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Design and Manufacturing of Chassis for Range Extended Hybrid Electric Vehicle (HEV)

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Abstract: *This research focuses on the development of an optimized chassis framework for a Range-Extended Electric Vehicle (REEV), transitioning from conventional modified car frames to purpose-built tubular space frames. Leveraging advancements in Computer-Aided Design (CAD) and Computer-Aided Engineering (CAE), the study prioritizes structural integrity, weight reduction, and compliance with stringent safety standards.*

A comprehensive literature review establishes the foundation for chassis design methodologies, vehicle dynamics, and structural engineering principles. The research systematically addresses deficiencies in existing chassis structures by optimizing material selection, structural geometry, and weight distribution. The methodology encompasses detailed dimensioning of primary and secondary chassis members, computational analysis through dynamic simulations, and impact assessments to validate real-world performance.

The results demonstrate significant improvements in structural robustness and weight efficiency, reinforcing the feasibility of the proposed design.

The study concludes with a detailed cost analysis and performance evaluation, offering valuable insights for future advancements in electric vehicle chassis development.

Keywords: Hybrid electric vehicle, Chassis, Design calculation Design, Manufacturing, analysis, testing, Material Selection, Impact Analysis

I. INTRODUCTION

The increasing demand for sustainable transportation has driven significant advancements in Hybrid Electric Vehicles (HEVs), necessitating innovative chassis designs that balance performance, safety, and efficiency. The chassis serves as the structural backbone of a vehicle, influencing its weight, durability, and crashworthiness. Optimizing the chassis design is crucial for enhancing energy efficiency, reducing emissions, and improving overall vehicle dynamics.

Traditional chassis systems have evolved from conventional body-on-frame and monocoque structures to more advanced space-frame designs tailored to electric and hybrid applications. These

developments have been driven by the need to reduce vehicle weight while maintaining structural integrity and occupant safety. The integration of advanced materials, such as high-strength steel and lightweight composites, further contributes to achieving these objectives.

This research focuses on the systematic design and development of a chassis system for an HEV, incorporating weight optimization, material selection, and structural robustness. A comprehensive methodology is employed, involving precise dimension selection, computational modeling, and impact analysis to validate the structural performance of the chassis. Utilizing Computer-Aided Design (CAD) and Computer-Aided Engineering (CAE) tools, dynamic simulations are conducted to assess resilience under real-world loading conditions.

The study aims to address existing limitations in chassis design by optimizing weight distribution, improving load-bearing capacity, and enhancing crashworthiness. The findings of this research provide valuable insights into the development of lightweight, high-performance chassis structures for next- generation HEVs, contributing to advancements in vehicle safety, efficiency, and manufacturability.

1.1 History
The tubular chassis has a long history in automotive engineering, evolving from early motorsports applications to modern lightweight vehicle architectures, including Hybrid Electric Vehicles (HEVs). This evolution has been driven by the need for structural efficiency, weight reduction, and safety improvements.

1. Early Development of Tubular Chassis (1920s– 1950s)
• The concept of a tubular space frame chassis originated in motorsports during the 1920s and 1930s. Engineers sought a lightweight yet rigid alternative to traditional ladder-frame structures.
• Mercedes-Benz W194 (1952) was one of the first vehicles to use a full tubular space frame, improving strength-to-weight ratio and handling.
• The design gained popularity in racing due to its ability to distribute loads efficiently, enhancing torsional rigidity while minimizing weight.

2. Expansion to Performance and Production Vehicles (1960s–1980s)
• Lotus pioneered lightweight chassis designs in road and race cars, utilizing space-frame techniques for improved structural integrity.
• Ferrari, Jaguar, and Porsche adapted tubular chassis designs in high-performance models.
• The focus remained on sports cars and endurance racing, where weight reduction and high strength were critical.
• However, tubular chassis were rarely used in mass-market passenger vehicles due to complex fabrication and high manufacturing costs.

3. Adoption in Early Hybrid and Experimental Vehicles (1990s–2000s)
• The push for fuel-efficient and alternative- energy vehicles led to research on lightweight structures, including aluminum space frames and hybrid chassis designs.
• The GM EV1 (1996), one of the earliest modern electric vehicles, used a partially tubular aluminum space frame to reduce weight.
• In hybrid applications, tubular chassis designs were mainly explored in experimental vehicles, prototypes, and racing hybrids.

