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THE POTENTIAL FLOW INTERACTIVE TEACHING TOOL (PFITT)

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ABSTRACT

Potential flow theory is a fundamental concept in fluid mechanics but is often challenging for students to visualize due to its mathematical complexity and reliance on ideal assumptions. To address this educational barrier, the Potential Flow Interactive Teaching Tool (PFITT) was developed as a web-based, interactive simulation platform that helps learners explore and understand the behavior of ideal flows. Built using Python and Streamlit, PFITT allows users to manipulate parameters of elementary flows such as uniform flow, source, sink, vortex, and doublet, as well as simulate their superpositions. The tool dynamically generates streamlines, stream function (ψ), and potential function (ϕ) plots based on user inputs, reinforcing key concepts such as flow symmetry, stagnation points, and scalar field orthogonality. The accuracy of PFITT was verified through case studies and compared against analytical solutions, showing strong agreement with theoretical expectations. With its clean user interface, real-time outputs, and browser-based accessibility, PFITT serves as a practical and scalable educational tool for enhancing conceptual understanding in fluid mechanics courses. Future enhancements may include extended flow scenarios, result exporting features, and integration with online learning platforms.

Keywords: *Fluid mechanics, Potential flow, Stream function, Python, Streamlit*

INTRODUCTION

Potential flow theory forms a critical component in the study of fluid mechanics, especially for analyzing ideal flows under the assumptions of inviscid, incompressible, and irrotational conditions. These assumptions lead to Laplace's equation, which governs both the stream function and the velocity potential, forming the basis for modeling various elementary flow cases such as uniform flow, source, sink, vortex, and doublet (White, 2016; Munson et al., 2013). Despite its fundamental importance, many students find it difficult to grasp the physical meaning behind these mathematical formulations, particularly when superpositions of multiple flow elements are introduced. Traditional instruction methods often rely on lectures and textbook examples, which can limit students' spatial and conceptual understanding of flow behavior. As a result, the need for more intuitive and visual approaches has grown in engineering education, especially for complex topics like potential flow (Kumar, Jain, & Pathak, 2021). To respond to this challenge, the Potential Flow Interactive Teaching Tool (PFITT) was developed as an educational simulation platform using Python and Streamlit. PFITT allows users to manipulate flow parameters and observe real-time changes in streamline patterns, velocity fields, and potential functions through a web-based interface. Studies have shown that incorporating interactive simulations can significantly enhance student engagement and improve conceptual understanding in engineering subjects. These tools serve as bridges between abstract theory and practical visualization, thereby promoting deeper learning (Shaikh & Khoja, 2012). PFITT aligns with this approach by enabling both predefined and custom scenarios for elementary and combined flows, allowing students to intuitively analyze flow interactions and phenomena such as stagnation points, streamline curvature, and the orthogonality of ψ and ϕ contours. PFITT is especially useful for courses such as MEC442, where students are first introduced to potential flow theory. The tool provides an accessible, platform-independent solution that complements traditional instruction methods and removes the need for commercial simulation software or physical laboratory setups. Its implementation supports independent exploration, facilitates active learning, and aligns with modern pedagogical trends in engineering education (Bower & Sturman, 2015).

METHODS

The development of the Potential Flow Interactive Teaching Tool (PFITT) followed a structured, iterative methodology that integrates interactive frontend design with mathematically rigorous backend computations to enhance student comprehension of ideal fluid flow. Built using Python as the core programming language and Streamlit as the web-based application framework, PFITT offers a real-time visualization platform that simulates elementary potential flows and their combinations. This technology stack was selected for its rapid development capability, browser-based deployment, and ease of access across devices, eliminating the need for local software installation. The graphical user interface (GUI) of PFITT was designed to be both intuitive and pedagogically effective. It features clean layout sections for predefined flow case selection, custom parameter inputs, optional visualization toggles, and an expandable theory guide. The predefined case dropdown includes classic flow patterns such as uniform flow, source, sink, vortex, and doublet, as well as common superpositions like Rankine half-body and flow around a cylinder. For each case, users can adjust the flow parameters, such as strength and location through labeled number input fields. Upon activating the simulation, the app dynamically computes velocity components, stream function (ψ), and velocity potential function (ϕ), and displays the resulting flow field as streamlines with color-coded velocity magnitude. The computational logic behind PFITT is rooted in the analytical expressions of potential flow theory. All flow types adhere to Laplace's equation, ensuring the incompressibility and irrotationality conditions are satisfied. The governing equations used for velocity fields and scalar functions are embedded in the backend using NumPy operations, with safeguards to prevent numerical instability near singularities. For example, the source and sink velocity components are derived using the radial distance formula:

$$u = \frac{m}{2\pi}\frac{x}{r^2}, \quad v = \frac{m}{2\pi}\frac{y}{r^2}, \quad \psi = \frac{m}{2\pi}\theta, \quad \phi = \frac{m}{2\pi}\ln r \tag{1}$$

