

Effect Of Flap Angle on Aircraft Takeoff and Landing Distances

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Abstract. Flaps are essential devices on aircraft that directly influence lift force then control aircraft performance during takeoff and landing phases. Flaps change the aerodynamic characteristics of the wing to increase lift or drag force, thereby impacting takeoff or landing distance which help adapt to different situations when takeoff or land. This paper investigates the relationship between flap angle and the takeoff and landing distances. A series of aerodynamic theory, computational models, and practical results from published literature were used to quantify these effects. Results show that flap angles in the range of 15° - 20° optimize the balance between shortening the distance and keeping aviation safety best, significantly reducing both takeoff and landing distances. However, excessive deflection can cause excessive drag, thus counteract the lift effect. The study highlights the foundational importance of flap setting improvement in aviation safety and efficiency. Findings provide valuable insights for both aircraft designers and engineers, while also identifying gaps between theoretical studies and real-world scenario using real flight data.

Keywords: Flap angle; Lift coefficient; Drag coefficient; Takeoff; Landing.

1. Introduction

The performance of aircraft during takeoff and landing phases is highly dependent on the high lift devices. Flaps are one of the high lift devices. They play a particularly significant role. They can generate additional lift at lower speeds by adjusting the effective surface area of the wing and make sure the aircraft to operate safely at slower speeds, which can help the aircraft reduce risks and shorten takeoff and landing distances in the initial phase and final approach phase. However, with the enhancement of the lift, drag will increase correspondingly, which directly affects the aircraft's requirements of runway length and fuel consumption. This relationship between lift and drag represents a fundamental balance requirement in aerodynamic engineering and shows how necessary of careful consideration during the operation phases.

Different flap configurations produce varying aerodynamic characteristics, they can influence both the magnitude of lift and the extent drag. And the choice of flap deflection angle can be affected by multiple factors, such as aircraft weight, wing geometry and surrounding air density. Thus, an in-depth study of how flap angle affects aerodynamic forces is necessary to optimize the design of aircraft and the development of operational procedures.

Kroo noted that trailing-edge flaps significantly increased the wing's camber and surface area, enhanced lift at low speeds, but also introduce additional drag that affects runway requirements and safety margins [1]. Abbott analyzed the influence of wing geometry on lift and highlighted how flap deflection modifies the effective wing shape to achieve higher lift coefficients, and discussed how flap increases maximum lift, improving low-speed performance [2]. Smith provided both experimental and theoretical insights into flaps' function in short takeoff and landing operations, demonstrating that flap deflection allows slower flight, reduces takeoff and landing distances, and enhances overall safety during critical flight phases [3]. In recent works, NASA emphasized how lift augmentation devices such as flaps are critical in enabling aircraft to achieve the necessary lift during takeoff and landing [4]; Hood discussed the optimization of design of a high-lift model, emphasized the contribution of flaps to lift generation, including flap deflection increasing the maximum lift coefficient by approximately 20–25% at high angles of attack, enhance low-speed performance and safety [5]. Mouton presented wind tunnel testing and the results showed that multi-element flap designs significantly increase the wing's lift coefficient, emphasized the essential role of flaps in ensuring safe takeoff and landing phases [6].

This study is motivated by the importance of the role flaps play in shortening the distance in the phases of takeoff and landing. In these phases, the speeds of the aircrafts are close to stall speeds and are highly sensitive to changes in aerodynamic forces. Although there are already a number of research of lift generation and flap aerodynamics, a quantitative study of how specific flap angles directly influence takeoff and landing distances remains limited and required.

This study investigates theoretically, experimentally, and computationally to provide a comprehensive analysis of how flap angle effects on aircraft takeoff and landing performance. Aerodynamic principles, including lift and drag equations, are used to understand the fundamental mechanisms of how flap works in the flight. Next, experimental data are collected using scaled aircraft models with varying flap deflection angles in controlled wind tunnel to quantify their impact on lift, drag, and resultant takeoff and landing distances. Finally, calculated simulations are performed to validate experimental results. By combining these methods, the research establishes a systematic framework for evaluating flap performance and conforming the relationship between the deflection angle and the distances of takeoff and landing.

