

# LIGHTWEIGHT DESIGN OF LOADER ROCKER ARM BASED ON STRUCTURAL OPTIMIZATION

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## Abstract

To enhance the structural efficiency and economy of the loader arm, this study, based on the structural optimization method and aiming at lightweighting, conducts multi-objective topology optimization design of the loader arm using Altair Inspire software. The research verifies the effectiveness of topology optimization technology in the lightweight design of the loader arm, significantly reducing manufacturing costs and fuel consumption, and providing a replicable technical path for the engineering optimization of complex structures. Through static analysis, modal analysis and multi-body dynamics simulation, the load conditions and mechanical characteristics of the bracket are clarified. By comparing different shape control schemes and model reconstruction methods, the optimal design scheme is selected. The results show that the weight of the optimized bracket is reduced by 22.89 %, and the minimum safety factor is 1.9, both meeting the design standards.

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**Key Words:** Excavator Boom, Structural Optimization, Inspire Software, Lightweight Design

## 1. INTRODUCTION

The working device of a loader, as the core system for material handling, directly determines the overall operational efficiency and reliability of the machine. In the typical composition of a working device, the rocker arm, as a key force-transmitting component connecting the bucket cylinder and the pull rod, plays a crucial role in converting hydraulic driving force into bucket movement. Through lightweight design, the ultimate goal is to reduce the structural weight while ensuring the strength, stiffness, and stability of the structure. Dimensional optimization theory, by establishing an optimization objective function and taking the structural weight as the optimization target while considering the structural performance requirements as constraints, achieves lightweight design of the structure. Combined with multi-condition finite element analysis, it can optimize the material layout. During the topology optimization process, different optimization objectives will lead to changes in the mathematical model of the optimization object. Inspire software, as an advanced structural optimization tool, allows designers to explore different design schemes by changing parameter values. This capability makes the design process more flexible and helps to quickly find the optimal solution. Meanwhile, the finite element analysis (FEA) function ensures the high accuracy of the optimization results. Through precise simulation and analysis, designers can ensure the performance and safety of the optimized loader rocker arm in practical applications. This study mainly accomplished the following tasks:

(1) After completing the lightweight design, a rigorous strength check was conducted on the component. The results showed that all mechanical performance indicators met the design specifications, effectively ensuring the reliability and safety of the component under actual working conditions.

(2) In terms of lightweight effect: The weight reduction ratio reached 22.89 % compared to the original design, indicating that the lightweight design achieved the expected goal in

reducing the component weight, providing strong support for performance improvement and cost control of the product.

(3) Regarding structural rationality and aesthetics: Based on the analysis of the equivalent stress cloud diagram, the surface of the reconfigured part is smooth and natural, meeting the mechanical performance requirements while also considering the rationality and aesthetics of the structure.

## **2. RELATED WORKS**

At present, there is basically no research specifically on the structural lightweighting of loader arms. However, lightweight design generally starts from two aspects. One is to achieve it by changing materials; the other is to achieve it by improving the structure. In terms of materials, Han et al. have identified the integration of carbon fibre sheets and dissimilar sheets in hybrid material bodies as a key technical challenge that needs to be addressed urgently. By systematically describing the principles, development, advantages and disadvantages of the bonding processes of carbon fibre composites, including existing adhesive bonding, mechanical connection, welding and hybrid connection techniques in carbon fibre composites, the latest progress in the merging process is introduced. This broadens the application scope of carbon fibre sheets and different sheets and provides a reference for their wide application in hybrid vehicle bodies and lightweight development [1, 2]. Zhao et al. proposed a multi-physics field topology optimization framework to solve the problem that the design of most magnetic soft materials relies on discrete remanent magnetization orientation, which may limit the driving performance because the selection of magnetization orientation is restricted, and the sharp change in magnetization orientation at the interface may cause strong repulsive force, thus possibly causing manufacturing challenges. This framework simultaneously optimizes the topology and continuous remanent magnetization intensity distribution in magnetic soft materials and structures, thereby expanding the programmability of magnetic soft materials and improving their manufacturability [3]. Dindarlou and Castelluccio proposed a method based on hybrid physical and numerical optimization to identify parameters related to mesoscale strengthening in FCC metals and alloys to address the issue that the modelling of material intergranular failure or crack initiation and other mesoscale mechanisms still strongly relies on related models, but the prediction ability of these models at the grain size scale is still low, leading to poor damage prognosis outside the experimental calibration set. The strength and novelty of this method depend on the independent calibration of parameters using single-crystal and polycrystalline stress-strain curves [4]. Zhang et al. proposed a topology optimization (TO) framework for isotropic and orthotropic anisotropic multi-material periodic microstructures based on the element-free Galerkin method (EFGM). Under the condition of meeting the specified volume constraint, negative Poisson's ratio was selected as the objective function. Under periodic boundary conditions, the effective elastic properties of multi-material microstructures were calculated using an energy-based homogenization method. The alternating active phase algorithm was integrated into the isotropic microstructure of the meshless solid, and the SIMP scheme was adopted. By solving the sub-problems of the distribution of each two-phase material, the optimal topology configuration of multi-phase composites was obtained [5]. Hu et al. proposed a new topology optimization method for the design of coated structures filled with multiple materials. Based on the ordered SIMP scheme, a new material interpolation model for topological description was established. By introducing two special Heaviside projections in the two-step filtering and projection process, the external coating and substrate regions can be well identified using a few modified design variables. Then, within the ordered SIMP framework, the material distribution of the multi-material fillers was obtained by multiplying the filler identification field with the piecewise projection design

variables through a mathematical programming algorithm. The uniform thickness of the external coating could be well controlled by using the eroded density field and its original field [6]. Dos Santos Junior and Cavalcante proposed an innovative approach to create efficient microstructure arrangements that meet necessary performance standards and minimize material weight. This approach combines topological optimization, a homogenization method based on the concept of unit cells, and the finite volume theory to design efficient periodic cellular materials with optimized macroscopic elastic properties. To determine the optimal microstructure topology, specific linear combinations of the homogeneous elastic matrix components are considered to achieve optimized elastic performance [7].

