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Optimization of the Old Design of Double Axle Truck Tailgate Arm and Comparison of Loading Simulation of the New Double Axle Truck Tailgate Arm Design Using FEM (Altair Inspire)

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Abstract: This study optimized and compares the structural performance of Type A and Type B tailgate frame arm designs for double commercial trucks to improve safety, efficiency, and regulatory compliance. Analytical calculations and Finite Element Analysis using Altair Inspire were employed under a 650 kg operational load. Three materials ASTM A36, Aluminium 7075-T6, and Stainless Steel AISI 304 were evaluated in terms of stress, displacement, and safety factor. Results indicate that the Type B design reduces displacement by approximately 40% compared to Type A, while improving load distribution and structural stiffness. Aluminium 7075-T6 provides the best strength to weight ratio, whereas ASTM A36 remains the most cost-effective option. Only the Type B design complies with the Indonesian Ministry of Transportation clearance requirement (<200 mm). These findings demonstrate that Altair Inspire supports an effective optimization workflow for developing lighter, safer, and regulation compliant tailgate frame arm designs.

Keywords: axel; tailgate; design; optimized; FEM



SDGs Problem Solving

Research and problem-solving in optimizing tailgate frame arms for double trucks directly support SDGs Chapter #9. Through FEM simulation, material evaluation, and regulatory compliance analysis, the study enhances safer, more efficient, and innovative transportation infrastructure while promoting sustainable industrial development and technological advancement.

Conflict of Interest Statement: The author(s) declares that the research was conducted in the absence of any commercial or financial relationship that could be construed as a potential conflict of interest.

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Conflict of Interest STATEMENT
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1. INTRODUCTION

Tailgate lift systems play a crucial role in improving loading and unloading efficiency for commercial trucks, particularly in the distribution and logistics sector where operational reliability is essential. The structural performance of the tailgate frame arm directly affects safety, stiffness, and long-term durability, especially when subjected to repetitive loading cycles and varying operational environments (Beihul *et al.*, 2020). As transportation demands continue to grow, manufacturers are increasingly required to design tailgate components that are stronger, lighter, and more energy-efficient while ensuring conformance to modern regulatory standards (Shamsuddoha, Kashem and Nasir, 2025).

Material selection becomes one of the most influential factors in determining the overall performance of a tailgate system. Aluminium alloys are widely recognized for their excellent strength-to-weight ratio, making them attractive for lightweight structural (Verma and Taneja, 2024). Low carbon steels such as ASTM A36 remain dominant in commercial vehicle fabrication due to their affordability and manufacturability (Arifin, Kustono and Widiyanti, 2020). Meanwhile, stainless steels provide high corrosion resistance and structural integrity, though at a higher material and processing cost (He *et al.*, 2020). Advancements in computer-aided engineering have significantly transformed the product development cycle. Finite Element Analysis (FEA) using tools such as Altair Inspire allows engineers to predict stress distribution, deformation behavior, and structural failure modes with high accuracy before physical prototyping (Chibinyani *et al.*, 2025). Altair Inspire enables early-stage optimization to reduce material usage while maintaining strength, whereas Altair Inspire provides detailed verification through nonlinear and static structural simulations (Ferede, 2020). Integration of these tools helps reduce production errors and accelerates the design iteration process (Ivanova, Lee and Jane, 2024; Koh, Perumal and Kok, 2024).

In addition to structural performance, tailgate design must comply with national regulations. In Indonesia, the Ministry of Transportation specifies a strict cargo-bed-to-tailgate clearance limit of 200 mm to ensure operational safety during loading activities (Özden and Gökçe, 2023). Many existing designs particularly older generation models struggle to meet this requirement due to geometric limitations, resulting in the need for updated and optimized configurations (Cadet and Paredes, 2024; Koh, Perumal and Kok, 2024). Moreover, hydraulic systems responsible for lifting the tailgate must be designed to deliver sufficient force to sustain operational loads without compromising stability (Tyflopoulos and Steinert, 2020; He *et al.*, 2024).

