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Wind Tunnel Experiment of UTM-LST Generic Light Aircraft Model with External Store

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Abstract – *This paper discusses the impact of the external store on the aerodynamic performance of the light aircraft model in the subsonic region. Light aircrafts are commonly used for pilots training, survey, leisure and transportation. To date, there have been a lot of small aircrafts used for strategic purposes where an external store, either external fuel storage or armament, has been installed on its wing. Examples of such aircraft are KAI-KA1, A29 Super Tucano, and Beechcraft AT-6. Therefore, it is important to study the effect of this external store installation on the aerodynamic characteristics of a small aircraft. An available light aircraft model of UTM Low speed wind tunnel (UTM-LST) has been modified so that a generic external store can be mounted on the lower surface of the wing. Two set of experiments were carried out on the model which were; experimental with an external store followed by experimental without external store as a benchmark of tested configuration. The experiments were conducted at two different speeds of 26 and 39 m / s that correspond to Reynolds numbers 0.4 × 10^6 and 0.6 × 10^6respectively. Three measurement techniques were employed on each configuration. The first measurement was the 6 component forces and moments measurement technique. The second technique was the pressure measurement on the wing, and the final test was the tufts flow visualization. The result of steady balance indicated that the external store has no effect on the coefficient of lift at low attack angle. However, it showed that there was a reduction of lift coefficient by 2% at higher angle of attack. The data showed that the coefficient of drag increases by 4% when the external is installed. Surprisingly, the installation of the store has insignificant effects on the pitching moment coefficient. An interesting feature observed from surface pressure studies where, the results showed that the pressure coefficient increased when the external is mounted on the wing at a low angle of attack. Such changes, however, do not occur at high angle of attack.*

Keywords: *Light Aircraft, External Store, Wind Tunnel Testing, Aerodynamic Characteristics*

Nomenclature

C_D	Drag coefficient
C_L	Lift coefficient
C_M	Pitching moment coefficient
Re	Reynolds number
V	Freestream velocity
α	Angle of attack

I. External Store Studies

This paper presents the results of the wind tunnel experiments of a light aircraft model which the external store has been placed under the wing. Light aircraft is defined as an aircraft that has the maximum gross take-off weight of 5,670 kg or less. This type of aircraft is widely use in aerial surveying, for training purposes, leisure and freight transport. However, due to its light characteristics, cost-effective surveillance and easy to handle, there some manufacturers are converting light aircraft for a combat mission. Such conversion requires an installation of the external store on its wing.

The external store may comprise of external fuel store, missile or digital camera. The airflow through the light plane model is relatively complicated. Many papers discussed the flow through the wing of the light aircraft either by simulation or experiment. Kostic et al [1] carried out numerical analysis to visualize the flow separation on the light aircraft wing at several angles of attack. This is shown in Figs. 1. The images show the flow separation moved upstream from the trailing edge towards the leading when angle of attack is increased. They reported that there is a growing of wake behind the plane when the angle of attack is increased. Intensive wind tunnel testing on light aircraft model has been performed by Ocokoljc et al [2] and Ristic et al [3]. The model has been tested in T-35 wind tunnel facility as shown in Fig. 2.

