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# Simulation Analysis of Adjustable Bracket Movement in the Design and Construction of a Water Turbine Simulation Device with Adjustable Bracket System

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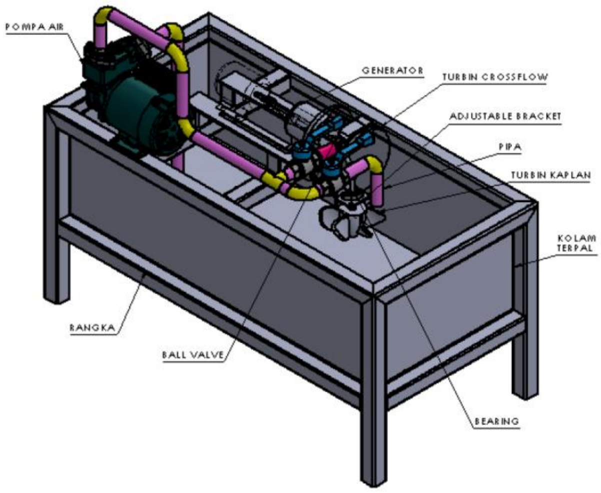


Highlights

- An adjustable bracket with universal joint allows a single device to test both crossflow (impulse) and Kaplan (reaction) water turbines by repositioning the shaft between 90° and 180°.
- SolidWorks 2022 simulation confirmed the SS316 shaft remains structurally safe at both operating positions, with maximum stress well below the material's yield strength.
- Crossflow turbine with half-valve opening achieved the most stable rotation speed at 619 RPM, outperforming the full-opening configuration.
- The device offers a cost-effective and space-efficient laboratory medium for renewable energy education.

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ABSTRACT

This study presents the simulation analysis of the adjustable bracket movement in the design and construction of a water turbine simulation device. The background of this research is the untapped renewable energy potential of hydropower plants in Indonesia, which has not reached its desired target. The aim is to design a water turbine simulation device that is effective, efficient, and adaptive to various types of water turbines. The research methods include document study, device design, simulation using SolidWorks 2022, and device testing. Results show that the adjustable bracket system with a universal joint can adjust the working radius angle of the turbine from 90° to 180°, allowing the combination of multiple simulation tools into one integrated device. Moment analysis on the shaft shows the 90° position (Kaplan turbine) has a higher maximum stress (1.136 ×

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$10^4$ N/m²) but lower maximum displacement (2.342 × $10^{-5}$ mm) compared to the 180° position (crossflow turbine) with stress of 8.687 × $10^3$ N/m² and displacement of 2.775 × $10^{-5}$ mm. Both values remain within safe limits for SS316 material. Actual testing shows the crossflow turbine with a half-opening achieves the most stable rotation (average 619 RPM), while the Kaplan turbine achieves the highest average speed (919 RPM) but with greater variability due to the absence of a flow basin. This simulation tool is expected to serve as a practical learning medium and provide education about the potential of water energy.

## 1. Introduction

The growing global demand for clean and renewable energy has accelerated research into small-scale hydropower systems capable of operating in low-head and low-velocity water environments. Among these systems, water turbines equipped with mechanically adjustable support structures have emerged as a promising solution for maximizing energy extraction across varying hydraulic conditions. These devices allow the turbine rotor to be repositioned relative to the flow stream, enabling operators to optimize the angle of incidence, immersion depth, and spatial alignment without requiring a complete redesign of the installation [1]. Despite the practical appeal of such adjustability, the structural and dynamic behavior of the bracket mechanism responsible for these positional changes remains insufficiently characterized in the literature, particularly under transient loading conditions induced by turbulent water flow.

Indonesia is currently developing new and renewable energy, with the government continuing to demonstrate a strong commitment to advancing renewable energy sources. As of the first semester of 2024 (January–June), the installed capacity of New and Renewable Energy (NRE) power plants reached 217.73 MW, representing approximately 66.6% of the annual target of 326.91 MW [1]. This capacity increase is dominated by hydropower plants (PLT Hidro) and solar power plants (PLT Surya). Hydropower achieved 66.4% of its target, indicating there remains room for further development to reach full capacity [2].

