STEM Education Meets HPC

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Abstract. STEM education is a teaching approach that combines Science, Technology, Engineering, and Mathematics. Rather than teach the four disciplines as separate and discrete subjects, STEM integrates them into a cohesive learning paradigm based on real-world applications. Based on the STEM approach, we developed a robotics course that engages students in middle school. We adopted the NodeMCU controller, electronic circuits, and free-designed materials to construct a cheap and resilient version of the remote control sailboat. Students design, build and test sailing the boat during the course. Students learn critical thinking, communication, and collaboration skills through the process. A CFD analysis of the model boat was done and demonstrated with augmented reality to help students understand the physics of sailing.

Keywords: HPC · STEM education · CFD

1 Introduction

Starting on August 1, 2014, Taiwan implemented the 12-Year Basic Education Plan. Curriculum Guidelines of the 12-Year Basic Education were developed based on the spirit of holistic education, adopting the concepts of taking the initiative, engaging in interaction, and seeking the common good to encourage students to become spontaneous and motivated learners. The curriculum also urges that schools be active in encouraging students to become motivated and passionate learners, leading students to appropriately develop the ability to interact with themselves, others, society, and nature. [1] There are many innovative designs in the guidelines that mimic the STEM education framework.

The STEM education framework is a teaching approach that integrates Science, Technology, Engineering, and Mathematics (STEM) programs in schools to strengthen students' competence in scientific inquiry and problem-solving skills; and to prepare students for future industrial demands [2]. Researchers have found that robotics courses can significantly increase positive attitudes toward the STEM framework [3]. Practicing STEM in the classroom can also improve test scores in science and mathematics.

To experiment with the STEM framework in marine education, we developed a robotics sailboat course that integrates science, technology, engineering, and mathematics, i.e., STEM, for students in grades 5–12. To better explain the physics of sailing, we computed the flow field with the CFD model. We demonstrated the flow field to the

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students with augmented reality. In the following sessions, we will describe the robotics course and the CFD computation in detail.

2 Method

2.1 The Robotics Course

We developed a robotics course that integrates science, technology, engineering, and mathematics, i.e., STEM, for students in grades 5–12. We adopted the NodeMCU controller, electronic circuits, and free-designed materials to construct a cheap and resilient version of the remote control sailboat. During the course, students are divided into groups; each group designed, assembled, and tested sail the boat in an inflatable pool. At the end of the course, each group presented the result in front of the class. Through the hands-on boat design and assembling process, students learnt the fundamental of naval architecture; and the navigation of the sailboat requires students' concentration and hand-eye coordination. The final presentation not only enhanced students' oral expression skills, but also promoted teamwork (Fig. 1).

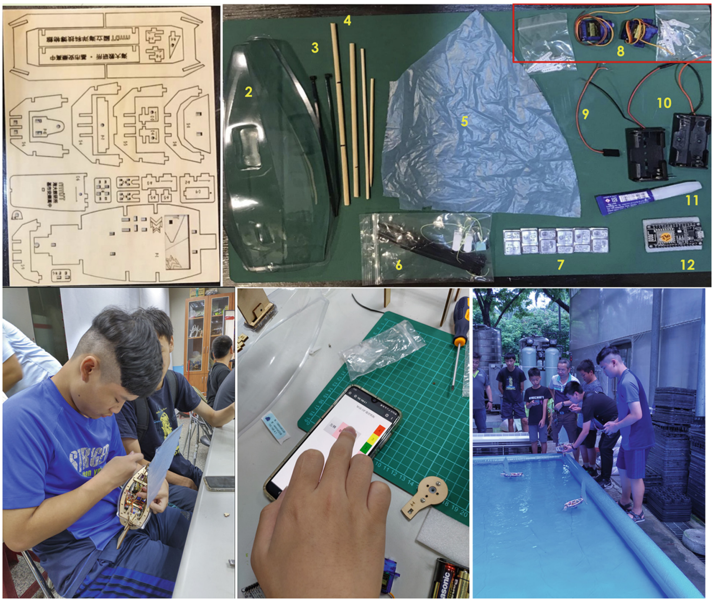

Fig. 1. Up: the layout and the materials of the experimental sailboat; Down: Students built, coded, and tested sail in a inflatable pool

2.2 The Physics of Sailing

Two questions loom if you start to think about sailing: 1. How is it possible that a sailing ship moves against the direction of the wind, reaching a destination situated windward; 2. How can the speed of a boat be over wind speed, both downwind and upwind? From the point of view of a physicist, a sailing ship is a system made up of two inter-connected hydrodynamic foils, interacting with media of different densities that meet them at different speeds at different angles. Figure 2 depicts a boat sailing close-hauled on the wind (i.e., at an acute angle to the wind direction), illustrating this fact.

