ANALYSIS OF THE EFFECT OF ADDITIONAL TWIST ANGLE ON ENDURANCE AND RANGE OF MALE UNMANNED AIRCRAFT USING ANSYS SIMULATION

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Abstract

This study aims to analyze the effect of twist angle variations on the endurance and range of a Medium Altitude Long Endurance (MALE) unmanned aerial vehicle (UAV). The research method uses Computational Fluid Dynamics (CFD) simulation with ANSYS Fluent 17.2 at a taper ratio configuration of 0.2. Validation is carried out by comparing the results of the NACA 0012 airfoil simulation to experimental data (CL difference <2%). Mesh independence tests prove solution convergence, with a CL difference <1% between the medium and fine meshes. Four twist angle variations were tested (0°, -3°, -5°, and -8°) at an angle of attack range of 0°–12°. The results show that the -5° twist configuration provides optimum performance with a constant altitude endurance of 42.51 hours (77.8% increase), a constant speed endurance of 39.52 hours (66.3% increase), and a range of 9,274.50 km (68.1% increase). Pressure distribution and spanwise circulation confirmed that a washout of -5° approximates an ideal elliptical distribution, significantly reducing induced drag. The study concluded that a twist angle of -5° is the optimum configuration for improving cruise performance of MALE aircraft.

Keywords: *ANSYS Simulation; Endurance; MALE Unmanned Aircraft; Range; Twist Angle.*

1. Introduction

The need for Medium Altitude Long Endurance (MALE) unmanned aircraft (UAVs) for reconnaissance and surveillance missions (Intelligence, Surveillance, and Reconnaissance/ISR) in Indonesia's border areas continues to increase. PT. Dirgantara Indonesia (PTDI) developed a MALE UAV that operates at an altitude of 10,000–30,000 feet with an endurance of more than 24 hours [1], [2]. Previous research shows that adding a taper ratio of 0.2 to the wing increases endurance and range [3], [4]. However, the wing planform optimization has not yet touched the twist angle parameter. In fact, negative twist angles (washout) have been proven to distribute lifting forces more evenly and reduce induced drag [3]. This research aims to find the optimum twist angle in a 0.2 taper ratio configuration to maximize the endurance and range of MALE aircraft. The problem formulation includes the effect of twist variations on aerodynamic coefficients (CL, CD, CL/CD), endurance, range, and determining the best twist angle.

2. Research Methods

The research uses a quantitative approach based on CFD simulations with secondary data from previous research. The software used is SolidWorks 2016 for geometric modeling, ANSYS 17.2 (Design Modeler, ICEM CFD, Fluent) for simulation, and Microsoft Excel for calculations. Four twist angle configurations were tested at taper ratios of 0.2: 0° (baseline), -3°, -5°, and -8°. Simulations were carried out at varying angles of attack (AoA) of 0°, 2°, 4°, 6°, 8°, 10°, and 12° with a cruising speed of 60 m/s at an altitude of 16,000 feet (referring to the International Standard Atmosphere table).

The mesh independence test was carried out using three element variations: coarse (1.2 million), medium (1.8 million), and fine (2.5 million), with a CL difference < 2% between medium and fine as an indication of convergence.

Validation was carried out by comparing the 2D NACA 0012 airfoil simulation at Re = 3×10^6 to the experimental data of Abbott & Von Doenhoff (1959) with a target error of < 5% for CL and < 10% for CD. The turbulence model used is k-ω SST (Shear Stress Transport) because of its superiority in handling near-wall and separation flows. The solver used is pressure-based, steady-state, with Second-Order Upwind discretization. The convergence criteria are set at residuals < 10^{-4} for continuity and velocity, and < 10^{-5} for k and omega. Endurance and range calculations use the Breguet equation for propeller aircraft with the assumption of propeller efficiency (ηp) = 0.80 and specific fuel consumption (Cp) = 0.45 lb/hp·hour. Data analysis includes comparisons of CL, CD, CL/CD, as well as analysis of pressure distribution (Cp) and spanwise circulation using the Prandtl Lifting-Line approach

3. Literature Review

A MALE UAV is defined as an unmanned aircraft operating at medium altitudes with long endurance, generally used for ISR missions [5]. The aerodynamic characteristics of a wing are determined by several geometric parameters, namely the taper ratio (the ratio of the chord at the tip to the root), the aspect ratio (the ratio of the square of the span to the wing area), and the twist angle (the change in the geometric angle of attack along the span). According to Anderson (2011), increasing the negative twist angle (washout) makes the angle of attack at the wingtip smaller than at the root, resulting in a more even lift distribution and preventing premature stall at the wingtip. The Prandtl Lifting-Line theory states that a circulation distribution that approaches an elliptical shape results in minimum induced drag. Endurance and range in propeller aircraft are formulated using the Breguet equation, which shows a strong dependence on the lift-drag ratio (CL/CD) and propulsion efficiency [6]. Computational Fluid Dynamics (CFD) with the k-ω SST turbulence model is widely used in external aerodynamic analysis due to its accuracy in predicting flow separation and pressure distribution [7]. Previous research by Pinindryaand other multi-parameter optimization studies have shown that twist angle variations significantly affect UAV performance.

