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Geometry Optimization of Filter House Components Fitted at Compressor Entry

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Abstract: ***One of the prime needs of the industries today is procuring clean air and liquids for various manufacturing or other processes. This air is then supplied for varied applications viz. Turbomachinery, HVAC and automotive applications. Our focus is the air filtered and supplied for Turbomachinery applications. Such air filters consist of various components such as anti-icing systems, weather hoods, bird screens and filter panels, followed by transition ducts and elbows at entry to transition ducts and elbows at entry to the turbomachinery. As the air flows through these sections, there occurs a pressure drop across them, in accordance with Bernoulli's principle. This, in turn, increases the amount of energy required to be provided to the machinery in order to maintain required discharge. Thus it is essential to minimize the pressure drop across various filter sections and transition duct. Our task here is to optimize the geometry of these components to enable smooth flow of air, minimize the pressure drop and reduce energy requirement. Initially, our task involves manual calculations, which will be followed by a MATLAB program to calculate pressure drop in weather hood, bird screen and transition section. Then we perform validation of calculations using computational techniques i.e. CFD software ANSYS 15.0.***

Keywords: CFD analysis, filter house, weather hood, bird screen, transition section, ANSYS FLUENT

1. Introduction

An inlet air filtration system is essential for the successful operation of a compressor. The filtration system protects the compressor from harmful debris in the ambient air, which can lead to issues such as erosion, fouling, and corrosion. These issues if not addressed will result in a shorter operational life and reduced performance of the compressor. Additionally, pressure of particulate matter increases the pressure drop in the system, which in turn leads to heightened power consumption by the compressor. Filter houses consist of various components such as weather hood, protective bird-screen, anti-icing unit, mist eliminator, filter panels, additional protective screen and transition section. As examining the entire assembly is a mammoth task requiring huge computational capabilities and excessive amount of time, here, we have endeavored to examine three of these components viz. the weather hood, bird-screen and transition section by using CFD analysis tools such as ANSYS FLUENT and MATLAB in order to determine the pressure drop.

2. Objective

There are a variety of factors which influence the quality of air drawn into turbomachines viz. particle size, nature of particles and meteorological factors, to name a few. Abrasive damage, fouling of the compressor blades, wet corrosion, high temperature corrosion and clogging of air slits are the major adverse effects of impure air on the system. To avoid this damage, elaborate filtration systems are installed at the entry to turbomachines in various industries. The geometry of these systems must be optimized such that the pressure drop resulting from passage of air through the system is minimized. Cost is another consideration while constructing these systems, and is directly proportional to the size and effectiveness of the system, and it is duly noted here, that cost considerations have not been accounted for in this study.

3. Construction of Filtration System

A conventional air filtration system fitted at compressor entry consists of the components as represented in Figure 1. At the entry, an anti-icing unit (1) is fitted in order to prevent blocking of filters by ice layer formation. This is followed by a weather hood (2), also known as the mist eliminator or louver. It prevents entry of water into the filter. Then, a bird screen (3) is provided to restrict entry of birds and insects into the filtration system. After this are fitted the various filtration stages, starting with the pre-filter (4), into which a droplet separator can also be incorporated to eliminate moisture in incoming air. This is followed by the 2nd and 3rd stage filters (5) of gradually decreasing pore size. Then a protective screen (6) is a final barrier to entry of debris into the system. Finally, a transition section (7) is fitted as per space and position constraints, followed by the duct (8) connected to compressor.

