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Comparative Study of Air Performance of Fully Ducted Damper for HVAC based on Different Blade Profiles

Gaurav Paudel [a], Vishwa Prasanna Amatya [b], Nawraj Bhattarai [c], Hari Bahadur Dura [d]

[a, b, c, d] *Department of Mechanical and Aerospace Engineering, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
Corresponding Email: [a] grv_pdl@hotmail.com, [b] amatya2003@hotmail.com,
[c] bnawraj@ioe.edu.np, [d] duraharis@pcampus.edu.np

Abstract

Volume control damper is a device for controlling and regulating the airflow into an indoor atmosphere and is one of the different fittings in a Heating Ventilation and Air Conditioning system. Airfoil damper blade is a best suited blade among the different damper blades in use, viz. airfoil, triple-V and flat. A comparative air performance analysis was done between same thickness blades, one is conventional airfoil and NACA0010, other being scaled down airfoil shape of conventional airfoil and NACA0006 for different air velocities. Computational Fluid Dynamics analysis of all four cases were done in Ansys software as per American National Standards Institute and Air Movement and Control Association Standard 500D configuration 5.3. Pressure drop from conventional airfoil was compared with the data available in the American Society of Heating Refrigerating and Air-conditioning Engineers duct fitting database for different air velocities. From the analysis of four different airfoil profile, it was found out that 4-digit NACA0010 airfoil has least pressure drop of all, and hence is the best suited profile for the damper among the damper profiles considered in the analysis.

Keywords

Damper blade, Airfoil, HVAC, CFD

1. Introduction

HVAC system has been designed with the purpose of providing healthy and comfortable indoor atmosphere which can be achieved by controlling temperature, pressure, moisture, and indoor air quality (IAQ) [1]. Temperature and moisture can be controlled by either cooling or heating the indoor air. To maintain the humidity level to the human comfort level, humidifier and/or dehumidifier can be used. Pressure can be controlled by the use of damper in the line of incoming air from the atmosphere [1]. Air handling unit (AHU) can be used to supply required level of fresh air into the system. Variation in system parameters, variable conditions, interaction between climatic parameters, intense non-linear factors, uncertainty in the model are factors to be considered while designing any of the HVAC systems [2].

Indoor air quality (IAQ) of the HVAC system can be achieved through the use of dampers and fans. They control the flow of air inward and outward of the conditioned space. According to the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE), over a 70-year lifespan in a developed region, indoor air constitutes around 65 percentage of the total lifetime exposure, whereas outdoor air makes up the rest [3]. It is therefore necessary to consider the IAQ along with temperature control of indoor environment which, if compromised, will have adverse effect on human health due to their long exposure.

Damper is a device for regulating and controlling the flow rates in a mechanical and Air-conditioning ductwork system [4]. It controls air flow pressure as per the signal transmitted from the sensor measuring the air flow pressure in the room to the actuator attached to the damper [5]. It is one of the elements in AHU for airflow control and pressurization of the indoor environment of any system [6]. Most common application of damper is in static balancing of air flow network to the design requirements [6].

Legg (1986) [7] experimentally found that over the wide range of blade angles, there is a linear relationship between the logarithm of the loss coefficient and the blade angle. Sinisa et al. (2015) [8]

made a comparison of energy consumption of four types of damper with non-cascading blades and also developed the mathematical model for these four types of damper. Fanyong et al. (2019) [9] proposed a robust air balancing (RABA) method based on data-driven model. Charles et al. (2003) [10] studied experimentally the pressure loss characteristics of thin, single-blade flat dampers in square branch ducts in the turbulent region for damper width ratios from 0.5 to 1.414 and the interactions between the damper blade and shaft. Pallavi (2008) [11] determined pressure loss coefficient for a circular duct with a circular damper using computational fluid dynamics package Star-CD to predict the air flow and pressure distribution in the duct. Godwine et al. (2014) [12] reviewed VAV systems modeling and simulations, control strategies and optimization tools, the airflow characteristics of VAV systems, some common VAV systems' faults, detection and diagnosis, energy usage and analysis, and the current applications of variable air volume (VAV) air-conditioning systems. Ligrani (2012) [13] studied the influences of a variety of different physical phenomena as they affect the aerodynamic performance of turbine aerofoil in compressible, high speed flows with either subsonic or transonic Mach number distributions. Mee et al. (1992) [14] experimentally measured losses of linear cascade of transonic turbine blades. Becelaere et al. (2003) [15] conducted experiment for triple V and airfoil blade profiles for different ANSI/AMCA standard 500D arrangements.

