

# SOFTWARE DEVELOPMENT FOR AERODYNAMIC CHARACTERISTICS ESTIMATION OF WING-BODY COMBINATION OF AIRCRAFT AT SUBSONIC SPEEDS

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## ABSTRACT

*The study of aerodynamic characteristics is an important aspects in designing of an aircraft. The estimate of the lift and drag coefficients of the combination of wings and bodies at subsonic speeds. The calculation of these aerodynamic characteristics is a tedious workout in the preliminary design, as it has to be carried out repetitively for every different combination. A software for determining the wing-body combination lift and drag coefficients known as **AC Estimator** is being developed to serve as a solution to the tedious and time-consuming design method. The development and capabilities of this software to predict varieties aerodynamic characteristics with good accuracy as compared to manual calculation are being presented and discussed in this paper.*

## 1.0 INTRODUCTION

The best way to obtain the aerodynamic characteristics for a wing-body combination is to carry out a wind tunnel testing. However, for different wing-body design, several new tests will need to be carried out and these are very time consuming. Besides, the designing cost will increase because the models are normally very expensive.

In order to save the design time and cost, preliminary estimation of aerodynamic characteristics for wing-body combination should be carried out. The best and the most convenient way to estimate the aerodynamic characteristics for wing-body combination is to use a computer-based software. This computer-based software was built up by using the semi-empirical methods, which combined theoretical and experimental data.

## 2.0 METHODOLOGY AND ANALYSIS

The two major references that have been referred to estimate the aerodynamics characteristics for wing-body combination,  $(C_L)_{WB}$  and  $(C_D)_{WB}$  were USAF Stability and Control DATCOM[1] and Airplane Design Part VI by Roskam[2]. All methods from the two major references are semi-empirical methods, which combined theoretical and experimental data.

### 2.1 Lift Coefficient, $C_L$

Lift is always defined as the component of the aerodynamic force perpendicular to the relative wind. It can be generated by any part of the airplane, but the wing generates most of the lift on a normal airliner.

Lift is also generated on a fuselage at angle of attack. When a wing is combined with a fuselage, there are some interference effects occur between the wing and the fuselage[1]. These interference effects can be classified as :

1. The effect of body upwash or cross flow on the local angle of attack of the wing.
2. The effect of local body-flow properties such as Mach number and dynamic pressure on the panel characteristics.
3. The effect of the lift carryover from the wing onto the body.
4. The effect of wing up-wash on the body ahead of the wing.
5. The effect of wing lifting vortices.

The lift on wing-body combination is taken to be the sum of three principal components :

1. Lift on nose including fore body.
2. Lift on wing in presence of body.
3. Lift on body due to the wing.

Generally, the lift coefficient varies linearly with the angle of attack of a wing-body combination before the stalling takes place. The typical graph of lift coefficient versus angle of attack for a wing-body combination is shown in the Figure 1.

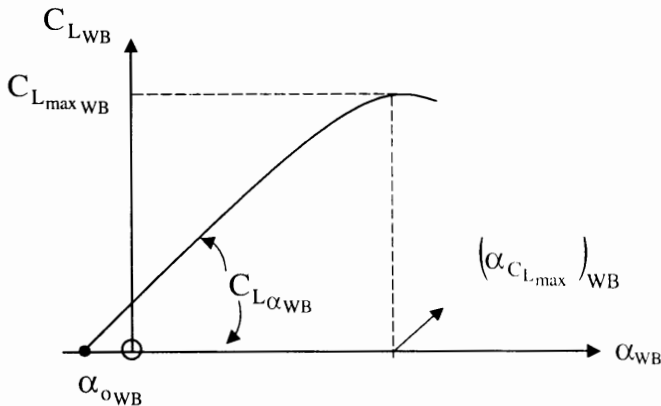


Figure1 Lift Coefficient versus Angle of Attack for Wing-Body Combination

### 2.2 Drag Coefficient, $C_D$

Drag is always defined as the component of the aerodynamic force parallel to the relative wind. Generally, the total drag coefficient for a finite wing at subsonic speeds could be written as follow:

$$\text{Total Drag} = \text{Profile Drag} + \text{Induced Drag (Drag Due to Lift)}$$

$$C_D = c_d + \frac{C_L^2}{\pi e A} \quad (1)$$

The composition of body zero-lift drag in the various speed regimes is very similar to that for wings. At subsonic speed the pressure drag of the fore-body is generally small and the total drag is composed mostly of skin friction.

