iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 **Issue:** V **Month of publication:** May 2026

DOI: https://doi.org/10.22214/ijraset.2026.82199

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue V May 2026- Available at www.ijraset.com

Enhancing Fuel Efficiency in LCVs through Structural Optimization of Suspension Components

Mr.KendreV.S., Mr.P.G.Sarasambi, Prof.S.P.Godase, Dr.S.D.Shinde
Department of Mechanical Engineering , Shree Ramchandra College Of Engineering, Lonikand,Pune, Maharashtra, India

ABSTRACT: The most important component in vehicle is a suspension system, which directly affects the safety, performance andnoiselevel. The unsprungmassisthemassof the suspension components whichisdirectlyconnected tothem, rather thansupportedbythesuspension.High unsprungweightexacerbates issues like wheel control, ridequality and noise. Unsprung weight includes the mass of components such as the wheel axles, wheel bearings, wheel hubs, springs,shockabsorbers,andLowerControlArm.Thelowercontrolarmisawishboneshapedmetalstrutthatattachesthewheeltoth evehicle'sframe.Differentoptimizationtechniquesundervariousloadconditionshavebeenwidelyusedinautomobilesectorforliht weightandfunctioningenhancement.ThisstudydealswithFiniteElementAnalysisofthe Lower control armof Mac-pherson suspension system andits optimization understaticloading condition.Theexisting design of lower control arm from one of the light commercial vehicles is selected for the study. In order to determine the deformation and stress distribution in the current design, the finite element analysis is carried out. The main aim of this paper is to optimize the lower control arm of Mac-pherson suspension system under the current boundary conditions for weight reduction. The baseline model of the lower control arm is created by using solid modeling software viz. CATIA. ANSYS Workbench is used for Finite Element Analysis and OPTISTRUCT solver module is used to generate the optimized model. The present studyis used toreducetheweight and cost ofthelower control arm bykeeping the factor of safety within permissible limits. The weight reduction in one lower control arm is observed to be 17.5%.

.

I. INTRODUCTION

Stability, road handling and comfort of vehicledepend on optimumdesign of suspension system. Mostly all passenger carsandlight trucks useindependentsuspension systembecauseofinherentadvantages overrigidsuspension systems. Suspensionsystemisthetermgiventothesystemof springs, shockabsorbers andlinkagesthat connect avehicletoits wheels. Whenatirehits anobstruction,thereisareactionforceandthesuspensionsystemtriestoreducethisforce.Thesizeofthisreactionforcede endsontheunsprungmassateachwheelassembly.Ingeneral,thelargertheratioofsprungweighttounsprungweight,thelessthebodyand vehicleoccupantsareaffectedbybumps,dips,andothersurfaceimperfectionssuchassmallbridges.Alargesprungweighttounsprung eightratiocanalsoimpactvehiclecontrol[1].

Therearethreedifferenttypesofsuspensionsnamely:Dependent(RigidAxle),independentandsemi-independent suspensions. In the independent suspension system, there are no linkages between two hubs of same axle and it allows eachwheeltomoveverticallywithoutaffectingtheoppositewheel.Itissubdividedintotwomaingroupi.e,McPherson Strut Suspension and Double Wishbone Suspension. This system has inherent advantages over dependent system such as morespacefor engine, better roll resistance, lesser un-sprung weight and better resistanceto steering vibration. The control arm is prominent component of McPherson Strut Suspension nearly flat and roughly triangular member, that pivotsin two places. The broad end of triangleis attached at the frame and pivotson bushing. Thenarrow end attaches to the steering knuckle and pivots on the ball joint [5]

II. LITERATURE REVIEW

A shorthistory of suspensionfieldhas beendocumentedinthe presentreview.Itreviews early developmentof varioustypesofsuspensionsystemsuchasdouble-wishbonesuspension,MacPherson Strutsuspension.Italsoreviews designanddevelopments,simulationanalysisforavehiclesuspensionsystem.AccordingtoChristianahO.Ijagbemi[2]etal."Designan dsimulationoffatigueanalysisforavehiclesuspensionsystem(VSS)anditseffectonglobalwarming" 9 June 2016, this study shows that for every gallon of gasoline burnt, 12.7kg of CO_2 is released. Fuel economy improvement isalmostlinear withareductioninweightof acar.Therefore,reducingvehicle weightresultsinlessfuel consumption and a decrease in CO_2 emission which in turn has an effect on global warming.

