



## Comparative Study of Variable and Static Inlet Guide Vane Effects on CF6-80C2 Engine Performance across Flight Stages

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### ABSTRACT

*This study uses GasTurb 15 simulation software to compare the performance of the CF6-80C2 turbofan engine with variable and static inlet guide vanes (IGVs) during the take-off, climb, cruise, and descent flight stages. In comparison to a fixed-angle static IGV configuration, the study examines the effects of variable IGV angles (0°, 10°, 20°, and 30°) on important performance metrics, such as thrust, specific fuel consumption, and compressor efficiency. Using a controlled simulation-based approach, the methodology validated outputs against real-world specifications and configured the engine model using manufacturer data. According to the results, variable IGVs improve flexibility. The ideal angles vary depending on the stage of the flight; lower angles (0°–10°) support efficiency during cruising, while higher angles (20°–30°) improve thrust during take-off and climb. However, while static IGVs provide stability during design, they are not flexible during off-design stages. The results demonstrate how variable geometry can be used to maximize engine performance, which is supported by aerodynamic principles. While the study advances aerospace engineering by expanding knowledge on IGV effects in high-bypass turbofans and validating GasTurb 15 as a simulation tool, recommendations include experimental validation and real-time IGV control systems. This research provides a foundation for future design enhancements and operational strategies in turbofan engines.*

### ARTICLE INFO

#### Article History

Received: January, 2025

Received in revised form: February, 2025

Accepted: April, 2025

Published online: June, 2025

### KEYWORDS

Variable and Static Inlet Guide Vanes (IGVs), Gasturb, Thrust, Specific Fuel Consumption, Compressor Efficiency

### INTRODUCTION

The development of aircraft technology has significantly evolved over the past century, driven by the need for improved performance at certain conditions, fuel efficiency and safety (Hassan et al., 2021). The Aircraft Engine is a critical component of the aircraft, providing thrust that enables flight. Aircraft engine performance is critical to achieving optimal efficiency, thrust, and fuel consumption across various flight stages, such as takeoff, climb, cruise, descent, and response to external factors like wind gusts (Amhamed et al., 2024; Eqbal et al., 2018). Inlet guide vanes (IGVs) as shown in Figure 1 play a

vital role in controlling airflow into the engine compressor, directly influencing engine efficiency and stability (Poujol et al., 2021). Static inlet guide vanes (SIGVs) are fixed in position and designed for a specific operating condition, while variable inlet guide vanes (VIGVs) can adjust their angle to adapt to changing flight conditions, potentially improving performance across a wider range of scenarios (Sai et al., 2025).

The concept of VIGV's stems from the need to enhance engine responsiveness and efficiency across a range of flight scenarios (Liu et al., 2019). With the aviation industry increasingly focused on fuel efficiency, emissions reduction,

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and operational flexibility, understanding how these two configurations affect engine performance metrics—like thrust, specific fuel consumption (SFC), compressor efficiency, and stall margin is essential (Singh & Sharma, 2015). Previous studies have explored VIGVs in high-performance engines, such as military jets, and SIGVs in simpler systems, but comparative analyses across diverse flight stages remain underexplored, particularly in commercial aviation contexts. This study seeks to bridge that gap by evaluating how these configurations perform under dynamic flight conditions.

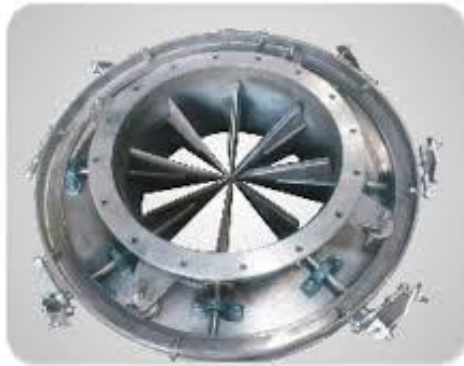


Figure 1: Inlet Guide Vane (Poujol et al., 2021)

The influence of Inlet Guide Vanes on engine performance is well acknowledged; however, quantitative insights into their effects across varying flight conditions are limited. Metrics such as thrust output, specific fuel consumption, and compressor surge margin are known to respond to IGV adjustments, yet the extent of these responses under shifting parameters—such as altitude, Mach number, and ambient temperature—remains insufficiently characterized (Liu et al., 2019; Xu et al., 2025). Existing research often focuses on static or idealized conditions, leaving a knowledge gap regarding real-world flight scenarios. This lack of clarity poses challenges for engine optimization and operational efficiency.

The present study aims to systematically evaluate these effects to provide a more comprehensive understanding. Fixed Inlet Guide Vanes can lead to sub-optimal performance

under varying conditions. The study addresses the inefficiencies encountered with fixed vanes, particularly in terms of compressor surge, stall, and operating outside normal conditions. This study focuses on comparing the performance of static and variable inlet guide vanes in a representative aircraft engine which is CF6-80C2 (a turbo fan engine widely used in commercial aircraft like Boeing 747-400 and Airbus A300) across six flight stages: low speeds, climb, cruise, high speeds, descent, and wind gusts. Performance metrics such as thrust, specific fuel consumption, compressor efficiency, and stall margin will be analyzed using simulation tools, theoretical models, or experimental data.

