ELECTRIFICATION OF TRANSPORT

LOGISTIC VEHICLES (ELOGV)

Report for Project Based Internship
Diginique TechLabs

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Apart from my effort, the success of this Project largely depends on the encouragement and guidance of our instructor. I take this opportunity to express my gratitude to the people who have helped us in the successful competition of this Project.

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ABSTRACT

In the United States, the trucking industry accounts for approximately 23% of total greenhouse gas emissions, equivalent to 1.475 million metric tons of carbon dioxide. In India, road transport contributes nearly 90% of greenhouse gas emissions, with trucking and logistics vehicles responsible for over 25% of that total. Transitioning this sector to renewable energy sources would represent a significant advancement in our efforts to combat climate change.

However, this transition is not as simple as retrofitting trucks with batteries and electric motors, as exemplified by Elon Musk's approach with the Tesla Semi Truck. Several technical challenges must be addressed first. The most pressing issue is the energy density of batteries, which refers to the amount of energy delivered per kilogram of battery weight.

Additionally, the development of specialized charging infrastructure designed specifically for trucks is essential. An efficient battery management system is necessary to minimize damage and maximize the lifespan of the trucks. Furthermore, improving the aerodynamic design of trucks will enhance power efficiency. It is also crucial to utilize high-capacity motors to ensure smooth transmission and performance.

This report discusses and presents the various challenges and potential solutions for transitioning the trucking industry to renewable energy sources, emphasizing the need for innovative technologies to overcome these obstacles.

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CHAPTER 1

Introduction

1.1 Types of Logistics Vehicles

There are several freight delivery options available. Choosing the right vehicle may be challenging at times. This page describes the most prevalent types of logistics vehicles.

Truck

Length : 6.10 - 13.60 meters
Height : 2.40 - 2.60 meters
Capacity : Up to 25 tons
Use : Everything that can be packed in solid items.
Characteristics : The cargo compartment of the box truck is enclosed and cuboid-shaped, and the cabin is separate from the cargo area.

Refrigerated/Reefer Truck (Frigo & Thermo)

Length : 13.60 meters
Height : 2.60 - 2.70 meters
Capacity : Up to 23 tons
Use : Products that need to be stored at certain temperatures (food, medicine, chemicals).
Characteristics : Can transport products at different temperatures.

Minivan

Length : 5 meters
Height : 1.94 meters
Capacity : Up to 3.5 tons
Use : Small amounts of load.
Characteristics : Because it is a tiny truck, it provides speed and cost advantages for cargo weighing less than 3.5 tonnes.

Sprinter

Length : 4.3 - 7 meters
Height : 3 meters
Capacity : Up to 3.5 tons
Use : Small amounts of load.
Characteristics : Because it is a tiny truck, it provides benefits in terms of speed and cost for cargo weighing less than 3.5 tonnes. There are two varieties that can transport both passengers and cargo.

Tautliner /Curtainsider

Length : 13.6 meters
Height : 2.50 meters
Capacity : Up to 24.5 tons
Use : Everything that can be packed in solid items.
Characteristics : Curtain sided trucks.

Bulk (dry) Transportation

Length : 14.6 meters
Height : 4.45 meters
Capacity : 20800 - 43900 liters
Use : Bulk items.
Characteristics : It is a mode of transportation for bulk products such as ore, grain, coal, cement, salt, and sugar.

Tanker

Length : 5.9 meters
Height : 2.30 meters
Capacity : 20800 - 43900 liters
Use : Liquid and Gas.
Characteristics : Truck that is formed like a cylinder and is used to transport liquids and gas. Tankers come in a variety of shapes and sizes, depending on the sort of liquid they transport. Large or tiny, pressurized or non-pressurized, insulated or non-insulated, and so on.

Coil Truck

Length : 13.62 meters
Height : 3 meters
Capacity : 34 Euro pallets
Use : Coil truck for transportation of coils over a crane track.
Characteristics : Has power curtains.

Container 20 FT

Length : 5.918 meters
Height : 1.30 - 2.90 meters (usually 2.59 meters)
Capacity : Up to 21.687 tons
Use : Everything with solid packaging.
Characteristics : Container that can be used on ships, trains and trucks.

Container 40 FT

Length : 12.015 meters
Height : 1.30 - 2.90 meters (usually 2.59 meters)
Capacity : Up to 26.385 tons
Use : Everything with solid packaging.
Characteristics : Container that can be used on ships, trains and trucks.

Container High Cube

Length : 12.033 meters
Height : 2.70 meters
Capacity : Up to 26.040 tons
Use : Everything with solid packaging.
Characteristics: Higher than 20 ft and 40 ft container.

Heavy & Project Cargo

Use: Transport of large, heavy, high value or critical pieces of equipment.
Characteristics: Oversized.

Jumbo Trailer /Mega Trailer

Length : 13.62 meters
Height : 2.94 meters
Capacity : 32.8 tons
Use : Everything that can be packed in solid items.
Characteristics: Bigger than standard trucks.

Low-Bed

Length : 13 -14 meters
Height : 1.250 meters
Capacity : 20-120 tons
Use : Everything that can be packed in solid items.
Characteristics: It is a trailer.

Swap-Body

Length : 7.15 - 13.6 meters meters
Height : Up to 2.80 meters
Capacity : Up to 28 tons
Use : Everything that can be packed in solid items
Characteristics: It is a freight container for rail and road transport.

1.2 EV Architecture

The electric vehicle architecture consists of five key components, and the power-train in an EV is completed by these components, which include the electric motor, battery pack, inverter, charger, DC-DC converter, and so on.

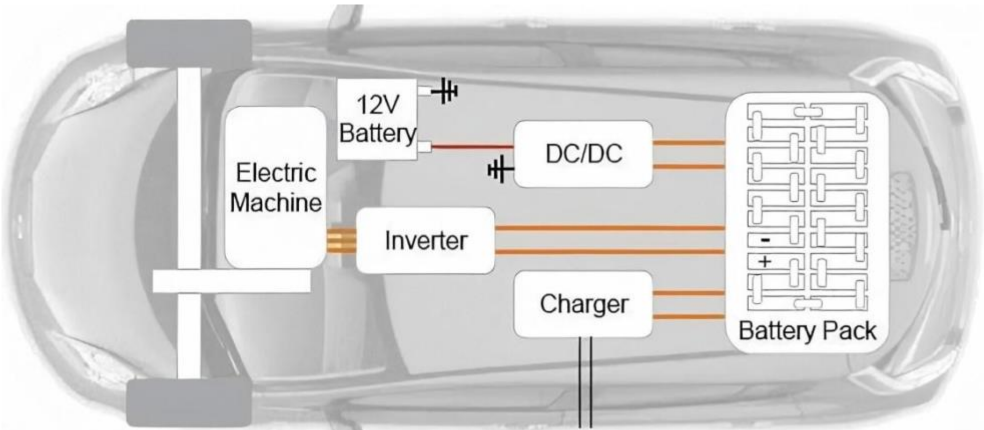

Figure 1.1 EV Architecture Schematic

Electric Motor

Electric motors deliver torque to a vehicle by exploiting electromagnetic fields and energy provided by a battery, and torque is regulated by changing the current flow. When compared to ICE, the electric motor delivers more than 90% efficiency; it generates torque at zero speed, allowing the vehicle to operate with a single gear ratio between motor and tire rather than multiple speed transmission.

Battery Pack

The battery pack is the energy storage device, and it must take and supply electricity to the electric machine. At their output terminals, battery packs deliver direct current (DC). An alternating current (AC) waveform is to be regulated by electric machines.

Inverter

This conversion between DC and AC, as well as torque control, is provided by the motor inverter.