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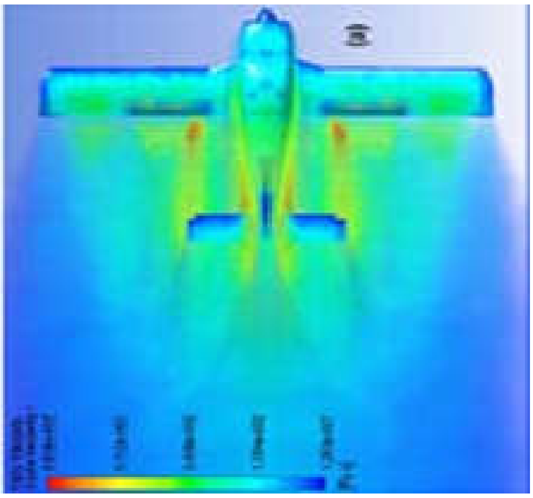
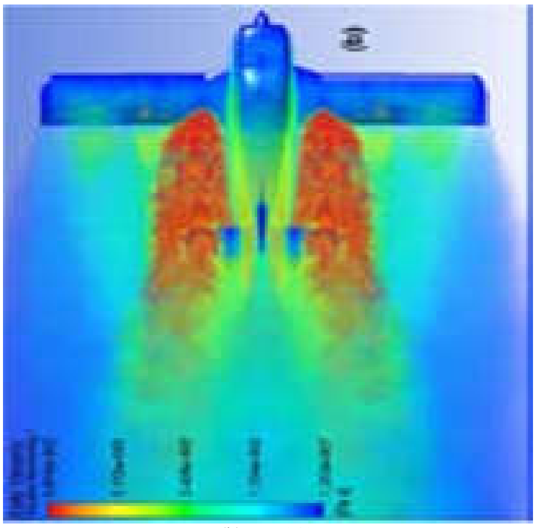
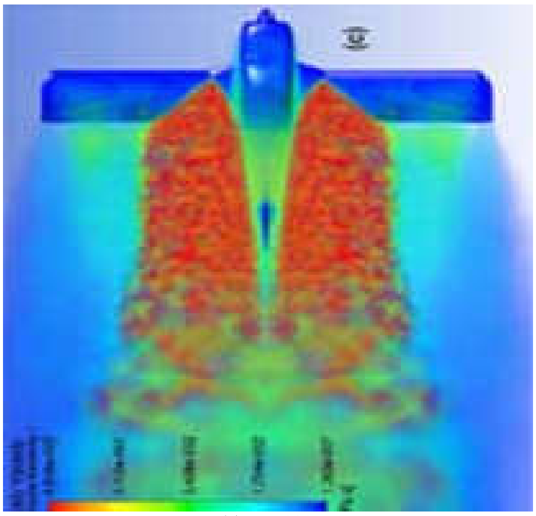


(a) α = 12°



(b) α = 14°



(c) α = 18°

Figs. 1. The effects of flow separation at different angle of attack α = 12°, 14° and 18° [1]

They discussed the results of the wind tunnel experiment and compared with the results obtained from the computer simulation. They suggested that it is necessary to employ more method of investigations to get more reliable results for light aircraft aerodynamic characteristics. Similar light aircraft model is also available in UTM-LST wind tunnel facility. Several experiments on the model have been performed in the UTM Low -Speed Wind tunnel facility by Ishak et al [4], Mansor [5], Bundu et al [6], Mat [7] and Bundu et al [8].

Fig. 2. The TAM mounted on the TEM support in the T-35 wind tunnel test section [2]

The wind tunnel has a test section of 2.0 m wide × 1.5 m height × 5.5 m length with a maximum speed of 82 m/s [5]. The focus of these projects was to determine the aerodynamics characteristics including the stability derivatives of UTM-LST light aircraft model. Bundu et al [8] and Mat [7] conducted several experiments to simulate the aircraft wing flow when the propeller is placed in front of the aircraft. The results indicated that the increase in fan rotation has delayed the flow separation formation on the wing. All the experimental results were systematically compared with CFD results for validation purposes and reliability [4]. The external store study on the lightweight subsonic fighter aircraft model in UTM has been initiated since 2004 [9] (Fig. 3). In this project, the results obtained from experimental studies were compared with those of numerical studies. It was concluded that the installation of external storage on a subsonic aircraft wing has tremendously affected the pressure distribution especially on the lower surface of the wing.

