Detailed Design Calculation & Analysis of Student Formula 3 Race Car

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Abstract: ***The main objective of this paper is to give detailed design calculation and analysis of formula 3 race car vehicle parts. Students team from all over India design and fabricate formula 3 race car in order to take participation in SUPRA SAEINDIA which is organized by Society of Automobile Engineers India. The intension of this paper is modeling and analysis of formula 3 race car vehicle parts according to their design calculation and simulation of part. This paper showcases modeling and analysis of formula 3 car which is performed by using 3D software such as LOTOUS 4.2, SOLIDWORKS 2016, and CREO PARAMETRIC 3.0 and subjected to simulation using ANSYS WORKBENCH 16.2 etc. Various impact analysis were performed in front, rear and lateral direction and then we observed the flexural rigidity of structure and their deformation. This paper deals with design stresses and effect of deformation acting on different components of vehicle parts such as stub axle and stub arm of steering system, temperature analysis of disk brakes and CFD analysis of intake manifold and based on the result obtained from these test the design is modified accordingly. The entire design and analysis process is done according to the requirement mentioned in the SUPRA Rulebook and knowledge of designing and manufacturing learned so far.***

Keywords: Simulation, Analysis, SAE Supra, Calculation

1. Introduction

SUPRA SAE is a event organized by Society of Automotive Engineers to give an opportunity to the engineering students for enhancing and implementing their practical knowledge by designing and fabricating formula 3 vehicles in order to compete with other students which are participating in the event. This paper mainly focuses on the difficulties faced by the students while performing calculations and designing of various parts of the formula 3 vehicle. The purposes of this research paper is to design, calculate and analysis different parts of vehicle so that the vehicle is fabricated at minimum possible cost without compromising with the safety of the driver. We are using LOTOUS 4.2 for the simulation of the suspension and for finding the suspension points, SOLIDWORKS 2016 for the designing of the chassis CREO PARAMETRIC 3.0 for the modeling of the vehicle after completing the modeling the design is tested against all types of failure, stresses and deformation by using ANSYS WORKBENCH 16.2. Based on design calculation and analysis result can be change as per further modifications in dimensions.

2. Methodology

Chassis is the main part of any vehicle it is used to mount all the components of the vehicle such as engine, steering system, suspensions etc. The design of the chassis should be strong enough so that it will support all the components of vehicle and will sustain all the load acting on it. Before designing the structure of the chassis we must keep all the rules and constrains in the mind which are mentioned in the SUPRA SAE rulebook. The chassis is designed in such a way that it should be light in weight and fabricated at minimum cost without compromising with the safety of the driver. The purpose of the frame is to connect rigidly the front and rear suspension of the vehicle which provides suspension points on the chassis. In order to design the structure of the chassis first we have to calculate these suspension points by using LOTOUS SOFTWARE. To calculate these suspension points we have to select the type of steering system and suspension used. In this paper we have selected rack and pinion type steering and double wishbone type suspensions. After calculating the suspension points the frame of the chassis should be designed along these suspension points. The frame of the formula 3 vehicle is designed by using SOLIDWORKS. After designing the structure the main challenge is to select the suitable material for the chassis of the vehicle. By comparing the properties of different material finally AISI4130 is selected for making the chassis. After selecting the material the next step is to perform analysis of the design. The analysis of the chassis is done by using ANYSIS. There are basically two types of analysis which are performed on the vehicle viz. static and dynamic analysis. As the name suggest the static analysis is performed for the vehicle is in stationary condition and the dynamic analysis is done for the vehicle is in motion. This paper mainly focuses on the static analysis. Based on the simulation result further modifications in design and manufacturing was start.

3. Design Specifications

All formula 3 specifications are made on theoretical calculation and can be change as per modification will be done.

Table 1: Design Specification

Chassis	
Weight	33.267 Kg
Material	AISI 4130
Outer diameter	25.4mm
Thickness	1.6mm
Engine	
Model	KTM DUKE 390
Displacement	390
Max.power	43BHP @9500 rpm
Max.torque	35 N-m @7250 rpm
Vehicle dimensions	
Wheel base	1575 mm

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Front track width	1100 mm
Rear track width	1160 mm
Ground clearance	3 inch
Steering	
Geometry	Ackerman
Turning radius	3.182 m
Braking system	
Outer disc diameter	400mm
Inner disc diameter	40mm

4. Design Methodology

By framing the goals and constraints according to the SUPRA SAE rulebook, we quickly identify the least flexible areas of design E. g. the first step of vehicle design was the selection of driver position, track width and wheel base.

