Drag Reduction in Flow Separation
Using Plasma Actuator in a Cylinder Model

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Abstract
Plasma actuators are alternative active flow control devices that are currently developed and very promising. Their ability to modify fluid flow with the approach of ionic particles gives answer to the development of a more effective and efficient oriented flow control. The plasma actuator is one solution to the problems commonly arise in active flow control, which usually are difficult to be controlled and difficult to be installed. The output of the plasma actuators is the ion wind generated from the ionization process at standard atmospheric conditions as a result of the emission of free electrons during electrical jump phenomenon. Ion wind occurs due to the suction in the upstream actuators and causes a region of empty space, which is then filled by new fluid causing the fluid movement towards the downstream of the actuator. In producing the ion wind, plasma actuator is connected to a 11 kVp-p power supply by using an square type wave with an initial frequency of 9 kHz. The plasma actuators are placed in three configurations to get a prediction of the position of the point of separation i.e at an angle of 55°, 90° and 125° of the stagnation point. This study investigates the performance of the actuator in a separated flow which aims in reducing the drag effect of a cylindrical model. From the experiment, it is concluded that the use of plasma actuator can reduce drag up to 20% with the separation point at 90° angle of curvature.

Keywords: Plasma Actuator, separated flow, ion wind, cylinder model

Introduction
In the aeronautics industry, both internal and external flow modification provides a very significant advantage in its application. The modification of fluid flow generally involves three basic phenomenon, namely the alteration from laminar to turbulent transition, separation and turbulence with drag reduction as its main goal. Drag reduction can provide advantages such as a reduction in fuel consumption, increased in speed and noise reduction \cite{1}.

In its development, fluid flow control technique is divided into two methods, namely passive flow control and active flow control. Passive flow control has limitations in its application as it highly involves turbulent flow in the modification of the flow, which causes it to be less applicable. Passive control equipment is also a single unit with the model so it is difficult to be manufactured and installed. Contributions in the use of passive flow control also can only reduce the drag of no more than 10%. This is considered less effective and efficient. Therefore some researchers further develop active flow control as a more promising method \cite{2}.

Active flow control researches advance rapidly in recent decades. Some active control devices that have been developed such as suction, blowing and synthetic jet has provided an increase in the reduction of the drag due to its ability of reaching areas where
the separation takes place. However, in its application, active control has several constraints, such as difficult to be control due to its more dynamic nature [3].

This study aims to investigate the ability of plasma actuators as an alternative to the latest model in the range of active flow control equipment, by utilizing negative ions that are released on the free atmosphere. This later forms a nitrogen plasma which can change the properties of the fluid that flows in the area of separation.

**Plasma Actuator**

Plasma actuators are the arrangement of two thin copper sheets separated by a dielectric material made from acrylic [4], where the copper acts as an electrical conductor and the dielectric material as a electrical insulator. A plasma actuator, by the time it is activated, will create a filament exactly on its upstream electrode. This filament is the result of an electrical jump phenomenon which occurs simultaneously and evenly along the electrode, which is usually called a plasma. The electrical jump which occurs physically produces negative ions or electrons to the free air, thus altering the properties of the air around the actuator and attracts some free molecules in the air by attracting its atomic core or protons to the source of the plasma.

The attraction of the free air molecules affected by the presence of the plasma causes an impact on some of space of the air and causes it to be voids, which then makes the air around it to fill in the empty space attracted by the plasma. The movement of the air causes a flow of the air around the actuator, which is called ion winds. These ion winds is the product of the plasma actuator which happens on the downstream area of the actuator. Fig. 1 is presented to help understand the mechanism of the actuator.

**Methodology**

To obtain a comprehensive separated flow, in this study, a cylindrical shaped model is used as test object, which is also commonly used in flow control researches due to its ability to give a good understanding on fluid flows. Another reason is because a lot of flow control applications also includes this type of shape. With the common use of cylindrical shapes, it can also be said that this shape has become a specific standard in flow manipulating researches.

Fig. 2 illustrates the configuration used. In this study, an acrylic hollow cylinder with an outer diameter of 99 mm and an inner diameter of 94 mm and length of 400 mm is used. To obtain a 60.000 Reynolds number, a 9 m/s speed is used as the reference value.