DC-DC Converter

A DC/DC converter is used to reduce the voltage of a battery pack to 12 volts. (For example, wipers, infotainment system, and mirror control)

On Board Charger

The charger serves three purposes:

- Rectification of grid-supplied alternating current electricity to direct current voltage.
- The DC output voltage is used to regulate the current going into the battery pack.
- Communicates with the vehicle and off-vehicle equipment.

Battery Management System

BMS is used to monitor the status of the battery and is in charge of taking the essential measures, such as SOC and SOH. It balances cells to get the most efficiency out of a battery pack, and it uses a tiny ECU to communicate with other components. Aside from these critical components, EV power-train architecture employs a plethora of hardware and software. Small monitoring ECUs are positioned for each function, and communication is accomplished using the CAN protocol. Components in electric vehicle architecture are selected, and the organization of such components determines the architecture; moreover, more components can be arranged in the design.

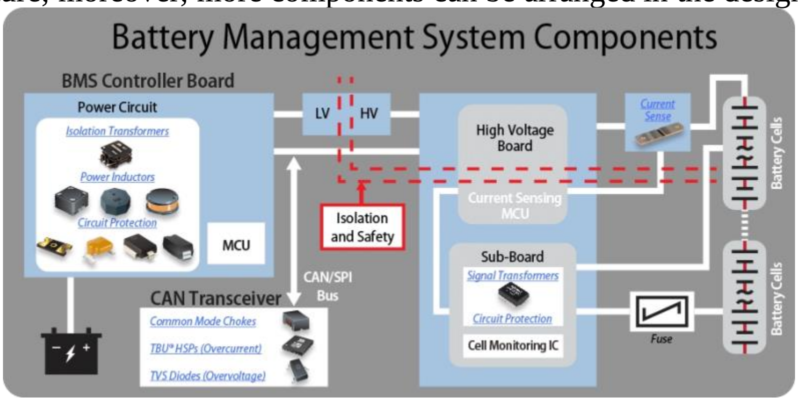

Figure 1.2 Battery Management Systems Components

1.3 Lithium Ion Batteries

A lithium-ion battery, often known as a Li-ion battery, is a rechargeable battery. Lithium-ion batteries are widely utilized in portable devices and electric cars, and their employment in military and aerospace applications is expanding. Akira Yoshino created a prototype Li-ion battery in 1985, based on prior research by John Goodenough, M. Stanley Whittingham, Rachid Yazami, and Koichi Mizushima in the 1970s–1980s, and a commercial Li-ion battery was developed in 1991 by a Sony and Asahi Kasei team led by Yoshio Nishi.

During discharge, lithium ions flow from the negative electrode to the positive electrode via an electrolyte, and vice versa during charging. Li-ion batteries employ an intercalated lithium compound as the positive electrode material and generally graphite as the negative electrode material. The batteries feature a high energy density of 100 to 250 Wh/kg, little memory effect (except for LFP cells), and a low self-discharge rate. They can, however, be a safety issue because they contain flammable electrolytes and can cause explosions and flames if broken or wrongly charged.

The chemistry, performance, pricing, and safety aspects of lithium-ion batteries differ. Handheld devices often employ lithium polymer batteries (with a polymer gel electrolyte), a lithium cobalt oxide cathode, and a graphite anode, all of which provide a high energy density. Lithium iron phosphate, lithium manganese oxide, and lithium nickel manganese cobalt oxide may have longer lifetimes and higher rate capabilities. These batteries are commonly used in electric tools, medical equipment, and other applications. NMC and its derivatives are frequently utilized in the production of electric cars.

Among the research areas for lithium-ion batteries include extending lifetime, boosting energy density, enhancing safety, lowering cost, and increasing charging speed. Based on the flammability and volatility of the organic solvents employed in the usual electrolyte, research has been conducted in the field of non-flammable electrolytes as a road to enhanced safety. Aqueous lithium-ion batteries, ceramic solid electrolytes, polymer electrolytes, ionic liquids, and highly fluorinated systems are among the strategies under consideration.

A lithium-ion battery's life is commonly described as the number of complete charge-discharge cycles required to achieve a failure threshold in terms of capacity loss or impedance rise. Manufacturers' data sheets generally use the phrase "cycle life" to define lifetime in terms of the number of cycles required to attain 80% of rated battery capacity. The capacity of these batteries is also reduced when they are stored inactively. The term "calendar life" refers to the whole life cycle of a battery, which includes both cycling and inactive storage activities. Temperature, discharge current, charge current, and state of charge ranges are all stress variables that impact battery cycle life (depth of discharge).

Figure 1.3 Lithium Ion Battery

1.4 Solid State Batteries

A solid-state battery is a type of battery that use solid electrodes and a solid electrolyte rather than the liquid or polymer gel electrolytes seen in lithium-ion or lithium polymer batteries. While solid electrolytes were found in the nineteenth century, various disadvantages, such as poor energy densities, have kept them from being widely used. Beginning in the 2010s, developments in the early twenty-first centuries sparked fresh interest in solid-state battery technology, particularly in the context of electric cars. It has energy density of 250-270 Wh/kg despite of huge cost.

Challanges

Cost: Solid-state batteries have traditionally been expensive to produce and use manufacturing techniques that are considered to be difficult to scale, necessitating the use of expensive vacuum deposition equipment. As a result, expenses in consumer-based applications become prohibitively expensive. In 2012, it was predicted that a 20 Ah solid-state battery cell would cost $100,000 based on then-current technology, and that a high-range electric car would require between 800 and 1,000 of such cells.

Temperature and pressure sensitivity: Low-temperature procedures can be difficult. Solid-state batteries have typically performed poorly. To maintain contact with the electrodes in solid-state batteries using ceramic electrolytes, considerable pressure is required. Mechanical stress can cause solid-state batteries with ceramic separators to fail.

Dendrites: Solid lithium metal anodes in solid-state batteries are lithium-ion battery replacement possibilities for better energy density, safety, and faster recharge periods. Such anodes are prone to develop Li dendrites. They cause short circuits by penetrating the separator between the anode and the cathode. This generates overheating, which can lead to fires or explosions as a result of thermal runaway. They usually develop during charge and discharge electrode-position.

Adavntages

By allowing lithium metal anodes, solid-state battery technology is expected to provide greater energy densities (2.5x). They may avoid using potentially hazardous or poisonous components present in commercial batteries, such as organic electrolytes. Solid-state batteries are thought to have a decreased danger of catching fire since most liquid electrolytes are combustible while solid electrolytes are nonflammable. Fewer safety measures are required, improving energy density.

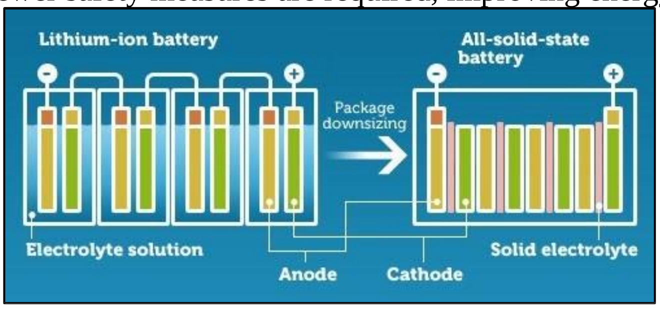

Figure 1.4 Lithium ion battery vs solid state battery

1.5 Technologies used in EVs

I Shift Transmission

Volvo has improved the industry's most sophisticated automatic gearbox. The newest I-Shift model has updated hardware and software, increased durability, and a redesigned counter-shaft brake for improved performance and smoother shifting. The computerized control unit is capable of handling any load and any road, shifting flawlessly every time. In addition, we've enhanced clutch durability and torsional dampening in both the D11 and D13 models. So, in addition to lowering maintenance costs, I-Shift can assist delay drive-line wear, reduce noise, lengthen transmission life, and reduce maintenance expenses.