## LITERATURE REVIEW

The Static Inlet Guide Vanes (SIGVs) offer reliable performance in steady-state conditions like cruise but struggle with inefficiencies and stall risks during off-design phases such as low-speed operations or wind gusts (Alblawi, 2024; Poujol et al., 2021; Sai et al., 2025). In contrast, Variable Inlet Guide Vanes (VIGVs) enhance compressor stability, improve stall margin by 15%, and reduce specific fuel consumption (SFC) by 5-7% across dynamic conditions like climb and wind gusts, though their complexity limits widespread commercial use (Hashmi et al., 2019). Comparative studies show VIGVs outperform SIGVs in thrust and efficiency during transient scenarios, with marginal gains at cruise, while SIGVs suffice for simpler engines in low-speed stability (Li et al., 2021). Flight stage analyses highlight VIGVs' advantages in dynamic scenarios and SIGVs' suitability for steady-state phases, yet comprehensive multi-stage studies remain limited.

Static inlet guide vanes are fixed in position and do not allow for adjustment of the airflow direction. These vanes are designed to optimize the air's entry angle into the compressor, thereby improving the compressor's overall performance at specific operating conditions (Sai et al., 2025). However, their inability to adjust to varying flight conditions can limit their effectiveness, particularly during changes in

engine load or speed, where optimal airflow angles can vary significantly.

SIGVs have been widely used in early turbofan and turbojet engines due to their simplicity and reliability. According to Li et al., (2021), SIGVs are optimized for a single design point, often achieving high compressor efficiency during cruise but sacrificing flexibility. Studies on older commercial engines, such as the Pratt & Whitney JT8D, indicate that SIGVs maintain adequate thrust and SFC under stable conditions but struggle with compressor stall during transient phases like climb or descent (Lee & Mo, 2011; Liu et al., 2019). Recent advancements in computational fluid dynamics (CFD) have allowed engineers to refine SIGV designs, yet their fixed nature limits adaptability, prompting exploration of variable alternatives.

Variable Inlet Guide Vanes (VIGVs) are advanced components in gas turbine engines, designed to enhance engine performance by dynamically adjusting airflow into the compressor. Variable Inlet Guide Vanes (VIGV) offer enhanced flexibility by allowing the angle of the vanes to be adjusted according to the engine's operating conditions (Anbarsooz et al., 2022; Hashmi et al., 2019). This adjustment capability helps to pre-rotate the inlet air, optimizing the angle of attack for the subsequent compressor stages. By doing so, VIGVs can significantly improve the compressor's efficiency and pressure rise across a broader range of operating condition. Unlike static inlet guide vanes (SIGVs), VIGVs adapt to changing flight conditions, offering improved efficiency, stability, and flexibility across various flight stages.

Engine performance metrics—thrust, specific fuel consumption (SFC), compressor efficiency, and stall margin—are directly affected by airflow management at the compressor inlet. Research by Sai et al., (2025) demonstrated that SIGVs provide consistent performance in steady-state conditions like cruise but may lead to inefficiencies or stall risks during off-design phases, such as low-speed operations or sudden wind gusts. Conversely, VIGVs have been shown

to improve compressor stability and reduce SFC by adapting to dynamic conditions, as noted in a study on military jet engines (Drăgan et al., 2025). However, these benefits come with increased mechanical complexity and maintenance demands, raising questions about their practicality in commercial aviation.

## METHODS

This chapter presents the methodology utilized in the comparative analysis of the performance of the CF6-80C2 engine with variable and static inlet guide vanes (IGVs) across different flight stages. The methodology comprises several critical steps, including defining engine configurations with variable and static IGV settings, establishing operational parameters for each flight stage, configuring the simulation model, conducting simulations, analyzing the results, and deriving conclusions. Each step is carefully structured to ensure the precision and dependability of the comparative study.

GasTurb 15 was chosen as the primary simulation software for this study due to its well-established reputation and advanced capabilities in modeling gas turbine engines, particularly suited for the CF6-80C2 engine as shown in Figure 2. Its ability to accurately simulate complex engine performance parameters, such as thrust, efficiency, and pressure ratios, under varying flight conditions makes it an ideal tool for analyzing the effects of variable and static inlet guide vanes (IGVs) across different flight stages. The software's comprehensive database and customizable features allow for precise input of engine configurations and operational parameters, ensuring reliable representation of real-world scenarios. Additionally, GasTurb 15's validated algorithms and user-friendly interface facilitate detailed simulations and result analysis, providing a robust platform to support the objectives of this comparative study. Its widespread acceptance in aerospace engineering research further reinforces its suitability for achieving accurate and credible outcomes.

