Analysis of Taper Ratio and Sweep Angle Effects on Flight Duration of the Wulung UAV Using OpenVSP

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Abstract - **The Wulung UAV has been carefully engineered to facilitate various surveillance and reconnaissance missions in Indonesian airspace. Flight endurance emerged as an important determinant of the UAV's overall performance. This research utilizes OpenVSP software, an open-source tool for aerodynamic simulation, to assess the design of the Wulung UAV. The research involves developing a UAV model featuring various taper ratio and sweep angle configurations using OpenVSP. Furthermore, aerodynamic simulations were conducted to ascertain the flight duration corresponding to each configuration. The analysis results show that the combination of a reduced taper ratio and an increased sweep angle with a value constraint can increase the flight duration of the Wulung UAV due to an increase in the lift-to-drag ratio. OpenVSP has demonstrated its performance as an instrument for preliminary analysis of the impact of wing design on UAV performance, and the results of this study can provide a basic foundation for optimizing the design of the Wulung UAV to achieve superior flight endurance.**

Keywords: UAV Wulung, Taper Ratio, Sweep Angle, OpenVSP, Drag Force, Lift Force.

I. INTRODUCTION

Taper ratio and sweep angle significantly affect aircraft aerodynamic performance and flight duration. Studies show that a taper ratio of 0.4 to 0.6 optimizes drags and lifts coefficients [1]. In UAVs, a taper ratio of 0.4 is able to maximize the lift-to-drag ratio, improve aerodynamic efficiency and reduce energy consumption [2]. Sweep angle also affects the lift-to-drag ratio, which is a key indicator of flight efficiency. An increase in sweep angle can increase the lift-to-drag ratio by 15% in high-speed flight which can optimize supersonic performance [3]. Conversely, at subsonic speeds, higher sweep angles generally reduce the lift-to-drag ratio which adversely affects flight duration [4]. A sweep angle of -15° can maximize the lift-to-drag ratio [5], while a proper sweep angle in supersonic and transonic conditions is essential to minimize drag [6]. The selection of wing configuration and airfoil shape is very important to optimize the lift-to-drag ratio where simulation tools such as XFLR5 can help in evaluating drag and lift coefficients at various angles of attack [7].

This research shows that the optimal taper ratio and sweep angle combination increases the flight efficiency of the UAV. Winglets with a taper ratio of 0.2 and a sweep angle of 30º produce superior aerodynamic characteristics [8]. The ideal taper ratio for a given sweep angle depends on the desired aerodynamic performance, with a low taper ratio improving stability at high sweep angles and increasing lift in post-stall laminar flow conditions [9]. Thus, this study aims to analyze the impact of taper ratio and sweep angle variations in the Wulung UAV on flight duration through OpenVSP simulation, aiming to improve the UAV design for efficiency and flight duration.

II. RESEARCH OBJECT

This research uses the Wulung UAV model, an Indonesian-made drone for strategic surveillance and data collection missions, both military and civilian. With the ability of long flight duration being an important requirement, aerodynamic design optimization is needed to extend flight time and improve operational efficiency.

The taper ratio is the ratio between the root chord and tip chord lengths of an aircraft wing that affects lift distribution, drag characteristics, and flight efficiency. When the taper ratio is lower, the lift distribution approaches an ideal elliptical shape, which directly helps to reduce induced drag. With this reduction in drag, aerodynamic efficiency improves, allowing the aircraft to operate more optimally, reduce energy consumption, and achieve better flight performance [10].

In addition, sweep angle also plays a crucial role in influencing the aerodynamic characteristics of the aircraft. Larger wing sweep angles are generally more suitable for aircraft operating at supersonic speeds as they reduce shock waves and supersonic drag. Conversely, a smaller sweep angle will result in a higher lift-to-drag ratio, which makes the aircraft more efficient, especially during critical phases such as takeoff, landing, and low-speed flight [11].

The Lift coefficient (Cl) and drag coefficient (Cd) are key parameters in aerodynamics that greatly affect aircraft performance. Lift coefficient describes the lift generated by a wing relative to air density, speed, and reference area, which is important for an aircraft's ability to take off, fly, and land [12]. On the other hand, drag coefficient measures the drag experienced by the aircraft during flight, which has a direct effect on fuel efficiency and engine power required to maintain a certain speed [13].

The lift-to-drag ratio is an important indicator in measuring the aerodynamic efficiency of an aircraft, as it shows how much lift is generated compared to the drag experienced. The higher this ratio, the more efficient the aircraft is at generating lift with less drag. This directly contributes to flight endurance and fuel efficiency. For unmanned aircraft (UAVs), the optimization of the lift-to-drag ratio is crucial as it enables the extension of operational range as well as the reduction of energy consumption, thereby improving the overall performance of the aircraft as well as the ability to perform various missions [14].

