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EXPERIMENTAL INVESTIGATION OF THE EFFECT OF MVGS[1] ON THE AERODYNAMIC PERFORMANCE OF A TYPE OF UAV[2] WITH THE BWB[3] CONFIGURATION

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ABSTRACT

Today the BWB configuration aircrafts are considered as a revolution in aerodynamic design. However, many challenges have been faced by scientists and researchers. These may be the occurrence of the flow separation in two areas of the blended wing and body region, and the outer region of the wing. In this paper, the effect of MVGs on the aerodynamic performance of a basic model of a typical BWB-UAV has been researched. The investigation was experimentally carried out at a speed of 18 m / s with varying angle of attack. In this work, the coefficients of lift, drag and pitching moment were measured and the effect of MVGs in different situations, were compared. The most important outcome of these experiments was enhancing L/D ratio in the presence of MVG on the model surface.

KEYWORDS: UAV, BWB, MVG, Flow separation

INTRODUCTION

Nowadays, aircrafts act well in the area of passenger and cargo transportation, meanwhile they can always be improved. Given the significant economic conditions in today world, increasing productivity has a prominent role in aircraft design. In the last thirty years, major technological developments have been achieved in the propulsion, structure, and electronic systems of airplanes. However, there has been little technological progresses in the field of aerodynamic geometry of the aircrafts in the last few decades. These modifications in the configuration of airplanes can be considered as an evolution, rather than a revolution. Moreover, increasing environmental concerns is a global issue encountered by numerous industries, and the airline industry is not an exception of this rule. This industry is responsible for 49% of global greenhouse gas pollution. Hence, now is the time to work and do research on new designs. One of these designs, which has been popularized a lot, is the blended wing body (BWB) configuration of the aircrafts, which is currently being developed by National Aeronautics and Space Administration (NASA), Boeing, and the US Air Force Research Laboratory (AFRL) jointly. This idea has been introduced since 1930, and now more significant advances are being made on this idea based on new technologies.

This type of configuration is also utilized in the design of drones or unmanned aerial vehicles (UAVs). Taking into account the crucial applications of UAVs in both the military and civilian sectors, the importance of this technology is increasing day by day. The most important advantage of this configuration for UAVs is the decreased radar cross-section (RCS) as well as the increased flight durability due to the elimination of some control surfaces causing interference drag.

This design is preferred in conventional airplanes with tube-and-wing body design, which is due to the removal of the body without lift and unnecessary surfaces on the aircraft, as well as proper blending of the

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propulsion system into the aircraft body. Based on the studies, it can be concluded that the potential of a BWB is not only innovative, but it is also a revolution in the aircraft industry. All investigations performed on this type of configuration indicate better performance in aerodynamics, structure, fuel consumption, direct operating cost, and noise reduction. This type of aircrafts has an aerodynamically smooth and uniform configuration due to the continuous lift surface. Therefore, additional drag created on conventional aircrafts is eliminated, hence increasing the aerodynamic efficiency. In addition, the removal of horizontal and vertical tail structure is significantly effective in reducing the total aircraft drag. Therefore, generally, this category of aircrafts creates much less interference drag in comparison to the traditional aircrafts, in addition to a higher L/D ratio making them suitable for applications with higher load capacity. With more aerodynamic effectiveness, a BWB aircraft requires less power, thus less fuel is needed to propel the aircraft compared to the conventional aircrafts. Based on the investigations, the BWB configuration is capable of increasing the lift through the central section by 60%, unlike conventional aircrafts, the body of which are aerodynamically inefficient.

However, besides the special features and characteristics of this type of configuration, the need to optimize and develop the design in various areas, including the aerodynamics sector, is still felt. One of the issues that is considered in the aerodynamics section of this configuration is the flow separation in the BWB area and the outer wing area.

