

A low-cost pitot tube-based experimental model for active teaching-learning of applied fluid mechanics: A demonstration from NTTU

Manuscript received 25 August 2023; revised 26 September 2023

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Abstract—Using hands-on experiments in the classroom is a highly effective way to deepen students' understanding of theoretical concepts. By researching and developing a practical and cost-effective experiment using a pitot tube, we can transform the teaching of fluid mechanics from a content-based approach to one that promotes competency and practical application. The research includes exploring pitot tube theory, developing and evaluating the experimental design, simulating flow through the designed pitot tube using computational fluid dynamics simulation software, and implementing and evaluating learner satisfaction. The feedback we received from the students showed high satisfaction with the practical equipment used in the classroom and confirmed that this hands-on approach helped them achieve their learning objectives.

Keywords—Active teaching-learning, Applied Fluid mechanics, Experiments, Pitot tube

I. INTRODUCTION

Nowadays, engineering education can be seen as realising the potential of multimedia as a learning and teaching tool. Computer multimedia provides a few valuable tools in general and mechanical engineering education. Classical engineering graphics using a combination of animation, audio description, and interactive exercises can help students. The most crucial benefit of multimedia can be considered as interactivity. Many studies show that interacting with information can positively affect learning because people remember/absorb more information when interacting with it (e.g., listen, see, and do). Multimedia provides an excellent means of creating interaction through interfaces that require users to make choices and perform actions. The integration of information technology in applied educational activities of mechanical engineering provides an excellent opportunity to increase the level of understanding of students with specific pedagogical resources during the teaching process. Teaches basic engineering disciplines, such as fundamentals of mechanical engineering, mechanics of materials, and mechanical vibration, in an interdisciplinary classroom lab [1]. Project assignments effectively promoted collaboration and active learning. Because project assignments are like math problems, students must spend more time reading and understanding. After overcoming the initial hurdle of mastering the basics of

the software tools, students can easily create models corresponding to the assigned problems and change essential parameters to set up different situations. In trying to establish correspondence between software solutions and analytical solutions for these different situations, it became clear that the students were moving from one model to another in an "active learning" framework rather than the "passive learning" to which they had long been accustomed. The software was available on all engineering student computers, allowing students to work independently. Stronger students who quickly master the software demonstrate an advanced understanding of the subject and help their teammates with some personal misconceptions. During project presentations, students are encouraged to ask questions to learn from other groups about their approaches and to seek clarification of related concepts. The project assignment also encouraged better use of faculty office hours by some (but not all) students excited about the software simulations and the correspondence with distributed solutions. Some students also put extra effort into mastering the software and spend time beyond the course requirements when they realise that the simulation environment is also suitable for mechanics and control systems courses and use it for project assignments [2].

Ref. [3] determined the effectiveness of using a mechanics course with Mdsolids software to improve the learning outcomes and learning independence of Sarjanawiyata Tamansiswa University Mechanical Engineering Education students in Yogyakarta. They did this using a semi-experimental method. The study results were collected with the experimental group and analysed using a *t*-test. Students' independence in learning during class is observed and further analysed by calculating the scores achieved. The *t*-test results of the difference test show that the experimental group's average performance significantly differs from the control class. Students who used the Mdsolids software program in their mechanics courses observed increased learning and independent learning at the end of each period with good performance.

Ref. [4] describes their experience with the possibility of using specialised software (via the Internet) for interactive and collaborative learning in mechanical engineering. In

mechanical engineering education, the concepts developed in the mechanics course are essential in preparation for design courses in engineering technology disciplines, providing designers with the tools to select an appropriate material and determine the dimensions required for the machine or machine mechanism. They also assert that for students, the key to success in the course is to develop engineering problem-solving skills by solving a series of problems drawn from various mechanical and structural situations in the context of the automatic engineering educational scene. Active learning enhances engineering education. Ref. [5] presents theoretical foundations, curriculum supplements, and approaches to active learning that can be seamlessly integrated into a traditional lecture-based engineering class. A pedagogical framework that structures dynamic learning experiences and addresses learning styles and preferences is discussed. They present innovative activities for engineering mechanics courses designed to meet student's diverse needs and learning styles. A total of 28 moves have been developed, ranging from quick practice activities that can be done during the lecture to multimedia tools. The exercises target complex concepts in the mechanics of materials. The key to the effective development of innovative teaching methods is their foundation in theoretical learning. A laboratory-based course was developed to complement the lecture-based course on statics and strength of materials [6]. The primary goal at the beginning of the course is to provide students with more problem-solving experience, with a secondary goal of hands-on experience to build intuition. More than 25 activities were developed with a limited budget. The richness of the course, both in terms of physics examples, additional problems, and time to work, clearly provided students with other engagement in this challenging subject. This experience also helps the instructors to get closer to the students.