Volvo's I-See option uses self-learning knowledge of road terrain in conjunction with I-Shift to optimize the truck's speed and gear-shifting in the most fuel-efficient manner. The I-Shift for Severe Duty combines efficiency and durability. The 12-speed automatic manual transmission is built for tough on/off-road use in construction and heavy haul applications. When maximum GCW loads and low-speed mobility are required, the I-Shift with Crawler Gears is the answer for maximum GCW loads, allowing controllable travel at extremely slow speeds.

Regenerative Braking

Regenerative braking is an energy recovery device that slows a moving vehicle or item by transforming its kinetic energy into a form that may be utilized immediately or saved until it is needed. The electric traction motor in this system leverages the vehicle's motion to recover energy that would otherwise be lost to the brake discs as heat. This is in contrast to traditional braking systems, in which surplus kinetic energy is transformed to undesired and wasted heat owing to friction in the brakes, or to dynamic brakes, in which energy is recovered by utilizing electric motors as generators but is instantly dissipated as heat in resistors.

Tribo-Electrification of wheels and steering wheels

Now how does this work? Let us consider two materials, A and B. When they physically contact each other, there is a charge transfer. If they separate from each other, there is a voltage generation. If we have two materials sliding against each other with two molds and then the voltage is generated. These are made with nanomaterials to increase the contact between the materials and more energy extraction. At an earlier stage, these triboelectric generators could create 12V, but now due to extensive research, these can create up to 10,000V, which Georgia Tech University research scholars created. So for the steering wheel, we can use a single mold triboelectric generator as there will be more contact rather than sliding. However, for wheels, we should install one mold on the roads and the other on the wheels of vehicles to generate voltage. This technology will be a game-changer if the molds are installed on roads and charging can be quickly done.

Solar Panels on Top of Vehicles

Solar panels can be installed on top of vehicles to charge the batteries in electric vehicles, but due to their shorter length, they cant be used in consumer vehicles, but for vehicles, with more significant lengths like logistics vehicles, this can be used, and this will increase the overall efficiency of EV and increase its range.

CHAPTER 2

Literature Review

2.1 Literature Survey

[1] So in this paper, the calculations are done for the energy required for a battery of an electric vehicle and, more importantly, how much they will weigh. To do this, first, we need to estimate how much energy this truck will consume for a given range.

This is relatively easy. Energy is simply given by power into time. We can calculate time by dividing the range by average speed. Furthermore, power equals force times velocity. We can swap in the power components Drag Component, Rolling Resistance Component, Road Gradient Component, and Inertial Component for the equation we made earlier. To adequately calculate the force acting on the vehicle, we first need to calculate the force required to overcome inertia, that is, how much force it will take to get the vehicle moving. This takes into account the efficiency of electric engines, brakes, and energy recovered from regenerative braking. Now, we need to calculate the forces slowing down the vehicle, such as drag, rolling resistance on wheels, and gravity as the vehicle uphills.

$$E_P = \left[\left(\frac{1}{2}\rho \cdot C_d \cdot A \cdot v_{rms}^3 + C_{rr} \cdot W_T \cdot g \cdot v + t_f \cdot W_T \cdot g \cdot v \cdot Z\right)/\eta_{bw} + \frac{1}{2} W_t \cdot v \cdot a \left(\frac{1}{\eta_{bw}} - \eta_{bw} \cdot \eta_{brk}\right)\right]\left(\frac{D}{v}\right)$$

where the pack energy, (E_P) depends on the energy utilized to overcome aerodynamic drag forces, frictional forces, the road gradient, and inertial forces. A significant fraction of the energy used to overcome inertial forces is recovered via regenerative braking when the vehicle is decelerating. The important parameters are the coefficient of drag (C_d), average velocity (v) and root-mean-square of the velocity (vrms), the coefficient of rolling resistance (C_{rr}), the gross on-road vehicle weight (GVW) represented by (W_T) (includes the payload and battery pack), the road gradient Z, and the total time taken for a fixed driving range determined from . The road gradient term is accounted for using the expression (Z = r/100), where r is the percentage road grade and (t_f) is the fraction of time the vehicle spends at a road grade of r%.

2.2 Motivation For Present work

In the U.S. alone, the trucking industry contributes to about 23% of total greenhouse emissions, equating to 1.475 million metric carbon dioxide. In India, road transport contributes almost 90% of greenhouse emissions in which trucking and logistics vehicles contribute more than 25% of that. Most of this energy is supplied by fossil fuels which are harmful to the environment and cause high carbon emissions and global warming. So, converting this industry into renewable energy sources would be a huge win in our battle with climate change.

CHAPTER 3

Objectives and Methodology

3.1 Basic Calculations & Objectives

Basic Calculations

Energy is simple given by power into time. We can calculate time by dividing the range by average speed. And power equals to force times velocity. To adequately calculate the force acting on the vehicle, we first need to calculate the force required to overcome inertia, that is how much of force it will take to get vehicle moving. This takes into account the efficiency of electric engines, brakes and energy recovered from regenerative braking. Now, we need to calculate the forces which are slowing down the vehicle such as drag, rolling resistance on wheels and gravity as the vehicle uphills.

$$E_P = \left[\left(\frac{1}{2}\rho \cdot C_d \cdot A \cdot v_{rms}^3 + C_{rr} \cdot W_T \cdot g \cdot v + t_f \cdot W_T \cdot g \cdot v \cdot Z\right)/n_{bw} + \frac{1}{2} W_t \cdot v \cdot a\left(\frac{1}{\eta_{bw}} - \eta_{bw} \cdot \eta_{brk}\right)\right]\left(\frac{D}{v}\right)$$

where the pack energy, (E_P) depends on the energy utilized to overcome aerodynamic drag forces, frictional forces, the road gradient, and inertial forces. A significant fraction of the energy used to overcome inertial forces is recovered via regenerative braking when the vehicle is decelerating. The important parameters are the coefficient of drag (C_d), average velocity (v) and root-mean-square of the velocity (vrms), the coefficient of rolling resistance (C_{rr}), the gross on-road vehicle weight (GVW) represented by (W_T) (includes the payload and battery pack), the road gradient Z, and the total time taken for a fixed driving range determined from . The road gradient term is accounted for using the expression (Z = r/100), where r is the percentage road grade and (t_f) is the fraction of time the vehicle spends at a road grade of r%.

We assume a road grade r of 1% and (t_f) of 15%. The other fixed parameters are ρ, the density of air (1.2 kg/m^3), g the acceleration due to gravity (9.8 m/s^2), A the frontal area of the vehicle,coefficient of drag (C_d), a the mean acceleration or deceleration of the vehicle (0.112 m/s2). η_{bw} is the battery-to-wheels efficiency of ~85% which includes the battery discharge efficiency of 95% and a drive-train efficiency of 90%. η_{brk} accounts for the efficiency of the brakes and is assumed to be 97%.

$$W_P = \frac{E_P}{S_P f_{burden}}$$

The pack weight, WP is given by the above formula is determined on the basis of a distribution of values for the specific energy SP at the cell-level and a fixed value of 0.48 for the packing burden factor.f_{burden} represents the weight for the thermal management systems, module hardware, battery jackets, and other non cell inactive materials used to assemble a practical battery pack. The specific energy (SP) is considered with a mean value of battery system used.

The maximum payload capacity for the vehicle (WL) is given by $W_L = W_T - (W_P + W_V)$ which is the weight that remains of the GVW after accounting for the weight of the pack (WP) and the empty vehicle weight (WV) with their respective distributions.

