Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 08, August-2019

Optimization and Analysis of Mechanical Power Flow in a Formula Student Car

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Abstract— **The purpose of this paper is to optimize and analyze the drivetrain of a Formula Student car along with its engine and tires i.e. POWERTRAIN. The paper basically focuses on the major components and factors which are involved in the flow of power right from the engine up to the tractive force transmitted by the tires to the road. The paper discusses the design of and analysis of a powertrain to utilize maximum efficiency from each component compatible with an economical project. Precisely, we will consider an engine with much less capacity and power than the limit mandated by the SAE rules which is 610cc, optimize it by designing an intake system (runner, restrictor and plenum) reducing pressure drop, maximizing volumetric efficiency and thus power, design an efficient transmission for minimizing losses and enhancing performance and select the tires which will be most suitable with the present configuration.**

Keywords:- Differential, slip, transmission, spool, slicks, AWT, adhesion, hysteresis, plenum, restrictor, wings, sidepod, downforce, halfshafts, constant velocity joint

1) INTRODUCTION

FS regulations mandates the team to use an engine with displacement less than 610cc,with a compulsory air intake having a 20mm restrictor after the throttle to restrict the dominance of powerful engine in the competition. Supra SAE is one of the Indian version of Formula Student competition, which is held nearly every year at the BIC, Noida. The paper will focus on optimizing and analyzing the powertrain in the given condition on this circuit. We will be considering the acoustic wave theory to determine the runner length using LOTUS engine simulation software. Along with this, we will also be using FLOW SIMULATION to minimize the power loss through the restrictor and testing air intake plenum for maximizing volumetric efficiency by SOLIDWORKS 2016.Tire and transmission will also be analyzed to get maximum performance out of them. It will involve some calculations to show the effectiveness of the optimization along with the emphasis on the need of aerodynamics in different cases and analysis of the track and ambient conditions .Racing is not about getting a powerful engine, efficient transmission, designing a light chassis, compatible suspension, brand new tires and a good driver to win the race, It might bag 3rd or 4th .But, some other team might get a similar combination tune them to perfection to bag the 1st place.

2) CONDITIONS AND CIRCUIT

A) CONDITIONS

Analysis of environment and racing track is important for the few calculations related to the car, as different circuits have different ambient conditions and different track conditions too. Since endurance is the biggest event in terms of points (300), a brief knowledge of track conditions is a must.

BUDDHA INTERNATIONAL CIRCUIT

The track length is around 5.125Kms with 16 turns and track width varies between16m-20m with tracks featuring 8% inclines and 10% descending slopes. The ambient temperature being around 36°C, when the competition takes place .Inclines and 16 turns will demand a decent acceleration with a good balance between top speed and acceleration. The turns are designed for F1 cars having a wheelbase around 3m contrary to the FS cars which have wheelbase around 1.65m.It is good for the endurance of FS car whose speed is limited to around 120 Kmph.

BIC NOIDA

3) TIRES

Tires are the final part of the car which transmits power to the road. Good balance between top speed and acceleration was to be maintained. Smaller tires provide more traction force for same torque, have less MOI, reduce the overall weight and also lower the center of gravity of the car .So, out of 16", 18" and 20",we decided to go for 16" tires. For tire type, we had an option between slicks and wets (together) and all

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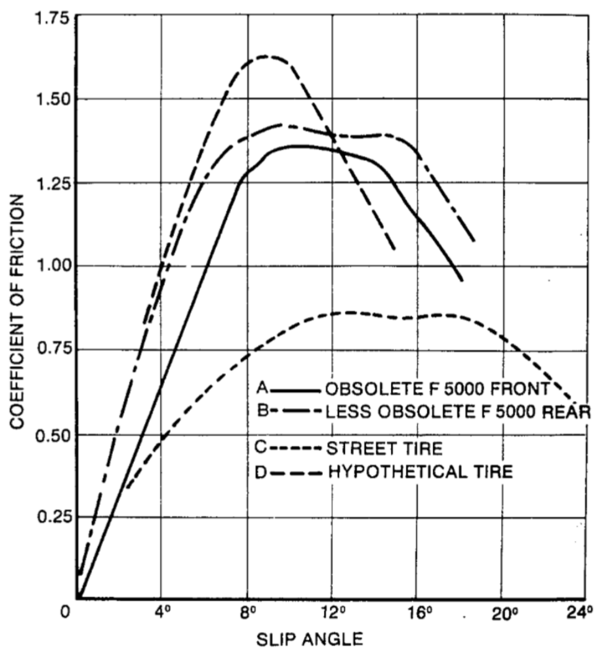
weather tires (AWT).Both slicks and AWT will be compared on different aspects and will be differentiated to get a better position in deciding the type of tire.

	Slicks	AWT
1)	It is almost twice the price of AWT and will also require a set of wets which will have a significant impact on the mediocre budget	It is very cheap as compared to a set of slicks along with a set of wets
2)	Durability is in between 50-100 miles which might just be enough for the competition	Durability is around 50000miles for normal use which might be sufficient for several competitions.
3)	Rapid wear of tire even in case of small misalignment or improper tuning	Rate of tire wear is very low as compared to slicks and wets
4)	Coefficient of adhesion/friction is around 1.6-1.8(in extreme cases)	Coefficient of adhesion/friction is nearly half of the slicks being around 0.8or less.
5)	More grip and stability at corners at high speed.	Not designed for high speed cornering.
6)	Better braking efficiency.	Braking efficiency is not that efficient.
7)	They are designed to bear very large forces in racing.	Designed for normal driving and unsuitable for large forces in racing.
8)	Rubber used is high hysteresis rubber.	Rubber used is low hysteresis rubber.
9)	Temperature dependent performance which is optimum around range of 80°C-90°C for F.S tires	Performance has very less dependence on temperature except in extreme conditions
10)	TTC for common racing tires are available which is an indispensable tool for vehicle dynamics analysis and tuning.	No TTC available, so there is very less probability of vehicle dynamics analysis and tuning.

