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Extensive Review on Blade Profile, Tip Clearance Gap and Vane Casing on Axial Flow Fan

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Abstract — This paper presents a review of the airfoil profile using Bezier curve, tip clearance gap and refining of vane casing treatment (RVCT) of an Axial-flow Fan. In turbomachinery field many important rotating component or element inside the system. To optimize fan performance by reducing energy demand by adjusting rotating components from an aerodynamic standpoint. The fan has a lot of energy-saving potential, but it needs to be enhanced in order to maximize performance and reduce power consumption. The Axial Flow Fan is used in the automotive, aircraft, and electrical and mechanical industries. As a result, the axial flow fan's efficiency is critical. Review of fan applications in engineering from the beginning to the present day, from basic to complex. The axial flow fan's aerodynamic nature, structure, and casing treatment are also critical for its efficient use. Efficient aerofoil profile with appropriate tip gap clearance and RVCT has been well-designed for a variety of layouts varying efficacy from the standpoint of a stabilizing mechanism after a half-century of research. This research focuses on one of the most important design features of mine ventilation fans industries and other industries. With the advancement of CFD and better measuring techniques, the mine ventilation fan combined with acceptable aerofoil profile and appropriate tip clearance gap, RVCT methodology will continue to exist as a broad and economical choice in the future, and the screening for its cogency texture will become more thorough.

Keywords: Axial Flow Fan, Energy, Tip Clearance Gap, Bezier Curve, Casing Treatment (RVCT), Stall Margin Improvement

I. INTRODUCTION

An axial fan is a compressor that raises the pressure of air passing through it. Axial Flow Fans are use blades to compel air to flow in line with the shaft around which the blades rotate. Fan makers are very interested in the possibilities of casing treatment to improve safety margins, dependability, and operating costs. Industrial fans can be used in a variety of applications. Since the casing treatments, tip clearance gap with acceptable blade profile potential applications in Gas Turbine, Tunnel Ventilations, and It was discovered that the axial fan could be used in a variety of other industrial applications.

Many researchers are working to modify the blade design and acceptable tip clearance gap. In that various fan system is the one of the major component to produce the majority of the power. In the upcoming portion the literature survey explains the various design modification of low speed fan blade profile using Bézier to enhance the system performances with tip clearance gap and casing treatment.

Bashir et al.[1] presents a new Bézier curve with various shape parameters, which provides a more thorough shape control than the one existing in the traditional Bézier curve. The curve preserves the rational quadratic Bézier curve geometric properties, enables to be manipulated controllably with weights and ensures G2 and C2 continuity for segment composition. Han, X et al.[2] has discussed a new type of piecewise quadratic trigonometric polynomial curve with C1 continuity in contrast to quadratic B-spline curve which have C2 continuity. The curve is not closer to the control polygon than Quadratic B-spline curve appeared by proposition. Dokken et al. [3] using a simple cubic Bézier curve that closely approximates a circular segment and provides tangent and curvature continuous approximation at connections of the segments. A sixth-order accurate approximation with an error of about 2×10−6 for 45° segments. Maqsood et al. [4] presented the GT-basis with two shape parameters based on generalized trigonometric functions, which inherits the geometry-preserving nature of the classical Bernstein basis by designing suitable shape parameters. GT-Bézier curves and surfaces, which are defined over these basis functions, allow appropriate adjustments of the shape and satisfy both the parametric and geometric continuity prerequisites, thus being excellent for modelling the curve and surface.

Fazil J et al. [5] performed while creating an airfoil profile in CAD, based on a camber cloud of points is easy, further manipulation of the profile for detailed study or optimization gets tiresome. In this paper, they use this as a base geometry and approach airfoil shape modeling as parametric modeling by shaping it in CATIA using control points, then Camber control points are algorithmically generated from Bézier curve control points using the Quintic Reverse Engineering formula with the help of point cloud. Hansen et al. [6] did a research of airfoil optimization for wind turbines, considering performance loss from leading edge contamination, using class-shape-transformation and a modified XFOIL panel code.

