Team VEGA Racing
JSS Academy of Technical Education, Noida
Car #14

Design Report for ESI 2018

ABSTRACT

This project required study of various systems incorporated into a Baja race car and also the design methodologies used in today's industrial scenario. The process started with the identification of the major goals of the project and conversion of those objectives into measurable quantities.

After this various constraints were identified. The team was then divided into various sections and work was allotted to each section according to their field of expertise. The design for each component was iterated until the desired objectives were fulfilled.

INTRODUCTION

Vehicle #14 has been designed with a vision in mind for success in the Baja endurance challenge. After having consulted automotive design literature, previous SAE competitors and an independent study on the Baja challenge. Key design features include 'one-size-fits-all' ergonomics, modular components, a fully adjustable suspension, and substantial rollover protection for the driver.

DESIGN OBJECTIVES

Design intent has been oriented towards optimum factors of safety. With regard to the competition, completion of the endurance challenge has been given priority including performance in minor events. Effort has been directed to the special challenges like hill climbing and acceleration as well as vehicle fully capable of completing four hours on the track. This motivation implies enhanced efforts towards weight reduction and vehicle performance.

VEHICLE CONCEPTS

In all respects, vehicle #14 is a first generation prototype. During initial project ramp-up, several major iterations were considered and discarded as different resources were consulted. Three different suspension options dominated early discussion, with Macpherson, Trailing arm and Double A-Arm in contention. Eventually Double A-Arm was used for front and a 3 link Trailing arm was used for rear suspension design, owing to improved manufacturability, reduced cost, and mechanical simplicity. Other concept revisions were primarily motivated by FEA testing.

TESTING

Designs have primarily been validated through extensive FEA analysis and testing has thus far effective ergonomics and structural improvement.

CHASSIS AND FRAME DESIGN

The chosen design is a triangulated space frame comprised of both cylindrical tubing. Tubing varies throughout the chassis depending on structural needs of that area, as well as severity of possible failure modes. Tube choice also depended on the mounting required.

Chassis Design - The chassis is designed keeping in account the safety of the driver, various force impacts on the vehicle, various catastrophic possibilities, sprung mass, etc. yet keeping the weight of the chassis as low as possible.

The chassis is made up of AISI 4130 CDS, an alloy of iron. This alloy has various advantages over the standard material suggested by the BAJA SAE-International rulebook.

Specifications -

Properties	AISI 1018	AISI 4130
Carbon %	0.148-0.2 %	0.28-0.33 %
Yield Strength	365 Mpa	460 MPa
Modulus of Elasticity	205 GPa	210 GPa

Specification	AISI 1018	AISI 4130
Outer diameter	25.4 mm	31.75 mm
Thickness	3 mm	1.57 mm
Bending Strength (Nm)	387.37	465.658 N-m
Bending Stiffness (Nm^2)	2763.12	3568.70 m-sq

Ergonomics -

1. Inclined Rear roll hoop for a comfortable natural seating posture.
2. Unhindered, open leg space to avoid component crowding and enhance free movement of legs during pedaling operations.
3. A more continuous RHO and FBM with bends resulting in continuous members and reduced material usage.
4. Comfortable seating position achieved through RULA.
5. Optimized clearance around the driver to aid effective driving operations.
6. Suspensions mount points given at nodes for better force transfer.

Frame Weight - This design resulted in an overall weight of 21.76 Kg which when compared with other BAJA SAE teams in India is quite low.
This stems from design intent focused on the goal of ensuring successful event completion, limited manufacturing time and experience.

FEA Analysis - Baja Frame needs to withstand any collision that it might be subjected to as part of the testing process or competition.
Four impact scenarios were analyzed to ensure the frame design will not fail.

1. Front Impact
2. Rear Impact
3. Side Impact
4. Roll Over

Front Impact and Roll Over analysis are shown below.

Front Impact Analysis –
V_i = 56km/hr or 15.55m/s (maximum car speed)
M_{total} = 250kg (car weight including driver's weight)
t = 0.1 sec (total time from top speed to full stop)
V_f = 0m/s (car speed after impact)
By,

$$a = |V_f - V_i| / t$$
$$a = 155.50 \text{ m/s}^2$$

Force,

$$F = M_{total} * a$$
$$F = 38875 \text{ N}$$

The force of 38888 N was divided by four and applied to the four front most points of the car i.e. 9718.75 N to each.