The problem of estimating the drag coefficient of a wing-body combination is one of properly accounting for the mutual interference that exists between its components. There are two principle approaches to the problem. One attempts to isolate the individual interferences, and the other combines the drag of components with the interference drag and analyzes the total configuration. The DATCOM method for subsonic speeds consists of applying an interference correction factor to the skin friction and pressure drag contribution of the exposed components.

Subsonic wing-body interference is caused by several phenomena, of which two are especially important. First, the wing and the body produce super velocities due to thickness that increase the skin friction in the vicinity of the wing-body junction. Second, the confluence of boundary layers at the junction can cause premature boundary layer separation[1].

### **3.0 SOFTWARE METHODOLOGY & IMPLEMENTATION**

Microsoft Visual Basic 6.0 (VB6) has been chosen to build up the AC Estimator because of its user-friendly interface, easy-to-learn programming language and compatible with Office 2000 and AutoCAD R14. Flow chart in Figure 2 shows the basic structure of AC Estimator.

The main menu is the most important page of graphic user interface for the software and it is shown in Figure 3. The picture at the top center of the main menu shows the shape of the selected configuration of wing. User can choose the wing planform by selecting the combo box below the "Wing Planform" which consists Delta Wing, Double Delta Wing, Rectangular Wing and Swept Back Wing. By selecting the wing planform, the picture in the main menu will change to the selected wing planform. Note that the required input data will also change at the same time. With the same step as above, the nose and after body shapes such as cone, ellipse and ogive can be selected. Besides, user can select desire airfoil section at the upper right corner on the main menu. The available airfoil section is NACA 4, 5 and 6 digits with 105 types of airfoil.

After filling all the required input data, the "Calculate" button is enabled. Single click on the button will assign the software to calculate the aerodynamic characteristics. After the calculation is completed, the result is shown in the "Result" column at the lower left corner of the main menu in numerical form. The "More Results" and "Graph" buttons are now enabled after calculation completed.

