Design And Analysis of a High-Performance Powertrain for a Sae Baja Racing Off-Road Vehicle

Authors: R.Shiva, R.Vamshi, S.Subhahan
Guide: Dr. M.Prakash babu, (M. Tech, Ph.D)
Department of Mechanical Engineering
Guru Nanak Institutions Technical Campus, Hyderabad

ABSTRACT - This paper presents the comprehensive design and analysis of a high-performance powertrain for an SAE Baja off-road vehicle powered by a 300cc, 10 horsepower engine. It focuses on the integration and performance of a Continuously Variable Transmission (CVT), emphasizing its role in delivering maximum torque and efficiency under varied terrain. Key contributions include detailed component selection, solid modeling using SolidWorks, and simulation via ANSYS for structural integrity and fatigue life estimation. The results show that a CVT combined with an optimized fixed gear ratio can achieve the torque multiplication needed for competitive acceleration and hill climb capabilities. Material selection using DFMA principles and fatigue-safe design ensures durability and compliance with SAE standards. The study concludes with a performance comparison against historical Baja benchmarks and proposes future enhancements including the use of electronic CVTs and AI-based tuning.

1.INTRODUCTION

The SAE Baja competition offers a rigorous platform for undergraduate engineering students to apply practical knowledge through the design and fabrication of off-road vehicles. Among various subsystems, the powertrain plays a pivotal role in ensuring performance and reliability across varied terrain. The vehicle must be capable of navigating dynamic events such as hill climbs, maneuverability challenges, and endurance tests. The choice and tuning of a Continuously Variable Transmission (CVT) allows teams to optimize engine performance by maintaining operation near peak torque. This paper addresses the methodology behind developing such a powertrain for a 300cc, 10 hp engine.

2. LITERATURE REVIEW

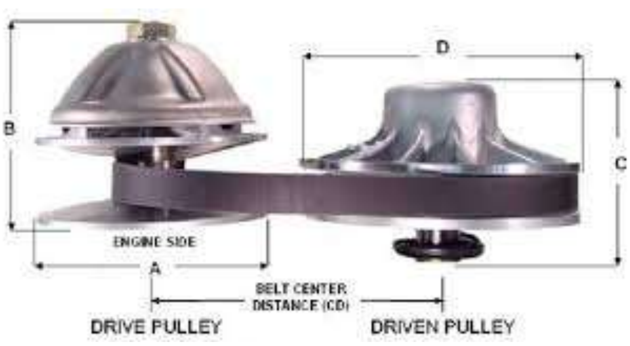
Multiple studies over the past two decades have explored powertrain advancements in off-road vehicles, particularly for Baja SAE applications. Anderson et al. (2005) proposed an early CVT framework for torque optimization in off-road applications. Roberts et al.

(2006) suggested that lightweight drivetrain components significantly boost vehicle acceleration. Mitchell and Lee (2007) favored wet clutches over dry ones for durability. Patel et al. (2009) found that EFI systems offer better throttle response than traditional carburetors. Richards et al. (2011) validated that gear calibration improves

acceleration and efficiency. More recently, Mehra and Sen (2025) proposed integrating AI-based real-time optimization for race-specific tuning. These studies collectively inform the powertrain configuration presented herein.

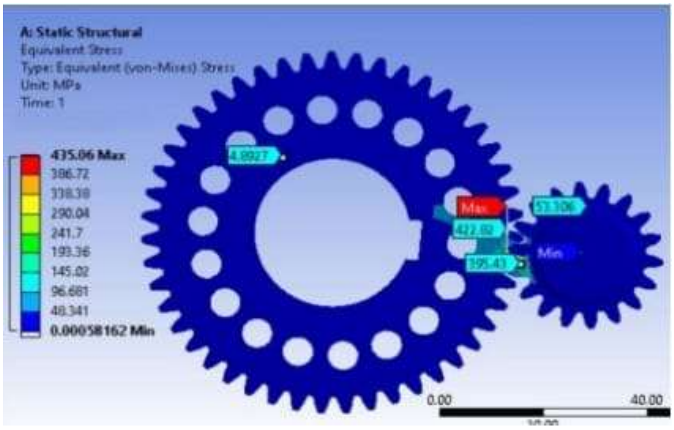
3. METHODOLOGY

The methodology includes CVT and final drive system selection, gear ratio optimization, SolidWorks modeling of components, and structural analysis using ANSYS. Key design metrics such as torque multiplication, rotational speed, tractive effort, and gradeability were computed. The CAD model was subjected to kinematic simulation and load-based analysis to evaluate durability under Baja race conditions.