Finally, the cost of the pack ($Cost_P$), given by $Cost_P = \frac{E_P}{Cost_{kWh}}$ is determined using the pack energy distribution obtained from eq 1 and a distribution of values for the cost per kilowatt-hour of the battery pack ($Cost_{kWh}$).

Objectives

- The vehicle has to cover up its destination range with its battery pack.
- The regenerative braking system should be implemented so that we gain more energy and charge the battery.
- The fast charging and emergency stations must be there along the destination to avoid interruptions and delays for logistics to supply items.
- The weight distribution between the battery, no-load vehicle, and payload must be perfect to use just the payload for the respective vehicle.
- The vehicle must be stiff enough to save its battery pack during a collision or accident.
- The vehicle must be safer to drive and should not create any kind of damage to the freight.
- The cost of a vehicle must be minimal so that the company that purchases the vehicle must do break even in terms of returns.

3.2 Finite element analysis

Approximate solutions of differential equations are commonly used as the foundation for structural analysis. This is generally accomplished by the use of numerical approximation techniques. The Finite Element Method (FEM) is the most widely used numerical approximation in structural analysis. It approximates a design as an assembly of elements or components connected by different means of attachments, each of which has an associated stiffness. Thus, a continuous system, such as a plate or shell, is represented as a discrete system with a finite number of elements interconnected at a finite number of nodes, and the overall stiffness is the sum of the stiffness of the various elements. Individual element behaviour is described by the stiffness (or flexibility) relationship.

3.3 Finite Volume Method

FVM is a popular approach in CFD codes because it has advantages in memory use and solution speed, particularly for complex problems, high Reynolds number turbulent flows, and source term dominated flows (like combustion).

CFD is a subset of fluid mechanics that evaluates and solves problems involving fluid flows using numerical analysis and data structures. The simulations used to model the fluid's free-stream flow and interaction with surfaces defined by boundary conditions are done on computers. Better solutions can be found with high-speed supercomputers, which are often used to solve the most significant and challenging problems. Ongoing study results in applications that increase the precision and speed of complex simulation scenarios like transonic or turbulent flows.

In the finite volume system, the governing partial differential equations (typically the Navier-Stokes equations, mass and energy conservation equations, and turbulence equations) are recast in a conservative form and solved over discrete control volumes. Using this discretization, a fixed control volume guarantees flux retention. The finite volume equation produces the following governing equations:

$$\frac{\partial}{\partial t}\iiint Q\ dV + \iint F\ dA = 0$$

where Q is the conserved variable vector, F is the flux vector (from Euler equations or Navier–Stokes equations), V is the control volume element's volume, and A is the control volume element's surface area.

3.4 Shear Stress Transport Model

SST model is used in the simulation since the tidal turbine is a rotating machinery in a fluid. Menter's Shear Stress Transport turbulence model, or SST, is a popular and reliable two-equation eddy-viscosity turbulence model in CFD. The model incorporates the k-omega turbulence model and the K-epsilon turbulence model, with the k-omega used in the inner boundary layer and the k-epsilon used in free shear flow.

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho u_j k)}{\partial x_j} = P - \beta^* \rho \omega k + \frac{\partial}{\partial x_j}\left[(\mu + \sigma_k \mu_t)\frac{\partial k}{\partial x_j}\right]$$

$$\frac{\partial(\rho\omega)}{\partial t} + \frac{\partial(\rho u_j \omega)}{\partial x_j} = \frac{\gamma}{v_t}P - \beta\rho\omega^2 + \frac{\partial}{\partial x_j}\left[(\mu + \sigma_\omega \mu_t)\frac{\partial k}{\partial x_j}\right] + 2(1 - F_1)\frac{\rho\sigma_{\omega 2}}{\omega}\frac{\partial k}{\partial x_j}\frac{\partial \omega}{\partial x_j}$$

3.5 Designing an EV Truck

Designing an EV Truck is not an easy task; it should meet all the objectives mentioned above. For a design, there is an inspiration. So, for designing an EV truck, I took the Mercedes Benz Actross Truck as an inspiration and modified it with two design iterations, demonstrated in the below picture.

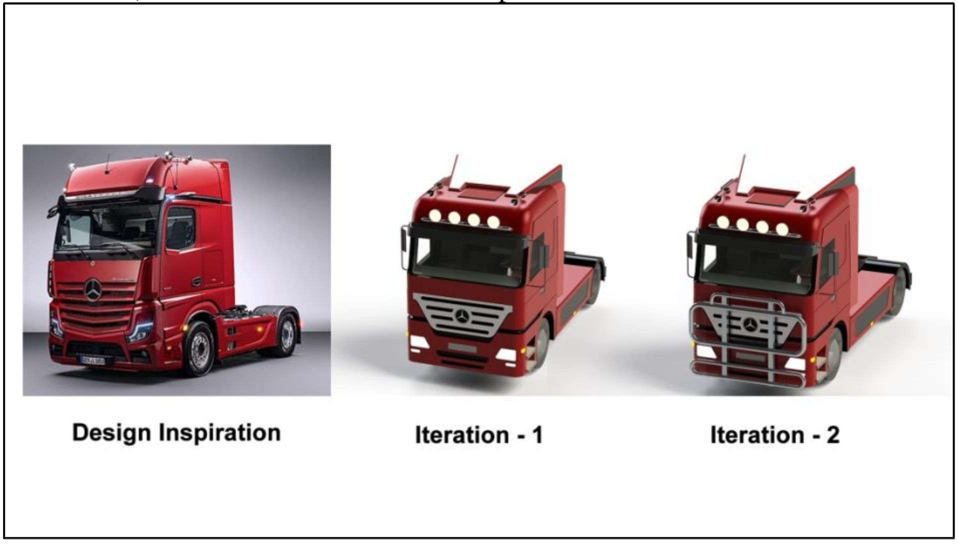

Figure 3.1 Design Iterations

Design Iteration 1

In this design iteration, the modifications were done according to Indian trucks, which were meant to be applied in India. On the top, four headlamps are used for better lighting during the night. On the truck's sides, the steps were designed to climb into the truck as the door is situated at more height than human to place the enormous battery pack under the vehicle with a good amount of ground clearance of 525 mm specially designed for Indian roads. On top, you can see two horns which are pretty standard in Indian trucks. The side mirrors are made bigger for better viewing purposes and safety in case of any thermal accident near the battery pack. A section is added at the backside of driver seats for the battery pack, which you can see in the below images, which also balances the weight distribution. Moreover, a slight elevation section is added on the top for better aerodynamics and even the battery pack. So overall, the weight distribution was good, but due to materials used in this design, the overall weight has been increased a lot, so this has been resolved in the second design iteration.

Figure 3.2 Different views of Design Iteration 1 of Designed Truck

On the back backside on top of the battery back, you can see a mounting screw for which the freight is attached to it. Generally, they range depending upon their uses and range, which are demonstrated in the introduction. I have designed a storage freight of 13.6 m with length with four wheels mounted on it for this model.

Figure 3.3 Different views of Assembled Truck (Iteration 1)

Design Iteration 1

In this design iteration, the modifications were done to reduce the weight and moderate weight distribution. On the top, four headlamps are used for better lighting during the night. On the truck's sides, the steps were designed to climb into the truck as the door is situated at more height than human to place the enormous battery pack under the vehicle with a good amount of ground clearance of 525 mm specially designed for Indian roads. On top, you can see two horns which are pretty standard in Indian trucks. The side mirrors are made bigger for better viewing purposes and safety in case of any thermal accident near the battery pack. A section is added at the backside of driver seats for the battery pack, which you can see in the below images, which also balances the weight distribution. Moreover, a slight elevation section is added on the top for better aerodynamics and even the battery pack. The bumper was added with less density in front, and strong materials are used to reduce the weight. So overall, weight has been reduced compared to design iteration one, and the weight distribution was good. The issues in design iteration one are solved in this iteration.

