# MINI-SCALE WINDTUNNEL DESIGN USING SOLIDWORKS

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**Abstract.** *Wind tunnels are essential facilities in aerodynamic studies to provide controlled airflow for testing aerodynamic performance. This study aims to design a mini-scale wind tunnel using SolidWorks as a practical solution for laboratories with limited space and budget. The design consists of a contraction, test section, and diffuser with a total length of 1 m and height and width of 0.25 m. Airflow analysis was conducted using the continuity and Bernoulli equations to evaluate velocity and pressure distribution. Structural strength analysis using Finite Element Analysis (FEA) shows a maximum displacement of 0.0016 mm, maximum strain of* $1.4\times10^{-5}$*, and a minimum factor of safety (FoS) of 4.4. However, a maximum stress of 571 MPa at the front joint exceeds the ASTM A36 yield strength (250 MPa), suggesting the need for design reinforcement with gusset plates. These results indicate the design's effectiveness with additional structural optimization.*

**Keywords**: *ASTM A36; Finite Element Analysis; Miniature Design; SolidWorks, Wind Tunnel*

## 1. INTRODUCTION

In the field of engineering and technology, particularly in the study of aerodynamics, wind tunnels are a crucial tool for testing. They generate controlled airflow, allowing the behavior of airflow around test objects such as vehicle models, airplane wings, and even building structures to be observed and analyzed. With wind tunnels, researchers and students can study the distribution of pressure, lift, drag, and turbulence before a design is realized into a concrete prototype.(Idris, 2019).

The benefits of using wind tunnels are enormous, especially for research and educational purposes. Wind tunnels help provide real, measurable experimental data, allowing theories learned in class to be demonstrated in practice.(Leni et al., 2023). Furthermore, wind tunnels can be used to validate initial product designs, detect potential aerodynamic issues, and refine designs for greater efficiency before production, ultimately saving costs and time.

However, despite its significant benefits, many campuses, laboratories, and educational institutions often face challenges: the high cost of constructing large-scale wind tunnels. Furthermore, large-scale wind tunnels require extensive space and require complex construction designs, making them difficult to implement in campus environments with limited budgets and space. Furthermore, wind tunnels remain essential to support learning and research processes (Tajuddin et al., 2022).

One solution to this problem is to design a mini-scale windtunnel. Despite its smaller size, a mini-scale windtunnel can still provide the experimental data and understanding of basic aerodynamic concepts needed by students and novice researchers. With its more compact size and more affordable cost, a mini-scale windtunnel can be an effective learning tool, especially in campus laboratories (Yuniarti et al., 2023).

The design process for a mini-scale windtunnel can be more efficient and accurate with the help of CAD-based design software, such as SolidWorks. With SolidWorks, the design can be visualized in detail in three dimensions, complete with measurements, air duct designs, and construction structures. Furthermore, SolidWorks also supports preliminary simulations, allowing for predictions of how airflow will operate within the windtunnel before it is physically constructed (Afnison & Alwi, 2019).

The title "Mini-Scale Windtunnel Design Using SolidWorks" was chosen because of the importance of providing affordable and easy-to-build aerodynamics research and practical tools. Furthermore, the use of SolidWorks software reflects technological advancements that increasingly facilitate the design, visualization, and simulation processes, meeting the needs of today's education sector (Chadry et al., 2023).

Through this design, it is hoped that a mini-scale wind tunnel model can be created that will not only be useful for supporting teaching and learning activities but also serve as a reference or basis for further development of test equipment. Thus, this research has not only academic value but also practical value for education and research in mechanical engineering and other related fields.

## 2. LITERATURE REVIEW

### *2.1 Design in Engineering*

Design is one of the fundamental stages in the engineering process, which aims to translate functional requirements and technical constraints into a product or system that can be implemented.(Leni et al., 2023)In the field of mechanical engineering and aerodynamics, design not only acts as an intermediary between theoretical concepts and physical realization, but also as a means to evaluate, optimize, and predict product performance before the manufacturing process is carried out (Sastrawan et al., 2021).

