Computational Fluid Dynamics Simulation and Wind Tunnel Testing on Microlight Model

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Abstract: This paper aims to highlight the wind tunnel testing techniques and the **C**omputational **F**luid **D**ynamics (**CFD**) studies on a scaled-down microlight model for its aerodynamic characteristics. The wind tunnel testing is conducted at a grace of *Universiti Teknologi Malaysia – Open Loop Subsonic Tunnel* facility with variations of angle of attack and flaps deflection angle. Wind tunnel corrections, such as 'blockage' effects, are considered during data reduction process in order to have results that will be almost precisely the same as in actual flight. In additional, the **CFD** simulation will be carried out using the software Fluent 6.1 on the model. Comparison of these two methods later depicts that the result obtained from the wind tunnel testing is agreeable with the result simulated by the **CFD**.
Key Words: Wind tunnel testing, **C**omputational **F**luid **D**ynamics (**CFD**), Microlight

1.0 INTRODUCTION

Of late, the implementation of wind tunnel testing and simulation by CFD is becoming a trend in the stage of the design analysis process. This paper will present the wind tunnel testing technique on a 1:25 scaled-down model of single-seated microlight and the data reduction procedures. CFD simulation is also carried out for comparison purposes.

2.0 EXPERIMENTAL STUDY

The objective of this testing is to determine the aerodynamic characteristics of a microlight which is designed previously under a student undergraduate project at Universiti Teknologi Malaysia. Its configurations as follow:

Microlight Configurations	
1) Wing specifications:	
Wing location	High wing
Dihedral angle	3^0
Wing plan form	Rectangular
Aerofoil section	NACA 2412
2) Aircraft gross weight	247.54kg
3) External dimension:	
Wing span, b	9 m
Total length	5.5 m
4) Cruising speed	92.67km/h
5) Service ceiling	3000 m

Table 1: Microlight Configurations

A 1:25 scaled-down model is fabricated for the purpose of this wind tunnel testing, as shown in **Figure 1**.

Figure 1: Microlight Model

The testing is conducted at a grace of *Universiti Teknologi Malaysia – Open Loop Subsonic Tunnel* facility. This tunnel is a suction type which the fan is situated at the exit of the tunnel. The test section is 0.457 m(H) x 0.457 m(W) x 1.27 m(L). The experiment is carried out at the wind speed of 20 ms^{-1} (Reynolds Number, *Re* = 71 170). For this kind of testing, the measuring device used is a *3-Components Balance* which is capable of measuring lift force, drag force and pitching moment.

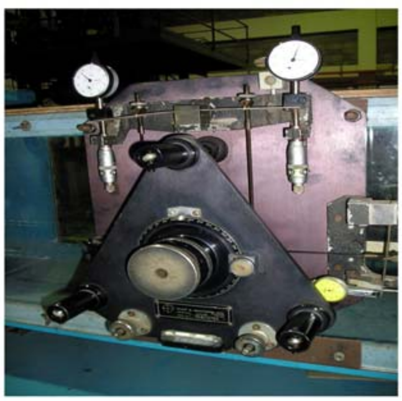

Figure 2: 3-Components Balance

Figure 3: Model during wind tunnel testing

2.1 Wind Tunnel Data Correction

Results obtained from wind tunnel testing need to be corrected following the blockage effect, buoyancy, wall interference and **STI** (**S**trut, **T**are and **I**nterference) effects. However for this kind of testing, only *blockage effect* is considered as it contributes quite significantly to the final result, the other corrections are assumed to be very less significant, and thus be ignored. The blockage is mainly comprised of **solid** and **wake** blockage.

2.1.1 Solid Blockage

The present of the model in the test section will actually reduce the area through which the air must flow. From the Continuity and Bernoulli's equations, this will increase the velocity of the air around the model. This is called **Solid Blockage [1]**. It is a function of the model thickness, thickness distribution and model size but is independent of the camber. For example, as the velocity around the model increase due to this effect, it will give the lift coefficient, C_L a higher value. Therefore the solid blockage correction needs to be performed to have the right C_L value.

