



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

IJRSET

International Journal of Innovative Research in
SCIENCE | ENGINEERING | TECHNOLOGY



INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 11, Issue 5, May 2022

ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 8.118

 9940 572 462

 6381 907 438

 ijrset@gmail.com

 www.ijrset.com

Analysis of High Volume Low Speed (HVLS) Fan Blade Profiles for Industrial Ventilation

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ABSTRACT: In areas of high humidity, fans and cooler play major role in keeping the surrounding cool. But the smaller traditional fans are not enough for it. The industrial fans also known as HVLS fans are made especially for such conditions. A fan with diameter greater than 6 feet is known as HVLS (High Volume Low Speed) fan. These fans distribute and create large air columns and rotate at very low speed. Generally, HVLS fans are mounted on ceiling as well as walls. The various applications of HVLS or where they are fitted are automotive companies, Stadiums, Malls, Restaurants, Airport, etc. This paper gives a detailed review about designing of airfoil blade of HVLS fan using Airfoiltools.com and software like Q-blade along with the help of standard NACA profiles from NACA organization.

KEYWORDS: HVLS, Q-blade, Design foil, NACA aero foil, Airfoil tools.

I. INTRODUCTION

The equator region is generally known for its high humidity. Therefore, the cooling machines like fans, coolers, Air conditioner, etc. play an important role for keeping the environment stable. Fans are one of the most affordable and effective means to use in regular as well as in industrial lives. But they prove to be costly where there are high ceilings and huge areas as regular fans are small in size and made for smaller spaces, one needs huge number of fans for proper ventilation. Mostly factories and industries where there are huge areas as well as large number of people and machinery, the problem of ventilation arrives frequently. Another problem regarding AC's and regular fans is they do not provide proper ventilation a cooling in open spaces (Airplane hangars, farmsetc.). They can only be used in closed spaces. The main benefits of HVLS fans are their capability to be used in both summer and winter together with the heating, ventilation and air conditioning; their low noise and gentle air flow and also the average energy savings of 49 percent plus consequent reductions in the generation of CO₂ and carbon.

The remedy for problem is HVLS (High Volume Low Speed) fans. The HVLS fans helps to improve thermal comfort and also ensure indoor air quality. These fans generate larger air columns and horizontal floor jet which helps in providing thermal air comfort in surroundings. Also, HVLS fans can be used in semi-closed areas. Unlike residential ceiling fans that are typically 0.9 m to 1.3 m in diameter, the diameter of HVLS fans is between 2.5 ~ 7.5 m. The HVLS Fans rotate at a very low speed of 45-80 RPM in comparison to normal ceiling fans [1].

HVLS fans can drive a large amount of air and circulate air across the floor. The air is pushed down to the floor below in conical shape. The HVLS fans are divided into two categories mainly industrial and commercial. Instead of installing air conditioner HVLS fans prove to be practical in commercial uses. HVLS fans are mostly used in malls, buildings, schools, etc. The cost of HVLS fans was approximately \$3,700-\$4,100 depending on diameter. Controls and installation cost were additional, bringing the approximate cost to \$4,000-\$5,000 per installed fan [2].

II. THEORY OF HVLS

The signature benefit of an HVLS fan is the production of air volume, which is created by a large diameter fan blade that can span up to 24 feet. A large fan diameter, however, is only part of the equation. Each blade must be capable of efficiently moving air or the result will be wasted energy. Fan blade design varies by manufacturer, so it is important to look for a design that produces uniform pressure and velocity from the hub to the tip of the blade. A lack of uniform pressure and/or velocity creates a number of issues, including backflow and increased energy consumption. To maximize performance, look for a tapered blade design that is narrow at the tip, where the blade velocity is higher, and widens toward the hub, where more blade area is required due to lower blade velocity. Also, it is important to look at the angle of the blade as it relates to the plane of rotation. The chord angle of the blade should be minimal at the tip and gradually increase as it gets closer to the hub. The overall shape and design of a fan blade is what produces maximum air volume – not the number of blades. It was found that blade designs and blade angles affect a fan's performance and area of coverage [3].

Shape and size of hub design effects largely on airflow. In case of HVLS fans there is no spacing between the hub and the blade due to connectors which can be seen in traditional fans. This results in large airflow beneath the fan as air recirculation towards the ceiling is close to negligible [4].

