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DESIGN AND MULTIBODY ANALYSIS OF H-ARM WITH SINGLE UPPER LATERAL LINK SUSPENSION SYSTEM OF AN ALL TERRAIN VEHICLE

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Abstract - *This research article presents a comprehensive analysis of the single upper lateral linked H-Arm suspension system of a vehicle conducted through a series of performance evaluations and simulations. The research mainly focuses on conceptualizing, designing and performing Multibody Analysis of the rear suspension system primarily focusing on H-Arms of a vehicle to prove that it is a viable option. The work also puts an emphasis on meshing parameters and static and dynamic loading conditions to precisely analyze and design the H-Arms. The multibody simulation was performed to study how the suspension system would behave in practice and in coherence with other components.*

Key Words: **All Terrain Vehicle, Rear Suspension, Design, Lateral Link, Multibody Analysis, H-Arm, Suspension Testing, Endurance Race**

1. INTRODUCTION

Suspension is defined as one of the important vehicle subsystems that essentially takes care of the forces and vibrations which causes significant wear and damage to the vehicle by damping it before they can be transmitted to the vehicle chassis frame. The suspension control arms or links connects a vehicle's chassis to its wheels which allows wheel movement independent of the body. [1]

This research article mainly focuses on the rear suspension design of an All Terrain Vehicle (ATV) with the objective that the vehicle should be able to traverse across the rough terrain and should not fail throughout its lifecycle. Additionally, the aim was to enhance the ATV's overall safety. Amongst the various rear suspension geometries, the H-Arm was mainly chosen due to its simplicity and control that it provides over the various suspension angles which is further discussed and considered during designing of the components.

Moreover, testing of the design was done to validate the FEA (Finite Element Analysis) results of the suspension assembly. These testing results provided us with real world insights that complemented the simulation and final fabricated designs.

1.1 Selection criteria for Rear Suspension Geometry

For selection of the suspension system geometry, these considerations were kept in mind:

- Packaging
- Unsprung weight
- Control over the suspension angles
- Manufacturing ease
- Cost

Based on these considerations, H-Arm with Single Upper Lateral Link was selected as it provided the following benefits-

- Elimination of rear toe variation as the H-Arm provides support from two ends and ensures no rotation of the Upright about z-axis. [2]
- Ability to support higher lateral forces generated by tyres with the help of lateral link.
- Better anti-squat properties.
- Camber angles can be adjusted by controlling the various link lengths. (Camber is the angle made by the vertical axis of the wheel with the vertical axis of the ATV when viewed from the front or rear of the vehicle. [3])

Figure 1 shows complete rear suspension assembly modeled on SOLIDWORKS 2022.

Fig -1: H-Arm Suspension System with Single Upper Lateral Link

1.2 Hardpoints

Hardpoints acts as pivot points for relative movement between suspension components and vehicle. These points are points on vehicle chassis where suspension connects to the vehicle frame. [4]

Table 1 shows considerations for the vehicle parameters to plot hardpoints in LOTUS SUSPENSION ANALYSIS v4.03.

Table -1: Vehicle considerations

Dimension	**Front**	**Rear**
Wheelbase (in mm)	1325	
Track Width (in mm)	1220	1180
Height of Centre of gravity (H) (in mm)	610	
Kerb Weight (in kg)	190	
Mass with 60 kg driver seated (in kg)	82.5 (33%)	167.5 (67%)
Sprung / Unsprung Mass (in kg)	57.2/25.3	132.5/35

Understanding hardpoints helps in designing vehicles that have improved performance as during acceleration, cornering and braking, the weight distribution within the vehicle dynamically shifts. The placement of hardpoints influences the weight transfer between the front and rear axles and also between the sides of the vehicle. Based on considerations for the accommodation of powertrain components and driver height, the wheelbase and track width of the ATV was set to achieve required turning radius. Further, based on the estimated weight, the hardpoints were designed keeping in mind the wheel travel over bumps and droops.

Due to the selection of H-Arm geometry, the toe variation was already eliminated. The Hardpoints were optimized to keep minimum variation in the camber angles to ensure proper grip is maintained throughout the wheel travel while the vehicle goes over a bump or droop. The target to keep the camber variation over wheel travel was set to be between -1 degree to +1 degree which was achieved and is shown in Chart 1 taken from LOTUS SUSPENSION ANALYSIS v4.03. [5,6]

Figure 2 illustrates the visual representation of H-Arm suspension geometry modeled in LOTUS SUSPENSION ANALYSIS v4.03.

