ISSN: 0974-5823 Vol. 6 No. 3 October-December, 2021

International Journal of Mechanical Engineering

Experimental and Numerical Validation of Cup Anemometer

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Abstract—-

The cup anemometer was designed and simulated numerically using CFD through which tangential velocity was determined for various input air velocities. Using the tangential velocity, the speed of the anemometer was calculated. This was verified experimentally by placing the cup anemometer in a subsonic wind tunnel where the speed was measured by means of a non-contact tachometer. Similarly, frequency of the cup anemometer was also noted and the relation between the wind speed and the frequency of the cup anemometer was established by using a least square regression.

Keywords— cup anemometer, dynamic mesh, blockage ratio

I. Introduction

Despite the onset of LIDAR or SODAR, the cup anemometer seems to be the most widely used wind speed sensors owing to its accuracy, cost, reliability and endurance [1]. But cup anemometers are more sensitive in case of increasing wind speeds than decreasing of the same magnitude [2]. Also cup anemometers show the increased response to fluctuating wind speeds [3].

The applications of cup anemometers are widely extended in fields such as wind energy production and meteorology. The accuracy of the cup anemometers is highly essential for optimum power production through wind energy. Cup anemometers usually containing AC motors, the frequency obtained from which is directly proportional to the wind velocities. Thus usually the wind velocities are identified by using the transfer function between the AC frequency and the wind velocities.

In the present study the cup anemometer was modeled using Solidworks and the numerical simulation was done through ANSYS Fluent R21 and verified with experimental values.

II. Numerical Simulation

A. Modeling of a Cup Anemometer

The specifications of the cup anemometer are listed below in the table 1.

Table 1 Specifications of the cup anemometer

S.No	Component	Dimensions
1	Cup diameter	51 mm
2	Rotor diameter	190 mm
3	Cup angle	45 ^{0}
4	Moment of Inertia	92.2×10^{-6} kg.m^2

The three dimensional model of the given cup anemometer designed using Solidworks. Figure 1.a represents the actual cup anemometer and figure 1.b represents the model.

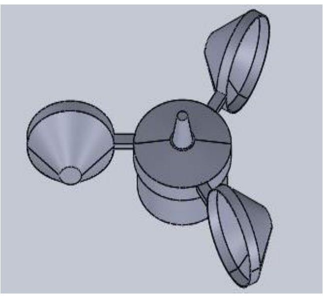


Fig. 1 –a 3D Model **Fig.1- b** 3D Model

B. Computational Fluid Dynamics

The model was imported in ANSYS Fluent in an enclosure of cushion 0.5 m.

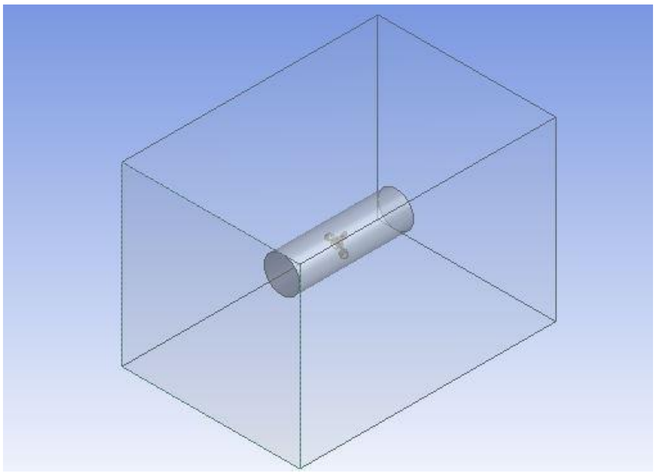


Fig.2 Enclosure

Figure 2 represents the enclosure provided to the cup anemometer.

Adaptive meshing was given to discretize the model into number of smaller elements as shown in figure 3.

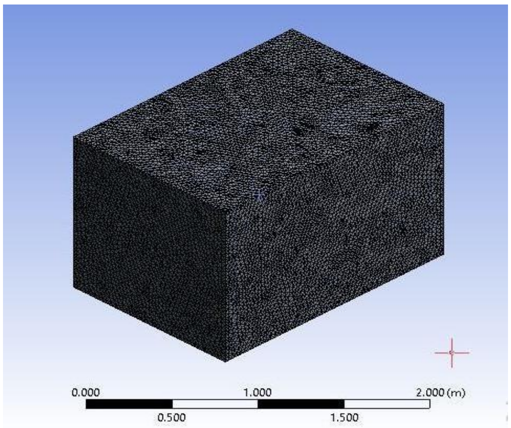


Fig.3 Mesh

The Standard k-ε model was used for the present study. The input velocities given are 4,6,8,10,12,14 and 16 m/s. The details of the numerical model are listed in Table 2.