Car manufacturers are facingincreasinglystringentCO2 emissionstandard. Inthispaper, aninvestigation wascarried outonvehiclesuspensionsystem(VSS)byemployingFiniteElementAnalysis(FEA)toanalyzethefatiguelife,vonmissesstress,factor ofsafety and stability of the suspension system and how the weight and size can be reduced.

According to Vinayak Kulkarni [3] et al. “Finite Element Analysis and Topology Optimization of Lower Arm of Double Wishbone Suspensionusing RADIOSS and Opti struct” May 2014, thispaperdealswithcalculatingtheforces actingonlowerwishbonearm whilevehiclesubjectedto criticalloading conditions.Suspensiongeometry and suitable materials for the suspension arm have been identified. Lower arm suspension has been modeled using Pro-Engineer.Vonmisesstress–strain iscarriedout in ordertofindout maximum inducedstressandstrain. Theseanalyses were carried using Altair Hyper works and solver used is Radioss. From the analyzed results, designparameters were compared fortwo different materials and bestonwastakenout.Fromresult obtainedit wasfound that currentdesign is safe and is somewhat overdesign. So, in order to save material and reduce weight of component, Topology optimization analysisiscarriedoutinHyper workswhichyieldedinoptimized shape. Thehigherfactorofsafetyleads to optimization of component.Topology optimization generates an optimized material distribution fora set of loads and constraints within a given design space. Optimization reduces weight, product design cycle time and cost.

From the previous studies, it can be noted that, even though several works are filed on Wishbone and Mac-pherson suspension, most of the work are focused on improvement of efficiency and performance

III. PROBLEM DEFINITION AND OBJECTIVE

Theunsprungweightofawheelcontrolsatrade-offbetweenawheel'sbump-followingabilityanditsvibrationisolation.

Aheavierwheelwhichmoveslesswillnot absorbas muchvibration; theirregularitiesoftheroad surfacewill transfer to the cabin through the geometry of the suspension and hence ride quality and road noise are thus worse. For longer bumps that the wheels follow, greater unsprung mass causes more energy to be absorbed by the wheels and makes the ride worse. High unsprung weight also complicates wheel control issues under hard acceleration or braking. The high unsprungmasscanleadtoseverewheelhop,compromisingtractionandsteeringcontrol.Thisisunsprungweightwhich increase the overall weight of suspension system and finally of vehicle. Also, it effects on performance & efficiency, handling capabilities. It also hassubstantial impact on emissions control aswell as overall cost.In ordertosolveabove mentioned problem, main aim of the project is summarized below:

- Tooptimizethelowercontrolarmforweightreduction”(unsprungweight)upto15-20%andsuggestalternate design.
- To carryoutstaticstructuralanalysisofexistingmodelusingFEAbasedsoftwareANSYSworkbench.
- Tocarryouttopologicaloptimizationoflowercontrolarmby OPTISTRUCTsolver.
- Tocomparethefactorofsafetyforoptimizedandbaselinedesignoflowercontrolarmbykeepingfactorof safety for optimized design within permissible limits.
- Toperformexperimentation on physical model of Lower Control Arm. To validate the FEA and Experimental results.

IV. THEORETICAL ANALYSIS

A. ThedimensionsofLowerControlarm

DimensionofLowerControlArmisasfollows:Overalllengthis463mm,widthis241.9mmandthicknessis3mm

B. Thematerialpropertiesofsteel

ThematerialisAISI1040,whichis havingallthesecharacteristics.