The engineering design process generally begins with identifying needs and specifications, followed by concept design, detailed modeling, and validation and technical documentation. These stages help ensure that the final product meets functional, aesthetic, ergonomic, cost-effective, and maintainable criteria (Waruwu, 2024).

The development of computer-aided design (CAD) technology has also revolutionized the way engineers design products. The use of CAD software like SolidWorks allows designers to accurately visualize three-dimensional models, evaluate dimensional and geometric fit, and perform preliminary simulations of mechanical and aerodynamic aspects. This not only increases the efficiency of the design process but also minimizes the risk of errors during production (Suharso et al., 2023).

In the context of designing a mini-scale windtunnel, the design process plays a key role in determining the dimensions of the test chamber, the configuration of the flow channels, and the layout of the fans and turbulence dampers, in order to produce a stable and representative airflow. The selection of a systematic design method and the use of CAD tools are crucial to ensure that the mini-windtunnel still fulfills its aerodynamic function despite its size and cost limitations.

### *2.2 WindTunnel*

A wind tunnel is one of the most important experimental devices in the fields of aerodynamics and fluid engineering. Its primary function is to generate controlled airflow that can be used to study the interaction between fluids and test objects, such as model vehicles, aircraft wings, or structural elements. Through a wind tunnel, important aerodynamic parameters such as lift, drag, pressure distribution, and flow behavior around an object can be systematically measured and analyzed (Widyantoro & Wahudin, 2024).

In general, wind tunnels are classified into two main types: open-circuit wind tunnels and closed-circuit wind tunnels. Open-circuit wind tunnels have simpler designs and lower construction costs because the airflow is drawn directly from the environment and discharged back into the environment. This type is well suited for laboratory-scale education or basic research, where the main focus is flow visualization and basic force measurement. In contrast, closed-circuit wind tunnels allow for recirculation of the airflow within a closed channel, thus producing higher velocities and more stable flow distribution, although at a higher construction cost (Purwanto et al., 2022).

Wind tunnels play a strategic role in supporting design research and development. With the experimental data obtained, designers can validate the results of theoretical calculations or numerical simulations, detect potential design issues, and optimize the geometric shape of an object for greater aerodynamics. Furthermore, in education, wind tunnels serve as an effective visual aid for explaining concepts such as streamlines, turbulent regions, and differences in pressure distribution on the surface of a test object (Firmansyah et al., 2023).

The design of a mini-scale wind tunnel in the context of this research aims to provide a test tool that is affordable, easy to manufacture, and still capable of producing airflow that is representative enough for basic learning and research purposes. Despite its limited size and speed, the mini wind tunnel can be used to conduct qualitative and quantitative tests, such as visualizing flow patterns, measuring simple drag forces, and introducing basic aerodynamic phenomena to students or novice researchers (Azzahra et al., 2024).

### *2.3 SolidWorks*

SolidWorks is a computer-aided design (CAD) software widely used in mechanical engineering, product design, and aerodynamics. Based on 3D modeling, SolidWorks allows designers to visualize in detail the shape, dimensions, and relationships between components of a product before creating a physical prototype (Kurniawan et al., 2022).

SolidWorks' strength lies in its ability to support the entire design process, from concept design and 3D modeling to technical drawings, through to simulation and initial analysis. In the context of wind tunnel design, SolidWorks' Flow Simulation feature can be used to estimate airflow behavior within a wind tunnel, visualize velocity and pressure distributions, and detect potential flow disturbances before the physical fabrication process begins (Lestari et al., 2022).

The use of CAD software like SolidWorks plays a crucial role in improving design efficiency and accuracy. Using SolidWorks can shorten design iteration times, facilitate model modifications when specifications change, and produce more structured technical documentation.(Furqani et al., 2022). In addition, three-dimensional visualization capabilities also help design teams and non-technical parties understand designs more intuitively (Thoharudin et al., 2023).