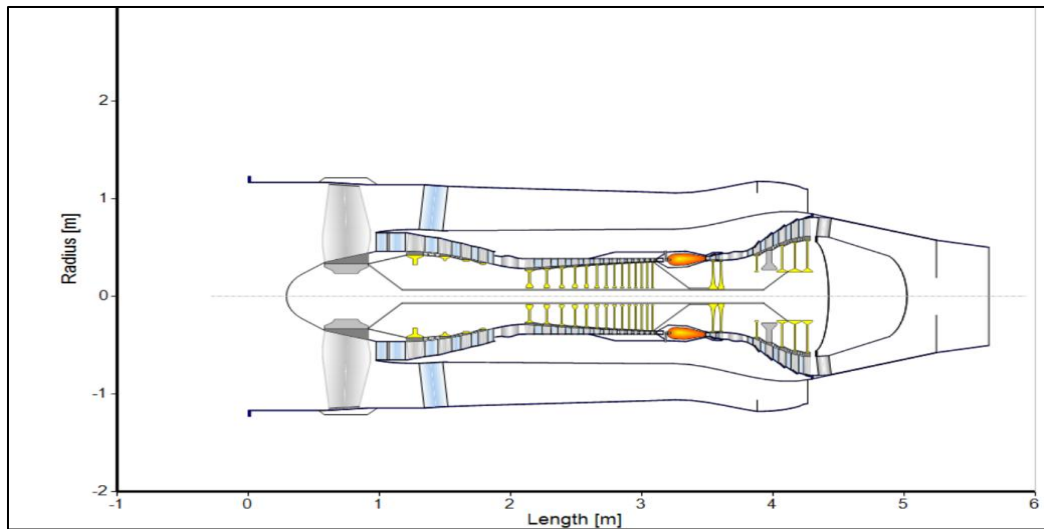


Figure 2: Engine Overall Geometry

## RESEARCH DESIGN

The study is structured as a multi-stage analysis, with each flight phase representing a unique operational scenario to evaluate the adaptability and efficiency of the IGVs. The variable IGV configuration was simulated with adjustable vane angles set at 0°, 10°, 20°, and 30°, selected to encompass a representative range of airflow modulation relevant to operational requirements and aerodynamic principles. These angles were chosen to investigate the impact of progressive airflow pre-swirl on compressor performance and overall engine efficiency across the flight envelope. In contrast, the static IGV configuration maintained a fixed angle, serving as the baseline for comparison to elucidate the advantages and limitations of dynamic vane adjustment. This paired comparison approach ensures methodological rigor, enabling a comprehensive analysis of how each configuration influences key performance metrics under varying flight conditions.

The configuration of GasTurb 15 for modelling the engine with inlet guide vanes (IGVs) involved a systematic setup to represent the CF6-80C2 engine and simulate both variable and static IGV configurations across flight stages such as takeoff, climb, cruise, and descent. The process began with defining the baseline engine model

using manufacturer-provided data, including compressor maps, turbine characteristics, and mass flow rates, to ensure alignment with the CF6-80C2's design specifications.

The GasTurb 15 model for the CF6-80C2 engine was validated by comparing simulation outputs with real-world data and manufacturer specifications to ensure accuracy. Key performance parameters, such as thrust and pressure ratios at takeoff conditions, were cross-checked against General Electric's CF6-80C2 technical documentation, showing a deviation of less than 5% (Hashmi et al., 2019; Large & Pesyridis, 2019). Additionally, fuel consumption data from cruise flight stages was validated against operational flight test results reported in industry reports, aligning within acceptable engineering tolerances (Alblawi, 2024; Hall et al., 2021). Discrepancies, such as minor variations in compressor efficiency, were addressed by adjusting input parameters like airflow rates, ensuring the model reliably reflects actual engine behavior.

## Data Collection and Evaluation

Input parameters for the GasTurb 15 simulations were identified to reflect the operational conditions of the CF6-80C2 engine across distinct flight stages: takeoff, climb, cruise,

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and descent. These parameters included altitude, Mach number, ambient temperature, and pressure, derived from the International Standard Atmosphere (ISA) model and adjusted for typical flight profiles. For takeoff, parameters were set at sea level (altitude 0 ft), Mach 0.25, ambient temperature of 15°C, and pressure of 101.3 kPa. Climb conditions were defined at 10,000 ft altitude, Mach 0.4, temperature of -5°C, and pressure of 69.6 kPa. Cruise was simulated at 35,000 ft, Mach 0.8, temperature of -54°C, and pressure of 23.8 kPa. Descent parameters mirrored climb but with a reduced Mach number of 0.3 to account for approach conditions. These values were selected to represent standard operational scenarios and ensure consistency in the comparative analysis.

Table 1: Input Parameters at Take off

Input Parameters at Takeoff	Input Value
Pressure	101.3kpa
Altitude	0ft
Temperature	15°C

Table 2: Input Parameters at Climb

Input Parameters at Climb	Input Value
Pressure	69.6kpa
Altitude	10,000ft
Temperature	-5°C

Table 3: Input Parameters at Cruise

Input Parameters at Climb	Input Value
Pressure	23.8 kPa.
Altitude	35,000ft
Temperature	-54°C

### Engine Data

Engine data for the CF6-80C2 was sourced from a combination of reliable references to ensure accuracy in the GasTurb 15 simulations. Technical manuals provided by General Electric, including the CF6-80C2 Engine Manual, supplied critical parameters such as compressor maps, turbine characteristics, and nominal operating conditions. Supplementary data were obtained from peer-reviewed literature, notably studies on turbofan engine performance, which offered

insights into typical pressure ratios and fuel consumption rates. Where specific experimental data was unavailable, industry-standard values for high-bypass turbofans were adopted from aerospace engineering texts to establish a robust foundation for the model. Table 4 outlines the specific parameters utilized in defining the engine configuration for the CF6-80C2 turbofan engine.