TABLEI MATERIALPROPERTIES

Material	AISI1040
Young’smodulus	2.1e5MPa
Poisson’sratio	0.3
Density	7850Kg/m3
Yieldstrength	415MPa
Tensilestrength	620 MPa

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue V May 2026- Available at www.ijraset.com

C. StaticLoadcalculationofLowerControlArm

GrossWeightof WagonR =1350Kg(consideringpassengers andaccessoriesweight),Total WeightinNewton W= 1350x9.81=13243.5N.Itisassumedthat52% ofweighttakenbyfrontaxle,duetomountingofengineonfrontside and remaining 48% weight taken by rear axle. Therefore, Weight on Front axle(F_1) = 0.52 x 13243.5 N= 6886.62 N WeightonRearaxle(F_2)=0.48 x13243.5 N = 6356.88 Reaction at each front wheel,R_W=WeightonFront axle/2=6886.62/2=3443.31N. Thisloadisconstitutedby spring,stubaxleandlowercontrol arm. Whilestubaxleof the wheel takes50% of thetotal load acting on each wheel. Therefore, force acting on the stub axleof wheel isgiven by,F= 1721.6 N. Following line diagram is a representation of the spring, and lower arm.

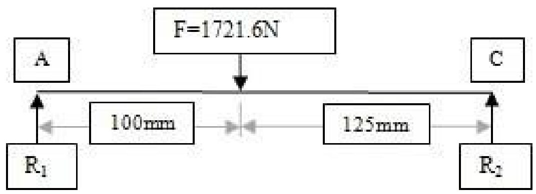


Fig.1.Linediagramforforcedistribution

Were,

R_1=Reaction for spring in Newton2=Reaction for lower arm in Newton= Force acting on stub axle in Newton Therefore,from equilibrium condition, taking moment atAisequal tozero.$\sum M_A$=0, Weget, R_2=765.15 N. Thisis verticalloadactingonthelowercontrolarm.Now,R_1+R_2=F.HenceR_1=956.45N.Thisreactionisactingvertically upwardatspring.Therefore,theReactionR_2=765.15N.ApproximatelytakenasR$_2\approx$765N,whichisactingin vertically downward direction on lower control arm.

V. FINITE ELEMENT ANALYSIS

ANSYSsoftwareisusedtomeshthesolidmodel.CADmodelwhichisinIGESformatisimportedtoANSYS.

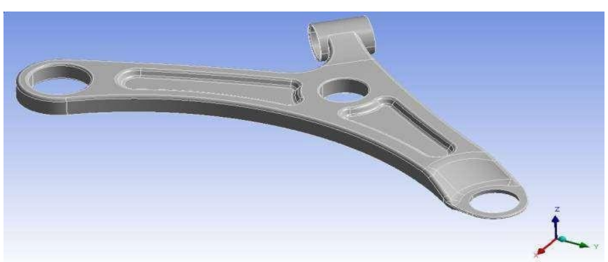


Fig.2.BaselineLowerControlArmforFEA

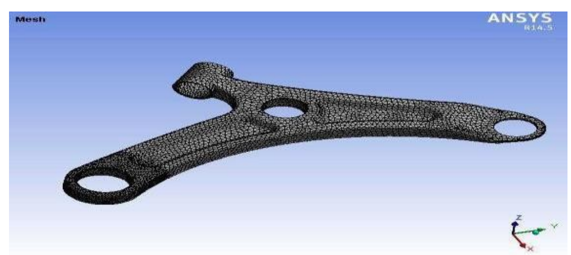


Fig.3.MeshingofLowerControlArm

A. Meshingofbaselinegeometry

The conventional model which was developed in CATIA software has to be meshed for analysis. For this ANSYS workbenchsoftwareisused.Itisahigh-performancefiniteelementpre-processorthatprovidesahighlyinteractiveand visual environment to analyze product design performance. With the broadest set of direct interfaces to commercial CADand CAE systems. The solid tetrahedron elements are used to generate the meshing of the control Arm.

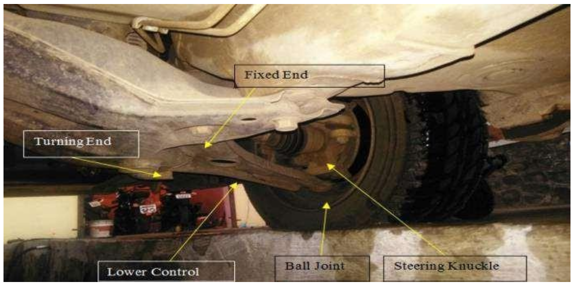
TABLEIIDETAILSOFMESHING

Sr. No.	Description	Values
1	NumberofNodes	53002
2	Numberof Elements	26694
3	ElementSize	Maximum5mm Minimum3mm

B. Designparameters

In case of vehicle in actual running conditions forces acting on it are of dynamic in nature and changes as per driving conditions. In order to make preliminary analysis steady state operating conditions are assumed.