2.1.2 Wake Blockage

A real body without suction type layer control will have a wake behind it and this wake will have a mean velocity lower than the freestream velocity. According to the *Law of Continuity*, the velocity outside the wake in a closed tunnel must be higher than the freestream velocity in order that a constant volume of fluid may pass through. This higher velocity has a lowered pressure and as the boundary layer grows on the model, puts the model in a pressure gradient. Hence, the velocity of the air around the model will increase and therefore, the result again needs to be corrected.

2.2 Data Corrections

After calculating the solid and wake blockage effect, the total blockage effect is as follow:

$$\varepsilon_{total} = \varepsilon_{sb,w} + \varepsilon_{sb,\,fuselage} + \varepsilon_{wb}$$

where $\varepsilon_{sb,w}$ = Solid blockage for wing

$\varepsilon_{sb,\,fuselage}$ = Solid blockage for fuselage

ε_{wb} = Wake blockage

Then the uncorrected freestream velocity and dynamic pressure can be corrected by applying these equations:

$$V_c = V_u\left(1 + \varepsilon_{total}\right)$$

$$q_c = q_u\left(1 + \left(2 - M^2\right)\varepsilon_{total}\right)$$

where q = Dynamic pressure
V = Freestream velocity
M = Mach Number

Hence, the corrected lift coefficient C_{Lc} , drag coefficient C_{Dc} and pitching moment coefficient C_{Mc} can be extracted by a simple relation as follow:

$$C_{Lc} = \frac{q_u}{q_c} C_{Lu} \qquad C_{Dc} = \frac{q_u}{q_c} C_{Du} \qquad C_{Mc} = \frac{q_u}{q_c} C_{Mu}$$

Others correction such as temperature, Mach number or pressure are not applicable here because the flow is *assumed to be* incompressible flow with constant temperature.

