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OPTIMIZATION OF SWING ARM FOR TADPOLE STRUCTURED ELECTRIC VEHICLE

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Abstract:

The automotive industry is facing a challenge to develop compact, fuel-efficient, and secure automobiles. Three-wheelers are becoming increasingly popular due to their low fuel consumption, ease of driving, and parking in densely crowded urban areas. This paper used a tadpole-shaped electric three-wheeled vehicle structure to optimize and select a lightweight structure. The swing arm is a single or double-sided mechanical device that connects a motorcycle's rear wheel to its body, enabling it to rotate vertically. It is a key component of the most contemporary rear assembly. System lightweight design is the process of putting together multiple parts or functions into a single part or system to make an assembly lighter. The material lightweight design takes advantage of what the material has to offer, while the structure lightweight design is a subset of the system lightweight design. Additive Manufacturing and Generative Design (DfX) were developed to meet the demands of highly competitive markets in terms of manufacturing costs, quality, and speed to market. In this paper, the generative design approach is used to optimize the weight of the swing arm for a tadpole structure electric vehicle.

Key words: Tadpole Structure, Electric Vehicle, Generative Design, Swing-arm.

1 Introduction

The increased urban population and accompanying rise in the number of cars has presented the automotive industry with a new challenge: the development of compact, fuel-efficient, and secure automobiles.[1] A fresh crop of compact automobiles follows this trend. There has been a recent uptick in interest in these vehicles because of their low fuel consumption, ease of driving, and parking in densely crowded urban areas.[2] In numerous nations, including India, Thailand, Peru, China, and even Italy, three-wheeled vehicles are already integrated into the public transit system.[3] Low fuel costs and zero pollutants are two major benefits of electric three-wheelers. Along with their widespread acceptance, three-wheelers have significance: they are particularly stable while performing complex maneuvers. A variety of solutions to increase their reliability have been presented.[4]

The swing arm connects the motorcycle's rear wheel to the frame and is critical to the bike's rear suspension system. The motorcycle's handling, stability, and performance may all benefit from a well-tuned swing arm. The swing arm may be improved in a number of ways.[5] The stability, traction, and handling of a motorbike are all affected by its wheelbase, which in turn is affected by the length of the swing arm. The stability gains from a longer swing arm may not be worth the potential loss of control. The opposite is true as well; a shorter swing arm might increase maneuverability but may compromise stability. The trick is to strike a balance between length and steadiness.[6] [7] The swing arm's weight, strength, and pliability may all be affected by the material it's made out of. The total weight of a motorbike may be reduced by using lightweight materials like aluminum or carbon fiber, while the use of high-strength materials like titanium or steel can increase its durability and strength.[8]

Suspension geometry, and hence handling and traction, is affected by the motorcycle's swing arm's form and angle. The degree of squat and anti-squat may be modified by adjusting the swing arm angle, which in turn helps enhance the vehicle's responsiveness and control under acceleration and braking.[9] In a vehicle, the suspension linkage is what attaches the swing arm to the chassis and the shock absorber. Improving the responsiveness and adjustability of the suspension through linkage optimization can boost the motorcycle's performance and handling.[10] Swing arm optimization is a multi-faceted procedure that must take into account the function of the motorbike, the preferences of the rider, and the limitations of the design. It entails weighing the benefits and drawbacks of different performance qualities and is often carried out with the use of computer simulations and physical testing.[11]

An electric vehicle needs to optimize the weight of each component to increase its range and handling of the vehicle. The single-wheel drive will give the solution for urban traffic and a more stable structure with zero pollution. This paper used a tadpole-shaped electric three-wheeled vehicle structure for study analysis. Weight distribution, suspension geometry, and tire choice are a few examples of the requirements for optimization; each of these elements must be carefully chosen and fine-tuned to achieve the best performance. In addition, it's crucial to evaluate these optimization strategies in real-world settings and do computer simulations to confirm their efficacy.

2 Tadpole Design

A tadpole design for an electric vehicle consists of two wheels in the front and one wheel in the back. A reverse trike layout is another name for this style of vehicle. Because the vehicle's weight is shared by all three wheels, it is more stable in this configuration. At higher speeds, in particular, this can improve the vehicle's stability and make it simpler to handle. In addition, having two wheels up front helps enhance the vehicle's handling and agility, particularly in confined locations.[10] Suspension systems that can accommodate the tadpole layout's weight distribution and handling characteristics may be trickier to develop.