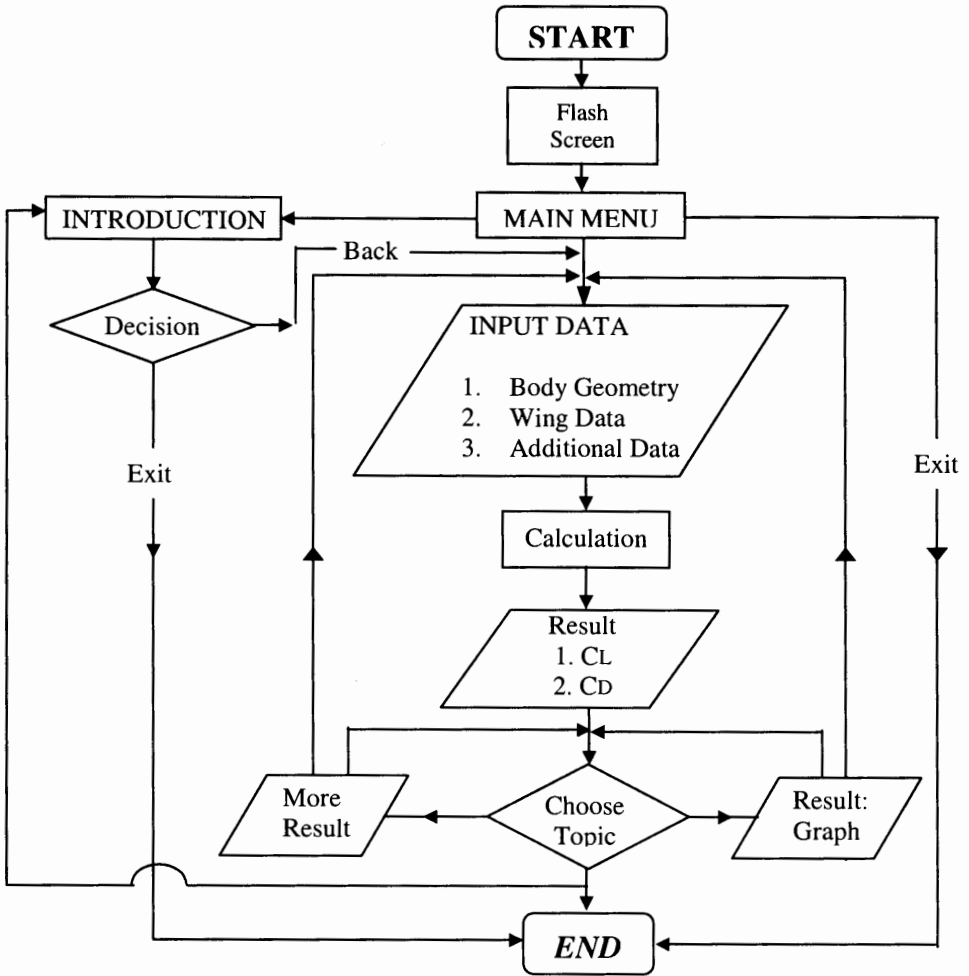


Figure 2 Program Flow Chart

The variation of output data to the angle of attack presented in graph mode can be achieved by clicking the “Graph” button in the main menu after calculation. Clicking the “Graph” button beside the result of lift coefficient will show the graph of lift coefficient versus angle of attack (Figure 4) while clicking the “Graph” button beside the result of drag coefficient will show the graph of drag coefficient versus angle of attack (Figure 5).

For user who is interested to get some additional results such as additional wing characteristics, exposed wing characteristics and other aerodynamic characteristics, output sheet on additional results (Figure 6) could be achieved by clicking the “More Results” button in the main menu.

By clicking the “Introduction” button in the main menu, the introduction sheet will pop up. User can choose the desirable topic in the combo box and the related file is shown in the white box below. The topics available are Introduction, Wing Configuration, Configuration of Bodies, Basic Theory of Aerodynamic Characteristics, Software Limitations and References.

