Design of Large-Scale Turbulent Flow Loop

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

Samuel Rudy, Alexander Weitzel, Fares Tello, Dr. Phillippe Bardet

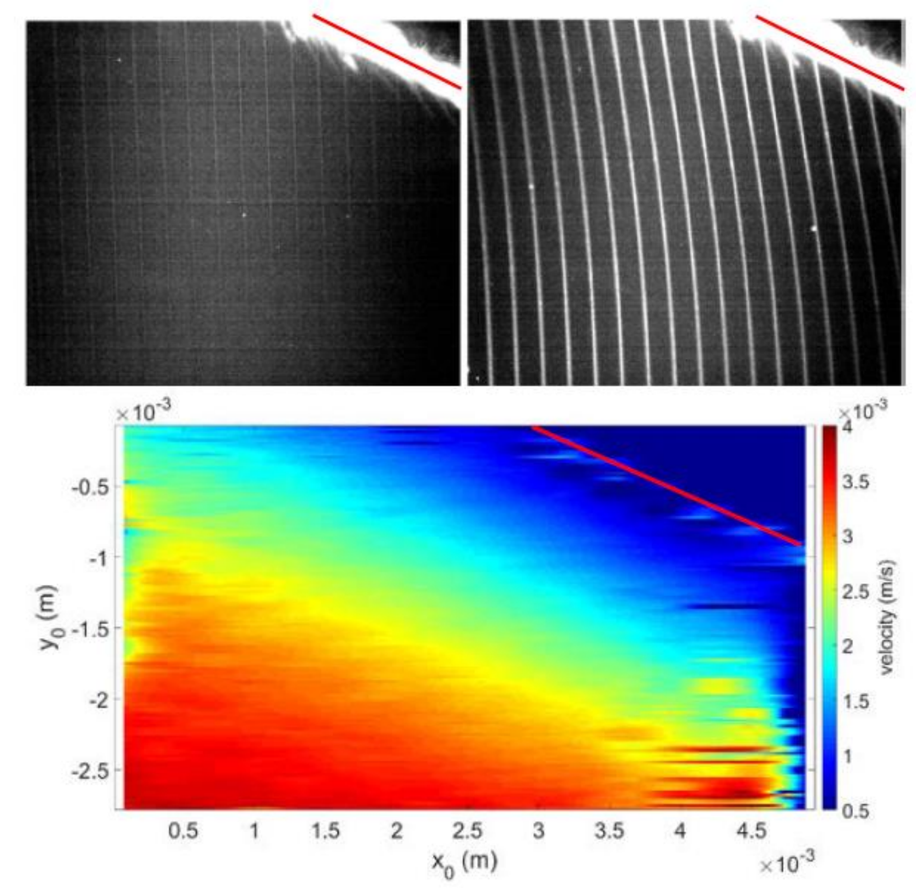
Introduction

The goal of this project is to study water flow at high Reynolds numbers. Under the mentorship of Dr. Phillippe Bardet and Ph.D. student Charles Fort and sponsored by the U.S. Navy Office of Naval Research, we are working to design, construct and analyze fluid flow at high Reynolds numbers. Our experimental method is to propel the working fluid through the loop and reduce the instabilities as much as possible while limiting head loss. Then, the fluid will enter an open channel at the top of the loop where we will trigger the transition to turbulence to obtain a well-established turbulent flow, which we plan to study through micro-molecular tagging velocimetry (µMTV).

Types of fluid flow are be characterized by the dimensionless Reynolds number, a ratio of inertial fluid forces to viscous forces. Flows with a Reynolds numbers on the order of $5x10^5$ or greater are classified as turbulent flows, in which the movement of molecules is chaotic and difficult to analyze. Despite the common appearance of turbulent flows in engineering applications, there exist few academic facilities to study boundary layer mechanics at high Reynolds numbers [1].