REASONs FOR SELECTION OF SLICKS-

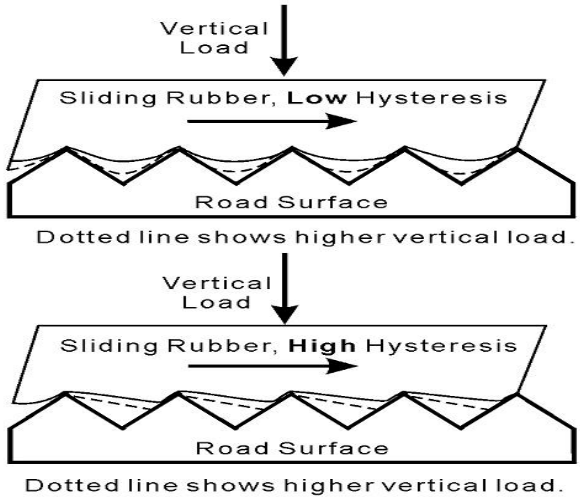
1) Almost double value of coefficient of friction /adhesion, resulting in almost twice the max possible traction force as compared to AWT, which means that more torque could be transmitted to the ground.
2) It is capable of permitting comparatively high speed cornering as compared AWT which is frequent phenomenon in FS competition, be it autocross, skidpad or endurance.
3) Availability of TTC which enables proper tuning of chassis with tires, analysis of vehicle dynamics and suspension design and also helps in deciding the team strategy in terms of attempts in dynamic sections.
4) It also provides us options according to the circuit in terms of compound (but very less flexibility in case of FS competitions).
5) The bald tires also have large area of contact which is also prevalent in case of cornering and bump providing it extra grip and thus stability.
6) AWTs are heavier as compared to slicks because the steel belts embedded for high durability whereas slicks have complex weave of nylon or polyester making it light.



COMPARISON OF DIFFERENT TIRES

GRIP OF RACING ARISES DUE TO-

1) Interlocking-Rubber deforms on the road irregularities.
2) Adhesion- Tire compound sticks best with road at around 80°C to 90°C.
3) Hysteresis-High hysteresis slicks recover very slowly from the deformed state as compared to AWT .So, high hysteresis tire can't push on the downstream and pushes only upstream of road irregularities. So, the pressure difference creates the forward thrust contrary to the AWT which pushes only download.



PROPERTIESS OF SLICKS-

1) As vertical load is increased, the peak lateral friction coefficient occurs at high slip angles comparatively.
2) Up to the peak force, the traction forces increases quickly to max in the slip ratio of 0.1-0.15 which depends on elastic force of tire. After that limit it depends on tread composition, road texture and surface.

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3) Prior to peak, increase in slip gives an increased force which tends to dampen the velocity.
4) Springing rate changes significantly at low inflation pressure.
5) Radial ply tires have soft sidewalls, rigid treads more ultimate grip and sharp decline after peak, making it compatible with experienced driver whereas cross ply has low ultimate grip with gradual runaway, with stiffer sidewalls making it easy for inexperienced drivers.
6) HOOSIER FSAE tires are stiffer than similar GOODYEAR tires.

TUNING AND OPTIMIZATION OF TIRES-

1) Tread circumference for all tires should be checked and the difference should not be more than couple of millimeters.
2)Tire should be inflated by dry nitrogen, as normal air contains some amount of water vapor which might expand on heating and condense on cooling, causing considerable change in the volume and thus radius of the tire.
3) Tires contain plasticizers, which keep them soft and sticky. When tires go through heat cycles, plasticizers melt and cause the tire tread to have a smooth shiny temperature, indicating the loss of softness and sticky nature. Tires can be cooled by deflating the tire and pouring some water on them .Tire temperature should be taken only by needle pyrometer.
4) Tires should not be operated at upper limit of temp for long period. This deteriorates the elastic property and stickiness of tires. The condition can be identified by sooty, black appearance of the tires.
5)Using TTC data to tune car which includes lateral force vs. slip angle ,longitudinal force vs. slip ratio, loaded radius vs. slip angle and several other data. These data can be used for vehicle dynamics analysis and to design the car to deliver targeted performance within the stability range.
6) The car should be tried to run over tire print area which has ability to provide more grip than asphalt rubber combination .Sometimes tire prints are also left intentionally by driver at pit to get better grip in the area.

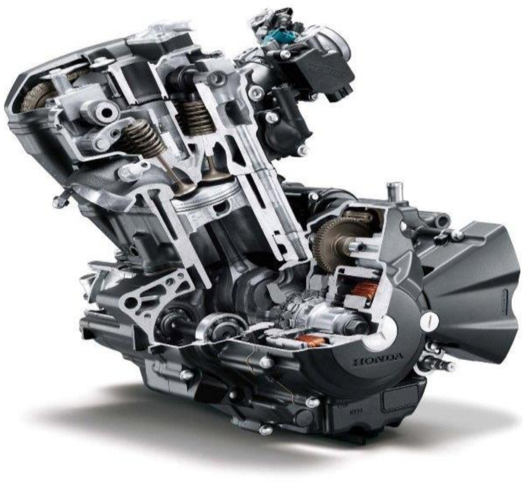
4) ENGINE

Engine selected was CBR 250R (2011 model) single cylindered with liquid cooling and DOHC producing 26 Bhp at 8500rpm and a torque of 22.9Nm at 7000 rpm and weighing just 35 Kg.

REASONS FOR SELECTING CBR250R-

1) Easy availability of this engine, as this low cc model of Honda is more common than other models of higher cc.
2) High Power/weight ratio, as the engine weighs just 35 Kgs.
3) Liquid cooling and better cooling efficiency than the most common engines used in SUPRA like KTM 390 and R.E500 with the stock radiator and fan. Cooling efficiency is also increased due to spiny cylinder sleeve, which also reduces blow by gas and oil consumption.
4) It is cheaper than other common engines used for FS competitions.
5)It has a primary balancer which is gear driven which reduces the vibration and shocks caused due to single cylindered engine having just one 1 stroke out of 4,which also reduces the size of flywheel.

Despite these merits, the engine is not very powerful , hence optimization and analysis of engine will be done, so that maximum output from a small engine can be extracted for desired results.
Apart from this, FSAE rules also mandate the use of 20mm restrictor after the throttle, which restricts the engine to use its max power by starving the engine of proper amount of air needed for complete combustion.



