STANDARD OPERATING PROCEDURE

Investigation of Propeller-Induced Tip Vortices Using Particle Image Velocimetry

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Introduction

This procedure outlines the steps to perform Particle Image Velocimetry (PIV) on a propeller rotating in still fluid. It covers the setup and procedure for conducting the experiment.

Equipment

- Water-filled Glass Tank - the domain for performing the experiment.
- Hollow glass spheres - tracer particles for PIV.
- Green laser pointer - To illuminate the tracer particles.
- Cylindrical lens - To generate a laser sheet from the laser pointer.
- Propellers - two bladed and three bladed propellers of radius 22.5 mm.
- Micro-coreless motor - Used for rotating the propellers.
- Voltage regulators - to control the speed of rotation of the motor.
- Photron UX Mini 50 - High speed camera for RPM characterisation
- DSLR - camera for recording the PIV experiment.
- Laboratory stand and clamps - To mount the propeller inside the water tank and to mount the laser-lens assembly.

Software Required

- Photron FASTCAM viewer - To record and save the high speed images for RPM measurement.

- PIVLab in MATLAB - To process the PIV Images to compute the velocity fields.
- MATLAB - For additional calculations, plotting etc.

Materials

1 Procedure

1.1 Initializing the Experimental Setup

- Clean and dry the glass tank thoroughly to ensure clear visualizations. Fill it with water to a sufficient depth and place it securely on the table.
- Place a black cloth on the side opposite the viewing direction to minimize laser reflections and enhance image clarity.
- Connect the propellers to the motor, and link the motor to the voltage regulator. Ensure that the wires are long enough to be fully submerged in water without strain.
- Mount the motor-propeller assembly inside the tank using the holding stand. Position it far enough from all tank walls to minimize wall-induced flow disturbances.
- Position the laser close to the cylindrical lens and adjust it to generate a clean, well-defined laser sheet at the desired observation region. Perform this step in a dark room with fans turned off to avoid disturbances.

1.2 RPM calculation using High speed camera

- Attach a small piece of tape to one of the propeller blades to serve as a visual marker for rotation tracking.
- Use a high-speed camera (e.g., 500 FPS) to capture the propeller's motion. The movement of the tape allows for accurate tracking of rotational speed and correlation with input voltage.
- Adjust the motor-propeller setup so that the propeller faces the camera directly for optimal visibility.
- Connect the high-speed camera to the laptop via an Ethernet cable and launch the PFV software. The frame rate is kept at 500 FPS and the shutter speed is $\frac{1}{500}s$. Adjust focus to ensure sharp imagery, and record the propeller motion long enough to capture multiple rotations.
- The high frame rate enables precise frame-by-frame analysis for determining the real-time RPM.

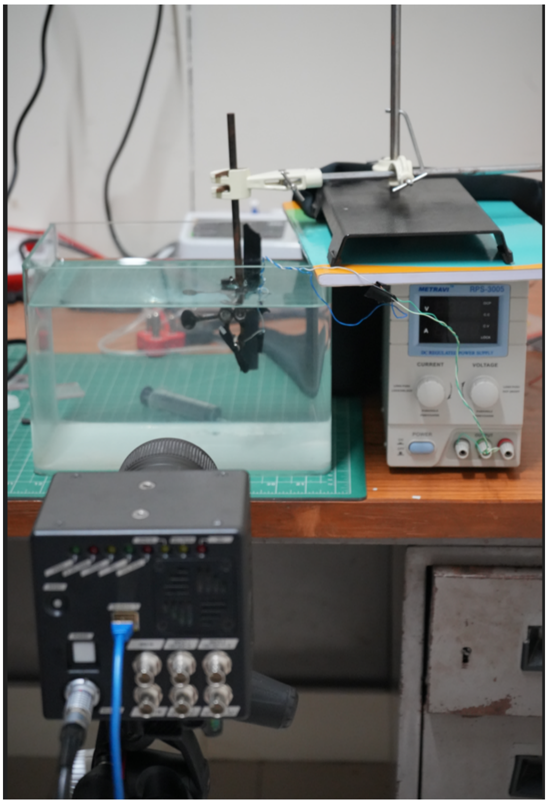
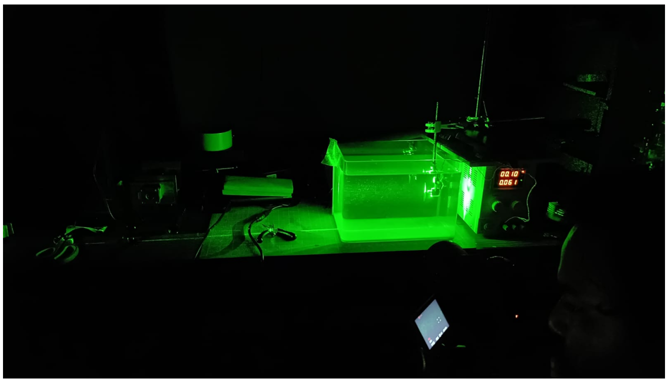