4. Integration into Hybrid and Electric Vehicle Platforms (2010s–Present)
• The rise of high-performance hybrid sports cars (e.g., McLaren P1, Ferrari LaFerrari, and Porsche 918 Spyder) saw the resurgence of tubular and carbon-fiber space-frame chassis to achieve ultra-lightweight and high- strength structures.
• Hybrid race cars, such as those in Formula E and Le Mans prototypes, adopted tubular or hybrid composite chassis designs for optimal weight distribution and aerodynamics.
• Some low-volume HEV manufacturers experimented with tubular chassis for small- scale production models, prioritizing performance and efficiency.
• However, mass-market hybrid vehicles (e.g., Toyota Prius, Honda Insight) still rely on monocoque (unibody) designs due to cost and ease of production.

1.2 Need of the Project
From this project the student teams that are participating into different competition will get an idea about the different materials that can be used to manufacture chassis and how to improve efficiency, enhance performance, meet regulatory compliance, and incorporate technological advancements in the automotive industry.

1.3 PROBLEM STATEMENT
“To Design a lightweight Tubular chassis for Range Extended Hybrid Electric Vehicle, which Sustain 30 KN load.

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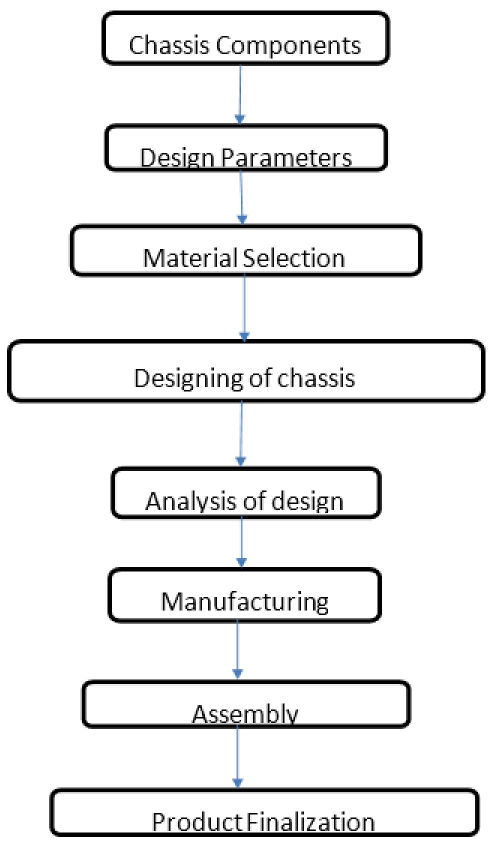
1.4 OBJECTIVE

• Hand on experience different mechanical operations welding ,drilling , cutting, buffing
• Building a chassis gives engineering students a chance to use what they learn in class for a hands-on project.
• Select materials from Design Data Book based on strength, durability, and cost, for maximum strength-to-weight ratio.
• Study of different shapes and cross section of the chassis.
• Design and Fabrication of durable and reliable Chassis.
• Modelling and analysis of chassis with the help of CAD software "Dassault System's SOLIDWORKS" and "ANSYS" software.
• Testing of Chassis in various Static and Dynamic conditions.

1.5 METHODOLOGY AND CHART

1. Chassis Components and Parameters: Component Identification: This includes listing all the components that the chassis will support and integrate. This includes the engine, transmission, suspension, body panels, and other additional systems specific to the vehicle's purpose (such as a battery pack for an electric vehicle). This includes its dimensions (length, width, height), weight distribution and attachment points. Software like AutoCAD or CATIA helps visualize insertion and removal.
2. Chassis Design: Computer Aided Design (CAD): Create a digital image of the chassis using 3D modeling software such as SolidWorks or Creo. Here, engineers consider the location of components, their dimensions, and how they will be integrated into the entire structure. CAD models allow visualization, dimensional analysis and effects of components.