2. Theoretical Analysis

The investigation of analyzing the effect of flap deflection angle on the distances of aircraft takeoff and landing is based on fundamental aerodynamic theory and supported by experimental data, and also be evaluated by the core aerodynamic equations, flap deflection models, and performance analysis.

2.1. Core Aerodynamic Principles

The essential knowledge is based on the relationships between lift, drag, and aerodynamic geometry. The equation for the lift is as follows:

$$L = \frac{1}{2} \rho V^2 S C_y \quad (1)$$

where L is lift, ρ is air density, V is flight velocity, S is the wing area, C_y is the lift coefficient. Similarly, the equation for the drag is as follows:

$$D = \frac{1}{2} \rho V^2 S C_d \quad (2)$$

Where D is drag, C_D is the drag coefficient.

When the flap deflection increases, the lift coefficient primarily increases with the angle of deflection due to the altered camber, while drag coefficient increases simultaneously.

During takeoff, the equation for the minimum velocity is as follows:

$$V_{stall} = \sqrt{\frac{2W}{\rho S C_{l_{max}}}} \quad (3)$$

where W is the weight of the aircraft.

Takeoff and landing performance can be quantified as the runway distance required. For takeoff, the equation for the required distance can be deduced from Raymer, and it is as follows:

$$S_T = \frac{W^2}{g \rho S C_L (T - D)} \quad (4)$$

where g is gravitational coefficient [7].

Similarly, for landing, the equation for the required distance of landing is as follows:

$$S_L = \frac{V_{ap}}{2g(\mu W - D)} \quad (5)$$

where V_{ap} is the approaching velocity, μ is the braking friction coefficient.

The equation above shows a balance relationship that while the stall velocity and approach velocity reduce, the corresponding drag extends.

2.2. Model Development

2.2.1 Flap Angle Definition

Flap deflection angles typically range from 0° (clean configuration) to higher settings such as 10°, 20°, and 30°, which are common in commercial aircraft operations. Each flap angle significantly changes the pressure distribution around the wing and directly influences both lift and drag characteristics. To quantify these effects, aerodynamic coefficients of lift and drag are obtained both from empirical datasets (e.g. wind-tunnel experiments) and through reliable computational fluid dynamics simulations. This step establishes the necessary aerodynamic independents for subsequent performance calculations.

2.2.2 Performance Calculation

Using the core force equations above, the equation for net acceleration during the ground roll is as follows:

$$a = \frac{T - D - \mu(W - L)}{m} \quad (6)$$

where T is thrust, μ is the friction coefficient, W is weight, and m is mass. Calculate the acceleration and yields the takeoff length. Similarly, required landing distance is determined by applying deceleration forces from drag, reverse thrust, and braking.

2.2.3 Accuracy Verification

The deduced model should be compared with authoritative published experimental datasets to ensure the consistency with the trends already existed. Thus, one need to record changes in the deflection angles' impact on other critical parameters such as stall speed. This process can provide assurance of the precision, universality and predictive accuracy.

2.3. The Application in the Area of Areospace Engineering

There are several direct applications in aerospace engineering of the models of flaps' effects on takeoff and landing performance. It plays a critical role in aircraft design, where manufacturers must demonstrate and follow the regulatory standards, such as field length and obstacle clearance requirements. Also, these models support airlines' management planning, making the selection of flap settings flexible to balance the runway performance according to fuel efficiency and safety margins under varying weather and aircraft conditions. In addition, flap performance models can be integrated into flight simulation and help optimize pilot training and provide realistic scenarios for the training of takeoff and landing decision-making. These applications show the fundamental role of flap modeling, which are pushing technical design and ensuring operational safety and efficiency.

2.4. Model Evaluation Metrics

When evaluating a model, accuracy is essential. It reflects how well the predictions match experimental or flight test results and helps check the model's robustness, such as variations in aircraft weight, weather, or runway surface. At the same time, applicability matters as well. One should consider whether the model can be extended to different aircraft types. Together, these measures ensure that the model is not only theoretically sound but also practical for engineering design and real-world operations.