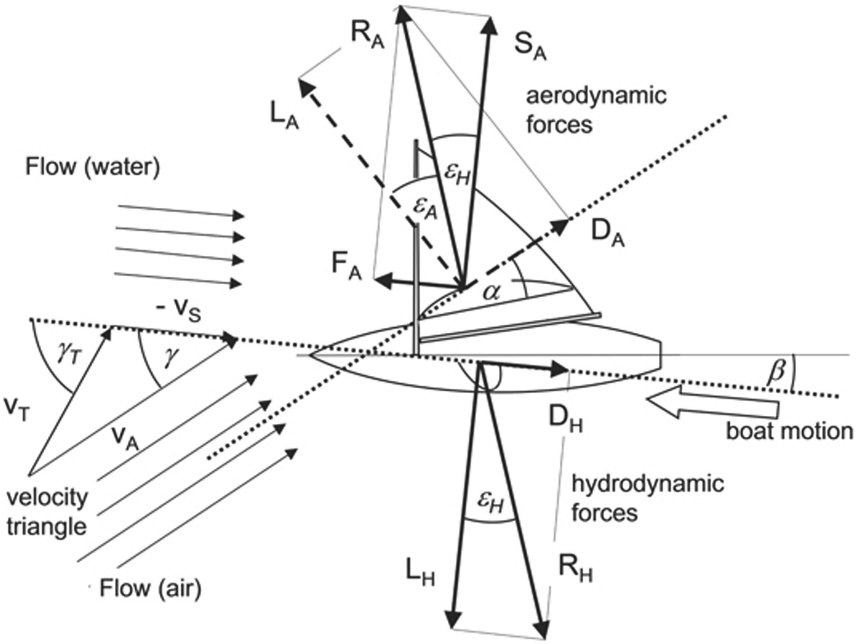

Fig. 2. A boat sailing steadily on the wind. Relative water flow evokes total force $\mathbf{R_H}$, air flow evokes total force $\mathbf{R_A}$. Adapted from [4]. Copyright Wiley-VCH Verlag GmbH & Co. KGaA.

In order to better explain the physics to students, we built a digital model of the sailboat and conducted a CFD analysis on the model. Figure 3 illustrated the mesh of the CFD model. The computation was done using Simcenter *STAR-CCM+* software package [5], and ran on the HPC facilities at NCHC.

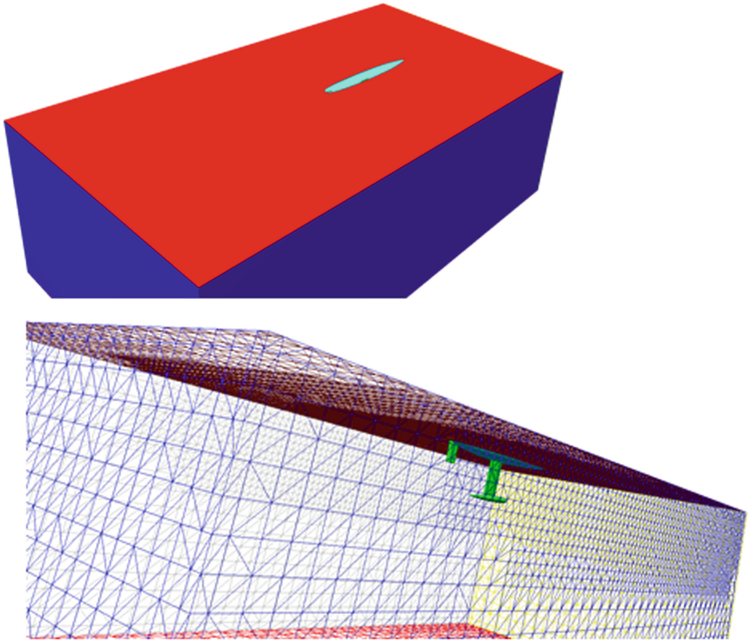

Fig. 3. The CFD model of the sailboat; we adapted DF95 sailboat to build the digital model and construct the mesh for modeling.

2.3 Scientific Visualization

Scientific visualization is the representation of data graphically using 2D images or 3D model animations, as a means of gaining understanding and insight into the data. For computational fluid dynamics (CFD) data, it's difficult to understand without scientific visualization given the complicated spatial data structure and large quantities of data points.

COVISE, the collaborative visualization and simulation environment [6], is a modular distributed visualization system. As its focus is on visualization of scientific data in virtual environments, it comprises the VR renderer OpenCOVER. The development of COVISE is headed by the High-performance Computing Center Stuttgart (HLRS).

In this study, we use COVISE to visualize the flow field of sailboat in different condition. To help students to better understand the spatial relations, we also demonstrated the fluid flow with augmented reality. The visualization of flow field is show in Fig. 4 and Fig. 5 shows the flow augmented to a physical sailboat model.

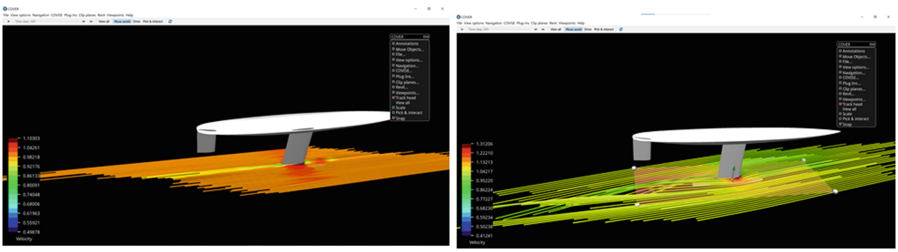

Fig. 4. The flow field around the keel in different attack angels; left: 0 degree; right: 10 degree. The data was visualized using COVISE.

Fig. 5. Flow field around keel was demonstrated with augmented reality

3 Future Work

In this study, we experimented using scientific visualization and augmented reality technology to blend complex engineering application like CFD simulation into middle school STEM education. The visualized unseen physics did bring the WOW effect to the classroom, and triggered students to think deeper. Many students mentioned that the course provided them with a better understanding of the concepts that were previously taught in the other courses such as physics and coding. The integrated STEM course linked abstract science concepts to practical work.

The experiment was done in a small class with only 15 students, and we got to learn the response from students closely. The overall responses were positive, that encouraged us to carry out the course in a larger scale.

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