Undergraduate Research: Experimental Study on Performance of Marine Propellers

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Abstract

Application of computer-aided technologies in design, manufacturing, and engineering analysis is one of the major undergraduate research in the MANE-manufacturing engineering program at Virginia State University. In summer 2017, a manufacturing engineering student engaged in a project titled Computer-Aided Reverse Engineering of a Boat Propeller. The objective of the project was to assist the student to boost his knowledge of reverse engineering and gain hands-on experience in the solid modeling of complicated products. Since 2018, the project has continued to investigate the performances of standard marine propeller models. In the present study, we aim to clarify the effect of the number of blades on the generated thrust force when the propellers are operating at their maximum capacities. We also aim to review the geometric characteristics of the different propellers' blades in marine industries. An experimental setup was established, and a series of propeller models were designed using NX 11.0, a commercial CAD software. Using a 3D printer, a set of propeller models with the same blade shape and geometric characteristics but a different number of blades (two-five blades) was prototyped. The results of the conducted experiments and students learning outcomes presented in this report.

Introduction

With a grant from the National Science Foundation (NSF), the Virginia State University provides research experience to science, technology, engineering, and mathematics (STEM) undergraduate students. The grant allows STEM undergraduate students to research topics of their choice in summer and the academic year. Students can perform one-on-one research with a faculty member and receive paid research internships. Students gain practical research experience with their faculty mentor in the project design, methodology, and implementation. Faculty members also select qualified freshmen STEM students to participate in the research project to gain the theoretical and practical knowledge of the research by outlining the research objectives, design experiment, data collection, and analysis. Then, they present the results orally and in written form at local or national conferences.

Using computer-aided technology, the design and manufacturing of boat propellers are one of the focuses of undergraduate research projects. The goal is to identify the effects of geometric characteristics and the efficiency of blades shape on the propeller's thrust force. The project is in two phases: In the first phase in summer 2017, a MANE sophomore student was involved in this project to redesign a propeller model using a Coordinates Measurement Machine (CMM) and NX 11.0 CAD software. This phase enhanced the student's hands-on experience in application of CMM and solid modeling in design process of parts with complicated geometric characteristics. Figure 1 provided the CMM setup for geometry detection of a boat propeller.

In the second phase, in summer 2018 the student-constructed an instrumental set up to identify the operational characteristics of the marine propellers. This phase enhanced the student's hands-on experience in technical instrumentation, data collection, and analysis. Moreover, the student acquired skills in designing and setting up the first experimental apparatus to operate and collect raw data proportional to the propeller thrust force. Figure 2 provided the CMM setup for geometry detection of a boat propeller.

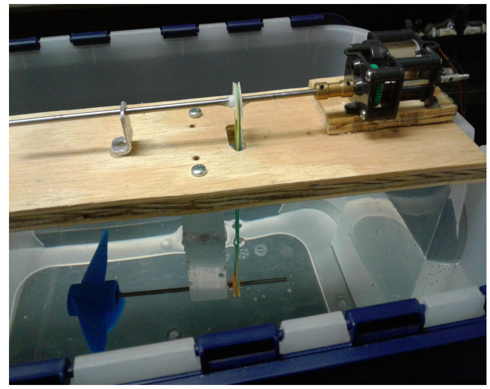

Fig. 1- CMM setup for geometry detection.

Fig. 2- The first experimental setup.

The project is open-ended research to improve the experimental setup and accuracy of collected data. In summer 2019, another MANE junior student continued to work on setting up an accurate experimental approach for the efficiency of the tests and collecting data.

Test Models

In his study, a series of propeller models were designed and prototyped to test the efficiency of the trust force. The models having the same shape and geometric characteristics, but with a different number of blades (two-five blades) designed and prototyped using a 3D printer. The projected view plane (normal to propeller axis) for a four-bladed model, led to the overlapping of the blades. This overlapping phenomenon was more severe in the five-bladed model. To better understanding the effect of number of blades on the propeller efficiency, the overlapping avoided by modifying the shape and size of the blade of the base model. Figure 2 presents the samples of the 3D printed models.

Fig. 3- Selected samples of 3D printed models

Experimental Setup

The focus of this project was to build a theoretical and experimental foundation to measure and analyze the marine propellers' performances and to maximize working efficiencies. Several approaches were investigated for the experimental setup.

