Wing configuration on Wind Tunnel Testing of an Unmanned Aircraft Vehicle

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Abstract. Control surface of an Unmanned Aircraft Vehicle (UAV) consists of flap, aileron, spoiler, rudder, and elevator. Every control surface has its own special functionality. Some particular configurations in the flight mission often depend on the wing configuration. Configuration wing within flap deflection for takeoff setting deflection of flap 20° but during landing deflection of flap set on the value 40°. The aim of this research is to get the ultimate $C_{L\text{max}}$ for take-off flap deflection setting. It is shown from Wind Tunnel Testing result that the 20° flap deflection gives optimum $C_{L\text{max}}$ with moderate drag coefficient. The results of Wind Tunnel Testing representing by graphic plots show good performance as well as the stability of UAV.

1. Introduction
The research development of new aircraft design for both manned and unmanned aircraft using wind tunnel test is a useful method to get the desired design. This paper discusses the result of wing configuration test of Unmanned Aircraft Vehicle (UAV). It is common that before an UAV’s prototype come to manufacture process, it should be known the aerodynamic characteristics, stability and performance provided an estimate aerodynamic characteristics to be done in the design phase simulation. However wind tunnel testing should be done to confirm the result of simulation, especially on the high Angle of Attack (AOA). An aircraft models installed in the wind tunnel which is connected to the external balance by the wing struts was carried out. An aerodynamic forces propelled by wind blows in subsonic regime at a speed of 65 meter per second was measured by the external balance.

A Wind Tunnel Testing (WTT) facility was used to do the test. This facility is parts of National Laboratory for Aerodynamics Aero-elastics and Aero-acoustics (B2TA3), The Agency for the Assessment and Application of Technology (BPPT). The tasks of National Laboratory for Aerodynamics Aero-elastics and Aero-acoustics provide aerodynamic testing services to both the customers from domestic and abroad. By having a 3 x 4 m2 test section, both complete model and component of the aircraft such as two dimensional wing model, half model, tail performance and air intake test can be tested at B2TA3.

The performance of the aircraft on take-off conditions is influenced by several factors, such as aircraft weight, wing design, and control surface configuration. The Control surface of the UAV are generally consist of flap, aileron, elevator, rudder and tail. Among of them it could be combined
and use for some missions. Combination of main wing, slat and flap generally which are called by High Lift Devices (HLD) are very useful for to control an UAV or of all type aircraft on generating lift. HLD also will give an enormous influence on how long the distance takeoff and landing of an aircraft. Furthermore the diagram of component aircraft generally can be shown such as in the figure 1[1].

![Diagram component of the aircraft](image)

**Figure 1.** Diagram component of the aircraft

2. **Wind Tunnel Testing**

Aircraft flight mission are generally contain of take-off, ascending, cruise, decending and landing [2] and those mission were done for both commercial aircraft and UAV. Takeoff and landing are a cycle aspect during flight and to do safely it needs enough lifting force and for landing situation it also needs drag force. Those aerodynamics characteristic could be known by putting an aircraft or UAV model to the wind tunnel testing (WTT). The WTT arrangement and result will be explained including some condition description in the following chapter;

2.1. **Model Testing**

The model aircraft tested, is a 1: 5 scale test model with 3022 mm wingspan. The sketch of model testing is show in the figure 2.

![UAV model sketch](image)

**Figure 2.** UAV model sketch
Flap of the model lied in the inner control surface. Flap deflection usually setting in the same direction for the right part and the left part to generate more lifting force of an aircraft. Here are the nomenclature for the part of the UAV model for WTT:

W : Wing
B : Body
T : Tail

2.2. Measurement technic
Methods and techniques of measurement refers to [3],[4][7]. The test model installed using wing support strut that connects to the external balance. The position of the test model is upside down. Wind speed was 65 m / s. For testing the alpha polar, alpha angle is varied from -12° to 20°, with interval data collection every 1°. As for the angle beta, test model driven from -20° to 20° angle beta, with interval data collection every 1°. Installed test model can be seen in Figure 3.

Figure 3. UAV model installed in the test section

External balance place in the top of test section. The diagram of external balance show in the figure 4. Each external balance component has the capacity and measuring direction show in the table 1.[7].

Figure 4. Diagram of external balance
Furthermore the maximum allowable error calculate by the equation (1)[5]

\[ E_i = \left( 0.3 + 0.7 \frac{P_i}{P_{imax}} \right) 0.001 f P_{imax} \] (1)

Where
- \( E_i \): The maximum allowable error.
- \( P_i \): The force or moment on the \( K_i \)-th component.
- \( P_{imax} \): The maximum capacity of the \( K_i \)-th component.
- \( f \): A factor, which depend on the force component.