A vehicle's design will ultimately be decided by a number of criteria, such as the market segment the vehicle is aimed at, the specifications the vehicle must meet, and the preferences of the maker and the buyer.[11] The vehicle's teardrop form makes it aerodynamic. Air flows readily over the vehicle's bodywork. For its stability, aerodynamics, and fuel efficiency, auto designers are favoring tadpole design. Many hybrid and electric concept cars feature a three-wheel configuration. Three-wheelers may become increasingly common as cars become more eco-friendly.

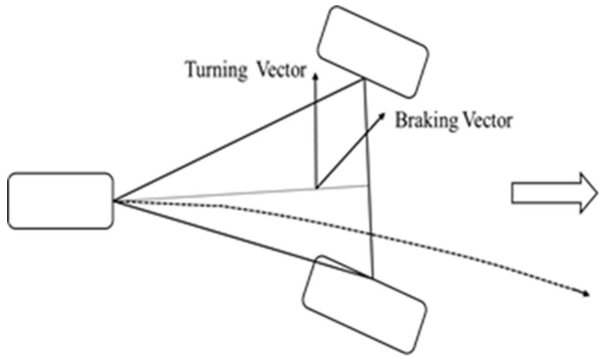


Fig.1 Tadpole Architecture

3 Swing Arm

A swing arm, also known as a swing fork or pivoted fork, is a single or double-sided mechanical device that connects a motorcycle's rear wheel to its body, enabling it to rotate vertically. The key component of most contemporary motorcycles and ATVs' rear suspension, it holds the rear axle solidly while rotating to absorb bumps and suspension loads caused by the rider, accelerating, and braking.[9]

3.1 Types of Swing-Arm

Swing-arm motorcycle suspension links the back wheel to the motorbike chassis. Swing arms come in a variety of styles, including:[10]

- Straight swing arms- are the most basic and widely used variety. It is made up of a single straight piece of metal that links the back wheel to the frame.
- Single-sided swing arms- are intended to enable for easy wheel removal for maintenance or repair. It features a single-sided framework that links the wheel to the frame and is often equipped with a hub-center steering mechanism.
- Dual-sided swing arm- This form of swing-arm has two arms, one on each side of the wheel, that link the wheel to the frame. This style is more stable than the straight kind and is typically found on heavy-duty motorcycles.
- Pro-link swing arms- are meant to improve suspension performance by utilizing a linkage system between the swing arm and the shock absorber. It enables more accurate suspension settings and enhanced handling.
- The banana swing arm- has a curved form that resembles a banana. Several racing motorcycles employ it to boost aerodynamics and save weight.

Ultimately, the choice of swing-arm type is determined by the vehicle's unique requirements and the rider's preferences.

4 System Light Weight Design

System lightweight design is the process of putting together multiple parts or functions into a single part or system to make an assembly lighter. The strategies for making things lighter, such as material lightweight design and lightweight structure design are parts of lightweight system design.[12]

4.1 Material Light Weight Design

This way of designing takes advantage of what the material has to offer. Different materials reach different levels of strength and/or stiffness based on their density and other properties. Material: Lightweight design can be done by using a single material with a high specific property or by combining different materials to take advantage of the best of each. This is called a composite or hybrid.[13]

4.2 Structure Light Weight Design

It is a way to think about making and designing parts by optimizing their topology, shape, and parameters. The goal is to change the shape and form to reduce the weight. The stiffness and structure of an assembly can lead to a light system, so structure lightweight design is a subset of system lightweight design or strength goes up or stays the same.[13]

5 Generative Design

Generative design is a method that uses algorithms and computer power to create and optimize designs depending on specified goals, restrictions, and inputs. This process involves the creation and optimization of designs. This strategy enables designers and engineers to investigate a vast variety of potential design options and determine the approaches that will produce the greatest results depending on the outcomes that are wanted.[14]

The generative design process generally consists of the following four basic steps:

- Describing the design's objectives and limitations: This involves stating the design goals, such as reducing weight or improving performance, as well as any production restrictions or functional requirements that need to be taken into consideration.[15]
- Generating design options: Generative design software can generate a wide range of design options based on the defined goals and constraints by utilizing computational algorithms and techniques such as artificial intelligence and machine learning. These techniques allow the software to learn from previous designs.[16]
- Assessing and improving the designs: When the designs have been developed, they are compared to the predetermined goals and limitations, and the solutions that appear to have the most potential are chosen for future development.[17]

The selected design is then further improved and optimized via the use of traditional design procedures, and the final product is manufactured by either conventional or additive manufacturing techniques.

