# Composite Car Rear Spoiler

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This thesis study was conducted using NASTRAN Software to perform a static load analysis over a Solidworks designed composite rear spoiler with a chord length of 1400 mm. Product design methods were incorporated in the manufacturing process of the fiberglass rear spoiler with vacuum infusion lamination of a female and male mould encapsulated with a honeycomb core.  The sandwiched material provided the product with very low weight, high stiffness and durability.

Based on the properties of standard air, an assumption of a wind speed of 150 km/h, with an angle of attack of 8°, Reynolds number of $6.7*10^5$ and a downforce of 829.614 N were calculated.

A downforce of 829.614 N was used in the static load simulation and presented graphically as downforce and stress effect. Finally, the fiberglass laminate thickness was calculated to be 0.51 mm.



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Finally, a warmth salutation goes to my family for their endless love and support, I gladly say in my heart, is where I will keep all of you as a secret.

## Symbols

$A$ = Reference Area ($mm^2$)

$C_d$ = Co-efficient Drag

$Cr$ = Span of the spoiler (mm)

$Ct$= Distance from the root to tip (mm)

$D$= Permeability of the fabric stack

$D_f$ = Downforce (N)

$\eta$ = Viscosity of resin system (Pa.s)

$\eta_\theta$ = Reinforcing Efficiency

$\upsilon$ = Velocity of wind (m/s)

$\delta$ = Stress (Pa)

Ec = Young Modulus of Composite (Pa)

$E_f$ = Young Modulus of fiberglass (Pa)

$E_m$= Young Modulus of matrix (Pa)

$F_d$ = Drag (N)

G = Shear Modulus (Pa)

I = Moment of inertia ($mm^4$)

L = Chord length (mm)

$\Delta$P = Pressure difference (Pa)

$R_e$ = Reynolds Number

$T_g$ = Transition Temperature (°C)

$t_f$ = fiber thickness (mm)

$t_c$ = Core thickness (mm)

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# 1. INTRODUCTION

## 1.1 Introduction to Rear Spoiler

## 1.2 Background

The purpose of this thesis is to analysis the aerodynamics effect of composite automobile spoiler and its importance when mounted at the back of a car. The study of aerodynamics influences the way a car cuts through air, aiming to create downforce at minimum additional dragging.

Spoiler is a device used in cars to channel air upwards to allow it tyres to stick to the road when in motion. A spoiler is a wing-like design attached to an automobile with the function to 'spoil' unfavourable air movement across a body of a vehicle in motion.

This notably improves vehicle stability by decreasing lift and drag in a car at high speed. Drag is that force that pulls back the car when in motion that is the force in opposition to the car direction while lift is the upward force that is generated under the chassis and causes the front tyres of the car to be slightly lifted off the ground when the motion car gains some speed.

Moreover spoilers are often mounted to race and high-performance sports cars, although they have become common on passenger vehicles, as well. Some spoilers are added to cars primarily for styling purposes and have either little aerodynamic benefit or even make the aerodynamics worse.

According to (Sunanda and Nayak, 2013), “the main function of a spoiler is diffusing the airflow passing over and around a moving vehicle as it passes over the vehicle. This diffusion is accomplished by increasing amounts of turbulence flowing over the shape; “spoiling” the laminar flow and providing a cushion for the laminar boundary layer thereby generating downforce as the air passes around the car spoiler.”

However, minimizing the drag caused by turbulence can act to slow the car down. To create the downforce to the car, the wing operates with air flow at different speeds over the two sides of the wing, thus creating the pressure difference around the airfoil contoured shape.

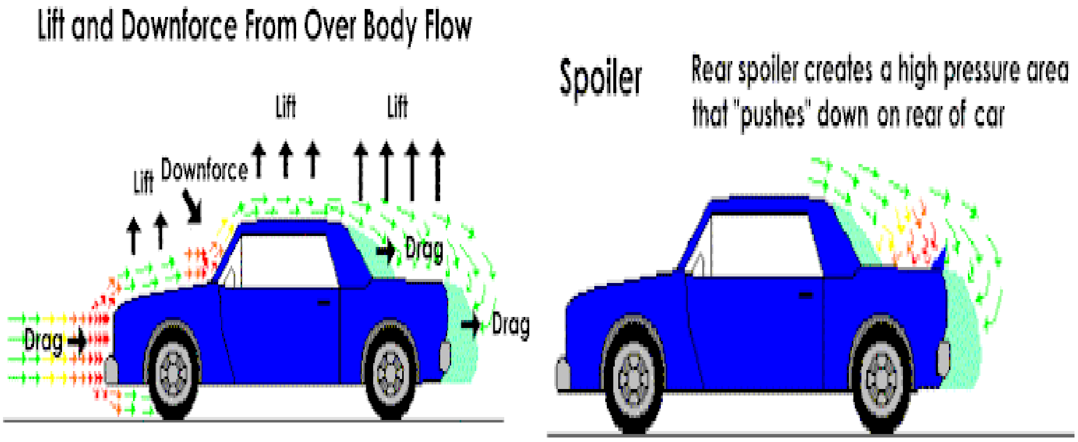


*Figure 1. Automobile without and with Spoiler effect* (Matt Gartner, 1999, - Aerodynamics)

Considering the left hand side vehicle without the spoiler, as the vehicle accelerates there is an equal amount of force called drag in the form of air that is in opposition to the direction of the automobile. This indicates that drag as a force is always present whenever there is speed. Thus in order to minimize this impedance to a motion car, the engine will produce more power to overcome the drag force. This results in burning of more fuel as well as rendering the car to be very lighter at a top speed.
Invariably there is little stability in the motion car, and this can make braking very difficult as well as negotiating a curve.

Therefore, to minimize the effect of the drag there is a need to create a greater downforce, thus the introduction of rear spoilers to an automobile, which is shown on the right hand side of figure 1.

The rear spoiler is designed with the gradual thickness towards the tail edge and this seeks to disrupt the movement of the air particles. In addition it adds stability to a motion car as it creates downforce which is a vertical force that acts on the tires causing traction to the road.

In the right hand side of figure 1; the moving air particles are impeded by the rear spoiler causing the particles to alter their movement. As the impeded air particles gain momentum the particles gather together and in effect create more force around the boot of the car; hence the downforce.

The figure 2, below, illustrates a cross-sectional wing profile with moving air particles around it. The designed spoiler has the shape of an airfoil to allow air to circulate faster from left to right and with the shape and airfoil suction, the air will move faster on the lower surface than the upper side. The resulting pressure difference is the force that pushes the car to the ground, sticking it to the road. Thus airfoil is the basic structure for the spoiler, with curved surfaces designed to give the most favourable drag whereas suction is the act or process of removing the circulating air moving along the body of the car in order to cause the tires to stick to the road.

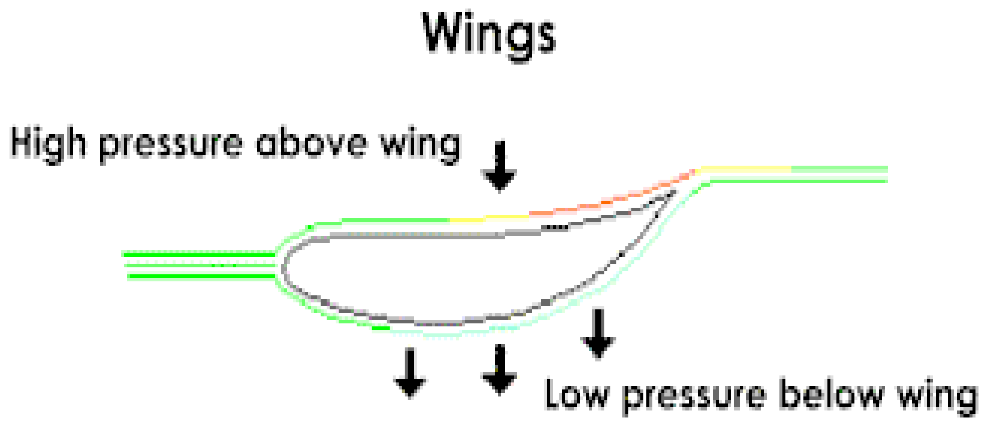


*Figure 2. Typical cross-section of wing/Spoiler (*Matt Gartner, 1999, - Aerodynamics)

The cross-sectional wing profile illustrates the pressure difference created by the movement of air particles around a wing.

## 1.3 Automated Spoiler

The introduction of automated spoilers has proven helpful as most vehicle spoilers are designed to disrupt unfavourable air flow in a fixed direction and condition.

A vehicle with a rear spoiler operating in a fixed condition, such as disrupting airflow at sharp turnings, will not be that efficient when that same vehicle is speeding in a streamline direction. Thus, the deployment of an automated spoiler is beneficial.

As previously mentioned, airfoils are designed in a wing-like shape with a rounded leading edge with gradual thickness toward the tail edge. This plays a major role in creating the pressure difference, as moving air particles travel faster on the lower surface than the upper side, and thus transit time of particle travel is normally less at the lower surface as compared to the upper side.

This in effect generates a pressure difference, therefore creating the needed pushing force called downforce on the automobile which eventually helps to achieve the much required speed and traction on the tires when the vehicle is in motion.

In an automated spoiler, the position and angle of attack can be altered by increasing the height of the rear spoiler and introducing the extra bracket structures with hinges in order to retract and adjust the automated spoiler.

A vehicle's automated rear spoiler comprises of at least one airfoil with elongated leading and trailing edge to provide the effective drag needed. The actuators can be retracted linearly to provide different positions to the airfoil.

The purpose of a controlled braking system is to detect events associated with the braking of the vehicle, and sensors to aid in the steering wheel system and the movement of the rear spoiler can be either automatically or manually operated.

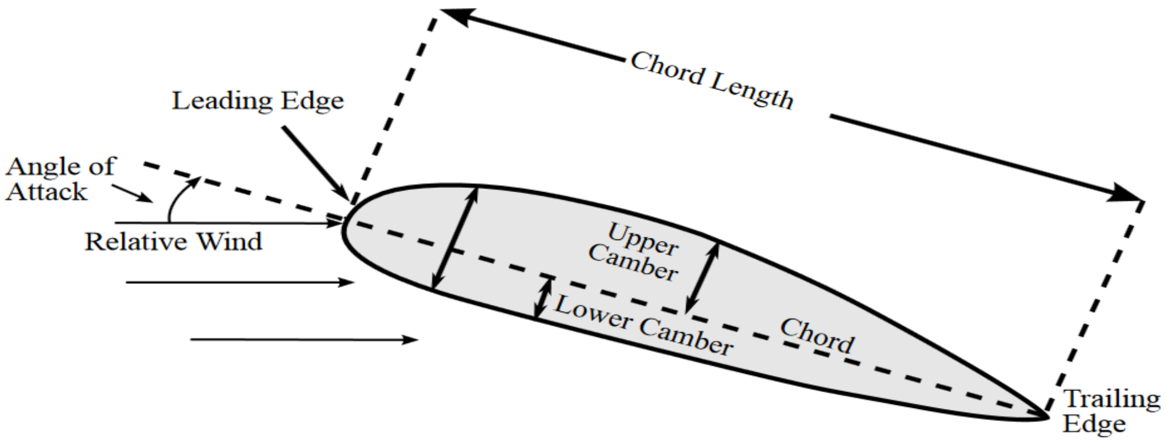


*Figure 3. A Typical Airfoil Wing with Angle of Attack.* (Chang, 1998.)

Figure 3, shows a well labelled airfoil which is a cross-section of the spoiler/wing with an angle of attack and the shape of the wing is varied along the blade radius to take advantage of airspeed around both of the upper and lower camber.

The chord line is an imaginary straight line through the spoiler/wing which connects the leading and trailing edges of the airfoil, whereas the chord length is the imaginary straight line from the leading edge to the trailing edge. It is measured as the longitudinal dimension of the spoiler.

The curvature of the spoiler is referred to as a camber, and the trailing edge is the back portion of the airfoil where the air flowing over both the upper and lower camber meets. The leading edge is that part of the airfoil where the air flow starts. Its shape determine the speed of the airfoil as an airfoil designed to operate at high speed will have very sharp leading edge to easily transport the flowing air particles the moment they hit the edge.

The angle of attack is the relation between the “chord” of the spoiler/wing and the vector created with the direction of the air flowing over the spoiler. It can be noted that as the angle of attack increases the dragging force will eventually increase and this will serve as impedance to an accelerated car.

Therefore, an automated spoiler can play a major effect to minimize the dragging force as it can be tilted to a desirable angle to generate more "spoiling" at extremely high speed. This will create a greater downforce which will in effect minimize the drag force.

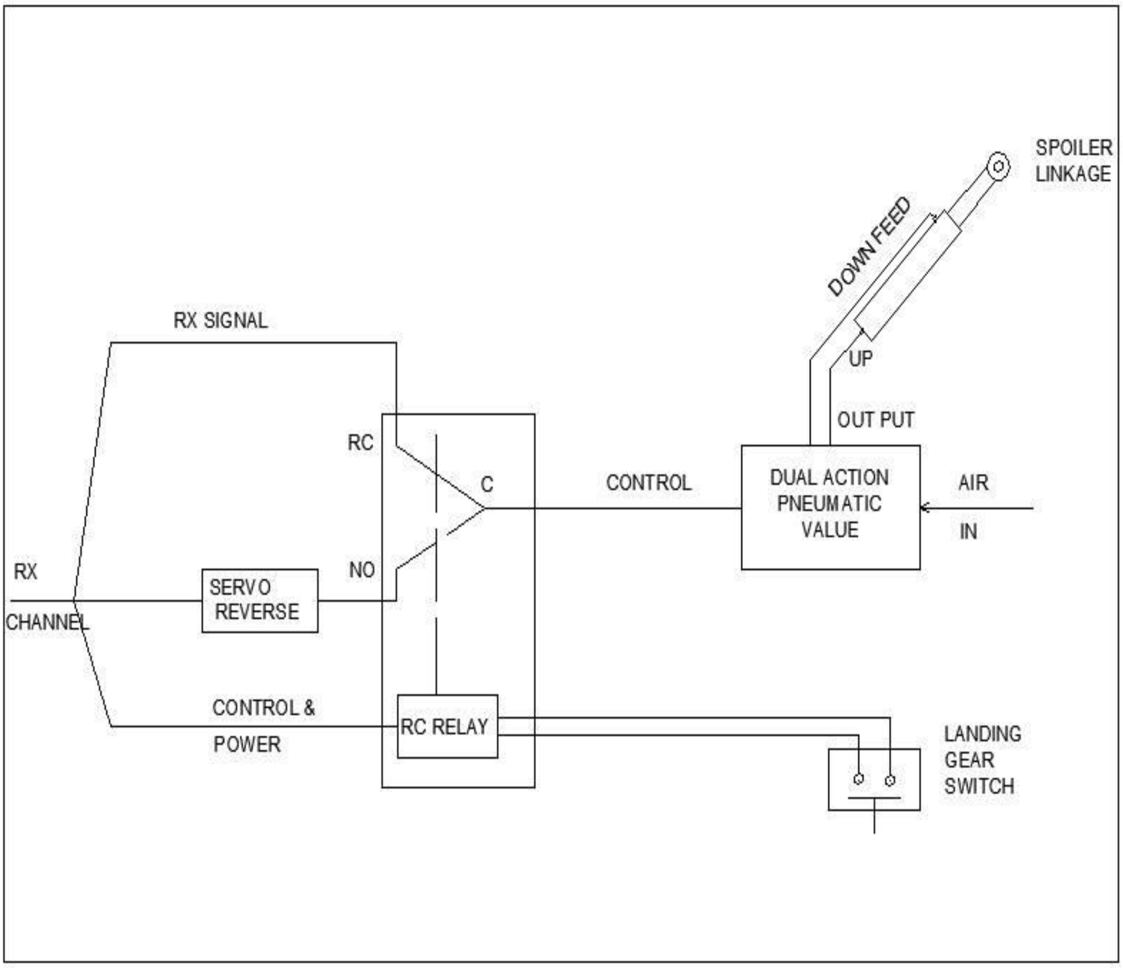


*Figure 4. A Schematic block diagram of a Spoiler.* (Rcuniverse schematic car spoiler diagram, 2009)

The operation of an automated rear spoiler can be done by adjusting and altering the angle of attack in the airstream about the body of the vehicle by pivoting on the hinge to provide the downward anti-lift force. In the Porsche 911 Series from Carrera to Panamera retractable rear spoilers are incorporated into the mechanical design of the vehicle.

