Research on Effecient Compressor Performance Based on Flow Behavior of Inlet Guide Vanes

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Abstract*—Regarding the compressor performance of aircraft jet engines, this research outlines efficient compressor performance following the investigation employed by the different researchers. It explores a consequence of the current understanding and the methods employed in recent experimentation for the "Inlet Guide Vane's" (IGVs) function used in various compressors. Firstly, some basics on the functional performance of compressors their performance parameters from literature are presented. "Variable Inlet Guide Vanes" (VIGVs) are typically designed to direct the air into the rotating blades at suitable angles for the different compressors. Adjustments of the setting angle or stagger angle of IGVs are used to develop the aerodynamics behaviour of compressors. Various literature reviews are evidence of how IGV is used for the performance control of the compressors, which improves the stability and efficiency of the engine. The IGVs can be rotated to a specific stagger angle to change their incidence with the airflow. In turbomachinery, guide vanes deal with the variations in inlet boundary conditions and design parameters of the stator blade. This paper especially emphasizes the performance examination of IGVs used in compressors at diverse stagger angles to enhance the operating performance of compressors. The outcome of this research gives an improved insight into the efficient use of a variable IGV for the future. It has practical implications in the modern aviation industry of the world.

***Keywords*—Stagger Angle, Axial Flow Compressor, Compressor Characteristics, DSP controller, Guide vane Drifts.**

I. INTRODUCTION

Modern gas turbine engines are multi-stage axial flow compressors equipped through VIGVs. Most compressors have IGVs with varying stagger angles [1-2], and changing stagger angle of IGVs, vane including geometrical variations of the stage would have resulted in variation of the stage's characteristic curves in compressors [3-4]. Theoretically, altering the stagger angle of the IGV will result in variations made in characteristics curves of the stage under study [5].

When the compressors operate under off-design circumstances, their efficiency drops due to rotational speed and mass flow alternations. That's why the compressor's pressure ratio is reduced [6-7]. As the IGVs stagger angle increases, the guide vanes enter into a high incidence condition. As a result, the loss coefficient increases rapidly that detrimental to the compressor's efficiency [8-9].

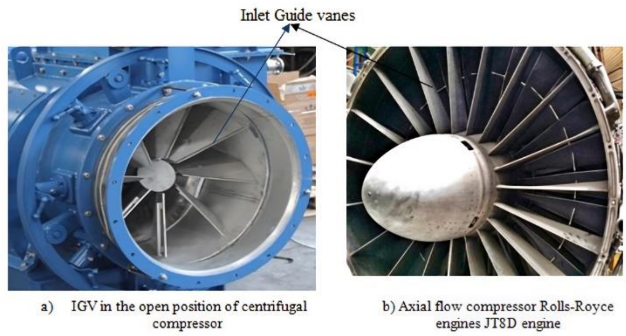

Fig. 1. IGVs in compressors.

The positioning of IGVs is critical for flow regulation in axial flow compressors and centrifugal air compressors, as depicted in fig.1. Basically, in centrifugal compressor IGVs, the positioning has become an obstacle for high-speed and exact flow regulation for surge prevention [10].

Fig. 2. Compressor with variable IGVs (JT8D engine-Pratt &Whitney).

The angular position of the guide vanes row manages the airflow through the axial flow compressor, regulating it between start-up and baseload settings. VIGV is associated with an adjustment ring with a rod used to change the setting angle as required, as illustrated in figure 3. With the help of alteration of IGVs stagger angles combined effect of three-shaft gas turbine engine (GELM1600) compressor performance. Also, its efficiency has been improved [11].

The concept of stagger angle "λ" is the angle surrounded by the blade of chord line and turbine axial direction. The particular geometrical angles with blade setting profile and their correlation with the flow angles for the compressor, the blade cascade is described below [12-13].

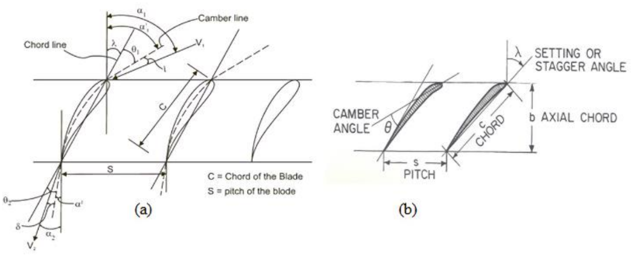

Fig. 3. (a) Concept of stagger angle, (b) Cascade Geometry of compressor blade [13].

