Journal of Engineering Education Transformations ,
Volume 37 , No. 2 , October 2023 , ISSN 2349-2473, eISSN 2394-1707

10.16920/jeet/2023/v37i2/23148

An Excel/VBA Teaching-Learning Solution of Velocity Triangle Analysis of Hydraulic Turbines

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Abstract : This study reports an investigation into the use of computational techniques applied to selected Turbo machinery problems. Students in their third year of a B.S./ B.Tech in Mechanical Engineering program often focus on this topic. As a result of being exposed to an overwhelming quantity of hypothetical ideas, loads of recipes, and references from information handbooks, students sometimes become overwhelmed during lessons on Turbomachinery. An intuitive learning scenario, such as a computerized setting, can be useful in some circumstances. Thus, computer-based exercises are essential to improve dynamic learning. This study will present an alternate technique of demonstrating the turbo machinery analysis using Excel/VBA. The classroom isn't the only setting where a powerful computer application can alter the way subjects are learned and homework is completed. Both students and teachers can benefit from the introduction of this technology. Students will benefit from having this tool available because it will eliminate the need for lengthy calculations and allow them to easily observe the effects of changing values on various variables, thereby improving their understanding of the subject matter and increasing their interest in and enthusiasm for studying it. Further, it will aid educators in conveying a variety of turbomachinery ideas to their students. In addition, students can use these resources in the project's design phase. This program can do more than just solve the equations; it can also tell you how the various parameters influence the forces. This means that students can complete as many calculations as they need with the touch of a button, without the risk of making a mistake or growing bored with the process.

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Keywords : Computational tool; engineering tool; Excel/VBA; innovative pedagogy; turbomachinery tool.

1. Introduction

Recently, the incorporation of computational tools into teaching and learning has become increasingly important, especially when it comes to the acquisition of software-related skills such as designing and analysis. Students have the flexibility to learn at their own pace with the help of a high-quality computer application that serves as a second teacher. In particular, because of its integration, students no longer need to resort to laborious calculations to tackle difficult problems in the engineering domain. Students have been prompted to think creatively by the necessity of analyzing the outcome of a lengthy computation that can only be done on a computer. With just a few clicks, we can investigate the impact of adjusting several parameters on a set of visually arresting graphs.

There are various platforms which allow the user to create computational tools they are Pyro, Python, Sci-Lab, MATLAB, MS Excel/VBA, Wolfram CDF, Cycle-pad, etc.

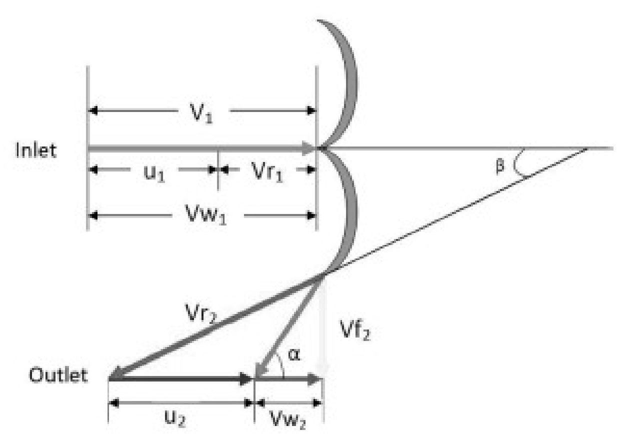
We settled on Excel/VBA as the platform of choice because it offers a user-friendly environment for computer-based learning of such ideas, allowing the user to easily adjust input parameters and acquire a dynamic answer with a single mouse click, all while avoiding error. For many of the engineering processes which entail a mathematical model that is already available, such tools provide crucial answers to important “What if” questions like "What is the need for this parametric variation?", "What will the result be, if a certain parameter is maximized?". Through the use of visualization, the scalability of the live graph allows for the answering of problems that aren't usually covered in textbooks. Excel/VBA is a neat engineering tool and to fully uncover its potential its more active integration into engineering curriculum and pedagogy is required (Tay et al. 2012). It's easy to use and comes with a wide range of specifications that may be applied to the development of envisioned instruments. Plug-ins are unnecessary for the operation of this interface. Excel/VBA platform has been utilized greatly in all aspects of science and engineering education, including mathematics (viz. Tay et al. 2012), mechanics of materials (Sachis et al. 2011), design and analysis of mechanisms and components (viz. Cheetancheri and Cheng 2009, Agarwal et al. 2022, Karn et al. 2023), heat transfer (Dwivedi et al. 2022a), fluid mechanics (Dwivedi et al. 2022b) and so on.

