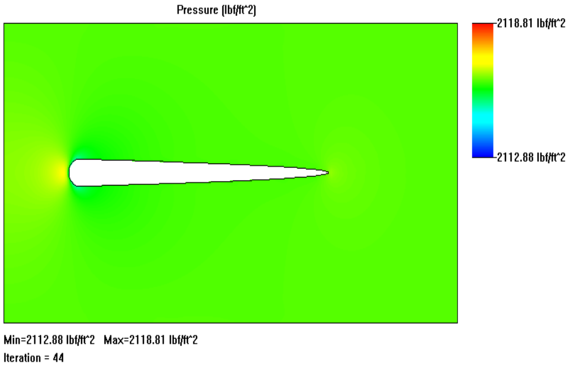


Figure 66 Pressure for Teardrop Airfoil 0

Airfoil 0 degree Incline **degree Incline**

Table 16 Numerical Data for Teardrop Airfoil 0 degree Incline

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value
Av Total Pressure	[lbf/ft^2]	2118.7	2118.6	2118.4	2118.7
Av Velocity	[ft/s]	45.6	45.2	45.0	45.6
X Component of Force	[lbf]	0.0	0.1	0.0	3.7
Y Component of Force	[lbf]	0.0	0.0	0.0	0.0

Major Components

Actuators

Figure 67 Actuators [17]

Purpose:

There will be two linear actuators which will be in charge of giving the motion to both wings. Linear actuators are more desirable than other motion providing systems for a couple of reasons. First of all since the driving parameter will be a linear displacement they are easier to program into the computer than other motion components. Also they meet the two most important requirements for our driving unit at a very reasonable price, they can withstand the loads that will come from the air resistance and they can move fast enough to keep up with the race.

Installation:

The linear actuators will be installed as follows. The bottom part of the actuator will be bolted to the main frame that holds the wing; the top part will be attached with a pin to the center-back of each wing. The power supply will come from a battery that will be placed under the wing and will be discussed later. The power will dictate the motion of the actuator, and it will be controlled by the computer.

Purchasing:

As of right now we are still looking into different types of actuators as well as different suppliers. It seems that the best option is to acquire electrically driven actuators instead of hydraulic or pneumatic. Not only they are cheaper but they are also easier to control since they only require a potential difference; also, they don't require a compressor which lowers the price and weight and increases the overall reliability of the system. We are focusing on two main parameters that the actuators must meet in order to be suitable for our design, the maximum vertical load and the maximum speed of engagement. [14][15][16]

Wings

Figure 68 Carbon Fiber Wing [18]

Purpose:

The purpose of the wings is to provide the braking force and the down force when engaged. We are looking into making them of carbon fiber because it is a light resistant material, ideal for racing purposes. The cross section of the wing will be analytically determined.

Manufacturing:

We are planning in manufacturing the wing ourselves, because this way we can dimension the wing according to the design requirements, performance specifications and SAE rules. We are still looking into the carbon fiber manufacturing process that we will be using, there will be a section explaining the process that we used.

Installation:

Each wing will be anchored in two different points in the front, this joints will most likely have ball bearings inside and will have a long shaft run through them, we are still perfecting this aspect of the design. In the back of the wing there will be one pin joint holding to the tip of the linear actuator that will drive the motion of the wing. Both wings will move about the same axis, which will be determined by the previously mentioned shaft.

Purchasing:

We are still looking for good local carbon fiber suppliers. Depending on what manufacturing process we decide is best for creating the wing we will need different materials, sheet thicknesses, etc. [19][20][21]

Control Unit

Figure 69 Control Unit [22]

Purpose:

The purpose of the wing is to provide the optimum combination of down force and drag at every possible situation that the car might find itself in during the race. In order to do this, a central processing unit is necessary; the computer will have a logic installed and three different inputs that will dictate what the position of the wings (output) will be. The three sensorial inputs are an accelerometer, a Pitot tube and a turning sensor; they will be discussed in more detail later on.

Installation:

The computer needs a 9V DC power supply that will most likely come from the same battery that is powering the actuators. We will design a cage to fit it in in order to protect it from the hazardous environment that it might be subjected to during the race. The three inputs will be properly connected as well as the two outputs. Before installation the computer will be programmed with a logic that has been previously derived from our dynamic and aerodynamic studies of the vehicle.

Purchasing:

The device we have chosen to perform this task is the Arduino UNO. The reason for our decision is that this is an open source processor which means that there is a lot of global knowledge and external insight that will draw some light in the future programming and installation stages. Also, we purchased this device at a very affordable price, $22. [22]

Sensors

Figure 70 Sensors [23][24][25]

Purpose:

As previously mentioned, the computer will need three sensorial inputs to fully define the conditions that surround the dynamic and aerodynamic analysis of the vehicle. The three variables that we need are the speed of the vehicle, which will be obtained from the air velocity sensor or Pitot tube, the tilting of the vehicle and sideways acceleration, which will be given by the accelerometer and finally the rotation in degrees of the front wheels, which will be given by the steering sensor.

Installation:

The installation of these three components is still a subject that we are looking into. As Mechanical Engineers we did not get enough knowledge regarding computers and sensors so how we are going to install them is still the air. We know certain key factors though.

- Steering sensor: Will be attached to the steering column and will provide raw data of how many degrees it turns. We have to account for power steering in our calculations.
- Accelerometer: Will be installed as close as possible to the center of mass of the vehicle. We have to be careful to orient it the right way.
- Air velocity sensor: Will be installed in an open space where the flow is as laminar as possible. The opening will be positioned perpendicular to the direction of the air flow.
- Pressure sensor: It will be installed under the pistons that push the brake pads. It will be calibrated by applying different forces to the pedal, plotting the pressure values corresponding to those forces and coming up with a formula that represents that curve.

Purchasing:

There are many companies that sell sensors, but before we can choose one in particular we have to do a closer study of the inputs that we will need, the types of sensors that we will use and the accuracy we require for the data. [26][27][28]

Power Supply

Figure 71 Power Supply [29]

Purpose:

Most of the components that need electric power to function use direct current at twelve volts; this will be supplied either from a separate battery or the car battery. Also, one of the requisites that we have to meet is to make the wing as independent from the car as we can, this is why we will purchase a small rechargeable battery that will run all the components that require electric power. Also, it will act as a backup power source in case there are issues with the electric power coming from the car supply.

Installation:

The battery will be tightly attached to the center of the structure under the wing to avoid any eccentric forces acting on it that could result in unwanted vibrations. It will be directly connected to either the main battery in the car or the car electric generator.

A protective plastic or methacrylate cage will be created to house the battery in order to protect it from environmental factors.

Purchasing:

Currently we are not concerned about where to purchase this part as it is very commonly found in any automotive shop. When the time to choose it comes along we will be looking for a small battery, since we are going to give priority to the size and weight of the battery before its power storage. [30][31][32]

Frame

Figure 72 Material for Frame [33]

Purpose:

This frame will mainly serve two purposes. First of all it will add rigidity to the assembly, this is important because the forces that we intend to transmit from the wings to the ground could be somewhat high and they need a solid structure to be transmitted through. Also the wing has to be made removable and independent from the vehicle; for this reason we are forced to build it on a structure independent from the frame of the car.

Installation:

This is probably one of the most important and at the same time hardest installations that we will face. The reason being is that since this whole assembly is a different entity from the rest of the car, how we connect them together is crucial for the effectiveness of the wing as well as for its reliability.

We are still waiting to get the blueprint for the frame of the car, until we get it we can only describe in a very general way what we intend to do. Basically the main concern that arises when connecting these two bodies together is to make sure that there are no major stress concentrations in the connections since they could result in buckling, bending or breaking the components. We will need to perform a static analysis of forces from which we will determine what points in the main frame of the car are the best choices for applying forces and later we will have to design a frame that will hold the wing and will apply the forces in such a way.

Purchasing:

As with some other parts, purchasing of these components is not an issue that we are concerned with as of right now. Most likely we will make the frame out of aluminum or carbon fiber due to its low density and good strength. [34][35]

Other Mechanical Components

Figure 73 Mechanical Components

[36][37][38]

Purpose:

The entire assembly will require of other minor mechanical components that we will be purchasing as we need, this might include pin joints, bearings, sliders, bolts and screws and more. These components are not listed as major due to their low cost, low importance when it comes to analysis and high availability. However it is very important to purchase high quality components that are rated for our application.

Installation:

Different components have specific ways of being installed, normally specified by the manufacturer, which we will have to rigorously stick to in order to ensure the overall integrity of the assembly. It is also important to analyze each of these components independently before approving them in the assembly.

Purchasing:

We will try and find a supplier that can provide most, if not all, of the components at a reasonable price. The reason we will try to purchase all parts from the same manufacturer is because they will come with a similar manual format, similar dimensions, and it is more likely to get a good deal. As of right now we still have not looked at this in much detail, however some possible companies are listed below. [39][40][41]

Other Electrical Components

Figure 74 Electrical Components [42][43]

Purpose:

In order to complete the circuitry of our system it is very likely that we need additional electronic and electrical components such as cables or resistors that we didn’t mention. The purpose of these components goes from sending signals to supplying power or changing the voltage. As with the other mechanical components, it is important to purchase good quality parts for the correct purposes.

Installation:

We are still working on a complete schematic of the circuit that will include the sensors, CPU, battery etc… The installation of these components will be dictated by how we decide to put them together in paper first. It is important to pay special attention to each component to ensure that they are being used for the right purpose and in they work in the manner they were designed for.

Purchasing:

In a similar way as with the other mechanical components we will try and purchase all the electrical parts from the same supplier, in order to reduce costs and integrate all the parts of the design with more ease. Some of the designs we are considering are listed below. As we can see we will try to purchase the sensors and the rest of the electronic and electrical parts from the same companies. [44][45][46]

Connecting Frame

A connection frame between the wing and the rest of the vehicle is necessary since one of the most important features that we are trying to achieve is to be able to remove this dynamic spoiler and install it on a different vehicle. The material that we have chosen for this connection frame is Cromoly since it provides enough stiffness without adding to much weight to the car; it is also easy to bend and weld together. An image of a prototype connecting frame is shown in figure 35.

Figure 75 Cromoly steel pipes

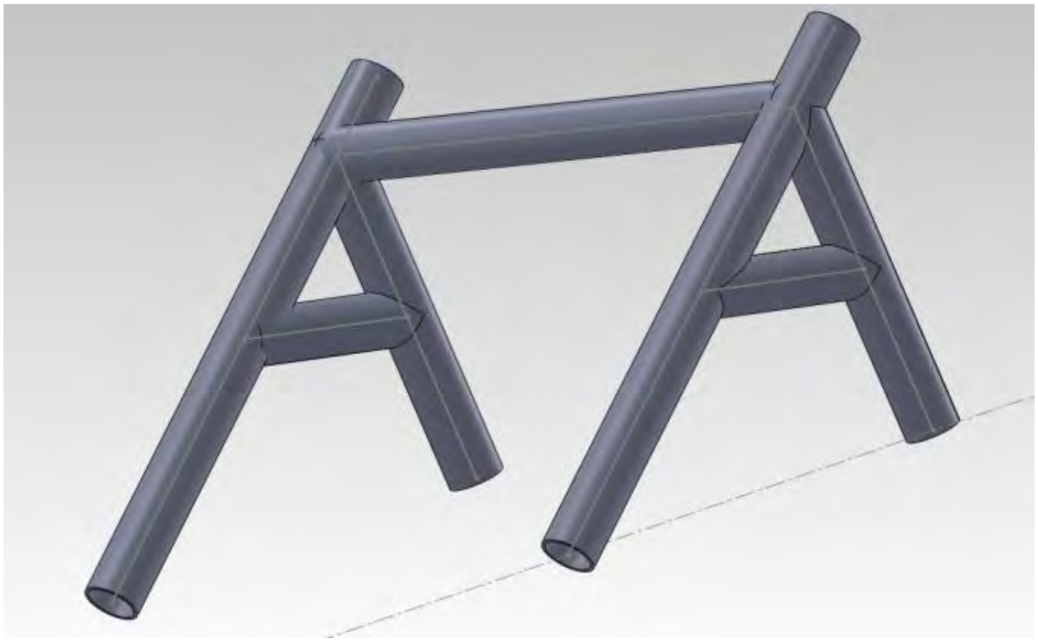


Figure 76 Design option 1 frame

Wing Design

The design of the wing can be sub divided into four different sections, the cross sectional profile of the airfoil, the inner frame, the outer connections and the material.

Airfoil cross section

Given the nature of our design, when choosing the cross sectional profile of the wing we have given preference to low drag designs as oppose to high down force. The reason for this is to ensure that the amount of drag will be minimized when the car is travelling on a straight line. Profiles with low drag when placed horizontally tend not to be thick; however we had to choose a profile with some thickness to be able to install the inner frame and the connection mechanism.

Inner frame

In order to provide the driving mechanism with an even surface area to apply force on the airfoil, as well as to ensure its structural integrity, an inner frame was installed in each wing. This frame consists of a square thin aluminum base, which has been designed with two connections; one to attach the wing to a mechanism around which it will rotate and the other one to receive the driving force from the servo motor or actuator.

We decided that aluminum would be a good material to use for the inner frame because it provides with the strength required to ensure structural integrity while still not adding to much weight to the final design. It is also reasonably affordable and easy to machine.

Outer connections

The inner frame will be connected to the car through the outer connections around which it will rotate. Several options have been considered for this part, being the determining factors reliability and low coefficient of friction. However, difficulties with the mechanical components and actuators have forced us to change this part from ball bearing to spring loaded hinges, which will provide enough torque to allow the servo motors to operate appropriately.

Wing material

The spoiler would be made up of different materials; there are multiple designs of the spoiler created to accommodate the final design. All materials being used for all the designs consist of aluminum, plastic, fiberglass, and carbon fiber.

The aluminum being used is the most common aluminum structural alloy, 6061-T6. The reason why aluminum was chosen for the wing is due to the properties it holds; aluminum 6001-T6 has a tensile yield strength of 35 ksi and a modulus of elasticity of 10,000 ksi, it also has a density of 0.098 lb./in^3 compared to stainless steel having a density of 0.284 lb./in^3, and the cost of aluminum is \$0.12/in^3 which is affordable to our standards. The aluminum used would be extruded into tubes, then cut in half to use as the front portion of the wing. (Kissell & Ferry, 2002)

The plastics used would be of PVC, reason being because of the cost and mechanical properties. Having a density of 0.047 lb./in^3 works with the spoiler since a main focus is to keep it light weight, another focus is the cost and plastics are a good choice for low costs.

Fiberglass would be used because of its ability to be modified after it's cured, it's possible to cut, drill, and mount objects to the fiberglass without many complications. Fiberglass is also strong enough to be used for the outer core of the spoiler; it has tensile strength of 35.8 ksi and compressive strength of 37.5 ksi. (Frame & Janke, 1991) There are two options for making the spoiler out of fiberglass; one is to create a mold and lay out fiberglass material with epoxy to harden, or purchase sheets which are already hardened with epoxy. The cost of fiberglass comes in to ¼ of the cost of carbon fiber, with our focus on weight and cost for the spoiler, fiberglass is a better option.

Carbon fiber is a regularly used material for cars, due to its light weight fibers and extremely strong properties. Carbon fiber would also have two options when manufactured for our spoiler; either by mold or by hardened sheets. With the mold, we would use a Prepreg material which is lined with an epoxy resin. When the Prepreg is ready for use, it's laid out on a negative mold and left to harden. The problem with this method is the mold would need to be vacuumed sealed and also fit inside an autoclave. If done incorrectly, the surface of the carbon fiber would not be smooth. Since the carbon fiber is most important when referring to smoothness due to it covering the wing and it needing to cause the least drag, the molding process just isn’t a sensible choice. The mechanical properties of the Prepreg carbon fiber have a composite tensile strength of 380 ksi and compressive strength of 230 ksi (Toraycfa) High tensile strength and compressions is directly proportional to price when compared with fiberglass. It cost as much as four times more than fiber glass.

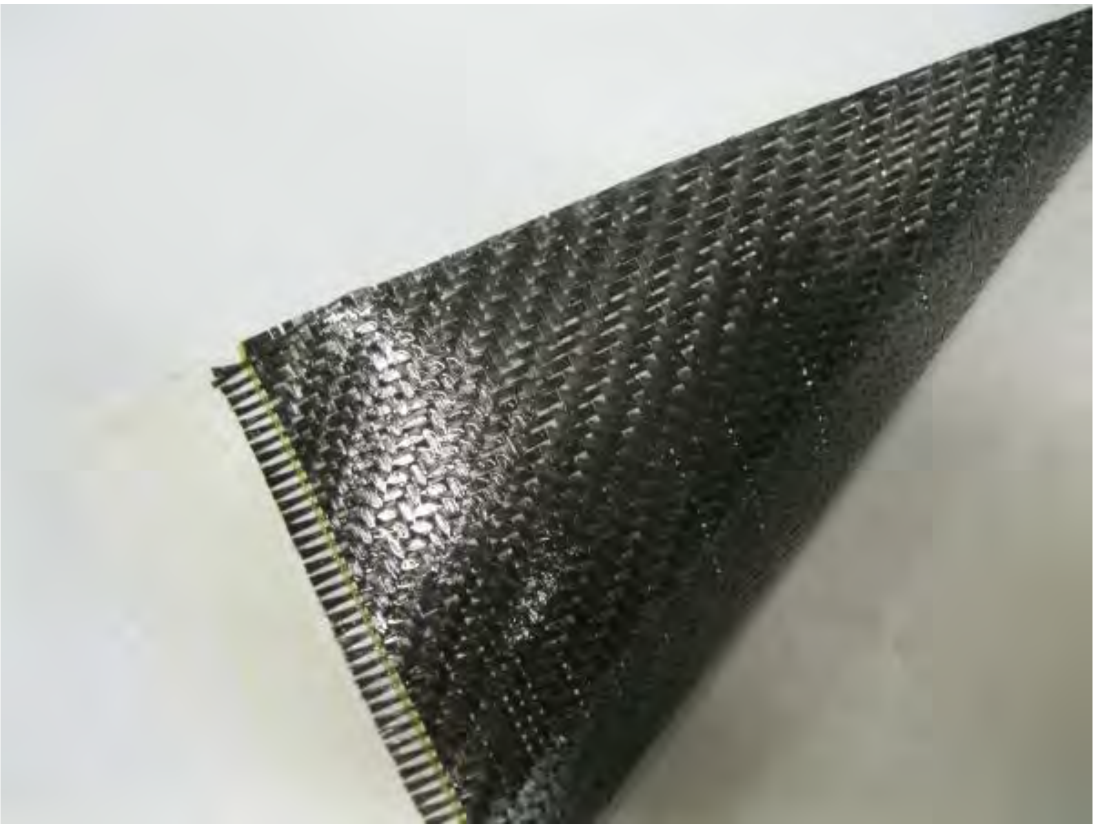
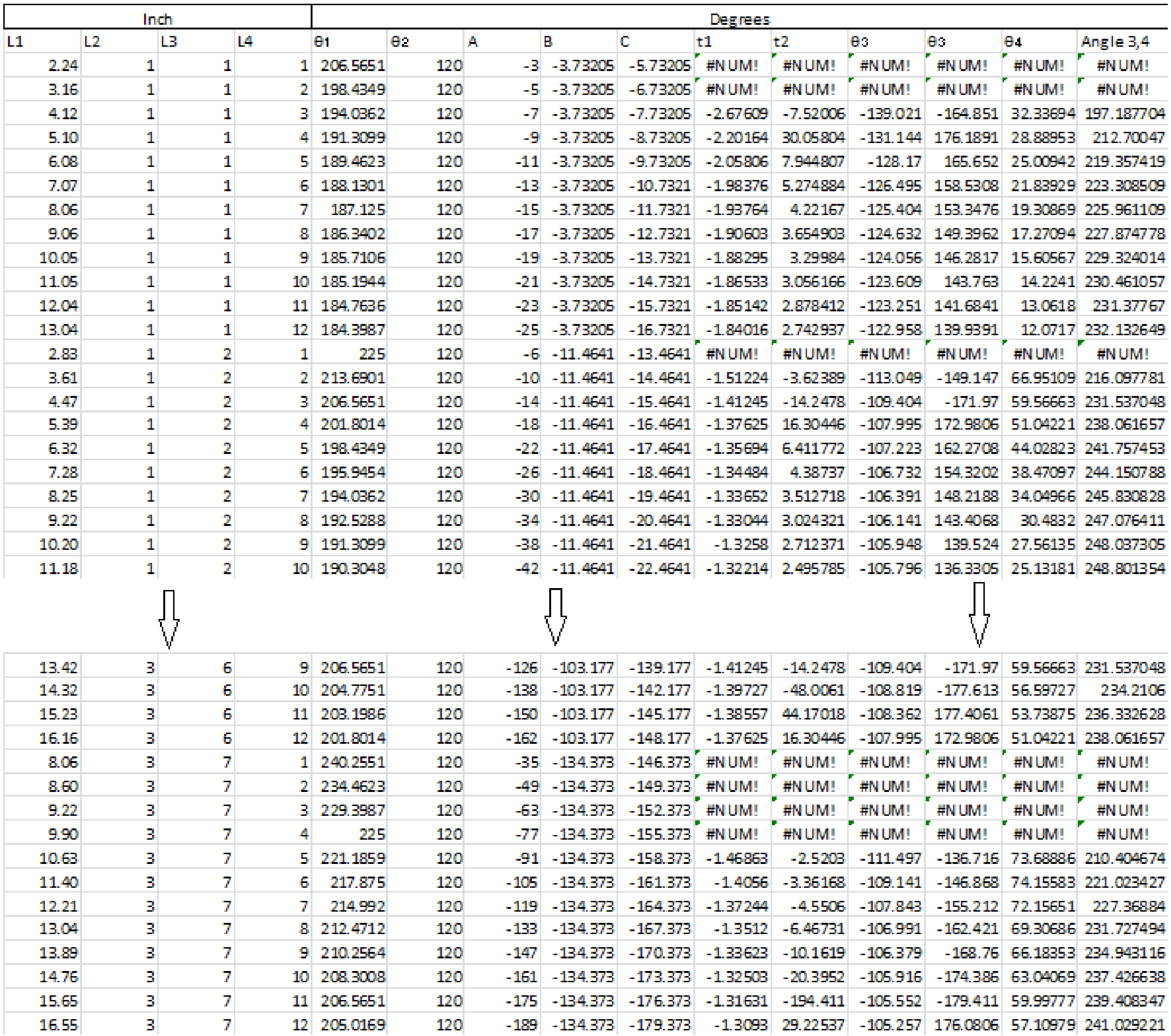


Figure 77 Prepreg Carbon Fiber

The different designs of the wing are mainly dependent on the actuators being used; one design is made for linear actuators, while the rotary actuators have two designs. With the design concerning the linear actuator, the wing would be made of carbon fiber; the axis of rotation would be located inside of the wing. An aluminum rod would have been used for its axis with mounted bearing on all ends. The actuators would have been clamped in the back of the wing due to the brittleness of the fibers. On each side of the wing, a plastic sheet would have been mounted as flaps, these flaps help prevent turbulence due to such a short wing.

