Optimization of Swingarm Design using Generative Design

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Abstract : This study aims to optimize the mass of the swingarm by using the generative design approach. Reducing the un-sprung mass becomes crucial in designing a performance vehicle and the key method in doing so is by designing a lightweight swingarm to attain lightweight wheel assembly. A conventional design approach is very tedious and many at times lead to dead ends so we are using the generative design approach to reduce the mass of the swingarm. It is a tool which runs on artificial intelligence to develop the component by performing many iterations on the basic design. The tool builds up the material only where it is needed based on the given loads and constrains which are set by us and It also takes care of the material selection and manufacturing methods of the design. In this study we had achieved 49% of mass reduction of the ATV swingarm by using the generative design module in Autodesk fusion 360 software. This study also helps in understanding how to perform the generative design study analysis.

IndexTerms **- Computer Aided Design, Design Optimization, FEM, Swingarm, Static Structural analysis.**

I. Introduction

A swingarm typically located behind the vehicle, for bikes it holds the wheel and for ATVs it holds the shaft. Swingarm is a crucial part of an automobile as it allows the wheel to rotate freely, it is also the component to which the suspension links coming from the chassis.

Since the swingarm has this extremely important task of being a connection between the rotating components and the suspension links which further transfers the forces to the chassis, it accounts to a large amount in the handling and performance of the vehicle. Thus, being an important part of the vehicle assembly, it accounts for the maximum portion of the un-sprung mass of the entire vehicle. lowering this component mass, not only benefits with various handling and performance characteristics it also makes it more economical in terms of fuel consumption and the added benefit of not having to spend more material in the manufacturing stage while simultaneously not maintaining the structural strength.

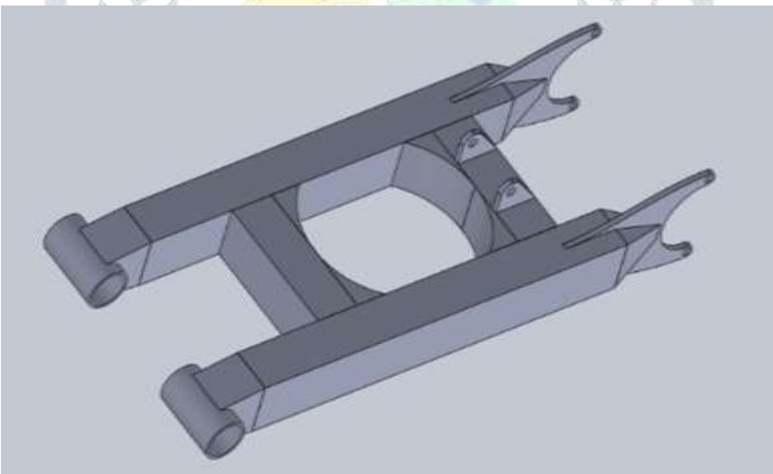

Figure 1.Isometric view of a swingarm.

An swingarm of a ATV vehicle is taken as an initial design as shown in ***Figure 1***, it is designed for the rear wheel assembly with a suspension link. The swingarm weighs 2680g which is designed with a conventional design approach according to packing limitations in the vehicle.

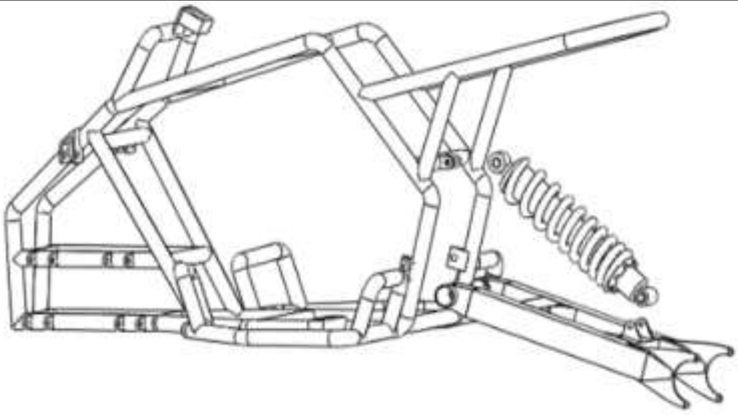

Figure 2. Exploded view of ATV chassis, swingarm and the suspension.

II. LITERATURE REVIEW

(Leitner et al., 1995) The research introduced a suspension system for the front wheel of a bicycle and motorcycle, which has a minimum amount of friction. The invention also includes various elements which provide for the structural rigidity of the suspension assembly and light weight.

(Mills, 2002) This paper certifies about swing arm suspension. This invention shows a swing arm suspension which can reduce the number of parts to thereby reduce the number of man-hours for assembly, the weight and the cost. According to the invention the cornering performance of the vehicle can be improved.

(Cassani & Mancuso, 2005) this paper gives the design process of Ducati Monster S4R single-sided swingarm by adapting numerical-experimental approach . In this study the matrix structural analysis of swing arm done by considering it as a beam. And overall properties were estimated by finite element method.

(Hong et al., 2005) this study derived modelling of suspension and swingarm for improved shock resistance in the micro optical disk drive using topology optimization and shape optimization. The objective of swing arm design is weight reduction for reducing power consumption and to achieve good result. The resultant swingarm has 15% mass reduction compared with last model.

(Yoo & Lee, 2007) The study is about Topology optimization of a swingarm type actuator. In this study , a revised topology technique based on the response surface method is used and generated a swing arm type actuator. Each single-objective function is derived by DOE (The design of experiments). The final optimized model shows 3% improvement of compliance.