It can be noted that if the rear spoiler cannot be extended in the Porsche 911 Carrera, driving stability will be adversely affected by the increased rear axle lift, which could lead to loss of control.

The 2012 Porsche 911 series in its automated mode and depending on the vehicle speed and position of the tilt roof, the rear spoiler can be extended automatically at above approximately 75mph (120km/h) and can eventually retract again at approximately 50mph (80km/h).

This is achieved by selecting the desired anti-lift that is the downward forces on the spoiler, an actuator in a form of a hydraulic cylinder and piston is mounted and this connection is control by a foot pedal or a bottom press. The actuator uses a servomechanism, as shown in the figure 4 as the servo reverse is an automatic device that gives feedback or error-correction signals of the input signal. It is measured by a transducer which is a device that converts the input pressure into electrical signals and thus the servo device compares the actual input with the received signal and with the help of the control and power chamber the unwanted signal is used to drive the system in the direction necessary to reduce or cancel the error.
The spoiler has column pivot pins, which are located at the centre so that the presence of a relative moving airstream forces the spoiler to assume a high negative angle of attack. This causes the spoiler to obtain a frontal profile shade to the airstream causing it to experience downwards and rearwards direct aerodynamic forces. This enhances traction on the wheels.

However, it is also designed to lessen or remove the anti-lift forces as the actuator can be pressurized to force the leading edges upward about their pivot pins. This invariably reduces the negative angle of attack and therefore the spoiler retracts to zero angle of the angle of attack to the airstream.

The retractable rear spoiler of the Porsche series improves the driving stability at high speeds and reduces fuel consumption at low speeds. However, vehicles with turbo engines have an enhanced rear spoiler with a larger and more effective spoiler surface due to additional flaps to improve the aerodynamics.

There are a few different spoilers positioned at strategic places on an automobile all serving specific purposes.

The pedestal spoilers are those actually with aerodynamic enhancers, which create the essential amount of downforce on the vehicle when mounted to the boot. These types of spoilers disrupt the aerodynamic drag and give better fuel economy and performance.
It is more or less of the same width as the vehicle's boot; and anchored at 2 or 4 points when fixed at the rear end of the boot.

## 1.4 Objectives

There are 3 objectives which this thesis seeks to fulfill;

- Describe rear spoilers' geometry with respect to its desired function in a car.
- Explore design alternatives that are manufacturable for composite materials.
- Apply Finite Element Analysis Methods (FEM) to spoiler structural design.

# 2. METHOD

## 2.1 PROCESS REVIEW FOR REAR CAR SPOILER

There are enormous traditional manufacturing processes used in the production of car spoilers. Some of these methods are hand layup molding, vacuum bag molding and spray-up. Thus in making a part there are three main considerations which are:

- Cost Estimation
- Raw Material
- Method

Thus depending on the manufacturing process chosen, a suitable raw material is selected such as fiberglass, and laid on the tool/mould. Afterwards, heat and pressure is applied to transform the raw materials into the finished or final product in the case the spoiler.

## 2.2 Cost Estimation

The cost of production in the automobile industry is very expensive which implies that producing a part like a spoiler with a composite may be costly; however most costumers in the automobile market are cost sensitive. Therefore the best suitable production methods are used to produce affordable spoilers of good quality and functional composite materials.

The factors that influence cost is raw materials, process cycle time and assembly part. The cost of the product depends also on the volume of production.

Thus cost estimation is a very essential element in manufacturing a product at low cost. This has significant impact on the market as in the area of composite materials the product must compete with well-developed traditional materials such as metal technologies.

Therefore, in selecting the right manufacturing processes the relationship between the production volume rate and product cost should be completely analyzed.

Cost estimation is done to predict the cost of the product and to provide a quotation or to establish the selling price. This also enables the engineer to compare other design alternatives.

It is also useful to compare cost of materials, labour, equipment and methods between various manufacturing options, as a well detailed specification of the spoiler product must include the type of fiber and matrix materials, the fiber orientation and the fabrication method to be used.

In addition, the cost of the product relies deeply on a good estimate which includes parameters such as detailed product drawing that is a well- sketched drawing as well as equipment and accessory requirements.

A good knowledge of the process cycle time and processing requirement is vital to give an insight of the production rate which must eventually allow for enough timing for packaging and delivery schedules.

## 2.3 Raw Materials for Composite Manufacturing Processes

Raw materials use in composite manufacturing processes can be categorized into two main parts. These are thermoset-based and thermoplastic-based composite materials.

Thermoplastics are those materials that can be reshaped or remelted once they have solidified whereas thermoset plastics cannot be remelted once cured.

Thermoset and thermoplastics each have their own advantages and disadvantages in terms of cost, processing, recyclability, performance and storage.

Thus some materials are best suited for specific manufacturing methods especially in part fabrications for example injection molding processes utilizes pellets, while a filament winding uses continuous fibers and wet resin systems in most processes.

Composite systems are made of two main constituents and these are reinforcements and resins matrix.

## 2.4 Reinforcements

Reinforcements are a rod-like structure used in composite for stiffness and strength. They are commonly made of glass, carbon, aramid and boron fibers. The diameter of a fiber typically ranges from 5μm to 20μm.

There are other common types of reinforcement such as continuous carbon tow, glass roving, aramid yarn and woven fabric. The properties of fibers are given in Table 1.

Table 1: Properties of composite Reinforcing Fibers (Roylance 2000)

| Material | Tensile Modulus (*E*) (GPa) | Tensile Strength (*δ*) (GPa) | Elongation (ϵ) (%) | Density (*ρ*) ($Mg/m^3$) | Specific Modulus (*E*/*ρ*) (Mg/kg) | Cost ($/kg) |
|---|---|---|---|---|---|---|
| E-glass | 72.4 | 2.4 | 2.6 | 2.54 | 28.5 | 1.1 |
| S-glass | 85.5 | 4.5 | 2.0 | 2.49 | 34.3 | 22-33 |
| aramid | 124 | 3.6 | 2.3 | 1.45 | 86 | 22-33 |
| boron | 400 | 3.5 | 1.0 | 2.45 | 163 | 330-440 |
| HS graphite | 253 | 4.5 | 1.1 | 1.80 | 140 | 66-110 |
| HM graphite | 520 | 2.4 | 0.6 | 1.85 | 281 | 220-660 |

## 2.5 Polymer Matrix Selection

Matrix selection is practically base on thermal properties, cost, availability, environmental and health concerns and ability to process the material.

Matrix of composite functions as a binder transferring load through the fiber network thereby maintaining the fiber orientation and protecting the individual strands when there is a fiber break.

When selecting a resin; the essential consideration should be the stiffness (elastic modulus) and the yield and ultimate strength as well as the toughness properties.

The two main polymer resin systems used in the automobile industries are thermoset and thermoplastics. In structural composite applications where good mechanical and thermal properties as well as good bonding to reinforcement is required with easy processing, low cost and low viscosity thermoset polymers dominate.

Thermoplastics exhibits high viscosity and poor bonding. However, it is efficiently used in areas where toughness, low volatile emissions and recyclability are essential.

Resin selection involves several factors.  For instance in choosing a specific resin the following chemical characteristics should be considered; resin viscosity, glass transition temperature, gel time, cure time, injection, thermal stability, environmental resistance and volatile emission during processing in order to obtain optimum functionality of that particular resin.

The mechanical properties that should be essentially considered when selecting the matrix are interlaminar fracture toughness, strength and elastic modulus in certain directions as well as environmental resistance.

Epoxies, polyesters and vinyl esters are thermoset resins commonly used in composite manufacturing because they offer satisfactory impregnation of reinforcing fibers such as fiber glass, carbon fiber or Kevlar during working processes when used as resins.

## 2.6 Matrix Materials

As was previously discussed, composites are made of reinforcing fibers and matrix materials. The matrix surrounds the fibers and enables the fibers to carry maximum load with lower modulus and greater elongation.

Matrix selection should be based on chemical, thermal, electrical, flammability, cost, environmental, performance and manufacturing requirements. The matrix determines the working operating temperature of the composite and the manufacturing processing.

## 2.7 Epoxy

Epoxy resins are polyether resins containing more than one epoxy group that can be converted into a thermoset form. The epoxy group consists of oxygen and two carbon atoms in their simplest representation.

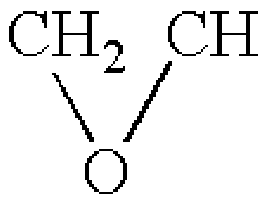


*Figure 5. An Idealized Chemical Structure of Epoxy.* (Suong, V., 2009, p.66)

Figure 5, shows a simplest epoxy in a three-member ring of an idealized chemical epoxy structure.

Epoxies are the most widely used resin materials because they are versatile with a wide range of properties and processing capabilities. It can be formulated with other materials or mixed with other epoxies to meet high performance requirements. The curing rate can be modified.

Typical properties of epoxy have been indicated in Nachiketa's lecture 8, publications of polymer matrix materials, as it has been illustrated in the table below.

Table 2: Typical range of epoxies properties. (Nachiketa,T,. n.d)

| Typical Property of Range of Epoxies | |
|---|---|
| Specific gravity | 1.2 - 1.3 |
| Tensile Modulus (MPa) | 2500 – 4500 |
| Tensile Strength (MPa) | 50 – 150 |
| CTE (per million per C) | 45 – 70 |
| Water Absorption (% over 24hrs) | 0.05 – 0.15 |

During curing processes, it does not become volatile in spite of the presence of violate solvent. The curing of epoxy groups can be initiated between the epoxide molecules themselves or by the reaction between the epoxy group and other reactive molecules with or without the presence of catalyst.

The curing of epoxy resin can be termed as exothermic as during the processes it heat is released resulting in reduction of molecular sizes. The effect of moisture on epoxy resins brings about degradation thereby causing a decrease in the glass transition temperature because of strong hydrogen bonds and thus toughness and strength of the epoxy resins below the glass transition temperature $T_g$ depends on the mechanism and mobility of the short segments in the solid state.

Epoxy resins are non-crystalline and cured resins are usually within the range of its structural applications that is below the heat distortion or glass transition temperature.

Epoxy resins have good electrical insulation properties with 3-6 di-electric constant as well as low dissipation, loss factor, good arc and volume resistance. These properties are however, affected by moisture and increase in temperature.

The applications of epoxy resins are extensive. It is used for adhesives, bonding, composites, laminates, coatings, moulding and finishing. Epoxy-based composites provide good performance at elevated and room temperatures and can operate at temperatures of around 90 to 120 °C.  Epoxies come in various forms such as liquid, solid and semi-solid forms.

The liquid epoxies are used in manufacturing processes such as filament winding, pultrusion, hand lay-up and processes with various reinforcing fibers such as glass, carbon, aramid boron etc. Epoxies are generally brittle but are toughened by adding thermoplastics, and it is more costly than vinyl esters and polyesters.

## 2.8 Polyesters

Polyester resins are generally made by dibasic organic acid and a dihydric alcohol. They can be categorized as saturated polyester, such as polyethylene terephthalate and unsaturated polyester.

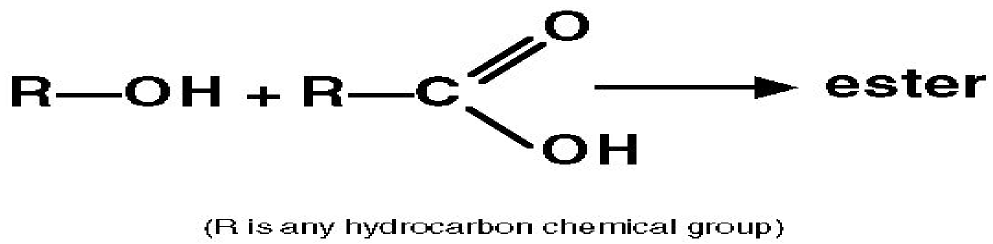


*Figure 6. Chemical Structure of Polyester.* (Schwartz –Polyester structure, 1996)

The structure of unsaturated polymer consists of mutually disconnected long chains of linear polymers and it’s accomplished by reactive and polymerized monomers such as styrene located at the unsaturated bonds.

The styrene dissolves the polyester which reduces the viscosity thereby fastening the processing; however benzoyl peroxide (BPO) and methyl ethyl ketone peroxide (MEKP) are commonly used as catalysts which cause the resin to cure.

The catalyst will then decompose during the reaction with the polyester resin to form free radicals and thus the processing temperature and the amount of catalyst can control the rate of polymerization.

The higher the temperature or the more the catalyst, the faster the reaction is. When the resin turns from liquid to brittle solid, a post cure at a higher temperature may be needed, as post cure increases transition temperature $T_g$ of the resin by complete cross-linking.

Orthophthalic polyesters are environmentally sensitive and have limited mechanical properties but isophthalic polyesters have excellent environment resistance and improved mechanical properties.

Table 3: General properties of thermoset polyester. (Nachiketa, T., n.d)

| Commonly Used Properties of Thermoset Polyester | |
|---|---|
| Specific gravity | 1.1 – 1.4 |
| Tensile Modulus (MPa) | 2000 – 4400 |
| Tensile Strength (MPa) | 33-104 |
| CTE (per million per C) | 55 – 100 |
| Water Absorption (% over 24hrs) | 0.15 – 0.65 |

Polyesters offer excellent corrosive resistance and are low-cost resins and also the workable temperatures for them are lower than epoxies. They can be thermosetting or thermoplastic resin and are widely used in manufacturing processes such as filament winding, pultrusion etc.

Unsaturated polyesters can be obtained through the reaction of unsaturated di-functional organic acids with di-functional alcohol. During the curing or cross-linking process the carbon-carbon double bonds in the unsaturated polyester molecules and an addictive such as styrene molecules forms the cross-linking site, thus, reactive monomers such as styrene is added in ranges of 30 to 50 wt%. Otherwise the use of styrene in polyester is been reduce due to growing health concerns.

## 2.9 Vinyl esters

Vinyl esters are formulated by the chemical reaction of unsaturated organic acid with an epoxide- terminated molecule. They are somewhat similar to polyester in their molecular structure but differ primarily at their reactive positions.

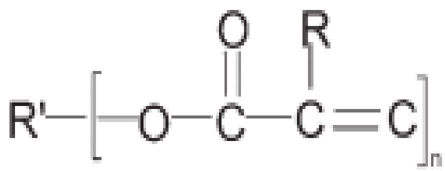

*Figure 7.Chemical Structure of Vinyl Ester (*Suong, V., 2009, p.66)

The $R_1$ and $R_2$ are alkyl groups which together may collectively contain about 6-8 carbon atoms.

Vinyl ester reactive sites are well positioned at the end of the chain and the whole length of the molecular chain readily absorb shock loadings making it tougher and more resilient than polyester.

They offer good chemical and corrosive resistance and are widely used in the automotive and other high-volume applications where cost is critical in material selection. Thus the vinyl ester has higher physical properties than polyester and cost less than epoxies.

The acrylic esters are dissolved in a styrene monomer to produce vinyl ester resins and these are cured with organic peroxides. Therefore a composite product containing a vinyl ester resin can withstand high toughness and demand and offer excellent corrosive resistance.

Vinyl esters can provide excellent permeation cover and are hydrolytic stabilized. They are commonly used in manufacturing processes such as filament winding, RTM-Resin Transfer Moulding, SMC- Sheet Moulding Compound etc.

A cured vinyl ester provides increased ductility and toughness because in vinyl ester molecules, there are fewer unsaturated sites for cross-linking than in polyester or epoxies.