3. Case Analysis: The Effects of Flap Angles on the Aerodynamic Performances of a Homebuilt Aircraft Wing Model

This case study deeply examines the research by Salam et al. on the aerodynamic characteristics of a homebuilt aircraft wing model based on the NACA 23012 airfoil. The central focus is understanding how different flap deflection angles affect the lift coefficient (C_L) and drag coefficient (C_D). By combining computational fluid dynamics (CFD) simulations with subsonic wind tunnel testing, the study delivers a thorough evaluation of these effects and offers practical insights for aircraft designers and aerodynamic engineers. The findings illustrate the trade-off between improved lift and increased drag, also highlight the critical role of flap optimization in real-world applications [8].

The NACA 23012 airfoil with moderate thickness-to-chord ratio ($t/c = 12\%$) was selected for its balanced performance in general aviation. The wing model which designed with a chord length of 1600 mm and a span of 290 mm represents a scale suitable for homebuilt aircraft applications. The investigation aims to quantify the impact of flap deflection on aerodynamic coefficients under realistic flight conditions while addressing gaps in earlier studies on comparable airfoils, such as the NACA 0012 and 4412 with flaps. Test conditions included a freestream velocity (U) of 40 m/s—corresponding to Reynolds numbers on the order of 4×10^6 , typical for low-speed aerodynamics—angles of attack (α) ranging from -5° to 20° , and flap angles (δ_f) from -15° to 45° . Negative flap settings were also examined to represent scenarios such as spoiler use or inverted configurations.

The work builds on foundational studies of plain flaps [1–10], emphasizing how deflection impacting airfoil camber, pressure distribution, and flow separation. The goals of the research were to validate CFD predictions against experimental data and to identify flap settings that achieve the best balance between lift enhancement and drag efficiency.

3.1. Methodology and Experimental Setup

3.1.1 CFD Simulations

For the computational setup, geometry modeling was carried out in Autodesk Fusion 360 Gambit 2.4.6, while Fluent 6.3.26 was used for simulations. This model was chosen for its accuracy in predicting separated flows around high-lift devices. The domain included a velocity inlet, pressure outlet, and no-slip walls. Pathline visualizations captured vortex structures at the trailing edge.

3.1.2 Wind Tunnel Experiments

Conducted at Hasanuddin University's Fluid Mechanics Laboratory, the subsonic wind tunnel featured a test section with dimensions suitable for the model. Equipment included a pitot tube for velocity profiling, manometer tubes for pressure measurements, and a model holder for precise α and δ_f adjustments. Calibration ensured airflow uniformity, and data acquisition repeated for the reliability.

Lift and drag forces were utilized with following formulas:

$$C_L = \frac{F_L}{\frac{1}{2}\rho U^2 A} \quad (7)$$

$$C_D = \frac{F_D}{\frac{1}{2}\rho U^2 A} \quad (8)$$

Where ρ is air density (1.225 kg/m^3 at sea level), A is the wing area. The lift-to-drag ratio (C_L/C_D) was derived to assess overall efficiency.