Similar expressions are applied for vortex and doublet flows, with coordinate transformations that account for the user-defined element positions. These expressions are superposed to produce total flow fields that represent more complex physical situations. To ensure robust performance, a minimum threshold is set for radial distances to prevent division by zero or log singularities during computation. The overall workflow of PFITT follows a linear sequence: flow case selection, input validation, backend computation, and layered output rendering. Outputs include streamline plots of the velocity field, stream function contours, potential function contours, and an optional overlay of ψ and ϕ. Each plot is accompanied by descriptive text to aid student understanding and to support self-paced learning. Figure 1 illustrates this workflow visually. To ensure computational integrity, input validation checks and default value fallbacks are implemented throughout the system. A built-in warning message is triggered when all inputs are zero, thus preventing meaningless simulations and guiding users to enter valid parameters. These mechanisms enhance both usability and pedagogical value.

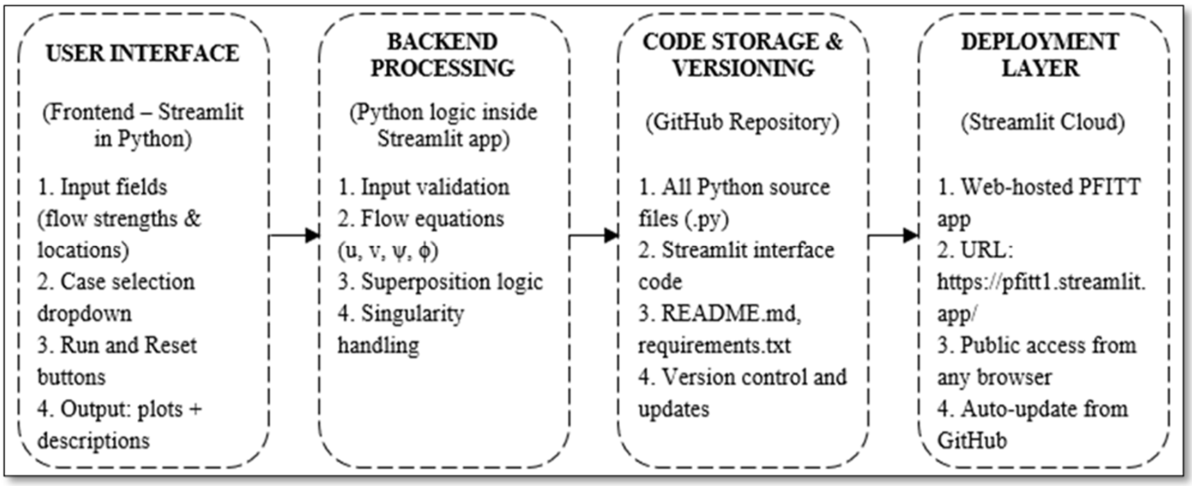

Figure 1.: PFITT System Workflow

The technology stack used in PFITT is summarized in Table 1. Each component contributes to the system's responsiveness, accuracy, and accessibility. Streamlit handles the frontend development, while NumPy supports the backend flow computations. Visualization is conducted using Matplotlib, and the source code is hosted on GitHub for version control and scalability. Public deployment is achieved through Streamlit Cloud, allowing users to run the application on any internet-enabled device without installation requirements. This combination of technologies ensures PFITT remains lightweight, robust, and adaptable for use in academic settings and beyond.

Table 1.: Technology Stack Used in the Development of PFITT

Component	Technology Used	Description
Frontend	Streamlit (Python)	GUI interface, dropdowns, buttons, user inputs
Backend	Python with NumPy	Flow computation, Laplace-based velocity fields
Visualization	Matplotlib	Streamlines, ψ and ϕ contour plots
Code Hosting	GitHub	Source code repository and version control
App Deployment	Streamlit Cloud	Public access to PFITT via browser-based link

RESULTS AND DISCUSSION

The user interface of the Potential Flow Interactive Teaching Tool (PFITT) was designed to provide an accessible and interactive learning environment for fluid mechanics students. As illustrated in Figure 2, the front page introduces the tool with a clean layout, guiding users to select predefined flow cases or input custom values. Upon entering the simulation, the main interface presents numerical input fields for each flow element (e.g., source strength, vortex location), checkboxes for optional scalar field visualizations, and an output area that dynamically renders streamlines, stream functions (ψ), and potential functions (ϕ). This intuitive layout ensures that users, even without coding experience, can simulate potential flows and observe results immediately.