Turbomachinery is one of the most challenging subjects for mechanical as well as civil engineering sophomore students. Specifically, it involves the analysis of hydraulic and impulse turbines, both of which are notoriously tricky to picture in action. Those who work as engineers need to have a thorough understanding of the profession and the ability to critically evaluate theoretical concepts in the context of practical implementation. So that they may best serve businesses and other organizations, mechanical engineers need to acquire the necessary knowledge by putting themselves in the position of a worker in those establishments. Students are typically made aware of how changing input parameters affects turbine efficiency, but they are rarely given the opportunity to investigate this phenomenon on their own due to the complexity of the calculations involved. This resource helps students bridge this gap by providing an interactive environment in which they can practice conceptualizing the tool. The current paper presents an understanding of hydro-kinetic turbines followed by equations utilized to solve them and its specification. Of course, there are a number of reports in the literature that advocate employing such design tools for turbomachines, particularly for machines such as fams, compressors, and turbines (viz. see Turner et al. 2011).

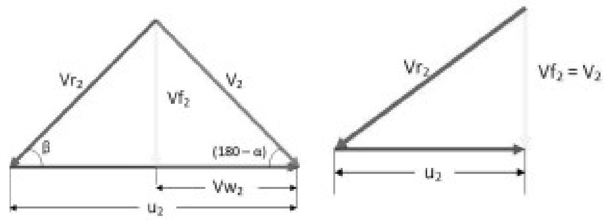
2. Hydraulic Turbines

Turbomachines are all pervasive - they are used in a wide variety of applications, including propulsion (of aircraft and machinery), motion (of fluids and gases), supercharging (of a device), compression (of a gas), and expansion (of a gas). Their usefulness extends from tiny computer cooling fans to cutting-edge huge bypass ratio turbofans to massive steam turbines producing over a million shaft horse horsepower. All turbomachines rely on a single, fundamental principle: the manipulation of swirl momentum. The Latin word for "swirl" (turbo) is whence they got their name. Simply put, a turbomachine is any device, large or small, that modifies the momentum of a swirling flow.

Hydro turbines are used to reduce overall energy consumption by drawing power from a fluid. This means that high-energy fluid is accessible at the turbine's input and that the fluid's energy is diminished as it exits the turbine. The principal role of the high-energy source might vary greatly from one use to the next. A hydro turbine's primary high energy source is the static head, which is turned into a velocity head by flow acceleration in the event of high-velocity fluid resulting from a large elevation difference. However,



(a)



(b) (c)

Fig. 1 : (a) Inlet and outlet velocity triangle of Pelton wheel as shown in (Dixon, 1998) . (b) Outlet velocity triangle for α > 90°. (c) Outlet velocity triangle for α = 90°. Where, Vr1 = jet velocity relative to the bucket at the inlet (m/s), Vw1 = velocity of whirl at inlet (m/s), u1 = tangential velocity of wheel at inlet (m/s), V2 = absolute velocity of water at outlet (m/s), Vr2 = jet velocity relative to bucket at outlet (m/s), Vw2 = velocity of whirl at outlet (m/s), u2 = tangential velocity of wheel at outlet (m/s), Vf2 = velocity of flow at outlet (m/s), β= angle made by the absolute velocity with the direction of vane motion, α= angle made by the relative velocity with the direction of vane motion.

the velocity head is the most important source of high energy for hydro turbines that are powered by river flow. Based on the type of stream and head they are classified into impulse and reaction turbines.

3. Impulse Turbine (Pelton Wheel)

In order to achieve a high head with little flow, impulse turbines like the Pelton wheel are employed. The turbine's strengths are its low cost, ease of production, and its reliability. This process transforms the potential energy of water (hydraulic energy) into motion. Hydroelectricity is generated when water from the penstock impinges on the blade of the turbine through a nozzle, setting in motion the runner (Oo, Nyi, & Khaing, 2019). In fact, the analysis of the turbomachines and Pelton wheel, in particular, has been attempted through numerous approaches such as numerical analysis (Kumashiro et al. 2019), computer-aided methods (Moukalled and Honein 1995), computational fluid dynamics (viz. Pujol et al. 2010).