Table 4: General properties of thermoset vinyl ester.
(Nachiketa, T., n.d – polymer matrix materials lecture 8).

| Commonly Used Properties of Thermoset Vinyl esters | |
|---|---|
| Specific gravity | 1.1 – 1.3 |
| Tensile Modulus (MPa) | 3000 – 3700 |
| Tensile Strength (MPa) | 70-81 |
| CTE (per million per C) | 50 – 55 |

# 3. MANUFACTURING PROCESSES

## 3.1 Hand lay-up Molding

Hand lay-up is one of the oldest dominant open molding techniques used in making the composite fabrication parts such as spoilers. It is labour intensive method which involves using reinforcing materials which are often in the form of chopped strand mat or aligned fabric such as woven rovings.  Epoxy, polyester and vinyl ester resins are mostly used in these processes.

They are positioned manually in a single sided female mould with the application of liquid resin inside the mold and the reinforcement placed on top.

A reinforcement material is the part of a composite that provides the desired stiffness, strength and the ability to withstand applied load.

Trapped air is then steadily removed by manually applying rollers to complete the laminate structure. This work is often done under room temperature for effective and efficient curing.

**3.1.1 Making of the Part**

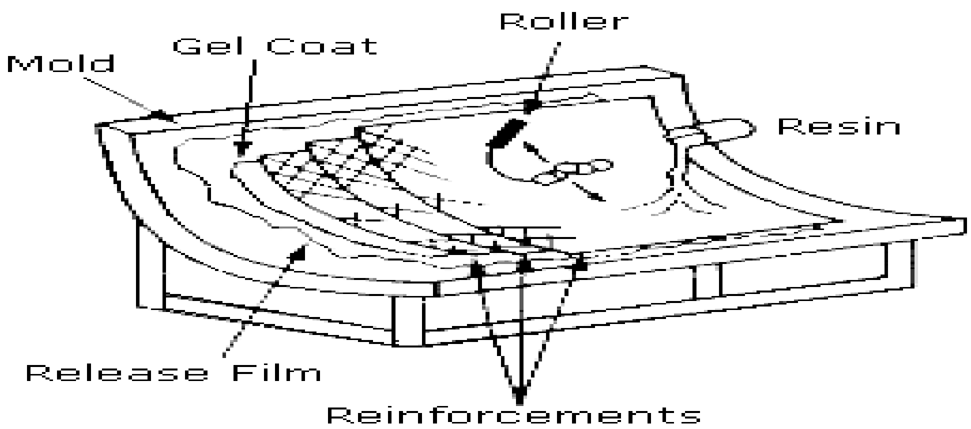


*Figure 8. Hand lay-up process.* (OSHA Technical Manual, 1999. Sec.3, Ch.1).

A schematic diagram of the hand lay-up process is shown in Figure 8, where the composite part is moulded by applying reinforcing layers and liquid resin and a roller to evenly distribute the resin completely on the surface and to remove trapped air before the release film is applied.

### 3.1.2 Method of Applying Heat and Pressure

As mentioned previously, the process is done under room temperature conditions. The resin is often left at that temperature for a day for complete curing but the curing time can be shortened by blowing warm air on the laminate, using the roller is use to apply pressure on it and the use of gel coat as a hardener.

### 3.1.3 Basic Processing Steps

The basic and main processing steps use in hand lay-up to obtain an acceptable surface finish greatly involves the use of release agent which provides easier removal of part during the time of demoulding and notably insufficient application of release agent will render some part sticking inside the mold.

The gel coat is applied to create finished surface and it is allow hardening sufficiently before reinforcing layers are placed in one at a time. The reinforcement layers placed on the mould surface are wet with catalyzed resin and evenly distributed by the help of a roller or brush. Afterwards the final part is allowed to cure at room or elevated temperature.

### 3.1.4 Merits of Hand Lay-Up Process

The hand lay-up processes have some few advantages as the product produce is mostly simple and versatile with its fiber orientation and the equipment cost is nearly negligible. This is suitable for low volume manufacturing and very low capital investment is involved.

### 3.1.5 Limitations of Hand Lay-Up Process

The major limitations of hand lay-up methods are that the process is labour intensive and needs much skilled work in order to obtain a quality final part. The quality of the finished part is mostly not constituent because of the lack of direct control over the part thickness, fiber content which implies that high fiber volume fraction cannot be manufactured with this process and there is dimension inaccuracy in producing the part.

## 3.2 Spray-Up Process

Spray-Up is another form of open mould method similar to the hand lay-up but the difference is the way and manner the fibers and the resin materials are applied onto the mould.  A spray- gun is used to apply the resin and reinforcement in this process unlike the roller used in hand lay up process.

This method deploys the used of chopped fiberglass reinforcement and catalyzed resin, which are applied onto the mould. The spray-gun simultaneously chops continuous fiber roving in a predetermined length of 10 to 40mm and impresses it through a catalyzed resin onto the mould. The spray-up process is much faster than the hand lay up and a less expensive choice when using rovings. Work is done at room temperature for curing.

### 3.2.1 Making of the Part

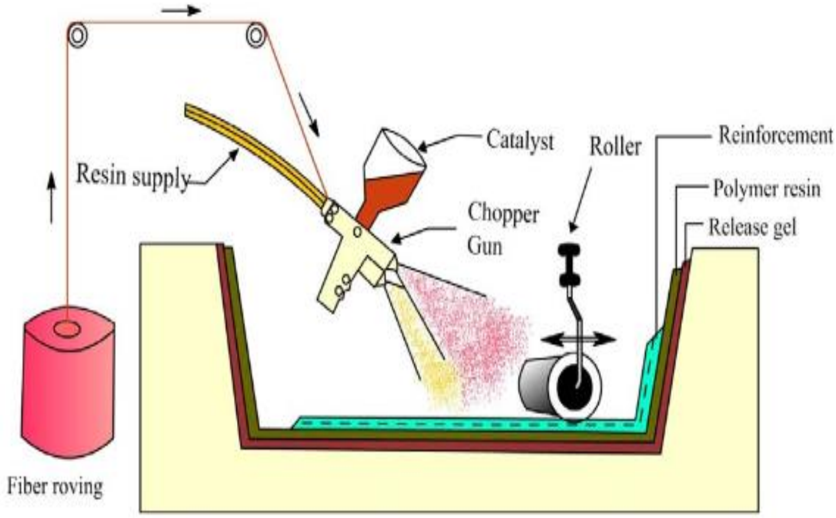


*Figure 9. Spray- up Molding Processes.* (Lecture 5.4: Hand lay- up and Spray lay- up)

In this process, the release agent is first applied to the mould and then after, it the gel coat. The gel coat is left for a few hours, often 2 hours, until it hardens. Then the spray-gun is used to deposit the fiber resin mixture onto the surface of the prepared mould.

In this process the thickness obtained depends on the pattern of the spraying. Next, rollers or brushes are used to remove entrapped air as well as ensure good fiber wetting and then curing is allowed to take place at room temperature.

### 3.2.2 Basic Processing Steps

The basic steps of a spray- up process involve the use of wax and polish on the mould to allow for easy demoulding.  The gel coat is applied to the mould surface, and is allowed to sufficiently harden before the laying of the fiber materials.

Another coat applied is the barrier coat which is placed in an oven to prevent fiber imprint through the gel coat during curing and most often the laminate is put in an oven to cure.

### 3.2.3 Merits of Spray lay–Up Process

The advantages spray-up offers during its processing are enormous as compared to the hand lay-up methods. This technique is suitable for small-to-medium –volume parts manufacturing with low-cost materials and this eventually uses less expensive tooling.

### 3.2.4 Limitations of Spray lay-Up Process

The finished part mostly have good surface at one side whereas the other side is somewhat rough, and it not ideal to use this method for making parts with high structural requirements. In this method controlling the fiber volume fraction as well as the thickness is difficult.

# 4. THEORY OF SPOILER

This chapter deals with the concept of aerodynamics of the spoiler and continues with the analysis of the design of the spoiler. NASTRAN is used to study the static load analysis when uniform load is applied on the spoiler.

## 4.1 History of Spoilers

Spoilers were first introduced on vehicles in the late 1960's and were experimented with in racing cars. Spoilers became popular with motorsport vehicles in the 1970's and also started to appear regularly on modern passenger automobiles as there was an aim to reduce drag and improve fuel efficiency at accelerated speeds.

The effect of aerodynamics on a vehicle is summarized in terms of drag, downforce and stability. Automobile manufacturers realized that vehicle stability can be improved by balancing the downforce and creating more traction on the tires whereas the weight of the car is unchanged.

Formula One racing cars considered the use of spoilers to produce downforce to the cars which can be likened to a virtual increase in weight as it presses the car to the road and causes swiftness when negotiating a curve as well as increasing frictional force on the road.

Apparently, the motion of air around an object enables the calculation of forces acting on the object. Velocity, pressure, density and temperature as a function of position and time are mostly the properties calculated.
A control volume around the flow field is mostly defined, equations for the conservation of mass, momentum and energy can be defined and used to solve for the properties. (Karman, 2004).

Nowadays, improved spoilers shapes and the study of aeronautic technology has considerably helped vehicle stability, and the use of light weight but strong materials to manufacture spoilers and automobiles parts have drastically enhance vehicle aerodynamics.

## 4.2 Design of a Rear Spoiler/Wing

In the process of designing a rear car spoiler, rules governing the specifications and requirements must be considered in order to achieve the optimum design objectives to efficiently minimize drag on an automotive vehicle.

The rear spoiler design requirements that need to be taken into consideration are performance in that the spoiler should be able to minimize drag, stability and control whereby the vehicle can stay grounded with the tires on the road at accelerated speed. The rear spoiler should be a cost effectively producible design and also be easily operated if it is an automatic spoiler.

The spoiler or wing must be oriented in a plane view with the quadrilateral defining the outside of the tires on the sides of the vehicle by a transverse line of 460 mm between the rears of the rear tires. The spoiler should be mounted in a suitable position so that it does not block the driver's egress or exit.

In the design geometry, the leading edges of the rear spoiler or wing should be of a 12.7mm minimum radius and it must be blunt or blunter than the required radii for an arc of plus or minus 45 degrees centered on the plane parallel to the ground.

The spoiler or wing edges must have minimum edge radii of at least 3mm that is a 6mm thick edge at least. When setting up a wing for an automobile vehicle, first the theoretical top velocity of air flowing on top of the trunk of the vehicle without wing and the top speed must be anticipated. Airflow velocity when the wing is mounted on the vehicle should also be calculated. This will assist the designer to decide on how best to knock off that top speed by the addition of the spoiler.

The calculated difference between the top speed with and without the spoiler obtained will be donated as the downforce. Thus, relatively small changes added to the rear wing configuration alter the downforce and also improve the vehicle's drag figure with a big difference.

## 4.3 The Airfoil Selection Process

The best form of airfoil selection is by initially considering the weight of the spoiler/wing because it is best to avoid adding unwanted weight to the automobile vehicle.

In table 4 below, illustrates the weight distribution over quantities relevant in obtaining optimum wing design.

Table 5: Illustrates a sample of airfoil weight distribution selection. (Sadraey, 2013).

| Design Objective | Weight (%) |
|---|---|
| Stability Requirement | 20 |
| Control Requirement | 15 |
| Cost Requirement | 10 |
| Producibility Requirement | 10 |
| Operational Requirement | 40 |
| Other Requirement | 5 |
| Summation | 100 |

The spoiler is designed with a cross-section called airfoil and its main function is the generation of optimum pressure distribution on both sides of the spoiler, meaning the top and bottom surfaces.

One of the wing parameters that must be considered in the wing design process is the position of the wing's vertical location relative to the trunk of the vehicle and its alignment with the body of the automobile.

A typical airfoil section is shown below in figure 10, where several geometric parameters are illustrated. The airfoil is referred to as symmetrical if the mean camber line is in a straight line, otherwise it is known as cambered airfoil.
The camber of an airfoil is normally positive and the angle of attack increases with the pressure difference between the upper and lower surfaces as it is illustrated in figure 11. (Sadraey,M., 2013.Ch.5).

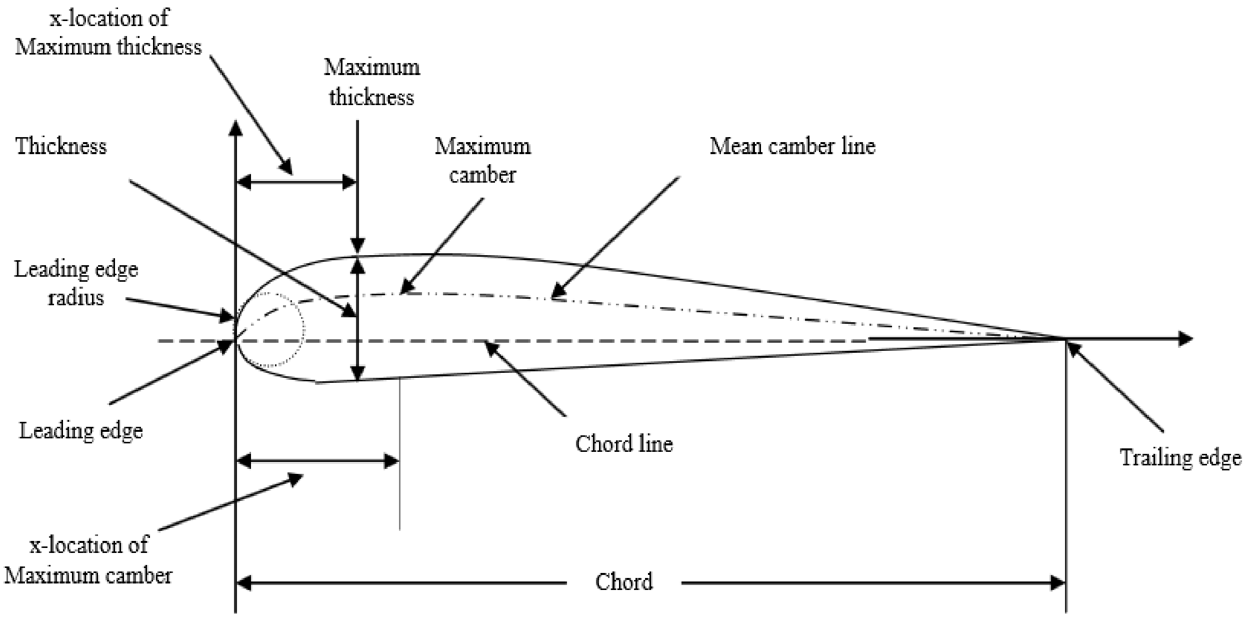


*Figure 10. The geometric parameters of airfoil*

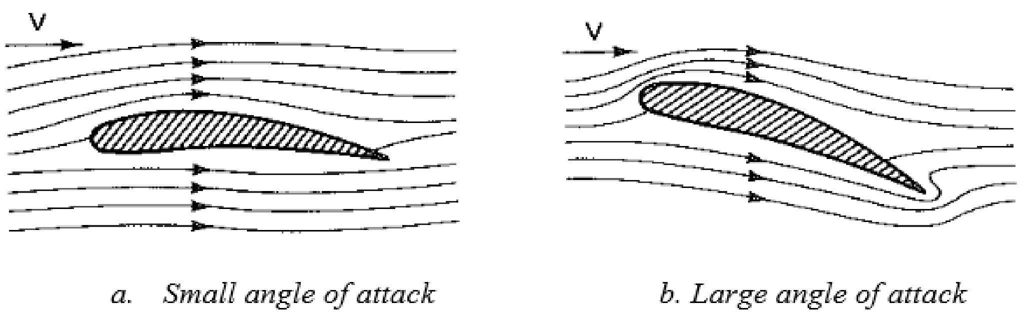


*Figure 11. The flow around an Airfoil*

The force divided by the area is noted as the pressure, thus the aerodynamic force generated by the airfoil in a flow field can be calculated mathematically by the multiplication of the total pressure by the area.
The total pressure can simply be obtained by the integration of the pressure over the entire surface. The magnitude, location and direction of the aerodynamic force are as a function of the airfoil geometry that is angle of attack, flow property and airspeed relative to the airfoil. In effect, the airfoil must be designed with the lowest minimum drag coefficient. Thus one of the most reliable resources and widely used databases in airfoil development is NACA profiles.

The NACA four-digits series aerofoil shapes are widely used standard to design a car spoiler. In a four-digit NACA airfoil, the first digit symbolizes the maximum camber in the percentage of the chord (airfoil length) whereas the second digit represents the position of maximum camber in tenths of chord length.
The last two digits indicate the maximum thickness as percent of the chord; however a zero in the first digit means that the airfoil is symmetrical in section.