(Tanaka et al., 2008) The study clearly explained the swing arm structure in motorcycle. The number of parts reduced and the removal and installation of the Swing arm is facilitated. In an embodiment of the present invention, the Swingarm is molded integrally.

(Connor, 2008) this paper assessed about an improved rear suspension system for bicycle and fulfil. a bicycle frame set including at least a seat tube, a top tube, a head tube, and a down tube having a bottom bracket fixed thereto, said seat tube being discontinuous and having a lower remote end.

(Bergman et al., 2010) this paper introduces REAR SWING ARM SUSPENSION FOR AN ATV. This paper concluded with a rear suspension system operably coupled to the axle and chassis of ATV. The swingarm's first end coupled to a rear axle coupled to the rear wheel, the second Swingarm end extends frontward beyond a vertical centerline bisecting the vehicle.

(Tohoda et al., 2012) this paper is patent of Motorcycle swing arm . In this paper the author published the design for a motorcycle swing arm.

(Stewart, 2015) The study focused on application of dampers in motorcycle rear swing arm suspension . His research is to explore the possible outcomes of using MR damping devices in motorcycle applications. For this research he decided to analyze a rear swing arm suspension system . It is concluded that dampers provides excellent long-term stability.

(Dixit et al., 2016) This research shows use of CATIA V5 for detail engineering of 3D models . From the optimization of swing arm the study was about the vibration response of the rear suspension swingarm of motorcycle. Model frequency and failure area of suspension arm were calculated from Ansys. The result clarifies by using case hardening method we can increase the strength and life of suspension arm.

(Negi & Kumar, 2017) The paper assessed about designing of All Terrain Vehicle (ATV) aka Quad-bike. In this design high safety and low production cost were accomplished. For developing of the cad model SOLIDWORKS was used and analysis was carried out by using the ANSYS software.

(Rankhambe & Kumar Nhaichaniya, 2017) The study was done on topology optimization of motorcycle swing arm by using CATIA software. The inner side and the middle part of the swingarm was analyzed. The results shows that inner side Swingarm will experience more force than outer one. Considering total mass on vehicle and average mass of person The resulting reduction in weight achieved 50%.

(Hassaan Abdullah et al., 2018) This study shows how to utilize the shape optimization method to further optimize the Moto GP Honda RC213V swingarm. Optimization was done based on the multi-axial loads and the analysis was done on the swingarm's CAD model. It has been observed that a 15% of mass reduction has been achieved without compromising the fos.

(Patil et al., 2019) The study is about the design and analysis of single-sided swingarm for the modified bike .The bike requirement is to support it with single sided swing arm .The analysis carried out in ANSYS software . Reduction of weight is observed. As in Ansys validation stress value is also low. So concluded that design swing arm can give good performance in actual working condition.

(Swathikrishnan et al., 2019) The study proves by using Autodesk Fusion 360 the design and analysis of swingarm for performance electric motorcycle. Analysis done by existing design CAD model. The resulting design has advantage of reducing weight up to 24%.

III. Rationale and Scope of Study

The optimization of design of a component can be done in many ways to improve the performance of the part. We will generally design a new swing arm or uses the topological optimization technique to optimize the swingarm. The topological optimization technique aims to optimize any single parameter such as weight, stiffness etc., and doesn't care about the manufacturing limits and assembly packing limitations. The design generated by this technique may be over safe. Thus this method of optimization needs human efforts to reconsider the design or compromise the design to some limits. By using generative design, we can design a swingarm that is well optimized without any manufacturing and assembly packing limitations.

The weight of a wheel assembly in a vehicle plays a crucial role in the handling and performance. As the un-sprung mass brings volatility in the ride and handling of a vehicle, reducing the un-sprung mass becomes the main factor to improve the performance of the vehicle. So, the key method in doing is by designing a lightweight swingarm to attain light-weight wheel assembly. A conventional design approach is very tedious and many times leads to dead end. The generative design approach gives us an iterative design approach by creating forms or shapes with a specific amount of material only where required, and we can achieve the best structural stiffness without wasting any material.

IV. Methodology

The CAD model of the swingarm is attained by using the Autodesk fusion 360's GENERATIVE DESIGN tool. It is an AI-guided feature in which a computer algorithm experiments with an initial design and then modifies it repeatedly to see whether the modified version fits the desired outcome parameters. The necessary boundary conditions and material will be imposed on the design. After millions of attempts, it eventually produces a certain number of solutions. The weight reduction will be done by meeting the required targets. We will choose an optimized design satisfying all the strength, vibration, stiffness and life-cycle performance targets.

Further, the design will undergo static structural analysis, in which we can validate the swingarm design under the loads that are acted on it. The complete approach is given in ***Figure 3*** below.