4.1. Chassis

4.1.1. Material selection: Selection of material for chassis is the most difficult task, as the chassis has to support all the components of the vehicle and should sustain all the forces as well as loads acting on it, without any deformation. It should be stiff enough to absorb all the vibrations and must be stable at high temperature. It is very difficult to select the suitable material out of various materials available in the market. According to the rulebook of the SUPRA SAE the material which is used for making the chassis should contain at least 0.3% of carbon content in it. In order to select the appropriate material the properties of various materials should be compared. The most common used two materials which are for making the chassis are AISI 1018 and AISI 4130. The different properties of these two materials is compared in the table below.

Table 2: Material Comparison

Properties	AISI 1018	AISI 4130
Density	7.8	7.8
Young's modulus (gpa)	210	210
Elongation at break (%)	19	19
Brinell hardness	120	200
Yield Strength (MPA)	360	460
Ultimate Strength (MPA)	420	560
Strength To Weight Ratio (KN-M/KG)	55-60	72-75
Cost Per Meter	300	350

By comparing the properties of these two materials it is decided to select mild steel AISI 4130 for the designing of the chassis as it contains comparatively better properties than AISI 1018.

4.1.2. Front Impact: For the front impact, driver and engine load was given at respective points. The rear suspensions mounting points and rear wheels position kept fixed. Front impact was calculated for an optimum speed of 60kmph. From impulse momentum equation, 5g force has been calculated. The loads were applied only at front end of the chassis because application of forces at one end, while constraining the other, results in a more conservative approach of analysis. Time of impact considered is 0.3 seconds as per industrial standards.

$F*t = m*(V_i – V_f)$

$F*0.3 = 280*(16.67 – 0)$

F= 15558.67 N

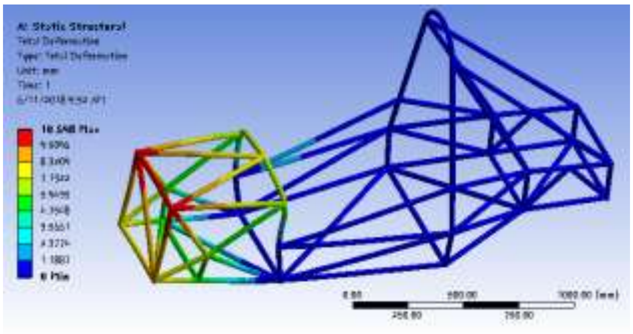

Figure 4.1.2: Total deformation

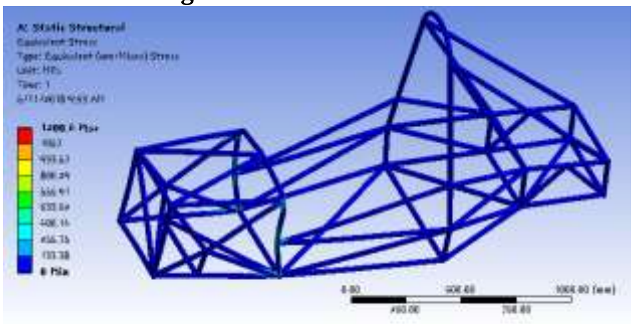

Figure 4.1.2: Equivalent stresses

4.1.3. Rear Impact: Considering the worst case collision for rear impact, force is calculated as similar to front impact for speed 60kmph. The value of 5g force has been calculated. Load was applied at rear end of the chassis while constraining front end and front suspensions mounting points. Time of impact considered is 0.3 seconds as per industrial standards.