Working Model 2D (WM 2D) is a powerful, easy-to-use planar multi-body software adopted by many educators of statics, dynamics, mechanics, machine design, and practising engineers. The programming and import/export capabilities of WM 2D facilitate the simulation of the motion of complex-shaped objects under many constraints. Ref. [7] describes several 2D WM applications that allow students to understand the fundamental properties of gears and how they are manufactured. Other applications enable students to study the kinematics of planetary gears, which are known to be less intuitive than fixed-shaft gears. This helps engage students in active learning and independent problem-solving.

Most first-year engineering students at the university take Calculus as their first math course. This course is designed to familiarise new students with the university, reinforce mathematical concepts, and introduce various areas of engineering. Interactive computer simulations have been created using the Working Model 2D and MDSolids modelling programs to teach and strengthen topics and skills related to the four engineering specialties (civil, electrical, materials, and mechanical) offered at the University. Ref. [8] showed that students enjoyed using simulations and found them an exciting addition to their learning. Students also felt that the simulations improved their confidence in taking future engineering courses and were willing to use more simulations in their academic careers. No significant correlation existed between students' dominant learning styles and their perceptions of the simulations. Therefore, learning style assessments may be optional to use simulations in similar learning environments effectively. MDSolids is a current educational software for mechanics courses typically

presented as tutorials, worksheets, or basic analysis packages. The new MDSolids software package provides an alternative solution for product types in mechanical engineering education. MDSolids was designed to help students solve and understand homework problems commonly used in a mechanics of materials course. The software is flexible, graphical, informative, and easy to use. MDSolids are used in a few schools worldwide, and users' feedback has been positive and enthusiastic [9]. Survey results show that MDSolids are used in various ways in all settings. Professors note that MDSolids motivate students and appear to be a factor in significant improvements in student performance in several subject areas [10].

Ref. [11] describes developing a set of active learning activities for an undergraduate course in the mechanics of materials. One of the primary motivations for creating and implementing new activities stems from the physical space in which the system is taught in a classroom specifically designed to encourage collaboration. The room's round tables and whiteboard-lined walls inspired an experienced mechanical engineering instructor to work with a graduate student in engineering education to create a series of learning activities. The focus is on the materials engineering industry. The goals of these activities are twofold: 1) to increase collaboration among students during lectures and 2) to increase students' conceptual understanding of complex yet informative topics. Preliminary results indicate that students found the activities useful for learning and felt comfortable with the target concepts. This manuscript-in-progress briefly describes each active learning activity and illustrates the pedagogical benefits of interdepartmental collaboration. They represent six functional learning exercises that resulted from an interdepartmental effort to enhance collaboration in an undergraduate mechanics of materials course. Students made a report on all the valuable activities supporting their learning of related concepts. In addition, their results from qualitative data showed that students benefit from collaborating with their peers. Based on their actions' apparent technical and social success, the instructor/lecturer plans to incorporate them into the curriculum.

The need to provide more "student-centred" instruction in higher education while improving retention has created a need to give students more flexible help outside the traditional classroom environment. A more profound challenge is how to do this within the realities of limited budgets. Ref. [12] describes how Eastern Washington University has chosen to meet this challenge in Strength of Materials teaching. Eastern Washington University decided to use a software package to allow students to get more "on-demand" help in solving problems in materials mechanics. The software package will enable students to work on issues and then use the software to check their work, helping them to understand where things might go wrong and providing an environment that encourages further exploration and discovery—experiences and lessons learned in using MDSolids software to enhance the effectiveness of traditional classroom-based experiential learning.

Ref. [13] developed an undergraduate course to introduce students to the basic principles of vehicle dynamics. Although genuinely interested in the subject, many students need help to grasp the physical principles necessary for a deep understanding of the subject to assist them in making design decisions. An exciting and potentially helpful fact is that the computer gaming world has widely developed highly complicated vehicle computer models with practical driver

interfaces. However, while computer games are exciting, they could be more suitable for helping undergraduate engineering students understand the fundamentals of automotive design. Therefore, as part of this course, students develop their own vehicle dynamics models (using Working Model 2D), starting with the vehicle's simple suspension and driving a four-wheel drive vehicle on rough roads. From a teaching standpoint, the innovation is that students can clearly understand a few three-dimensional effects, and thus the design principles that result from that understanding, using a relatively simple program and available 2D dynamics simulation software. This assists students in learning to be proactive and creative in designing and solving vehicle dynamics problems.