Roll Over Analysis –
V_i = 56km/hr or 15.55m/s (maximum car speed)
M_{total} = 250kg (car weight including driver's weight)
t = 0.3 sec (total time from top speed to full stop)
V_f = 0m/s (car speed after impact)
By,

$$a = |V_f - V_i| / t$$
$$a = 51.83 \text{ m/s}^2$$

Force,

$$F = M_{total} * a$$
$$F = 12958.33 \text{ N}$$

The force of 12958.33 N was divided by two and applied to the top most points of the car i.e. 6479.165 N to each.
The bottom of the car was constrained to prevent movement.

SUSPENSION SYSTEM

Due to its proven success in Baja competitions and the team's better familiarity with the double A wishbone along with 3 link trailing arm suspension systems were decided for total control afforded over wheel movement and critical suspension geometry characteristics.
The suspension system allows for complete front and rear camber and toe adjustment in the front and rear of the vehicle.

Front Suspension - The front suspension used in the vehicle is Double A-arms. This provides better stability to the vehicle. The various parts of the suspension are designed to optimize the dynamics and reduce the weight of the assembly as well.

Rear Suspension - The rear suspension used in the vehicle is 3 link-trailing arms. This provides better stability and maneuverability to the vehicle. The various parts of the suspension are so designed so as to optimize the structure as well as reduce the weight of the assembly. Components such as knuckle and hub are designed to reduce the weight and for simple assembly of rear suspension system.

Specifications -

Anti-dive	22 %
Anti-squat	65%
Camber angle	-3
Toe angle	+2
Front caster angle	4
Rear caster angle	0
Front KPI	7
Rear KPI	0
Front Scrub Radius	2.43''
Roll Center Position	277.114mm
Kinematic Trail Front	0.77''

FEA Analysis - Analysis of wishbone is necessary in order to determine the induced maximum stress and maximum deflection in wishbones. For analysis, wishbones are first needed to be modeled in software.

Lower A-Arm Analysis – The Lower A-Arm has been provided a fixed support at the chassis pick up points and the lower damper installation point. Forces that have been considered are:

1. At full acceleration, the inertia of unsprung will exert a force in opposite direction of the ball joints of knuckle. So, the force has been an calculated by the mass and acceleration of vehicle and applied on the joint of A-Arm.
2. At full bump, the damper is compressed keeping in mind the motion ratio. The displacement is multiplied by spring rate to get reaction force at the ball joint end of A-Arm.
3. While turning, the centrifugal force calculated by mass and velocity of vehicle at turning radius of 5m is applied on the ball joint.

Upper A-Arm Analysis - The Upper A-Arm has been solved by the same force analogy, except that the force due to damper compression has not been considered.

Various boundary conditions and load cases were applied for determining the maximum stress and maximum deflection.

STEERING SYSTEM

The next stop in the designing journey is the Steering System. If the steering system is not properly designed, the wheel may toe in or toe out during suspension travel, owing to "Bump Steer."

In order to minimize this event, the Instantaneous Centre of the tie rod must coincide with that of the control arms. This ensures that the tie rod travels in the same curvature as that of the control arms and there is no unintentional relative movement between the kingpin and the tie rod.

Geometry - While Ackermann geometry is very effective in slow speed turns, it is not suitable for high speed cornering. During a high speed turn the inner wheel provides far very little cornering force therefore its slip is irrelevant and can be neglected. Most of the frictional force is generated by the outer wheel and therefore it accounts for much of the steering. Parallel or even reverse Ackerman geometry is used in these cases. A compromise between parallel and Ackermann geometry was chosen by the team.

Steering Ratio - Overall steering ratio is an important parameter because it determines how "quick" we could steer around. Although steering ratio is partly a driver's preference, but some guidelines do exist. A very high ratio will be more sensitive to the driver's steering inputs, but extreme sensitivity may increase driver fatigue or make it difficult for the driver to keep the car pointed in the desired direction when road inputs jerk the driver's hands. At the other extreme, too low a ratio will require large hand movements, which is not desirable for the tight ESI 2018 courses.

Driver does not have to shuffle his or her hands around which would again reduce the car's maneuverability. In order to negotiate the tightest corners (outer diameter) for the ESI circuits with less than one rotation of the steering wheel, a steering ratio of about 6:1 was decided by us.

Caster Angle - Positive caster angle induces a self-cornering force that provides straight line stability, but increases steering effort. Toe is the angle made by the wheel with respect to the longitudinal axis of the vehicle. Static toe of front and rear wheel is taken as zero to maintain directional stability.

