Analysis the Vortex Effect on the Performance of Savonius Windmill Based On Cfd(Computational Fluid Dynamics) Simulation and Video Recording

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Abstract. Savonius windmill is ideal for areas that have low wind speeds and fluctuating. However, the weakness of Savonius windmill is the efficiency or better known as Cp (power coefficient) is lower than horizontal axis wind turbine and Darrieus wind turbines. One cause is the formation of vortex when the blade was rotating. Vortex will absorb the energy of the wind flow or cause a negative kinetic energy. CFD simulation can be used as one tool that can be used to help analyze the loss of wind flow, including the formation of vortex on Savoniusblades. Wind speed of 2 m/s and 5 m/s is used as a simulation variable to obtain an overview of wind flow losses occurring in blade Savonius. The largest vortex formed at an angle of 165^{o}rotating blade is good for wind speed of 2 m/s and 5 m/s. The larger the vortex area are formed causing the lower the pressure and torque acting on the blade surface.

Keyword: wind speed, vortex, Savonius windmill, CFD Simulation

1. Introduction

Savonius windmill is a type of windmill in accordance with the character of Indonesian winds that on average only have wind speeds in the range of 2.5–6m/s [1]. Savoniuswindmill has several advantages, namely simple construction to build, cheap, wind reception from all directions so it requires no steering and had initial good torque at low wind speeds [2]. Savonius windmill is also designed to work in an area that is the fluctuating nature of wind in terms of both direction and speed

As for the shortage of Savoniuswindmill is the value of efficiency or better known as Cp lower (Cp:15%) when compared to the horizontal axis wind turbine (Cp: 45%),Darrieuswindmills (Cp : 35%) and combined Savonius + Darrius turbine (Cp: 19%) [3,4,5]. One cause of low efficiency Savonius windmill is the formation of the vortex both in and around the Savonius rotor blade . Vortex occurs due to the pressure difference between the vortex center with its surroundings. The pressure at the center of the vortex is at a minimum. The greater the pressure difference between the vortex center with the surrounding vortex diameter increases. Vortex will consume wind energy so it is very insufficient to the windmill . Vortex causes the kinetic energy of the wind to be converted into torque to be low.Fujisawa visualized the flow in and around the Savonius rotor and studied the effects of the rotation of the rotor to form the air flow on the surface of the blades. Another phenomenon observed is thrust on the concave side of the blade and the convex side of the blade resulting in a force that contributes to the amount of electricity production from Savonius rotor [6]. Nakajima experimentally also visualize the pattern of water flow in blade Savonius that rotates both clockwise and counterclockwise direction. One disclosed is the formation of vortex at the rotor position when the rotation angle 135^o [7].Visualization of fluid flow can also be done through CFD simulation approach. Most researchers also took advantage of the CFD simulation program to strengthen the analysis in his article. CFD simulation as a preliminary assessment of considerable assistance in the depiction of airflow profile on the Savonius rotor vortex formation process included. CFD simulation also provides the added benefit of saving time and cost compared to using real experiments, although in the end the simulation remains to be tested by experiment. The article [8,9] investigated the characteristics of wind turbines using CFD simulationbased on the velocity profile and pressure distribution when wind hitting the blades of the conventional Savonius. The simulation results showed a concentration of pressure on the convex side of the blade so that trigger the formation of the negative torque to the rotation angle 90°. The SukantaRoy [10] and also Joao Vicente Akwa [2], utilize CFDs to get the effect of variations in the width of the overlap of C_T(torque coefficient) and Cp of Savonius windmill. Value C_T minimum is obtained when the position of the blade concave angle of 165° in the direction the wind is coming but havenot discussed what causes [10].

Turbulence modeling

Turbulent flow is a characteristic that occurs because of the increased flow velocity. This increase resulted in a change of momentum, energy and mass of course. Vortex is a major component in a turbulent flow. Vortex is an area in which the fluid flow of largely moving around on the imaginary axis, moving either straight or curved. In the vortex, the fluid velocity is greatest is in addition to the imaginary axis, and a decrease in speed is inversely proportional to the distance from the imaginary axis. Vortex is very high in the core region around the axis, and almost zero at the end of the vortex; while the pressure fell deeply when approaching the area.

