A PROJECT REPORT ON

WIND TUNNEL

Submitted in partial fulfillment of the award of the

BACHELOR OF SCIENCE
IN
AERONAUTICS(Mechanical)
By

MUZZAMIL SAYYED ARIF

PRN NO: 2018016400828042

Under the guidance of

Dr. M Suresh Kumar

Ph.d. M.Tech B.Tech MCSE

University of Mumbai

PSD SHASTRI EDUCATIONAL FOUNDATION

WINGSSS COLLEGE OF AVIATION TECHNOLOGY

Affiliated to University of Mumbai

S.NO-85, NDA Road, Shivane,Warje, PUNE, 411023.

2020-21

BONAFIDE CERTIFICATE

This is to certify that project report entitled **“WIND TUNNEL**”, is a bonafide record of work carried out BY Muzzamil Sayyed Arif (2018-M-17) during the final semester from January to June 2021 under my guidance, in partial fulfillment of the **requirements for the award of Bachelor of Science in Aeronautics** (Mechanical).

Project guide
Mr Pankaj Salunke

Prof. Dr. Suresh Kumar

Principal

DECLARATION

I, Muzzamil Sayyed Arif (2018M17) hereby declared that this project report titled **Wind Tunnel** submitted in partial fulfillment of the requirement for the award of **“BACHALOR OF SCIENCE –in AERONAUTICS(** Mechanical) is my original work and it has not formed the basis for the award of any other degree.

Muzzamil Sayyed Arif
2018-M-17

PROJECT RECORD BOOK

Name of the students

1. Chinmay Manoj Dholam (Roll No. 2018-M-04)
2. Muzzamil Arif Sayyed (Roll No. 2018-M-17)
3. Laleet Pandurang Nawale (Roll No. 2018-M-18)
4. Nobin Dineshkumar Chalaune (Roll No. 2018-M-02)

Name of project guide- **Mr Pankaj Salunke**

Class and Branch

- B.sc. Aeronautics 3rd year

Semester

- 6th Semester

Stream

- Mechanical

ACKNOWLEDGEMENT

It is my pleasure to be indebted to various people, who directly or indirectly contributed in the development of this work and who influenced my thinking, behavior, and acts during the course of study.

I express my sincere gratitude to my Project Guide **Dr.M Suresh Kumar** for providing me an opportunity to work under him. I am thankful to him for his support, cooperation and motivation provided to me during the project for constant inspiration, presence and blessings.

I also extend my sincere appreciation to **Mr. Pankaj Salunkhe** who provided his valuable suggestions and precious time in accomplishing my project.

Lastly, I would like to thank my parents for their moral support and my friendswith whom I shared my experience and received lots of suggestions that improved my quality of work.

Index

TABLE OF DIAGRAMS

ABSTRACT

An unsteady wind tunnel was designed and built for the study of unsteady aerodynamics. The wind tunnel was designed as an open-loop configuration, and an active flow control system was designed as a series of horizontally aligned shutters placed in front of the test section which can block oncoming airflow to create time-varying shear flows in the test section. The wind tunnel was constructed using primarily acrylic and plywood and was run by an axial fan. The active flow control system was composed of four shutters that were held in position and rotated using steel rods and actuators located just outside the shutter frame. Computational Fluid Dynamics (CFD) was used throughout the design processes, ensuring the generation of unsteady flows in the test section.

1.INTRODUCTION

Unsteady aerodynamics involves time-varying flow conditions, and is regularly experienced in real- world operations such as wind turbines, aircraft, and cars. For example, some of today's wind turbines have a height of 140 meters, and its blades have lengths of 60 meters alone. The velocity of wind gusts differ significantly over ranges in height of this magnitude and can introduce fatigue loads on the turbine blades, which can then lead to damage of its components over time. An understanding of unsteady aerodynamic behavior is necessary in the calculation of products' performances and loads, and the innovation for the optimization for conditions they face in their environment