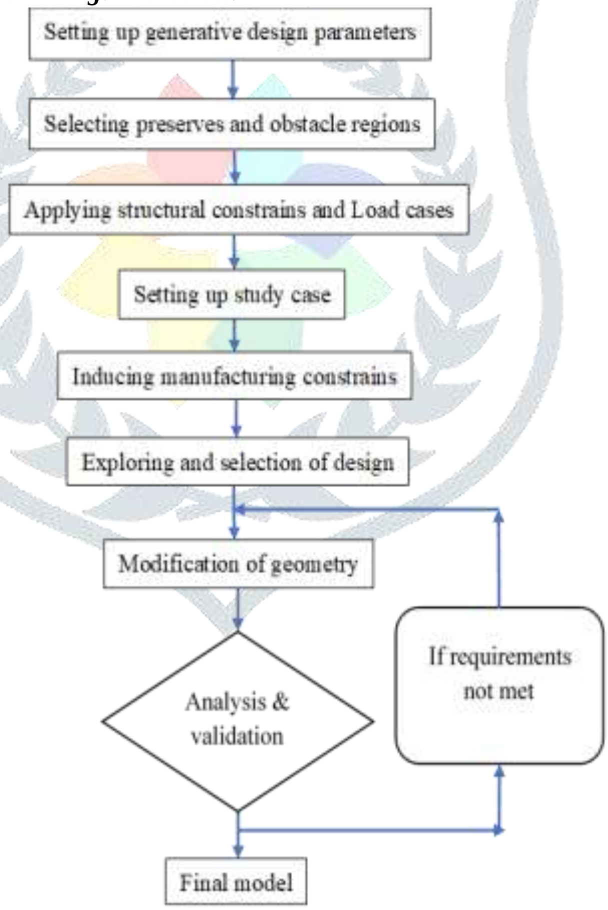

Figure 3. Flow Chart of Methodology followed.

V. Calculations

We have to calculate the forces that are acting on the swingarm under different conditions. The generative design needs to know what are the forces that are acting on the model. The tool generates the design that can sustain the loads.

5.1 Vehicle drop :

In the drop test, the vehicle will be dropped from a height of 6 ft (1.82 m) to test whether the vehicle and its components can sustain the impact force. Mass of the vehicle (without driver) is 170 kg & weight distribution ratio from front to rear is taken as 2:3. Therefore, mass of rear portion of the vehicle is 102 kgs. In the rear portion of the mass 30% of the mass accounts for the upsprung mass such as swingarm, brake caliper, brake disc, shaft & tires etc. so the total mass acting on the swingarm is approximately 72 kgs.

From the work- energy principle, average impact force = (change in kinetic energy)/(distance travelled)

f = KE/d = mgh/d

Where,

m = mass

g = gravitational acceleration

h = height

d = distance travelled after the impact

The impact force transferred to the swingarm through the suspension which is making an angle of 53°. So are force can be resolved into vertical and horizontal forces. Therefore, the forces acting on the swingarm during vehicle drop at the suspension mounts are

Vertical force = f_v = fsin(53)

Horizontal force = f_h = fcos(53)

5.2 Braking :

Mass of the driver is 80 kgs & we know that mass of the vehicle is 170 kgs. So total mass would be 250 kgs. Let's assume that, vehicle moving at a speed of 60 kmph and the stopping distance has taken as 5 meters.

= 60/3.6 = 16.66 m/s

Kinetic energy of the vehicle KE = 1/2 mv^2

Where,

v = Velocity of the vehicle

m = mass

We know that, Energy = force × stopping distance

Braking Force = Energy/stopping distance

VI. RESEARCH AND EXPERIMENTAL WORK DONE

As generative design doesn't require the entire CAD model, having an basic idea of the swingarm helps us to decide the preserved regions as seen in ***Figure 4***. We have taken a swingarm design from a ATV and the forces are calculated according to the mass of the vehicle. The structural loads and constraints were imposed along with manufacturing limitations to finally get various results where one of them will be selected.

6.1 Generative design Parameters

The first step after creating the CAD model of preserved regions and obstacles is to setup study resolution under the study settings. We have to set the resolution weather it has to be coarse or fine. Since our design needs material build up in concentrated and small places between obstacles and preserves so, we set the resolution to very fine as seen in ***Figure 5***.

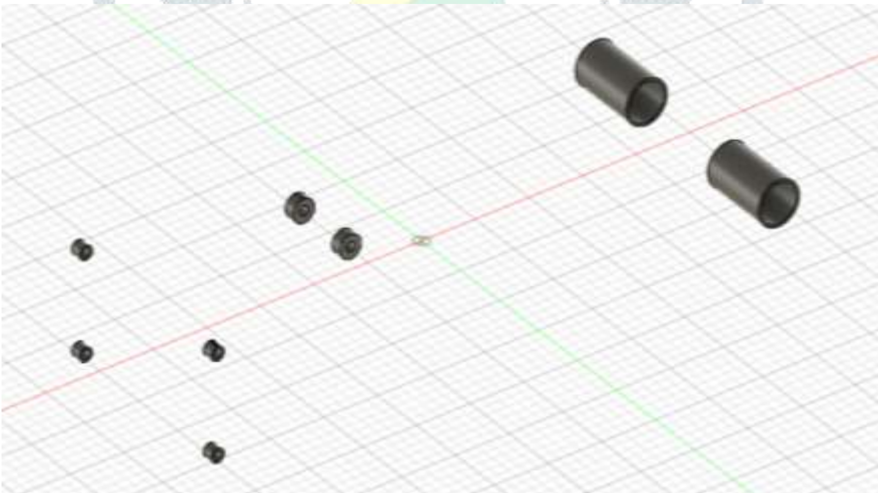

Figure 4. Identified preserved regions from the basic design.