$F*t = m*(V_i – V_f)$

$F*0.3 = 280*(16.67 – 0)$

F= 15558.67 N

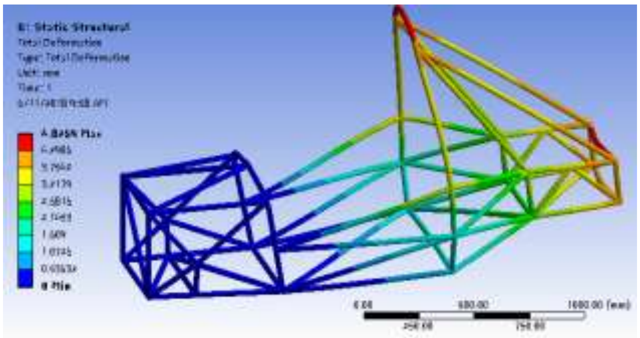

Figure 4.1.3: Total deformation

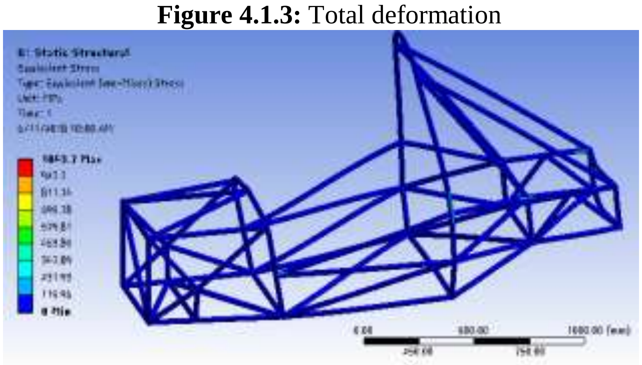

Figure 4.1.3: Equivalent stresses

4.1.4. Side impact: The most probable condition of an impact from the side would be with the vehicle already in

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motion. So it was assumed that neither the vehicle would be a fixed object. For the side impact the velocity of vehicle is taken 60kmph and time of impact considered is 0.3 seconds as per industrial standards. Impact force was applied by constraining left side of chassis and applying load equivalent to 3g force on the right side.

F*t = m*(Vi – Vf)*0.5

F*0.3 = 280*(16.67 – 0)*0.5

F= 7779.33 N

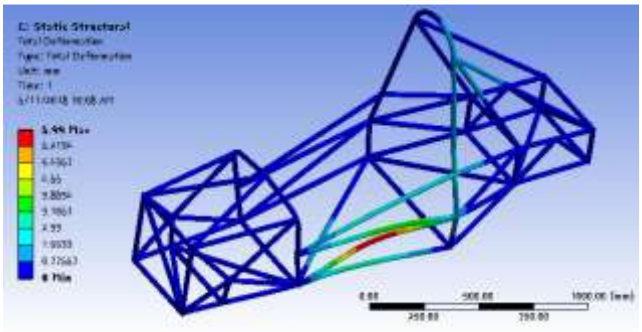

Figure 4.1.4: Total deformation

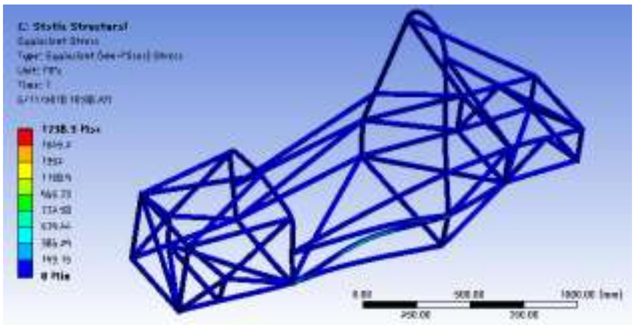

Figure 4.1.4: Equivalent stresses

4.1.5. Modal analysis: During modal analysis, the chassis was tested at the maximum engine RPM that is 9500. This frequency was applied to the entire chassis, and the total deformation was obtained.

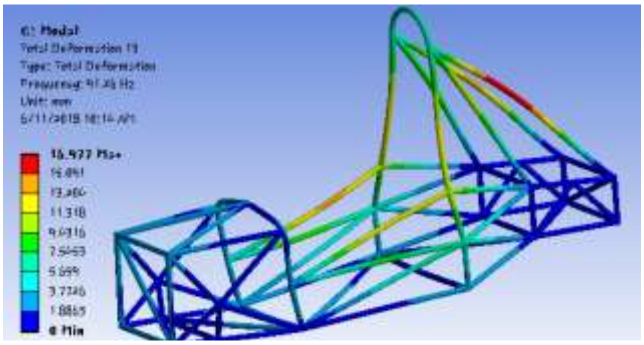

Figure 4.1.5: Total deformation

4.2. Engine & transmission

4.2.1. Introduction: A single cylinder four stroke 390 cc engine is selected. So there had number of options for the selection of engine such as CBR-250R, KTM 390 and RE-500 etc. After long research work and survey, it is decided to use KTM DUCK 390cc ENGINE to power a vehicle. It have inbuilt gear box of manual 5 speed constant mesh gear box, with the multi plate wet multidisc clutch. So the design is according to the engine specification.