Introduction of wind tunnel

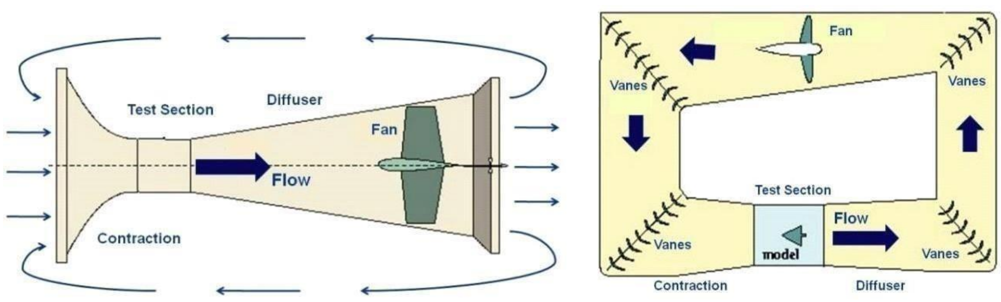
Fig 1.1

The purpose of this project was to create an experimental facility for the study of unsteady aerodynamics, and to conduct proof-of-concept testing for successful of time-varying flow conditions. To narrow the scope of the project, and give a clear expectation of the conditions the testing would ideally provide, the objective of the wind tunnel was to produce a sinusoidal shear flow in time through the wind tunnel's test section. The flow would provide researchers with added flexibility in experiments: a number of standalone varying shear conditions, or a constantly changing shear flow. In order to successfully achieve the goal, the project was divided into a number of elements: the wind tunnel, the active flow control system, and the testing for proper unsteady aerodynamic conditions.

2. **BACKGROUND**

Wind Tunnels

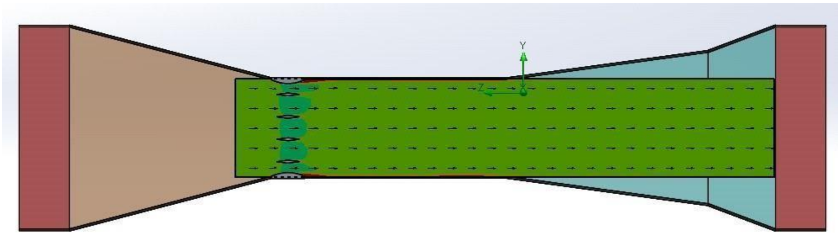
A wind tunnel is an apparatus that allows researchers to move air over a body to simulate flight and analyze aerodynamic properties of the flow such as lift and drag. Wind tunnels are designed to deliver a consistent, steady stream of air to the test section and minimize turbulence.



Types of wind tunnel fig2.1

Wind tunnels are essential to the study of aerodynamics. They have undergone a number of iterations in terms of design; the two most common designs are the open-loop wind tunnel, and the closed-loop wind tunnel--shown below in Figure 1. Both have the same essential components, but their overall design and construction differ greatly. Open-loop wind tunnels draw air from the ambient environment and exhaust it back to the ambient after exiting the fan, while closed-loop wind tunnels create a circuit with air which repeatedly circulates through the tunnel. The closed-loop wind tunnel design delivers improved efficiency and generates less noise, but is more expensive and more difficult to manufacture.

For the project's purposes, an open-loop wind tunnel design suffices performance criteria while adhering to budget and manufacturing constraints and was therefore selected as the chosen design.



Open loop wind tunnel fig 2.2

An open-loop wind tunnel consists of 5 primary components, listed from left to right on a settling chamber, contraction section, test section, diffusing section, and a fan .

The first section of any open-loop wind tunnel is the settling chamber, designated in yellow .

The purpose of the settling chamber is to reduce any turbulence in the air flow before entering the converging section. In order to regulate turbulence, the section generally contains a honeycomb structure and a series of woven-wire screens. Honeycombs are effective in reducing lateral turbulence, and common designs include square, circular, or hexagonal celled cross-sections. Hexagonal honeycombs are most effective due to the smallest loss in pressure over the section. Following the honeycomb is one or more woven screens, which are effective in reducing longitudinal turbulence.

Non-turbulent air then enters the contraction section, denoted by the color green. The purpose of the contraction section is to uniformly accelerate the air flow while minimizing turbulence. In order to smoothly take high volume low-velocity air from the settling chamber and transfer it to a smaller volume with a higher velocity, the shape of the section must be carefully chosen for the desired wind tunnel performance.