The process of generative design has a number of advantages, the most notable of which is the capability to generate designs with complicated geometries as well as designs that are optimal with regard to a broad variety of considerations, such as cost, weight, and strength. Also, it can cut down on the amount of manual input and iteration that is required during the design phase.[17]

The fields of aerospace, automotive, and architecture are just a few of the many that make use of generative design in their product development processes. It is especially helpful in applications where aspects such as reducing weight, increasing performance, and improving customization are primary considerations.

5.1 Generative Design (GD) Methodology

A design approach known as generative design is one that makes use of algorithms and computing power to generate and optimize designs in accordance with a set of predetermined limitations and goals. This method enables designers to investigate a wide variety of potential design options and select the most effective design solutions by basing their decisions on the results that are intended. Additive manufacturing and generative design are two technologies that may be used to improve the design and production of components and finished goods. Both technologies are complementary to one another and can be utilized together. The generative design allows for the creation of designs that are optimized to make full use of the one-of-a-kind capabilities of 3D printing. This is accomplished by capitalizing on the design freedom and flexibility offered by additive manufacturing.[18]

For instance, generative design may be used to produce lightweight structures that are optimized for certain load circumstances. This results in components that are both more durable and more efficient than parts that are built using conventional methods. Additive manufacturing can then be used to produce these complex geometries with a high degree of precision and accuracy, which enables the creation of parts that would be difficult or impossible to produce using traditional manufacturing methods. Additive manufacturing is a relatively new manufacturing technique that was developed in the 1990s.[18] Ultimately, the combination of additive manufacturing with generative design has the potential to transform the way in which we design and build parts and products, making it possible to achieve better levels of efficiency, usefulness, and creativity

6 Material Selection

Lightweight structural materials allow automobiles to carry improved emission control, safety, and integrated electrical systems without adding weight. Hybrid, plug-in, and electric cars need lightweight materials. Lightweight materials may reduce the weight of power systems like batteries and electric motors, enhancing efficiency and all-electric range. Lightweight materials might reduce battery size and cost while maintaining plug-in car all-electric range.[12]

Lightweight materials' cost, recycling, integration with cars, and fuel efficiency advantages depend on research and development. The most commonly used materials for lightweight structures in automotive industries and their properties of it are given below.

Table 1 Material Properties

Material	Material Strength (MPa)	Cost Per Kg. (Rs.)
High Strength Steel	*500*	*125*
Advanced high-strength steel	*700*	*175*
Glass fiber composites	*3500*	*200*
Titanium	*1400*	*5500*

Aluminum and Al matrix composites	*240*	*200*
Carbon fiber composites	*3500*	*8000*
Magnesium	*440*	*90*
7076 T6 Aluminium Alloy	*570*	*600*

It is crucial to consider the particular needs and restrictions of the system being optimized while thinking about design factors. This comprises elements including price, size, and performance objectives.

By considering the cost-effectiveness and strength of the material used for the automobile and ease in manufacturing 7076 T6 Aluminium alloy material is selected for the swing-arm of a tadpole structured electric vehicle.

7 Methodology

Optimization techniques including material selection, structural design, and suspension tuning are all geared toward enhancing the strength, longevity, and performance of the swing arm under varied driving circumstances. With tadpole-shaped electric cars that mainly rely on the swing arm suspension system, these optimization approaches are essential for attaining the best handling and stability.

7.1 Selection of the Swing Arm for Tadpole Structure

As there are different types of swing in the market for different purposes such as for Sport and Commercial bikes. But we are designing for the tadpole structure as it consists of 3 wheels in this type of structure. So, to support the rear wheel of the structure we would select the double-sided swing arm for the Tadpole structure. As it supports all the types of force acting on the structure of the design.