## 3. RESEARCH METHODS

This research aims to design a mini-scale wind tunnel that can be used as a practical tool and for basic aerodynamics research. The design engineering method used combines literature studies, CAD-based design modeling, design analysis, and validation to ensure the design meets its intended function. This approach is expected to produce a design that is not only theoretically feasible but also suitable for implementation as a test prototype.

This research goes through several stages as shown in the research scheme below:


**Figure 1.** Research Scheme (Source: Authors, 2025)

The explanation of the research scheme above is as follows:

1. Literature Study

The initial stage of the research began with the collection of references related to wind tunnels, basic aerodynamic concepts, and computer-aided design methods. The sources reviewed included aerodynamic engineering textbooks (such as Anderson, 2010), machine design literature, and standard documents and publications related to the use of CAD software. The literature study aimed to strengthen the researcher's understanding of Wind Tunnel functions, the type of wind tunnel suitable for mini-scale, and important design parameters such as flow velocity, test chamber dimensions, and comparison of inlet and outlet shapes.

2. Design

The next stage was the design process for a mini-scale wind tunnel using SolidWorks software. The design began with a two-dimensional sketch to determine the basic configuration, then developed into a three-dimensional model containing the main components: an inlet (contraction cone), a test section, an outlet (diffuser), a fan, and a turbulence damper (honeycomb). During this process, consideration was given to the limitations of the laboratory's size and material availability to ensure the design remained realistic for prototyping.

3. Design Analysis

After the 3D model was completed, a design analysis was performed using the Flow Simulation feature in SolidWorks. This analysis aimed to predict the distribution of airflow velocity, check for potential excessive turbulence, and evaluate whether the test chamber design produced a relatively stable flow, meeting the test objectives. The airflow in the wind tunnel was then analysed using equations 1 and 2. During contraction, the cross-sectional area decreases, increasing air velocity.

$A1V1 = A2V2$...(1)

where: A1 = inlet cross-sectional area ($m^2$),
A2 = cross-sectional area of the test section ($m^2$)
V1 = air velocity at inlet (m/s),
V2 = speed in test section (m/s)

$P1 + \frac{1}{2}\rho V_1^2 = P2 + \frac{1}{2}\rho V_2^2$...(2)

4. Results and Discussion

This stage includes the interpretation of the airflow simulation results in the designed mini windtunnel. Velocity contours and flow direction are visualized for each main section, namely the contraction cone, test chamber, and diffuser. The results show a relatively uniform flow pattern in the test chamber with velocities close to the target values. Several areas indicating the potential for vortex formation or flow instability are also analyzed as a basis for design evaluation. The discussion focuses on the suitability of the results with basic aerodynamic theory and the effectiveness of the geometry applied in the design. This analysis also compares variations in results based on small changes in component dimensions or shape.

5. Validation of Results

To ensure the accuracy of the simulation results, validation was performed by comparing the numerical data from the simulation with experimental data from previous studies with comparable parameters. The main references came from journals and experimental studies such as those conducted by Barlow et al. (1999) in small-scale subsonic wind tunnel testing. Comparisons were made on the parameters of maximum velocity in the test chamber, pressure distribution, and flow stability. The validation results showed that the deviation between the simulation and reference data was still within the engineering tolerance limits, indicating that the design and simulation are reliable for initial prototype purposes.

6. Finish

The research concludes with conclusions drawn from all stages and recommendations for further development. The conclusions confirm that the designed mini wind tunnel has aerodynamic performance that is both theoretically and simulated. Recommendations are directed at the physical prototype fabrication stage and direct experimental testing to improve design validity. Furthermore, it is recommended to improve the precision of the honeycomb and fan control to improve flow stability. Complete documentation of the design and simulation results is prepared as a technical reference in the future prototype fabrication and testing process.

## 4. RESULTS AND DISCUSSION

### *4.1 Results*

Design planning is essential in concept development, especially in the construction of a wind tunnel. Wind tunnels themselves are useful as test equipment in the form of closed or open channels designed to produce controlled airflow through a test object, so that aerodynamic phenomena in the object can be observed, measured, and analyzed. From all the studies, the design results for a mini-scale wind tunnel were obtained.