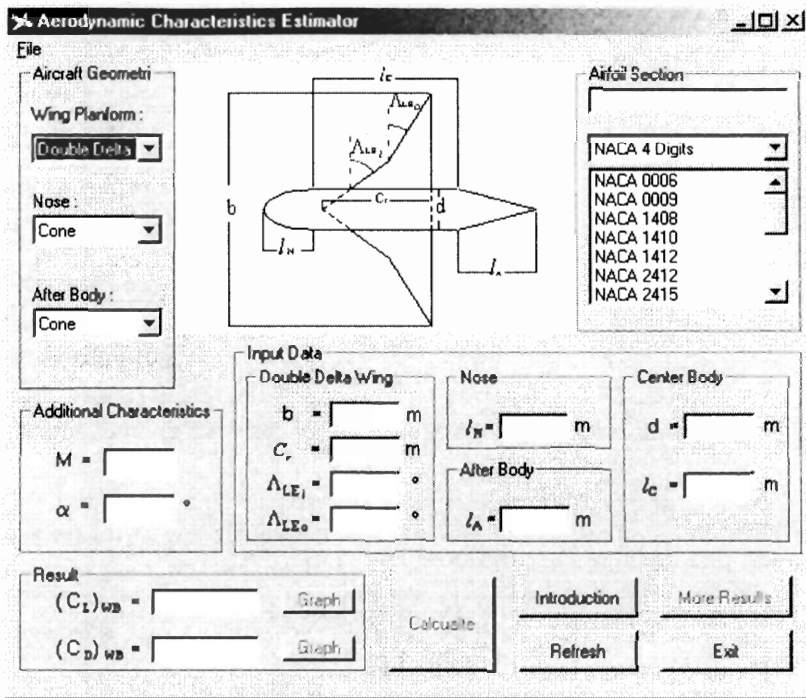


Figure 3 Main Menu

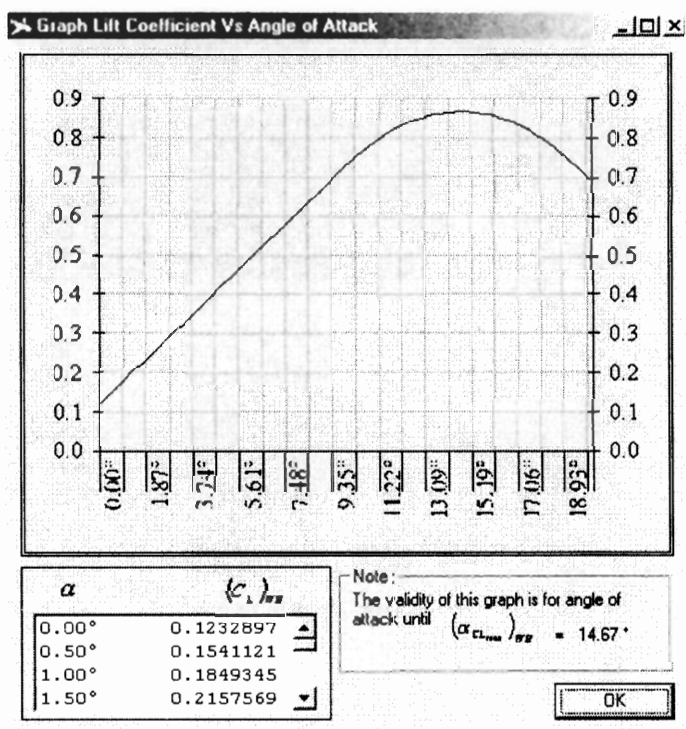


Figure 4 Graph sheet of Lift Coefficient vs Angle of Attack

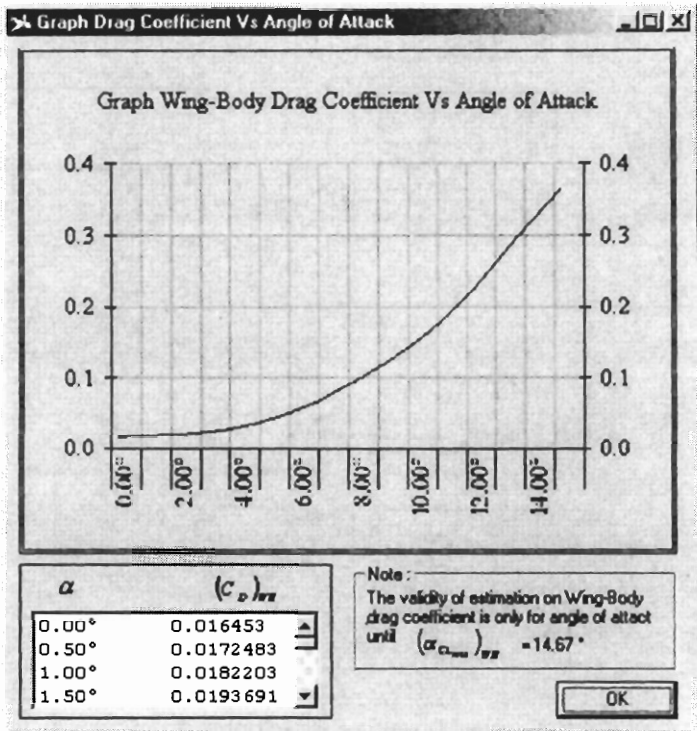


Figure 5 Graph sheet of Drag Coefficient vs Angle of Attack

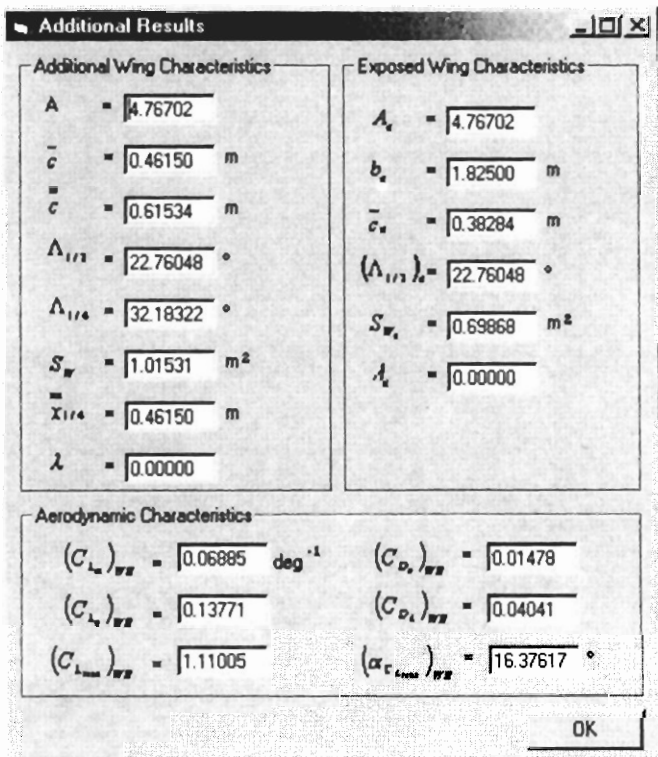


Figure 6 Output Sheet on Additional Results

### 3.1 Software Limitations

There are few general limitation for the AC Estimator as follow:

1.  $0 < M \leq 0.6$
2.  $Re_{fus} \leq 2.4 \times 10^7$
3.  $\alpha \leq (\alpha_{C_{L,max}})_{WB}$
4. Estimation made at standard sea level
5. Body with constant cross section with circular shape
6. Nose and after body with cone, ellipsoidal and ogive shape
7. Untwisted wing
8. Wing with 105 types of NACA 4, 5 and 6 digits airfoil.
9. Rectangular Wing, Swept Back Wing, Delta Wing and Double Delta Wing

For Straight Tapered Wing (Rectangular Wing, Swept Back Wing & Delta Wing), the additional limitations are as below:

- $2 \leq A \leq 10.7$
- $0 \leq \lambda \leq 0.713$
- $19.1^\circ \leq \Lambda_{LE} \leq 60^\circ$
- $0.72 \times 10^6 \leq Re_{MAC} \leq 16.6 \times 10^6$

For Double Delta Wing, the additional limitations are shown below:

- $2.91 \leq A \leq 8.47$
- $49.2^\circ \leq \Lambda_{LE_i} \leq 72^\circ$
- $6.6^\circ \leq \Lambda_{LE_o} \leq 61.7^\circ$
- $\Lambda_{LE_{eff}} \leq 60^\circ$

### 4.0 RESULTS AND DISCUSSION

The results for the wing-body lift and wing-body drag coefficients estimated by computer using the created software mere then compared with the result from manual calculation. For the comparison, aircraft configuration of set 1 was used and is shown in Table 1.