Although various studies have discussed general frame optimization and material comparisons, research specifically addressing tailgate frame arm optimization for Indonesian commercial trucks remains limited (He *et al.*, 2024). Few studies combine analytical calculations, FEA simulation, material evaluation, and regulatory compliance into a single integrated framework (Özden and Gökçe, 2023). Therefore, this study aims to analyze and compare two tailgate frame arm type A designs and type B models using both Altair Inspire and ANSYS. The analysis includes material selection (ASTM A36, Aluminium 7075-T6, and Stainless Steel AISI 304), structural performance evaluation, hydraulic force calculations, clearance conformity, and weight-cost considerations (Mohiuddin and Khan, 2020). The novelty of this research lies in its holistic approach, integrating topology optimization, detailed FEA, analytical mechanical calculations, and regulatory assessment

to produce a comprehensive and optimized tailgate design suitable for double/engkel commercial trucks (Ferede, 2020).

In this study, the term “double commercial truck” refers to medium duty trucks commonly used in Indonesian logistics operations. The main structural component analyzed is referred to as the “tailgate frame arm,” which functions as the primary load bearing element of the tailgate lift system. Two configurations are investigated: the original design (Type A) and the optimized design (Type B).

2. METHODOLOGY

The methodology of this study consists of analytical calculations, 3D modeling, optimization design, and finite element validation. The overall workflow integrates Altair Inspire simulations with material and regulatory evaluations to compare the type A and type B tailgate frame arm designs.

The applied load of 650 kg represents the maximum typical operational load encountered during tailgate lifting activities in commercial truck applications. This value was selected to reflect conservative working conditions while ensuring compliance with safety margins commonly adopted in tailgate system design.

2.1. Research Workflow

Figure 1 shows a flowchart for a systematic research strategy that is often used in engineering design and analysis. The process begins with identifying and defining the problem, which is the foundation for the whole study. Following this, there are two activities happening at the same time: a literature study and field research that includes observation and interviews.

The first steps are meant to gather important background information and useful tips. After that, data is collected, focusing on two main things: acquiring design data for the current tailgate arm (A) and getting the right material properties. After then, the evaluation and choice of a new product idea for the tailgate arm (B) takes place. This is necessary for innovation and improvement. The next step is to use CAD software to create a digital model of the new design. After that, the design must be checked against the target specifications. If the design doesn't meet the requirements, the process goes back to the redesign step. After getting the green light, the workflow moves on to calculations that use simulation tools and stress analysis to check the strength of the structure. A key decision point checks to see if the calculated stresses are within the material's limits. If not, the process goes back to the modeling stage. Once all the requirements are met, the study moves on to analysis and discussion, which leads to the conclusion and finalization of the research. This meticulous technique makes sure that the design is strong, safe, and meets all the requirements.

2.2. Vehicle Stability Analysis

Vehicle stability during tailgate operation is evaluated using the lever equilibrium principle:

$$W \cdot Lb = F \cdot Lk \quad (1)$$

where W is Vehicle weight (kg); L_b = Distance from center of mass (m); and L_k is Lever arm distance (m).

