Experimental Study of Fully Developed Flow in an Axial Ducted Fan Set Up

Mahendra M. Dhongadi,[1]* K. V. Sreenivas Rao,[2] G. R. Srinivas,[1] C. P. S. Prakash[1]

[1] Department of Mechanical Engineering, Dayananda Sagar College of Engineering, Bangalore.

[2] Department of Mechanical Engineering, Siddaganga Institute of Technology, Tumkur.

Abstract

In an axial ducted fan set up there is an air flow. Through the calculation it is found that fluid is incompressible at given conditions, and flow is steady, viscous and turbulent. Experimental efforts have been made to understand the effect of different speeds, on developed flow, hydrodynamic length, viscous layer and velocity profile. In an axial fan set up, at the inlet of fan, three reference planes are taken at convenient positions. At these three planes velocity is measured in radial direction. Velocities are measured using hotwire. Using these velocity gradients, profile plots and fluctuation plots are drawn and studied.

Keywords: *Fully Developed Flow, Turbulent Flow, Axial Ducted Fan, Turbomachinery.*

1. Introduction

Consider the know flow illustrated in fig 1 where a steady viscous flow enters a tube from reservoir. Wall frictions cause a viscous layer and grow in thickness downstream, and inevitably the viscous layer must coalesce at some distance X_L, so that the tube is then completely filled with boundary layer. Slightly further downstream of the coalescence, the flow profile ceases to change with axial position and is said to be fully developed.

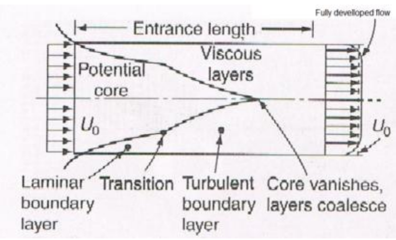


Fig1: Flow in the entry region of a tube [1]

Although the theory of fluid flow is reasonably well understood, theoretical solutions are obtained only for very few simple cases such as fully developed laminar flow in a circular pipe. Therefore, we must rely on experimental results and empirical relations for most fluid flow problems rather than closed-form analytical solutions. [2]

Laminar flow is strictly limited to finite values of a critical parameter- Reynolds number, Grashof number, Taylor number, Richardson number. Beyond that, laminar flow is unstable and evolves to a new flow regime if the critical parameter is high enough. That new regime, not predicted by stability theory but nevertheless inevitable, is a fluctuating, disorderly motion called turbulence. Because turbulence is so complex, its complete analysis and quantification will probably never be achieved. Turbulent flow will be the subject of research in the foreseeable future, and hundreds of papers and articles being published every year.

Much is known now about the structure of turbulence, due to excellent experimental techniques. [3] First there is advanced flow visualization; second there is superb modern miniature instrumentation: hot wires, laser-Doppler system, particle image velocimetry [4] and other measurement techniques.

2. Methodology

2.1 Test facility and instrumentation

For experiment, an axial ducted fan [5] set up with bell mouth type of inlet is used this is shown in fig 2a and 2b. In which air is made to flow using axial fan. Flow patterns, which are created due to flow under normal condition (no distortions to flow, at inlet and at out let) are studied.

2.2 Specification of ducted fan

In this axial fan set up, axial fan is located at distance of 2120 mm from bell mouth inlet. Duct inner diameter is 370 mm. The total length of duct is around 4000 mm. A 2 HP Variable frequency 3-phase induction drive is coupled to the electrical motor of axial fan to drive variable speed ranges. This is shown in fig 3.

Fig 2a: Pictorial Representation of Axial Ducted Fan Set Up

3. Results and discussion

Following tables indicate the readings of axial velocities of air flow at specified reference planes 1, 2, and 3 which are at distance of 405 mm, 1200 mm, and 1730 mm respectively from inlet of bell-mouth. At these reference planes velocity measurements will be made in radial direction for different speed of fan like 2400, 3000, 3600 rpm respectively.

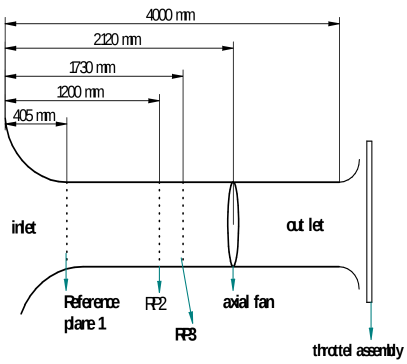


Fig 2b: Schematic Representation of Axial Ducted Fan Set Up

Fig 3: A 2HP Variable frequency 3-phase induction drive

From these velocity gradients the difference in velocities at planes 2, 1 and planes 3, 2 is calculated and fallowing observations are made.