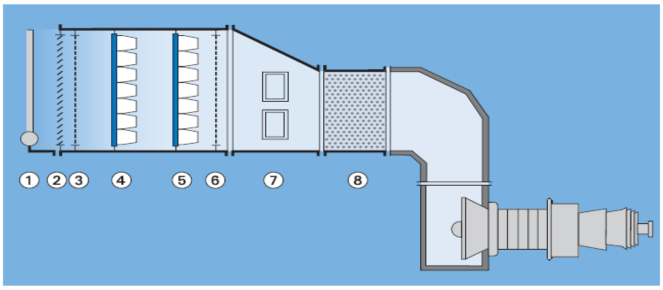

Figure 1: Filter House Construction

4. Methodology

Initially, we have performed manual calculations using empirical relations as given by Idelchik [1] . Following this, we have developed a MATLAB code to calculate the minimum pressure drop for various angles. Then we have performed computational analysis on various shapes of weather hood and transition section, and also on bird-screen separately. Hence, we validate the manual calculations by MATLAB and ANSYS FLUENT.

5. Calculations

We assume the following quantities - Relative humidity (RH) as 50%, Dry bulb temperature (DBT) as 28ºC, Absolute roughness of material of filter house (stainless steel) as 0.015 mm, Velocity of air inlet (v_0) as 3 m/s.

We obtain values for specific volume and dynamic viscosity from hygrometric chart and friction factor from Moody's friction chart. We vary the angle of the weather hood and thereby calculate the hydraulic diameter. Using this calculated value, we obtain value of friction factor. We use the empirical relation given by Idelchik [1]. The value of coefficient of flow resistance (K_{loc}) is given by (1)

$$K_{loc} = 0.95 * \sin^2(\delta/2) + 2.05 * \sin^4(\delta/2) \quad (1)$$

Where δ is the angle of turn (refer Fig. 2)

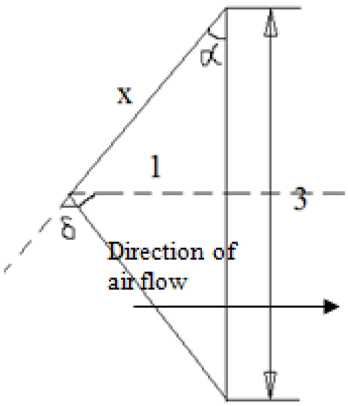

Figure 2: Geometry of weather hood

For the bird-screen, the value of coefficient of flow resistance ($K_{birdscr}$) is given by (2)

$$K_{birdscr} = 1.3 * (1 - A_0/A_1) + ((A_1/A_0) - 1)^2 \quad (2)$$

Where A_1 = pipe upstream flow area

A_0 = open area on screen

For the transition section, we vary the angle of convergence for two geometries i.e. square to square cross-section and square to circular cross-section.

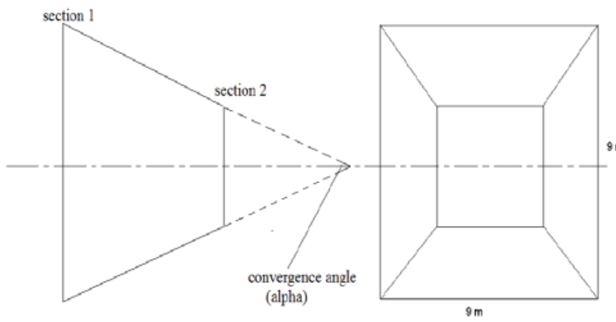

Figure 3: Geometry of transition section

Accordingly, value of coefficient of flow resistance (K) is given by (3).

$$K = (-0.0125*n_o^4 + 0.0224*n_o^3 - 0.00723*n_o^2 + 0.00444*n_o - 0.00745)*(\alpha_r^3 - 2*\pi*\alpha_r^2 - 10*\alpha_r) \quad (3)$$

Where $n_o = A_i/A_2 = 0.12$

A_i = cross sectional area at inlet

A_2 = cross sectional area at outlet

α_r = angle of convergence (refer Fig. 3)

The total pressure loss (Δp_{tot}) is the sum of friction loss, local pressure loss and pressure loss due to bird-screen, as given by (4).

$$\Delta p_{tot} = (1/2)*(fL\rho v_0^2/D_h) + K_{loc}*(1/2)*\rho v_0^2 + K_{birdscr}*(1/2)*\rho v_0^2 \quad (4)$$

Where f is the friction factor, L is the Reference length and v_0 is the air velocity.

