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Research Article

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Performance and Effectiveness Study on the Aileron as Control Surface of an Unmanned Aircraft Vehicle

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Abstract Studies performance and effectiveness of control surface in the engineering design process of an Unmanned Aircraft Vehicle (UAV) by using Wind Tunnel Test (WTT) is very important. Control surface such as flap, aileron, spoiler, rudder, of the aircraft has a special function in controlling the aircraft flew missions. This paper discusses the study of the performance and effectiveness of the aileron control surface UAV with the deflection angle on the rudder dCHR and dCHL equal to zero on WTT. Analysis of the test results the performance and effectiveness aileron control surface canapplyonthe flight control UAV.

Keywords Performance, effectiveness, control surface, Wind Tunnel Test, aircraft

Introduction

The study on new aircraft designs both manned and unmanned for the development by using the wind tunnel is a usefull method to get the desired design. This paper discusses studies aileron effect on the performance and effectiveness Unmanned Aircraft Vehicle (UAV). Inspite of that before the UAV prototype flown should be known aerodynamic characteristics, stability and performance. In the design phase simulation method conducted to provide an estimate aerodynamic characteristics. However wind tunnel testing is still required. Wind tunnel test carried out on aircraft models installed in the wind tunnel connected to the external balance by the wing struts. Aerodynamic forces due to wind at a speed of 65 meter per second was measured by the external balance.

The WTT facility is belonging to National Laboratory for Aerodynamics Aero-elastics and Aero-acoustics, 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.Test objects that can be done in National Laboratory for Aerodynamics Aero-elastics and Aero-acoustics not only complete the test model of the aircraft, but also allows for the test model which is a component of the aircraft, such as two dimensional wing model, half model, tail performance and air intake test.

Control surface of the UAV generally consist of flap, aileron, elevator, rudder and tail. During flight of the UAV need to maneuver due to destination. Aileron is the one control suface to make direction of flight together with the rudder. In this study we set up the deflection angle configuration rudder *i.e.* dCHR and dCHL equal to zero with the diflection of flap as dFlap 0°. Furthermore the diagram of component aircraft generally can be shown such as in the figure 1 [1].

Wind Tunnel Testing

Aircraft flight mission generally contain of take-off, ascending, cruise, decending and landing [2]. All of mission were done either commercial aircraft or UAV. Maneuver is one aspect during flight. For example the direction of the flight should be changed in order to reach of the place who want to achieve. The maneuver of aircraft can be done by setting of surface control aileron and rudder. WTT will be done with some condition description in the following chapter;

a. *Model Testing*

The model aircraft tested, is a 1: 5 scale test model with 3022 mm wingspan. The sketch of model testing show in the figure 2.Aileron of the model lied in the outer control surface. Aileron deflection usually setting in the oposite direction for the right part and the left part to generate maneuver of the aircraft.

Here are the nomenclature for the part of the UAV model for WTT:

W : Wing

B : Body

T : Tail

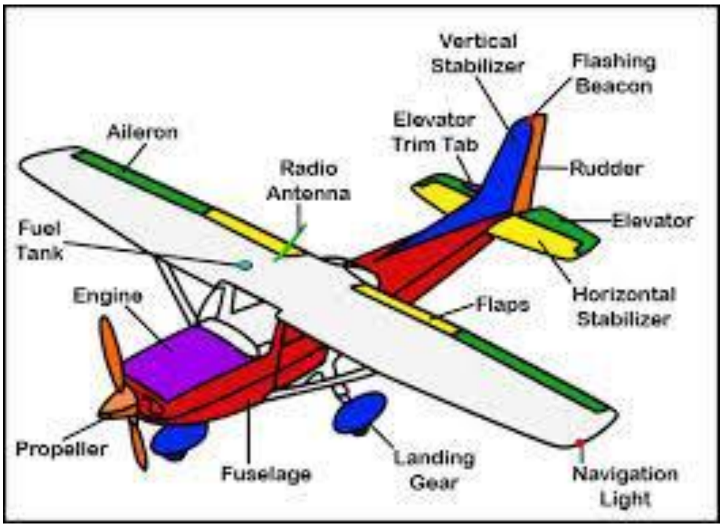

Figure 1: Diagram component the aircraft

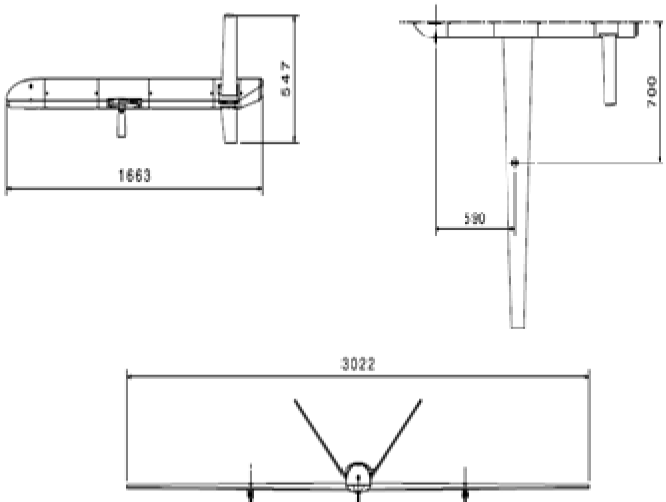

Figure 2: UAV model sketch

Meassurement 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^{o} to 20^{o}, with interval data collection every 1^{o}. As for the angle beta, test model driven from -20^{o} to 20^{o} angle beta, with interval data collection every 1^{o}. Installed test model can be seen in Figure 3.

Figure 3: UAV model installed in the test section

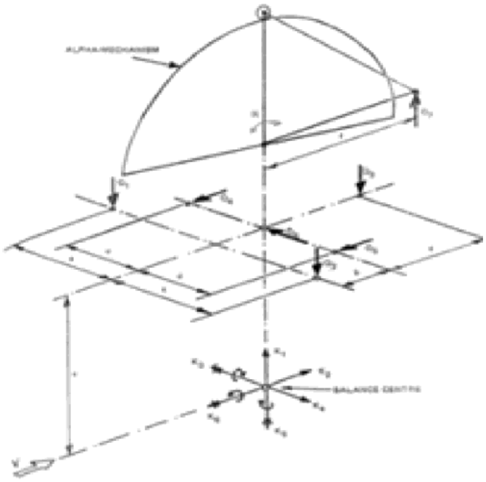

Figure 4: Diagram of external balance

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.

Table 1: The maximun load each external balance component [7]

No.	Component	Load Capacity	Accuracy (%)
1	*Lift (K1)*	17500 N	0.1 % FS
2	*Drag (K2)*	3500 N	0.1 % FS
3	*Pitching Moment (K3)*	3750 Nm	0.1 % FS
4	*SideForce(K4)*	3500 N	0.1 % FS
5	*Yawing Moment(K5)*	3250 Nm	0.1 % FS
6	*Rolling Moment (K6)*	3000 Nm	0.1 % FS

Furthermore the maximum allowable error calculate by the equation (1)[5]

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

Where Ei : The maximum allowable error.

Pi : The force or moment on the Ki-th component.

Pimax : The maximum capacity of the Ki-th component.

f : A factor, which depend on the force component.

b. 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]. The six components of forces and moments can be formulated as follows:

Three component forces:

$$L = {}^1/_2\, \rho V^2 S C_L \tag{2}$$

$$D = {}^{1}/_{2}\,\rho V^2 S C_D \qquad (3)$$
$$S_F = {}^{1}/_{2}\,\rho V^2 S C_Y \qquad (4)$$

Three component moments:

$$M_P = {}^{1}/_{2}\,\rho V^2 S C_M \qquad (5)$$
$$M_R = {}^{1}/_{2}\,\rho V^2 S C_{Roll} \qquad (6)$$
$$M_Y = {}^{1}/_{2}\,\rho V^2 S C_{Yaw} \qquad (7)$$

Where ρ: 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.