This paper presents the active teaching-learning model based on a low-cost pitot experimental device for applied fluid mechanics. The research objectives are to demonstrate the procedure of making the pitot tube and its relevant theory and investigate the satisfactory level of a learner and their learning outcomes from the course with questionnaire design.

II. ACTIVE LEARNING IN FLUID MECHANICS

Fluid mechanics courses often rely on experimentation to enhance the learning experience. Ref. [14] introduces a novel and comprehensive educational model for fluid mechanics laboratories, emphasising a hands-on approach and integrating multiple disciplines. This model offers several advantages, including improved pedagogy due to economies of scale. Consequently, it justifies allocating dedicated academic resources to develop laboratory courses and focusing on designing activities that align with desired learning outcomes. The paper discusses four specific examples of how this approach is applied to fluid mechanics experiments, highlighting the strategies devised. Within this laboratory setting, novice students who lack prior knowledge of fluid mechanics are carefully guided through a step-by-step process that ensures comprehension and lays the foundation for future laboratory activities.

In civil, chemical, and mechanical engineering, fluid mechanics is a fundamental undergraduate course that typically incorporates lectures, tutorials, and laboratory work. Within the laboratory setting, students often follow written procedures to conduct experiments. However, without a thorough understanding of the experiment's design and operation, students often rely on lab reports from previous years to guide their analysis and documentation process. This practice has led to inconsistent learning outcomes, as students may perform experiments before or after being introduced to the relevant theory, missing out on valuable reinforcement learning opportunities [14].

Traditionally, fluid mechanics labs have been organised in a fragmented manner, with instructors assigning a few labs throughout the year, each focusing on a specific unit or equipment. Consequently, students can take these labs at any point during the year. To address this issue and ensure a cohesive learning experience, a dedicated team has been established to provide lectures, tutorials, and tests and set up a comprehensive and progressive laboratory curriculum [14]. The labs are designed to be manageable, allowing the entire group to conduct experiments quickly. Integrating practical and theoretical work enhances the learning process to turn students into competent, reflective, and independent experimenters by the end of their second year.

In an article by Ref. [15], a short simulation activity utilising Computational Fluid Dynamics (CFD) is introduced

to support theoretical teaching in the Bachelor of Mechanical Engineering program. This activity helps improve the overall capacity of the fluid mechanics course by providing visual and numerical information that requires students to critically analyse and compare results obtained through equation-based analysis taught in theory classes. The activity is designed to fit within limited class time, lasting up to four hours. To optimise resources and save computational time, the activity recommends a meshing and simulation strategy using Solidworks Flow Simulation software, which automatically sets up the computational domain based on the modelled geometry.

To achieve the activity's learning objectives, students must pay attention to the importance of pressure drop, which is often calculated using CFD simulations. The training emphasises that small changes in geometry, such as the introduction of an obstacle, can lead to significant variations in results that may not be apparent when relying solely on the Bernoulli equation. The proposed CFD-based methodology enhances students' understanding of the consequences of neglecting energy losses, even in seemingly simple geometries like a smooth nozzle, enabling live calculations within a real-world context. A notable strength of the Solidworks Flow Simulation software is its ability to quickly visualise various fluid properties, such as pressure, velocity, and turbulence intensity, further enriching the learning experience.

Ref. [16] conducted a study to investigate the impact of computer simulations on engineering students' comprehension of fluid mechanics. Their research applied a "lesson study" approach, incorporating constructivist educational theory and phenomenological learning theory to inform the design of learning and assessment activities. The researchers utilised the Fluid Mechanics Concepts Inventory to assess students' struggles with fluid mechanics concepts, with difficulties identified in pressure measurement, fluid flow through pipes of variable diameter, and fluid velocity profiles between flat plates. To address these challenges, they developed three simulations and evaluated their effectiveness. Most sophomore fluid mechanics students participated in the entire exercise, and significant improvement was observed in two of the three problem areas. Student feedback regarding the additional training was highly positive. This study demonstrated the value of employing a "learning research" framework informed by educational theory when designing classroom activities, particularly those that facilitate conceptual visualisation, thereby fostering an enhanced understanding of fluid mechanics. Such actions can complement traditional teaching methods and may include physical demonstrations, or computer simulations utilised in research.

