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Numerical Investigation of Aerodynamic Characteristics of Wings During Flap Retraction and Deployment

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Abstract:*The deployment and retraction of wing flaps significantly alter the airflow over an aircraft wing, leading to changes in surface pressure distribution. These variations, in turn, affect the aerodynamic force distribution, particularly the lift generated before and after flap actuation. Such changes can have a substantial impact on the aircraft's stability and control characteristics. This study presents a numerical investigation into the aerodynamic behavior of the Su-30MK2 wing under flap deployment and retraction conditions using the Ansys CFX computational fluid dynamics (CFD) software. The simulation results provide a quantitative evaluation of the flap system's effectiveness on the Su-30MK2 aircraft.*

Keywords:*Flap deployment; Flap retraction; Su-30MK2; Aerodynamic characteristics; Computational fluid dynamics (CFD); Ansys CFX; Pressure distribution; Lift force; Aircraft stability.*

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I. INTRODUCTION

Flaps are wing mechanization devices designed to increase the lift generated by the wing during takeoff, landing, climb, or descent, and are typically deployed at low flight speeds. They are located along the trailing edge of the main wing. When not in use, flaps are retracted into the wing; during operation, they are extended at larger deflection angles and may even move outward from the wing structure. Changing the flap deflection alters the camber of the airfoil, while flap extension increases the effective wing area—both contributing to enhanced lift generation. Additionally, flaps help improve aircraft stability and balance during low-speed flight.

Figure 1. A plain flap installed on the wing of a Cessna 172

Figure 2. A split flap installed on the wing of an Avro Lancaster

Figure 3. Multi-segmented flaps on the wing of a Boeing 737

Figure 4. Leading-edge slats and multi-element trailing-edge flaps on the wing of an Airbus A310

Modern aircraft are generally equipped with flaps, with various types commonly in use. For example, the Cessna 172 is fitted with plain flaps (Figure 1); the Avro Lancaster uses split flaps (Figure 2); the Boeing 737 is equipped with two multi-segmented flaps on each wing, capable of both extension and angle adjustment (Figure 3); and the Airbus A310 incorporates both multi-element trailing-edge flaps and leading-edge slats (Figure 4).

II. THEORETICAL BASIS

2.1 Geometric Parameters of the Wing and Flap Under Investigation

To investigate the variations in aerodynamic characteristics during flap retraction and deployment, the wing of the Su-30MK2 aircraft is utilized (Figure 5). This wing features a rotating-type flap symmetrically arranged along the aircraft's longitudinal axis (Figure 6). The geometric parameters are as follows [1]:

a. Wing geometric parameters:

Wing area: 62.03 m²; Wingspan: 14.7 m; Aspect ratio: $\lambda = 3.5$; Leading edge sweep angle: $\chi = 42^0$; Trailing edge sweep angle: $\chi = 15^0$; Airfoil profile: P44.

b. Flap geometric parameters:

Root chord: 0.91 m; Tip chord: 0.44 m; Span (one side): 2.92 m; Airfoil profile: P44

Figure 5. A flaperon installed on the wing of a Su-30MK2

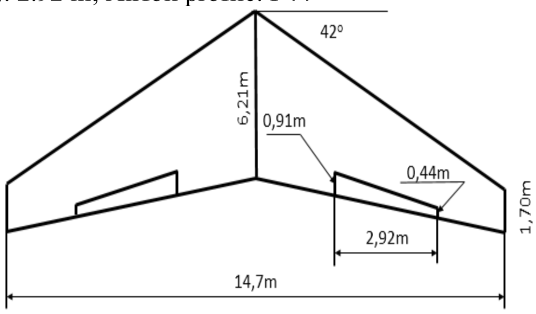

Figure 6. Geometric parameters of the wing and the flap.