In this aerodynamic analysis, Open Vehicle Sketch Pad (OpenVSP) was used in conjunction with VSPAERO which utilizes the Vortex Lattice Method (VLM). VLM works by breaking the aircraft geometry into small panels from which the lift and drag distributions are calculated. Vortices are placed in each panel to represent the airflow around the wing and fuselage surfaces. This simulation uses a potential flow approach which means that changes in airflow velocity around the aircraft surface are analyzed based on the vortex distribution. By varying the angle of attack, OpenVSP can predict the distribution of lift and drag under various flight conditions. This provides a complete picture of the aerodynamic performance of the aircraft which includes changes in efficiency and stability based on wing design and other configurations.

III. DATA FOR ANALYSIS

Table 1 and Table 2 present information on the weight and performance of the Wulung UAV. Table 1 includes weight details, while Table 2 summarizes the UAV's performance, which is important for assessing its operational capabilities.

Table 1: Weight of the Wulung UAV

No.	Parameter	Value
1	Max. take-off weight	125 kg
2	Max.weight of the structure	92 kg
3	Max.payload	20 kg
4	Max. fuel	26 kg

Table 2: Performance of the UAV Wulung

No.	Parameter	Value
1	Max.cruising speed	70 Kts
2	Operating speed	50 Kts
3	Take-off distance	425 m
4	Flying endurance	3 hours
5	Landing distance	440 m

To understand the aerodynamic performance of the Wulung UAV, aircraft dimensions, such as wing size and body length, are important in determining efficiency, stability, and maneuverability. Figure 1 shows the geometry of the UAV with a taper ratio of 0.4 and a sweep angle of 30°.
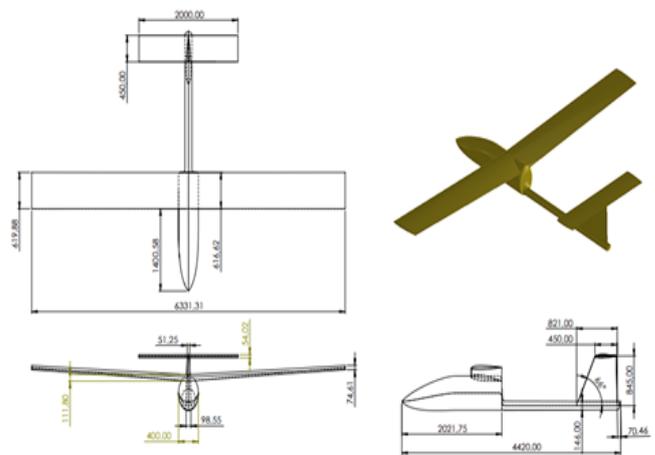

Figure 1: Engineering drawing of the Wulung UAV

In this analysis, variations in taper ratio of 1, 0.8, 0.6, and 0.4 and sweep angle of 10°, 20°, 30°, and 40° are considered to evaluate their effects on the aerodynamic performance of the UAV. Changes to these two parameters aim to understand how the combination of taper ratio and sweep angle affects flight efficiency, lift and drag distribution, which ultimately plays an important role in determining the flight duration of the Wulung UAV.

In this study, the assumptions and simulation conditions used are very important to determine the validity of the analysis results obtained. Therefore, Table 1 describes the various assumptions made as well as the simulation conditions applied, which will form the basis for further modeling and analysis.

Table 3: Simulation Boundary Condition

No.	Parameter	Value
1	Speed	25.72 m/s
2	Flow type	Steady state
3	Fluid density	1.125 kg/m3
4	Flow model	Ideal potential flows
5	Temperature	15°C
6	Compressibility	Incompressible

Each taper ratio and sweep angle variation will be modeled using OpenVSP, resulting in a total of 16 models. Each model will be simulated using VSPAERO with the Vortex Lattice Method (VLM), involving 50 iterations and considering appropriate boundary conditions. The simulation results of each variation will be compared based on the lift-to-drag (L/D) ratio and angle of attack (AoA) values to determine the best aerodynamic performance.