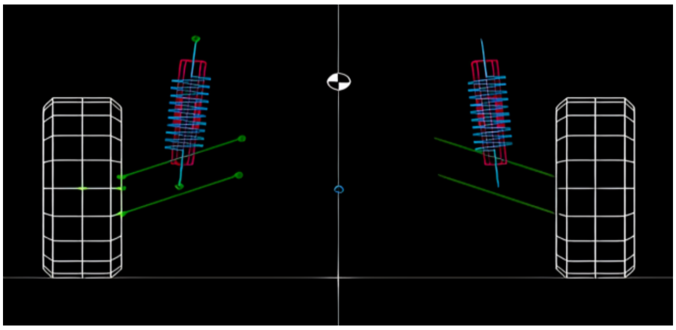

Fig -2: Rear Hardpoints Model

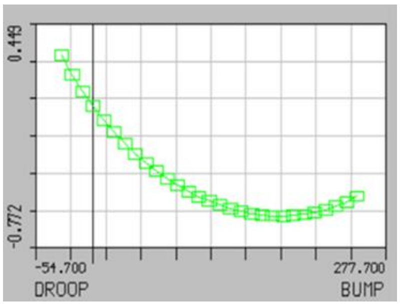

Chart -1: Camber variation over wheel travel

1.3 Force Calculations

To perform static and dynamic analysis of the components, we have to take into account the various forces resulting from the vehicle conditions over the rough terrain of the ATV. These conditions include braking, turning around a corner, navigating bumps and trenches. [7]

These forces arising from different conditions have been used as constraints in the FEA analysis software (ANSYS WORKBENCH 2022) to simulate adverse conditions that the vehicle will have to endure.
The static analysis of the components performed with assumptions that will replicate the terrain conditions are as follows:

a. Normal Force
b. Bump Force
c. Cornering Force
d. Braking Force

a) Normal Force (Force due to self-weight):

The Normal force acting on the vehicle is the counterforce to the weight of the vehicle acting in the upward direction.

$F_n = m*g$
$F_n = 250kg * 9.8\ m/s^2$ ... (with weight of driver)
$F_n = 2450\ N$

b) Bump Force:

Forces that act on the ATV as it encounters bumps and droops on the track are considered under bump force. When the ATV encounters a bump, the bump force is absorbed by the coil springs as it compresses and the same magnitude of force is given back during its expansion.

Stiffness of Coil Spring (k) = 60.6 N/mm
Maximum compression of spring (x) = 80 mm
Coil spring makes an angle of 85˚ with the horizontal axis of the wheel.

Force applied by Coil Spring (f) =
Stiffness (k) * Maximum compression (x)
f = 60.6*80
f = 4848 N
Vertical component of above force (f_v)= f*sin (85˚)
f_v = 4829.55 N

Figure 3 shows representation of distances (in meters) L1 and L2 that have been calculated using coordinates of points obtained from LOTUS SUSPENSION ANALYSIS v4.03.

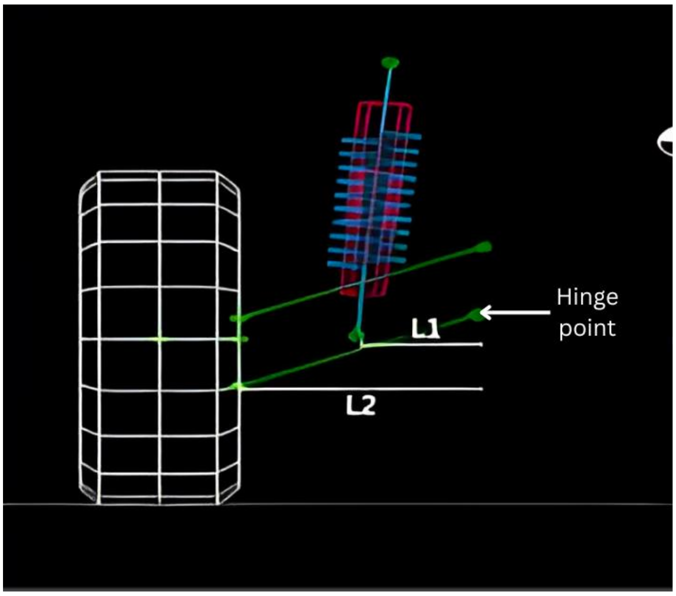

Fig -3: Respective distances from spring and outer pivot

Torque applied about hinge = Force applied by Coil Spring * L1
τ = 4829.55 * 0.146 N-m
τ = 705.114 N-m

Bump force on Upright (F_b)= Torque applied about hinge / L2

F_b = 705.114 /0.270 N
F_b = 2611.53 N
To take into account unknown forces acted during events of rollover or impact loading, bump force is considered as three times the weight of the vehicle.

c) Cornering Force:

While turning around a corner, the ATV is acted on by centrifugal force and because of it the weight of the vehicle is shifted to the outer wheels. This is known as cornering force. Cornering force determines the maximum lateral grip a vehicle can achieve before losing traction. Higher cornering forces generally indicate better traction, allowing the vehicle to maintain control during cornering maneuvers.

