Bulgarian Academy of Sciences. Space Research and Technology Institute.
Aerospace Research in Bulgaria. 36, 2024, Sofia

DOI: https://doi.org/10.3897/arb.v36.e13

PERFORMANCE ANALYSIS OF CURVED SHAPE ON THE INLET GUIDE VANES IN CENTRIFUGAL BLOWERS

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Keywords: *Centrifugal blower, Inlet guide vane, Curved shape, CFD analysis*

Abstract

This study aims to analyze the performance of two types of stator blades used in centrifugal blowers: forward-curved blades and backward-curved blades (concave and convex shapes), under various operating conditions and tilt angles. The primary goal of the research is to evaluate compression performance by comparing the results obtained for these two blade types. Ultimately, the objective of the study is to provide clearer insights for choosing the correct shape of the inlet guide vane in the specific field of application for centrifugal blowers.

Introduction

The development and improvement of centrifugal blowers hold significant importance in the realm of mechanical engineering. Extensive research has been conducted in this domain, exploring various facets such as impeller aerodynamic performance analysis [1], volute analysis [2], stator analysis [3], optimization of rotor and stator geometry [4], assessment of operational conditions on efficiency, enhancement of acoustic characteristics, vibration reduction, and more. For instance, C. Ji et al. [5] demonstrated that by accurately defining the flow channel, it is possible to eliminate the impact of tip clearance on Inlet Guide Vane (IGV) blades, thereby expanding the control range of mass flow rate.

Optimizing the profile selection of IGV contributes to enhancing the performance of compressors and an efficient flow control. In the same vein, H. Cao et al. [6] examined the efficiencies achieved by three different airflow control systems in a centrifugal fan. Furthermore, D. A. Nguyen et al. [7] concluded that the direction of the inlet flow into the impeller influences the performance of an axial pump, and adjusting the IGV blade angle can improve energy efficiency. The optimal positioning of IGV blades relative to the centrifugal impeller is a critical requirement for designers of centrifugal compressors, directly impacting efficiency [8]. Additionally, excessive clearances within turbomachinery result in diminished performance when chosen with excessively high values [9].

To enhance the compression process, J. Xin et al. [10] investigated the effect of introducing slots in the aerodynamic blades at various placement angles. Their study aimed to modify the geometry of the Inlet Guide Vane (IGV) blade, with the goal of improving overall compression efficiency.

CFD analyses have gained significant momentum in recent years due to their high accuracy in reproducing fluid behavior, particularly within turbomachinery [11], [12]. Through these simulations, S. Rabet et al. [13] highlighted the fluid behavior in a centrifugal pump when changing the number of blades on the impeller. Additionally, the selection of the optimal number of blades on the IGV plays a crucial role in centrifugal compressors [14]. According to the conclusions brought by O. Dumitrescu et al. [15], it has been demonstrated that the size of the discretization grid and the choice of turbulence model have a significant impact on the performance resulting from CFD numerical simulations. Through CFD analyses, J. Fang et al. [16] demonstrate the potential for improving the isentropic efficiency of a centrifugal blower by modifying the blade curvature.

Description

This article focuses on the performance analysis of curved-shaped inlet guide vanes in centrifugal blowers, involving numerical simulations with two types of stator blades (Type I - concave shape and Type II - convex shape) used at three different tilt angles (-15 degrees, 0 degrees, and +30 degrees). The setup employed for this study is illustrated in Fig. 1.

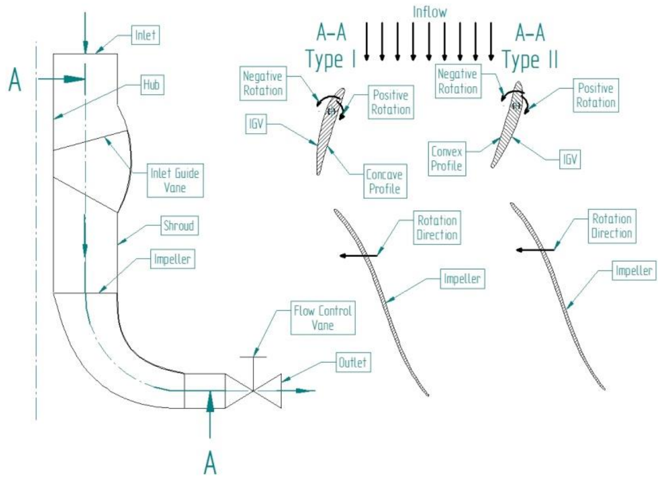
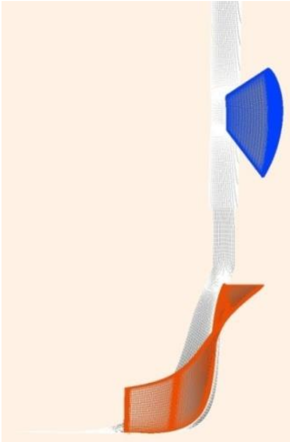
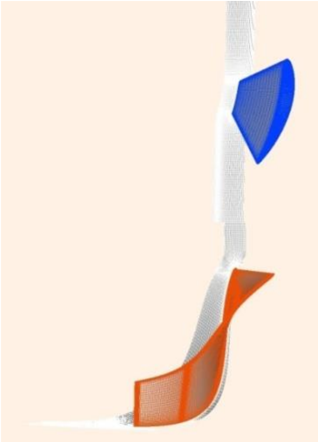