C. Boundaryconditionsofbaselinegeometry



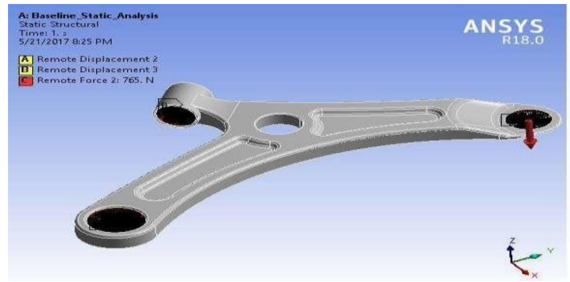
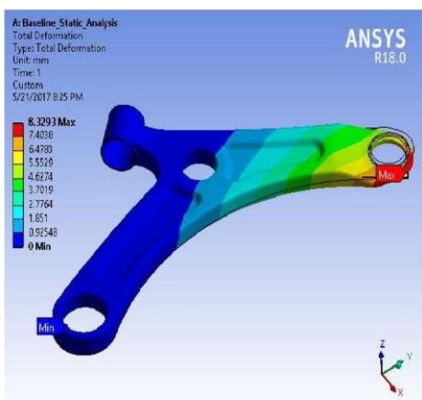


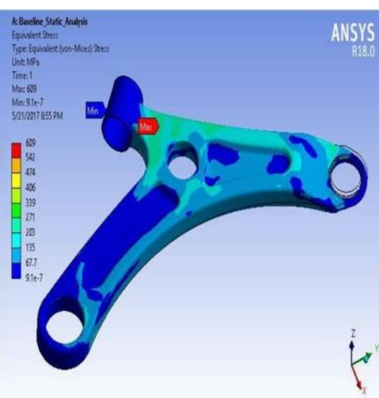
Fig.4.ConnectionofLowerControlArm Fig.5.BoundaryConditionsoflowercontrolarm

Wheelismountedonstubaxlewhichisconnectedtosteeringknuckle.Thissteeringknucklehasthreearmsletsayupper arm, lateral arm andlower arm. Upper arm is connected vertical helical coil spring strut, lateral armis connected totie rod of steering mechanism and lower arm is connected towishboneor lower control arm by a ball joint. The other two ends of LCA are connected to chassis frame, out of which one is fixed and other end turn about a pivot.

D. AnalysisResultofBaselinemodel

After Finite Element analysis on ANSYS workbench 18.0 following results have been find out. The displacement contour plots are shown in the below figure10.





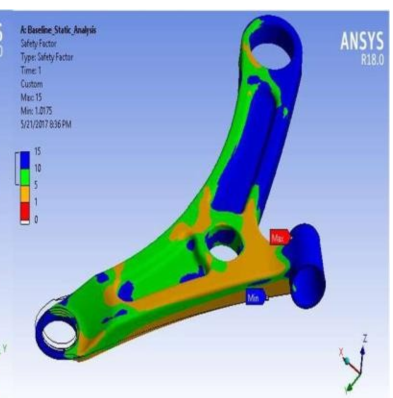


Fig.6.MaximumDeformationPlot Fig.7.EquivalentStressPlot Fig.8.Safetyfactor

Themaximumdisplacementshownbythebaselinelowercontrolarmis8.32mm.Theabovefigure6showscontourplot ofthevon-MisesstressAsperdistortionenergytheory,themaximumequivalentstressobservedinthelowerarmmodel is512MPa.Thetensilestrengthofthematerialis620MPa.Accordingtoresults,thevon-Misesstress512MPaislower tensile strength of the material. The factor of safety of the baseline lower Arm is 1.21. Mass of the Baseline design =
1.2 Kg

E. TopologyOptimizationbyFEA

TopologyOptimization isdefined asfinding out thebest possiblesolution of problem byconsideringthegiven setsof objectiveandnumberofconstraints.Forsolvinganytopologyoptimizationproblem,ithavetospecifythreeparametersthatisDesignVariables(materialdensity),Designobjective(Weightreduction)anddesignconstraints (Volume)[6].
Topologyoptimizationisperformedonamodeltocreateanewtopologyforthestructure,removingany unnecessary material.
The resulting structure is lighter and satisfies all design constraints.

