Caleb Young

USP Board

Experimental Fluids Research Laboratory - Barnard Hall

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Quantifying Flow Structures around Rowing Blades

Introduction:

Rowing is a highly competitive sport where every second counts. As the sport has continued to innovate, a new blade attachment, the RANDALLfoil, has been introduced. This is a plastic part that fits on the top of the blade, aiming to generate higher propulsion with each stroke by reducing blade "slip" or the amount the blade travels in the opposite direction of motion without acting as an anchor to propel the boat forward. The objective of this project is to ***quantify the forces and flow structure of water around rowing blades both with and without the RANDALLfoil attachment*** (RANDALLFoil shown in Figure 1), to determine what benefits this addition may have to overall rowing performance (propulsion in the boat-forward direction). We hypothesize that the RANDALLfoil attachment should increase the size and strength of the leading edge vortex (LEV) forming around the blade. This will increase the hydrodynamic drag of the blade, therefore increasing rowing propulsion and efficiency.

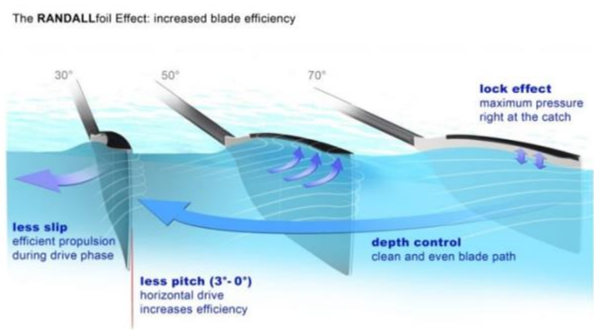


Figure 1 – RANDALLfoil with benefits to rowing propulsion(Aramtraining)

Background:

In this project area, preliminary research has been conducted concerning the Randall blade and its effectiveness in rowing, but results have thus far focused on limited force measurements and qualitative descriptions. In experiments involving tethered boats in a pool by Cardoso et al. (2025), data was gathered on the potential effectiveness of this new blade via both exertion surveys and impulse data. Whilst they showed that the RANDALLfoil produces higher values of force, and athletes reported that the rate of exertion was higher, existing works do not relate this to the flow physics around the blade. The objective of the current research is therefore to expand on these studies by relating any increases in efficiency from the RANDALLfoil attachment to the hydrodynamics around the blade, using laboratory analyses such as particle image velocimetry (PIV) and 6-axis force-torque data. By including torque data, this study also aims to investigate how the plastic top edge of the Randall foil reduces underwater slippage.

Previous works on rowing blades (without a RANDALLfoil) have used PIV to great success to study the fluid dynamics of an oar blade in water. For example, Grift et al. (2021), in a study on the hydrodynamics of rowing propulsion, investigated how the leading edge vortex (LEV) produced by rowing blades can enhance the force over the blade and propel the boat forward. It was shown that the LEV enhances lift (here, resulting in hydrodynamic drag) over the blade, as it remained close to the convex side of the blade as it went through the water. This study also showed that slip increases with a headwind in a M4+(Mens coxed four), compared to standard wind conditions M4-(Mens coxless four). This "slip" is a helpful factor to note, as less slip will promote boat acceleration, and a more efficient stroke.

In the scope of this project, I believe that I am capable of successfully completing my desired goals because of my previous experience in Dr. Morris's Experimental Fluids Research Laboratory (EFRL), my personal rowing experience in a crew, my prior knowledge of fluids based on previous classes, and the assurance that my professor and laboratory mates are there to help. I spent most of summer 2025 working in EFRL obtaining preliminary data (discussed in my previous research experience paper attached to this application). This gives me familiarity with the process of this research, and how to work to gather data. My research over summer focused on obtaining PIV data over the blade moving at low (1:8 scale of a real blade) speeds; moving forwards in this proposal, I plan to integrate a newly purchased linear stage motor into the experimental setup to achieve high (1:4 scale, to match our 1:4 scale blade) speeds. With this new setup, I will: ***(1)*** run experiments to obtain brand new 6-axis force-torque data both at low (1:8 scale) and high (1:4) speeds, and ***(2)*** run experiments to acquire PIV data at high (1:4) speeds. ***This data will allow me to correlate the forces over the blade with the underwater flow structures around the blade.*** This project will contribute highly to my academic and professional goals because I will be gaining valuable experience outside of the classroom. This I believe is extremely important because I get to step outside of a space where there is an "answer" and explore the endless possibilities of research, and this excites me. I have already experienced this over the summer in the lab, and I am thrilled to have an opportunity to continue this process moving forward into the school year. In terms of my career, I believe that this also prepares me quite well, as real world scenarios require thinking outside of the box for a solution, instead of just following the answer key to solve an engineering problem.

Methods:

To perform this work, I will be using both PIV and force-torque measurement techniques. The equipment that will be used is a 24'' x 24'' x 24'' quiescent tank, with Zaber motors and a new linear stage that controls the motion of a 3D printed blade (one with a RANDALLfoil, one without). The new linear stage will increase the velocity of the blade to 1:4 the real speed, as in

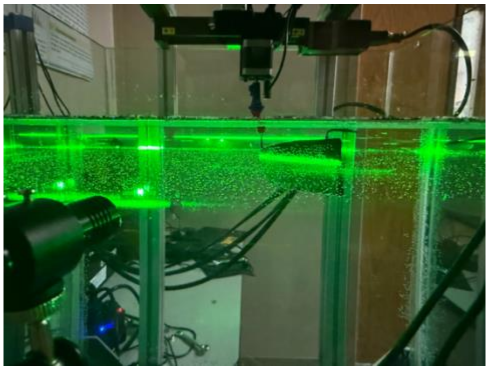


Figure 2 - Laser sheet shown illuminating blade(Schutt 2017)

preliminary testing it was 1:8 speed. The 3D printed blade is mounted with a screw on connection. The desired blade position will be achieved by setting the blade at two starting angles from horizontal, 40 degrees and 55 degrees. The blade angle offset of 15 degrees, or β, was chosen to be consisted with the works of Grift et al. (2021).