2.2. Simulation and Calculation of Aerodynamic Parameters of the Wing

The Ansys CFX software was employed as a tool for model design, mesh generation, boundary and initial condition setup [2], numerical computation, and post-processing of results. The wing model and computational domain were constructed as shown in Figure 7. The mesh was generated using the Meshing tool in Ansys CFX [3], with tetrahedral volume elements and triangular surface elements, as illustrated in Figure 8.

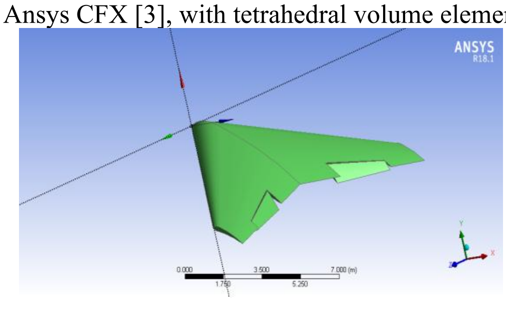

Figure 7. Wing model with the flap in the deflected position

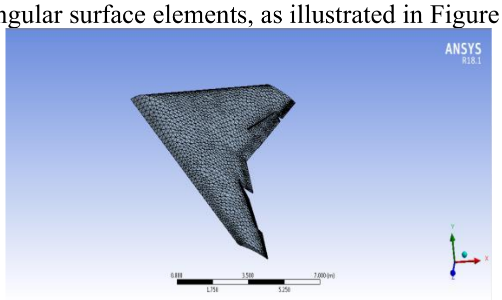

Figure 8. Surface mesh of the wing and the flap

The selected flight velocity is V=123,5 m/s, and the operating altitude is H=10 m. Atmospheric parameters at this altitude, based on standard conditions, include: air density ρ=1,225 kg/m3 and pressure p=101325 Pa.

The boundary conditions [2] are defined as follows:

- At the far-field upstream boundary (Figure 9): $\rho = \rho_\infty$; $p = p_\infty$, $T = T_\infty$,
- At the internal solid boundaries (Figure 11), the no-penetration condition is applied: $V_n = 0$.
- The upper, lower, left, and right boundaries are defined according to Figure 10;
- The downstream (outlet) boundary is shown in Figure 12.

Given the low-speed nature of the flow, a turbulence model is employed with a turbulence intensity of 5%.

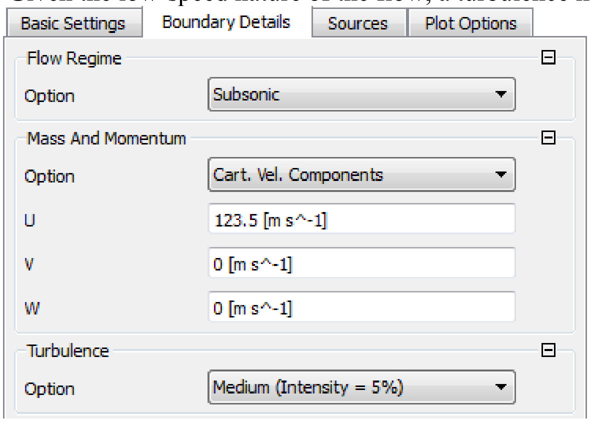

Figure 9. Inlet boundary condition.

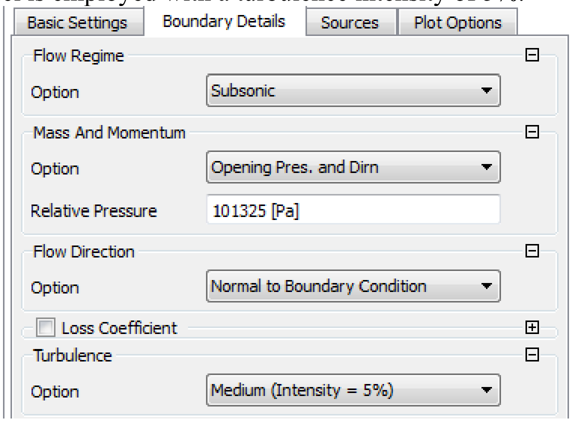

Figure 10. Boundary conditions at the top, bottom, left, and right boundaries.