Table 2 Mesh details

No of nodes	79535
No of elements	411599
Inlet	Velocity inlet (m/s)
Outlet	Pressure outlet

It was initially run in steady state condition until convergence was reached. Then, it was shifted to transient one. Then the dynamic mesh was enabled and the conditions given were listed in Table 3.

Table 3 Dynamic mesh details

Mass of the component	0.3 kg
Moment of Inertia	92.2×10^{-6} kg.m^2
Implicit update	1
Time step size	0.005 (Seconds)
No of time steps	2000
Iterations per time step	150

These conditions were obtained through repeated trial and error methods. Higher the implicit update interval or higher the time step size resulted in the failure of convergence. The computational time taken for each of the case was around 50 hours. The results obtained through the numerical simulation were displayed below in the figures.4. a-g.

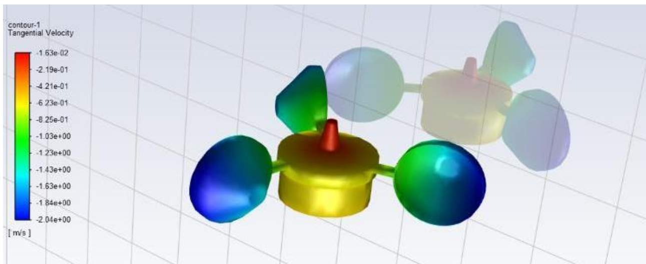


Fig. 4- a Inlet velocity-4 m/s

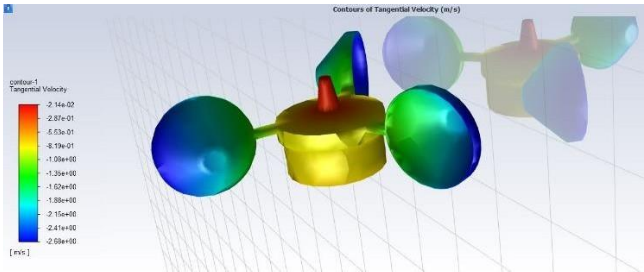


Fig. 4-b Inlet velocity- 6 m/s

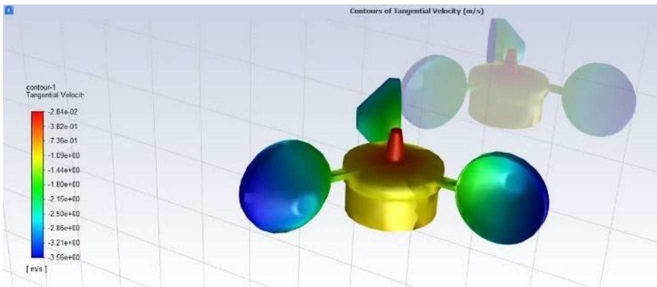


Fig. 4-c Inlet velocity- 8 m/s

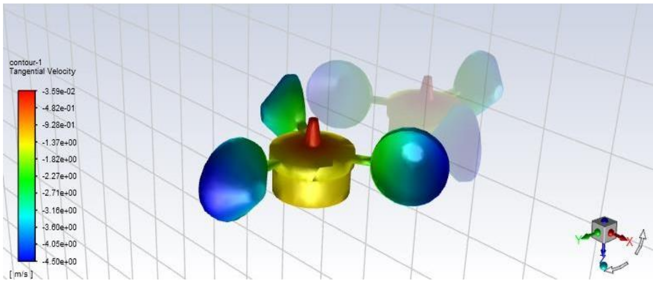


Fig. 4- d Inlet velocity- 10 m/s

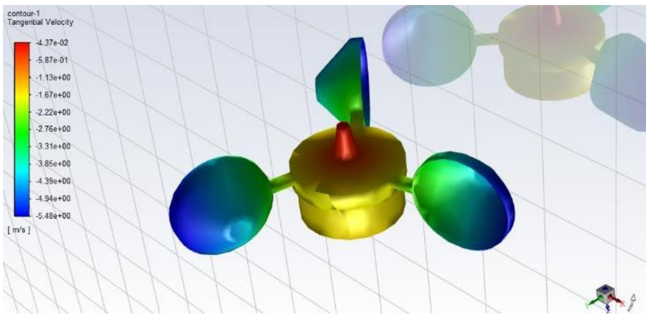


Fig. 4-.e Inlet velocity- 12 m/s

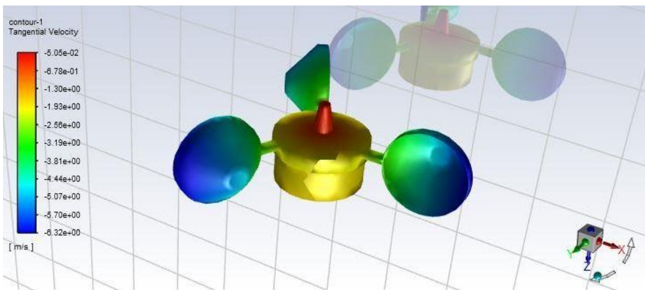


Fig. 4-f Inlet velocity- 14 m/s

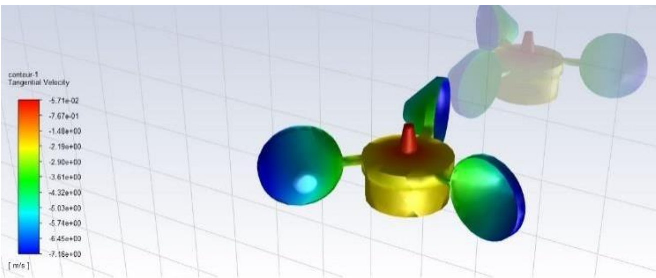


Fig. 4- g Inlet velocity- 16 m/s

The inlet velocity represents the air velocity while the velocity represented in the contour denotes the tangential velocity of the cup anemometer. Since the direction of the rotation is counter clockwise the values of the tangential velocity represents negative. Hence the absolute values in the contour plot were taken. From this it can clearly infer that the blade velocity is minimum at the center and maximum at the periphery. The tangential velocity obtained through the numerical simulations was used to determine the speed (RPM) of the anemometer.

III. Experimental Verification

The numerical simulation is a mathematical form of analysis which is based on certain assumptions. Hence the results need to be validated through experimental values.