1) Diffuser manufacturing calculations

To determine the diffuser size, you need to know the fan size. The fan used is a 6" fan with an outlet wall of 17.5 cm.

$$A_{out} = s_{out}^2 = (0{,}175)^2 = 0{,}03063 m^2$$

$$A_{inlet} = \frac{A_{out}}{1{,}2} = \frac{0{,}03063}{1{,}2} = 0{,}02552\ m^2$$

$$\Delta^s = s_{out} - s_{in} = 0{,}175 - 0{,}159 = 0{,}0152\ m \rightarrow \frac{\Delta^s}{2} = 0{,}0076\ m$$

Opening angle

$$\tan(0{,}87^\circ) = 0{,}0152$$

Diffuser Length

$$L = \frac{(s_{out} - s_{in})/2}{\tan(0{,}87^\circ)}$$

$$L = \frac{0{,}0076}{0{,}0152} = 0{,}5\ m = 50cm$$

The length we use is 0,5m or 50 cm

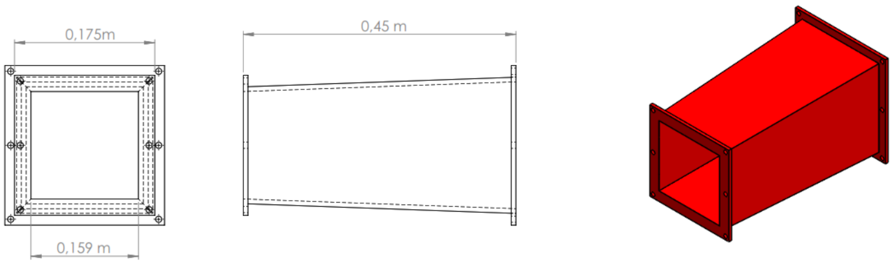


**Figure 2.** Diffuser (Source: Authors, 2025)

2) Test Section Calculation

Because we want a stable flow, the inlet and outlet areas use the same ratio of 1:1, measuring 15.9 with a length of 50cm.

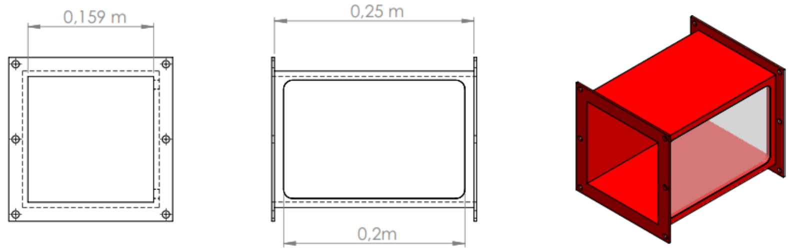


**Figure 3.** Test Section (Source: Authors, 2025)

3) Contraction Calculation

Area Contraction

$A_{in} = s_{in}^2 = (0{,}25)^2 = 0{,}0625m^2$

$A_{outlet} = s_{out}^2 = (0{,}159)^2 = 0{,}02552\ m^2$

Contraction area ratio

$\text{CR} = \frac{A_{in}}{A_{out}} = \frac{0{,}0625}{0{,}02528} = 2{,}47$

$\Delta^s = s_{in} - s_{out} = 0{,}25 - 0{,}159 = 0{,}091\ m \rightarrow \frac{\Delta^s}{2} = 0{,}0455\ m$

Opening angle

$\tan(5{,}2^\circ) = 0{,}091$

Long Contraction

$$L = \frac{\Delta s/2}{tan(\theta)} = \frac{0{,}0455}{0{,}091} = 0{,}5\ m = 50\ cm$$

So the size of the inlet contraction is 27.5 cm with an outlet of 15.9 cm which has a length of 50 cm.

