Critical Design Review Report Cover Page &
Vehicle Description Form
Human Powered Vehicle Challenge
Competition Location: Digital
Competition Date: 5th-6th March, 2022

This required document for all teams is to be incorporated into your Critical Design Review Report. Please Observe Your Due Dates; see the ASME HPVC website and rules for due dates.

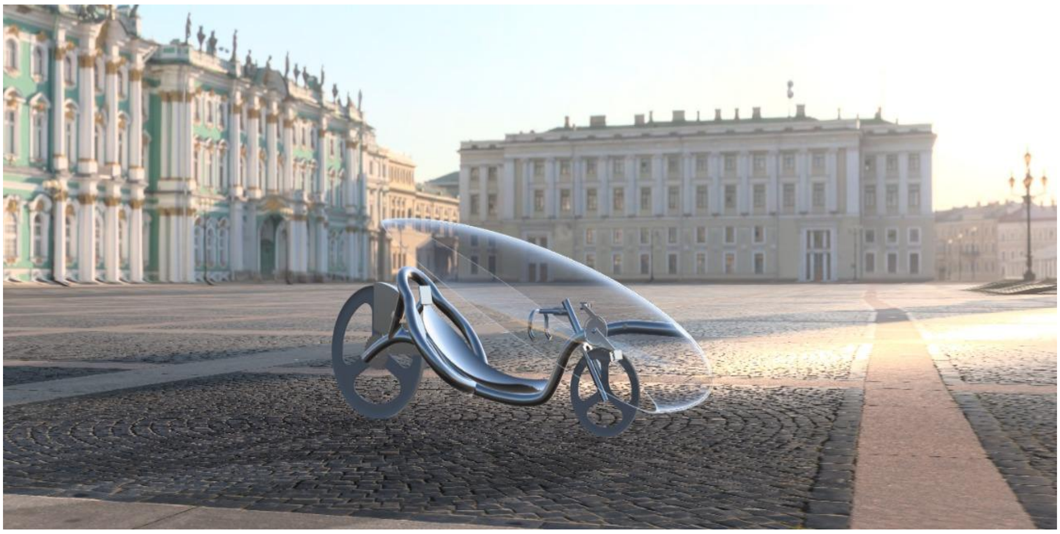
Vehicle Description

University name: National Institute of Technology Silchar
Vehicle name: TEJAS 7.0
Vehicle number: 27
Vehicle configuration:
Upright: Semi-recumbent: ✔
Prone: Other (specify):
Frame material: Carbon Fiber Prepreg
Fairing material(s): Polycarbonate
Number of wheels: 2
Vehicle Dimensions (m)
Length:1.96
Width: 0.668
Height: 0.92
Wheelbase: 1.5
Weight Distribution (kg)
Front: N/A
Rear: N/A
Total Weight (kg):14 (approx.)
Wheel Size (m)
Front: 0.380
Rear: 0.640
Frontal area (m^2):1.3
Steering (Front or Rear): Front
Braking (Front, Rear, or Both): Both
Estimated Coefficient of Drag: 0.123
Vehicle history (e.g., has it competed before? where? when?):
TEJAS 7.0 is a completely newly manufactured vehicle which is completed in the academic year 2021-22. It is exclusively made for competing in HPVC 2022.

(CRITICAL DESIGN REVIEW REPORT 2022)

TEJAS 7.0

(VEHICLE NUMBER-27)



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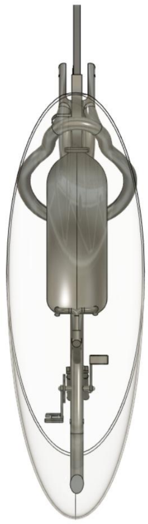
- DASARI NAGESHWARA RAO
- ARNAVJYOTI BHUYAN
- TANMOY NATH
- ANURAG DEBNATH

III. <u>3-View Drawing of Vehicle</u>

Side View



Top View

Front View

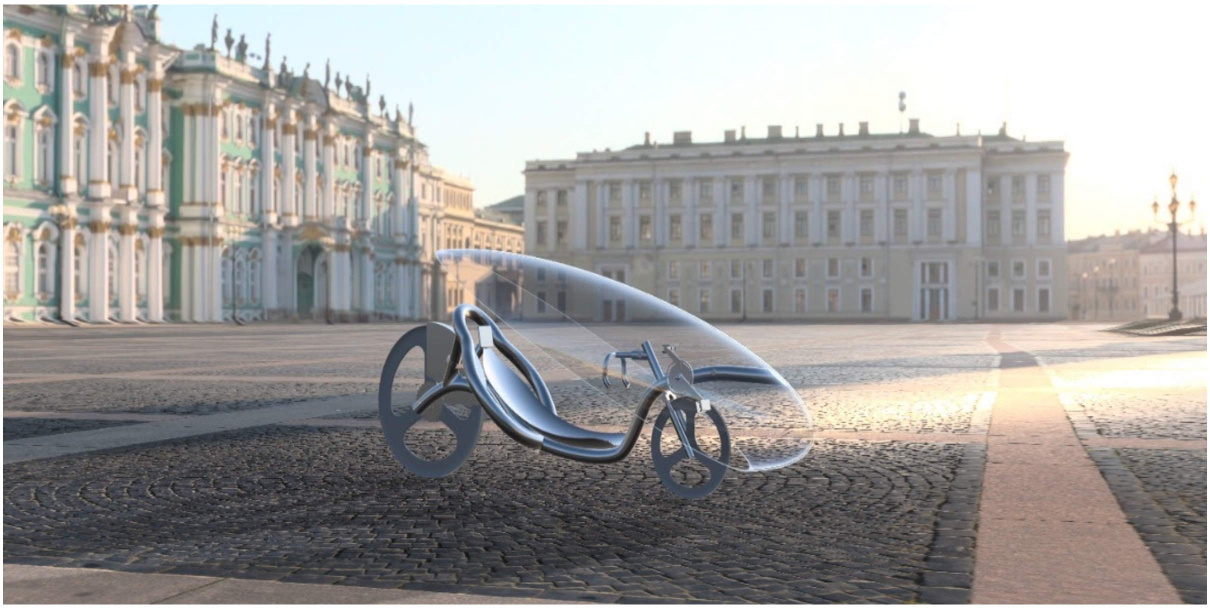
Isometric View

IV. ABSTRACT

The NIT Silchar Human Powered Vehicle team Tejas 7.0 continues on its endeavour to take forward the legacy set by previous initiatives. With various designs having been tested and fabricated by teams from NIT Silchar over the years, team Tejas 5.0 finally managed to make a breakthrough in HPVC at ASME E-Fest Asia-Pacific 2020, achieving a speed of 55 km/h with a compact semi-recumbent bicycle with a short wheelbase. Wishing to continue its search for another engineering adventure, our team has decided to give it a fresh start with the objective of achieving high speeds while maintaining the stability and giving the design more of an aerodynamic feel.

Tejas 7.0 as the name suggests continues the naming scheme with a nod not just to the iteration number, but also to the legacy which our seniors carried so far. We decided to come up with a brand-new design so that we could put our abilities to use to the full extent which would add to our experience.

The team aimed to have a better engineered vehicle. A negative fork offset was considered, which increased the trail, thereby providing better self-centring ability which added to the stability of the ride. The bicycle also incorporates an improved suspension system for better comfort and handling. Furthermore, taking the rider’s safety into consideration, an appropriate RPS was incorporated in the design. With these features, the NIT Silchar Human Powered Vehicle Team is determined to produce its finest vehicle yet.



Tejas 7.0

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VI. <u>DESIGN:</u>

a) <u>OBJECTIVE</u>: Team "Tejas" from the National Institute of Technology Silchar has always aimed at making our design better than ever before year after year. For 2022, the team starts afresh with a brand-new design Tejas 7.0, making everything from scratch with the main objective of achieving greater speeds while maintaining stability and making it highly aerodynamic to minimise the losses due to aerodynamic drag.