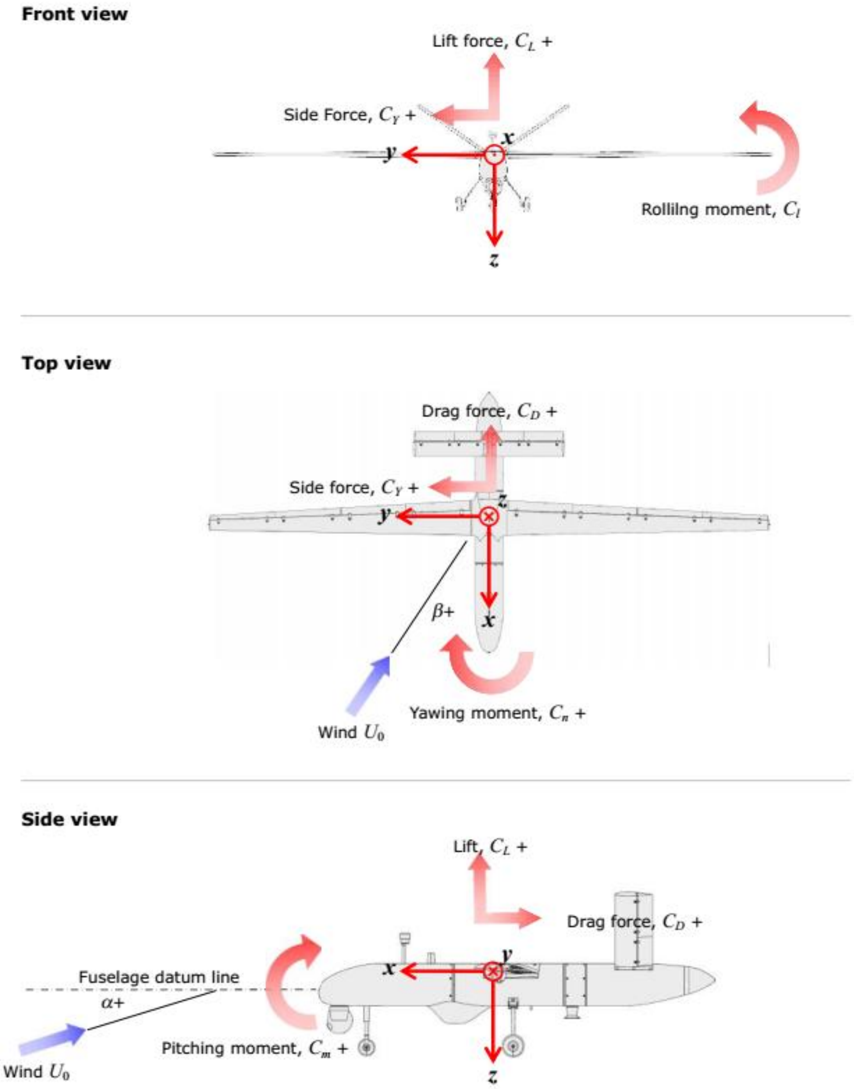

Figure 5: Convention magnitude, Sign and direction forces and moments

All of the aerodynamic force and moment measured by load cell corelated 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:

$$K_i = a_{ij} R_j \qquad (8)$$

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 CL, CD, CY, C_M, C_{Roll}, C_{Yaw} are the coefficient of lift, drag, side force, moment of pitch, rolling moment, and the yawing moment respectively.

Results and Discussions

WTT in order to observe the effect of control surface aileron deflection we make some running test such written in table 2.