Table 3: Engine Specification

Engine	KTM DUCK 390CC
Displacement	390CC
Max power	43BHP@9500RPM
Max torque	35NM@7250RPM
Compression ratio	12.9:1
Weight	36KG
Bore	89MM/60MM
Coolant system	WATER COOLED

4.2.2. Air intake: In an internal combustion engine, during the suction the engine takes in the air from the atmosphere through the intake port. A proper ratio of air fuel mixture is required in order to increase the efficiency of the engine and to achieve greater torque. The air intake system mainly comprises of three parts restrictor, plenum and runner. The air comes in from the restrictor then flows through the plenum and finally through the runner which feeds the air to intake port of the engine. According to the rule of SUPRA SAE the diameter of the restrictor should be 20mm which limits the engine power capability by reducing the mass of air passing through the restrictor. Thus air intake system is designed in order to get maximum possible mass flow of air with high velocity in order to meet the requirement of the engine. To achieve stagnation of air plenum is used. Runner is used to connect the plenum with the engine. The length of the runner is the key factor to decide as the as the performance of the whole intake system depends upon the runner length.

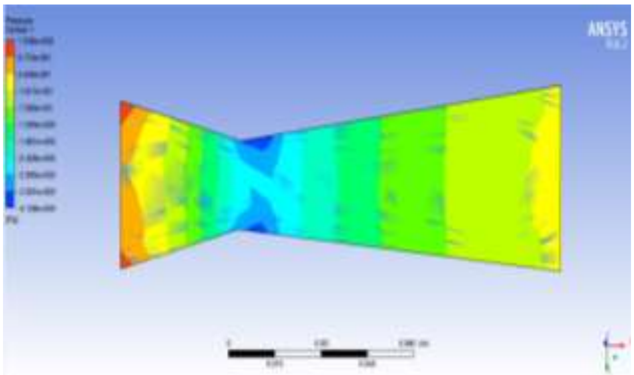

Figure 4.2.2: Air Intake CFD analysis

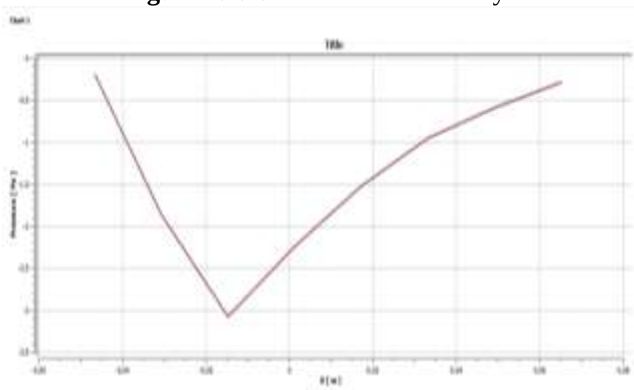

Figure 4.2.2: Pressure Displacement Graph

4.3. Suspension

Suspension is one of the most important component of the vehicle it allows relative motion between the wheels and the vehicle. The type of suspension used depends upon how forces are transferred from the wheels to the chassis. In

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SUPRA SAE formula 3 car generally double wishbone type suspension is used. It consist of two arm upper and lower arm between which the spring and damper is connected. The upper and lower arms are of different structure according to the requirement. The points at which the wishbone is connected to the chassis is located by using LOTUS V5 called as suspensions points.

