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Studies of Fuselage Effect on Vortex Dynamics and Performance of Bird's-body Type Fuselage (BBTF)-Fighter in Water Tunnel

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ABSTRACT :*The fuselage effect on vortex dynamics and performance on BBTF model aircraft investigated using water tunnel. Flow visualization testing uses a water tunnel because it can reveal the vortex dynamics phenomenon easily visually. Testing was conducted by varying some form of the fuselage to observe the effect of shape fuselage on vortex dynamics and aerodynamic force on the aircraft model. Three models used such as original, wall symmetric and without the fuselage. The test used a fluid velocity of 0.1 m/s and Reynolds number 6.577 x 103 on a 1: 110 scale model. The flow visualization was measured using dye injection method. This study used a print ink type with a mixture ratio of 1:8. The result of the research using GAMA water tunnel showed the aerodynamic force and vortex dynamics phenomenon that happened on BBTF model aircraft. The fuselage effect made the difference in lift and drag coefficients. The highest lift coefficient occurred in the original fuselage model about 1.47 on the angle of attack of 40°. In addition to differences on aerodynamic forces, fuselage also affected the formation of vortex cores and vortex breakdown. Furthermore, on the original fuselage model, the vortex breakdown location on the main wing was much farther than the symmetric wall fuselage and without fuselage models on a small angle of attack. However, at the high angle of attack, the vortex breakdown location was the same. The resulting correlation equation can be used to estimate the power generated by the turbine by the size of the field well in the operating area of the tip speed ratio of the turbine design.*

KEYWORDS :*watertunnel, visualization,fuselage effect, BBTF, vortex core, vortex breakdown.*

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I. INTRODUCTION

The aerodynamic design of an aircraft continues progressing since its introduction in the 1920s. Previous research activities on aircraft design aim to reduce drag and usually focus on wing design and lift surface forces, and especially on airfoil design. However, at high-speed conditions (low lift coefficients and low induction drag), precise aircraft design is significant to reduce the total drag of an aircraft and improve flight performance (Simpson, 2001).

Airplane performance, such as maximum flight speed or fuel consumption, depends on the drag coefficient and lift which can be improved with the better aerodynamic design (Della Vecchia and Nicolosi, 2014). One of the essential items in the aerodynamic design of a plane is the meeting between the wing and body. This meeting was identified as a body relationship with different aircraft components, in the particular case of the wing and body shape of the aircraft. In particular, this meeting induces interactions between components, especially the combined layer boundary which causes flow phenomena to be complicated to explain and simulate (Simpson, 2001).

The application of the fuselage effect is the interaction between the main wing and the canard. Airplane/fuselage body influences vortex dynamics and lifts force generation. Some researchers have observed the influence of the fuselage on the dynamics of vortices that occur. Sutrisno et al. observed the effect of the fuselage on vortex canard formation on J-10 aircraft models (Sutrisno et al., 2018). The research results showed that the higher coefficient efficiency of the canard wing, the more negative pressure of the fuselage models. The pitching moment is bigger; the axial vortex velocity is higher, moreover, the vortex breakdown location further away, compared to the fuselage models. The formation of the fuselage vortex on the X-31 plane model has also been observed (Boelens, 2012). The interaction between vortex core forebody and LEX in the F-18 plane model has been observed (Delfrate, Zuniga, and Fisher, 1991; L. P. Erm, 2003).

There are two types of canard fighter body configurations, common or straight type aircraft configurations are Euro-fighter,Rafale, Grippen, and Chengdu, and the other type is a curved bird-body type fuselage (BBTF) is a configuration type such as Sukhoi Su-27, Sukhoi Su-30, and Sukhoi Su-33. Several previous researchers have observed many fuselage effects on types of straight type aircraft body models such as Chengdu, X-31 and F-18. In this study, we focused on observing the influence of the fuselage on a curved aircraft body model, BBTF fighter aircraft.BBTF fighter aircraft has excellent maneuverability and stability in high attack angle conditions. This high agility allows the aircraft to release weapons in all directions. It is due to the dynamics of vortices formed on the wings and body of the aircraft. Therefore, detecting the occurrence of vortex dynamics becomes a crucial thing to indicate a lift force. Flow visualization method is an effective way of determining the phenomenon of vortex dynamics.