In some cases, between two consecutive reference planes velocities are increasing, and in some cases between two consecutive reference planes velocities are decreasing where as in some cases, between two consecutive planes velocities are either increasing or decreasing that remains stable.

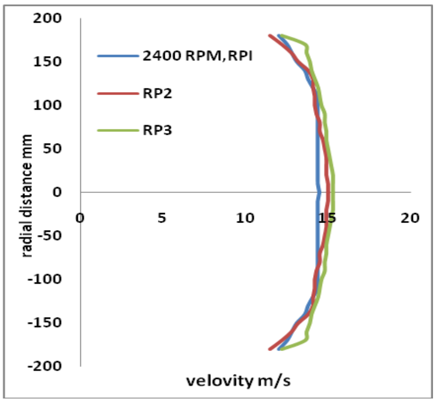
The calculation indicates the behaviours of flow. Where increase in velocity between two consecutive planes indicates developing flow, decreasing velocity indicates eddies, back flow and unsteadiness, and stable velocity indicate developed flow. And this method is simple and economical to identify nature of flow pattern.

Table 1, and its profile plot 1, makes clear about development of fluid flow profile in the given duct, at inlet of fan, at 2400 rpm.

From calculation it is found that velocity is increasing at reference plane 3. Means velocity is not stable. Therefore it is said to be flow is still developing at plane 3.

At fan speed 2400 rpm Fluctuation plot 1, is drawn for the difference in velocities between plane 2, 1 and 3, 2. The plot which is drawn for the difference in velocities between the plane 2, 1 shows retardation of flow at radial distance of around 90 mm and at 120 mm from centre of duct, this indicates reduction of flow between the consecutive planes 1, 2.

It is due to eddy formation, reverse flow and unsteadiness in the flow. Fluctuation curve helps to find viscous layer and potential core in the fluid flow.

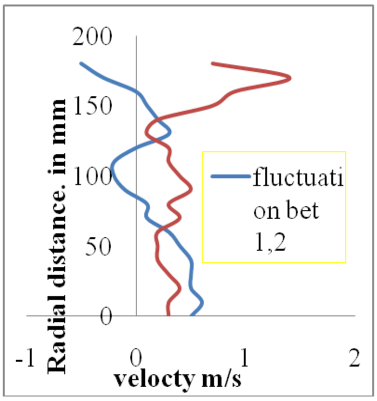


Profile plot 1: Drawn from table 1 Represents the growth of velocity at inlet of axial ducted fan at the three planes for fully opened condition at 2400 RPM

Probe distance(mm)	*Opening 7 cm At Speed 2400 rpm and Throttle*			***Difference of 2nd and 1st plane***	***Difference bet 3rd and 2nd plane***
	Velocity at different planes in m/sec				
	1st plane	*2nd Plane*	*3rd plane*		
0	14.5	15	15.3	0.5	0.3
10	14.4	15	15.3	0.6	0.3
20	14.4	14.9	15.3	0.5	0.4
30	14.4	14.9	15.2	0.5	0.3
40	14.4	14.9	15.1	0.5	0.2
50	14.4	14.8	15	0.4	0.2
60	14.4	14.7	14.9	0.3	0.2
70	14.4	14.5	14.9	0.1	0.4
80	14.4	14.5	14.8	0.1	0.3
90	14.4	14.3	14.8	-0.1	0.5
100	14.4	14.2	14.6	-0.2	0.4
110	14.4	14.2	14.5	-0.2	0.3
120	14.1	14.1	14.4	00	0.3
130	13.8	14.1	14.2	0.3	0.1
140	13.6	13.8	14	0.2	0.2
150	13.1	13.2	13.9	0.1	0.7
160	12.8	12.8	13.7	00	0.9
170	12.5	12.2	13.6	-0.3	1.4
180	12	11.5	12.2	-0.5	0.7

Table 1: Velocity at fully open condition and at 2400 RPM

Function curves for negative values of velocities indicates viscous layer and fluctuation curve for positive values indicates potential core.