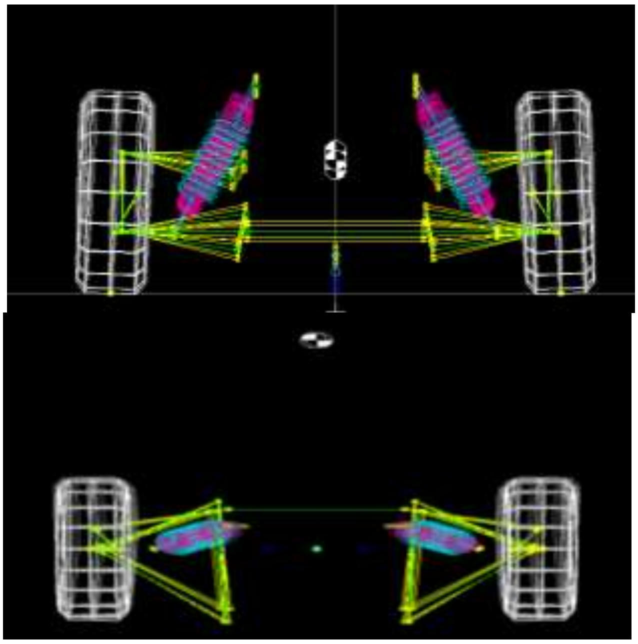

Figure 4.3: Front Suspensions Analysis

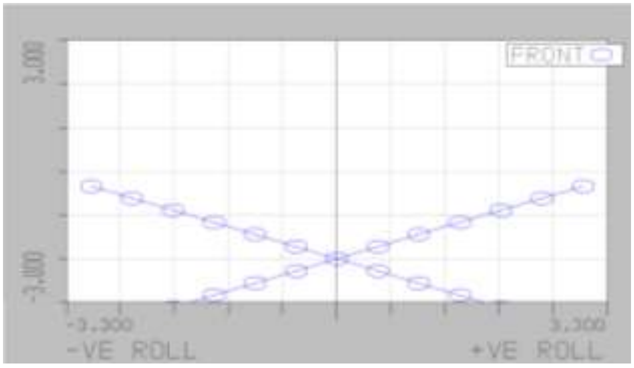

Figure 4.3: positive & negative chamber graph

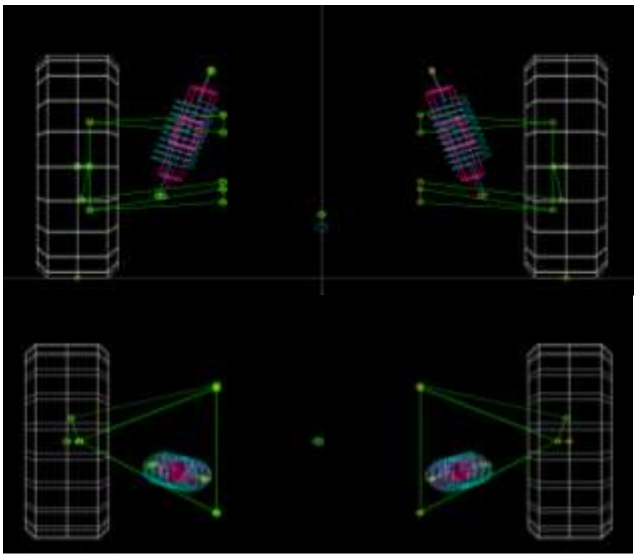

Figure 4.3: Rear Suspensions Analysis

4.4. Steering system

The main purpose of formula 3 car steering system is to take sharp turn with less effort without skidding of the front wheel. While taking a turn if both the wheels turn by same angle then there is a possibility of skidding. To avoid this skidding phenomenon Ackerman principle is used. Ackerman geometry helps to turn the inner wheel by greater angle as compared to outer wheel and thus avoiding skidding. We are using rack and pinion steering system because of its simple construction, less space required and reduced complexity.

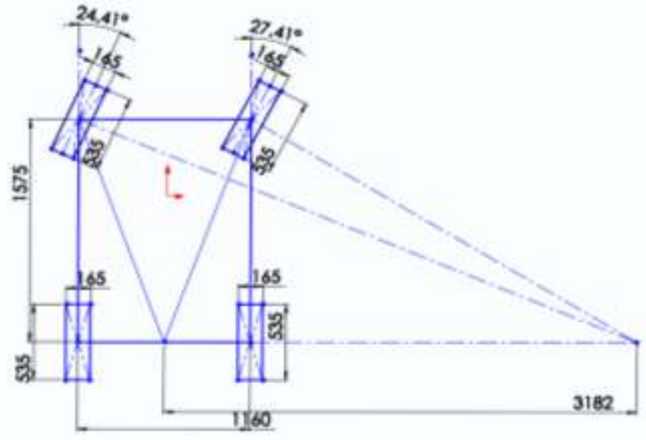

Figure 4.4: Ackermann's Steering Geometry

Table 4: Steering Parameters

Wheel Base	1575 mm
Front Track Width	1100 mm
Rear Track Width	1160 mm
Minimum Turning Radius	2449.95 mm
Maximum Turning Radius	3182 mm

4.4.1. Weight distribution

The total weight of vehicle is 280kg including driver, the weight distribution is very important to understand the vehicle dynamics and analyzing the vehicle in various aspects. The weight distribution was assumed to be 40% of total weight that is 280kg in the front and 60% in rear portion of vehicle. By the theoretical calculation the location of center of gravity was calculated.

4.4.2. Steering calculation

- Wheel Base(L) = 1575 mm
- Front Track Width (a)= 1100 mm
- Rear Track width (b) = 1160 mm
- Track Rod (d) = 910 mm
- Track arm (r) = 350 mm
- Inner steering angle = θ
- Outer steering angle =φ

Slip angle $\alpha = \tan^{-1}$(0.5*front track width (a)/wheel base (L))
Slip angle $\alpha = 20.22^{o}$

According to Ackermann's steering method,
Now, assuming $\theta = 40^{o}$ and $\alpha = 20.22^{o}$
Hence, $\cot\varphi - \cot\theta = (b/L)$
$\cot(\varphi) - \cot(40) = 1160/1575$
$\varphi = 27.410^{o}$
Maximum Turning Radius