Approach 1:

In this approach, the angular position of the rod is used to determine the magnitude of the thrust force produced by the propeller. The angle of the rod rotation is measured by a potentiometer attached to its pivot axis. Then, we can determine the equivalent thrust force of the propeller using simple calculations.

Approach 2:

In this approach, the rod is treated as a cantilever beam, which has a strain gauge embedded in a specific position on the beam. The applied thrust force of the free end of the beam is derived from the numerical value of strain, which is proportional to the changes in wire resistance of the strain gage. The magnitude of the thrust force will be derived by measuring strain and using the geometric characteristics and material properties of the rod. Figure 4 provided the relationship between moment and strain in a cantilever beam.

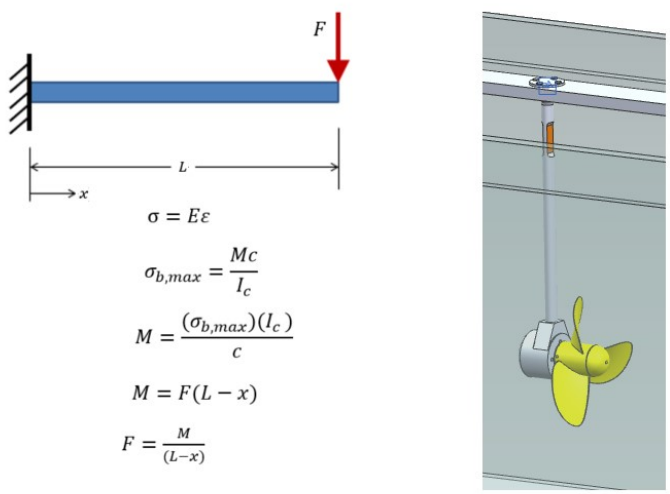

Fig. 4-Set up of the first experimental approach

Approach 3:

To measure the working performance of the propellers, an experiment is performed to measure the thrust force component. In this approach, a small DC motor is attached to a pendulum rod to drive the attached propeller.

Preventing the rotation of the rod by a digital scale or an installed force sensor, we can stablish statically equilibrium equation of the rod with the amount of the forces applied to the ends of the rod. The equilibrium condition of the rod implies that the resultant moment respect to pivot must be zero. Therefore, the amount of thrust is determined through a simple calculation using reading data from the digital scale or a force sensor. Figure 5 provided the experimental setup and calculation method of the thrust force.

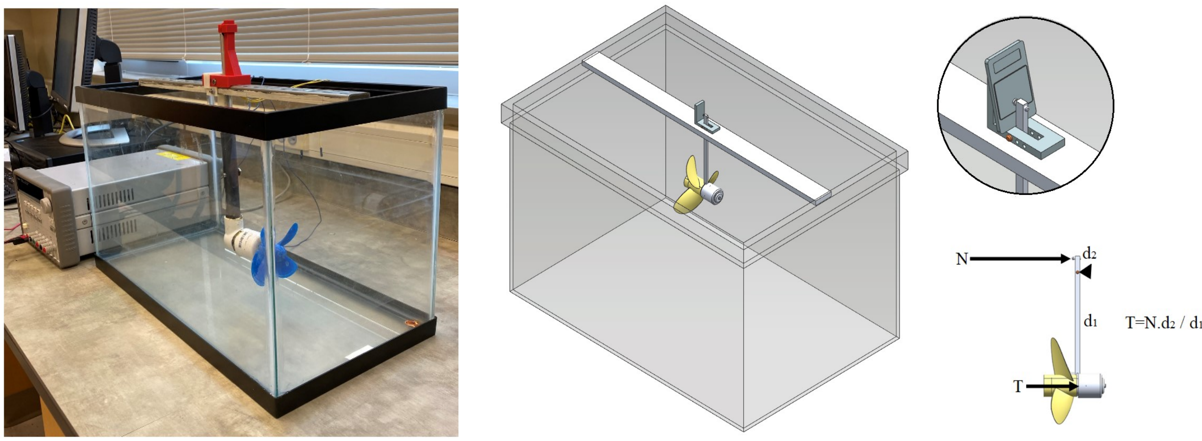

Fig. 5-Set up of the third experimental approach.