MTV is a non-intrusive method of visualizing fluid flows. Tracer molecules are added to the working fluid and subsequently excited by a laser sheet. The fluorescence of the molecules can be captured in motion by a camera, producing an outline of the flow. This method is efficient for visualizing flows at a micro scale. [2] In this experiment, we will use caged dyes which must first be activated by a passing through a separate laser sheet. [3]

Previous experiments by André [4] successfully visualized interfacial boundary layer growth at micro scale with particle image velocimetry (PIV). However, in this facility the extended length of the test section will allow for greater growth of top and bottom boundary layers before interaction.

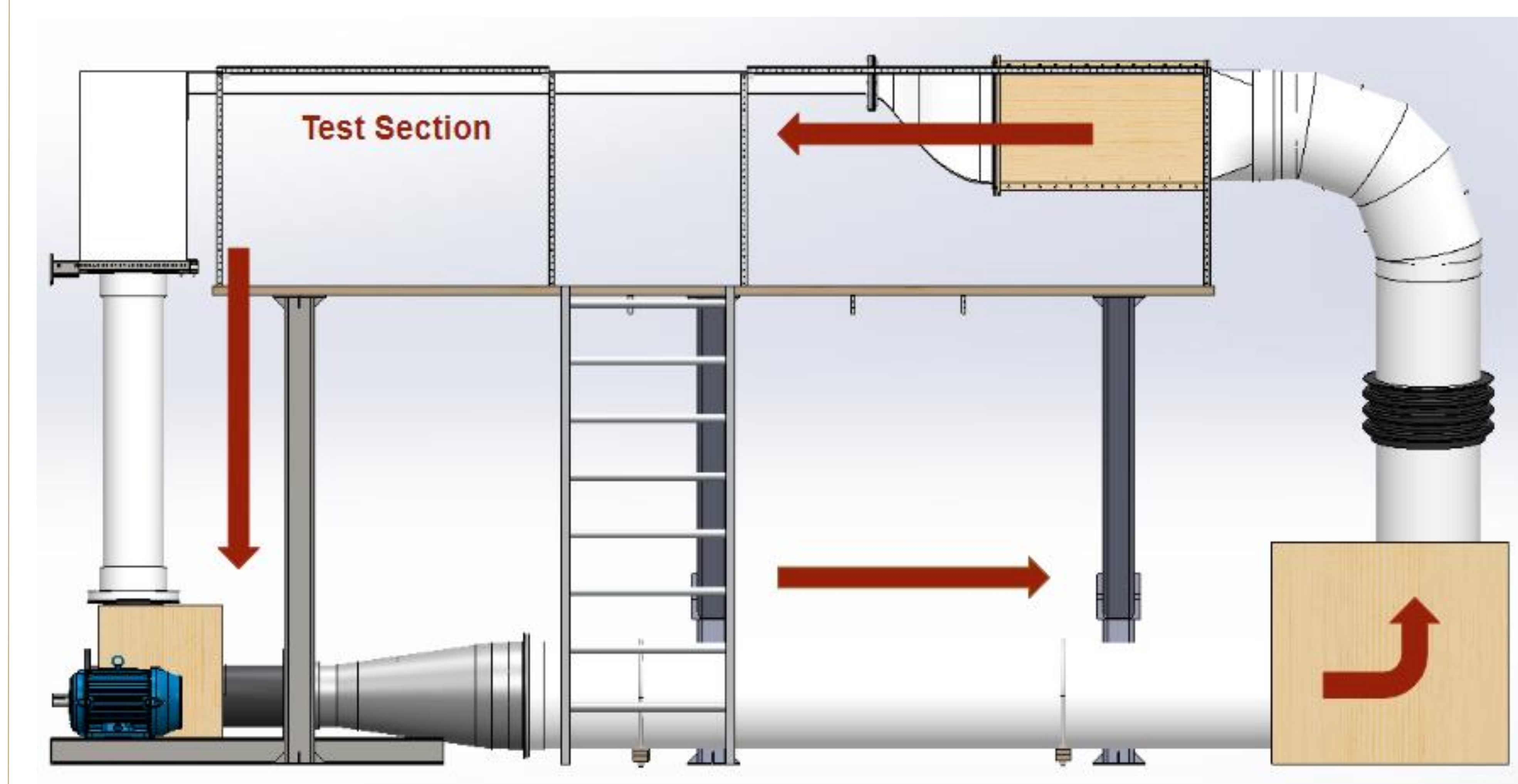


Consecutive MTV images from a previous experiment using caged dye, and the visualization of an interpolated velocity field between frames. [3]

