Subsonic Wind Tunnel for Agriculture Purpose Wind Turbine Blade Testing for Oman Topography

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Abstract:- **Public Authority of Electricity and Water(PAEW), Oman is keen on operating the partially finished wind turbines of 1200 MWH capacity in the rural areas of Oman. Wind turbines established here are 120 to 145 meters high depending on the topology. These wind turbines are expected to be efficient and effective in meeting the power demand during summer, where the power requirement for irrigation is peak. Additional wind turbines at different capacities are the current requirement. The design of wind turbine blade profiles for different capacities varies. A perfect designed wind turbine blade is the key in wind power optimization. Knowledge on aerodynamic modelling and testing is the basic requirement for a perfect design and development of wind turbine blade profile. Modeling software is ideal in modeling a perfect aerodynamic profile. But, testing decides the performance of a wind turbine profile and turn into the key in optimizing wind power generation. Wind mill holds the sole responsibility for testing and analyzing the performance of any aerodynamic component, deals with lift and drag forces. In view of developing and testing an optimized wind mill blade, suitable for Oman topography, a subsonic wind tunnel is designed and constructed in the college premises. In this paper, the design and testing principles of a wind turbine blade profile for Oman conditions are discussed for the benefit of the readers, who are interested in optimization of wind power generation in Sultanate of Oman. It is strongly believed that the fabrication of a subsonic wind tunnel would help the student community to move ahead in the field of design of efficient wind mills, generating the optimal power.**

Keywords—*Wind Turbine blade profile, Lift and Drag forces, Topology of Oman, Flow modeling, Flow visualization.*

1 INTRODUCTION

Wind tunnels are in general used generate uniform air flows, with low turbulence intensity, for thermal and hydraulic testing. These devices are in practice for about a century, and are used for many applications in industries like aerospace, energy, automotive, and defense to analyze and predict the amount of force generated by solid objects. Wind tunnels play a vital role in finding solutions for the miniaturization issues in electronics industries also. This kind of analysis help the aerodynamicists to choose the proper size for things such as wings, spoilers, Turbine blade profiles and so on. This is possible by testing a small model and get information about the full-size object. Wind tunnels are designed and constructed based on industrial requirements and applications at different shapes and sizes, from as small as 30 cm long to large enough to contain a big passenger airplane [2]. However, the basic idea for wind tunnel utilization is universal.

2 SUBSONIC OPEN RETURN WIND TUNNEL

2.1 Basics on Wind Tunnels

A wind tunnel is a tool used in aerodynamic research to study the effects of air moving past solid objects. Air is passed through the contraction by suction, flows through the test section and exit through the diffuser as shown in fig.2.1. There are a few basics to be learnt about wind tunnels. First, there are two main types of wind tunnels: closed-circuit and open-circuit. A closed-circuit wind tunnel is a very large and expensive type of wind tunnel. It gives engineers and scientists the greatest control over the flow of air, and produces the most efficient and precise results when models are tested [3]. The wind tunnel built here is an open-circuit tunnel, which is more like a tube that is open at both ends. While this design is not expected to have complete control of the airflow, it is less expensive to build and run. It is built using readily available materials, and it is an effective design for educational purposes.

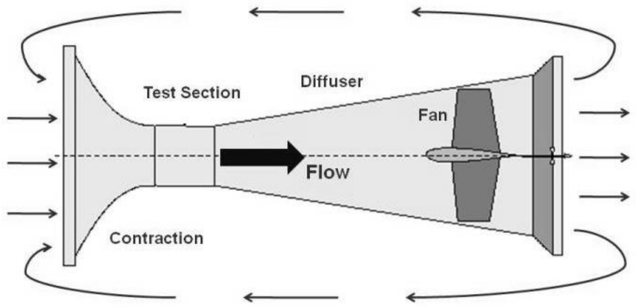

Fig. 2.1 Open Return Wind Tunnel

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2.2 Open Return Wind Tunnel

The wind tunnel built in in this project has a fan to draw air into the tunnel and pass it over the model kept inside the test section, and then release the air out of the other end. When the air flows around the model, it simulates it to fly by foced generated around, the model. The Instrumentation will help to predict how well it pulls the model up (lift) and how much the air blows it backward (drag). These two measurements are the most interested to look after while designing an aero foil, considered to be the turbine blade of a wind mill. Mathematical relations will let us know how well the wind turbine blades rotate to generate optimized power and how well it cuts through the air and resists the force of the air. Lift measurement gives the force of upward motion of the air on the model, and drag gives the force of backward motion of the air on the model.