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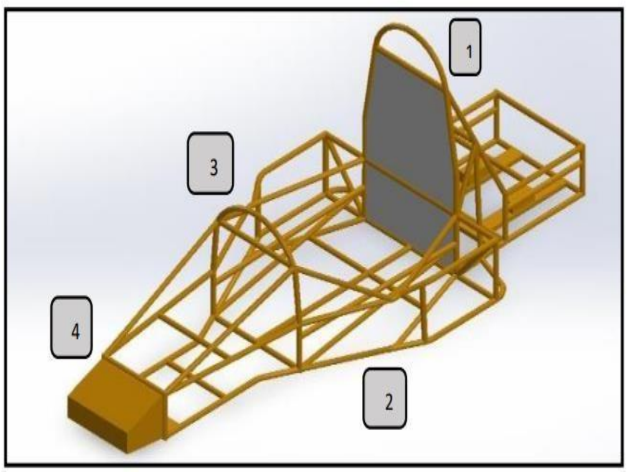
3. Material selection: Material selection affects case performance, weight and cost. Options include steel (high strength, suitable for conventional vehicles), aluminum (lightweight, suitable for high-end vehicles) and carbon fiber (very light, used in expensive, high-end parts). Important factors to consider are: Strength and stiffness: The material must withstand forces during operation (speed, stop, angle) without excessive deformation. and maneuverability. Equipment cost is especially important for larger vehicles.
4. Stress Analysis: Finite Element Analysis (FEA) software like ANSYS or Abaqus is used to simulate the stresses and strains that the chassis will experience under various loading conditions. The 3D CAD model is virtually divided into small elements, and computer calculations predict how these elements will deform or break under applied loads. This analysis helps identify weak points in the design and optimize the material distribution for maximum strength and weight efficiency.
5. Physical inspection: Prototype design: The physical model of the chassis can be designed based on the completed CAD model. The modelsare then subjected to rigorous testing that mimics real world conditions: Static load test: simulates the weight of the vehicle and cargo. Crash test: Test the chassis' ability to protect passengers in the event of a crash. Any differences will indicate an area where the design may need to be changed.
6. Production: Production Planning: Once the design is verified by testing, the production process can be planned. This includes selecting the appropriate manufacturing process (such as welding, riveting, assembly) and ensuring that the chosen method is compatible with the selected product



II. BASIC COMPONENTS OF CHASSIS

The Primary Structure is comprised of the following Frame components:

1. Main Hoop

• The main hoop is the large vertical roll bar located behind the driver's seat.
• It provides rollover protection, ensuring driver safety in case of a crash.
• Typically made from high-strength steel (e.g., AISI 4130 Chromoly) or aluminum.
• Designed to meet FSAE or FIA safety standards, resisting deformation under impact.

2. Frame Members

• Frame members consist of the interconnected tubular elements forming the chassis.
• They provide structural integrity, distributing loads efficiently across the chassis.
• Designed to minimize weight while maximizing strength and stiffness.
• Usually fabricated using welded steel tubes or lightweight aluminum alloys.

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3. Front Hoop
• The front hoop is positioned ahead of the driver, forming a protective structure around the cockpit.
• Helps prevent intrusions into the driver compartment case of a front-end
• Often connected to side-impact structures to enhance crashworthiness.
• Made from the same high-strength materials as the main hoop.

4. Front Bulkhead
• The front bulkhead is a reinforced structural component at the front end of the chassis.
• It provides mounting points for suspension, steering, and crash structures.
• Acts as a barrier between the driver and frontal impacts, contributing to crash safety.
• Usually reinforced with additional braces or impact-absorbing materials.

III. DESIGN CALCULATION

3.1 Selection of Dimension for Primary Member:

Bending Strength Criteria:

Rule: Bending strength of selected material and tube must be greater than bending strength of AISI 4130 steel having OD 1" and thickness 3 mm. The wall thickness must be at least 1.57 mm.

Bending Strength of AISI 4130 steel (for tube having OD 25.4 mm and thickness 3 mm) = 387.38×10^3 N/mm²

Bending Strength Formula:

Bending Strength=Sy∗I/c

Where:

Sy: Yield strength (365 MPa for AISI 4130 steel) C: Distance from neutral axis to extreme fiber

I: Second moment of area for the structural cross section

Thickness of tube to satisfy the Bending Strength criterion (with OD 31.75 mm):

We calculate the thickness of tube having O.D

31.75 mm to satisfy this criterion.