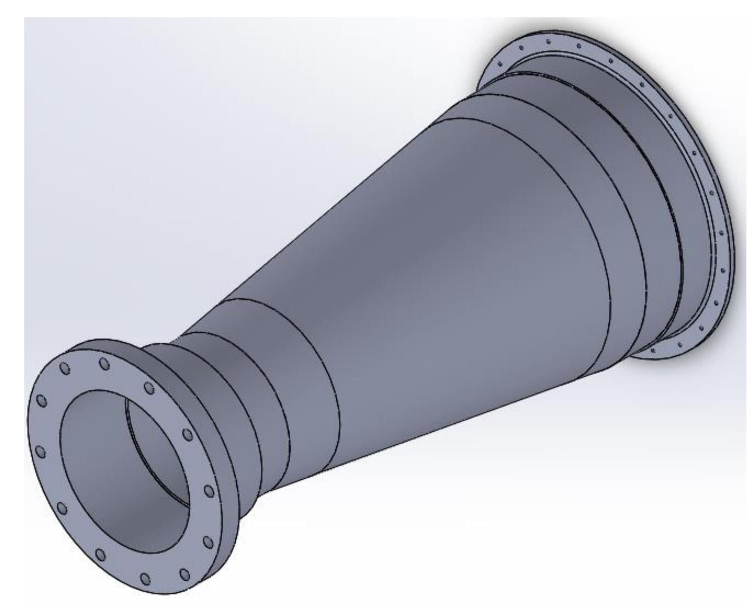
Desired Specifications

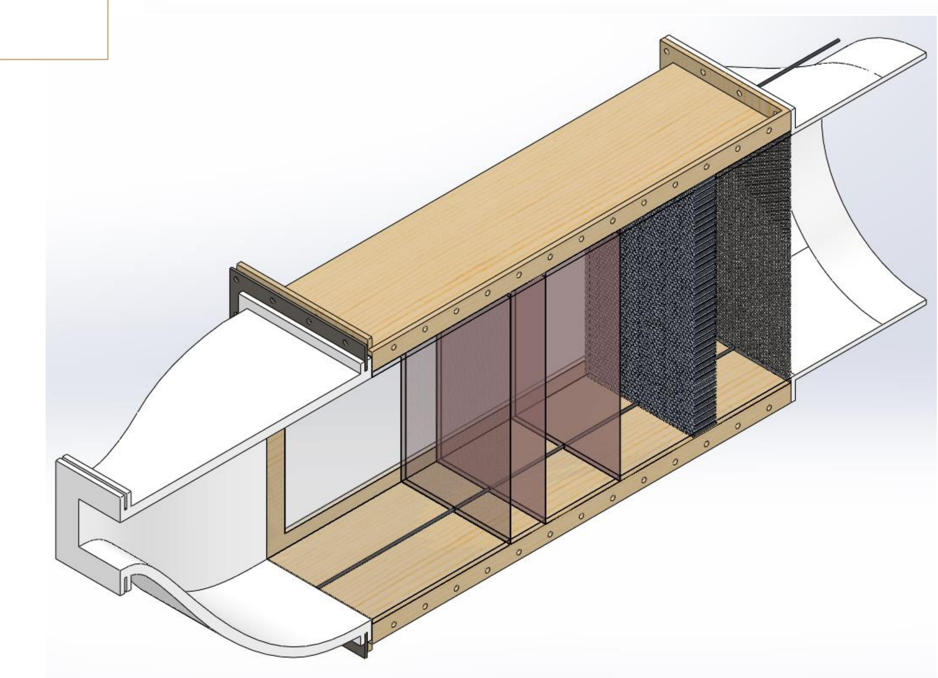
- Achieve a uniform flow in the test section of 5-10 m/s with the development of a fully turbulent state
- Pass working fluid through a series of metal screens and a honeycomb section to reduce swirl and local velocity fluctuations [3]
- Use laser-based diagnostic techniques to visualize turbulent flow regimes in the test section
- Transport the fluid through the loop by means of a propeller with minimal pressure losses
- Avoid boundary layer separation in the expansion section