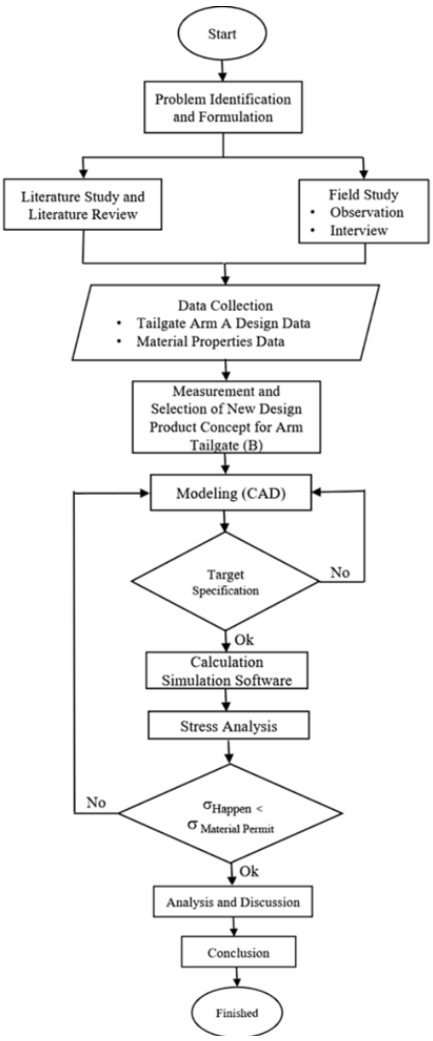


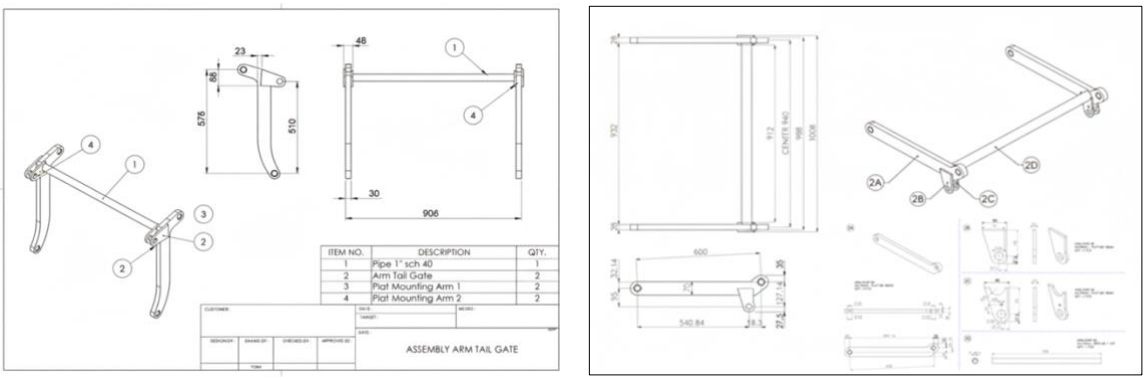
Figure 1. Research workflow diagram

2.3. 3D Modeling and Geometric

AssessmentType A and Type B frame arm designs were modeled using CAD software. Key parameters include:

1). Cross-sectional geometry (rectangular hollow profile)
2). Material selection: ASTM A36, Aluminium 7075-T6, Stainless Steel AISI 304
3). Tailgate hinge position and load distribution
4). Clearance measurement against the truck bed

Figure 2a illustrates the detailed geometry of the type A tailgate frame arm design, including the main arm structure, hinge locations, and mounting points. The drawing shows that the type A configuration uses a conventional rectangular hollow section with a symmetrical arm layout. The hinge and pivot points are positioned closer to the tailgate platform, which affects the load path distribution and contributes to higher displacement under loading conditions, as later confirmed in the simulation results (Fan *et al.*, 2025). The dimensions shown in the drawing also indicate that the frame arm has limited stiffness reinforcement, which becomes one of the constraints in meeting the clearance requirement of <200 mm.



(a). Type A (b). Type B

Figure 2. Tailgate frame arm design

Figure 2b presents the geometric configuration of the type B tailgate frame arm design, which features an updated arm layout and optimized hinge placement. Compared to type A, the type B design incorporates a wider base, longer lever arms, and improved triangulation, resulting in better load distribution and increased structural stiffness. The detailed dimensions shown in the drawing highlight the addition of reinforcement elements that reduce overall deformation during lifting operations. This improved geometry is one of the key factors enabling the type B model to meet the Indonesian Ministry of Transportation's clearance requirement of <200 mm and achieve superior structural performance in the simulation results.

2.4. Simulation Using Altair Inspire

Altair Inspire was used for optimization design and initial structural simulation. Table 1 shown the simulation parameters for tailgate frame arm design analysis. The output of simulation includes Von Mises stress distribution, Total displacement, Safety factor, and Optimized geometry recommendations.