Wind Tunnel Design

The wind tunnel is composed of five primary sections: the settling chamber, converging section, test section, diffusing section, and the fan. Several considerations had to be made in order to achieve desirable wind tunnel properties. Design criteria for the wind tunnel are listed below:

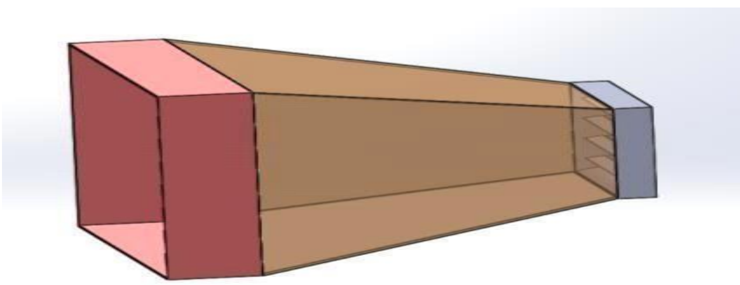
- Low cost
- Portability
- Ease of manufacturing
- Test section dimensions
- Maximum operating speed in the test section

The following sections outline the design of each component of the wind tunnel.

The settling chamber cross-sectional area matches the dimensions of the converging section inlet, and contains a hexagonal honeycomb and a woven-wire screen in order to reduce flow turbulence. A hexagonal honeycomb was used for its efficiency over other honeycomb structures.

Research indicated that sufficient flow quality can be generated using a contraction ratio of N = 4 , contraction semi-angles of $\alpha/2 = \beta/2 = 12$ degrees, and a straight line duct from entrance to exit of the section. A

CAD model of the settling chamber and contraction section.



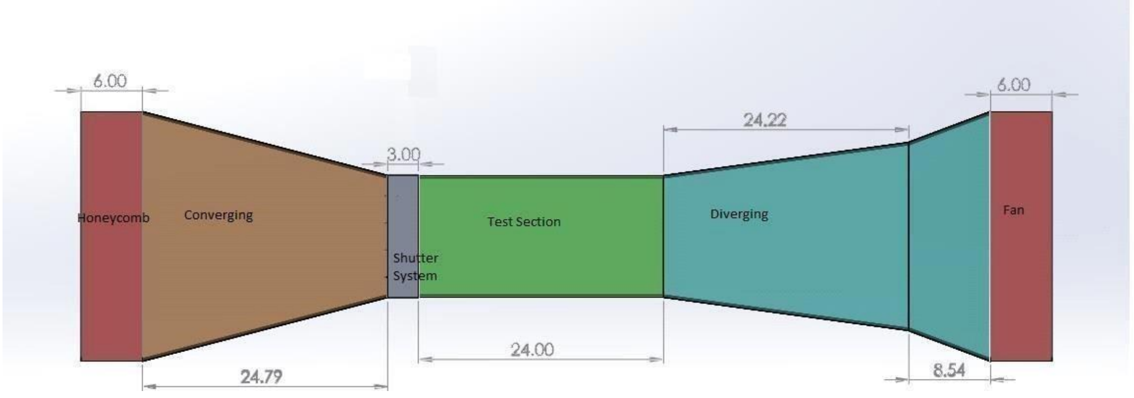
CAD model of Settling Chamber & Contraction Section fig 3.1

Provided the design criteria, the test section will be 24 inches in length, with a square cross-sectional area of 144 in^2. This section will be produced out of ¼ inch Plexiglas for ease of observing while running an experiment.

Research indicates that an acceptable range for the semi-opening angle is between 5 and 10 degrees.