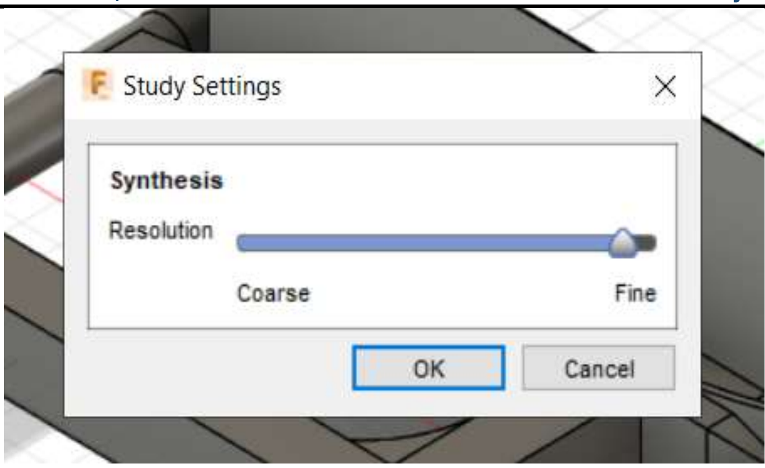

Figure 5. Study resolution.

The next step is to select the materials which we are taken into our considerations for the design. We had selected aluminium and steel alloys which are Mild steel, Aluminium, AL6061 and AL7075.

6.2 Selecting preserves and obstacles

After giving the material constraints we have to select the preserves and obstacle geometries. The preserves are the geometries at which the material build- up will be done and it will be included in the final result. The basic design of the preserved geometry includes swingarm mounts, suspension mounts and bearing casing mounts. When we selects these preserved geometries they will turn into green colour as shown in ***Figure 6***.

The next step is to select the obstacle geometry. We will choose the regions at which the material build up will be avoided in the generation of the design. The material build up can happen around these obstacle geometries so we have to select the obstacle geometries very carefully. The generative design tool provides the connector obstacle in the edit model module where, the bolts and bolt heads with tool access space are taken into consideration during the material build up. The obstacle regions of our swingarm design has been identified as the bearing casing, swingarm connector regions, suspension connector regions and chain rotating area where the chain connected with driver and driven sprocket. After selecting the obstacle geometry we can see the selected geometries will turn into red as shown in the ***Figure 6***.

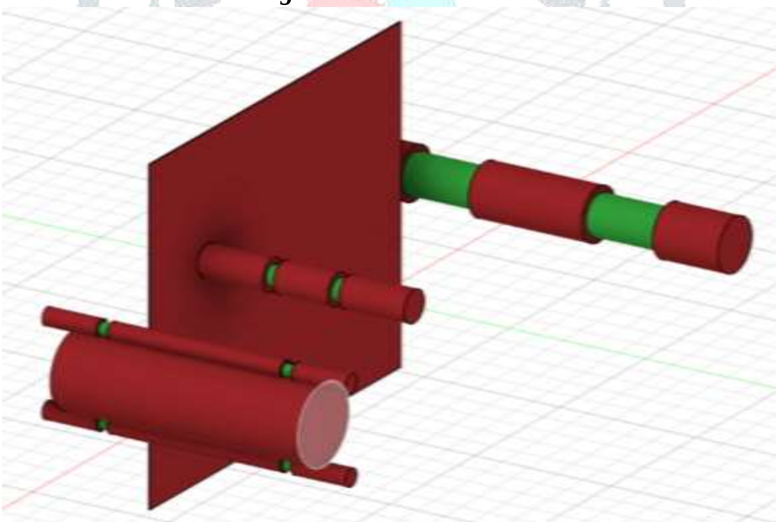

Figure 6. Preserved and obstacle regions of the geometry.

6.3 Design conditions

*Structural constraints : I*t is required to select the correct constraints in both optimization and analysis to get the good outcome. In this case, the swingarm mounts are considered as fixed geometries and hence they are fixed in all axis.

Structural loads : While coming to imposing the loads in generative design, the gravity comes as a default load. If one can want not to consider the gravity load, in the module they can deselect the gravity load. In our case, the gravity load is considered and the vertical load coming from the suspension was applied. The braking force will be transferred to the swing arm through the bearing casing mounts. So, the braking force is applied to the bearing casing mounts in horizontal direction. The loads in **Table 1** are imposed on the design as shown in **Figure 7**.

Table 1. calculated loads that are considered in the study.

Forces	Value
Vertical force on suspension mount	10.27 kN
Horizontal force on suspension mount	7.74 kN
Braking force	6.9 kN
Bump force	5.0 kN

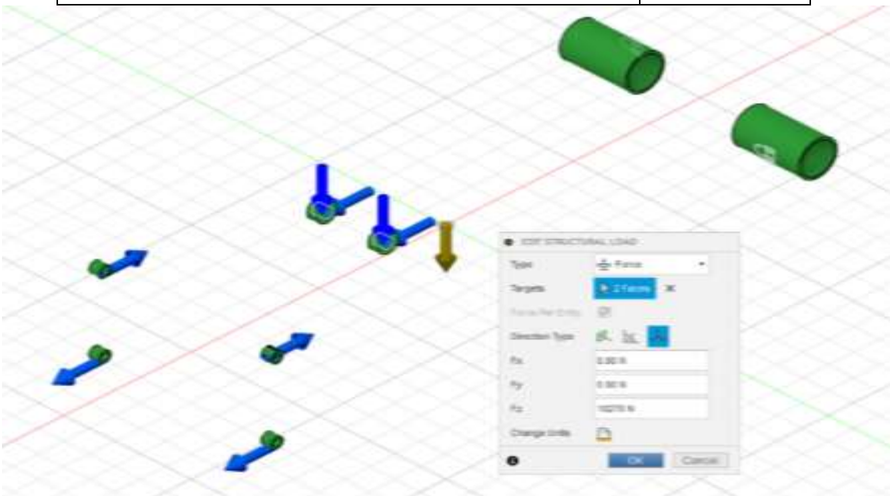

Figure 7. Imposing loads on the geometries.