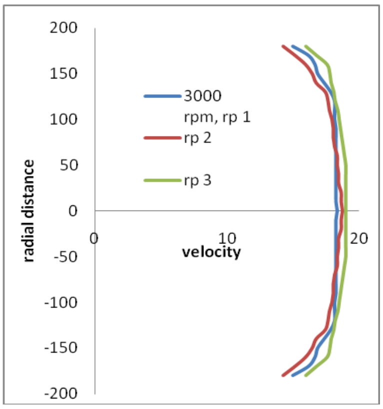


Fluctuation plot 1: Indicates fluctuation and retardation in flow

Similarly table 2 and table 3 shows velocity distribution of flow at 3000 and 3600 rpm respectively. And corresponding profile plots are drawn as profile plot 2 and as profile plot 3, this helps to understand the zone of retardation of flow or boundary layer at particular speed.

When these fluctuation curves for different speeds are compared, it is noted that at higher speed we can clearly make out difference between potential core and viscous layer. From fluctuating float 3 it is very clear that viscous layer reduces as speed increases

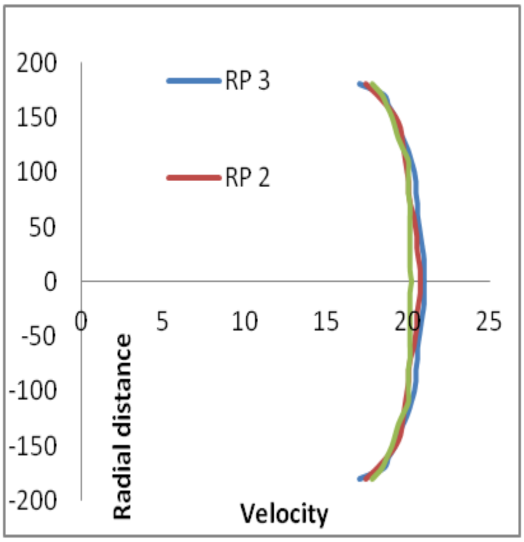
Frome table 3 and its corresponding profile plot 3, it is clear that between plane 2and 3 velocity is less fluctuating , that is tending to stable, since it can say at plane 3 or immediately after plane 3 flow will be fully developed. Since developed flow will be found approximately at distance of 2000 mm when the speed is 3600 rpm, here it is found that for given duct dimensions entrance length increases as speed decreases.



Profile plot 2: Drawn from table 2, at 3000 RPM

opening 7 cm At speed 3600rpm and throttle				*Difference bet 2nd and 1st plane*	*Diffnence bet 3rd and 2nd plane*
Probe distanc (mm)	*Velocity in m/s*				
	1st plane	*2nd plane*	*3rd plane*		
0	20.2	20.7	21	0.4	0.3
10	20.1	20.7	21	0.4	0.3
20	20.1	20.6	21	0.4	0.4
30	20.1	20.5	20.9	0.2	0.4
40	20.1	20.5	20.8	0.2	0.3
50	20.1	20.4	20.7	0.1	0.3
60	20.1	20.3	20.6	0.1	0.3
70	20.1	20.1	20.6	0.1	0.5
80	20	20	20.5	0.2	0.5
90	20	20	20.5	0.2	0.5
100	20	19.9	20.4	-0.2	0.5
110	20	19.8	20.2	-0.4	0.4
120	19.7	19.7	20	-0.5	0.3
130	19.4	19.6	19.7	-0.4	0.1
140	19.2	19.5	19.4	-0.6	-0.1
150	19	19.2	19.2	-0.4	00
160	18.7	18.7	18.8	-0.7	0.1
170	18.4	18.1	18.5	-1.0	0.4
180	17.8	17.4	17	-0.7	0.4

Table 2: Velocity at fully open condition and at 3000 RPM



Profile plot 3: Drawn from table 1 Represents the growth of velocity at inlet of axial ducted fan at the three planes for fully opened condition at 3600 RPM