PIV is a technique where neutrally buoyant particles in water are illuminated by a thin laser sheet (Figure 2), and imaged using a camera beneath the tank. The camera in this experiment has FOV (field of view) limitations, which creates the need for multiple positions, as the full motion of the blade cannot be seen in just one frame. As such, up to four different imaging positions are required for every PIV experiment. PIV post-processing will involve taking the averages of all the takes from each position, which will then be stitched together to create one unified image. Analysis will be conducted at the end of PIV data collection by calculating the circulation of particles in vorticity plots.

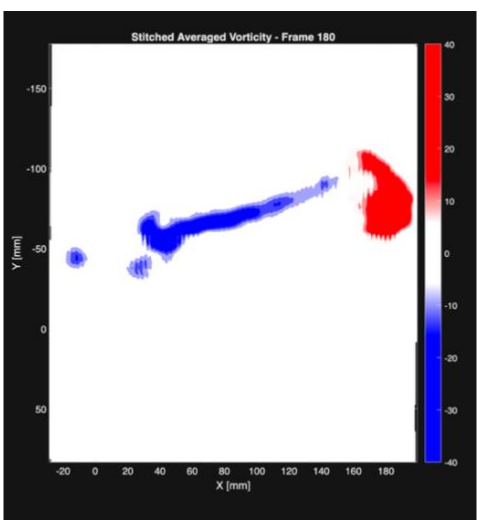
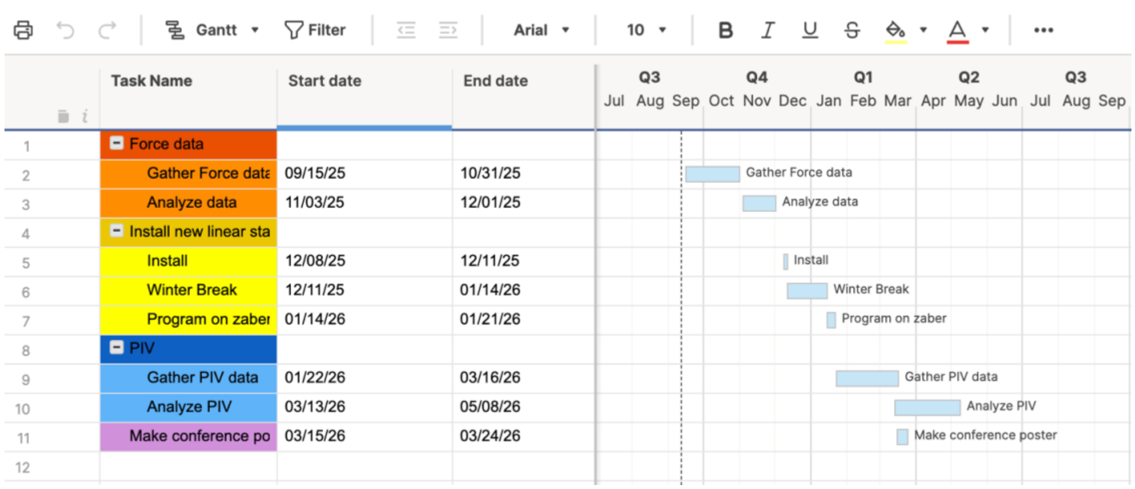


Figure 3 – Average vorticity plotted in MATLAB

During preliminary summer testing, I developed a MATLAB code to stitch together the four different imaging positions and extract vorticity data, and plot this in an animated sequence. I will use this newly developed code to process new PIV data with the new, faster linear stage motor proposed in this project. Figure 3 shows an image of the vorticity contour obtained from 4 imaging positions stitched together. With the stitched frames together, the viewer is able to analyze with a full FOV. The goal of this analysis is to have at least 50% overlap between positions (Schutt 2017). This MATLAB code is very effective in creating this new vorticity plot, and I am confident that I will be able to use this to gather high-speed PIV data.

To gather force data on the blade, I will need to integrate force sensors above the 3D printed blade place to gather force-torque data over the moving blade. For this proposed work, I will gather force-torque data at both 1:4 and 1:8 speeds, to correlate the data with the PIV flow fields. With the gathered force data, efficiency will be measured from gathered propulsion values and energy spent in the blade motion. It is expected that running the force-torque experiments and analyzing this data in MATLAB will take the first semester of this project. Running the high-speed PIV experiments and processing them in MATLAB, and correlating them to the force-torque data, will take the second semester.

Timeline:



	Task Name	Start date	End date
1	Force data		
2	Gather Force data	09/15/25	10/31/25
3	Analyze data	11/03/25	12/01/25
4	Install new linear sta		
5	Install	12/08/25	12/11/25
6	Winter Break	12/11/25	01/14/26
7	Program on zaber	01/14/26	01/21/26
8	PIV		
9	Gather PIV data	01/22/26	03/16/26
10	Analyze PIV	03/13/26	05/08/26
11	Make conference po	03/15/26	03/24/26
12			

Collaboration with faculty sponsor:

During this study, I will be collaborating with PhD candidate Ward Cereck and Dr. Sarah Morris to accomplish this project. I will have weekly meetings with Ward Cereck to discuss the updates from the previous week and ongoing work. Additionally, I will be attending Dr. Morris's group meeting every week, and sharing my progress every three weeks, where I will receive feedback to ensure continued success.

References Cited

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