Because it is too expensive to perform analysis directly from turbulent flow which has a small scale with a high frequency, it would require a manipulation to be easier and cheaper. One of them is the turbulent modeling..CFD software package Fluent has an option of choosing various k-ε turbulence models that contains transport formulation for the turbulence kinetic energy (k) and the energy dissipation rate (e). In order to achieve accurate results, the standard k-ε turbulence model was adopted, which used Pope at al. [11]. This model is a complete semi-empirical turbulence models. Athough still modest , allowing for two equations that turbulent velocity and the length scale is determined freely (independent) . Stability and accuracy are sufficient to make these models are often used in the simulation of fluid and heat transfer

The transport equation for (k-ε) Standard Model are

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho k u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+G_k+G_b-\rho\varepsilon-Y_M+S_k$$

And

$$\frac{\partial}{\partial t}(\rho \varepsilon)+\frac{\partial}{\partial x_i}(\rho \varepsilon u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right]+C_{1\varepsilon}\frac{\varepsilon}{k}(G_b+C_{3\varepsilon}G_b)-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}+S_\varepsilon$$

Where,

- G_b is the generation of turbulence kinetic energy due to buoyancy , calculated as described in Effects of Buoyancy on in the k- ε Turbulence Models.
- Y_M is the contribution of the fluctuating dilatation in compressible turbulence with the overall dissipation rate , calculated as described in Effects of Compressibility on in the k- ε Turbulence Models. ,
- $C_{1\varepsilon}$, $C_{2\varepsilon}$ and $C_{3\varepsilon}$ is constant each worth 1:44 , 1.92 , and 0.09 .
- σ_k and σ_ε turbulent Prandtl numbers for k and ε each worth 1 and 1.3 .

2. Research Methodology

Fig. 1 illustrates the sectional geometryof rotor Savonius simulated model.The diameter of the blade mountingplate (Dep) = 200 mm, diameterrotor (d_r) = 180mm, diameter blade or a semi-circle = 100 mm,blade thickness (e)= 0.3 mm , the width of the blade gap or overlap (a) = 20 mm , width of spacebetween the blade (s)= 0 mm. The length sides of a square are 250mm.

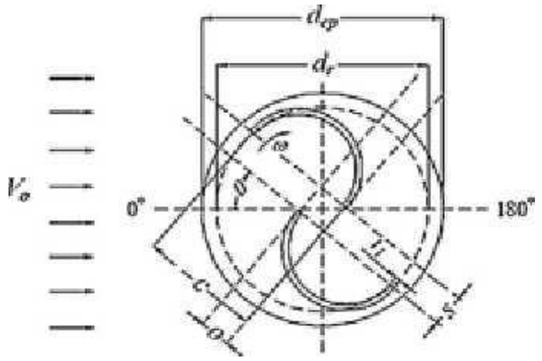

Fig. 1. Cross-section 2D models Savoniusrotor[2]

There are two methods of testing conducted in this study. The first method is simulated using a CFD program. CFD simulation is used to obtain the flow behavior prediction, the vector velocity and pressure. Simulations performed on rotor angular position from 0° to 180° with a change position every 15° to the direction the wind is coming. The boundary conditions are used for all simulations are created the same as has been used in a simulation study [8]. Set- up boundary conditions used in CFD simulation is the inlet v = 2 m/s and 5 m/s (constant), outlet: pressure outlet = 101325 Pa (constant). Solution method includes the scheme: semi-(simple), the momentum: orderupwind second. Mesh sizing: on curvature and proximate .

The second method is observationsthat made by recording using a high speed camera at 1000 fps which is set at 75 fps recording capability. Subsequently, the tape was slowed 1% by using KMP Player program and record the travel time of each rotor rotates 15°. Wind speed selected in the recording process is the rotation of the rotor 2 m/s and 5 m/s. Fig. 2. illustrates the observation and recording of the rotation speed of the rotor within a distance of the circumference of the starting position 0° - 180°.