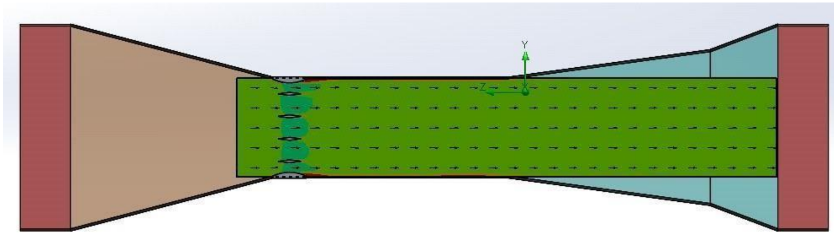
The final component in designing the wind tunnel system was to select a fan to move air through the system. An axial fan was used for the project due to convention in the field of aerodynamics. Axial fans pull air through the tunnel as opposed to pushing it, creating a smoother flow through the system. The wind tunnel will be used exclusively in the study of low-speed aerodynamics, meaning the fan would operate at a maximum speed of 5 m/s. In order to ensure a speed of 5 m/s in the test section of the wind tunnel, the maximum fan flow rate was an important specification which was analyzed in choosing a fan; the desired flow rate for the purpose of this project given the cross-sectional area of the test section and the desired flow velocity was 0.45 cubic meters per second.

Compiling the chosen designs for each component described above, a CAD model and a CFD simulation were generated for the unsteady wind tunnel system. The CAD model and corresponding CFD results are shown in Figures 4 and 5, respectively.



Wind tunnel design generated using CAD

Fig 3.2



Flow velocity simulated using CFD fig 3.3

Results obtained from the wind tunnel system modelling were promising, with minimal flow separation through the system, and a successful 5 m/s flow speed, indicated by the light green color, through the test section. Positive results in CFD modelling allowed the wind tunnel system design to then be manufactured, keeping in mind the original design criteria of low-cost, portability, and ease of manufacturing.

- **Wind Tunnel Manufacturing**

Given the scope of the project and allotted budget, the wind tunnel body was manufactured primarily out of plywood and acrylic. The wind tunnel was constructed component-by-component, with sections attached together to complete its construction; a guide for the manufacturing of each section is below:

Settling Chamber

Completed wind tunnel settling chamber
Fig3.4

The settling chambe was designed as a frame to hold the honeycomb section, which is vital to flow straightening in a wind tunnel. During the manufacturing process, it was determined that the cell size of each honeycomb cell was too large to effectively straighten the flow for the purposes of the project. In order to remedy the issue, a second honeycomb section, with a much smaller cell size, was inserted at the end of the contraction section.

Second honeycomb structure, located at end of contraction section

Contraction Section

Completed contraction section, aerial view

Fig 3.5

Completed contraction section, side View fig3.6

Each individual piece was then sanded and coated in a primer and glaze in order to create a smooth surface allowing for higher flow quality.

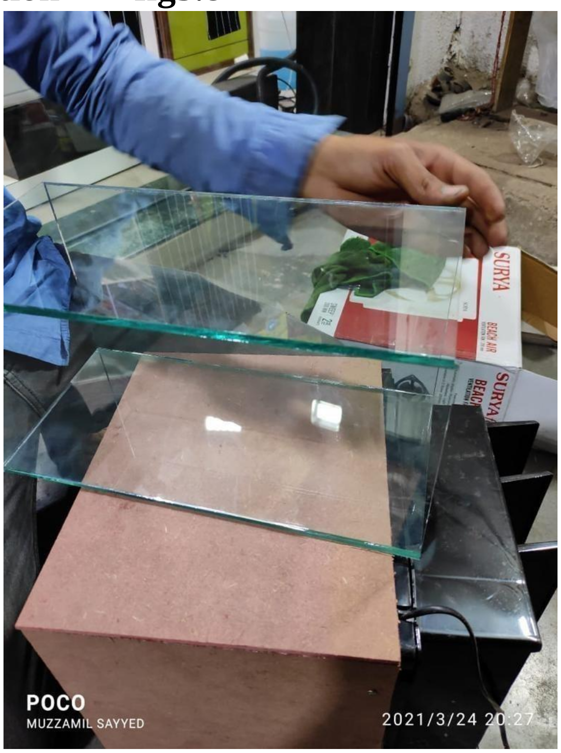

fig 3.7

Plywood sheet sanded and coated in primer and glaze

With all sides of the section cut and coated, wood glue was used to attach wooden corner guards to the edges of each side of the section, and then to connect the individual sides together.