Turning Radius - According to the rulebook, the turning radius of hairpin turn is 4.5m. So we designed our steering geometry to take a turn of minimum 2.7m radius of circle. Table below shows the different steering and suspension geometry.

Specifications -

KPI	7
Caster angle	+4
Camber angle	-3
Toe angle	+2
Steering ratio	6:1
Bump Steer	0
Turning Radius	2.7m

BRAKES

Brakes of a vehicle matter a lot in the performance of a vehicle. To get maximum heat dissipation, team decided to use disc brakes with onboard disc brakes at the rear. Parameters which define the performance of braking system were defined and calculated below.

Weight Transfer - To get a desirable tractive force on drive wheels (i.e. rear wheel in our car) we fixed the static weight ratio of front and rear as 40:60 and it becomes 67:33 at the time of retardation in brake test as given in rulebook.

Brake Efficiency - Braking efficiency is defined as the ratio of maximum wheels-unlocked vehicle deceleration to tire-road friction coefficient. The braking efficiency expresses the extent to which a given tire-road friction coefficient available to a vehicle is transformed into maximum wheels-unlocked deceleration. Brake system is designed as to achieve maximum retardation of “0.984g”.

Braking Force - Brake system is designed to achieve the ratio of 1100:750 braking force on disc by calipers in front and rear wheels (which obtained according to the longitudinal weight transfer). Selected pedal ratio was 4:1 due to which pedal force require for this is 300-350 N which can be easily applied by the driver.

FEA Analysis – Stress analysis of brake pedal was carried out by applying maximum force normal to the footrest which the driver can apply under panic.

When the force is applied the footrest is at its maximum play and both the hinge points at this position become fix and the maximum force acting normal to the footrest is taken 350N and the stress analysis is carried out at this position.

Specifications -

Break split	50:50
Pedal ratio	4:1
Pedal force	300-350N
Stopping distance (From 46km/hr)	8.09 m
Braking force	1100N (Front), 750N (Rear)
Disc diameter	170mm (Front), 170mm(Rear)
Braking torque	350Nm(Front), 108Nm(Rear)
Maximum deceleration	0.984g
Brake efficiency (μ=0.7)	88%

ENGINE AND DRIVETRAIN

Engine - For the purpose of ESI 2018 competition our team has chosen the designated Briggs and Stratton engine. Our team´s intention is to build a small and light Off Road vehicle and this compact power train unit perfectly fits to our car conception. It is a four stroke water cooled single cylinder SI engine with a displacement of 305cc and it weighs just 26.4 kilograms.

Specifications –

Engine Displacement	306cc
Torque	18.85N-m
Engine Configuration	Horizontal Shaft
Engine Technology	OHV
Length	12.3 in
Width	15.4 in
Height	16.4 in
Weight	26.4 Kg
Spark Plug	RC12YC
Bore	3.12 in
Stroke	2.44 in

Drive train - The drive train system consists of every component from the engine output shaft to the wheels.

The gearbox used in the vehicle is a two step reduction type Gear Box. It consists of 3 gears, namely Input, Idler and Output Gears.

Assembly consists of CVT and FNR.

Continuously Variable Transmission – The intermediate drive was narrowed down to a chain drive and a continuously-variable transmission (CVT). The required gear ratio combined with packaging constraints eliminated the chain drive option, leaving the CVT as the most viable design. Additionally, the use of a CVT implies that manual shifting is not necessary. Several makes of CVT were considered, including options from Gauged, Polar, Comet, Polaris and CVTech. The Polaris was chosen primarily due to packaging constraints given that it mates directly to the Model 20 engine.