Results and Discussion

The structural configuration of all three methods is almost identical, and we set up the first approach. In this approach, the experimental setup consisted of a small DC motor attached to a pendulum rod to drive the propeller. A small size digital scale (later replaced by a force sensor) was assembled on the other end of the rod to stop the rotation of the pivot and detect the amount of force owing to the thrust force.

We measured the thrust force of the three geometrically identical propellers. All the three propellers had the same geometrical characteristics, but the number of their blades (three, four, and five) were different. Table 1 summarizes and Figure 5 illustrates the results of the test, respectively.

By increasing the voltage of the motor (rotational speed of the propellers), the magnitude of the thrust forces for the three propellers increased almost linearly till reaching maximum value then droping down for each propeller. Several factors can be responsible for this. The cavitation phenomena are most likely the cause of this problem, particularly in a four-bladed propeller where the thrust value drops sharply. The next challenge was the fluctuation of the rod during the tests that led to a severe vibration of the rod. In many cases, increasing the rotational speed was impossible. The following methods could resolve these problems.

(a) Retest the same rod and propeller assembly using methods in approaches 1 and 2.
(b) Use pully and belt mechanism to rotate the propeller. In this case, the shaft length will be minimized, and vibration issue will be solved (work is in the process).
(c) Design and build a new rigid hinge and install guiding support to prevent the rod deflection.

(d) Design and develop a new testing station (fourth approach) appropriate for more advanced undergraduate research for junior and senior engineering students in summer 2020.

Table 1- Summary of the Test Results

Input Voltage (volts)	Generated Thrust Force (Newton) 3 Blade	4 Blade	5 Blade
3.5	0.882	1.176	1.2348
4	1.078	1.568	1.4308
4.5	1.176	1.8816	1.6856
5	1.372	2.156	1.8228
6	1.4308	2.548	1.9208
7	1.372	2.352	1.9208

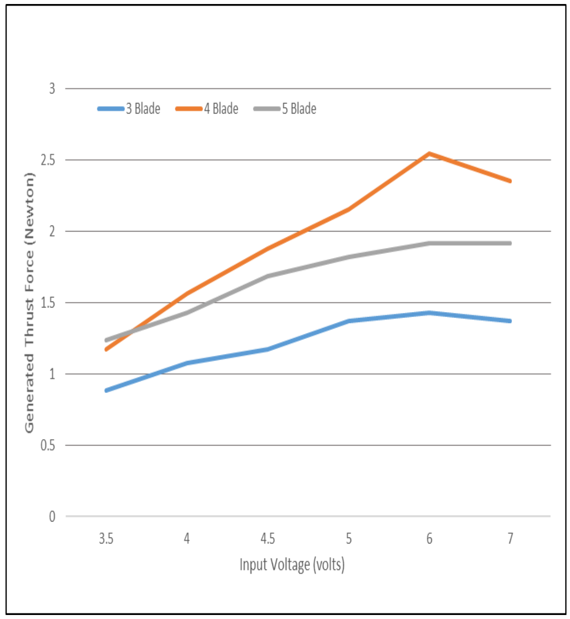

Fig. 5-Variation of thrust respect to motor voltage

Conclusion

Design and build an experimental setup to test a propeller assist students to explore manufacturing engineering principles and gain knowledge on tool safety and technical principles in DFM and DFA procedures. Students also acquired knowledge during any hands-on projects, which helps to identify problems, follows steps to solve the issues, and complete the tasks to achieve the project's goal(s).

At different stages of this project, students encouraged to design, build, and test the performance of a propeller. While the hands-on experiences are essential, it is crucial to learn how to share those experiences concisely and clearly with others. These skills will be necessary to prepare students for senior-level projects. Some of the concepts the students learned in this project are:

- *Design and Build*
- *Testing and Troubleshooting*
- *Engineering Mechanics principles*
- *Manufacturing Processes*
- *Project Management Skills*
- *Communication Skills*
- *Problem Solving Skills*
- *Physics of Motion*
- *Measurement Skills*

The focus of the project was to investigate the effect of the number of blades on the thrust of the propellers. Although the initial study has been conducted, more works need to be carried out to validate the expected results. Since availability of the junior and/or senior students for research work is mostly limited to the summer time, this phase of the study is still in process and more time required for achieving the expected goal(s).

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