Jeong & Kim et al. [7] optimized several thick airfoils for wind turbines via the employment of a GA method coupled with CFD and an Akima curve fitting. This optimization increased lift-to-drag ratios by 30%-40% and was directed toward increasing aerodynamic efficiency of the blade without increasing the thickness of the blade which resulted in an increased torque coefficient 5-11%, and minimize thrust coefficient at blade root.

Yang et al. [8] introduces an aerodynamic design optimization procedure of aerofoil section profile, based on Bézier curve parameterization with application in radial basis interpolation, which allows the aerofoil shapes to be varied over a large range. Benchmarked via wing and blade airfoil optimizations with a genetic algorithm, the technique increases aerodynamic efficiency rapidly and offers a valuable advantage in designing flight vehicles. Reddy et al. [9] with three smoothly blended elements and a total of 33 design parameters. Optimization of a multi-element winglet (symmetric gull winglet and inverted gull winglet) was performed by Reynolds-averaged Navier-Stokes solver with multi-objective optimization through mode FRONTIER at multiple flight points for subsonic and transonic speeds in the perspective of maximum lift and lift-to-drag ratio, as well as the minimum drag and moment coefficients. Vala, J et al. [10] performed the among complexity of turbomachinery, axial flow fan design is one of the most important parts that can directly affect the pressure rise and other performance characteristics of fan. The mentioned literatures are proved that the various techniques implemented over the aerofoil to modify the shape and improve the performances.

There are two types of SC methods: PSC and ASC. Treatments for casings have been demonstrated to improve fan function and noise level by lowering the susceptibility of a fan to inlet distortion. The casing's form is changed in passive stall control by securing extra gadgets to the casing, hence widening the range of the pressure increase characteristic. Depending on how big they are in comparison to the blades, passive stall management approaches can be classed as small or large casing treatments. The circumferential and axial, in the casing around the blade tip region are used in the small CT procedure. a gap between the casing wall and blade tip is required to ensure that there is relative motion between the two blade and casing. Fluid might leak from the pressure surface to the suction surface thanks to the tip clearance. Tip leaking flow causes a clog in the route and lowers efficiency. The most essential word in the performance and stability of an axial flow turbomachinery is tip clearance.

The fan at a power plant consumes 30% of the all electricity consumed. Style of operation and cost are inextricably linked to the power plant's cost of operation. In India and other countries, margins of 20% to 30% are typically required for flow rate and total pressure increases, resulting in actual fan operation parameters that are significantly higher than the needed values. The mechanism and novel process of leakage flow, as well as the impacts of varied effect of blade tip clearance sizes on turbomachinery performance and noise, were the main emphasis of tip clearance.

Cranfield University conducted experiments over the previous two decades to see how RCT affected the SM, operational efficiency, flow behavior of a minimum speed fan. Researcher improved the stall margin by more than half while losing only a small amount of efficiency.

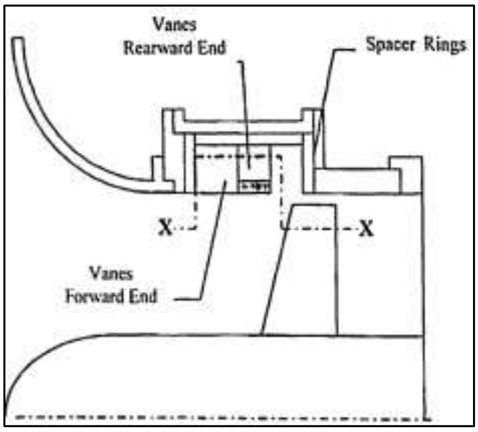

Fig. 1: RVCT test by Azimian et al [12]

Casing Treatment:- The idea is based on a patent by Ivanov et al.[11]. Azimian's et al. researches, as well as others [12], Bard et al. [13,14], Basharhagh et al. [15], Hill et al. [16], Kang et al. [17], Miyake et al. [18] and more recently by Akhlaghi et al. [19].