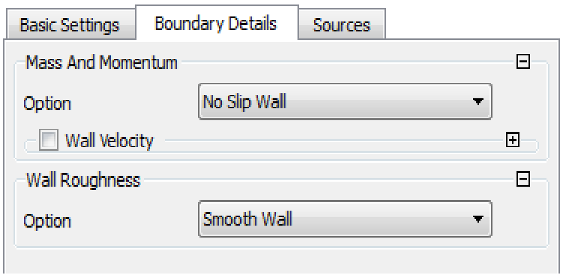

Figure 11. No-penetration condition at the internal solid boundaries.

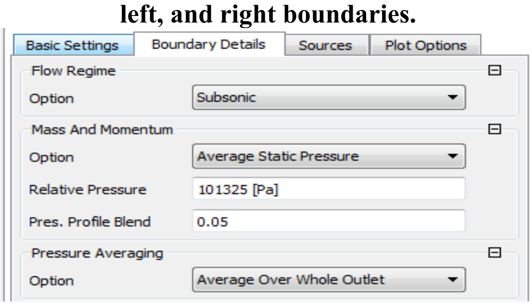

Figure 12. Outlet boundary condition.

III. RESULTS AND DISCUSSION

3.1. Numerical Results

The numerical simulations were conducted over a range of angles of attack α from -10^0 to 30^0, with an increment Δα of 5^0, for both flap-retracted and flap-deployed configurations. Following the computations using Ansys CFX [2], the obtained results include pressure distribution on the wing surface, as well as streamlines around and downstream of the wing (Figure 13). In addition, plots showing the variation of drag coefficient C_x, lift coefficient C_y, and aerodynamic efficiency K with respect to angle of attack α for both flap configurations are presented in Figures 14, 15, and 16.

Based on the numerical simulation results [4], the plotted dependencies exhibit behavior consistent with physical laws. As shown in Figure 14, the lift coefficient C_y versus angle of attack α curve shifts to the left when the flaps are deployed. This indicates that, for the same angle of attack, the value of C_y is higher in the flap-deployed configuration compared to the flap-retracted case. The graph also shows that both the maximum lift coefficient and the corresponding stall angle are greater when the flaps are deployed.

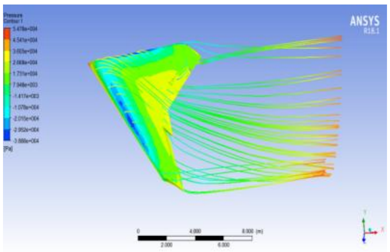

Figure 13. Pressure distribution and streamlines over and behind the wing

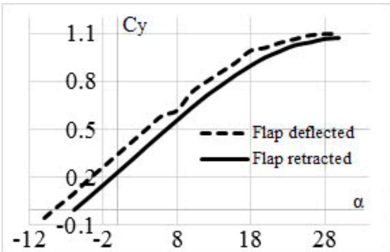

Figure 14. Variation of the lift coefficient Cy with the angle of attack α

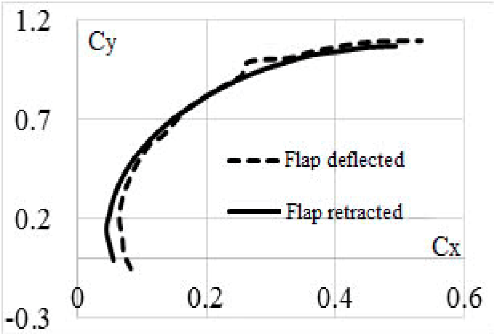

Figure 15. Lift-drag polar plot of the wing

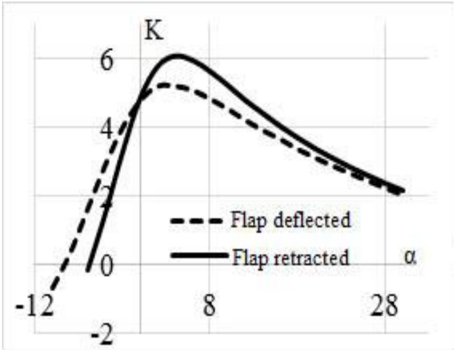

Figure 16. Variation of the lift-to-drag ratio with the angle of attack.