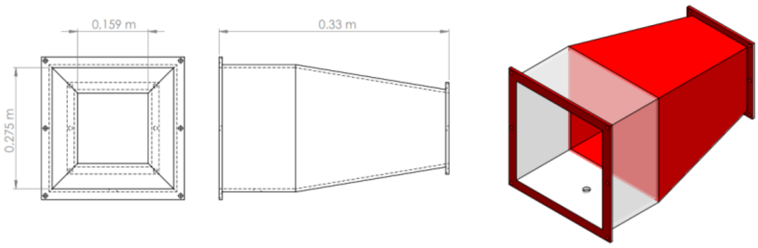


**Figure 4.** Contraction (Souce: Authors, 2025)

After calculating everything for the design, a concept is created with 3D modeling as in the example.

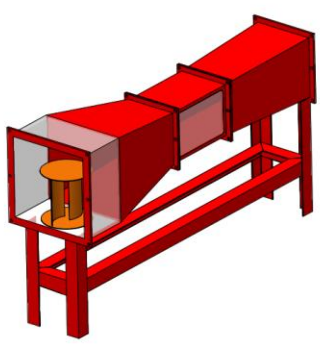

**Figure 5.** Win Tunnel design results (Souce: Authors, 2025)

In addition, the wind tunnel support frame was designed using ASTM A36 steel in the form of an angle profile with a thickness of 3 mm. This material was selected based on its good mechanical properties, including adequate tensile strength and yield strength for laboratory-scale structural applications. The results of the Finite Element Analysis (FEA) analysis on the frame showed that the structure with ASTM A36 material was able to withstand static and dynamic loads during operation, thus ensuring the strength and stability of the entire system. ASTM A36 was also selected due to its ease of fabrication through cutting, welding, and assembly processes, as well as its relatively economical cost. The complete specifications of ASTM A36 material are presented in Table 2.

**Table 2.** ASTM A36 Specification

| ASTM A36 Specification | Mark |
|---|---|
| Yield Strength (σy) | 250 MPa |
| Tensile Strength | 400–550 MPa |
| Modulus of Elasticity (E) | 200 GPa |
| Density (ρ) | 7.85 g/cm$^3$ |
| Minimum Elongation | 20% |

(Souce: Authors, 2025)

The frame structure is equipped with cross bracing to strengthen the rigidity against dynamic vibrations from a 6-inch diameter fan. The frame strength of this wind tunnel design was tested using Finite Element Analysis (FEA) simulation. The results of the Finite Element Analysis (FEA) simulation on the wind tunnel frame with ASTM A36 steel material are shown in Figure 3 to Figure 6. This analysis aims to determine the structural response to static loads, which include stress distribution (von Mises stress), displacement, strain, and safety factor (Factor of Safety, FoS). The results of this simulation serve as the basis for evaluating whether the frame meets the design criteria that are safe and suitable for use in wind tunnel applications.