7.2 Load Consideration

There are different loading conditions such as static conditions and dynamic conditions. In static conditions, the equal forces are acting on both beams of the swing arm, and in the dynamic condition we would consider the corning condition where there will be unequal loading on both sides of the beam of the chassis.

7.3 CAD Model of the swing-arm

Designing of the swing arm in the Cad model by considering load conditions for the modeling of the swing arm. From the modeling of the swing arm, we would get the dimension of the model and properties of the swing arm. And also would put the material to it.

7.4 Generative Design Software

The process of generative design involves using Altair Inspire Software to produce several CAD solutions that satisfy predefined constraints and we would be getting many design iterations which would be optimized models.[19]

7.5 Design Constraint for GD

We considered the 3 design constraints for the GD which would be the load acting on the swing, the stiffness & Weight reduction of the swing arm. This weight reduction will be based on getting the max stiffness.

7.6 Iteration for GD

There will be five iterations generated by the GD in the bases of weight reduction percentage from 70 to 90%.

7.7 Analysis of the Model

The analysis will be done in the ansys software which will be static structural. The results will be on the basis of total deformation, and maximum principal stress.

7.8 Selection Process

Selection will be based on different criteria such as weight, stiffness and aesthetics. The selection method that would be considered will be of MCDM which is called Multi Decision Criteria Decision Making method. In this we would be using the best and worst method in the MCDM for the selection of optimized solutions of our design.[20] When making a choice between many options, it might be helpful to take into account as many factors as possible. This is where "Multi-Criteria Decision Making" (or "MCDM") comes in handy. In multi-criteria decision making (MCDM), the decision maker takes into account a number of elements, or criteria, in order to make a final choice. MCDM assists decision makers in determining the best-suited option by taking into consideration multiple views and preferences. MCDM is widely utilized in many sectors, including engineering, management, economics, and environmental research.[16]

7.9 Final Design

The final iteration would be finalized based on the optimum value of all the selection parameters that would be considered. That would be the final design of the optimization of the swing arm.[21]

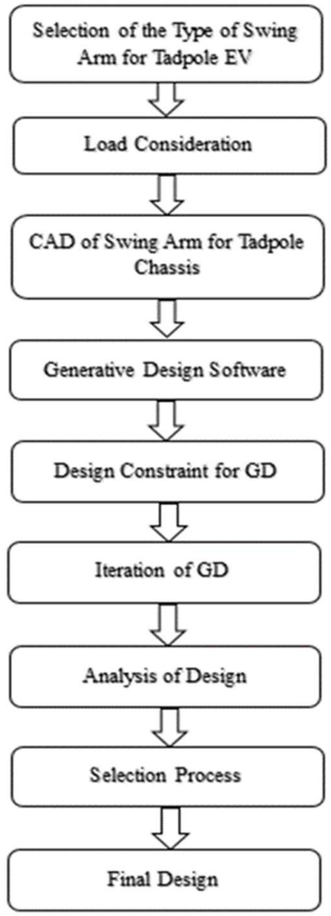


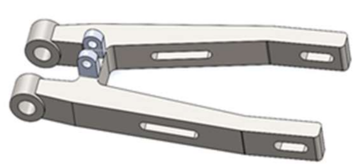
Fig.2 Flow Chart of Swing Arm Generative Design for Tadepole Structured EV

9 Analysis and Results

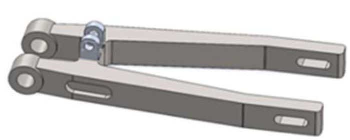
By using Solidworks software CAD model of the swing arm is prepared and assigned given properties to the model.

9.1 Generative Design Iteration

a) Iteration 1



b) Iteration 2



c) Iteration 3

d) Iteration 4

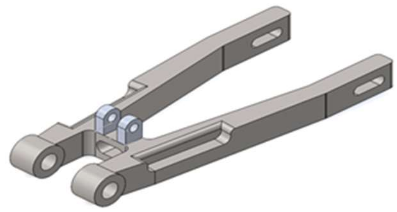


Fig.3 Weight and Shape Optimization Iterations

The initial Weight of the Swing Arm was 11.70 Kg. After application of the generative design concept and getting different iterations as follows with varying mass.