A. Velocity Triangle Calculations of Pelton Turbine

The kinematics of the flow of a turbomachine may be represented as a velocity triangle. Previous work has established that a change in the head is attributable to a change in the tangential velocity components multiplied by the tangential speed at that position. This requires knowledge of both absolute and relative velocities. It is worth noting that the absolute frame of reference is non-rotating and fixed with respect to the ground, whereas the relative frame of reference is rotating with the rotor. The tangential speed of the rotor “u” at that place is the velocity of the frame of reference that links absolute and relative velocities. Typically, the letter "V" is used to represent absolute velocity, while the letter "V_r" is used to represent relative velocity. Figure 1 depicts the overall scheme, clearly showing the angles α and β. It is worth mentioning that the component of absolute water velocity along the blade velocity is typically referred to as the whirl velocity (V_w), and the other orthogonal component is known as the flow velocity (V_f). Figure 1a and the other two cases clearly display the inlet-outlet velocity triangle. From figure 1a it can be seen that the inlet parameters like $\alpha = \beta = V_{f1} = 0$. Whirl velocity at the outlet is zero (Figure 1c) and for V1 considering the friction loss in the nozzle, the velocity of the water jet can be calculated by $V_1 = K_v \sqrt{2gH}$, where Kv is the coefficient of velocity approximated as 0.985 (Oo, Nyi, & Khaing, 2019) and H is the net head available. For calculating u, the tangential velocity at the inlet and outlet can be equated at mean pitch (Oo, Nyi, & Khaing, 2019). Therefore, $u_1 = u_2 = u = \pi DN/60$, where D is pitch circle diameter of pelton wheel and N is RPM of the turbine runner. For calculating V_{r1}, it can be assume that the bucket surfaces is smooth and energy losses due to impact at the turbine are neglected, K = 1 (Oo, Nyi, & Khaing, 2019). So $V_{r1} = V_1 - u = V_{r2}$. The outlet flow velocity V_{f2} can be obtained by applying sine rule in all the three cases. In outlet triangle of figure 1 (a), (b) and (c) by using to find the flow velocity at the outlet which is given by $V_{f2} = V_{r2} \sin\beta$. The value of V_2 can be calculated by $V_2 = \sqrt{(V_{f2}^2 + V_{w2}^2)}$. Whirl velocity at outlet can be calculated by using figure 1 (a) and(b). The formula derived is $V_{w2} = V_{f2} / \tan(180-\alpha)$.

4. Sample Problem

To test the efficacy of our designed computational tool on the Pelton wheel, the input values are taken from a recent article (Oo, Nyi, & Khaing, 2019) and the obtained output is checked against the reported solution. The problem statement reads thus: “ It is required to design a Pelton wheel which provides an output power of 220kW working under a head (H) of 213 m. The RPM (N) of the turbine is 1000 and β = 17.14°. The angle made by relative velocity to the direction of vane motion (α) is 66°. The pitch circle diameter of 0.56m is taken and friction factor (K) =1. The above input is entered into our program to obtain a solution which is shown in figure 2.

A. Solution Using Excel/VBA.

Given the input parameters, D = 0.56m; N = 1000; H = 213m; K = 1; α = 66° and β = 17.14° are the given parameters.

The output values and the graph of the exit velocity triangle are calculated after the aforementioned input parameters are entered in the "INPUT PARAMETERS" column of Figure 2. As soon as the necessary input parameters are entered into the appropriate cell in Excel/VBA, the velocity triangle is plotted. Slider bars have also been included for improved compatibility and user experience. The user can now easily adjust settings with a single click. Because of these assumptions, the solution presented in Figure 2 may not accurately represent the true values of the velocities. The results are meant to help students become more analytical thinkers who can solve problems with intuition rather than just numbers. The numerical and graphical representation as seen in Error! Reference source not found. is obtained through the following steps and methods:-

Step 1: The programming is done in Excel/VBA environment to make it user-friendly and compact in nature.

Step 2: Calculation of output

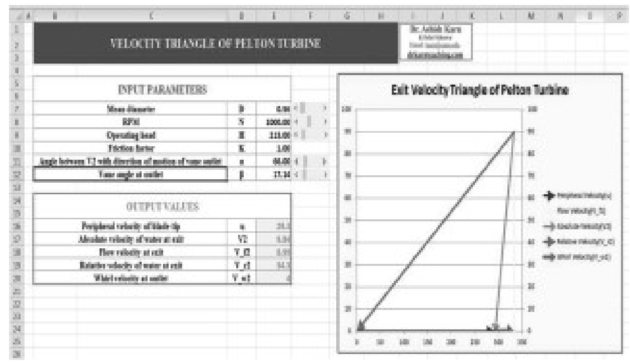
- The "u" value is derived from the equations used to determine the performance of a Pelton turbine. The formula for calculating the mean diameter (D) and the mean rotational speed (N) is built into a VBA program, and the results are displayed in cell E16 of Figure 2a.

- The value of the Operating head (H) is entered in cell E9 as shown in Figure 2a and its value gets entered in the VBA program coded with the required equation of "Vr2" and "V1 is calculated and the output is obtained in cell E19 as shown in Figure 2a.

- The value of "β" is entered in cell E12 as shown in Figure 2a and its value gets entered in the VBA program coded with the required equation and value of "Vf2" is calculated and the output after the calculation is obtained in cell E18 as shown in Figure 2a.

- The value of "V2" and "Vw2" is simply calculated using the appropriate equation and the output after the calculation is obtained in cells E17 and E20 as shown in Figure 2a. The values required for calculation are automatically entered in the VBA program internally as soon as entered the value of α in cell E11.