CBR 250R ENGINE

USE OF ACOUSTIC WAVE THEORY-

Acoustic wave theory will be used for determining runner length which will give optimum performance by increasing the volumetric efficiency.
PRINCIPLE- The suction created by the piston in first stroke creates a momentum of air going in that direction, when the intake valves are closed in path of that moving air, compression wave is created. This compression wave travels all the way back to plenum gets reflected from there and return to the intake port .If at that time valve is open and piston will be at max velocity, then the engine will have max volumetric efficiency. So, the runner length is to be made of that length such that the intake valve opens at the time when compression wave reaches the port. Similarly when piston creates suction rarefaction waves are generated which travel till the plenum volume, from where it gets reflected as a compression wave. So, similarly the intake pipes can be used to increase the volumetric efficiency and thus the power of engine.

LOTUS ENGINE SIMULATION SOFTWARE was used to simulate the engine test with various runner lengths for various performance parameters including Power, torque, BMEP and BMFC vs. rpm.

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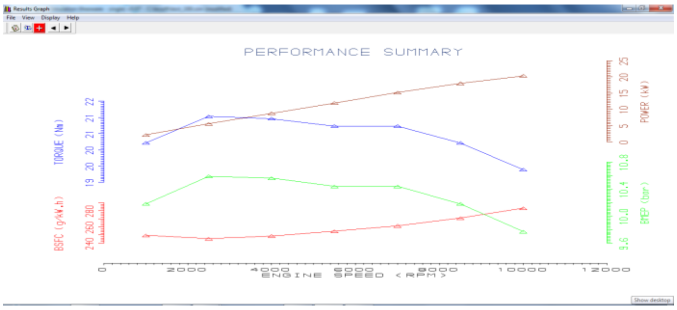
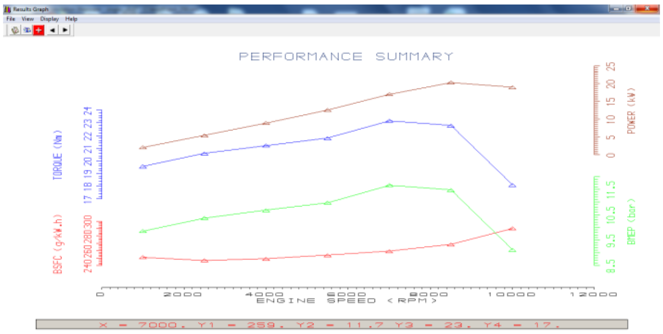


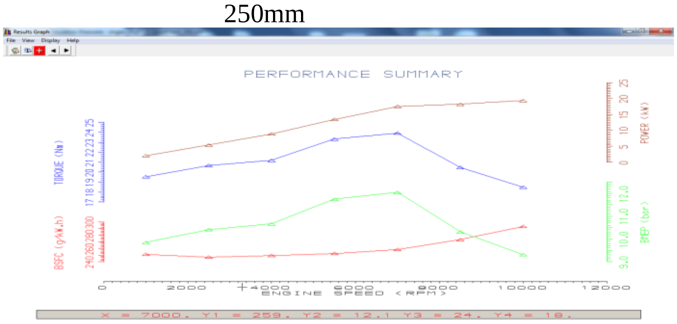
100mm

150mm

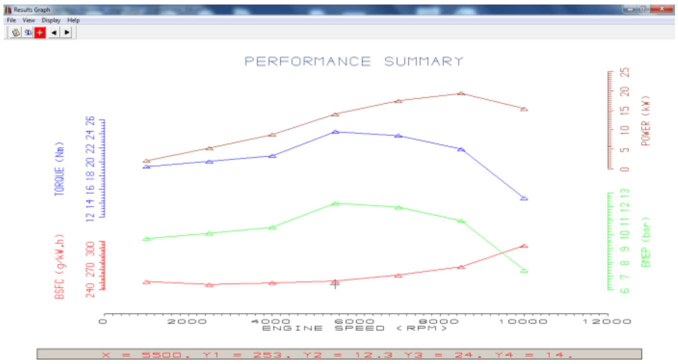
200mm



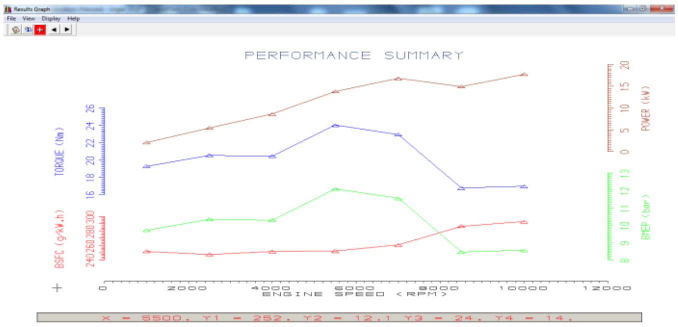
250mm



300mm



350mm



400mm

The 350mm runner pipe was selected after comparing the graphs of other runners on following factors-

1) Highest peak torque which is equal to 24Nm.
2) Peak torque at low rpm for increase in initial acceleration.
3) Good initial torque.
4) Flat torque band in low rpm range for good acceleration at low rpm or speed.
5) Decent increasing power curve.

The runner length is a bit long but it can be adjusted as the engine is small.

<u>Minimization Of Loss Through 20mm Restrictor</u>-

Benefit of a small engine is that it needs much less air as compared to a big and powerful engine like a 4 cylindered 600cc engine, which means much less mass flow rate and also reduced velocity of air, which also leads to less pressure drop across the restrictor.

For restrictor, we had to choose between orifice and C-D Nozzle (or venturi) .On one hand orifice was easy and cheap to manufacture with coefficient of discharge around 0.62 whereas venturi which is a bit difficult and expensive to manufacture and has a discharge coefficient of 0.985 and also has less pressure drop across the restrictor as compared to the orifice.

Different C-D Nozzles were tested for the max flow of air through them at different combinations of converging and diverging angles of venturi and preferring the design with minimum pressure drop.

