Performance and flow visualization of Sukhoi Su-30MKI like model using GAMA water tunnel

Z Anwar\textsuperscript{1*}, S Sutrisno\textsuperscript{1}, B W Setyawan\textsuperscript{1,2}, R S Firdaus\textsuperscript{1} and F N Wega\textsuperscript{1}

\textsuperscript{1}Department of Mechanical and Industrial Engineering, Faculty of Engineering, Gadjah Mada University, Yogyakarta 55281, Indonesia
\textsuperscript{2}Department of Mechanical Engineering, Vocation Program, Gadjah Mada University, Yogyakarta 55281, Indonesia

*zzainurianwar@gmail.com

Abstract. The flow visualization of Sukhoi Su-30MKI like-model using GAMA water tunnel has been conducted to investigate the vortex dynamics on canard and main wing. This work aimed to observe the aerodynamic force and the vortex-dynamic phenomenon. The water tunnel is an effective visualization method to determine the vortex-dynamic phenomenon which was used in this research. The usage of water tunnel would make it easier to reveal the phenomenon that occurred. The results of GAMA water tunnel experiment showed the aerodynamic force and vortex dynamics phenomenon on the model of Su-30MKI aircraft. The increasing of lift force was started from a small angle of attack (AoA) to a maximum value at an angle of 45 degrees. The maximum lift value on the test using GAMA water tunnel was about 1.38. The vortex dynamics have been particularized using observation of vortex core formation and vortex breakdown location. The higher of AoA caused unstable vortex core flow so that the vortex breakdown location would lead to leading edge.

1. Introduction
Surfaces on the wings greatly affect the formation of vortices that will create lifting forces [1]. The aircraft's maneuverability will increase when the layers separation of the vortex pair from the side of the wing has occurred. Much research has been done to examine the characteristics of the occurrence of the phenomenon of rolled-up vortex and vortex breakdown showing the character of wing aerodynamics [2].

The phenomenon of rolled-up vortex and vortex breakdown usually occurs on the delta wing which is the basic configuration for supersonic aircraft or fighter aircraft. The delta's wings can improve good maneuverability and agility. At the high angle of attack, the delta wings result in the greater lift and better stability compared to the square wing [3]. In the delta wing, the flow will be divided through the leading edge to the wing surface down and up. Consequently, there is a pressure difference that will form a vortex from the bottom upward flow to lift the lifting force. On the upper surface area of the wing will form a low pressure which causes the occurrence of vortex cores as the highest lift area.

A large three-dimensional separation flow usually dominates flow field on aircraft in high-angle attack conditions. Strong and concentrated vortices are derived from various aircraft locations, such as the fuselage, wings, canards, and LEX [4]. Detecting the occurrence of vortex dynamics becomes a very important thing that indicates a lift force and a stall delay. The flow visualization method is an effective
way of determining the dynamics phenomenon of the vortex. The use of water tunnel will make it easier to reveal the phenomenon that occurs visually. For a long time, many studies have used a water tunnel to visualize flow tests on moving or fluidized objects, especially on combat aircraft. The use of a water tunnel is excellent for studying flow visualization because it has a higher density and a lower-than-air period diffusion, another advantage in the case of dynamic measurements of the required rotation rate maneuverability is much lower than the use of wind tunnel, resulting in inertial effects load can be ignored [5].

Whenever models are tested in water tunnels, an attempt is made to satisfy similarity requirements, so that the water tunnel tests are representative of the operation of full-size vehicles. There are three levels of similarity that must be satisfied, namely geometric, kinematic and dynamic similarity [6].

Many research results using water tunnel were reported in the flow visualization studies on F/A-18 [7][8][9][10][6]. Utilization of water tunnel to see the dynamics of the flow that occurs on the plane is very visible and is its advantages compared with wind tunnel [11][12]. The results show that the water tunnel can display a good simulation of real flow in the full-scale configuration under certain conditions.

In this research, has conducted the performance testing and flow visualization analysis on Sukhoi Su-30MKI like model aircraft that occur around canard and main wing using GAMA water tunnel facility.

2. Method
Experiments were performed using closed-type GAMA water tunnel with the dimensions of work section of the water tunnel: 200 mm height, 200 mm width and 1500 mm length. The maximum speed the water tunnel produces is about 0.84 m/s. GAMA water tunnel was previously used by Wibowo et al. for testing delta wings and compared with CFD results and the other references. The results show that GAMA water tunnel can display the visualization results and aerodynamic forces as the aerodynamic depiction of the delta wing. The results of the water tunnel test are compatible with the test using CFD and the results of the other reference studies [13].

![Water tunnel scheme](image)

**Figure 1.** Water tunnel scheme.

Water tunnel has a storage tank of 1200 liters. Water was drained from the storage tank through the pipe to the work section. After that from the water tank will pass through two honeycombs before passing through the test section. Honeycomb works to keep the laminar flow. The flow rate was regulated through the inlet valve and exhaust valve. The water coming out of the exhaust valve was then pumped back into the storage tank.
2.1. Set-up
The model was clamped on the load cell vertically to measure the value of coefficient lift (Cl) and coefficient drag (Cd). The load cell measurements have been tested by Firmansyah et al. The experimental results show that 3 degrees of freedom aerodynamic measurement system has worked well and can be implemented into a water tunnel to perform aerodynamic force measurements [14].