In many developing countries, fluid mechanics courses primarily rely on traditional teaching methods and need more computer-aided techniques. However, due to the impact of the COVID-19 pandemic, South American universities have begun to incorporate these techniques for online teaching. In this context, the present paper describes a pedagogical intervention spanning eight semesters (2016-2019) in an undergraduate fluid mechanics course. The intervention combines physical (hands-on) experiments and virtual (computational fluid dynamics-based) simulations for the laboratory module alongside flipped classroom prompts for the theoretical module. This intervention followed a design-based research approach guided by heuristic mapping and fidelity to performance standards. The results of the intervention indicate that it effectively improved the

instruction of fluid mechanics laboratories, albeit with some reliance on other educational components such as teaching assistants and laboratory technicians. The scores of lab reports were distributed according to the Gompertz probability distribution. The researchers also shared some of the intervention results as open educational resources and advocated for collaborative efforts to scale educational interventions for fluid mechanics. There is a pressing need to investigate further laboratory guidance procedures, a challenge that has yet to be addressed in developing countries [17].

Civil and environmental engineering students at the University of Delaware conducted the Vessel Project as a fluid mechanics laboratory based on a new design [18]. Students were asked to design/build/test a device to transport two teammates across the university diving pool and back. The lab course focuses on buoyancy and stability while improving communication and teamwork skills. Students can spend at most \$100 on materials and are encouraged to use free donated items in various campus labs. Students strongly preferred the new course layout to a more traditional lab course with prescribed testing on multiple devices. Positive comments focused on creativity, building/testing a ship after the design process, and teamwork. A few remarks for improvement related to fear of using shop tools and more checkpoints throughout the building process to help teams maintain progress.

In a study of 27 undergraduate chemical engineering students, Ref. [19] explored the effects of desktop learning modules that were low-cost and hands-on in a fluid mechanics class. The current work [20] aims to recover this missed learning opportunity by enhancing student involvement through a learning approach based on inquiry. In the summer of 2017, 61 students took part in the course on fluid mechanics of motion and performed five experiments with a custom-made project-based learning kit. Project-based learning has many advantages but seems especially beneficial for self-confidence and career skill development. With this method, students are not passive observers but co-creators of their learning experience. This paper evaluates student achievement and career skill development as assessed by themselves through quantitative and qualitative analysis of various surveys and assessments that measure career skill development. The findings show that the most critical engineering-related attribute was the impact of technology on society and the environment, economics and project management, and lifelong learning, which all improved significantly. Project-based labs had lower performance from fourth-year students than their classmates, which may indicate a lack of motivation related to taking a course for second or third-year students.

Integrating software packages into chemical engineering courses is widely seen as beneficial to students in two ways. First, the active learning environment promotes a deeper understanding of the course material. Second, it gives students hands-on experience with "state of the art" tools used in industry. However, chemical engineering program surveys have shown that software packages used in traditional fluid mechanics courses could be higher (less than 10%). Recently, the PIPE-FLO software package (from Engineered Software Inc.) has been integrated into a second-year fluid mechanics course at McMaster University [21]. The software performs a complete hydraulic network analysis for various piping configurations with multiple piping components such as pumps, compressors, and control valves. The implementation

of PIPE-FLO as a simulation tool is consistent with a recent initiative by the Canadian Engineering Accreditation Board (CEAB) to identify directions for program improvement. Ten self-paced tutorials have been created to teach students how to use the full professional version of PIPE-FLO, available in school computer labs. The set of ten tutorials is designed to be wholly self-paced and, therefore, has little impact on the lecture time required for other course content. Each tutorial includes detailed examples with step-by-step instructions, practice exercises, and references to appropriate equations, tables, and figures in the course textbook. Each tutorial is designed to enhance understanding of the theory learned in class and includes references to relevant equations from the course textbook. Student feedback has been positive and encouraged greater software integration into future course offerings. An assessment based on student's ability to "use PIPE-FLO to calculate design parameters (pressure drop, flow rate, pipe size) for specific piping networks containing a variety of fittings, connections, and valves" shows that most of these students (59%) were in the "meets expectations" category [21]. Ref. [22] prepared students for industrial skills by integrating PIPE-FLO software into the teaching of a fluid mechanics course. Students complete the course with experience using commercial software to automate processes learned in fluid mechanics. This is done using professional and reliable software, but it still requires complete understanding and does not require a lack of critical thinking or understanding of fluid mechanics principles.