The concept of stagger angle of IGVs and its geometric angles are illustrated in figure 3(a) and defined below:

$$\alpha_1 = \lambda + \theta_1 \tag{1}$$

$$\alpha_1^{'} = \lambda - \theta_2 \tag{2}$$

Where, α_1 = inlet angle of blade, α'_1 = outlet angle of blade, λ = stagger or setting angle, θ_1= Inlet chamber angle, θ_2= Inlet chamber angle.

Equations (1) and (2) avoid the angle of the incident and deviation, which has a significant impact on the inlet angle of the blade and the outlet angle of the blade. Based on the angle of the incident and deviation, the equations are followings:

$$\alpha_1 = \lambda + \theta_1 + i \tag{3}$$

$$\alpha_1^{'} = \lambda - \theta_2 - \delta \tag{4}$$

Hence, ε represents deflection of flow, therefore:

$$\varepsilon = \alpha_1 - \alpha_1^{'} = \theta + i - \delta \tag{5}$$

Where, δ = deviation angle between camber and outlet flow V_2 at exit. i=Angle of incident.

The above parameters play a significant role in the cascade geometry of the compressor blade. As a result, variable IGVs are selected for this research, and research on the off-design performance of the IGV is required to improve the compressor's performance.

II. LITERATURE REVIEW

The primary aim of this paper is to provide a review of the flow behaviour of VIGVs and their impact on gas turbine engine compressors. IGVs are a row of stator vanes, and their angles can be altered using a control system to enhance the off-design performance [14-15]. Compressor performance maps are only an inlet flow angle (stagger angle) technique. VIGVs are frequently used to alter inlet flow angle to transform the performance maps in definite input of operating range.

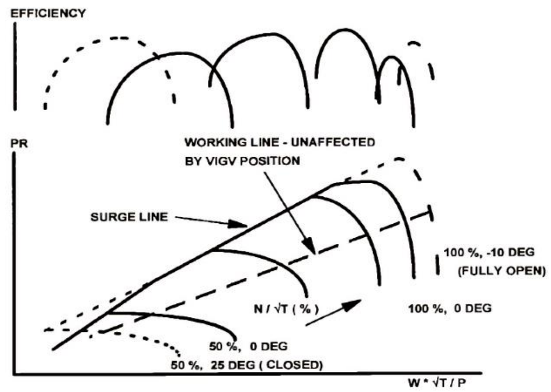

Fig. 4. Axial compressor performance maps due to consequence of VIGV angles [15].

Figure 4 represents the impact of VIGV with the help of the compressor performance curve. The VIGV shift specifies speed lines relatively parallel on the performance maps at slow speed. VIGVs give a method to moderate this by increasing the part speed surge line.

Srikanth et al. presented a logical design path recycled in this study to intend an axial flow compressor. It described the three dissimilar stagger angles that played a main role in the blade twist and discussed the compressor's design specification for the standard operating conditions. Present the calculation of blade geometry of NACA 65010 at different stagger angles [16].

The phenomena of the stagger angle effect of guide vanes would be that the typical curve will move towards higher coefficients of pressures and temperature [17-18] through the more open setting of the guide vanes to the stage. This article emphasises the axial flow compressor's interstage parameter and the stage characteristics.

T.W song et al. researched the performance investigation of compressors by adjusting the setting angle of guide vanes on various characteristic curves by literature reviews. The author discussed the performance and methodology of multistage compressors by using different performance curves for fixed and variable geometry of the IGVs [19].

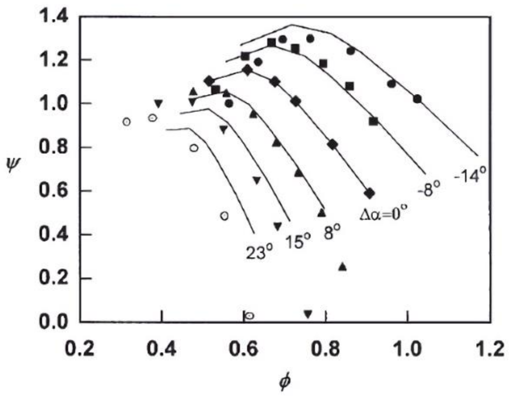

Fig. 5. Illustrate performance characteristics of a compressor stages with IGV angle variation [19].