2.3 Parts of open return wind tunnel

A wind tunnel consists of a tubular passage with the object under test mounted in the middle. Air is made to move past the object by a powerful fan system or other means. The test object, often called a wind tunnel model, is instrumented with suitable sensors to measure aerodynamic forces, pressure distribution, or other aerodynamic-related characteristics. Wind tunnel consists of five main parts as shown in fig. 2.2. The honeycomb structure is at the very front of the wind tunnel which straighten out the air and reduce turbulence. The Contraction Cone forces a large volume of air through a small opening in order to increase the wind velocity in the tunnel. The Test Section is the place where a model is mounted embedded with instrumentation to measure the forces. The Diffuser is at the end of the Test Section, and keeps the air running smoothly as it goes toward the back. It also increases in volume in order to slow the air down as it exits the tunnel. Finally, the Drive Section is at the very back of the wind tunnel, and it is where the fan is housed. At first, it might seem odd that the fan is at the back of the tunnel, facing outward, instead of at the front; but this is actually the best placement, because it will draw air into the wind tunnel by blowing air out of it. Drawing air in is better than blowing air in, because it does not compress the air by force, not to produce as much turbulence, and it allows for greater control of the airflow through the tunnel.

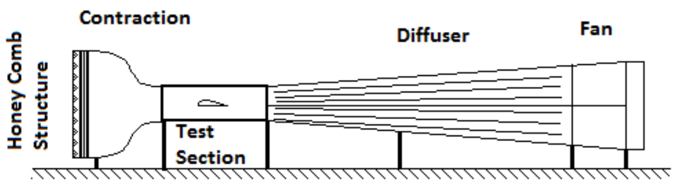

Fig. 2.2 Parts of an Open Type Wind Tunnel

2.4 Importance of Wind Tunnel Testing

Many instances occur where theoretical and/or computational techniques are approximation based and inadequate, either due to the complexity of the problem or the lack of suitable computational resources. Wind tunnel testing often serves as the most cost-effective approach for these reasons, as well as the expenses involved in many forms of full-scale testing which can be related to wind-tunnel tests through appropriate parameter matching.

Wind tunnels are so important for the engineers deal with aerodynamic system designing. In the early planning stages, careful attention to the effects of wind, snow, ventilation, vibration and related microclimate environmental issues structures are proven to save time, save money and reduce risk. Meanwhile, miscalculations or design flaws will turn out to be a miserable failure in operation. So the wind tunnel, supposed to be perfectly designed and it is expected to deliver

- Accurate results to minimize assumptions
- Opportunity for architectural expression
- Construction savings for the owner
- Assurance – often recommended by code
- Increased litigation protection

3 DESIGN OF SUBSONIC OPEN RETURN WIND TUNNEL

Subsonic or low-speed wind-tunnel is the most common type and the wind tunnel described in this paper is of this type. Wind-tunnel design should be tailored to meet the specific goals and subject to budget and facility space limitations also. Guidelines for the basic design of subsonic wind-tunnel components are provided in this section for flow straighteners, contraction, test section, diffuser, and fan.

3.1 Contraction Tube

The contraction area is perhaps the most important part of a wind tunnel's design. Its main purpose is to make the flow more uniform. It also increases the flow at the test section, which allows flow conditioning devices to be at lower flow section with less pressure drop. The contraction tube designed here is based on basic requirement of maintaining velocity at inlet and contraction cone end with a nominal 3.6:1 contraction ratio[5].(Fig. 3.1). The curvature of the wall along the flow direction is too large at certain points, will maintain the local velocities at these points till the end of the contraction cone. The regions of adverse pressure gradient along the wall and the boundary layer were also considered to maintain the uniform velocity during operation. In order to ensure good flow quality in the test section, the wind tunnel entrance, the setting chamber contains honeycomb structure of 0.015 m diameter and 0.02 m length, which can partially remove the turbulence intensity.