2. Loss Mechanisms

2.1 Pressure loss

The pressure loss through a damper is a function of a number of geometric, inherent construction methods and structural configurations. Factors affecting pressure drop in damper are ratio of open free area of damper to area of the duct or wall, losses due to entrance or exit effects, velocities of flows, flow profile before and after the damper, shapes and geometry of the damper frame edges, type of blade and Aspect ratio [6].

2.2 Turbulence

Whether a flow is laminar or turbulent depends on the relative importance of fluid friction and flow inertia. Near a solid boundary the flow has a distinct structure, called a boundary layer. The most important aspect of a boundary layer is that the velocity of the fluid goes to zero at the boundary. This is called the ”no-slip” condition. Turbulence is an instability generated by shear. The stronger the shear, the stronger the turbulence. The presence of turbulence creates fluctuations in concentration [16].

2.3 Surface Roughness

Surface roughness is defined as the shorter frequency of real surfaces relative to the trough [17]. Roughness may arise from the manufacturing process, long period of service, and/or natural accumulations. The surface roughness can not only promote boundary layer from laminar to turbulent, but also affect significantly the subsequent flow development at Reynold's numbers well beyond the critical value. For the frame material as galvanised steel, effective roughness is 0.00592in [3]. For airfoil as 6063 T5 extruded aluminum, roughness is 0.0015in [3].

2.4 Geometry

A damper restricts airflow by obstructing the duct. The free area changes slightly with comer braces, linkage in airstream, frame, blade profile, and with type of frame.The two basic types of control dampers are parallel blade (PB) and opposed blade (OB). The linkages from blade to blade can be located on the blades themselves but are more commonly located on one side within the frame [6].

3. Fluid parameters

3.1 Density

The density of a substance is the quantity of matter contained in unit volume of the substance. The flow is said to be 'incompressible' if the density remains nearly constant throughout [18]. In this research, calculation is made for standard density of 0.075 lb/ft3 (1.201 kg/m3) as per ANSI/AMCA 500D.

3.2 Viscosity

When two solid bodies in contact move relative to each other, a friction force develops at the contact surface in the direction opposite to motion. The property that represents the internal resistance of a fluid to motion is called as viscosity. In this research, viscosity value considered for density 0.075 lb/ft3 is 1.22 lb/(ft-s) [19].

3.3 Temperature

Temperature is the measure of hotness and coldness of a system. In thermodynamic sense, it is the measure of internal energy of a system. For density of 0.075 lb/ft3 , temperature of air is 21°C.

3.4 Velocity

Flow of highly viscous fluids at low velocities is laminar. The fluid motion that typically occurs at high velocities is characterized by velocity fluctuations are called as 'turbulent.' The flow that alternates between being laminar and turbulent is called 'transitional'. The dimensionless number, Reynolds number, is the key parameter that determines whether the flow is laminar or turbulent and steady or unsteady flow when there is no change in fluid property [18].

3.5 Speed of sound

An important consequence of compressibility of the fluid is that the disturbances introduced at some point in the fluid propagate at finite velocity. The velocity at which these disturbances propagate is known as acoustic velocity/speed of sound. As the Mach number for the different velocities taken into consideration in the research are less than 0.3, airflow is assumed to be incompressible [18].

4. Methodology

4.1 Geometry of model

Geometry of the blade profiles that are considered for the analysis is presented in figure 1. Length and width of all profiles are 12 inches and 6 inches respectively. All dimensions are in inches.