Performance calculations at different stagger the angles of the axial-flow compressor as presented and plotted between pressure coefficient and flow coefficient depicted in figure

5. The positive sign of the stagger angle represents the closing of the IGVs.

TABLE I. Performance summary of multi axial flow compressor [19].

Compressors	Stages	Mass flow rate (Kg/s)	Pressure Ratios	Speed (r/min)	IGVs
A	3	16.1	2.2	17000	F
B	5	48.96	5.96	6894	F
C	8	19.72	7.21	16542	F
D	10	26.08	6.45	10000	F
E	12	20.0	12.4	14000	F, V
F	16	65.32	17.21	9160	V
G	17	36.3	15.8	10800	V

Table 1 represents the overall performance of axial flow compressors and their physical performance parameter values at the specific mass flow rate, pressure ratio, and speed 'N', which influence the performance of the axial flow compressor. 'F' and 'V' denotes the fixed and variable geometry of IGVs used in compressors.

Khan et al. examined the theoretically and experimentally effect of flow separation on the performance of the NACA-65 series blade profile. In this paper, the static and total pressures were calculated at preferred points among the two blades for different stagger angles of 4, 0, -4, 8, and -12 degrees by using pitot-static tube and multi-tube to examine the outcome of the stagger angles on flow partition through the fundamental CFD analysis with many boundaries setting which optimizes the performance of the axial flow compressor with staggering [20].

TABLE II. Table 2 Operating and Boundary conditions for analysis [20].

Cases	Stagger angle (γ)	Inlet Velocity (m/s)	No. of grid points	Static pressure ratio
1	4	35	63	1.18
2	0	35	63	1.12
3	-4	35	63	1.2
4	-8	35	63	1.07
5	-12	35	63	1.04

Table 2 presents the operating boundary condition used to analyse the axial-flow compressor's optimised performance with staggering. The theoretical part depends on the flow simulation between the two blades by using software FLUENT for analysis.

Alireza Navai et al. [21] scrutinized compressor characteristics due to IGVs stagger angle variation. Alteration of stagger angles of the IGVs stated as a geometrical deviation of the stage would result in the displacement of pressure coefficient.

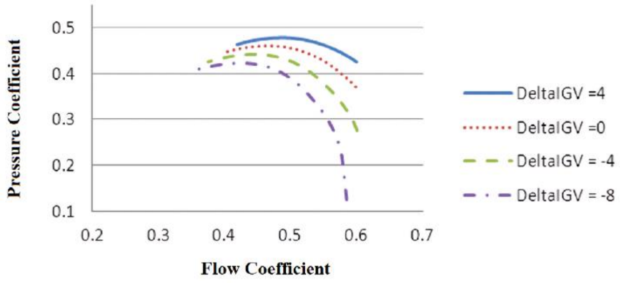

Fig. 6. Outcome of the IGVs stagger angles deviation on characteristics curve [21].

Figure 6 illustrates the pressure coefficient performance curve based on the flow coefficient of the first stage of the IGT25 industrial compressor, prepared through drop base one-dimensional code, where stagger angle of IGV is altered at design speed.

Sun et al. the performance parameters had been investigated at stagger angles of −20, 0, 20, 40, and 60 degrees. These optimized IGVs can enhance the compressor efficiency and assist in diminishing the mass flow and the power of the compressor. Consequently, the enhanced profile can significantly develop the variable performance of IGVs [22-23].

David et al utilized VIGVs, the swirl can be varied in a wide range to control the compressor's operating point. The author presents the performance map between Reynolds number and Mach number. Also, vanes with symmetric profiles are often found as their stagger angle can be changed in both positive and negative directions without the preference of one of the turning directions. At stagger angles < 90° the boundary layer state (laminar/turbulent, transition, separation) and low Reynolds numbers, a flow division occurs on the pressure plane trailing edge without reattaching [24-25].