ThetopologyoptimizationofcontrolarmmodeliscarriedoutinOPTISTRUCTsoftware.TheMaterialdatafor carbon steelremainsameasusedinthestaticstructuralanalysis.Theoptimizationmodelincludessameboundaryconditionsas used in the static analysis of baseline model. Topology optimization carried out for the following objective

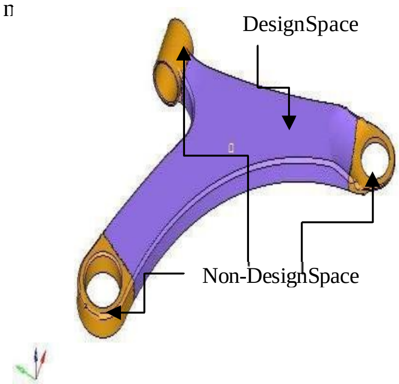
Objective	To minimize volume (reduce weight)
Constraints	von-Misesstress<620MPa (Tensile strength of material)
DesignVariables	Thedensityofeachelementinthe design space.

F. Opti structModel

The Optimized CAD is prepared in the CATIA software. The same CAD is exported in step format and imported in HYPERMESH. Following is the CAD imported in HYPERMESH for meshing. The prepared CAD is divided into design space andnodesignSpace. The designspace is the region where designoptimizationwill be carried out. The optimized CAD model is meshed in HYPER MESH with CTETRAelements is shown in above figure

ondesignspaceistheregionwhere, no designchangewillbedonebythesoftware.

n



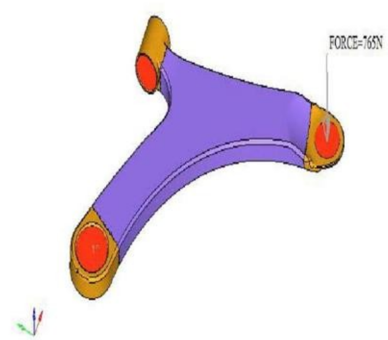


Fig.9. Optimized geometry

Fig.10.MeshmodelforOptimization

Fig.11.B.CsforTopologyoptimization

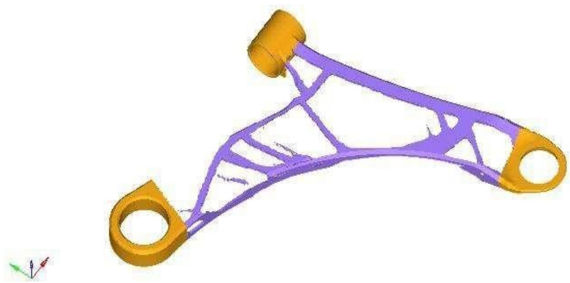
TABLEIIIDETAILSOFMESHING

Sr. No.	Description	Values
1	NumberofNodes	32537
2	Numberof Elements	98130
3	ElementSize	2mm

TherigidbodymotionoftheLowercontrolarmisrestrainedbyconstrainingthefacesoftheholeswhereitisfixedwiththescrewconnectionsasshowninthefigurebelowinredcolorregion.Thex,y,ztranslationandROTX,ROTY,ROTZ rotations are fixed in all directions.

G. Analysisresultforoptimizedmodel

Theelementdensityplotsshowtheoptimizedpatternofthemodel.Thewhiteregioninlower control armindicatesthe unnecessary material to be removed from the design. The optimized design is extracted from the raw design obtained through analysis. The optimized design is prepared in the CATIA software.