2.3. Forces and Moments Aerodynamics

The measurement characteristic aerodynamic of UAV test model in the wind tunnel measure three forces components i.e. lifts (\( L = \) lift), Drag (\( D = \) drag), Side Force (\( SF = \) side forces) and three components moments are pitching moment (\( M_p = \) pitch moment), a rolling moment (\( M_R = \) rolling moment), and yawing moment (\( M_Y = \) yaw moment ) [6],[7]. The six components of forces and moments can be formulated as follows:

Three component forces:

\[ L = \frac{1}{2} \rho V^2 S C_L \] (2)
\[ D = \frac{1}{2} \rho V^2 S C_D \] (3)
\[ SF = \frac{1}{2} \rho V^2 S C_Y \] (4)

Three component moments:

\[ M_p = \frac{1}{2} \rho V^2 S C_M \] (5)
\[ M_R = \frac{1}{2} \rho V^2 S C_{Roll} \] (6)
\[ M_Y = \frac{1}{2} \rho V^2 S C_{Yaw} \] (7)

Where \( \rho \): air density, \( V \): free stream velocity, \( S \): reference area, \( C_L \): Lift Coefficient \( C_M \): Pitch Moment Coefficient, \( C_D \): Drag Coefficient, \( C_Y \): Side Force Coefficient, \( C_{Roll} \): Rolling Moment Coefficient, \( C_{Yaw} \): Yawing Moment Coefficient.

All of the aerodynamic force and moment measured by load cell corretlated with the appropriate position in the external balance. Offset small geometry and strain and friction gives the deviation coefficient of the actual value. Therefore the forces and moments obtained from the measurement results, in software multiplied by the coefficient matrix external balance calibration. The relationship between the aerodynamic forces and moments in units of measurement and raw data matrix shown in the following equation:

\[ [K_i] = [a_{ij}] \cdot [R_i] \] (8)

Where:
- \( K_i \): Forces or moments
- \( a_{ij} \): External Balance Calibration Coefficient
- \( R_i \): Raw data
Forces and moments of the measurement results are normalized to the dynamic pressure, reference area of wings, and the mean aerodynamic chord. Agreements signs and directions to all the coefficients shown in Figure 5 where $C_L$, $C_D$, $C_Y$, $C_M$, $C_{Roll}$, $C_{Yaw}$ are the coefficient of lift, drag, side force, moment of pitch, rolling moment, and the yawing moment respectively.

**Figure 5.** Convention magnitude, Sign and direction forces and moments

3. Results and Discussions
During the WTT, some wing configurations combining with main wing flap representing control surface were observed. The flap configurations are written in table 2.
### Table 2. Running list Flap investigation

| No | RUN | configuration | V(m/s) | AOA | Beta | dFL | dFR | dAL | dAR | dCHL | dCHR |
|----|-----|---------------|--------|-----|------|-----|-----|-----|-----|------|------|
| 1  | 1   | WBT           | 65     | A   | 0    | 0   | 0   | 0   | 0   | 0    | 0    |
| 2  | 2   | WBT           | 65     | A   | 0    | 10  | 10  | 0   | 0   | 0    | 0    |
| 3  | 3   | WBT           | 65     | A   | 0    | 20  | 20  | 0   | 0   | 0    | 0    |
| 4  | 4   | WBT           | 65     | A   | 0    | 30  | 30  | 0   | 0   | 0    | 0    |
| 5  | 5   | WBT           | 65     | A   | 0    | 40  | 40  | 0   | 0   | 0    | 0    |

### 3.1. Flap effect on the aerodynamics

A series of setting up Flap deflection left (dFL) and right (dFR) are shown in the table 2. The effect of Flap on the wing configurations to lift aerodynamics coefficient versus Angle of Attack (AOA) show in figure 6.

![Figure 6. Effect Flap on wing configuration to the Lift coefficient](image)

The Curves in figure 6 shows for different flap setting on wing configuration RUN 1, RUN 2 up to RUN 5 are gradually increase CLmax from 1.4652 up to 1.6538. The maximum lift (CLmax)=1.6538 occurred at RUN 5 which is set at dFL=dFR=40°, the maximum lift for take-off condition (CLmax)=1.6235 occurred at RUN 3 at the flap deflection about 20° and minimum lift (CLmax)=1.4652 occurred at RUN 1.

Figure 7 explained how the drag values change due to the change of flap deflection. Base on the force measurement graphic plot of drag coefficient shown in figure 7, setting Flap on the wing configuraton theorectically will change the frontal surface of UAV. Increasing frontal surface will conseqency change the drag of UAV. The maximum increasing of the drag UAV is about 90 drag account. From view of this result result are reasonable although the deference of flap on the wing configuration have difference purpose. Flap deflection 20° use for takeoff condition but flap setting angle 40° for landing condition. Even flap setting angle have highest CL but also have high value of drag.
Furthermore the pitching moment coefficient show in the figure 8. Generally the graphich plot of pitching moment coefficient versus AOA have negative slope that is indicate UAV will be stable during flight. However in some point AOA the slope of graphich plot have positive value. Maybe in this case need the dynamics analysis or more information in the flight test.