3.2. Results and Quantitative Analysis

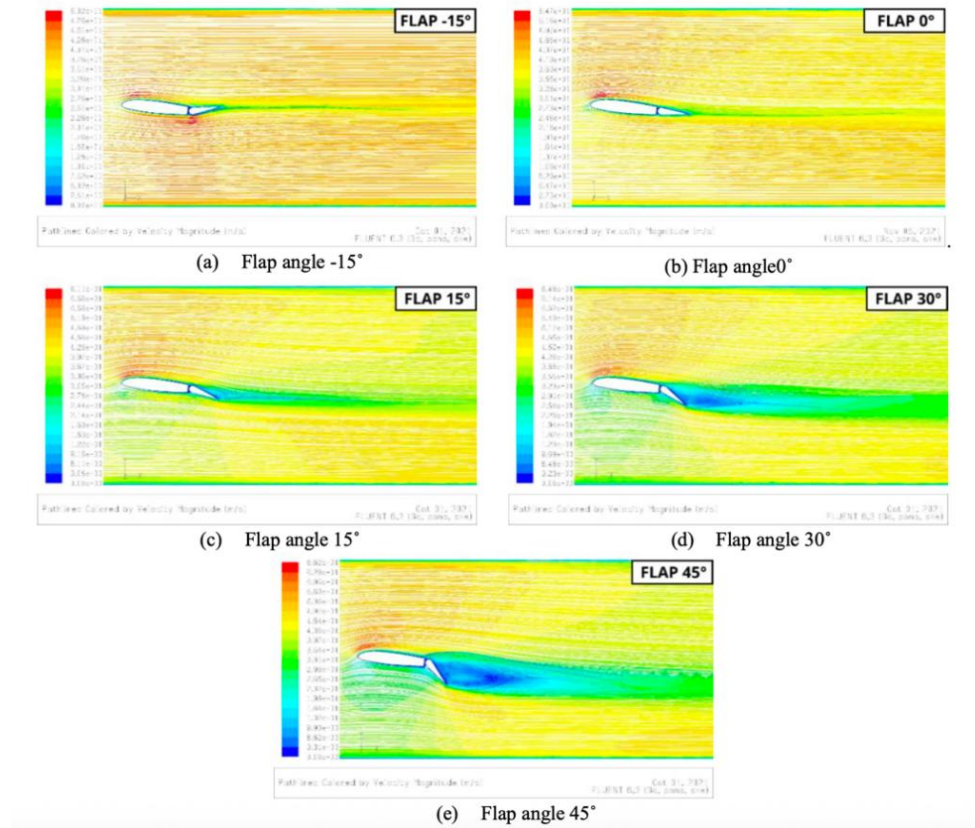


Fig 1. Flow characteristics on the airfoil with a 5° angle of attack and different variations of flap angle at a freestream speed of 40 m/s [8].

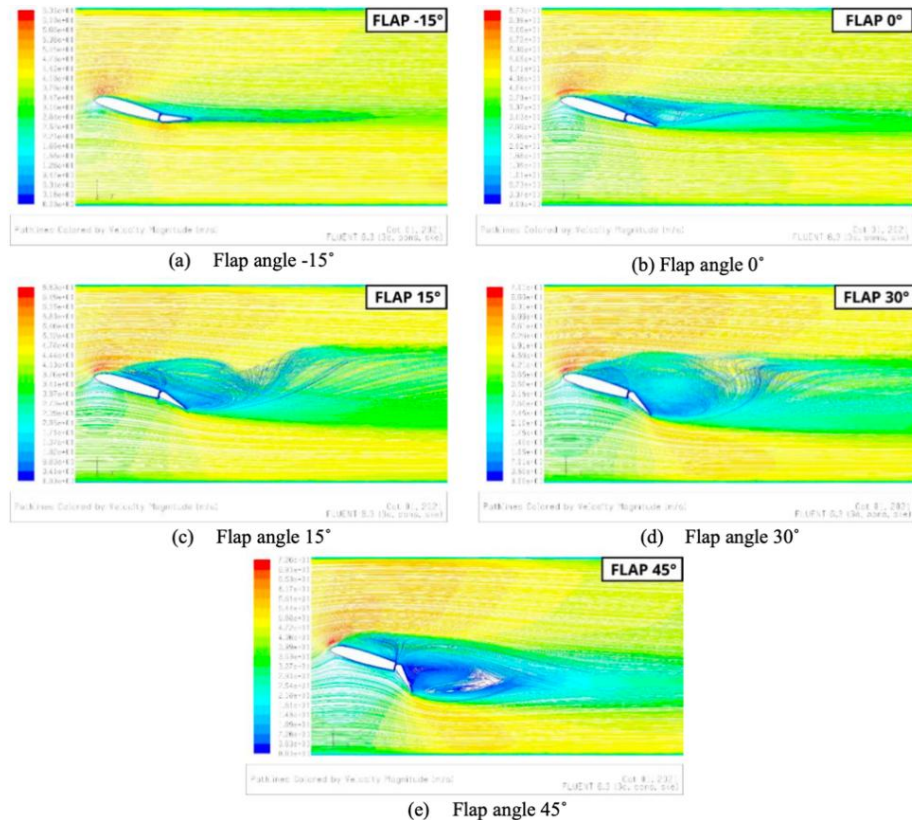


Fig 2. Flow characteristics on the airfoil with a 15° angle of attack and different variations of flap angle at a freestream speed of 40 m/s [8].