<u>Speed</u>: The primary objective of our design is to achieve high speeds. Taking inspiration from previous year results, we are motivated to improve upon this achievement even more by using a much lighter frame and accessories.
<u>Stability</u>: For stability purposes, a negative fork offset was used which provided an increased trail which further provides better self-centring, thereby adding to the stability. Lowered center of gravity & a long wheelbase helped in improving the directional stability
<u>Fairing</u>: Keeping the aerodynamics as well as the aesthetics in mind, the fairing for this year's edition has been properly designed resulting in an optimal value of the drag coefficient and streamlined airflow around the vehicle.

b) <u>BACKGROUND</u>: Team Tejas HPVC NIT Silchar is motivated by our seniors for participating in E-fest Digital 2022, so we decided to innovate a design for the same. We went through the design reports of other Teams and scanned them properly to become familiar with the basic outline of dimension ideas, drivetrain possibilities and material choice options for our initial concepts. The "Rules for the Human Powered Vehicle Challenge" packet dictates all necessary information for vehicles entering the competition and was used as an underlying reference in our design process. All specifications in this document were followed including safety, dimensions, and class designations. The conventional bicycle design comprises front wheel steer and rear wheel drive. After weighing the pros and cons of the front wheel and rear wheel drives, it was decided to come up with front wheel steer and rear wheel drive. For material selection, Aluminium, Carbon fiber and Steel were considered. After a thorough examination carbon fiber was the obvious choice since Aluminium has many drawbacks including the requirement of pre-working to make it strong and machinable. Whereas for steel, it added to the weight of the vehicle significantly, which was a big barrier in our objective of achieving high speeds. Carbon fiber on the other hand, is much stiffer than either of the materials. Moreover, carbon fiber exhibits anisotropism by virtue of which its stiffness can be tuned based on how the carbon fiber is oriented. In this way we can effectively maximise the strength in desired directions. We eventually zeroed in on Carbon fiber prepreg.

c) <u>PRIOR WORK</u>: All of the work – Design, Analysis and Testing for "Tejas 7.0" has been done in the current academic year by a new team from scratch. On the state of prior work, we only have basic data which we have collected by analysis of our previous years' work and other teams' reports from the past year. We are also well versed with CAD, CFD, Analysis and testing software like Fusion360, SolidWorks, Ansys and Blender.

d) ORGANIZATIONAL TIMELINE:

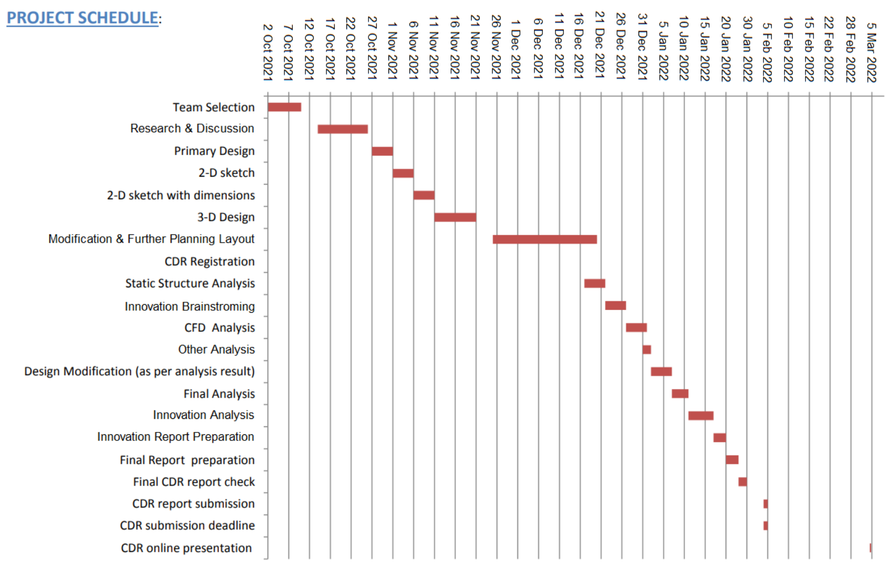
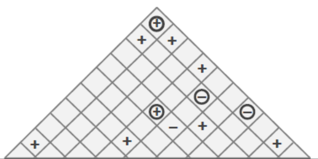


Fig.: Gantt chart showing the schedule for the creation of TEJAS 7.0

e) DESIGN SPECIFICATIONS: QFD is a method of ensuring consumer requirements are accurately translated into relevant technical specifications from product definition to product design, process development and implementation. The QFD shows the needs & requirements of the consumers (our riders in this case) as rows and the approaches in the design to be made as columns. The correlation values between needs and design approaches, relative importance values and their impacts were assigned by team consensus.



	Roll Bar Strength	Safety Harness Strength	Field of View	Turning Radius	Ingress/Regress Time	Drivetrain Efficiency	Drag	Low Speed Stability	Vehicle Volume	Weight
Rider Safety	●●	●●	●					●		
Surrounding Awareness			●							
Maneuverability						●		●●		
Top Speed						●●	●			●●
Acceleration						●●	●●			●●
Comfort										
Braking							●●			
Durability and Ease of Repair						●●				
Transportation									●●	●

Correlations:
Strong Positive
\+ Positive
⊖ Strong Negative
– Negative

Relationships:
●● Strong
● Weak

Table 1-QFD Chart for Design Specifications

Design specification	Constraint	Justification	Methods to achieve
Top speed	>35 km/hr	Necessary to be competitive	efficient drivetrain and aerodynamic profile
Total weight	< 20 kg	Efficient ride and more speed	Material & Design
Breaking from speed of 25 km/hr	< 6m	Competition requirement	Powerful brakes
Slow speed travel in a straight line	5-8 km/hr	Competition requirement	Handling mechanism
RPS top loading	> 2670 N	Competition requirement	FEAe & physical testing
RPS top load elastic deformation	< 5.1 cm	Competition requirement	FEA & physical testing
RPS side loading	> 1330 N	Competition requirement	FEA & physical testing
RPS side load elastic deformation	< 3.8 cm	Competition requirement	FEA & physical testing
Innovation compatibility	Attached	Competition requirement	Research and analysis

Table 2- Design Specifications

f) CONCEPT DEVELOPMENT AND SELECTION METHODS: Weighted Decision Matrix was used by our team to determine the type of vehicle which fits best for our needs. Each type was graded on the basis of several parameters and the importance of each parameter has also been depicted in the score weight as shown below:

PARAMETERS	SCORE WEIGHT	Upright	Recumbent Delta Trike	Recumbent Tadpole Trike	Semi Recumbent
AERODYNAMICS	10	5	6	7	10
COMFORT	9	6	7	10	9
DESIGN SIMPLICITY	10	7	6	5	8
VEHICLE'S WEIGHT	8	6	7	6	8
PART AVAILABILITY	9	7	6	7	8
RIDER'S SAFETY	10	6	8	9	10
INNOVATIVE	8	6	8	8	9
	Total	393	437	475	569

Upon evaluating the scoresheet, it was evident that the semi recumbent type design was best suited for our needs. Thus, our team settled for the semi recumbent design.

g) Description:

1)Frame: There were many materials that are easily available in the market, first decision we have taken which material should we better for our objective, so finally analysing all the properties we have decided to choose Carbon fiber for our frame material as Carbon fibre is significantly stronger than aluminium as well as steel. While carbon fiber components may cost a bit more, they are stronger, lighter, and built to last much longer than a steel counterpart.Once we had the material, we modelled our frame and then did the stress analysis calculations. Our frame ended up being as shown in the figure below with curved shaped members across the back of the RPS providing the required strength and rider space to the RPS. We also found it to be visually appealing. Design of this member is such that it can bear the forces that are given in the rule book for the protection of the driver.

Affecting factors for the frame: Compared with last year we increased recumbent angle (taken clockwise w.r.t. horizontal axis according to figure that is given below) for better aerodynamics.Lower centre of gravity providing more stability.Different approach in frame with large diameter cross-section for better overall strength of the frame. Which can be seen in analysis with very low deformation values.

Fig.: Vehicle Frame

2)Braking: Considered braking systems were rim and disc brakes. Among these, we have considered disc brakes because of their superior advantages. Hydraulic configuration of the disc brake was selected based on the below decision matrix. **(5 point scoring**)
We have used hydraulic disc brakes on both front and rear.