Ref. [23] has taught fluid mechanics in France for more than four decades with passion and satisfaction in various domains. In mechanical engineering, he has enthusiastically conducted undergraduate and postgraduate activities before and after the Bologna process (a reform that sometimes altered traditional teaching and learning), considering the changes in the student's daily social life. At the same time, he has also successfully implemented practical training for students who aspire to become teachers for more than ten years. The chance to learn and teach this specific method to the younger generation and the motivation to bring experimental science to the classroom have greatly enriched his knowledge of educational science and changed his teaching methods. Ref. [24] organised an activity and contest called "Fun with liquids". The event consisted of four segments: (1) fun with fluids, (2) frugal lab, (3) design a thinking problem, and (4) a PowerPoint presentation on fluid concepts matter. They had two cabin meetings with each group (registration/topic selection guidance and presentation rehearsal). Through this activity, students were able to design and perform experiments. It also allowed them to assess their communication skills, work in multidisciplinary teams, and understand current issues. Each exhibition was judged in three stages. Before the event, faculty and teaching assistants evaluated the projects. Three experts from outside the Institute were invited. The evaluation was based on scientific content, novelty, presentation, and answers to questions. The contest allowed students to choose projects based on their acumen and attitudes, such as innovative thinking, design thinking, lifelong learning, modern learning, and presentation skills. Ref. [25] designed and built two laboratory devices at the University of Miami for fluid mechanics classes. These devices were designed, built, and tested so that they could be replicated for both Miami facilities and regional sites. The objectives were (1) to design and build laboratory equipment for fluid mechanics classes at the University of Miami and (2) to provide equipment that enables students to learn and apply concepts and principles learned in class.

III. PITOT TUBE

When a moving fluid is stopped by a fixed obstruction, the pressure created is greater than the pressure of the fluid flow. The magnitude of the increased pressure is related to the velocity of the moving fluid. The pitot tube uses this principle to determine the rate, as shown in Fig. 1. The hollow pitot tube is positioned so the open end is directly in the fluid flow. The pressure at the top of the line creates a column of fluid. The fluid inside the tip of the box is stationary (at rest), and this point is called the stagnation point. We can use the energy equation to establish a relationship between the pressure at this point (stagnation point) and the velocity of the fluid. If point 1 is in the non-scattering flow before the tube tip, and point s is the stagnation point.

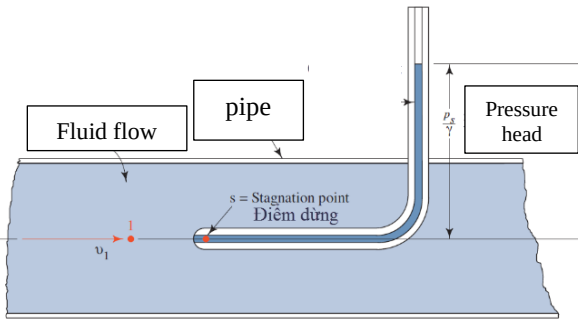


Fig. 1. Pitot tube

$$\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_s}{\gamma} + z_s + \frac{v_s^2}{2g} \quad (1)$$

We see that $v_s = 0$, $z_1 = z_2$, so $h_L = 0$. Thus, we have:

$$\frac{p_1}{\gamma} + \frac{v_1^2}{2g} = \frac{p_s}{\gamma} \quad (2)$$

Note that the components in formula (2) are presented as follows:

- p_1 = static pressure in the primary fluid flow
- p_1/γ = static pressure head height
- p_s = pressure at a breakpoint or overall pressure
- p_s/γ = overall pressure head height

The overall pressure head height equals the sum of the static pressure and velocity heads. Solving equation (2), we find the velocity as follows:

$$v_1 = \sqrt{2g(p_s - p_1)/\gamma} \quad (3)$$

Note that the only difference between the p_s and p_1 pressures is needed to calculate velocity. For this reason, most pitot tubes are constructed, as shown in Fig. 2, so both pressures can be measured with the same device.

The device shown in Fig. 2 measures static and differential pressures simultaneously, sometimes called a pitot-static tube. The pitot tube design shown in Fig. 2(b) is a tube within a tube. The small central tube has an open end and functions similarly to the simple pitot tube shown in Figure 1. Therefore, the pressure at the stagnation point is also referred to as the total pressure through this tube. The total pressure tap at the end of the tube is connected to the gauge.