Water turbines are one of the most efficient and environmentally friendly renewable energy solutions. However, their utilization remains limited to easily accessible areas, while many regions with high water flow potential remain untapped due to geographical and technical constraints. A water turbine is defined as a prime mover that uses water as its working fluid, converting potential energy of water into kinetic energy and subsequently into mechanical energy[3].

Water turbines are classified into two main types: impulse turbines and reaction turbines. Impulse turbines, such as the Pelton and Crossflow turbines, operate at equal pressure—the pressure at the nozzle outlet equals atmospheric pressure. The potential energy stored in water at a given height is converted into kinetic energy through a penstock, and the high-velocity jet strikes the turbine buckets, causing rotation[4]. Reaction turbines, such as the Kaplan turbine, feature specially profiled blades that cause a pressure drop as water flows through them. The Kaplan turbine is particularly notable for its adjustable runner blades, which can be modified to suit varying flow conditions at low-head sites[5].

Conventional water turbine simulation tools are typically designed for a single turbine type, which is inefficient in terms of laboratory space and budget. Each turbine type generally requires a dedicated simulation apparatus, making it costly for institutions to test multiple turbine designs. Therefore, there is a need for an adaptive simulation device capable of accommodating multiple turbine types within a single system [6].

The present research addresses this gap by developing a simulation model for an adjustable bracket system integrated into a water turbine simulation device. The study focuses on analyzing the movement behavior of the bracket through multiple angular positions and evaluating the resulting structural response under hydrodynamic loading. The simulation device is designed as an educational and research platform that allows systematic variation of bracket orientation, thereby enabling controlled investigation of how positional changes influence both turbine performance and structural integrity. SolidWorks and ANSYS software platforms are employed for three-dimensional modeling, meshing, and coupled fluid-structural simulation, following methodologies established in recent literature [7-9].

Simulation analysis serves to identify deficiencies in flow patterns, providing a basis for design improvement. Simulation activities are carried out as one of the initial stages in reverse engineering [10]. In this study, SolidWorks 2022 was used to perform motion and structural analysis of the adjustable bracket system prior to physical construction, ensuring the system's mechanical reliability.

This paper presents the design, simulation, and testing of a water turbine simulation device incorporating an adjustable bracket system equipped with a universal joint. The adjustable bracket enables the turbine shaft to be repositioned between 90° and 180° relative to the generator, allowing the same apparatus to test both impulse (crossflow) and reaction (Kaplan) turbines. The universal joint is a critical component that enables smooth power transmission between misaligned shafts [11]. The research aims to contribute to more efficient and cost-effective laboratory learning tools for renewable energy education.

## 2. Methods

The research methodology consisted of four main stages: document study, device design and simulation, physical construction, and device testing.

### 2.1 Document Study

A document study was conducted to gather theoretical and technical information relevant to the design process. Documents reviewed included journals and textbooks on mechanical engineering and renewable energy (particularly water turbine working principles, fluid flow characteristics, and energy conversion), literature on adjustable bracket mechanisms, and previous final project reports related to water turbine simulation apparatus.

### 2.2 Device Design and Simulation

The device was modeled in three dimensions using SolidWorks 2022. The design process followed these steps: (1) two-dimensional sketching based on measured dimensions; (2) three-dimensional modeling using Extrude, Revolve, and Assembly features; (3) motion simulation of the adjustable bracket system; and (4) structural analysis (stress and displacement) of the shaft assembly at two key angular positions (90° and 180°) using the SolidWorks Simulation module. The analysis employed a centrifugal force at 1000 RPM and used SS316 stainless steel as the shaft material (elastic modulus: 193 GPa, yield strength: 200–290 MPa).
The overall device dimensions are 50 cm × 50 cm × 100 cm. The shaft has a diameter of 10 mm and an effective length of 100 mm, supporting a turbine with a mass of 0.1 kg. The shaft moment of inertia and maximum bending stress were calculated analytically as follows:

$$I = \frac{\pi d^4}{64} = \frac{\pi 0.001^4}{64} = 4.9087 \times 10^{-10} m^4 \quad (1)$$

$$\omega = \frac{2\pi N}{60} = 104.73\, rad/s \quad (2)$$

$$fc = m\omega^2 r = 0.1 \times 104.72^2 \times 0.10 = 109.66\, N \quad (3)$$

where I is the second moment of area ($m^4$), d is the shaft diameter (m), F is the applied lateral force (N), L is the effective shaft length (m), c is the distance from the neutral axis to the outer surface (m), and σ is the bending stress (MPa).