Disc Brakes		
Criteria	**Hydraulic**	**Mechanical**
Weight	5	3
Smoothness of Operation and Braking Consistency	4	3
Pricing	3	4
Stopping Power	5	4
Brake Maintenance	3	4
Modulation and Precision of Braking Force	5	4
Parts Availability	3	4
Overall score	28	26

3)Transmission: The objective in designing this year's drivetrain was to consider various parameters that affect the performance and efficiency of the drivetrain and selecting the optimum values for each of them. For selecting the drive type for the HPV we analyzed different aspects of the available chain drive and belt drive and due to the benefits like transmission efficiency, adjustable length and tensioning chain drive was chosen.
Considering all of these factors **chain drive** was opted.
While selecting between FWD and RWD a concept scoring (out of 5) was used as following:

Criteria → / Options ↓	Balance	Cost	Traction	Weight	Design complexity	Steering	Pedaling force	Score
FWD	3	3	4	4	3	2	4	23
RWD	5	4	3	3	5	4	3	27

As suggested by the above decision matrix RWD is more advantageous than FWD along with the added advantage that for our longer wheelbase HPV the chain tensioning will be easier in the RWD than FWD.

Crank length: Generally to achieve high speed standard crank length is preferred. As for our design the bottom bracket is relatively at a higher position than the seat, spinning at high cadences can be difficult with standard length crank arms. Thus a shorter crank length is preferred which also is an aerodynamic benefit due to lower area of pedaling circle in air. Thus we went with a **145 mm** crank length for the Crank set.

Drivetrain: The available options for drive train were – 1) Internal Hub Gear 2) Derailleur

Criteria → / Options ↓	Shifting	Efficiency	Maintenance	Cost	Gear range	Weight	Score
Internal Hub Gear	4	3	4	3	2	3	18
Derailleur	3	5	3	4	5	4	24

On the basis of the above grading **derailleur system** is chosen.

Crankset and cassette cogs: For the efficient use of the derailleur gear system a good combination of crankset and cassette cog is necessary. As a **2x** system provides better gearing ranges and better speed options it was selected over a 1x system. Considering various aspects a comparison was done between the available 2x standard, semi-compact and compact crankset-

Crankset	Gear inches	Cadence maintenance	Operating regions	Aerodynamic benefit
Standard	high	low	High gear	Low
Semi compact	moderate	moderate	Both high and low gears	Moderate
Compact	low	moderate	Better at lower gears	high

Thus considering the above aspects **Semi compact crank** set was chosen among the available options.

For the cassette cogs in accordance with our chain offset and overall drivetrain design 7 speed cassette cogs were considered. Out of the options available **Shimano 11-13-15-18-21-24-28 7-speed** cassettes were chosen for our operation.

4)Steering: There are two common arrangements of the steering mechanism. In the design of steering, we have decided to use Above-Seat-Steering so that aerodynamic configuration can be minimized and stability is more as compared to Under-Seat-Steering. The rider's comfort and performance can also be enhanced by the introducing an appropriate steering system. The bicycle handlebar will be used as the steering control. The handlebar will provide a convenient mounting place for the front components like brake levers, shifters, bells etc. The handlebar is attached to the bike's stern which in turn attaches to the fork. An adjustable steering handle is being proposed for this year's design by keeping in view riders arm adjustment. The steering handle can adjust at different lengths throughout the stem length.

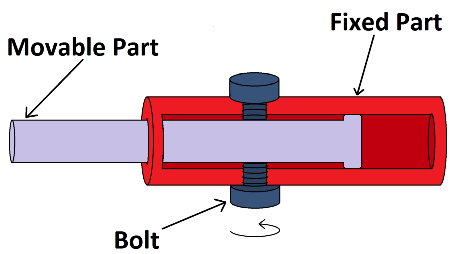
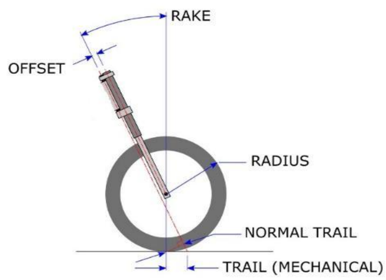


Fig.: Movable Stem

For this the steering stem is converted in a piston cylinder type assembly where two bolts with their end with rubber padding were mounted in the assembly for fixing the adjustable stem at a particular length.

Steering geometry: For the steering geometry we considered head tube angle, fork offset, trail, wheel flop as important parameters and did our analysis. We went with 60-degree head tube angle and a negative 28 mm fork offset which resulted in a 142 mm trail and 62 mm flop which are optimum values for a stable steering geometry to operate in different speed conditions.



5)Suspension: The types of suspensions available are : telescopic suspension ; upside down suspension, lauf suspension, trust performance suspensions.For front suspension we used telescopic fork .Inclusion of proper suspension is essential to account for the uneven road conditions. For any suspension the following parameters are required to compare among them.

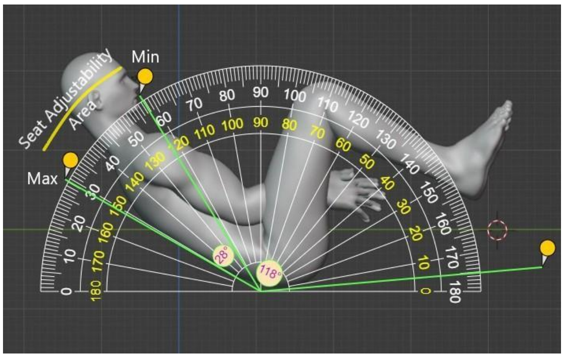
Parameters	Weight	Oil spilling	Speed limit at which it is used	Stability at corners	Maintenance	Damping	Rigidity	Cost	Total
Telescopic Suspension	4.5	5	3	4	5	3	3	5	32.5
Upside down suspension	3	2	4.8	3.5	2	3.5	4	2.5	25.3

From the above conclusion we consider the main parameters like stability at corners, oil spilling, maintenance, weight etc. Keeping those parameters in mind we've chosen telescopic suspension at the front.

<u>6)Seat</u>: The main idea behind this design is to have a lighter seat & economic cost, ensuring the safety and ergonomically comfort for the driver. Some of its features are:

A. Material: This seat offers a breathable mesh filter-like seat that can provide hours of comfort. These types of seats encourage the flow of fresh air and can provide the driver with cool comfort, especially during riding. It also ensures a lighter seat.

B. Support back: A good seated posture is one that is comfortable and does not put a lot of stress or strain on the user's buttocks, back, or arm muscles. Maintaining the neutral, or standing shape of the lumbar, or lower spinal area, is important for comfort and posture. Chairs can give appropriate and correct lumbar support which helps the driver to give maximum output power without any pain.



C. Adjustable back: The driver's back can be adjusted maximum 146 degree and minimum 118 degree without affecting its maneuverability. The main reason behind this adjustable back feature is that everyone has their own comfort zone and accordingly he/she can give his maximum output. So, adjusting his/her back position the maximum human power can be obtained. Moreover, this feature also helps us to have a better field of view. At a lower seat angle, the driver will be able to have a wider view of the frontal area of the HPV.

D. Mechanism: Two sets of ratchet pawl mechanisms are used each on either side. This will allow the seat back to rotate forward & rearward direction hinged at the base of the seat. One set will help in changing the back angle gear in anticlockwise direction while the other will resist the forward motion (clockwise motion) produced due to the coil spring force and vice versa.

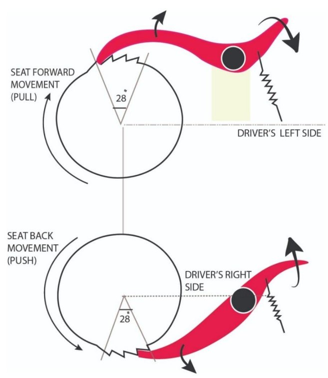


fig.- Ratchet Pawl assembly when the seat is at minimum position

To rotate the seat in backward direction,the pawl handle at B needs to pull. To rotate in forward direction, the pawl handle at A needs to push downward.

