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Effect of External Store on a Generic Subsonic Fighter Aircraft

K M Tafsirul Hoq [1], Abdelrahman Talal [1], Shabudin Mat [1 *], Yahaya Ramli [1], Abd Rahim Abu Talib [2], Mazuriah Said [3], Nur Amalina Musa [3], Airi Bin Ali[1]

[1] *UTM Aerolab, Institute of Vehicle System Engineering, 81310 UTM Johor Bahru, Johor, Malaysia.*
[2] *Aerodynamics, Heat Transfer & Propulsion Group, Department of Aerospace Engineering, Faculty of Engineering, Universiti Putra Malaysia.*
[3] *Faculty of Engineering, City University Malaysia, 46100 Petaling Jaya, Malaysia.*

ABSTRACT

In contemporary military and transport aircraft, wing-mounted external storage is commonly used when there is insufficient space within the fuselage. The installation of these external stores can significantly alter the flow around adjacent components, causing a change in aerodynamic characteristics. The objectives of this research are to investigate the effects of different locations of external stores and the effects of flaperon deflection on the aerodynamic characteristics and stability of a generic subsonic fighter aircraft. The study involves examining six different configurations of external stores mounted under the wing, and for the flaperon, four deflection angles were chosen with the aim of measuring the aerodynamic forces and moments. These experiments were carried out at wind speeds of 30 m/s corresponding to Reynolds numbers of 0.6×10^6 for angles of attack ranging from -2° to 24°. The analysis revealed that the presence of external stores positioned at both the tip chord and 38 cm from the root chord significantly increased the lift coefficient to a value of 1.09 compared to other configurations. The introduction of flaperon deflection also led to increased drag at higher angles of attack and demonstrated its maximum efficiency at an angle of attack (α) of 10 to 12 degrees.

Keywords: External store, Aerodynamics, Stability, Wind Tunnel Testing, Flaperon

I. INTRODUCTION

Airplanes could not fly without aerodynamics; when considering the performance and design of airplanes, aerodynamics is an important aspect. In aviation, aerodynamics has three important components: the aircraft, relative wind and the atmosphere. Wind tunnel testing is one of the best options to investigate the aerodynamic characteristics of aircraft [1]. The design of internal weapon bays, compared to external mounting bombs, offers reduced Radar Cross Section (RCS), enhancing the combat effectiveness and defensive capabilities of modern fighter aircraft [2]. However, modern military multifunctional fighter aircraft still typically come with a variety of wing-mounted external storage. When there is no room inside the fuselage of an aircraft, external storage is a necessary component. The deployment of weaponry or drop tanks in combat aircraft, which has been quite frequent since the early days of aviation, is a typical example of an application of external supplies. External storage, such as auxiliary fuel tanks or weaponry like missiles, bombs, rockets, and gun pods, are often mounted on the underside and tip of an aircraft wing. The flow on its surrounding components, such as the control surfaces, can be significantly altered when these stores are fitted. This might bring about a number of aerodynamic interference characteristics, including modifications in aerodynamic force, flow separation, downstream

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* To whom correspondence should be addressed, E-mail: shabudin@utm.my

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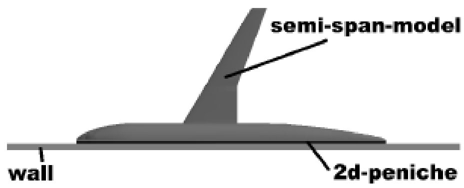
extension and also an increase in turbulence. The controllability and stability of the aircraft may be impacted by these phenomena, which may also have a negative impact on other aircraft parts like the horizontal tail and vertical stabilizer. By combining the functions of flaps and ailerons, flaperons serve as both flaps and ailerons. Flaperons are typically located on the trailing edge of the wing. Both work by deflecting up or down to produce lift on one wing and down force on the other, causing the aircraft to roll in the desired direction. Flaperons are hinged surfaces that can be extended downward to increase lift, like flaps, and are typically found on small, light aircraft that do not have separate flaps and ailerons. Flaps are another type of control surface found on the wings of an aircraft that are used to increase lift and drag. Flaps can be extended downward to increase the camber, or curvature of the wing, which in turn increases lift and drag [4]. Flaps help the aircraft achieve the necessary lift to become airborne or to slow down during landing. Replacing these control surfaces with flaperons could potentially simplify the design of the aircraft, reduce weight, and may also increase the effectiveness and precision of the control surfaces that will assist the fighter aircraft to easily maneuver [5].

This study aims to examine the effects of external store position on the aerodynamic characteristics and stability of a semi-span subsonic fighter aircraft. In this experiment, a half model of a generic subsonic fighter aircraft has been used. The fighter aircraft requires high maneuverability; thus, it needs very effective control surfaces during the operation [3]. The experiment also focuses on examining the impact of flaperon deflection on the fighter aircraft for two different wing configurations: a clean wing and a wing with an external store positioned at the wingtip. The model was built about 20% of the aircraft's original size which the main focus is to understand the phenomenon of change in aerodynamic characteristics when several parameters of testing are changed. The experiments were performed in the UTM Low Speed Tunnel (UTM-LST) located at Universiti Teknologi Malaysia (UTM), Johor Bahru. The model has a wingspan of 0.72 m and is installed in the 2 x 1.5 x 6-meter test section size.

II. BACKGROUND STUDY

2.1 Half body or semi span testing

Throughout the history of wind tunnel testing for aircraft models, semi-span testing has been a widely used technique to achieve higher Reynolds numbers and improve the quality of measurement data while reducing costs associated with balances and models. The core idea behind this method is to consider the mid-plane of the aircraft as a plane of symmetry. By mounting the mid-plane on the wind tunnel wall (even floor or ceiling), the tunnel wall acts as a symmetrical plane. However, the tunnel walls themselves are not ideal symmetry planes due to the growth of boundary layers upstream of the model. To prevent interactions between the tunnel boundary layer and the model, a stand-off, often called a peniche, is typically employed between the wind tunnel wall and the half-fuselage. The peniche is commonly designed in a two-dimensional (2D) configuration as shown in Figure 1, extending the fuselage symmetry plane from the tunnel wall.