This form of treatment often consists of a ringed cavity, which is located outside but open to the fan or compressor's outer annulus wall. For minimal efficiency losses, the treatment has had a notable impact on improving stall margins and increasing pressure. Basharhagh et al.[15] demonstrated that these for a variety of machines, casing treatments improved stall margin while simultaneously enhancing tolerance to inlet distortion. Kang et al. [17] looked at numerous the vaned recess geometrical designs and came to the conclusion that removing an obstruction in the flow of information an important a component of the stall delay system, and inside the recess flow measurements revealed that the treatment significantly lowered the component of swirl velocity.

Simulation models seem to be more advantageous, giving an effective tool for fluid machinery analysis and design. Despite the fact that a significant the amount of research has been done in the past to understand and regulate stalling effect on fan or compressor employing RVCT. Despite the fact that CFD has been highly engaged in the foretelling many Recent developments in turbomachinery, RVCT due to its difficulties. It shows promise as a tool for deciphering the intricacies of phenomena related to casing treatments. Mirner et al. [20] claimed that there was no universally agreed-upon term for the difference between a fan and compressor first stage. The residential ventilator is a common type of axial-flow fan.

There are different types of stall in blades like Individual blade stall, Stall Flutter and Axi-symmetric stall. It is very important to control the stall because of to improve efficiency and there are different types of techniques (Active and Passive) to control stall of the blade. Passive stall control divided into 2 parts such as small scale CT and large SCT. This literature survey is concentrate only large scale CT. Vaned RCT is a latest type of CT created by the industry of low pressure fans. Since this treatment and edge lengths are of the order. It occurs commonly as a ringed hollow or recess with vaned and vaneless sections that is located outside but open to the fan's outer annulus wall. This type of treatment has proved to have a significant impact on SM improvement

(50-67%) and pressure increase for insignificant efficiency minimize.

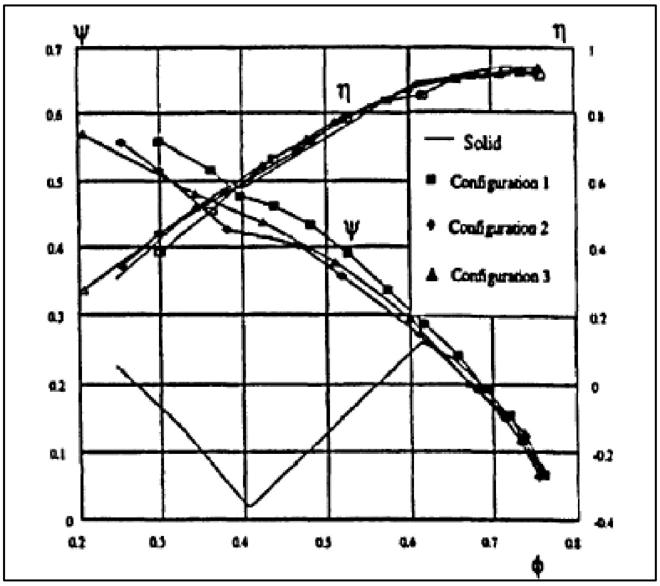

Fig. 2: Overall performances with various casing treatment [17, 21]

Kang et al. [17,21] in the same way exploratory testing by Azimian three various geometries designs of RCT in the Fig. 2. In the Recess of each, there were 24 vanes, with insignificant peak efficiency penalties, higher 65 percent of SMI and twice as much as much pressure was raised achieved. According to the research, it will be tough to understand improve this rig further through CT because the stall, there is a separation. Bard et al. [22] The RVCT technique was studied and fitted around the fan's casing by the researchers. Determine whether the blade tip blockage can bleed into the cavity and then inject into the main passage. Miyake et al. [23] They changed the RVCT geometry and discovered that keeping the bleeding flow above the critical value solved the fan's unstable characteristics. Azimian et al. [24] They tested RVCT on a single low-speed axial fan and found that the increase in flow range was significantly greater for RVCT than for conventional casing treatments.