2.3 Results

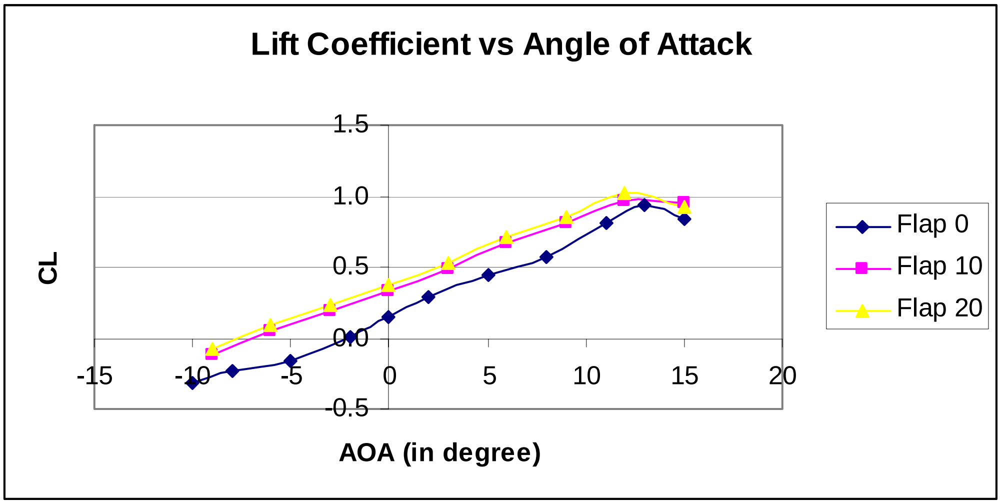

Figure 4: Lift Coefficient vs Angle of Attack

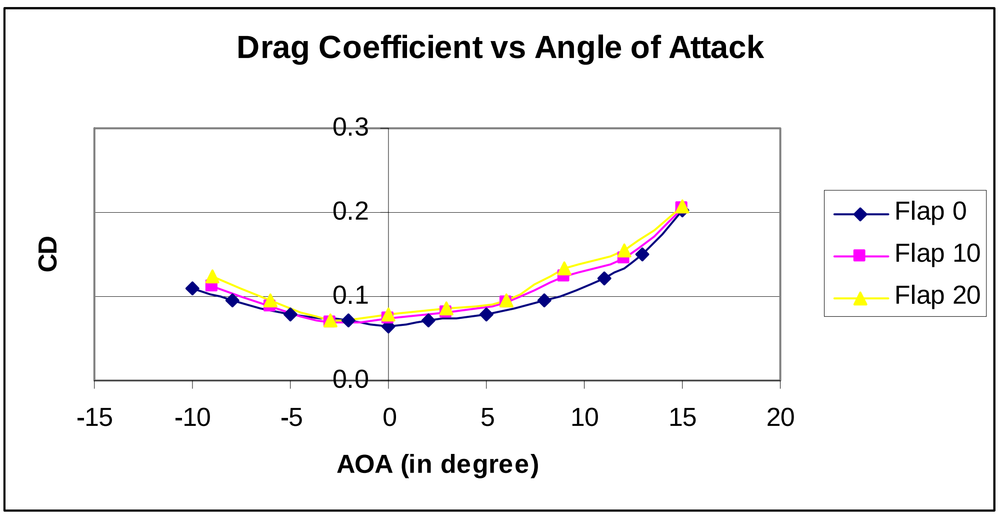

Figure 5: Drag Coefficient vs Angle of Attack

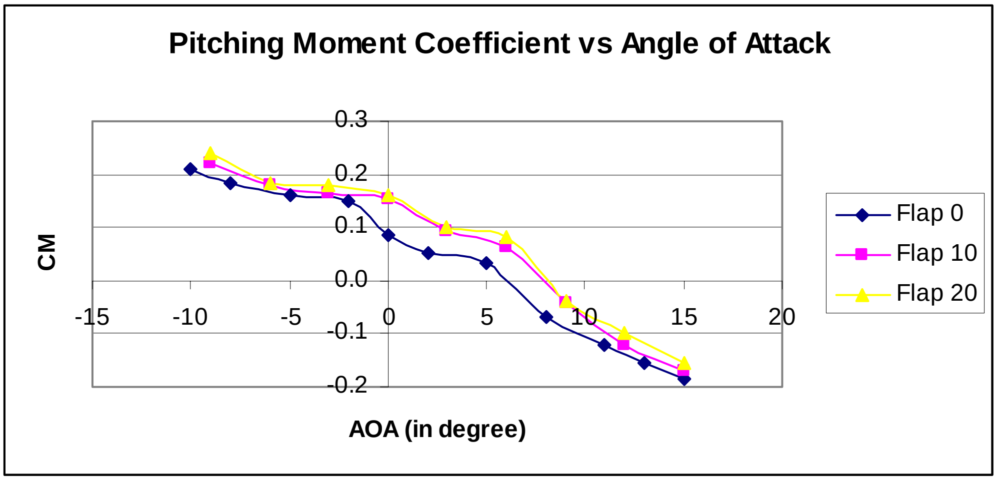

Figure 6: Pitching Moment Coefficient vs Angle of Attack

3.0 CFD SIMULATION

As an alternative way to obtain the aerodynamic characteristic and to verify the wind tunnel result, *Computational Fluid Dynamics* (**CFD**) is used. The first step of setting up Fluent 6.1 is to draw a solid model. This task is carried out by a *SolidWorks* software. The 3D drawing of microlight model has been generated and then be cut at the symmetry plane becoming a half model. This is to shorten the simulation time while the results obtained will be the same. The half solid model in shown in **Figure 7** meanwhile results at zero angle of attack are shown in **Figure 9** and **10** respectively.