Fig. 1. The schematic representation for comparing those two types of IGV configurations

The geometry for the impeller and flow channel was created using the Ansys CCD software, while the geometry of the IGV blade was defined using the NACA 6412 airfoil profile.



a) IGV type II, tilted at 0 degrees



b) IGV type II, tilted at -15 degrees

Fig. 2. The resulting mesh for a single flow channel at a different angle of the IGV

The structured mesh for a single flow channel (Fig. 2) was generated using the Numeca Autogrid 5 software. For this purpose, two different IGV shapes were defined, each positioned at three angles (-15, 0 and +30 degrees). As a result, the mesh consists of two subdomains: the impeller domain, comprising a total of ~975k cells (Fig. 4) and the stator domain, consisting of ~900k cells (Fig. 3), which vary slightly depending on the blade placement angle within the grid.

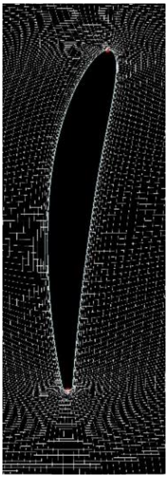


Fig. 3. B2B mesh for stator domain

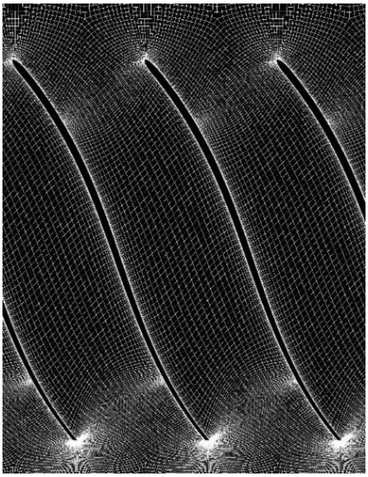


Fig. 4. B2B mesh for impeller domain

The boundary conditions employed in the simulations, for a steady-state case, are outlined in the table provided below (Table 1):

Table 1. CFD Simulations: Boundary and Initial Conditions Overview

Inlet (IGV) Total pressure	101 325 Pa
Inlet (IGV) Total temperature	273.15 K
Outlet (impeller) Mass flow rate	1.7 kg/s* at nominal point
Rotational speed (impeller)	20 800 rpm
Turbulence model	SST k-omega
Number of blades – IGV / impeller	8 / 11 blades

**To generate the characteristic curves, the imposed flow rate at the impeller outlet varied from the surge to the choke point.*

In order to validate the grid refinement, an analysis was conducted on the ***y+*** term, which describes the accuracy of the results obtained when using the turbulence model in the current study. The resulting ***y+*** value from the simulations was a maximum of 2.3 (Fig. 5), indicating that the influence of the mesh on the results can be considered negligible.

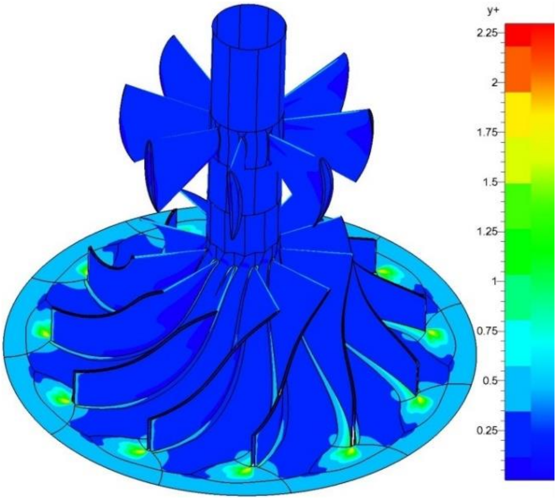


Fig. 5. The y+ values reported for the hub and blades

Numerical results

Due to the 0° position imposed on the IGV blades, they are arranged to guide the fluid in order to achieve a 90° angle for the α_1 term (the absolute angle at the inlet) at the entry into the impeller domain. It can be observed that both, the concave and convex profiles, exhibit the same characteristic curves, indicating that the obtained values (pressure rise or efficiency) are close or identical. The maximum differences recorded are at most 0.31% in terms of pressure increase and 0.24% in terms of efficiency (according to Fig. 6). These errors are primarily caused by small angular deviations in the positioning of the stator blades.