6.4 Design criteria

Objectives : In the objectives module we can get to choose between two options, weather you want the generative design to obtain the design with maximum stiffness or minimum mass. As our main objective is to minimize the upsprung mass so we had chosen the minimize mass option with a minimum factory of safety limit of 1.5 as shown in ***Figure 8***. With the help of this selection of minimum fos limit we can get considerable structural strength and not over safe design.

Figure 8. Setting up objectives.

Manufacturing : In manufacturing method section we had chosen unrestrictive manufacturing method where the results will be obtained without manufacturing restrictions. We also selected 5- axis milling and additive manufacturing methods. This allows the generative design tool to produce more number of results. At the end we can choose our design and can make changes to it.

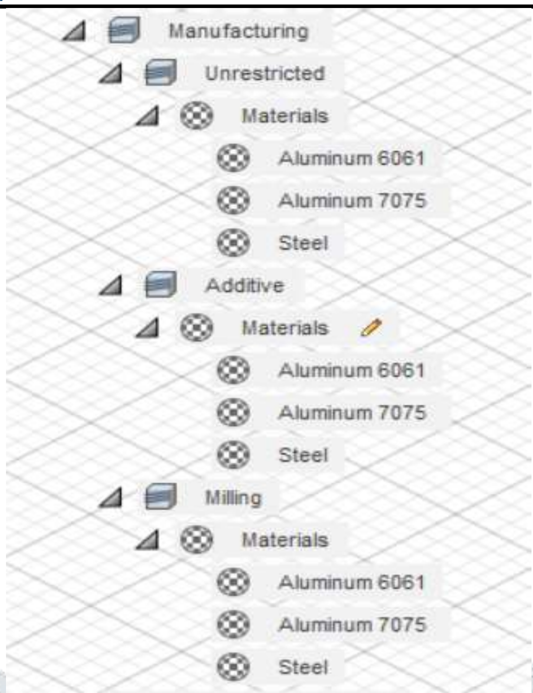

Figure 9. Setting up manufacturing constraints.

VII. RESULTS & DISCUSSION

After setting up the study, we can get to see the basic model with the help of pre-check option. If the desired shape of the preview hasn't come then we have to change some geometry and we have to give proper preserves and obstacles. If the preview was in our favour then we can proceed to click the generate option. The generative design runs on cloud and we need 25 cloud credits to run the analysis. After running the analysis we got 32 results which are based on different materials and manufacturing methods given below.

Table 2. No. of solutions based on manufacturing.

Manufacturing method	No. of solutions
Unrestricted	6
Additive	18
5- axis milling	8
Total no. of solutions	32

Table 3. No. of solutions based on material.

Material type	No. of solutions
AL6061	9
AL7075	10
Aluminium	9
Mild steel	4
Total no. of solutions	32

After getting the results by comparing the fos, mass, material and manufacturing methods, we had selected the best 4 designs out of 32 results which are shown in ***Figure 10***.

Figure 10. Final four selected outcomes.

Table 4. Properties of the final four selected outcomes.

Outcome	Material	Manufacturing process	Mass (kg)	Fos
Outcome- 05	AL7075	Additive manufacturing	4.474	1.5
Outcome- 03	Mild steel	5- axis milling	7.559	1.5
Outcome- 01	Aluminium	5- axis milling	2.594	1.5
Outcome- 07	Al 6061	5- axis milling	1.375	1.5

The results which are having unrestrictive and additive manufacturing constraints are being excluded due to the cost parameter. Finally, outcome- 07 was finalized as it was having the least mass i.e., 1.375 kg. The mesh design was exported from the outcome- 07 and some operations were performed like cleaning up rough edges, smoothing the sharp edges and few changes were done to allow the Ansys software to create mesh in some concentrated areas.

Figure 11. Isometric view of the exported mesh file.

7.1 Meshing

The finalized design was exported to STEP file and further it was imported to Ansys workbench for the verification. AL6061 material and fine mesh settings was imposed to the design to obtain good results. As the material build up done in very concentrated areas we had opted to go for very fine meshing which can give us the maximum and minimum parameters in a detailed way.

Table 5. Mesh data.

S.No	Particulars	Value
1.	Size	2 mm
2.	Nodes	432386
3.	Elements	274656
4.	Analysis system	Static structural

Figure 12. Isometric view of final meshed swingarm.

7.2 Structural analysis

We are performing the static structural analysis on the component to check the von mises stress and factor of safety. The forces which are imposed in the generative design module were applied in the Ansys analysis settings. We have to perform the analysis under three different conditions.

Vehicle drop : The swingarm mounts and bearing casing mounts are fixed and loads were applied to the suspension mounts as per the calculations.