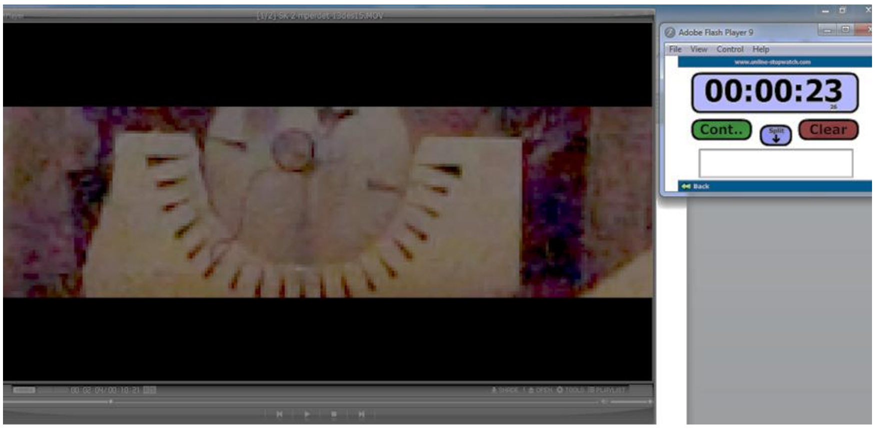

Fig. 2. The observation of the rotational speed of the Savonius rotor

3. Results and Discussion

- **Effect of Wind Speed to Torque**

The concave side of the blade that receives the wind comes is the most important part because it produces a positive torque. But it cannot be avoided if the convex side blades also produce negative torque.Torqueis resulted from the multiplication of turning force with the arm. The arm length is the distance between the center of turning force to the center of rotation or shaft.Position of the rotation angle of the blade determines the length of the arm between center ofthe rotation force against the shaft.

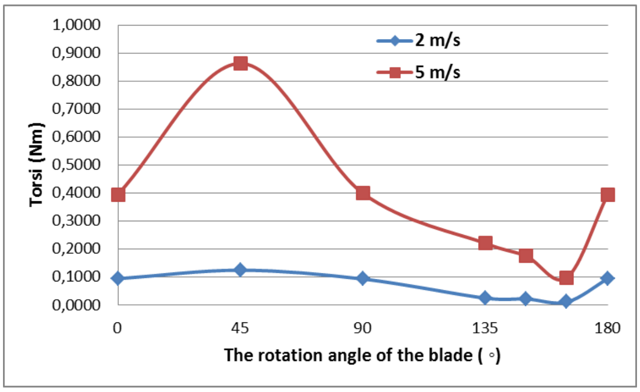

Fig.3. Effect of wind speed on the torque based on the rotating angle of the blade

Based on Fig.3,the torque value is directly proportional to the wind speed. The form of the graph in Figure 2 has a likeness to the studies that have been done before [2,7,10, 12]. The highest torque value, or to a previous study is the coefficient of torque and coefficient of performance is obtained when the side concave blade is in a position of 45°. The rotational force that represented by the value of the maximum pressure. Fig. 4 shows the maximum pressure that generated when the position of the blade is in the angle between 90°-120° to wind direction came.

On the position of the blade rotation angle of 45° to the direction the wind is coming, the force center is located on the outer edge of the concave side of the blade.Thus the blade produces a maximum positive torque.As for the negative torque generated is at a minimum due to arm the force on the convex side is very short. When the blade rotates past the angle of rotation 45° causes arm the force on the concave side of the blade becomes smaller. Instead arm the force on the convex side into an elongated blade. This causes a decrease in the value of positive torque and increased negative torque values.Thus , although the value of the force or identical to the pressure value on the rotation angle of 45° is smaller than the rotation angle of 90° , but the rotation angle of 45° is able to generate a higher torque than 90°. What is interesting is the lowest torque and lowest pressure generated on the rotation angle of 165° or (-15°).This indicates the position of the blade at the rotation angle of 165° is a critical position for Savonius rotor.

- **The effect of the vortex of the maximum pressure on the blade surface**

The concave side of the blade receiving wind is the most important part of Savonius rotor for producing a positive torque. However, due to rotation of the rotor blade is not always in a position to absorb the kinetic energy of the wind to the fullest. By CFD simulation, fig.4 and fig. 5 show the conversion of wind speed to be pressure on the blade.Fig. 4 has the same form with the results of experimental studies on the value of C_D(the coefficient of drag) for each position of the rotation angle [13]. Fig. 5 shows a decrease in the value of wind pressure on the surface of the concave side of the blade after the blade rotates past the rotation angle of 120°. This is caused by the formation of a vortex in front of the concave side of the blade.