When dealing with rotary actuators, one of the two designs would have the axis of rotation inside the wing. The actuator would drive a gear mounted on the axis. The axis on the wing would be made up of a square sleeve; the gear leading to the actuator would have a square rod mounted to it. The front of the wing would be made up of an aluminum pipe and the square sleeve would be welded onto the pipe to act as its axis of rotation. To cover the wing, hardened sheets of fiberglass would be used on both sides, then epoxy onto the aluminum to form the profile of a teardrop airfoil. Plastic flaps would also be used on its side to prevent turbulence. The issues with the design are the welding of the square aluminum sleeve to the aluminum pipe in the front. When it comes to aluminum, increasing its temperature would affect the strain hardening, also arc welding would bring the material to melting point, and this will lower the aluminums strength at its welds. (Kissell & Ferry, 2002) Our second design when using the rotary actuators is having the fiber glass sheets as the top and bottom of the wing. This will allow us to install a rod in the middle of the wing which will lead to a lever mounted on the actuator; this will control the movement of the spoiler. The Wing would be mounted using spring loaded hinges; this will help the movement of the wing and remove some load from the actuator. Since the rotational axis is located on the hinges, a thinner profile and smaller radius aluminum pipe can be used in the wing since no moving pieces such as bearings would be needed on an axis. For the final design, the dimensions should roughly fall into a 2’ by 1’6’’ wing area and a thickness on the front to be 1’’ and a thickness on the back to be less than 0.5’’. This will give it the teardrop airfoil. The reason we are going with a teardrop airfoil is due to it causing the least amount of drag once the wing is traveling horizontal to the surface of the track. Any other airfoil used would cause a down force on the formula car and lead to more unwanted drag.

Using a rotational actuator gave us multiple options to maneuver the spoiler; we ended up with two basic functions, one where the wing would have the axis of rotation on the inside of the wing and the other by having the axis of rotation on the outside of the wing. When having the axis of rotation inside the wing, we were thinking of mounting the motors with a belt leading straight to the wings axis, the advantages of the were to create a closer fit between the wings, but the disadvantages were the amount of torque needed would increase which would need expensive motors. Having the axis outside of the wing would be done by mounting spring loaded hinges to the bottom of the wing; this would also help decrease the amount of force done by the motor to do work. The motor rather than use belts to drive the wing, will use two rods to move the wing, this allows us to decrease the angular velocity and angular displacement of the motor. Running analysis on linkage using equations for For-Bar Linkages was used to produce the angles and velocities of the linkages.



Inch				Degrees										
L1	L2	L3	L4	θ1	θ2	A	B	C	t1	t2	θ3	θ3	θ4	Angle 3,4
2.24	1	1	1	206.5651	120	-3	-3.73205	-5.73205	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!
3.16	1	1	2	198.4349	120	-5	-3.73205	-6.73205	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!
4.12	1	1	3	194.0362	120	-7	-3.73205	-7.73205	-2.67609	-7.52006	-139.021	-164.851	32.33694	197.187704
5.10	1	1	4	191.3099	120	-9	-3.73205	-8.73205	-2.20164	30.05804	-131.144	176.1891	28.88953	212.70047
6.08	1	1	5	189.4623	120	-11	-3.73205	-9.73205	-2.05806	7.944807	-128.17	165.652	25.00942	219.357419
7.07	1	1	6	188.1301	120	-13	-3.73205	-10.7321	-1.98376	5.274884	-126.495	158.5308	21.83929	223.308509
8.06	1	1	7	187.125	120	-15	-3.73205	-11.7321	-1.93764	4.22167	-125.404	153.3476	19.30869	225.961109
9.06	1	1	8	186.3402	120	-17	-3.73205	-12.7321	-1.90603	3.654903	-124.632	149.3962	17.27094	227.874778
10.05	1	1	9	185.7106	120	-19	-3.73205	-13.7321	-1.88295	3.29984	-124.056	146.2817	15.60567	229.324014
11.05	1	1	10	185.1944	120	-21	-3.73205	-14.7321	-1.86533	3.056166	-123.609	143.763	14.2241	230.461057
12.04	1	1	11	184.7636	120	-23	-3.73205	-15.7321	-1.85142	2.878412	-123.251	141.6841	13.0618	231.37767
13.04	1	1	12	184.3987	120	-25	-3.73205	-16.7321	-1.84016	2.742937	-122.958	139.9391	12.0717	232.132649
2.83	1	2	1	225	120	-6	-11.4641	-13.4641	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!
3.61	1	2	2	213.6901	120	-10	-11.4641	-14.4641	-1.51224	-3.62389	-113.049	-149.147	66.95109	216.097781
4.47	1	2	3	206.5651	120	-14	-11.4641	-15.4641	-1.41245	-14.2478	-109.404	-171.97	59.56663	231.537048
5.39	1	2	4	201.8014	120	-18	-11.4641	-16.4641	-1.37625	16.30446	-107.995	172.9806	51.04221	238.061657
6.32	1	2	5	198.4349	120	-22	-11.4641	-17.4641	-1.35694	6.411772	-107.223	162.2708	44.02823	241.757453
7.28	1	2	6	195.9454	120	-26	-11.4641	-18.4641	-1.34484	4.38737	-106.732	154.3202	38.47097	244.150788
8.25	1	2	7	194.0362	120	-30	-11.4641	-19.4641	-1.33652	3.512718	-106.391	148.2188	34.04966	245.830828
9.22	1	2	8	192.5288	120	-34	-11.4641	-20.4641	-1.33044	3.024321	-106.141	143.4068	30.4832	247.076411
10.20	1	2	9	191.3099	120	-38	-11.4641	-21.4641	-1.3258	2.712371	-105.948	139.524	27.56135	248.037305
11.18	1	2	10	190.3048	120	-42	-11.4641	-22.4641	-1.32214	2.495785	-105.796	136.3305	25.13181	248.801354
13.42	3	6	9	206.5651	120	-126	-103.177	-139.177	-1.41245	-14.2478	-109.404	-171.97	59.56663	231.537048
14.32	3	6	10	204.7751	120	-138	-103.177	-142.177	-1.39727	-48.0061	-108.819	-177.613	56.59727	234.2106
15.23	3	6	11	203.1986	120	-150	-103.177	-145.177	-1.38557	44.17018	-108.362	177.4061	53.73875	236.332628
16.16	3	6	12	201.8014	120	-162	-103.177	-148.177	-1.37625	16.30446	-107.995	172.9806	51.04221	238.061657
8.06	3	7	1	240.2551	120	-35	-134.373	-146.373	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!
8.60	3	7	2	234.4623	120	-49	-134.373	-149.373	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!
9.22	3	7	3	229.3987	120	-63	-134.373	-152.373	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!
9.90	3	7	4	225	120	-77	-134.373	-155.373	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!
10.63	3	7	5	221.1859	120	-91	-134.373	-158.373	-1.46863	-2.5203	-111.497	-136.716	73.68886	210.404674
11.40	3	7	6	217.875	120	-105	-134.373	-161.373	-1.4056	-3.36168	-109.141	-146.868	74.15583	221.023427
12.21	3	7	7	214.992	120	-119	-134.373	-164.373	-1.37244	-4.5506	-107.843	-155.212	72.15651	227.36884
13.04	3	7	8	212.4712	120	-133	-134.373	-167.373	-1.3512	-6.46731	-106.991	-162.421	69.30686	231.727494
13.89	3	7	9	210.2564	120	-147	-134.373	-170.373	-1.33623	-10.1619	-106.379	-168.76	66.18353	234.943116
14.76	3	7	10	208.3008	120	-161	-134.373	-173.373	-1.32503	-20.3952	-105.916	-174.386	63.04069	237.426638
15.65	3	7	11	206.5651	120	-175	-134.373	-176.373	-1.31631	-194.411	-105.552	-179.411	59.99777	239.408347
16.55	3	7	12	205.0169	120	-189	-134.373	-179.373	-1.3093	29.22537	-105.257	176.0806	57.10979	241.029221

Figure 78 Analytical Linkage Analysis

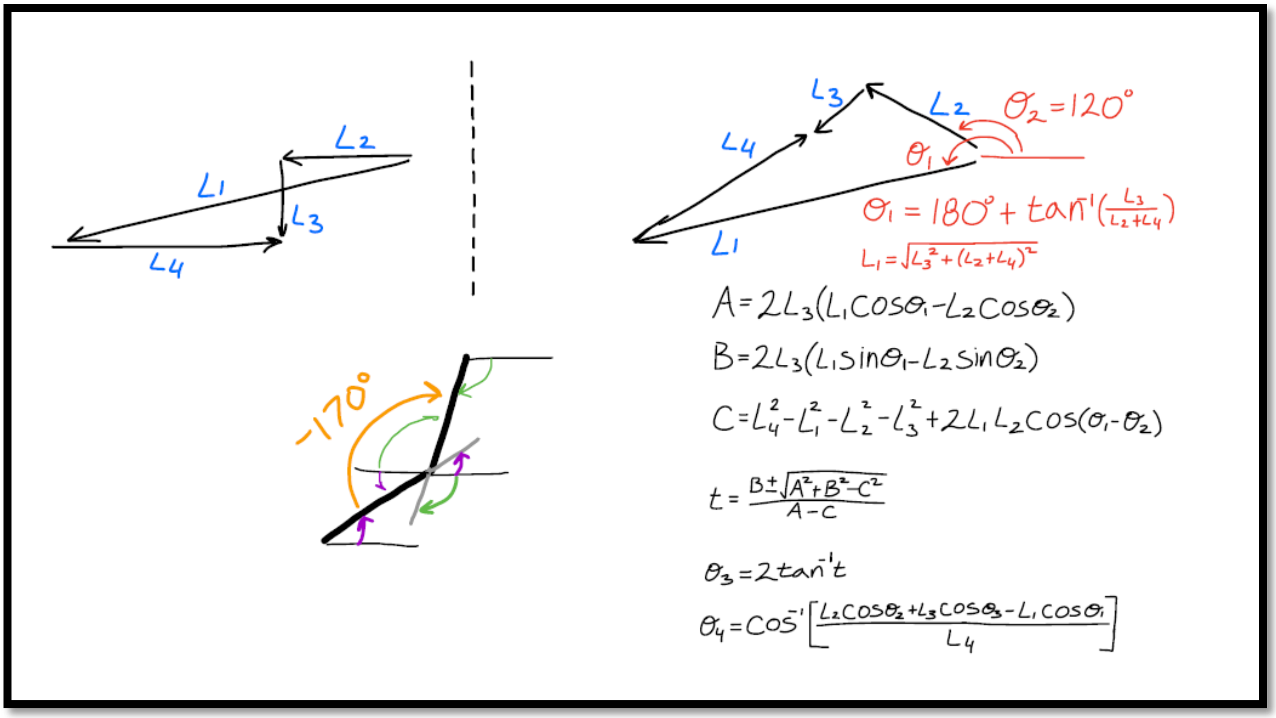
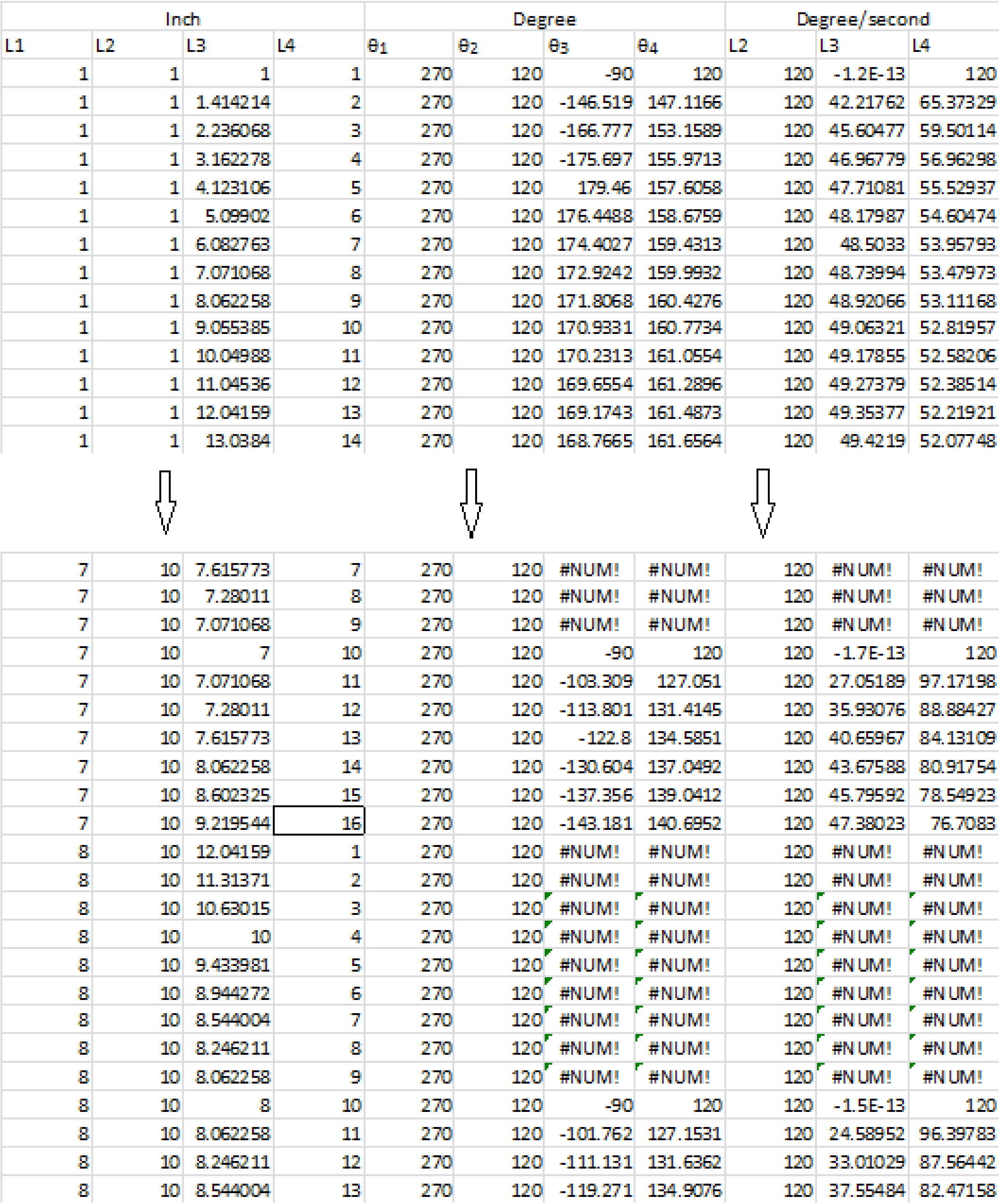


Figure 79 Analytical Linkage Formulation

Having the angles from bars 3 and 4 go over 170 degrees are to be assumed the mechanism would, due to the bars changing directions and causing the linkage to fail. When running the data, this showed every possible combination of link sizes would cause the links 3 and 4 to go over 170 degrees.

Another way we could still use a rocker crank system is if we would change the location of the motor. By having the motors arm move in the same angular direction as the wing, this would allow many successful combinations of linkages.



Inch				Degree				Degree/second		
L1	L2	L3	L4	θ_1	θ_2	θ_3	θ_4	L2	L3	L4
1	1	1	1	270	120	-90	120	120	-1.2E-13	120
1	1	1.414214	2	270	120	-146.519	147.1166	120	42.21762	65.37329
1	1	2.236068	3	270	120	-166.777	153.1589	120	45.60477	59.50114
1	1	3.162278	4	270	120	-175.697	155.9713	120	46.96779	56.96298
1	1	4.123106	5	270	120	179.46	157.6058	120	47.71081	55.52937
1	1	5.09902	6	270	120	176.4488	158.6759	120	48.17987	54.60474
1	1	6.082763	7	270	120	174.4027	159.4313	120	48.5033	53.95793
1	1	7.071068	8	270	120	172.9242	159.9932	120	48.73994	53.47973
1	1	8.062258	9	270	120	171.8068	160.4276	120	48.92066	53.11168
1	1	9.055385	10	270	120	170.9331	160.7734	120	49.06321	52.81957
1	1	10.04988	11	270	120	170.2313	161.0554	120	49.17855	52.58206
1	1	11.04536	12	270	120	169.6554	161.2896	120	49.27379	52.38514
1	1	12.04159	13	270	120	169.1743	161.4873	120	49.35377	52.21921
1	1	13.0384	14	270	120	168.7665	161.6564	120	49.4219	52.07748

7	10	7.615773	7	270	120	#NUM!	#NUM!	120	#NUM!	#NUM!
7	10	7.28011	8	270	120	#NUM!	#NUM!	120	#NUM!	#NUM!
7	10	7.071068	9	270	120	#NUM!	#NUM!	120	#NUM!	#NUM!
7	10	7	10	270	120	-90	120	120	-1.7E-13	120
7	10	7.071068	11	270	120	-103.309	127.051	120	27.05189	97.17198
7	10	7.28011	12	270	120	-113.801	131.4145	120	35.93076	88.88427
7	10	7.615773	13	270	120	-122.8	134.5851	120	40.65967	84.13109
7	10	8.062258	14	270	120	-130.604	137.0492	120	43.67588	80.91754
7	10	8.602325	15	270	120	-137.356	139.0412	120	45.79592	78.54923
7	10	9.219544	16	270	120	-143.181	140.6952	120	47.38023	76.7083
8	10	12.04159	1	270	120	#NUM!	#NUM!	120	#NUM!	#NUM!
8	10	11.31371	2	270	120	#NUM!	#NUM!	120	#NUM!	#NUM!
8	10	10.63015	3	270	120	#NUM!	#NUM!	120	#NUM!	#NUM!
8	10	10	4	270	120	#NUM!	#NUM!	120	#NUM!	#NUM!
8	10	9.433981	5	270	120	#NUM!	#NUM!	120	#NUM!	#NUM!
8	10	8.944272	6	270	120	#NUM!	#NUM!	120	#NUM!	#NUM!
8	10	8.544004	7	270	120	#NUM!	#NUM!	120	#NUM!	#NUM!
8	10	8.246211	8	270	120	#NUM!	#NUM!	120	#NUM!	#NUM!
8	10	8.062258	9	270	120	#NUM!	#NUM!	120	#NUM!	#NUM!
8	10	8	10	270	120	-90	120	120	-1.5E-13	120
8	10	8.062258	11	270	120	-101.762	127.1531	120	24.58952	96.39783
8	10	8.246211	12	270	120	-111.131	131.6362	120	33.01029	87.56442
8	10	8.544004	13	270	120	-119.271	134.9076	120	37.55484	82.47158