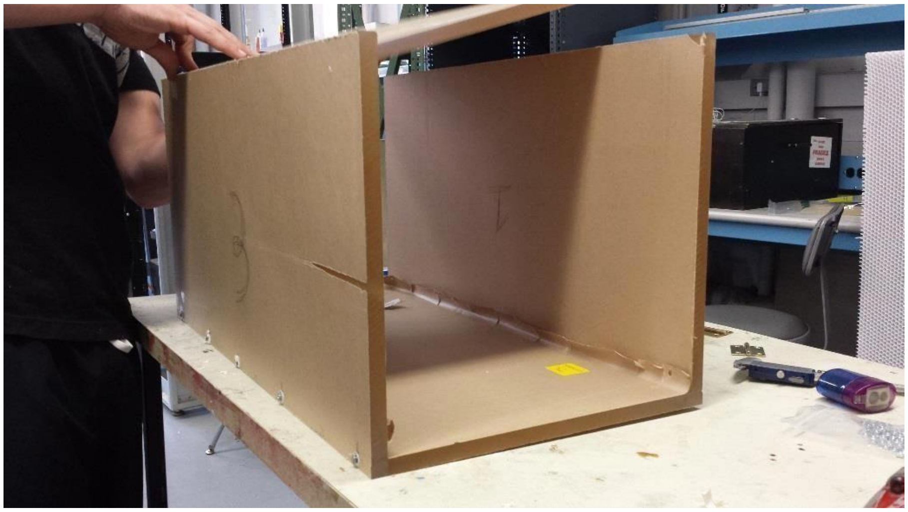
Wooden corner guard connecting plywood sides of diverging section

Test Section fig3.8



Completed wind tunnel test section

The sheets were connected along the longer edges using screws and glue for reinforcement.

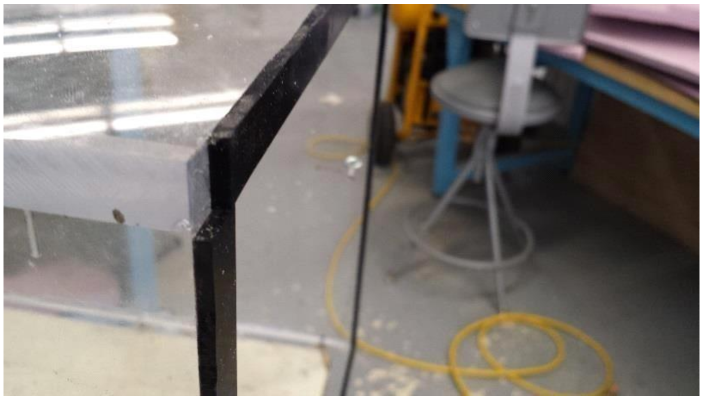


All standalone sides of the test section were connected perpendicularly to one another in this fashion.

In order to allow researchers access to the test section, the final sheet was connected to one edge using hinges, allowing it to be swung open.

Hinge connection used in test section construction fig3.9

To then keep the test section airtight, the other edge was lined with a rubber gasket strip and clamped to the bottom edge of the test section.



Rubber gasket used to line test section connecting edges fig 3.10

Diffusing Section:

Completed wind tunnel diffusing section fig 3.11

Diffusing section extension shown to fit fan enclosure

fig 3.12

Assembling Sections

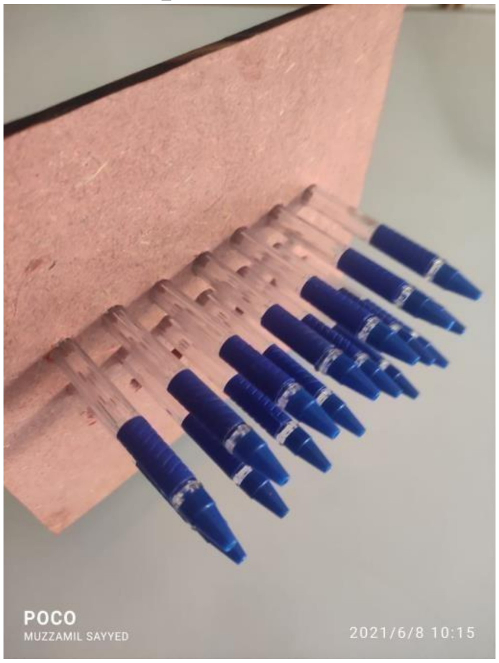
In selecting a method by which to connect the different sections of a wind tunnel, it is important to ensure an airtight seal from one section to the next for smooth, uninterrupted airflow. Given the scope of the project, it was also important to focus on maintaining portability for the entire system of the wind tunnel.