2.1 Aerofoil

An airfoil-shaped body moved through a fluid produces an aerodynamic force. The blade shape has evolved from flat or slightly curved blades to aerofoil blades to increase efficiency [5]. The component of this force perpendicular to the direction of motion is called lift. The component parallel to the direction of motion is called drag. The lift on an airfoil is primarily the result of its angle of attack and shape. When oriented at a suitable angle, the airfoil deflects the oncoming air, resulting in a force on the airfoil in the direction opposite to the deflection. This force is known as aerodynamic force and can be resolved into two components: lift and drag.

2.2 Aerofoil Terminology

An aerofoil's properties are defined by using specific terminology:

- ✓ Chord is a distance between the leading and trailing edges measured along the chord line;
- ✓ Chord line is a straight line joining the leading and trailing edges of an aerofoil;
- ✓ Leading edge is a part of an aerofoil (edge) that hits the air particles first;
- ✓ Lower surface is the surface of an aerofoil between the leading and trailing edges, on the lower surface;
- ✓ Mean camber line is a line joining the leading and trailing edges of an aerofoil, equidistant from the upper and lower surfaces;
- ✓ Maximum camber is the maximum distance of the mean camber line from the chord line;
- ✓ Maximum thickness is the maximum distance of the lower surface from the upper surface.
- ✓ Trailing edge is a part from an aerofoil (edge) that hits the air particles last;
- ✓ Upper surface is the surface of an aerofoil between the leading and trailing edges, on the upper surface.

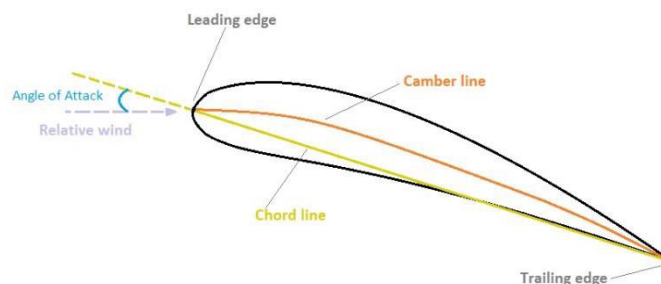


Fig 1 Airfoil Terminology

2.3 Parameters of Aerofoil

1. Angle of Attack (AOA):

It is the angle between aerofoil chord line and the relative wind. The direction of wind is usually taken parallel to ground surface. Angle of attack has very much importance in designing of aerofoil. It is angle of attack which decides lift and drag of aerofoil angle of attack is directly proportional to lift till maximum angle of attack, after further increase in maximum angle of attack lift is decreased and stalling occurred.

2. Camber:

An imaginary curve on an aerofoil that divides it roughly into an upper half and lower half. At a given angle of attack, increasing camber can increase lift.



3. Drag Coefficient:

A unit less number for estimating the effective force produced by drag on an object. For aerofoils with very low drag, you can expect drag coefficients of roughly 0.0040. Typical aerofoils have drag coefficients on the order of 0.0100.

4. Lift Coefficient:

A number that tells you a relative measure of how much lift an aerofoil is producing at a given angle of attack. It grows linearly by about 0.10 per degree of angle of attack until stall, typically around 15 degrees.

5. Pressure Coefficient:

It is the no dimensional representation of the pressure applied to an aerofoil at one distinct point. An orderly summation of pressure coefficients around an aerofoil can be used to generate the lift and pitching moment coefficients.

6. Mach Number:

The ratio of velocity divided by the local speed of sound. Mach number indicates the change in density of fluid. For Mach number greater than 0.30 there is change in density of air. Mach number is smaller than 0.30 has apparently no effect on angle of attack.

16 feet HVLS fan has around 70 rpm speed, this speed was taken in consideration while calculating Mach no. speed of sound 343 m/s.

$$\begin{aligned} \text{Mach} &= \frac{v}{C} \\ &= \frac{17.87}{343} \\ &= 0.0520 \end{aligned} \tag{1}$$

The calculated value of Mach number is used to obtain values of lift and drag for selected NACA profiles

7. Reynolds number: In aerofoils the Reynolds number plays major role in performance of aerofoils. To calculate these values of Reynolds number properties of air are considered [6] as provided in Table 1 Given below,