In terms of structural optimization, Priarone et al. are addressing the issue of enhancing the mobility of ground vehicles. They explore the lightweighting of automotive components through material substitution for weight reduction, component redesign, or a combination of both, using additive manufacturing. They aim to quantify the results of systemically integrating redesign and material substitution. Initially, the cast iron bracket was manufactured through an optimized topology based on the powder bed-based AlSi10Mg amplitude modulation technology. Both manufacturing routes were evaluated through a cradle-to-grave boundary comparison life cycle assessment (LCA). A 69 % weight reduction was achieved, and the carbon dioxide emissions and energy requirements of the two schemes were compared [8]. Wu et al. proposed a novel approach to enhance the electrical contact performance at the interface between the armature and the track and to achieve armature lightweighting by integrating the backpropagation (BP) neural network with the genetic algorithm for optimizing the armature structure. Through Latin hypercube experiments, structural dimension samples of planar armatures and convex arc armatures were extracted, and training datasets were generated via finite element simulation. The results showed that after optimizing the planar armature, the mass was reduced by 10.4 % and the contact pressure distribution coefficient was decreased by 55.7 %. For the convex arc armature, the mass was reduced by 25 % and the contact pressure distribution coefficient was decreased by 46.5 % [9]. Jin et al. proposed a finite-time convergent continuous action iterative dilemma (CAID) with topology optimization to overcome the limitations of traditional methods. The asymptotic stability in the traditional CAID cannot provide information on the convergence rate or dynamics of the system within a finite time. In previous work, there was no effective method to analyse its convergence time. By introducing a finite-time convergence analysis based on the Lyapunov function, a better game structure was explored. Simulation results demonstrated the effectiveness of the proposed method [10]. Alizadeh et al. proposed a high-resolution topology optimization framework for porous flow reactors based on the Non-dominated Sorting Genetic Algorithm II for pore size simulation. A pore network model of the advection-diffusion-reaction system was developed to simulate reactor performance. This model was integrated with a mathematical optimization algorithm, combining background grids and Delaunay triangulation. The optimization framework generated enhanced porous structures while maximizing conversion rates and minimizing pumping costs [11]. Cascino et al. proposed a design method to improve the quality and reliability of railway vehicle components by innovating the railway support beam using topology optimization technology. The impact of different manufacturing constraints on the casting process was evaluated. Comprehensive numerical testing activities were conducted to establish an effective testing procedure. Two different static and dynamic designs were obtained and compared, and the differences in terms of quality, mechanical performance, and manufacturability were evaluated [12]. Eltanany et al. used topology optimization to reduce the volume and weight of the struts in vehicle suspension systems without affecting their structural integrity and reliability. A strut specifically designed for racing cars was selected. The strut was optimized using the finite element software ANSYS. The results showed that after 48 iterations of topology optimization, the strut was significantly enhanced while maintaining a safety factor

of 2.5 [13]. Petrov used topology optimization to reduce the volume of permanent magnets in synchronous motors to improve their operational efficiency. A complex topology optimization method developed using genetic algorithms, the optimization results, and the methods for testing the obtained structures were utilized. Optimization allows for a reduction of 22–32 % in the volume of neodymium iron boron magnets, thereby lowering the motor cost by 14–21 %, or alternatively, by switching to ferrite magnets, the cost can be reduced by 24–33 %, with the torque value varying within 2 % [14]. Turan et al. investigated a narrow suspension seat with negative stiffness structure [15].

### **3. RESEARCH METHOD**

With the rapid development of structural topology optimization technology [16, 17], topology optimization of continuum structures has become a research hotspot in the field of structural optimization. Among numerous mathematical modelling algorithms, the Solid Isotropic Material with Penalization (SIMP) method has been widely applied in practical engineering due to its simple model and ease of implementation. Essentially, this method is a combinatorial optimization problem of 0-1 discrete variables. To effectively address the combinatorial explosion problem caused by discrete design variables, the SIMP method uses a power function to establish the relationship between element density and material elastic modulus in the isotropic material penalty model, while a rational function is employed in the reasonable approximate model of material properties to describe this relationship. The SIMP model assumes that the material is isotropic and the Poisson's ratio is constant. It introduces relative density elements with density values ranging from 0 to 1, and the material elastic modulus and element density satisfy the following relationship:

$$E(x_e) = E_{min} + x_e^p(E_0 - E_{min}) \quad (1)$$

$$\begin{cases} \text{find } x = [x_1, x_2, \dots, x_N]^T \\ \min c(x) = F^t U = U^t K U = \sum_{e=1}^N E(x_e) u_e^T k_0 u_e \\ \text{s. t. } V(x) = \sum_{e=1}^N x_e v_e \leq f V_0 \\ F = K U \\ 0 < x_{min} \leq x_e \leq 1, (e = 1, 2, 3, \dots, N) \end{cases} \quad (2)$$

In the formula,  $x = [x_1, x_2, \dots, x_N]$ ;  $T$  represents the design variables, whose values can continuously vary within the interval  $[0, 1]$  to avoid singular matrices during the calculation process;  $x_{min}$  is usually set to 0.001;  $N$  is the total number of elements;  $c(x)$  represents the structural compliance, which is the objective function;  $U$  is the structural displacement matrix;  $u_e$  is the element displacement matrix;  $K$  is the structural stiffness matrix;  $k_0$  is the stiffness matrix of the solid element;  $F$  is the load vector;  $V_0$  is the initial volume of the structure;  $V(x)$  is the volume of the optimized structure;  $v_e$  is the volume of element  $e$ ;  $f$  is the preset volume ratio, representing the constraint condition.