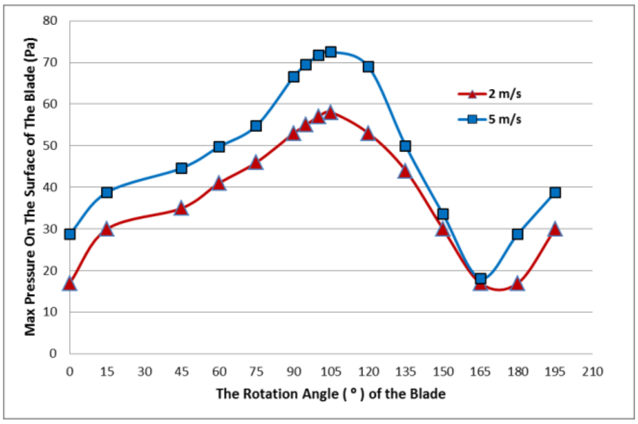

Fig.4. Effect of wind speed to maximum pressure on the blade based on the turning angle of the blade

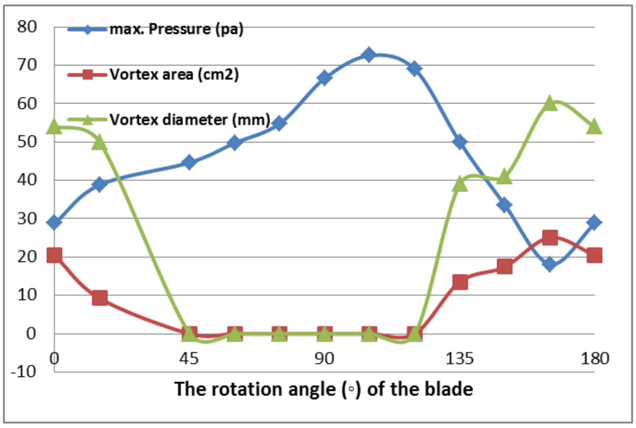

Fig.5. Vortex area on the blade based on the turning angle of the blade (v = 5 m/s)

Fig.5 and appendix show when theposition of the blade on the rotation angle of 135°,looks vortex formed in the front concave side of the blade. In therotation angle of 135°, the back portion of the blade began to cover the concave surface of the blade and directing the wind to follow the curvature of the blade profile. Vortex formation is influenced by the pressure difference betweenthe concave surface of the blade with surrounding of the rotor. Wind flows along the surface of the blade toward the low pressure area located around the rotor. The wind also flows from the outer edge of the blade toward the low pressure on the overlap of rotor.

Fig. 6 illustrate vortex formed in front of the concave side of the blade will absorb most of the kinetic energy of the wind.Vortex which has the largest diameter occurred in rotation angle of 165°. The larger the diameter of the vortex , the greater the pressure difference that occurs between the center of the vortex to the outside of the circular vortex.So the loss of kinetic energy due to it is absorbed vortex also getting bigger. This causes the pressure acting on the concave surface of the blade to be low.

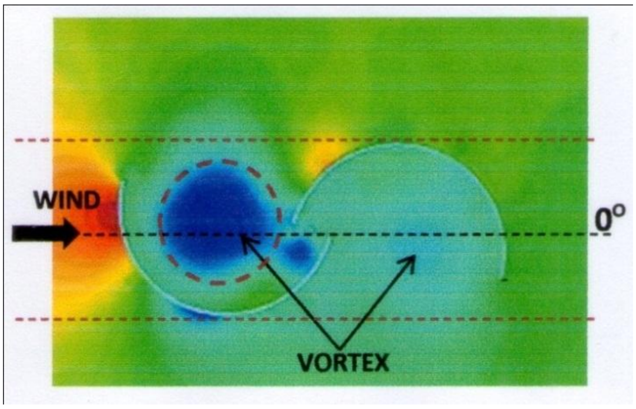

Fig.6. Position Savonius rotor blade 165°or (-15°) Against Direction, Wind Come

At lower wind speeds, 2 m/s, vortex is formed only seen when the blade is at its lowest torque position, namely the rotation angle of 165° and 180^0 (or 0°). Vortex is not formed on a rotation angle 15°– 150°. At low wind speeds generate laminar flow profile and generate value working pressure evenly on the surface. This also explains why the Savonius windmill has good torque at low wind speeds

- **Therotation time of the rotor blade**

High speed camera was used to record the rotation of the blade each time taking rotation angle 15°. The recording regarding the time of rotation of the blade is required to strengthen the CFD simulation related to torque or vortex. Between the rotation angle of 165°to 60°, rotor speed up rotation. The fastest time was when the blades rotate of 45° to 60°. Based on the simulation, the position of the angle of rotation of 45 to 60 have the highest torque and doesnot produce a vortex.When the rotation angle between 60° to 165°, the rotor rotates more slowly . Time longest of rotor rotation occurs at rotation angle of 165° to 180° .Based on CFD simulation, the rotation angle of 165° has the lowest values of torque and pressure, because at the rotation angle of 165° also produces a vortex in front of the concave side of the blade which has the largest values of wide and diameter.