Figure 1: Setup for RPM estimation

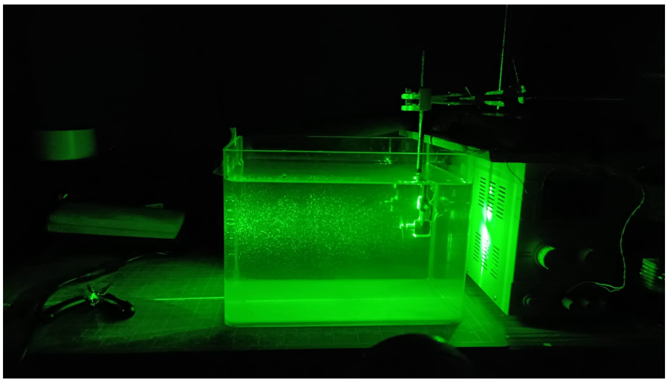
1.3 PIV Experiment

- Rotate the motor-propeller assembly such that the streamwise direction aligns with the longest dimension of the tank.
- Position the DSLR camera to ensure that the region of interest is fully within the frame.
- Add an adequate amount of tracer particles into the water. Turn on the motor to help distribute the particles evenly throughout the tank.
- Ensure the room is dark, then switch on the laser. Adjust the laser sheet so that it aligns precisely with the central plane of the propeller.
- Focus the DSLR camera until the tracer particles are clearly visible in the field of view. This can be achieved by zooming in on the tracer particles and using the auto-focus option.
- For each desired voltage setting, record the propeller rotation, capturing the motion of the particles for flow analysis.

(a) PIV setup



(b) PIV setup with illumination



(c) Tank illuminated by the laser sheet

Figure 2: PIV setup with and without illumination

2 Precautions

- Do not look directly into the laser beam. Direct exposure can cause serious eye injury.
- Do not point the laser directly to the camera as it is very light sensitive.
- Ensure that the water is completely still before each run to avoid introducing flow artifacts that can compromise the results.
- Tracer particles tend to aggregate and settle over time. Use a sufficient quantity to maintain visibility and accuracy throughout the experiment.
- Only a single laser sheet should be produced. If the laser is misaligned or not perpendicular to the tank, multiple overlapping sheets may form, reducing the clarity and accuracy of particle tracking.

- Switch off the laser between runs to conserve battery life and avoid unnecessary exposure.
- Review the results from the initial run to confirm that all components are functioning correctly and adjustments are not needed.
- Do not alter or move the experimental setup before capturing a calibration image. This is essential for post-processing and scaling.

3 Limitations

- Operate the motor at low rotational speeds, as the DSLR camera used has a maximum frame rate of 100 FPS. At higher speeds, the resulting flow structures become difficult to capture clearly due to motion blur (streaking) and insufficient temporal resolution.
- The laser power is relatively low ($< 100\,\mathrm{mW}$), which limits its effectiveness with high-speed cameras. Since the exposure time is inversely proportional to the frame rate ($\sim 1/\mathrm{FPS}$), videos captured at high frame rates tend to be underexposed and lack sufficient illumination.
- Due to the limited size of the tank, only small propellers can be used. This may lead to interaction between tip vortices and hub vortices, potentially altering the flow characteristics. Additionally, at higher rotation speeds, flow reflections from the downstream wall may occur. It is advisable to begin recording immediately after the motor starts to minimize the impact of these reflections.