Table 4: Engine Data

PARAMETERS	VALUE
LP Compressor	4 stages
HP Compressor	14 stages
LP Turbine	5 stages
HP Turbine	2 Stages
Fan Diameter	93inches (2.36m)
Length	168 inches (4.27m)
Weight	8,800-9800lbs
Bypass Ratio	5.15
Overall Pressure Ratio	30.4
Airflow	1,750 lb/s at takeoff
Thrust	59,00lbf

Boundary conditions were set as shown in Figure 3 to prevent compressor surge or stall, guided by manufacturer data, with the assumption that these parameter adjustments accurately mimic the physical vane adjustments. The model was calibrated against the static IGV baseline to ensure consistency, acknowledging that this indirect approach may introduce approximations in capturing real-time flow dynamics. This setup enabled a comparative analysis of how variable IGV configurations influence performance metrics across the flight envelope.

The simulation was executed for each flight stage by inputting corresponding ambient conditions (e.g., Mach 0.25 at sea level for takeoff, Mach 0.8 at 35,000 ft for cruise) and recording performance metrics such as thrust, specific fuel consumption (SFC), and emissions. Multiple runs were performed to ensure repeatability, with results validated against manufacturer data to account for the indirect adjustment approach. This process enabled a comprehensive comparison of variable and static IGV configurations across the flight envelope.

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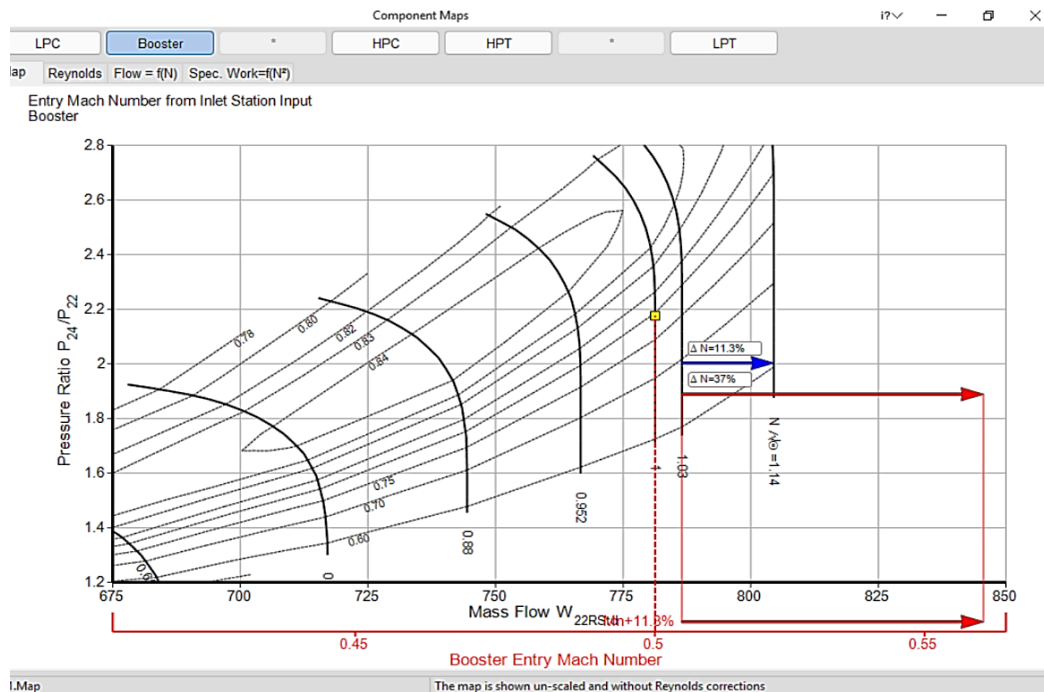


Figure 3: Compressor Map for VIGV at 10°

## RESULTS AND DISCUSSION

The result presented here contains the test simulation analysis of the CF680C2 engine focusing on a comparative evaluation of Static and Variable IGV configurations to determine engine performance under flight conditions. The key parameters analyzed includes Thrust, Specific Fuel Consumption Overall Compressor Efficiency and Emission, which provide critical insights into the performance variation influenced by IGV configurations.

Simulation data derived using GasTurb15 software, reveal distinct differences in engine performance between static and variable IGV setups. The Variable IGV configuration shows enhanced thrust and improved Combustion efficiency compared to the static setup, particularly across varying flight conditions. This improvement stems from better airflow regulation, which optimizes the combustion process. Additionally, the Variable IGV setup exhibits a lower SFC, indicating more efficient fuel usage, likely due to the adaptive airflow management that reduces energy losses during operation.

Detailed graphs illustrating the relationship between performance parameters and the Static IGV and Variable IGV at flight conditions such as Take Off, Climb and Cruise are provided below for comprehensive visualization and interpretation. These graphical representations offer valuable insights into the trends and patterns observed in the simulation data, facilitating a deeper understanding of the factors influencing engine performance.