## **4. EXPERIMENTAL VERIFICATION**

### **4.1 Experimental software**

Altair Inspire software, through its built-in topology optimization module, can determine the optimal distribution of materials within a given design space via algorithms to minimize weight while meeting performance constraints; the morphogenesis optimization module optimizes the surface shape of thin-walled structures (such as rib layouts) to enhance stiffness and stability; the structural analysis module provides static and modal analysis to verify the stress, deformation, and vibration characteristics of the design under load; the motion analysis module

simulates the kinematics and dynamics behaviour of mechanical systems to check for interference and force conditions; the PolyNURBS modelling tool converts the geometry generated by topology optimization into smooth, manufacturable CAD models; additive manufacturing support optimizes the design to adapt to 3D printing, generating lattice structures or minimizing support materials; finally, the casting simulation module predicts defects (such as shrinkage cavities and hot cracks) during the casting process and optimizes mould design.

## 4.2 Experimental setup

1. Material settings: To conduct topological optimization, it is necessary to establish conditions such as materials and driving forces to better achieve lightweight design. Firstly, set the analysis solver to "OptiStruct" constraints and import the *stmod* format model file. Create a new material and name it "Loader". Modify its material performance parameters in sequence as follows: Young's modulus:  $1.62 \cdot 10^5$  MPa; Poisson's ratio: 0.3; density:  $7.1 \cdot 10^{-6}$  kg/mm<sup>3</sup>; yield stress: 400 MPa.

2. Load conditions: Select "Left Rear Wheel" (which includes the left rear tire and left rear wheel hub) and "Right Rear Wheel" (which includes the right rear tire and right rear wheel hub), and set them as ground constraints.

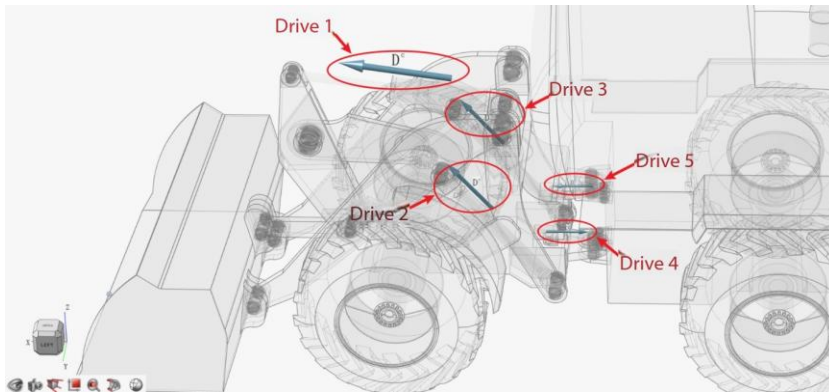


Figure 1: Impose constraints.

Drive 1 is composed of "Drive-Hydraulic Rod" and "Drive-Hydraulic Cylinder Tube", with a driving mode of "Multi-Signal", divided into 4 sections in total. The driving parameter type is displacement, and the driving profile curve data is shown in Fig. 2. Drives 2 to 5 are composed of the left "Drive-Hydraulic Rod" and "Drive-Hydraulic Cylinder Tube", with a driving mode of "Step-Hold-Step", and the driving type is displacement. The driving profile curve data is shown in Fig. 3. Gravity is set to align with the Z-axis of the global coordinate system, and it should be noted that the direction of gravity is the -Z direction.

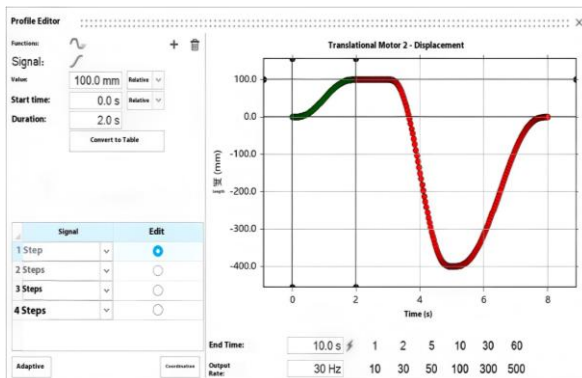


Figure 2: Parameter settings (Motor 2).

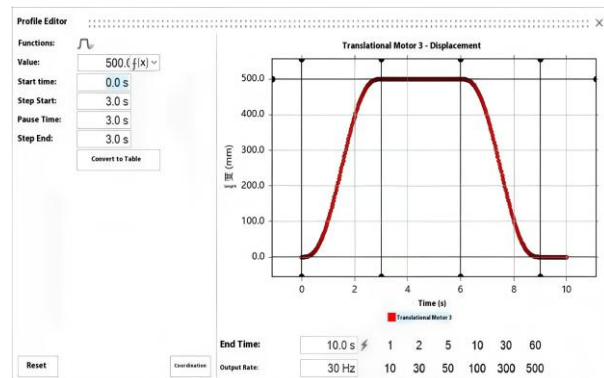


Figure 3: Parameter settings (Motor 3).