For the calculation of forces, we have only considered total mass on rear wheels (refer Table 1) to get accurate force values.

Total mass on Rear Wheels (m_r) = 167.5 kg
Max velocity of vehicle (v) = 50 km/hr (Assumed)
= 13.9 m/s

F_c = ½*m_r* v^2
F_c = ½*167.5* 13.9
F_c = 1164.125 N

d) Braking Force:

During deceleration of the vehicle, the weight of the vehicle is shifted on the front axle. Force acting due to this weight transfer is known as braking force. Braking force affects the distribution of weight and load transfer between the tyres during deceleration. Due to the weight transfer to the front axle, the grip in the front tyres increases and reduces the traction on the rear tyres. It may cause potential instability if the braking force exceeds the available traction on the tyres.

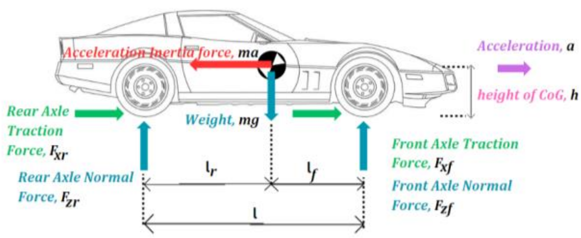

Fig -4: Vehicle under Braking

Total mass on Rear Wheels (m_r) = 167.5 kg
Braking distance (s) = 7 m
L_r = 525 mm

L_f = 800 mm
Height of Centre of gravity (H) = 610 mm
Wheelbase (L) = 1325 mm
Maximum velocity of vehicle (u) = 50 km/h = 13.9 m/s

$v^2 = u^2 + 2as$
$0 = (13.9)^2 + 2*a*7$
$a = 13.8\ m/s^2$ (deceleration)

Load transfer on the rear wheels,
$F_{br} = W_r + m_r*a*(H/L)$

$F_{br} = 1225 + 167.5*13.8*(610/1325)$

$F_{br} = 2289.16$ N

Forces obtained from the previously discussed calculations are used in Static and Multibody Analysis.

During Static and Multibody Analysis, we consider entire weight of vehicle on one wheel. This is because of the rare case where the vehicle may be airborne over very tall bumps that can result in the ATV landing on a single wheel. This results in the full weight of the ATV being placed on the suspension assembly of the corresponding wheel.

1.4 Design of H-Arms

Hardpoints have been established using LOTUS SUSPENSION ANALYSIS v4.03 software. CAD modeling for all suspension components was done on SOLIDWORKS 2022. Design of the H-Arms was done around these sets of points which are fixed according to the geometry of the vehicle. These hardpoints influence the dynamics of the vehicle which allow for good traction, cornering and overall vehicle performance. Figure 5 shows plotting of hardpoints in SOLIDWORKS 2022.

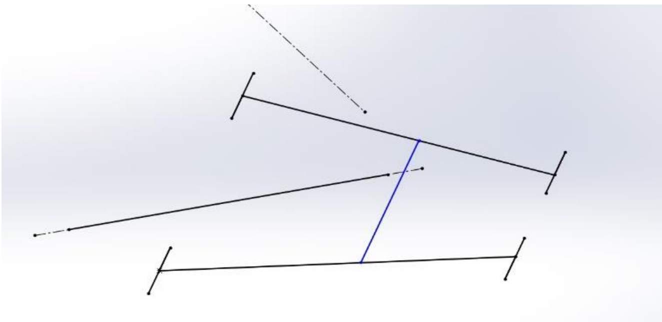

Fig -5: Hardpoints plotted in SOLIDWORKS 2022

Further, necessary lines were sketched and geometry was created around them. Geometry was then extruded around the sketch using the Weldments feature in SOLIDWORKS 2022 as shown in Figure 6, thus giving us the required CAD model.