Table 2: Running list Ailron effect investigation

No	Run	configuration	V(m/s)	AOA	Beta	dFL	dFR	dAL	dAR	dCHL	dCHR
1	14	WBT	65	A	0	0	0	0	0	0	0
2	35	WBT	65	A	0	0	0	30	-30	0	0
3	36	WBT	65	A	0	0	0	20	-20	0	0
4	37	WBT	65	A	0	0	0	10	-10	0	0
5	38	WBT	65	A	0	0	0	-10	10	0	0
6	39	WBT	65	A	0	0	0	-20	20	0	0
7	40	WBT	65	A	0	0	0	-30	30	0	0

c. *Aileron effect on the aerodynamics*

Set up aileron deflection left (dAL) and right (dAR) are shown in the table 2. The effect of aileron configurations to the lift coeffecient aerodynamics versus Angle of Attack (AOA) show in figure 6.

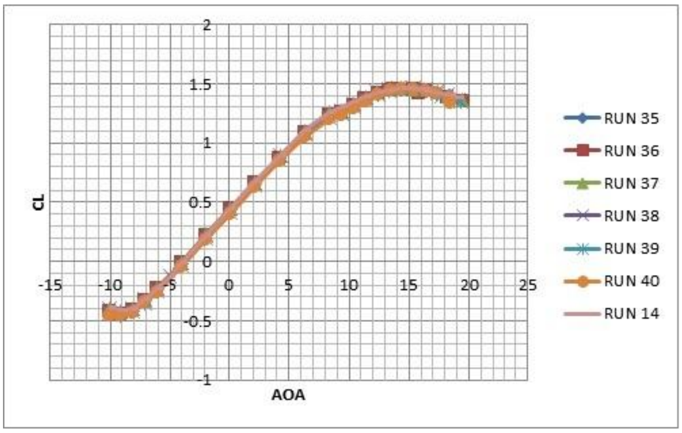

Figure 6: Effect aileron configuration to the Lift coefficient

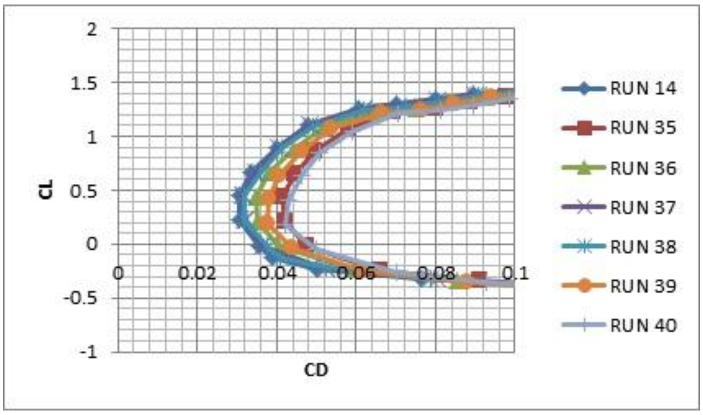

Figure 7: Effect aileron configuration to the drag coefficient

The effect aileron configuration to the lift coefficient are not changing CL anymore. The graphic plot of several aileron configuration RUN 14, RUN 35 up to RUN 40 are almost exactly same. In these case maneuvering UAV by using aileron can be done without change CL of the UAV. During maneuver UAV can safely fly to the destination.

How about the drag value because the change of aileron deflection? Base on the force measurement graphic plot of drag coefficient show in the figure 7. Set up aileron configuraton theoritically change the frontal surface of UAV. The increasing frontal surface conseqency change the drag of UAV. The maximum increasing of the drag UAV is about 12 drag account. From view of this result maneuverability by using aileron configuration make just small drag and also usually maneuver of UAV do in the short time.

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 9 show the graphich plot of side force coefficient CY versus AOA. RUN 14 is the basic condition without setting aileron deflection. The value CY of RUN 14 can be seen for zero offset condition. RUN 38 up to RUN 40 have higher value of CY compare with RUN 14. RUN 38 , RUN 39 and RUN 40 have setting value dAR 10°, 20° and 30° respectively. For a while RUN 35 , RUN 36 and RUN 37 have setting value dAR -30°, -20° and -10° respectively.