The Fixed Parameters That Were Assumed For Ambient Conditions-

P=101325Pa

T=311K

Relative Humidity=42%

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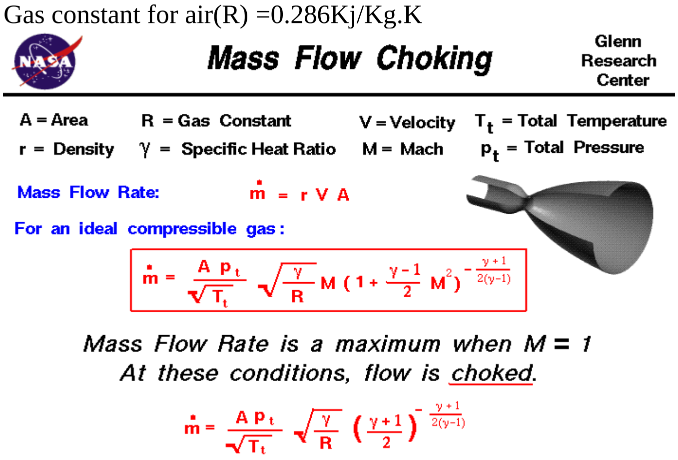
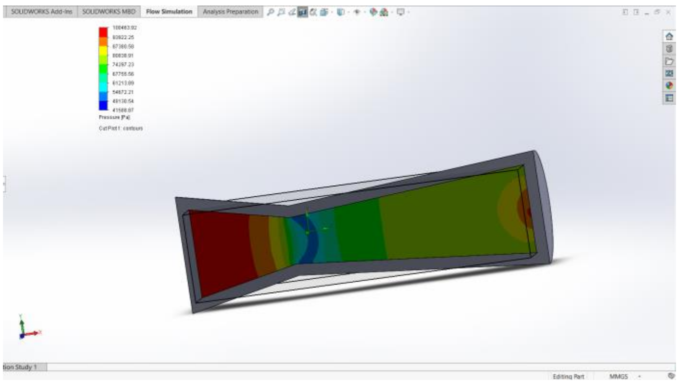
Area for restrictor =0.000314m^2
γ = 1.4 (for air)
Gas constant for air(R) =0.286Kj/Kg.K

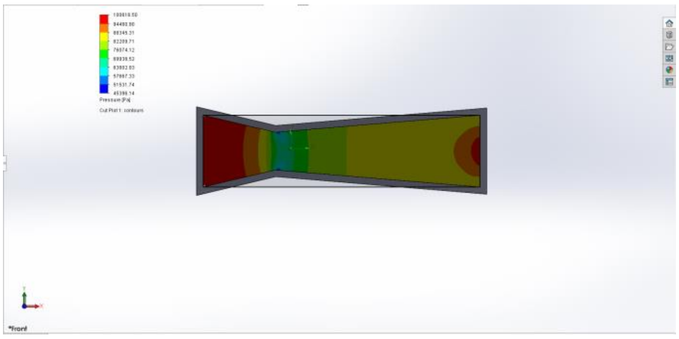


So, applying this formula for incompressible flow for max flow rate of air through the restrictor, we get mass flow rate as-
m = 0.07Kg/s
The C-D nozzles were simulated with the above ambient conditions with varying diverging angles(4°,5°and 6°),inlet and outlet diameter of 38mm and converging angles(12°,14°,16°and 18°) for the given mass flow rate.

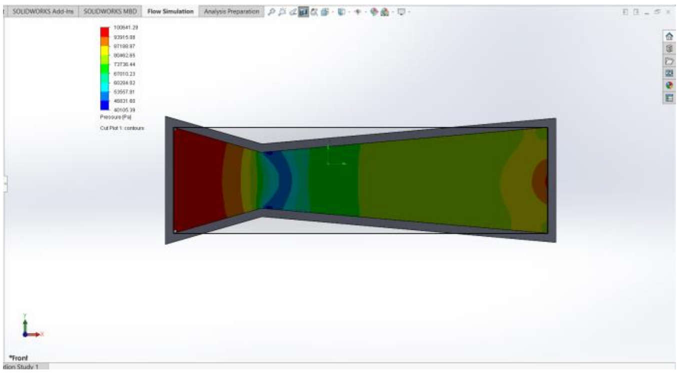
(We will be considering the ambient temperature of around 311K for the calculations related to air intake and engine because due to significant amount of heat radiation and convection the area around the engine and intake will be a bit higher than the ambient air. Whereas the air density calculation for aerodynamics will be calculated with 300K as the ambient temperature)



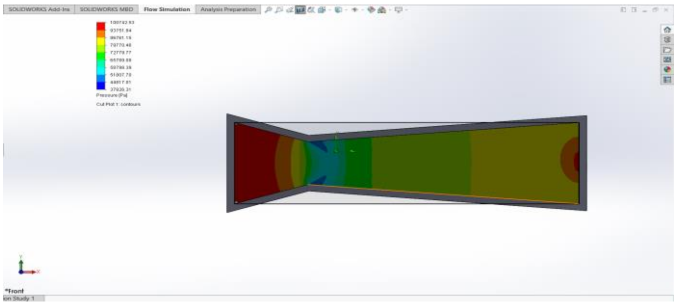
12°-5°



14°-5°



16°-5°



18°-5°

CFD of nozzles with 5° divergent angle with various convergent angles.

Similarly divergent angles of 4° and 6° were also simulated with divergent angle combinations of 12°, 14°, 16° and 18°. Out of these combinations, the combination of 14°-5° was found to have least pressure drop of around 8872.4 Pa. So, the venturi with inlet and outlet of diameter 38mm and C-D angle of 14°-5° was chosen.