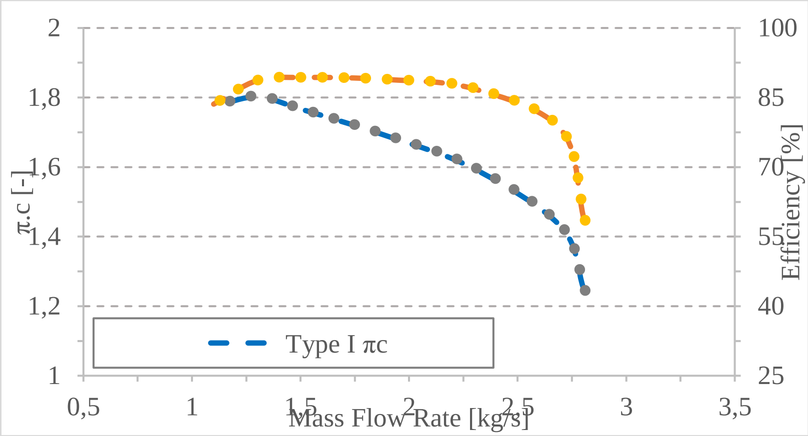
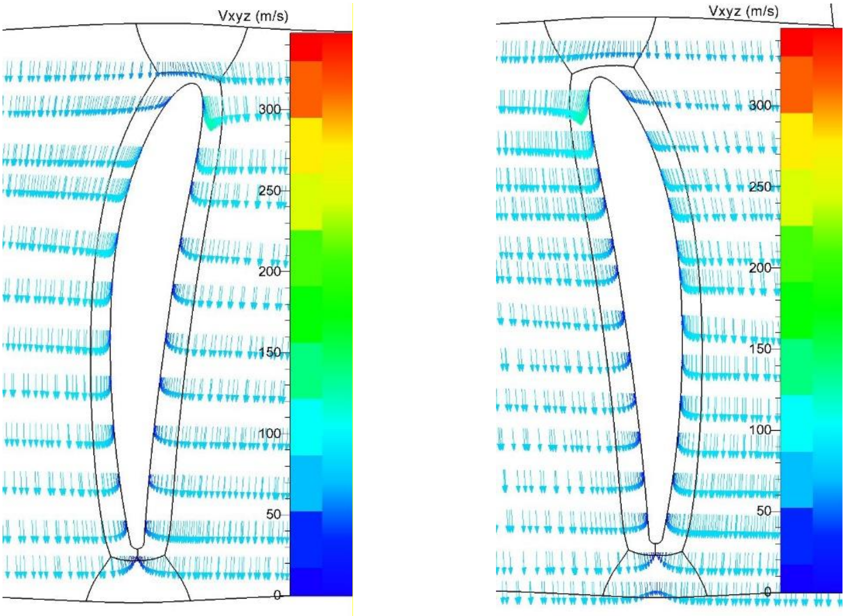


Fig. 6. Pressure ratio and Efficiency vs Mass Flow Rate with IGV Tilt Angle at 0°

Through simulations, the streamlines and aerodynamic forces developed along the profiles have been obtained, with the only visible differences resulting from the reversal of the two surfaces of the profile, namely the pressure side and suction side (Fig. 7).



a) type I (concave shape) *b) type II (convex shape)*

Fig. 7. Velocity vectors of the IGV blades positioned at 0°

In contrast to the previous case, as a result of simulations conducted for blade-tilted angles of -15 degrees (Fig. 8) or +30 degrees (Fig. 9), the characteristic curves no longer overlapped. It is observed that the concave shape enhances pressure rise and performance at negative rotation angles of the IGV blades, while the convex shape of the blades (Type II) is favorable at positive rotation angles. Moreover, it is noted that the shapes of the curves exhibit similarities: "Type I π_c" at -15 degrees with "Type II π_c" at +30 degrees; "Type I Efficiency" at -15 degrees with "Type II Efficiency" at +30 degrees, and so forth.