### 2.3 Physical Construction

The device frame was fabricated from 45 mm iron plate using welding, grinding, and drilling processes. Key materials and components included: iron plate (4.5 m), welding wire, a 200 W generator, two mini universal joint couplings, a 10 mm shaft, a bore flange bearing, a crossflow turbine propeller (PLA 3D-printed), and a Kaplan turbine propeller (PLA 3D-printed). The water supply was provided by a 220 V electric pump circulating approximately 12,500 $cm^3$ of water in a closed-loop system using a tarpaulin pool.

### 2.4 Device Testing

Three testing configurations were evaluated: (1) crossflow turbine with full valve opening, (2) crossflow turbine with half valve opening, and (3) Kaplan turbine without basin. For each configuration, turbine rotation speed was measured using a digital tachometer (DT-2234C). Measurements were taken five times per configuration, starting

10 seconds after the pump was activated, with readings captured every 5 seconds. The average of five readings was used as the representative RPM for each configuration.

## 3. Results and Discussion

### 3.1 Design and Working Mechanism

The adjustable bracket system is the core innovation of the simulation device. It functions by adjusting the working radius angle of the turbine shaft relative to the generator, enabling the integration of multiple turbine types into a single apparatus. The slotted frame provides stop positions that define the minimum (90°) and maximum (180°) shaft angles. A universal joint connects the turbine shaft to the generator shaft, ensuring smooth torque transmission even when the shaft angle changes. This joint is capable of operating across the full range from 90° to 180° as required[11].

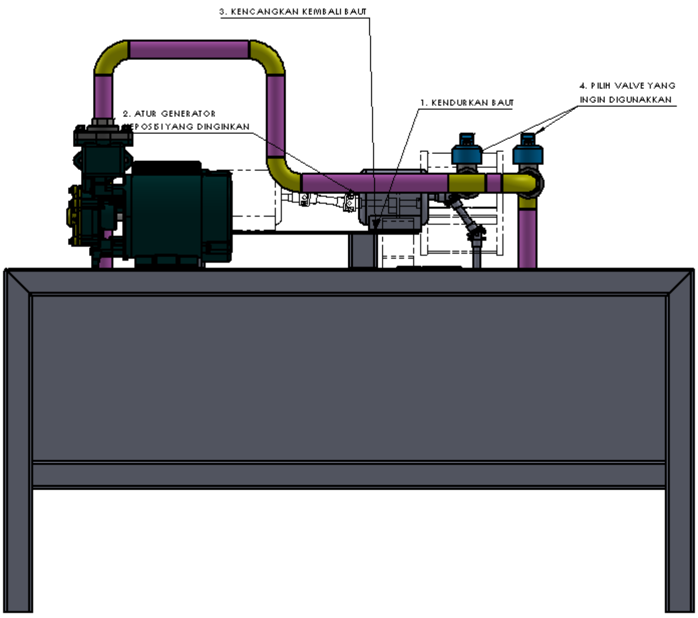



Figure 1. Working Mechanism Adjustable Bracket

The operating procedure as Fig 1. involves: (1) loosening the generator-mounting bolts to allow lateral sliding; (2) repositioning the generator to the desired angle (90° for Kaplan, 180° for crossflow); (3) re-tightening the bolts; (4) attaching the appropriate turbine propeller to the shaft end and securing it with a locking pin; and (5) opening the corresponding ball valve (right valve for reaction turbines, left valve for impulse turbines) and activating the pump.