Bending Strength=Sy∗I/c

Therefore t = 31.75-28.69/2=2mm

Bending Stiffness Criteria:

Rule: Bending stiffness of selected material and tube must be greater than that of AISI 1018 steel tube having OD 25.4 mm and thickness 3 mm.

Bending Stiffness = E × I Where E = 205 GPa for steel.

Bending stiffness of AISI 4130 steel (OD 25.4 mm, thickness 3 mm) = 2.7631×10^9 N-mm²

Table :Optimization Table

Weight of Primary Members:

Weight = Tube Length × Area × Density

= $18.32 \times 1.5155 \times 10^{-4} \times 7870$

= 21.85 kg

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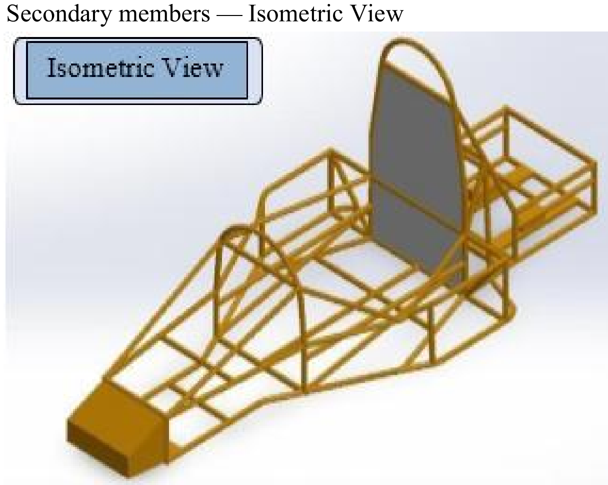
Sr no.	O.D. (mm)	Thickness(m m)	Bending Stiffness (N-mm^2)*10^6	Bending Strength N/mm^2* 10^3	Weig ht (kg/ m)
1.	25.4	3	1654.96	292.40	1.66
2.	25.4	2.5	1421.12	251.09	1.37
3.	25.4	2	1171.41	206.97	1.55
4.	25.4	1.6	986.665	174.329	1.19
5	29.2	1.6	1518.578	233.37	1.27
6	29.2	2	1807.618	277.79	1.32
7	31.75	1.6	1968.54	277.913	1.39

List of Primary Members:
- Rear Roll Hoop (RRH)
- Roll Hoop Overhead Members (RHO)
- Front Bracing Members (FBM)
- Front Lateral Cross Member
- Lateral Cross Member (LC)

Fig. 3.2.1 shows Primary and Secondary members — Isometric View



3.3 Selection of Dimension for Secondary Members:

Goal: Reduce chassis weight without violating rules and compromising safety.

Rule: Secondary member must have wall thickness minimum 1.75 mm and minimum O.D. 25.4 mm irrespective of steel type.

Table 3.3.1: Optimization Select Value

Sr no.	O.D. (mm)	Thickne ss (mm)	Bending Stiffness *10^9	Bending Strength *10^3	Weig ht (Kg/ m)
1.	25.4	1	1.171	164.221	0.6
2.	25.4	1.2	1.372	192.415	0.73
3.	25.4	1.5	1.654	232.019	0.884
4	25.40	1.75	1.744	244.521	0.94
5.	28.75	1	1.722	213.337	0.686
6.	28.75	1.2	2.023	250.676	0.817

Final Selection: Steel tube OD 25 mm and thickness
1.6 mm (easily available).

3.4 List of Secondary Members:

- Lateral Diagonal Bracing (LBD)
- Lower Frame Side (LFS)
- Side Impact Member (SIM)
- Fore/Aft Bracing (FAB)
- Under Seat Member (USM)
- Other Required Cross Members
- Safety Belt Mounting Tubes

3.5 Weight of Secondary Members:

Weight = $11.916 \times 1.963 \times 10^{-4} \times 7870 = 11.218$ kg

3.6 Weight of Tubing

So, the weight of all members

Total weight of tubing =Weight of primary member + Weight of secondary member Therefore, total weight of tubing without considering weld weight is

Sr No.	Types of Members	Tubing Length(m)	Weight (Kg)
1.	Primary Members	18.320	21.85
2.	Secondary Members	11.916	11.218
	Total	30.236	33.068

IV CAD MODLE

CAD Software Used: SolidWorks for design and ANSYS Student version for impact testing.