Ziabasharhagh et al. [25] RVCT was found to increase the tolerance of inlet flow distortion during inlet distortion tests. Kang et al. [26] based on 3D flow measurements; the most important feature of RVCT was implied to be the guide vane's ability to eliminate swirling flow at the rotor tip. Yamaguchi et al. [27] Researcher Changed the location, cavity inlet, and outlet width of RVCT and some guidelines for the design were obtained. Corsini et al. [28] they conducted tests on the performance of upstream single RVCTs as well as upstream and downstream double RVCTs. Aubert et al. [29] the results showed that both single and double RVCTs can provide a characteristic curve without a saddle point by varying the relative axial position between RVCT and blades. Ghila et. al [30,31,32] Analyzed a fan from Cranfield University, both the solid casing fan and fans with RVCTs were simulated, which showed a good agreement with the experimental results. In particular, Simulations that are both fast and turbulent were both performed. The results indicated a simulation of a steady-state situation was sufficient to capture RVCT’s fundamental characteristics.

Yelmar et al, Corsini et al, Bonanni et al [30,31,32] they studied the RVCT by using OpenFOAM respectively, revealing the flow field. However, the majority of the experimental or numerical analyses were qualitative; only a few quantitative studies were ever conducted. The performance of a large-scale, low-speed axial flow fan with a solid case and RVCTs was investigated in this paper. The RVCT cavity outlet axial span and blade chord exposure were both varied. The mechanism of how RVCT affects fan performance was investigated because visualization provides insight into the flow field. The flow exchange between the cavity and the mainstream was quantitatively examined, and conclusions on how the exchange affects fan performance were drawn. Kiran Yelmar et al. [36] they discovered that the pr. Increase co-efficient for the TC demonstrates that the characteristics raise constantly and the fan can utilize without stalling up to a significantly lower flow coefficient, and that is the new stalling point for the treated casing; (SMI) Stall Margin Improvement increases as recess vertical increased height and exposure. At lower heights, the Increase in SMI was greater.

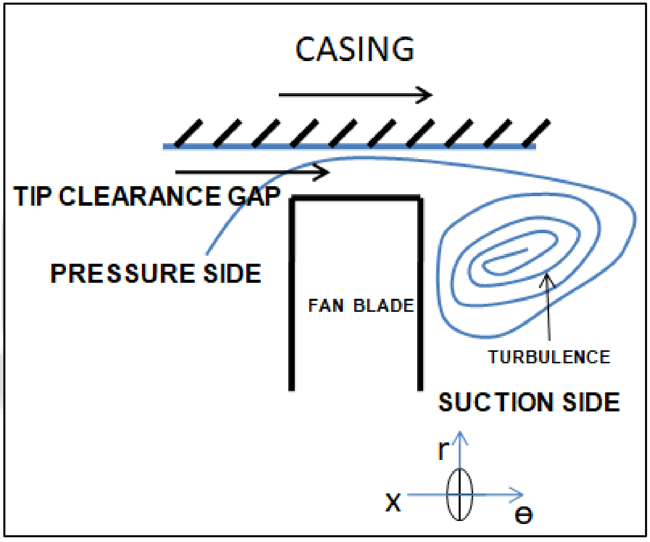

Fig. 3: 2D image of fan blade with tip clearance gap [49]

Tip clearance gap is very important for fan overall performance. This can be seen in the Fig. [49] Stability in Aerodynamic field is a big question regarding the design of fans/compressors [37]. The global automotive, aerospace, and mechanical sectors are expanding due to the growing need for rotating components such as fans, compressors, and turbines. In order to improve performance in this area, rotating component industries are essential. To increase performance, numerous researchers are adjusting different aerodynamic design parameters. An investigation into the volumetric flow rate and tip gap clearance for axial flow fans is presented in the literature review that follows. The literature mentioned below demonstrated the improving the axial fan's performance is primarily dependent on the tip gap clearance.

According to Liu S. et al.'s study [37], abnormally large clearance and eccentricity cause a considerable decline in fan efficiency. According to experimental and computational assessments, the outstanding performance characteristics of the mix flow fan are maintained by keeping appropriate clearance and parallel orientation, which prevent contact with the impeller shell. A numerical analysis of self-induced unsteadiness in the NASA Rotor 67 tip leakage flow is conducted by Du J et al. [38]. The effect is surface contact between the main flow field and the tip leakage flow which creates oscillations in blade loading associated with momentum ratio of flows at take-off. Numerical simulations on the tips of axial compressor blades by Hou, J. et al. [39] show that vorticity transfer has a significant impact on TLV development and stability, which in turn impacts compressor performance. The relationship between TLV strength and vorticity transport from the end wall and blade tip is critical to optimizing end wall motion and clearance height for increased compressor efficiency.