In 2013 Shim and Park presented the results of experiments carried out on a BWB model of the UAV. Based on these findings, the pitch-up[4] phenomenon was observed at an angle of attack of more than zero. Furthermore, at higher angles of attack, the flow separation in the wing outer area and the phenomenon of flow exit to the tip of the wing in the trailing edge region, were clearly observed. In 2015, continuing their research on this UAV model, Shim and Park investigated the effect of the vortex generator on the pitch-up phenomena. The presence of the vortex generator caused the pitch-up phenomenon to occur at an angle of attack of more than the previous case [1, 2].

EXPERIMENTAL SET-UP

In the current study, using the MVGs in two areas of the blended wing and body region, and the outer region of the wing on a base BWB model, it has been tried to investigate the flow separation control and, hence, the aerodynamic performance of the model.

These tests were conducted in the subsonic wind tunnel of the Space Research Institute (SSI) of Shiraz, Iran, at a speed of 18m/s. The dimensions of the test section of this tunnel were 80 cm, 80 cm, and 200 cm in width, height, and length, respectively. The turbulence intensity in this tunnel was about 0.13, as it is clearly visible in figure 1.

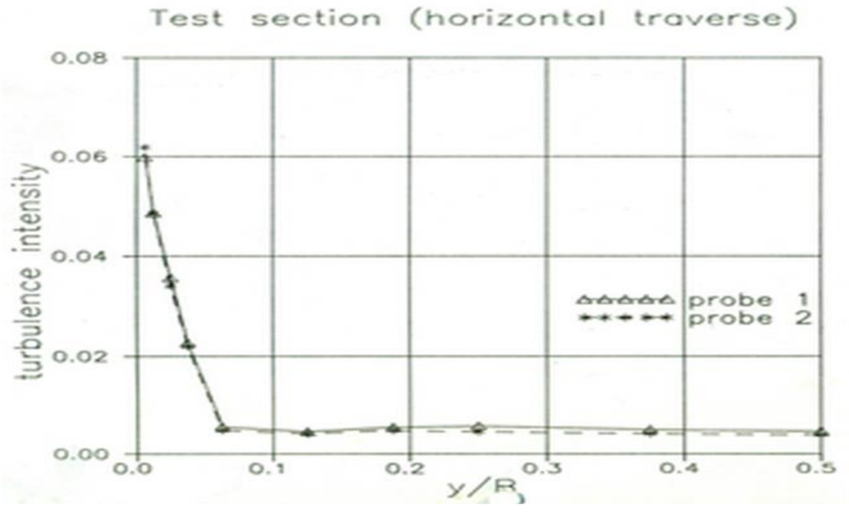

Figure 1. Changes in turbulence intensity relative to the distance from the wall at the test section

In order to do the test, a base model of an UAV with BWB configuration and two types of vortex generators with blade and wedge configuration, was designed. The base three-dimensional model was designed based on the information derived from the paper by Paudel and his colleagues [3]. The choice of this model [3] was due to the fact that all of the aerodynamic design parameters of the model were taken into account in this study. Since, in order to minimize the blockages resulting from the presence of the model in the test section, a smaller scale of the Paudel model should be considered for designing the experimental model. Therefore, the design dimensions of the experimental model were changed on a smaller scale. These models were fabricated using three dimensional printing technology and with a polylactic acid (PLA) type filament [4].A schematic of the three views of the UAV model with the BWB configuration and a schematic of the MVGs [5, 6, 7, 8], has been illustrated in figure 2 and figure 3, respectively. In addition, the details of the UAV model tested in this study and MVGs employed in this experiment have been given in table 1 and table 2, respectively.

With defining $\rho = 1.15$ and $\mu = 1.85 \times 10^{-5}$, the mean Reynolds number was obtained as 5.59×10^{5} based on the mean aerodynamic chord (MAC) in this experiment. The six-component external balance was used to measure the forces and moments, and data acquisition performed by the Lab View software.