As per calculations for weather hood, minimum pressure drop is obtained at an angle of 20° and at a convergence angle of 40°, in case of transition section.

6. MATLAB Code

The code developed by us, reads the values of friction factor from Moody's friction chart and psychrometric properties from hygrometric chart. Hence, using the same approach as stated above, optimum shape corresponding to minimum pressure drop is evaluated. The optimum weather hood angle is found to be 18°. This discrepancy can be accounted for, by considering that, in case of manual calculations, the angles were considered in steps of 5°. In case of transition section, the optimum angle of convergence was found to be 40°, which is in perfect agreement with manual calculations.

7. CFD Analysis

7.1 Weather Hood (Louver)

The CFD analysis was performed using ANSYS FLUENT V15.0. In the current model, we consider the flow to be incompressible and turbulent. The fluid is considered to be air with a density of 1.165 kg/m^3. The solid is considered as stainless steel with a density of 8000 kg/m^3.

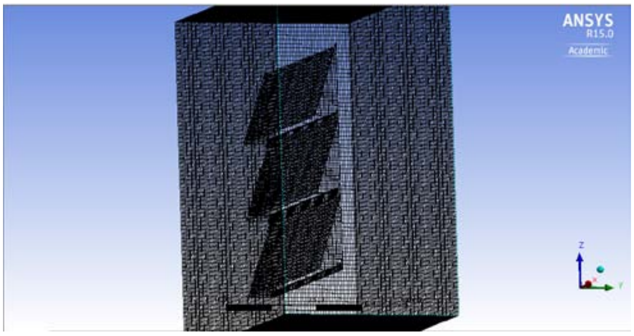

Figure 4: Mesh scene (weather hood)

In case of weather hood, we have used the method of volume extraction (Enclosure method in Design Modeler) in order to define the domain of fluid flow. The mesh used was Cut-Cell.

The FLUENT setup used is as follows- Solver Preference is Density-based; Boundary conditions are velocity inlet (velocity 3m/s), outflow (weight 1). Physics models used are Energy equation, Turbulent flow, Realizable k-ε, Enhanced wall treatment with Turbulent Intensity as 5%. Solution Methods are as follows- Formulation is Implicit and Flux type is Roe-FDS. Gradient used is Green-Gauss Node Based. Numerical schemes used are as follows: Momentum: Second-order upwind scheme, Turbulent Kinetic Energy: First order upwind scheme and Turbulent Dissipation Rate: First order upwind scheme. Type of Initialization is Hybrid. Once convergence is attained, we use the CFD-Post module in order to obtain pressure and velocity plots.

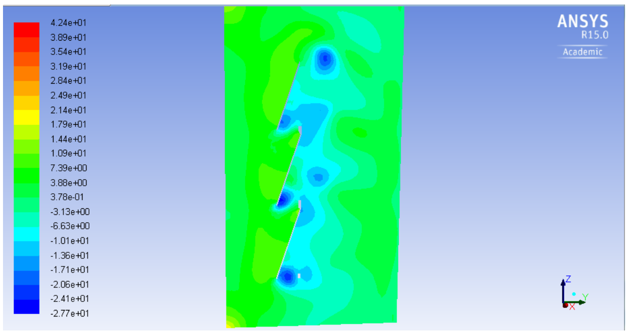

Figure 5: Pressure contour (weather hood)

For the weather hood, we have analyzed five different shapes viz. Curved weather hood, right- angled weather hood, and weather hood at an angle for 20°, 30° and 45°.