Table 2 Weight Reduction by Optimization

Iterations No.	Mass (Kg)	Mass Reduction %
Iteration 1	*11.08*	*2.3%*
Iteration 2	*11.41*	*1.00%*
Iteration 3	*8.75*	*25.22%*
Iteration 4	*10.80*	*7.7%*

9.2 Load Applied for Analysis

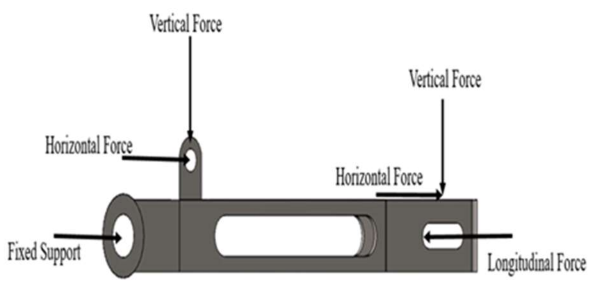
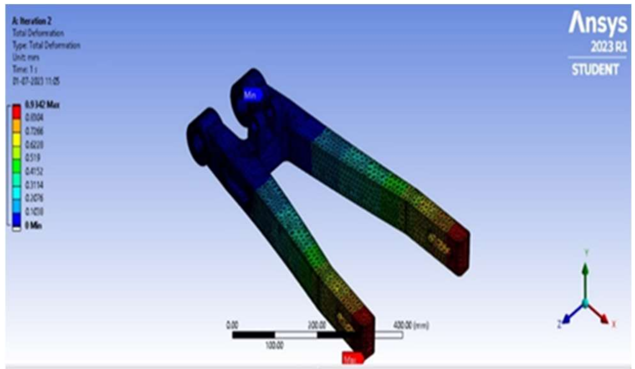


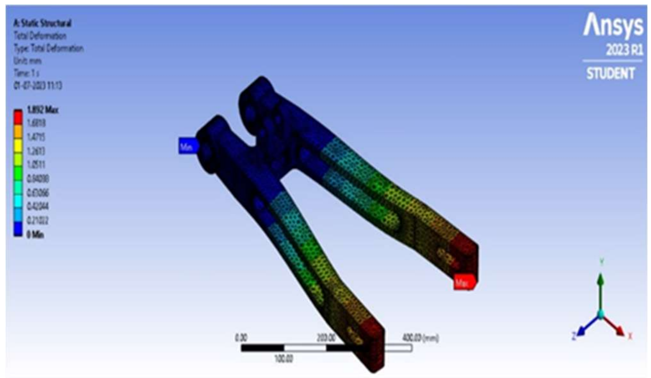
Fig.4 Loading Conditions

In Ansys software loads are applied as shown in Fig. 4. For analysis purpose at the eye end fixed support is considered and vertical forces of 325 N and horizontal force of 1925 N is applied on the swing arm by considering bump due to tire and forces due to suspension. Also, the longitudinal force due to acceleration and braking is applied at 2000 N.

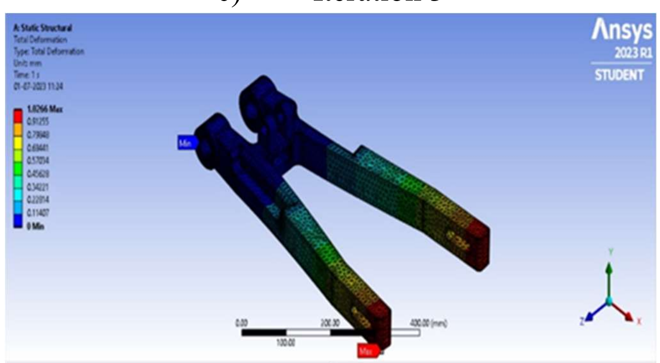
a) Iteration 1



b) Iteration 2



c) Iteration 3



d) Iteration 4

Fig.5 Analysis of Iterations by using ANSYS Software

Now here we are assigning the ranking for the geometry parameters as follows as per the manufacturability and aesthetics of the swing arm.