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Sinα = w/R = a/R
ThereforeR = a/sinα
= 1575/sin(20.22)
Maximum Turning Radius =3182mm=3.182m

Minimum Turning Radius
Tanα = w/R = a/R
Therefore R = a/tanφ
= 1575/tan(27.410)
Minimum Turning Radius = 2449.95mm
= 2.449m

Assumptions:-
Mass in front tires (m) =96.1kg
Average velocity (v) = 30 km/hr =8.33 m/s
μ =0.6

Normal Force on Stub Axle:
N=m*g
=96.1*9.81
= 942.74 N

Lateral Force on stub axle:
Lateral Force = mv^2/r
= 2095.62 N

Tractive force:
Force due to traction = μ*Normal force
= 565.64N

4.4.3. Structural analysis of stub axle of wheel: Mass in front was considered 96.1kg, thus weight on one wheelstub axle would be half of front weight.

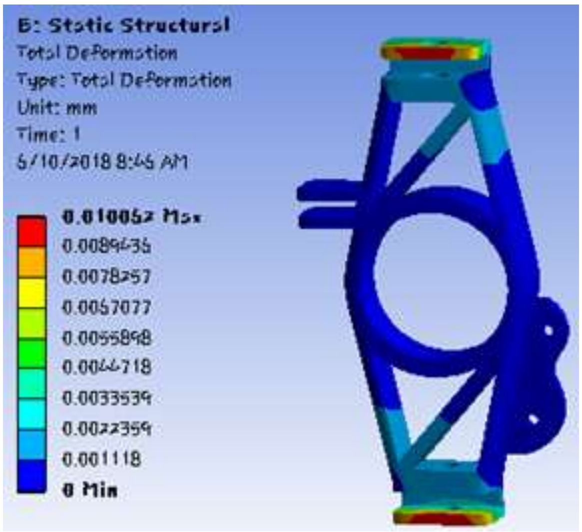

Figure 4.4.3: Total deformation

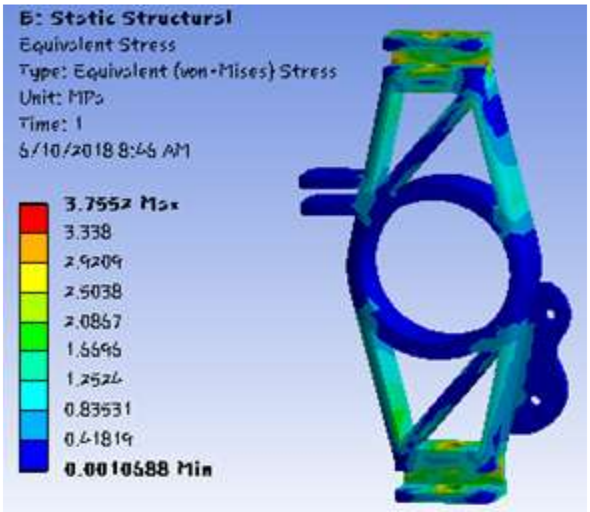

Figure 4.4.3: Equivalent stresses

0.010062mm of deformation is occurred when the load o 565.64 N was applied. Internal stress generated due load applied was 3.7552Mpa.

4.4.4. Analysis at Lateral Force (while turning): Lateral force calculated was 2095.62 N. Only half load are applied in one side 1047.84 N