Figures 1 A half-span model with a peniche attached with tunnel floor

2.2 Past research experience on external store

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 a 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 [6]. The outcomes are shown in Figures 2, 3 and 4, respectively.

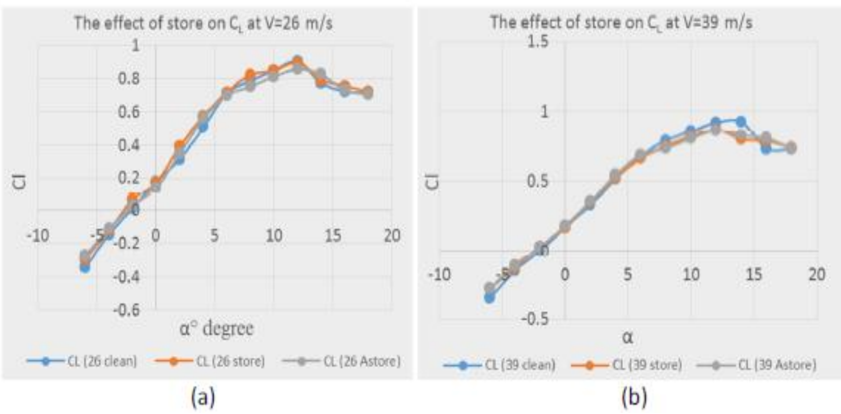


Figure 2 Effects of store on lift coefficient: (a) V = 26 m/s, and (b) V = 39 m/s [6]

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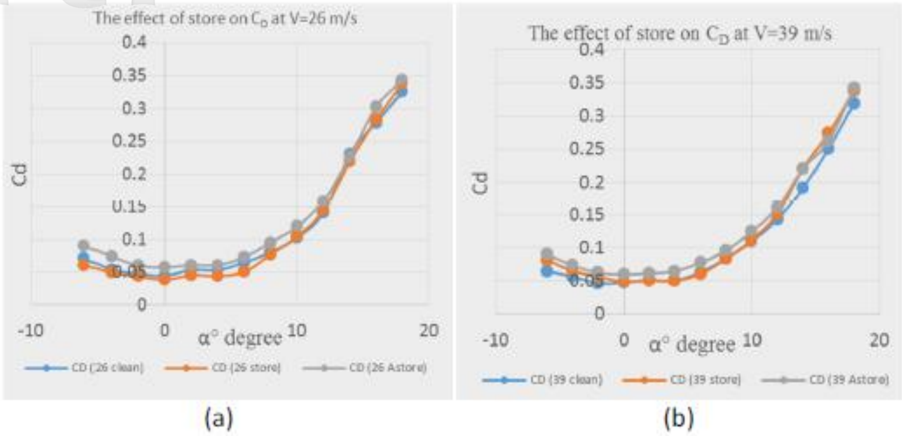

Figure 3 Effects of store on drag coefficient: (a) V = 26 m/s, and (b) V = 39 m/s [6]

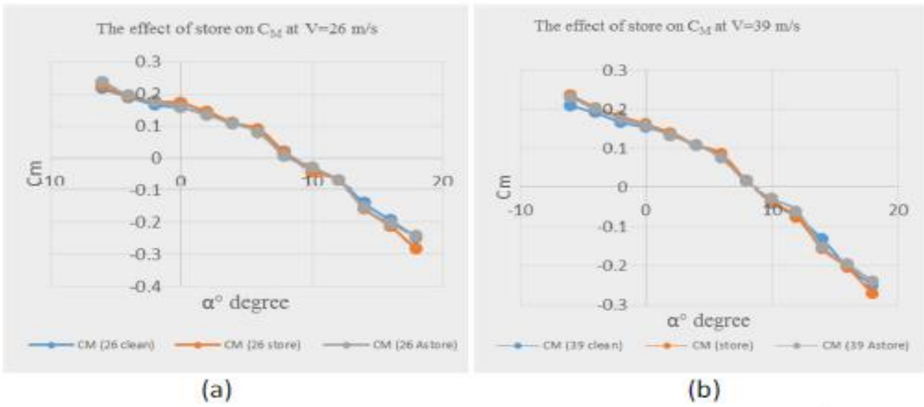

Figure 4 Effects of store on pitching moment coefficient: (a) V = 26 m/s, and (b) V = 39 m/s [6]

The model was subjected to three established measurement techniques, namely steady balance assessment, surface pressure measurement, and tuft flow visualization. An important finding of this study is that the presence of an external store has resulted in a reduction in lift and an increase in drag. This decrease in lift is attributed to the disruption of airflow caused by the installation of the external store. Conversely, the increase in drag can be attributed to the enlargement of the wake behind the model, as the wake generated by the external store combines with the wake produced by the fuselage. Another noteworthy observation is that the position of the external store relative to the wing center line has no impact on lift but does affect the generation of drag. Furthermore, the investigation highlighted that the external store does not influence the pitching moment characteristics, but it does affect the pressure coefficient, especially at low angles of attack, as per the analyzed data.

2.3 Flow separation of flaperon

Flow separation and adverse pressure gradient can occur when the flaperon is deployed. A flaperon is a movable surface that can be used to control the roll and maximum lift coefficient of an aircraft. When the flaperon is deployed, it changes the shape and angle of attack (α) of the wing, which can cause the fluid flow to become turbulent and detach from the surface of the wing. This can lead to flow separation and an increase in drag, which can reduce the performance and stability of the aircraft. Additionally, the deployment of a flaperon can cause an adverse pressure gradient on the upper surface of the wing, as the fluid flow moves from the leading edge to the trailing edge. If the pressure on the upper surface of the wing increases as the fluid flow moves towards the trailing edge, it can cause the fluid flow to detach from the surface and form a turbulent boundary layer, leading to flow separation. The location and intensity of flow separation can vary significantly depending on specific conditions, such as at angle of attack, the deflection angle of the flaperon, and the chord of the flaperon [7]. Comparing a streamline at wing at angle of attack of 15° with different wing configurations: (a) No Flap, (b) Plain Flap, and (c) Flap and Flaperon. As shown in Figure 1, the streamline becomes turbulences behind the flap and flaperon which result in higher lift, high induced drag, and high lift to drag ratio compared to that of the wing of without flap and with plain flap [4].