PLENUM

Plenum in air intake system acts like a reservoir of air from which the engine sucks the air primarily. Air in the plenum is sucked from atmosphere through the air filter and the C-D nozzle. Plenum stores air at relatively higher pressure than the runner pipes So, it compensates the deficit of air when the power requirement is high at high rpms, when required mass flow rate increases.
The volume of plenum must be large enough, so that the air requirement of the engine at high rpms is satisfied without a large drop in air pressure in the air intake system and it should not be very large too, which delays the throttle response.
By thumb rule, the volume of plenum must be greater than 1.5 times the volume engine displacement. The plenum volume ranges from 2x to 10x depending upon the capacity, power and other parameters affecting the performance of engine.
Since the engine chosen was CBR 250 R, which has very less engine displacement (250cc) and produced just around 26bhp at 8500rpm.Applying 1.5x rule directly would result in a very small volume of the plenum and also the engine produced max power at high rpm. So a volume greater than 1.5x or 2x will be required. It was decided to design a plenum having a volume of 1L and different shapes of plenum were tested for that volume using CFD in SOLIDWORKS 2016. The inlet boundary condition was taken as the outlet condition of C-D

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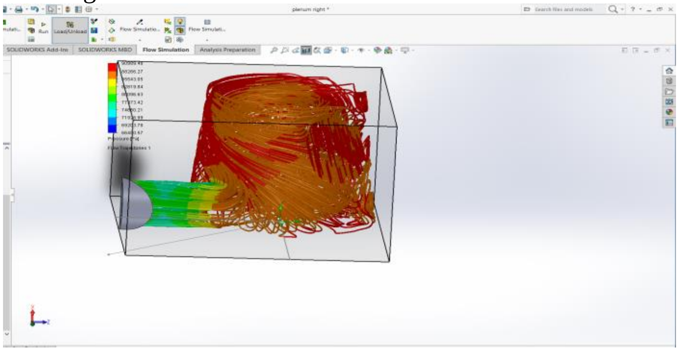
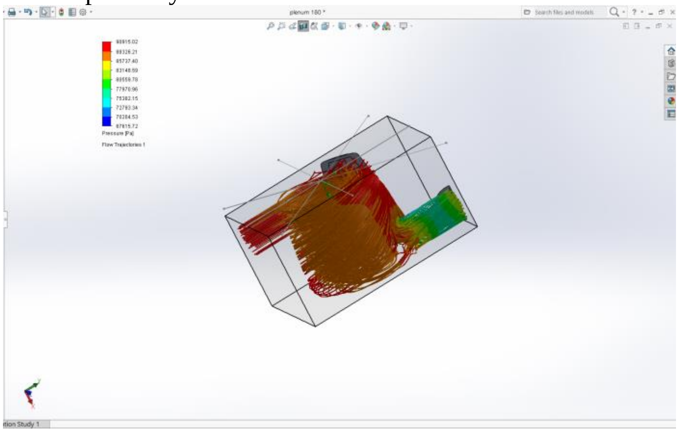
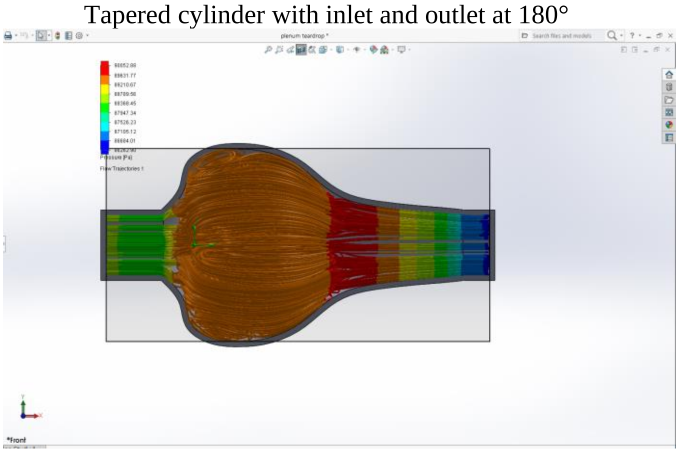
nozzle which was 92452.6Pa and outlet condition was taken as the max air flow through the restrictor which was 0.073Kg/s.



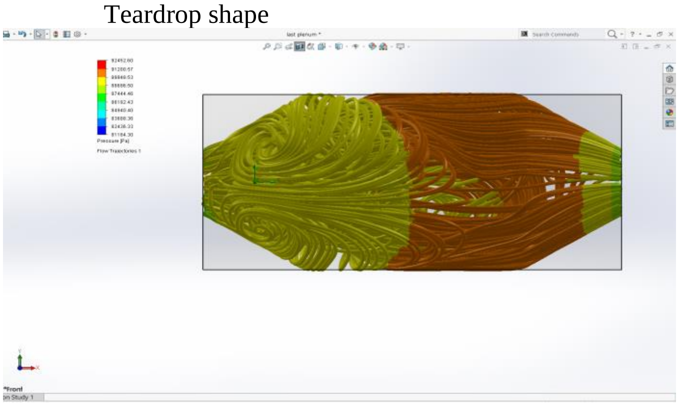
Tapered Cylinders with inlet and outlet at 90°



Tapered cylinder with inlet and outlet at 180°

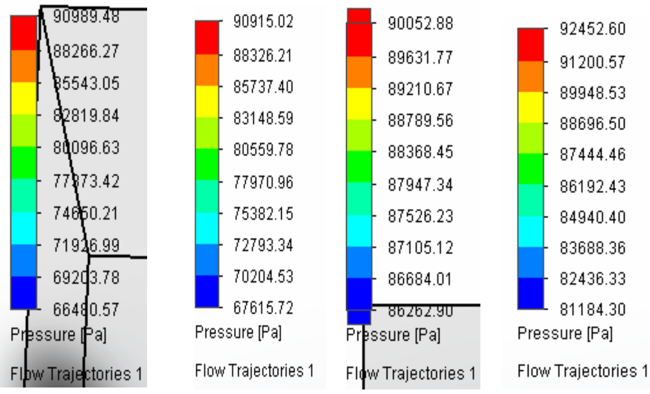


Teardrop shape



Cylinder with ends of frustum shape
(Different shapes have different scales for same color)

After analyzing the flow and pressure drop and trajectories it was observed that the pressure drop was minimum in the tear drop shaped plenum and none of the plenum out of these 4 reduced the vortex formation to a significant amount. So, teardrop shape was adopted. The manufacturing of this shape accurately was difficult by conventional process .So 3-D printing was preferred for manufacturing as few vendors who were accessible offered this service. Apart from this the Centre Of Excellence in BIT SINDRI has advanced manufacturing lab set up by Siemens has facilities for advanced CNC for manufacturing of complex shapes which will reduce the cost involved in manufacturing.