3. Initial strength analysis: According to the working condition requirements, describe the key operation steps and parameters of the analysed part, and provide illustrations; describe the initial strength analysis parameters and provide illustrations; describe the analysis results, including the minimum safety factor, maximum displacement, and maximum von Mises stress. Through the tracker, select the "Tracking Line" option, and choose the midpoint of the midpoint of the bucket frame as the tracking point. Use the analysis motion to complete several cycles of motion video. Finally, set the analysed part as the "Design Space" analysis zero, where the "Element Size" is set to 30 mm, and select "Use all 5 maximum loads (each connection)" for the motion load, then click Run. When the "Run Status" window prompts completion, double-click the result to view. The following results can be obtained as shown in Fig. 4: the minimum safety factor is 7.9, the maximum displacement is 0.2577 mm, and the maximum von Mises stress is 50.77 MPa.

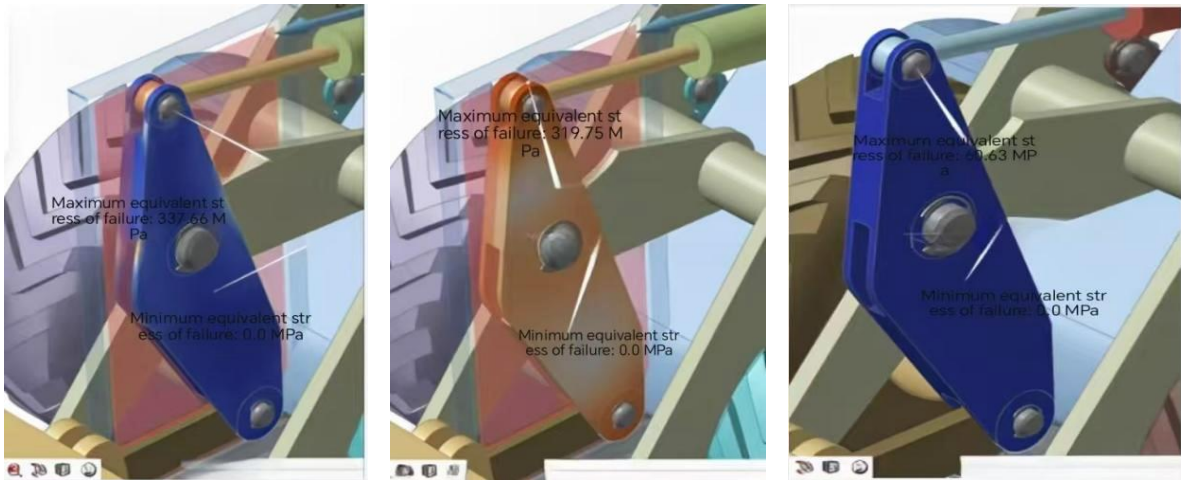


Figure 4: Initial strength parameters of parts.

4. Topology optimization: There are several design space schemes in combination with the actual situation (the motion load selection is all "using the five maximum loads (for each connection)"): Option One: XOZ plane symmetry, YOZ plane rotation 20° symmetry, XOZ plane bidirectional draft, maximizing stiffness, mass target 20 %, minimum thickness 55 mm, maximum thickness 110 mm, as shown in Fig. 5.

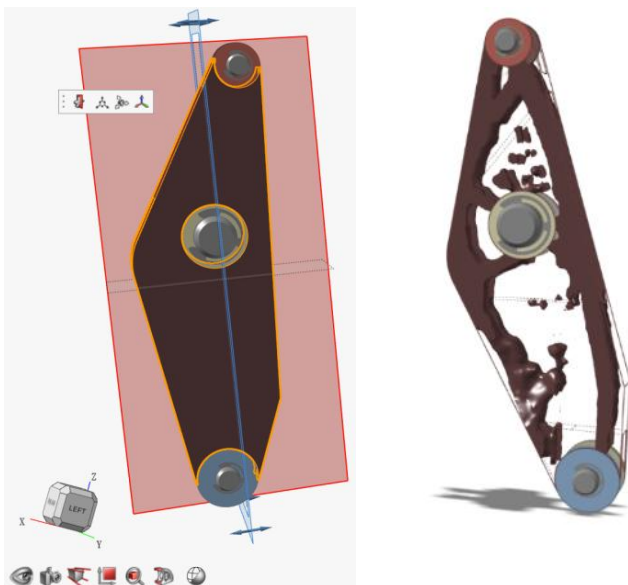


Figure 5: Topology optimization scheme 1.

Option Two: Symmetrical about the XOZ plane, bidirectional draft about the XOY plane, maximizing stiffness, with a mass target of 20 %, minimum thickness of 55 mm, and maximum thickness of 110 mm, as shown in Fig. 6.

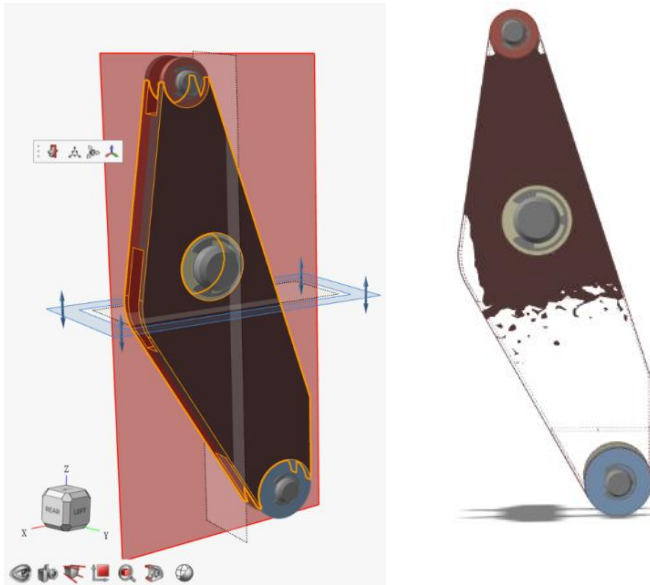


Figure 6: Topology optimization scheme 2.