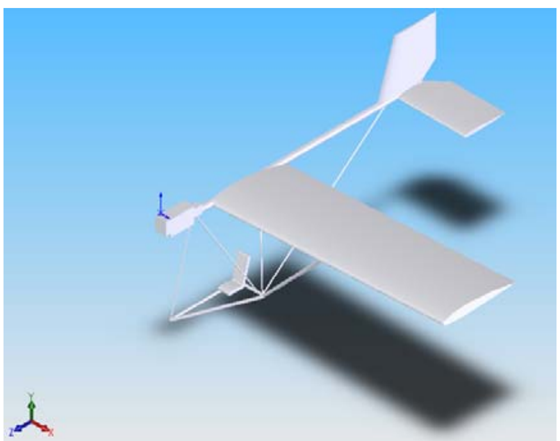

Figure 7: The Half of Solid Model

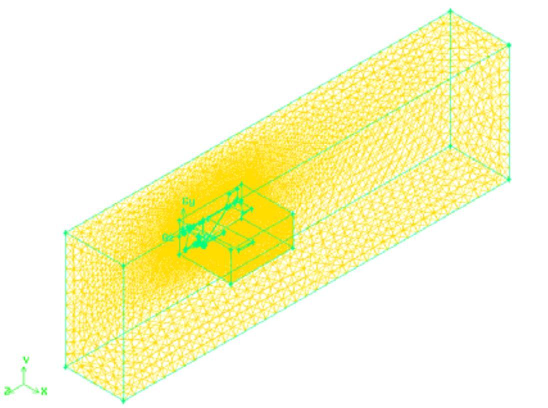

Figure 8: Meshed volume of microlight model

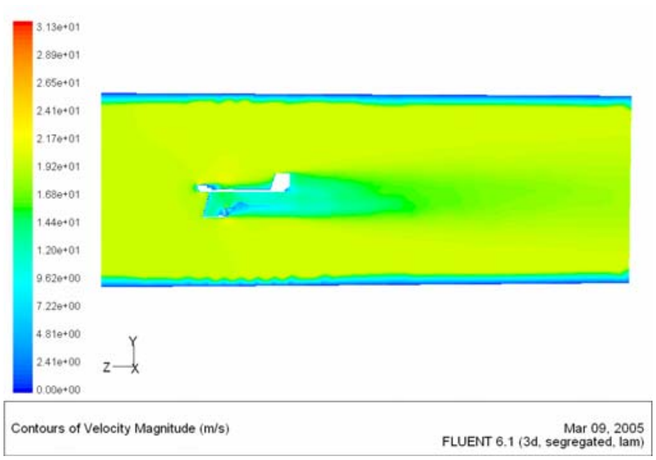

Figure 9: Velocity contours by 0^0 angle of attack at 20 m/s

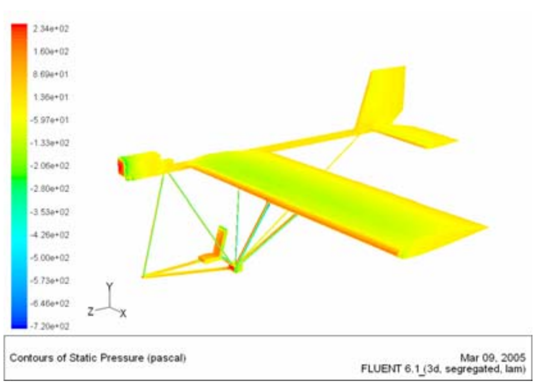

Figure 10: Pressure contours by 0^0 angle of attack at 20 m/s

4.0 DISCUSSION

It can be noticed from **Figure 4**, the graph for Flap 20 (*i.e. flaps are deployed at* 20^0) is located at the above, followed by the graph for Flap 10 and then at the bottom, the graph for zero deployment of flaps. This trend is correct as in principal; flap deployment will increase the lift coefficient and, unfortunately, same goes for the drag coefficient! From **Figure 6**, it can be concluded that this microlight is statically stable in longitudinal axes as the curve demonstrate a negative slope. **Figure 11** and **12** depict the differences between results obtained form wind tunnel testing and CFD, respectively.