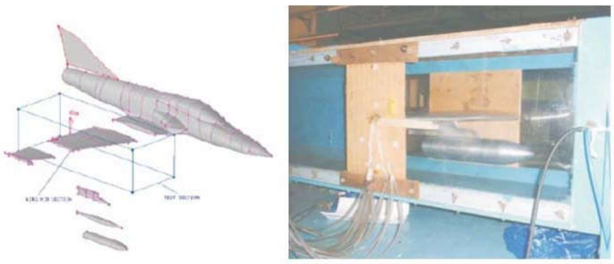


Fig. 3. A subsonic fighter aircraft wing been tested in wind tunnel testing with external store installed on its wing [9]

According to Mouton et al. [10] who performed numerical and experimental studies on the nacelles, the external store (nacelles) indeed has a very significant impact on drag and very little influence on lift and stability. The results obtained contrast with Yang [11] who numerically shows the external store can affect the flow of the mother aircraft. The store can cause several longitudinal stability effects. Later work by Yang [12] showed that the relative distance between the mother aircraft and the store has significant influence on the lift coefficient curve slope and pitching moment curve slope.

Several other researches were performed to identify the aerodynamic characteristics of light aircraft at lower Reynolds number such as by Aziz and Elsayed [13], Mehta [14], Ahmed [15], Razaami et al [16] and Khurana [17]. These researchers found that the nature of separation on the light aircraft is unresolved and need further investigations. However, there is no experimental work carried out yet to study the effect of the external store on the aerodynamic performance of UTM LST light aircraft model. A research grant was then secured to investigate the effect of the external store on the aerodynamic characteristics of this model. In this project, UTM LST light aircraft wind tunnel model has been modified and tested to investigate the store effects on the aerodynamic characteristics of this model. This paper highlights the experimental data of light aircraft model with external store, where the available data on this is very limited.

II. External Store Design

The CAD drawing for the external store, mother aircraft and its installation in UTM-LST is shown in Fig. 4. The external store is positioned at about 17% and 31% from the model center line. The final dimensions of the external store have an overall length of 209 mm with a diameter of 40 mm. It has been manufactured using aluminum. The model has been attached to 6 axis forces and moments external balance system located underneath the test section through 3 strut supports. The model angle of attack, α can be altered by adjusting the rear strut vertically.

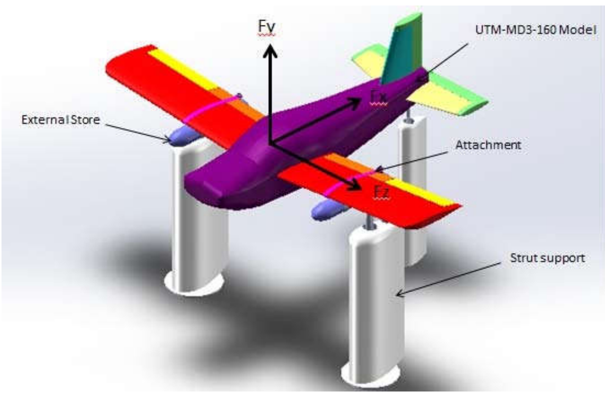


Fig. 4. CAD model of UTM-LST with external store

III. Wind Tunnel Testing

There were two main parts of the experiment performed on this project, i.e; the first experiment was the experiment without the external store which is the *clean wing configuration* and followed with the *external store experiment.*

The experiments were conducted in 2.0 m (width) × 1.5 m (height) × 5.8 m (length), closed-circuit UTM at speeds of 26 m/s and 39 m/s, equivalent to Reynolds number 0.5 × 10^6 and 1.0 × 10^6 respectively based on the mean aerodynamic chord of the wing. The solid and wake blockage calculation and standard testing procedures discussed by Pope [18] and [19] have been followed in conducting experiments and data analysis.

III.1. Clean Configuration Experiments

The final installation of the light aircraft model inside the test section for clean wing configuration is shown in Fig. 5.