Figure 3.4 Different views of Design Iteration 2 of Designed Truck

On the back backside on top of the battery back, you can see a mounting screw for which the freight is attached to it. Generally, they range depending upon their uses and range, which are demonstrated in the introduction. I have designed a storage freight of 13.6 m with length with four wheels mounted on it for this model. A hydraulic jack is added to storage freight. The battery pack is placed under removable storage freight, which increases the range of the vehicle and even helps to replace the battery pack with fully charged ones when the battery is drained or any damages. The hydraulic jack is mainly designed for this detachable battery pack, which makes replacing the battery easier. The top of storage freight is attached to solar panels to gain energy during the morning and store that energy in the battery pack to increase the range and efficiency. So, these advancements are made in design iteration 2. To decrease the vehicle's overall weight, the front wheel axel volume has reduced as there is very little weight at the front of the truck, and even this will help us accelerate faster at the initial stage. You see all these in below images.

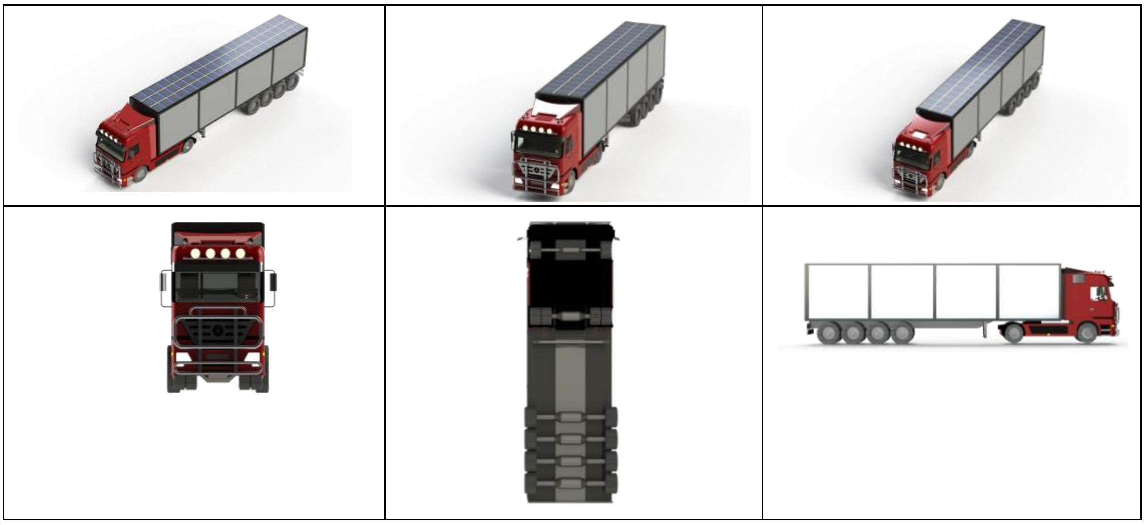

Figure 3.5 Different views of Assembled Truck (Iteration 2)

So, now after completing this design, the validation has to be done, which are discussed under these sections. The static structural analysis is done from the front bumper for its strength and rigidness nature, and CFD simulation is done to validate the vehicle's aerodynamic efficiency.

CHAPTER 4

Numerical Analysis of Designed Truck

4.1 Static Structural Analysis of Bumper

For doing static structural analysis for the front, it has been designed to be a rigid structure. First, a material is to be assigned to the 3d object, and Structural Steel has been chosen for this purpose. The properties of the material are given in the table below.

Parameter	Value
Density	7850 kg/m^3
Young’s Modulus	200 GPa
Poisson’s Ratio	0.3
Bulk Modulus	166 GPa
Shear Modulus	76 GPa
Tensile Yield Strength	250 MPa
Tensile Ultimate Strength	460MPa

Table 4.1 Structural Steel Properties

Then, at one end, where the front bumper is placed on the front face of truck , a fixed boundary condition is applied. The nodal displacement will be zero at that point. Next, a gravitational load is applied to the body to examine the effect of gravity on the bumper. Here we are only considering the frontal impact test. So, a force component of 100000 N is applied to the blade section normal to the bumper face.

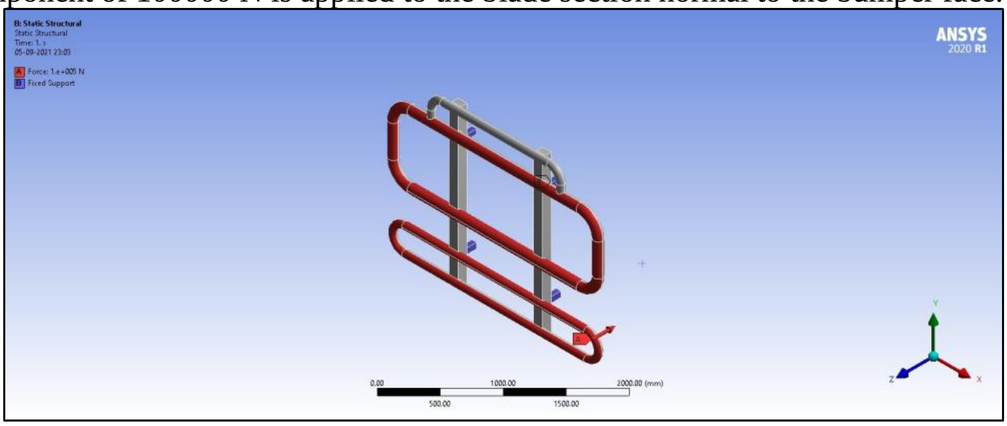

Figure 4.1 Physics Setup of Static Structural Analysis

This is Following that, a mesh convergence analysis was conducted to determine the best mesh quality and accuracy. There are 1261577 nodes and 798950 elements in the mesh. The body sizing for the mesh is 5 mm. Detailed results are shown in the results section.