Table 1. Simulation parameters

No	Parameter	Value
1.	Load	650 kg
2.	Boundary conditions	Fixed hinge and pin joints
3.	Mesh type	Adaptive tetrahedral
4.	Objective	Minimize displacement

2.5. Altair Inspire Static Structural Validation

Altair Inspire provides detailed validation using Finite Element Analysis (FEA):

1). Boundary conditions:
   a. Pivot joint modeled as a fixed or frictionless hinge
   b. Load distributed on tailgate platform
   c. Material models applied based on standard mechanical properties

2). Mesh settings:
   a. Element type: tetrahedral
   b. Mesh refinement: fine at stress concentration regions

3). Evaluation criteria:

a. Von Mises stress
b. Total deformation
c. Equivalent elastic strain
d. Safety factor based on yield strength

2.6. Mesh and Model Validation

To ensure the reliability of the finite element model, mesh refinement was applied in regions with high stress gradients, particularly near hinge connections and load application areas. Mesh sensitivity was evaluated to confirm convergence of displacement and stress results. Additionally, the simulation outputs were compared with analytical calculations based on lever equilibrium and material yield strength, showing consistent trends and validating the numerical model.

3. RESULTS AND DISCUSSION

This section presents the results of analytical calculations, Altair Inspire simulations, Altair Inspire structural validation, material comparison, cost evaluation, and regulatory compliance assessments. All data correspond to the 2015 and 2024 tailgate frame arm designs under a loading condition of 650 kg. All displacement values are reported in millimeters (mm), stress values in megapascals (MPa), and clearance measurements in millimeters (mm).

3.1. Altair Inspire Structural Simulation Results

The results of the stress and displacement evaluation for both designs are summarized in Table 2. Table 2 displays the simulation outcomes for frame arms fabricated from three distinct materials—ASTM A36, Aluminium 7075-T6, and Stainless Steel 304—across two frame configurations, A and B. Three critical parameters were assessed: maximum Von Mises stress, displacement, and safety factor.

Table 2. Frame arm simulation results

Simulation	Type Frame	Material		
		ASTM A36	Aluminium 7075-T6	Stainless Steel 304
Max Von Mises Stress (MPa)	A	26.40	25.58	26.40
	B	38.27	38.99	38.27
Displacement (mm)	A	0.0189	0.0500	0.0190
	B	0.0160	0.0446	0.0170
Safety Factor	A	10.8	16.0	8.1
	B	7.4	10.6	5.6

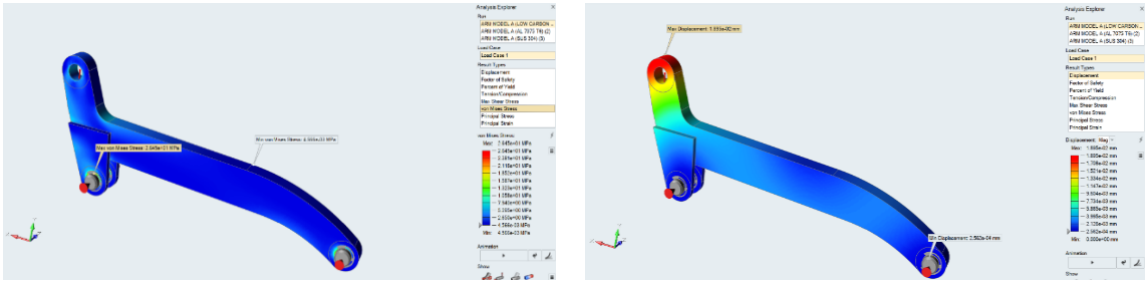
Frame A demonstrates comparable maximum Von Mises stress values of 26.40 MPa for ASTM A36 and Stainless Steel 304, although Aluminium 7075-T6 registers a little lower value of 25.58 MPa. In Frame B, Aluminium 7075-T6 exhibits the maximum stress at 38.99 MPa, whereas both ASTM A36 and Stainless Steel 304 register at 38.27 MPa. This signifies that Frame B typically endures greater stress than Frame A, irrespective of the material used.