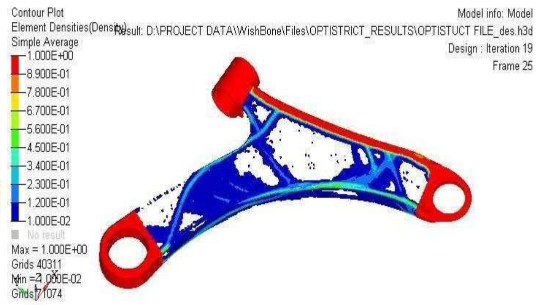
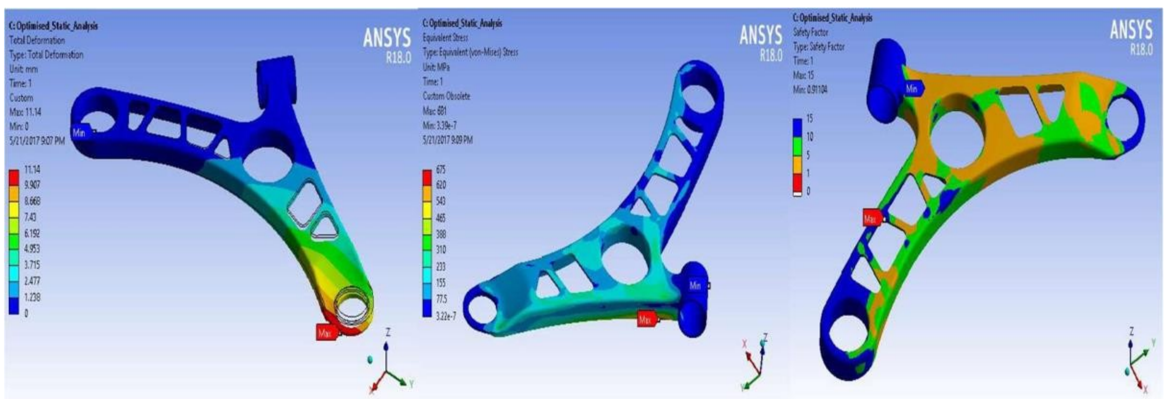


Fig.12.ElementDensityPlot Fig.13.ElementDensityContourPlot

Above figure shows that low space blue region can be removed from the design space while keep the red region in the designspaceasitis.Massoftheoptimizeddesignisobservedtobe0.99Kg.Thetotalreductioninmassisobservedby 17.5%.Since,Massofthemodelisdecreasedfrom1.2Kgto0.99Kg.AsperElementDensityplotnewoptimizedLCA model is designed in CATIA and it is analyzed in ANSYS for same boundary and loading conditions.



(a) (b) (c)

Fig.14.(a)DeformationPlot –Optimizeddesign ,(b)Max.von-Misesstress, (c)Safetyfactorforoptimizeddesign

Themaximumdeformationfortheoptimizeddesignisobservedupto11.14mm.Thevon-Misesstressisobserved up to 555Mpa for optimized model. Factor of safety of optimized model=620/555=1.11

VI. EXPERIMENT ALANALYSIS

Universaltestingmachinealsoknownas Universaltesterormaterialtestingmachinewhichisusedtotestthetensile strength and compressive strength of materials. For mounting of LCAon UTMfor testing, proper fixturehasbeen design. Following figure shows assembly of LCA and fixture