IV. RESULT AND DISCUSSION

In this section, the results of the analysis on the effect of taper ratio and sweep angle on the flight duration of the Wulung UAV will be presented. The results obtained from the simulation using OpenVSP will discuss the relationship between the tested variables and the lift to drag ratio. Figure 2, Figure 3, Figure 4, and Figure 5 show the relationship between taper ratio and sweep angle to the lift to drag ratio.
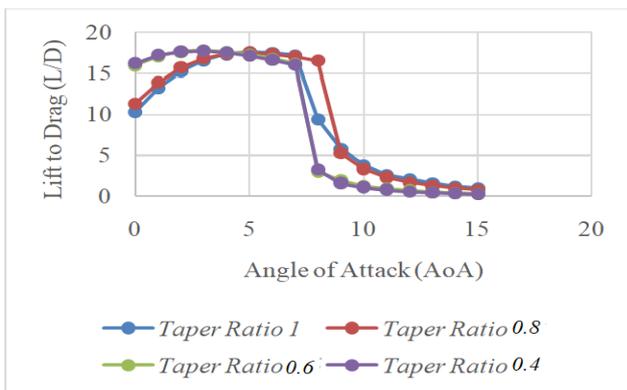

Figure 2: L/D graph for 0° of sweep angle

In Figure 2, the L/D ratio peaks at an AoA of about 5° for a high taper ratio and 3° for a low taper ratio. After this peak, the L/D ratio decreases sharply, especially above 8° AoA, which can cause stall. A low taper ratio gives better L/D performance at low AoA, while a taper ratio of 0.8 shows the best performance at high AoA. The maximum L/D value is almost the same for all taper ratios, but the low taper ratio reaches the maximum value faster at low
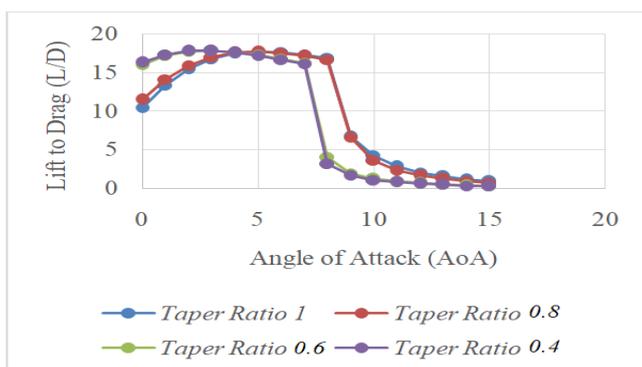

Figure 3: L/D graph for 10° of sweep angle

In Figure 3, the L/D ratio peaks at an AoA of about 5° for high taper ratio, and 3° for low taper ratio at a sweep angle of 10°. After that, the L/D ratio decreases sharply above an AoA of 7° for low taper ratio, and 8° for high taper ratio. Taper ratio 1 is almost equivalent to taper ratio 0.8, while taper ratio 0.6 is similar to 0.4. Low taper ratio shows a sharper L/D decrease at high AoA, similar to sweep angle 0°, which suggests low taper ratio is less efficient at high AoA with sweep angle 10°.
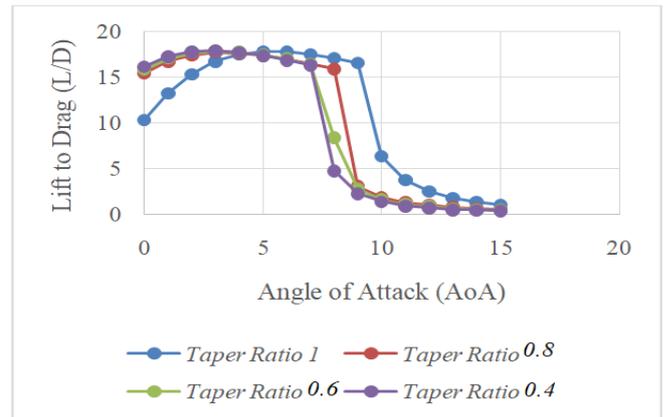

Figure 4: L/D graph for 20° of sweep angle

Figure 4 shows that taper ratio 1 performs worse at AoA 0° to 3° resulting in a lower lift-to-drag ratio than smaller taper ratios. All taper ratios reach their maximum L/D at 3° AoA, except taper ratio 1 which reaches its maximum at 5° AoA with a value of about 17. After the peak, the L/D ratio decreases. Taper ratios of 0.6 and 0.4 stall at 8° AoA, while higher taper ratios stall at 9° to 10° AoA. This indicates the small taper ratio is less efficient at high AoA.
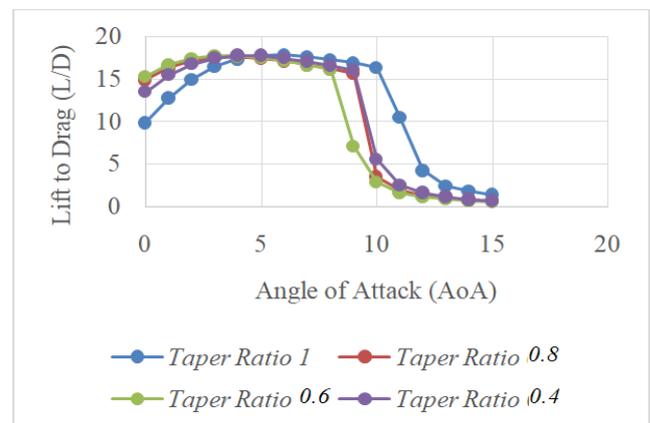

Figure 5: L/D graph at 30° of sweep angle

Figure 5 shows that taper ratios of 0.8, 0.6, and 0.4 produce similar L/D values at AoA 1° to 5°, with the high taper ratio achieving maximum L/D at AoA 3°-4°, while taper ratio 1 at AoA 6°. The decrease in L/D is more significant at low taper ratios. Taper ratio 1 stalls at AoA above 10°, while

the smaller taper ratio stalls at AoA 8°-9°. Taper ratio 1 is more efficient at high AoA, while taper ratio 0.4 is more efficient at low AoA.