E. Coil Spring: To avoid a catastrophic jerk while changing back angles coil spring is provided at the hinge.

<u>7)Bicycle Fairing:</u> A bicycle fairing is a partial or complete covering attachment for a bicycle in order to reduce the aerodynamic drag force. To reach our goals for aerodynamic performance, we designed a wind fairing made from polycarbonate. The development of fairing was rather a gradual and iterative process with several stages of development hence a lot of time was devoted to this. We focused on this method because the previous vehicles from our institute either suffered due to absence of fairing or due to lack of a properly designed fairing. The fairing is designed as a streamlined body, optimized to fit the geometry of the

Fig.: First iteration of fairing design

Fig.: Final iteration of faring design rider and cover the whole vehicle, and reduce drag while also not blocking the field of view of the rider being transparent. Apart from reducing air resistance, it is an effective shield against bugs, rain, cold air, and road debris. Vehicles with full fairings are very expensive and also add to the weight of the bicycle. Therefore, we have used partial fairing in this design.

VII. INNOVATION:

IDEA: Innovation is the creation, development, and implementation of a new idea to improve efficiency, effectiveness, or competitive advantage. Our proposed innovation is designed keeping in view all these important factors. In our case a pedal electric assist can reduce the human effort required in riding the HPV, this is the main idea of our innovation. The design of our innovation is such that it fits our HPV model without any safety issues and minimal aerodynamic drag. However, with some minute changes, it will be able to fit in any kind of HPV. Here we introduce a motor that is connected to the rear wheel by a chain through a freewheel. The motor is in turn connected to a controller which controls the RPM of the motor. The task of determining the RPM of the motor is done using a sensor that is connected to the freewheel of the main chain drive which is then connected to the controller. There is also a switch using which the rider can turn ON or OFF the assist whenever he or she wants to. There is also a mechanism connected from the brakes to the switch whose job is to turn OFF the mechanism whenever the rider applies the brakes past a critical point and it also turns it ON after the rider releases the brakes.

a) PURPOSE:

NEED: It is difficult to drive a vehicle for long-distance or at a high speed by only means of human power. Therefore, an assist will be very helpful in this case. We are developing a mechanism that will reduce the force required to drive a cycle by the means of electrical stored energy. It is eco-friendly and reduces the effort of the rider while riding. Also, it will noticeably increase the top speed of the vehicle.

BENEFITS:

1. Reduction in the human effort: The electric assist reduces the human effort to a significant amount. Mainly if we are talking about long-distance travel and a speedy ride, it will do some amount of work so that the total estimated human effort will be reduced.

2. No pollution: As we are using electrical stored energy it is clean and produces no air pollution. Also, the mechanism we are using doesn't produce much noise, so no noise pollution also.

3. Cost: The innovation will cost approximately about 9000 INR.

b) CONCEPT EVALUATION:

INNOVATION DESIGN: Our aim is to increase the speed of the vehicle and reduce the effort of the rider. To achieve this, we developed an electrical pedal assist mechanism. This comprises primarily - 1) motor 2) Battery 3) Cadence sensor 4) Controller.

We are taking the rpm of the rear wheel with the help of a cadence sensor that will fit in the rear wheel axle hub. We use this signal as the input to a BLDC controller and we activate an assist system that is attached to the opposite side of the main drive chain. To turn the wheel with electric assist we attach a freewheel to the rear axle hub and connect it to the motor with a chain. We connect a power control knob or regulator switch to the controller assist control line. The controller has PWM circuits that control the power output without any loss (in form of heat). So that the rider can adjust the amount of assistance he needs or is suitable for him. The controller is rated 24 Volts and 12 A with unrated output. We connect a cut-off switch to the controller which turns off the assist system when brakes are applied to more than a certain extent. We connect a pressure switch to the brake lever, so that when riders apply brakes the power connection cuts off.

FUNCTIONALITY OF THE DESIGN: We connect the chain drive of the motor to the free wheel. When the rpm of the motor is less than that of the wheel it neither provides any assist nor any drag. But after an instant when the motor rpm exceeds the wheel rpm provided by the rider it starts to provide a driving force that reduces the rider's effort.

Cadence Sensor: These sensors involve a magnet ring attached to the crank arm or spindle or to the wheel axle, with a sensor that detects the passing magnets when the pedals are turned. This outputs a signal from 0 to 5V. The sensitivity increases with the number of magnetic poles in the sensor. There should be a min 4-5 mm gap between the magnetic plate and sensing pod.

Fig: Pedal Assist Cadence Sensor

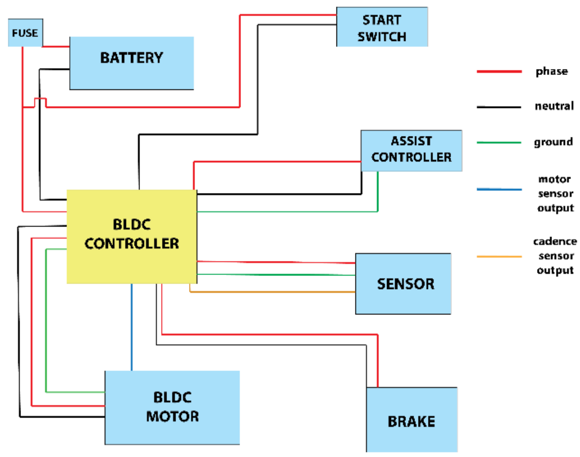


Fig: Electric Connections

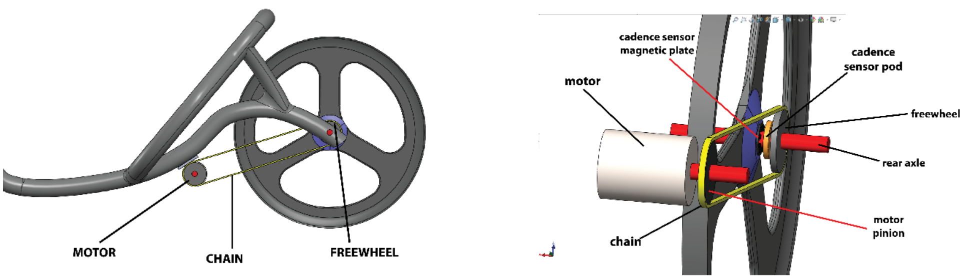


Fig: Schematic diagram of the innovation

UNANTICIPATED BENEFITS: While developing the assist system we found out that we can attach our model to any and almost every HPV made. Unlike many other assist systems in e-bikes, we do not require to purposefully manufacture a part of the HPV for our assist system as we did not use the hub motor or any other components that are directly joined to the HPV. We are using an external motor with a chain drive that's why we can use it in any kind of HPV. It gives us the added benefit of easily removing the system in case of customization or repair.

Calculations for motor output:

We decided to use a 24V 10Ah battery with 24V 240-watt BLDC motor. We found out that the total weight of the vehicle including the innovation is 13 kg. We take the rider weight to be 75 kg. Therefore, the total weight is 88kgs or we can take 90 kgs. The power required to maintain the vehicle at a constant speed V is:
P = (power to overcome rolling drag) + (power to overcome aerodynamic drag)
Power in watts = (mass × g × V × rolling resistance) + (0.5 × air density × coefficient of drag × Area × V^3).
Cd is 0.123 and the perpendicular area of our vehicle is $1.3m^2$.
Power of our motor is 240-watt, if we consider 80% efficiency of the assist system,

We get, $240\times\frac{80}{100}=(90\times9.8\times V\times0.01)+(0.5\times1.1293\times0.123\times1.3\times V^3)$

V = 10.01 m/s = 36 km/hr

c) LEARNINGS:
Failures:

- The main drive train and the drivetrain of assist was not synchronized when we are using direct fixed pinion to the rear axle.
- When we apply brakes until the vehicle stops completely the motor runs by sensing small rpm. And this causes inconvenience for the rider.
- It was difficult to find a place to fit the battery as the HPV's design was low to ground to make it aerodynamic.
- When we connect the cadence sensor to the pedal hub, the relation constant of rpm of the wheel to that of the pedal changes due to change in gear ratios, for that the assist doesn't work as we expected.

Learning from failures:
1. Using a Freewheel: Due to non-synchronization of the main drive train and the drivetrain of the assist mechanism we decided to use a freewheel for the motor. This helps us in synchronising both human and motor power. This also helps us avoid the drag when we start the motor or when the rpm of the motor is less than the rpm of the wheel.

2. Power-cutting while braking: By applying a mechanical cut-off mechanism at the handle bar, we turn off the assist when the brakes are applied to a certain extent. Also, when we release the brakes, the assist gets turned on automatically.