The camber of a four-digit airfoil consist of two parabolas with one of the parabolas used to generate camber geometry from the leading edge to the maximum camber and the other produces the camber shape from the maximum camber to the trailing edge. (Sadraey,M.,2013.Ch.5).

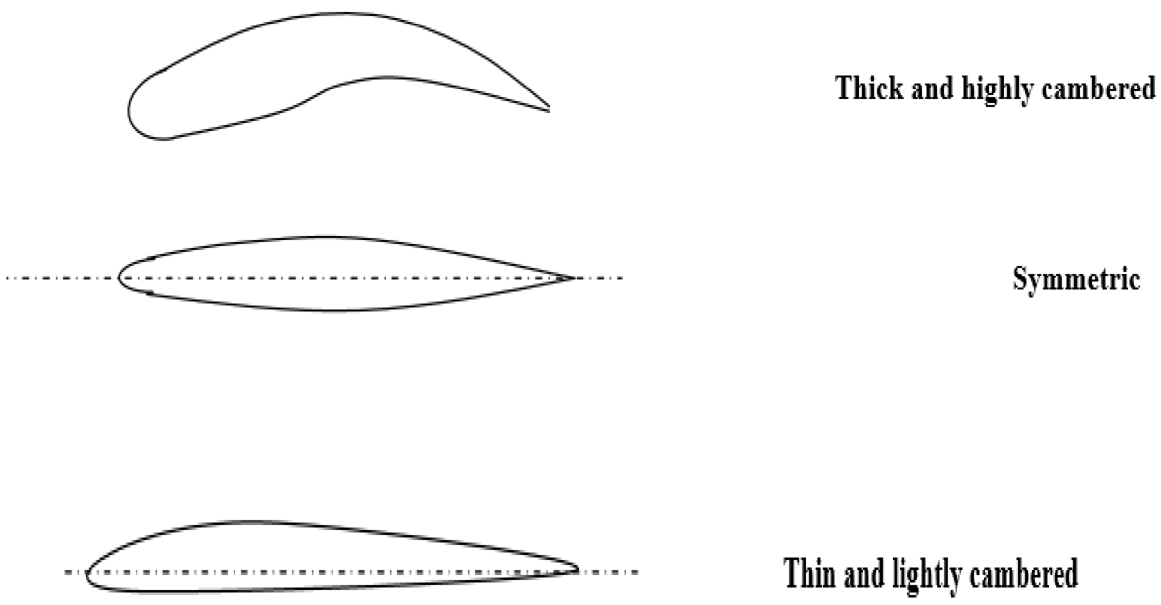


*Figure 12. Sample of Airfoil Section*

The NACA 1408 airfoil section shown below in figure 13, has 8 percent thickness-to chord ratio $(t/c)_{max}$ which is the last two digits, its maximum camber is 10percent, and its maximum camber location is at 40percent of the chord length.

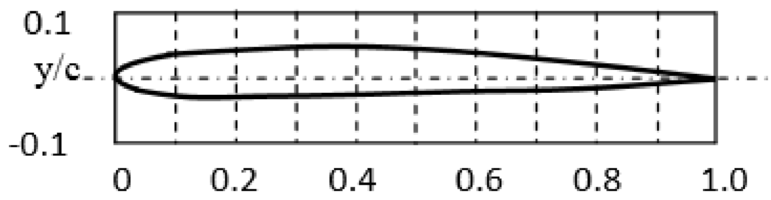


Figure 13: NACA 1408 airfoil section. (Sadraey,M., 2013.Ch.5).

## 4.4 Drag

According to (Steven. D.G, 2009) the definition of drag is: "Drag is the aerodynamic force that is in opposition to the velocity of an object moving through air or fluid. It is directly proportional to the speed differential between air and the solid object.

Drag comes in various forms; frictional drag is as a result of the friction of the solid molecules against air molecules in their boundary layer.

Friction and its drag depend on the fluid and the solid properties because a smooth surface of the solid for example produces less skin friction compared to a rough one.

Friction varies with its viscosity along with airflow and the relative magnitude of the viscous forces to the movement of the flow; this is expressed as the Reynolds number.

Low energy flow generated along the solid surface depends on the magnitude of the skin friction and conditions in the boundary layer.

Thus, the form of drag is dependent on the particular shape of a wing profile.
The changes in air pressure and the velocity of the motion air flowing around the spoiler effectively create the required force to enable traction on the tires to the road.

Induced drag or interference drag is a result of vortices that are generated behind the solid object due to the change of the direction of the air around the spoiler.

A vortex is considered the region within fluid mechanics where the flow is mostly in a spinning motion."

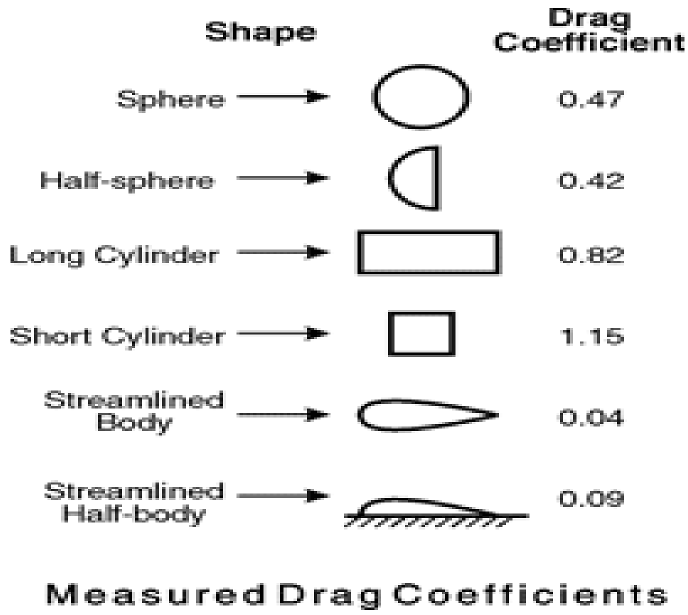


*Figure 14. Type of drag co-efficient $C_d$* (Steven. D.G 2009)

Thus, the amount of drag that is induced as the automobile motions can be quantified as drag coefficient. This coefficient is expressed as the ratio of the drag force to that of the force induced by the dynamic pressure times the area whereas at relatively high speeds of high Reynolds number ($R_e > 1000$), the aerodynamic drag force can be calculated as:

$$F_d = \frac{1}{2} \rho \upsilon^2 A c_d \qquad \text{[Eq.1]}$$

Where

$F_d$ = Force of drag

$\rho$ = Density of the air

$V^2$ = Speed of the object relative to the fluid (m/s)

A = Reference surface Area

$C_d$ = coefficient Drag

The above formula indicates that aerodynamic drag increases with the square of the speed.

The drag co-efficient formula can be derived from Daniel Bernoulli's equation for pressure in a fluid which is given as:-

$$P_1 + \rho g y_1 + 1/2\rho \upsilon_1^2 = P_2 + \rho g y_2 + 1/2\rho \upsilon_2^2 \qquad \text{[Eq. 2]}$$

The first term on either side of the equation is referred to as atmospheric pressure which is observed as outside pressure of the fluid content whereas the second term is the gravitational force which causes buoyancy.

The third term is the kinetic or dynamic contribution to the pressure been experienced, which is related to the flow and relevant to the derivation of the Drag Force.

$$P = \frac{F}{A} \qquad \text{[Eq. 3]}$$

$$\Rightarrow \mathrm{F} = \mathrm{P}A \qquad \text{[Eq. 4]}$$

Therefore, in Bernoulli's equation the pressure, $\mathrm{P} = \frac{1}{2}\rho \upsilon^2$ [Eq. 5]

Inserting equation 4 into 5 gives $F_d = \frac{1}{2}\rho \upsilon^2 AC$ [Eq. 6]

In equation 6, there is an additional factor that is the symbol *C*, which is the coefficient of drag, which implies drag, is influenced by factors such viscosity, texture and shape which results in viscous drag and skin friction.

Thus viscous drag is observed in a laminar flow when fluids flow around an obstacle; it exerts a viscous drag on the obstacle whereas skin friction is the resistance around the surface of the spoiler encounter by a moving air.

Therefore, it can be deduced that drag is directly proportional to density and the area but there is always a resistive force with a moving vehicle, which implies that the more the acceleration the greater the resistive force. Thus from the Bernoulli's equation it is the square of the velocity. It can clearly be concluded that drag is related to speed by some form of a polynomial. (Glenn, 2014)

## 4.5 Downforce

Sir Isaac Newton in 1686; Energy is constant in a closed system, even though it can be converted from one form to another. Thus out of this theory, Daniel Bernoulli deduced a formula proving that the total energy in a steadily flowing fluid system is a constant along the flow path.

An increase in fluid's speed must be aligned by decrease in its pressure. Adding up the pressure variation multiplied by the area around the entire body determines the aerodynamic force on the body. (Steven D.G 2009).

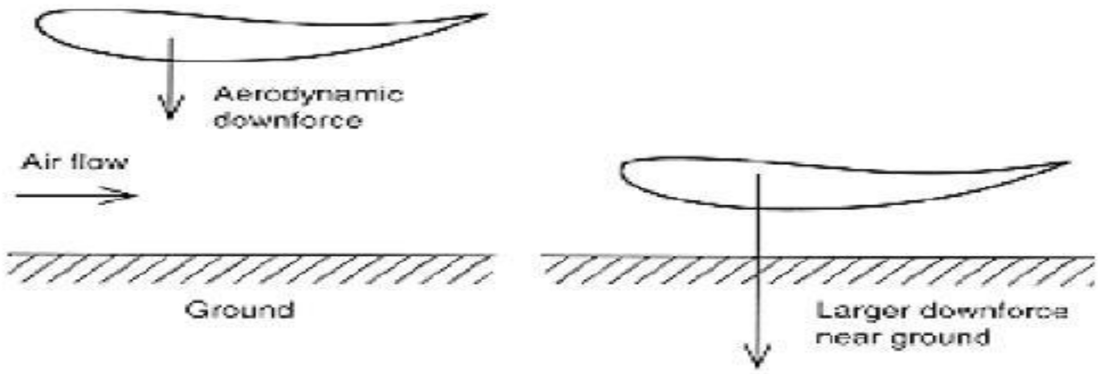


*Figure 15. Aerodynamic downforce* (Kasravi, n.d vehicle aerodynamics)

An aerofoil's operation is better explained with a wing/spoiler in a steady laminar flow of air. Spoilers are designed with more thickness at one end and thus molecular free air moves around with different speed at different locations in airstreams.

Therefore, increasing the flow speed and decreasing the pressure would slightly reduce the airstream on the lower surface. The pressure difference will generate a downward force on the wing due to the lower airspeed on top of the spoiler.

The wing is designed with contour shape to induce a new turning of the airflow creating the downforce. (Steven. D.G, 2009).

However, the air on the longer side of the wing will flow much faster, further increasing the downforce effect. The simultaneous conservation of mass, momentum and energy of a fluid (while neglecting the effects of air viscosity) are termed the Euler Equations named after Leonard Euler. (Steven.D.G, 2009).

## 4.6 Flows: Laminar and Turbulent

When a vehicle moves through still air, its shape disturbs the air particles such that their velocity is not equal at all positions in the flow. If the air particles travel in “well organized” parallel lines then this is known as laminar. On the other hand it is possible to have the same average speed in the flow, but eventually the average speed of the fluid particles will momentarily move in the a disorder /opposite direction along the spoiler.

The fluid in this behavioral manner is called turbulent, even though the average velocity could be the same in both the laminar and turbulent flows.

It is essential to know the type of flow being dealt with, whether it is laminar and turbulent, since features such as flow separation and vehicle drag can change dramatically between these two flows.

In “Race car Aerodynamics” normally when an automobile travels in an undisturbed environment, the prevailing flow can be considered laminar. However, conditions such as spoilers or the motion of other vehicles can cause the flow to become turbulent.

The flow can even be laminar initially, but it may turn turbulent due to the disturbance created by the vehicle itself.

This is what the spoiler is designed to achieve. As the streamline moving air particle hits the spoiler, it turns to turbulence, causing swirl around the boot of the vehicle, and thereby pushes the tires to the ground creating the needed downforce. (Katz, 2006).

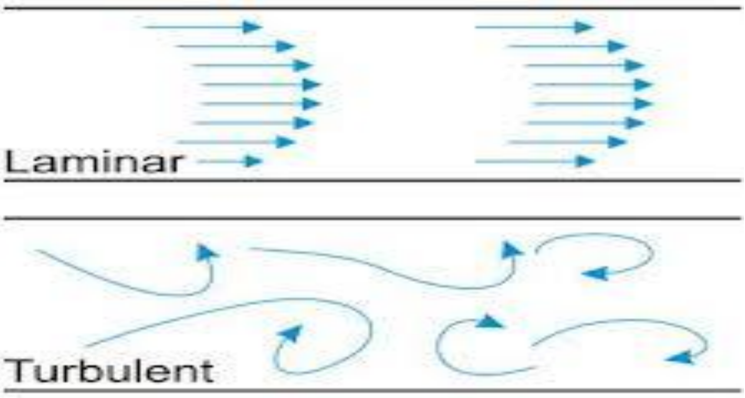


*Figure16. Types of air flow* (Generalic, Eni. *"laminar flow"* 2014).

## 4.7 Reynolds Number

The Reynolds Number is vital in the aerodynamics of automobiles as it helps to determine the type of flow to be expected. A high Reynolds Number indicates turbulent flow whereas a low Reynolds number gives laminar flow.

Increasing the Reynolds number in both laminar and turbulent boundary layer gives lower skin friction drag. Thus the skin friction effect indicates the level of friction between the vehicle surface and the flowing air.

Notably the range of the Reynolds Number under laminar or turbulent flow conditions depends on the profile shape of the spoiler and its surface finish, as well as the absence of vibration during a steady initial flow.

Thus the Reynolds Number, *Re* is defined as the ratio between inertia and viscous forces created in the air and it is formulated as:

$$Re = \frac{\rho\, VL}{\mu} \qquad [Eq. 7]$$

Where;

$Re$= Reynolds number

$\rho$ = Density of the fluid

$V$ = Velocity

$L$ = Length of the spoiler/wing

μ = Dynamic viscosity of fluid

Thus the Reynolds Number is very essential in the aerodynamics of a car and the build-up of spoilers, as the resistance encountered by the spoiler/wing is a function of the Reynolds Number.

## 4.8 Mach Number (M)

The Mach number is another useful parameter that defines the physical nature of particular flow over the upper camber of the spoiler. Thus as the travelling air particles attain the speed of sound at high speed of an accelerated vehicle, the air particle begins to compress resulting in compressible particles. The speed of sound is referred to as the rate at which pressure disturbance in the air is propagated in the atmosphere with respect to temperature changes. Thus, at higher temperature air mass generate effective and more collisions than low temperatures.

The Mach number is defined as the ratio of flow speed to the speed sound in a given medium such as air, and it is a non –dimensional quantity. (Benson, 2014)

$$M = \frac{\upsilon}{a} \qquad [Eq.8]$$

$\upsilon$= flow velocity.

$a$= speed of sound.

The role of Mach number can be expressed in subsonic, transonic and supersonic in terms of race cars. Subsonic conditions can be expressed at low speed and the Mach number is less than one; **M<1** and the square of the Mach number is very small which signifies that the compressible fluid at this stage can be ignored. This normally occurs when the travelling air particles are slower than sound. The flow adjusts itself to any object that serves as a hindrance and thus passes smoothly along the object.

When the speed of the particles approaches the speed of sound, the Mach number is equal to 1; **M=1** and this type of flow is referred to as transonic which indicates that the change in density is nearly equal to the change in velocity.

As the speed increases beyond the speed of sound, the Mach number is greater than one, **M>1**; thus the density changes faster than the velocity changes and quantities such as pressure and temperature increase depending on the flow intensity.

# 5. PRODUCT REVIEW

## 5.1 Analyzing the Product Development Process

In this chapter, a complete product development process in the manufacturing of a spoiler to achieve its physical and performance potential is understudied.