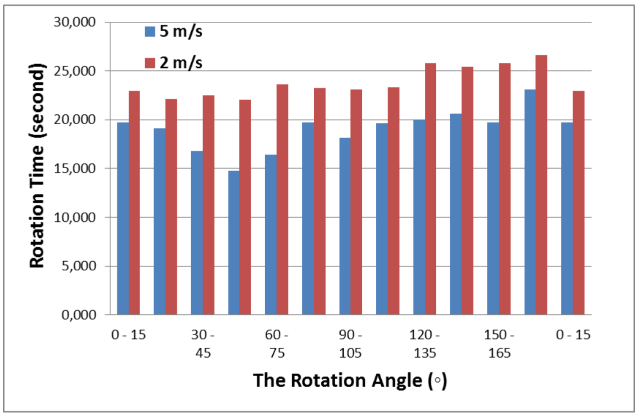

Fig.7. The rotation time of the blade each rotation angle 15°

3. Conclusion

Based on CFD simulation, a vortex is formed when the blade is on the rotation angle of 165° to 180° to the wind speed of 2m/s and rotation angle 135º to 210º (30º) for a wind speed of 5 m/s. This causes the low value of pressure acting on the surface of the blades. The rotation angles at 165º is a critical position for the rotation of the blade Vortex diameter rotation angle formed at 165º, good for a speed of 2 m/s and 5 m/s . The largest vortex causes the minimum torque. The rotor has the greatest torque on the rotary blade 45º. . The rotor has the smallest torque on the rotary blade on 165º.

In other hand if base on video recordings strengthening the results of CFD simulation if the rotation angle 165º to 180º is the worst condition for the rotation of the rotor. The fastest of rotation time when the blade rotates from 45º to 60º. The longest of rotation time when the blade rotates from 165º to 180º.

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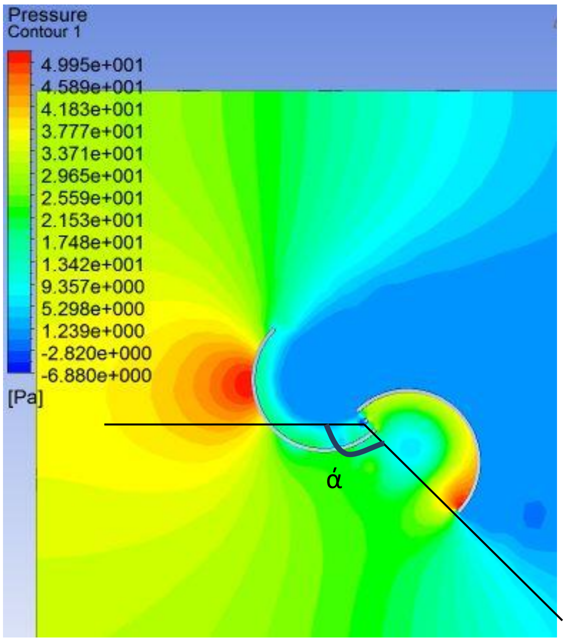
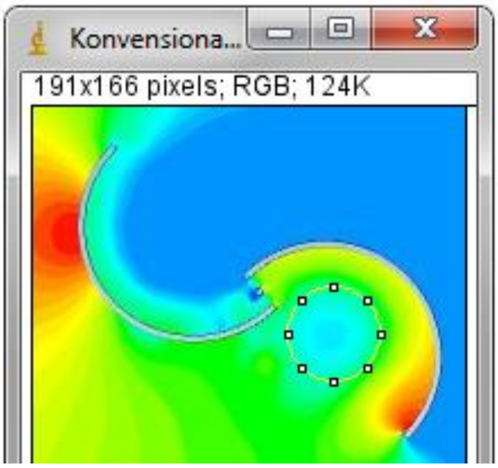
Appendix



ά =135º (-45º)