3.2.Evaluation of the effect of flap deflection angle on the aerodynamic characteristics of the wing.

Based on the previously described model construction, meshing strategy, simulation method, and results, the influence of flap deflection angle on the aerodynamic characteristics of the wing is investigated. In this study, the flap deflection angle α_{flap} is varied from 0^0 to 30^0 in increments of 5^0, while the wing angle of attack is kept constant at 0^0.

Simulations were carried out using Ansys CFX, following the same procedure as described earlier. For each flap deflection angle, a separate 3D model was built, meshed, and computed under identical boundary and initial conditions. After completing the simulations, the resulting data were used to generate plots showing the variation of lift coefficient with flap deflection angle (Figure 17), and the variation of drag coefficient with flap deflection angle (Figure 18).

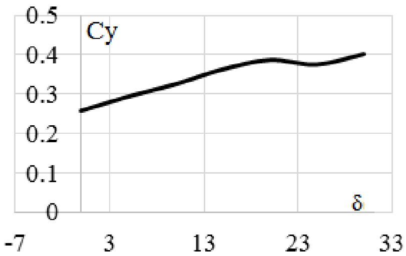

Figure 17. Dependence of the lift coefficient of the wing on the flap deflection angle

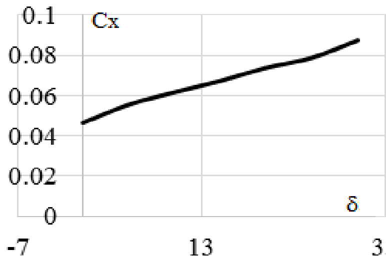

Figure 18. Dependence of the drag coefficient of the wing on the flap deflection angle.

From Figures 17 and 18, it can be observed that the lift coefficient C_y increases linearly within the flap deflection angle range α_{flap} from 0^0 to 20^0, accompanied by a corresponding increase in the drag coefficient C_x. As the flap deflection angle continues to increase beyond 20^0, the lift coefficient C_y initially decreases before rising again, while the drag coefficient C_x continues to increase. This behavior aligns with physical expectations: increasing the flap deflection enhances the wing camber, thereby increasing lift; however, exceeding a critical

IV. CONCLUSION

This study has presented a simulation-based methodology for evaluating the aerodynamic characteristics of an aircraft wing under varying flap deflection angles. Using Ansys CFX software, the influence of flap deflection on the aerodynamic behavior of the Su-30MK2 wing was investigated. Graphs showing the dependency of lift coefficient C_y and drag coefficient C_x on flap deflection angle were developed. Based on the analysis, the effectiveness of flap control was assessed, leading to the identification of an optimal flap deflection angle range.

Conflict of interest

There is no conflict to disclose.

FUTURE DEVELOPMENT

Future research will extend the current simulation framework to incorporate three-dimensional modeling of the complete aircraft configuration. This enhancement will allow for a more detailed assessment of the aerodynamic interactions among the wing, fuselage, and empennage across a range of flap deflection angles. Furthermore, transient flow simulations will be performed to capture unsteady aerodynamic phenomena associated with flap deployment and retraction, particularly under maneuvering flight conditions. Experimental validation, through wind tunnel testing or flight data analysis, will also be considered to assess the reliability and accuracy of the numerical predictions. These advancements are expected to enhance the fidelity of the computational model and contribute to the development of more effective aerodynamic control strategies for aircraft such as the Su-30MK2.

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