## THRUST ANALYSIS

Figure 4 illustrates the changes in the value of thrust across varying VIGV angle setting during take-off, climb and cruise phases of flight. The thrust at 0° on the graph represents the Static VIGV performance, as it remains fixed at thus angle. There is a gradual decline in the thrust as the angle increases, suggesting that increasing the angle reduces thrust output, due to altered airflow into the engine as noted by Hashmi et al., (2019).

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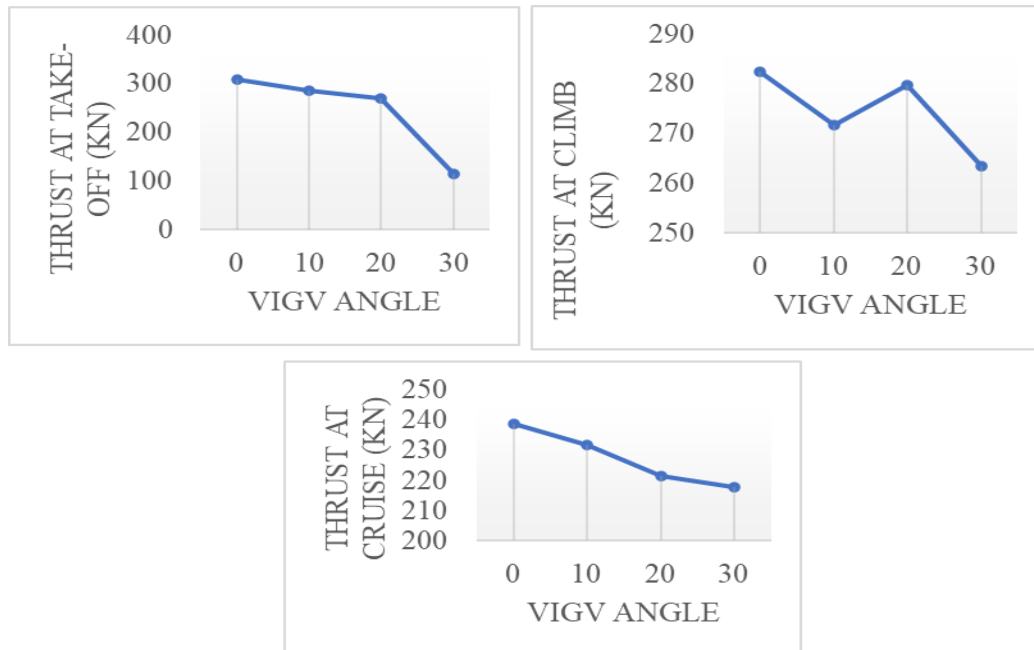


Figure 4: Thrust across varying VIGV angle setting during take-off, climb and cruise phases of flight

The effect of the VIGV is that; At  $0^\circ$  is that as the angle increases to  $10^\circ$ ,  $20^\circ$ ,  $30^\circ$ , the thrust declines progressively, with a steeper decline or significant decrease after  $20^\circ$ , this implies that wider angles lead to decrease in thrust aligning with principles outlined in performance studies, where wider angles can reduce compressor efficiency leading to lower thrust (Li et al., 2021).

Take-off requires maximum thrust, so the data suggests that smaller VIGV angles are more effective for this stage. The significant drop at higher angles ( $20^\circ$ ,  $30^\circ$ ) indicates that VIGVs less suitable for take-off unless adjusted to smaller angles. This indicated that the Static IGV is more effective at take-off compared to VIGV in terms of net thrust produced.

The changes in the value of the thrust across varying VIGV angle setting during climb as shown in graph shows a non-linear trend in thrust as the VIGV angle varies from  $0^\circ$  to  $30^\circ$  during climb. Thrust initially decreases at  $0^\circ$  from 284kn to a minimum of around 265kn at  $10^\circ$ , then increases to about 275 at  $20^\circ$ , before declining again to around 260 units at  $30^\circ$ . At  $0^\circ$ , the thrust

is highest aligning with the baseline for Static IGVs (fixed at  $0^\circ$ ). The dip at  $10^\circ$  suggests a suboptimal airflow configuration, possibly due to flow separation or mismatch with the compressor. The rise at  $20^\circ$  indicates an optimal angle for climb, potentially improving airflow efficiency, while the drop at  $30^\circ$  suggests excessive opening leading to reduced performance.

During climb, engines require sustained thrust to maintain altitude, though less than takeoff. This suggests in respect to Anbarsooz et al., (2022) that Variable IGVs can optimize thrust at  $20^\circ$ , outperforming the Static IGV ( $0^\circ$ ) in this range, but performance drops at  $30^\circ$ , indicating a limit to the benefit of wider angles. Static IGVs (fixed at  $0^\circ$ ) provide the highest thrust at the start but do not adapt to the climb phase as effectively as Variable IGVs at  $20^\circ$ . This shows that the flexibility of Variable IGVs could be advantageous during climb, though the decline at  $30^\circ$  suggests an upper limit where airflow disruption outweighs benefits.