Figure 80 Four Bar Linkage

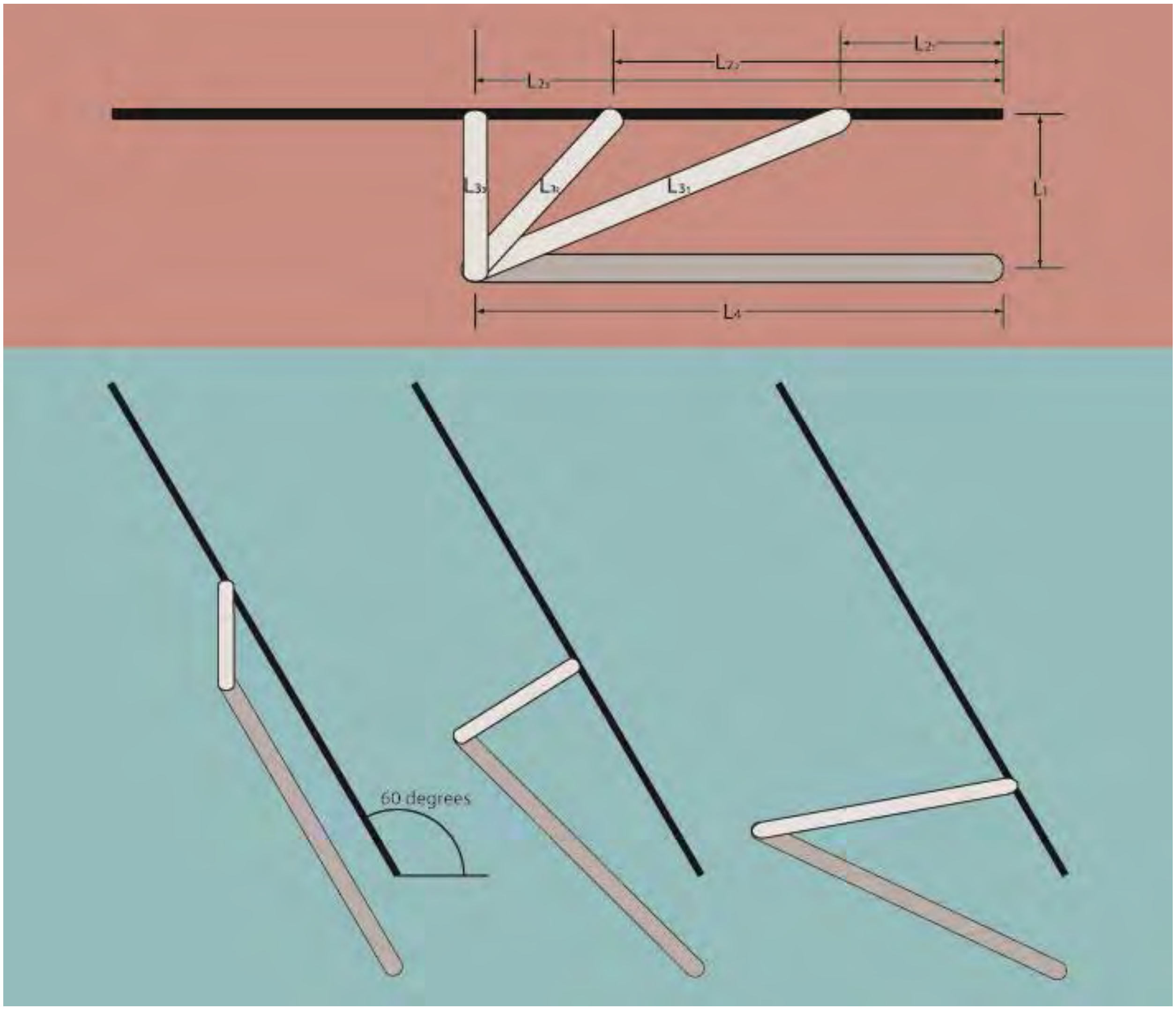


Figure 81 Four-Bar Link

Once we finalize the amount of down force created by the angles of attack, we will use the data to calculate which size linkage causes the least amount of work on the motor while at the same time using least amount of space and material.

To create our program to run our wing, we need to create formulations that contain the variables; drag, force, turn radius, and velocity. In order to relate all of the variables to each other, we will start by comparing the ratios to each. This will allow us to visualize how the formula would act when comparing it to other variables.

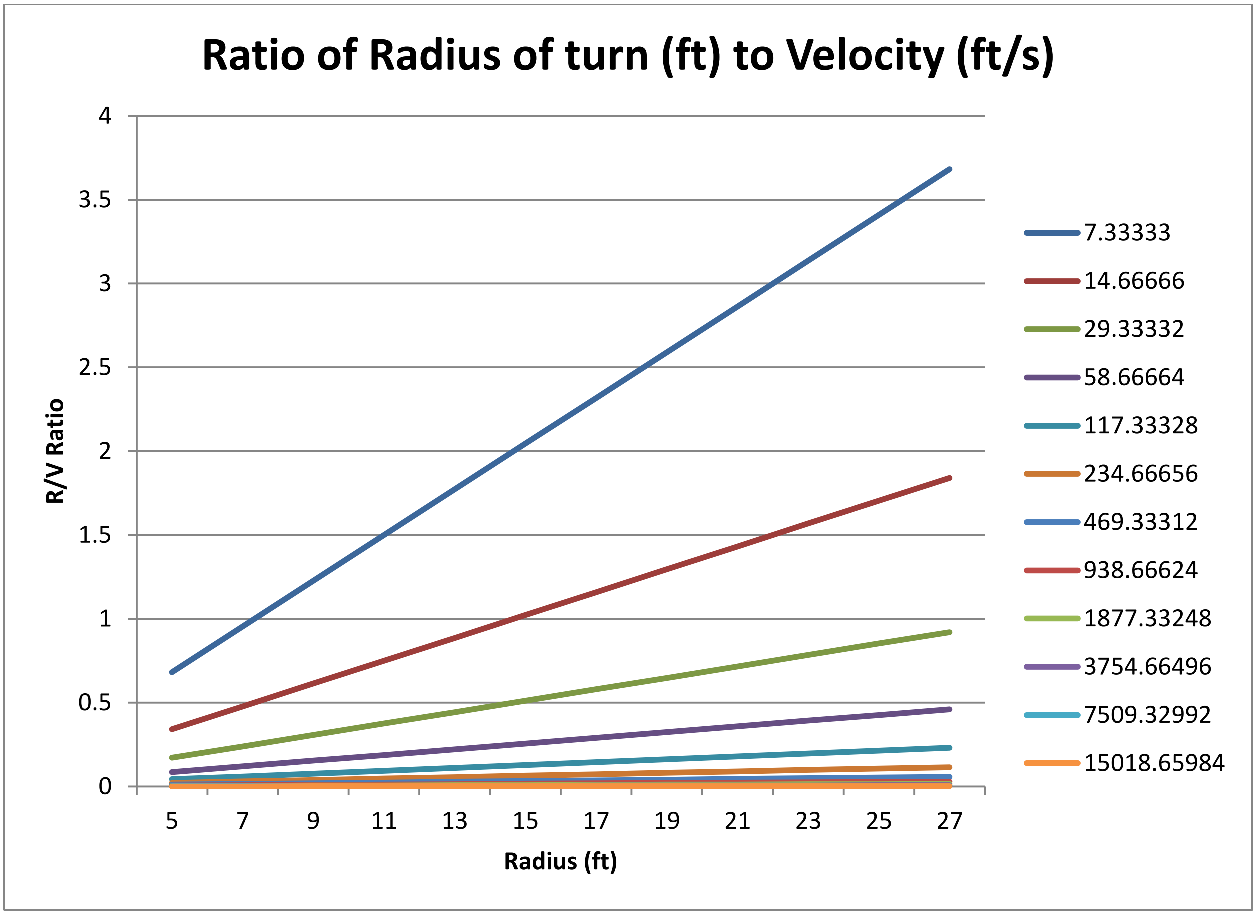


Figure 82 Radius to Velocity Ratio

We see how using the ratios of velocity to radius of the turn will look like. Also giving priority to velocity by having it to the power will decrease the ratio between the radiuses to velocity.

Electrical Components and Sensors

To fully integrate the wing with the car and ensure that it behaves in such a manner that it benefits the dynamics of the vehicle while in race it is fundamental to add digital and analog signals that will accurately describe and compute the parameters that characterize the cars motion. The other option would have been to design a mechanism that will be mechanically driven and that engaged when the forces involved in the car's dynamics triggered it. However this option would have been both very complicated to design and integrate in the vehicle and not accurate enough since it wouldn't be able to account for variables such as the slip angle or the environmental conditions.

After doing extensive research we came to the conclusion that there were three fundamental parameters that we would need to obtain in order to fully describe the dynamics of the car. Those parameters are the car's velocity, the angle at which the steering wheels are turned and the force with which the driver is braking. There are many ways to calculate each of these values; below we will discuss and evaluate some of the most important options that we have considered to perform this task and we will give reasons for our final choice.

Velocity of the car

The first parameter that we are going to discuss is the velocity of the car. In order to obtain this value we came up with several different ideas, the most important being a Pitot tube, getting the signal from the ECU or generating our own signal from the wheel's RPM.

Pitot tube

The first option that we considered was to use a Pitot tube since one of the important features that the spoiler had to have been to be easily removable. However we decided not to use this method for a couple of reasons. First of all a Pitot tube would generate an analog signal that would have to be digitalized before it could be useful for any computational purposes, this introduced some extra work that we wouldn't have to face if we were getting a signal that was digital, such as the one that we could get from the ECU. Also since we needed a signal of about 10 Hz (ten new pieces of information per second), a Pitot tube was not the best choice as it wound not be able to provide information at such rate, thus delaying the output of the microprocessor and therefore making the entire set up much less efficient. Finally a Pitot tube would add extra cost to our design, something that wouldn't happen if we could get a digitalized signal directly.

ECU

The other option would be to get the signal from the rotation of the wheels. To do this we could take two different approaches, either we obtained the signal directly from the wheels using a distance sensor (infrared, ultrasound…) pointed at the wheel or we could obtain the signal from the cable that is already connecting such sensor to the ECU in order to control the engines traction control. We spoke to the Engine Manager from the FIU FSAE team and agreed to use their signal for our device; taking this approach saved both time and money without jeopardizing the accuracy of the signal.

Figure 83 ECU

Steering angle

The next important piece of information that we would need to obtain is the steering angle of the front wheels. Knowing this angle would give us information about the radius of gyration of the vehicle when cornering from which we would obtain the centrifugal acceleration that the vehicle is withstanding, that acceleration will be finally used to compute the lateral force acting on the wheels. In order to calculate how much the car is steering we had two different options that we will discuss below, a steering sensor which would be connected in the steering column of the car, or a three axis accelerometer that would be placed in the center of mass of the vehicle.

Three axis accelerometer

The first option that we considered to obtain this information was a three axis accelerometer that can be easily obtained in any electronics shop. The reason we chose this is because it would not give us information regarding the radius of the curve the car is going through, but information related to the sideways acceleration that the car is withstanding, which is exactly the information that we were looking for. However we decided not to use this for the following reasons. First of all, although a 3 axis accelerometer would give us very accurate information, it would not be easy to calibrate; once installed in the vehicle the only way to test its accuracy would be to do it in track which is something that most likely will not be possible as the car was not expected to be drive until one week before the competition.

Steering column sensor

A steering column sensor is essentially a rotating potentiometer that increases the value of a resistor as it is rotated round its own axis. Such potentiometer would wrap around the steering column and will provide us with an analog signal that we would use to define the position of the wheels at all times. Since the car doesn't count with power steering this was an easy task. One disadvantage that this sensor has against the three-axis accelerometer is that it doesn't account for any slippage of the wheels; if the track is wet we would have to re-calibrate the microprocessor to account for it. A big advantage however is that it is very easy to calibrate, since we will be able to test it in the shop without having to drive the car, also, although the potentiometer will provide us with an analog signal, this is very easy to digitalize and make it useful for computation in the microprocessor.

Figure 84 Steering column sensor

Braking sensor

Finally, the last piece of information that we are interested in knowing is how much braking force the driver is applying. Again for this purpose we had several different options from which we ended up using one, the most important were a pressure sensor in the brake line, an accelerometer and a potentiometer installed in the axis of rotation of the braking pedal.

Pressure sensor

The most common way to obtain the braking force for racecars is to install a pressure sensor in the braking lines that will calculate changes in pressure in the brake fluid. Knowing this change in pressure and the areas of the piston and the braking shoe engineers are able to calculate how much normal force is there between the rotor and the shoe, with the coefficient of friction between them they are able to calculate the braking force. Although this might sound like a very good option we decided not to do it this way for the only reason that it could put the safety of the driver at risk as we would be adding one extra element to the brake circuit and potentially adding risk for leaks or other dangerous situations.

Accelerometer

As we know when a car brakes the center of mass displaces forward provoking the vehicle to dig the front slightly in. We considered the possibility of installing another accelerometer by the center of mass of the car when static that would tell us how much the car is tilting forward. However we quickly rejected this idea as we understood that it would be extremely inaccurate for the following reasons. First of all the deceleration of the car will interfere with the acceleration of gravity which is what the accelerometer is calculating, also small vibrations and grabble on the road will quickly become noise that will make the signal less accurate. Finally the amount of rotation that the car is going through is really small to be able to accurately calculate it using an accelerometer.

Flex sensor

After communicating with SAE club members, it was concluded that the brake sensor could not affect the performance of the car or inhibit the driver from applying the brake. The design of the brake pedals and placement was reviewed, and showed that limited clearance for the brake sensor. The idea of using a flex sensor was then presented. A flex sensor is a thin strip about 4.5 inches long. A flex sensor is a type of variable resistor that changes its resistance as it bends. The flex sensor chosen for the brake changes its resistance when the metal pads on the outside become closer together. This sensor will be mounted, to the underside of the brake pedal and measure the angle the brake pedal makes. With 0^0 being the resting position of the pedal and 90^0 being fully engaged. This will be further described in a later section.

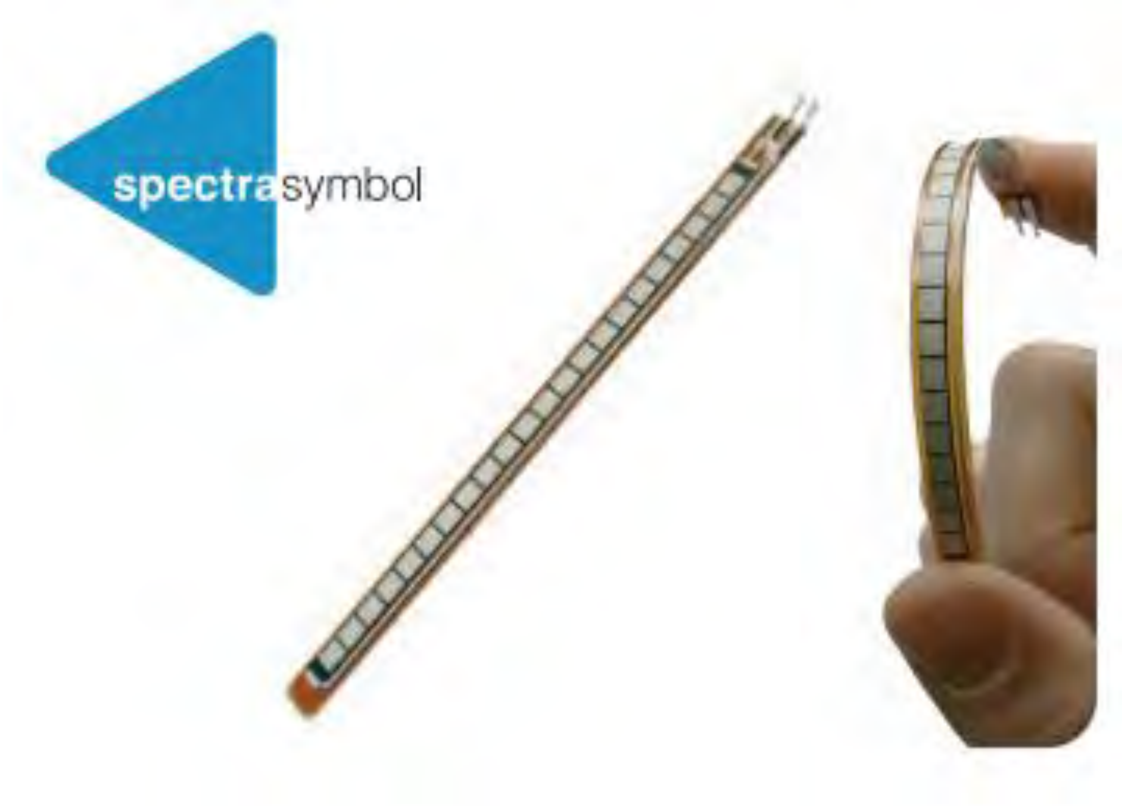


Figure 85 Flex sensor

Potentiometer in braking pedal

The last option that we considered was a potentiometer that would rotate around the same axis of rotation as the brake pedal. After installing it we would calibrate it by inserting a pressure gage between each brake rotor and shoe and finding a curve that relates the rotation of the brake pedal to the amount of pressure in the brake assembly. Finally by simply knowing the area of the brake shoe we will be able to easily calculate the force being applied to the brakes. This last option turns out to be the most affordable and safe, also the amount of accuracy that we can achieve by using the method described above is reasonably high.

Figure 86 Potentiometer

Microprocessor

All the information collected by the three sensors will be sent to a microprocessor that will use a pre-installed logic to calculate the optimum angle of attack that each airfoil. Below we will discuss this in more detail.

The microprocessor that we have chosen for this task is the Arduino UNO as shown in figure 29. The Arduino Uno was chosen for its qualities, which are the unit is inexpensive, widely used and reasonably easy to program. Since the Arduino programming language is based on Wiring, an open source-programming framework for microcontrollers there are many examples of coding available. The Arduino Uno allows stand – alone projects that incorporate inputs and outputs to run freely without the aid of a dedicate computer system.

Logic

Probably one of the most important aspects of this project is optimizing the behavior of the wing for different circuit configurations. In order to provide the best drag to down force combination we have to study the general status of the car and the type of circuit that it is going to race in, after doing that we will assign different “weights” to the three variables in order to increase the importance of some of them according to the race needs.

The three pieces of data that we are going to get from the sensors are the velocity of the vehicle, the braking force and the steering angle of the front wheels. Once collected we have to find the most efficient way to have them interact so that the output angle at which the airfoils are tilted provides the optimum results, in order to do that we first have to study the three variables more closely.

VARIABLES

Velocity

We are not interested in providing down force when the car is going very fast since the amount of lift generated at the velocities we are travelling is negligible. Therefore we will simplify the equations by stating an inverse proportionality between the velocity of the vehicle and the angle of the wing.

Braking

When braking the required tractive force with the ground is increased since slippage becomes more likely; therefore we will use the braking force as a scale factor which will amplify the behavior of the spoiler in order to provide the required additional down force.

Steering

The behavior of the spoiler will be symmetrical when steering left or right, we will derive the equations for only right steering and we will mirror the results to the left steers.

The first step is to determine a basic equation from which we will develop different possible configurations. The most basic expression that can be derived is shown and explained below.

$$R = \frac{S}{V} \times \left(\frac{100+B}{100}\right)$$

Equation 1 Ratio of the wing

Where:

- S=Steering angle [-135^{o},135^{o}]
- V=Velocity [1 mph, 60 mph]
- B=Braking force (derived from the brake pedal angle) [0^{o},100^{o}]

As we can see the equation shown above depends on the three variables obtained by the sensors, it will output a value of R that can be between $\underline{+}$270. However, in order to determine the angle at which the airfoils are going to be engaged at every moment we have two look at two separate parts of the above equation.

RATIO

The ratio of the angle of attack of both airfoils will be dictated by the ratio between the steering angle and the velocity of the car. For simplicity we are going to only look at positive angler, or in other words the car only steering to the right. However we understand that the behavior of the spoiler when steering at negative angles is a mirror image of this.

The ratio between the steering angle and the velocity can be expressed as an array of numbers that goes from 0 to 135. We also know that the angle freedom that the wings can move around goes from 0 to 60 degrees. In order to avoid errors we are going to get ‘zero’ out of the arrays and substitute it by a very small number, for simplicity of the explanation we are calling that number 1. If we name the left wing “**Wing A”** and the right wing “**Wing B”** and the angles at which they engage α and β respectively, we can come up with a new ratio that will be **A/B** and will spam from 1 to 60, however it will most of the time oscillate between 1 and 5 as we will see later on.