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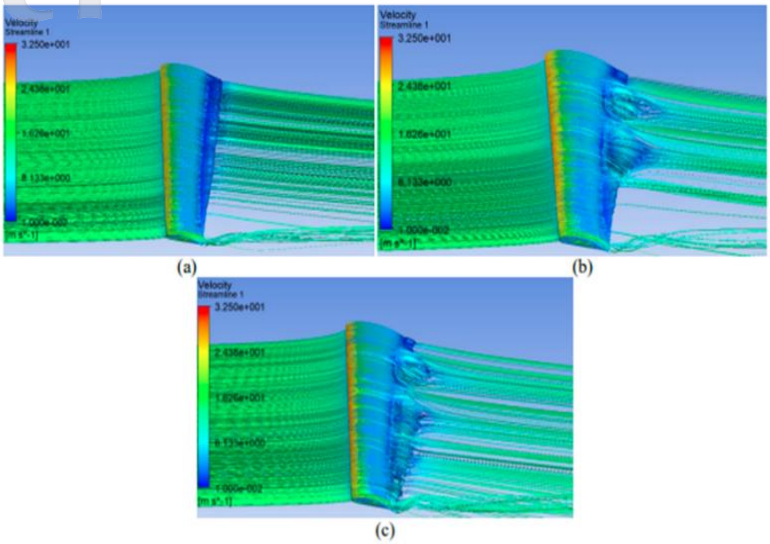

Figure 5 Flow separation: (a) Without flap, (b) Plain flap, and (c) Plain flap and flaperon [4]

2.4 Comparison between falperons and flaps

A study has been conducted to design a flaperon for a wing and compare the performance characteristic of this flaperon-wing combination with that of conventional wing design that makes use of separate flap and aileron. The flaperon extends from the wing root till 95% of the wingspan. While the flap is approximately 40% of the wingspan. The result concluded that when the flaps are deflected, the lift produced 3607 N which can be used for the take-off. If we use the flaperons instead of the flaps, the compression produced at the lower part causes lift augmentation which is around 5067 N. Thus, the lift produced increases as we increase the span length of the flaps by using flaperons [5]. Another study had been made of using flaperon instead of conventional flap in a biplane, the summary of the research showed that flaperons were able to increase lift, improve the landing attitude, and able to be synergistically arranged such that the net pitching moment with symmetric flaperon deflection was minimal [8].

2.5 Comparison between falperons and ailerons

Due to the importance of roll control in a fighter aircraft, span of the flaps must be selected as short as possible, so that the span of the aileron is long enough. Therefore, in a fighter aircraft, it is advised to design the aileron prior to flap design. Even though, the rolling rate can be more improved when applying flaperon as a control surface to have a long extension of wingspan. Comparing the ailerons and flaperons, it has been observed that the roll rate is increased by 35% by employing flaperon for roll control instead of using the previously used aileron [5]. The flaperon generate significant rolling moments and maintain high roll rates and improve maneuvering capability by decreasing drag [8].

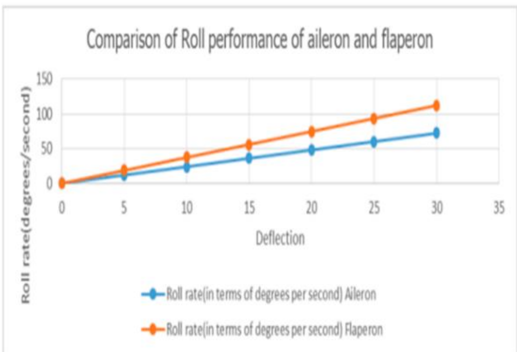

Figure 6 Comparison of roll performance of aileron and flaperon [5]

The outcome of this background study has shown that there are many aerodynamic characteristics of subsonic fighter aircraft such as changes in aerodynamic properties and stability when the flaperon changes are still unknown. Not many publications available in the literature review on the aerodynamic data on a generic subsonic fighter aircraft. Thus, this research is carried to obtain clear insight into flow characteristics of subsonic fighter aircraft.

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III. EXPERIMENTAL SETUP AND METHODOLOGY

3.1 Test facility and model specification

The investigation takes place at the Aeronautical Laboratory facility of Universiti Teknologi Malaysia (UTM), specifically in the Low-Speed Wind Tunnel (UTM-LST). The UTM-LST is a closed-circuit, single-return wind tunnel capable of achieving a maximum speed of 80 m/s. The test section has cross-sectional dimensions of 2.0 m (width) x 1.5 m (height) x 5.8 m (length). For this experiment, a generic half-span model of a subsonic fighter aircraft has been selected. The model consists of a port wing from the full-span model and a semi-fuselage, which is fabricated using a mold of the full-span fuselage [9,10]. The wing incorporates control surfaces such as flaps and ailerons, while the tail section includes a horizontal stabilizer and vertical stabilizers. Notably, the rudder and the elevator were kept fixed. Detailed dimensions of the model can be found in Table 1 and Figure 7.