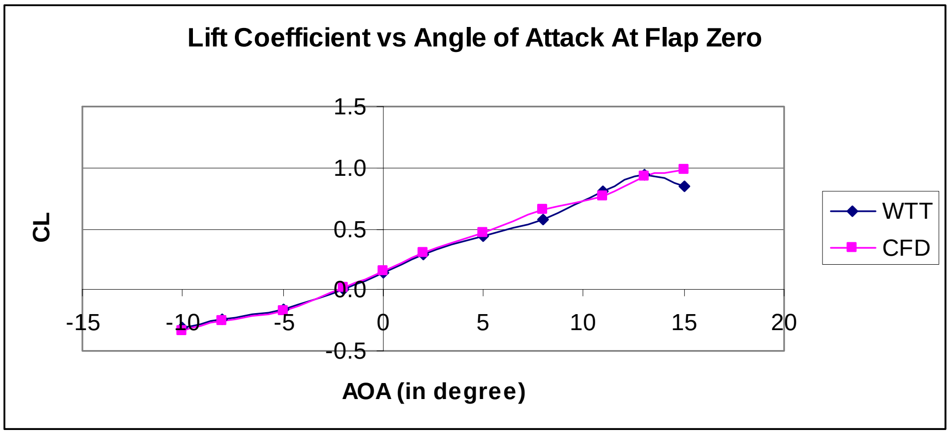

Figure 11: Comparison between Wind Tunnel Testing and CFD Results for Lift Coefficient

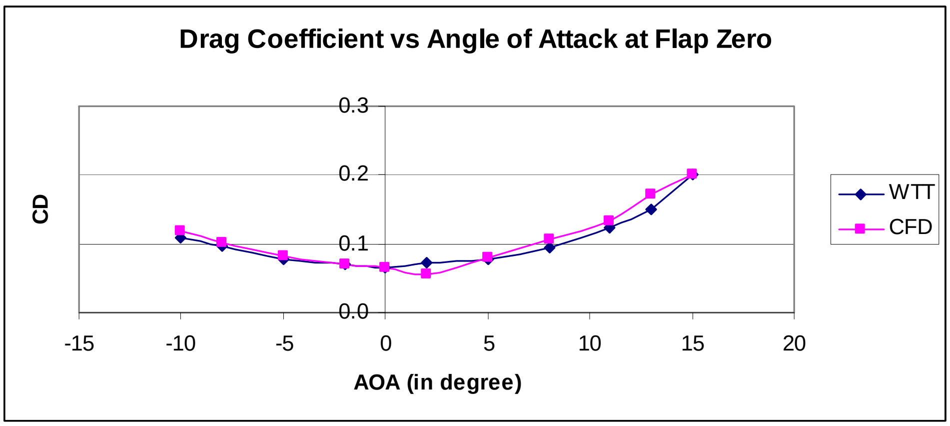

Figure 12: Comparison between Wind Tunnel Testing and CFD Results for Drag Coefficient

From both graphs plotted, it can be seen how similar the results obtained from both methods. Both trend lines almost overlap each other. Means both methods are agreeable with each other.

However, errors still occurred here and caused the results differential. Some errors predicted are:

i. The model is not exactly 100 % same as in the CFD due to the delicate model-making process.
ii. Different density between CFD (default 1.225 kgm^{-3}) and Wind Tunnel Testing (1.1784kgm^{-3}).
iii. The flow quality of UTM-Open Loop Subsonic Tunnel.
iv. A *slightly* vibration of 3-Components Balance device during testing.

CONCLUSION

As for plain speaking, the wind tunnel results that be presented throughout this paper can be accepted for future aerodynamic analysis as the results are *following* the correct trend and also *agreeable* with the CFD result. However for a better result, it is recommended to conduct the wind tunnel testing at a higher *Re* in order to have dynamic similarity. Some advance tests such as rolling and yawing testing are suggested to be carried out in the future development.

ACKNOWLEDGEMENT

Md Nizam Dahalan, Universiti Teknologi Malaysia.

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