The use of a water tunnel will make it easier to reveal the phenomena that occur. For a long time, many studies have used water tunnels to see a visualization of flow testing on moving objects or fluid flow, especially on fighter aircraft. The vortex phenomenon of breakdown location that occurs on the delta wing has been observed using water tunnel by (L. P. Erm, 2003; LU and ZHU, 2004; Jaroszewicz et al., 2011; Lincoln P Erm and Ol, 2012). In addition, water tunnels have also been widely used to observe the phenomenon of vortex dynamics above the LEX wing in F / A-18 aircraft models by (Erickson, 1982; D.H. Thompson, 1990; Sandlin and Ramirez, 1991; Suarez et al., 1994; Thompson, 1997; Lincoln P Erm and Ol, 2012). The use of water tunnels is perfect for studying flow visualization because it has a higher density and a lower mass diffusion than air (Lincoln P Erm, 2007). So, this study focuses on observing the effect of fuselage variations on vortex dynamics and aerodynamic performance on aircraft models similar to the BBTF using GAMA water tunnel.

II. METHOD

The experiment is done using GAMA water tunnel. GAMA water tunnel is produced by the Department of Mechanical and Industrial Engineering at Gadjah Mada University and is designed with a closed channel model. GAMA the water tunnel shown in Fig. 1 holds about 1200 liters of water and has a horizontal flow test section with a height of 200 mm, a width of 200 mm and a length of 1000 mm. The free stream speed in the test section can be varied between 0 and 0.25 m / s. The sidewalls and floors of the test section are made of glass to facilitate flow visualization studies. GAMA water tunnels were previously used by Wibowo, et al. for vortex breakdown testing on the delta wing and compared with CFD results and other references (Wibowo et al., 2018). The results show that GAMA water tunnel can display the results of visualization and aerodynamic forces as aerodynamic depictions of the delta wing. The results of the water tunnel testing have conformity with testing using CFD and the results of research from other references. Water flows from the pond through a pipe to a sedation tank. After that from the water sedation tank, it will pass two honeycombs before passing the test section. Honeycomb functions to maintain laminar flow. The flow rate is regulated through the inlet valve and the exhaust valve. The water that comes out of the exhaust valve is then pumped back to the reservoir. There is a dye ink tube for transferring ink to the aircraft model. The ink flow rate is controlled by a valve that is operated manually.

A. *Experimental Set-up*

The plane model is clamped to loadcell vertically to measure the coefficient of lift (CL) value and the coefficient of drag (CD). The loadcell measuring instrument has been tested by (Firmansyah, Wibowo, and Mareta, 2017). The experimental results show that the aerodynamic force measuring system of 3 degrees of freedom has worked well and can be implemented into a water tunnel to measure aerodynamic forces.

The experiment is carried out on a water tunnel with a speed of 0.105 m / s and Reynolds number 6577 (based on the model wing chord) at angle of attack (AoA) 0-60º. The ink used is a type of ink print magenta color with a mixture ratio of 1: 8. During testing the ink is flowed out through the ink duct on the model to see the vortex core phenomenon and vortex breakdown that forms above the canard surface and main wing and fuselage.

B. *Experimental Model*

Research conducted by (Lee, 2000), on the F/A 18 aircraft model, (Lincoln P Erm and Ol, 2012) on the F-15 and (Gary E. Erickson, 1981) X-31A aircraft models, each model size is different depending on the dimensions test section in a water tunnel. The majority of tests use 1/48 scale models, and several tests are also carried out using 1/72 and 1/32 scales. The size of the model with a scale of 1/72 and 1/48 will give the same results in the breakdown position (D.H. Thompson, 1990).

The aircraft model used in this study is a type of BBTF fighter aircraft model. BBTF is a type of aircraft with canard with longitudinal triplane aerodynamic configuration. This study uses 3 test models to determine the aerodynamic style and fuselage influence on the vortex dynamics that occur in the aircraft model. The model used in this test is the BBTF aircraft model with various fuselage shapes including the original fuselage, without fuselage, wall symmetric fuselage. The scale of the aircraft model is made around 117: 1 adjusting the work section in the water tunnel.The airplane model is then printed using 3D printing separately, and then the hose is installed. After the hose is attached to the body of the aircraft, it is then combined using G glue. After printing, the hose is fitted with a function that functions for ink injection. The next model is coated with plastic putty then sanded until smooth and then painted. After that, the model is paired with an iron holder to link the model to the loadcell. The finishing results of the model can be seen in Fig. 3.