Pressure scale zoomed for plenums 1,2,3 and 4 serial no. respectively.

5) AERODYNAMICS

Race cars utilize aerodynamics to increase the down force, thus increasing traction force and stability while cornering and regulating the flow around the bodywork to reduce the turbulence and boundary layer separation phenomenon, thus reducing the drag and also directing max amount of clean air to the rear wings for more downforce. Air is also directed into sidepods for efficient radiator cooling. With aerodynamic components like wings, sidepods and other protrusions comes a lot of drag, which is responsible for useless dissipation of a considerable amount of power. The max possible traction force available is 3616N and max amount of traction force which can be generated by the car without any loss is 2997.357N, whereas considering the loss leaves us with a traction force of 2161.7N, which is around 1454.3N less than the max possible limit, this means we don't need any increment in downforce and the drag resulted henceforth. The focus will be laid only on the bodywork which includes streamlining the body to prevent boundary layer separation and redirecting the airflow for minimizing drag.

The downforce can be increased by wings in a powerful engine like a CBR 600RR engine, which creates a high torque of 66Nm @13500rpm for which we need high max. possible traction force, for which we need to increase the downforce on rear wheels through aerodynamics .Owing to the high power of engine – 118hp@13500rpm, we can also bear some drag force losses by wings , sidepods and other protrusions.

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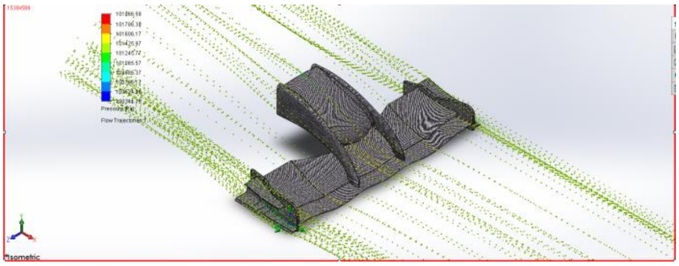


CFD For Airflow Over The Front Wing

Solver: Project(1) [Predeterminado] (FW-26.SLDPRT) - [Goal plot 1]
File Calculation View Insert Window Help

Name	Current Value	Progress	Criterion	Averaged Value
GG Av Velocity (X	-24.6517 m/s	Achieved (IT = 70)	0.00890005	-24.6517 m/s
GG Av Velocity (Y	0.499845 m/s	Achieved (IT = 70)	0.0144925 r	0.500083 m/s
GG Av Velocity (Z	0.00171253 m/s	Achieved (IT = 212)	6.10451e-0(	0.00181158 m/s
GG Force (X) 1	-83.073 N	Achieved (IT = 65)	2.41807 N	-83.1314 N
GG Force (Y) 1	-241.757 N	Achieved (IT = 70)	4.20086 N	-241.963 N
GG Force (Z) 1	-0.363181 N	Achieved (IT = 91)	0.121756 N	-0.462767 N
GG Max Velocity (	7.07054 m/s	Achieved (IT = 85)	0.25039 m/s	7.13812 m/s
GG Max Velocity (	18.361 m/s	Achieved (IT = 78)	0.184749 m,	18.335 m/s
GG Max Velocity (	10.8083 m/s	Achieved (IT = 87)	0.196835 m,	10.8527 m/s
GG Min Velocity (	-30.5464 m/s	Achieved (IT = 72)	0.223879 m,	-30.5596 m/s
GG Min Velocity (	-15.6053 m/s	Achieved (IT = 71)	0.180807 m,	-15.6909 m/s
GG Min Velocity (	-18.3397 m/s	Achieved (IT = 74)	0.267164 m,	-17.4982 m/s

Values Of Velocity And Forces Acting On The Wing

The front wing was simulated for a wind speed of around 88Kmph, which was the top speed of car. At this speed the wing had a downforce of 241N (which was of no use in the CBR 250R's case) at the cost of a drag force of 83N which ruled out the idea of aerodynamic protrusions in the project.

6) TRANSMISSION-

The gearbox used was the integrated gearbox of the engine, as the stock gear box of a bike or a car is compatible with its original engine resulting in least power loss and best possible performance .So, the gearbox integrated with the CBR 250R engine was finalized. The gear ratios of last three gears are close to each other which is beneficial in reducing the minimum time required to reach the top speed. Apart from the primary and final reduction, the gearbox provided ratio ranging from 3.33 to 0.962 which provided us high starting torque for better initial acceleration in the first gear(3.33) to a 6th gear of ratio 0.962 for a good cruising speed. This range is more than its close rivals R.E500 and KTM 390 engine (2 most common engines used in SUPRA SAE). The final drive decided was also inspired with the stock one. The sprockets had the same no. teeth as on the bike 14 and 38 respectively and the same pitch as well.

The final ratio in chain driven transmission can be easily changed by changing the sprocket. But, as the final ratio provided a good balance between top speed and acceleration, the sprockets were left unaltered. However, the modification to be done was the installation of a differential/spool integral with the rear sprocket and change in chain length, depending upon the final center distance between the sprockets.

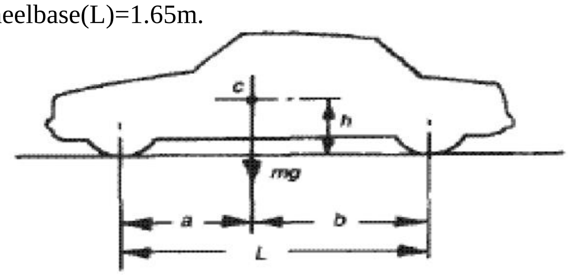
For better transmission efficiency, the angle between the differential axis and halfshafs should be minimum. This point will also be considered while deciding the position of differential.

CALCULATIONS-

<u>CBR 250R rated performance</u>-
Power-26Bhp@8500rpm
Torque-22.9Nm@7000rpm

Performance After Runner Inclusion-
Power-27Bhp@8500 rpm.
Torque-24Nm@5500rpm.