Table 1. Result of computation of lift coefficient (C_L) at freestream speed 40m/s in change of angle of attack (α) and flap angle [8]

$\alpha(\text{deg})$	Flap -15°	Flap 0°	Flap 15°	Flap 30°	Flap 45°
-5	-1.0926	-0.3547	0.3636	0.8401	1.0047
0	-0.6586	0.9155	0.8733	1.2498	1.4350
5	-0.1711	0.5934	1.3344	1.6283	1.8265
10	0.2844	1.0544	1.6070	1.8982	2.1273
15	0.7417	1.3998	1.6568	1.9987	2.3547
20	0.9155	1.3654	1.4935	1.6794	1.9475

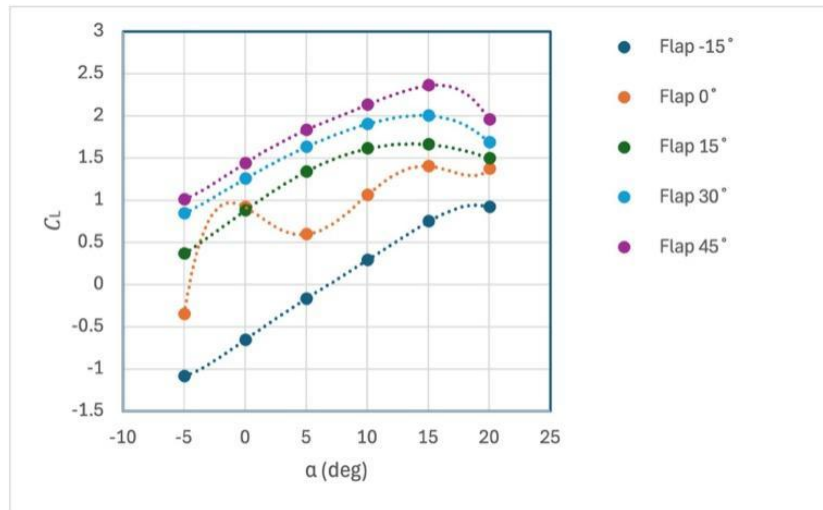


Fig 3. Flow characteristics on the airfoil with a 15° angle of attack and different variations of flap angle at a freestream speed of 40 m/s [8].

Table 2. Result of computation of coefficient drag (C_D) at freestream speed 40m/s in change of angle of attack (α) and flap angle [8]

$\alpha(\text{deg})$	Flap -15°	Flap 0°	Flap 15°	Flap 30°	Flap 45°
-5	0.1508	0.0616	0.0663	0.1336	0.2159
0	0.0821	0.0397	0.0939	0.1781	0.2818
5	0.0569	0.0648	0.1576	0.2601	0.3911
10	0.0772	0.1327	0.2524	0.3916	0.5553
15	0.1418	0.2604	0.4184	0.6441	0.8581
20	0.2609	0.4125	0.6459	0.9582	1.2563