Fig.1. BBTF model fighter aircraft

In the study of fluid flow, the surface roughness is very influential on the formation of vortex dynamics that pass through the object. Therefore, the surface of the aircraft model is made as smooth as possible to minimize friction between the fluid and the surface of the plane.

Fig.2. Finishing of BBTF model, 1) The original fuselage, 2) symmetric wall fuselage, and 3) without fuselage

III. RESULT AND DISCUSSION

A. Simulation result

Fig. 4 shows the visualization of flow in BBTF aircraft models with the original fuselage, symmetric wall fuselage and without the fuselage. Vortex core formation, vortex breakdown and fuselage vortex that occur above the canard surface, main wing, and body on aircraft models similar to the BBTF original fuselage type. Vortex core on canard and main wing start to form in AoA around 15°. Whereas in low AoA, only a flow line is called streamline. Based on the video of the test results that have been observed, the increase in AoA will cause a difference in the flow velocity between the upper surface of the wing and under the wing. The flow velocity above the wing surface will be higher than the flow velocity below the wing. This condition will cause the formation of the rolled-up vortex from the tip of the wing to the downstream of the wing which in the middle part of the coil there is a vortex core or also called the vortex core which has the lowest pressure. This Vortex core has a higher speed than the freestream speed. Thus, the vortex core makes negative pressure above the wing surface. The formation of a vortex core indicates the lift force that occurs.