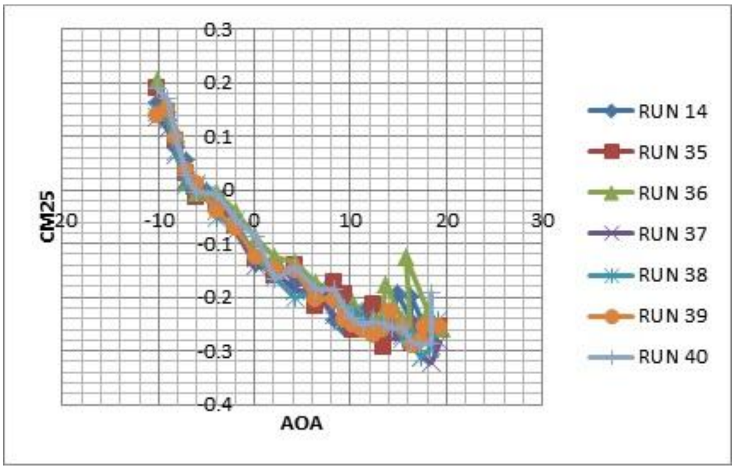

Figure 8: Effect aileron configuration to the pitching moment coefficient

The value CY RUN 35 , RUN 36 and RUN 37 lower than RUN 14. Positive value of CY mean UAV will be maneuvered to the right direction and negative value of CY to the left. This is show the aileron could be used to make UAV turn right or left.

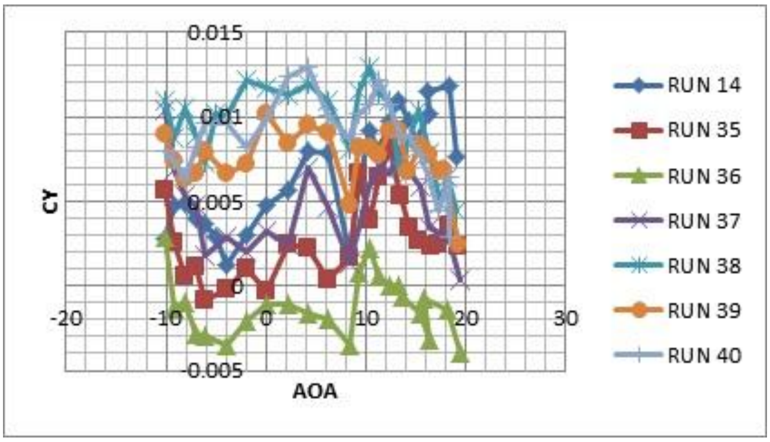

Figure 9: Effect aileron configuration to the side force coefficient

The graphich plot of yawing moment coefficient show in the figure 10. The value yawing moment coefficient depend on the AOA because aileron configuration work highly influence by AOA. Relative position aileron left and right component to the free stream make yawing moment direction change. The change of yawing moment direction occured at AOA about -4° of all aileron configuration.