Table 1 Specifications of the model

Part	Dimension
Fuselage length	2.00 m
Semi wingspan	0.70 m
Wing mean aerodynamic chord	0.32 m
Wing area	0.22 m^2
Flaperon span	0.30 m
Flaperon chord	0.09 m
Flaperon area	0.03 m^2

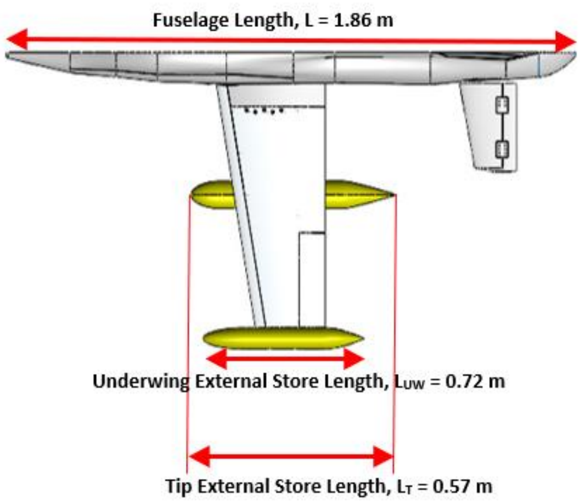

Figure 7 Dimension and SolidWorks view of the model

3.2 Wind tunnel testing

The semi-span model is positioned within the UTM Low Speed Wind tunnel, as depicted in Figure 8.

Figure 8 The installation of the model attached to a JR3 balance in UTM LST

The model was subjected to testing at a velocity of 30 m/s, which corresponds to a Reynolds number of 0.6 × 10^6 based on the mean aerodynamic chord. The speed of 30 m/s corresponds to a Reynolds number that is typical for subsonic testing of scaled-down models. This ensures that the aerodynamic characteristics, including stall behavior, are observed in a regime that is representative of the full-scale aircraft's behavior. At this Reynolds number, the flow around the wing and external stores will exhibit similar transition and separation characteristics as id does for the actual aircraft, making the experimental results more realistic for the real aircraft during operation. The choice of 30 m/s also reflects practical considerations such as safety, data accuracy, and the ability to control and measure the flow conditions effectively within the wind tunnel environment. The model itself has a total length of 2 m, while the wing area measures 0.220 m^2. Throughout the experiment, the angle of attack varied within the range of -2° to 24°. The experiments were conducted for a total of 14 different configurations. These configurations are: (a) Clean wing, (b) External store mounted at tip chord, (c) External store mounted both at tip chord and 38 cm from root chord, (d) External store mounted both at tip chord and 50 cm from root chord, (e) External store mounted 50 cm from root chord, and (f) External store mounted 38 cm from root chord. All these configurations are illustrated in Figure 9. Additionally, examining the impact of flaperon deflection on lift, drag, and pitching moment coefficients. For the flaperon, the deflections applied are 0°, 10°, 20°, and 35° for two different configurations of the wing: clean wing and wing with tip external store.

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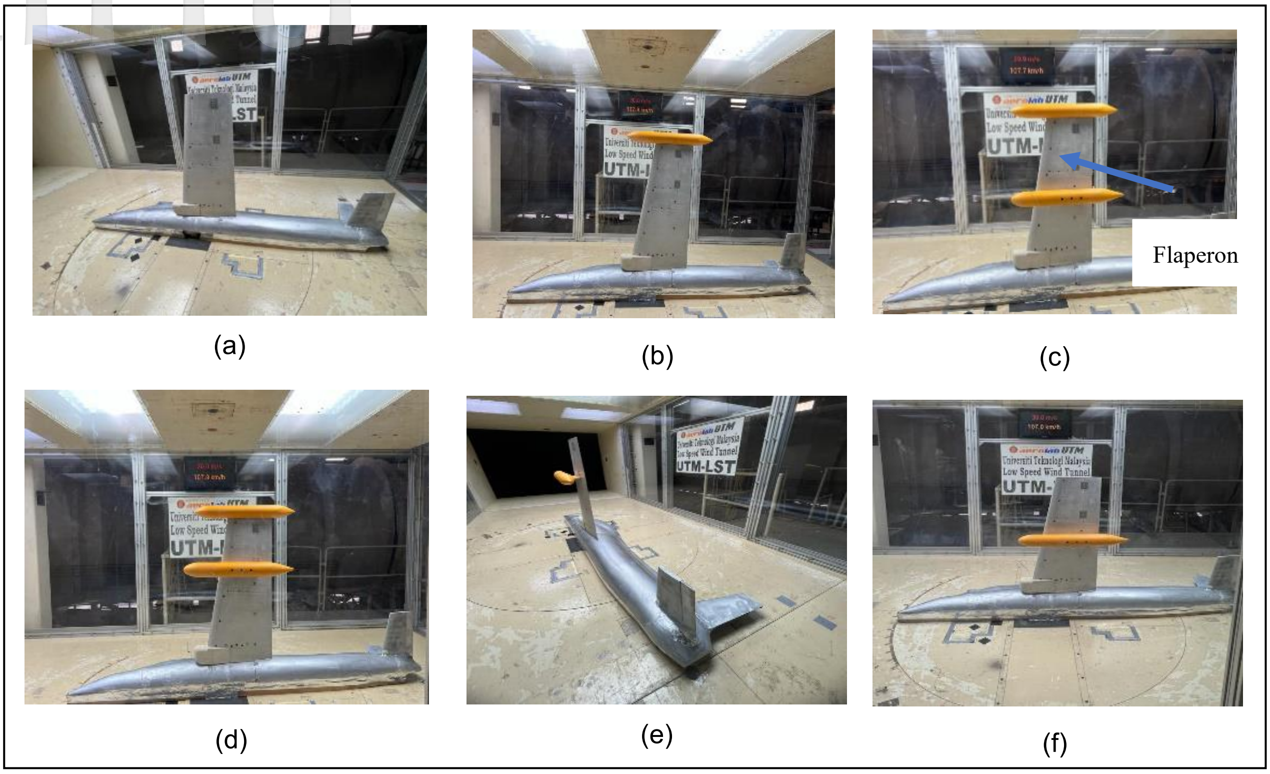

Figure 9 All six testing configurations of the model

The results that we obtained from the JR3 balance is in the body axes. The body axes values for the lift (*L*), drag (*D*) and pitching moment (*M*) are converted to wind axes in accordance with the relationship as:

$$L = F_x sin\alpha - F_y cos\alpha \tag{1}$$

$$D = F_x cos\alpha - F_y sin\alpha \tag{2}$$

$$M = -\left(\frac{b}{c}\right) M_Z cos\alpha \tag{3}$$

where b is the wingspan and c is the mean aerodynamic chord.