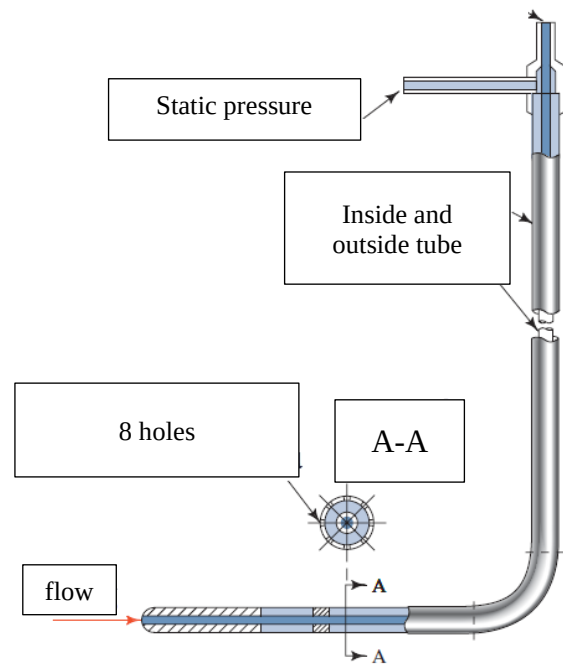


Fig. 2. Detail drawing of the pitot tube

The large outer tube encloses the centre tube through the tube ends, creating a closed annular cavity between the outer and centre tubes. Section A-A is a series of small-diameter holes drilled through the outer tube but not the centre tube. When the tube is oriented in the direction of flow, these radial holes are perpendicular to the flow and are, therefore, sensitive to the local static pressure, called p_1 . Note that the static pressure tap is bonded to the end of the tubing for connection to the gauge. The gauge does not need to measure both p_s and p_1 because the pressure difference ($p_s - p_1$) is required for equation (2). Manufacturers make differential pressure gauges for such applications. When a differential pressure gauge is used, as shown in Figure 3, the liquid head deflection h in the indicator can be directly related to velocity. We can write the equation describing the pressure difference between p_s and p_1 starting at the static pressure holes in the pipe wall, continuing through the gauge, and ending at the open end of the pipe at point s:

$$p_1 - \gamma x + \gamma y + \gamma_g h - \gamma h - \gamma y + \gamma x = p_s$$

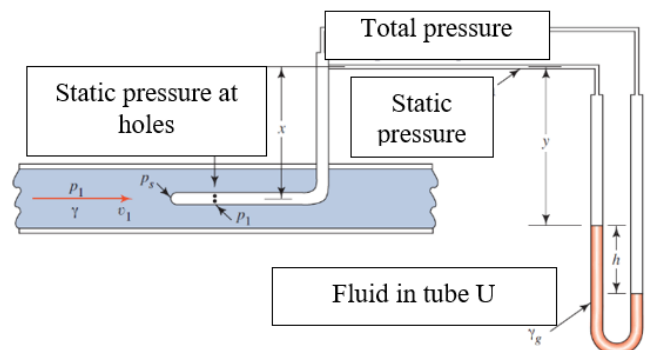


Fig. 3. Differential manometer for use with pitot static pressure tube

The distance-related quantities x and y are eliminated. Therefore, we solve for the pressure difference and obtain expression (4):

$$p_s - p_1 = \gamma_g h - \gamma h = h(\gamma_g - \gamma) \quad (4)$$

Substituting this equation into equation (4), we get:

$$v_1 = \sqrt{2gh(\gamma_g - \gamma) / \gamma}$$

IV. CFD MODEL OF PITOT TUBE

The model is designed using CAD 2D Solidworks 2020 with the shape and size shown in Figure 2. We are using MdSolids 4.0 software [10] to check the allowable pressure of the pipe to limit the pressure applied to the pipe to avoid broken glass pitot tubes. Then, we perform computational fluid dynamics simulation for airflow through the pitot tube using Solidworks Flow Simulation software [11].

A. k - ε turbulent flow model

In this model, the airflow through the pitot tube is assumed to be isothermally turbulent, and the fluid is incompressible [12]. The continuous equation is as follows.

$$\nabla \cdot \mathbf{u} = 0$$

B. Navier-Stokes equations

$$\rho(\mathbf{u} \cdot \nabla) \mathbf{u} = \nabla \cdot \left[-p\mathbf{I} + (\mu + \mu_T)(\nabla \mathbf{u} + (\nabla \mathbf{u})^T) \right] + \mathbf{F}$$

The turbulence model uses single-phase flow simulation with the k - ε model. The time-independent transfer equation for turbulent kinetic energy k is calculated for unit mass.

$$\rho(\mathbf{u} \cdot \nabla) k = \nabla \cdot \left[\left(\mu + \frac{\mu_T}{\sigma_k} \right) \nabla k \right] + P_k - \rho \cdot \varepsilon$$

With a turbulent viscosity coefficient,

$$\mu_T = \rho C_\mu \frac{k^2}{\varepsilon}$$

And the group of terms:

$$P_k = \mu_T (\nabla \mathbf{u} : (\nabla \mathbf{u} + (\nabla \mathbf{u})^T))$$