Option Three: Symmetrical about the XOZ plane, with bidirectional draft on the XOZ plane, maximizing stiffness, with a mass target of 20 %, minimum thickness of 55 mm, and maximum thickness of 110 mm, as shown in Fig. 7.

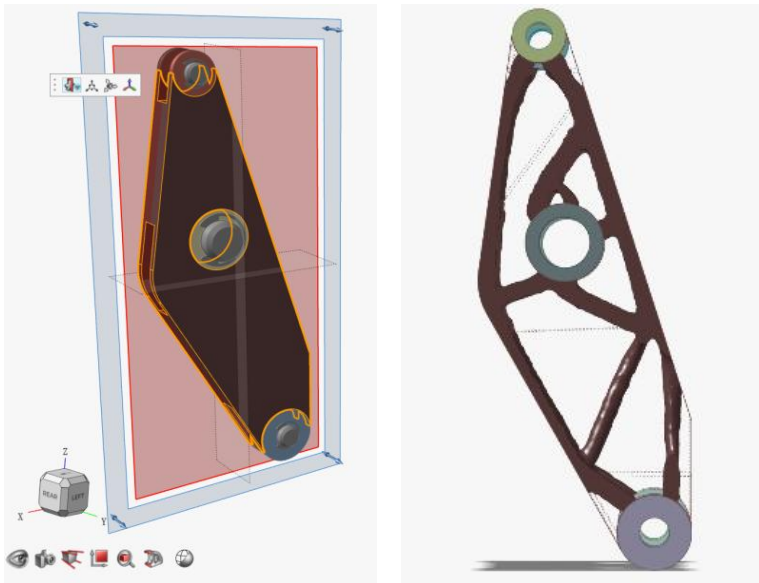


Figure 7: Topology optimization scheme 3.

After comparing the above several schemes, the result of scheme 3 is relatively complete. Our team made minor adjustments to the minimum thickness on the basis of scheme 3. Eventually, when the minimum thickness is 55.6, the conceptual model of topology optimization is the best as shown in the figure. Finally, we chose the conceptual model with XOZ plane symmetry, bidirectional draft on the XOZ plane, a mass target of 20 %, a minimum thickness of 55.6, and a maximum thickness of 111.2, as shown in Fig. 8.

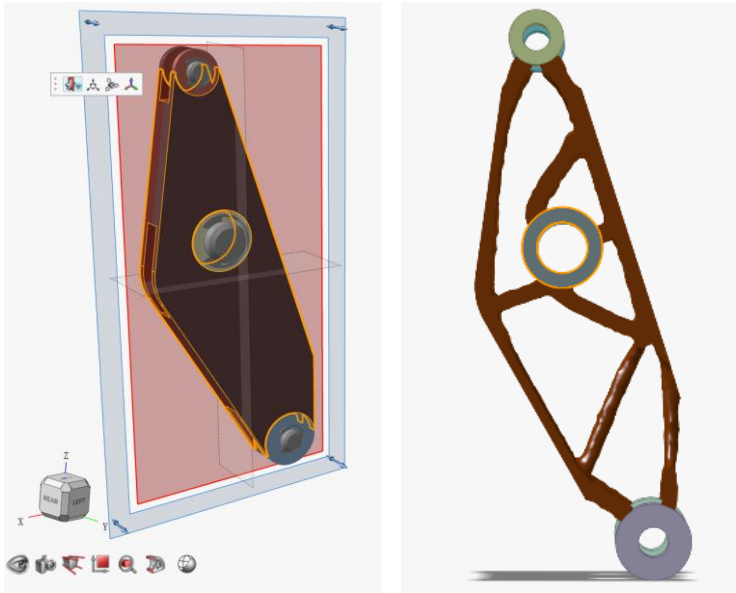


Figure 8: Optimization results of topology optimization scheme 3.

5. Geometric reconstruction: Based on the optimized part structure, describe the operation method for the smoothing processing of the conceptual model and provide a picture of the geometrically reconstructed model.

(1) Method One: Fit PolyNURBS.

For the obtained conceptual model, after selecting an appropriate topological degree, click the "Fit PolyNURBS" button to obtain the automatically reconstructed model as shown in Fig. 9.

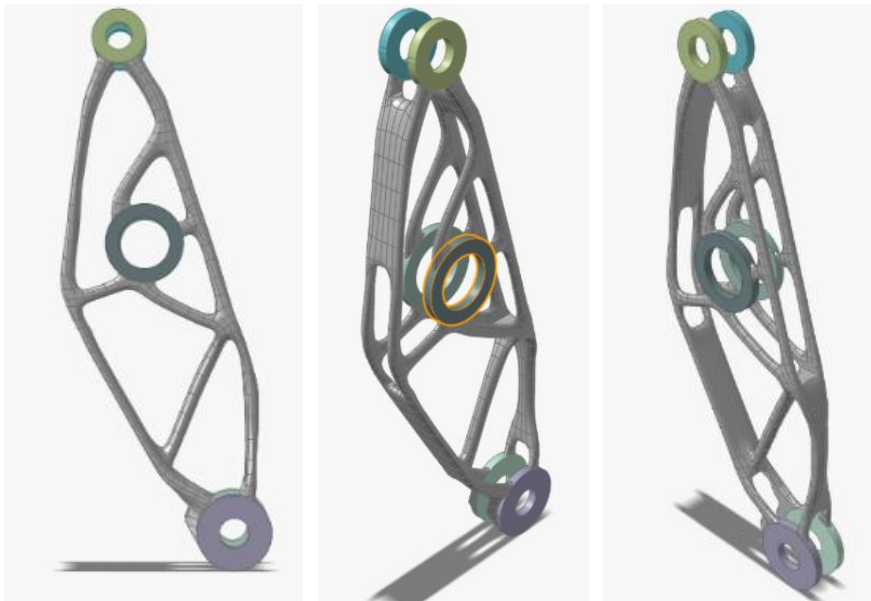


Figure 9: Fit PolyNURBS.