The experiment was performed by testing Su-30MKI model on water tunnel with speed 0.224 m/s and Reynolds number 13997 (based on chord of the model) at Angle of Attack (AoA) 0-70º. During the ink, test-flowed out through the ink duct on the model to see flow phenomena formed on canard and main wing surfaces.

2.2. Model
The test model used is a Su-30MKI like model aircraft. Su-30MKI has a canard plane with canard position parallel to the main wing. In this study, the model was made similar to the original shape, and the dimensions are adjusted to the test section of the water tunnel, so we get the scale of the model 1/117. The model printed by using 3D print with length 19 cm and width 14.5 cm. There is an ink nozzle in front of the canard and a 0.8 mm diameter main wing for ink output. Canard wings and main wing respectively 4.2 mm² and 35 mm².

![Figure 2. Sukhoi Su-30MKI-like model.](image)

Once printed, the wings and body of the aircraft smoothed. After that, the model was painted with the white color so that when the ink flows over the wing surface can be seen in detail.

3. Result and discussions
From the results of research conducted obtained value of lift force coefficient and drag force. The values of Cl and Cd in the water tunnel are obtained from the load cell sensor device mounted on the GAMA water tunnel. From the results of these data can be seen the performance of the Su-30MKI like-model.

![Figure 3. Coefficient of lift vs. angle of attack.](image)
The results show that there is an increase in lift force starting from small AoA to maximum lift force on AoA 45° after that lift force began to decrease up to AoA 65°. The maximum lift value obtained in the test model of Su-30MKI aircraft using a GAMA water tunnel is 1.38.

![Coefficient of drag vs. angle of attack](image1)

**Figure 4.** Coefficient of drag vs. angle of attack.

Figure 4 shows the drag coefficient in the test result on Su-30MKI like model using a GAMA water tunnel. The drag force increases from a small AoA to the maximum value at 50° AoA.

The increase in lift force on the Su-30MKI aircraft model resulted in the formation of the rolled-up vortex on the wing due to the pressure difference on the top of the wing. The center of the rolled-up vortex would form the vortex core that has the lowest pressure as can be seen in figures 5 and 6.

![Vortex core visualization on canard of Su-30MKI](image2)

**Figure 5.** Vortex core visualization on canard of Su-30MKI.
Figure 5 shows the vortex core formation above the canard of the model Su-30MKI. From the figure, it can be seen that the vortex breakdown is still 100 percent under AoA condition of 20 degrees. At high AoA about 40º - 55º vortex breakdown tends to stick to the leading edge and then break.

![Vortex core formation above the canard of the model Su-30MKI.](image)

**Figure 6.** Vortex core visualization on the main wing of Su-30MKI.

In figure 6, it showed the dynamics of the vortex occurring above the main wing on the Su-30MKI like-model. In AoA 20º indicates that vortex cores still occur along the wing body, at the end of the wing coils being destroyed with the outbreak of the vortex core. The increasing AoA would lead to increased velocity of the core vortex resulting in increased lift. However, the increase makes the vortex core flow unstable so that the vortex breakdown will move forward. At high AoA, the flow from the vortex core is divided into two directions, the ascetic vortex core attached to the leading edge and the other toward the center of the fuselage of the aircraft. This is due to the interaction between the vortex cores on the wing and the vortex fuselage so that the vortex core was elevated to the center of the wing.

![Vortex core visualization on the main wing of Su-30MKI.](image)

**Figure 7.** Side view of vortex core visualization.

In Figure 7 we can see that the boundary layer is formed by testing the model of Su-30MKI. At a small AoA of about 20 degrees, the boundary layer above the wing still tends to be close to the wing surface. However, at a high AoA, the boundary line moves out leaving the wing surface and heading forwards. That means the negative pressure on the wing surface begins to disappear which will result in less lift.

![Side view of vortex core visualization.](image)
The occurrence of vortex breakdown will remove the lift force. Vortex breakdown location can be seen in Figure 8 which shows that up to 45° AOA angle vortex breakdown location has reached about 1/8 part of wing length. In this condition, C1 can still reach the maximum. After AoA 45° than on the wing of the plane has been in the dominance of the vortex breakdown, so the lift style began to decline.

4. Conclusion
The test result of conducted using GAMA water tunnel on the Su-30MKI aircraft model obtained a value of the aerodynamic force and flow visualization phenomena that occur around canard and main wing. The lift coefficient starts at a small AoA and reaches a maximum value of 45 degrees. The maximum lift force value in this test is about 1.38.

Flow visualization test using a water tunnel shows the occurrence of the rolled-up vortex with the vortex core section which causes the addition of lift force on the Su-30MKI aircraft model. AoA increase will cause lifting force, but the vortex breakdown location would progress forward. In the high AoA vortex can still form and break into two directions, the first formed along the leading edge and the other towards the fuselage.

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