3.2 Blockage correction

A standard wall correction method, as described in [11], is adopted in this investigation. The wall correction accounts for two main factors: solid blockage and wake blockage. The estimation of the solid blockage is carried out using a simple relationship for solid-blockage correction as shown in Equation (4):

$$\varepsilon_{sb} = \frac{K_1(model\ volume)}{C^{\frac{3}{2}}} \tag{4}$$

where K_1 represents the spanning configuration factor with a value of 0.52 for a model that spans across the height or vertical direction of the wind tunnel. The volume of the model is 0.0055 m^3, and '*c*' represents the tunnel test-section area.

Furthermore, the correction for wake blockage is performed for the two-dimensional case using simplified relationship as outlined by Equation (5),

$$\varepsilon_{wb} = \frac{\frac{c}{h}(C_{du})}{2} \tag{5}$$

To obtain the corrected values of lift coefficient, we will apply the following formula:

$$C_L = C_{LU}(1 - \sigma - 2\varepsilon) \tag{6}$$

where

C_L=corrected lift coefficient

C_{LU}=uncorrected lift coefficient

$\sigma = \frac{\pi^2}{48}\left(\frac{c,mean\ aerodynamic\ chord}{h,height\ of\ the\ test\ section}\right)^2 = \frac{\pi^2}{48}\left(\frac{0.32}{1.5}\right)^2 =$ 0.0094

ε=total blockage correction (solid+wake)

To obtain the corrected values of drag coefficient, we will apply the following formula proposed by Maskell for airfoil wings:

$$C_D = \frac{C_{DU}}{1+0.9C_{DU}BR} \tag{7}$$

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where

C_D=corrected drag coefficient

C_{DU}=uncorrected drag coefficient

$$BR = blockage\ ratio\ \left(\frac{projected\ area\ of\ the\ model}{area\ of\ the\ test\ section}\right) = \frac{0.039}{3} = 0.0130$$

IV. RESULT ANALYSIS AND DISCUSSION

This study founds that addition of 5% of Aluminium inside beeswax as HRM solid fuel gives the highest increment of regression rate

4.1 at different location of external stores

As shown in Figure 10 for the lift coefficient at different angle of attack, it is observed that the configuration with external stores positioned at both the tip chord and 38 cm from the root chord ((c) configuration) generates higher lift compared to the configuration with only one external store located at 38 cm from the root chord ((f) configuration). This increase in lift can be attributed to two aerodynamic effects: wingtip vortices and spanwise flow. Upon comparing the graphs of the six different configurations, it is evident that the aircraft experiences higher drag when external stores are positioned at both the tip chord and 50 cm from the root chord (d) configuration). On the other hand, the configuration with the least drag is achieved when an external store is mounted 50 cm from the wing root (f) configuration). This is attributed to the reduced interference with the smooth airflow around the aircraft when the external store is positioned away from the root chord or fuselage. By allowing cleaner airflow over the store, turbulent regions and separation points are minimized, resulting in lower drag production.

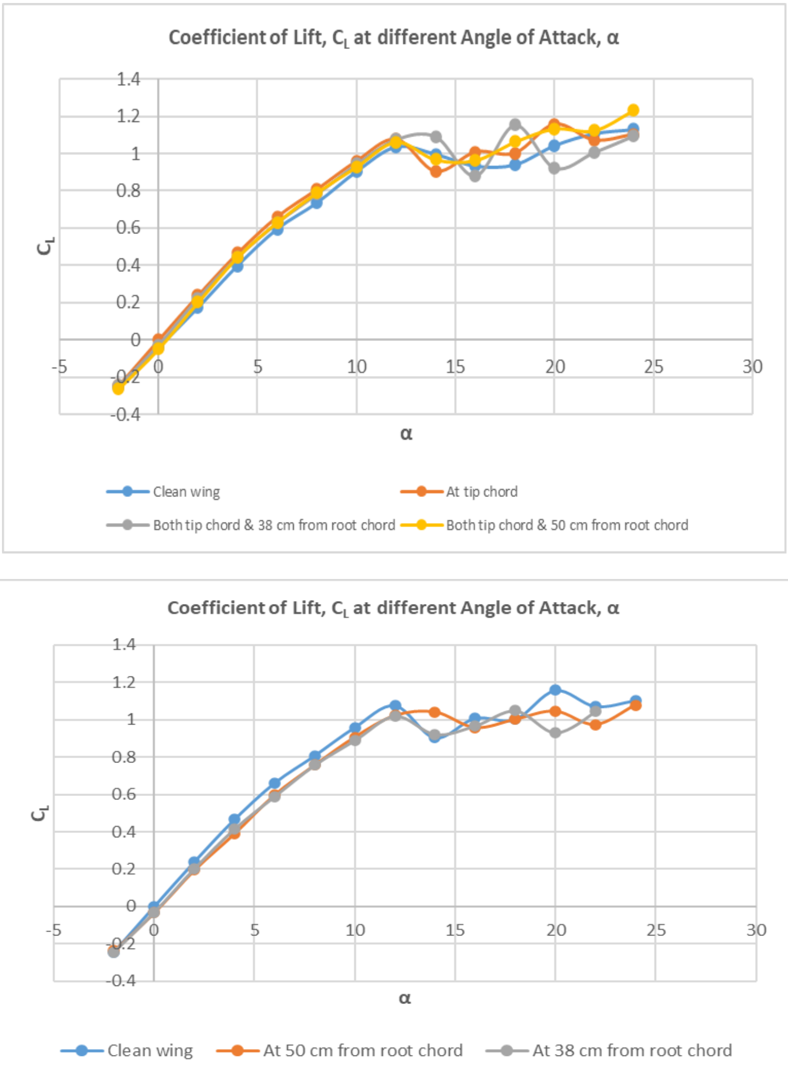

Figure 10 Lift coefficient at different angle of attack for all six different configurations