Table 3 Ranking for Geometry Parameter

Description	Ranking
Low	*1*
Below Average	*2*
Average	*3*
Good	*4*
Excellent	*5*

Dividing parameters into beneficial and non-beneficial categories as per their effect on the swing arm as maximum or minimum. So considering Geometry and stiffness as beneficial parameters as they should be maximum and mass, stresses induced, and deformation as non-beneficial parameters as they should be minimum.

Values were observed for different parameters after ANSYS and applying generative design concept for each iteration as follows.

Table 4 Observation Values of Different Parameters

	Beneficial		Non Beneficial			
Iteration	**Geometry**	**Stiffness**	**Mass (Kg)**	**Stress (MPa)**	**Deformation (mm)**	
1	*4*	*5893.79*	*11.08*	*35.582*	*0.33934*	
2	*5*	*2140.87*	*11.41*	*25.502*	*0.9342*	
3	*2*	*1057.08*	*8.75*	*53.634*	*1.892*	
4	*1*	*1948.18*	*10.8*	*23.002*	*1.0266*	
Max	***5***	***5893.79***	***8.75***	***23.002***	***0.33934***	***Min***

For decision-making by using multi-criteria here considering the maximum value of beneficial criteria and minimum value of non-beneficial criteria. After dividing these values to actual values will get the multiplication factor as follows.

Table 5 Multiplication Factors for Parameters

	Beneficial		Non Beneficial		
Iteration	Geometry	Stiffness	Mass	Stress	Deformation
1	*0.8*	*1*	*0.78971*	*0.64645*	*1*
2	*1*	*0.36324*	*0.76687*	*0.90196*	*0.363241*
3	*0.4*	*0.17935*	*1*	*0.42886*	*0.179355*
4	*0.2*	*0.33054*	*0.81018*	*1*	*0.330547*

After getting multiplication factors will assign the weightage to each criterion as per importance in tadpole structured electric vehicle and get the total weightage for deciding the optimized iteration of swing arm for tadpole EV.

Table 6 Total Weightage and Ranking of Parameters

	Beneficial		Non Beneficial			Total	
Weightage	20	25	20	20	15	100	
Iteration	Geometry	Stiffness	Mass	Stress	Total Displacement	Total	Ranking
1	*16*	*25*	*15.79*	*12.92*	*15*	*84.72*	*1*
2	*20*	*9.08*	*15.33*	*18.03*	*5.44*	*67.90*	*2*
3	*8*	*4.48*	*20*	*8.57*	*2.69*	*43.75*	*4*
4	*4*	*8.26*	*16.20*	*20*	*4.95*	*53.42*	*3*

10 Conclusions

Generative design software involves producing several CAD solutions that satisfy predefined constraints. Multi-Criteria Decision Making (MCDM) is an important tool for making a choice between many options, as it takes into account a number of elements, or criteria, to make a final choice.

In this paper, by applying the generative design method and Multi-Criteria Decision Making (MCDM) process the weight of the swing arm for a tadpole structured electric vehicle is assed with its initial weight of 11.7 Kg.

From the results iteration number one has ranking one, So iteration no. 1 is the optimized result for the material 7076 T6 Aluminium alloy material of the swing arm in which weight is reduced by 0.7 kg, geometry is optimized and having ease in manufacturing and getting higher strength with allowable induced stress and deformation.

References

1 B Kosankar, Sharda, and Chetana Khandar. "A review of vehicular pollution in urban India and its effects on human health." Journal of Advanced Laboratory Research in Biology 5, no. 3, 2014.

2 D'Amato, Gennaro, and Cezmi Akdis. "Global warming, climate change, air pollution and allergies." Authorea Preprints, 2020.

3 Xu, Bingjie, Arshian Sharif, Muhammad Shahbaz, and Kangyin Dong. "Have electric vehicles effectively addressed CO2 emissions? Analysis of eight leading countries using quantile-on-quantile regression approach." Sustainable Production and Consumption 27, 2021.

4 Gnann, Till, Thomas S. Stephens, Zhenhong Lin, Patrick Plötz, Changzheng Liu, and Jens Brokate. "What drives the market for plug-in electric vehicles?-A review of international PEV market diffusion models." Renewable and Sustainable Energy Reviews 93, 2018.