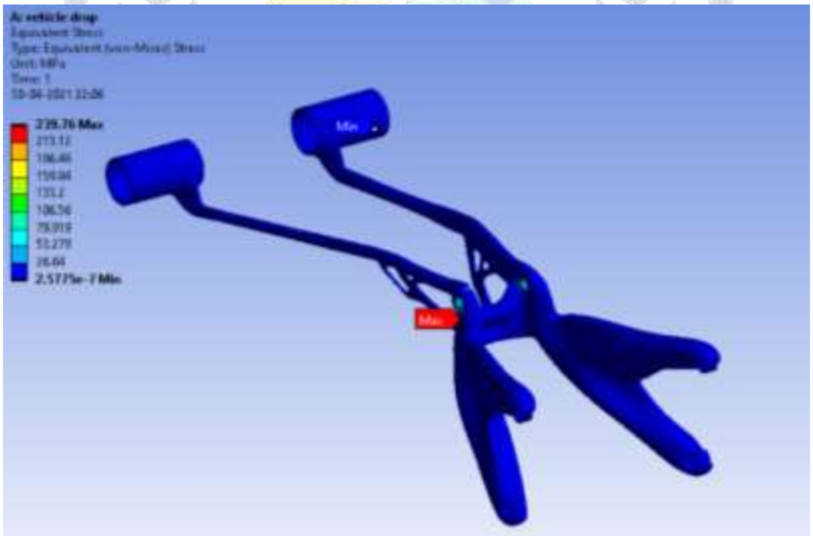

Figure 13. Maximum equivalent stress during vehicle drop.

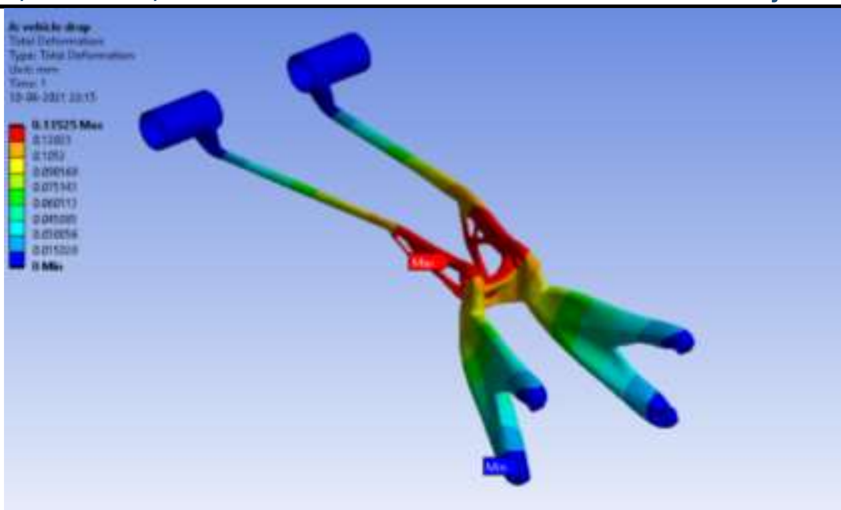

Figure 14. Total deformation during vehicle drop.

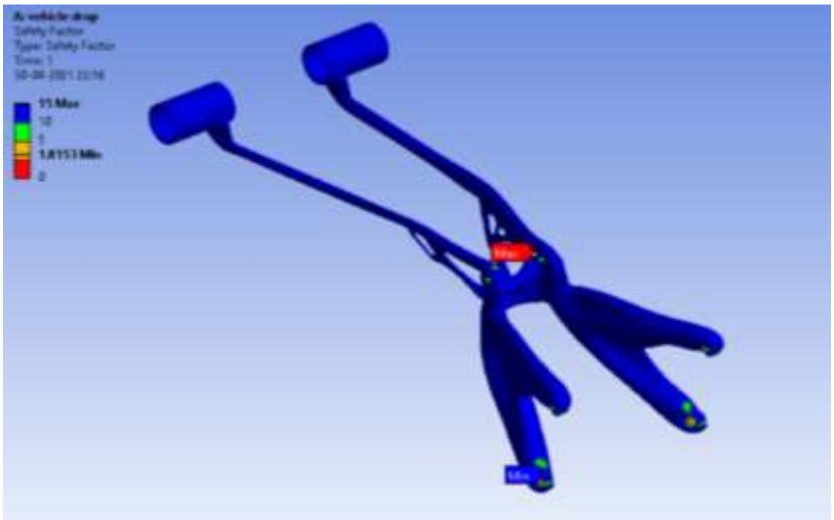

Figure 15. Factor of safety during vehicle drop.

Table 6. vehicle drop results.

Parameter	Value
Factor of safety	1.81
Maximum total deformation	0.13 mm
Maximum equivalent stress	239.76 MPa

Braking : The swingarm mounts ae fixed and loads were applied to the bearing casing mounts because, bearing casing hoses the brake calliper and the loads are transferred to the mountings.

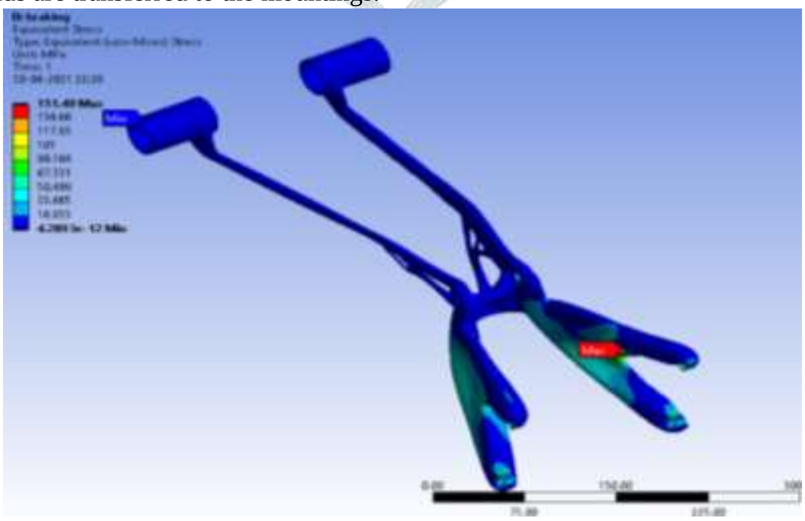

Figure 16. Maximum equivalent stress during braking.