Table 1. Properties of air at 30°C and 1 atm pressure

Sr. No.	Parameter	Values Considered
1	Kinematic Viscosity ν in (m ² /s)	1.608 x 10 ⁻³
2	Dynamic viscosity μ in (kg/m-s)	1.872 x 10 ⁻³
3	Density ρ in kg/m ³	1.164

Using the above parameters, the values of Reynolds number were calculated using the expression as follows,

$$R_e = \frac{\rho V l}{\mu} = \frac{V l}{\nu} \tag{2}$$

The values of Reynolds number at various velocities obtained from above equation are as follows,

Table 2. Reynolds number at various velocities at aerofoil

sr.no	Velocity	Reynold's Number
1	21	195895
2	22	205223
3	23	214552
4	24	223880
5	25	233208

The calculated values of Reynolds number are used to obtain values of lift and drag for selected NACA profiles.
8. Stall:

As an aerofoil is tilted further and further up, the airflow will eventually break loose from the airfoil resulting in a sudden loss of lift. This situation is called "stall". It usually occurs around angles-of-attack of 15 degrees.

9.Thickness:

Usually refers to the maximum thickness of an aerofoil in terms of a percentage of the chord length.

10.Trailing Edge (TE):

The most rearward point on the camber line. The sharp tail of the aerofoil.

III. SELECTION OF BLADE

NACA Organization National Advisory Committee for Aeronautics (NACA) is an aeronautical research body which has developed different airfoil shapes for aircraft wings. These air foils are described by NACA followed by series of numbers.

3.1 Selection of NACA Profile

- ✓ The NACA organization mainly divides aerofoil in three parts as 4-digits, 5-digits, and 6-digits NACA aerofoils. For designing and analysis purpose a 4-digit NACA aerofoil is chosen here in this work.
- ✓ Following are the 3 selected NACA Aerofoil profiles
1) 4412 2) 6409 3) 6412
- ✓ The coordinates of selected profiles are gathered from the website of Airfoiltools.com the coordinates are then used in Ansys software for analyzing CFD of the profiles.

Taking 150 chord length which is 150mm

NACA 6412

- Maximum camber line height percentage of chord length
Therefore 6% of 150 mm = 9mm
- Where the maximum camber line height will occur chordwise as a percentage of chord length in lengths
Therefore 41% of 150mm = 61.5mm
- Last two digits together designated to the thickness of airofoil in percentage of chord length
Therefore 12% of 150mm = 18mm
- It will occur at 30% of chord length from leading edge
Therefore 30% of 150mm = 45mm

This is the nomenclature for one of the selected NACA Profile for the HVLS Fan Blade [7]. Similarly, the nomenclature can be obtained for other 2 profiles.

3.2 Analysis of Chosen NACA profiles

The analysis of selected aerofoil profiles is done by using software such as Q-blade.

Q-blade:

This software helps in analyzing NACA profile as well as formation of blade on the basis of standard NACA profiles, an aerofoil is formed which leads to formation of blade of fan. An exact snap of number of blades of fan and details about the blade and the aerofoil can be obtained over here. The selected NACA profiles are analyzed by selecting an appropriate Reynolds number and a Mach number on the basis of 16 feet HVLS Fan for a 1600 sq. ft. [8] and contain atmospheric conditions like 1 atm pressure and 30⁰temperature. After the analysis of blades at different angles are done and the values of lift and drag are noted. Further the boundary layer diagrams of the profiles are taken.

The analysis of NACA profiles depending upon various velocities ranging from 21mph to 25 mph is shown in table 3,4 and 5



Table no.3 Analysis NACA 4412 parameters

NACA PROFILE 4412			
VELOCITY (MPH)	ANGLE	LIFT (Cl)	DRAG (Cd)
21	11	1.364	0.030
	12	1.360	0.039
	13	1.366	0.048
	14	1.376	0.058
	15	1.392	0.067
	16	1.399	0.079
22	11	1.366	0.030
	12	1.366	0.038
	13	1.371	0.048
	14	1.378	0.057
	15	1.392	0.067
	16	1.397	0.079
23	11	1.368	0.029
	12	1.372	0.038
	13	1.375	0.047
	14	1.381	0.057
	15	1.393	0.067
	16	1.398	0.079
24	11	1.368	0.029
	12	1.376	0.037
	13	1.379	0.047
	14	1.384	0.057
	15	1.393	0.067
	16	1.398	0.079
25	11	1.373	0.029
	12	1.378	0.037
	13	1.382	0.046
	14	1.387	0.057
	15	1.395	0.067
	16	1.399	0.078