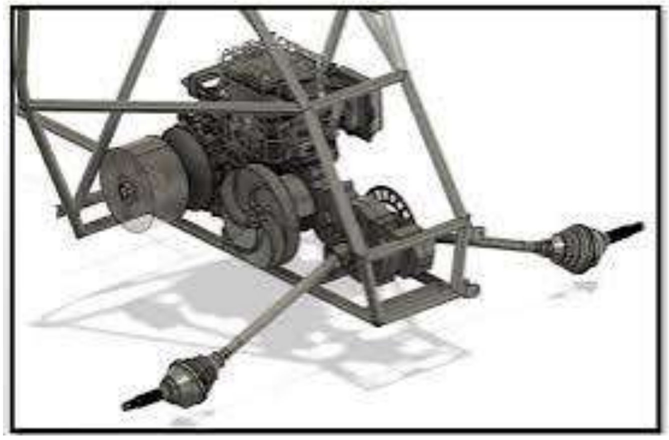
4.MATERIAL SELECTION

Material choices were driven by strength-to-weight ratio, machinability, and availability. AISI 4130 steel was selected for drive shafts and gears due to its excellent tensile properties. 6061-T6 aluminum was chosen for the gearbox casing and pulley sheaves to reduce unsprung weight. V-belts were reinforced with steel cords to manage torque demands. Material properties were also used as inputs in ANSYS for stress simulation and fatigue analysis.



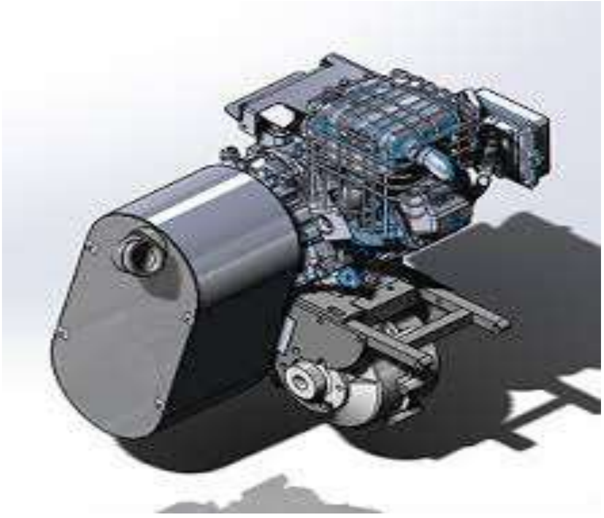
5.RESULTS AND DISCUSSION.

The CVT showed a low-gear ratio of 3.5:1 and a high-gear (overdrive) ratio of 0.9:1. Paired with a fixed gear reduction of 8:1, the system delivered a maximum effective gear ratio of 28:1. Tractive effort peaked at over 1100 N and the vehicle achieved a gradeability of 26.09°. FEA revealed stress concentrations within acceptable yield limits for selected materials, with a Factor of Safety (FOS) above 2 in critical zones. Acceleration was measured at 4.81 m/s^2, validating design goals.



6.CONCLUSION.

The project demonstrates that a properly tuned CVT with a high-strength lightweight material combination can deliver superior performance in SAE Baja competitions. Engineering analysis confirmed structural robustness and power delivery efficiency. Future developments can explore regenerative braking, machine-learning-based real-time tuning, and lightweight composite materials for additional weight reduction.



7. References

[1] Anderson et al., 'CVT Framework for Off-Road Racing', 2005.

[2] Roberts et al., 'Weight Reduction in Baja Drivetrains', 2006.

[3] Mitchell and Lee, 'Clutch Durability in SAE Baja', 2007.

[4] Patel et al., 'Fuel Efficiency through EFI', 2009.

[5] Richards et al., 'Gear Ratio Optimization', 2011.

[6] Mehra and Sen, 'AI-Based Powertrain Optimization', 2025.