Table 3: velocity at fully open condition and at

opening 7 cm At speed 3000 rpm and throttle				*Difference bet 2^{nd} and 1^{st} plane*	*Difference bet 3^{rd} and 2^{nd} Plane*
Probe distanc (mm)	*Velocity in terms of m/sec*				
	1st plane	*2nd plane*	*3rd plane*		
0	18.4	18.8	19	0.4	0.2
10	18.3	18.7	19	0.4	0.3
20	18.3	18.7	19	0.4	0.3
30	18.3	18.5	19	0.2	0.5
40	18.3	18.5	19	0.2	0.5
50	18.3	18.4	19	0.1	0.6
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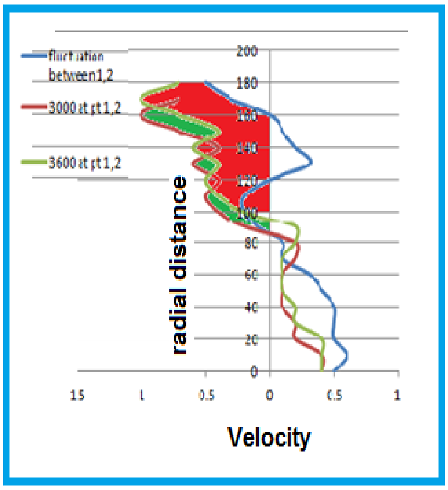
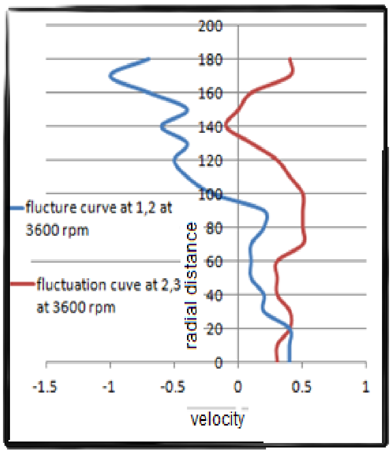
100	18.2	18	18.5	-0.2	0.5
110	18.2	17.8	18.4	-0.4	0.6
120	18.2	17.7	18.2	-0.5	0.5
130	17.9	17.5	18.1	-0.4	0.6
140	17.4	16.8	17.9	-0.6	1.8
150	16.9	16.5	17.8	-0.4	1.6
160	16.7	16	17.6	-0.7	0.6
170	16.2	15.2	16.8	-1.0	1.6
180	15	14.3	16	-0.7	1.7

3600 RPM



Fluctuation plot 2: comparison of retarding flow at 2400 rpm and 3000 and 3600 rpm.



Fluctuation plot 4, at plane 1,2 and 2,3. at 3600 rpm

For turbulent flow, there is a numerical equation for hydraulic length that is (HL) ≈ 10 D Where D is inlet diameter of duct.

Give duct inner diameter is 370mm and since through numerical method the approximate hydraulic length is 3700 mm. But as turbulence increases hydraulic length decreases. And at lower speed entrance length increases.

For given fan speeds the minimum velocity is 10 m/s. And maximum velocity is 20m/s Therefore the Mach number and Reynolds number are calculated as follows.

Flow is said to be incompressible flow if Mach number is less than 0.3

The Mach number is defined as the ratio of the flow velocity to the local speed of sound. Therefore.

Mach number for the given flow

$M = v / c$

Where, M = Mach number

v = fluid flow speed (m/s)

c = speed of sound , the speed of sound is 340.3 m/s

From table, velocity of air (v) is 19m/s

Therefore M= 19/340.3 = 0.056

This is much less than 0.3 hence flow is consider as incompressible.

Atmospheric air density

$\rho = P/RT$

P=Atmospheric pressure

T=Atmospheric temperature in Kelvin

R= Specific Gas constant value is 287 J/kg.

Atmospheric pressure measured by barometer

P=ρxgxh

=13600X9.81X0.684

=91256.544 atm

And atmospheric temperature measured by Thermometer=27+273=300 K

Hence, Air Density (ρ) =P/RT

56.544/(278+300)=1.09 kg/m3 Therefore,

Reynolds number (Re) [4]

$Re = \rho VD/\mu$

D= is the hydraulic diameter of the pipe(m)

ρ= is the density of the fluid (kg/m³)

V= is the mean velocity of the fluid (m/s).