Step 3: Coordinates for plotting velocity triangle in excel.



(a)

	A	B	C
1	Exit velocity triangle coordinates		
2			
3		X co-ordinates	Y co-ordinates
4	blue- S	0	0
5	blue- E	293	0
6			
7	red- S	333.00	89.9
8	red- E	0	0
9			
10	yellow- S	333.00	0
11	yellow- E	333.00	89.9
12			
13	green-S	333.00	89.9
14	green-E	293	0
15			
16	pink- S	293	0
17	pink- E	333.00	0

(b)

Fig. 2 (a) Solution of problem using Excel/VBA, (b) Co-ordinates for exit velocity triangle

- Each output values in Figure 2a represent a velocity vector that has a color assigned to it as shown in Error! Reference source not found. (The same 5 colors can be seen in Figure 2b which depicts those vector's x and y coordinates).

- To plot a vector two points i.e. Start and end points (or any two points) are required. In the code, it has been considered as the start and end points. So blue_S in Figure 2b represents the blue color vector's starting x and y coordinate point in adjacent cells and blue_E in Error! Reference source not found. represents the blue color vector's ending x and y coordinate point in adjacent cells (equal to the magnitude). For proper scaling, each vector has been multiplied by the factor of 10.

- The initial coordinates of Vw2 (pink_S as shown in Error! Reference source not found.) are the final coordinates of u (blue_E as shown in figure 2(b)) and the end of Vw2 (pink_E as shown in Error! Reference source not found.) is either (u+Vw2) or (u-Vw2) depending whether α is less than 90 0r greater than 90 respectively.

- The initial coordinates of Vf2 (yellow_S as shown in Error! Reference source not found.) are the final coordinates of Vw2 (pink_E as shown in Figure 3b) and the final coordinates of Vf2 (yellow_E as shown in Error! Reference source not found.) are (x co-ordinate of Vw2, Magnitude of Vf2 (value in cell E 18 as shown in Figure 2a).

- The initial coordinates of Vr2 (red_S as shown in Error! Reference source not found.) are the final coordinates of Vf2 (yellow_E as shown in Figure 2b) and the final coordinates of Vr2 (red_E as shown in Figure 2b) are the origin as shown in Error! Reference source not found..

- The initial coordinates of V2 (green_S as shown in Figure 2b) are the final coordinates of Vf2 (yellow_E as shown in Figure 2b) and the final coordinates of V2 (green_E as shown in Figure 2b) are the final coordinates of u (blue_E as shown in figure 2b).

Care much be exercised while entering the values of each coordinate as these are interrelated to each other. Once the magnitudes are obtained, the velocity triangles are plotted accordingly, as shown in Figure 2a.

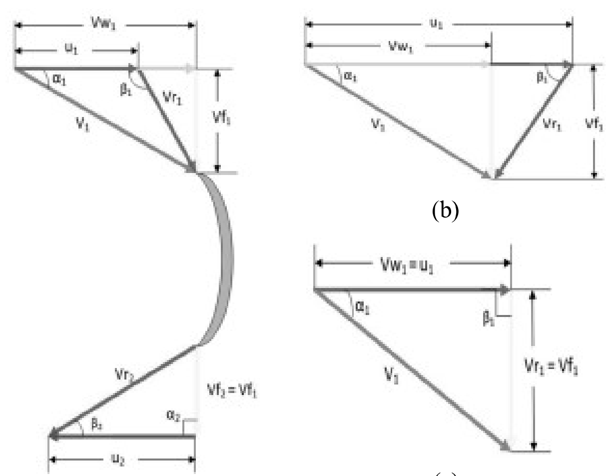
5. Reaction Turbines

A. Francis Turbine

A Francis turbine is a radial machine with a moderate to substantial degree of reaction (0.55–0.75). The water runs via adjustable flow-controlling guide vanes. The vanes are capable of being shut down to zero flow. Typically, the rotor contains 12 to 16 blades. The rotor's input is radial (there is no axial velocity component), but its output is nearly axial (small radial velocity component). This type of rotor is termed radial and rotor blades can't be adjusted. Radial discharge at the outlet means the absolute velocity vector (V_2) and wheel's tangent (u_2) are perpendicular to each other. Another way to interpret it is that the whirl velocity at the outlet is zero (V_{w2}=0). This also means limiting the three outlet cases to one case i.e. (α_2=90°) to reduce the kinetic losses and maximize the output efficiency which makes the flow velocity at exit (V_{f2}) equal to the exit velocity (V). The inlet and outlet velocity triangle of Francis turbine is shown in Figure 3a. The other two cases of inlet velocity triangles are shown in Figure 3b and Figure 3c.