A. Setting up of Wind Tunnel

Wind Tunnel situated at PSG College of Technology, Coimbatore was used for experimental analysis of the Cup Anemometer. It has a square test section of side 1.5 m with length 6 m. Pitot tube was placed 1 m before the anemometer mounting to measure the reference free stream velocity [4]. Figure.5 represents the Pitot tube setup for reference velocity measurement and figure 6 represents its position in the test section. The pitot tube is connected to the calibrated digital manometer to obtain accurate readings.

The Blockage Ratio has significant impact in the anemometer readings [5]. Hence we determined the blockage ratio for the present study which comes around 0.0121. This was well below the minimum standards as mentioned in IEC 61400-12-1 [6]. All the procedures for analysis of Cup Anemometer was followed as mentioned in the above IEC standard.

Fig.5 Pitot tube for reference velocity measurement

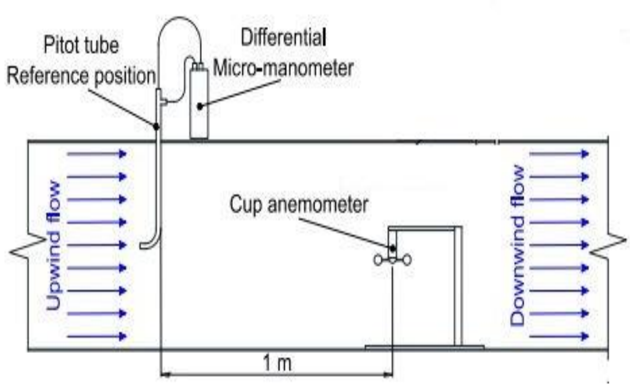


Fig.6 Pitot tube position in the test section

B. Measurement of Cup Anemometer Speed

An Infrared non-contact tachometer was used for measurement of cup anemometer rotating speeds. Figure.7 represents the tachometer setup in the wind tunnel. The tachometer was connected with the Arduino which in turn was connected with the computer. The RPM values were noted every 0.3 Seconds for 1 minute and the average of the 300 values was noted.

Through the reference pitot tube the wind speed is set for 4,6,8,10,12,14 and 16 m/s [6]. The same procedure was followed for each case. Before taking the readings, about 5-10 minutes was given to reach the steady state.

Fig.7 Tachometer setup

C. Measurement of Cup Anemometer Frequency

Generally, wind speeds were calculated from the cup anemometer by measuring its output frequency. Hence the frequency was determined by using the Arduino with an interval of 0.3 seconds for 1 minute. The inlet velocities were set from 4 m/s - 16 m/s with an increment of 1 m/s.