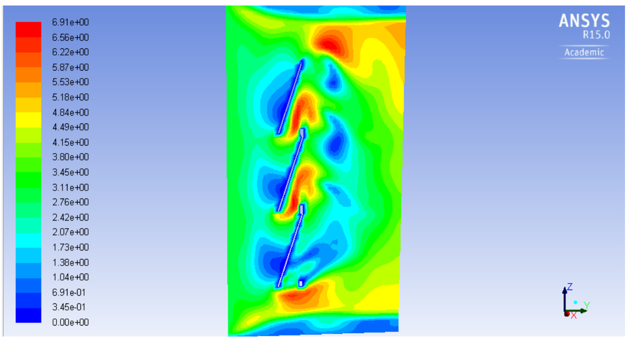

Figure 6: Velocity contour (weather hood)

Analyzing all the variations in weather hood angle is a time consuming, not to mention repetitive task, and hence we have narrowed down our analysis to these five shapes. The minimum pressure drop was obtained at an angle of 20°, which concurs with the manual calculations and MATLAB results. Even though the pressure drop obtained for the curved weather hood was even lower, this shape is not used commercially and has been analyzed purely from a research point of view.

7.2 Bird Screen

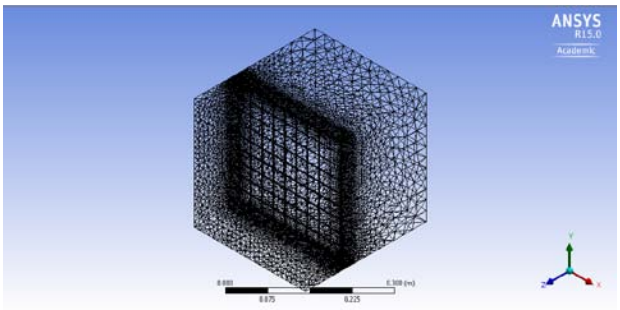

Figure 7: Mesh scene (bird screen)

In case of bird-screen, we have used the method of volume extraction (Enclosure method in Design Modeler) in order to define the domain of fluid flow. The mesh used was Tetrahedrons. We have analyzed only a scaled down version of the bird screen, since meshing the entire bird screen was proving to be very difficult and time consuming.

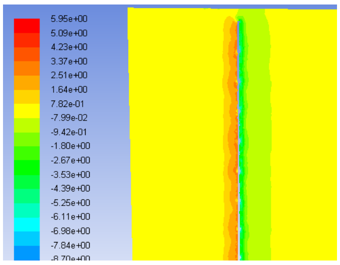

Figure 8: Pressure contour (bird screen)

The FLUENT setup used is as follows- Solver Preference is Density-based; Boundary conditions are velocity inlet (velocity 3m/s), outflow (weight 1). Physics models used are Energy equation, Turbulent flow, Realizable k-ε, Enhanced wall treatment with Turbulent Intensity as 5%. Solution Methods are as follows- Formulation is Implicit and Flux type is Roe-FDS. Gradient used is Green-Gauss Node Based. Numerical schemes used are as follows: Momentum: Second-order upwind scheme, Turbulent Kinetic Energy: First order upwind scheme and Turbulent Dissipation Rate: First order upwind scheme. Type of Initialization is Hybrid. Once convergence is attained, we use the CFD-Post module in order to obtain pressure and velocity plots.

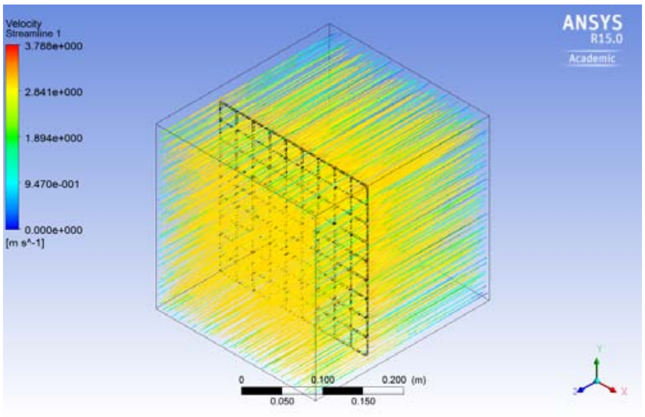

Figure 9: Streamlines (bird screen)

The pressure drop obtained was 1.7199 Pascal.