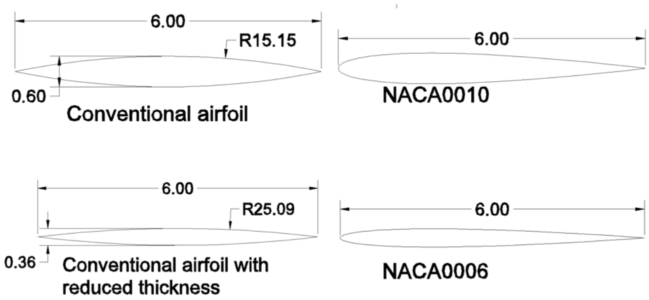


Figure 1: Blade profiles

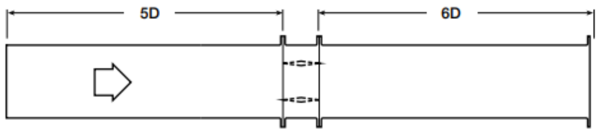


Figure 2: ANSI/AMCA 500D configuration 5.3

where,

$$D = \sqrt{\frac{4WH}{3.14}} \tag{1}$$

where W and H are width and height of a damper respectively
Testing for profiles is done as per ANSI/AMCA 500D configuration 5.3 [20] which is shown in fig 2.

4.2 Meshing

Meshing of conventional airfoil for 500 fpm is shown in the figure 3. this is the refined mesh after performing mesh independency test. Mesh independency test conventional airfoil for 500 fpm in graphical form is presented in the figure 4.

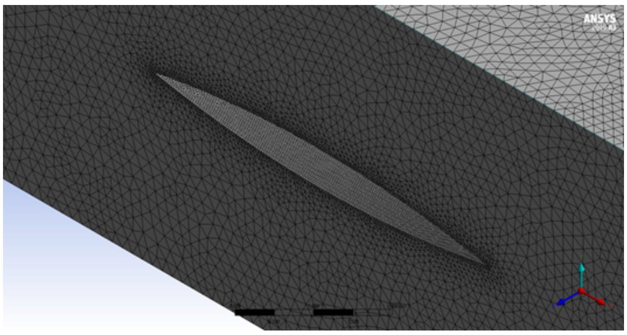


Figure 3: Meshing of conventional airfoil for 500 fpm

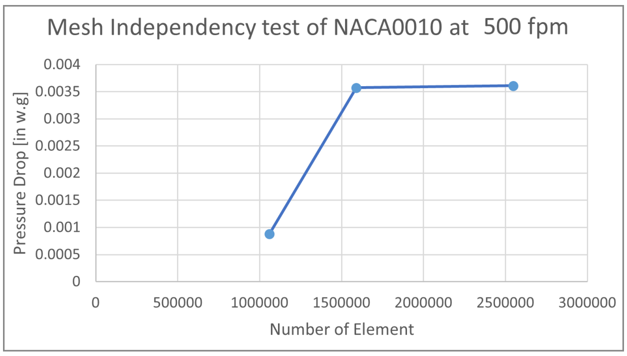


Figure 4: Mesh independency test of conventional airfoil for 500 fpm

4.3 Physics Setup

Physics setuup in done as shown in table 1 for standard k-e with standard wall function model for inlet, outlet, wall and airfoil.Same boundary conditions are applied in other cases as well other than varying velocity at inlet.

Table 1: Boundary conditions for conventional airfoil at 500 fpm

S. N	Name	Boundary Condition	Boundary Value
1	Inlet	Velocity	500fpm
2	Outlet	Gauge Pressure	0 in w. g
3	Wall	No slip	Roughness height of 0.00591 in
4	airfoil	No slip	Roughness height of 0.0015 in

4.4 Postprocessing

Result of pressure drop between a plane 1 D before damper and outlet was calculated as mass flow averaged total pressure for surface integral as per ASHRAE standard 120 [21] in ANSI/AMCA 500D configuration 5.3 [20].

4.5 Assumptions

Assumptions that are made during this research are:

- Air flow is fully developed
- Density and viscosity is constant
- Inlet turbulence intensity is constant with the value of 5 percentage
- Roughness of wall and airfoil profile is smooth

5. Result and Discussion

5.1 Total Pressure Drop

Table 2: CFD results of all the simulations performed

Velocity (fpm)	For the thickness of 0.6 in			For the thickness of 0.36 in		
	Pressure drop (in w.g)		Percentage variation (%)	Pressure drop (in w.g)		Percentage variation (%)
	Conventional	NACA0010		Conventional with reduced thickness	NACA0010	
500	0.00361	0.00195	46.0	0.00382	0.00382	0.00
1000	0.01030	0.00624	39.4	0.01012	0.01007	0.49
1500	0.02147	0.01313	38.8	0.02110	0.02093	0.81
2000	0.03678	0.02254	38.7	0.03614	0.03578	0.10
2500	0.05627	0.04098	27.2	0.05537	0.05471	1.19
3000	0.08088	0.04834	40.2	0.07784	0.07765	0.24

Result of total pressure drop is tabulated in table 2 for all the profiles those are considered in the analysis.It can be seen that NACA0010 blade outpass all other three blades with its least pressure drop.