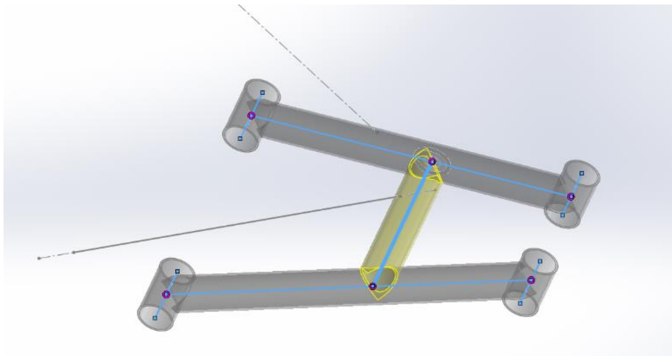

Fig -6: Weldments in SOLIDWORKS 2022

The H-Arm has been designed using hollow tubes of AISI 4130. Circular members of AISI 4130 were selected as they have excellent bending strength and stiffness.
Figures 7 and 8 have been taken from ANSYS WORKBENCH 2022.

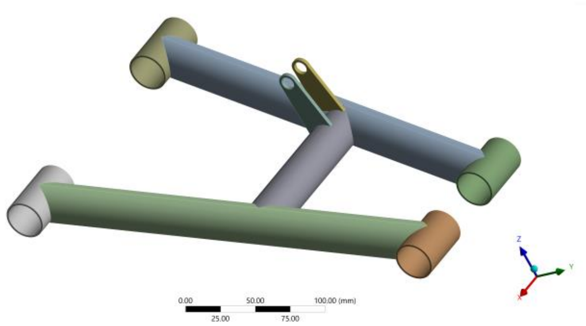

Fig -7: H-Arm Frame

The mountings of H-Arms were press fitted with polyurethane bushings to dampen vibrations. Mild steel inserts have been used to fit rod ends to the lateral link which provide articulation and structural integrity to sustain the stresses and loads of the tough terrain. Final construction of the suspension arm is as follows-

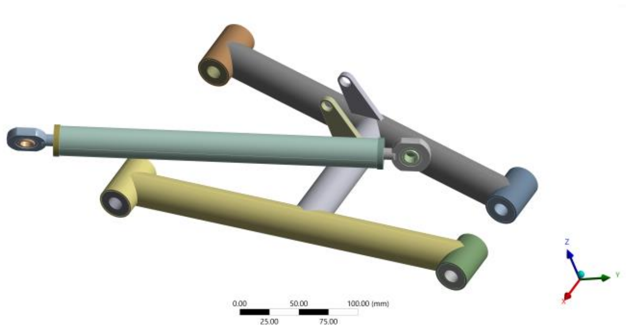

Fig -8: H-Arm with Lateral Link Assembly

1.5 Rear Wheel Hub Design

Design of the Wheel Hub was done keeping in mind all the forces previously discussed above in the force calculations and also depending on the dimensions of the assembly components, i.e. wheel rim, bearing, driveshaft and disc brake rotor. Table 2 shows design parameters of the Wheel Hub.

This design has been selected as it completes the essential purpose of the component with minimum material being required for fabrication without having to compromise on its structural integrity. The material used for manufacturing of the Wheel Hub was Al-7075-T6 because of its high strength to weight ratio.

Table -2: Wheel Hub Design Parameters

Pitch Circle Diameter (PCD) of the wheel rim	144 mm
PCD of the disc brake rotor	75 mm
Drive Shaft Outer Diameter	24 mm
Bearing Inner Diameter	35 mm

Figure 9 shows image of Wheel Hub taken from ANSYS WORKBENCH 2022.

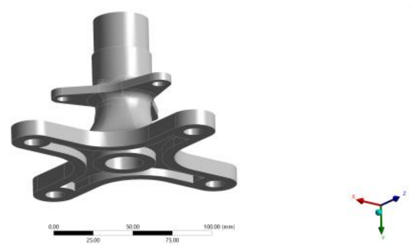

Fig -9: Wheel Hub

1.6 Upright design

The Upright is a component that connects the Wheel Hub to the suspension arms. It is designed around hardpoints of the outer end of the suspension arms. To increase the cost effectiveness of the research, Al 6061-T6 was selected for the Upright as it is not a huge compromise in strength and other important parameters. By means of analysis, the Upright was optimized from its first iteration as shown in Figure 10.

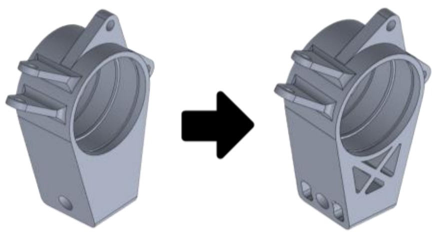

Fig -10: Upright design (designed on SOLIDWORKS 2022)

2. ANALYSIS

Our primary focus was to ensure minimum weight and maximum performance capability of the vehicle. Finite Element Analysis (FEA) is a computer-aided engineering tool that analyzes how a component design reacts under real-world conditions. It has been used in our research for conducting structural analysis. ANSYS WORKBENCH 2022 was used for all analyses in our research. It allowed us to generate analytical mathematical models and perform complex calculations to check the stresses and deformation developed in the CAD model of the component.