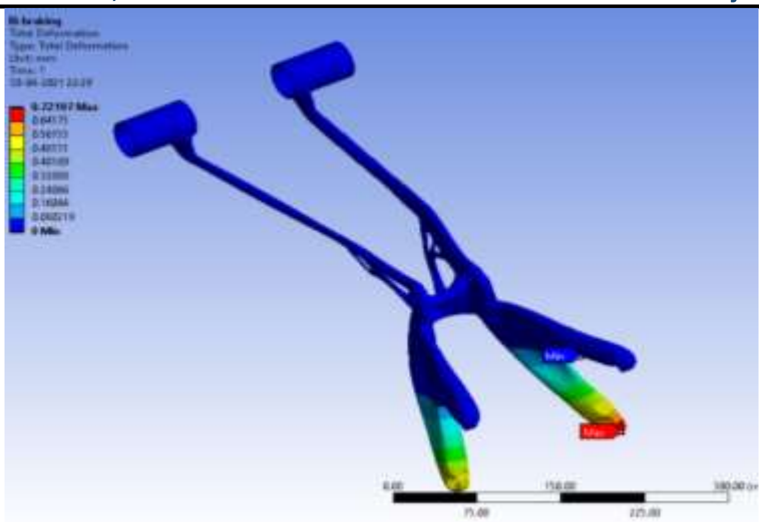

Figure 17. Total deformation during braking.

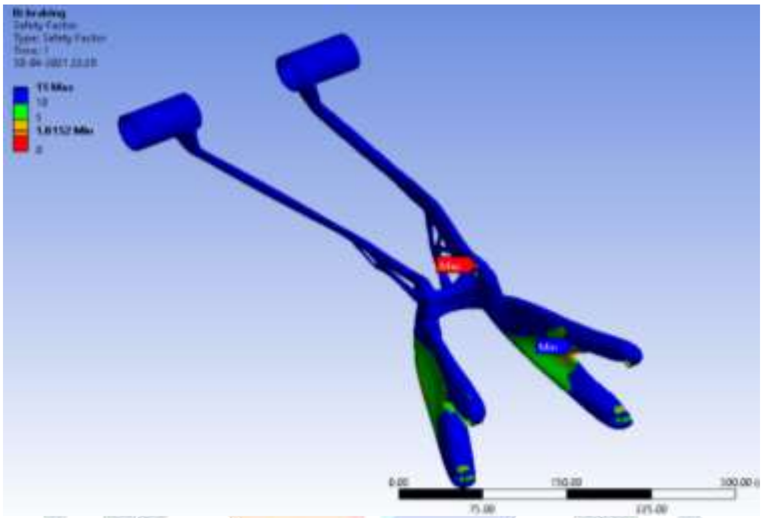

Figure 18. Factor of safety during braking.

Table 7. Braking results.

Parameter	Value
Factor of safety	1.81
Maximum total deformation	0.72 mm
Maximum equivalent stress	151.49 MPa

Vehicle hitting a bump : Due to the symmetry of the swingarm we are considering the vehicle hits the bump on one side. So, the swingarm experiences twisting forces and the impact force was applied to one side of the bearing casing mounts in vertical direction and on the other side same force is applied in the opposite direction. Suspension mounts and swingarm mounts are fixed.

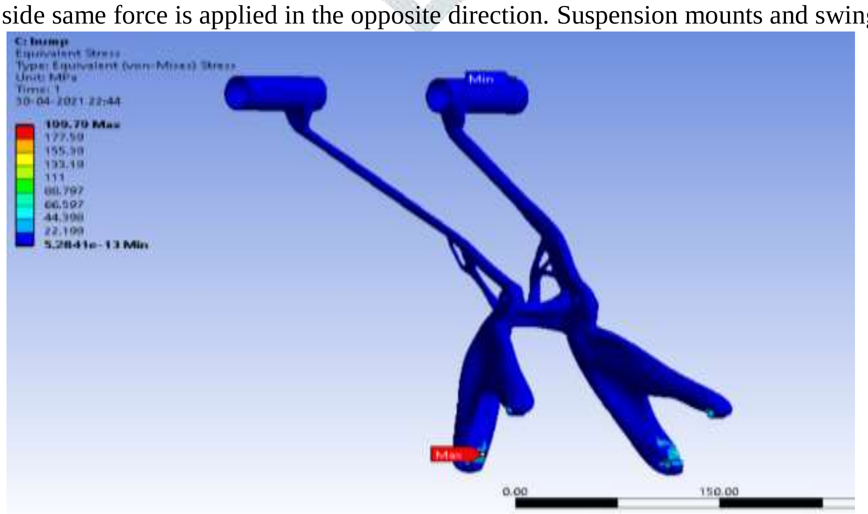

Figure 19. Maximum equivalent stress during bump.