5 Ijaz, Muhammad, Muhammad Zahid, and Arshad Jamal. "A comparative study of machine learning classifiers for injury severity prediction of crashes involving three-wheeled motorized rickshaw." Accident Analysis & Prevention 154, 2021.

6 Luo, Shi-Jian, Ye-Tao Fu, and Yu-Xiao Zhou. "Perceptual matching of shape design style between wheel hub and car type." International journal of industrial ergonomics 42, no. 1, 2012.

7 Tang, Chen, Ling He, and Amir Khajepour. "Design and analysis of an integrated suspension tilting mechanism for narrow urban vehicles." Mechanism and Machine Theory 120, 2018.

8 Mr. Ketan Patil, Mr. Gaurav Rajpurohit, Mr. Rohan Magade, Mr. Akshay Shirphule, "Design and Analysis of Single Sided Swing Arm for Modified Bike," International Research Journal of Engineering and Technology (IRJET), Volume: 06 Issue: 05, May 2019.

9 Sariman, F & Cipto, Cipto & Rahangmetan, Klemens & Asmal, S., "Analysis of static characteristics of a motorcycle swing arm of a twin-shock suspension type using the finite element method," IOP Conference Series: Earth and Environmental Science. 343, (2019).

10 Ashish Powar, Hrishikesh Joshi, Sanket Khuley and D.P. Yesane, “Analysis and Topological Optimization of Motorcycle Swing-Arm,” International Journal of Current Engineering and Technology, Special Issue-6, Oct 2016.

11 Palanivendhan, M., S. Devanand, J. Chandradass, Jennifer Philip, and S. Sajith Reddy. "Design and analysis of 3-wheeler chassis." Materials Today: Proceedings 45, 2021.

12 Stephan Rosenthal, Fabian Maaß, Mike Kamaliev, Marlon Hahn, Soeren Gies, and A. Erman Tekkaya, “Lightweight in Automotive Components by Forming Technology,” Springer: Automotive Innovation (2020) 3:195–209.

13 Wen Zhang and Jun Xu, “Advanced lightweight materials for Automobiles: A review,” Elsevier: Materials & Design 221 (2022).

14 Shahroz Khana, and Muhammad Junaid Awana, “A Generative Design Technique for Exploring Shape Variations,” unpublished.

15 M. Fenoon, O. Alquabeh, M.M.Nisar, and S. Zia, “Generative Design of a Mechanical Pedal,” International Journal of Engineering and Management Sciences (IJEMS) Vol. 6. (2021).

16 Ersin Toptas, “Innovative approach to the design of mechanical parts,” Journal of Mechatronics And Artificial Intelligence In Engineering.June 2020, Volume 1, Issue 1.

17 Nitheesh.B.K, Sathya Vijaya Ram. P, Neranjen.S, Naveenkanna.M, Jithin.K.V, and Rajesh, P.K., “Mass Optimization Using Generative Design for Rear Accessory Assembly in a Two-Wheeler,” International Journal of Mechanical Engineering, Vol. 6 No. 3 (December, 2021).

18 Tristan Briard, Frédéric Segonds, and Nicolo Zamariola, “G-DfAM: a methodological proposal of generative design for additive manufacturing in the automotive industry,” Springer: International Journal on Interactive Design and Manufacturing (IJIDeM) (2020) 14:875–886.

19 Alastair R. Ruddle, Anthony J. M. Martin, "Adapting automotive EMC to meet the needs of the 21st century", IEEE Electromagnetic Compatibility Magazine, vol.8, no.3, pp.75-85, 2019.

20 C. Wachter et al., "Electric three-wheelers as an alternative to combustion-engined autorickshaws in Dar es Salaam - Generation of a standard drive cycle, Power Train modelling and simulation of the energy demand of light electric vehicles," 2020 Fifteenth International Conference on Ecological Vehicles and Renewable Energies (EVER), Monte-Carlo, Monaco, 2020.

21 V. D. Diwakar, S. R. Nedumthaly and R. Prakash, "Objective based modelling and simulation within a context of an electric vehicle development program," 2013 World Electric Vehicle Symposium and Exhibition (EVS27), Barcelona, Spain, 2013.