Displacement values exhibit notable disparities among the materials. Aluminium 7075-T6 has the greatest displacement for both frame types (0.0500 mm for A and 0.0446 mm for B), signifying its

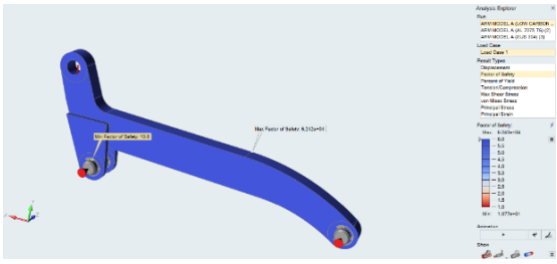
superior flexibility under load. ASTM A36 and Stainless Steel 304 exhibit comparable and lower displacement values (about 0.0189-0.0190 mm for A and 0.0160-0.0170 mm for B), indicating a stronger structural response.

The safety factor indicates the materials' capacity to endure loads prior to failure. Aluminium 7075-T6 offers the greatest safety factor for both frame types (16.0 for A and 10.6 for B), rendering it the safest material of the three. ASTM A36 is succeeded by values of 10.8 and 7.4 for frames A and B, respectively. Stainless Steel 304 exhibits the lowest safety factors, recorded at 8.1 for Frame A and 5.6 for Frame B.

In summary, Aluminium 7075-T6 provides enhanced safety margins but incurs greater displacement, whilst ASTM A36 and Stainless Steel 304 exhibit increased stiffness but yield lower safety factors. The selection of material and frame type will consequently rely on the application requirements, balancing rigidity, safety, and permissible deformation.



(a). Von Mises Stress (b). Displacement



(c). Safety Factor

Figure 3. Simulation tailgate frame arm Type A design for ASTM A36 material

Figure 3 shows a detailed look at the Type A tailgate frame arm design, which is made of ASTM A36 material. The finite element analysis (FEA) results are divided into three main groups: Von Mises stress distribution, displacement, and safety factor. Each of these groups gives important information about how well the component works and how safe it is.

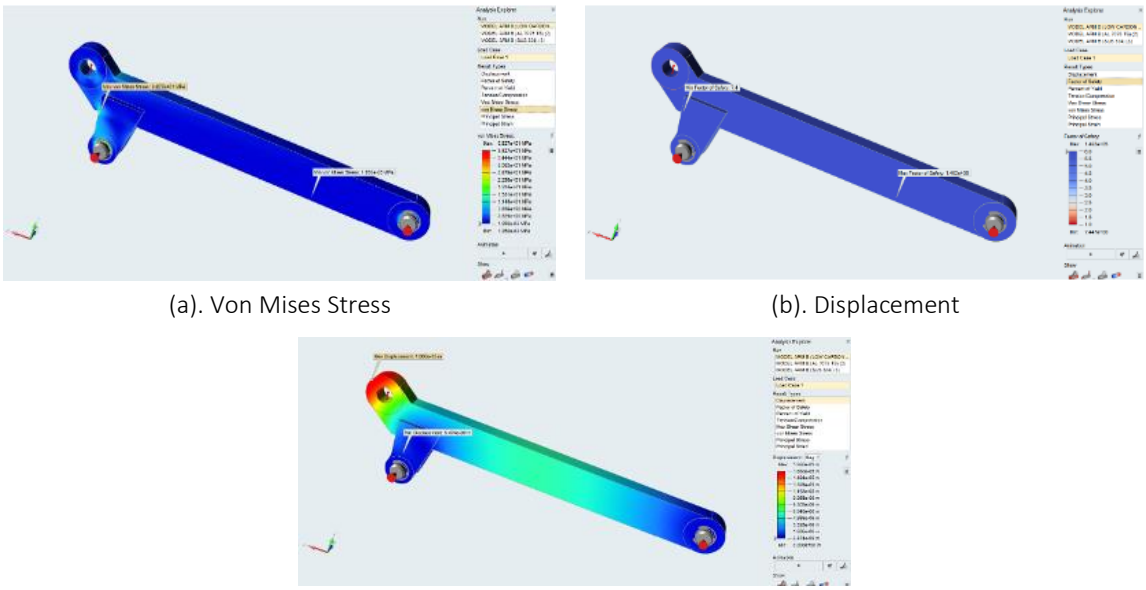
Von Mises stress is a key factor in predicting when ductile materials will yield when they are put under complicated loads. The colour gradient shows on Figure 3a, where the component has the most and least stress. The results show that the mounting points have the highest Von Mises stress, which is about 23.66 MPa. The rest of the structure has much lower stress levels. This shows that the areas around the mounting points are important for possible failure, and the design must make sure that these areas can handle the stresses of operation.