2.1 Rear Wheel Hub

Analysis of the Wheel Hub gives us vital information about its behavior when subjected to loading. It helps in weight reduction and thereby boosting the overall vehicle performance. After the analysis of the Wheel Hub, it was found that even after considering the weight of the whole ATV on a single wheel the minimum Factor of Safety (Factor of Safety is the ratio of the metal's load bearing capacity to the actual load it experiences) was 1.9311 as shown by the legend in Figure 11. As the value of Factor of Safety (F.O.S) is above 1, the component will withstand the loads subjected to it. [8]

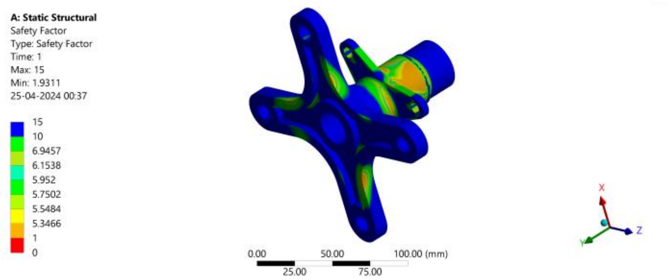

Fig -11: Factor of Safety (F.O.S) of Wheel Hub

2.2 Rear Upright

Analysis of Upright gives us critical information which helps in optimization of the component. The Upright was subjected to all the above calculated forces and resulted in Factor of Safety (F.O.S) of 3.193 as shown by Figure 12.

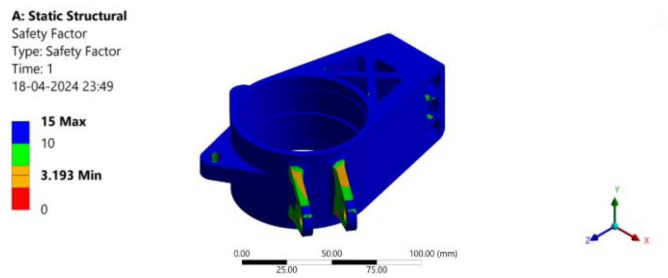

Fig -12: F.O.S of Upright

This indicates that the Upright will not undergo failure when subjected to all the above considered forces.

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2.3 H-Arm Static analysis

H-Arms are responsible for making the connection of the unsprung mass to the structural module that is assembled to the tubular chassis of the vehicle, therefore, they are the critical parts of the entire assembly since they are responsible for modifying and transmitting the forces acting on the suspension system. [9] Design of H-Arms has been performed by knowing the behavior of the suspension components with the force calculation in order to check whether the geometry of the parts is correct and whether or not they are capable of withstanding the adverse conditions of difficult and bumpy terrain. The main design criteria for H-Arms of a suspension system are to maintain integrity without undergoing permanent deformation.

Following figures show the Static Analysis results of H-Arm obtained in ANSYS WORKBENCH 2022-

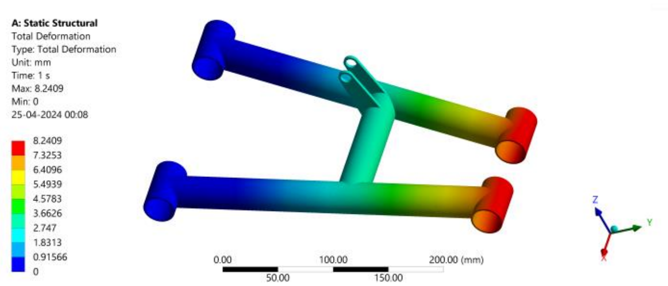

Fig -13: Total Deformation of H-Arm under static loading

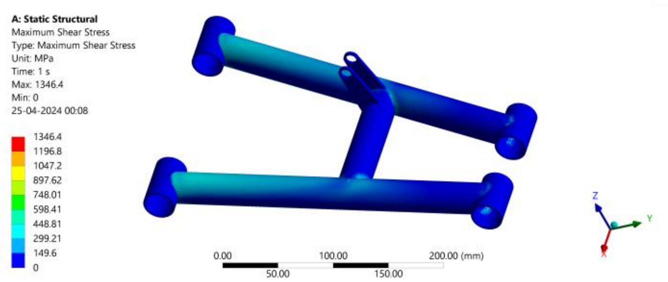

Fig -14: Maximum Shear Stress of H-Arm under static loading

Upon performing necessary analysis on ANSYS WORKBENCH 2022, we conclude that the suspension arms of the rear suspension system can sustain the bump, brake and cornering resultant of force components with an acceptable margin for Factor of Safety.