Table 1 Configuration of Aircraft, Set 1

Aircraft Geometry			
Wing	Nose	Center Body	After Body
Straight Tapered (Sweptback)	Ogive	Cylinder	Cone
B = 1.9 m c <sub>r</sub> = 0.6 m λ = 0.45 Λ <sub>LE</sub> = 30° Λ <sub>TE</sub> = 13° Airfoil NACA 2415	l <sub>N</sub> = 0.5 m	d = 0.375 m l <sub>C</sub> = 1.4 m	l <sub>A</sub> = 0.75 m
Additional Characteristics			
M = 0.2	l <sub>B</sub> = l <sub>N</sub> + l <sub>C</sub> + l <sub>A</sub> = 2.65 m		
Surface : Smooth matte paint, carefully applied	k = 0.25 x 10 <sup>-3</sup> in = 6.35 x 10 <sup>-6</sup> m		

### 4.1 Variation of Wing-Body Lift Coefficient to Angle of Attack

The variations of wing-body lift coefficient obtained by manual calculation and also by the created software prediction are shown in Table 2.

Table 2 Variation of wing-body lift coefficient

Set 1			
Manual Calculation		Created Software	
A (°)	$(C_L)_{WB}$	$\alpha$ (°)	$(C_L)_{WB}$
0	0.1431	0	0.1431
2	0.2863	2	0.2862
4	0.4295	4	0.4293
6	0.5727	6	0.5725
8	0.7159	8	0.7156
10	0.8591	10	0.8587
17.01	1.2053	16.07	1.1956

For the purpose of comparison and discussion, the result above is presented in Figure 7.

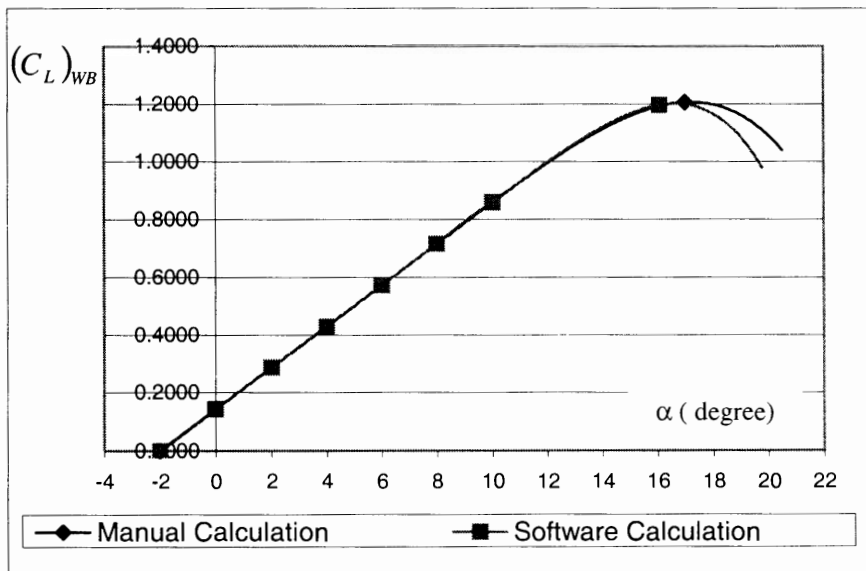


Figure 7 Graph of the variation of wing-body lift coefficient calculated by manual and by created software

From Figure 7, it is noted that both curves show a linear relationship between wing-body lift coefficient and the angle of attack until the lift coefficient reaches its maximum value at stalling angle of attack. However in both cases there is a slight difference in the values of maximum lift coefficient and the stalling angle of attack (angle of attack for maximum lift coefficient). This is normally caused by the “human error” and “round off error”.



### 4.2 Variation of Wing-Body Drag Coefficient to Angle of Attack

The variations of wing-body drag coefficient obtained by manual calculation and also by the created software are shown in Table 3.

Table 3 Variation of wing-body Drag coefficient

Set 1			
Manual Calculation		Created Software	
$\alpha(^{\circ})$	$(C_D)_{WB}$	$\alpha(^{\circ})$	$(C_D)_{WB}$
0	0.0204	0	0.0200
2	0.0246	2	0.0242
4	0.0317	4	0.0313
6	0.0417	6	0.0414
8	0.0547	8	0.0545
10	0.0707	10	0.0706
12	0.0898	12	0.0898
14	0.1121	14	0.1123
16	0.1376	16	0.1379
17.01	0.1517	16.07	0.1389

For the purpose of comparison and discussion, the result above is presented in Figure 8.