3. Cadence sensor placement: To overcome the problems faced due to the placement of the cadence sensor in the pedal hub we decided to attach it at the freewheel of the main chain drive. This maintains the linear relationship of the bicycle and the motor rpm.

Why we selected to use a cadence sensor: Torque sensor actuated motors are good for uphill or start but it is sometimes dangerous. For example, while crossing a speed breaker the cycle's speed may boost up unwantedly. A torque-based control directly couples the motor power to the rider's power output. That means that going uphill you need to pedal hard to get sufficient power to climb. But if we use a cadence-based sensor, we don't face those problems. Because the motor is determined by the rpm of your pedals or wheel. And you can get the right behaviour of the assist by controlling the assist level.

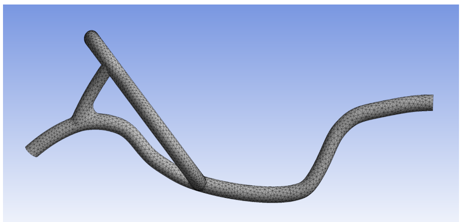
BLDC Motor: We choose brushless DC motors over brushed ones because they have Less overall maintenance due to a lack of brushes. They operate effectively at all speeds with rated load. BLDC have high efficiency and high output power to size ratio. They have better thermal characteristics and higher speed range and lower electric noise generation.

d) EXECUTION: Due to the current situation of Covid-19, there was no physical meeting of the members, which has affected the smooth flow of ideas and their implementation and access to the workshops and labs in college. The production of the physical prototype of the design was not possible.

We have analysed and calculated the working and efficiency of the innovation. And we found out that the idea is working satisfactorily. We are very sure if further experimentation is done on this concept, we can turn it into reality.

We calculated that we can achieve a max of 36 km/hr if the motor only runs the vehicle without any human effort. But with the added human effort we can achieve a greater limit with this assist.

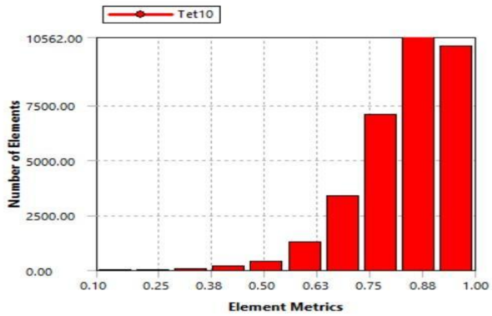
VIII. Analysis:



Structural analysis is a critical step in testing the structural integrity of the vehicle frame and ensuring rider safety under different loading conditions. The design was modeled in Autodesk Fusion 360 and the analysis was done in ANSYS workbench 2021 R1.

Meshing: The model was appropriately meshed, maintaining a good element quality overall for accurate results.

Summary:
Number of elements = 32978
Number of nodes = 53449

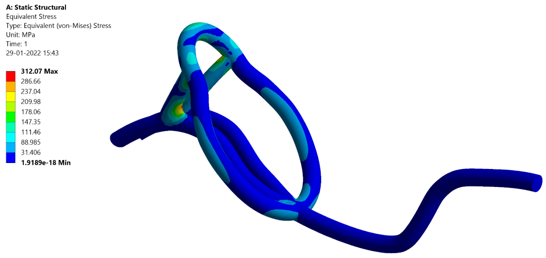


a) Rollover protection system(RPS) analysis:
The vehicle is provided with a rollover protection system (RPS) to ensure rider safety in case of a sudden fall or rollover. So the RPS was analyzed for top and side loading conditions as per ASME HPVC 2022 rules requirement.

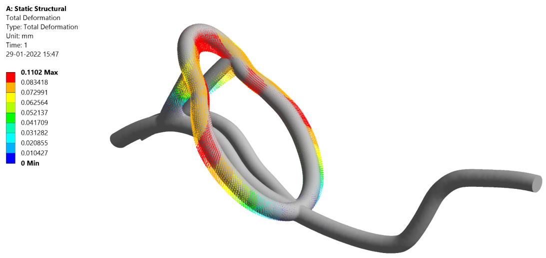
Top loading condition:

Objective	To design a feasible RPS ensuring rider safety in case of a rollover accident involving an inverted RPS.
Methodology	The RPS was analyzed by applying a load of 2670N directed downward at an angle of 12° on the part of the frame directly above the rider's head and setting appropriate fixed supports.

Result	Maximum elastic deformation of 0.11 mm and maximum equivalent stress of 312.07 Mpa was observed. Maximum elastic deformation was less than 5.1cm as per the rules.



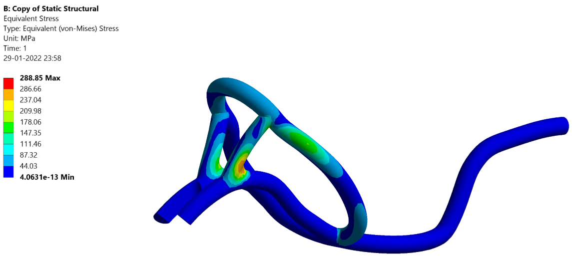
Equivalent stress in top-loading condition



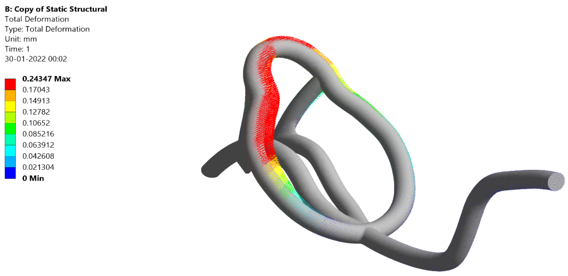
Total deformation in top-loading condition

Side-loading condition:

Objective	To ensure rider safety in case of a rollover accident in which a vehicle falls on one of its sides.
Methodology	A force of 1330N was applied sideways at the shoulder height on the RPS.
Result	Maximum elastic deformation of 0.243 mm and maximum equivalent stress of 288.385 Mpa was observed. The deformation was less than 3.8 cm as per the rules.



Equivalent stress in side-loading condition



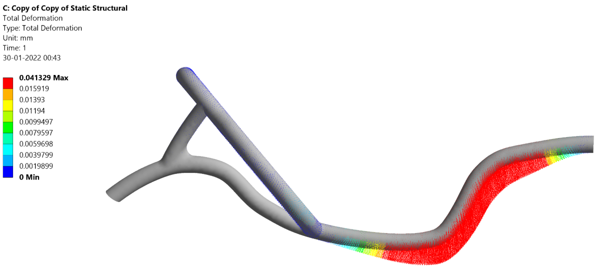
Total deformation in side-loading condition

b) <u>Structural Analysis</u>:

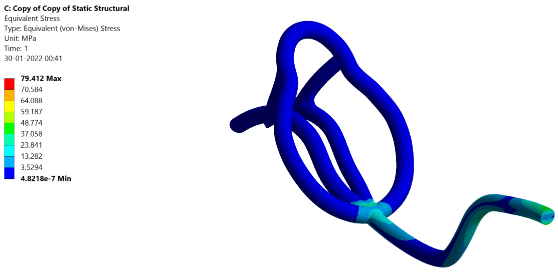
i)Body weight analysis:

Objective	To calculate the deformation and stress that occur in the vehicle frame due to the rider’s weight.
Methodology	The rider's body weight was taken to be 800 N (~80kg). The load was distributed over the frame in the following way considering the recumbency of the vehicle- ● 80% of the weight in the seat mounting point. ● 20% of the weight in the front part of the frame.

Result	The total deformation came out to be 0.04mm and the maximum equivalent stress was 79.412 Mpa. Both the values were in acceptable ranges.