The plasma actuator is places on a 55°, 90° and 125° from the front or the leading edge of the cylinder, as mentioned in Table 1. The determination of those angles is based on the prediction that the separation starts at the 90° angle. Therefore, the points taken into account in this study is the points in front and behind the hypothetical separation point.
To produce ion winds, the plasma actuator is connected to a high voltage AC power source, which supplies a 11 kVp-p with a square 9 Hz frequency. In the preliminary study, it is inferred that excitation caused by 9 Hz square waves produces an optimal amount of ion winds. The upper electrode is connected to the positive pole, whereas the bottom electrode is connected to ground, as illustrated by the installation of plasma actuator presented in Fig. 3.

Table 1. Plasma actuator placement configuration on cylinder

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Geometry</th>
<th>Orientation</th>
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<tbody>
<tr>
<td>1. 55°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. 90°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. 125°</td>
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This study is conducted experimentally to obtain precise and comprehensive data. First, 10 holes are evenly created on the surface of the cylinder. Then, these holes are connected by pipes to a pressure tapping and then connected to a multi-tube manometer, which uses kerosene as the fluid and acts as a measuring device on each points on the surface of the cylinder. The diameter of the holes of the pressure tapping is 3 mm. The fluid movement in the manometer is recorded by a DSLR camera, which the output is a video. The video is then processed by Avidemux software to obtain the values in each second. To understand the process of data collecting, Fig. 4 is presented below.
Drag can be presented as a non-dimensional value to be used in the interest of prototype-making. This is called the Coefficient of Drag.

\[ C_D = \frac{D}{\frac{1}{2} \rho U^2 A} \]  

(1)

Pressure Coefficient is a non-dimensional value to represent the distribution of pressure on the surface, which in this case is on the surface of a cylinder.

\[ C_p = \frac{P - P_0}{\frac{1}{2} \rho U^2} \]  

(2)

Results and Discussion

From the measurement of pressure distribution, and after the data is processed to be statistically recalculated and substituting it to the equation of coefficient of drag and equation of coefficient of pressure, the result is presented in Fig. 5 and 6. From Fig. 5, it can be known that by placing the actuator exactly on the point of separation, a decrease in pressure is obtained. This is predicted as the arrangement of actuator which is placed alters a little turbulence in the flow and also affects the streamline so that flow can penetrate deeper into the area of separation. In Configuration A and C, it is concluded that the presence of the actuator doesn’t affect the change of pressure. On the other hand, in configuration B, that is with a 90°, a change in flow pattern and pressure occurs significantly.

Fig. 6 presents the data obtained when the actuator is operating and produces ion winds. The ion winds cause a significant change in the pressure and in the alteration of the flow pattern around the surface of the cylinder. In this case configuration B seems to produce an optimal effect. Configuration A and B shows a nearly same result as the previous condition. This is predicted to be caused by the position, which does not give the actuator a bigger opportunity to alter the flow.
Therefore it can be understood that the best position of placement of this actuator is in the 90° angle and if the actuator is placed in a lower or higher angle, the effect is not as significant as when it is place on the 90° angle configuration.

The comparison of drag coefficient obtained in case the cylinder is without the actuator, with the actuator and when the actuator is operated can be seen in Fig. 7. It can be concluded that by using the plasma actuator in the right angle, causes a significant decrease in pressure which then result in a lower coefficient of drag of the object. This decrease in coefficient of drag indicates a good performance of the actuator, with a 20% reduction of drag as compared to the objects original coefficient of drag.
Conclusion

The application of plasma actuator in decreasing drag, from this experiment, result in a significant effect. It is concluded that by placing the plasma actuator on a 90° angle at the surface of a cylinder from the point of stagnation, a significant effect occurs in altering the flow. This identifies that the best position of placing the plasma actuator is exactly on the point where the separation begins, while in different configuration result in a not so significant effect.

Analytically, a 20% of drag reduction is obtained and this indicates the performance of the actuator is effective with a low energy consumption.

Reference


Figure 7. Coefficient of drag comparison