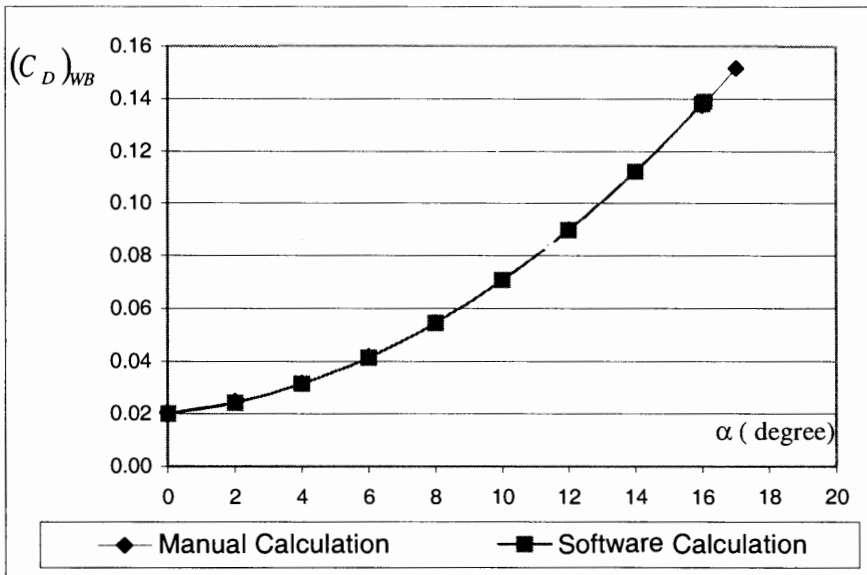


Figure 8 Graph of the variation of wing-body Drag coefficient estimated by manual and created by software.

As expected, Figure 8 shows a parabolic relationship between wing-body drag coefficient and the angles of attack. The results from manual calculation are almost the same with the results from software calculation.

## 5.0 CONCLUSION

A user friendly software, AC Estimator has been developed successfully to estimate the aerodynamic characteristics i.e. lift and drag coefficients for wing-body combination of aircraft at subsonic speed. The created software is capable to estimate the aerodynamic characteristics for any combination of the following wing and body shapes:

- a) Straight Tapered Wing – Rectangular Wing, Swept Back Wing and Delta Wing
- b) Non- Straight Tapered Wing – Double Delta Wing
- c) Fore Body and After Body – Ellipse, ogive, Cone
- d) Center Body Cross Section – Circle
- e) Airfoil section for NACA 4, 5 and 6 digits.

The future development is to improve the created software as well as its estimated results. The future software will include more methods and other aerodynamic characteristics (moment and normal force coefficients) and more types of wing planform (cranked wing, ogee and gothic). It should also be extended to include body with inconstant cross section, wing-body-tail combination, and also more types of airfoil section.

## REFERENCES

1. D.E.Hoak, R.D.Finck, et al, 1978, *USAF Stability and Control Datcom : Flight Control Division*, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio.
2. Dr. Jan Roskam, 1990, *Airplane Design Part IV : Preliminary Calculation of Aerodynamic, Thrust and Power Characteristics*. Kansas : Roskam Aviation and Engineering Corporation.
3. The Royal Aeronautical Society, 1981, *ESDU 76003 – Geometrical Properties of Cranked and Straight Tapered Wing Planform*, United Kingdom : The Royal Aeronautical Society.
4. John D. Anderson, 1989, *Introduction to Flight*. Singapore : McGraw Hill International Edition.
5. Abbott, Ira-H. and Doenhoff, Albert-E.-Von, 1959, *Theory of Wing Section*, New York : Dover Publication, Inc.
6. Frederick O. Smetana, 1984, *Computer Assisted Analysis of Aircraft Performance Stability and Control*, United State of America : McGraw Hill Inc.
7. E L Houghton & N B Carruthers, 1982, *Aerodynamics for Engineering Student*, Scotland : Edward Arnold.
8. Che Rahim Che The, 2000, *Kaedah Berangka, Malaysia* : Faculty of Science, University of Technology Malaysia.