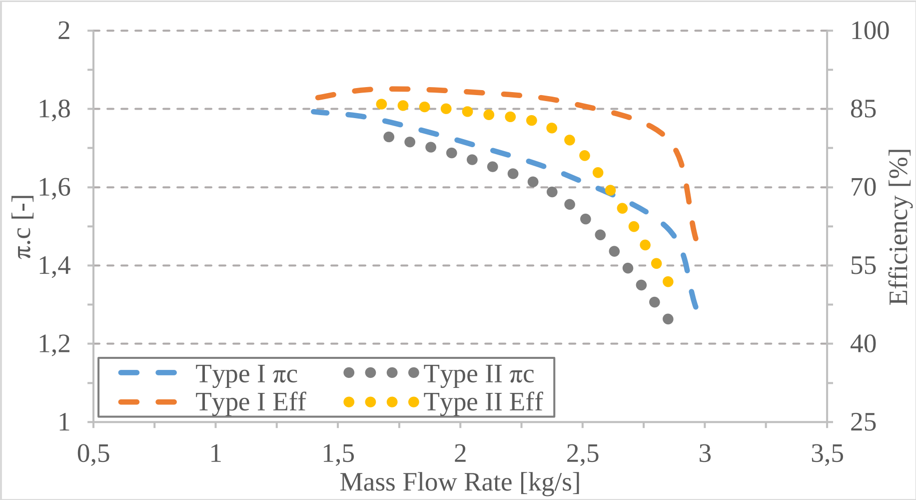


Fig. 8. Pressure ratio and Efficiency vs Mass Flow Rate with IGV Tilt Angle at -15°

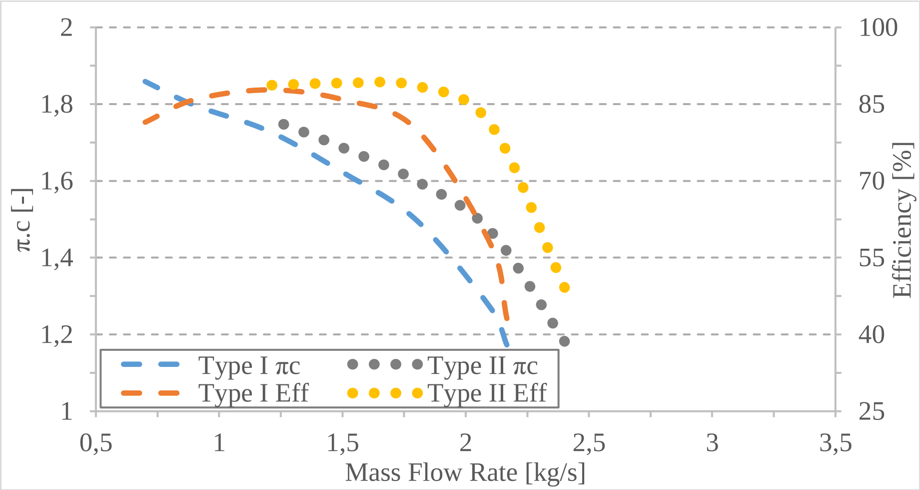
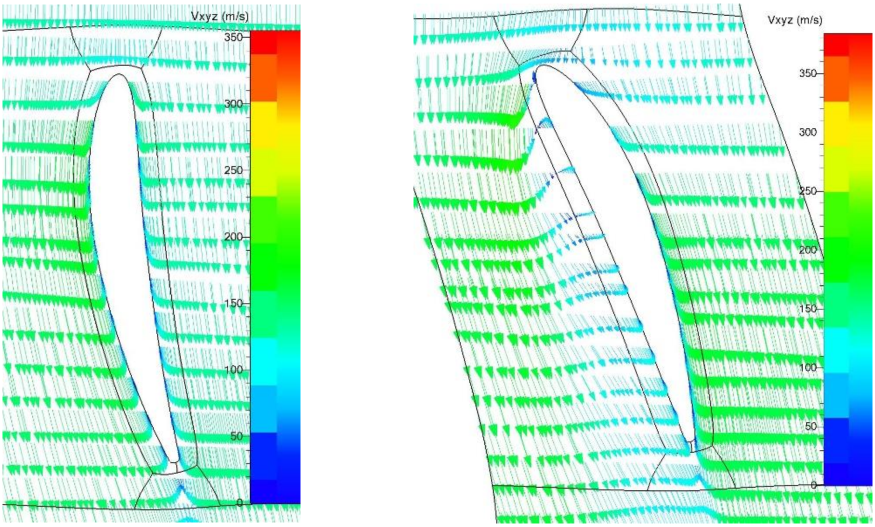