### 3.2 Shaft Structural Analysis

The shaft was analyzed at two positions representing the two turbine configurations. At 90° (Kaplan configuration), the shaft is aligned parallel to the direction of gravity, making the centrifugal force the dominant lateral load. At 180°

(crossflow configuration), the shaft is perpendicular to gravity, so gravitational force adds to the lateral bending load. Manual calculations yielded the following results:
Kaplan configuration for the 90° position as Fig 2. :
Bending moment:

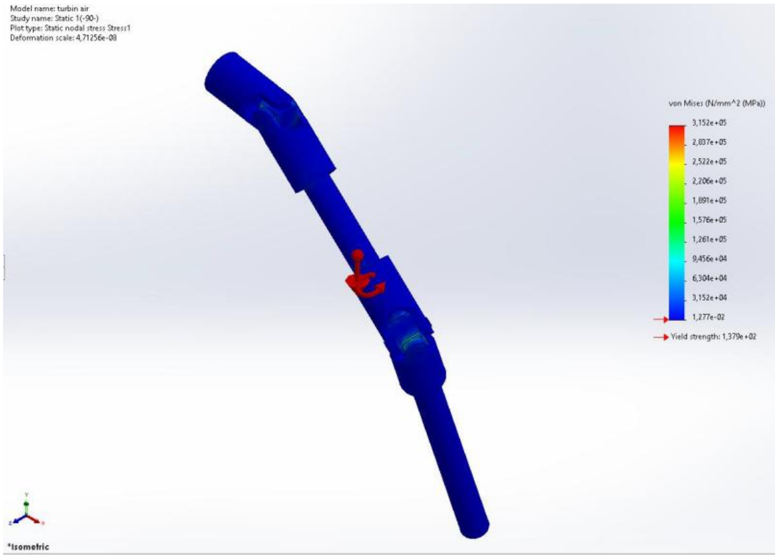
$$M_{90=}FC\ \times L = 190.66\ \times 0.10 = 10.966\ N/m \quad (4)$$

Maximum bending stress:

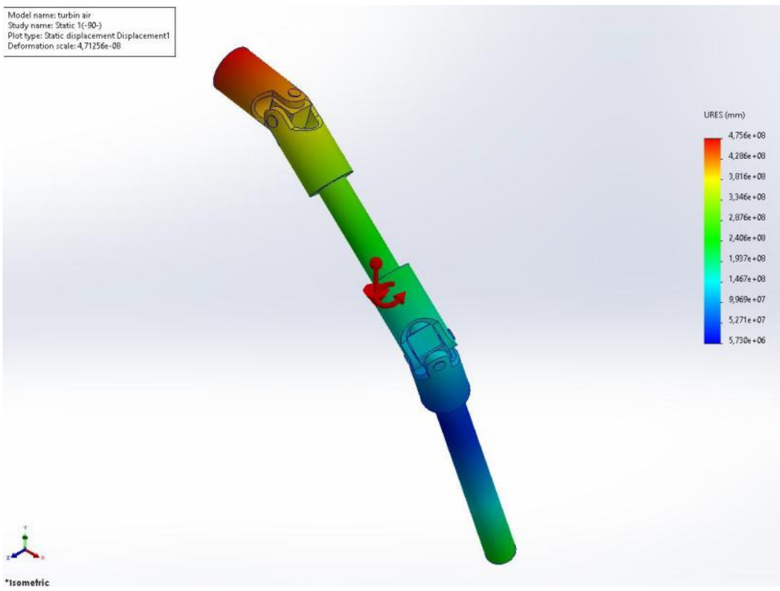
$$\sigma 90 = \frac{M_{90c}}{I} = \frac{10.966\times 0.005}{4.9087\ \times 10^{-10}} = 111.7\ Mpa \quad (5)$$

Tip deflection :

$$\delta 90 = \frac{FcL^3}{3EL} = \frac{109.66\times(0.10)^3}{3\times 193\times 10^3\times 4.9087\ \times 10^{-10}} = 0.3858\ mm \quad (6)$$




(a)




(b)

Figure 2. Kaplan configuration for the 90°: (a) Stress Calculation 90°, (b) Displacement Calculation 90°

Crossflow configuration for the 180° position as Fig 3:

Total lateral force

$$F180 = Fc + Fg = 109.66 + 0.981 = 110.64\ N \quad (7)$$

Bending moment

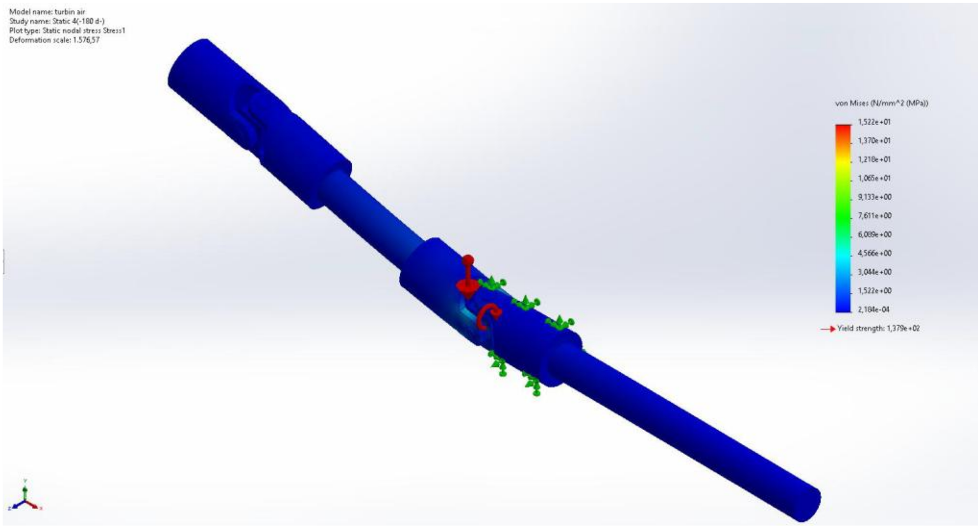
$$M180 = F180 \times L = 11.064\ N/m \quad (8)$$

Maximum bending stress

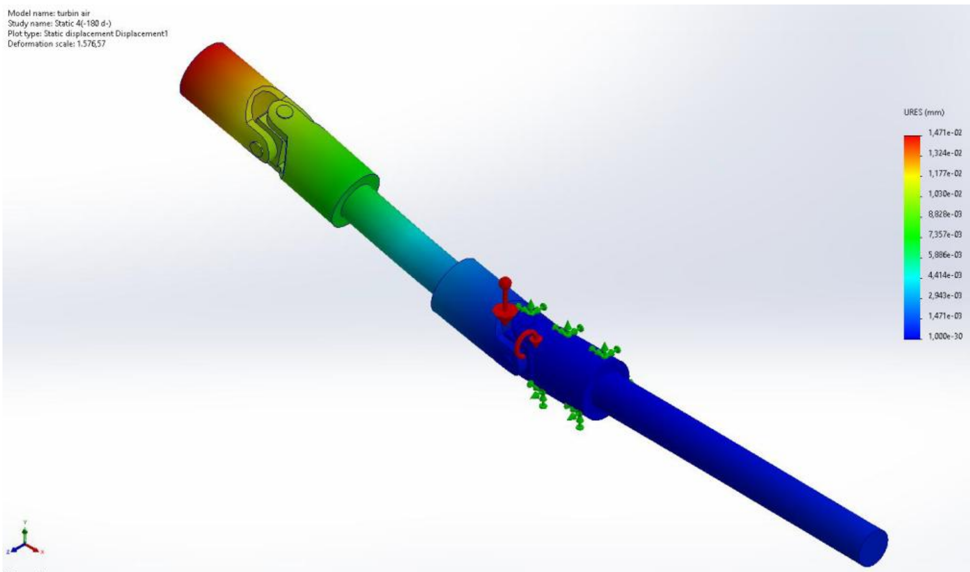
$$\sigma180 = \frac{M_{180c}}{I} = 112.7\ Mpa \quad (5)$$

Tip deflection :

$$\delta90 = \frac{FcL^3}{3EL} = 0.3893\ mm \quad (6)$$




(a)




(b)

Figure 3. Crossflow configuration for the 180°: (a) Stress Calculation 180°, (b) Displacement Calculation 180°

Both calculated stress values (~112 MPa) remain well below the yield strength of SS316 (200–290 MPa), confirming the shaft design is safe under static loading. The SolidWorks software simulation results are summarized in Table 1.