Appendix

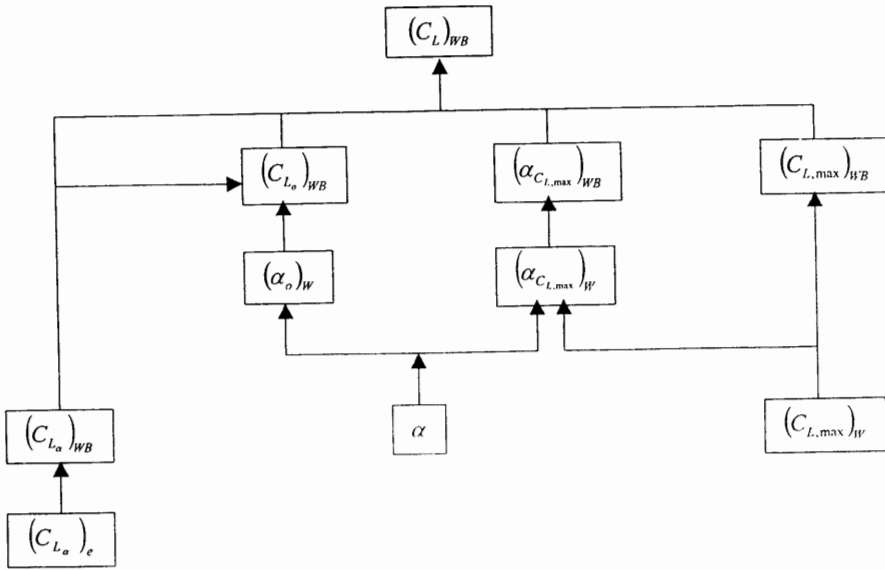


Figure 9 Flow Chart for the Calculation of Wing-Body Combination Lift Coefficient

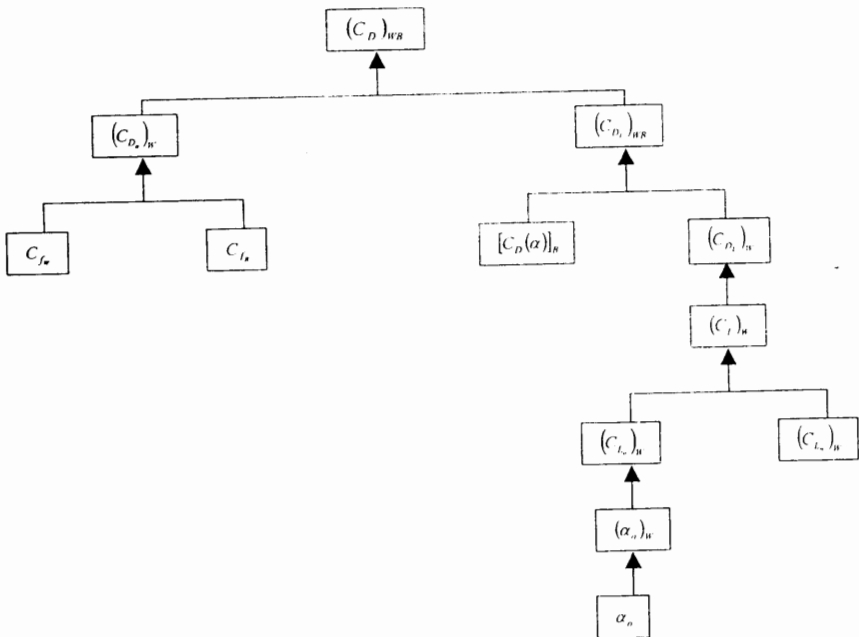


Figure 10 Flow Chart for the Calculation of Wing-Body Combination Drag Coefficient