7.3 Transition Section

In case of transition section, we have used the method of volume extraction (Fill in Design Modeler) in order to define the domain of fluid flow. The mesh used was Tetrahedrons.

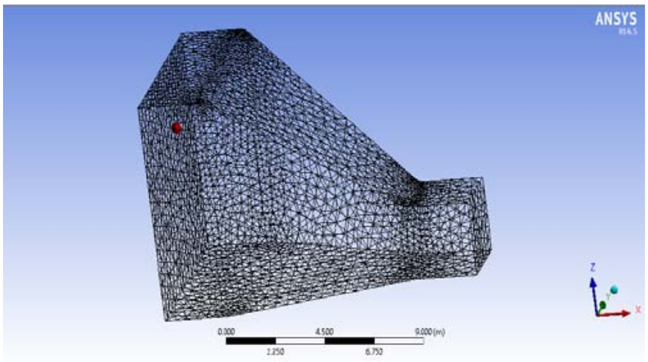

Figure 10: Mesh scene (transition section)

The FLUENT setup used is as follows- Solver Preference is Density-based; Boundary conditions are velocity inlet (velocity 3m/s), outflow (weight 1). Physics models used are Energy equation, Turbulent flow, Realizable k-ε, Enhanced wall treatment with Turbulent Intensity as 5%. Solution Methods are as follows- Formulation is Implicit and Flux type is Roe-FDS. Gradient used is Green-Gauss Node Based. Numerical schemes used are as follows: Momentum: Second-order upwind scheme, Turbulent Kinetic Energy: First order upwind scheme and Turbulent Dissipation Rate: First order upwind scheme. Type of Initialization is Hybrid. Once convergence is attained, we use the CFD-Post module in order to obtain pressure and velocity plots.

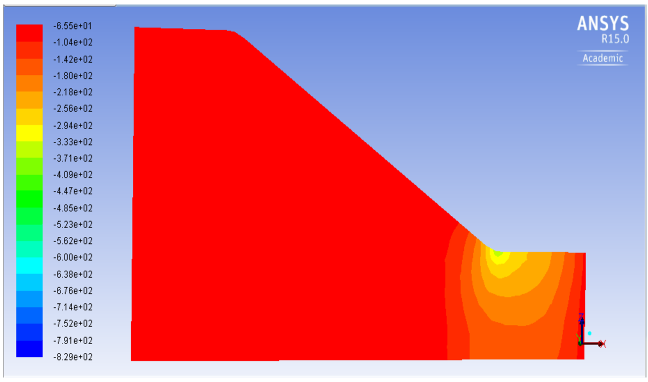

Figure 11: Pressure contour (transition section)

For the transition section, we have analyzed eight different shapes viz. Square to square (35°, 40° and 45° convergence angle), square to circular (35°, 40° and 45° convergence angle), Skewed square to square and Skewed square to circle. The pressure was found to be minimum at 40° square to square and 40° square to circle configurations, which is in accordance with the calculated values.

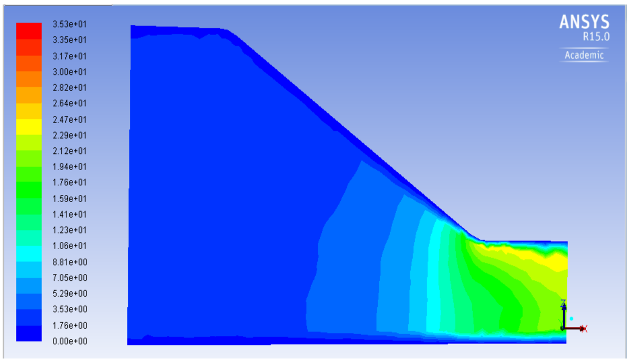

Figure 12: Velocity contour (transition section)

8. Results

For the weather hood, minimum pressure drop is obtained at a weather hood angle of 20°.