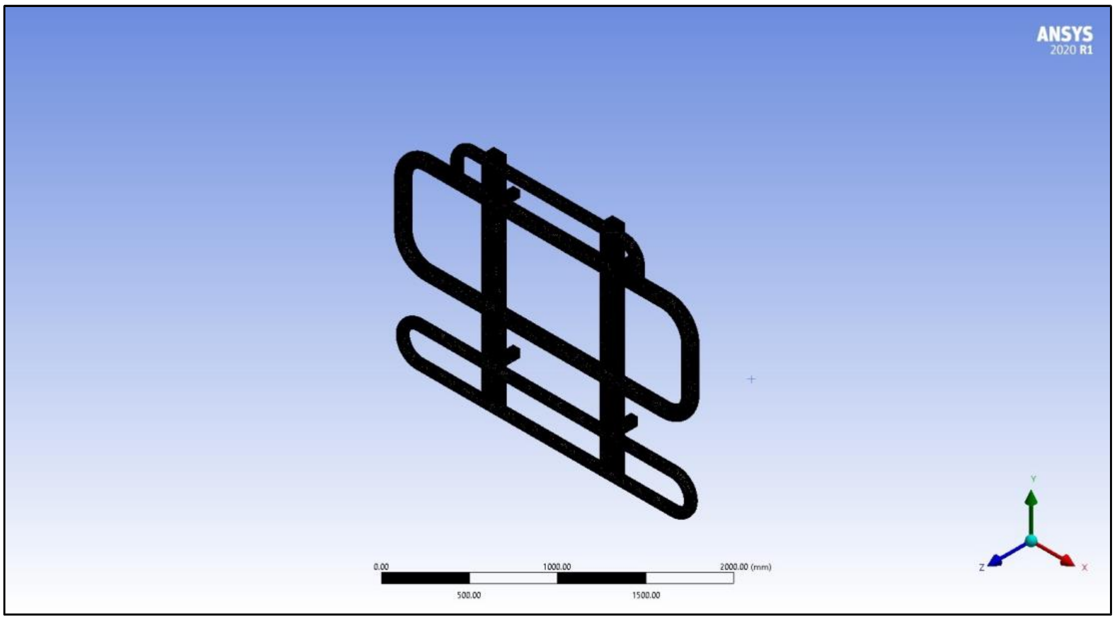

Figure 4.2 Mesh for Static Structural Analysis

4.2 Flow Analysis of Truck

For doing CFD analysis, a enclosure area is required over the truck region. The enclosure of a 5x10 rectangular region is created. From the front of the truck, the distance to the square region is 10 m, while from the rear, it is 20 m. The 3D object's front face is called "inlet" and the back face is named "outlet" The top-to-bottom and left-to- right faces were dubbed “symmetry” and the truck faces are named as “truck”.

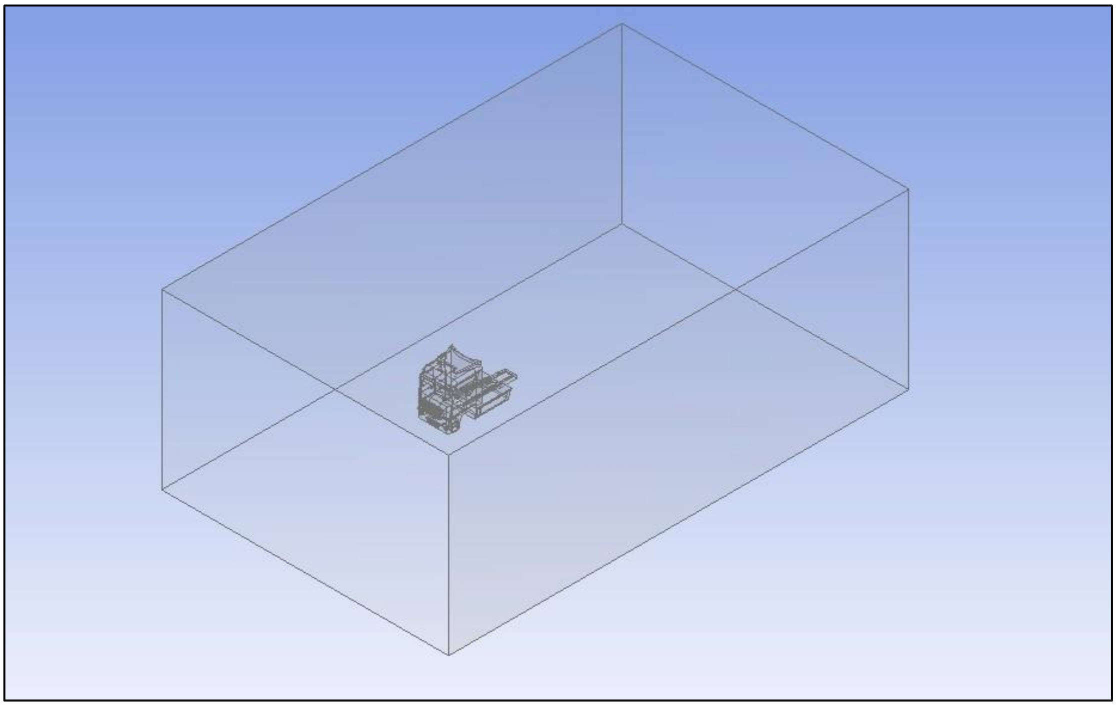

Figure 4.3 The enclosure made for CFD Analysis

After that mesh convergence study was done to find the best mesh quality and accurate results. The mesh consists of 1214010 nodes and 6614693 elements with body sizing of 400mm and face sizing of 20mm is done truck faces. The mesh has been generated and updated to the fluent module.

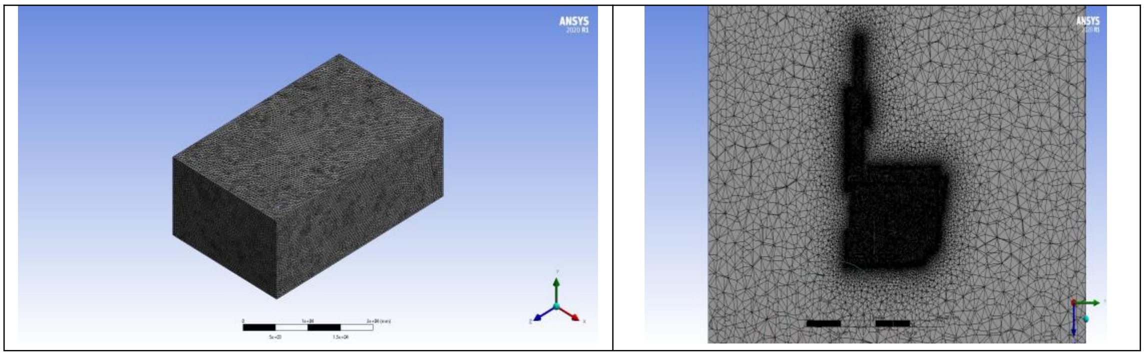

Figure 4.4 Mesh used for CFD analysis

The inlet has condition of 44.705m/s and outlet has atmospheric pressure condition. The truck has no slip wall condition which means there is zero velocity at the surface of the truck. SST turbulence model is used in this analysis. Detailed results are shown in the results section.

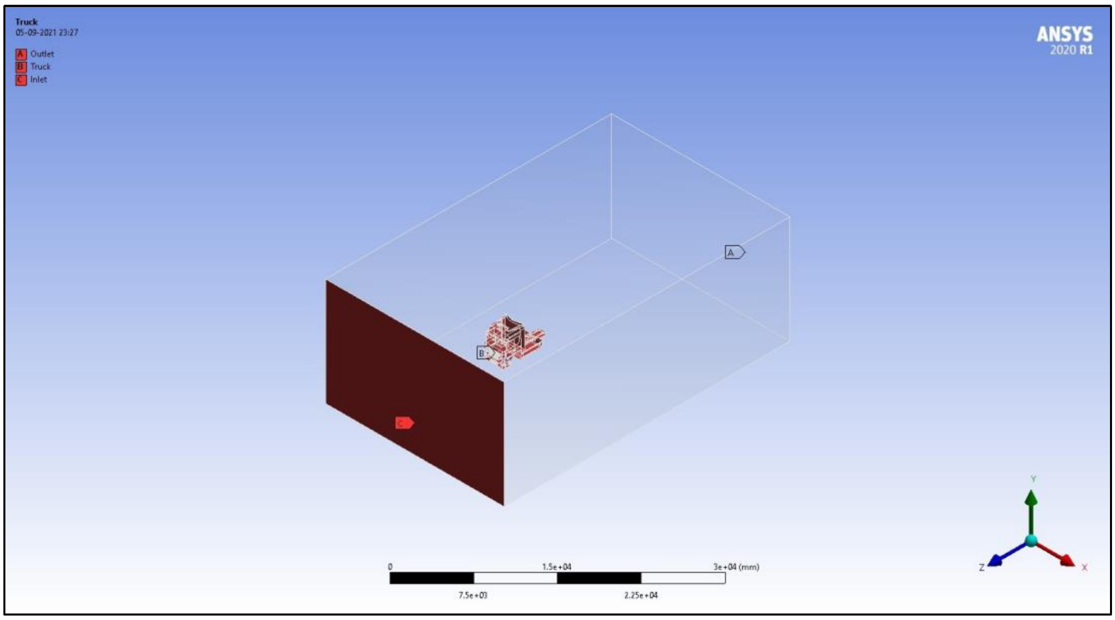

Figure 4.5 Physics Setup for CFD Analysis

4.3 Battery Weight, Energy Density and Cost Analysis

We need to calculate the forces which are slowing down the vehicle such as drag, rolling resistance on wheels and gravity as the vehicle uphills.