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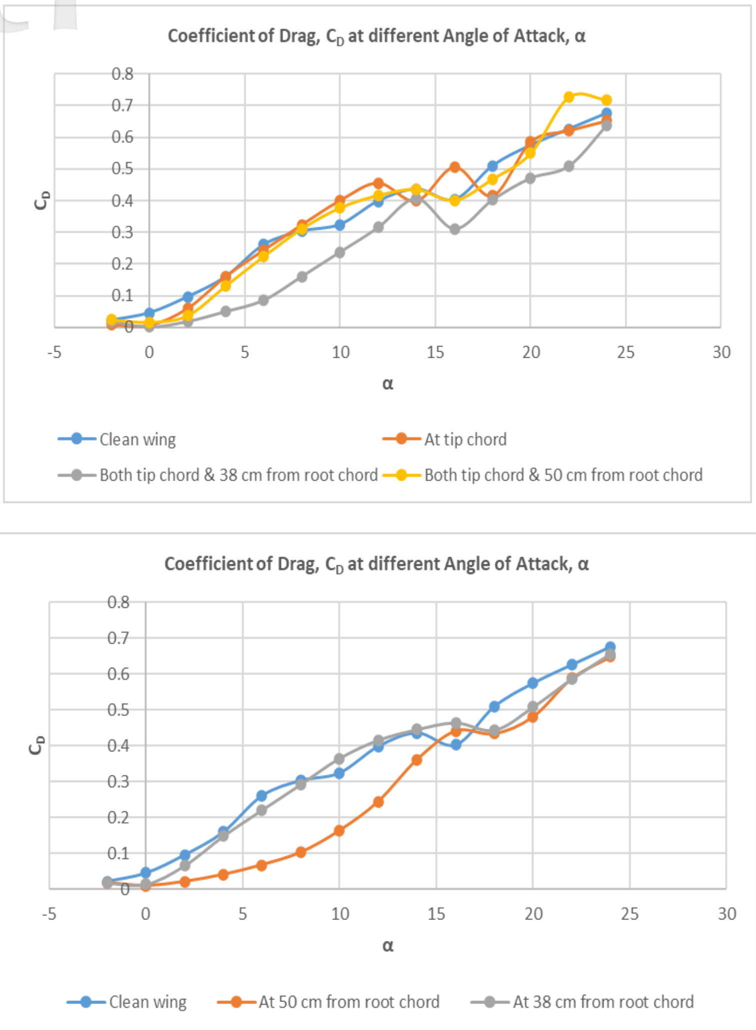

Figure 11 Drag coefficient at different angle of attack for all six different configurations

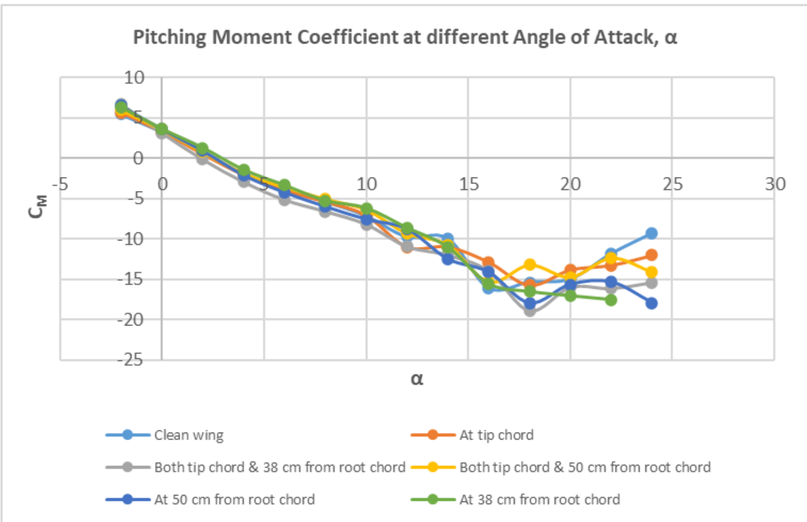

Figure 12 Pitching moment coefficient at different angle of attack for all six different configurations

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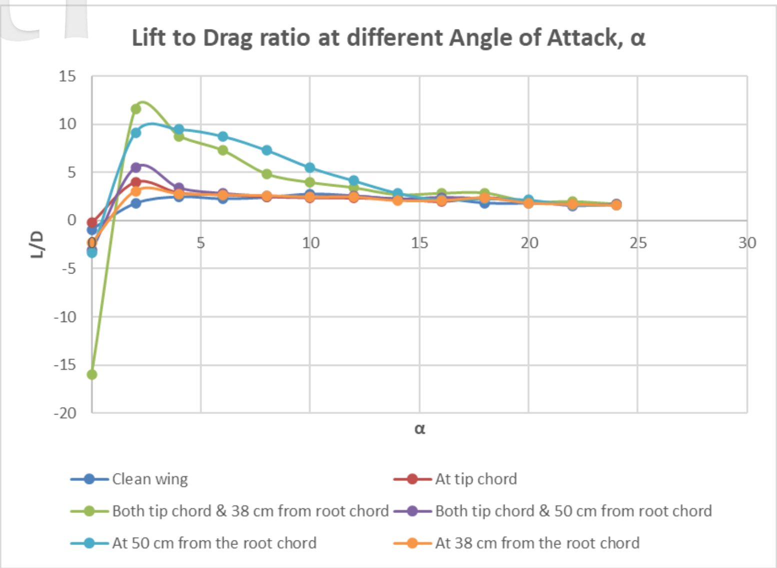

Figure 13 Lift to drag ratio at different angle of attack for all six different configurations

Figure 12 shows the pitching moment coefficient for all configurations at different angles of attack. For all six configurations, the outcomes show a decreasing slope. The negative slope observed in all configurations signifies a stable behavior of the half-body model aircraft. A negative slope indicates that as the angle of attack increases, the pitching moment coefficient decreases. This implies that as the aircraft's nose pitches up (increasing angle of attack), there is a restorative force that tends to bring the nose back down, maintaining stability. Furthermore, observation shows all the negative slopes are trimming at positive angle of attack. This is the angle of attack where the aircraft requires minimal control input to maintain equilibrium. Trimming the aircraft at a positive angle of attack allows it to fly at a desired angle of attack without constant control inputs. As compared in terms of the values from both Figure 10 and 12, the lowest positive trim angle of 1.9° is experienced by the (c) configuration for external stores mounted both at the tip chord and 38 cm from the tip chord. Alternatively, the highest positive trim angle of 3° is experienced by the (e) configuration for external store mounted 38 cm from the root chord. For a subsonic fighter aircraft, it is generally considered better to trim at a higher positive. Subsonic fighter aircraft often operate in dynamic and challenging environments, requiring excellent maneuverability. Trimming at a higher positive angle of attack allows the aircraft to generate more lift, improving its ability to execute maneuvers such as tight turns, high-G maneuvers, and rapid changes in direction.