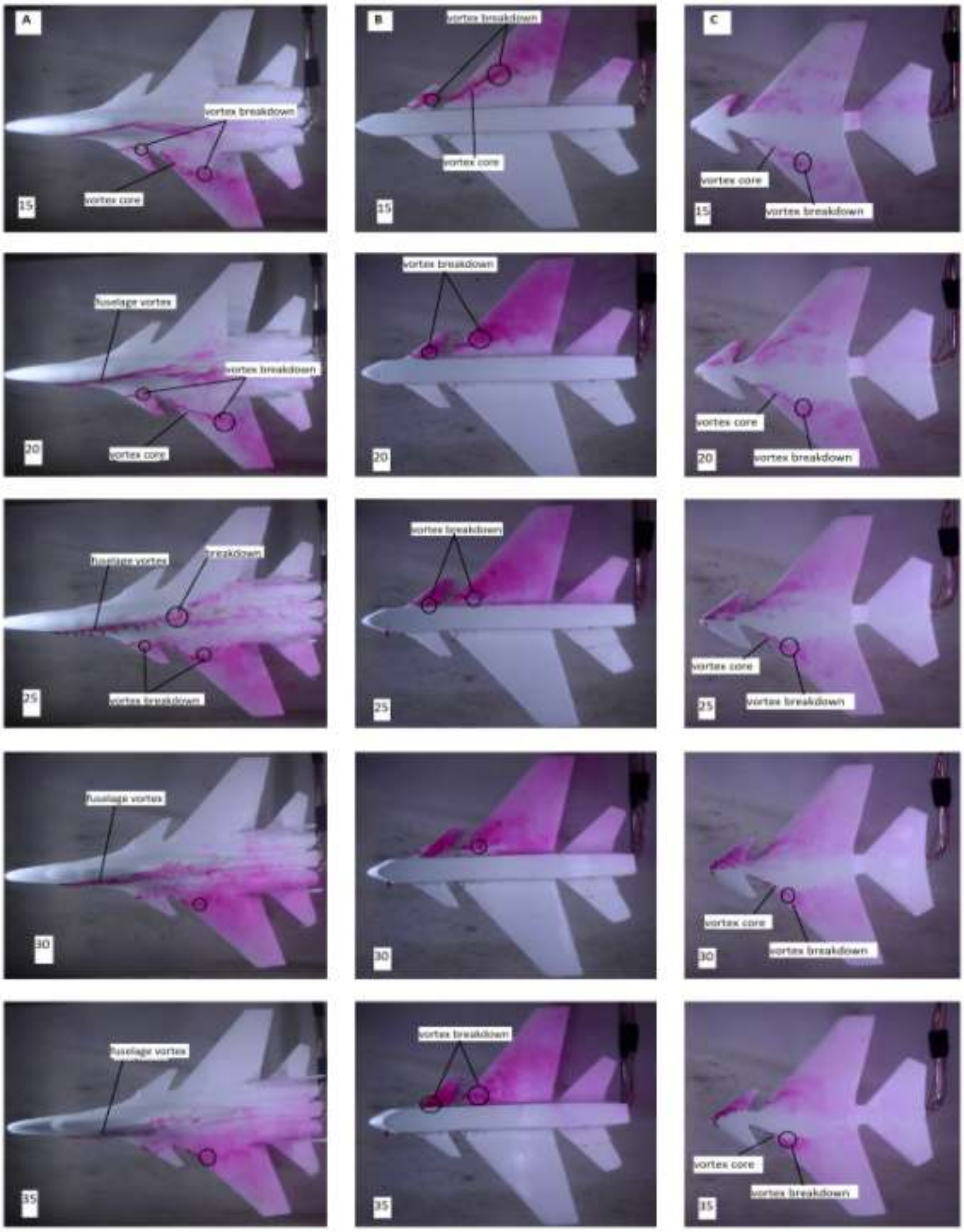

Fig.3. Flow visualization of the BBTF model, a) original fuselage, b) wall symmetric fuselage, c) without the fuselage.

In low AoA, vortex core and vortex breakdown have not been seen. In the original fuselage model, the vortex core above the main wing surface began to be seen in AoA 15 ° and breakdown about 62.5% of the wing length of the wing chord. At AoA 25 °, the location of the breakdown vortex occurred about 43% of the wing length of the wing chord. At AoA 35 °, the location of the breakdown vortex is at 25% of the wing chord. Every increase in AoA causes the location of the breakdown vortex to move further towards the top of the wing. At a high AoA of about 20˚ to 35˚, vortex core tends to move away from the leading edge and is attracted towards the fuselage. This condition is caused by the interaction between the vortex core on the wing and the fuselage vortex so that the vortex core is attracted to the fuselage area. Whereas in small AoA, the vortex core that forms is along the leading edge. As in the results of a study by Boelens (2012) found that the fuselage vortex occurs strongly when AoA is high at around 20˚ resulting in negative pressure on the body which results in pulling by playing vortex wings. The phenomenon that occurs is called vortex margin. The merging phenomenon occurs when two vortices of a point with an almost parallel axis, in particular, critical distances the vortex nucleus will do both mixes into a single vortex.

In the symmetric fuselage wall model, when the model is in low AoA conditions around 5º to 20º, the vortex core is formed above the canard surface, and the main wing moves along the leading edge. However, when AoA is high, the vortex core starts to be drawn toward the fuselage wall. This condition is caused by the interaction between fuselage vortex which is formed because of the boundary wall with canard vortex and playing vortex wing, resulting in a combination of vorteX. Fuselage vortex makes a negative pressure on the symmetrical wall so that the vortex core is pulled towards the fuselage wall. At AoA 20º, the location of the breakdown vortex is around 25% of the wing length of the wing chord. In this model, vortex damage occurs so fast that at AoA 35º, the vortex breakdown location is close to the top of the wing.

In the BBTF aircraft model without fuselage, the formation of vortex cores is more accessible and more apparent. At AoA 20º, the vortex core length is still around 48% of the wing chord's length. While at AoA 25º the length of the formed vortex core is still around 39% of the wing length of the wing chord. In this model, the damage to the vortex core occurs more slowly than each increase in AoA compared to the model with the fuselage, so that at AoA high 30º vortex core still forms about 25% of the wing length. In models without fuselage, vortex cores that occur above the wing from low to high AoA flow around the leading edge. This is due to the absence of two vortex interactions so that the vortex flow only goes in one direction.