The model is attached to 3 strut support structure which connected to a heavy capacity 6-component external balance located underneath the test section. The experiments were performed at two different speeds of 26 and 39 m/s that correspond to 0.4 and 0.6 × 10^6 of Reynolds number respectively. The model angles of attacks, α were automatically changed from 0^o to 25^o degrees.

Fig. 5. The installation of UTM-LST light for clean wing configurations

III.2. External Store Experiments

The installation of the model for external store experiments is shown in Figs. 6(a) and (b). The external was fixed at two different positions on the lower surface of the wing.

The first position was at about 23 cm (31%) from the wing center line while another position was at 13 cm (17%) from the wing centre line as shown in Fig. 6(a).

The experiments were also performed at similar speeds of 26 and 39 m/s that correspond to Reynolds number of 0.4 × $10^6$and 0.6 × 10^6 respectively based on the mean aerodynamic chord.

The forces and moments in *x, y* and *z* axes plus the surface pressures at 40 cm from the wing centre line were logged simultaneously.

IV. Results

IV.1. Steady Balance Data

Figs. 7, 8 and 9 show the results obtained from steady balance data, i.e coefficients of lift (C_L), drag (C_D) and pitching moment (C_M) measured at wing reference chord line.

(a)

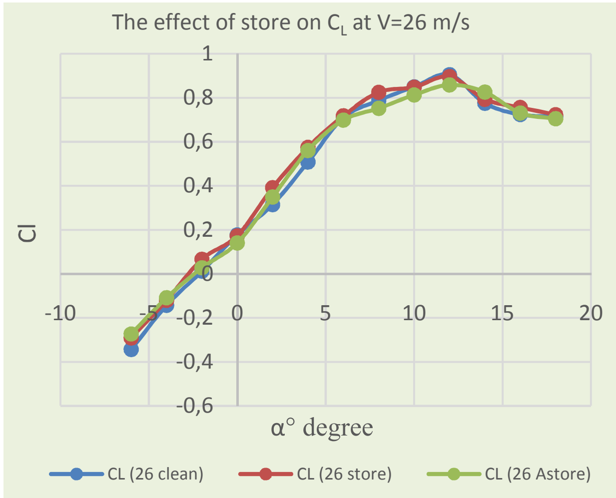
(b)

Figs. 6. The installation of UTM-LST light aircraft model with external store in UTM-LST

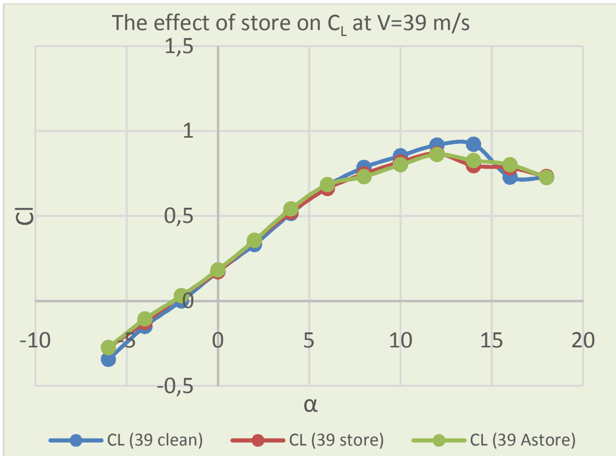
The solid and wake blockage corrections have been considered based on Pope [13]-[14]. To compare the effects of the Reynolds number, each coefficient has been plotted separately for velocities of 26 m/s and 39 m/s. In the figures, the blue dotted line, the red dotted line and the green dotted line represents the clean wing configuration, the model with storage attached at 23 cm, and model with storage attached at 13 cm from the wing center line respectively.

At 26 m /s freestream velocity as shown in Fig. 7(a), it is observed that the coefficient of lift changes only slightly for the entire angle of attack range from α= 0° to 23°. At higher velocities, the lift coefficient does not change much at α lower than 7° whereas at angles higher than 7°, the external store caused a general reduction in the coefficient of lift (Fig. 7(b)). The alpha stall angle also decreases in this condition. This situation happens because the steady laminar flow has been interrupted due to the installation of the external store. Another important observation is that the external store position from the wing center line does not affect the overall lift force production. The coefficient of drag obtained from this experiment is shown in Figs. 8.