	Area	Mean	Min	Max
1	1354	155.549	122	172



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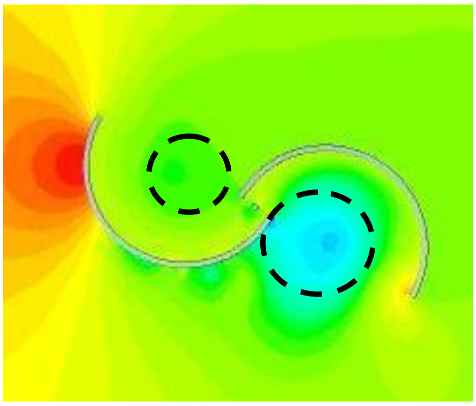
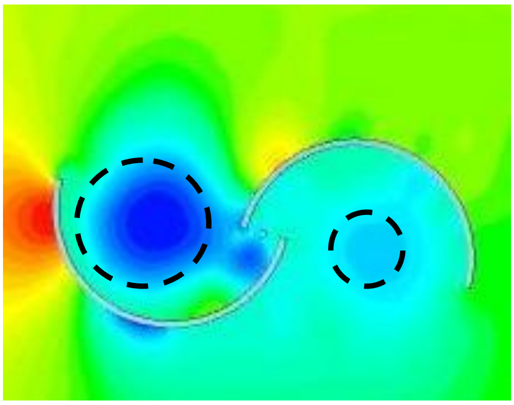
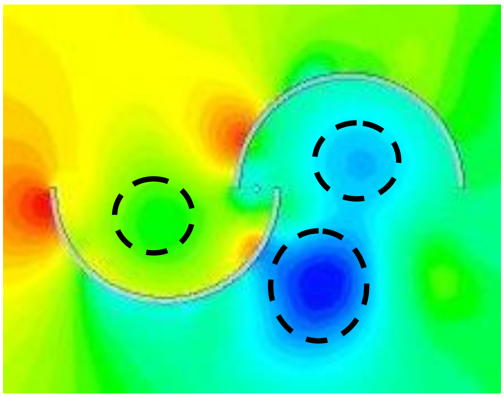


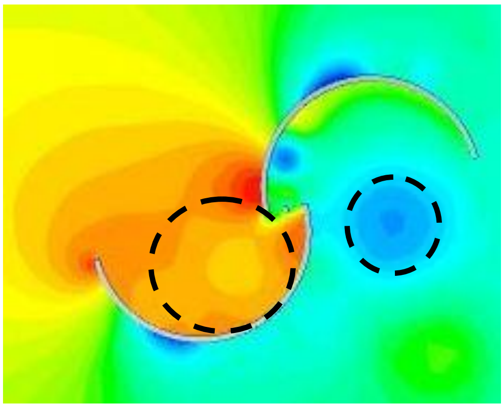
ά =150º (-30º)



ά =165º (-15º)



ά =0º (180º)



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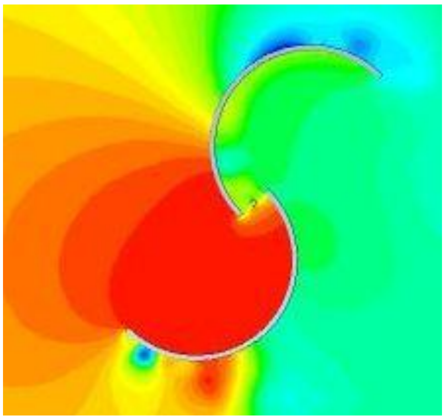

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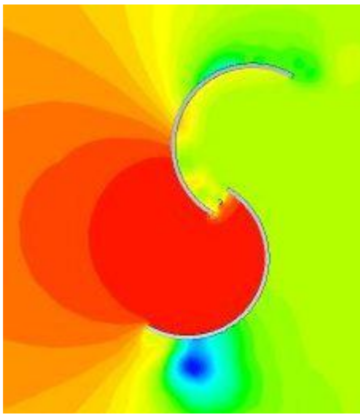

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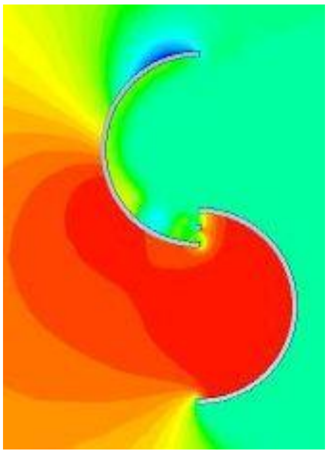

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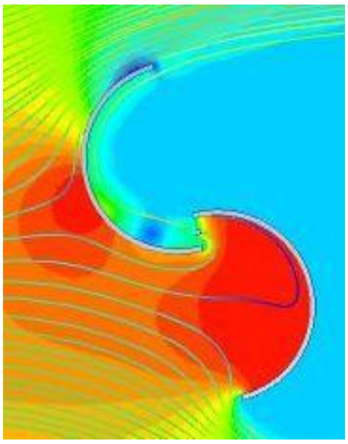

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