1. Von Mises Stress

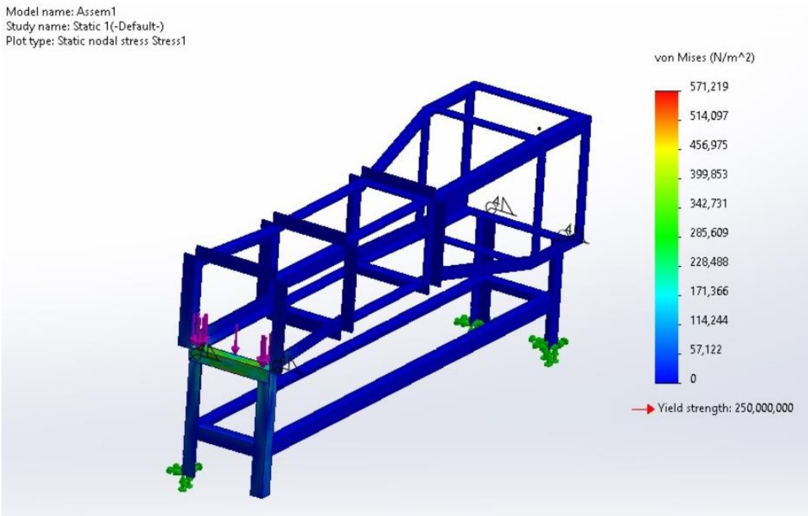


**Figure 3.** Von Mises Stress (Souce: Authors, 2025)

The von Mises stress distribution in the frame is shown in Figure 3. Based on the simulation results, the maximum stress value occurs at the front frame connection that supports the test section and fan housing. The highest stress value detected is 571.219 N/m² (571 MPa), indicated by the red color gradation in the image. This value is greater than the yield stress of ASTM A36 steel material which is 250 MPa. This condition indicates that at that point the structure is at risk of plastic failure, where the material will experience permanent deformation if the load continues to be increased, the minimum stress value is close to 0 N/m², indicated by the blue color in parts of the frame that are not directly affected by the load, such as the bottom side of the frame far from the connection. The significant difference in stress values between the maximum and minimum points indicates a stress concentration at the connection that requires special attention in the redesign. From a design perspective, these results indicate that although most frames are able to withstand the load well, the front connection should be strengthened by adding gusset plates or larger structural profiles to reduce stress concentration.

2. Displacement

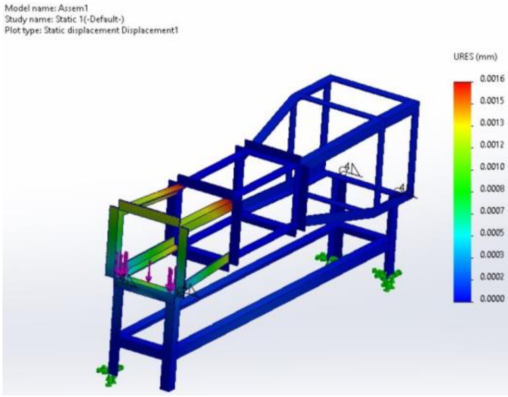


**Figure 4.** Displacement (Souce: Authors, 2025)

The distribution of total displacement is shown in Figure 4. The simulation results show that the maximum displacement occurs at the top of the front end of the frame with a value of 0.0016 mm (shown in red). This value is very small when compared to the geometric tolerance of the wind tunnel components, so it will practically not interfere with the stability or precision of the test section position. The minimum displacement (in blue) of 0 mm is at the frame legs that are designated as fixed supports. This result is in accordance with expectations because these points are defined as supports that do not experience translational or rotational movements. This very small displacement throughout the structure confirms that the frame has good structural stiffness (high stiffness), so it is able to maintain its original shape when receiving operational loads.

3. Strain

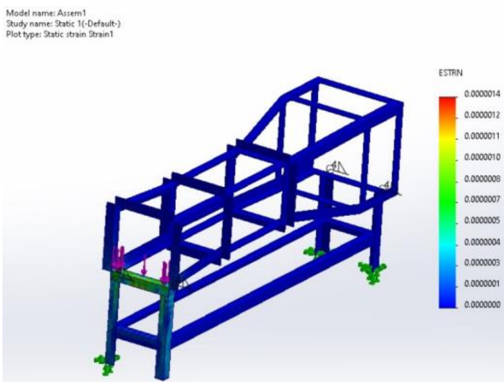


**Figure 5.** Strain (Souce: Authors, 2025)

The distribution of strain due to load can be seen in Figure 5. The maximum strain value recorded was $1.4 \times 10^{-5}$, which is in the same area as the highest stress concentration, namely the front frame connection. This value is still within the elastic limit of ASTM A36 material, so it will not cause permanent deformation (plastic deformation).

The minimum strain value approaching 0 (blue) is found in the frame section that is not subjected to large forces or is located far from the load source. This strain distribution indicates that the majority of the frame operates with very small strains, indicating good structural stability and load-absorbing capacity.