The results at two velocities indicated that the installation of the external store has increased the drag coefficient. The drag is increased mainly due to the installation of external store which also increased the frontal area for overall aircraft towards the incoming flow.



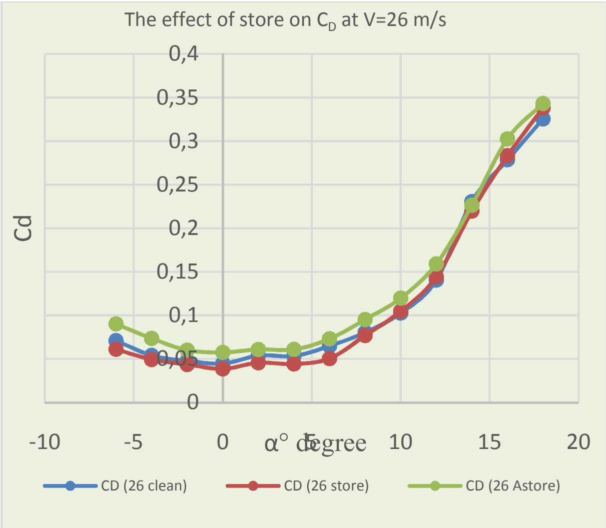
(a) V= 26 m/s



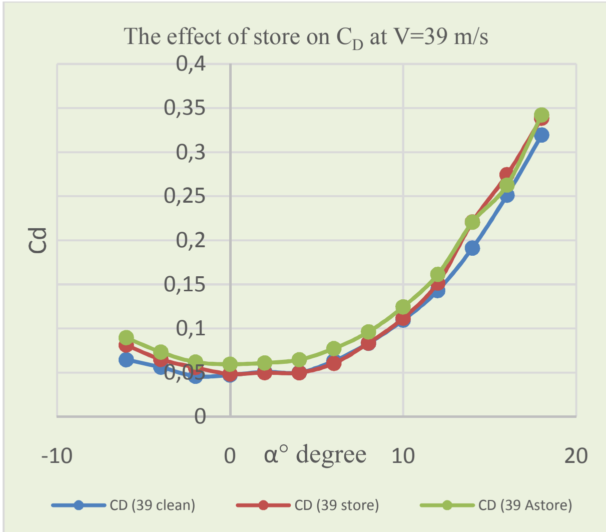
(b) V= 39 m/s

Figs. 7. The effects of store on lift coefficient at V= 26 and 39 m/s

Other factors that caused an increment in drag include the shape of the frontal outline, the induced drag of the stores, and the interference drag of the store and the aircraft. At the speed of 26 m/s which correspond to Reynolds number of 0.4×10^6, it is noted that the drag coefficient obtained is bhigher when the external store is mounted at 13 mm from the wing centre line compared to the drag than the clean wing configuration. This occurs because the wake generated by the external store installed near the fuselage, joined the wake generated by the fuselage, thus creating a bigger wake behind the aircraft, resulting in highertotal drag. Similar situation can be observed at the speed of 39 m/s for Reynolds number of 0.6×10^6.