As shown in Figure 13 for the lift to drag (L/D) ratio, the most efficient configuration for generating lift while minimizing drag is observed when the external stores are attached at both tip chord and 38 cm from root chord with lift to drag ratio of 11.8. Moreover, the (c) configuration (external stores mounted at both tip chord and 38 cm from root chord) and (e) configuration (external store mounted at 50 cm from the root chord), produce a longer period before flattening after an angle of attack of 14°. This outcome suggests that the aircraft has a narrower operating envelope and seems to be more sensitive to variations in the angle of attack. Small changes in the angle of attack within this range can have a significant impact on the L/D ratio, resulting in a more pronounced increase or decrease in efficiency. This characteristic implies that the aircraft requires precise control and careful adjustment of the angle of attack to achieve optimal performance. Pilots need to be attentive in maintaining the aircraft within the specified range of angles of attack to maximize its efficiency, as well as to achieve the desired L/D ratio. Furthermore, we can see that clean wing configuration has the lowest lift to drag ratio of 2.8 as compared to the case when external stores are attached under the wing for all other five configurations. This is because external stores mounted under the wing can generate additional lift compared to a clean wing due to effect known as wing-body interference effect. The changes in the aerodynamic properties is mainly due to the complex aerodynamic interaction and flow separation between the fuselage, wing, flaperon, external store. More experiments are needed to visualized the flow characteristics of this model in the future.

4.2 At different flaperon deflections

As observed from Figure 10, the coefficient of lift increases with the angle of attack to 12° for all configurations except when the flaperon deflects at 20° for the clean wing the stall occurs at angle of attack of 14. The coefficient of lift is increasing for high flaperon deflection, at deflection of 35°, we have obtained the highest recorded coefficient of lift. The streamline becomes turbulences behind the flaperon which result in higher lift, high induced drag, and high lift to drag (L/D) ratio [3]. We can also notice that the presence of the external store at the tip of the wing has a minimal effect. On the other hand, the existence of external store has increased the drag force compared to the clean wing resulting in a flow separation around the wing, the undeflected flaperon and 10° deflection maintain the stability of an aircraft while higher angles of deflection resulting in disturbance in the flight stability. The aircraft maintains its lift to drag ratio until

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the stall occurs at 12°. The lift to drag ratio starts to decrease indicating high induced drag. Coefficient of pitching moment showed differences among the deflection angles, indicating varying aerodynamic behavior after the flaperon deflection of 10° degrees and show statically instability of the fighter aircraft due to negative trim point.

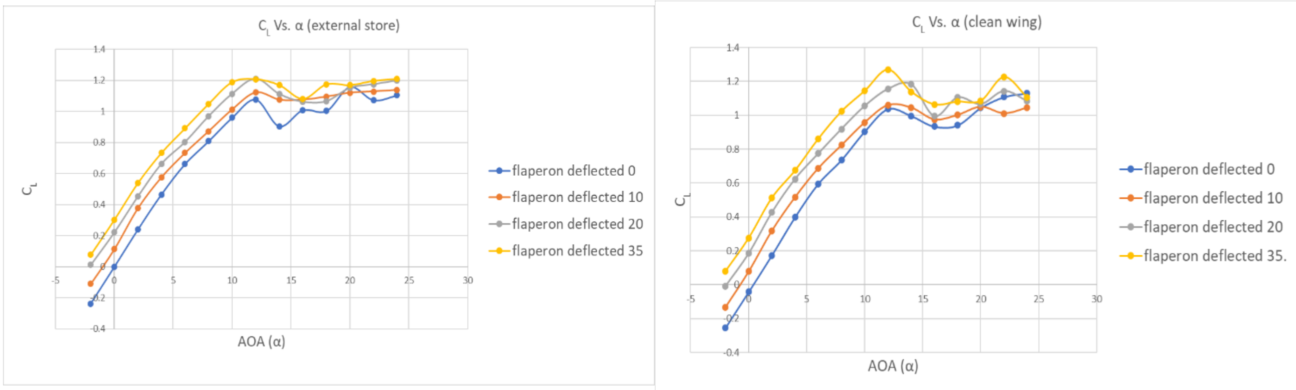

Figure 14 Lift coefficient at different flaperon deflection angles for both configurations

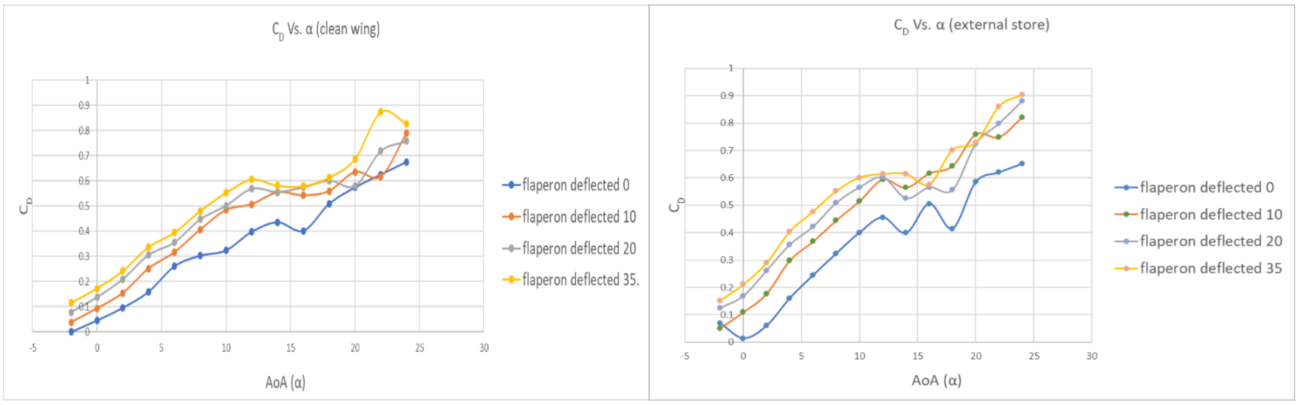

Figure 15 Drag coefficient at different flaperon deflection angles for both configurations