4. Factor of Safety (FoS)

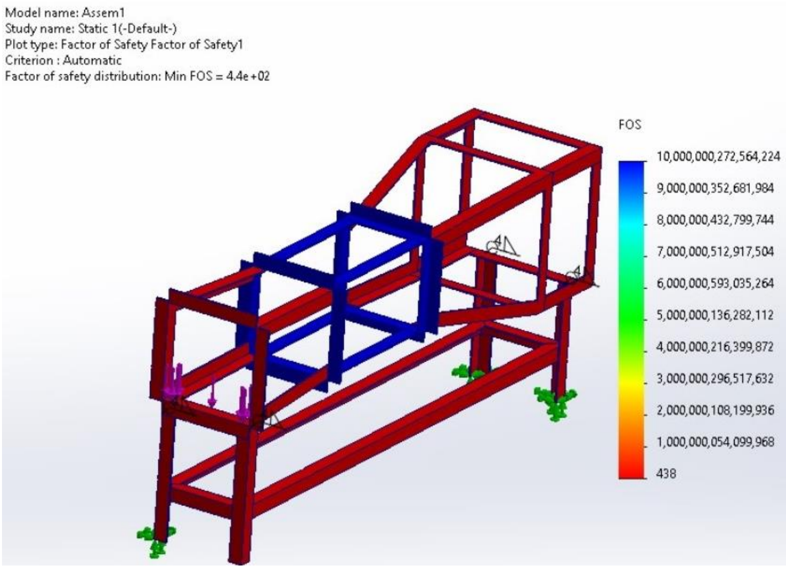


**Figure 6**. Factor of Safety (Souce: Authors, 2025)

The results of the distribution of safety factors are shown in Figure 6. The minimum FoS value is found at the front joint with a value of 4.4 (in blue), while the FoS value in most of the frame is in the very high range, indicated by the red color in the figure. In theory, ASTM A36 steel is used with a minimum safety factor of 2.0 for static load conditions, so the value of 4.4 is still well above that threshold. This indicates that the structure has a fairly large margin of safety against failure. However, it should be noted that the high FoS value in most areas of the frame does not mean optimal material efficiency, because the imbalance in the load distribution makes the front joint a critical point.

*4.2 Validation of Results*

FEA results showed a maximum stress of 571 MPa at the front connection of the wind tunnel frame, significantly exceeding the ASTM A36 yield stress of 250 MPa, indicating a stress concentration phenomenon common in structural gusset plate connections (Persson, 2023; Syed, 2011). However, the maximum strain was only $1.4 \times 10^{-5}$, which is still within the elastic limit, indicates that the structure has not entered the plastic phase, similar to the findings of Hsiao et al. (2012), where plastic strain only appears after the stress exceeds the yield strength of the gusset connection. The minimum safety factor of 4.4 also supports that the structure is still safe, but the distribution indicates a load imbalance that is in line with the improvement strategy widely recommended in the literature review, which involves the addition of gusset plates or stiffeners to reduce stress concentration (Song et al., 2023). Thus, the application of additional gussets or cross bracing is highly recommended to improve stress distribution and increase the structural reliability of this wind tunnel frame.

**CONCLUSION**

Based on the design and Finite Element Analysis (FEA) results, the wind tunnel frame using ASTM A36 material demonstrated good overall structural performance. The maximum displacement recorded was 0.0016 mm and the maximum strain was 1.4 ×

$10^{-5}$ indicates that the majority of the frame area operates within the elastic limits of the material, so it will not experience permanent deformation that could disrupt the wind tunnel's function. However, the analysis results show a significant stress concentration at the front joint of the frame with a maximum stress value of 571 MPa, which exceeds the ASTM A36 yield stress of 250 MPa. This condition indicates the potential for local plastic failure in this area if the operational load increases. The minimum factor of safety (FoS) obtained of 4.4 is still above the standard safety limit for steel structure design (FoS ≥ 2.0), but the uneven distribution of FoS indicates the need for design improvements to distribute the load more evenly. Therefore, it is recommended to add gusset plates or cross bracing at critical joints and consider the use of materials with higher yield stress to improve the reliability and service life of the wind tunnel structure.

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