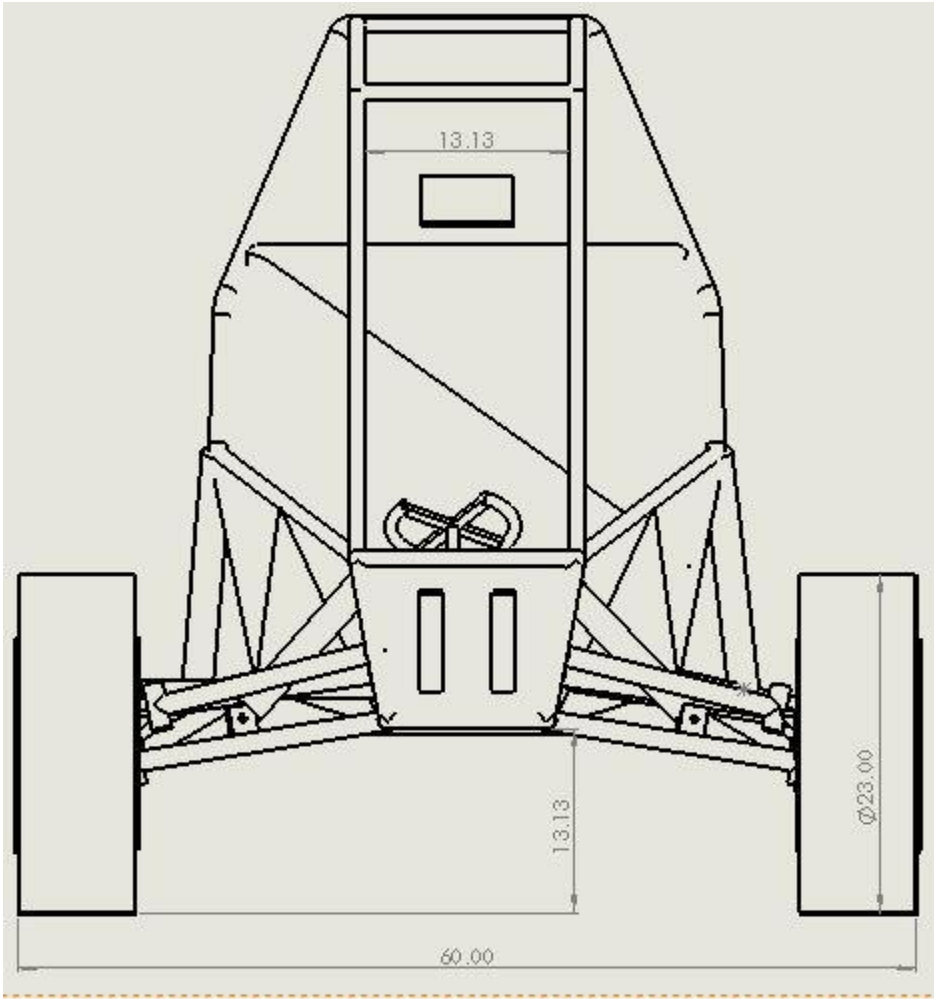
Specifications –

Sub Assembly	Ratio	Feature	Mass
CVT	0.6≤Ratio≤3.5	CC dist. 199mm	7Kg
Customized Gearbox	9	Spool drive	6Kg

Gradeabilty(μ=0.7)	83.9%
Rolling Resistance(μ=0.15)	367.875 N
Maximum Drag(c.d.=0.4)	67.18 N
Mass of vehicle(with driver)	250 Kg
Overall Ratio	6.84 to 34.47
Maximum Traction Force	1196.760916 N
Maximum Acceleration	5.203 m/s^2
Maximum Velocity	56.17 Km/hr