B. Kaplan Turbine

A Kaplan turbine is an axial machine with a high degree of reaction (0.75 and higher). The turbine features a volute supply and a radial stator with variable vanes. Upstream of the adjustable stator vanes are fixed stator vanes that contribute to the structure's support. These are known as stay vanes,



(a) (c)

Fig. 3 : (a) Inlet and outlet velocity triangle of inward flow reaction turbine where β1 > 90° and α2 = 90°. (b) Inlet velocity triangle for β1< 90°, (c) Inlet velocity triangle for β1 = 90°

and they are frequently used also with Francis turbines. The rotor is axially flowing and features changeable blades. It differs from a propeller turbine as the vanes of the hub are adjustable in a Kaplan turbine. It differs from the Francis turbine as the inlet and outlet peripheral velocity is equal in the case of the Kaplan turbine. The calculation of inlet peripheral velocity is also different in this case. The inlet velocity cases for the Kaplan turbine is same as Francis turbine and is shown in Figure 3a-3c.

6. Velocity Triangle Calculations for Reaction Turbine

Peripheral velocity can be calculated by using $u_1=(\pi D_1 N)/60$ and inlet flow velocity by $V_{f1}=K_f \sqrt{2gH}$. It is known that $V_{f1}=V_{f2}$ (Dick 2015). K_f varies from 0.15 to 0.30 and in our calculation, we have considered it as 0.20. whirl velocity for all 3 cases will be different which can be calculated by $V_{w1}=u_1+V_{f1}$ $\cot(180-\alpha)$ for $\beta_1>90°$ (Figure 3a), $V_{w1}=u_{1\text{-}V}$_f1 $\cot(180-\alpha)$ for $\beta_1<90°$ (Figure 3b) and $V_{w1}=u_1$ for $\beta_1=90°$ (Figure 3c). The jet velocity can be calculated by $V_1=\sqrt{(V_{f12}+V_{w1}{}^2\ )}$ for each case and the relative velocity at the inlet will be $V_{r1}=\sqrt{(V_{f1}{}^2+(V_{w2}-u_1)^2\ )}$ for cases (a) and (b) and for (c), it will be equal to inlet flow velocity. The inlet guide vane angle will be calculated by $\alpha_1=\tan^{(-1)}V_{f1}/V_{w1}$ for all 3 cases.

For the outlet velocity triangle, the outlet peripheral velocity for the Kaplan turbine will be as same as the inlet peripheral velocity whereas for the Francis turbine it will be u_2=(πD_2 N)/60. The exit relative velocity and outlet blade angle (β_2)will be equal for both the turbine i.e. $V_{r2}=\sqrt{(V_{f1}{}^2+u_2)^2)}$ and $\beta_2=\tan^{(-1)}V_{f1}/u_2$.

7. Sample Problem

Here is a sample problem on a Francis turbine, that can be solved using the developed computational tool:

"Determine guide blade angle, guide vane angle, outlet blade angle, inlet whirl velocity and relative velocity at inlet also draw the graph of inlet and exit velocity triangle, given Flow ratio (kf) = 0.2; Working head (H) = 60m; RPM of the runner (N) = 700rpm; inlet blade angle= 138.91°; outer diameter of the runner (D1) = 0.54m."

Figure 4 displays the result of plugging the aforementioned data into our Excel interface. As soon as the sliders are adjusted, a new velocity triangle appears on the screen. When the appropriate parameters are entered into the appropriate cell in Excel/VBA, the velocity triangle is automatically plotted. The addition of slider bars enhances both the user experience and the degree of compatibility. Changing the parameters is as easy as a click of the mouse now. It is possible that due to certain assumptions, the solution presented in figure 4 may not reflect the true values of the velocities. The results are meant to improve students' analytical skills so that they can grasp the concept behind velocity triangles without resorting to purely numerical solutions.

The steps involved in the programming of this tool can be described as under:

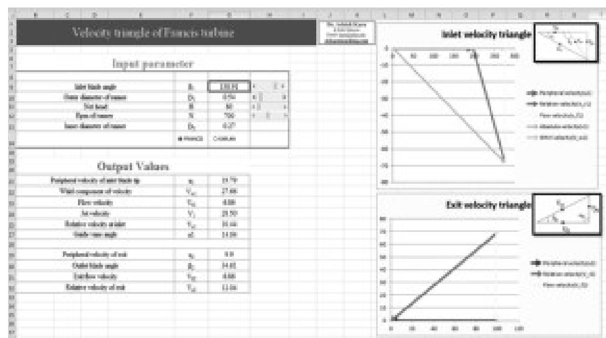


Fig. 4: Numerical and graphical representation of the reaction turbine.

Step 1: Calculation of output parameters

For a given type of turbine, the equation used for the calculation of the reaction turbine yields a value for "u1" and "u2" that are specific to that turbine. In Figure 4, the value of D1 is entered into cell G10, and the values are entered into our VBA program coded with the equations, with the results appearing in cells G21 and G29.