B. The coefficient of lift and drag

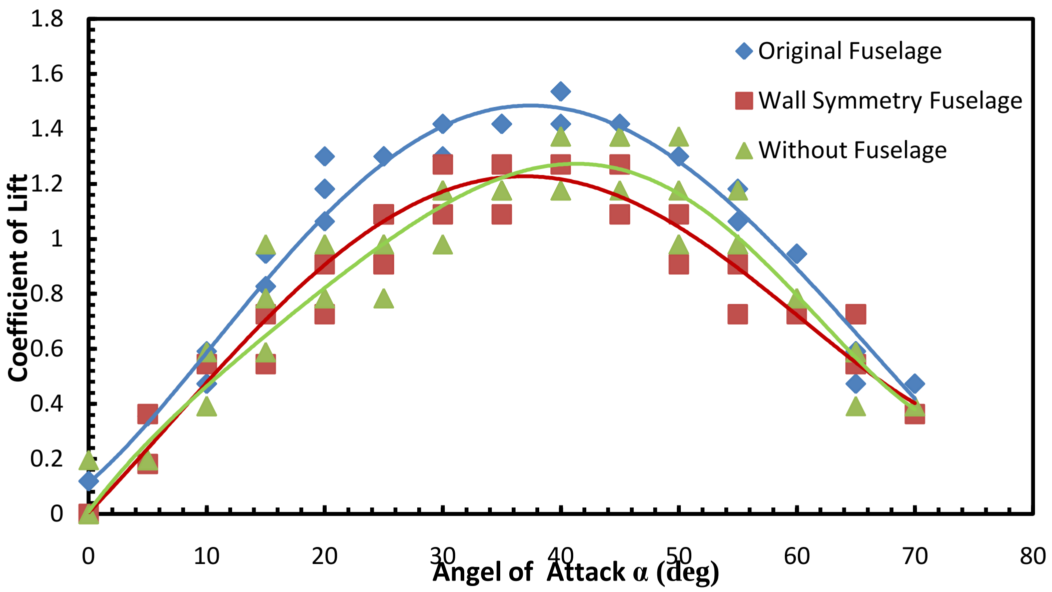

Fig.4. The coefficient of liftvsangle of attackof BBTF fighter aircraft

Fig. 5 shows the differences in CL values produced between the three original fuselage aircraft models, symmetric wall fuselage and without the fuselage. The highest maximum CL value occurs in the original fuselage type model at AoA 40˚ around 1.47. This is because the fuselage formation in the original fuselage model causes the formation of a fuselage vortex roll up so that the vortex core on the main wing is drawn towards the fuselage body. The BBTF model has a bird-like fuselage, a slender head and a blended body, which creates a negative pressure on the body surface that causes lift. However, on the symmetric fuselage wall model, vortex cores that are attracted to the body cause a loss of CL value because of the fuselage shape which is like a symmetrical wall, so that the lift force occurs perpendicular to the wall which causes the aircraft to be unstable. Whereas in the model without fuselage, the CL value is generated entirely by the wing without any influence from the fuselage. The value of CL without fuselage is almost the same as the symmetric wall fuselage, but at high AoA the CL value on the model without fuselage is more excellent.

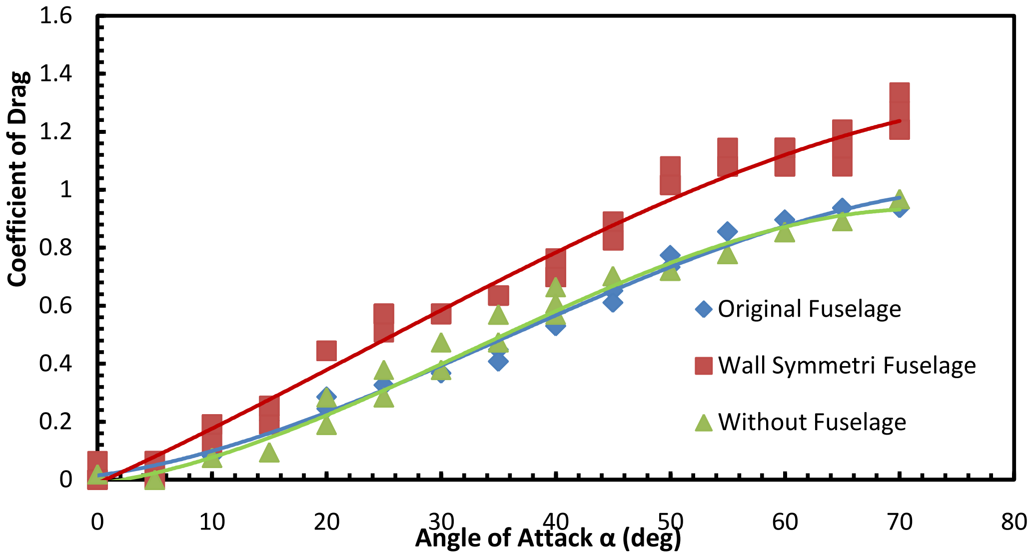

Fig.5. The coefficient of drag vs. angle of attackof BBTF fighter aircraft

C. Vortex Breakdown Location

The increase in CD value increases every increase in AoA; this is due to the higher contact surface of the plane when AoA increases so that the drag force will increase. The most significant CL value occurs in the symmetric fuselage wall type model around 1.1.Fig. 7shows the location of the vortex breakdown of the AoA increase in each test model. At low angles, the original fuselage model has a vortex breakdown location that is farther than the symmetric fuselage and without fuselage walls, but at AoA the high breakdown vortex location is relatively the same