- laminar when Re < 2300
- transient when 2300 < Re < 4000
- turbulent when Re > 4000

Hence, Re = ρVD/μ

= 1.09x10x0.37)/0.00001

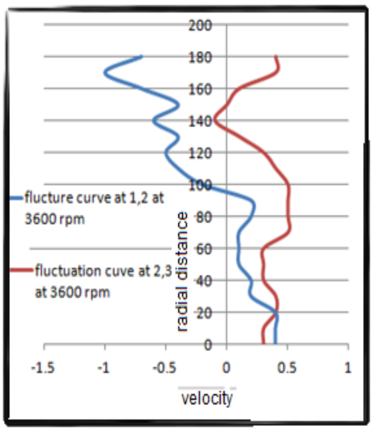
= 403300

= 4.033x105

4. Conclusion

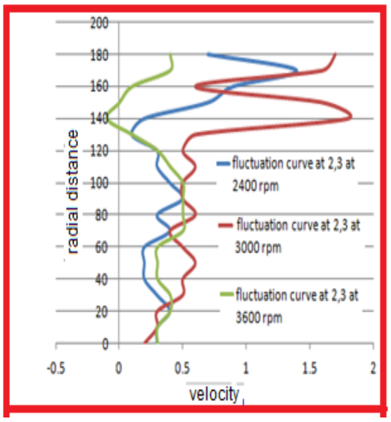
From the above studies it is observed that the flow is turbulent and incompressible. At higher speed we can classify viscous layer from potential core easily. And viscous layer will reduce as speed increases.

Developed flow, hydrodynamic length, viscous layer and velocity profile in axial direction depends on the type of flow, coefficient friction of duct, duct diameter, velocity of flow, speed of fan and type of inlet of duct.



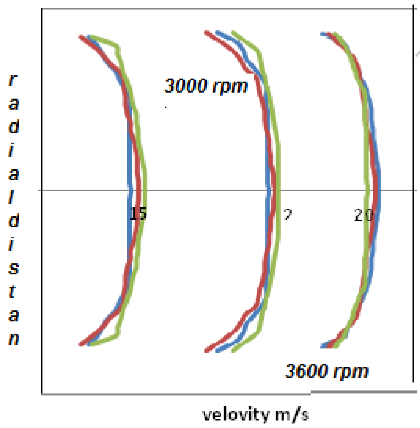
Fluctuation plot 4, at plane 1,2 and 2,3. At 3600 rpm

Fluctuation plot 4 indicates the change in fluctuation range along the flow in radial direction , between plane 1,2 there is very high reduction in velocity at nearer to the wall surface and fluctuation range is also high ,but between plane 2,3 reduction of velocity is less at near to wall surface and flow fluctuation is also less it indicates that flow is trying to flow with uniform velocity and with less fluctuation. as it moves nearer and nearer to fan at higher speed of fan like 3600 rpm



Fluctuation plot 5 Comparison of fluctuations curves between plane 2, 3 at specified speeds

When we compare fluctuation plots of different speeds (as shown in fluctuation plot 5) it is found that, If speed increases fluctuation in flow will increase up to certain speeds and further increase in speed reduces the fluctuations in flow, because flow is finding redeem at high speed, And when we compare velocity profile it is found that , As speed increases there will be change in velocity profile it will be more puller at higher speed, because it is trying to overcome viscous layer, as velocity increases viscous layer decreases. This is shown in profile plot 5



Profile plot 5: Comparisons of Velocity profiles of flow at specified speeds 2400, 3000, 3600 rpm respectively

5. Future Scope

In some practical applications, there are different types of distortion, to the flow, at inlet. Similar type of distortion can be created at inlet. Under these distortion behaviours of fluid will change. This will be studied in future. Similarly Using throttle at outlet fluid flow behaviours under stall and unstall region will also can be studied using the same axial ducted fan set up.

6. References

[1] Frank M.White "Viscous fluid flow"TATA McGraw-Hill,Third Edition 2011.

[2] Jigar S. Patel, "Parameter Affecting the Performance of Axial Fan Performance" International Journal of Engineering Research & Technology (IJERT), Vol 1,pp 1-3, 2012.

[3] Tienfun Kerh "Measurement of velocity distribution for flow through a bileaflet valve using colour coded digital particle tracking velocimetry " Journal of marine science and Technology. Vol. 13. No 1,pp 1-10(2005)

[4] Francesca Satta, Daniele Simoni, Marina Ubaldi, Pietro Zunino, "Velocity and turbulence measurements in a separating boundary layer with Laser Doppler Velocimetry", XIV AIVELA Conference, Rome, 2006

[5] Mahendra M. Dhongadi "Distortions in Axial Flow Ducted Fan and Solving Techniques " Proceeding Of National Conference On "Innovations In Mechanical Engineering" At Sinhgad Institute Of Technology, Lonavala, Pune, Maharashtra. 410 401 April 19th & 20th, 2012

[6] Yunus A.Cengel "Fluid Mechanics" TATA McGraw-Hill, Edition 2006