CALCULATIONS
Wheelbase(L)=1.65m.



a=0.964m, b=0.686m giving weight distribution as 41.6% and 58.4%
h=0.195m
Mass of car=260Kg, Mass of driver=60Kg
(1)Total mass (m) = 320Kg (These parameters were inspired by the car designed by team of BIT in 2017)
(2)Coefficient of adhesion/friction (μ) =1.6(for slicks)
(3)Load on rear wheels due to weight (Wr) =320×9.81×0.584=
1833.293N.
(4)Weight of the car (W)=9.81×320=3139.3N
(5)Coefficient of rolling friction (f) =0.025
(6)Radius of tire(R) =8"=8×0.0254=0.2032m
(7)Max. possible traction force without slipping (F') $=\frac{Wr\times\mu}{1-\frac{h\mu}{L}}$

F'=3616.85N

(8)Max. possible torque which can be transmitted without slipping

(T')= F'×R
T' =734.944Nm

(9)Net driving force on car (F) = (Traction force developed by car)-(Rolling resistance on car)
(10)Rolling friction force on car (Fr) = $\frac{fW}{R}$
=386.22N

Primary reduction	2.808
Gear ratio, 1st	3.333
2nd	2.117
3rd	1.571
4th	1.304
5th	1.115
6th	0.962
Final reduction	2.714

Details Of Transmission Ratios For CBR 250R

MAX. POSSIBLE ACCELERATION-

Peak torque corresponding to the optimized Performance = 24Nm.
Taking 85% transmission efficiency theory in account,
Transmission efficiency (η) = 0.85

Published by :
http://www.ijert.org
International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 08, August-2019

Max. Torque Developed (T) =Peak Torque × Primary red. ratio×1st gear ratio × final red. Ratio ×efficiency
=517.7Nm
Max. Tractive Force Developed=2547.7N
Net max driving force on car (F) = 2161.68N.
Net max acceleration = 6.75m/s^2

POWER LIMITED ACCELERATION-

Max. torque for the engine with 35cm runner occurs at 5500rpm and power produced at that rpm is 14KW.This occurs at a low rpm and the power available is also 2\$3^{rd}$ of the max. power available, so pressure drop and power loss will also be very less.So, analysis of power limited acceleration will consider two cases. One with 10% power loss and 85% transmission efficiency and the other with no power loss and 85% transmission efficiency. Power loss due to drag force is neglected as the speed will be very less.
Speed of car in 1st gear at max torque point (5500rpm) (v)
= 4.61m/s
=16.6Kmph

Case-1 (with 10% power loss)

Power available after restrictor- 14×0.85×0.9=10.71KW
Power loss due to rolling friction= 386.22v=1780.47W.
So, net power available for acceleration=10710-1780.47
=8929.59W

Force=$\frac{Net\ Power}{Velocity}$ = $\frac{8929.53}{4.61}$ =1936.99N

Acceleration = $\frac{Force}{mass}$ =1936.99/320 = 6.053m/s^2

Case-2(without restrictor loss)

Power available after restrictor- 14×0.85= 11.9KW
Net power available for acceleration = 10.119KW
Similarly, acceleration= 6.86m/s^2
So, max. acceleration (considering losses) = 6m/s^2

TOP SPEED CALCULATION (MAX. VELOCITY)-

Assuming 85% efficiency for transmission and 90% of engine power due to 20mm restrictor in a single cylindered engine.
From the graph of optimized performance
Power = 20KW@8500RPM
Reduced Power due to losses -20×0.85×0.9=15.3KW

Conditions Of Circuit-
Altitude (h) - 200m from sea level (approx.)
Temp (T_2)- 300K
Density of air at sea level at 15°C (ρ_1) =1.225Kg/m^3(standard)
Temperature at sea level assumed (T_1)= 15°C
$P_{sea\ level}$=P_1=101325Pa
$P_2 = P_{sea\ level} \times e^{-\frac{h}{2000}}$

Using Ideal Gas Law-
$\frac{P_1}{\rho_1 \times T_2} = \frac{P_2}{\rho_2 \times T_2}$
ρ_2=1.24Kg/m^3 (at the circuit)
Assuming frontal area of a general FS car with no Aerodynamic package (A) = 0.8m^2
Drag coefficient of a non-aero car (C_d)= 0.85

Terminal speed of car is max speed when all the power of engine is consumed against drag and rolling friction.
Total power by engine= Power dissipated in overcoming drag + Power in overcoming rolling friction

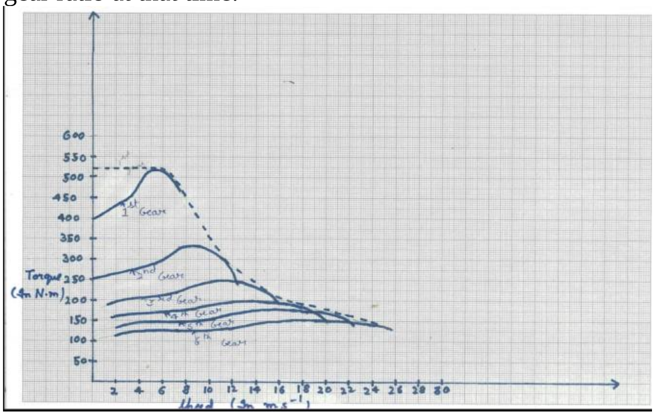
Power dissipated in aerodynamic drag= 0.5×C_d ×A×v^3×ρ
=0.421v^3
Power dissipated in rolling friction=386.22×v
Max. theoretical power by engine = 20KW@8500rpm.
Energy

Considering the losses of transmission and intake restrictor, Power =15.3KW.
This gives the equation-
0.421v^3 +386.22v -15300= 0.
Solving the equation gives us the value of 87 Kmph

Max. speed can be achieved at max power and at the highest gear, so at 6^{th} gear where gear ratio is 0.962, at 8500 rpm can deliver max. speed
=$\frac{2\times\pi\times engine\ rpm\times radius\ of\ wheel}{60\times Primary\ red.ratio\times final\ red.ratio\times 6th\ gear\ ratio}$
=88 .8Kmph
This is in agreement with the terminal speed (approximately)

Analysis For Best Performance

The gears must be changed at a particular speed for best performance (pickup).This can be determined by the performance graph (torque vs. speed) of car at different gears plotted on same set of axes.
The torque and speed at different gears were calculated by considering the primary and final reduction along with the gear ratio at that time.