The time-independent transfer equation is for the energy dissipation rate ε :

$$\rho(\mathbf{u} \cdot \nabla) \varepsilon = \nabla \cdot \left[\left(\mu + \frac{\mu_T}{\sigma_\varepsilon} \right) \nabla \varepsilon \right] + C_{\varepsilon 1} \frac{\varepsilon}{k} P_k - C_{\varepsilon 2} \rho \frac{\varepsilon^2}{k}$$

The coefficients of the k - ε turbulence model are predefined at default values [13]:

$$C_{\varepsilon 1} = 1.44; \quad C_{\varepsilon 2} = 1.92; \quad C_\mu = 0.09; \quad \sigma_k = 1; \quad \sigma_\varepsilon = 1.3$$

The steps required to simulate CFD for fluid flow through a pitot tube are as follows:

- **Step 1:** Boundary conditions with pressure at the two inlets are set and adjusted by pressure gauges. Fluid density $\rho = 1.18415 \text{ kg/m}^3$ and dynamic storage coefficient $\mu = 1.85508 \times 10^{-5} \text{ Pa}\cdot\text{s}$.
- **Step 2:** Set up the computational domain for the CFD model of the pitot tube. The computational part is the overall size of the CAD model for the pitot tube in three dimensions: x, y, and z.
- **Step 3:** Set Targets - Calculated Targets. The average value of static pressure (Pa) and the average value of

velocity (m/s). At the same time, we set up observation targets on the pressure difference (Fig. 4).

- **Step 4:** Create the mesh for the CFD model: Mesh modes are set with automatic and adaptive default modes in Solidworks Flow Simulation to quickly calculate results with acceptable accuracy. The simulation results show that the static pressure field in the pitot tube is as shown in Fig. 5. The pressure distribution field and the pressure difference can also be readily displayed.

V. PITOT TUBE EXPERIMENTS

In 1732, hydraulic engineer Henri Pitot created the Pitot tube, a device used to measure fluid flow velocity, particularly in rivers. To determine the flow velocity, Pitot submerged a right-angled glass tube in water, with one end open to the atmosphere, which allowed him to obtain accurate measurements of the dynamic pressure of the fluid.

A. Required equations

$$V = \sqrt{\frac{2(p_0 - p_1)}{\rho}}$$

V is the velocity (m/s), p_0 is stagnation pressure, and p is the static pressure.

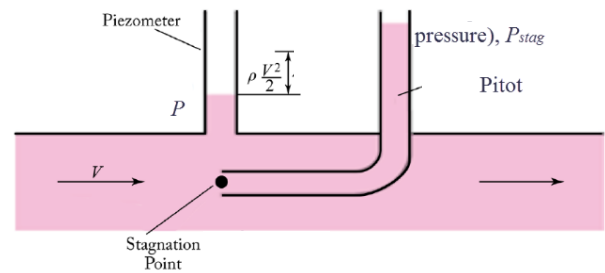


Fig. 4. Static, dynamic and stagnation pressures

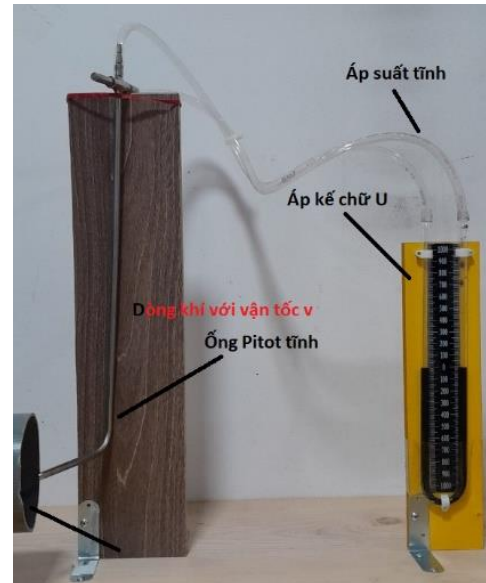


Fig. 5. U-pressure device measures the pressure difference according to the fluid column deviation

Bernoulli equation with head loss:

$$\frac{p_a}{\gamma} + \frac{V_a^2}{2g} + z_a = \frac{p_b}{\gamma} + \frac{V_b^2}{2g} + z_b + h_L$$

B. Experiment procedure

- Using a pressure gauge and pitot tube (Fig. 5), measure the pressure head and velocity head at the upstream and downstream ends.
- Compare the experimental velocity with the simulation velocity using computational fluid dynamics and calculate the percentage error.