Design Focus: Emphasized on roll cage, drive-train, and Battery Management System for optimal performance valuable in boosting pneumonia classification accuracy by combining multiple CNN models. Techniques like bagging and boosting aggregate predictions, which help reduce false positives and negatives [7]. Hybrid models that integrate attention mechanisms improve interpretability by directing attention to the most relevant regions of X-ray images. These innovations enhance prediction stability and make deep learning-based diagnostic tools more reliable and transparent, fostering greater acceptance in medical practice.

SIP reprocessing techniques, such as contrast enhancement and noise reduction, improve image quality before training, ensuring that subtle pneumonia-related features are preserved. Statistical validation techniques like k-fold cross-validation are frequently used to evaluate the generalizability of models. Explainable AI approaches, such as Grad-CAM, improve model interpretability, enabling radiologists to better understand predictions prior to making clinical decisions. These integrations ensure that deep learning models align with medical expertise, boosting driver is estimated to be 320 kg. It is considered for the static analysis that the vehicle comes to net 1 sec after the impact. The Boundary conditions for this test are

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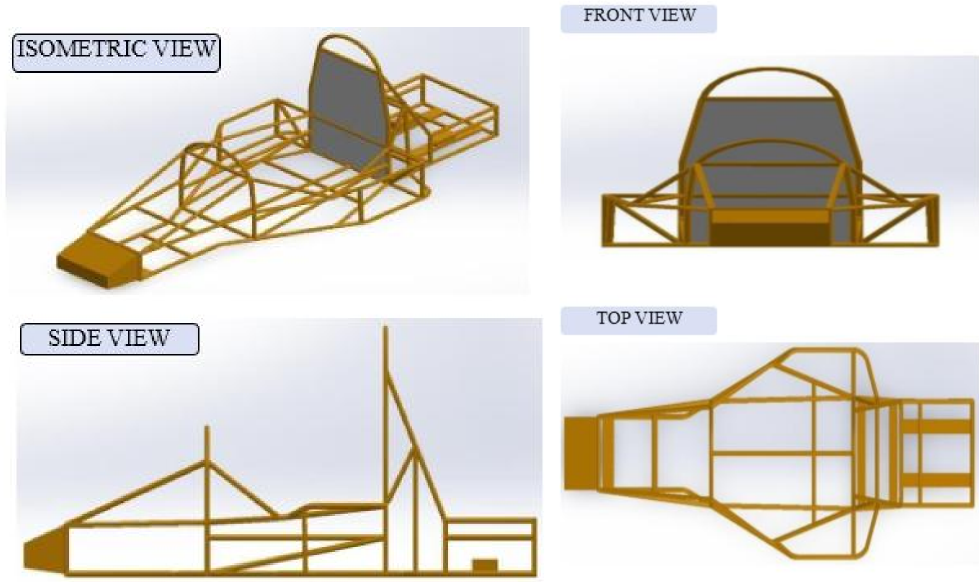

V IMPACT ANALYSIS

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

- Front Impact Test.
- Rear Impact Test.
- Side Impact Test.

(Note: All of this test are done in ANSYS.)

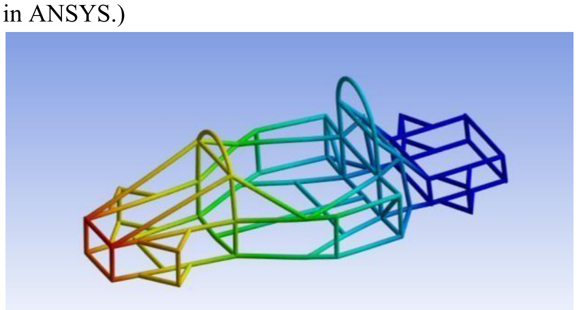

Fig. 2. Front Impact Test

The vehicle is designed for maximum speed of 80 km/ph. The total weight of the vehicle including the

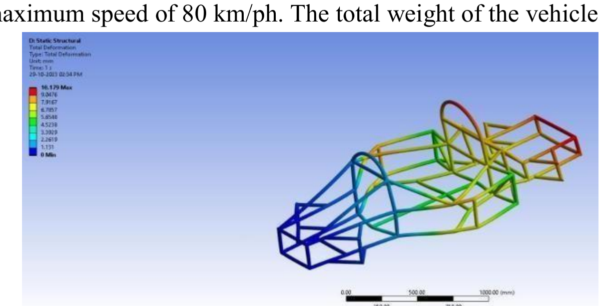

Fig. 3. Rear Impact Test

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In this case the vehicle is assumed to be in rest condition and the vehicle of same mass is assumed to collide with our vehicle with the speed of 80 km/Ph, and we observe the maximum deformation in that condition.