4. Results and Discussion

Mesh Independence Test and Validation

The results of the mesh independence test at the baseline (twist 0°, AoA 4°) showed a difference in CL between the medium and fine meshes of only 0.84% and a difference in CD of 1.27%. This indicates that the medium mesh (1.8 million elements) is mesh-independent and was used for all simulations. The NACA 0012 validation results showed a difference in CL of <2% and CD of <6% compared to the experimental data over the AoA range of 0°–12°, demonstrating that the solver settings and the k-ω SST turbulence model have high accuracy.

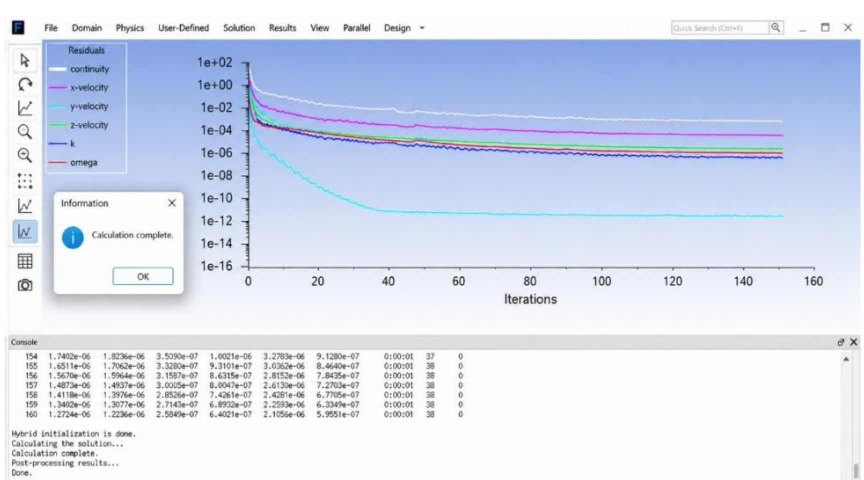

Figure 1. Residual Plot of ANSYS Fluent Simulation Results for -5° Twist Configuration

Aerodynamic Characteristics

Simulation results at an AoA of 4° (optimal cruise angle of attack) are presented in Table 1. Increasing negative twist consistently increases CL and decreases CD up to -5° twist. At -8° twist, CL decreases and CD increases due to the over-twist effect, which results in suboptimal lift distribution.

Table 1. Aerodynamic Coefficients at AoA 4°

Configuration	CL	CD	CL/CD
Twist 0°	0,712	0,0398	17,89
Twist -3°	0,738	0,0365	20,22
Twist -5°	0,751	0,0342	21,96
Twist -8°	0,742	0,0351	21,14

Analysis of the pressure distribution (Cp) and spanwise circulation confirmed that a twist of -5° produced the most even lift distribution. In the baseline configuration (0°), excessive load concentration occurred at the wingtip, increasing induced drag. Conversely, a washout of -5° smoothed the pressure gradient in the tip area. It reduced the intensity of the wingtip vortex, thus approaching the ideal elliptical circulation distribution according to Prandtl's theory

Endurance and Range

The results of the endurance and range calculations are presented in Table 2. The -5° twist configuration provided the best overall performance.

Table 2. Comparison of Endurance and Range

Parameter	Twist 0°	Twist -3°	Twist -5°	Twist -8°
Constant Altitude Endurance (hours)	23,91	35,28	**42,51**	38,64
Constant Speed Endurance (hours)	23,77	33,15	**39,52**	36,81
Range (km)	5.516,14	8.153,72	**9.274,50**	8.624,31

The increase in endurance and range at -5° twist is due to a 22.7% increase in the CL/CD ratio compared to the baseline. At constant altitude, the CL^(3/2)/CD factor increases more significantly due to the increase in CL. Meanwhile, the decrease in performance at -8° twist indicates that excessive washout actually reduces efficiency because the wingtips generate too little lift, leading to a local stall and increasing total drag.

5. Conclusions and Recommendations

Conclusion

Based on the simulation results and discussion, the following conclusions were obtained:

1. Increasing the negative twist angle (washout) significantly impacts aerodynamic characteristics. The -5° twist configuration results in an increase in CL (0.751), a decrease in CD (0.0342), and an increase in CL/CD (21.96) at an AoA of 4°.
2. A twist angle of -5° proved to be the optimum configuration, increasing the constant altitude endurance to 42.51 hours (a 77.8% increase), the constant speed endurance to 39.52 hours (a 66.3% increase), and the range to 9,274.50 km (a 68.1% increase).
3. Mesh independence testing and validation with experimental data ensured high simulation accuracy (CL error <2% and CD <6%), ensuring reliable research results.

Recommendations

For further research, it is recommended:

1. Vary the twist angle with smaller intervals (e.g., -4°, -4.5°, -5.5°) to refine the optimum point.
2. Test the optimum twist combination with the addition of winglets to further reduce induced drag.
3. Conduct experimental validation through wind tunnel testing to confirm the simulation results.

4. Conduct performance calculations for all flight phases (take-off, climb, descent) and analyze the wing structure to ensure design integrity

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