VI. SURVEY RESULTS

A student satisfaction survey results from two fluid mechanics classes with 120 students. Of these, 92 student opinions were collected and processed. Survey results with evaluation criteria according to 5 levels: 1 - strongly disagree, 2 - disagree, 3 - average, 4 - agree, and 5 - strongly agree. Specifically, teachers stimulate students' interest in the subject: 83.7% level 5; teachers observe and manage learning activities, teaching and learning speed in class is good: 80.4% level 5 and 12% level 4; teachers organize and prepare well for each category: 82.6% level 5, 8.7% level 4; teachers encourage discussion and answer questions during course: 81.5% Level 5, 10.9% Level 4; Teachers encourage students to think independently and creatively: 80.4% Level 5, 12% Level 4; Teachers demonstrate in-depth knowledge of the subject: 83.7% Level 5 and 8.7% Level 4; Teachers show enthusiasm and interest in teaching: 83.7% Level 5, 8.7% Level 4; Teacher used many teaching methods to achieve the subject objectives (e.g.: group discussions, presentations, student homework, class exercises...): 80.4% Level 5, 10.9% Level 4; Teachers created challenges for students to complete the best lessons and activities: 79.3% Level 5, 13% Level 4; Teachers have a connection between theory and practice: 81.5% Level 5, 9.8% Level 4;

Teachers provide valuable and constructive feedback, especially during lessons and exercises: 78.3% level 5, 14.1% level 4; Teachers clearly explain the content of the subject: 81.5% level 5, 10.9% level 4; Teachers are willing to provide personalized help to students to complete the issue in the best way: 82.6% level 5, 10.9% level 4; Teachers care about students' progress: 80.4% level 5, 13% level 4; Teachers can be away from the classroom by teaching online: 79.3% level 5, 13% level 4; Teachers were proactive and tried to prevent cheating in this subject: 77.2% level 5, 15.2% level 4; Teachers use information technology devices well to support teaching: 78.3% level 5, 14.1% level 4; Information about assessment, testing and final exam was communicated clearly: 76.1% Level 5, 17.4% Level 4; Student learning outcomes are assessed accurately, objectively, and somewhat: 79.3% Level 5, 14.1% Level 4; Exam questions are close to the curriculum: 80.4% Level 5, 13% Level 4; Teacher feedback is provided within the specified time frame: 78.3% Level 5, 14.1% Level 4; Feedback that shows how to improve learning (such as correcting assignments and other ideas): 77.2% Level 5, 15.2% Level 4; The amount of time (number of periods) devoted to the subject is appropriate: 76.1% level 5, 16.3% level 4; The library has enough reference materials for the issue: 69.6% level 5, 15.2% level 4; Instructor's instructions on where to find documents: 75% Level 5, 18.5% Level 4;

Classroom equipment meets teaching and learning needs: 76.1% Level 5, 15.2% Level 4; The outline was introduced and explained at the beginning of the course: 100% agreement; The course was delivered as outlined in the syllabus: 98.9% agree; The instructor explains the grading criteria for the subject: 100% agree; Exams/tests related to subject outcome

standards: 98.9% agree; Major assignments/tasks related to learning outcomes and subject learning outcomes: 98.9% agree; This is a subject worth learning: 100% agree; Would you recommend this subject to future students? 98.9% agree; how would you rate your experience in this subject? Excellent 44.6%; Good 7.6%; Fair 38%; Average 8.7%; How many hours per week do you prepare and do homework for the subject?: 0-4 hours is 64.1%; 5-8 hours is 23.9%; You have contributed to the creation of lessons and classroom activities: 53.3% chose level 5, 20.7% chose level 4; You feel that you are achieving the learning outcomes and subject outcomes: 57.6% level 5 and 25% level 4.

VII. CONCLUSION

Using hands-on equipment to conduct experiments in the classroom is an engaging approach to enhance understanding and stimulate students' ability to explore phenomena. This project implements the low-cost Pitot Experimental Model to conduct experiments to explain Bernoulli's Law and the General Equation of Energy. The manufacturing model will be used for active teaching, with student surveys to verify learning effectiveness. Empirical data and surveys for positive teaching-learning effects of the Pitot model will be designed and manufactured. In addition, CAE Solidworks flow simulation capabilities to observe pressure and velocity fields in pitot tubes also contribute to the learning of theoretical knowledge of Bernoulli equations and continuous equations.

ACKNOWLEDGEMENT

The authors thank the Nguyen Tat Thanh University for supporting the research grant for the project "*Design and manufacture of Pitot and Pitot tube test equipment for the teaching of fluid mechanics*" with the number 2021.01.159.

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