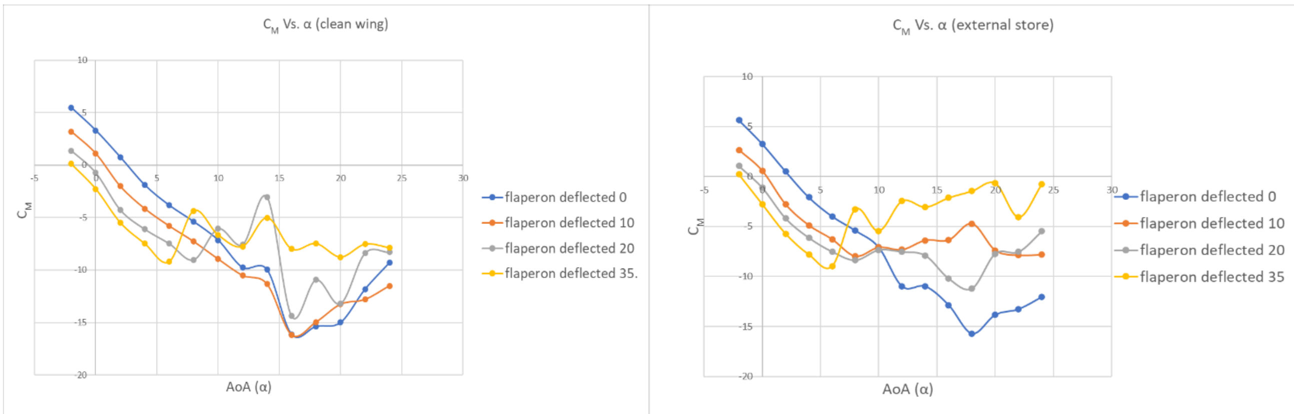

Figure 16 Pitching moment coefficient at different flaperon deflection angles for both configurations

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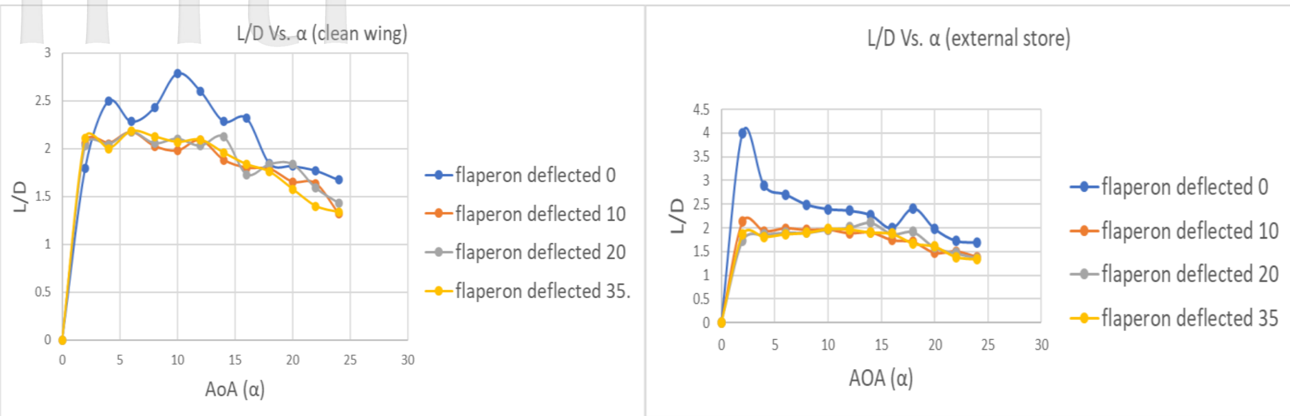

Figure 17 Lift to drag ratio at different flaperon deflection angles for both configurations

IV. CONCLUSION

An experimental investigation was conducted in the UTM Low-Speed Tunnel (UTM-LST) using a half-body model of a generic subsonic fighter aircraft. The aim was to analyze the aerodynamic characteristics at different angles of attack and mounting positions of an external store under the wing and also at different flaperon deflection. The study found that placing external stores at both the tip chord and 38 cm from the root chord significantly increased lift compared to having only one store at 38 cm. This was due to the combined effects of wingtip vortices and spanwise flow. The configuration with stores at both the tip chord and 50 cm from the root chord experienced higher drag, while the lowest drag was observed when the store was mounted 50 cm from the wing root. All six configurations were statically stable, with the (e) configuration having the highest positive trimming angle suitable for maneuverability. As for the flaperon, increasing the flaperon deflection angle generally enhanced lift generation, with the highest lift production observed at a deflection of 35°. The lift coefficients peaked at around 12° angle of attack, indicating the maximum lift capability. However, the introduction of flaperon deflection also led to increased drag at higher angles of attack, particularly in the critical region. The coefficient of pitching moment exhibited differences between flaperon deflection angles, indicating varying aerodynamic characteristics. The clean wing configuration achieved maximum efficiency at an angle of attack of 10 to 12°, with higher flaperon deflection angles slightly reducing the lift to drag (*L/D*) ratio. When integrating an external store at the wingtip, similar trends were observed in terms of lift and drag characteristics, with flaperon deflection still influencing lift generation and higher deflection angles increasing drag on the external store.

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