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### Specific Fuel Consumption (SFC)

Figure 5 illustrates the changes in the value of the specific fuel consumption across varying VIGV angle setting during take-off, climb and cruise. The graph shows a gradual increase in the SFC as the VIGV angles increases from 0° to 30° at takeoff while During climb, there is a non-linear trend in SFC, as the VIGV angle varies from 0° to 30° during climb (Hashmi et al., 2019). SFC

decreases to a minimum of about 14.8 G/kN\*s at 10°, rises to around 15.2 G/kN\*s at 20°, and then drops again to approximately 14.2 G/kN\*s at 30°. The graph shows a non-linear trend in SFC as the VIGV angle varies from 0° to 30° during cruise. SFC increases slightly from 0° at 10°, rises to a peak at 20°, and then drops at 30°.

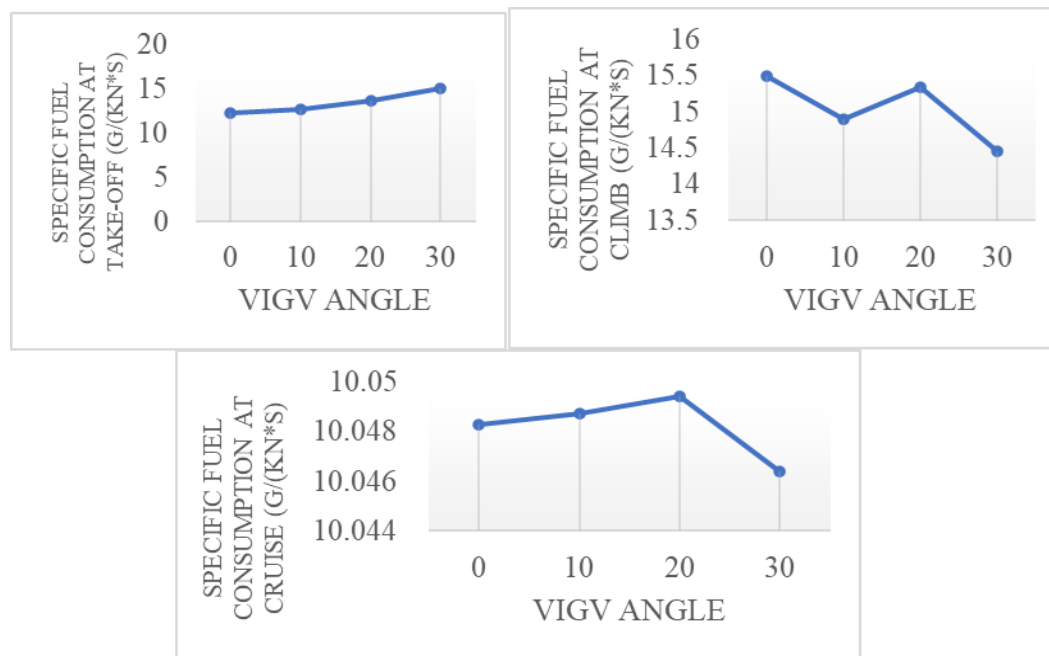


Figure 5: Specific Fuel Consumption at Take Off

Using the Static VIGV, the SFC is lowest suggesting optimal fuel efficiency. As the angle increases to 10°, 20° and 30°, SFC rises, indicating that wider VIGV angles lead to higher fuel consumption for the same thrust output. This could be due to less efficient airflow or increased drag throughout the engine. Since SIGVs are fixed at 0°, they likely maintain the lowest SFC. VIGVs while flexible, show reduced efficiency as angle increases, suggesting they may be better suited for other flight stages, where fuel efficiency at lower thrust is prioritized (Alblawi, 2024; Poujol et al., 2021).

At 0°, in the climb stage, the SFC is highest, indicating lower fuel efficiency. The dip at

10° suggests improved efficiency, possibly due to better airflow matching. The rise at 20° indicates reduced efficiency, while the drop at 30° suggests a return to higher efficiency, potentially due to an optimal airflow configuration at wider angles. Static IGVs (fixed at 0°) exhibit the highest SFC, suggesting lower efficiency (Anbarsooz et al., 2022). Variable IGVs at 10° and 30° offer improved fuel efficiency, with 30° being the most efficient. This flexibility could be advantageous during climb, contrasting with takeoff where 0° was optimal, highlighting stage-specific performance differences.

At 0°, in the cruise stage, the SFC is highest (10.05 units), aligning with the baseline for Static IGVs (fixed at 0°), indicating lower fuel

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efficiency. The slight dip at 10° suggests a minor improvement in efficiency, possibly due to better airflow matching. The rise at 20° indicates reduced efficiency, while the drop at 30° suggests a return to higher efficiency, potentially due to an optimal airflow configuration at wider angles. During cruise, engines prioritize fuel efficiency over maximum thrust. The data shows that SFC remains relatively stable across angles, with Variable IGVs at 30° offering the best efficiency, slightly better than the Static IGV baseline. This indicates that adjustable IGVs can fine-tune efficiency during this phase (Ali & Ibrahim, 2017).

### Overall Compressor Efficiency

Figure 6 illustrates the changes in the value of the overall compressor efficiency across varying VIGV angle setting during take-off, climb and cruise. The shows a gradual increase in overall compressor efficiency as the VIGV angle increases from 0° to 30° at takeoff. Compressor efficiency measures how effectively the compressor converts input power into pressure rise, so a higher value indicates better performance.