We can now express a relationship between the ratio of the steering angle to the velocity, and the ratio between the angles of the two wings. This relationship in its simplest form will look like this.

$$\frac{A}{B} \equiv \frac{S}{V}$$

Equation 2 Ratio between wing angles

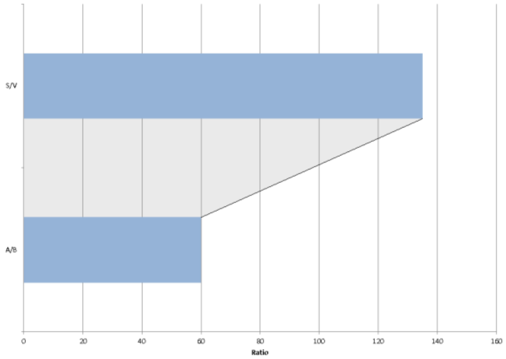


Figure 87 Ratio of wing movement

Where:

- [A/B, 1, 60]
- [S/V, 1/135]

In the diagram above we show the two arrays, the first one going to 60 and represent the angle difference between the two airfoils, and the other one goes up to 135 and represents the ratio between the steering angle and the velocity.

MAGNITUDE

Once the ratio between the angles of the two wings has been established we will shift the magnitude up and down depending on the amount of braking that is taking place. The more the car is braking the higher up the wings will be, but always maintaining the same ratio established by the process shown before.

In the expression shown before, this magnification factor is expressed as:

$$M = \left(\frac{B + 100}{100}\right)$$

Equation 3 Magnification Factor

where B is the angle of the braking pedal which spams between 0 and 100 degrees.

We can feel comfortable doing this as long as we assign a limit to the angle the wings can reach, since the links mechanically can't go over around 60 degrees, we must program that into the board. In the cases there is a lot of braking and a lot of steering both the wing towards the curve will initially lift much more than the other one but this will quickly catch up to it as the first one reaches its limit.

TUNING

The equation shown a few pages before can be adjusted in order to suit the needs of a certain circuit, for instance in a very fast circuit with lots of straights we want the wing to be more sensitive to velocity since it is what will give the driver the advantage, in order to increase the sensitivity of the velocity we can increase it by a constant M (M=2, 3…) or even raise it to a power. As follows:

$$R = \frac{S}{2V} \times \left(\frac{100 + B}{100}\right)$$

Equation 4 Ratio of the wing option 2

We might also encounter a circuit in which we have a lot of steering going on; in such case increasing the sensitivity of the steering constant would be beneficial to the performance of the car:

$$R = \frac{2S}{V} \times \left(\frac{100 + B}{100}\right)$$

Equation 5 Ratio of the wing option 3

We can also increase the sensitivity of the braking factor by either changing the constants in the numerator and denominator or multiplying the braking constant by a factor N (N=2,3…)

$$R = \frac{S}{V} \times \left(\frac{100 + 2B}{100}\right)$$

Equation 6 Ratio of the wing option 4

$$R = \frac{S}{V} \times \left(\frac{50 + B}{50}\right)$$

Equation 7 Ratio of the wing option 5

As we get more familiar with the behavior of the wing and with how these variables interact with each other we can easily tune the sensitivity of the wing by adjusting more than one variable, for instance one example for a fast circuit could be as follows:

$$R = \frac{2S}{5V} \times \left(\frac{75 + 3B}{75}\right)$$

Equation 8 Ratio of the wing option 6

We could potentially attach three potentiometers to the logic board that will control the three variables that we have just described, this way we could tune the wing without having to reprogram the logic board until we got the best results.

Mechanical Components and Actuators

Probably the most important part of this design is to have a fast, accurate and reliable mechanical system that will allow it to move at high speeds and under high forces while still moving the wing to its exact location at all times. Finding the appropriate devices to do this was not an easy task since there is an inverse relationship between the strength of an actuator and the force that it can withstand. Most strong actuators move very slowly while most fast actuators can’t hold enough force; strong and fast actuators tend to be very big, very pricey or both. Below we will discuss two of the most important options that we have considered and we will give reasons for our final choice.

Linear actuators

The first design that we came up with had two linear actuators that would provide a force perpendicular to the plane of the airfoil. These linear actuators would expand and retract pulling and pushing on the wing. Several different types of actuators were considered, including hydraulic, pneumatic, electric and lead screw. Unfortunately none of the linear actuators that were commercially available were able to provide enough force or speed to drive the wings.

Figure 88 Linear Actuator

Servo motor

The next option was to install two servo motors that will turn a mechanism which will lift the wings to their appropriate position. Servo motors are cheaper faster and stronger than linear actuators; unfortunately we had to design a mechanism that will convert the rotational motion of the servos to an angular displacement of the wings. The following two options were considered:

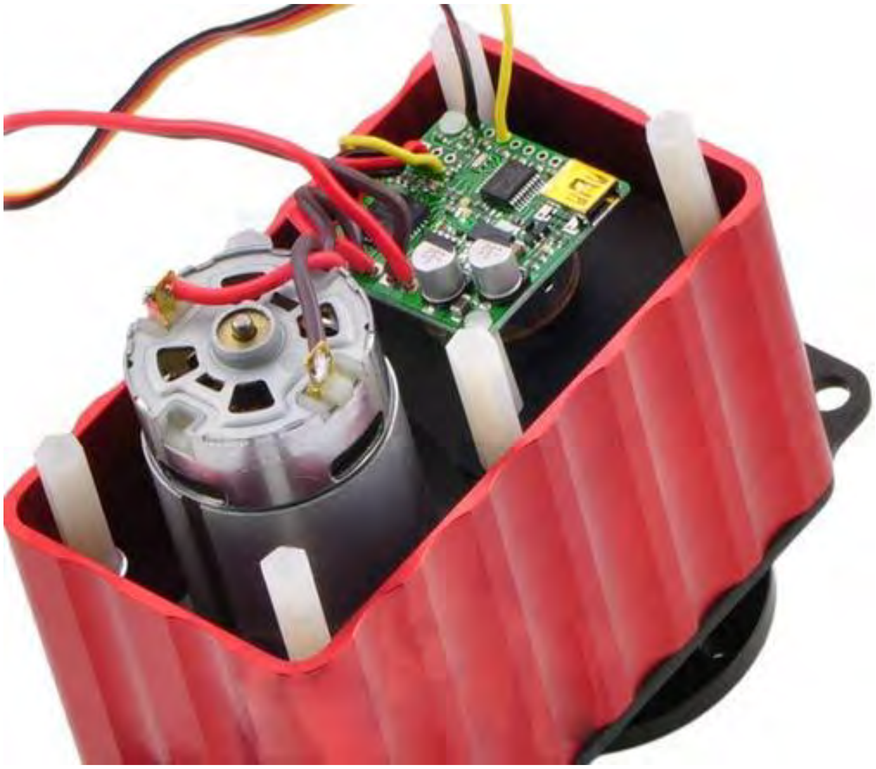


Figure 89 Servo Motor

Install servos on axis of rotation of the wing

Installing the servos on the axis of rotation of the wing seemed at first like the best option, since the rotating motion of the servo would be directly transferred to the wing therefore avoiding having to design any mechanism to transform this motion, however doing this would put too much load on the motors which could potentially lead to damaging the internal components. We considered the option of transferring the force with a belt or chain from the servo motor to a gear and finally to another gear installed on the axis of rotation of the wing; this option would give us the possibility of taking advantage of a gear ratio that would minimize the torque loaded on the servo. Unfortunately we were not able to proceed with this design as we couldn’t find any combination of gears that would satisfy our needs.

Convert to linear motion

The option that we decided to use in our final design was to design a mechanism (lever) that would offset the spinning motion of the servo motor into a circular path, then attaching a link to the end of the lever and connecting it to the bottom of the wing. However we found ourselves with the same problem as before, the servo motors would have to take too much force with this design; the solution that we came up with to solve this problem is to install spring loaded hinges around which the wing will rotate, this hinges will naturally push the wing up so that the force that the servo motors have to fight against is only in the opposite direction. As of right now we are still finalizing this design so we are unable to provide more details on how we are planning to have it work.

Testing of Prototype

When gathering data for the spoiler, we have three main sources to gather information from. Using CFD analysis on our prototype will help us choose what size the wing should be to produce the amount of down force needed. Once the final design is complete, we will compare the analysis from SolidWorks Flow Simulation and ANSYS CFD software for fluid flow, this data will then be used to calculate if it produces enough down force when needed.

Our physical prototype will be tested inside a wind tunnel in order to gather live data of how the spoiler dynamics act towards producing force. In the wind tunnel, the prototype will be mounted onto the back of the Formula 1 so the information gathered will include the air dynamics of the cars effect on the spoiler and also, the spoilers' effect on the car. The prototype will also be tested by mounting it on the Formula 1 car and taking it on a test run. This will show if our computations for the dynamic part of the spoiler was calculated correctly. Have the car run a lap with the dynamic spoiler will help us gather if the system as a whole is working together, we need the programming to calculate when to produce the force on either side of the car and we will need to make sure the right amount of down force is being produced.

As of completion of this report the SAE formula 1 car was not fully constructed. This inhibited the ability to perform analytical testing on the performance of the spoiler mounted on the SAE Formula car. With the competition in mind, the testing of the dynamic spoiler will be conducted once the SAE formula car is completed. This will give valuable data, which will be presented during competition to the judges.

The method of conducting the testing of the dynamic spoiler and the overall performance on the SAE formula car will incorporate wind tunnel testing and measuring the down force generated by the wing. Using the force sensor static forces can be observed during the test allowing for the performance of the dynamic spoiler to be analyzed.

Cost Analysis

The cost analysis will be based on the material for the structure, components and materials for the airfoil that could be used for this dynamic spoiler design and prototype design. The analysis will be based on the cost of purchasing materials and components that are to be used for the design. Major components such as the material of the airfoil and the piston that will be used to adjust the angle of the spoiler will be focused on and compared to alternative options. The analysis of both aluminum and steel are considered for the structure of the dynamic spoiler.

The design team meets on Tuesdays and Thursdays, and occasionally on Sunday to formulate design and run simulations. SAE club mandatory meetings are held on Tuesday nights starting at 9:00 and ending at 11:00 every week. Each member spent on average 12 hours per week working on the project. The estimate total number of hours that will be required for the project is 381.

Prototype estimate cost analysis

The prototype cost analysis will be based on the structure, components and materials needed for the dynamic spoiler. The analysis will compare multiple options for both the piston analysis and the material for the airfoil. The quotes of the components will come from online venders. This analysis will not include the operating cost of an oven or autoclave.

For the airfoil multiple materials were considered, factors that were important for choosing a material was strength and easy to shape or form. The first material considered for the airfoil was ABS plastic. Acrylonitrile butadiene styrene is a thermoplastic that has the ability to be shaped by injection mold. This would be an ideal material for the dynamic spoiler, since it is a typically material used for automotive body panels. ABS plastics are relatively inexpensive and common. US plastics [47] sell sheets of dimension 48" x 96" by 1/16" thick for $36.28. The problem with ABS plastics is forming the material; the typical method of forming ABS plastic is to use injection molding. Injection molding is an expensive method for forming one or two airfoils.

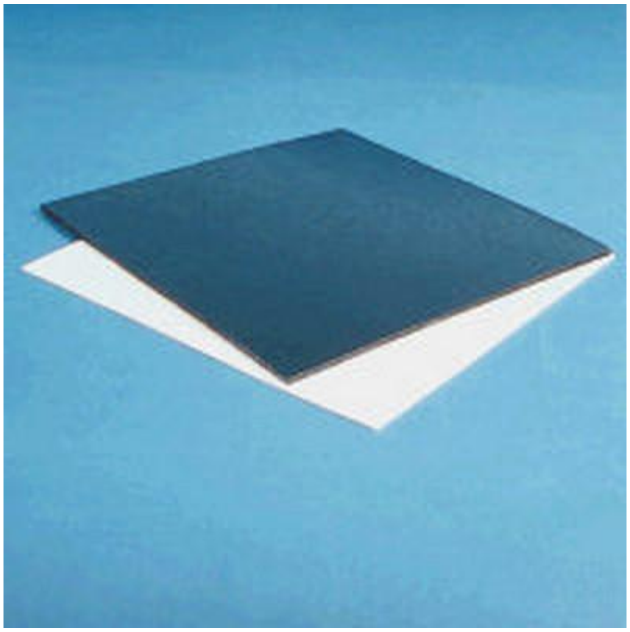


Figure 90 ABS Plastic Sheet Dimension 48" x 96" by 1/16" thick [47]

The second material considered for the airfoil was fiberglass. Fiberglass is a robust material most notable for its strength and lightweight. Fiberglass is very common in marine hulls and airplane wings and fuselage. A feasible method of forming or shaping fiberglass is to apply layers or sheets of fiberglass and lay resin over each layer. The fiberglass would then have to be baked in either an autoclave or oven. The cost for using fiberglass cloth would include the cost of the fiberglass, the resin and the safety material needed to apply the resin. According to fiberglass supply depot [48] for every yard of 50” 10oz cloth it takes about 1 quart of resin. Assuming that for each airfoil ten layers of fiberglass is need. The cost of a sheet fiberglass cloth 10oz with dimensions 10” x 60” is $2.99. Based on the dimensions for every two fiberglass cloth purchased one quart of resin will be needed Assuming that twenty sheets of fiberglass cloth is bought equaling $59.80 and 10 quarts of resin are needed to apply to the fiberglass. The cost of 1 gallon fiberglass resin according to auto body tool mart [49] is $59.99. This means that 3 gallons of resin is needed in order to sufficiently apply fiberglass to an airfoil mold. The cost of safety equipment that includes three 3M Maintenance Free Organic Vapor Half-Face piece Respirator one for each group member, tarps and gloves estimated at $100. The total amount needed to build an airfoil out of fiberglass would total $340. The total cost does not include ship cost.

Figure 91 Fiberglass Cloth 10oz. [48]

Figure 92 Polyester Resin Fiberglass Repair [49]

The third material considered for the airfoil was carbon fiber. Carbon fiber is most notably the strongest and the lightest material of the three. Carbon fiber is very common in the application of aerospace and Formula One. Similar to fiberglass carbon fiber can be layer over a mold or shape using resin between each layer. The material carbon fiber gains its strength from baking the layers and resin in an autoclave. Similar to fiberglass the cost of carbon fiber would have to include the material, the resin and the safety material used during the application of the resin. Unlike fiberglass, carbon fiber products can be cured using vacuum bags. This technique would allow an alternative method if an autoclave does not become available for the baking process. According to US composites [50] the cost for a sheet of carbon fiber with the dimensions of 5.7oz x 50” x 4 yards is $25.50/yard. The cost for the material of carbon fiber comes to around $102 for 4 yards of carbon fiber at that width and weight. If the same amount of resin is needed as for fiberglass, three gallons of resin would be needed. According to composite envision [51] the cost of one gallon polyester resin is $36.99. The total cost of the resin would be $111. The cost of the miscellaneous and safety equipment would equal about $100. The total cost of carbon fiber would be $313.

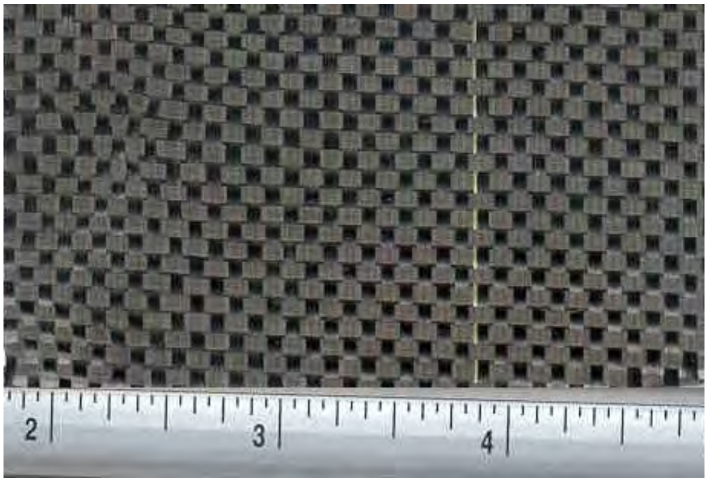


Figure 93 5.7 oz. Plain Weave Carbon Fiber 50" width [50]

Figure 94 Carbon Fiber Polyester Resin [51]

The major components that will analysis are the logic board and the pistons. They are the hardware that will move or adjust the angle of the spoiler. The logic board that has been purchased for the dynamic spoiler is Arduino UNO Figure 69. This logic board was purchased for its easy of programing and for the cost which was $21.95.

The two pistons that will be used to move the angle of the airfoil have to be compatible with the logic board, meet the force and speed requirement and be conservative on weight. Two types of piston have been analyzed, a pneumatic piston and linear actuator. The pneumatic piston will have the force requirement and will be compatible with the logic board. The cost of a pneumatic piston was quoted from allied electronic was $29.76. For two pistons the cost would be $60, mounting brackets and compressor are also needed. The problem with using pneumatic piston for the motion is the cost and weight of the accessories needed. Compressors, valve regulators, position sensors and pressure gages are needed. The weight of the components does not make pneumatic piston practical for a Formula race car.

Figure 95 Cylinder, Pneumatic, Front Nose Mount, 3/4IN. Bore, 6IN. Stroke, Magnetic Piston [52]

Linear actuators are light weight and can apply the required force and speed needed to achieve our goals for the dynamic spoiler. They require only an external power supply and the mounting brackets for installation. The cost of a linear actuator from Frigelli Automation was $ 129.99 each. For the dynamic spoiler the cost of the two linear actuators would be $260.

Figure 96 6" Stroke Tubular Actuator 150 lbs. force [53]

Depending on the parts and components chosen for the dynamic spoiler we estimate that the total cost of this project will be under $ 700.

Prototype actual cost analysis

The cost analysis is based on the parts and material used to build this prototype. The labor of manufacturing or the cost of tools required to manufacture this prototype are not included in this cost analysis. Most of the components used in the dynamic spoiler prototype where purchased from online venders, where a shipping charge was added. For this analysis just the cost of the component or the material will be analysis.

Frame material

The materials used to make the frame that is mounted on the Formula SAE racecar include steel hinge/ tracks bent flat bars. The SAE competition rules dictates that the factor of safety of all components associated with the frame have to be above 2. Based on this rule the wing frame and all associated component were built above this standard.

- Hinge/track – $14.91
- Bent Flat Bar - $28.15
- Bent Flat Bar - $20.00
- Ball bearings - $4.00
- Miscellaneous material - $ 72.13

The SAE formula Car was not finished before the completion of the report; steps were taken to present the dynamic spoiler on a wooden frame. The cost of material for the wooden frame was $66.00

Wing

Foam sheets were used to make the wing profiles for the carbon fiber. The wing profiles were milled into the foam sheet, saving time in the manufacturing process. The cost of the foam sheets was $14.44.

The carbon fiber used to make the wings was molded to the profiles in the foam sheets. Three layers of carbon fiber were used in the manufacturing process. The cost of the carbon fiber material was $255, SAE reimburse us $150 making the total cost that was paid $105

Electronic components

Torxis i00800 Servo

The servo chosen to drive the Dynamic spoiler wings is the Torxis i00800 from Invenscience. The Torxis servo is a super high Torque servo with 800 oz*in at 12 VDC, 60 degrees in 500 ms. The servos are controlled by PWM signals from the Arduino logic board. Each servo cost $289.99 from Invenscience, and with two servos needed the total cost of the servos came up to $579.98.

Arduino Uno R3

The Arduino Uno R3 is the logic board used to control the motors, based on the inputs from the sensors. This logic board was chosen for its ease to program and the wide variety of open source projects that incorporate the sensors and motors in a similar fashion. The average cost of an Arduino Uno logic board is $29.95 this is from the Adafruit industries the manufacturers of the Arduino boards.