Figure 8. Effect Flap on wing configuration to the pitching moment coefficient

Figure 9 show the graphich plot of side force coefficient CY versus AOA. RUN 1 is the basic condition without setting flap deflection. The value CY of RUN 1 can be seen for zero offset condition. RUN 1 up to RUN 5 have value of CY relatively small varies between -0.0031 up to 0.0091 so we can say side force all of flap set up deflection have CY near zero. Base on this result flap deflection have small effect on the side force so we could not use flap deflection as control surface for directional of UAV.
Figure 9. Effect Flap on wing configuration to the side force coefficient

Figure 10. Effect Flap on wing configuration to the yawing moment coefficient

The graphich plot of yawing moment coefficient show in the figure 10. The value yawing moment coefficient as well as side force also very closed to zero. Let us see RUN 1 is the basic condition without setting flap deflection. The value CYAW of RUN 1 can be seen for zero offset condition. Take the difference relative value for RUN 2 up to RUN 5 to RUN 1 we will find the difference value close to zero. These mean flap deflection have the small effect to yawing moment CYAW.

Finally effect of flap setting on the rolling moment coefficient show in the figure 11. Here, RUN 1 is basic condition without setting flap deflection. The value CROLL of RUN 1 can be seen for zero offset condition. Take the difference relative value for RUN 2 up to RUN 5 to RUN 1 we will find the difference value close to zero. These mean flap deflection also have the small effect to rolling moment CROLL. This is show the flap could not use to make UAV rolling to the right or left direction.
3.2. Performance prediction of UAV

UAV performance base on the characteristic aerodynamics can be predict. Performance of the UAV consist of efficiency, induce drag and endurance. Efficiency of the UAV represent by the ratio of CL/CD. More higher ratio of CL/CD that mean UAV can generate optimal lift with lowest drag. Graphic plot of CL/CD versus AOA show in the figure 12. The maximum value of ratio CL/CD=23 occurred at AOA about 6°~7° for RUN 1 with flap deflection setting equal zero. The RUN 4 the bigest flap deflection have lowest value of CL/CD because RUN 4 have highest value of CD. Between the curve CL/CD versus AOA for RUN 1 and RUN 4 there are RUN 2, RUN 3 and RUN 5. All of curve have maximum value CL/CD at AOA about 6°~7°.

3.2.1. Induced drag

Induced drag in term aerodynamics proportional to the value CL^2. Graphic plot of induced drag can be seen in the figure 13. The value of CL^2 versus AOA of all configuration as well as the value of CL are have the maximum value. Figure 13 show the maximum value CL^2 occurred at AOA about 6°~7°.

![Figure 11](image1.png)

**Figure 11.** Effect Flap on wing configuration to the rolling moment coefficient

![Figure 12](image2.png)

**Figure 12.** Efficiency of the UAV
Induced drag varies depend on the AOA. The increasing of AOA should be increased the value induced drag.

![Graph showing induced drag proportional to the value CL^2](image1)

**Figure 13.** Induced drag proportional to the value CL^2

![Graph showing endurance representation of UAV](image2)

**Figure 14.** Endurance representation of UAV

Figure 14 show graphic plot endurance representation of UAV. The value of \( \frac{(CL)^{3/2}}{CD} \) represent of endurance flight of UAV. All of RUN configuration have maximal value \( \frac{(CL)^{3/2}}{CD} \) at the AOA around 6°~7°. It is means UAV will be had longest endurance if UAV flight by that conditions. The highest value of \( \frac{(CL)^{3/2}}{CD} \) 25 up to the lowest 13 due to the setting flap deflection from 0° up to 40° respectively.
4. Conclusions
Flight mission of an UAV or aircraft should be supported by control surface devices, such as flap, aileron, rudder, elevator, some equipment and instrumentation. In this study performance and stability of flap setting angle deflection observed by WTT. Based on the measurement result we can conclude in the following below:

a) Setting flap deflection will contribute lift force of UAV represented by Lift Coefficient.
b) Setting angle deflection of flap 0° have minimal CL but with drag minimal. In this setting good for cruise flight because ratio of CL/CD have maximal value.
c) Setting angle deflection of flap 20° have moderate CL about 1.6235 also with moderate drag. In this setting good for takeoff and climb flight.
d) Setting angle deflection of flap 40° have biggest value CL about 1.65 compare with other setting, however this setting have highest value of Drag CD.
e) On the flight mission need high lift and drag force especially at the landing situation so setting angle of flap 40° are the appropriate condition.
f) During operation with flap deflection do not change side force coefficient, Pitching Moment Coefficient, Yawing Moment Coefficient and Rolling Moment Coefficient of UAV significantly.
g) There are Drag Coefficient increasing on the operation of Flap control surface because of frontal surface area of UAV changed.

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