Asgarshamsi et al. conducted a practical and effective augmentation method to enhance the efficiency and pressure ratio of the axial turbine is presented. He studied the 3D shape optimization for the effects of the turbine rotor and stator blades stagger angle variations on the turbine stage working performance with two objective functions. The span-wise blade stagger angle distribution is manipulated to enhance the aerodynamic performance of the turbine [26].

Compressor performance with Re-staggered presented in this paper. Stator re-staggering is a commonly and easily employed method to adjust the working conditions of blades in a multistage environment. Yin et al. [27-29] reviewed the compressor performance and calibrated it through the flow and CFD methods. And also, calculated overall performances of the re-staggered compressors are compared with those of the baseline compressor.

According to the studies cited, the IGVs' setting angle is critical for getting the best fan performance. Large changes in the IGV's setting angles will reduce the fan's efficiency and pressure ratio. Different exit setting angles for IGVs are examined to see how well they increase surge margins in each situation.

III. VARIABLE INLET GFUIDE VANE DRIFT

Hashmi et al. studied that vane drifts in the changeable geometry method usually develops when an individual or additional IGVs are not stunning according to the plan implemented in the control system of the gas turbine engine, as described in figure 6. Infrequently, breakdown in several bolts or wearing off the links in the variable IGVs mechanism can also cause drift [30].

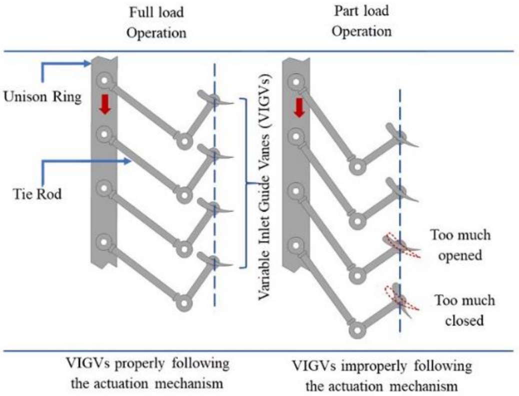

Fig. 7. VIGV drift & actuation mechanism [31].

Figure 7 depicts the control mechanism improperly and adequately with the actuation mechanism. The VIGV down-drift schedule has enhanced performance parameters like 14.53 % power output, 5.55% thermal efficiency, and 32.08 % surge as the SFC decreased by 5.23%. The characteristics of a low-pressure compressor with fixed and IGV up and downdrift geometry phenomenon.

IV. DIGITAL SIGNAL PROCESSOR (DSP) CONTROLLER

Yan Ming et al. used the Digital Signal Processor controller (DSP) techniques to regulate the IGVs stagger angles to enhance the engine's efficiency at any operating state. The performance optimization using simulation and experiment to develop further efficiency of the compressor characteristics parameters are mainly the efficiency and stall margin [31].

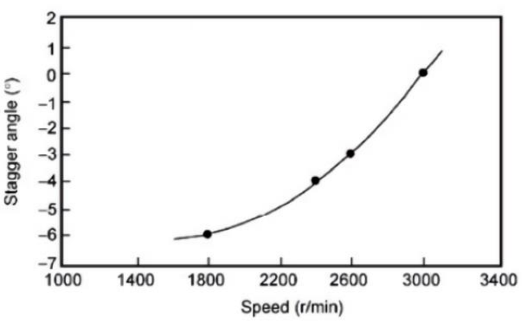

Fig. 8. Fitted curvature for the IGV stagger angles and rotational speed [31].

Figure 8 represented a fitted curvature of the involvement among the stagger angles of IGVs and rotational speed. Curve analyzed the range of rotational speeds and fitted curve to replicate better the inclination of the stagger angles of IGV altered in the speed deviation.

Jichao et al. present the control technique of IGVs to optimize the three-stage axial flow compressor efficiencies under various conditions. IGVs stagger angle altered by using Digital Signal Processor (DSP) controller to optimize compressor efficiency and pressure rise coefficient. The range of IGVs stagger angle varies from -5 to +5 degrees for the determination to enhance the efficiency. The DSP controllers are considered to control the stagger angles of IGVs mechanically to augment the efficiency at several working conditions [32].

V. DIVERSE CLIMATE CONDITION

Chang et al. investigated the performance of 15 stages of axial flow compressor at diverse climatic at seven different stagger angles and optimized the overall performance of the compressor. The author states the different modes stagger is calculated under all working circumstances and presents the 21 performance characteristics of the compressor. The value of the ststator labels the stagger angles are 22, 35, 42, 49, 55, 62, and 70, respectively [33].