There are different phases a product undergoes after the idea has been conceptualized before the physical product is designed or manufactured. The main aim of these phases is to minimize potential errors and reduce product costs. (Mazumdar, 2002).

“A design process is the series of activities by which the information known and recorded about a designed object is added to, refined, modified or made more or less certain” (Dixon & Poli,1995).

The design process becomes successful with conceptualizing an idea and narrowing the idea down with detailed specifications, such that the information gathered can be use to design the required object or spoiler (Dixon & Poli, 1995).

### 5.1.2 Conceptual Design Phase

This phase is initiated by a customer or a market need of the product with associated functional and performance requirements that are identified and analyzed by a team from the various departments such as engineering, manufacturing, materials, marketing, sales, finance and sometimes customers.

The team transforms customer needs into a three- dimensional product shape and size, without much consideration of the geometries, manufacturing or technical details.

The reason behind this is to create a preliminary design and production scenarios as well as evaluate and study the technical feasibilities in order to estimate the expected cost. Thus, a study of the market with other competitive product type is evaluated and afterwards preliminary product and process designs, project cost and return on investment are reviewed leading to a final decision regarding the commencement of the project or aborting it. (Mazumdar, 2002).

### 5.1.3 Detailed Design

This phase utilizes the various schemes generated from the conceptual phase to come up with multiple concepts about the product and this leads to many design options for the spoiler.  A complete drawing is done with detail dimensions with the aid of Solidworks software. The material and specifications are also well noted.

Next, the design product is tested for functionality, performance and other requirements. The product and the material specifications observed and developed are used to produce the prototype parts.

Thus, once the part meets the required dimension the prototype is tested for performance and other functionalities.  The purpose of the testing is to determine the design capabilities of the products such as exposure to extreme temperature, fluid exposure and reliability of the spoiler’s performance over time.

The purpose of the prototype testing is to gives valuable insights of the design feasibility and the adequacy of the design process before committing resources to subsequent stages as while as guidelines and directions for future production.

Figure 17, below, shows the relevant stages to undertake when developing and manufacturing a product.

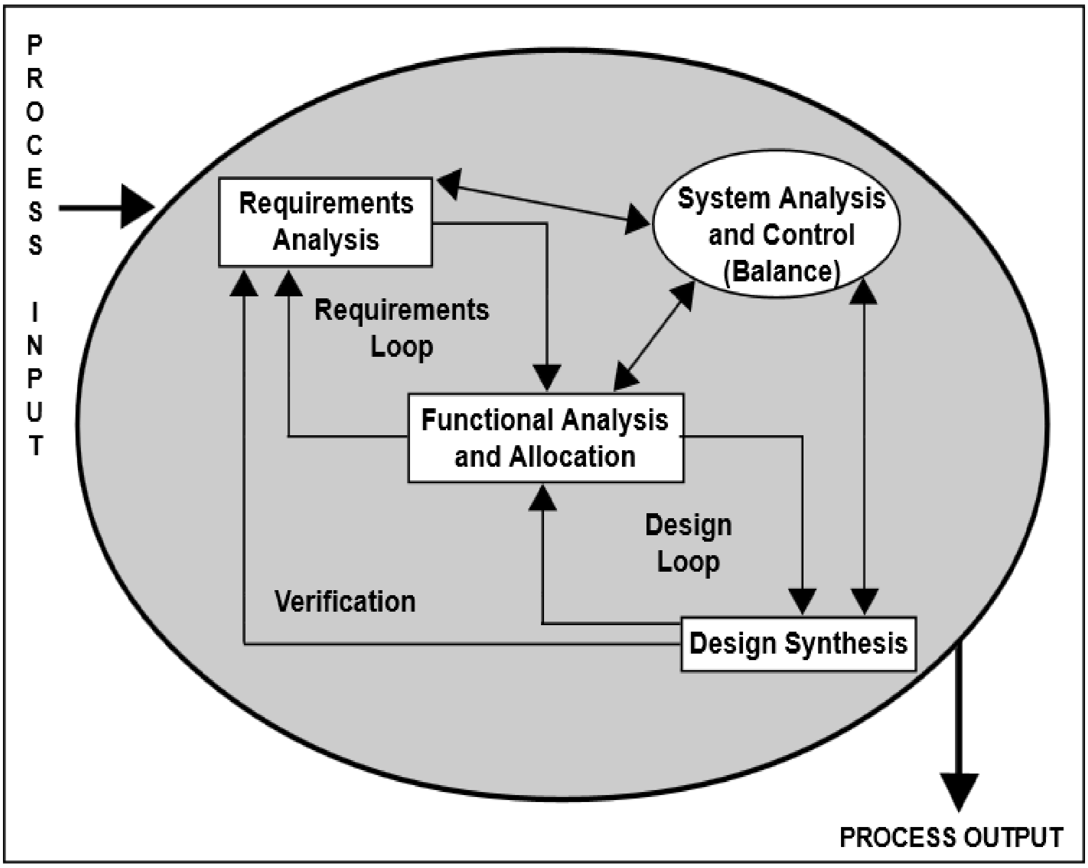


*Figure 17. The Design Process Undertaken In Developing A Product* (Systems_Engineering_Process, 2001).

## 5.2 Design Evaluation Method

Products need to be fully evaluated to verify whether it has fully met the design features and requirements that are essential to customers.

Thus selection processes such as Pugh analysis and other techniques can ease the task for the best design selection. The Pugh method deploys the use of matrix to create criteria selection and design options in composite manufacturing as illustrated in table 6.

Table 6: The Design Concepts for Evaluation. (Mazumdar, 2002).

| Factors | Weight (%) | Design "A" | Design "B" | Design "C" |
|---|---|---|---|---|
| Weight | 15 | 3 | 4 | 3 |
| Cost | 20 | 4 | 5 | 3 |
| Performance | 10 | 3 | 4 | 3 |
| Reliability | 5 | 2 | 4 | 3 |
| Noise | 5 | 3 | 3 | 4 |
| Assembly Time | 15 | 3 | 5 | 3 |
| Robustness | 7 | 3 | 4 | 3 |
| Number of Parts | 10 | 2 | 4 | 3 |
| Aesthetics | 5 | 3 | 4 | 4 |
| Ease of Servicing | 8 | 2 | 5 | 3 |
| Total | 100 | 2.92 | 4.38 | 3.1 |

The best design selection is chosen from the criteria with the highest ratings.

## 5.3 Testing

The prototype part that is considered the best design after selecting the materials for the manufacturing processes must be validated and tested.

Thus, the prototype for an automobile spoiler requires more tests to ensure that the part functions safely and is reliable under various service conditions, for example testing the spoiler in a wind tunnel to ascertain the braking effect on the car.

Static and dynamic tests must also be conducted for automotive fluid exposures such as water and salt exposures and temperature extremes of -40 and +150°C.

Thermal cycling testing is also carried out and the effect of the test done on the spoiler at two extreme temperatures and stone impingement helps to understand the performance and stability of the spoiler product.

# 6. RESULTS

## 6.1 COMPOSITE REAR SPOILER

The materials used to fabricate the rear spoiler are glass fibre and polyester resin. Composite properties are mostly determined by their chemical and mechanical interaction with other combined materials.

“The reinforcing material or fiber provides strength and stiffness to the composite whereas the matrix adds rigidity and environmental resistance”. (Mazumdar, 2002).

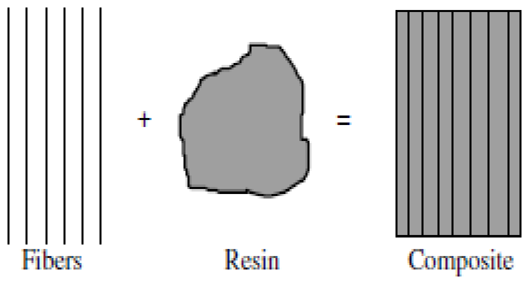


*Figure 18. Composite formation*. (Mazumdar, 2002).

## 6.2 Fiberglass

Fiberglass materials are made by the combination of two or more materials to obtain a unique combination of material properties. In this experiment the fibre reinforced composite material used primarily as it main structural component is E-glass fiber.

The E-Glass is made of a continuous strand of filaments that are plied and twisted into yarns. It is relatively lightweight with moderate tensile and compressive strength as well as high strength and dimensional stability. The light weight nature of fiberglass makes it ideal and durable in applications such as manufacturing rear spoilers.

It has excellent electrical properties and design flexibility which gives it optimum performance. This makes it excellent material to use in situations where strength and high electrical resistivity is required.

The fiberglass has low moisture absorption and it is not affected by most chemicals such as salty water and acid rain making it environmentally workable, and can be moulded into complex shapes, thus reducing assembly and handling time as while as manufacturing cost.  Below is a list of some chemical and mechanical properties of the E-glass fibre. (Bagherpour, 2012).

Table 7: Chemical Properties of E-glass Fibre. (Bagherpour, 2012).

| Chemical Properties of E-glass fiber | |
|---|---|
| $SiO_2$ % | 52-56 |
| $Al_2O_3$% | 12-16 |
| $B_2O_3$% | 5-10 |
| CaO% | 16-25 |
| MgO% | 0-5 |
| ZnO% | 2-5 |
| $Na_2O$+$K_2O$% | 0-2 |
| $TiO_2$% | 0-4 |
| $Fe_2O_3$% | 0-0.8 |

Table 8: Mechanical Properties of E-glass Fibre. (Bagherpour, 2012).

| Mechanical Properties of E-glass Fibre at different temperature | |
|---|---|
| Density ($g/cm^3$) | 2.58 |
| Tensile Strength (MPa) at 196°C | 5310 |
| Tensile Strength (MPa) at  23°C | 3445 |
| Tensile Strength (MPa) at 371°C | 2620 |

| | |
|---|---|
| Tensile Strength (MPa) at 538°C | 1725 |
| Modulus of Elasticity(GPa) at 23°C | 72.3 |
| Modulus of Elasticity(GPa) at 538°C | 81.3 |
| Elongation% | 4.8 |

## 6.3 Designed Spoiler

The design and shape of the spoiler conforms to that of a NACA automobile profile, and it is customized with a dimension of total length of 1400 mm. The spoiler is designed with a spring-like object mounted just beneath with the support or stands attached to it.

The spring is an improvised attachment which significantly assists the spoiler to operate automatically when a button is pressed to either increase or decrease the angle of attack.

The dimensions of the rear spoiler are tabulated below.

Table 9: Spoiler's of dimensions.

| **Dimension** | **Units (mm)** |
|---|---|
| Length | 1400 |
| Distance between two support | 804.5 |
| Width | 206.9 |
| Support Height | 48.20 |
| Thickness | 25.80 |

Additionally, honeycomb material would be used as a sandwiched core for the rear spoiler. The honeycomb NH-09 core used as a sandwiched material provides the product with very low weight, high stiffness and durability.

The honeycomb has excellent body joint rigidity as well as improved performance with net body structure mass. The density of a standard cell used in automobile application is $32kg/m^3$ according to the manufacturer specifications and production process.