In order to comply with aforementioned criteria, hook-springs were used in connecting components of the wind tunnel together. This method allows the system to be modular—increasing mobility—and if tensioned properly, could create a tight seal between components. To ensure this seal, contact points between primary sections were lined with strips of rubber.

An image of the completed wind tunnel system structure

Making of Aerofoil Shape

Preparation of Jet



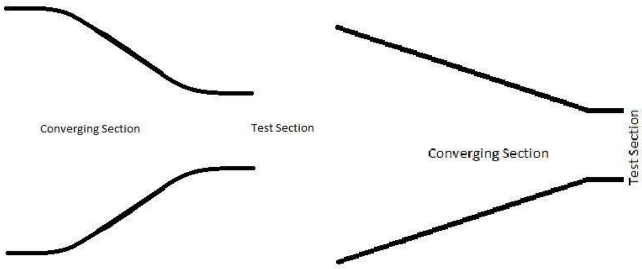
Fully assembled wind tunnel structure fig 3.13

2. Computational Fluid Dynamics (CFD) Analysis

Computational fluid dynamics (CFD) simulation software is a valuable tool which allows for the simulation and analysis of fluid flow. It provides users with the opportunity to test flow quality in simulated 3-D designs in order to determine which design would lead to best results.

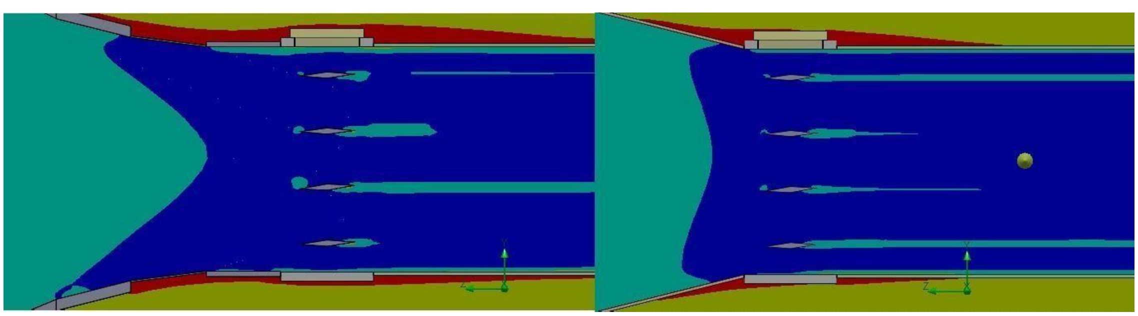
CFD simulation through SolidWorks was used in designing the contraction section of the wind tunnel. SolidWorks uses the k-ε turbulence model in order to calculate flow conditions. Proper design of the contraction section of a wind tunnel is essential to its construction and its effectiveness as an experimental facility. 2-D and 3-D simulations were ran on the model initially, but based on the symmetry of the model and computational time, a 2-D simulation was used with no effect on overall flow calculations. Background research showed that many low-cost wind tunnels were constructed using a flat contraction section, designated below in Figure 35 as Design 2, rather than one with a curve leading into the test section, shown on the left in Figure 35 which is commonly seen in large-scale wind tunnels.

These two conditions were both analyzed in a CFD simulation, with results revealing that a flat-edge contraction section, with contraction semi-angles of less than 12 degrees, as found in research, led to acceptable flow quality for the scope of the current project.



Contraction Section Design 1 (Left); fig4.1Contraction Section Design 2 (Right)

CFD analysis showed that Design 1 causes a non-uniform flow profile, with air travelling faster in the center of the test section and slower at the edges. This is an unwanted non-uniform flow, as compared to unsteady requirements of the project, air flow would have to be uniform going into the active flow control system, and then manipulated by the system to create a controlled shear flow in the test section. Alternatively, Design 2 allows for a uniform flow to enter the test section, allowing for accurate flow manipulation and proper experimentation.