2.4 H-Arm Multibody Analysis:

A simulation of Multibody Analysis has been performed in ANSYS WORKBENCH 2022 to validate the results that we got from Finite Element Analysis by using forces obtained through static calculations and to simulate the entire assembly with time stepping to provide varying loading conditions. For Multibody Analysis, CAD model of the components in the suspension assembly have been simplified to reduce the solving time of the analysis.

For this purpose, custom CAD model of the components have been created in SOLIDWORKS 2022. [10] Minimum contacts were necessary to improve the efficiency of the mechanical solver within Ansys WORKBENCH 2022.

For this, a single lateral link, insert and rod end entity was created to eliminate those contacts as shown in Figure 15. Similarly, a bolt was integrated to the H-Arm that connects it with the Upright as shown in Figure 16.

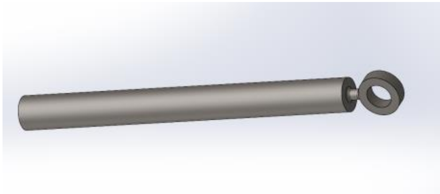

Fig -15: Custom Lateral link CAD

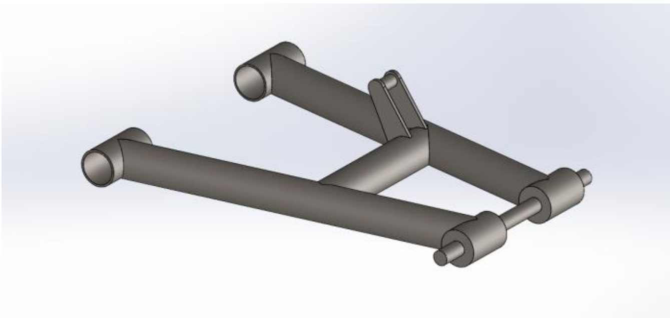

Fig -16: Custom H-Arm with integrated bolt

The number of contacts were reduced from 18 down to 2 contacts as shown in Figures 17 and 18. This greatly reduced the solving time and complexity without compromising the quality of analysis. Frictionless contact was assigned to the respective contact and target bodies to simulate smooth motion during wheel travel.

Fig -17: Link to Knuckle Connection

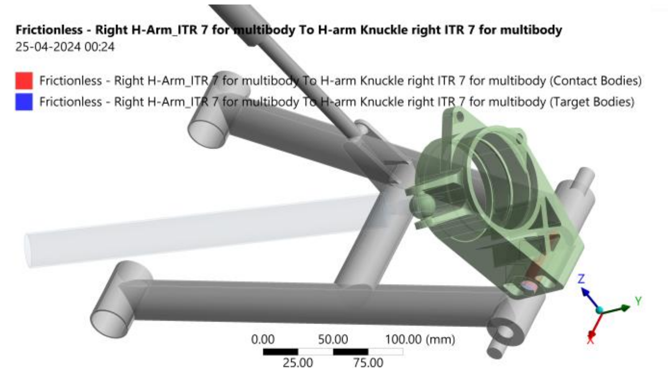

Fig -18: H-Arm to Knuckle Connection

For shock absorber, a custom spring damper model as per our specifications has been used which comes as a pre-installed package in the software (ANSYS WORKBENCH 2022) to make the simulation more accurate which is shown in Figure 18.

Meshing enhancement has been performed to improve overall mesh quality which then gives us more accurate results. This was done by applying complex mesh methods to adjust the proximity and curvature parameters that successfully captured the complex geometry of the system.