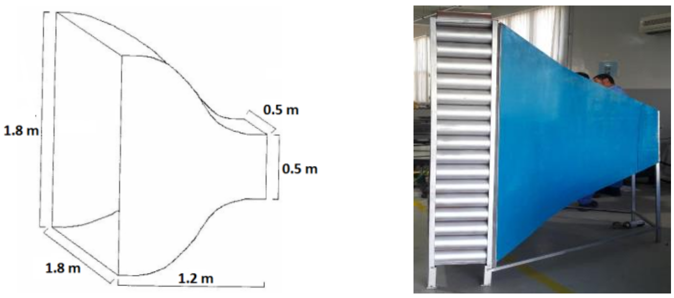

Fig. 3.1 Contraction tube @ 3.6:1ration

3.2 Test Section

Airfoil performance is highly dependent on the behavior of the laminar boundary layer, low turbulence levels within the wind-tunnel test section are necessary to ensure that laminar flow does not prematurely transition to turbulent flow[6]. The part of the wind tunnel preceding the test section serves the purpose of 'catching', stabilizing and accelerating the flow. It is expected to have a flow uniformity and turbulence intensity within 0.5-2%. With the aid of conservation of mass equations, the test section for the wind tunnel discussed here is designed with 0.5×0.5 m in inlet cross section and 0.51×0.51 m of outlet cross section [1]. The length has a nominal flow length of 1 m. This increase in area along the flow is expected to avoid flow separation. Flow separation is possible after a large contracted flow just before the test section; hence, the width is increased by 0.01 m to account for boundary layer growth along the sidewalls (Fig. 3.2).

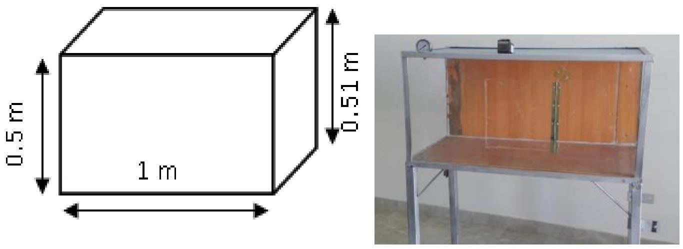

Fig. 3.2 Test section with boundsry layer consideration

3.3 *Diffuser*

Diffusers are typically designed with an area increase along the flow direction with the purpose of decreasing the exit velocity, thereby recovering pressure and decreasing total pressure losses throughout the system. Bernoulli's principle is followed here in estimating the diffuser exit dimension to ensure the pressure recovery, hence flow separation and its consequences through the system is reduced. Total pressure recovery is estimated through the ratio of the average total pressure to the free stream total pressure at exit. Keeping this as a criterion, the diffuser is designed with an angle of 6^0 along the upstream flow direction.

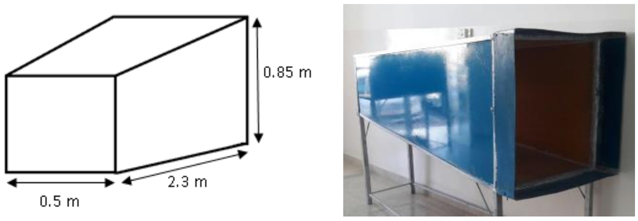

Fig. 3.3 Diffuser @ 6^0 diffusing angle

3.4 *Suction Fan*

Test section speeds are expected to provide a nominal wind velocity up to 30 m/s [4]. Here in this project, a 1.5 kw AC motor connected to a six-bladed fan (Fig. 6) is used to provide the requirement of around 5 m/s air stream by suction. The electric drive and fan configurations are opted to produce a flow with Reynolds number of around 1,00,000. Flow velocity of 2 to 8 m/sec, is suitable for performance testing of a prototype wind turbine blade of profile length 0.015 m., considering the kinematic viscosity of fluid at 15 ^{0}C is $1.48\times10{-}5$ m^2/s.

Fig. 3.4 Suction fan powered by AC moter

3.5 *Honeycomb Structure*

The performance of the model to be tested is highly dependent on the behavior of the internal compressible flow characteristics like laminar boundary layer, turbulence levels within the wind-tunnel test section and so on. It is necessary to ensure that, laminar flow does not prematurely converge to turbulent flow through the test section. To maintain a developed boundary layer flow through the test section it is important to supply a flow without separation at the entry of test section. This is possible in a good wind tunnel by straightening the flow through honeycombs at the entry of contraction tube. In order to ensure good flow quality in the test section, the wind tunnel entrance, the setting chamber is designed with a honeycomb structure, made of 0.015 m diameter and 0.02 m length, which can partially remove the turbulence intensity also.