According to S. A. et al. [40], the larger tip spacing improves vortex formation inside and outside the fan. In this case, an increase in tip gap is the cause of the enormous vortices at the blade tips. Under design conditions, larger tip gap clearances result in spiral vortex breakdown, whereas at off-design conditions, lower tip gap clearances degrade more quickly.

Smaller tip gaps, according to Pogorelov A et al. [41], remove blade-wake interaction on turbulent transition mechanisms on the suction side of the blades and lessen the "tip-gap" vortex's wandering, which results in significant changes in noise emission. The impacts of axial fan performance resulting from tip clearance on aero acoustic noise generation when flight restrictions tighten are the focus of this study by Luo B et al. [42]. It describes how airflow influences tip clearance levels, leading to higher noise from heightened blade-tip vortex activity coupled with turbulence boundary layer variations by conducting a thorough analysis and experimental verification.

Using numerical modeling and experimental validation, Zhang L et al. [43] investigated the impact of various tip flange forms and numbers on the performance and noise characteristics of an axial fan. The fan efficiency and noise level were found to be affected by tip flanges. The maximum efficiencies were found to shift to partial flow, and the noise characteristics declined in comparison to datum fans. Better design for small axial fans is made possible by this understanding of the relationship between tip vortex shedding and fan characteristics. The nuances of compressor aerodynamics are covered by Akula P. K. et al. [44]. They focus on dynamic complications including rotating motion and tip gap vortex aerodynamics, which result in flow instability and turbulence and lower compressor performance.

Li C et al.'s study [45] used numerical simulations to examine the impact of impeller trimming on axial fan performance, taking into account varying amounts of trimming and tips clearance. The outcomes of the simulations showed that there was a performance decline at first, followed by a recovery; the blades without any trimming at the time of the degrading process demonstrated better functionality close to design rates and continued to function when stretched beyond their intended bounds.

According to Corsini et al. [46], improved blade tip designs have been investigated utilizing sophisticated computational analysis in order to comprehend the complex three-dimensional vortical flow structures of axial fans in fully-ducted configurations. Through the employment of contoured end-plates, vortex leakage and near-wall fluid flow path behaviors differ dramatically, potentially leading to less aerodynamic noise and increased rotor efficiency. Aktürk & Camci analyze tip leakage flow and how it interacts with the case. [47] The researchers added specially made pressure side extensions to prevent tip leaks. This is critical to both boosting energy efficiency and preventing turbulent tip leakages' detrimental effects on it.

Vala J et al. [48] He developed new airfoil like circular arc cambered airfoil and compared the different types of tip clearance gap for various volumetric flow rates, concluded that minimum tip clearance gap gives the best performance of axial fan and consumes low power means energy

II. CONCLUSION:

Aerodynamic changes in an Axial flow fan/compressor blade profile using Bézier curve with various shape parameters, acceptable tip clearance gap and vane casing treatment systems are essential for the improving efficiency (Stall margin, Pressure) and minimizing energy. From the research work by different scientists following points are drawn as a conclusion:

The effect of the RVCT with different dimensions on the aerodynamic analysis behavior of axial flow fans was investigated in a numerical and experimental study. The 3D commercial code was used to analyze the flow field, stall margin, pressure, noise source analysis, and deformation. With reasonable mesh and computing, accurate estimates of overall performance, including pressure rise and efficiency.

Different researchers carried out steady and unsteady simulations. The fan with developed airfoil using Bézier curve and accurate tip clearance, RVCT distributes the flow field more evenly and improves stall margin.

III. NOMENCLATURE:

- SC -Stall Control
- PSC -Passive Stall Control
- ASC -Active Stall Control
- RCT -Recess Casing Treatment
- ST -Stall Margin
- CT -Casing Treatment

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