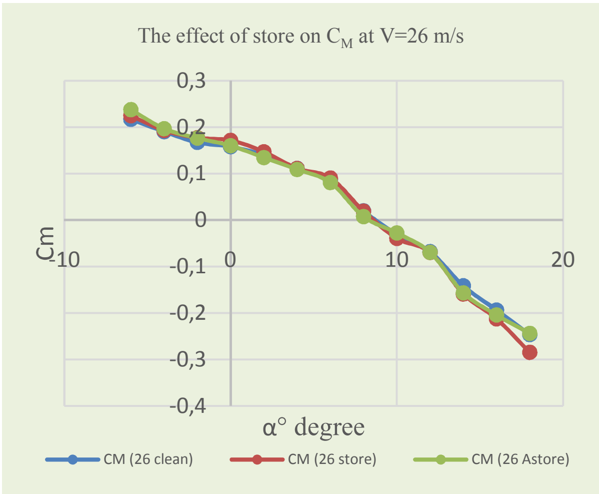


(a) V=26 m/s

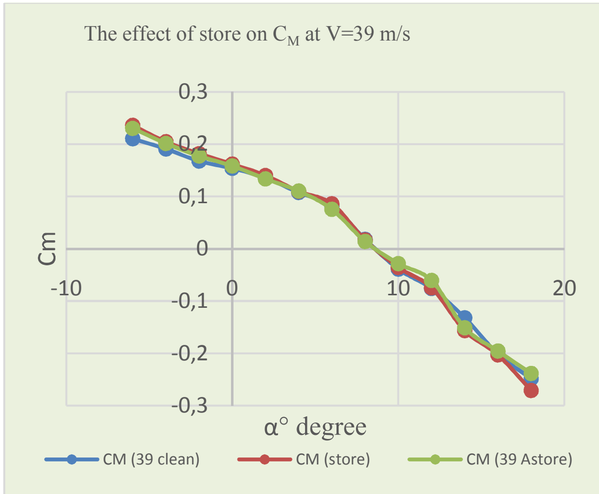


(b) V = 39 m/s

Figs. 8. The effects of stores on drag coefficient at V= 26 and 39 m/s



(a) V = 26 m/s



(b) V = 39 m/s

Figs. 9. The effects of stores on pitching moment coefficient at V= 26 and 39 m/s

The pitching moment results from the external balance are shown in Figs. 9. The figures show that the installation of external stores does not affect the pitching moment coefficient. The negative slope indicates that the aircraft is longitudinally stable. The results are consistent with Kostic [1] and Goran [2]. It is important to note here that the piching moment has a positive intercept, that is, C_{mo}> 0 to trim at positive angles of attack.

IV.2. Surface Pressure Measurement at Low Angle of Attack

This section discusses the results obtained from the surface pressure experiments performed on the model.

There are 21 pressure taps to measure the pressures located at a distance of 30 cm from the wing centre line (14 on the upper surface and 7 on the lower surface). Figs. 10 show the results obtained at the lower angle of attack i.e at α= -4° (Fig. 10(a)), α= 0° (Fig. 10(b)) and α= 2° (Fig. 10 (c)). Here, the 2^{nd} *configuration* is for the store at 23 cm and the 3^{rd} *configuration* is for the store at 13 cm from the wing center line. For the upper surface, at low angle of attack (α= -4°) the external store caused the pressure coefficients to increase at the trailing edge (Fig. 10(a)).

It can also be seen in the figure that the external store position tremendously affects the pressure coefficient. In this case, when the external store is installed near the fuselage, the pressure coefficient increment was higher.

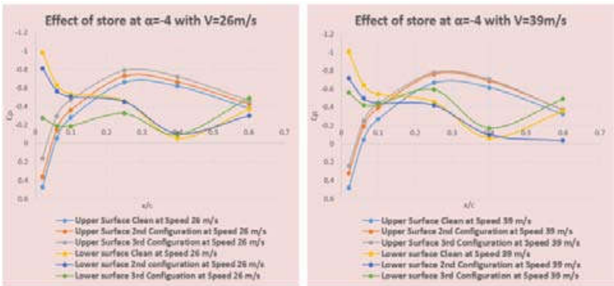
The same situation can be observed when α is increased to 0°, where the pressure coefficient is still high when the external store is installed.

When attack of angle is increased to α= 2°, the airflow behavior from the leading edge to 30% of the wing chord is seen to have affected by the external store.