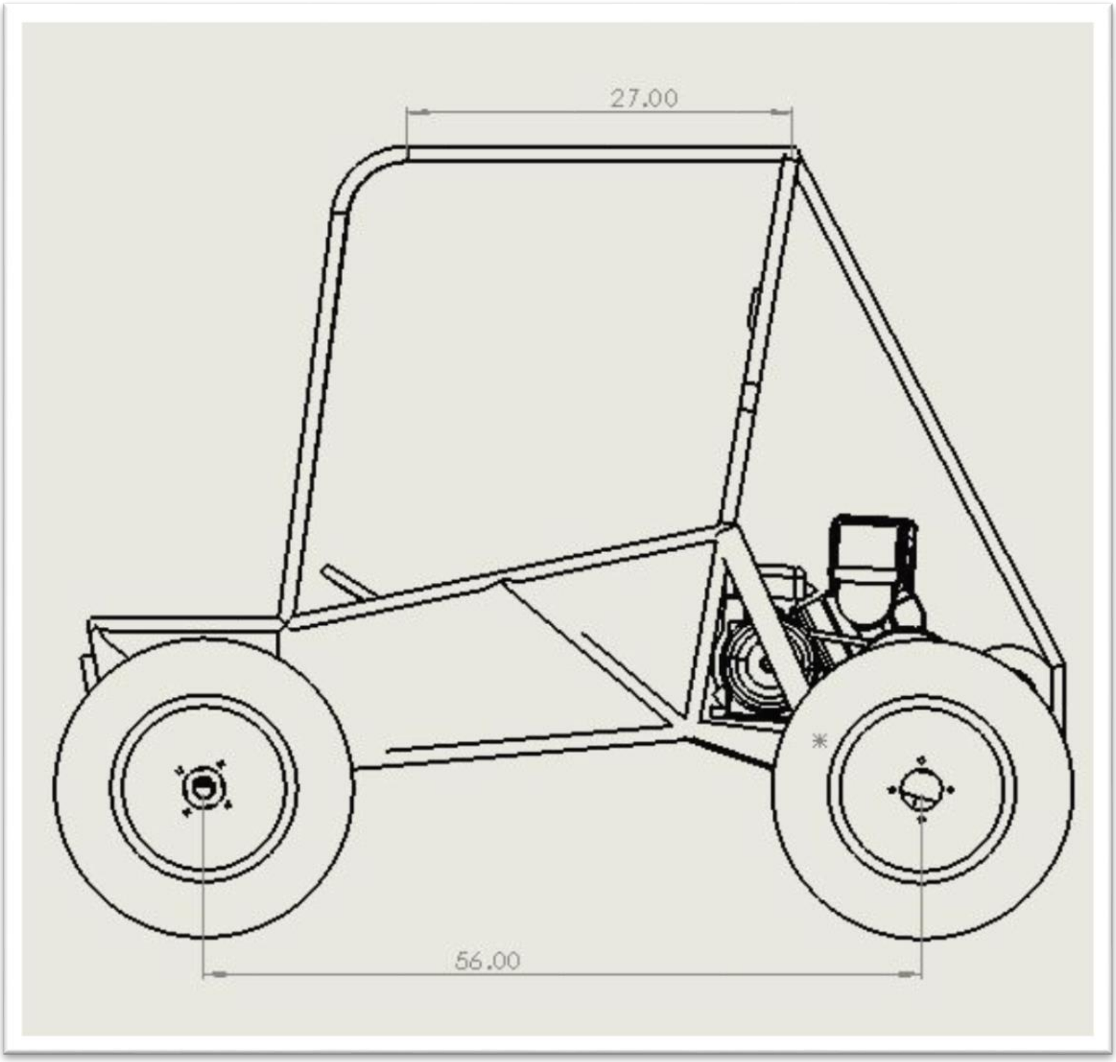
FEA Analysis – Analysis of gearbox is carried out by taking the force exerted by gears on bearings. Gearbox consists of three gears namely Input, Output and Idler gear. Analysis is carried out by taking force of 1500N, 500N and 1500N on input, idler and output gear respectively.