Table 4: Lift to drag maximum value and angle of attack

AoA	Configuration	L/D	Original configuration	L/D
0	TR 0.4 & SA 10	16.33480	TR 1 & SA 0	10.36261
1	TR 0.4 & SA 10	17.34053	TR 1 & SA 0	13.23429
2	TR 0.4 & SA 10	17.80975	TR 1 & SA 0	15.30640
3	TR 0.4 & SA 20	17.91250	TR 1 & SA 0	16.63294
4	TR 0.4 & SA 30	17.81148	TR 1 & SA 0	17.34367
5	TR 1 & SA 20	17.82146	TR 1 & SA 0	17.59297
6	TR 1 & SA 30	17.83344	TR 1 & SA 0	17.51151
7	TR 1 & SA 30	17.65548	TR 1 & SA 0	17.21005
8	TR 1 & SA 30	17.29779	TR 1 & SA 0	9.40382
9	TR 1 & SA 30	16.84485	TR 1 & SA 0	5.76835
10	TR 1 & SA 30	16.32071	TR 1 & SA 0	3.77848
11	TR 1 & SA 30	10.52661	TR 1 & SA 0	2.7985
12	TR 1 & SA 30	4.28057	TR 1 & SA 0	2.00796
13	TR 1 & SA 30	2.44873	TR 1 & SA 0	1.51132
14	TR 1 & SA 30	1.87460	TR 1 & SA 0	1.14845
15	TR 1 & SA 30	1.41742	TR 1 & SA 0	0.93969

Table 4 shows the maximum lift-to-drag. At an AoA of 1°-4°, a taper ratio of 0.4 with sweep angles of 10°, 20°, and 30° produces the highest L/D, while at an AoA of 5°-15°, a taper ratio of 1 with a sweep angle of 30° excels. These values will be compared with the original configuration (taper ratio 1 and sweep angle 0°), where the Wulung UAV flew for 3 hours, to see the difference in flight duration.

Based on the data in Table 4, the comparison between the maximum lift-to-drag value and the original configuration at each angle of attack results in the flight duration of the Wulung UAV for each angle of attack, as shown in Figure 6.
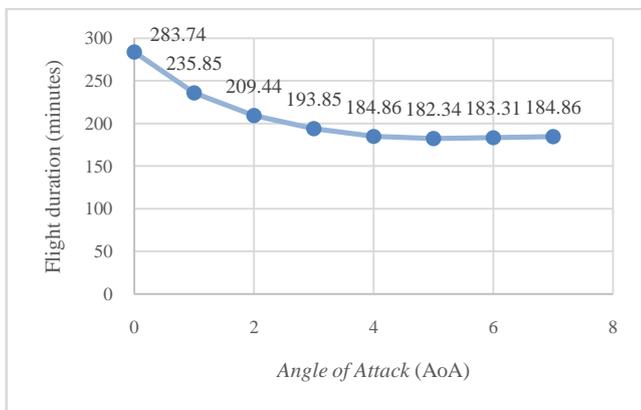

Figure 6: Maximum flight duration for each angle of attack

Figure 6 shows that the taper ratio and sweep angle configurations affect the flight duration of the Wulung UAV. The Wulung UAV normally flies for 180 minutes, but with

the new configuration it can reach 283.74 minutes, although this comparison is less relevant as it is based on the maximum L/D at 0° AoA, where the original configuration would stall. A more relevant comparison is at 2° AoA, where the flight duration reaches 209.44 minutes with a taper ratio of 0.4 and sweep angle of 10°.

V. CONCLUSION

The analysis shows that lower taper ratios (0.6 and 0.4) achieve maximum L/D at 3° AoA, while taper ratios of 1 and 0.8 require higher AoA to achieve maximum L/D. A high taper ratio provides good L/D at high AoA, but the optimal configuration is one that achieves maximum L/D at low AoA. A higher sweep angle generally increases L/D, but it is not always optimal if it is too high. The best configuration extended the flight duration to 209.44 minutes, showing that the right combination of taper ratio and sweep angle can improve flight efficiency.

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