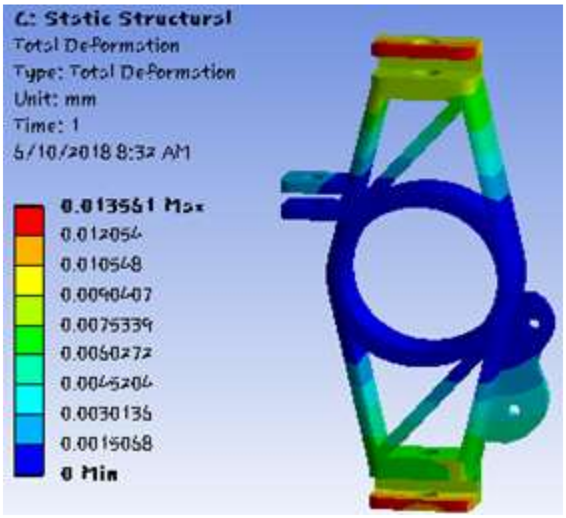

Figure 4.4.3: Total deformation

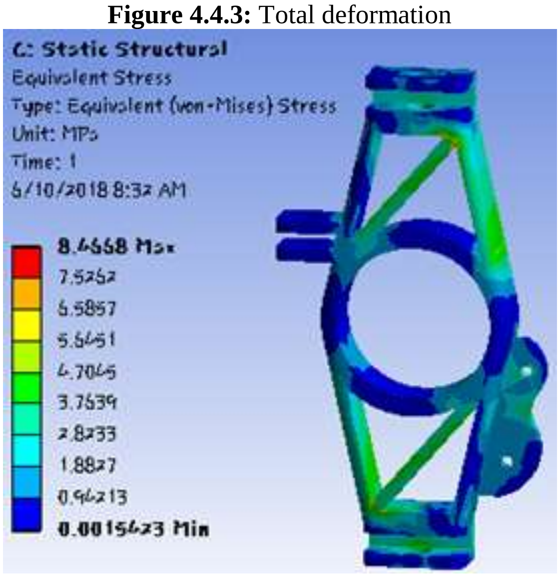

Figure 4.4.3: Equivalent stresses

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0.013561mm of deformation is occurred when the load of 1047.84 N was applied. Internal stress generated due load applied was 8.4668Mpa.

4.4.5. Structural Analysis of stub arm: load on the both the front wheels, so on one stub arm 50% load with factor of safety was taken.

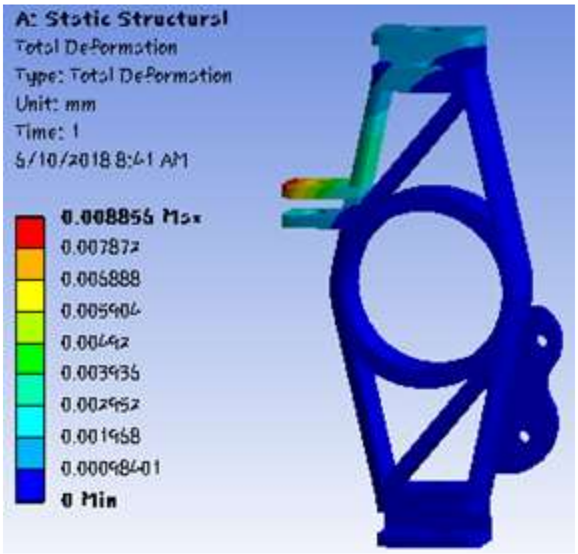

Figure 4.4.3: Total deformation

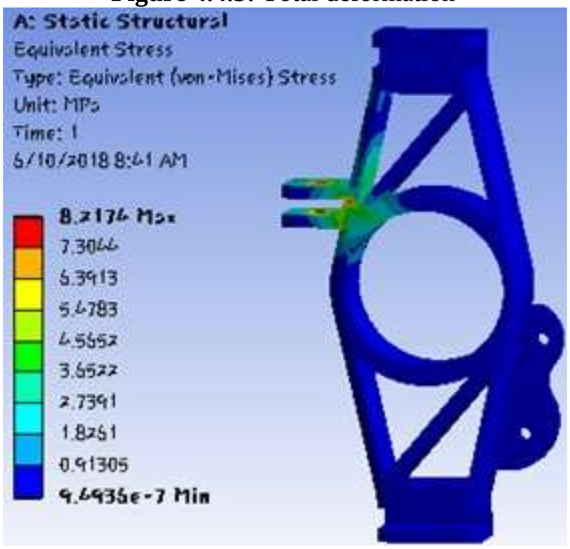

Figure 4.4.3: Equivalent stresses

0.008856 mm of deformation is occurred when the load of 1047.84 N was applied. Internal stress generated due load applied was 8.2174Mpa.

4.5. Braking system

Braking system is one of the important part of the all the racing vehicle, it is necessity for the safety point of view, in all the condition it is necessary for their perfect functioning. As per the rule book of SUPRA SAE it was compulsory for the system to consist of two independently operated hydraulic circuits. Also, all the four wheels must lock simultaneously. In order to implement fool proof safety we also has to keep a brake over travel switch.

4.5.1. Brake disc calculation

Mass of the vehicle = 280kg
Initial velocity (u) = 16.67 m/s (60kmph)
Final velocity (v) = 0 m/s
Brake rotor diameter = 0.4m
γ =0.3
Percentage of kinetic energy that disc absorbs (90%)
K =0.9
Coefficient of friction for dry pavement μ = 0.9
Stopping distance
$S = u^2/2g\mu$
$= (16.67)^2/2*9.81*0.9$
S = 15.46 m
Deceleration of vehicle
$a = v^2-u^2/2*S$
$= 0^2-(16.67)^2/2*15.46$
a = 8.98 m/s
Stopping time
V = u + at
0 = 16.67+8.98*t
t = 1.85 sec

a. Energy generated during braking
$K. E. = \gamma K * m (u-v)^2/2$
K. E. = 10504.2 J

b. Brake power
$P_b = K. E. /t$
P_b = 5677.93 W

c. calculate the heat flux (Q)
$Q = P_b/A$
$Q = 405560 W/m^2$

Steady state thermal analysis coupled with static structural analysis was performed in ANSYS WORKBENCH. The CAD modal of disk brake was created in SOLIDWORKS 2016 per the real disk brake of APACHE RTR and then was exported for analysis.