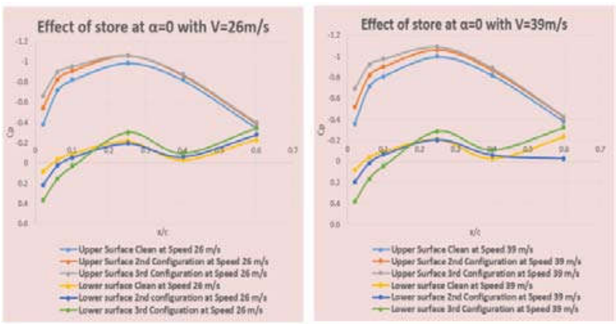
Beyond this position, the external store has no aerodynamics effect on the flow. The result obtained here is inconsistent with Mat Lazim [9] who showed that the flow on the upper surface is not affected by the external store. The results also show that the increase in Reynolds number from 0.4×10^6 to 0.6×10^6 has no effect on the flow.

On the lower surface, the effect of external store installation can be observed at α= 2°, in this case, the location of the external store has influenced the pressure distribution in chordwise direction. It is notable that the pressure coefficient is comparatively low when the external store is mounted near the fuselage.

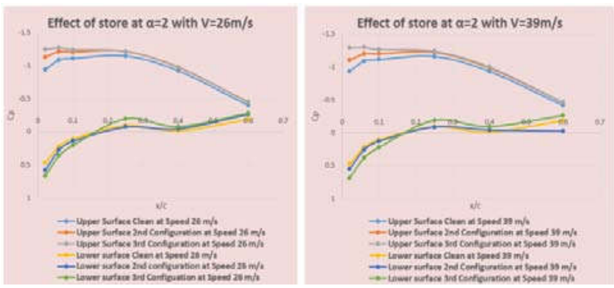
This indicates that the wake generated by the external store has joined the wake generated by fuselage and reduces the coefficient of pressure significantly. When the angle of attack is increased from α= -4° to α= 2°, the external store effect reduces. This results are consistent with Mat Lazim [9] who experimentally and numerically showed that the external store has effects on pressure coefficient at lower angle of attack only.



(a) α= -4°



(b) α= 0°



(c) α= 2°

Figs. 10. the effects of store on pressure coefficient at lower angle of attack, α =-4° to α= 2°)

IV.3. At High Angle of Attack (From α= 8° to α= 12°)

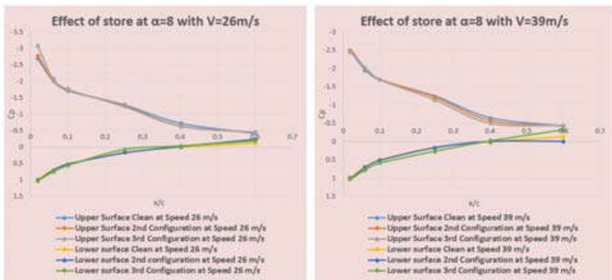
The results obtained at the higher angle of attack α= 8°, 12° and 16°are shown in Figs. 11. The results showed that flow separation shift upwards to the leading edge when the angle of attack is increased regardless the position of the external store. The results obtained also showed that the external store does not affect the flow characteristics at higher angle of attack.

The increased in Reynolds number from 0.4×10^6 to 0.6×10^6 also showed insignificant influence on pressure coefficients. At α= 8°, flow separation covers 80% of the wing.

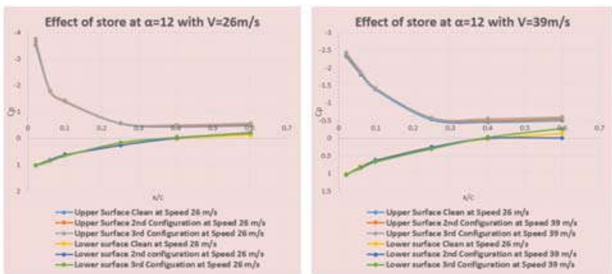
When the angle of attack is increased to α= 12°, flow separation covers 90% of the wing. Finally, the whole wing is covered with flow separation as the angle of attack is increased to α = 16°.