- Figure 4 shows where the values for k_f and H should be entered in order to run the VBA program containing the equations and calculate the value of "V_{f1}," with the resulting values appearing in cells G23 and G31.

- The value of β1 in cell G6, as seen in Figure 4, determines the needed calculation equation, and the value "V_{w1}" is calculated. As illustrated in figure 4, the output is generated in cell G22 when the data are inserted into our VBA application containing the equations.

- The output of "V_1" is calculated is obtained in cell G24 as shown in figure 4.

- The value of "V_{r1}" is calculated from the code depending upon the type of turbine chosen by the user and the output is obtained in cell G25 as shown in figure 4.

- The value of "α_1" is calculated and the output is obtained in cell G27 as shown in figure 4.

- The value of "V_{r1}" is calculated depending on the type of turbine chosen by the user and the output is obtained in cell G31 as shown in figure 4.

- The value of "β_2" is calculated which depends upon the type of turbine chosen by the user and the output is obtained in cell G30 as shown in figure 4.

Step 2: Coordinates for plotting the inlet velocity triangle in MS Excel.

- The initial coordinates of u_1 (blue_S as shown in figure 5a) is origin i.e. (0, 0) and the final coordinates (blue_E as shown in figure 5a are (Magnitude of u1 , 0).

- The initial coordinates of V_{w1} (pink_S as shown in figure 5a) are the origin and the end coordinate (pink_E as shown in figure 5a) are (Magnitude of V_{w1}, 0).

- The initial coordinates of V_{f1} (yellow_S as shown in figure 5a) are the same as the final coordinates of Vw1 and the final coordinates (yellow_E as shown in figure 5a) are (Magnitude of V_{w1}, -Magnitude of V_{f1}).

- The initial coordinates of V_{r1} (red_S as shown in figure 5a) are the same as the final coordinates of u1 and the final coordinates (yellow_E as shown in figure 5a) are the same as the final coordinates of V_{f1}.

- The initial coordinates of V_1 (green_S as shown in figure 5a) are the origin and the final coordinates (green_E as shown in figure 5a) are the same as the final coordinates of V_{f1}.

Step 3: Coordinates for plotting the outlet velocity triangle in MS Excel.

- The final coordinates of u_2 (blue_E as shown in figure 5b) are the origin i.e. (0, 0) and the initial coordinates (blue_S as shown in figure 5b) are (Magnitude of u_2, 0).

- The initial coordinates of V_{f2} (yellow_S as shown in figure 5b) are (Magnitude of u_2, Magnitude of V_{f2}) and the final coordinates (yellow_E as shown in figure 5b) are initial coordinates of u_2. It is already known that $V_{f2} = V_{f1}$

- The initial coordinates of V_{r1} (red¬_S as shown in figure 5b) are the initial coordinates of v_{f2} and the final coordinates (red_E as shown in figure 5b) are the origin i.e., final coordinates of u_2.

	A	B	C
1			
2			
3	Inlet velocity triangle		
4		X co-ordinates ⇩	Y co-ordinates ⇩
5	blue- S	0	0
6	blue- E	197.9	0
7			
8	red- S	197.9	0
9	red- E	276.6	-68.6
10			
11	yellow- S	276.6	0
12	yellow- E	276.6	-68.6
13			
14	green-S	0	0
15	green-E	276.6	-68.6
16			
17	pink- S	0	0
18	pink- E	276.6	0

(a)

Exit velocity triangle		
	X co-ordinates ⇩	Y co-ordinates ⇩
blue- S	99	0
blue- E	0	0
red- S	99	68.6
red- E	0	0
yellow- S	99	68.6
yellow- E	99	0

(b)

Fig. 5:(a) The coordinates of the inlet velocity triangle, (b) The coordinates of the outlet velocity triangle.

Finally, after having developed computational tools for both impulse (i.e Pelton wheel) and reaction (i.e. Francis Turbines) turbines and implemented them in the teaching and learning of hydraulic turbines in an undergraduate turbomachinery class, a survey of the entire class (consisting of 50 students out of which 30 responded) was taken. In this anonymous survey, the students were asked a number of questions related to the teaching methodology that integrated such a tool. The results of the survey were then subjected to hypothesis testing.