Total deformation due to bodyweight

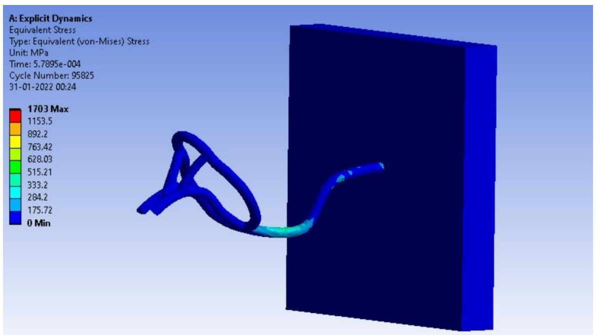


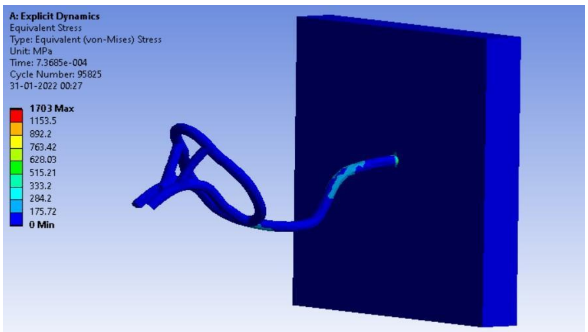
Equivalent stress due to bodyweight

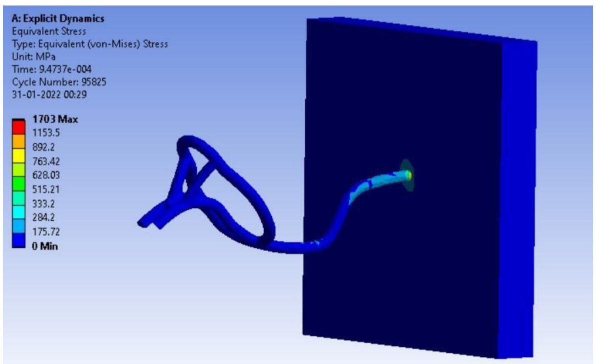
ii) Crash analysis:

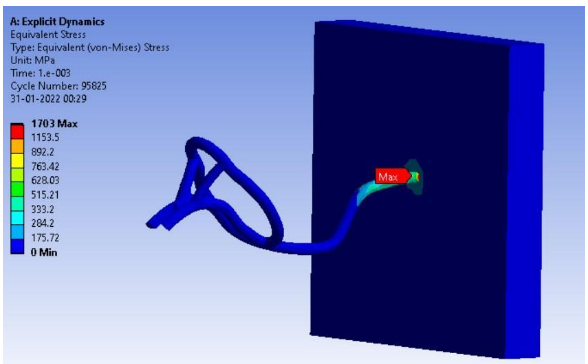
Objective	To test the structural integrity and rider safety in case of a head-on collision of RPS into a wall.
Methodology	The vehicle was given a velocity of 15 km/hr with which it collided with a concrete wall. Non-critical parts were not considered while analyzing. The stresses developed in the frame were observed for the total impact time from 0 to 0.001 seconds. This was done using ANSYS explicit dynamics.
Result	Maximum equivalent stress of 1703 Mpa was observed after 0.001 seconds and the total deformation was 2.78 mm. The maximum stress developed was less than the ultimate tensile strength.

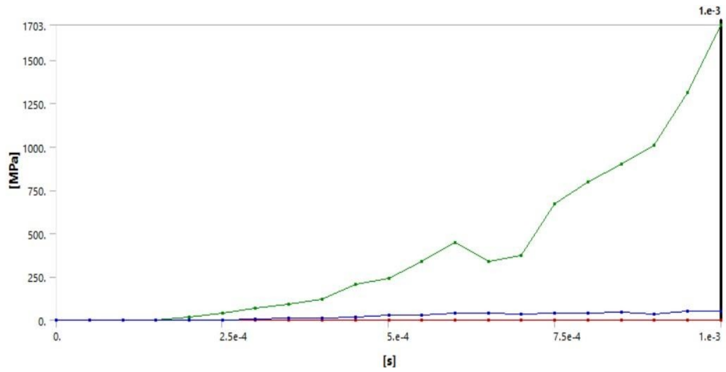
The stresses developed in the frame at different timestamps are given below:-







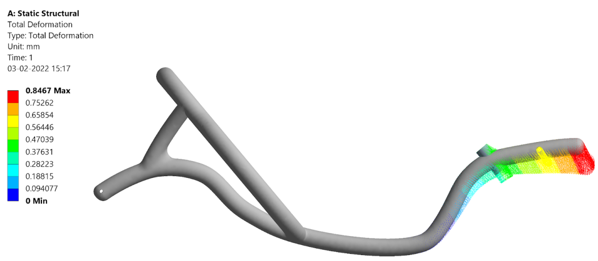


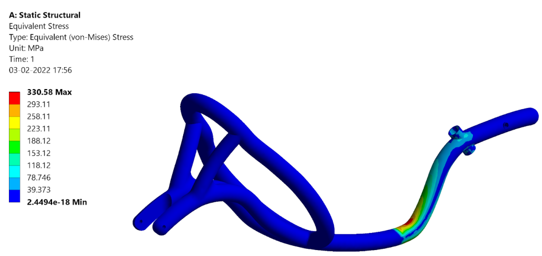


Stress developed vs time in crash analysis

iii)Bottom bracket analysis:

Objective	To test the structural integrity of the bottom bracket when maximum pedalling force is applied.
Methodology	Maximum pedalling force of 321N was applied horizontally on the bottom bracket.
Result	Total deformation of 0.8 mm and maximum equivalent stress of 330.58 Mpa were observed. The maximum equivalent stress was less than the ultimate tensile strength.



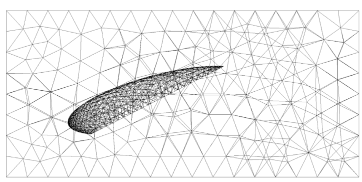


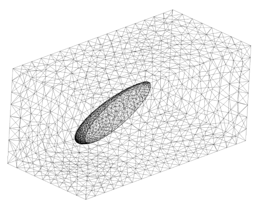
Total deformation due to maximum pedaling force

Equivalent stress due to pedaling force

c) <u>Aerodynamic analysis</u>: Aerodynamic analysis was conducted to evaluate the drag force, coefficient of drag, and other associated parameters that affect the performance of the vehicle. The final model of the fairing was developed after many iterations of design and testing. The design was developed in Autodesk Fusion 360 and the CFD analysis was done using ANSYS Fluent.

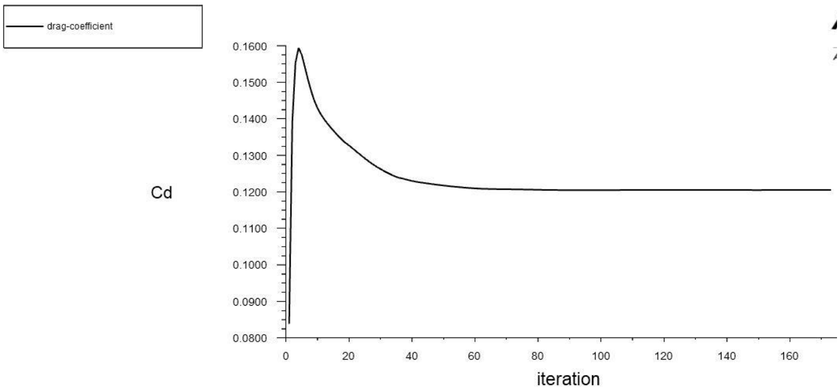
Meshing: The geometry was enclosed and the flow domain was appropriately meshed. Mesh refinement was done on the surface of the fairing to capture the boundary of the fairing properly.