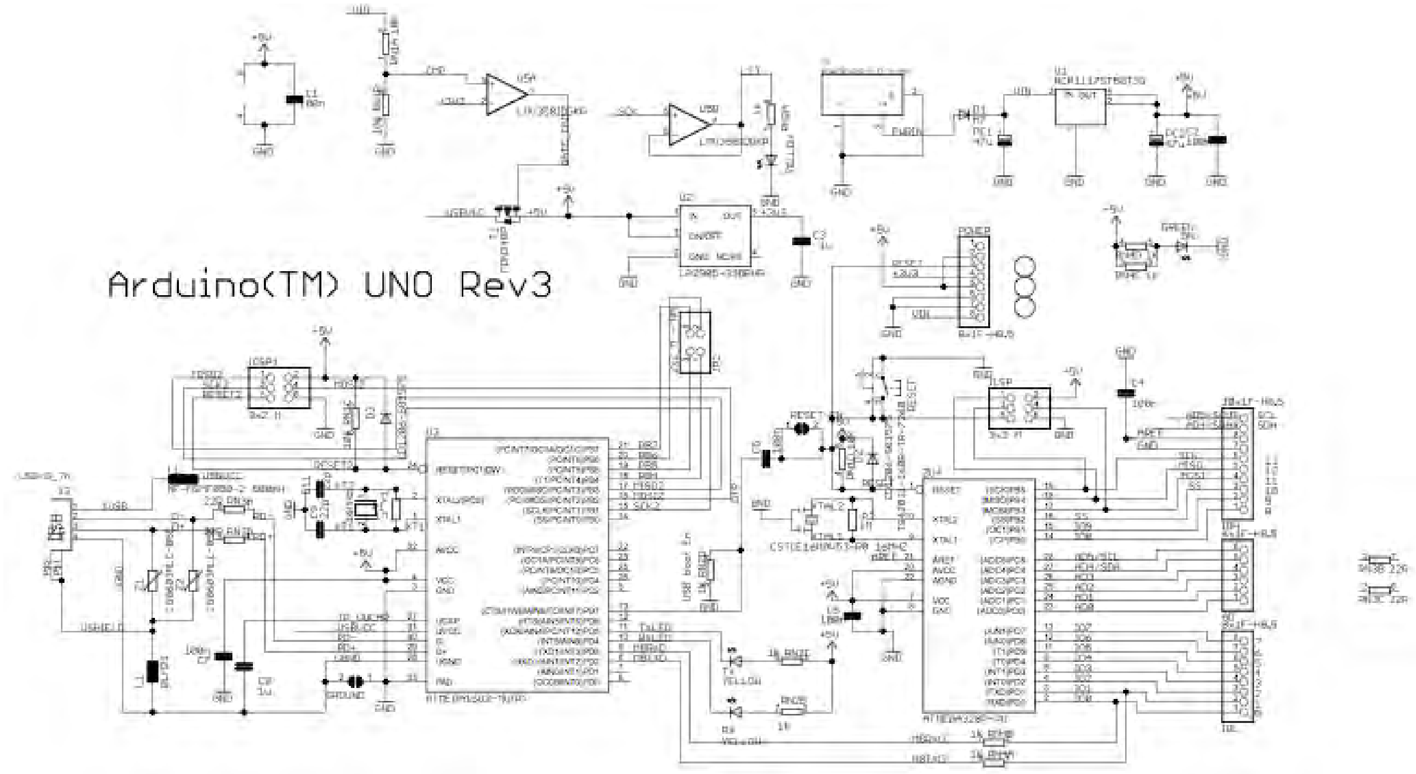
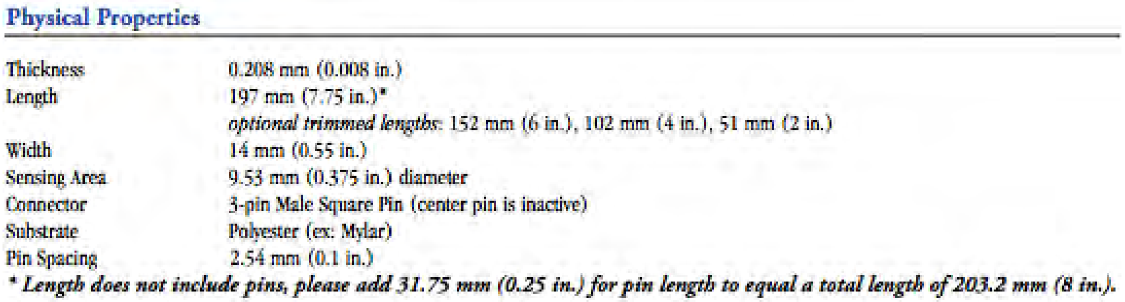


Figure 97 Arduino Uno Rev 3 Electrical Schematic

Flexiforce Pressure Sensor

The Flexiforce pressure sensor is used for calibrating the dynamic spoiler. The force sensor will measuring the down force generated by the dynamic spoiler when the wing is tested in a wind tunnel, and the pressure generated in the brake disc when the car is static. From the data gathered the required angle of the spoiler could be calculated for different braking conditions that the car will experience. The cost of Flexiforce standard force & load sensor model #A201 equals about $19.95.



Physical Properties

Thickness	0.208 mm (0.008 in.)
Length	197 mm (7.75 in.)*
	optional trimmed lengths: 152 mm (6 in.), 102 mm (4 in.), 51 mm (2 in.)
Width	14 mm (0.55 in.)
Sensing Area	9.53 mm (0.375 in.) diameter
Connector	3-pin Male Square Pin (center pin is inactive)
Substrate	Polyester (ex: Mylar)
Pin Spacing	2.54 mm (0.1 in.)

Length does not include pins, please add 31.75 mm (0.25 in.) for pin length to equal a total length of 203.2 mm (8 in.).

Figure 98 the physical properties of the Flexiforce standard force & load sensors model # A201

Flex Sensor

The flex sensor will be used to measure the displacement of the brake pedal as the driver applies pressure. This sensor will send inputs to the Arduino about the position of the brake pedal, and its relation to its resting position. The flex sensor was chosen for its size and qualities, giving an increased resistance in relation to its bending angle.

Figure 99 How a flex sensor works

The price of the flex sensor is $12.95, this is the price listed at sparkfun.com.

Ring Potentiometer

The RK45B1A0002 ring potentiometer from Alps was chosen to measure the turning angle of the steering column of the SAE formula racecar. The other diameter of the ring potentiometer is 45 mm with an inner diameter of 24mm. Ring potentiometers are only made by Alps; this specific model was chosen because of its inner diameter, which is close to the steering column shaft diameter and the max turning angle of 270 degrees. The price of the ring potentiometer is $6.16 from mouser.com.

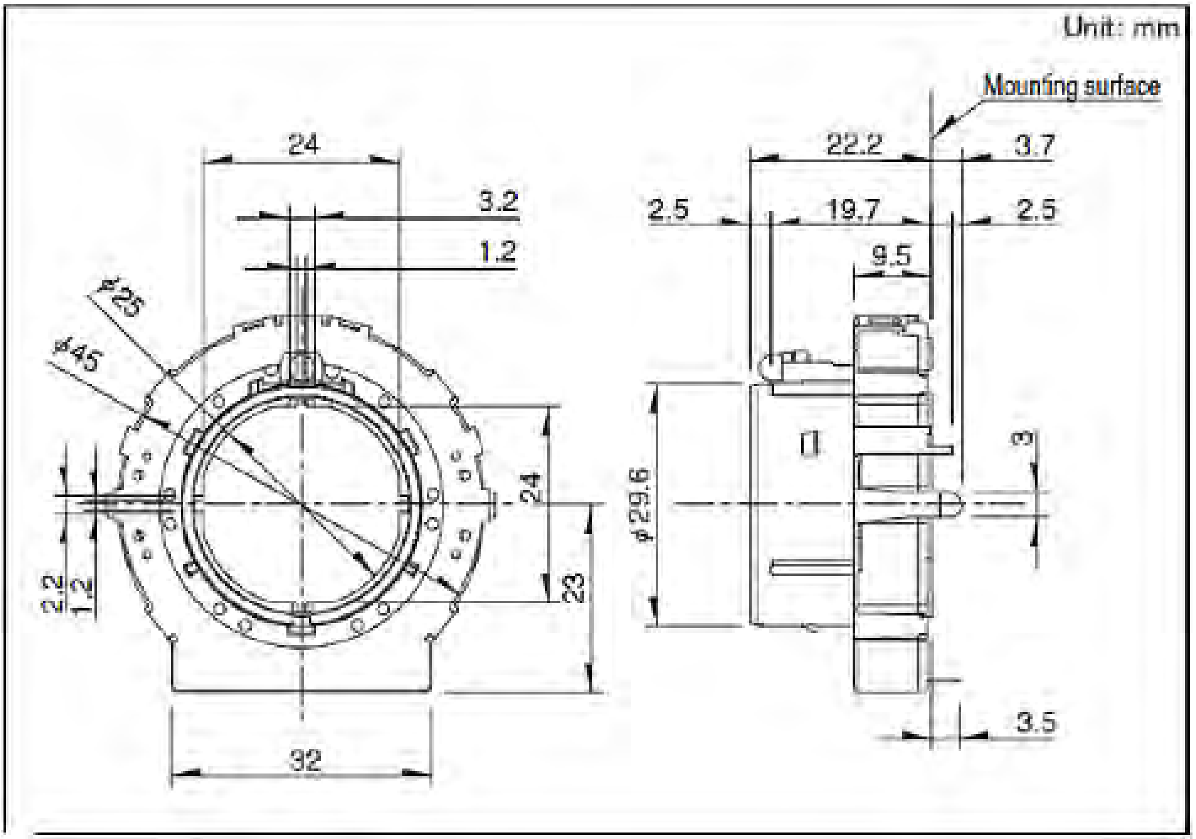


Figure 100 RK45B Ring potentiometer dimensions

Miscellaneous Electronic components

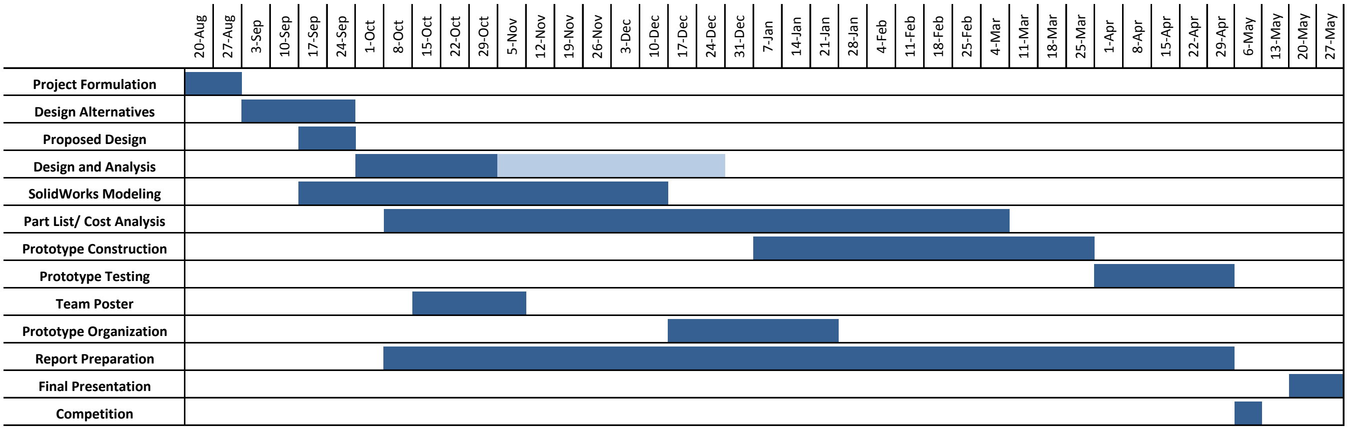
These electrical components are used for connecting the sensors to the Arduino Uno. Jumper wire is used to connect sensors to the Arduino board without the need to solder the pins to wire. They cost about $1.95 each, for this project ten were used which amounts to about $19.50. Proto board which allows for easy circuit set up was used; the average price of a proto board is about $9.99. A basic wire jumper kit is needed to connect leads from the proto board to the Arduino, from radio shack they cost about $6.99. A 9v battery, which is used to power the Arduino during the competition, cost about $6.99. The 12v rechargeable battery needed for the Torxis servo cost about $18.68, the battery also needs a charger. The Diehard 6v/12v battery charger is a good model, found at sears for $22.99. A/B male to male USB cable is used to program the Arduino Uno R3, this is not an essential component for the dynamic spoiler prototype, but is necessary for setup of the Arduino, the average cost is about $9.99. 6" heat – shrink tubes which allows for neat and organized cables, also prevents shorts from exposed wiring, cost 6.99 at radio shack. The resistors needed for the sensors 330ohms, 10K ohms, 22k ohms, and 100 ohms, they typically come in a pack that cost 1.49 individually, and the total amount for the four packs is $5.96. The total cost of all of the miscellaneous components used for the prototype dynamic spoiler is $108.08.

The total cost of the electrical components equals $ 177.09.

Project Management

Timeline

Table 17 Timeline of senior project



Schedule – Spring Semester

January 7 - Week 1

- Meet and Organize
- Set weekly meeting and individual responsibilities
- Meet with SAE
- Discuss money and potential options for fundraising

January 14 - Week 2

- Discuss structure design
- Discuss actuators and motors options
- Start simulation for wing profiles
- Develop parts list
- Autoclave and wind tunnel testing who to call and how to setup an appointment

January 21 - Week 3

- Optimize wing design
- Optimize structure design
- Select linear actuator or motors and how to control from the logic board
- Meet with SAE about mounting location

January 28 - Week 4

- Start Simulation for forces and movement
- Find autoclave and carbon fiber material
- Discuss methods for manufacturing wing and frame
- Plan to manufacture the wing during spring break (March 11-16)

February 4- Week 5

- Continue simulation for forces and movement
- Start purchasing electric components
- Manufacture a presentation table
- Estimate the total cost of carbon fiber

February 11 - Week 6

- Continue simulation for forces and movement
- Start writing coding for logic board
- Purchase actuators or motors
- Purchase sensors
- Schedule time for autoclave (spring break)

February 18 - Week 7

- Finish simulation for forces and movement
- Finish parts list
- Continue coding for logic board
- Start to price carbon fiber

February 25 - W eek 8

- Optimize coding for Logic board
- Purchase carbon fiber
- Start to price material needed for manufacturing

March 4 - Week 9

- Finish coding for Logic Board
- Seek advice on techniques for manufacturing carbon fiber into wing
- Setup building location with materials for manufacturing

March 11 - Week 10

- Manufacture
- Electronic equipment delivery (sensors, and presentation material)
- Start construction of frame

March 18 - Week 11

- Adjust coding for Logic Board
- Continue on frame construction
- Confirm wind testing time (month of April)

March 25 - Week 12

- Finish coding
- Continue on frame construction
- Check clearance of spoiler to SAE Car (sensors, electrics, and frame)

April 1 - Week 13

- Tuning motors and clearance with spoiler frame
- If needed mill out wing profiles templates

April 8 – Week 14

- Laying carbon fiber in mold and drying wing
- Prepare for senior presentation

April 15 - Week 15

- Senior Presentation

Breakdown of Responsibilities

Table 18 Breakdown of responsibilities

	Project Formulation	Design Alternatives	Proposed Design	Design and Analysis	SolidWorks Modeling	Part List/ Cost Analysis	Prototype Construction	Prototype Testing	Prototype Organization	Report Preparation	
Adrian Ortuño Crespo	3	2	5	15	20	10	23	24	15	10	127
Brent Alexander Lougheed	2	1	3	13	15	19	23	24	17	10	127
Richard Pelaez	2	1	3	25	18	10	23	20	15	10	127
Time in hours											381
											Total hours

Richard – Wing Designer

- Selecting the material and profile used for the wing
- Simulating the force the wing will produce and endure
- Select the maximum and minimum angle the wing will move
- Responsible for selecting autoclave and pricing materials needed

Adrian – Frame Designer

- Selecting the material and design for the frame
- Simulating the force the frame can handle
- Selecting mounting location on the SAE car
- Selecting the method the wings will move
- Responsible for wind testing and contacting the world of wind

Brent – Programing

- Selecting the logic board and sensors
- Programing the logic board
- Creating a formula that relates the velocity, braking and turning angle of the SAE car
- Scheduling and productivity

Conclusion

A spoiler is a device designed to spoil turbulent air as it passes over the body of a vehicle. Some spoilers or wings are designed to increase the grip or downward force that is applied to the vehicle. A dynamic spoiler aims at spoiling the unfavorable air that passes over the air, and increasing the down force on the rear wheel when needed. This technology has been applied to high performance vehicles such as the Bugatti Veyron and such Formula 1 cars as the Red Bull Formula 1 racecar.

Our design for a dynamic spoiler incorporated two movable wings that adjust according to the speed of the car, the turning angle, and the braking force. The goal of this design is to reduce drag when traveling straight at high speeds, increase grip on the rear wheels when corning and increase down force when braking. This design should prove to be superior to conventional spoiler designs, by actively adapting to what the car needs as the driving conditions change.

Our dynamic spoiler is to be featured on the SAE Formula car, which they are planning to take to competition in Michigan. The design and dimensions of our dynamic spoiler take into account the mounting location of the SAE car frame and the competition rules that were posted online. The competition is split into two parts, the endurance part which test the abilities of the car and the design aspect which take into account the aesthetics of the car.

A stipulation that SAE wanted in the design of the dynamic spoiler is that is removable from the frame of the car. This meant that all of the mounts had to be coordinated with the SAE frame design team. Before the spoiler's frame design could be finalized, SAE's frame design had to be completed first. In addition to the mounts of the frame, all of the sensors could not be permanent. The design for the frame and linkage was kept as simple as possible. This was aimed at keeping the weight of the spoiler low and easy to manufacture. As manufacturing started, the scope of constructing and wielding the frame proved to be time consuming and tedious. Milling any part takes time and one mistake can destroy the part as discovered on multiple occasions.

As the planning for the design continued the one challenge was finding a practical method of moving the individual wings. Some of the ideas that came up were to use pneumatic cylinders to drive the wing. Pneumatic pistons are very fast and can hold large loads. The problem with pneumatic cylinders is that they require a compressor, and compressors are bulky and heavy. This would be counterproductive on a racecar were weight is limited. The second method considered for the wing was to use electric linear actuators, controlled by a logic board. This design would have been much lighter than the pneumatic piston and potentially have the same speeds and strength. As we started to look for an electric linear actuator that can handle our targeted speed and weight goals, cost became an issue. Electric linear actuators that can handle large load at high speeds are very expensive, way outside of our budget. At this point servo motors were chosen to drive our dynamic spoiler. They were still expensive when compared to the pneumatic pistons, but the weight was considerably less. The Torxis motors chosen to drive our dynamic spoiler has more than enough strength to lift the wing under heavy loads and the speed to travel the full 60 degree range.

The programing of the servos and sensors was difficult, since the group lacked any real programing knowledge, and electrical experience. The Arduino logic board had many examples of how to setup servo motors and sensors which came handy. The Torxis servo proved to be the most challenging of the electrical components. The servos have a motor controller that runs their own language. After many trial and errors it was discovered that the motor control had to be set to receive PWM signals from the Arduino and if any errors occurred on the motor controller, they have to be cleared by the motor controller computer interface.

The plan to use Carbon fiber for the wing material had to do with how the body of the car was being manufactured. The material of the car was Carbon fiber, and to keep a uniform look across the car the spoiler was constructed out of Carbon fiber. The original plan for manufacturing the wing was to use an autoclave to manufacture the wing. The problem with autoclaves in Miami is that none of them were large enough to handle the wings in one shot. To solve this problem the wing was manufactured using heat guns and molds, this process is time consuming and tedious.

References

[1] http://www.ozracingwrap.com/news/formula-1/2537-the-f1-movable-rear-wing-drag-reduction-system-explained.html

[2] http://www.f1rules.com/

[3] http://aeromotions.com/products/s-series/

[4] http://www.bugatti.com/en/veyron-16.4/technology/speed.html

[5] Valkenberg, Paul. *Race car engineering and mechanics*. Updated 2000. ed. Seal Beach, Ca.: Paul Van Valkenberg, 2000. Print.

[6] Milliken, William F., and Douglas L. Milliken. *Race car vehicle dynamics*. Warrendale, PA, U.S.A.: SAE International, 1995. Print.

[7] Abbott, Ira Herbert, and A. E. Von Doenhoff. *Theory of Wing Sections*. S.l.: Dover Pubns., 60. Print.

[8] Fraden, Jacob. *Handbook of modern sensors physics, designs, and applications*. 4th ed. New York: Springer Verlag, 2010. Print.

[9] Schmidt, Maik. *Arduino: a quick-start guide*. Raleigh, N.C.: Pragmatic Bookshelf, 2011. Print.

[10] Boldea, I., and S. A. Nasar. *Linear electric actuators and generators*. Cambridge: Cambridge University Press, 1997. Print.

[11] Parr, E. A.. *Hydraulics and pneumatics a technician's and engineer's guide*. 3rd ed. Amsterdam: Butterworth-Heinemann, 2011. Print.

[12] Burrill, Daniel, and Jeff Zurschmeide. *How to fabricate automotive fiberglass & carbon fiber parts*. North Branch, MN: CarTech, 2012. Print.

[13] Plummer, Frederick B.. *Project engineering the essential toolbox for young engineers*. Amsterdam: Butterworth-Heinemann/Elsevier, 2007. Print.