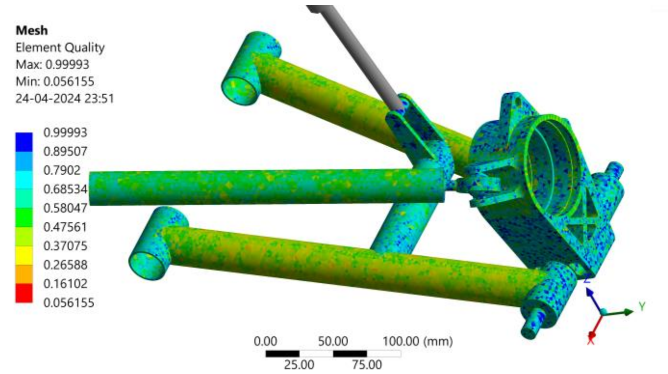

Fig -19: Mesh quality of H-Arm Assembly using default parameters

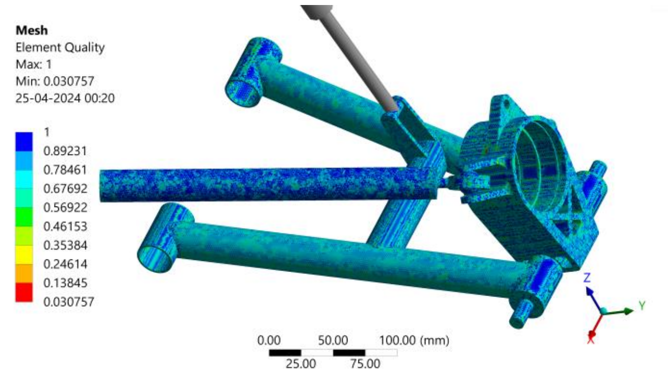

Fig -20: H-Arm Assembly Mesh quality after enhancement

Necessary constraints such as fixed support, remote displacement to simulate the rotational freedom of H-Arm about chassis mounting pivot and forces have been applied to the model.

As explained at the end of force calculations, we have taken the full weight of the ATV on a single wheel. Table 3 shows the force constraints of Multibody Analysis taken from the previously discussed force calculations.

Table -3: Force constraints of Multibody Analysis

x component	Brake	3678.8 N
y component	Cornering	2943 N
z component	Bump	7357.5 N

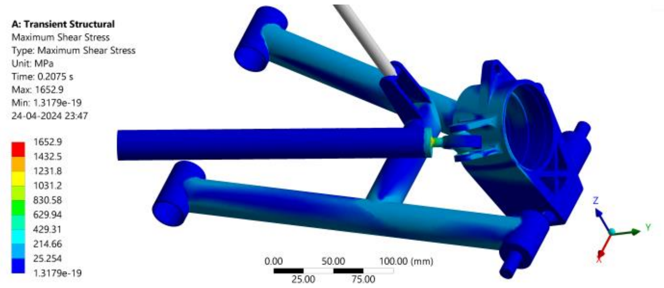

Fig -21: Maximum Shear Stress of H-Arm Assembly

Shear stress does not exceed the value of 450 MPa in the entire geometry except for the rod end connected to the Upright. This particular region highlighted by red color indicates stress concentration as a result of sharp edges in the geometry.

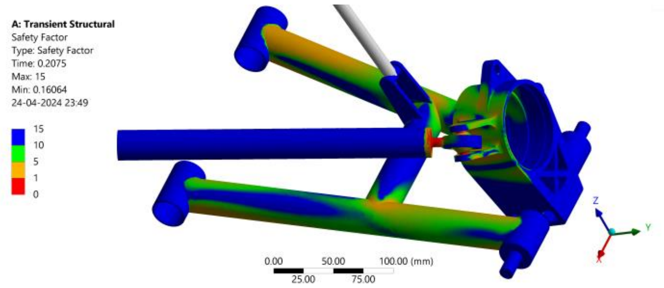

Fig -22: F.O.S of H-Arm Assembly

An average F.O.S of 2.4 was achieved in the overall H-Arm suspension system. Minimum F.O.S is achieved at the same connection point between rod end and insert, thus indicating need for more resilient rod end. Rod end selection was done considering this extreme load at the connection between itself and insert.

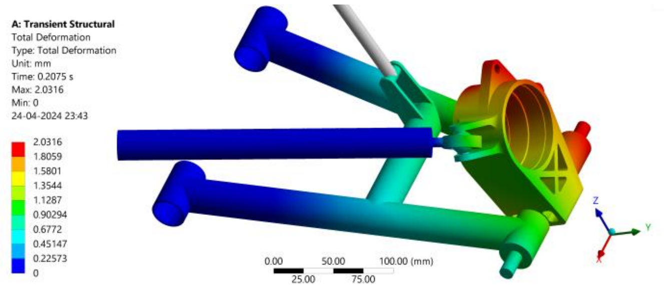

Fig -23: Total Deformation of H-Arm Assembly

Connection points between tubes of the H-Arm are joined using Tungsten Inert Gas (TIG) Welding, thus reinforcing the component's connection strength between those tubes.