The figure shows Torque vs. Speed graph for car at different gear ratios. The dashed line shows the gear which should be adapted for best performance at a particular speed which could take the car to the top speed in minimum time. This graph shows the torque received by wheels after suffering 15% transmission loss.

SPOOL VS DIFFERENTIAL

In 2014 motec data was taken by(GFR) using locked and unlocked mode of Drexler LSD and it was recorded that the car took less time in autocross event in the locked configuration as compared to unlocked one due to reduced

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 08, August-2019

slip and due to the capability to accelerate out of corners fast(case study by GFR).

Since the acceleration and top speed calculated theoretically seem to strike a good balance between themselves ,we will use a stock gearbox with same sprocket sizes of 14(primary sprocket) and 38(secondary) teeth with an OEM chain of pitch 520,whose length can be changed according to the position of the two sprockets.

Working Of Spool –

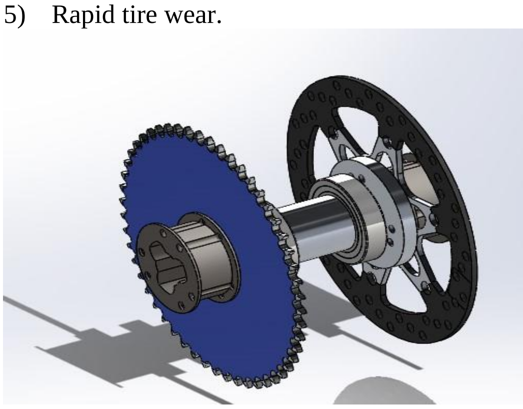
Sprocket is attached to the spool which rotates with sprocket as a single integrated entity. The spools have inserts of CV joints .The halfshafts are connected to spools on one end and spindle on the other. They are hollow and are made by alloy steels for strength with bearing tripod at both the ends. The sprocket can be moved forward or backward using turnbuckle chain tensioner or eccentric type chain tensioner, so that half shafts have better angles and reduced stress and thus better efficiency for power transmission. With an improved angle of 0.5°, there is an improvement of the efficiency of 0.33% in the joint.

Merits of spool-

1) Compact nature provides a room for inboard brakes.
2) Very low or no maintenance.
3)3-4 times lighter than the standard LSD differential.
4) Easy to design and manufacture especially for new teams.
5) It is cheap and is compatible with the low budget F.S projects.
6)Less power loss in straight line movement owing to the small no. of moving parts and less MOI of spool and thus better mechanical efficiency of transmission in straight lines.

Demerits Of Spool-

1) Understeer is induced as both rear wheels exert same force and thus decreases the steering effect.
2) Power loss through tires is significant while turning.
3) Understeer induced due to locked wheels results in slow corner entry and exit which is predominant at low speeds.
4) More steering effort for desired steering effect.
5) Rapid tire wear.



Spool with CV Inserts

Compensation Through Design –

The vertical load on outer tire is more than that of inner tire while cornering due to lateral load transfer. Outer rear slip angle differs from inner rear slip angles, the difference in slip angles can be used to create a differential effect, despite of the locked rear wheels.

The data of TTC of the tires provides us with the information of slip angles at different lateral and longitudinal loads as well as different longitudinal and lateral force produced by tire at different vertical loads and slip angles. These data along with extensive knowledge of vehicle dynamics and rigorous testing at various configuration of car and suspension and observation of the pattern of tire wear will give us an idea of the slip of rear wheels and also help in tuning of car with the tires. Detailed discussion of this topic will require a detailed discussion of vehicle dynamics which is beyond the domain of this paper.

Compensation Through Handling –

For tackling the understeer induced by spool, the inside wheels can be unloaded by lifting it off the ground while turning. So that there is no longer scuffing and slipping of the outside wheel and letting it transmit almost all the torque alone .This can be done by stiffening the suspension so that the car can lean outward during the turn. The weight is shifted from inside to outside wheel, resulting in reduced traction. This can be handled only by an experienced driver.

Differential

Open Differential-It has sun and planet gears ,the planet gears mounted on cross spiders and the sun gears attached to the halfshafts which facilitates the rear wheels to rotate at different speeds while negotiating a turn eliminating the scuffing and slipping of tires and thus eliminating tire wear, loss of power, instability,understeer,increased steering effect and stressed transmission parts.

Open Differential

Drawbacks Of Open Differential-

1)When wheels of car having open differential has one wheel on a slippery wheel and other one on a good traction surface, then the transmission will start sending all the power on the wheel with less traction in form of high speed rotation. This drawback can be eliminated by a limited slip differential which sends more torque to the wheel with high traction.
2) Differentials are heavier than spool which increases mass of the transmission parts.
3) More maintenance as compared to spool.
4) It is more expensive than the spool.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
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Analysis-

Given the budget, engine capacity and weight, open differential was decided .Due to the presence of extremely light weighed engine, compensation for extra weight added by open differential was provided. Low budget and extra weight constrained the use of LSD because track mostly consists of good traction area. With the engine, which was not so powerful, energy loss through tires was not affordable although we had some power loss due to the differential, which was not very significant. The low budget also did not permit the rigorous testing with spool for tuning of tire with the spool and observing the wear pattern as extra set of slicks could not be afforded just for testing.

CONCLUSION-

After analyzing various sections of the powertrain, it was decided to use a CBR 250R Engine with stock gearbox and radiator,35cm intake runner and C-D Nozzle with converging and diverging angles of 14°and 5°respectively along with a teardrop shaped plenum having volume approximately 1L.The final drive ratios along with the gear box were unaltered. However the chain length can be changed depending upon the distance between the sprockets. The rear sprocket will be a part of an open differential. No aerodynamics will be used except streamlining of the bodywork, which will restrict any type of aerodynamic protrusion for downforce or stability benefit. The tires which will be used are 16 inch slick tires by Hoosier manufactured exclusively for FSAE .The driver has to adapt the driving and gear changing pattern similar to the way shown in the graph. After adapting this design, the car is most probably going to give the performance as analyzed.

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