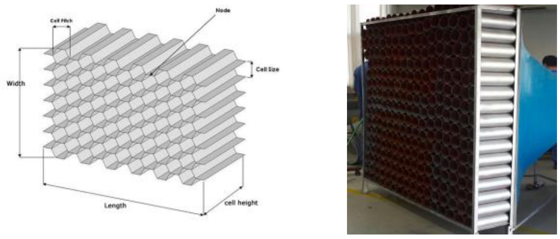

Fig. 3.5 Honeycomb Structure and Settling Chamber

4 WIND TUNNEL CLAIBRATION AND TESTING

A professional calibration of a probe is essential for reliable measurement results. Calibration means defining the relationship between the concerning local total pressure the local wind velocity and the angle of fluid flow. For this purpose, an anemometer is held at different positions along the cross section of the test section to measure the local velocities at different flow generated by varying the fan speed. The local wind velocities at the entry and exit of the contraction, test section and diffuser are also measured to estimate the friction coefficients along the walls at different flow. Coefficients for minor losses are also estimated and these coefficients are set as the system coefficients for future analysis with known flow field generated by suction system. When the probe later recognizes an unknown flow field during experimental analysis, it implies the unidentified velocity of this flow by using the measured pressure and the earlier defined calibration factors. The wind tunnel constructed here will be calibrated in the form of test data repeatability. Based on this methodology the overall reliability of this wind tunnel will be validated.

5 SELECTION OF MINIMUM VELOCITY FOR GIVEN SHAPE OF WIND TUNNEL

Intake part of the wind tunnel is designed to facilitate airflow at minimal turbulence and at required flowrate. Honeycomb structure ensures the flow at minimal turbulence and flow rate should be estimated based on the testing requirements. Here the velocity is estimated using boundary layer thickness formula for the compressible flow at NTP conditions, given below.

$$\delta_x = \frac{4.9 l_x}{\sqrt{Re_x}}$$

$$\delta_x = \frac{4.9 l_x}{\sqrt{\frac{\rho v d}{\mu}}}$$

$$v = \left[\frac{4.9 l_x}{\delta_x}\right]^2 \frac{\mu}{\rho x}$$

It is assumed that the aero foil is not influenced by the boundary layer formed by the test section walls.

6 AEROFOIL GEOMETRY AND MESHING

An aerofoil profile was generated based with coordinates points from airfoil database and was Imported to Fusion 360 to generate codes for Heidenhain based CNC milling. The following figures (Fig 6.1 (a-c) refers to the profile and tool path generation for fabrication in CNC machine. The coordinates generated are furnished in Table 6.1.

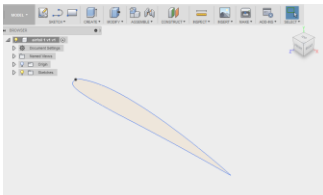

Fig.6.1(a) Profile generation.

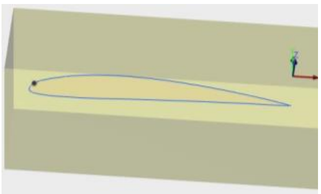

Fig.6.1 (b) Stock generation.

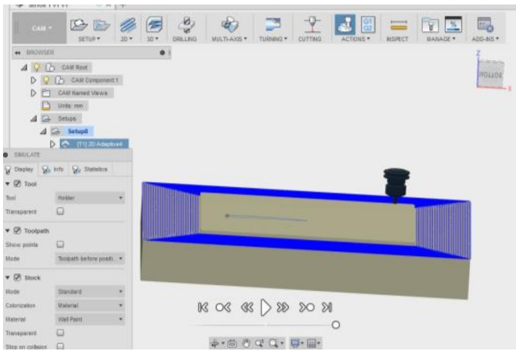

Fig. 6.1 (c) Tool path generation.