Chang investigated the performance parameters of an axial flow compressor by setting a stagger angle greater than 70 degrees in summer conditions, set between 35 and 42 degrees in winter conations, and 55 degrees in winter conditions were appropriate. Thus, the angle of IGVs is set more in summer and low in winter for optimum results.

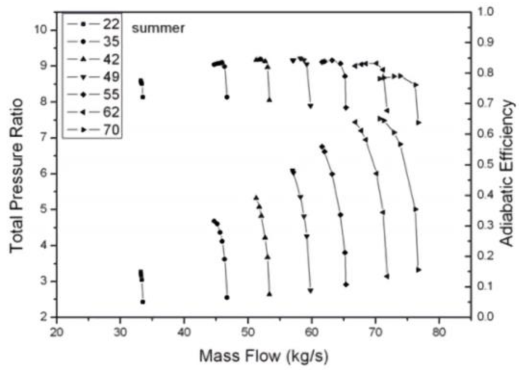

Fig. 9. Performance map in summer condition at different stagger angle.

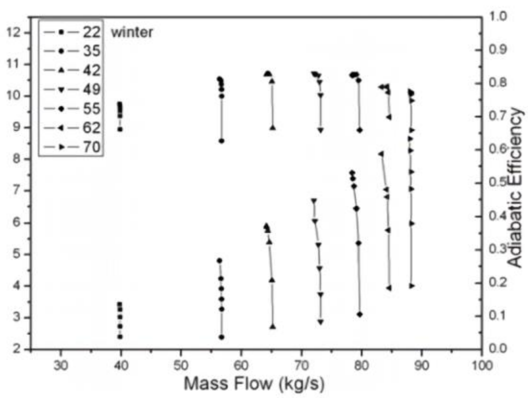

Fig. 10. Performance map in winter condition at different stagger angle.

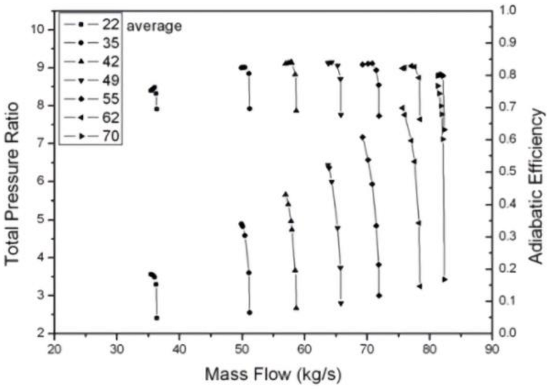

Fig. 11. Performance map in average condition at different stagger angle.

NACA-65 series aerofoil of 31 blades rows used in this study for analysis. Figure 10, 11, and 12 depicted the multi-stage compressor's adiabatic efficiency at a high stage comparatively when the stagger angles are between 40 to 60 degrees. Consequently, the maximum efficiency of the multi-axial flow compressor in summer conditions and in but winter working environment is comparatively a bit low.

VI. CONCLUSION

Studying the effect of a VIGV stagger angle on compressors is valuable to examine the performance parameters at the off-design condition. Many studies recognize that the IGV is very important to augment the performance parameter of the compressor to improve the working performance of a gas turbine engine. The following outcomes can be concluded for efficient compressor performance:

- It varies the IGV angle to enable the axial flow compressor to work effectively at speeds below the design state. As the pressure ratio increases, the inclusion of variable IGVs ensures that the airflow is directed onto the succeeding stage of rotor blades at an adequate angle.

- It can be evident from the previous research by the different researchers on IGVs, the efficient method of improving the performance of IGVs is the stall avoidance method. As a result, the application of the stall avoidance method is examined in the present research to resolve the delaying the access of rotating the stall and increase the surge margin of fan axial flow to promote a more comprehensive operation range.

- Another possible advantage of an IGV is reduced losses at lower stagger angles. Many aircraft engines resist noise and vibration issues at higher stagger angles. One way to mitigate this problem is to create a better-behaved flow through the flow path. It is also found that VIGVs direct the air onto the runner blades at a suitable angle, which gives optimum results at diverse climatic conditions.

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