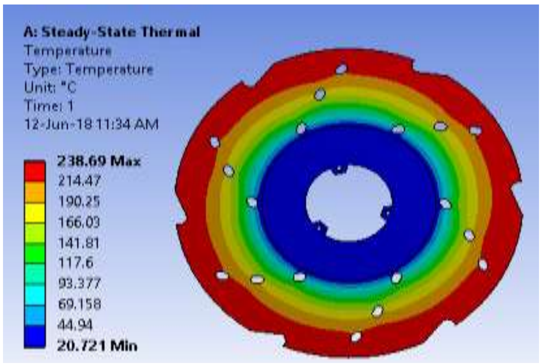

Figure 4.5.1: Temperature Analysis

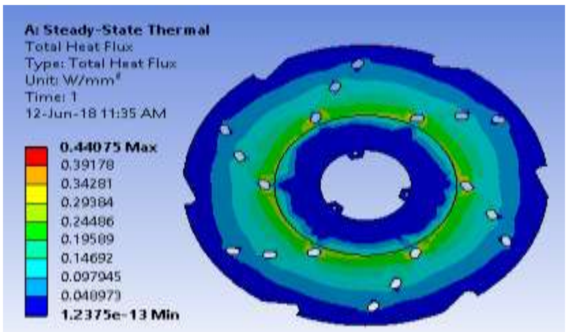

Figure 4.5.1: Heat Flux Analysis

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5. Result

Chassis impact test: The maximum forces are applied on the chassis and the test is performed and finally we got the following result.

Sr. no.	Impact	Force	Total Deformation	Equivalent-stress
1.	Front	15.558KN	10.698 mm	1200.4 Mpa
2.	Rear	15.558KN	4.8045 mm	1043.7 Mpa
3.	Side	7.7793KN	6.99 mm	1738.33 Mpa

Modal Analysis: The following result is found by applying the possible maximum frequency.

Sr. no.	Frequency	Total deformation
1.	91.26 Hz	16.97 mm

Wheel stub axle: The maximum force is applied on the wheel stub axle and calculated the result as shown below.

Sr. no.	Force	Total deformation	Equivalent-stress
1.	565.64 N	0.010062 mm	3.7552Mpa

Turning stub axle: The maximum force is applied during the turning of the wheel and tested which gave result as follows.

Sr. no.	Force	Total deformation	Equivalent-stress
1.	1047.84 N	0.013561 mm	8.4668Mpa

Stub arm: The Tie-rod force is applied on stub arm and tested to get the following result.

Sr. no.	Force	Total deformation	Equivalent-stress
1.	1047.84 N	0.008854 mm	8.2174Mpa

Brake disc: Temperature of disc brake is increased to 238.69 °C which gave the total heat flux of 440700 W/m^2.

Sr. no.	Temperature	Total Heat flux
1.	238.69 °C	440700 W/m^2

6. Conclusion

This paper focus on the design, analysis and calculation of various components that is necessary for fabrication of a formula 3 race car. We have performed various types of static analysis and applied different loading condition on the chassis and it if found to be safe according to their factor of safety. We also learn how to select appropriate material for the safe design of chassis. Successful analysis was perform on the chassis of CAD modal using ANSYS WORKBENCH to determine, equivalent stresses, and total deformation results. The engine is selected and drive train designed such as to give maximum performance in terms of designed such as to give maximum performance in terms of speed as well as fuel economy. We have designed air intake system and also performed CFD analysis. The convergent and divergent angles are selected so as to get minimum pressure loss though the restrictor. The suspension pints is find out using LOTOUS. The type of steering system used is rack and pinion and all the calculation are done using Ackerman's principle. The design of knuckle is done using SOLIDWORKS and analysis is performed. Detailed calculation of brakes is discussed in this paper and the maximum temperature is evaluated using software. Thus, after all the calculations and analysis, it is finally conclude that this formula 3 vehicle is safe for fabrication under healthy engineering practices and meets the performance targets.

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