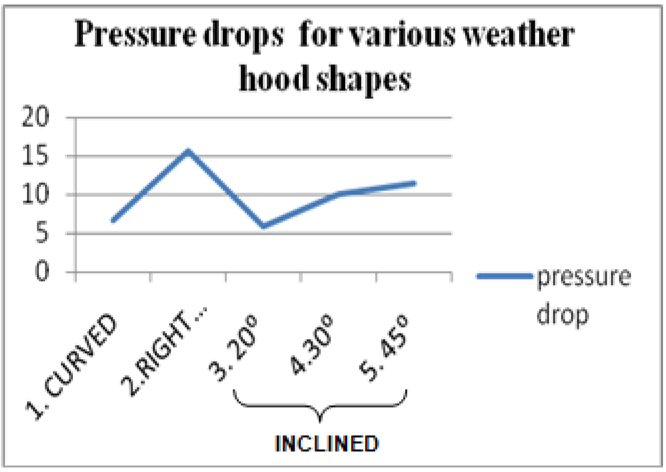

Figure 13: Pressure drops for various weather hood shapes

For the bird screen, pressure drop obtained was 1.7199 Pa.
For the transition section, minimum pressure drop is obtained at a convergence angle of 40°.

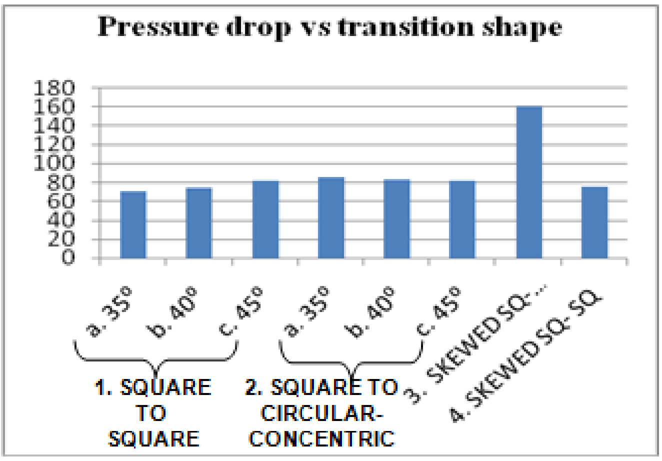

Figure 14: Pressure drops for various transition shapes

9. Conclusions

From the calculations for the weather hood with the bird screen, it can be seen that minimum pressure drop is obtained for weather hood angle of 20°. From the calculations for transition section, it can be seen that minimum pressure drop is obtained for transition angle of 40°.

The results of the MATLAB programs are found to concur with the results of manual calculations. Since performing CFD analysis for all values of weather hood angles is tedious and time consuming, it has been performed only for three values. The CFD analysis for the weather hood gives results that are analogous with the manual calculations and MATLAB program i.e. minimum pressure drop is obtained for weather hood angle of 20°. Hence this shape is optimum.

The CFD analysis of the right-angled and curved weather hood has also been performed, and the pressure drop values are shown in the results above. Since these values have no criteria for comparison with manual calculations, they have been presented as they are. Although the pressure drop for the curved weather hood is minimum, it is not commercially used as of now. Similarly, for the transition sections, CFD analysis has been performed for three values of 'square to square' and 'square to circular-concentric' transitions, and also for 'square to square- skewed' and 'square to circular-skewed'.

The results for the first two shapes are found to be in agreement with the calculations and MATLAB programs, with minimum pressure drop occurring at transition angle of 35°-40° range. Hence this angle (with 'square to square' or 'square to circle' configuration) is optimum.

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Author Profile

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