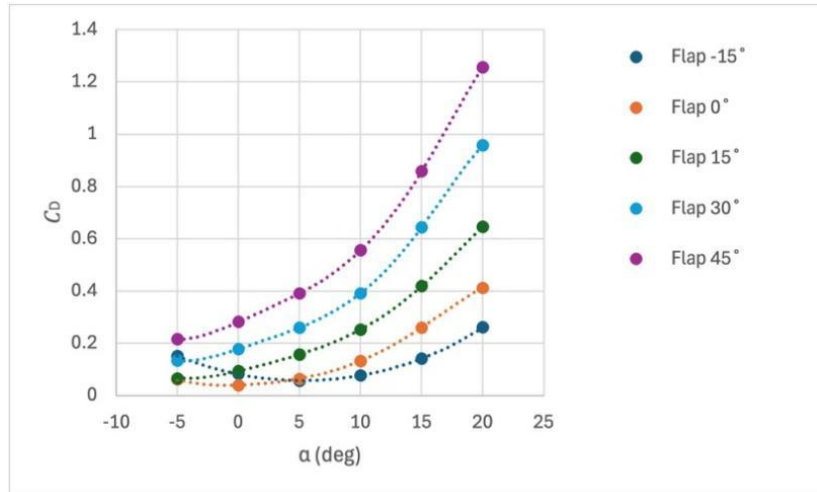


Fig 4. Graph of computed result of drag coefficient (C_D) with angle of attack (α) at freestream speed of 40 m/s and each level of change in flap angle [8].

Table 3. Result of computation of lift coefficient with the drag coefficient (C_L/C_D) at freestream speed 40m/s in change of angle of attack (α) and flap angle [8]

α (deg)	Flap -15°	Flap 0°	Flap 15°	Flap 30°	Flap 45°
-5	-7.2470	-5.7571	5.4883	6.2882	4.6538
0	-8.0236	2.4146	9.2982	7.0175	5.0927
5	-3.0052	9.1535	8.4651	6.2602	4.6704
10	3.6849	7.9481	6.3675	4.8477	3.8310
15	5.2297	5.3756	3.9595	3.1031	2.7439
20	3.5083	3.2570	2.3125	1.7526	1.5501

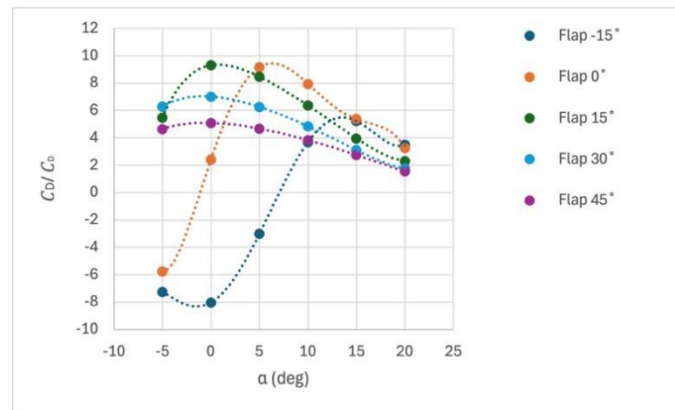


Fig 5. Graph of computational results for the ratio of lift coefficient and drag coefficient (C_L/C_D) and angle of attack (α) at a freestream speed of 40 m/s at each level of flap angle [8].

Table 4. Result of computation of lift coefficient with the drag coefficient (C_L/C_D) at freestream speed 40m/s in change of angle of attack (α) and flap angle [8]

α (deg)	Flap -15°	Flap 0°	Flap 15°	Flap 30°	Flap 45°
-5	-1.0083	-0.3417	0.3417	0.7833	0.9833
0	-0.6167	0.0917	0.8167	1.1750	1.4167
5	-0.1583	0.5750	1.2667	1.5167	1.7417
10	0.2750	1.0083	1.5084	1.8250	2.1084
15	0.7083	1.2750	1.5584	1.9084	2.2084
20	3.5083	3.2570	2.3125	1.7526	1.5501