The numerical interpolation was done to establish the relationship between input velocity and measured frequency by using least square regression. The repeatability of the data was ensured by repeating the experiment for 5 times.

D. Uncertainties in the measurement

In the measurement of reference free stream velocities, the accuracy of the calibrated digital manometer is ± 0.03 %.

The five sets of readings were taken for the measurement of frequency the maximum variations obtained from the data is ± 0.1 %. In the measurement of cup anemometer speed the maximum variations obtained is ± 1 %.

IV. Results And Discussion

The speed of the cup anemometer which was measured experimentally and numerically speed of the cup anemometer are listed in the below table 4.

Table 4 Speed of the cup anemometer at various winds speeds

S. No	Inlet velocity (m/s)	Experimental RPM	Numerical RPM
1	4	73.54	103.08
2	6	93	125.71
3	8	153.43	175.99
4	10	199.33	227.29
5	12	246.55	275.56
6	14	288.88	317.9
7	16	322.48	362.05

Figure 8 represents the comparison of numerical and experimental velocities of the cup anemometer. Both values are matching well with minimum deviation.

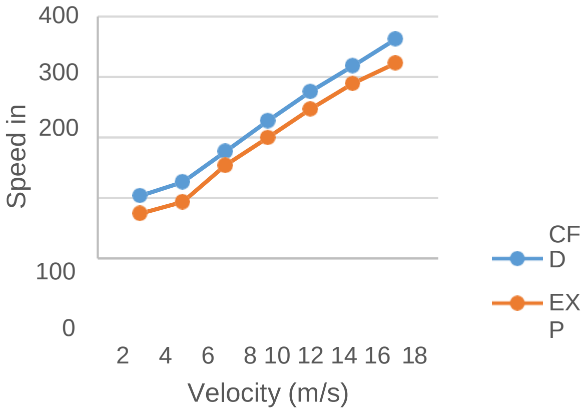
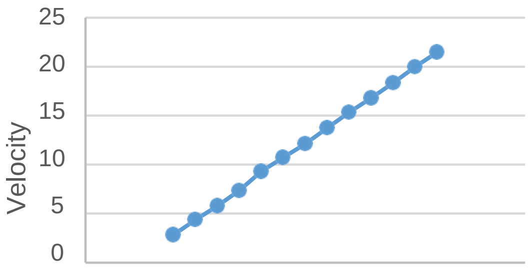


Fig. 8 Comparison of numerical and experimental velocities

Figure.9 represents the frequencies obtained from cup anemometer for various wind velocities. It shows linear trend.



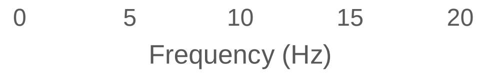


Fig.9 Frequencies obtained for various wind velocities

The frequency obtained from the cup anemometer at various input velocities are listed below in Table 5.

Table 5 Frequency of the cup anemometer at various wind speeds

S.No	Input velocity (m/s)	Frequency (Hz)
1	4	2.80
2	5	4.35
3	6	5.75
4	7	7.34
5	8	9.29
6	9	10.72
7	10	12.10
8	11	13.74
9	12	15.33
10	13	16.78
11	14	18.34
12	15	19.96
13	16	21.46

From the above data, numerical interpolation was done using Least Square Regression Method to establish relationship between frequency and wind velocities.

The general form of linear equation is

$$y = a_{o} + a_1 x + e, \text{ then} \quad [1]$$

$$e = y - a_{o} - a_1 \quad [2]$$

For this error to be minimum if first derivative is equal to zero.

Thus we get the below two equations

$$\Sigma\, y_i = n\, a_{o} + a_1 \Sigma\, x_i \quad [3]$$

$$\Sigma\, y_i\, x_i = a_{o}\, \Sigma\, x_i + a_1 \Sigma\, x_i^2 \quad [4]$$

Here x denotes the cup anemometer frequency and y denotes the wind velocity.

Solving the two equations we get the coefficients a_o & a_1 and the required correlation is

$$y = a_1\, x + a_o \quad [5]$$

Here, The obtained equation was

$$y = 0.6411\, x + 2.2109 \quad [6]$$

V. CONCLUSION

The wind velocities can be determined with the help of the frequency obtained from the cup anemometer by equation [6].

The speed of the anemometer determined experimentally nearly same trend as the one determined numerically. The might be due to the frictional resistance of the bearings in the cup anemometer.

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