Fig. 4 shows the Side Impact Test in which the Vehicle is in Rest Position and the vehicle of same specifications and same mass is assumed to collide with our vehicle sideways so in this condition the maximum deformation is noted and studied upon.

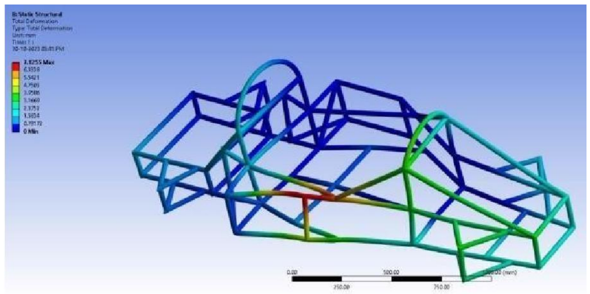

Fig. 4. Side Impact Test

After the Front, Rear, and Side Impact test we Perform the last type of test i.e. Vehicle Rollover test. In this test we assume the vehicle rollover condition and the position of vehicle is changed and the maximum force gets exerted on the main hoops Bracing

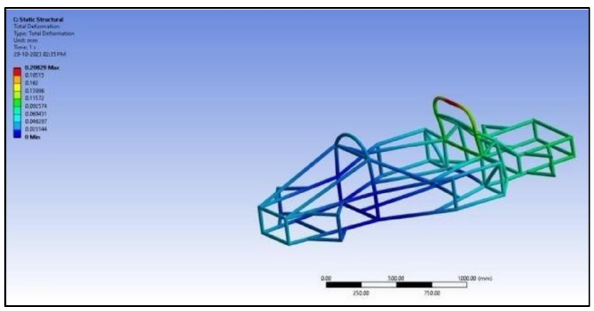

Fig. 5. Rollover Test

RESULT TABLE:

Sr. No	Scenario	Boundary Condition	Results
1.	Front Impact Test	Velocity–80 kmph	(Max.Def. =27.534 mm) (F.O.S=2.3867)
2.	Rear Impact Test	Force = 22204 N	Max.Def.=10.179mm) (F.O.S. = 2.7433)
3.	Side Impact Test	Force = 9417 N	(Max.Def. = 7.1255 mm) (F.O.S. =3.237)
4.	Roll Over Test	Force = 6270 N	(Max.Def. = 0.2082 mm) (F.O.S. = 3.897)

VI. CONCLUSIONS

The study on the design and manufacturing of a lightweight tubular chassis for an range extended Hybrid Electric Vehicle (HEV) has provided significant insights into the evolution of chassis systems in the automobile industry. The research highlighted the importance of chassis as the structural foundation of a vehicle, with advancements made to improve performance, safety, and fuel efficiency. The study also highlighted the importance of material selection and design optimization, with CAD modeling and Finite Element Analysis (FEA) simulations helping optimize the design for maximum strength-to- weight ratio.

The chassis underwent comprehensive testing, including static load tests, impact scenarios, and roll-over tests, providing valuable insights into its performance under different conditions. The designed lightweight tubular chassis demonstrated enhanced performance attributes, such as improved speed, handling, and fuel economy, contributing to the efficiency and sustainability of hybrid electric vehicles. The project also serves as a valuable resource for student teams participating in automotive competitions, offering insights into material selection, design methodologies, analysis techniques, and testing protocols. Overall, this research contributes to ongoing advancements in automotive engineering, particularly in sustainable mobility solutions and the transition towards electric and hybrid vehicle techniques improves pneumonia detection and supports early diagnosis, particularly in resource-limited settings where access to radiologists may be restricted.

VII. ACKNOWLEDGEMENT

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