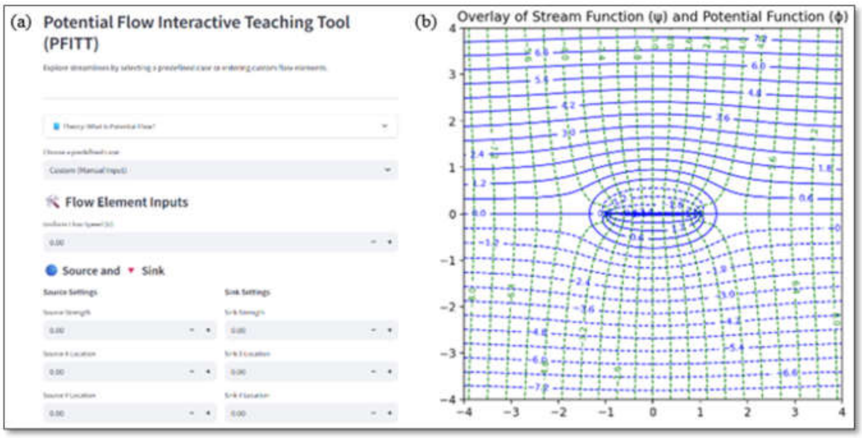

Figure 2.: PFITT User Interface: (a) Before Execution, (b) After Execution

To evaluate the correctness of PFITT's computational engine, two benchmark simulations were performed and compared with analytical solutions based on potential flow theory. The first case simulated a source flow at the origin with a strength of 5.0 units. The second case involved a uniform flow with a velocity of 2.0 units combined with a doublet, which theoretically represents flow around a cylinder. For each case, key characteristics such as flow symmetry, stagnation points, and streamline patterns were compared visually and numerically to standard textbook solutions. The streamline results in both cases closely matched theoretical expectations. For the source case, radial streamlines and circular, equipotential lines were observed, as predicted by the logarithmic potential and angular stream function equations. For the uniform + doublet case, the resulting streamline pattern exhibited a symmetric closed streamline contour around the origin, consistent with classic flow around a circular cylinder. These results are summarized in Table 2, which compares PFITT visual outcomes with expected textbook behavior.

Table 2.: Comparison of the Result of PFITT with the Theoretical Calculation

Case Study	Expected Flow Behavior	Observed in PFITT	Match
Case 1: Source Only	Radial streamlines, circular ψ and ϕ contours	Radial and circular contours correctly plotted	Yes
Case 2: Uniform + Doublet	Closed streamline loop, symmetric cylinder-like pattern	Symmetric loop observed, with stagnation points	Yes

CONCLUSION

The Potential Flow Interactive Teaching Tool (PFITT) is a practical and user-centered educational platform designed to support the understanding of ideal flow behavior in fluid mechanics. By allowing users to manipulate flow element parameters such as velocity, strength, and location, and instantly visualize resulting streamline patterns, stream functions (ψ), and potential functions (ϕ), PFITT bridges the gap between theoretical instruction and experiential learning. Its simulation results, validated through comparison with textbook flow behavior, confirm its reliability and accuracy in illustrating core principles of potential flow. From an educational perspective, PFITT addresses long-standing challenges in teaching abstract concepts such as flow superposition, irrotationality, and scalar field orthogonality. Its clean, guided interface and dynamic outputs provide learners with immediate visual feedback, enabling them to explore the influence of individual and combined flow elements in an intuitive manner. This reinforces foundational topics such as Laplace's equation, stagnation points, and flow around bodies without the need for high-cost physical experiments or commercial software. Developed using Python and Streamlit, PFITT is accessible through any web browser without installation, making it highly adaptable for classroom use, remote learning, and self-paced study. Its lightweight architecture and modular codebase also enable collaborative development, version control, and customization through open-source distribution. These features position PFITT as a scalable and flexible teaching tool, well-suited for integration into undergraduate courses like MEC442 or other fluid dynamics modules. The broader impact of PFITT lies in its ability to translate mathematical models into interactive visual learning experiences. By embedding the analytical expressions for potential flows into a responsive simulation environment, the tool highlights the pedagogical value of real-time computation and graphical interpretation. Future enhancements may include the ability to export plots, overlay multiple flow cases, and analyze velocity or pressure distributions. Additional integrations with learning management systems or embedded quizzes could further support formal instruction and assessment. As engineering education increasingly shifts toward digital and experiential platforms, PFITT exemplifies how simulation-based tools can demystify theoretical concepts and promote deeper engagement. With continued refinement, PFITT has the potential to evolve into a comprehensive instructional resource for fluid mechanics, supporting both fundamental understanding and advanced exploration of flow phenomena.

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