8. Hypothesis Testing

Hypothesis testing is a conventional methodology that examiners use to test whether a hypothesis can be acknowledged or not with respect to a populace boundary. A hypothesis is essentially a presumption about something. For the duration of the hypothesis, we must gather an increasing quantity of data in an effort to disprove or support our original assumption. Testing hypotheses can be done in a number of ways, each appropriate for a different population and set of data. We found that the "t-test" was the most helpful statistical tool for the given population size. In order to ensure that two products are compatible, the "two-sample t-test" is commonly used to compare the distributions of two sets of continuous data. To do this, we will assume (via the null hypothesis) that there is no distinction between the two sets. By averaging the data from each group, the "two sample t-test" can determine whether or not the data supporting the hypothesis is reliable. In most cases, it reveals the public's perception of the product. Excel's "t-test" tool is part of the program's Data Analysis tool pack; after the user selects a range of variables, the programme then calculates the variance, mean, number of observations, and P-value (both for one and two tails) automatically. When testing hypotheses based on observed data, the p-value (meaning "probability value,") is crucial. Its primary function is to determine whether or not a piece of evidence has any real bearing on the truth. The significance level required to reject or confirm a null hypothesis is typically expressed as a percentage or a decimal. Excel's built-in P-value function was used to determine significance. This computational tool can be used in conjunction with the Turbo machinery course to help students learn the material. Fifty undergraduates in their third and fourth years were given access to an Excel/VBA file that had been uploaded to https://www.drkarnteaching.com/turbomachinery-tools to evaluate Turbo Machinery Tools' efficacy. Students are to rate the hypothesis from 1 to 5 when responding to it (1-Strongly Disagree to 5- strongly agree). The t-test was used to analyse the results of the Hypothesis. It is a common method for determining probabilities and validating hypotheses. Table -1 present several survey questions posed to the students that directly correspond to the alternative hypotheses in the current study.

Table 1 : Statement of survey questions given to the Users/ different alternative hypotheses in hypothesis testing

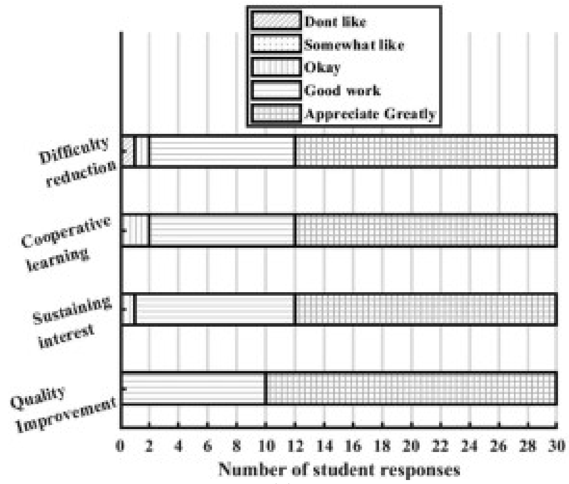
#	Hypotheses
1.	The difficulty level of the subject was considerably reduced with the help of this computational solver
2.	The strategy of employing computational tool helps in cooperative peer learning.
3.	The developed computational tool helps retain the interest and attention of the students in the turbomachinery course.
4.	This computational design tool inspires students to do quality work.
5.	The developed computational tool is helpful in honing problem solving skills during the tutorial sessions.
6.	The interactive tools on velocity triangles of Pelton Wheel and Francis turbines is a great lecture demonstration to aid students' understanding.
7.	This computational solver helps students significantly in applying theoretical concepts to real-life problems
8.	This teaching strategy will help students to see integration of computers in engineering education.
9.	The developed computational tool considerably improves the overall teaching-learning experience of velocity triangle analysis of hydraulic turbines.
10.	Based on the benefits derived from this solver, such a computational tool is recommended for other courses.

A. Student Perception on Learning

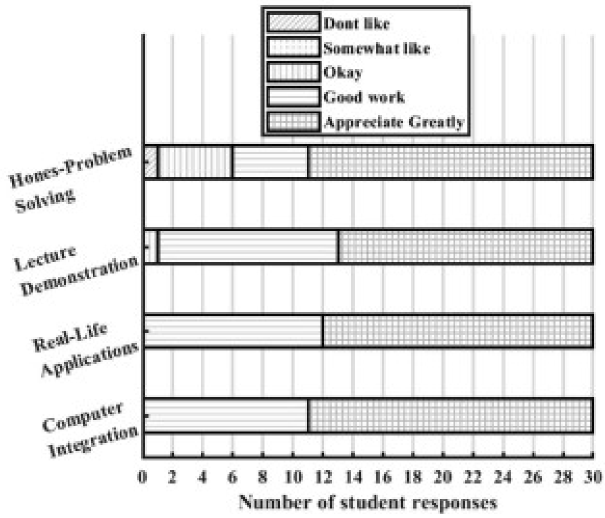
Figure 6a demonstrates that the majority of students highly agree (5) and agree (4) that this teaching pedagogy fosters a communal and cooperative classroom environment. Students' participation has grown after the implementation of this learning method. Few students gave a neutral rating of 3, suggesting that they may not be frequent class attendees; if they were, they might also participate in the conversation. 0% of students disagree that this instructional method will not promote effective learning.