$$E_{\mathrm{P}} = \left[\left(\frac{1}{2}\rho \cdot C_{\mathrm{d}} \cdot A \cdot v_{rms}^{3} + C_{\mathrm{rr}} \cdot W_{\mathrm{T}} \cdot g \cdot v + t_{f} \cdot W_{\mathrm{T}} \cdot g \cdot v \cdot Z\right)/\eta_{\mathrm{bw}} + \frac{1}{2} W_{t} \cdot v \cdot a \left(\frac{1}{\eta_{\mathrm{bw}}} - \eta_{\mathrm{bw}} \cdot \eta_{\mathrm{brk}}\right)\right]\left(\frac{D}{v}\right)$$

where the pack energy, (E_P) depends on the energy utilized to overcome aerodynamic drag forces, frictional forces, the road gradient, and inertial forces. A significant fraction of the energy used to overcome inertial forces is recovered via regenerative braking when the vehicle is decelerating. The important parameters are the coefficient of drag (C_d), average velocity (v) and root-mean-square of the velocity (vrms), the coefficient of rolling resistance (C_{rr}), the gross on-road vehicle weight (GVW) represented by (W_T) (includes the payload and battery pack), the road gradient Z, and the total time taken for a fixed driving range determined from . The road gradient term is accounted for using the expression (Z = r/100), where r is the percentage road grade and (t_f) is the fraction of time the vehicle spends at a road grade of r%.

We assume a road grade r of 1% and (t_f) of 15%. The other fixed parameters are ρ, the density of air (1.2 kg/m^3), g the acceleration due to gravity (9.8 m/s^2), A the frontal area of the vehicle,coefficient of drag (C_d), a the mean acceleration or deceleration of the vehicle (0.112 m/s2). η_{bw} is the battery-to-wheels efficiency of ~85% which includes the battery discharge efficiency of 95% and a drive-train efficiency of 90%. η_{brk} accounts for the efficiency of the brakes and is assumed to be 97%.

$$W_P = \frac{E_P}{S_P f_{burden}}$$

The pack weight, WP is given by the above formula is determined on the basis of a distribution of values for the specific energy SP at the cell-level and a fixed value of 0.48 for the packing burden factor.f_{burden} represents the weight for the thermal management systems, module hardware, battery jackets, and other non cell inactive materials used to assemble a practical battery pack. The specific energy (SP) is considered with a mean value of battery system used.

The maximum payload capacity for the vehicle (WL) is given by

$$W_L = W_T - (W_P + W_V)$$

which is the weight that remains of the GVW after accounting for the weight of the pack (WP) and the empty vehicle weight (WV) with their respective distributions.

Finally, the cost of the pack ($Cost_P$), given by $\mathrm{Cost}_P = \frac{E_P}{\mathrm{Cost}_{kWh}}$ is determined using the pack energy distribution obtained from eq 1 and a distribution of values for the cost per kilowatt-hour of the battery pack ($Cost_{kWh}$).

The lithium ion batteries have 250 (Wh/kg) of energy density and the solid state batteries have 270 (Wh/kg) of energy density. Lithium ion costs around 190$/kg and solid state batteries costs around 250$/kg. Detailed results are shown in results section.

CHAPTER 5

Results and Discussions

5.1 Static Structural Analysis of Bumper Results

In the static structural analysis, Equivalent (von-mises) stress is computed to check whether the bumper falls under the maximum stress limit. In this analysis, stress near the hub and blade contact of the bumper is shown in the below figures with 107.56 MPa maximum stress and minimum stress of 11.951 Pa. Due to the applied load, the bending of the blade near the tips of the bumper is shown in the below figures. So, the front bumper is rigid enough to save the vehicle during collisions or accidents. The maximum deformation is 0.92723mm which is negligible for such a high load of force application. All the results are shown below.

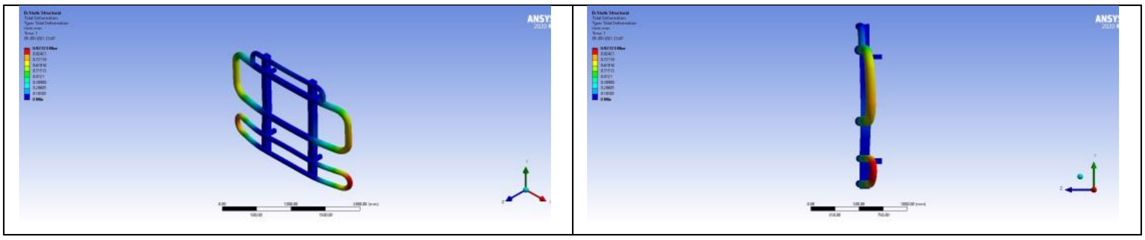

Figure 5.1 Total Deformation Results

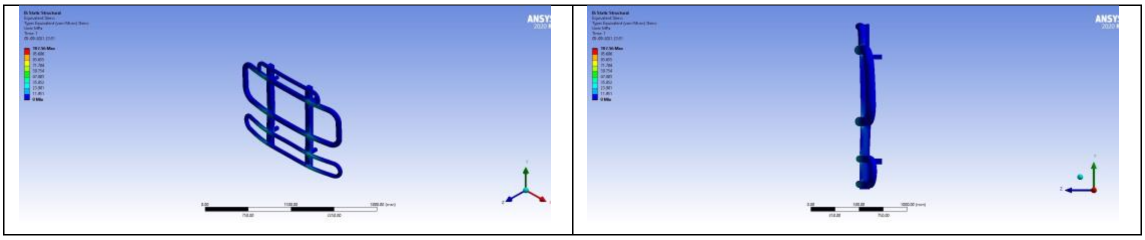

Figure 5.2 Equivalent Stress Results

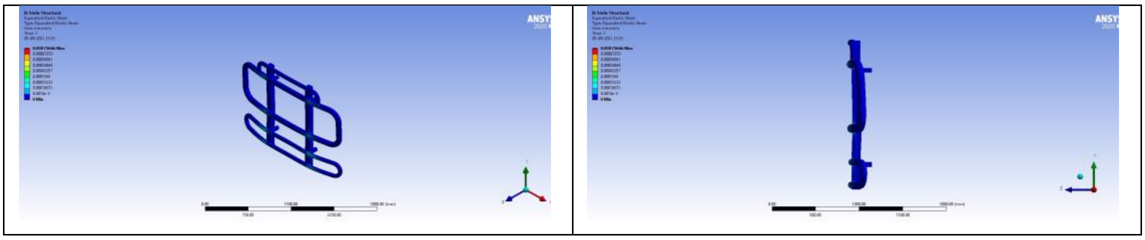

Figure 5.3 Equivalent Strain Results

5.2 Flow Analysis of Truck Results

In this flow analysis, the simulation is done for the velocity speed of 100mph, for which this speed is dangerous for trucks, and the details of the numerical simulation are shown below.