The displacement graph shows on Figure 3b, that the arm's end has a peak value of 1.1134 mm, while the rest of the structure has much smaller deformations. The colour contour helps you find

areas of maximum deflection, which is important for keeping deformation within acceptable limits so that the system stays aligned and works properly. The minimal displacement value means that the structure is strong enough to resist bending or deforming significantly when it is loaded as expected.

The safety factor distribution shows on Figure 3c, a minimum value of 10.3, which is much higher than the standard design threshold, which is usually between 1.5 and 3 in most engineering applications. The high safety factor means that the frame arm is over-engineered for strength, which gives it a lot of protection against failure. This ensures safety and durability, but it could also mean that the design could be improved by using less material while still meeting safety standards.

The simulation results show that the Type A tailgate frame arm, made of ASTM A36 material, is structurally sound, has low stress and movement, and a large safety margin. The results show that the design is suitable for real-world use and highlight the potential for reducing weight and cost in the future.



(a). Von Mises Stress (b). Displacement

(c). Safety Factor

Figure 4. Simulation tailgate frame arm Type B design for ASTM A36 material

Figure 4a shown the stress distribution across the frame arm indicates that the maximum stress concentration is located near the mounting holes and connecting joints, as shown by the red regions. The remainder of the arm has markedly reduced stress levels, shown by the blue hue. The peak Von Mises stress recorded is significantly lower than the yield strength of ASTM A36 steel (about 250 MPa), suggesting that the component is improbable to experience plastic deformation under the simulated loading circumstances. This confirms that the design is robust in terms of withstanding the applied forces without experiencing failure due to yielding. The displacement simulation on Figure 4b, elucidates the deformations encountered by the tailgate frame arm. The findings indicate that the highest displacement is observed at the free end of the arm, as anticipated, as this area is the most distant from the fixed supports. The displacement values, as shown in the colour bar, stay below permissible limits, hence preserving the structural integrity and operational performance of the tailgate. Minimal movement is noted at the mounting points, which is crucial for maintaining

alignment and ensuring tight connection to the vehicle structure. The safety factor analysis is a direct measure of the reliability of the design under the given loading scenario. The safety factor is defined as the ratio of the yield strength of the material to the actual stress it endures as shown on Figure 4c. The minimum safety factor is found at the area of maximum stress (next to the mounting holes), although the total safety factor for the entire arm stays much above one. This guarantees an adequate safety margin, including uncertainties in material characteristics, loading circumstances, and any manufacturing defects. The simulation indicates that the Type B tailgate frame arm design, constructed from ASTM A36 material, has an advantageous stress distribution, little displacement, and a substantial safety factor. These findings validate the design's suitability for its intended purpose, guaranteeing both safety and durability in operation.

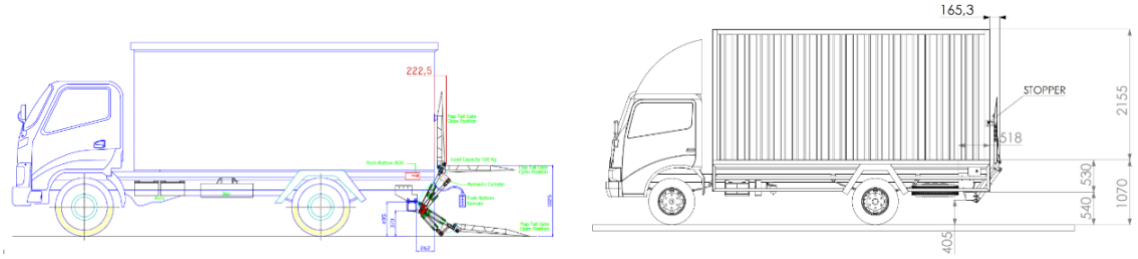
3.2. Comparison Between Type A and Type B Designs Results