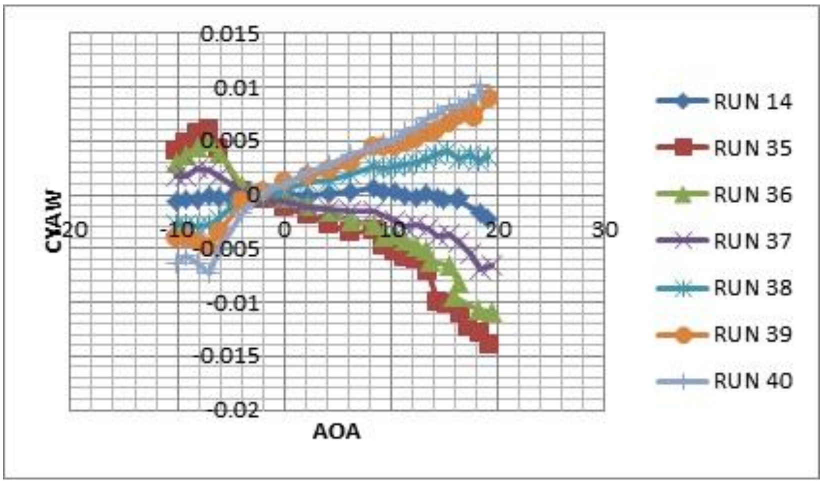

Figure 10: Effect aileron configuration to the yawing moment coefficient

Finally the highest effect of aileron configuration occured on the rolling moment coefficient. Figure 11 show the effect of aileron configuration. Here, RUN 14 is basic condition without setting aileron deflection. The value CRoll of RUN 14 can be seen for zero offset condition. RUN 38 up to RUN 40 have negative value of CRoll. RUN 38 , RUN 39 and RUN 40 have setting value dAR 10°, 20° and 30° respectively. For a while RUN 35 , RUN 36 and RUN 37 have setting value dAR -30°, -20° and -10°. The value Croll of the RUN 35 , RUN 36 and RUN 37 hihger than RUN 14. Positive value of CRoll mean UAV will be rolled to the right direction and negative value of Croll to the left. This is show the aileron could be used to make UAV rolling to the right or left direction.

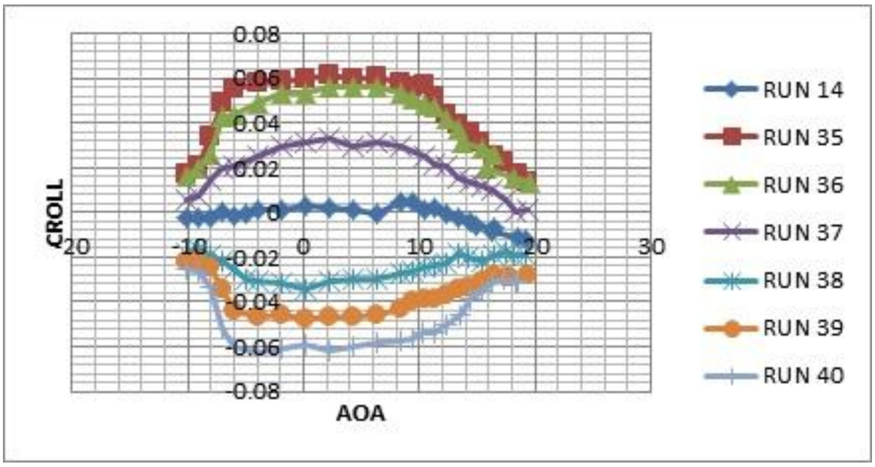

Figure 11: Effect aileron configuration to the rolling moment coefficient

d. *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 equivalent to 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 occured at AOA about 6°~7° for RUN 14 with aileron configuration setting equal zero. The RUN 35 and RUN 40 with the bigest aileron deflection have lower value of CL/CD because RUN 35 and RUN 40 have highest value of CD. Between the curve CL/CD versus AOA for RUN 14 and RUN 40 there are couple of RUN 36 and RUN 39, RUN 37 and RUN 38. All of curve have maximum value CL/CD at AOA about 6°~7°.

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 almost same except for RUN 39. That is any indication in the RUN 39 maybe during took the data something happened even whole of configuration setting on the normal situation. Induced drag varies depend on the AOA.