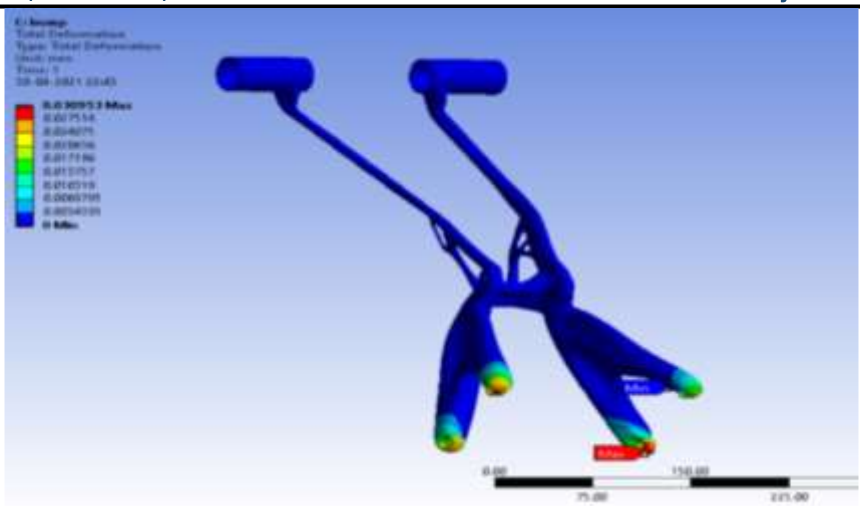

Figure 20. Total deformation during bump.

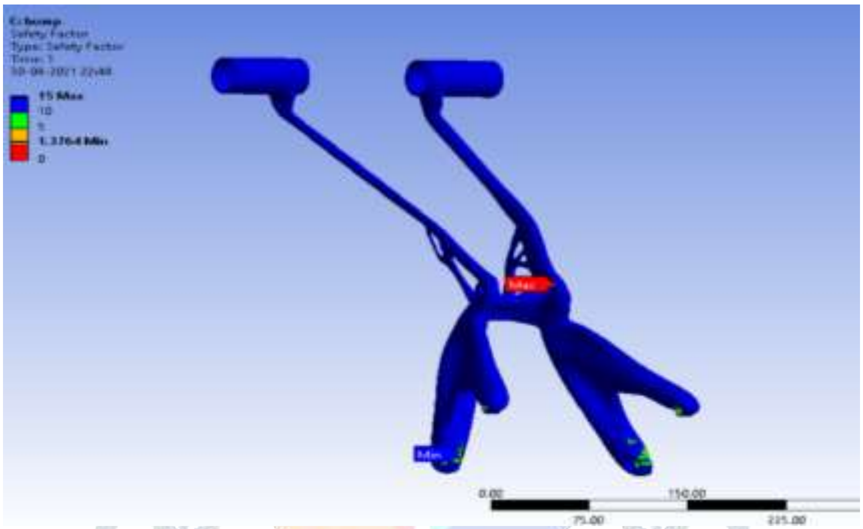

Figure 21. Factor of safety during bump.

Table 8. Bump results.

Parameter	Value
Factor of safety	1.37
Maximum total deformation	0.03 mm
Maximum equivalent stress	199.79 MPa

VIII. CONCLUSION

Reducing mass of the components is much more needed factor in the motorsports world. In conventional design approach to optimize a component we have to design and perform analysis and again redesign to make changes and again we will perform the analysis. We keep doing this process until we get the best result and it consumes much more time. Also there are other optimization techniques like topology optimization but at the end it needs human efforts to reconsider the design or compromise with the design. The generative design optimization techniques based on iterative process which saves both human efforts and time. It is based on artificial intelligence which builds the basic model within the given constrains and reduces the material build up at unwanted regions and it keeps on doing many iterations until we get the good result. With the help of generative design we can build models that are not over safe and structurally rigid. It also takes care of material and manufacturing process. With the help of Autodesk generative design tool we had reduced the mass of the swingarm of ATV from 2.68 kg to 1.37 kg which is about 49% of mass reduction. For the swingarm, AL6061 and 5- axis milling were selected as the material and manufacturing method respectively.

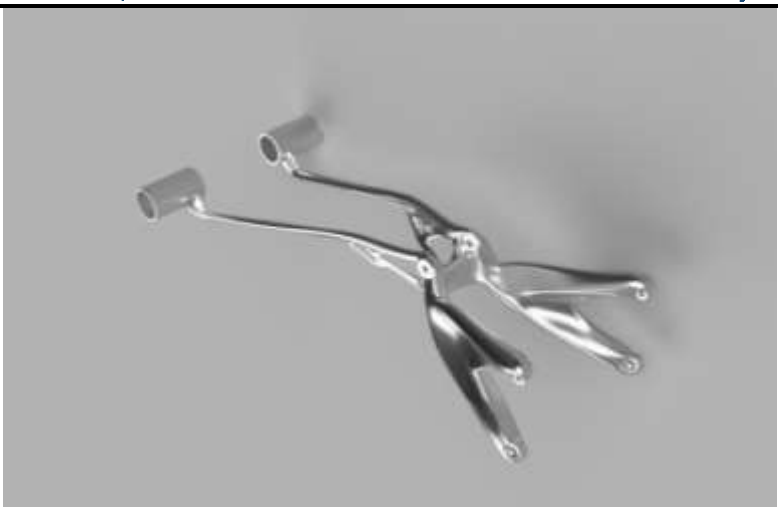

Figure 22. Final rendered cad model of swingarm.

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CONFLICT OF INTEREST

The Authors declare that there is no conflict of interest.

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