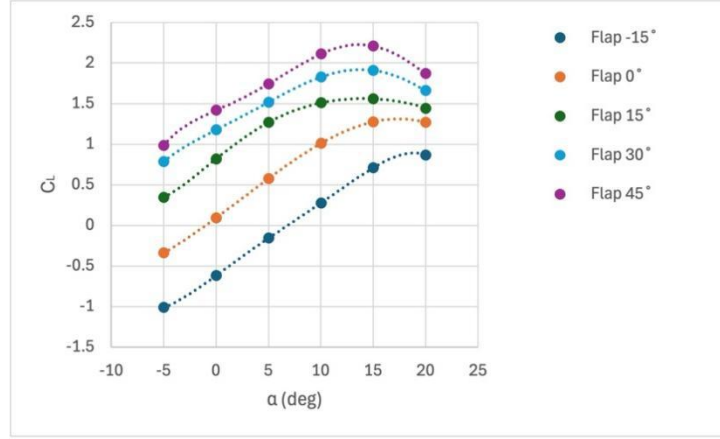


Fig 6. Graph of experimental results of the relationship between lift coefficient (C_L) and angle of attack (α) at a freestream speed of 40 m/s and each level of change in flap angle [8].

3.2.1 Lift Coefficient (C_L) Trends

As in Table 2 (CFD) and Table 4, C_L increases with both α and positive δ_f due to enhanced camber and circulation. At $\delta_f = 45^\circ$, maximum C_L reached 2.3547 (CFD) and 2.2084 (experimental) at $\alpha = 15^\circ$, representing a 150–200% increase over the clean configuration ($\delta_f = 0^\circ$). Negative flaps ($\delta_f = -15^\circ$) reduced C_L , yielding negative values at low α (-1.0926 at $\alpha = -5^\circ$), useful for drag modulation in descent. Stall angles decreased with higher δ_f (from 20° at $\delta_f = 0^\circ$ to 15° at $\delta_f = 45^\circ$), as illustrated in Figure 1 ($\alpha = 5^\circ$) and Figure 2 ($\alpha = 15^\circ$), where the separation zones expand with increasing flap angle. Figure 3 (CFD) and 6 (experimental) illustrate C_L vs. α curves for each δ_f , showing steeper initial slopes (lift curve slope $\frac{dC_L}{d\alpha} \approx 0.1 - 0.15$ per degree) for $\delta_f = 30^\circ - 45^\circ$.

3.2.2 Drag Coefficient (C_D) Trends

Table 1 (CFD) and Table 4 (experimental) indicate C_D increases quadratically with δ_f and α , driven by induced drag from vortices. Maximum C_D was 1.2563 (CFD) at $\alpha = 20^\circ$ and $\delta_f = 45^\circ$, a 500% rise from baseline. Negative flaps minimized C_D (e.g., 0.015 at $\alpha = 0^\circ$), enhancing glide efficiency. This trend is evident in Figure 4, where drag rises sharply at higher δ_f , and in the flow visualizations of Figures 1 and 2, where larger vortices appear with increasing angle of attack and flap angle.

Figure 3 plots C_D vs. α , highlighting drag discrepancy at $\delta_f > 30^\circ$, corroborated by lines in Figures 1 ($\alpha = 5^\circ$, minimal separation) and 2 ($\alpha = 15^\circ$, large trailing vortices).

3.2.3 Lift-to-Drag Coefficient (C_L/C_D) Analysis

Lift-to-Drag ratio (C_L/C_D) analysis: Table 3 (CFD) and Table 4 (experimental) show peak ratios at low α and moderate δ_f . The global maximum was 9.2982 (CFD) at $\alpha = 0^\circ$ and $\delta_f = 15^\circ$, dropping to < 2 at high α and δ_f due to drag dominance. Figure 5 clearly depicts this behavior, showing how the maximum ratio shifts toward lower α as δ_f increases. Figure 4 depicts C_L/C_D vs. α , with optimal shifting leftward (lower α) as δ_f increases, indicating flaps' role in low-speed efficiency but penalty in cruise, while Figure 6 provides experimental confirmation of this trend, showing good agreement with CFD results.

Flow visualizations revealed that higher δ_f makes boundary layer separation, forming Coanda-like effects at moderate angles but leading to massive vortices at extreme numbers, explaining the C_L plateau and C_D sudden surge.

3.3. Comparative Analysis and Theoretical Perspectives

Compared to referenced studies, such as Gurney flaps on NACA 0012 [8-9], this work shows similar C_L gains (20–25% per 10° δ_f increment) but higher C_D penalties in NACA 23012 due to

its thicker profile. Unlike multi-element flaps [10], single-flap configurations here exhibit earlier stall, suggesting potential for slotted flaps in future designs. The $k - \varepsilon$ model's limitations in capturing transition flows explain minor CFD-experimental mismatches, aligning with viscous ground-effect studies [11].