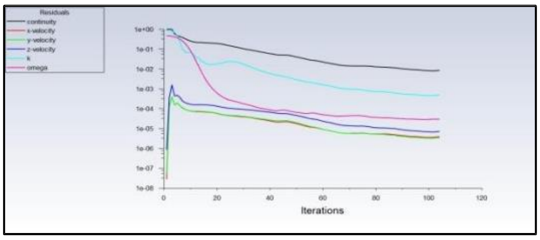

Figure 5.4 Residual plot for CFD Analysis

After these plots from flow analysis simulation, the computational diagrams for Pressure Contours, Velocity Contours and Streamlines are generated. All the results are shown below.

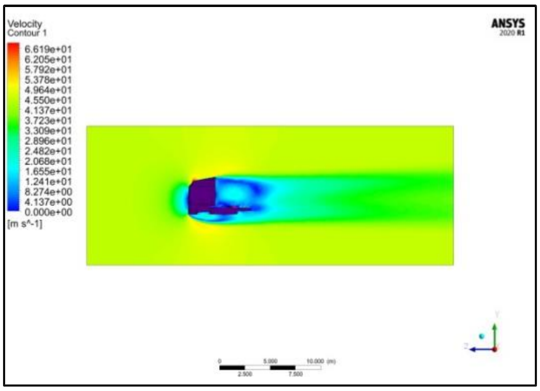

Figure 5.5 Velocity Contour

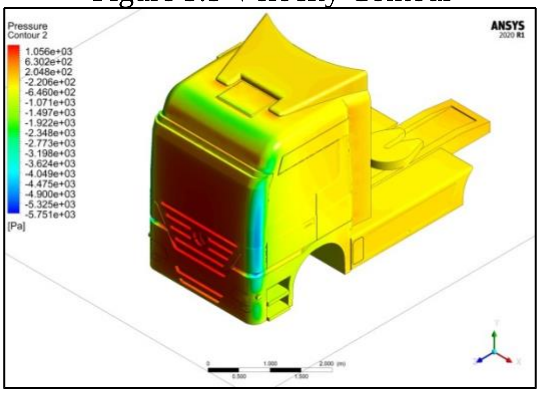

Figure 5.6 Pressure Contour

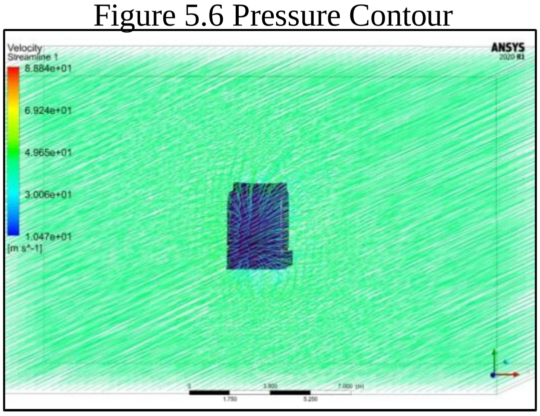

Figure 5.7 Stream Lines

We can even see smooth flow over at the top of the battery pack, and it has increased aerodynamic efficiency. As the surface area increases, the fluid obstruction will be more; then, there will be a decrease in the fluid velocity. From the above figure 5.5, it can be inferred that the velocity is increasing near the tip and significantly less near the vehicle's hub. Even the pressure on the vehicle is moderate. This simulation is done without considering the storage freight. As this simulation is for knowing C_d value so this value is used in the energy equation. After the simulation is generated, the C_d value calculated is 0.75, which is low compared to the inspired design MB Actross which has C_d of 0.875.

5.3 Battery Weight, Energy Density and Cost Analysis

For doing these calculation we need to fix a certain range, overall weight with freight and average velocity to know the battery weight, energy density and it's cost. So, lets us consider a vehicle of a range of 500 miles with an average velocity of vehicle 50 miles per hour having a total weight of 55 tonnes. The maximum weight that is allowed on our Indian Highways by the Ministry of Road Transport & Highways of India is 55 tonnes so lets us consider that weight. Our car has front area of $10m^2$

Truck with Lithium Ion battery without road gradient

Component	Value
Drag Component (N)	24121.42
Rolling Resistance Component (N)	75900.69
Road Gradient Component (N)	0.00
Inertial Component (N)	24231.12
Required Battery Capacity (Watt Second)	5108538103.35
Required Battery Capacity (kWh)	1419.04
Weight of Battery (kg)	11825.32
Cost of Battery ($)	269617.29

Table 5.1

Truck with Lithium Ion battery with road gradient of 0.25 with 0.15 time spent of whole journey

Component	Value
Drag Component (N)	24121.42
Rolling Resistance Component (N)	75900.69
Road Gradient Component (N)	451789.80
Inertial Component (N)	24231.12
Required Battery Capacity (Watt Second)	24243117368.06
Required Battery Capacity (kWh)	6734.20
Weight of Battery (kg)	56118.33
Cost of Battery ($)	1279497.86

Table 5.2

Truck with Solid State battery without road gradient

Component	Value
Drag Component (N)	24121.42
Rolling Resistance Component (N)	75900.69
Road Gradient Component (N)	0.0
Inertial Component (N)	24231.12
Required Battery Capacity (Watt Second)	5108538103.35
Required Battery Capacity (kWh)	1419.04
Weight of Battery (kg)	10949.37
Cost of Battery ($)	354759.59

Table 5.3

Truck with Solid State battery without road gradient of 0.25 with 0.15 time spent of whole journey

Component	Value
Drag Component (N)	24121.42
Rolling Resistance Component (N)	75900.69
Road Gradient Component (N)	451789.80
Inertial Component (N)	24231.12
Required Battery Capacity (Watt Second)	24243117368.06
Required Battery Capacity (kWh)	6734.20
Weight of Battery (kg)	51961.41
Cost of Battery ($)	1683549.82

Table 5.4

So with including a significantly less road gradient with very less time spent, the cost has been increased a lot and even the battery weight has increased more than overall weight. However, in solid-state batteries, the battery's weight is reduced despite its enormous cost. However, if there is no road gradient, including battery subsidies, the overall cost burden can be reduced which is practically impossible and even in some areas the rolling resistance can be reduced and after many days of use the tires rolling resistance is increased. But keeping this all aside we can say it will cost very huge amount to build an EV truck when compared to gasoline truck.

CHAPTER 6

Conclusion

After analyzing the results, it is clear that producing an affordable electric vehicle (EV) truck using current technologies and battery energy densities presents significant challenges. The cost of batteries alone is prohibitive. For instance, with a Lithium-Ion battery and no road gradient, the cost is approximately $269,617.29. When factoring in a road gradient of 0.25 for 15% of the journey, the cost rises to $1,279,497.86. Similarly, using a solid-state battery without a road gradient results in a cost of $354,759.59, but with the same road gradient, the cost escalates to $1,683,549.82.

Even with such substantial investments in battery technology, achieving the ideal balance between vehicle weight and battery capacity remains elusive, especially when road gradients increase. For solid-state batteries in particular, the issue of weight savings becomes more critical, leaving significantly less capacity to accommodate additional loads. At these price points, it becomes nearly impossible to achieve a break-even point in terms of return on investment (ROI).

In theory, solutions such as integrating solar panels and triboelectric nanogenerators may alleviate some of these challenges. However, these technologies would also drive up the overall cost, complicating the affordability of EV trucks. Therefore, relying solely on theoretical values is insufficient—physical models must be developed and tested in real-world scenarios to validate these ideas.

Only time will tell if affordable EV trucks can be realized through advancements in technology and battery development. Nevertheless, I hope that my ideas can inspire and assist others in continuing the pursuit of innovative EV truck solutions. Let us remain hopeful that affordable EV trucks will soon become a reality with the help of the latest technologies and battery innovations.

References

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