(2) Method Two: PolyNURBS Adaptive.

For the conceptual model obtained, select "Adaptive" as shown in Fig. 10.

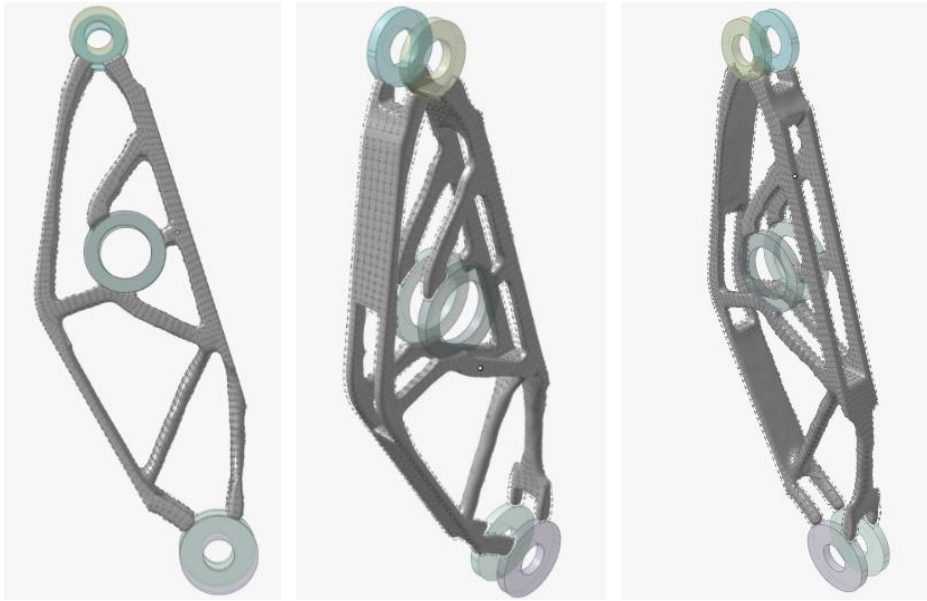


Figure 10: PolyNURBS Adaptive.

(3) Method Three: Manual PolyNURBS Reconstruction.

Manually fit using the shown tool options and pay attention to adjusting the shape to be relatively smooth and flat. Considering both weight and shape, Method Three (Manual PolyNURBS Reconstruction) is ultimately selected as the final optimization result. After manual reconstruction, continuously select the non-design space, right-click to copy and paste it under the manually reconstructed part. Then, follow the above operation to copy and paste the manually reconstructed part under any part of the non-design space. After selecting all the copied parts, click the Boolean operation to merge the non-design space and the manually reconstructed part. Then, click the command in the middle to uncheck the non-copied design space, non-design space, and the manually reconstructed part (the purpose of this is to prevent part accumulation). After merging into one whole, fillet the connection position between the model and the non-design space to reduce stress. Finally, draw a sketch on the area to be cut and extrude the excess part of the model. Thus, the geometrically reconstructed part "bucket arm" is obtained as shown in Fig. 11.

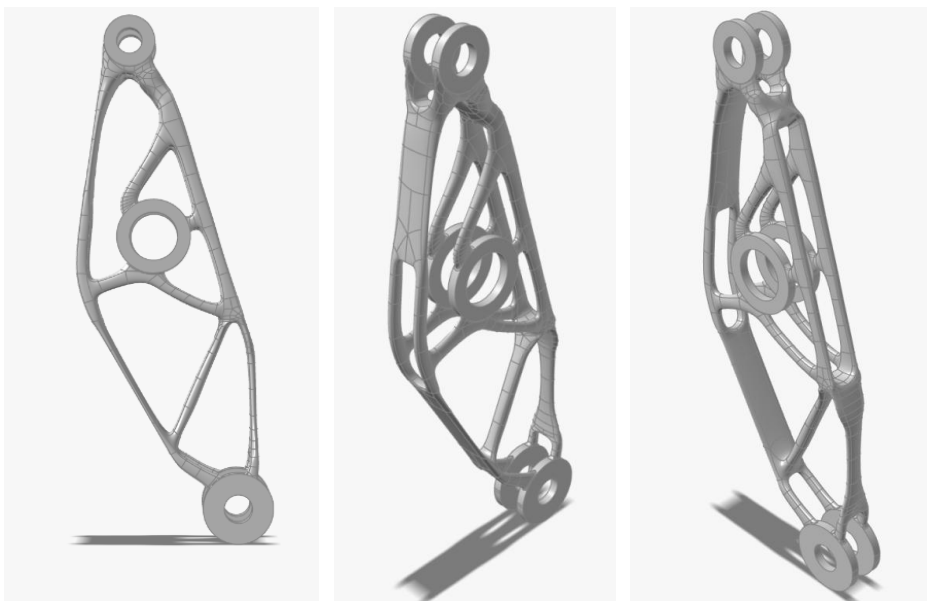


Figure 11: Manual PolyNURBS Reconstruction.