IV.4. Flow Visualization

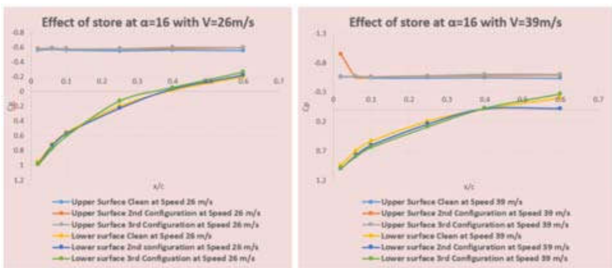
The final experiment performed on the model was the tuft studies. The images of the tuft during the experiments were capture using high resolution digital camera to observe the flow separation above the wing and the location where the external store is mounted. The simple images at the speeds of 39 m/s are shown in Figs. 12. The angle of attack was varied from α=0° to α= 18°.



(a) α = 8°



(b) α = 12°

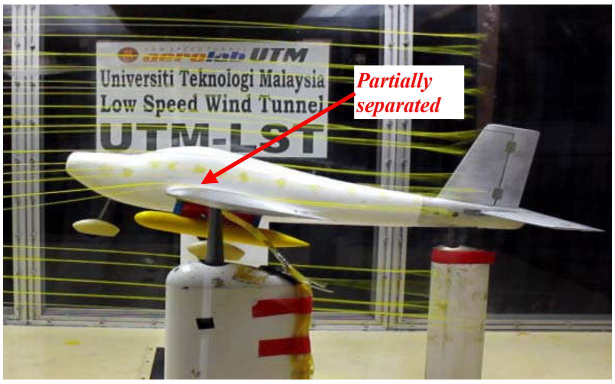


(c) α = 12°

Figs. 11. The effects of store on pressure coefficient at higher angle of attack, α = 8° to α = 12°)

On the upper surface of the wing, it is notable that the flow is attached to the wing surface at α= 0°.

(a) α =0°



(b) α = 10°

(c) α = 16°

(d) α = 18°

Figs. 12. Flow tuft experiment

The flow then begins to separate particularly near the trailing edge and eventually moved towards the leading edge when the angle of attack is increased to α=10°. At α= 16° and above, the entire wing is completely covered with the separation flow. The results obtained here are consistent with Bundu [6] and Mat [7].

However, the flow separation on the lower surface particularly in the region where the external store is mounted could not be observed using this flow technique. Further experiments with better photography techniques are necessary to observe the flow on the lower surface.

V. Conclusion

A light aircraft model has been tested in the UTM LST facility. The main purpose of this project was to study the influences of the external store on the aerodynamics performance of light aircraft model. The model has been tested at the speeds of 26 m/s and 39 m/s that correspond to Reynolds numbers of 0.4×10^6 and 0.6×10^6 respectively.

Three established measurement tools were employed on the model, i.e steady balance, surface pressure measurement and tuft flow visualization study techniques. An important observation of this study is that the external has reduced the lift and increased the drag.

The lift is reduced because the flow has been interrupted by the installation of the external store.

Meanwhile, the drag is reduced due to the bigger wake created behind the model as the wake generated by the external store has joined the wake generated by the fuselage.

Another important note here is that the external store position from the wing center line does not affect the lift but the production of the drag force. In addition, the results obtained from this study also showed that the external store does not affect the pitching moment characteristics and the external store position has affected the pressure coefficient particularly at low angle of attack based on the analyzed data. Further experiments have been planned to observe the flow separation on the lower surface of the wing in the near future.

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The data presented, the statement made, and views expressed are solely the responsibility of the authors.

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