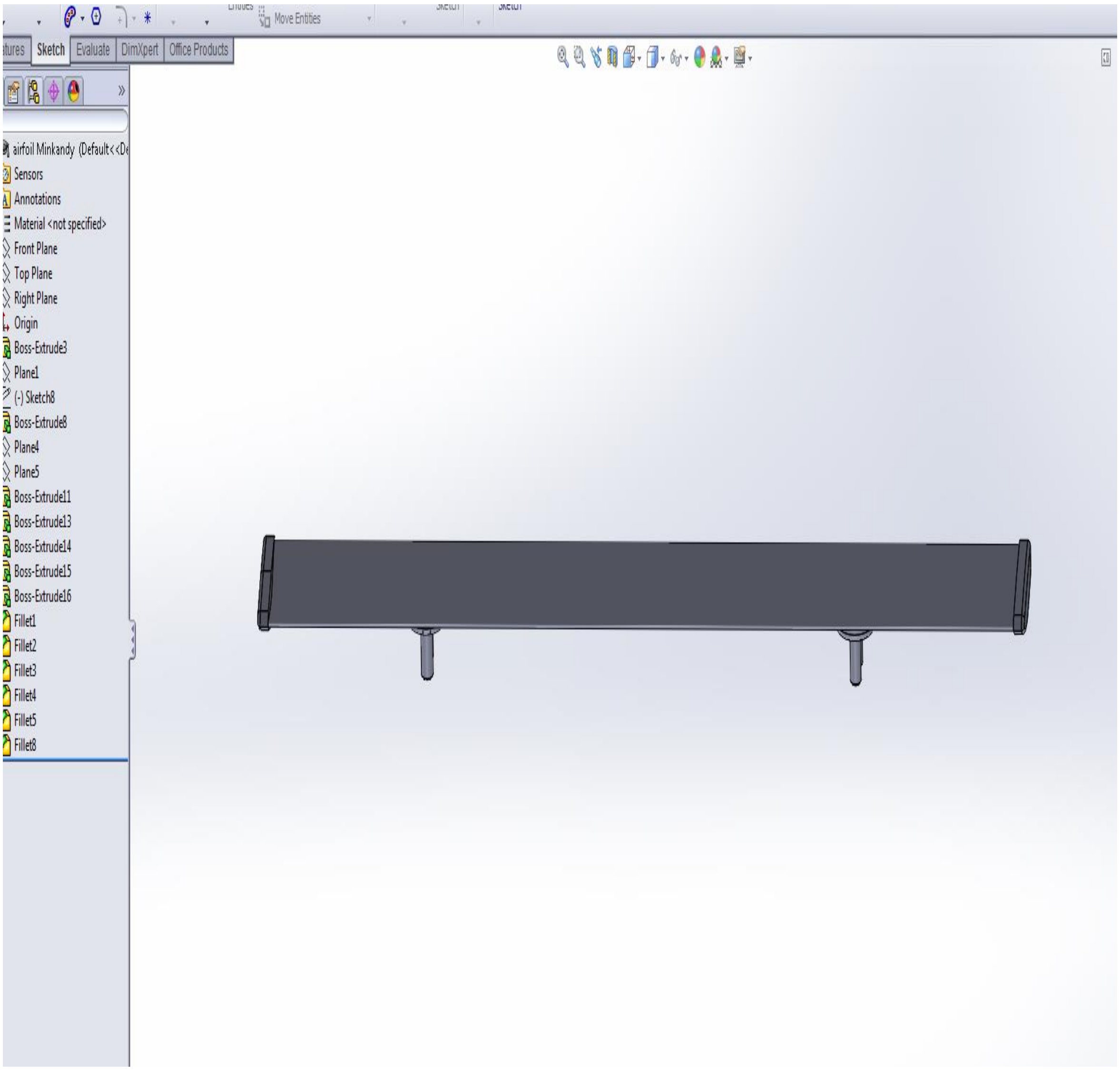


*Figure 19. Solidworks Design of spoiler*

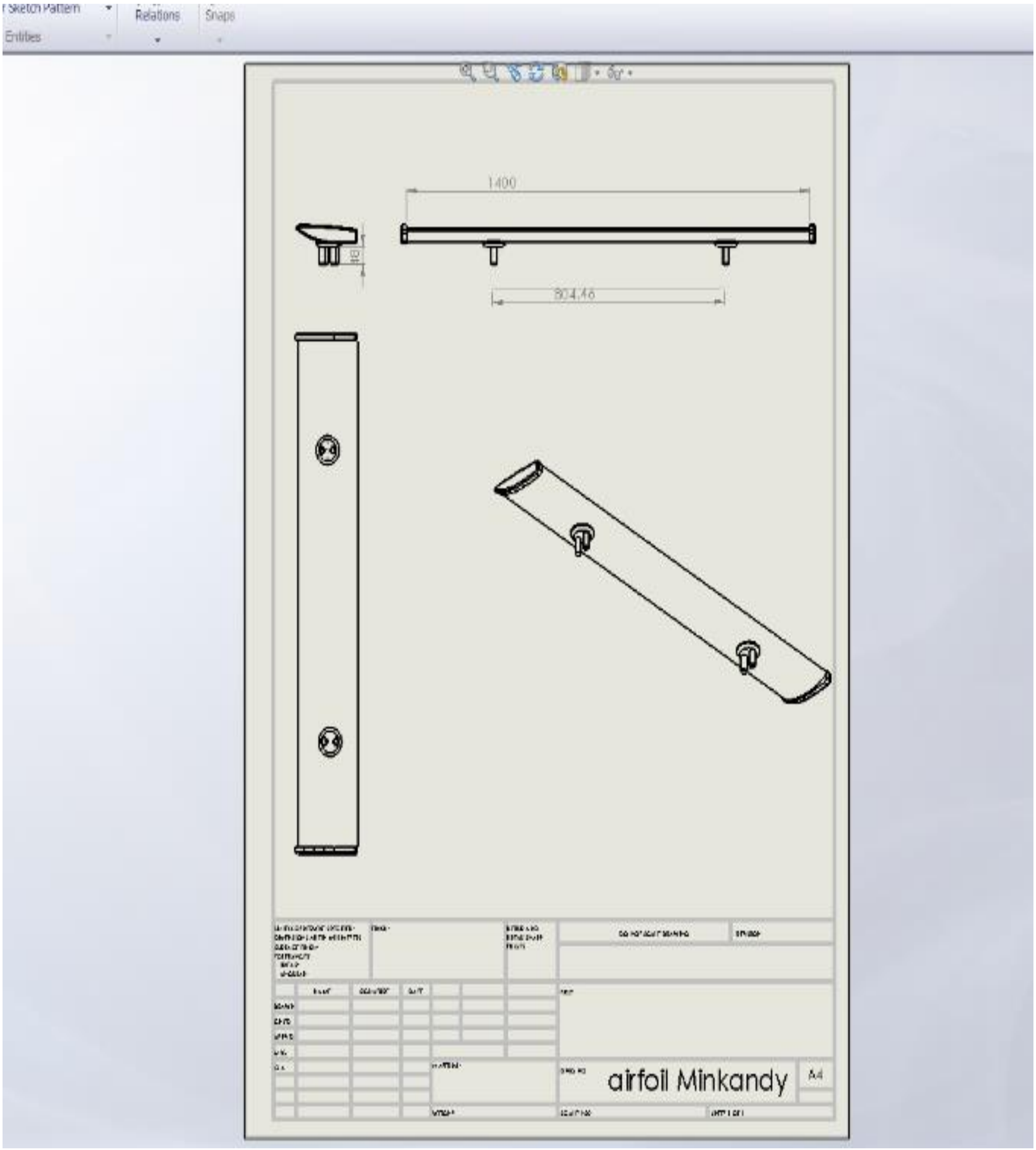

*Figure 20. Isometric drawing view of the spoiler*

## 6.4 The Manufacturing Process

The spoiler is manufactured using a vacuum infusion process, whereby the vacuum pressure is used to drive resin into the laminate. Thus the vacuum reduces the pressure at one end of the fabric stack allowing atmospheric pressure to force the resin through the layers of glass fibers. The speed and the distance to infuse the stack of fiberglass will be dependent on the relationship between the resin viscosity systems with respect to the speed of the infusion process as given below:    (Gurit, 2014)

$$\upsilon \approx \frac{D\Delta P}{\eta} \qquad \text{[Eq. 9]}$$

The viscosity of the resin system $\eta$

The permeability of the fabric stack $D$

The pressure gradient acting on the infused resin $\Delta P$

Thus the speed of the infusion process (υ) increases with increasing permeability of the stack of fibre (D) with increasing pressure gradient ($\Delta P$) while it decreases with increasing viscosity ($\eta$). The mould consists of two halves, which are the female and the male part. The process has a better fibre to resin ratio and produces a strong laminate with a low void content than other processes such as hand laminate.

The required equipment used in this process is Chemlease 75 which helps to eliminate debris in the prepared mould. Peel ply and release film are placed inside the mould, whereas a flow mat over the release film to provides an easy flow passage or conduit for the resin. Vacuum and resin lines are carefully set up to avoid air leakage before the vacuum is switched on for the infusion process. Afterwards the two halves will be carefully assembled.

### 6.4.1 Laminate Preparation

A female mould with a curvature profile of that of the spoiler face would be prepared and the lamination would be structured to have a symmetrical fiber orientation.

The fiber orientation of [0±45/90] which would be a 4 layer fabrication is considered for the design. The prepared half profile of the spoiler will be fitted into the female mould which is of the same copy as that of the half spoiler profile.

In “The Fundamental Principles of Composite Materials Stiffness Predictions” the Krenchel factor takes into account the angle of the fibre in the rule of mixtures. (Richardson, n.d)

Therefore, $E_c = \eta_\theta E_f V_f + E_m V_m$ [Eq.10]

Reinforcing Efficiency; $\eta_\theta = \sum a_n \cos^4\theta$ [Eq.11]

Where; Ec Young Modulus of the composite

$E_f$ Young Modulus of the fiberglass

$V_f$ Volume fraction of the fiberglass

$E_m$ Young Modulus of the matrix

$V_m$ Volume fraction of the matrix

Hence, the efficiency factor for the laminate lay up [0±45/90]

Where: $\eta_\theta = \cos^4\theta$ [Eq.12]

0°= 1

45°= 0.7071

90°= 0

Laminate in the x-direction.

(0.65*1) + (0.35*0.25) =0.7375

Laminate in the y-direction.

(0.65*0) + (0.35*0.25) = 0.0875

Prediction of the Young Modulus in x-y direction

$E_x = \eta_\theta E_f V_f + E_m V_m$

$E_f$ = 25GPa, $E_m$ = 3.5GPa, $V_f$ = 0.65, $V_m$= 0.35

$E_x$= (0.07375*25*$10^9$*0.65) + (3.5*$10^9$*0.35)

= 13.21GPa

$E_y = \eta_\theta E_f V_f + E_m V_m$

$E_y$ = (0.0875*25*$10^9$*0.65) + (3.5*$10^9$*0.35)

= 2.65GPa

### 6.4.2 Resin Preparation

The resin used in this lamination is polyester resin which is extensively discussed in chapter two. A locally manufactured polyester resin with a code R 10-03 would be used because of its rigid orthopthalic nature. A mixed styrene monomer will be added to the resin to decrease the viscosity of the resin. Hardener with a ratio of 100:33 would be mixed with the resin to start the curing process and also build a thorough crosslinking in order to make the laminate stiffer.

### 6.4.3 Lamination Process

The pre oriented half profile would be covered with peel ply film to help detach the laminate from the assembly whereas on top of it a release film is applied which serves as a conduit for easy flow of resin. The laminate would then be wrapped up with a flow mat that will evenly help in distributing the resin thoroughly over the lamination.

The laminate is effectively done with inlet and outlet pipes for resin injection as well as for exhaling air traps after the laminate is covered with vacuum bag and finally sealed with adhesive tapes.

This would be followed up with fixing the male mould against the female mould to close and complete its formation. The resin is gently released into the mould for uniform distribution over the frame profile, and then the vacuum is opened for the infusion process to commence. Finally sanding and trimming of unwanted parts should to be done after the lamination process.

## 6.5 Downforce of the Rear Spoiler

In the “Theory of Wing Sections” the lift force of a wing is expressed as:

$$f_L = \frac{1}{2} \rho\, \upsilon^2 S\, c_L \qquad \text{[Eq.13]} \quad \text{[Abbot and Doenhoff, 1959]}$$

But, since downforce is anti-lift, then the downforce of the spoiler can be written as;

$$D_f = \frac{1}{2} \rho\, \upsilon^2 A\, c_L \qquad \text{[Eq.14]}$$

Where: $D_f$ Downforce

P Density of moving air particle

$\upsilon$ Velocity of the flowing wind

$c_L$ Co-efficient of lift

However, in “Aerodynamics Aspect of Formula S Racing Car” the fastest speed recorded at any Formula Student driven car event is 140km/h. (Pehan and Kegl, 2002)

Thus, taking the flow speed of wind over the spoiler to be 150km/h which is 42m/s and also considering the angle of attack to be 8°; the co-efficient of lift can be calculated. Stall normally occurs within the boundary layers at high speed of moving air particles over the surface of the spoiler/wing as a result of retarded air.

Therefore, the co-efficient of lift ( $c_L$) = 2Πa [Eq.15] (Benson, 2014)

Where “a” is in radians; thus the 8° = 0.14rads

$$c_L = 2\Pi\ (0.14)$$

$$c_L = 0.873$$

The spoiler airfoil conforms to an elliptical shape from the side view, therefore, its’ side view area can be calculated as;

$$A = \Pi * C_r * C_t \quad \text{[Eq.16]}$$

Where, $C_r$ Span of the spoiler

$C_t$ Distance from the root to the tip

$$A = 3.142 * 1.4 * 0.2069$$

$$A = 0.910 m^2$$

At atmosphere pressure of 150km/h; density of air particle is 1.184kg/m$^3$.

Therefore the downforce required to act on the spoiler

$$D_f = \frac{1}{2}(1.184)\ (42)^2(0.910)\ (0.873)$$

$$D_f = 829.614N$$

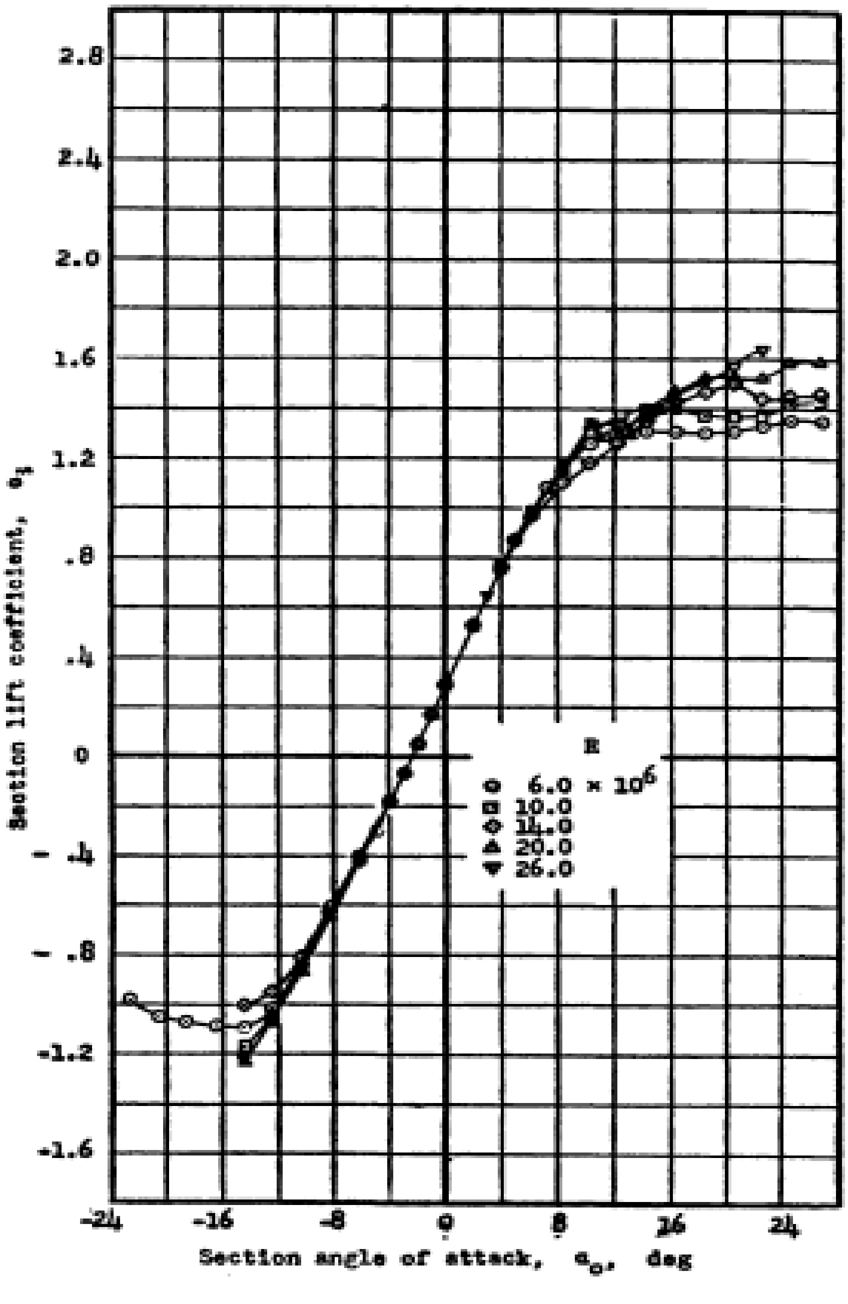


*Figure 21: Co-efficient of lift versus Angle of Attack at high Reynolds number (Abbot and Doenhoff, 1959)*

In order to determine the type of flow within the set speed limit the Reynolds number is calculated.

$$Re = \frac{\rho VL}{\mu}$$

Considering, air particles at 1 atmospheric pressure at 25°C, the kinematic viscosity is $1.5*10^{-5}$ $m^2/s$. (Yunus, 2008, p.798)

However, the chord width of the spoiler = 206.9mm = 0.2069m

$$Re = ((1.184)(42)(0.2069)) / (1.5*10^{-5})$$

$$Re = 6.7*10^5$$

Therefore, based on the results of the Reynolds number the flow is turbulent.

Thus, the maximum stress on the spoiler when a uniform load of 829.614N of down force acts on it can be calculated using the geometry below. (Engineers edge, 2014).

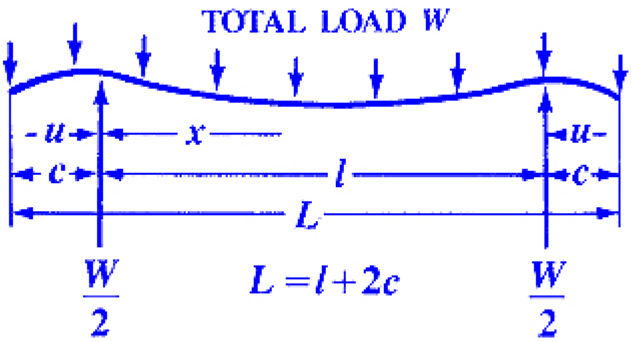


*Figure 22: Beam Deflection with uniform load/downforce*

$$\delta_{max} = \frac{F}{2Il}[c]^2 \qquad \text{[Eq.17]}$$

But $$I = \frac{\pi s t^3}{4} \qquad \text{[Eq.18]}$$

Where: δ Stress at the cross-section being evaluated

*F* Downforce acting on the spoiler

x Distance as indicated

*u* Some distance as indicated

*l* Distance between the two support

*I* Distance from the neutral axis to the extreme fiber edge

*S* Width of the airfoil

t Thickness of the of the airfoil

The closest shape of the airfoil when viewed from the side is taken to be an elliptical solid cross section. The toughness and stiffness of any cross section is subjected to stress and mass moment of inertia about the centroid. Therefore, the mass moment of inertia about the centroid of the solid cross section taking from the side view is given as:

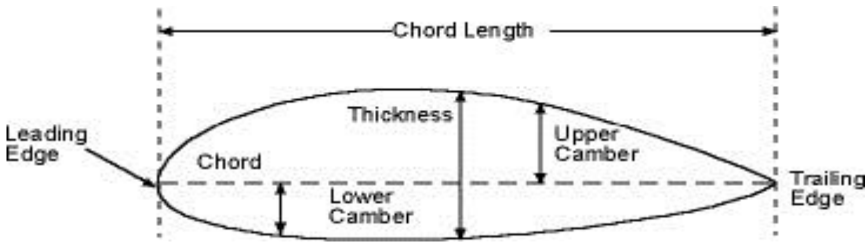


*Figure 23. Side view of an airfoil (Abbot and Doenhoff, 1959)*

$I_{solid} = I_y + I_z$ where: $I_y = \frac{\pi s t^3}{4}$ and $I_z = \frac{\pi t s^3}{4}$ *(eformulae -moment_of_inertia, 2005).*

$$I_{solid} = \frac{\pi\, st\,(s^2+t^2)}{4} = \frac{\pi\,(103.42)(12.9)\,(103.42^2+12.9^2)}{4}$$

$$=11.382*10^6\ mm^4$$

Elliptical solid cross section (Torsion Stiffness) =G $I_{solid}$ [Eq.19]

Where: - G, is the shear modulus of the E-glass fiber.