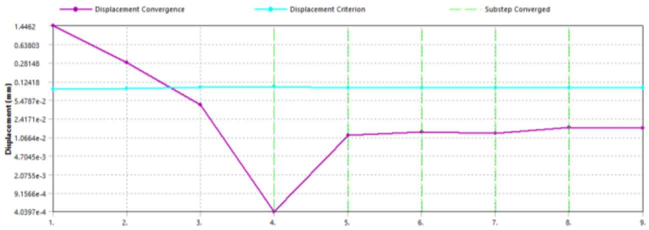

Chart -2: Displacement convergence solution

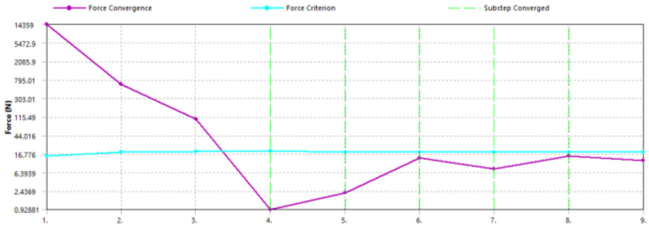

Chart -3: Force convergence solution

3. Testing and Validation:

Vehicle testing was carried out at a motorsport academy to evaluate the safety and reliability of the suspension system and check its overall performance and capability on a multi-faceted course with challenging terrain.

Photograph -1: Suspension Testing

It was found that the suspension system was able to bear the loads of the tough terrain without affecting the structural integrity of the vehicle components. Upon rollover, following points were observed-

- H-Arm: H-Arm experienced bending and twisting about chassis side mounting pivot after rigorous testing on various obstacle courses. The nature of bend of the fabricated component closely resembled the bend model demonstrated in analysis as shown in Figure 24 and Photograph 2.
- Rod end: Bending was induced in the rod end due to extreme force and torsion, which resulted in rod end failure as predicted by the analysis as shown in Figure 25 and Photograph 3.

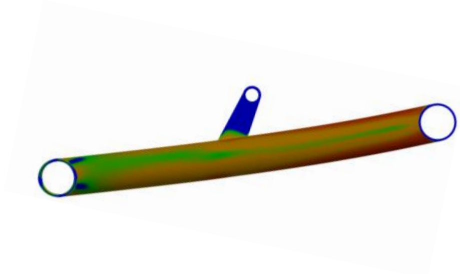

Fig -24: Virtual bending of H-Arm under extreme loading conditions

Photograph -2: Actual H-Arm bend after vehicle testing as predicted from analysis from 2.3

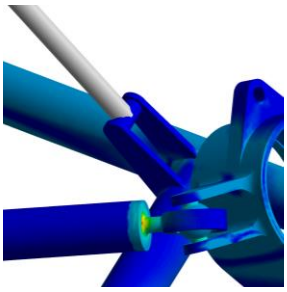

Fig -25: Virtual representation of stress concentration for Rod end (This is a zoomed-in part of Figure 21)

Photograph -3: Actual Rod end failure as predicted from analysis from 2.4

Photograph -4: Rear Suspension System before Endurance Race

Table -4: Stress results of both analyses

Component	Stress (σ) (in MPa)	
	Static Analysis	Multibody Analysis
Upright	346.12	323.69
H-Arm	448.81	429.74

Table -5: F.O.S results of both analyses

Component	Factor of Safety	
	Static Analysis	Multibody Analysis
Upright	3.193	2.753
H-Arm	3.2	2.51

The results obtained from static analysis of both components has provided us with a good sense of understanding about the structural integrity of each component and how much load can be sustained by them.

Dynamic testing of the suspension system was conducted rigorously on an obstacle course, where the vehicle traversed various terrain challenges to evaluate its performance and durability under real-world conditions.

To further test the vehicle's limits and durability, we decided to enter the ATV in the 4-hour long Endurance race. The vehicle completed the Endurance Race without any major damage as shown by our analyses.

Photograph -5: Rear Suspension System after successful completion of Endurance Race

Photograph -6: Vehicle performance during Endurance Race through bumps and droops

Multibody Analysis has been created with a transient simulation model using which we were able to simulate actual working conditions of the suspension and provide varying loads over particular time periods. This has helped us understand the suspension behavior to a far greater extent beyond the scope of just static analysis.

Thus, both the suspension H-Arms and Upright are able to withstand these extreme scenario force constraints, allowing us to design and manufacture robust rear suspension systems that can tackle any challenging terrain with ease.

4. CONCLUSION:

Design and structural analysis of the suspension system was done for weight reduction without compromising its load bearing capability.

The designs were meticulously reviewed and perfected over time, empirical methodology was used to optimize it even further. Improving mesh parameters and tweaking the analytical models gave us more insightful knowledge about the components.

Static and dynamic tests were performed on the H-Arms to test its practicality and functionality.

Subsequently, Multibody Analysis was done on the assembled rear suspension to see whether the components work together harmoniously and withstand the forces acting on them.

After such intricate and continuous evaluation, we would like to conclude that the H-Arm Suspension System with a Single Upper Lateral Link is a viable option while choosing a Rear Suspension System for an All Terrain Vehicle.

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