Table no.4 Analysis NACA 6409 parameters

NACA PROFILE 6409			
VELOCITY (MPH)	ANGLE	LIFT (Cl)	DRAG (Cd)
21	11	1.407	0.044
	12	1.416	0.054
	13	1.460	0.062
	14	1.481	0.074
	15	1.446	0.090
	16	1.407	0.108
22	11	1.414	0.044
	12	1.417	0.054
	13	1.457	0.061
	14	1.483	0.073
	15	1.463	0.087
	16	1.403	0.109
23	11	1.420	0.043
	12	1.420	0.053
	13	1.455	0.061
	14	1.485	0.072
	15	1.455	0.089
	16	1.390	0.111
24	11	1.425	0.042
	12	1.423	0.053
	13	1.453	0.061
	14	1.485	0.071
	15	1.450	0.089
	16	1.395	0.110
25	11	1.429	0.042
	12	1.427	0.052
	13	1.451	0.061
	14	1.491	0.072
	15	1.452	0.087
	16	1.399	0.109

Table no.5 Analysis NACA 6412 parameters

NACA PROFILE 6412			
VELOCITY (MPH)	ANGLE	LIFT (Cl)	DRAG (Cd)
21	11	1.656	0.024
	12	1.631	0.032
	13	1.555	0.047
	14	1.498	0.065
	15	1.465	0.081
	16	1.457	0.094
22	11	1.656	0.024
	12	1.637	0.032
	13	1.555	0.047
	14	1.499	0.065
	15	1.472	0.080



23	16	1.460	0.094
	11	1.655	0.024
	12	1.626	0.032
	13	1.554	0.047
	14	1.506	0.064
	15	1.476	0.080
24	16	1.463	0.094
	11	1.654	0.024
	12	1.623	0.032
	13	1.555	0.047
	14	1.510	0.064
	15	1.481	0.079
25	16	1.466	0.093
	11	1.653	0.023
	12	1.621	0.032
	13	1.556	0.047
	14	1.513	0.063
	15	1.484	0.079
16	1.469	0.093	

The above table gives calculated results of the lift, drag, L/D ratio of Reynold's number at various angles for various velocities. From table it is derived that NACA profile 4412 and 6409 are unfit for research as they do not have maximum lift at three different velocities of NACA 6412 at an angle of 11°.

Table No.6 Parameters of NACA6412 at 11° angle

VELOCITY (MPH)	LIFT (Cl)	DRAG (Cd)	L/D
21	1.656	0.024	68.305
22	1.656	0.024	69.163
25	1.653	0.023	70.777

As shown in table no.6 the L/D ratio vary according to the lift and drag.

IV. RESULTS AND DISCUSSION

The efficiency of the NACA profiles and HVLS blade does not depend alone on lift and drag. The boundary layer separation which is responsible for the turbulence in fans also play major role. The figures 2, 3&4 below are CFD analysis of the selected NACA profile at 21,22 and 25 m/s velocities.