The stress analysis for the Type B design shows that the stress levels are higher than normal, but they stay below the acceptable operating limits. This suggests that the materials are being used more efficiently and that there is less overengineering. The Type B frame arm has a 40% smaller displacement than the 2015 construction, which means it is stiffer and better at carrying loads.

The stress comparison for the Type B design shows that the stress values are higher, but they are still within safe operational limits. This finding means that materials are being used better and that overdesign is less common. The Type B frame arm shows a 40% decrease in displacement compared to the 2015 structure in the displacement comparison. This shows that it is stiffer and more efficient at carrying loads.

3.3. Regulatory Compliance Assessment

Figure 5 shown the category A and Type B designs against a regulatory clearance standard and displays compliance with criteria for each category. Clearance for each design is specified in millimeters (mm).



(a). Type A model with gap >200 mm (b). Type B model with gap <200 mm

Figure 5. The allowable clearance between the cargo bed and tailgate

Type A possesses a clearance beyond 200 mm, whilst Type B has a clearance below 200 mm. The table indicates that regulatory compliance is contingent upon whether the clearance is below or over the 200 mm threshold. Type A, having a clearance over 200 mm, is designated as “Not Compliant.” This indicates that regulatory requirements mandate a maximum clearance of 200 mm or less. Any amount beyond this level fails to satisfy regulatory standards, resulting in a non-compliant status. Conversely, Type B, with a clearance under 200 mm, is designated as “Compliant,” signifying its adherence to regulatory standards. This evaluation is crucial for design validation and quality

assurance, particularly in sectors where safety, accessibility, or operational requirements are regulated by governing authorities. Organizations may utilize these evaluations to promptly detect and rectify non-compliant designs, so guaranteeing that only sanctioned and safe goods or constructions are executed. Figure 5 shown the interpretation of compliance status for stakeholders, such as engineers, regulatory inspectors, and project managers, without requiring intricate technical explanations (Thavamani, Devaradjene and Yogeshkumar, 2014). It underscores the significance of complying with regulatory requirements throughout the design process and delineates the repercussions of noncompliance.

4. CONCLUSION

This study evaluated and compared the structural performance of type A and type B tailgate frame arm designs for double trucks using analytical calculations and Altair Inspire simulations. The results show that type B design provides superior structural efficiency compared with type A configuration. The improved geometry delivers lower displacement, better load distribution, and reduced structural mass across all evaluated materials.

Among the three materials studied, Aluminium 7075-T6 demonstrates the best strength-to-weight performance and exhibits the lowest deformation, making it highly suitable for lightweight tailgate applications. However, ASTM A36 remains the most economical and practical option for commercial scale manufacturing because it offers an adequate safety factor and low material cost. Stainless Steel AISI 304 also performs safely but is less efficient due to its higher density and moderate yield strength.

Regulatory assessment indicates that only type B frame arm design complies with the Indonesian Ministry of Transportation's clearance requirement (<200 mm), confirming its feasibility for real-world application. The use of Altair Inspire proved effective for structural evaluation, including stress, displacement, safety factor, and material efficiency analysis, enabling a streamlined and data driven optimization workflow.

Overall, the optimized type B tailgate frame arm is structurally stronger, lighter, more efficient, and fully compliant with national regulations. Therefore, it is recommended as the preferred design for future tailgate development and implementation in double commercial trucks.

Despite these findings, this study is limited to static loading conditions and does not account for fatigue behavior, dynamic loading, or experimental validation. Future work is recommended to include fatigue life assessment, dynamic simulation under real operating conditions, and physical testing to further validate the optimized design.

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