[14] http://www.firgelliauto.com/product_info.php?cPath=78&products_id=11

[15] http://progressiveautomations.com/linear-actuators-c-8.html

[16] http://stores.ebay.com/The-Parts-Bar?_trksid=p2047675.l2563

[17] http://www.firgelliauto.com/popup_image.php?pID=11&osCsid=170b58eded566dd56f22859f76af4b12

[18] http://www.reverie.ltd.uk/225_curved_01.php

[19] http://www.uscomposites.com

[20] http://www.carbonfiberworks.com/

[21] www.globalspec.com

[22] http://www.amazon.com/Arduino-Rev-3-Uno-R3/dp/B006H06TVG/ref=sr_1_1?ie=UTF8&qid=1352252110&sr=8-1&keywords=Arduino+Uno

[23] http://ecx.images-amazon.com/images/I/31EPAW5VV-L._SL160_.jpg

[24] http://mbed.org/media/uploads/aberk/sca3000.jpg

[25] http://www.onetemp.com.au/images/product-images/854-Air-Velocity-Sensor-T-DCI-F900-S-O--0-5-m-s,-1-Piece-Body.jpg

[26] http://www.digikey.com/

[27] http://www.trossenrobotics.com/c/Arduino-sensors.aspx

[28] http://www.radioshack.com

[29] http://www.cctvco.com/ACDC_Power_Boxes/Batteries/12V-battery-MX12070.html

[30] http://www.autopartswarehouse.com/

[31] http://www.amazon.com

[32] http://www.ebay.com

[33] http://mastil-boom.com.es/presta/145-216-home/aluminum-square-tube-15x15x1000.jpg

[34] http://www.rockwestcomposites.com/

[35] http://www.metalsdepot.com/

[36] http://img.directindustry.com/images_di/photo-m2/miniature-ball-bearings-65987-2485321.jpg

[37] http://www.mttusa.net/id452.htm

[38] http://www.boltdepot.com/

[39] http://www.mcmaster.com/

[40] http://beta.globalspec.com/

[41] http://www.skf.com/portal/skf/home

[42] http://us.cdn3.123rf.com/168nwm/shur23/shur230709/shur23070900016/1639341-a-set-of-transistors-of-different-types.jpg

[43] http://boatwiringstore.com/ProdImages/home-cables-175.jpg

[44] http://www.digikey.com/

[45] http://www.trossenrobotics.com/c/Arduino-sensors.aspx

[46] http://www.radioshack.com

[47] http://www.usplastic.com/catalog/item.aspx?itemid=23013&gclid=CMGX35_iu7MCFQu0nQodwCUA4A

[48] http://fiberglasssupplydepot.com/FIBERGLASS-CLOTH-10oz.html

[49] http://www.autobodytoolmart.com/polyester-resin-fiberglass-repair-gallon-01403-p-10957.aspx?gclid=CLGvpu_vu7MCFQeynQodhUYAIA

[50] http://www.uscomposites.com/shortroll.html

[51] http://compositeenvisions.com/epoxy-and-polyester-resins-65/carbon-fiber-polyester-resin-dries-clear-1-gallon-535.html

[52] http://www.alliedelec.com/search/productdetail.aspx?SKU=70070581

[53] http://www.firgelliauto.com/product_info.php?cPath=74&products_id=47

[54] Frame, B., & Janke, C. (1991). *Fiberglass material specification III.* Washington, D.C.: Martin Marietta.

[55] (2002). Aluminum structures : a guide to their specifications and design. In J. R. Kissell, & R. L. Ferry, *Aluminum structures : a guide to their specifications and design* (pp. 8, 12, 31-34, 105). New York: J. Wiley.

[56] *Toraycfa.* (n.d.). Retrieved January 10, 2013, from

[57] http://www.toraycfa.com/pdfs/T800HDataSheet.pdf

Appendix

Appendix A: SAE RULE BOOK 2013

Location

In plain view, no part of any aerodynamic device, wing, under tray or splitter can be:

a. Further forward than 762mm (30inches) forward of the fronts of the front tires
b. No further rearward than 305mm (12 inches) rearward of the rear of the rear tires
c. No wider than the outside of the front tires or rear tires measured at the height of the hubs, whichever is wider.

Minimum Radii of edges of Aerodynamics Devices

All wing edges including wings, end plates, gurney flaps, wicker bills and under trays that could contact a pedestrian must have a minimum radius of 1.5 mm (.060 inch)

Ground Effect Devices

No power device may be used to move or remove air from under the vehicle except fans designed exclusively for cooling. Power ground effects are prohibited.

Driver Egress Requirements

All drivers must be able to exit to the side of the vehicle in no more than 5 seconds. Egress time begins with the driver in the fully seated position, hands in driving position on the connected steering wheel and wearing the required driver equipment. Egress time will stop when the driver has both feet on the pavement. The wing or wings must be mounted in such positions, and sturdily enough, that any accident is unlikely to deform the wings or their mountings in such a way to block the driver's egress.

Compressed Gas System and High Pressure Hydraulics

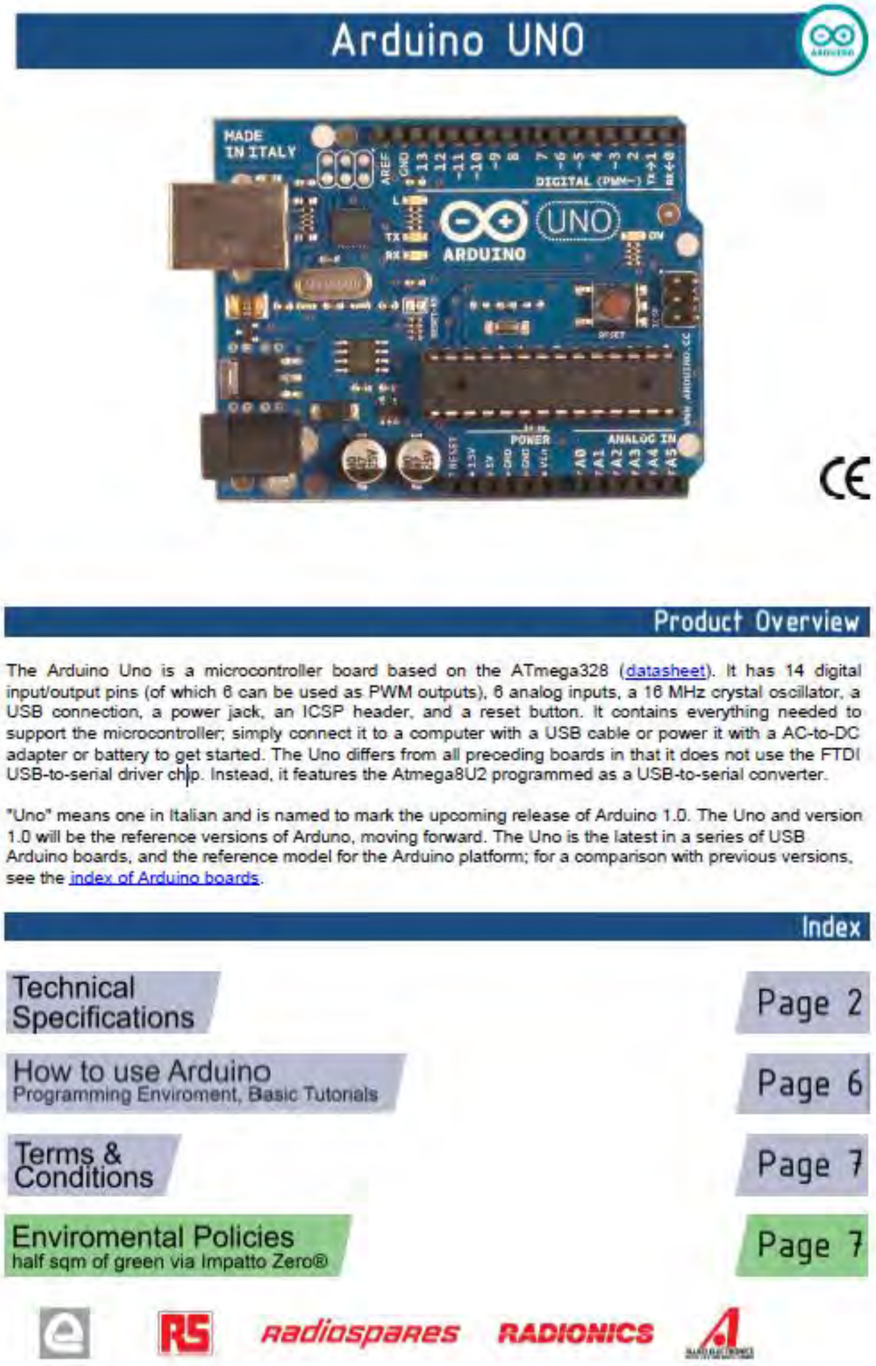
Compressed Gas Cylinders and Lines

Any system on the vehicle that uses a compressed gas as an actuating medium must comply with the following requirements:

a. Working Gas-The working gas must be nonflammable, e.g. air, nitrogen, carbon dioxide.
b. Cylinder Certification- The gas cylinder/tank must be of proprietary manufacture, designed and built for the pressure being used, certified by an accredited testing laboratory in the country of its origin, and labeled or stamped appropriately.
c. Pressure Regulation-The pressure regulator must be mounted directly onto the gas cylinder/tank.
d. Protection – The gas cylinder/tank and lines must be protected from rollover, collision from any direction, or damage resulting from the failure of rotating equipment.
e. Cylinder Location- The gas cylinder/tank and the pressure regulator must be located either rearward of the Main Roll Hoop and within the envelope defined by the Main Roll Hoop and the Frame (see T3.3), or in a structural side-pod. In either case it must be protected by structure that meets the requirements of T3.25 or T3.34. It must not be located in the cockpit.
f. Cylinder Mounting- The gas cylinder/tank must be securely mounted to the Frame, engine or transmission.
g. Cylinder Axis- The axis of the gas cylinder/tank must not point at the driver.
h. Insulation- The gas cylinder/tank must be insulated from any heat sources, e.g. the exhaust system.
i. Lines and Fittings- The gas lines and fittings must be appropriate for the maximum possible operating pressure of the system.

Appendix B: Spec Sheets

Arduino Uno



Arduino UNO

Product Overview

The Arduino Uno is a microcontroller board based on the ATmega328 (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. The Uno differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega8U2 programmed as a USB-to-serial converter.

"Uno" means one in Italian and is named to mark the upcoming release of Arduino 1.0. The Uno and version 1.0 will be the reference versions of Arduno, moving forward. The Uno is the latest in a series of USB Arduino boards, and the reference model for the Arduino platform; for a comparison with previous versions, see the index of Arduino boards.

Index

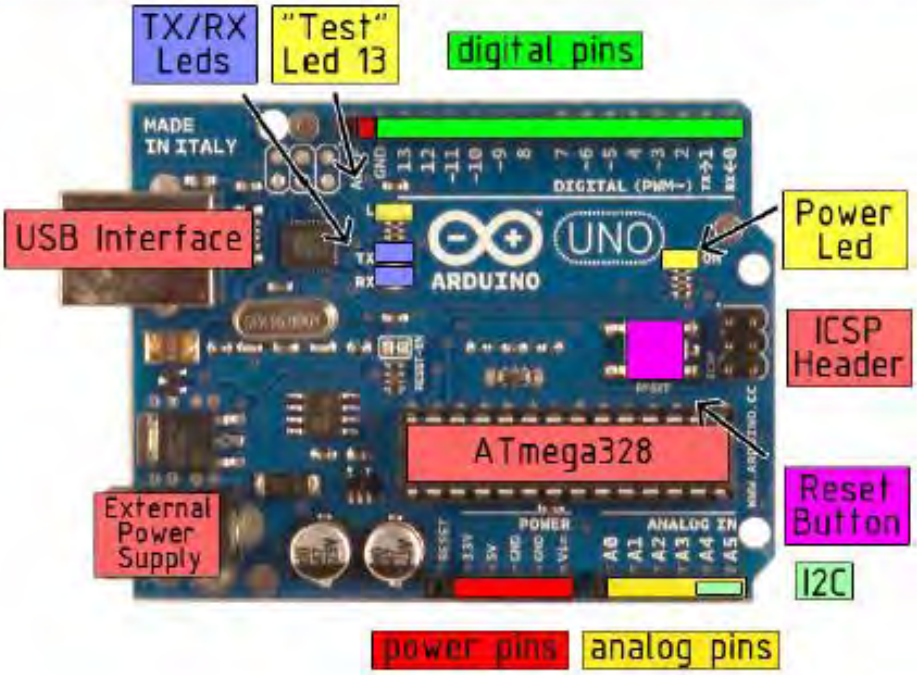
Technical Specification

EAGLE files: arduino-duemilanove-uno-design.zip Schematic: arduino-uno-schematic.pdf

Summary

Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB of which 0.5 KB used by bootloader
SRAM	2 KB
EEPROM	1 KB
Clock Speed	16 MHz

the board



Power

The Arduino Uno can be powered via the USB connection or with an external power supply. The power source is selected automatically.

External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the Gnd and Vin pin headers of the POWER connector.

The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.

The power pins are as follows:

- **VIN.** The input voltage to the Arduino board when it's using an external power source (as opposed to 5 volts from the USB connection or other regulated power source). You can supply voltage through this pin, or, if supplying voltage via the power jack, access it through this pin.
- **5V.** The regulated power supply used to power the microcontroller and other components on the board. This can come either from VIN via an on-board regulator, or be supplied by USB or another regulated 5V supply.
- **3V3.** A 3.3 volt supply generated by the on-board regulator. Maximum current draw is 50 mA.
- **GND.** Ground pins.

Memory

The Atmega328 has 32 KB of flash memory for storing code (of which 0,5 KB is used for the bootloader); It has also 2 KB of SRAM and 1 KB of EEPROM (which can be read and written with the EEPROM library).

Input and Output

Each of the 14 digital pins on the Uno can be used as an input or output, using pinMode(), digitalWrite(), and digitalRead() functions. They operate at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 kOhms. In addition, some pins have specialized functions:

- **Serial: 0 (RX) and 1 (TX).** Used to receive (RX) and transmit (TX) TTL serial data. TThese pins are connected to the corresponding pins of the ATmega8U2 USB-to-TTL Serial chip .
- **External Interrupts: 2 and 3.** These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. See the attachInterrupt() function for details.
- **PWM: 3, 5, 6, 9, 10, and 11.** Provide 8-bit PWM output with the analogWrite() function.
- **SPI: 10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK).** These pins support SPI communication, which, although provided by the underlying hardware, is not currently included in the Arduino language.

- **LED: 13.** There is a built-in LED connected to digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off.

The Uno has 6 analog inputs, each of which provide 10 bits of resolution (i.e. 1024 different values). By default they measure from ground to 5 volts, though is it possible to change the upper end of their range using the AREF pin and the analogReference() function. Additionally, some pins have specialized functionality:

- **I^{2}C: 4 (SDA) and 5 (SCL).** Support I^{2}C (TWI) communication using the Wire library.

There are a couple of other pins on the board:

- **AREF.** Reference voltage for the analog inputs. Used with analogReference().
- **Reset.** Bring this line LOW to reset the microcontroller. Typically used to add a reset button to shields which block the one on the board.

See also the mapping between Arduino pins and Atmega328 ports.

Communication

The Arduino Uno has a number of facilities for communicating with a computer, another Arduino, or other microcontrollers. The ATmega328 provides UART TTL (5V) serial communication, which is available on digital pins 0 (RX) and 1 (TX). An ATmega8U2 on the board channels this serial communication over USB and appears as a virtual com port to software on the computer. The '8U2 firmware uses the standard USB COM drivers, and no external driver is needed. However, on Windows, an *.inf file is required..

The Arduino software includes a serial monitor which allows simple textual data to be sent to and from the Arduino board. The RX and TX LEDs on the board will flash when data is being transmitted via the USB-to-serial chip and USB connection to the computer (but not for serial communication on pins 0 and 1).

A SoftwareSerial library allows for serial communication on any of the Uno's digital pins.

The ATmega328 also support I2C (TWI) and SPI communication. The Arduino software includes a Wire library to simplify use of the I2C bus; see the documentation for details. To use the SPI communication, please see the ATmega328 datasheet.

Programming

The Arduino Uno can be programmed with the Arduino software (download). Select "Arduino Uno w/ ATmega328" from the **Tools** > **Board** menu (according to the microcontroller on your board). For details, see the reference and tutorials.

The ATmega328 on the Arduino Uno comes preburned with a bootloader that allows you to upload new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol (reference, C header files).

You can also bypass the bootloader and program the microcontroller through the ICSP (In-Circuit Serial Programming) header; see these instructions for details.

The ATmega8U2 firmware source code is available . The ATmega8U2 is loaded with a DFU bootloader, which can be activated by connecting the solder jumper on the back of the board (near the map of Italy) and then resetting the 8U2. You can then use Atmel's FLIP software (Windows) or the DFU programmer (Mac OS X and Linux) to load a new firmware. Or you can use the ISP header with an external programmer (overwriting the DFU bootloader).

Automatic (Software) Reset

Rather than requiring a physical press of the reset button before an upload, the Arduino Uno is designed in a way that allows it to be reset by software running on a connected computer. One of the hardware flow control lines (DTR) of the ATmega8U2 is connected to the reset line of the ATmega328 via a 100 nanofarad capacitor. When this line is asserted (taken low), the reset line drops long enough to reset the chip. The Arduino software uses this capability to allow you to upload code by simply pressing the upload button in the Arduino environment. This means that the bootloader can have a shorter timeout, as the lowering of DTR can be well-coordinated with the start of the upload.

This setup has other implications. When the Uno is connected to either a computer running Mac OS X or Linux, it resets each time a connection is made to it from software (via USB). For the following half-second or so, the bootloader is running on the Uno. While it is programmed to ignore malformed data (i.e. anything besides an upload of new code), it will intercept the first few bytes of data sent to the board after a connection is opened. If a sketch running on the board receives one-time configuration or other data when it first starts, make sure that the software with which it communicates waits a second after opening the connection and before sending this data.

The Uno contains a trace that can be cut to disable the auto-reset. The pads on either side of the trace can be soldered together to re-enable it. It's labeled "RESET-EN". You may also be able to disable the auto-reset by connecting a 110 ohm resistor from 5V to the reset line; see this forum thread for details.

USB Overcurrent Protection

The Arduino Uno has a resettable polyfuse that protects your computer's USB ports from shorts and overcurrent. Although most computers provide their own internal protection, the fuse provides an extra layer of protection. If more than 500 mA is applied to the USB port, the fuse will automatically break the connection until the short or overload is removed.

Physical Characteristics

The maximum length and width of the Uno PCB are 2.7 and 2.1 inches respectively, with the USB connector and power jack extending beyond the former dimension. Three screw holes allow the board to be attached to a surface or case. Note that the distance between digital pins 7 and 8 is 160 mil (0.16"), not an even multiple of the 100 mil spacing of the other pins.

How to use Arduino

Arduino can sense the environment by receiving input from a variety of sensors and can affect its surroundings by controlling lights, motors, and other actuators. The microcontroller on the board is programmed using the Arduino programming language (based on Wiring) and the Arduino development environment (based on Processing). Arduino projects can be stand-alone or they can communicate with software on running on a computer (e.g. Flash, Processing, MaxMSP).

Arduino is a cross-platoform program. You'll have to follow different instructions for your personal OS. Check on the Arduino site for the latest instructions. *http://arduino.cc/en/Guide/HomePage*

Linux Install **Windows Install** **Mac Install**

Once you have downloaded/unzipped the arduino IDE, you can Plug the Arduino to your PC via USB cable.

Blink led

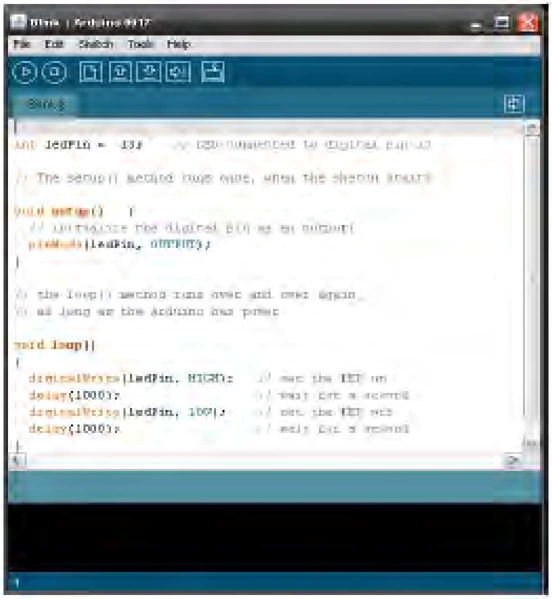
Now you're actually ready to "burn" your first program on the arduino board. To select "blink led", the physical translation of the well known programming "hello world", select

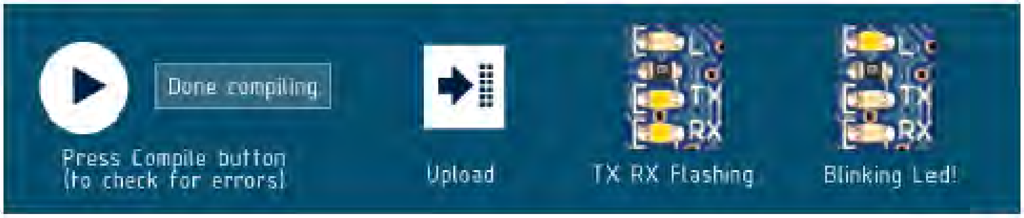
File>Sketchbook>
Arduino-0017>Examples>
Digital>Blink

Once you have your skecth you'll see something very close to the screenshot on the right.