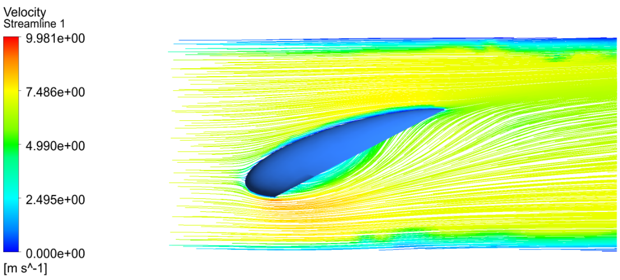


Front flow analysis:

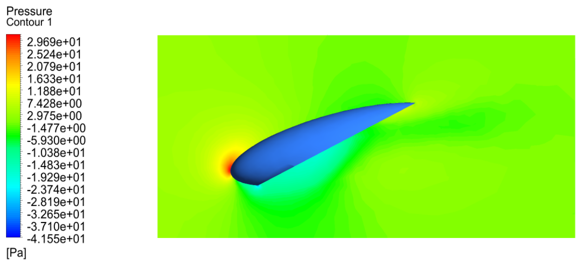
Objective	To determine the coefficient of drag.
Methodology	Air of density 1.225 kg/m^3 was chosen as the fluid material. Inlet velocity was assumed to be 8m/s(~29km/hr). K-omega SST model was used for simulation. The CFD analysis was conducted at atmospheric temperature (25 degrees Celsius) and 1 atmospheric pressure.
Result	The coefficient of drag was found to be 0.123



Cd vs number of iterations



Velocity streamline



Pressure contour

Calculation of drag force:

Frontal projection area (A) = 1.3 m^2; Coefficient of drag (C_d) = 0.123;Flow speed (u) = 8m/s

Density (d) = 1.225 kg/m^3

The formula for drag force is given by, $F_d = 0.5 x d x A x C_d x u^2$

Substituting the values, we get, drag Force = 6.208 N

d) Cost analysis:

The prices of the products are given below.

FRAME	PARTS	QUANTITY	UNIT COST	TOTAL
	Prepreg - Carbon Fiber + 250F Epoxy-50" Wide X 0.011" Thick - Standard Modulus - 3k 2x2 Twill Weave	5 yards	7000/yard	35000

DRIVETRAIN	Crankset(custom)	1	1000	1000
	7 speed cassette cog	1	400	400
	Chain	1	250	250
	Derailleur	2	500	1000
	Pedal	2	150	300
	Bottom Bracket	1	220	220
BRAKING SYSTEM	Shimano MT 200 Hydraulic disc brakes	2	2000	4000
	Brake rotor(180mm)	2	300	600
	Shifters	2	700	1400
OTHER	Front Wheel	1	3500	3500
	Rear Wheel	1	5000	5000
	Fairing material	35 sq feet	45/sq feet	1575
	Seat	1	2000	2000
	Safety(Seat belts)	2	1000	2000
	Steering	1	600	600
	Suspension	1	3500	3500

TOTAL = Rs 62345

e) Other Analysis:

1. Steering analysis: The objective of steering analysis is to achieve optimum steering geometry for better handling at different speed modes. We evaluated various parameters affecting the steering geometry as following:

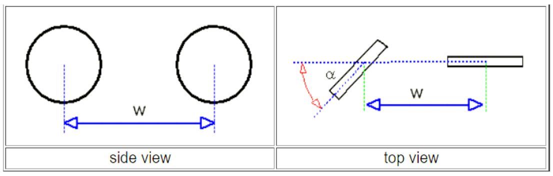
PARAMETERS	EFFECT ON INCREASING	AVAILABLE RANGES(BASED ON OUR HPV'S DESIGN)
Head tube angle	Makes steering more sensitive	55-60
Fork offset	Makes steering light	25-30(-ve)
Trail	Increases stability of steering	Depends on head tube angle and fork offset
Flop	Increases the destabilizing force of steering	Depends on head tube angle and fork offset

We methodize a way to analyze the optimum steering geometry by keeping in view our HPV's design constraints. A good amount of trail gives us good stability but with the increasing trail, the wheel flop which acts as a destabilizing force for the steering is also increased. Thus a higher ratio between these two parameters can ensure more stable steering. We calculated this ratio for 5 different head tube angle and fork offset combinations which are compatible with our design as following:

Head tube angle	55	56	57	58	59	60
Fork offset(-ve)	30.3	29.9	29.4	28.9	28.5	28
Trail (T)	170	164	158	153	148	142
Flop (F)	80	76	72	69	65	62
T/F	2.125	2.15	2.19	2.217	2.261	2.29

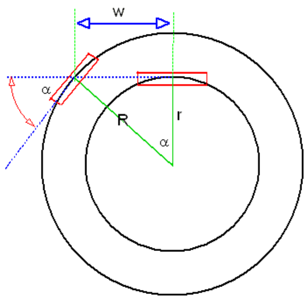
The highest ratio is obtained for the head tube angle of **60 degrees** and for a fork offset of **28 mm(-ve),** which results in a good amount of trail (142 mm) for the stability of the steering system.

2. <u>Turning Radius Analysis</u>: The turning radius or turning circle of a vehicle: It is the radius (or diameter, depending on usage) of the smallest circular turn (i.e., U-turn) that the vehicle is capable of making.



The turning radius of our vehicle is determined by using simple trigonometric calculation by using the formula:

W = Rsinα, where symbols hold their usual meaning W:- 1.5m, α = 25 deg



Thus calculating the turning radius of our vehicle is **3.549** m.

3. <u>Braking Analysis</u>: Brake analysis is done to find the distance required for a bicycle to stop after the brakes are applied.
Braking analysis consists of two major parts:

a. Deceleration: With the help of Newton's equation of motion, deceleration is calculated as: $v^2 = u^2 + 2as$,
where symbols hold their usual meaning & v = 0, u = 25km/hr, s = 6m.
On putting the values in above equation we get deceleration = 4.02 m/s^2

b. Braking Force: Braking force = mag,
where symbols hold their usual meaning & m = 14 kg, g = 9.81m/m^2
On calculating, we get the braking force = 552.11 N.
For the HPV to come to a stop from 25km/hr at a distance of 6m, the braking force applied should be greater than 552.11 N.

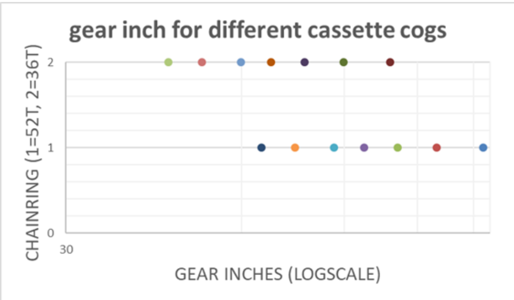
c. Conclusion: For this requirement, we have used Shimano MT 200 hydraulic disc brakes, which is powerful enough to produce a braking force greater than 552.11 N.

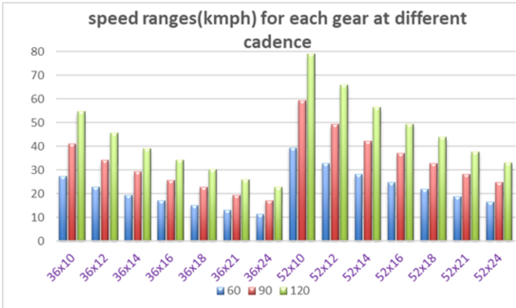
4. <u>Drivetrain Analysis</u>: An efficient drivetrain depends upon various factors out of which the combination of the front chainring and rear cassette sprockets is an essential one. For the front chainring, we had 3 options in the 2x systems namely compact(50/34), semi-compact(52/36), standard (53/39). Considering the aerodynamic benefits, optimal cadence maintenance, moderate speed range, and good top speed the semi-compact

(52/36) crankset is selected. Now for this semi-compact crankset, we had three rear cassette sprocket options which are analyzed as follows:

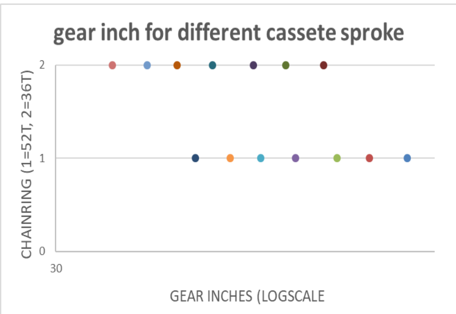
Even gear spacing and speed at different cadence: For smooth operation of gear shifting ideally the fractional increase from one gear to the next should be constant. Such that each shift feels like the same amount of change. To analyze this spacing gear inches for different rear sprockets for the three cassette options were plotted on a logarithmic plot corresponding to the two front chainrings, this also provides insight into gear redundancy. Also to analyze different speeds provided by different gear combinations plots were made.