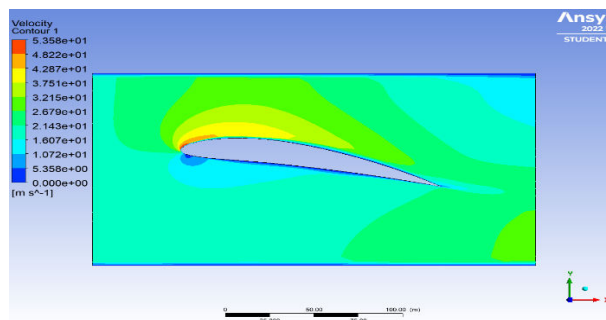


Fig.2 CFD of NACA 6412 at velocity 21m/s

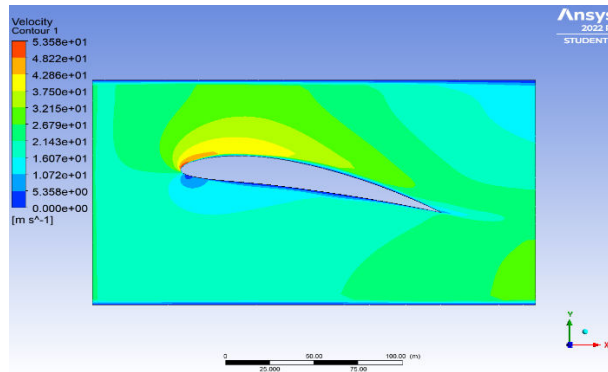


Fig.3 CFD of NACA 6412 at velocity 22m/s

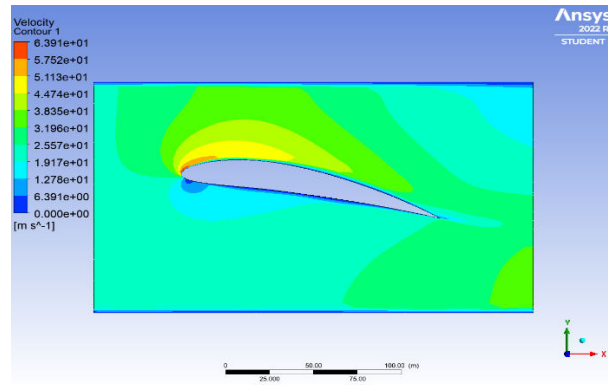


Fig.4 CFD of NACA 6412 at velocity 25m/s

It is observed that there is minimum boundary layer separation at 25m/s velocity from the final observations.

The angle of attack plays an important in boundary layer separation. The figures shown below are the boundary line separation images obtained with the help of Q-blade software by varying angle of attack.

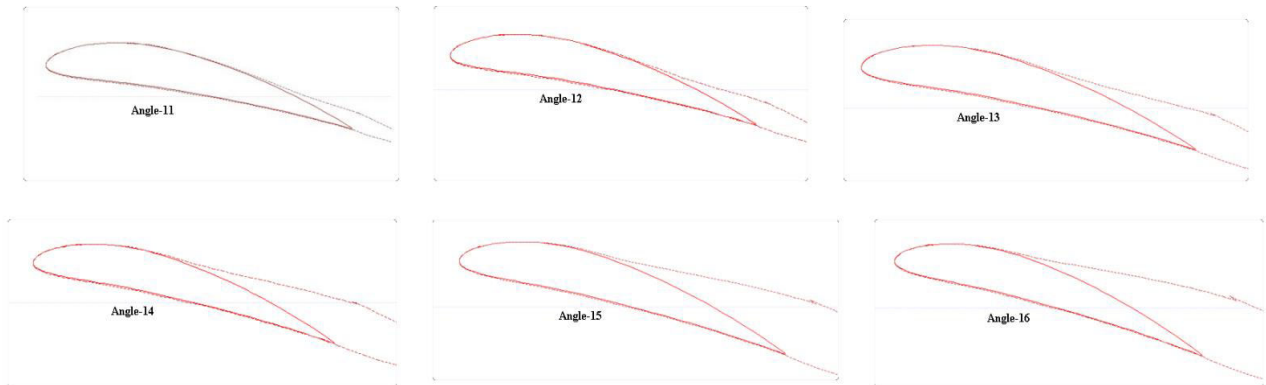


Fig.5 Boundary layer separation of NACA 6412 at velocity 25m/s

From above figure it is clear that with increase in angle of attack boundary layer separation increases.



V. CONCLUSION

In this research, analysis of different aerofoil blades was carried out and it was observed that out of three profiles under study the NACA6412 seems promising from the point of view of maximum lift. Among all the angle of attack taken in consideration the 11° angle of attack gives the best results for minimum boundary layer separation. The analysis with aerofoil parameters as velocities it was observed that NACA 6412 with velocity 21, 22, 25 respectively provides more lift at 21 m/s and 22m/s. However, L/D ratio gives more value at 25 m/s which helps in maximizing the efficiency of aerofoil blade.

VI. FUTURE SCOPE

The selection and analysis of aerofoil is done by using three standard NACA profiles. Similarly other profiles can be studied in the future. Further one can study about airflow of complete HVLS fan and also simulation, CFD and meshing of complete room.

VII. NOMENCLATURE

Symbol	Description
v	Velocity in that medium(m/s)
C	Speed of sound in that medium(m/s)
μ	Dynamic viscosity(kg/m-s)
ρ	Density (kg/m ³)
Re	Reynolds number
ν	Kinematic Viscosity in (m ² /s)
C _l	Lift
C _d	Drag
L/D	Lift to Drag Ratio

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