FRONT VIEW



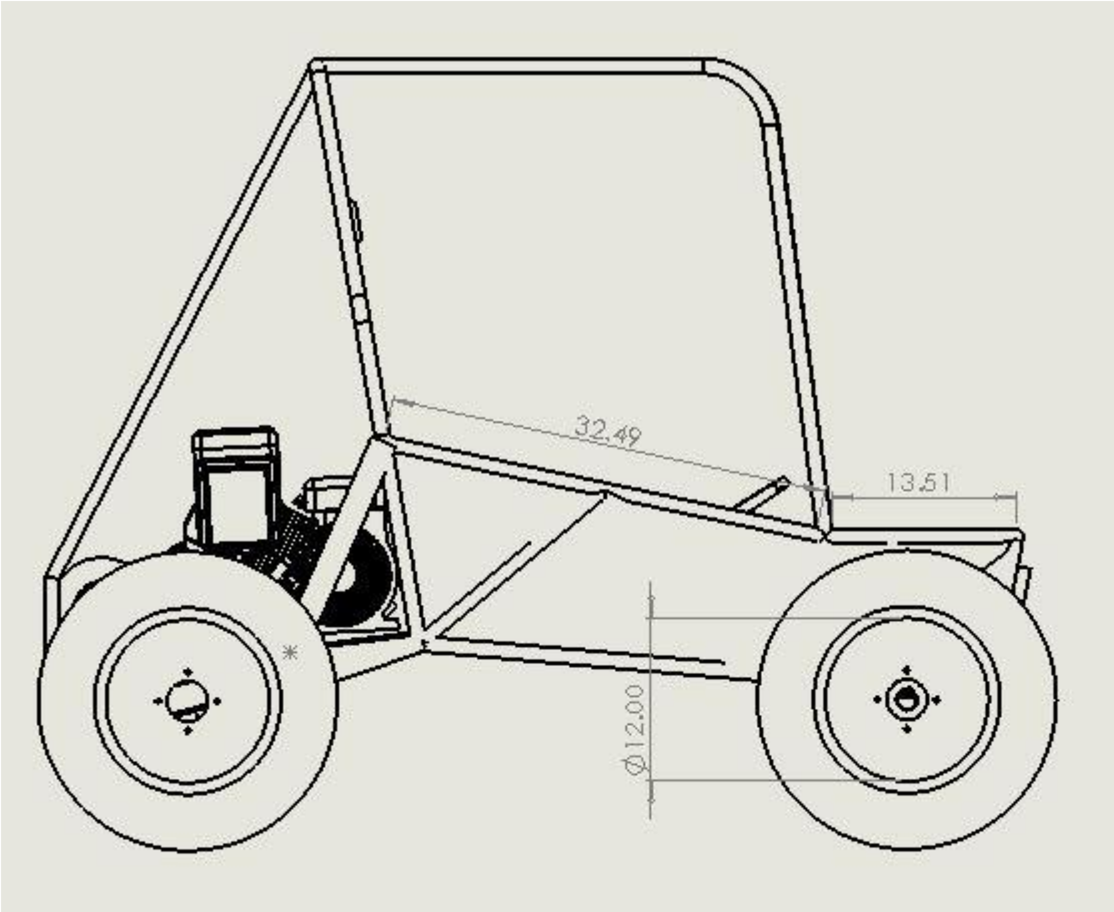
FRONT VIEW
Team Name- Team Vega Racing College Name- JSS Academy of Technical Education Car Number- 14 Date- 05/08/2017

LEFT SIDE VIEW



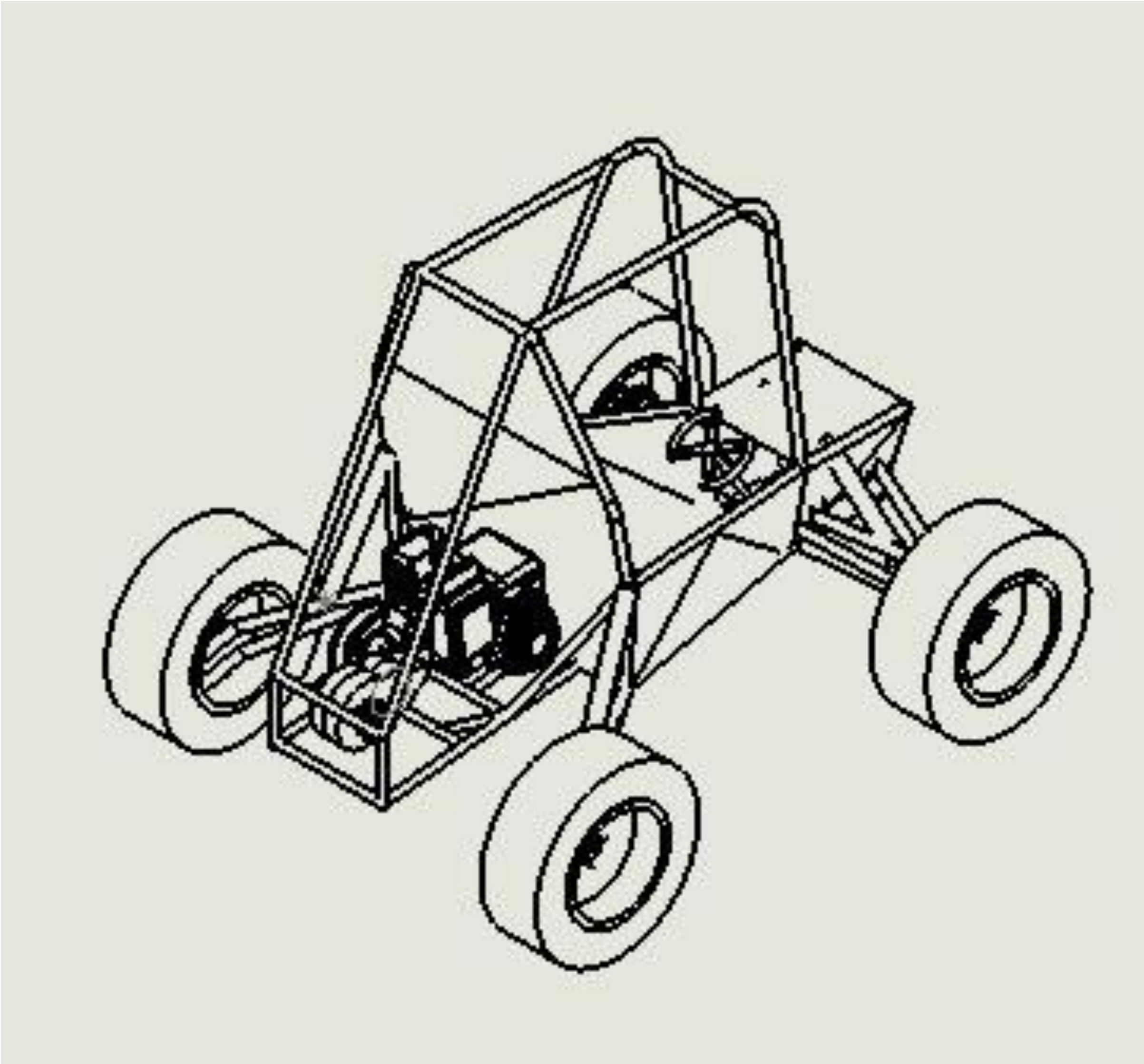
LEFT SIDE VIEW
Team Name- Team Vega Racing College Name- JSS Academy of Technical Education Car Number- 14 Date- 05/08/2017