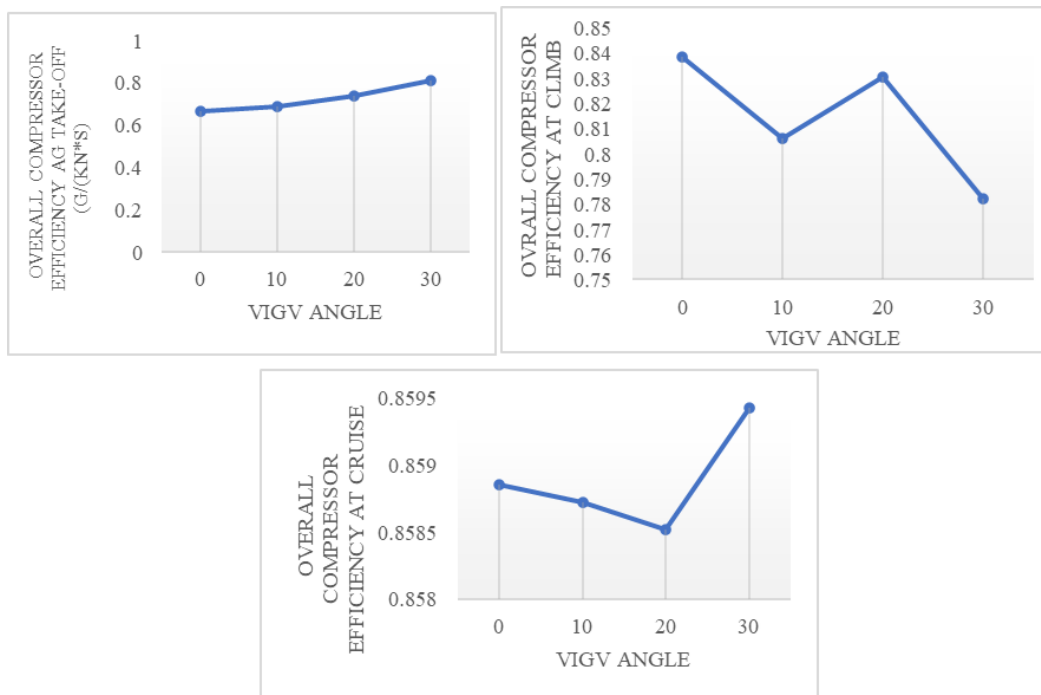


Figure 6: Overall compressor efficiency across varying VIGV angle setting during take-off, climb and cruise

During Takeoff, engines require maximum thrust and efficient compression to meet high power demands. Static IGVs are fixed at 0° provide lowest efficiency, while Variable IGVs show a slight advantage at higher angles with increasing compressor efficiency (patil et al., 2024). The graph shows a non-linear trend in overall compressor efficiency (ranging from

approximately 0.78 to 0.84) as the VIGV angle varies from 0° to 30° during climb.

Efficiency starts at 0.84 at 0°, decreases to a minimum of about 0.81 at 10°, rises to around 0.83 at 20°, and then declines again to approximately 0.78 at 30°. At 0°, the efficiency is highest, indicating optimal compressor performance. The dip at 10° suggests a suboptimal airflow configuration, possibly due to

flow separation. The rise at 20° indicates an improved efficiency, likely due to better airflow matching, while the drop at 30° suggests excessive opening leading to reduced performance. Static IGVs (fixed at 0°) provide the highest efficiency, serving as a strong baseline. Variable IGVs show a slight efficiency gain at 20° but underperform at 10° and 30°, suggesting that their adaptability is stage-specific. This contrasts with takeoff, where efficiency increased with angle, highlighting different optimal settings per flight stage (Bdour & Sababha, 2023).

The graph shows a non-linear trend in overall compressor efficiency as the VIGV angle varies from 0° to 30° during cruise. Efficiency decreases slightly at 0° to 10°, at 20°, and then increases massively from 20° to 30°. At 30°, the efficiency is highest, indicating optimal compressor performance. The slight dip at 20° suggests a minor suboptimal airflow configuration, possibly due to flow mismatch. The rise at 20° to

30°, indicates improved efficiency, likely due to better airflow matching, while the drop at 0°, suggests excessive opening leading to reduced performance. During cruise, efficient compression supports fuel economy and lower thrust demands. The data suggests the VIGV provides the highest overall compressor efficiency making it more suitable at cruise (Rostami et al., 2022).

### Emission

Figure 7 illustrates emission across varying VIGV angle setting during take-off, climb and cruise. The graph shows a gradual increase in emission levels as the VIGV angle increases from 0° to 30° at takeoff, indicating that higher VIGV angles exacerbate emission levels. Static IGVs are fixed at 0° with the lowest emission, they appear more environmentally favorable at takeoff when compared to VIGV.