6. Motion simulation verification: Reconfigure the hinge of the new part in the same way as the previous connection, and then set the drive in the same manner. Finally, conduct motion analysis.

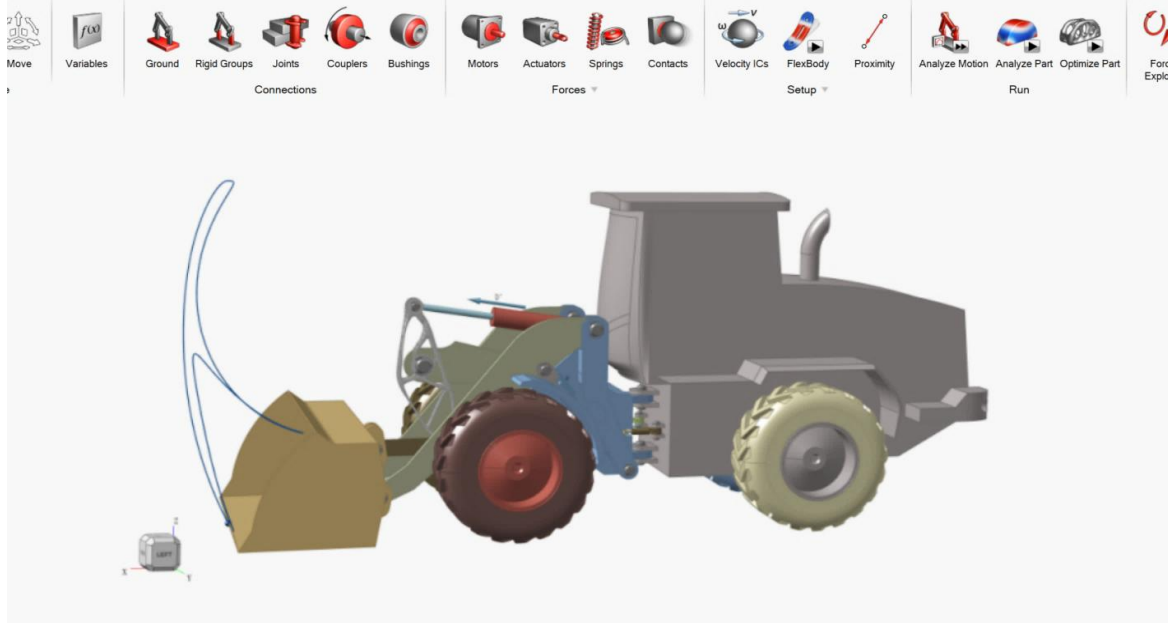


Figure 12: Motion analysis.

The analysis results of the motion after optimization are exactly the same as those before optimization, indicating that the team's previous operations were correct, as shown in Fig. 12.

7. Strength check: Set the key parameters for strength check for the geometrically reconstructed part. The part analysis should have the same parameter settings as the initial part analysis. As shown in the figure, the element size is 30 mm. The analysis results are obtained: the minimum safety factor is 1.9. The maximum displacement is 0.9037 mm, and the maximum von Mises equivalent stress is 215.1 MPa, as shown in Fig. 13.



Figure 13: The optimized result.

## **5. CONCLUSION**

This paper adopts Inspire software to conduct lightweight design on the loader rocker arm. During the actual operation of the loader, the working device needs to withstand multiple mechanical forces such as digging resistance and impact loads. By calculating and determining its initial rigidity and strength data, it ensures that the optimization scheme can meet the load requirements. This evaluation system based on the working condition weight coefficient enables the lightweight design to not only consider static strength but also take into account the structural stability under dynamic loads. The main research results of this study are as follows:

(1) In terms of component strength verification: After the lightweight design was completed, a rigorous strength verification was carried out on the component. The results showed that the minimum safety factor reached 1.9, the maximum displacement was 0.9037 mm, and the maximum von Mises equivalent stress was 215.1 2MPa. After a comprehensive assessment, all mechanical performance indicators met the design specifications and requirements, effectively ensuring the reliability and safety of the component under actual working conditions.

(2) In terms of lightweight effect: Before optimization, the weight of the component was 352,899 g. After scientific lightweight design optimization, the weight was significantly reduced to 80,783 g. The overall mass was reduced by 272,116 g, with a weight reduction ratio of 22.89% compared to before optimization. This indicates that the lightweight design achieved the expected goal in reducing the component weight, with a very significant lightweight effect, providing strong support for the performance improvement and cost control of the product.

(3) In terms of structural rationality and aesthetics: From the analysis results of the equivalent stress cloud diagram, the maximum von Mises equivalent stress was 215.1 MPa, which was within a reasonable design range. At the same time, the surface of the reconstructed part was smooth and natural, with gradual changes in cross-section and smooth transitions. It not only met the mechanical performance requirements but also took into account the rationality and aesthetics of the structure, demonstrating the successful exploration of comprehensive performance optimization in this lightweight design.