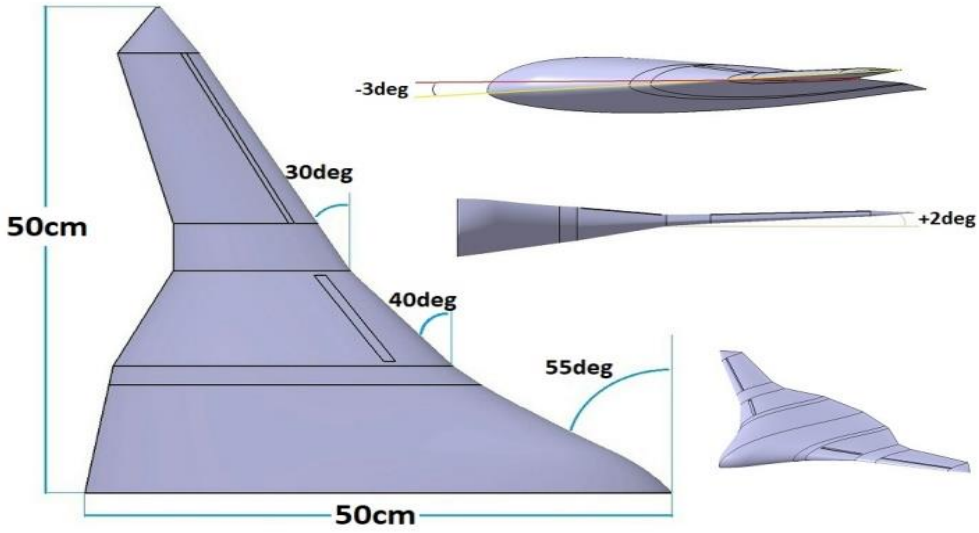

Figure 2. Schematics of the UAV model with BWB configuration

Table 1. Specifications of the BWB-UAV unmanned aerial vehicle model with blended wing body configuration

Characteristic	Size
Span	0.5 m
Length of the central line of the model	0.5 m
Reference surface area	0.0983 m^2
Airfoil of wing area	MH45 (9.85%)
Airfoil of body area	HS522 (14%)
Sweep angle of the body leading edge	55°
Sweep angle of the wing leading edge	30°
Wash out	3°
Dihedral angle	+2°

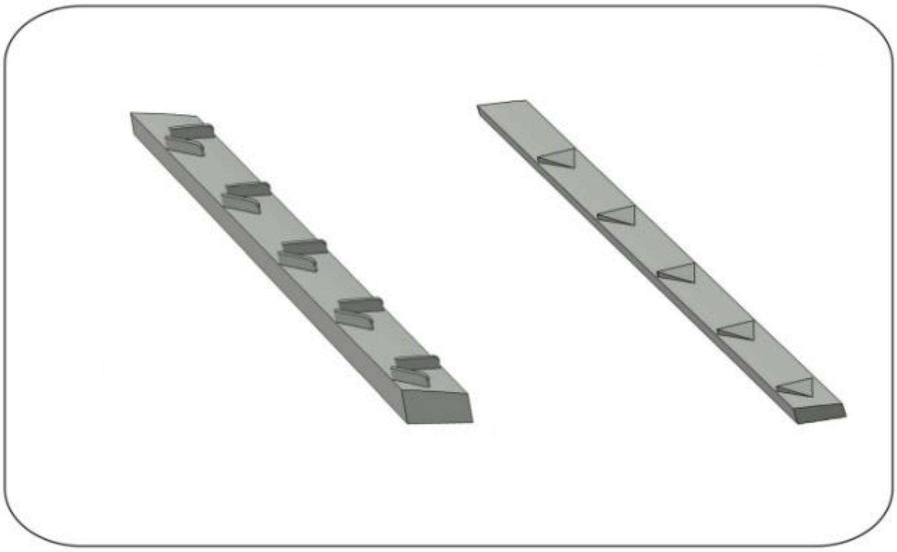

Figure 3. Schematics of the of vortex generators and their dimensional characteristics