S.NO	X	Y	Z	S.NO	X	Y	Z
1	0.001	0		19	0.013	-0.01	0
2	0.95	0.015	0	20	0.025	-0.02	0
3	0.9	0.027	0	21	0.05	-0.02	0
4	0.8	0.049	0	22	0.075	-0.03	0
5	0.7	0.067	0	23	0.1	-0.03	0
6	0.6	0.081	0	24	0.15	-0.03	0
7	0.5	0.092	0	25	0.2	-0.03	0
8	0.4	0.098	0	26	0.25	-0.03	0
9	0.3	0.098	0	27	0.3	-0.02	0
10	0.25	0.094	0	28	0.4	-0.02	0
11	0.2	0.088	0	29	0.5	-0.01	0
12	0.15	0.079	0	30	0.6	-0.01	0
13	0.1	0.066	0	31	0.7	-0.01	0
14	0.075	0.058	0	32	0.8	-0	0
15	0.05	0.047	0	33	0.9	-0	0
16	0.025	0.034	0	34	0.95	-0	0
17	0.013	0.024	0	35	1	-0	0
18	0	0	0				

Table 6.1

For discretization of the airfoil in 2D, free mesh at the middle of the airfoil was selected. The 2-D aero foil configuration and mesh used for the analysis are shown in the Fig.6.2 (a & b)

7 AEROFOIL GEOMETRY AND MESHING

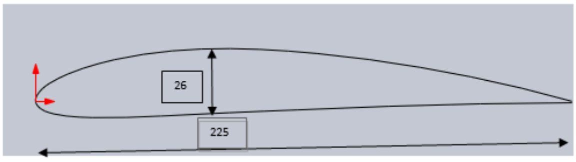

Fig.6.2(a) Aero Foil 2-D Configiration

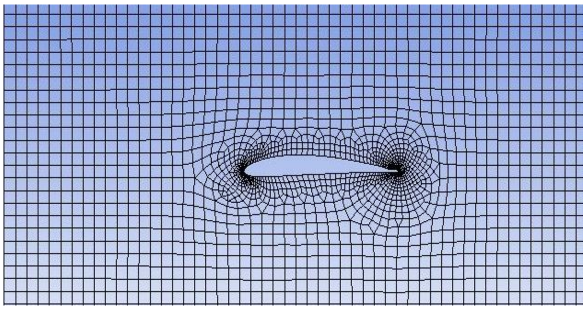

Fig. 6.2 (b) 2-D Meshing

8 WIND ENERGY POTENTIAL OF OMAN

Oman benefits from a long coastline and exposure to the strong summer and winter monsoon winds. It has an average wind speed slightly over 5 m/s and an estimated 2,463 hours of full load per year, making wind power an economically viable form of renewable energy [4]. Studies undertaken in Oman show that, in general, wind speed is higher during the summer months of June, July and August and is lower during October and November. However given that wind speeds are higher during the months that Oman reaches peak demand, this is a further indication of the feasibility of wind powered electricity generation for the Sultanate.

9 WIND TUNNEL – ENGINEER'S CURRENT NEED

Despite Oman's extensive potential for power generation through wind energy, it has not been extracted at its maximum. To yield the maximum possible energy through the season, it is expected to design advanced airfoil profile design for wind turbines. Flow modeling analysis through wind tunnel when encouraged among the young student community, a transformation can be expected in the field of renewable energy utilization. Result oriented wind mill will be the outcome of continuous designs on trial and error basis experimentation. Hereby continuous attempts will be made to design an airfoil for wind turbines using the indigenous subsonic wind tunnel shown in fig. 6.1, suitable for fluctuating conditions and loads.

Fig. 6.1 Newly buit subsonic wind tunnel in IBRICT.

10 CONCLUSION

Despite Oman's extensive potential for power generation through wind energy, it has yet to be extracted at its maximum. To yield the maximum possible energy through the season, it is expected to design advanced design of airfoil profiles of wind turbines. Flow modeling analysis through wind tunnel when encouraged among the young student community, a transformation can be expected in the field of renewable energy utilization. Result oriented wind mill will be the outcome of continuous designs on trial and error basis experimentation. Hereby continuous attempts will be made to design an airfoil for wind turbines using the subsonic wind tunnel, suitable for fluctuating conditions and loads.

Fig. 6.1 Newly buit subsonic wind tunnel in IBRICT.

11 CONCLUSION

The potential of wind power generation is immense, a historical source of energy, can be used as a source of electricity and for irrigation and agricultural uses. Presently greener source of energy is the need of the hour, wind energy is a promising resource, waiting to be harnessed to its true potential. Uncertainty in dynamic behavior of wind turbines, a great hurdle in present days wind energy production is expected to be handled with good know how on aerodynamic characteristics. The subsonic wind tunnel fabricated here is to help the renewable energy engineers of Oman to focus more on designing innovative wind turbine profiles. This will overcome the uncertainties in dynamic behavior of wind turbines, and to help the designers to optimize the wind power generation.

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