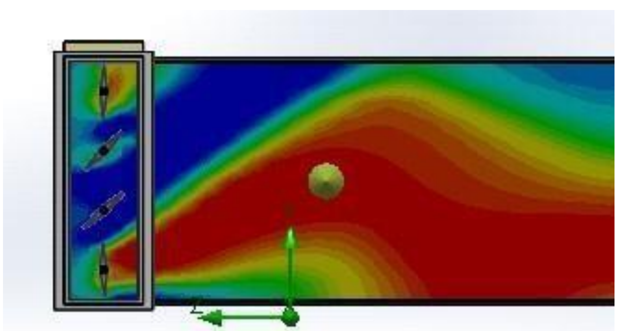


Design 1 flow (Left); Design 2 flow (Right) fig4.2

Computational design was also used in the design of the shutter system. The shutter system is an 11.5” x 11.5” x 4” structure that is placed at the inlet of the test section, this device uses four horizontal shutters 11.5” x 2.875” with an oblong cross section that will minimal flow separation. These shutters can be turned 180 degrees and are controlled with servos. This allows the user to set up a test procedure for the servos to follow.

The original design had 4 shutters each 11.5” x 2.88”, enough to cover the entire shutter cross sectional area, with overlap between each shutter to allow for no air flow. Under these conditions the CFD results showed that the shutters were able to create sinusoidal shear flow in time. The shutters are

extremly thin diamon shapes, to limit their impact on air flow. And the edges of the shutter section created no boundary layer issues connecting to the test section.

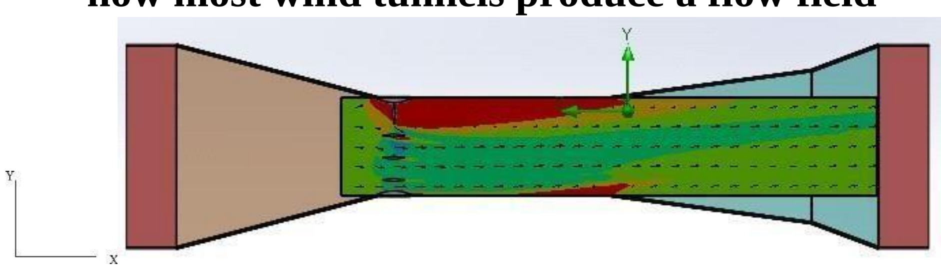


Example of shear flow with original shutter design

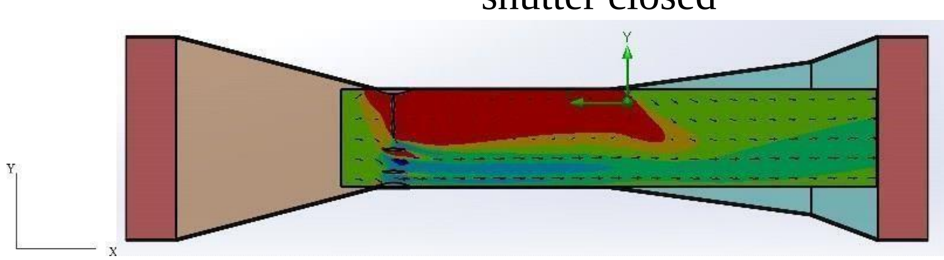
There were issues with the manufacturing process of the shutters. The shutters were supposed to have a width of 2.875” but came out to be 2.66” which caused a large gap between the shutters. The shutter assembly required a modification to still be functional. If the shutters cannot create a ”sealed” wall flow will slip past and affect the test section results. The issue was solved by placing the shutters slightly closer together to still maintain the flow blockage which is necessary. If an elliptical shape, cut in half is placed at the bottom and top of the shutter system this allows flow to pass through with minimal impact to the flow itself. The only issue noticed with testing is there approximately (2/3) through the test section the air seems to push back up, causing the opposite shear force. There is a “Prime spot” for testing within the first 2/3 of the test section. Although based on the CFD simulations you can move the testing object back and forth in the tunnel based on test requirements.

CFD calculations based on our model, with possible testing configurations, velocity readings in the stream wise direction range from 0-6 m/s. Throughout the CFD testing, using a rectangular computational domain allowed calculation time to decrease from roughly ten minutes to two minutes, there were no differences in test section flow.