B. Students Perception on Teaching

Figure 6b reveals that student opinions on how the quality of instruction may be enhanced were divided, with the majority (those who strongly agreed) being in



(a)



(b)

Fig. 6 : (a) The student survey responses on the novel way of computational learning, and (b) student survey responses on the novel teaching methodology.

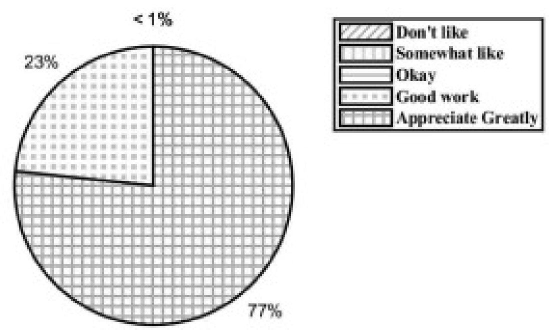
favour of such an endeavour. It claims that this method of instruction is preferred by students over the use of PowerPoint slides. Some (45%) students are on the fence about the instructor's methods since they are unfamiliar with them. No one thinks this strategy for educating students will not raise standards in the classroom. Some students who don't see the point in learning the material could change their minds.

C. Overall Acceptance of New Method

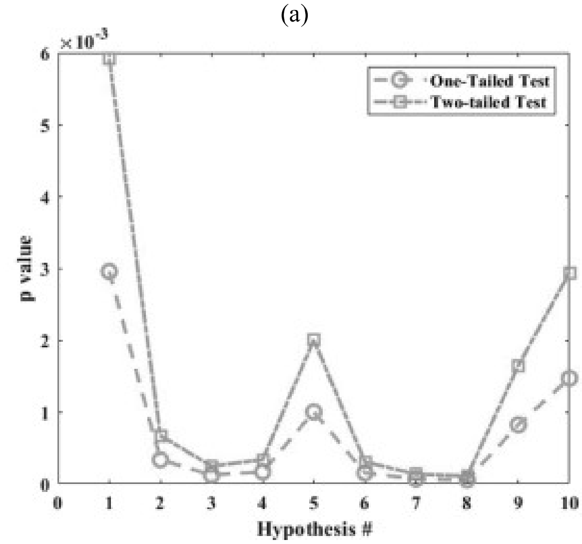
Figure 7a shows that the vast majority of respondents (94%), either strongly agree (5) or agree (4) with the new pedagogical approach. The report concludes that the students' capacity to conceptualize the fundamentals of turbo-machinery was enhanced by the new teaching approach. Six percent of students (neither agree nor disagree-3%) are on the fence about the new methodology. This could be because they found Excel/VBA to be too complicated to use or because they were bored with the course subject. We have developed a new pedagogy for teaching and learning, and, interestingly it has found a very receptive audience and no one seems to have any difficulties with it.

D. The p-Value of the Hypothesis

The p-value (one tail and two tail) for all of the above hypotheses is less than 0.05, as shown in figure 7b, indicating that the majority of students found support for the ten hypotheses presented. A p-value less than 0.05 suggests that the null hypothesis can be rejected in each case, and the alternative hypothesis can be accepted. Putting it simply in words, the developed computational tool for the teaching and learning of hydraulic turbines is found to reduce



(a)



(b)

Fig. 7 : (a) The student survey responses indicating the overall acceptance of new methodology in the Turbomachinery course, and (b) the p-value corresponding to the ten hypotheses using one-tailed and two-tailed t-test.

difficulty in the learning process, induce cooperative and peer learning, help students to sustain interest in the subject, and improves the overall quality of the teaching delivery. In addition, it also affirms that these computational tools hone the problem-solving approaches of students, serve as excellent lecture demonstrations and give an insight into real-life applications of the course material and the integration of computers in engineering education. The student responses clearly indicate that the proposed methodology is an excellent intervention in the teaching-learning experience of velocity triangles of hydraulic turbines, and is something that the students would appreciate in other engineering courses as well.

9. Conclusion

The current paper proposes the integration of computational tools in the teaching and learning of velocity triangle analysis of hydraulic turbines. Two distinct tools on Pelton wheels and Francis turbines were developed and implemented in the undergraduate turbo machinery course. Finally, student responses were sought to ascertain the efficacy of such an approach in the overall pedagogy. The student responses indicate an overwhelming acceptance of the proposed methodology in various aspects of teaching and learning. Subsequently, hypothesis testing was conducted on all the hypotheses (as shown in Table 1) and a p-value of less than 0.05 for all the hypotheses presents significant evidence to reject the null hypothesis and accept the alternative hypotheses. Overall, the statistical analysis of the student responses confirms the overall effectiveness of such a tool as a robust pedagogical technique for turbomachinery. It is hoped that such tools will provide students an insight into the functioning of both impulse and reaction turbines for multiple scenarios with a single click and without the tedium of repetitive or iterative calculations, thereby facilitating the learning process.

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