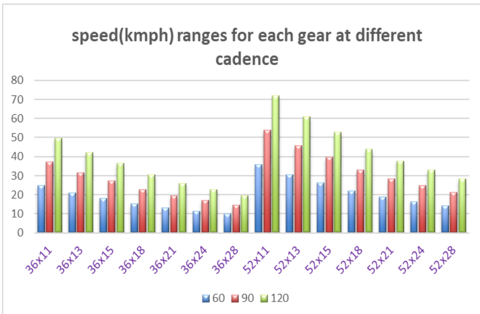
1. SRAM 10-12-14-16-18-21-24 7-speed Cassette:



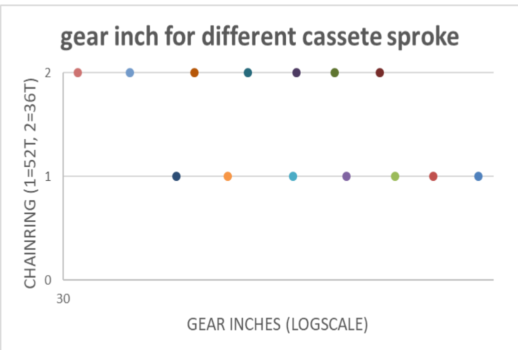


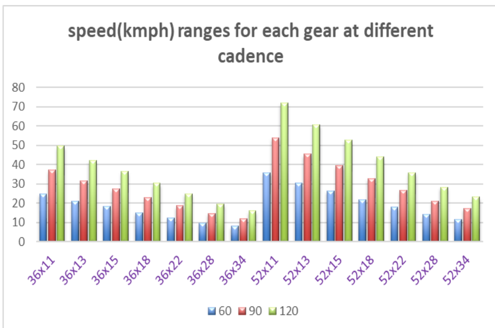
2.27Shimano 11-13-15-18-21-24-28 7-speed:





3. SunRace 11-13-15-18-22-28-34 7-speed Cassette:



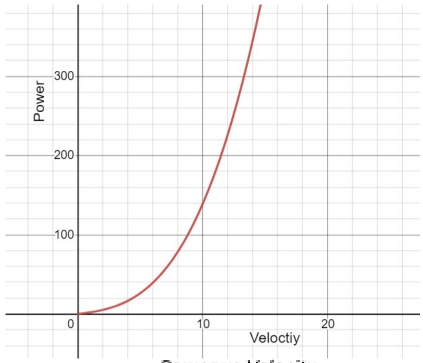


Gear Range: The gearing range for the three cassettes are found by dividing the highest available gear inch by the lowest available gear inch. The gear range for SRAM,Shimano and Sunrace are **3.46, 3.67, 4.46** respectively.

Results: Based on the above analysis it was decided that the optimal values can be found for the ***Shimano 11-12-13-14-15-17-19 7-speed Cassette*** which along with the semi-compact crankset provides smooth gear shifting as it is more evenly spaced, moderate top speed, less gear redundancy and an optimal gear range for application in different terrains and conditions.

5. Power Model Analysis: The velocity of an HPV provides the power input by the rider along with all the necessary constraints like aerodynamic drag, rolling resistance, vehicle, and rider's weight can be calculated by the following cubic power model equation.

$\mathbf{P_{total} = C_1V_{cr}^3 + C_2V_{cr}^2 + C_3V_{cr}}$



Power vs Velocity

Here, the coefficients are:

$C_1=\rho/2\eta(C_DA+A_{DW})$

$C_2= 1/\eta\{\rho(C_DA+A_{DW})\cos(D_w-D_B)V_w+0.06/\pi d_f^2 + 0.006/\pi d_r^2\}$

$C_3=1/\eta\{\rho/2(C_{DA}+A_{DW})[\cos(D_w-D_B)V_w]^2+MgC_{rr}+0.03(1/d_f+ 1/d_r) + MgG + (M+CI)a_x\}$

Where,

$\mathbf{C_D}$= Coefficient of drag= **0.123**; **A**= frontal area= 1.3m^2; $\mathbf{A_{DW}}$= Drag of spokes= **0.01m^2**; $\mathbf{V_W}$=Velocity of wind= **N/A(no wind condition)**; $\mathbf{d_f}$ = diameter of front wheel= **0.38m; $\mathbf{d_r}$** = diameter of rear wheel= **0.64m; $\mathbf{C_{rr}}$**= Rolling resistance coefficient= **0.002(smooth track); M**= Total mass of the vehicle + Rider= **75kg(rider)+ 14kg(HPV)**; **CI= Inertia Coefficient**= **3.8kg**; **G**= Gradient= **0 (level ground)**; $\mathbf{a_x}$= acceleration= **0 (going at constant speed)**; **η**= Drivetrain Efficiency= **98% (7 speed derailleur).**

A healthy adult man can generate a power of 350 watts for a few minutes and an expert cyclist can maintain the power for almost an hour.

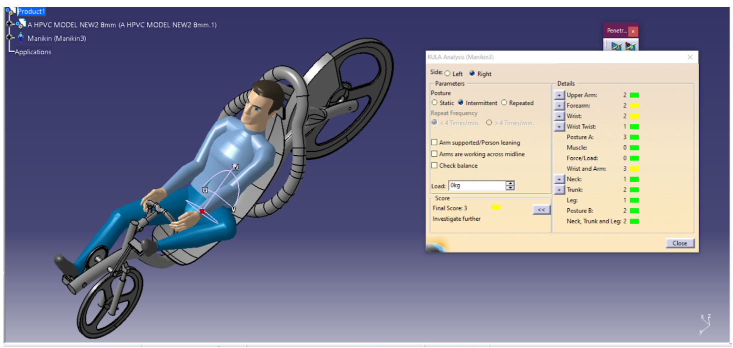
Thus, $\mathbf{P_{total}}$**=350W**

After calculation**, $\mathbf{C_1 = 0.106; C_2 = 0.14; C_3 = 1.89}$**

solving for $\mathbf{V_{cr}}$ from power equation we get, $\mathbf{V_{cr}}$**=14.45 m/s= 52.02km/hr**

6. Ergonomics Analysis:

RULA analysis was done on the proposed HPV frame design. With an added research on rider's ideal posture for experiencing least musculoskeletal hazards while maintaining the efficiency, it was determined that the most efficient position for a rider in the recumbent position is with the HPV seat at a 30° incline (angle between the rider's back and the ground).



Result- RULA analysis score = **3 (satisfactory)**

IX. CONCLUSION:

a) Comparison- Design, goals and analysis:

TEJAS 7.0 GOALS	RESULT
Better stability	A negative fork offset was used which provided better self-centering. Lowered center of gravity & a long wheelbase helped in improving the directional stability
Reduced aerodynamic drag	Use of fairing improved the overall aerodynamics of the HPV by reducing the air turbulence resulting in more streamlined flow
Rider's comfort	The increased recumbency and the knee angle put the rider in a comfortable posture while pedaling. Provision of back rest and strong suspensions provides support to rider's body and absorbs shocks while riding.
Compliance with ASME HPVC design specifications and requirements	The analysis result conforms to the ASME design requirements of various parts. The values obtained lie within the safe range and are expected to give proper results during practical testing.
Efficient drivetrain and better speed	Power model analysis and gear analysis shows more than 50 kmph speed feasible in optimal condition
Rider's safety	Installation of a sturdy cushioned RPS makes the rider less prone to injury during a fall. Inclusion of a seatbelt and protective gears further ensures the rider's safety

b) Evaluation: TEJAS 7.0 was designed keeping in mind the ASME Design Requirements and the team-imposed Design Specification. The proposed design was simulated and analyzed on technical software for the assessment of various parameters. The analysis results were satisfactory & met the team's idea of constructing a HPV which is lightweight, safe, comfortable and efficient than conventional HPVs. adjustable seat and adjustable steering makes the HPV rideable for different height riders. The low Centre of gravity imparts the vehicle stability and balance. TEJAS 7.0 incorporates a rigid and tested RPS for protecting the rider in case of a fall and a large frontal fairing to reduce the aerodynamic drag making it possible for the vehicle to achieve high speeds. Other design decisions such as usage of disc brakes, chain drive mechanism & derailleur

c) Recommendation: Tejas 7.0 is the product of new ideas and experimental concepts. but as we all know innovation is a process of iteration, further modifications based on testing can be evaluated. Synchronizing the innovation and main drivetrain can give us better speed and riding performance. Stability control system can be installed to measure the lean angles and alert the rider when the lean angle is changing too quickly. Field of view can be analyzed more to make the riders view optimum.

X. REFERENCES:

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