Methods



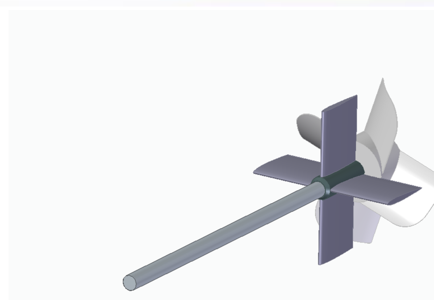
Diffuser: Manufactured using a fiberglass mold, the diffuser increases the diameter of the pipe from 14" (the diameter of the low-inlet tee) to 24" (the diameter of the pipe between the diffuser and test section).



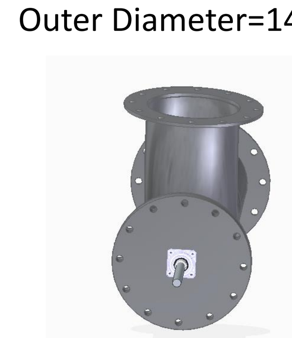


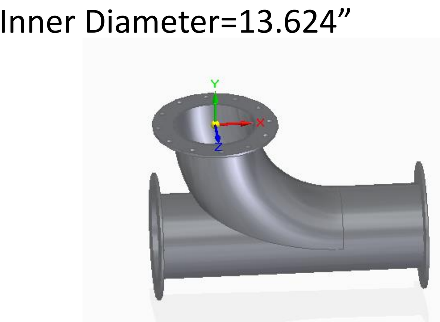
Settling Chamber: A series of steel mesh screens of decreasing mesh size in conjunction with an aluminum honeycomb work to remove swirl and local velocity fluctuations, thereby smoothing the flow into the test section. The components are housed in a wooden box set apart by acrylic frames to observe dirt or air bubbles that may contaminate the flow.
The flow finally passes through a nozzle of 3D profile created to limit boundary layer growth and cavitation before the test section.

Propeller:
13.4" Diameter
Pitch 12
5 Blades



Flanged Low Inlet Tee:
Supported by a "cone" and NACA Airfoils inside the pipe
Outer Diameter=14"; Inner Diameter=13.624"





Shaft is driven by the motor-belt system
1.25" diameter
36" Long
Includes a key to connect the pulley-belt mechanism to the 50 HP, 1800 RPM motor, which rests on a set of I-beams for support as it is running.

Future Work

- Currently in analysis phase to verify selection/production of facility components. We want to minimize pressure losses throughout the flow loop to produce a higher velocity flow in the test section, and therefore test turbulent regimes at higher Reynolds numbers.
- Manufacturing or ordering of critical components will occur after a full analysis of the design.
- The facility will be assembled on-site in GWU's Tompkins Hall.
- Measurements of interest include visualization of the free-surface interface, surface vorticity, and primary break-up of the flow once the turbulent boundary layer has been tripped [3].
- Application of data includes validation of computational fluid dynamics calculations at micro scales.

References

[1] Elbing, B. R., Daniel, L., Farsiani, and Y., Petrin, C. E., "Design and Validation of a Recirculating, High-Reynolds Number Water Tunnel," ASME J. Fluids Eng., 140(8), pp. 1-6.
[2] Thompson, B. R., Maynes, D., and Webb, B. W., "Characterization of the Hydrodynamically Developing Flow in a Microtube Using MTV," ASME J. Fluids Eng., 127(5), pp. 1003-1012.
[3] Fort, C., and André, M. A., "Development of Aqueous Molecular Tagging Velocimetry to Measure Wall Shear Stress," Proceedings of NURETH-18, Portland, OR, August 18-22, 2019
[4] André, M. A., 2014, "Measurement of Interface Dynamics and Transfer Applied to a Free Surface Shear Instability," Ph. D. dissertation, The George Washington University, Washington, DC.