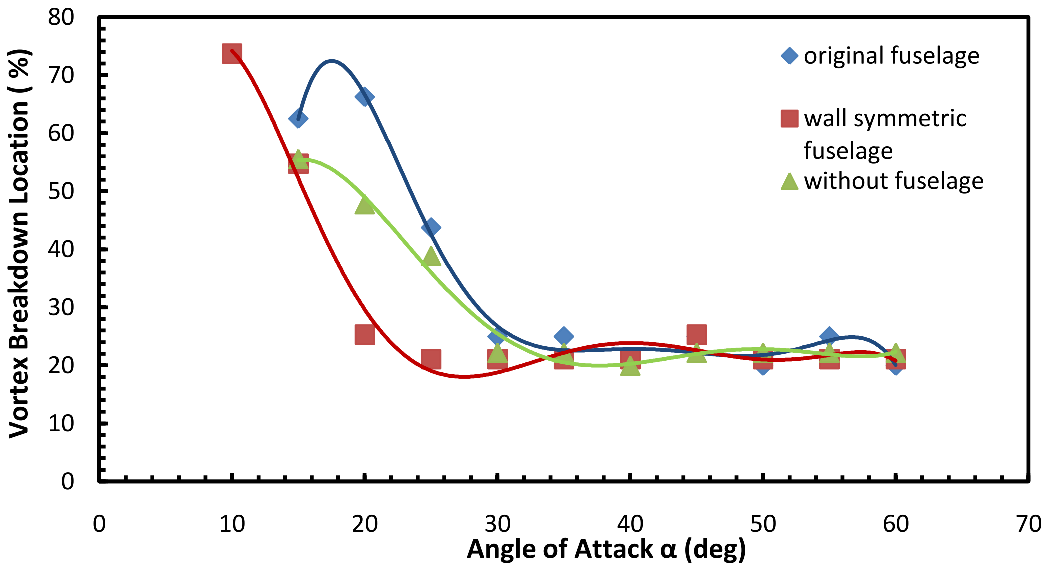

Fig.6. Vortex breakdown location vs. angle of attackof BBTF fighter aircraft

IV. CONCLUSION

The maximum coefficient of lift in models that use original fuselage is higher than the model without fuselage and wall symmetry fuselage. The CL value that occurs in the original fuselage model is around 1.47. Whereas, the symmetric fuselage and without fuselage wall models are about 1.27 and 1.3 respectively. This condition can be seen from the formation of vortex cores in the main wing and fuselage vortex which is still visible in AoA 40° which contributes to the addition of lift values.

Differences also occur in the location of the breakdown vortex above the canard and main wing on the aircraft model. The location of the vortex breakdown affects the lift force produced. The further the breakdown vortex location from the top of the wing, the CL value increases. In AoA 20˚, the location of the vortex breakdown with the BBTF model with original fuselage is still at 66% wing length, while for the symmetric fuselage and without fuselage wall models 25% and 48% respectively. Vortex breakdown location will be further with the model using original fuselage compared to models without fuselage and wall symmetric fuselage on low AoA, but at high AoA it is relatively the same.

In high AoA conditions, vortex cores and vortex breakdowns that occur above the wings of the original fuselage model and symmetric wall fuselage will tend to be attracted towards the fuselage. The higher the AoA, the vortex rolls up on the fuselage will be as strong as it will form, resulting in the reaction or incorporation of vortex cores in the canard and main wing with the fuselage vortex. In the original fuselage model, the process of combining vortex will be beneficial because it forms a blended body that creates negative pressure so that it increases the style of the gate. Whereas on the symmetric fuselage wall, the fuselage vortex interaction will cause negative pressure around the vertical wall. Unlike the fuselage model without fuselage, vortex cores are formed on edge along the leading edge.

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