Theoretically, flaps alter pressure distribution (higher suction peak on upper surface), per Bernoulli's principle, boosting lift while increasing form drag. Reynolds number effects ($Re \approx 4 \times 10^6$) indicate scale-up challenges for full-size aircraft, where higher Re might delay separation.

4. Limitation & Future Outlooks

4.1. Limitations

4.1.1 Simplified Modeling Assumptions

Many aerodynamic models rely on linearized lift and drag coefficients or assume ideal stable conditions. While these simplifications are useful for building equations and models, they exclude nonlinear effects such as uniform air density and unsteady wake dynamics. These may lead to discrepancies between model predictions and actual aircraft performance.

4.1.2 Limited Representation of Conditions

Experiments are often conducted under controlled wind tunnel settings or computational simulations that assume a smooth, uniform airflow. However, in real flight, atmospheric turbulence and crosswinds play a significant role in influencing flap effectiveness. These factors are difficult to reproduce consistently in laboratory or numerical setups, which reduce the universality of results.

4.1.3 Scale and Accuracy Constraints in Simulations

Due to resource limitations, many models are validated using reduced-scale models or simplified geometries. Such approaches cannot fully capture three-dimensional flow phenomena or structural interactions experienced by full-scale aircraft, which constrains accuracy.

4.1.4 Operational Feasibility

Real aircraft performance is also influenced by operational factors such as pilots' actions, aircraft loading, and runway surface conditions. These elements are seldom considered in purely aerodynamic modeling frameworks, leaving a negligence between theoretical predictions and operational outcomes.

4.2. Future Outlooks

4.2.1 Incorporation of Real Flight Data

With the growing availability of flight data recorders and airline operational datasets, researchers can analyze flap behavior under authentic operating conditions instead of using wind tunnel and computational studies. This would improve the realism of predictions and allow models to be validated across a variety of weather, loading, and runway conditions.

4.2.2 Integration of Machine Learning Approaches

Data-driven models trained on flight records and simulation outputs can provide more precise and more practical models than traditional aerodynamic equations, which only rely on a few factors and ignore many significant real-world factors. Such methods may enhance predictive accuracy, particularly in capturing dynamic stall or instantaneous data.

4.2.3 Interdisciplinary Integration

Future research may combine aerodynamic modeling with structural, noise, and fuel-efficiency considerations, producing optimization strategies for flap deployment. This would align better with industry goals of reducing emissions, minimizing community noise, and improving sustainability.

4.2.4 Application in Next-generation Aircraft

As aviation transitions toward electric aircraft and unconventional designs, flap systems will require re-optimization. More advanced modeling frameworks will need to adapt to these novel configurations to ensure safe and efficient performance in the future.

Based on the limitations and future directions outlined above, the current model is still facing challenges such as oversimplification, operational variability, and limited environmental fidelity. However, advancements in computational power and data integration present promising opportunities to address these issues. By gradually incorporating greater real-world complexity, future research can move toward developing models that are not only more accurate but also practically applicable within the dynamic context of aviation.

5. Conclusion

This paper investigates the influence of flap deflection on aircraft takeoff and landing distances. The results demonstrate that flap angle is a critical factor in these phases of flight. Moderate deflections markedly increase the lift coefficient, also allows operations at lower speeds and reduce runway length. However, excessive deflections cause drags to rise disproportionately relative to lift, resulting in reduced efficiency and potential safety concerns. These findings emphasize the need to balance lift and drag in flap operation.

Furthermore, while simplified aerodynamic models effectively capture the fundamental lift–drag trade-off, discrepancies remain when applied to real-world conditions. External factors such as turbulence, weather variations, runway friction, and pilot control introduce complexities beyond the scope of theoretical models. Even so, the close alignment with experimental measurements and existing studies lends strong support to the validity of the trends identified in this work.

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