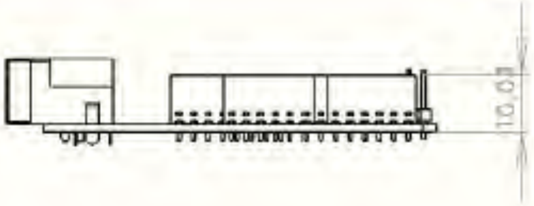
In **Tools>Board** select

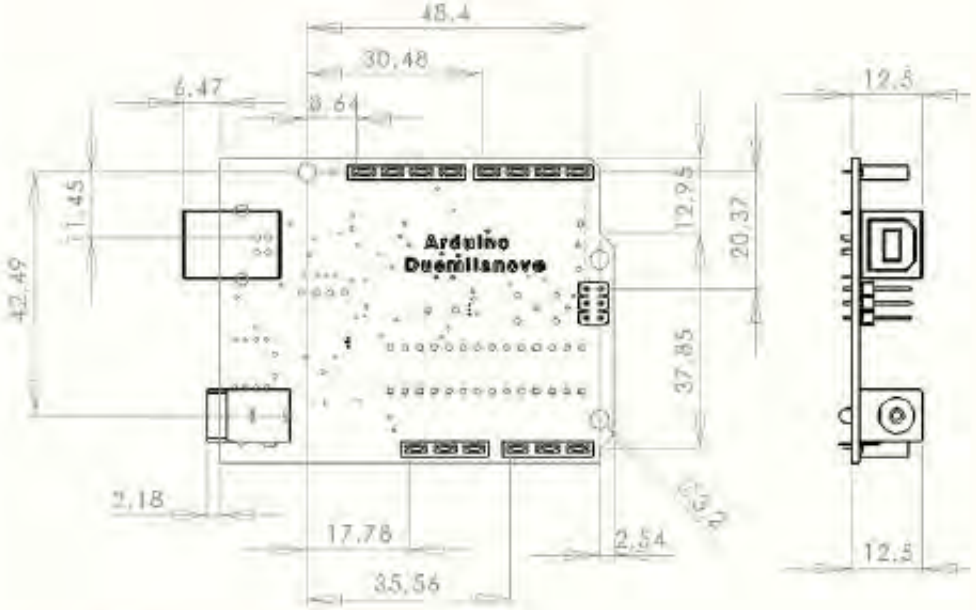
Now you have to go to
Tools>SerialPort
and select the right serial port, the one arduino is attached to.

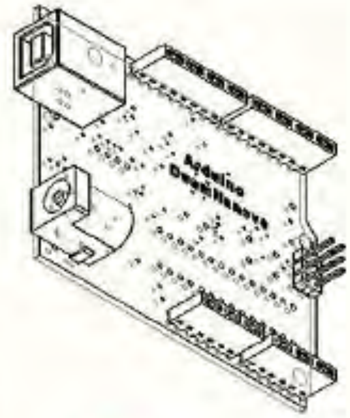




Dimensioned Drawing







Terms & Conditions

1. Warranties

1.1 The producer warrants that its products will conform to the Specifications. This warranty lasts for one (1) years from the date of the sale. The producer shall not be liable for any defects that are caused by neglect, misuse or mistreatment by the Customer, including improper installation or testing, or for any products that have been altered or modified in any way by a Customer. Moreover, The producer shall not be liable for any defects that result from Customer's design, specifications or instructions for such products. Testing and other quality control techniques are used to the extent the producer deems necessary.

1.2 If any products fail to conform to the warranty set forth above, the producer's sole liability shall be to replace such products. The producer's liability shall be limited to products that are determined by the producer not to conform to such warranty. If the producer elects to replace such products, the producer shall have a reasonable time to replacements. Replaced products shall be warranted for a new full warranty period.

1.3 EXCEPT AS SET FORTH ABOVE, PRODUCTS ARE PROVIDED "AS IS" AND "WITH ALL FAULTS." THE PRODUCER DISCLAIMS ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, REGARDING PRODUCTS, INCLUDING BUT NOT LIMITED TO, ANY IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE

1.4 Customer agrees that prior to using any systems that include the producer products, Customer will test such systems and the functionality of the products as used in such systems. The producer may provide technical, applications or design advice, quality characterization, reliability data or other services. Customer acknowledges and agrees that providing these services shall not expand or otherwise alter the producer's warranties, as set forth above, and no additional obligations or liabilities shall arise from the producer providing such services.

1.5 The Arduino™ products are not authorized for use in safety-critical applications where a failure of the product would reasonably be expected to cause severe personal injury or death. Safety-Critical Applications include, without limitation, life support devices and systems, equipment or systems for the operation of nuclear facilities and weapons systems. Arduino™ products are neither designed nor intended for use in military or aerospace applications or environments and for automotive applications or environment. Customer acknowledges and agrees that any such use of Arduino™ products which is solely at the Customer's risk, and that Customer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

1.6 Customer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products and any use of Arduino™ products in Customer's applications, notwithstanding any applications-related information or support that may be provided by the producer.

2. Indemnification

The Customer acknowledges and agrees to defend, indemnify and hold harmless the producer from and against any and all third-party losses, damages, liabilities and expenses it incurs to the extent directly caused by: (i) an actual breach by a Customer of the representation and warranties made under this terms and conditions or (ii) the gross negligence or wilful misconduct by the Customer.

3. Consequential Damages Waiver

In no event the producer shall be liable to the Customer or any third parties for any special, collateral, indirect, punitive, incidental, consequential or exemplary damages in connection with or arising out of the products provided hereunder, regardless of whether the producer has been advised of the possibility of such damages. This section will survive the termination of the warranty period.

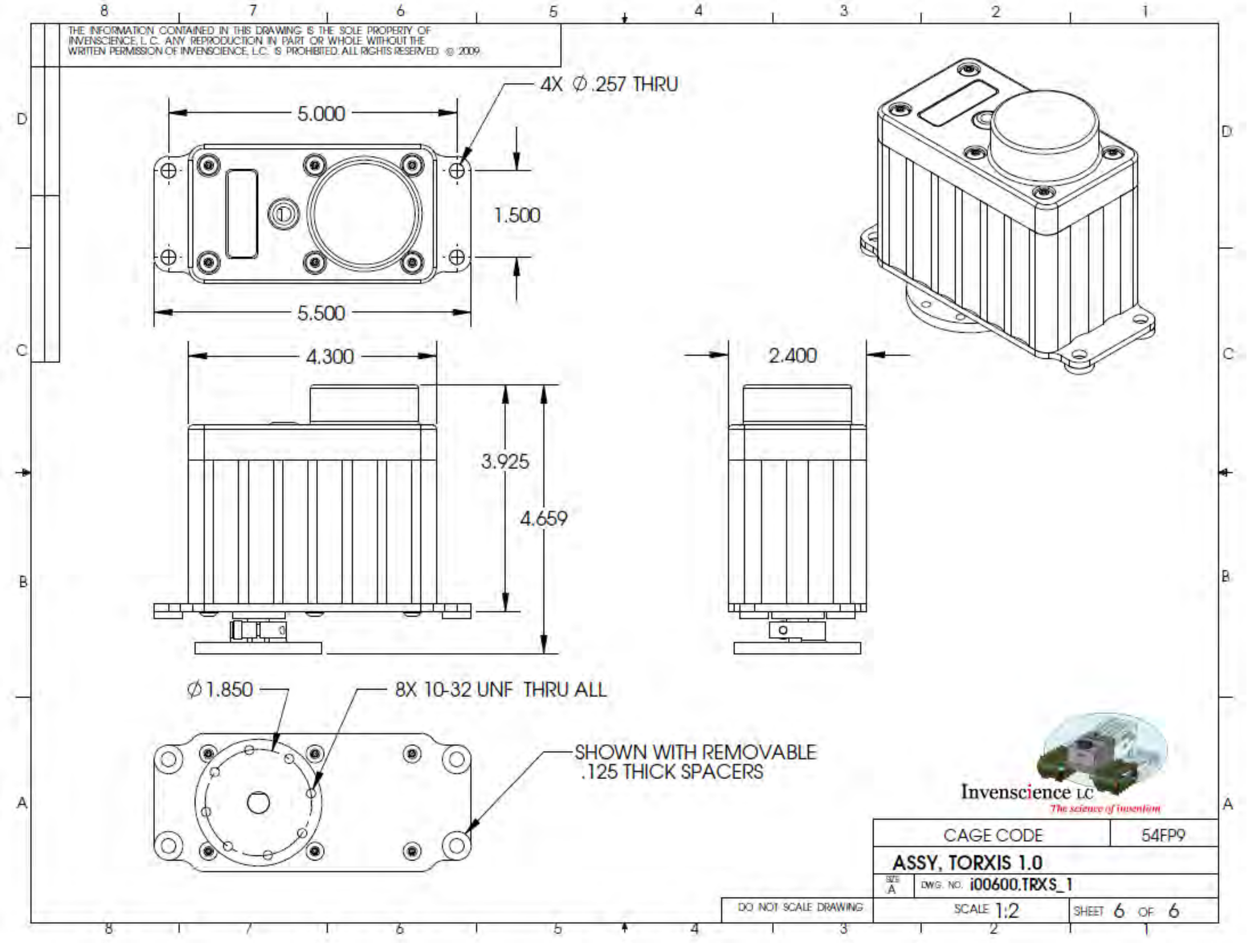
4. Changes to specifications

The producer may make changes to specifications and product descriptions at any time, without notice. The Customer must not rely on the absence or characteristics of any features or instructions marked "reserved" or "undefined." The producer reserves these for future definition and shall have no responsibility whatsoever for conflicts or incompatibilities arising from future changes to them. The product information on the Web Site or Materials is subject to change without notice. Do not finalize a design with this information.

Enviromental Policies

The producer of Arduino™ has joined the Impatto Zero® policy of LifeGate.it. For each Arduino board produced is created / looked after half squared Km of Costa Rica's forest's.

Torxis i00800 Servo Motor



Torxis Servo Instructions and Cautions

Red Series (Red Housing) Electrical Connection:

The heavy gauge red and black wire pair with tinned ends provides the supply power for the motor at 12VDC. Black is power ground, red is +12VDC. Applying reverse voltage will damage the unit and will not be covered by warranty. Be sure power ground is connected. Loose or un-connected power ground will cause back feed through signal ground and may damage receiver, wiring or both.

Control signal is provided by the RC servo styled connector and will plug into popular RC receivers. In the RC connector, the white wire provides the PWM signal. The black wire in the servo connector provides signal ground.

Industrial Series (Black Housing) Electrical Connection:

Red wire is +12VDC
Black wire is 12VDC ground
White wire is 5VDC signal (pwm or analog depending on model)
Green wire is signal ground

Applying reverse voltage will damage the unit and will not be covered by warranty. Applying voltages higher than 5VDC to the signal cable will damage the unit as well.

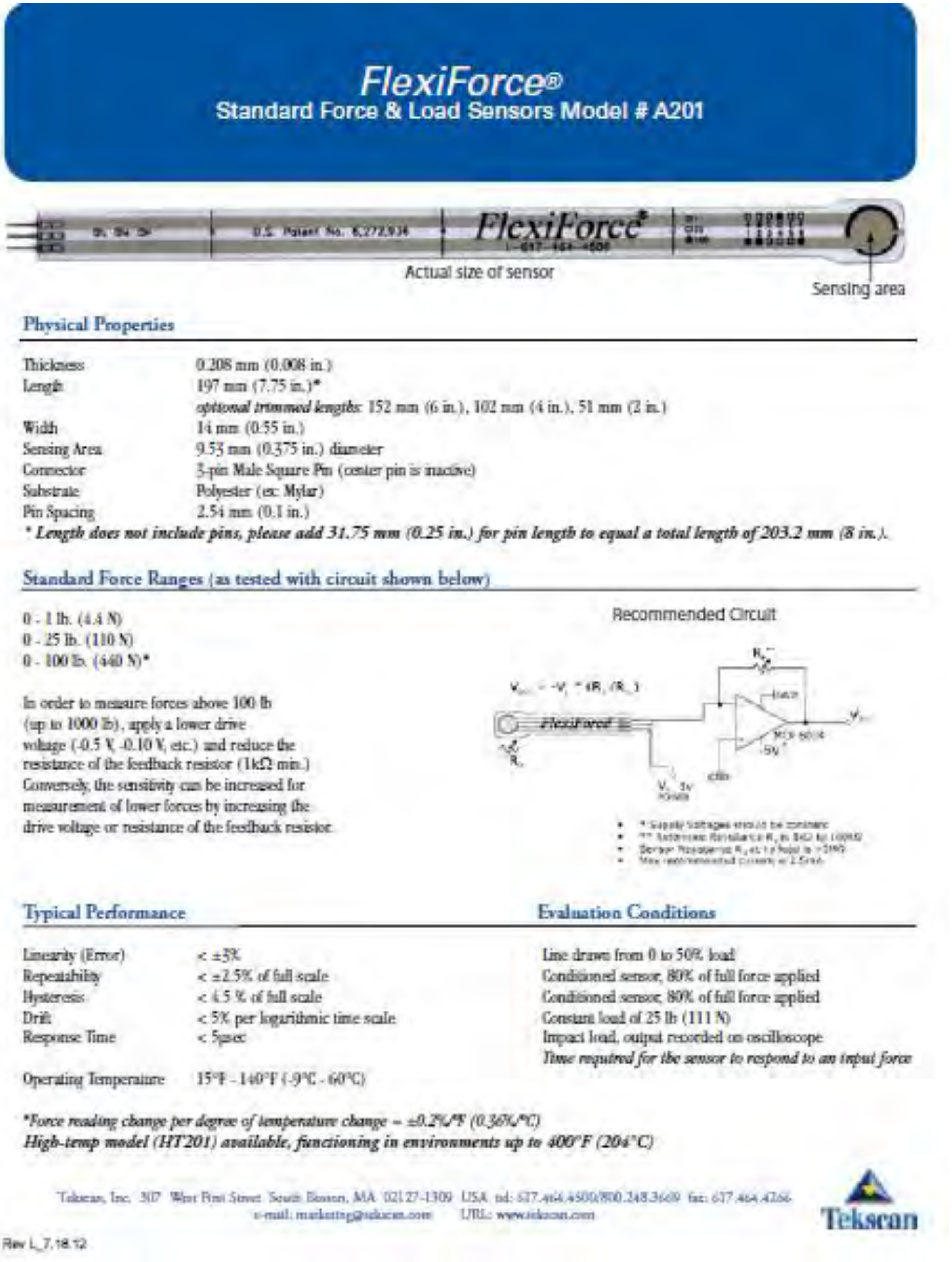
Mechanical Details:

By default, the servos are programmed for 90 degrees of travel with popular RC radios unless you have ordered one of the specially programmed industrial units (black housing). These limits can be reprogrammed to allow travel in excess of 180 degrees. For additional information go to www.torxis.com.

The supplied horn is tapped with #10-32 holes. Included with the assembly are white nylon spacers that can be used to stand the servo off for flush mounting to clear the screws in the face plate of the unit. Mounting holes are provided for ¼ screws or 6mm screws as applicable.

Caution: This unit provides extremely high torque and can pinch, cut or severe body parts placed in the area of the moving components. Output shaft may move suddenly when power is applied.

Flexiforce Standard Force & Load Sensors Model #A201



FlexiForce®

Standard Force & Load Sensors Model # A201

Physical Properties

Thickness	0.208 mm (0.008 in.)
Length	197 mm (7.75 in.)* *optional trimmed lengths*: 152 mm (6 in.), 102 mm (4 in.), 51 mm (2 in.)
Width	14 mm (0.55 in.)
Sensing Area	9.53 mm (0.375 in.) diameter
Connector	3-pin Male Square Pin (center pin is inactive)
Substrate	Polyester (ex: Mylar)
Pin Spacing	2.54 mm (0.1 in.)

**** Length does not include pins, please add 31.75 mm (0.25 in.) for pin length to equal a total length of 203.2 mm (8 in.).***

Standard Force Ranges (as tested with circuit shown below)

0 - 1 lb. (4.4 N)
0 - 25 lb. (110 N)
0 - 100 lb. (440 N)*

In order to measure forces above 100 lb (up to 1000 lb), apply a lower drive voltage (-0.5 V, -0.10 V, etc.) and reduce the resistance of the feedback resistor (1kΩ min.) Conversely, the sensitivity can be increased for measurement of lower forces by increasing the drive voltage or resistance of the feedback resistor.

Recommended Circuit

- * Supply Voltages should be constant
- ** Reference Resistance R_F is 1kΩ to 100kΩ
- Sensor Resistance R_S at no load is >5MΩ
- Max recommended current is 2.5mA

Typical Performance		**Evaluation Conditions**
Linearity (Error)	< ±3%	Line drawn from 0 to 50% load
Repeatability	< ±2.5% of full scale	Conditioned sensor, 80% of full force applied
Hysteresis	< 4.5 % of full scale	Conditioned sensor, 80% of full force applied
Drift	< 5% per logarithmic time scale	Constant load of 25 lb (111 N)
Response Time	< 5μsec	Impact load, output recorded on oscilloscope *Time required for the sensor to respond to an input force*
Operating Temperature	15°F - 140°F (-9°C - 60°C)	

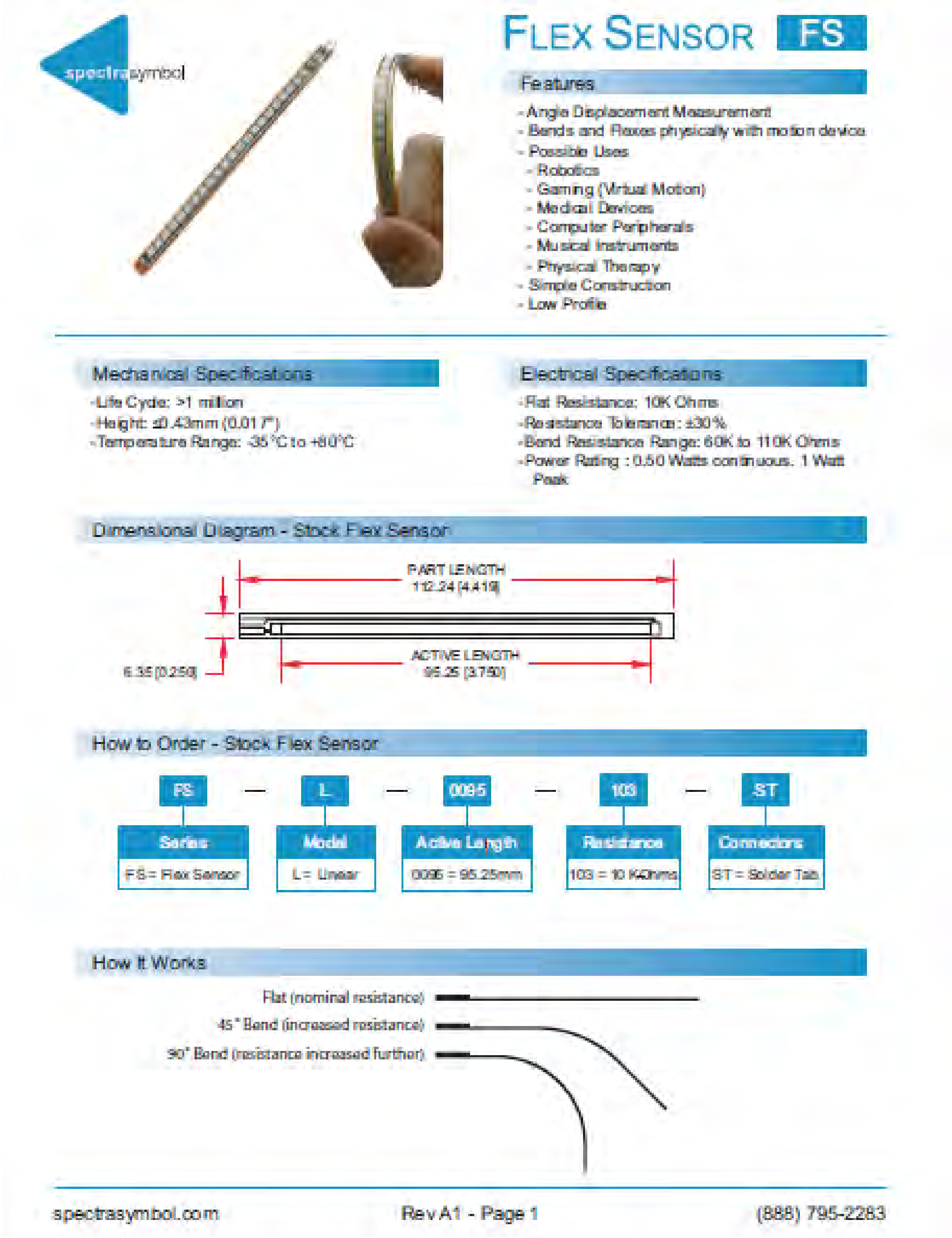
**Force reading change per degree of temperature change = ±0.2%/°F (0.36%/°C)*
High-temp model (HT201) available, functioning in environments up to 400°F (204°C)