Table 1. Comparison of shaft simulation results at 90° and 180° positions

| No | Calculation | **90° Kaplan** | **180° Crossflow** |
|---|---|---|---|
| 1. | Maximum Stress ($N/m^2$) | $1.136 \times 10^4$ | $8.687 \times 10^3$ |
| 2. | Maximum Displacement (mm) | $2.342 \times 10^{-5}$ | $2.775 \times 10^{-5}$ |

The software simulation results are consistent with the manual calculations in relative terms: the 90° position (Kaplan) exhibits higher maximum stress but lower deformation compared to the 180° position (crossflow). Both stress values remain far below the SS316 yield strength indicated in the simulation ($1.370 \times 10^2$ MPa), confirming the structural safety of the shaft in both operating configurations. The deformation values are extremely small (on the order of $10^{-5}$ mm), indicating the shaft is highly rigid and suitable for laboratory-scale use.

### 3.3 Shaft Structural Analysis

Actual testing was performed for three configurations. Table 2 presents the measured rotation speeds for each trial and the average values

Table 2. Turbine rotation speed testing results (RPM)

| Trial | Crossflow Full (RPM) | Crossflow Half (RPM) | Kaplan (RPM) |
|---|---|---|---|
| 1 | 113.0 | 619.0 | 796.7 |
| 2 | 113.0 | 619.0 | 1899.8 |
| 3 | 113.0 | 619.0 | 987.2 |
| 4 | 113.0 | 619.0 | 1368.7 |
| 5 | 113.0 | 619.0 | 911.6 |
| Average | 113.0 | 619.0 | 919.0 |

The crossflow turbine with full valve opening recorded a consistent average of 113.0 RPM across all five trials. The crossflow turbine with half-opening achieved a significantly higher and equally stable average of 619.0 RPM. This counterintuitive result—higher speed with half opening—can be attributed to the increased water jet velocity resulting from the reduced nozzle cross-section, which concentrates the water flow and improves impulse force on the runner [12].

The Kaplan turbine without a basin achieved the highest average RPM (919.0 RPM) but showed considerable variability between trials (ranging from 796.7 to 1899.8 RPM). This instability is attributed to the absence of a proper flow basin, which is a necessary design requirement for reaction turbines. In a reaction turbine, the runner must be fully submerged in a pressurized water environment to generate consistent reaction forces. Without the basin, the water flow was unconfined, leading to irregular turbine loading[13].

These results validate the effectiveness of the adjustable bracket system: both impulse and reaction turbine configurations operated successfully within the same apparatus, demonstrating the device's adaptability. The crossflow half-opening configuration is recommended for educational demonstrations due to its high and stable RPM output.

## 4. Conclusion

This study successfully designed, simulated, and tested a water turbine simulation device incorporating an adjustable bracket system. The key findings are as follows:

1. The adjustable bracket with universal joint enables the turbine shaft to be repositioned between 90° (Kaplan reaction turbine) and 180° (crossflow impulse turbine), allowing a single apparatus to accommodate two distinct turbine types. This design significantly improves laboratory space efficiency and reduces equipment cost.
2. Structural analysis using SolidWorks 2022 confirmed that the SS316 shaft remains safe at both operating positions. Maximum stress values (111.7–112.7 MPa from manual calculation; $1.136 \times 10^4$ N/m² and $8.687 \times 10^3$ N/m² from software) are well within the material's yield strength, and maximum displacements are negligibly small (order of $10^{-5}$ mm).
3. Actual testing demonstrated that the crossflow turbine with half-opening achieved the most stable performance (619.0 RPM average), while the Kaplan turbine without a basin reached higher average speeds (919.0 RPM) but with significant variability. Adding a proper basin for the Kaplan configuration is recommended for future improvements.

This simulation device is expected to serve as an effective educational medium for undergraduate laboratory activities related to renewable energy and fluid mechanics, providing hands-on experience with both impulse and reaction turbine principles.

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**CRediT Authorship Contribution Statement**
**Siti Maretia Benu**: Supervision, Corresponding, Writing – Review & Editing. **Muhammad Ahza Zaidan Pramanda**: Conceptualization, Methodology, Software, Formal Analysis, Investigation, Writing – Original Draft. **Surya Dharma:** Conceptualization, Methodology, Formal analysis. **Muhammad Anhar Pulungan**:

Resources, Review. **Fazril Ideris:** Resources, Review. **Fayaz Hussain:** Resources, Review, Visualization.

**Conflicts of Interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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