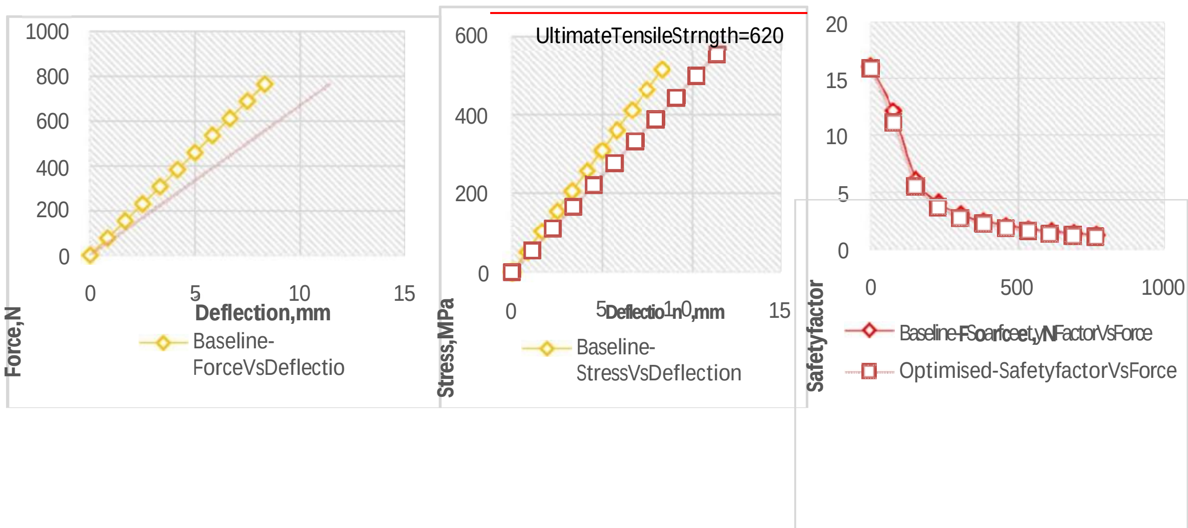
Fig.15(a)Fixture,ExperimentalSetup

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue V May 2026- Available at www.ijraset.com

ToverifythedeflectionandstressvaluesofLowercontrolarm,experimentaltestingofboththearmstructureisdoneon universal testing machinein metallurgical laboratory. Thereadings from the machine areused to verifywith the Finite element analysis results. Figure 22 shows the experimental setup for lower control arm. Load is applied on arm
by using of load cells of universal testing machine. The peak 765N load is applied on both arm models to find out deflection value on that peak load. A deflection value for the baseline arm is 7.7 mm and for new model is 10.4 mm.

VII. RESULTS AND DISCUSSION

StaticanalysisofexistingandmodifiedLCAiscarriedoutbyexperimentallyandFiniteelementmethod.Followinggraph shows the results of both model by Finite element method



(a) (b) (c)

Fig.16.(a)GraphplotofForcevs.Deflection,(b)PlotofStressvs.Deflection,(c)GraphplotofSafetyfactorvs.Force

Fromtheabovegraphitisobservedthatdeformationofaoptimizedmodelascomparedtobaselinemodelisvariedupto 11.14mm with the gradual application of load, maximum stress induced in both model is below the ultimate tensile strength of material. This indicates that design is safe for the applied load, also it is observed that there is a increase in stressoccurinoptimizedmodelduetoreductioninmassbutthisincreasedstressisbelowtheultimatelimit.Abovegraph showsthatthereisslightvariationinfactorofsafetyby10%canleadsto17.5%reductionofmassofsinglelowercontrol arc.Totalweightreductioninonecontrolarmisfoundtobe210gm.ThereispresenceoftwolowercontrolarminMac-pherson suspension system. So overall weight reduction infront su suspension systemis420gm.The costof AISI1040 is Rs.51.36 perKg. According to this baseline lowercontrolarm (LCA)of 1.2Kg requires material of Rs.61.95 whereas optimized LCA of 0.99 Kg requires material of Rs.51.11. So total cost saving in material ofone arm is as follows

$C_T=C_B-C_O=61.95-51.11=Rs.10.84$

Where, C_T = Total cost saving in material of one arm$_B$ = Cost of material for baseline LCA.C_O = Cost of material for optimizedLCA...Let sayin massproductioncompany manufactures1000 parts perweek,sototal costsavingper1000 parts will be Rs.10842.75 which is good achievement in company prospective.

TABLEIVRESULTANALYSIS

Sr.No.	Method	Description	BaselineDesign	OptimizedDesign
1	ExperimentalMethod	Deflection,mm	7.7	10.4
2		Von-Misesstress,MPa	475	520