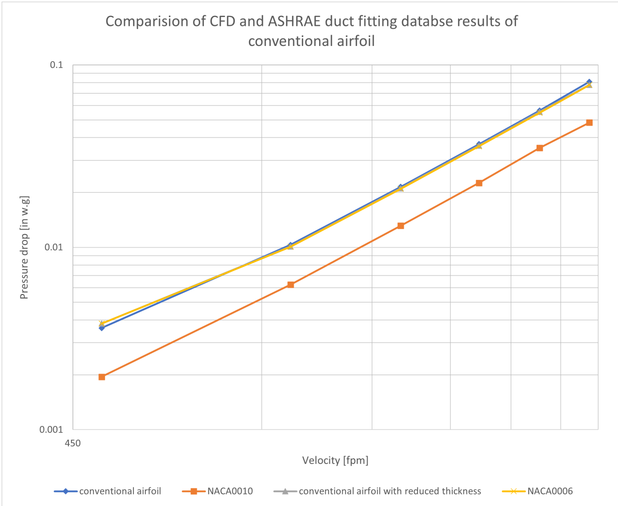


Figure 5: Logarithmic chart of CFD results of all the simulations performed

5.2 Validation of Result

Total pressure drop result of CFD analysis and total pressure drop data from ASHRAE Duct Fitting database [22] were compared to validate the result. Results are tabulated in table 3. Result of CFD and data of airfoil blade damper from Ashrae duct fitting database has ±30 percentage variation.Graphical representation of total pressure drop in table 3 is represented in fig 6.

Table 3: Results of CFD analysis and ASHRAE duct fitting database

Velocity (fpm)	Total pressure drop (in w.g) from CFD software	Total pressure drop (in w.g) from ASHRAE Duct fitting Database	Percentage Variation (%)
500	0.00361	0.00281	-28.5
1000	0.01030	0.01122	8.20
1500	0.02147	0.02525	15.0
2000	0.03678	0.04489	18.1
2500	0.05627	0.07014	19.8
3000	0.08088	0.10100	20.0

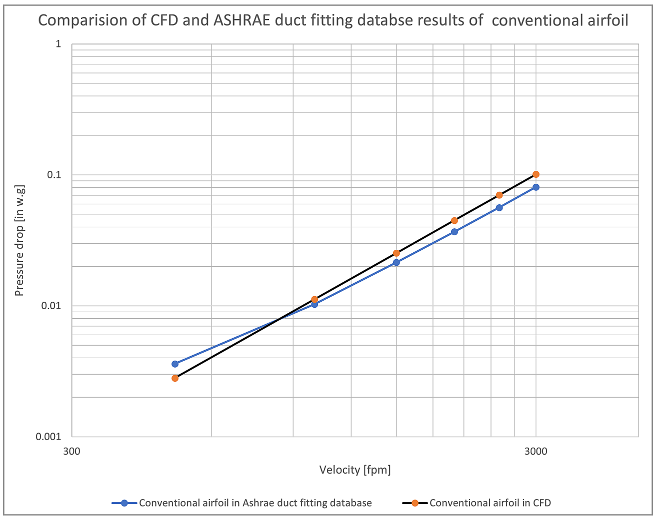
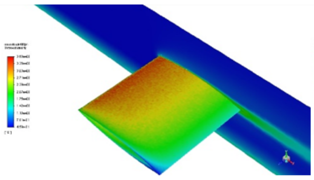


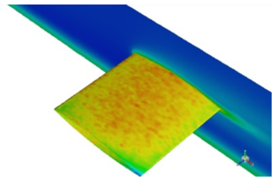
Figure 6: Logarithmic chart of CFD and ASHRAE duct fitting database results of conventional airfoil

5.3 Turbulence Intensity

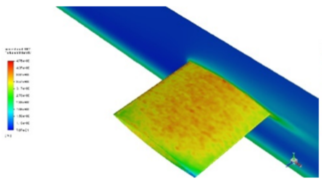
Contour plot of turbulence Intensity for different velocities of air for conventional airfoil damper in shown in figure 3.