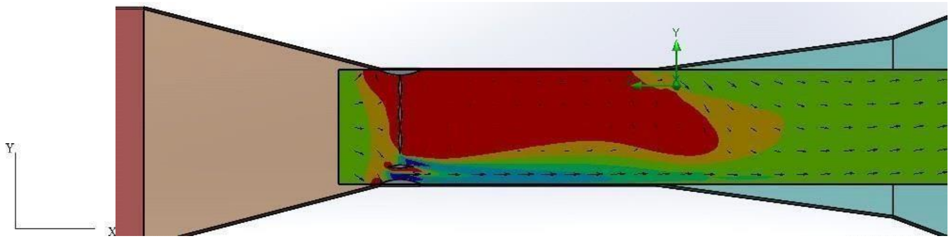
CFD simulation, shutters open uniform flow similar to how most wind tunnels produce a flow field



CFD simulation, top shutter closed



CFD simulation, top two shutters closed



CFD simulation, top three shutters closed

Fig 4.3

3.Conclusion

The goal of this project was to create an experimental facility for the study of unsteady aerodynamics, and to conduct proof-ofconcept testing for successful recreation of these conditions. The team compiled research on wind tunnel design, the study of unsteady aerodynamics, and the concept of active flow control systems in order to understand the scope of the project and to prepare a building plan. Completed research and Computational Fluid Dynamics (CFD) analysis were then used in the actual construction of the unsteady wind tunnel system.

The wind tunnel structure was an open-loop design and was constructed primarily out of 1/8” plywood for the settling, contraction and diffusing sections, and ½” acrylic sheets for the test section. Wind tunnel components were attached in a modular fashion using springs and spring-hooks as connectors, and the entire wind tunnel system sat on a table for maneuverability purposes.

The shutter system was a series of 4 horizontally aligned shutters aligned perpendicularly to the air flow in the wind tunnel. Housing the shutter system was an acrylic frame measuring 11.5” x 11.5” with two foam rollers located at the top and bottom of the section to fill gaps caused by a manufacturing error and ensure flow quality.

Unfortunately, given the allotted time dedicated to the project, the team was not able to go through the testing phase to verify successful recreation of unsteady conditions in the wind tunnel test section. Alternatively, a flow simulation was completed using Computational Fluid Dynamics (CFD) software whose results looked promise

REFERENCES

Journal / Conference Papers

[1] J. C. Crown and W. H. Heybey, "Supersonic nozzle design (project NOL 159", NAVAL ORDNANCE LABORATORY MEMORANDUM, 10594, 1950, Pg. 2-19.

[2] MILAN VLAJINAC, "Design construction and evaluation of a subsonic wind tunnel", Massachusetts Institute of Technology, U.S.A, June 1970, Pg. 1 to 13

[3] Kelly Butler, David Cancel, Brian Earley, Stacey Morin, Evan Morrison, Michael Sangenario, "Design and construction of a Supersonic Wind Tunnel

Reference / Hand Books

[4] John D. Anderson, Jr., "Modern compressible flow with historical perspective", McGraw-Hill Publishers, 3rd Edition, ISBN-13: 978-1-25-902742-0.

[5] Alan Pope, "Wind Tunnel Testing", John Wiley and Sons, Inc, New York, 2nd Edition November 1958.

[6] Alan Pope, Kenneth Goin, "High-speed Wind Tunnel testing", John Wiley and Sons, Inc, 1965

[7] John D. Anderson, Jr., "Fundamentals of Aerodynamics", McGraw-Hill Publishers, 5th Edition

Web/Other

[8] Trying to achieve supersonic flow in a pipe, www.cfd-online.com

[9] Nozzles and diffusers, www.wiley.com

[10] Diffusers, www.navier.stanford.edu

[11] 2-D Nozzle design, www.mathworks.in

[12] Use of K-Epsilon and K-Omega models, www.cfd-online.com

[13] Starting Problem of Supersonic Wind Tunnels, Georgia Tech College of Aerospace Engineering course

[14] Navier-Stokes equations, ANSYS 14.0 Help section