Tekscan, Inc. 307 West First Street South Boston, MA 02127-1309 USA tel: 617.464.4500/800.248.3669 fax: 617.464.4266
e-mail: marketing@tekscan.com URL: www.tekscan.com

Tekscan

Rev L_7.18.12

Spectra Symbol Flex Sensor



spectrasymbol

FLEX SENSOR FS

Features

- Angle Displacement Measurement
- Bends and Flexes physically with motion device
- Possible Uses
  - Robotics
  - Gaming (Virtual Motion)
  - Medical Devices
  - Computer Peripherals
  - Musical Instruments
  - Physical Therapy
- Simple Construction
- Low Profile

Mechanical Specifications

-Life Cycle: >1 million
-Height: ≤0.43mm (0.017")
-Temperature Range: -35°C to +80°C

Electrical Specifications

-Flat Resistance: 10K Ohms
-Resistance Tolerance: ±30%
-Bend Resistance Range: 60K to 110K Ohms
-Power Rating : 0.50 Watts continuous. 1 Watt Peak

Dimensional Diagram - Stock Flex Sensor

How to Order - Stock Flex Sensor

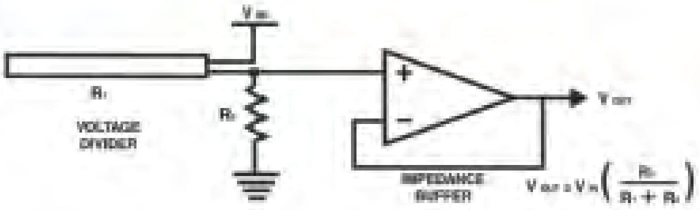
FS	L	0095	103	ST
Series	Model	Active Length	Resistance	Connectors
FS= Flex Sensor	L= Linear	0095 = 95.25mm	103 = 10 KOhms	ST = Solder Tab

How It Works

spectrasymbol.com Rev A1 - Page 1 (888) 795-2283

Schematics

BASIC FLEX SENSOR CIRCUIT:

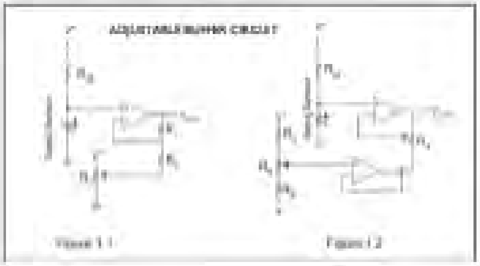


Following are notes from the ITP Flex Sensor Workshop

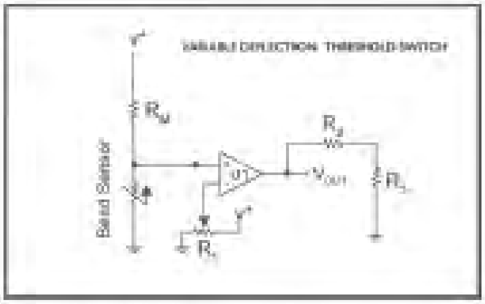
"The impedance buffer in the [Basic Flex Sensor Circuit] (above) is a single sided operational amplifier, used with these sensors because the low bias current of the op amp reduces error due to source impedance of the flex sensor as voltage divider. Suggested op amps are the LM358 or LM324."

"You can also test your flex sensor using the simplest circut, and skip the op amp."

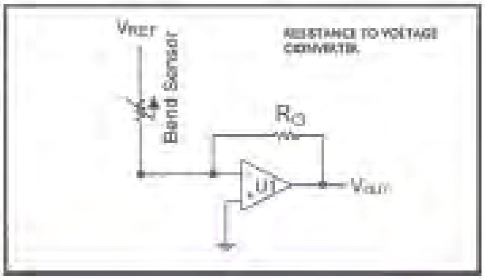
"**Adjustable Buffer** - a potentiometer can be added to the circuit to adjust the sensitivity range."



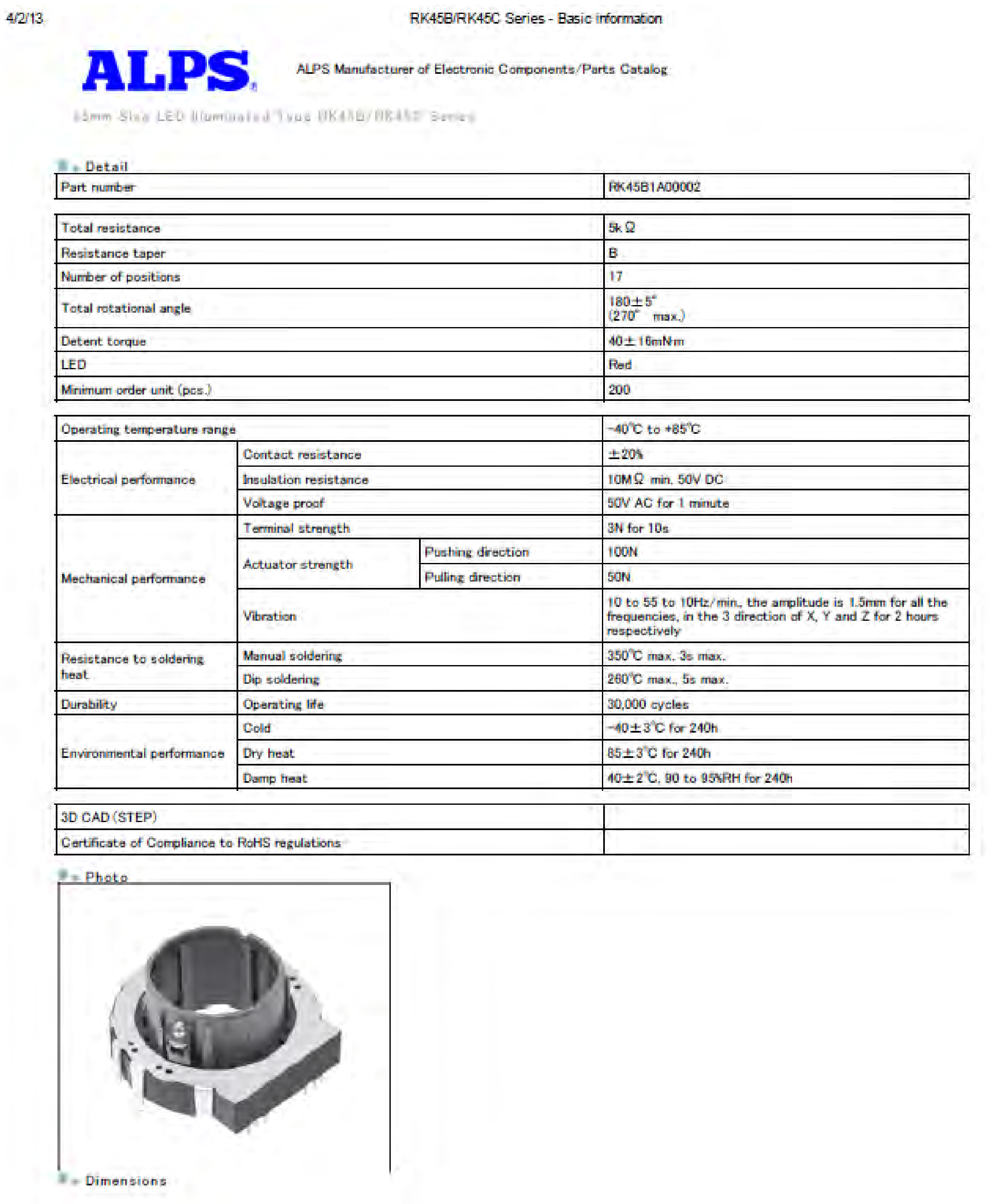
"**Variable Deflection Threshold Switch** - an op amp is used and outputs either high or low depending on the voltage of the inverting input. In this way you can use the flex sensor as a switch without going through a microcontroller."



"**Resistance to Voltage Converter** - use the sensor as the input of a resistance to voltage converter using a dual sided supply op-amp. A negative reference voltage will give a positive output. Should be used in situations when you want output at a low degree of bending."



ALPS Ring Potentiometer- RK45BRK5C



4/2/13 RK45B/RK45C Series - Basic information

ALPS Manufacturer of Electronic Components/Parts Catalog

65mm Size LED Illuminated Type RK45B/RK45C Series

Detail

Part number	RK45B1A00002

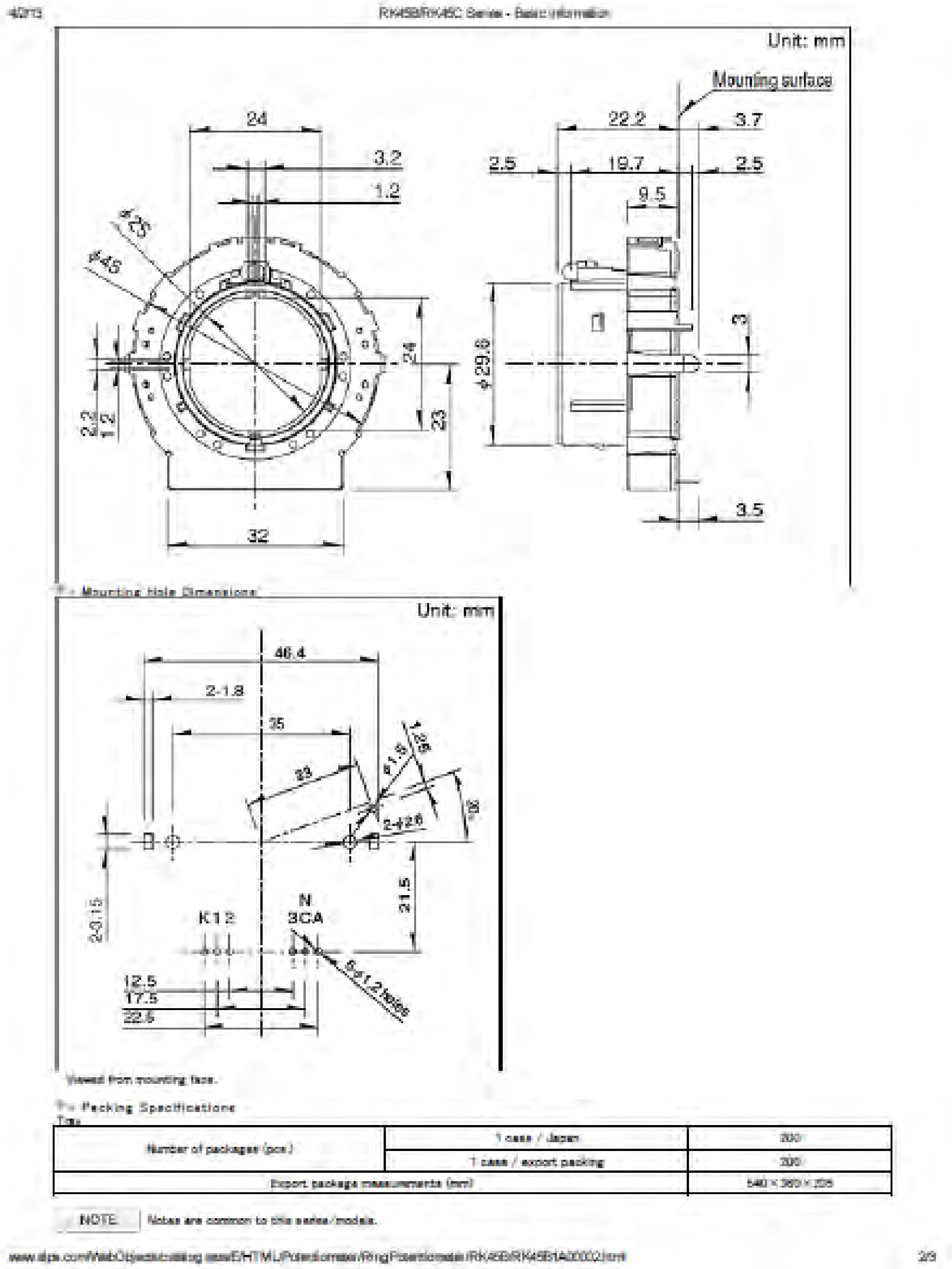
Total resistance	5k Ω
Resistance taper	B
Number of positions	17
Total rotational angle	180±5° (270° max.)
Detent torque	40±16mNm
LED	Red
Minimum order unit (pcs.)	200

Operating temperature range			-40°C to +85°C
Electrical performance	Contact resistance		±20%
	Insulation resistance		10MΩ min. 50V DC
	Voltage proof		50V AC for 1 minute
Mechanical performance	Terminal strength		3N for 10s
	Actuator strength	Pushing direction	100N
		Pulling direction	50N
	Vibration		10 to 55 to 10Hz/min., the amplitude is 1.5mm for all the frequencies, in the 3 direction of X, Y and Z for 2 hours respectively
Resistance to soldering heat	Manual soldering		350°C max. 3s max.
	Dip soldering		260°C max., 5s max.
Durability	Operating life		30,000 cycles
Environmental performance	Cold		-40±3°C for 240h
	Dry heat		85±3°C for 240h
	Damp heat		40±2°C, 90 to 95%RH for 240h

3D CAD (STEP)	
Certificate of Compliance to RoHS regulations	

Photo

Dimensions



4/2/13 RK45B/RK45C Series - Basic information

Mounting Hole Dimensions

Viewed from mounting face.

Packing Specifications

Tray

Number of packages (pcs.)	1 case / Japan	200
	1 case / export packing	200
Export package measurements (mm)		540 × 360 × 205

NOTE Notes are common to this series/models.

www.alps.com/WebObjects/catalog.woa/E/HTML/Potentiometer/RingPotentiometer/RK45B/RK45B1A00002.html 2/3

1. This site catalog shows only outline specifications. When using the products, please obtain formal specifications for supply.
2. Please place purchase orders per minimum order unit (integer).
3. Products other than those listed in the above chart are also available. Please contact us for details.
4. We can also provide LED colors other than the above mentioned. Contact us if you have such requirements.
5. This products can be used in vehicles.
   Although these products are designed to perform over a wide operating temperature range, please ensure that you receive and read the formal delivery specifications before use.

Inquires about Products

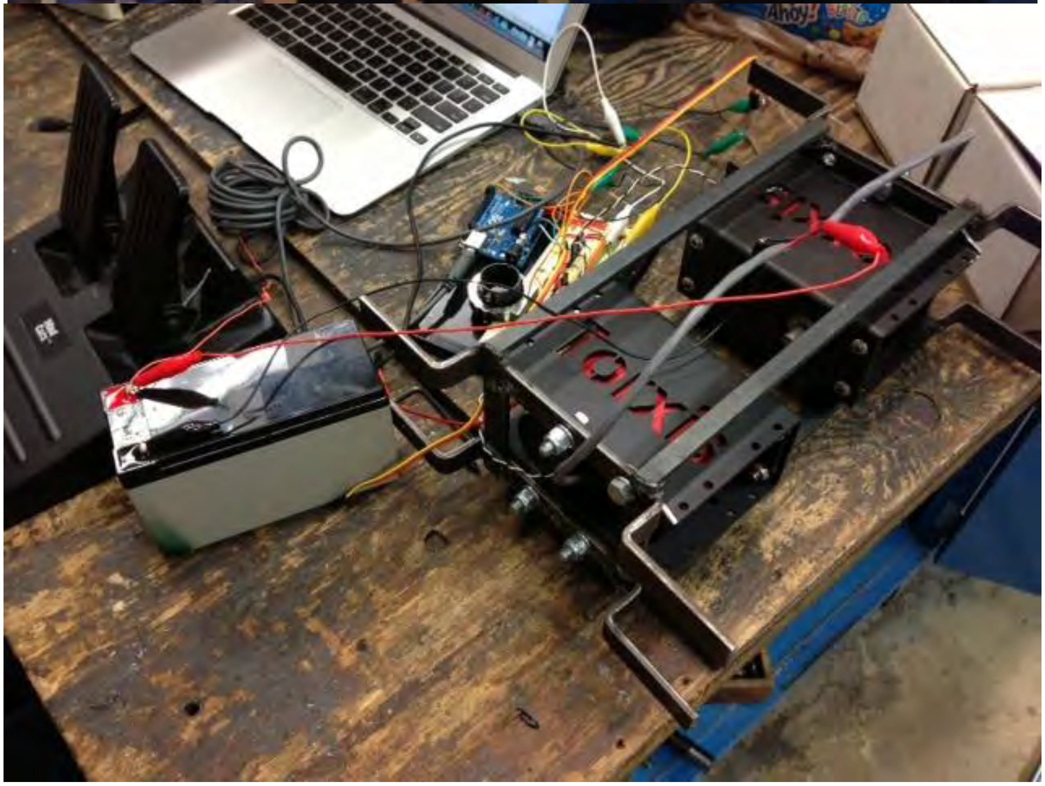
For more information please contact: Products Information Center.

1-7, Yukigaya-otsukamachi, Ota-ku, Tokyo, 145-8501, Japan

Phone: +81 (3) 5499-8154

Appendix C: Construction


CAUTION
EYE PROTECTION REQUIRED
LATHE


Torxis

Appendix D: Code

```
#include <Servo.h>

Servo leftMotor;  // create servo object to control a servo
Servo rightMotor;  // create servo object to control a servo

void setup()
{

  // Start serial at 9600 baud
  Serial.begin(9600);
  Serial.println("Calibrating Motors");
  leftMotor.attach(3);
  rightMotor.attach(5);

  //Calibrate Motor
  leftMotor.writeMicroseconds(1400);
  rightMotor.writeMicroseconds(650);
  delay(3000);
  leftMotor.writeMicroseconds(650);
  rightMotor.writeMicroseconds(1400);
  delay(3000);
  Serial.println("Completed Calibrating Motors");
}

void loop()
{
  //------------------------------------------------------------------
  // [ Set Variables and pins]
  float steeringSensor = analogRead(A0);
  int PressureSensorVal = analogRead(A2);
  float rightPedal = analogRead(A3);
  float leftPedal = analogRead(A4);
  float flexSensorVal = analogRead(A5);
  float degrees = 0;
  float steering = 1;
  float brake = 1;
```

```
float velocity = 1;
float left_motor = 0;
float right_motor = 0;
int left_motor_angle = 0;
int right_motor_angle = 0;
float offset = 0;
float steeringSensor_voltage;
//-----------------------------------------------------------------
// [ Motor Control Code ]
steering = map(steeringSensor, 831, 917, 0, 90);
steeringSensor_voltage = steeringSensor * (5.0 / 1023.0);
velocity = map(rightPedal, 0, 25, 1, 60);
brake = map(leftPedal, 0, 35, 1, 30);

steering = constrain(steering, 0, 180);

offset = (90 - steering) * 10;

left_motor = pow(brake, 2) * sqrt(velocity) + offset;
right_motor = pow(brake, 2) * sqrt(velocity) - offset;


left_motor_angle = map(left_motor, 0, 2727,1400, 650);
right_motor_angle = map(right_motor, 0, 2727, 650, 1400);

//left_motor_angle = constrain(left_motor_angle, 650, 1400);
//right_motor_angle = constrain(right_motor_angle, 650, 1400);

//Print motor calculation Information
Serial.print("   steeringSensor_voltage: ");
Serial.print(steeringSensor_voltage);
Serial.print("   steeringSensor: ");
Serial.print(steeringSensor);
Serial.print("   Steering: ");
Serial.print(steering);
Serial.print("   Brake: ");
Serial.print(brake);
Serial.print("   Velocity: ");
Serial.print(velocity);
Serial.print("   offset: ");
Serial.print(offset);
Serial.print("   right_motor: ");
Serial.print(right_motor);
```

```
  Serial.print("   Right Angle: ");
  Serial.print(right_motor_angle);
  Serial.print("   Left Motor: ");
  Serial.print(left_motor);
  Serial.print("   Left Angle: ");
  Serial.println(left_motor_angle);

  //--------------------------------------------------------------------------------
  // [ Pressure Sensor Code ]
  // Convert the analog reading (which goes from 0 - 1023) to a voltage (0 - 5V):
  float voltage = PressureSensorVal * (5.0 / 1023.0);
  float voltage2 = PressureSensorVal ;

  //Print out the value you read:
  //Serial.print("voltage 1: ");
  //Serial.print(voltage);
  //Serial.print(" PressureSensorVal: ");
  //Serial.println(voltage2);

  //--------------------------------------------------------------------------------
  // [ Flex Sensor Code ]
  // convert the voltage reading to inches
  degrees = map(flexSensorVal, 34, 11, 0, 180);


  // print out the result
  //Serial.print("analog input: ");
  //Serial.print(flexSensorVal);
  //Serial.print("   degrees: ");
  //Serial.println(degrees);

  //--------------------------------------------------------------------------------
  // [ Write Angle to Motors ]

  leftMotor.writeMicroseconds(left_motor_angle);
  rightMotor.writeMicroseconds(right_motor_angle);

  // Wait 100 milliseconds
  delay(30);
}
```