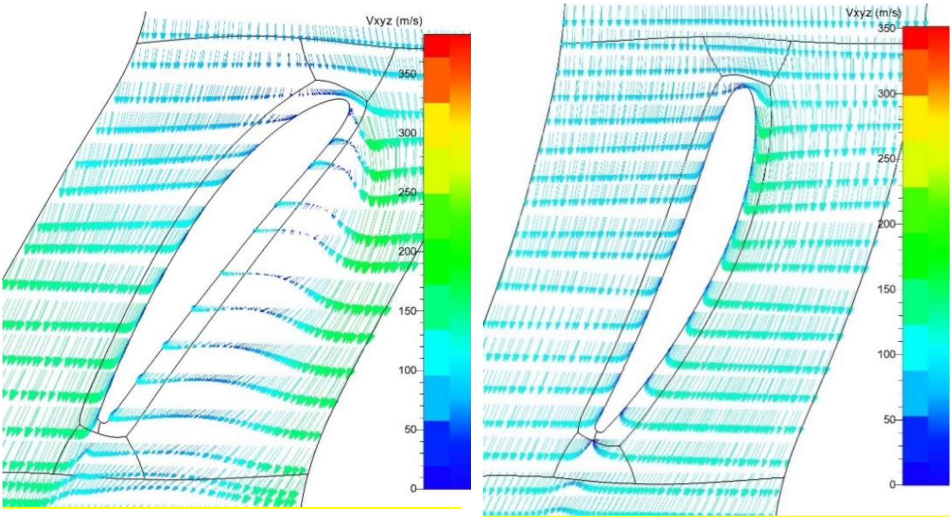
Fig. 9. Pressure ratio and Efficiency vs Mass Flow Rate with IGV Tilt Angle at +30°



a) type I (concave shape) *b) type II (convex shape)*

Fig. 10. Velocity vectors of the IGV blades positioned at -15°

The high performance achieved by the concave shape at negative incidences of the IGV blades is attributed to the smooth flow along the aerodynamic profile (Fig. 10 a.). In the case of the convex shape (type II), separation or detachment is observed on the pressure side (Fig. 10 b.), resulting in penalties of 8.4% in terms of efficiency and 4.4% in terms of pressure rise at a flow rate of 2.45 kg/s.



a) type I (concave shape) *b) type II (convex shape)*

Fig. 11. Velocity vectors of the IGV blades positioned at +30°

Similar to the previous case, when the stator blades with a concave shape are rotated in a positive direction, detachments are observed on the pressure side (Fig. 11 a.), resulting in 10.6% lower efficiencies and 6.8% lower pressure rises compared to the convex shape at a flow rate of 1.8 kg/s.

Conclusions

In this studied case, a 27% efficiency difference was observed between these two blade shapes (concave and convex) at an IGV blade inclination of -15 degrees and a 23% difference at an IGV blade inclination of +30 degrees. Both points where efficiency values showed significant differences were near the choke point, where the flow rate was high, and the influence of separations/detachments on the IGV aerodynamic profile resulted in significant losses.

On the one hand, the concave shape (Type I) is favorable for higher flow rates and pressures compared to the nominal point or for negative inclinations of the IGV blades, while the convex shape (Type II) is more favorable for lower flow rates and pressures compared to the nominal point or for positive inclinations. On the other hand, for a turbomachinery operating under variable conditions (with the flow rate varying above or below the nominal point), the radial shape is the most advantageous, achieving a compromise between these two shapes.

Additionally, the use of the morphing blade can lead to higher efficiency compared to the radial-shaped blade. However, it is important to note that the manufacturing and control of the morphing blade are much more complex.

Acknowledgment

The authors would like to acknowledge the support provided by the National Research and Development Institute for Gas Turbines COMOTI (Romania) in making this study possible.

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АНАЛИЗ НА РАБОТАТА НА ЦЕНТРОБЕЖНИ КОМПРЕСОРИ В ЗАВИСИМОСТ ОТ ЛОПАТКИТЕ С ИЗВИТА ФОРМА НА ВХОДНИЯ НАПРАВЛЯВАЩ АПАРАТ

Т. Стънеску, Д. Ушериу

Резюме

Това проучване има за цел да анализира ефективността на два типа статорни лопатки, използвани в направляващия апарат на центробежни компресори: лопатки с предно извит профил и лопатки със задно извита форма на профила (вдлъбнати и изпъкнали форми), при различни работни условия и ъгли на завъртане на лопатките. Основната цел на изследването е да се оцени производителността на компресора чрез сравняване на резултатите, получени за тези два типа лопатки. В крайна сметка, целта на проучването е да предостави по-ясна представа за избора на правилната форма на лопатката на входния направляващ апарат в специфичната област на приложение на центробежните вентилатори.