## **REFERENCES**

- [1] Han, S.; Guang, X.; Li, Z.; Li, Y. (2022). Joining processes of CFRP-Al sheets in automobile lightweighting technologies: a review, *Polymer Composites*, Vol. 43, No. 12, 8622-8633, doi:[10.1002/pc.27088](https://doi.org/10.1002/pc.27088)
- [2] Xing, H. R. (2024). Optimizing human-machine systems in automated environments, *International Journal of Simulation Modelling*, Vol. 23, No. 4, 716-727, doi:[10.2507/IJSIMM23-4-CO19](https://doi.org/10.2507/IJSIMM23-4-CO19)
- [3] Zhao, Z.; Wang, C.; Zhang, X. S. (2024). Multiphysics topology optimization of magnetic materials with continuous magnetization orientations, *Mechanics of Materials*, Vol. 198, Paper 105089, 15 pages, doi:[10.1016/j.mechmat.2024.105089](https://doi.org/10.1016/j.mechmat.2024.105089)
- [4] Dindarlou, S.; Castelluccio, G. M. (2024). Optimization of crystal plasticity parameters with proxy materials data for alloy single crystals, *International Journal of Plasticity*, Vol. 174, Paper 103894, 14 pages, doi:[10.1016/j.ijplas.2024.103894](https://doi.org/10.1016/j.ijplas.2024.103894)
- [5] Zhang, J.; Zhang, Z.; Zhang, H.; Wu, S.; Wu, S.; Zuo, Z.; Gong, S. (2024). Topology optimization of auxetic microstructures with isotropic and orthotropic multiple materials based on element-free Galerkin method, *Engineering Analysis with Boundary Elements*, Vol. 166, Paper 105811, 17 pages, doi:[10.1016/j.enganabound.2024.105811](https://doi.org/10.1016/j.enganabound.2024.105811)
- [6] Hu, T.; Wang, Y.; Li, H.; Yu, M.; Furuta, K.; Izui, K.; Nishiwaki, S. (2024). Topology optimization of coated structures infilled with multiple materials, *Finite Elements in Analysis and Design*, Vol. 235, Paper 104165, 24 pages, doi:[10.1016/j.finel.2024.104165](https://doi.org/10.1016/j.finel.2024.104165)
- [7] Dos Santos Júnior, A.; Cavalcante, M. A. A. (2025). Topology optimization of periodic cellular materials employing the finite-volume theory, *Engineering Optimization*, Vol. 57, No. 7, 1952-1971, doi:[10.1080/0305215x.2024.2379019](https://doi.org/10.1080/0305215x.2024.2379019)

- [8] Priarone, P. C.; Catalano, A. R.; Settineri, L. (2023). Additive manufacturing for the automotive industry: on the life-cycle environmental implications of material substitution and lightweighting through re-design, *Progress in Additive Manufacturing*, Vol. 8, No. 6, 1229-1240, doi:[10.1007/s40964-023-00395-x](https://doi.org/10.1007/s40964-023-00395-x)
- [9] Wu, J.; Li, S.; Yang, B.; Zhang, Y. (2024). Optimized design for armature lightweighting and contact pressure distribution uniformization based on BP neural network and genetic algorithm, *IEEE Transactions on Plasma Science*, Vol. 52, No. 6, 2359-2367, doi:[10.1109/tps.2024.3406200](https://doi.org/10.1109/tps.2024.3406200)
- [10] Jin, X.; Li, H.; Yu, D.; Wang, Z.; Li, X. (2024). Topological optimization of continuous action iterated dilemma based on finite-time strategy using DQN, *Pattern Recognition Letters*, Vol. 182, 133-139, doi:[10.1016/j.patrec.2024.04.010](https://doi.org/10.1016/j.patrec.2024.04.010)
- [11] Alizadeh, M.; Gostick, J.; Suzuki, T.; Tsushima, S. (2024). Topological optimization for tailored designs of advection–diffusion–reaction porous reactors based on pore scale modeling and simulation: a PNM-NSGA framework, *Computers & Structures*, Vol. 301, Paper 107152, 17 pages, doi:[10.1016/j.compstruc.2024.107452](https://doi.org/10.1016/j.compstruc.2024.107452)
- [12] Cascino, A.; Meli, E.; Rindi, A. (2024). Development of a methodology for railway bolster beam design enhancement using topological optimization and manufacturing constraints, *Eng*, Vol. 5, No. 3, 1485-1498, doi:[10.3390/eng5030079](https://doi.org/10.3390/eng5030079)
- [13] Eltanany, A. S.; Hamada, A. T.; Kadri, K.; Al Hussaini, O.; Alkhader, M. (2024). Design and topological optimization of a wheel upright using finite element analysis, *Applied Mechanics and Materials*, Vol. 924, 13-22, doi:[10.4028/p-kfvdi8](https://doi.org/10.4028/p-kfvdi8)
- [14] Petrov, T. (2024). Topological optimization of the design of a permanent magnet synchronous motor using a genetic algorithm, *ITM Web of Conferences*, Vol. 59, Paper 02010, 6 pages, doi:[10.1051/itmconf/20245902010](https://doi.org/10.1051/itmconf/20245902010)
- [15] Turan, M. K.; Erzan Topcu, E.; Karpat, F. (2024). Modelling and investigation of a driver seat suspension with negative stiffness structure, *International Journal of Simulation Modelling*, Vol. 23, No. 2, 275-286, doi:[10.2507/IJSIMM23-2-684](https://doi.org/10.2507/IJSIMM23-2-684)
- [16] Yu, G.; Zhao, Y.; Lu, W.; Wang, G.; Yang, J.; Liu, S. (2025). Research on advanced materials and design optimization of lightweight automotive structures under uncertain conditions, *Technical Gazette*, Vol. 32, No. 6, 2385-2395, doi:[10.17559/TV-20250527002705](https://doi.org/10.17559/TV-20250527002705)
- [17] Zhang, C.; Li, S.; Zhang, Z. (2025). Modeling and simulation of industrial robot arms using Simscape Multibody, *Facta Universitatis, Series: Mechanical Engineering*, Vol. 23, No. 2, 265-286, doi:[10.22190/FUME230215017Z](https://doi.org/10.22190/FUME230215017Z)