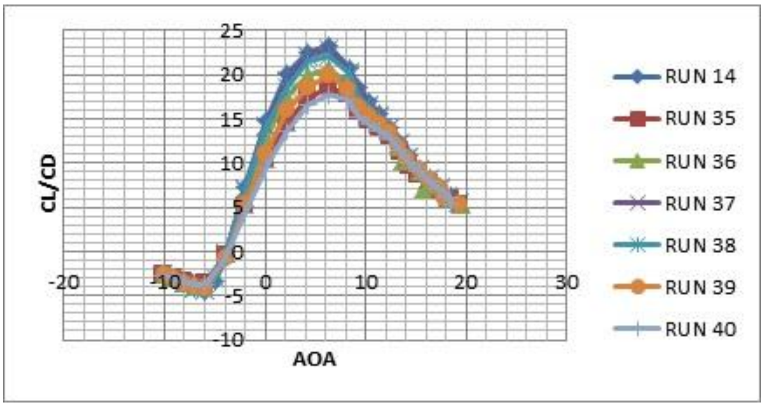

Figure 12: Efficiency of the UAV

The increasing of AOA should be inreased the value induced drag.

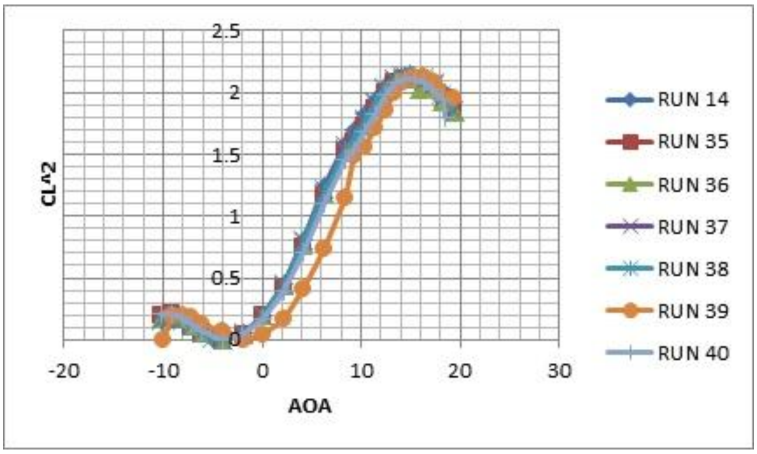

Figure 13: Induced drag proportional to the value CL^2

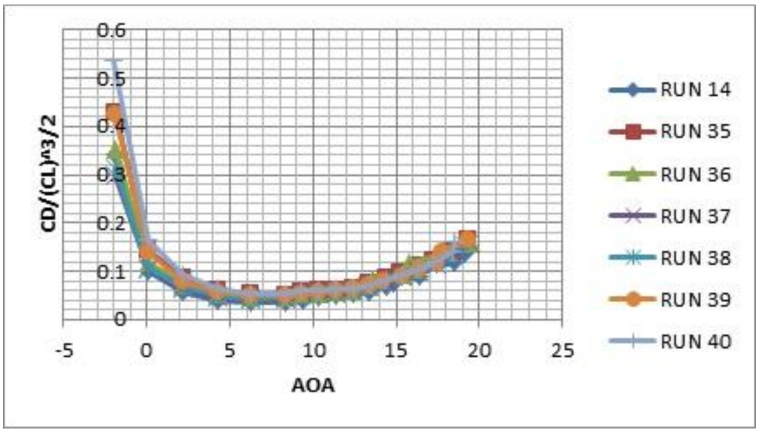

Figure 14: Endurance representation of UAV

Figure 14 show graphic plot endurance representation of UAV. All of RUN configuration have minimal value $CD/(CL)^{3/2}$ about 0.04~0.06 at the AOA around 6°~7°. It is means UAV will be had longest endurance if UAV flight by that conditions. It is also operation of aileron do not change endurance of UAV significantly.

Conclusions

Flight mission of an UAV or aircraft should be supported by control surface devices, such as aileron, rudder, elevator, some equipment and instrumentation. In this study performance and effectiveness of aileron observed by WTT. Base on the meassurement result we can conclude in the folllowing below;

- Aileron control surface are effective for maneuverability of UAV represented by Rolling Moment Coefficient.
- During operation of aileron control surface do not change Lift Coefficient, Pitching Moment Coefficient and Endurance of UAV significantly.
- There are Drag Coefficient increasing on the operation of aileron control surface because of frontal surface area of UAV changed.

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