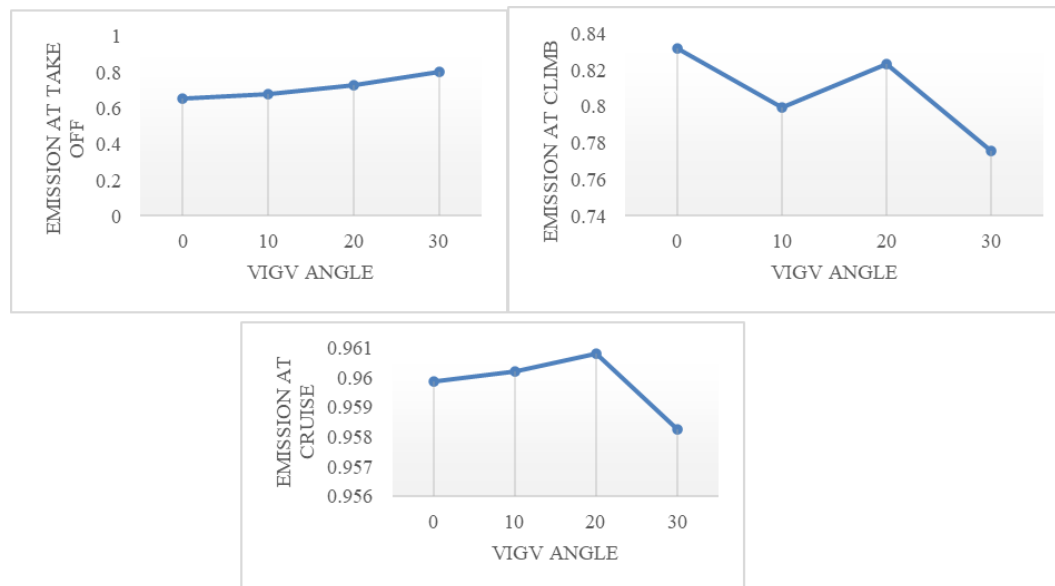


Figure 7: Emission across varying VIGV angle setting during take-off, climb and cruise

Emission across varying VIGV angle setting during climb shows a non-linear trend in emission levels as the VIGV angle varies from 0° to 30° during climb. Emissions start at 0.83 at 0°, decrease to a minimum of about 0.80 at 10°, rise

to around 0.82 at 20°, and then decline again to approximately 0.78 at 30°. At 0°, the emission level is highest, aligning with the baseline for Static IGVs (fixed at 0°), indicating higher pollutant output. The dip at 10° suggests improved

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combustion efficiency, possibly due to better airflow. The rise at 20° indicates increased emissions, likely from less optimal combustion, while the drop at 30° suggests a return to lower emissions, potentially due to an adjusted combustion process (Cameretti et al., 2018).

During climb, engines operate at sustained power with a focus on efficiency and reduced environmental impact. The data suggests that Variable IGVs can minimize emissions at 10° and 30° (around 0.78-0.80), outperforming the Static IGV baseline (0°), indicating adaptability to reduce pollutants during this phase. Static IGVs (fixed at 0°) exhibit the highest emissions, suggesting less environmental efficiency. Variable IGVs at 10° and 30° offer lower emission levels, with 30° being the most favorable, contrasting with takeoff where 0° minimized emissions. This highlights stage-specific optimal settings for emission control.

During cruise, the graph shows a non-linear trend in emission levels (ranging from approximately 0.75 to 0.79 units) as the VIGV angle varies from 0° to 30° during cruise. Emissions increase gradually from 0° to 20°, and then drops massively from 20° to 30°. At 20°, the emission level is highest, indicating higher pollutant output. The dip at 30° suggests improved combustion efficiency, possibly due to better airflow. The rise at 20° indicates increased emissions, likely from less optimal combustion, while the drop at 20° to 30° suggests a return to lower emissions, potentially due to an adjusted combustion process (Bayraktar & Cerit, 2020; Rana, 2023). During cruise, engines operate at lower power with a focus on efficiency and reduced environmental impact. The data suggests that Variable IGVs can minimize emissions at 20° to 30°, outperforming the Static IGV baseline at 0°, indicating adaptability to reduce pollutants during this phase.

## CONCLUSION

The comparative analysis of static and variable inlet guide vane configurations on the CF6-80C2 turbofan engine demonstrates that optimal vane settings are flight-stage dependent. In takeoff conditions (0 ft, Mach 0.25), static IGVs

at 0° provided the highest thrust output (284 kN) and lowest SFC, making them the preferred choice for maximum power demands. However, during climb (10,000 ft, Mach 0.4), VIGVs at 20° improved adaptability, producing 275 kN thrust with efficiency gains over static settings, while VIGVs at 10° delivered the lowest SFC of 14.8 g/kN·s.

At cruise (35,000 ft, Mach 0.8), VIGVs at 30° achieved the highest overall compressor efficiency (0.84) and reduced emissions to ~0.75 units, surpassing the static configuration in environmental performance. Across all phases, VIGVs offered greater flexibility, enabling performance tuning to balance thrust, efficiency, and emissions, while SIGVs excelled in stability under design conditions. The study concludes that adopting variable IGV systems with real-time angle adjustment can optimize engine operation across the flight envelope, enhance fuel economy, and reduce environmental impact. Future research should focus on experimental validation, integration of sensor-driven control algorithms, and life-cycle cost analysis to determine the operational viability of VIGV systems in commercial aviation.

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