RIGHT SIDE VIEW



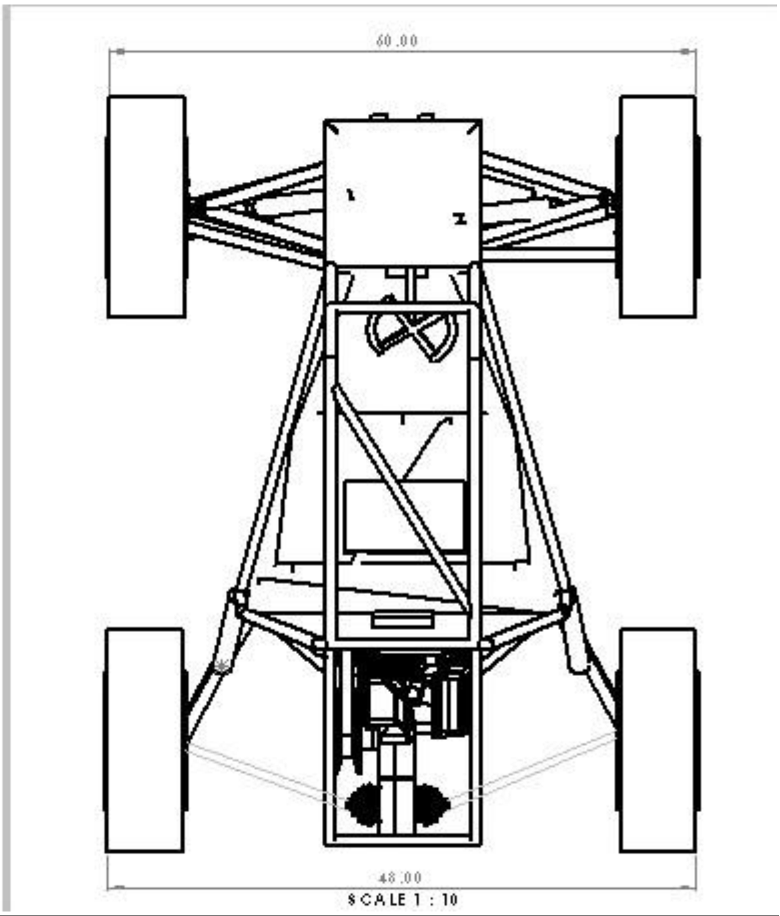
RIGHT SIDE VIEW
Team Name- Team Vega Racing College Name- JSS Academy of Technical Education Car Number- 14 Date- 05/08/2017

ISOMETRIC VIEW



ISOMETRIC VIEW
Team Name- Team Vega Racing College Name- JSS Academy of Technical Education Car Number- 14 Date- 05/08/2017

TOP VIEW



TOP VIEW
Team Name- Team Vega Racing College Name- JSS Academy of Technical Education Car Number- 14 Date- 05/08/2017