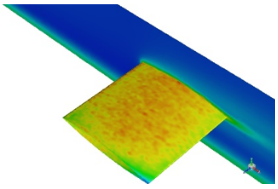
(a) 500fpm



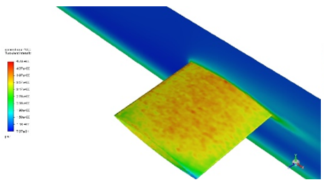
(b) 1000fpm



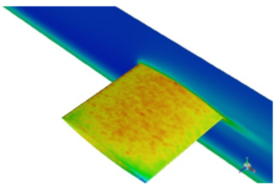
(b) 1500fpm



(d) 2000fpm



(e) 2500fpm



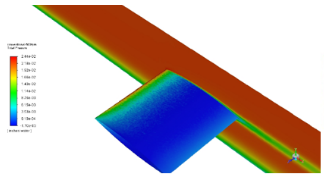
(f) 3000fpm

Figure 7: Contour plot of turbulence Intensity for different velocities of air for conventional airfoil

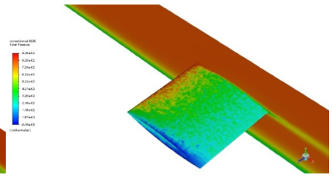
From the figure 3, it is found that turbulence intensity is higher in higher velocities. Turbulence intensity range for 3000fpm is 2.36-12.0 percentage, while it is 0.459-3.69 percentage in 500fpm velocity for conventional airfoil. It can be seen that trailing edge of airfoil for 500fpm has lower turbulence intensity than that in leading edge. But for 3000fpm, higher turbulence intensity is spread all over the profile.

5.4 Pressure Drop

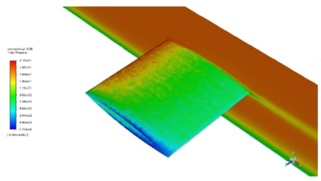
Contour plot of pressure drop for different velocities of air for conventional airfoil damper in shown in figure 4.



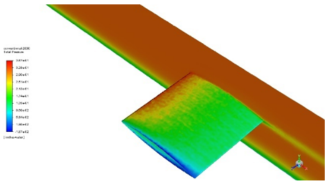
(a) 500fpm



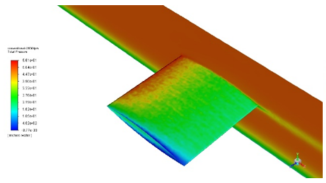
(b) 1000fpm



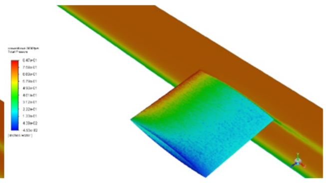
(c) 1500fpm



(d) 2000fpm



(e) 2500fpm



(f) 3000fpm

Figure 4 Contour plot of pressure drop for different velocities of air for conventional airfoil

From the figure 4, it is found that total pressure drop is higher in leading edge than that in trailing edge. Also, total pressure drop is n egative short after leading edge in 500 fpm but it is positive throughout in 3000fpm expection being on wallside of the profile. Total pressure drop range from -0.0017 to 0.0244 in w.g for 500fpm, while 3000fpm has its range from -0.0453 to 0.847 in w.g.

6. Conclusion

From the analysis of four different airfoil profile, it is found out that 4-digit NACA0010 airfoil has least pressure drop of all. Hence it can be concluded that NACA0010 is best suited profile for the damper among the damper profiles considered in the analysis. Also it is found that NACA0010 has less pressure drop than the conventional damper profile and is the same case with respect to NACA0006 and conventional damper profile reduced to the thickness of 0.36 in. Here, it can be distinguished the superiority of 4-digit NACA profiles with conventional profiles of blade for the purpose of use in HVAC dampers.

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