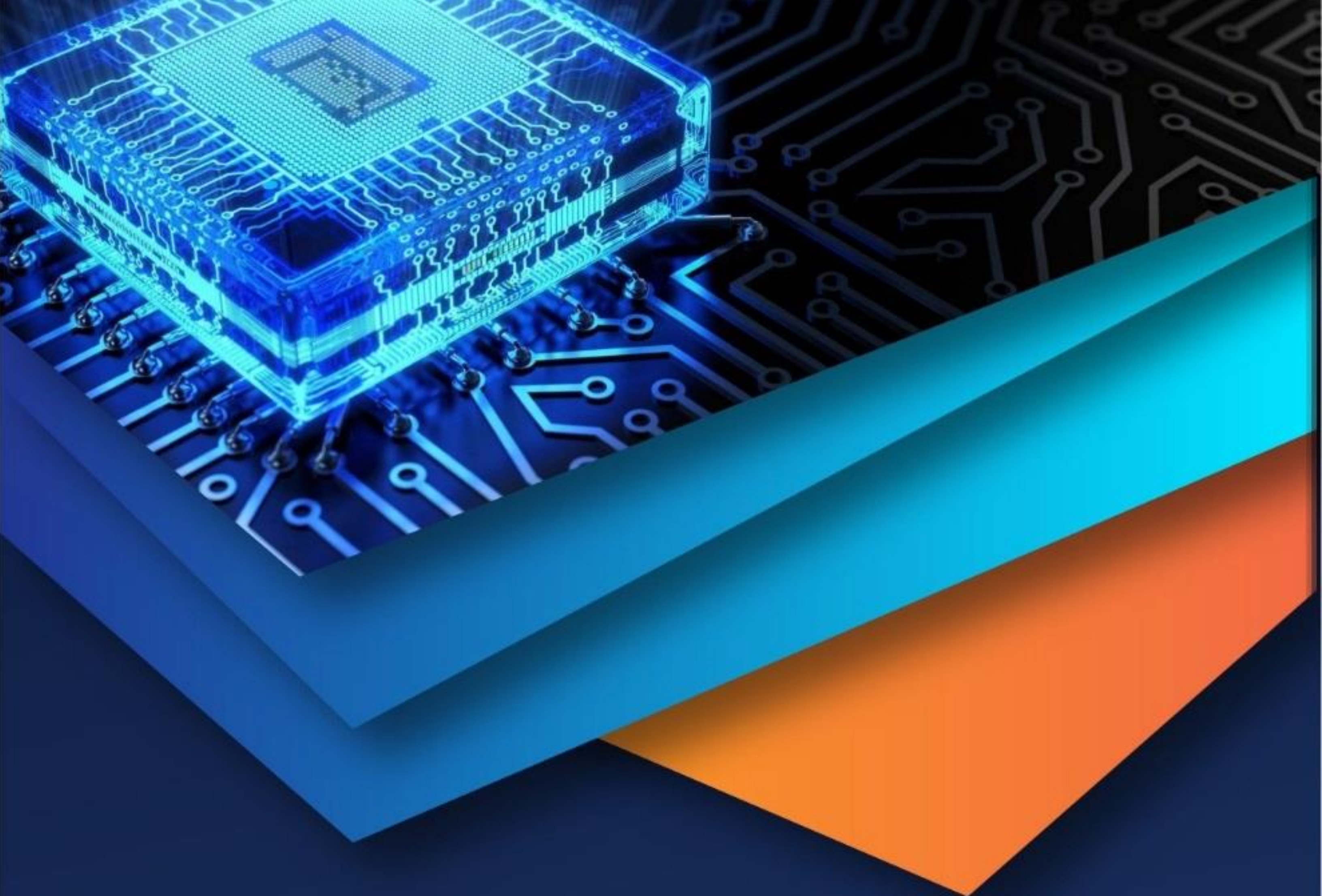
3		Mass,Kg	1.20	0.99
4	FEAMethod	Deflection,mm	8.33	11.14
5		Von-Misesstress,MPa	512	555
6		Mass,Kg	1.20	0.99
7	Theoreticalanalysis	FactorofSafety	1.21	1.11

VIII. CONCLUSION

AsdeflectionandstressofmodifiedLCAiswithintherange.Thus,themodifieddesignissafe.Weightofthefinal optimizedmodelis0.99kg.Thetotalreductioninmassisobserved17.5%bykeepingFactorofsafetyforoptimized design within permissible limits. Thus the objective of weight reduction of un sprung mass and cost reduction has been achieved.

IX. ACKNOWLEDGMENT

ItakethisopportunitytothanksProf.P.G.Sarasambi,andProf.S.P.Godaseforvaluableguidanceand for providing all the necessary facilities, which were indispensable in completion of this work.



10.22214/IJRASET

INDEX COPERNICUS

45.98

ISRA JIF

IMPACT FACTOR: 7.129

TOGETHER WE REACH THE GOAL

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY