# ENGINEERING DESIGN REPORT: ORION RACING INDIA

## TEAM GOAL: CAR NO.18

The team's focus this year was to refine system designs. System evaluation by physical, track testing and tuning was given emphasis with the aim of understanding the designs better. Data acquisition and real time data display were additional features that the team worked on with the intent of achieving better interfacing between man and machine.

The following 3 parameters were considered around which the car was designed

1. **TIRE :**
   The tire selection was based on TTC tire data treatment. Further considerations to cost and availability narrowed the selections down to 2 tires , Hoosier and Continental 34M .
   Continental achieves a peak lateral force of 3800 N at 6 degrees slip whereas Hoosier achieves a peak lateral force of 3600N at 10 degrees of slip.
   The curves for cornering stiffness v/s slip angle shows Continental to be more sensitive but less controllable than Hoosiers at high loads. (Fig. a below). The combination of high peak lateral forces and transient response helped in finalizing the Continental tires. On comparing the acceleration characteristics Continental gave a peak force of 2600 N at 7 % slip ratio. The added weight of the Continental tire was the compromise on performance
2. **Engine:**
   The Team chose to expand on the developments of the previous year's usage of the Honda CBR F4i Engine. With the knowledge gained over the past years about the intake, exhaust & cooling system, we aim to utilize more of its potential.
3. **Ergonomics:**
   The Ergonomics was given better emphasis by designing a mock setup. Considerations to driver forces and driver fatigue were made. The cockpit was developed to accommodate drivers for their varying physique. The development of the seat, shifter, adjustable pedal box was based on these values which gave the best adjustment for our drivers. Further considerations to line of sight and accessibility led to the design of the steering wheel and onboard dash controls.

## SYSTEM DESIGNS

1. **SUSPENSION AND STEERING DESIGN**
   The suspension design was developed considering tire forces. Wheelbase of 1580mm was taken considering ergonomics, engine position and longitudinal load transfer. The front and rear track widths are 1220mm and 1200mm respectively, taking into consideration the lateral load transfer.
   The selected ride frequencies for the front and rear are 3.2 Hz and 3.1Hz. The higher frequency in the front was aimed at recovering faster from a corner. A roll gradient of 0.9 deg/g was decided with the intention of reduced chassis roll leading to better ride recovery. With the designed weight distribution of 45: 55 the roll stiffness distribution was calculated accordingly . Anti roll bars of stiffness 241.6 Nm/deg at front and 275.5 Nm/deg at rear were designed to achieve the desired roll rates. The motion ratios of 1.3(front) and 1.25(rear) have been selected and bellcranks were designed with decreasing rates to reduce wheel travel .Roll center height of 30.3mm (front) and 44.17mm (rear) was achieved in order to have less geometric weight transfer and reduced jacking forces. The chassis pick up points have been selected considering front view side arm of 735 mm (front) and 1040 mm (rear) to provide minimum camber angle change (0.9°)
   The tie rod and the steering rack points have been designed for minimum bump steer of 0.08mm at 1 inch of droop and an Ackerman of 107%.

**Part Design :** The development carbon fibre A-arms using metal inserts has helped in achieving a weight reduction of 40% in the A-arm packaging providing a lighter unsprung package .The forces were calculated using vector analysis and the metal- fibre adhesion was tested for bond gaps varying from 0.15 to 1mm.

The Implementation of a helical pinion has helped in improving the sturdiness of the steering assembly and bringing the steering ratio down from 5.2:1 to 4.6:1.

## 2. CHASSIS

The Space frame was designed considering availability of resources, faster production and extensive time towards testing .Driver Ergonomics and frame stiffness were considered in the primitive stages of design. The design of tetrahedron geometry around the cockpit contributed to the torsional stiffness and allowed more compact packaging. The frame was also analysed for braking at 1.7g's, cornering at 1.5 g's and impact of upto 3 g's. The material considerations were made by gathering effects of their physical and chemical properties apart from strength.

DIN 2391 st52 was selected with 1inch tubing with thicknesses varying from 1.25 to 2.5mm.

The welding was carried out using tungsten electrode inert gas welding to ensure stronger joints which were tested in the UTM .Error of ±2% was realized by evaluating the position of all the mounts and brackets using a co-ordinate measuring machine.

The torsional stiffness of the frame was designed for 1400 Nm/deg hub to hub. The torsion rig test conducted gave a value which was 26 % less. Further tests conducted with engine and other reinforcing attachments helped reduce the deficiency to 17 % which was 1150 Nm/deg.

The chassis weighs 38 kgs which is 5 kg lighter compared to last year. Further analysis on vibration has also been done considering ride and engine frequency which will be evaluated using a vibrometer.

## 3. BRAKES

The brake pedal box has been designed with adjustability of upto 45 mm fore and aft. This value was obtained from the mock ergonomics setup for different drivers. Pedal forces for actuation of different pedals were done using a force sensor. The calipers, Discs and master cylinders have been selected to generate the required braking torque and also the availability, cost and weight of the same. The braking torque calculation was initiated by accounting the co-efficient of friction of tires (Tire data).

Master Cylinders of unequal bore sizes were used to maintain a natural bias of 65% which could be further changed dynamically by bias knob provided on the dash board.

The wheel hub diameter was increased from 30 to 50mm which helped in improving the fatigue cycles by 200 times considering the fatigue failure of hubs after 200 kms from the previous year. The refined designed made from Al-6061 T6 was reduced by 102 grams.

A 4-point floating disc system has been introduced to reduce the power loss due to the undesirable static friction between the pads and disc wheel hubs. A radial compliance of 0.5mm

And an axial compliance of 1.5mm has been provided to account for thermal expansion.

## 4. POWERTRAIN

The system goal was to provide a flatter torque curve in a useable RPM range for the driver, which was determined to be from 4000 to 9000 rpm by analyzing the track data.

### Intake

Intake was refined considering the previous plenum design. OEM Throttle body with Internal Diameter of 40mm at outlet was selected due to ease of availability. Intake runner length was tuned to 12th harmonic using Helmholtz Theory having a theoretical value of 383mm. Further this value would be evaluated on a dynamometer by varying the lengths in steps of 5mm, 10mm and 15mm. Fuel Injector angles were changed from 29.74 (stock) to 26degrees so as to spray the fuel closer to intake valve as it would help in pre-heating the fuel. Intake manifold was manufactured using RP SLS. The internal surface finish of the rapid prototyped plenum caused eddies in the flow, for which the surface was smoothened and roughness test was done. $R_a$ for rough surface was 16.83µm and that of smooth surface was 4.11 µm.

**Cams**

The intake & exhaust camshafts have been ground to a new profile to reduce the reverse flow of gases during the cam overlap duration and improve the performance of the engine in the desired RPM range. The new profile obtained from simulation results shows 8.25% increase in volumetric efficiency and increase in peak torque from 60.84 Nm to 65.85 Nm (Figure C). The idle rpm has reduced from 3300 rpm to 2200 rpm. Hardness test was conducted to make sure cam lobes have retained their hardness after grinding. It has been ensured that the static and dynamic stresses acting on the valve train system do not exceed their safe limit.

**Exhaust**

The exhaust system was designed using a tri-y configuration with unequal length primary runners. The runner lengths were calculated considering change in the pulse generated by new cam shaft timings. Unequal length primaries are incorporated so that each cylinder will peak at a different rpm so that smooth torque curve can be achieved. Primary runner lengths are incremented from 15.5" to 16.5". Secondary tubes are 10" in length and tertiary 8".

These design decisions that shift the engine characteristics from high peak power to a broader power band, which will be validated on a chassis dynamometer.

**COOLING**

The cooling system has been designed to maintain the operating temperature of the engine around $95^0$C. The radiator used is dual core and has vertical arrangement. NTU method has been adopted for the design purpose of the radiator wherein the performance of different sized radiators was checked theoretically before fixing the final size. The radiator has a frontal area of 290x280 $mm^2$. The maximum required operating pump flow rate has been theoretically found out to be 69 LPM, thus Davies Craig E WP80 was selected for the system. The pump flow rate is ECU controlled at different engine & vehicle speeds. The flow of air over the radiator core is enhanced with CFR Performance fan of 1700 CFM. The shroud was designed to assist the fan in pulling the air through the radiator core. The material used for shroud fabrication was Carbon fiber because of its high strength and low weight.

## 5. DRIVETRAIN

A final drive ratio of 3.9 was calculated theoretically. The optimum value in range of 3.81 to 4 will be selected based on longitudinal acceleration v/s time and longitudinal force v/s the slip ratio graph. The Clutch Type Drexler Limited Slip differential was selected which has 6 different ramp angle settings. The 50/40 setting was selected based on mid-cornering performance using a steering angle sensor and wheel speed sensor.  The constant velocity joint were incorporated which give an articulation of about 21 degrees. One of the major aims was to have an efficient light weight system. The tripod housing is made of Aluminum 7075 T6 as opposed to EN-24 used previously. This resulted in a weight reduction 62.63%. Also the sprocket with an integrated hub was designed instead of the conventional sprocket with adapter with 300 grams of weight reduction. Overall a 15.38% weight saving was achieved in the system as compared to last year. For chain tensioning an eccentric mechanism is used which gives a variation of 10 mm in the centre to centre distance equal to about one and half chain links.

## 6. ELECTRONICS

Objective for this year's electronics team was to develop an efficient system which includes developing a simple interface for the driver, achieving reduction in total system packaging volume and providing the necessary data to the other systems which helps them to validate their designs. The interface includes arduino based gear position display and a motec shift light module having 8 multicolour leds which are user configurable and communicates with the ECU via CAN bus. Power distribution unit developed by n-channel mosfet (irlz44n) results in compact system; providing high switching frequencies upto 7.34MHz thus can easily drive water pump at 100Hz. Replacing relays with mosfets reduces power consumption during its on time. PCB based sensor hub is made with 12 analog and 4 digital inputs. The cooling system can be switched between two states either in full capacity or controlled by a PWM signal from the ECU, enabling us to implement variable control over the water pump and fan. Motec   M400 ecu is used for data logging of analog and digital sensors, with a user-friendly GUI and analysis software (i2 standard).

The entire electronics system is packaged in an enclosure and a reduction in volume by 75% was obtained. Wiring harness is colour coded and labelled according to its function, which will simplify diagnosis

## 7. AERODYNAMICS

The objective was to have a simple and lightweight aero package which could be simulated and tested with the available resources.
Body works has been developed around the car with the objective of minimum drag. The side pods incorporate a duct for uniform pressure distribution at the face of the radiator.
The Implementation of the Diffuser was to channel the underbody air effectively to produce downforce.
The diffuser was designed considering 3 parameters; ground clearance, inlet /outlet angles and location of the centre of pressure wrt to centre of gravity.
The design was an iterative process and gave a simulated downforce value of 12 kgs at 65 km/hr with an inlet angle of 4 degrees and outlet angle of 21 degrees.
The effectiveness would be further evaluated by track testing using shock travel sensors and accelerometers.

## TESTING AND TUNING

### 1. Fuel & Ignition Map

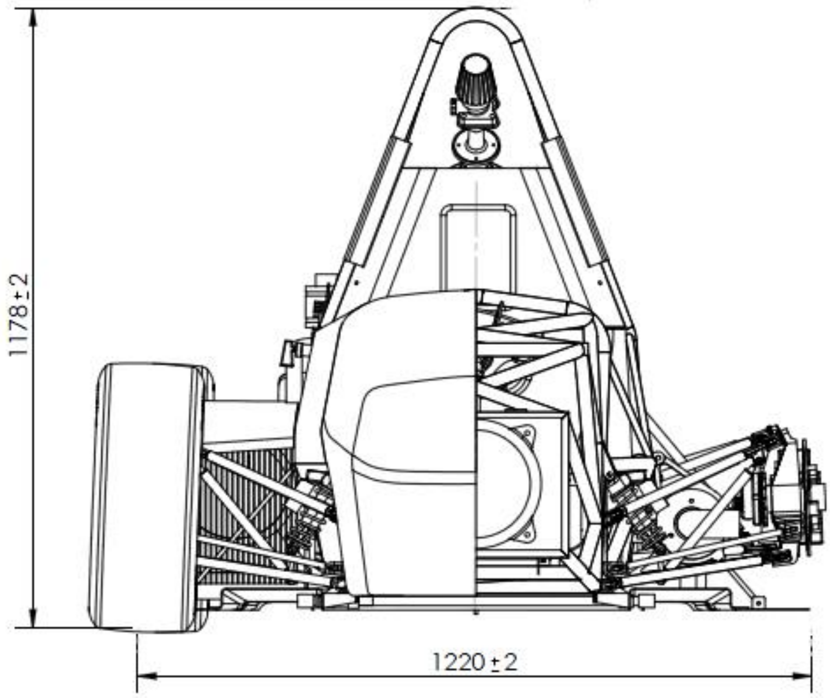
Alpha-N method has been employed to setup the fuel & ignition maps. The maps will be fine tuned on a chassis dynamometer by adjusting the injector pulse width and ignition advance at a set throttle position and RPM intervals until desirable lambda and torque values will be achieved. The engine will be tuned for fuel economy under low loads and for maximum power under high loads. Enrichments for cold starts and engine temperature will be refined for a consistent performance under varying ambient conditions.

### 2. Launch Control & Overrun fuel cut

Launch Control is set up with the help of ECU. The theoretical rpm limit values were calculated from the chassis dynamometer graph and tire data (Longitudinal force V/s slip ratio graph). After the initial setup, tuning was done based on the longitudinal G force values.
To reduce the fuel consumption the overrun fuel cut feature of the ECU has been used that cuts of fuel supply when the driver lifts his foot from the throttle.

### 3. Suspension tuning and testing

The suspension settings were tuned and evaluated based on the various competition events.
The Roll rate was determined by shock travel sensors and accelerometer.
Evaluation of motion ratios was done by running the car on different sized bumps and evaluated by shock travel sensors.
Camber variation in roll was determined to ensure camber control in the given designed range.
Damper tuning would be carried out based on driver feedback, shock travel sensors and dynamometer Graphs.
Cornering performance would be determined with front and rear anti roll bars and analysed using accelerometer with the intent of achieving minimum lap times.
Endurance tuning would be done on the basis of best results obtained from the above tests.




All dimensions are in mm

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| | VIEW : FRONT VIEW |
| | CAR # 18 ORION RACING INDIA |

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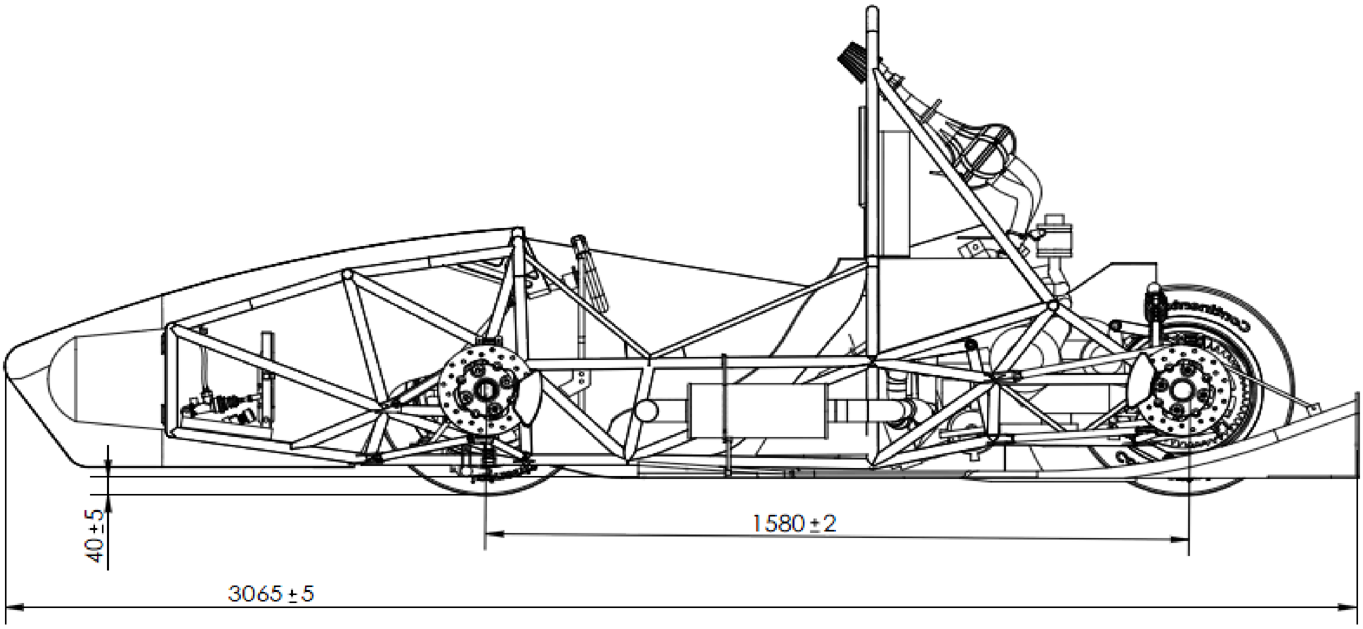


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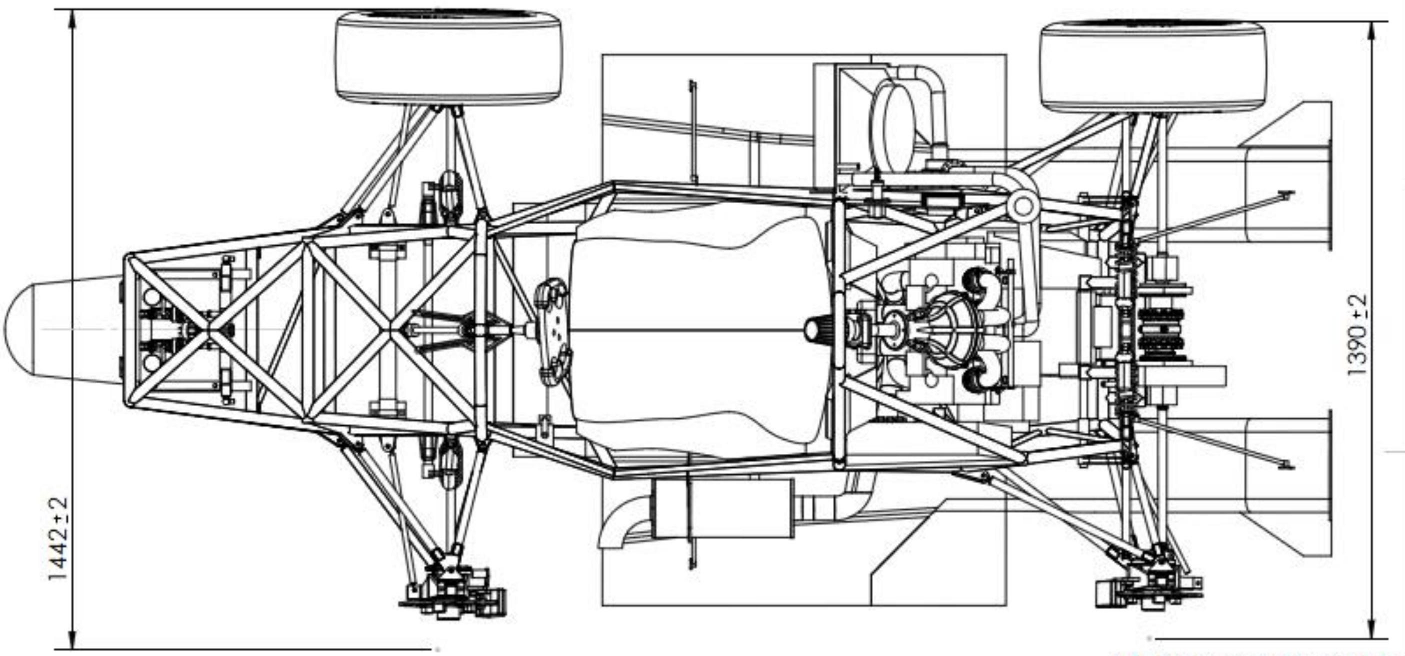


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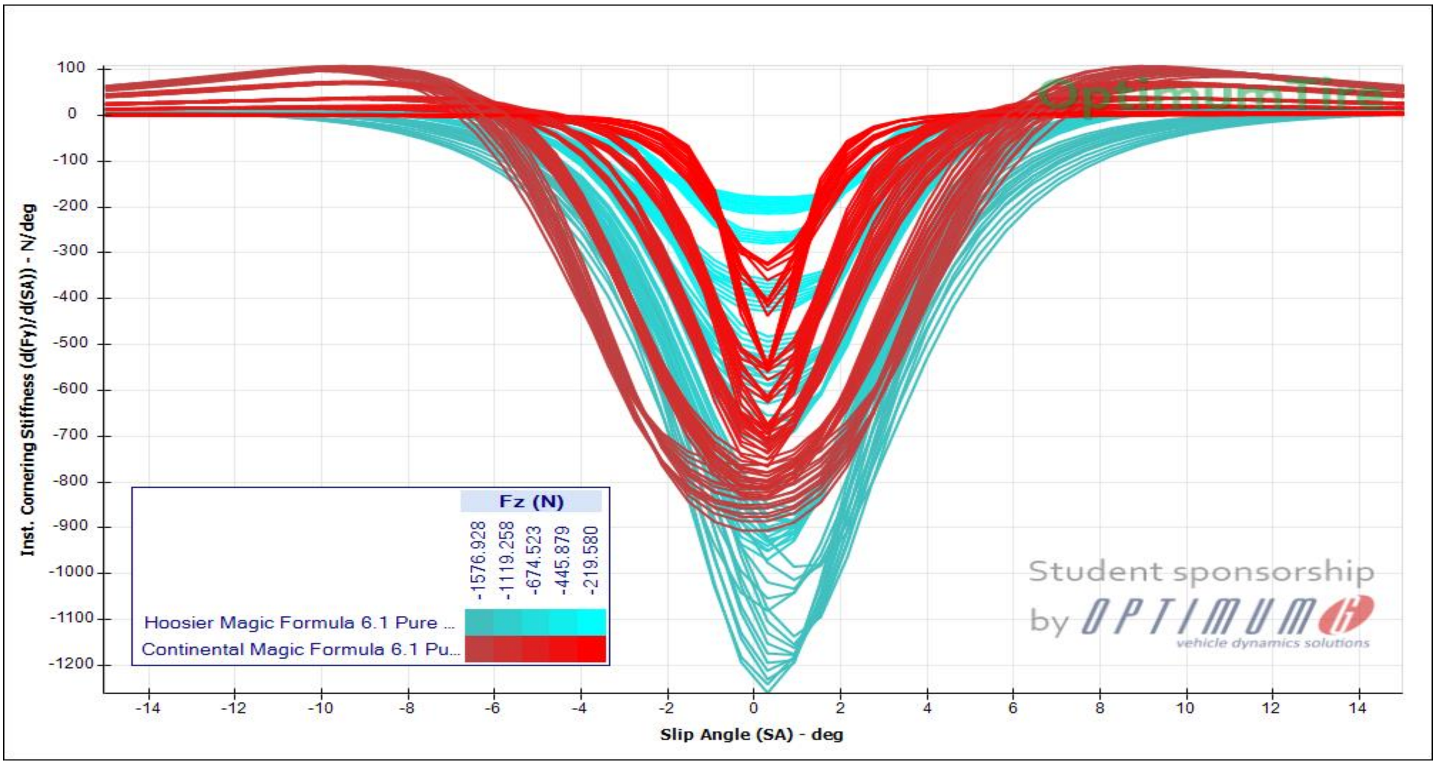
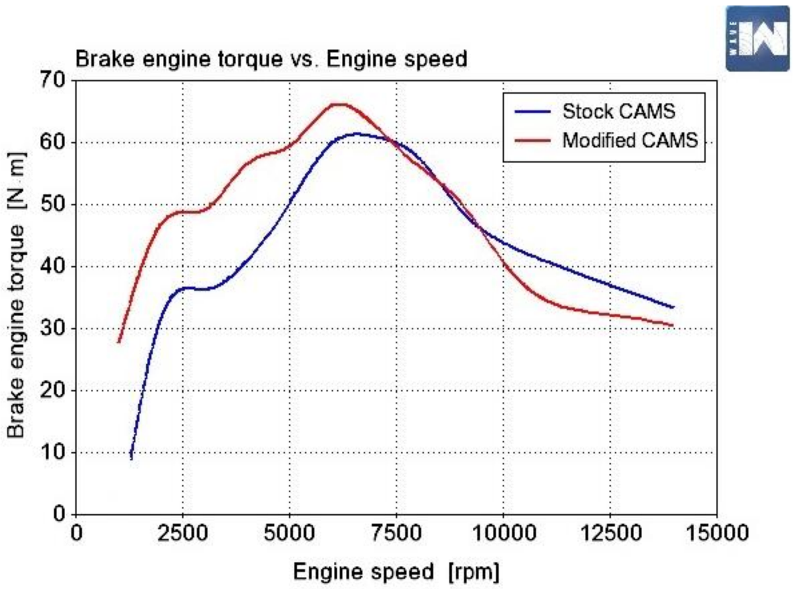



**Fig.a  Cornering stiffness v/s slip angle**




**Torsion rig test**

**fig C. torque curves**