Thus, the torsional stiffness = $(30*10^9)*(11.382*10^6)$

$$= 3.414*10^{17}\ Nmm/rad.$$

The theoretical calculation of the deflection (y) between the support points and the outer end can be deduced as follows:

$$y = \frac{Fx(l-x)}{24EIl}\,[x\,(l-x) + l^2-6c^2] \quad [Eq.20]$$

$$y = \frac{829.614*0.51(0.805-0.51)}{24(25*10^9)(1.8210*10^{-4})(0.8045)}[0.51(0.805-0.51) +0.805^2-6*0.29^2]$$

$$y = 4.149*10^{-7}\ m$$

## 6.6 Simulation and Analysis

The external flow of air particles around an automobile is considered laminar or turbulence depending on the speed of the car, as previously discussed in Chapter four above. The governing numerical solved equations used to predict the aerodynamic features for two-dimensional incompressible steady-state are the Navier Stokes, which is incorporated with the continuity and momentum equations, given below in the $k-\in$ turbulence model: (Halil et al. 2012)

$$\frac{\partial \mu}{\partial x} + \frac{\partial \upsilon}{\partial y} = 0 \quad \text{[Eq.20]}$$

$$\rho \left( \mu \frac{\partial \mu}{\partial x} + \upsilon \frac{\partial \upsilon}{\partial y} \right) = - \frac{\partial \rho}{\partial x} + \mu \left(\frac{\partial^2 \mu}{\partial x^2} + \frac{\partial^2 \mu}{\partial y^2}\right) \quad \text{[Eq. 21]}$$

$$\rho \left( \mu \frac{\partial \mu}{\partial x} + \upsilon \frac{\partial \upsilon}{\partial y} \right) = - \frac{\partial \rho}{\partial x} + \mu \left(\frac{\partial^2 \upsilon}{\partial x^2} + \frac{\partial^2 \upsilon}{\partial y^2}\right) \quad \text{[Eq.22]}$$

The $k-\epsilon$ turbulence model illustrates two terms with the k symbolizing the turbulent kinetic energy of the transported variables whereas the second transported term $-\epsilon$ is the turbulent dissipation which determines the rate of dissipation of the turbulent kinetic energy.

## 6.7 Finite Element Analysis (FEA)-Nastran

A static load simulation is applied to the spoiler which conforms to a NACA four digit deep cambered thin section airfoil with Nastran software.

The Nastran software is written in FORTRAN which is an imperative programming language that is applicable in evaluating scientific and numerical computational models.

Mathematically, the finite element analysis (FEA) provides numerical approximate solutions to partial differential equations to minimize an error function and give stable solution. The spoiler was analyzed with a uniform load of 829.614 N, which is the maximum downforce of the designed spoiler. This resulted to a maximum stress of 2.309 MPa at a displacement of 4.451 mm. Further analysis was executed with uniform load between 700 N to 100 N with their corresponding stress and displacement as tabulated below.

Table 11: Nastran Simulation data of spoiler

| **Downforce (N)** | **Stress (MPa)** | **Displacement (mm)** |
|---|---|---|
| 829.614 | 2.309 | 4.451 |
| 700 | 1.949 | 3.755 |
| 600 | 1.670 | 3.219 |
| 500 | 1.392 | 2.682 |
| 400 | 1.113 | 2.146 |
| 300 | 0.835 | 1.609 |
| 200 | 0.557 | 1.073 |
| 100 | 0.278 | 0.536 |

The simulation was executed by exporting the solidworks designed spoiler in IGES format.  Nastran simulation offers the capability to geometrically mesh the spoiler in 3D tetrahedral, triangular nodes.  Mesh is the grip that encompasses the spoiler. A fixed constraint is applied at the faces of the fulcrum before exerting the uniform load.

The figure below shows the meshed spoiler with the constraint at the supports when uniform load is applied.

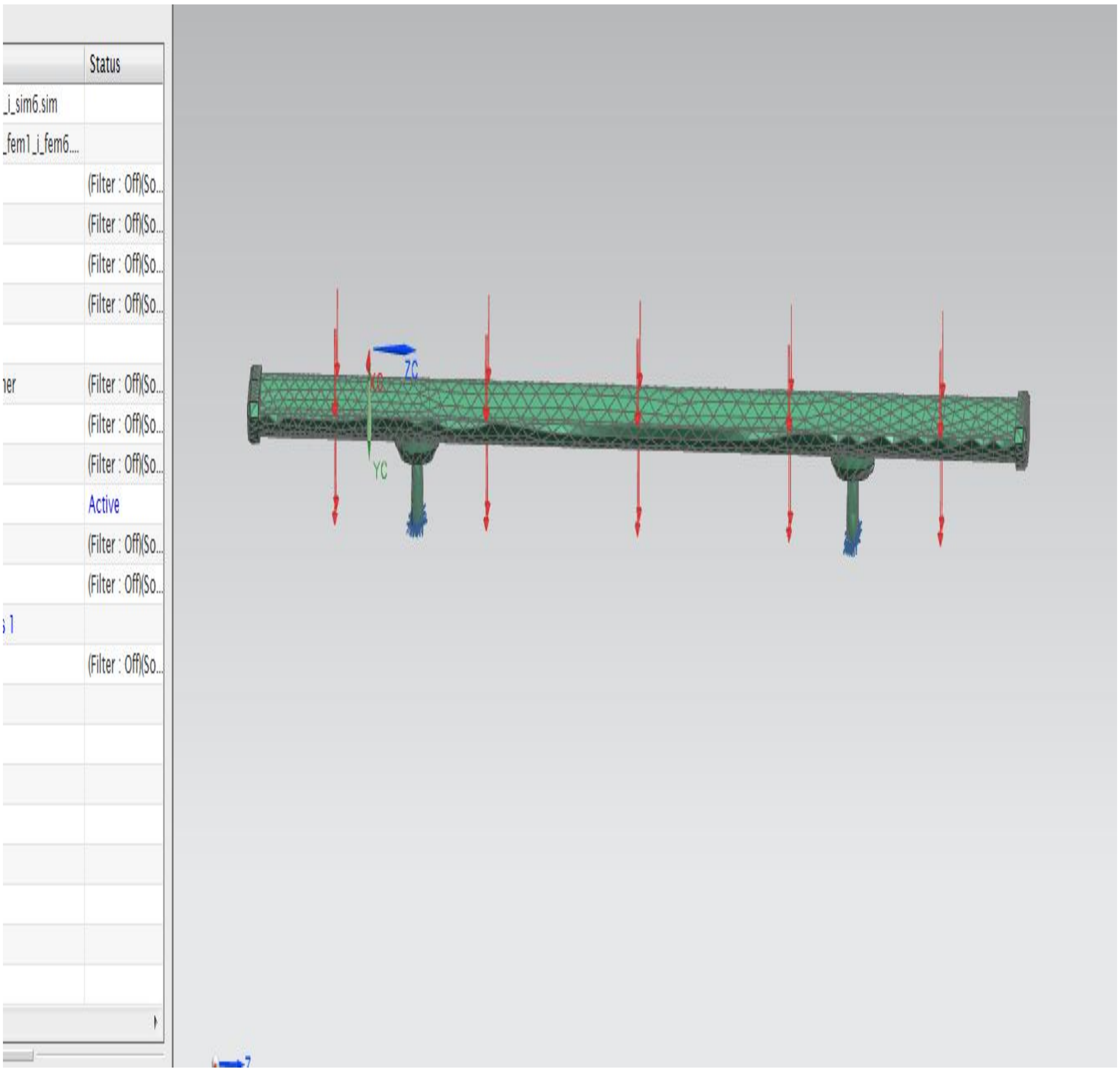


*Figure 24. Fixed constraint and uniform load applied on the meshed spoiler.*

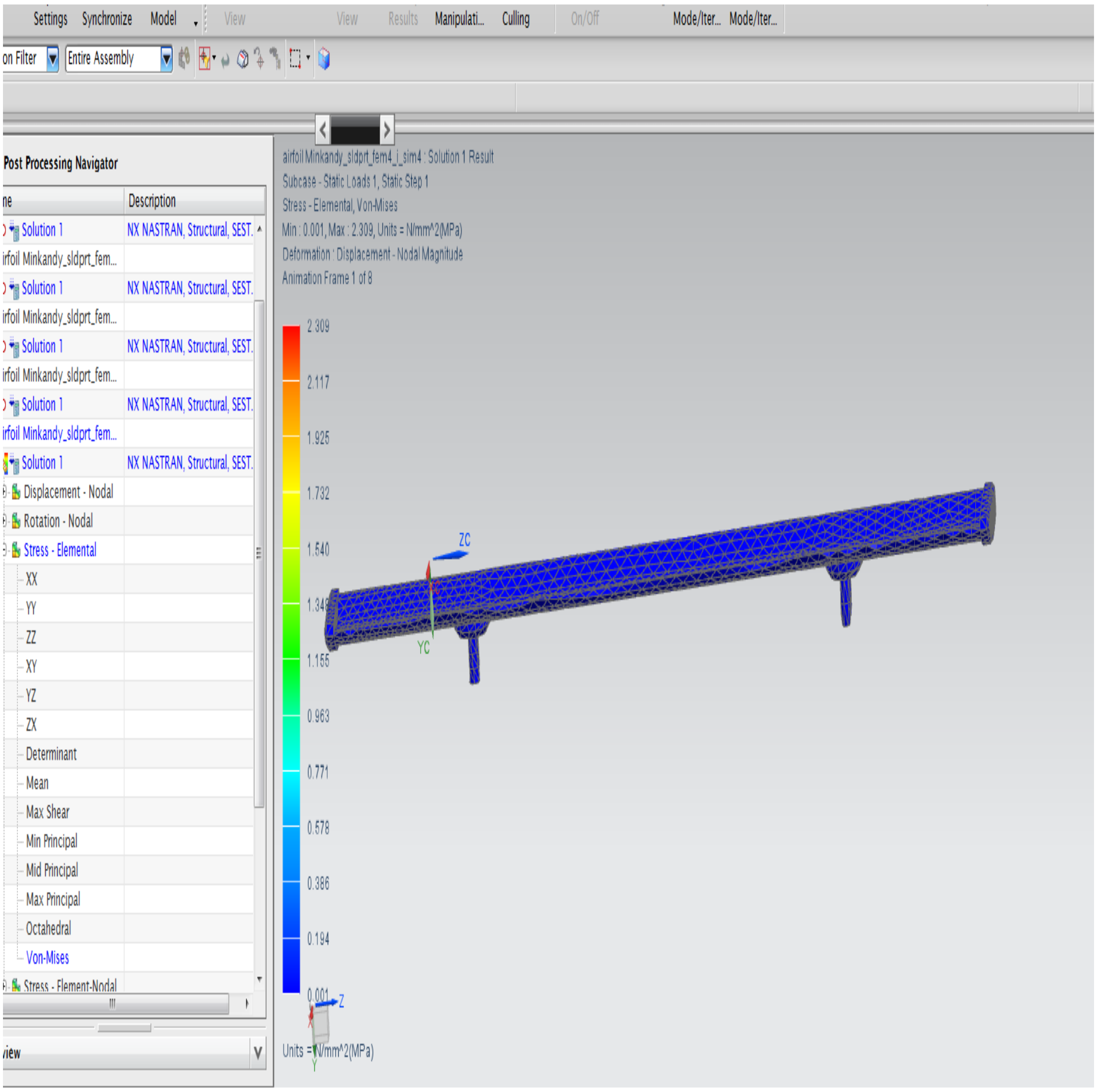


*Figure 25. Maximum Stress of the spoiler at maximum downforce.*

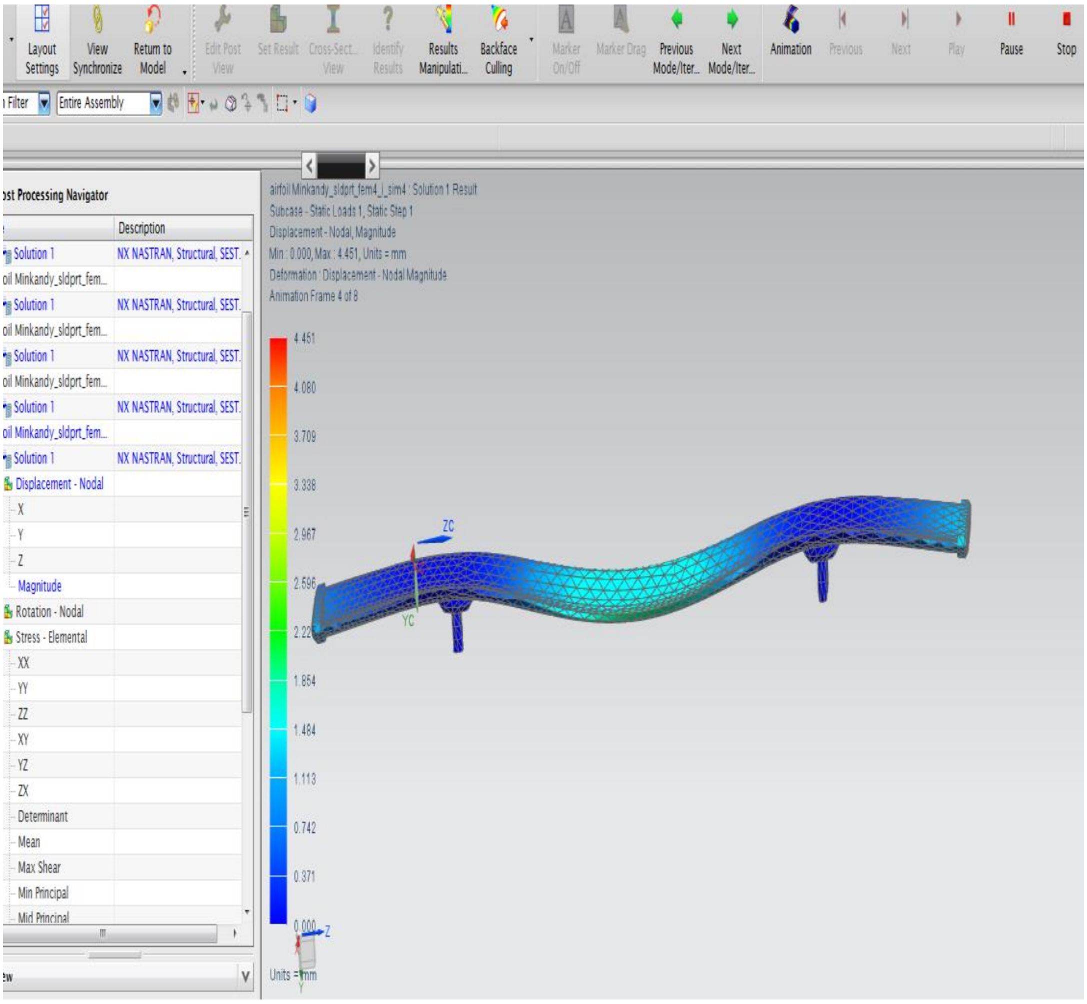


*Figure 26. Maximum Displacement of the spoiler at the maximum downforce.*

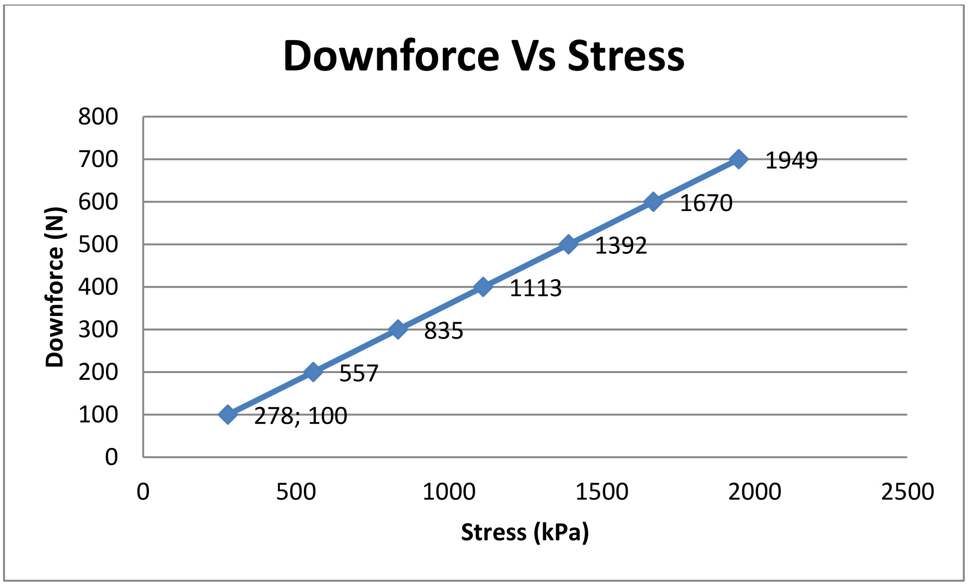


*Figure 27. Downforce versus Stress.*

The graph shows a linear relation between the downforce and the stress exerted on the spoiler.

The results indicate that there is a direct linear relation between the downforce and the stress exerted on the spoiler/wing. It is observed that the downforce exerted on the spoiler is dependent on the flow speed of the wing as well as the pressure difference thereby creating the stress on the fiberglass composite material that encapsulate the rear spoiler.

## 6.8 Determination of Laminate Thickness.

The rear composite spoiler is made of a honey core material. From a top view, the rear spoiler conforms to a rectangular shape. Therefore, from Diab sandwich handbook, the thickness of the laminate can be deduced from the illustration below.

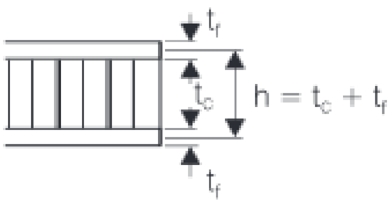


*Figure 28. Fiber thickness of a sandwich panel (Honeycomb sandwich design, 2000)*

Therefore, for a rectangular beam, the moment of inertia will be given as:

$$I= \frac{btd^2}{2} \qquad \text{[Eq.23]}$$

From [Eq.17] the stress at the support is given as: $\delta_{max}= \frac{F}{2Il} c^2$

Therefore, substituting [Eq.23] into [Eq.17], and applying the sandwich concept; the whole equation can be written as $\delta_{max}= \frac{F(tc+2tf)}{4lbtf(tc+tf)^2} c^2$ [Eq. 24]

Where; $d = t_c + t_f = h$

h height of the beam/spoiler

$t_c$ core thickness

$t_f$ fiber thickness

b breath

Thus, in order to find the thickness of the laminate ($t_f$ ),

$$\frac{4\delta \text{max} lb}{Fc^2} = \frac{(tc+2tf)}{tf(tc+tf)^2}$$

Therefore; $$\frac{4*2.309*10^6*1400*206.9}{829.614*297.75^2} = \frac{(25.80+2tf)}{tf(25.80+tf)^2}$$

$$-t_f^3-51.6t_f^2-25.8t_f+0.00071= 0$$

Let $0.00071 \approx 0$;

Thus; $t_f(t_f^2-51.6f_t-25.80)=0$

Therefore, solving the quadratic equation, $t_f^2-51.6t_f-25.80=0$

$$t_f = \frac{51.6 \pm \sqrt{51.6^2-4(25.80)}}{2}$$

$$= 25.80 \pm 25.295$$

Since, the laminate thickness is that layer coverage around the spoiler, then

$t_f$= 25.80-25.295 = 0.51mm.

## 6.9 Estimated Cost Breakdown

Table 10. Estimated cost for the spoiler production (Alibaba, 2014)

| No | Items | Unit | Amount | Unit Cost ($) | Total Cost ($) | Comment |
|---|---|---|---|---|---|---|
| 1 | Fiberglass | $m^2$ | 5 | 2.0 | 10 | |
| 2 | Honeycomb NH-09 | $m^3$ | 1 | 44.00 | 44.00 | |
| 3 | Polyester resin | kg | 2 | 4 | 8 | |
| 4 | Hardener | kg | 1 | 4 | 4 | |
| 5 | Resin pipes | m | 4 | 0.17 | 0.68 | |
| 6 | Styrene monomer | kg | 1 | 5 | 5 | 10% |
| 7 | Flow Mat | $m^2$ | 2 | 0.5 | 1 | |
| 8 | Release film | Roll | One roll | 7.8 | 7.8 | |
| 9 | Labour Fixed Cost | number | 2 | 20*2 | 40 | |
| **Total Cost Estimation** | | | | **$120.48** | | |

# 7. DISCUSSION

This thesis primarily focused on the product design method necessary to manufacture a composite rear spoiler. It touches on the composite material and its properties as well as the suitable method in selecting an airfoil to produce the rear spoiler. The most cost effective method was considered in the manufacturing process for the rear spoiler.

However, the study was based on a lot of research work deployed in the theory of wing profile and its essential functionalities. It also focused on NACA profile of a four digit wing and some applied knowledge acquired from NASA articles.

The spoiler is dimensioned with a chordline of 1400mm and the downforce of 829.614N which was theoretically calculated with assumption of an angle of attack of 8 degrees and wind velocity of 150km/h.

Moreover, the Nastran simulation focused on the most important feature, that is, with the calculated downforce, the maximum stress and displacement exerted on the fiberglass composite rear spoiler.

The effect of the composite sandwich in this design with the thin thickness serves as an effective method to increase bending rigidity without compromising with the structural weight.

# 8. CONCLUSION

This thesis work deployed the use of product design methods in the manufacturing of fiberglass rear car spoiler and Solidworks software for the design of the rear spoiler.

The Nastran NX 8 software was used to simulate and analyze the effect of uniform load when exerted on the fiberglass rear spoiler and the stress it will create on it.

This study was accomplished with some assumptions around the geometry of the rear spoiler with an angle of attack of 8 degrees and the wind speed of 150 km/h in order to calculate the maximum downforce of 829.614 N for the spoiler.

The maximum downforce of 829.614 N was used to analyze the maximum stress on the rear spoiler and this resulted to 2.309 MPa.

However, further simulation was done with downforce from 100 N to 700 N. This shows that the downforce exerted on the spoiler is dependent on the flow speed of the wing as well as the pressure difference thereby creating the stress on the fiberglass composite material that encompasses the rear spoiler.

The lightweight sandwiched structure with a thickness of 0.51 mm provides the overall stiffness to the spoiler. The thin thickness withstood the stress of 2.309 MPa meted on it by the downforce. The stress theoretically calculated for the elliptical shaped airfoil from the side view is an evident that some of the finite elements cannot be totally accounted for, as the simulation outcome accomplished.

# 9. SUGGUESTION FOR FURTHER WORK

This piece of work can be pursued by designing and building a prototype of the composite rear spoiler at the laboratory.

However, further analysis and simulation can be considered; that is different angle of attack for the rear spoiler can be graphed at different downforce.

Wind tunnel testing can be considered when a prototyped rear spoiler is designed and manufactured.

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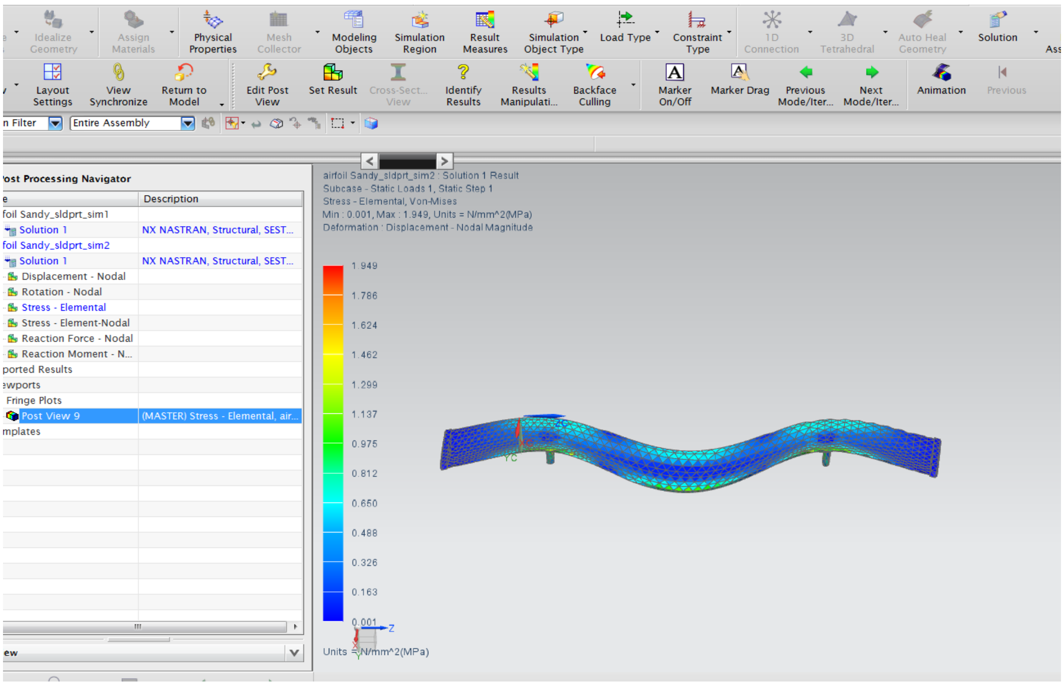
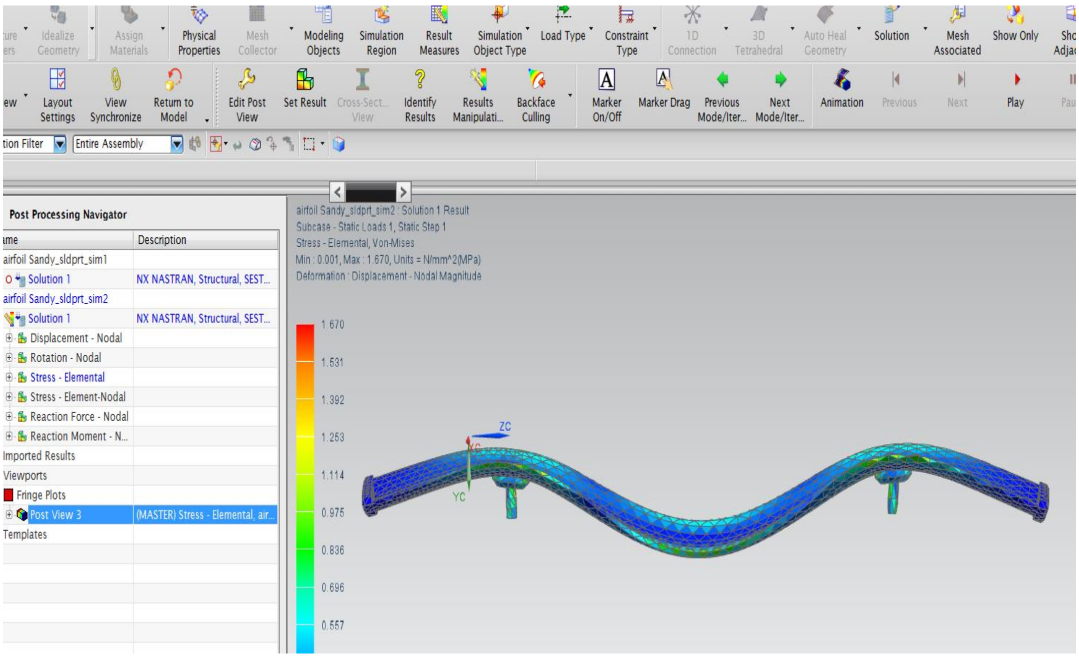
**APPENDIX**

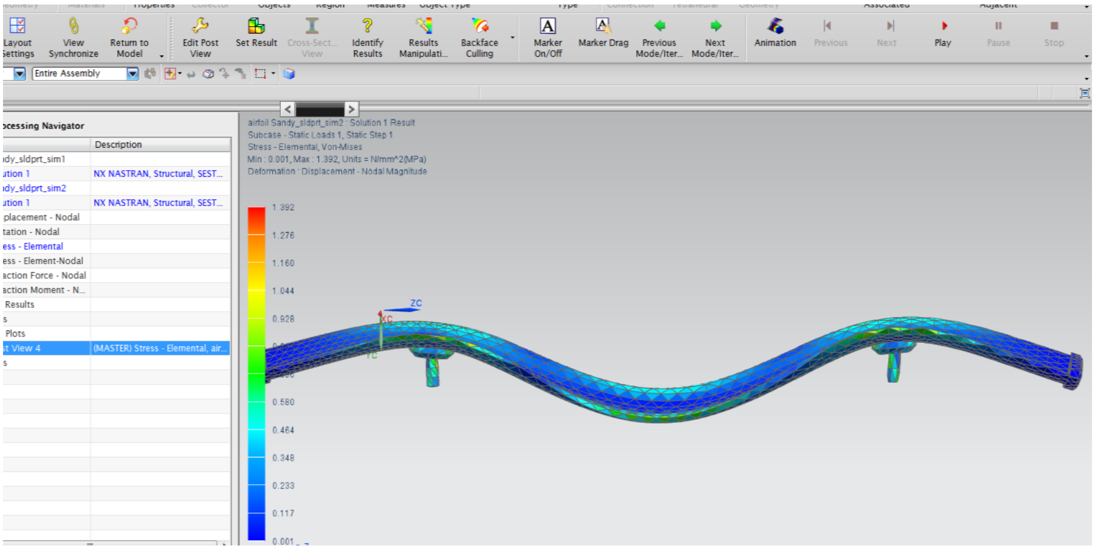
Some of the simulation of Static load with uniform force between 700N to 400N on the designed spoiler.



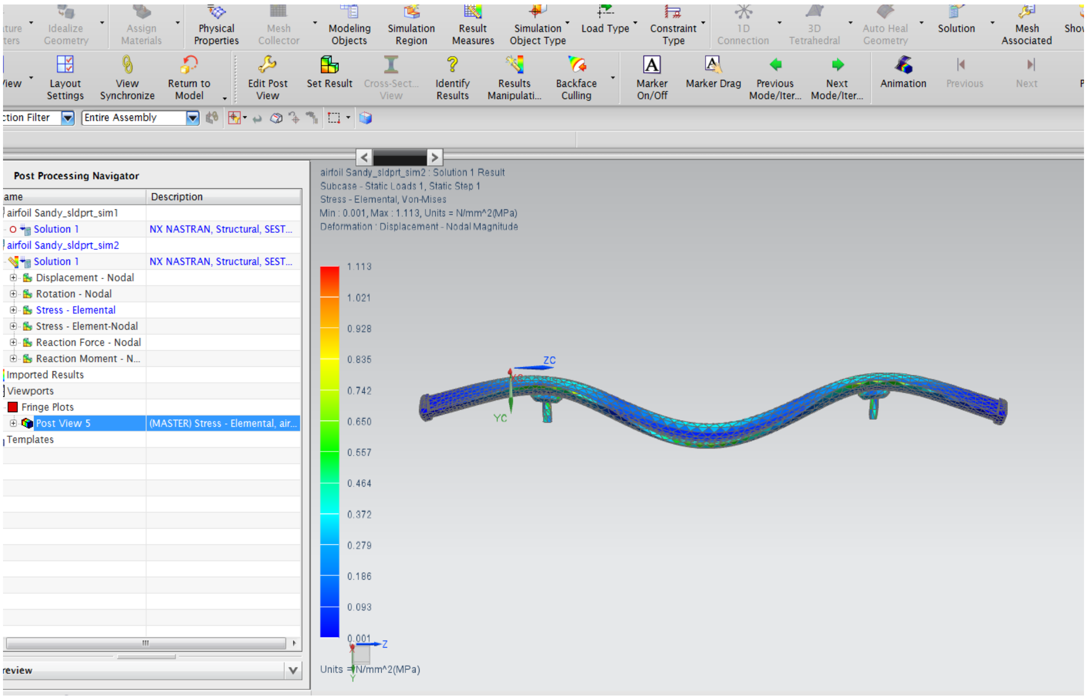

*Downforce of 700N at 1.949MPa*




*Downforce of 600N at 1.670MPa*




*Downforce of 500N at 1.392MPa*




*Downforce of 400N at 1.113MPa*