Table 2. Dimensional specifications of the micro-vortex generators (MVGs) used in the test

Parameter	**Wing outer area**	**BWB area**
Position	0.15 of chord	0.15 of chord
Mounting angle	20°	20°
Height (average)	1 mm	2 mm
Length	5 mm	10 mm
Lateral width	15 mm	18 mm

In this study, the model was tested at the angle of attack of zero to 15° with a 3-degree interval in the presence of a MVG on the model surface with five different cases (Table 3) at a speed of 18m/s. The blockage ratio of the model in the test section at the 15° angle of attack was 4.55%, and this ratio is within the permissible range(less than 5%). so no correction was required to be applied.

Table 3. Positions of micro-vortex generators (MVGs) on the model surface

Mode	**Type and position of MVGs**	**Title**
1	Simple model without MVG	Simple
2	Model with a blade MVG in the outer wing area	O.blade
3	Model with a blade MVG in the BWB area and outer wing area	Blade
4	Model with a wedge MVG in the outer wing area	O.wedge
5	Model with a wedge MVG in the BWB area and outer wing area	Wedge

Figure 4 demonstrates the test model mounted on the base plate in the test section of the wind tunnel. The base plate was used for placement of the test model in the completely uniform flow region free of the wall turbulence in the test section. The lower surface leading edge of this plate, which was placed in front of the incoming flow into the test section, was chamfered with a 20 degree angle [9] to minimize the turbulence of the flow around the model.

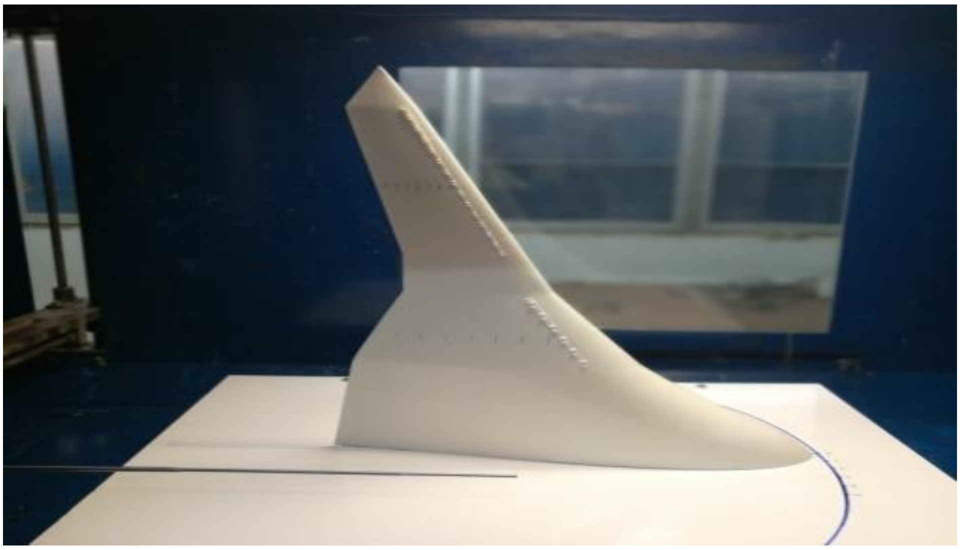

Figure 4. Test model mounted on the base plate in the test section

RESULTS AND DISCUSSION

STANDARD DEVIATION

The application of each measurement is sharply dependent on the assessment of its accuracy in some logical ways, and the exact assessment of each measurement is very difficult. Therefore, all aspects of a specific experiment are required to be analyzed. Prior to analyzing the results, in order to determine the accuracy of the experiments performed, using the uncertainty method (Gaussian probability distribution), the standard deviation (SD) of the obtained data was calculated and applied on the data. For instance, the SD of the drag data measured is shown in Figure 5.

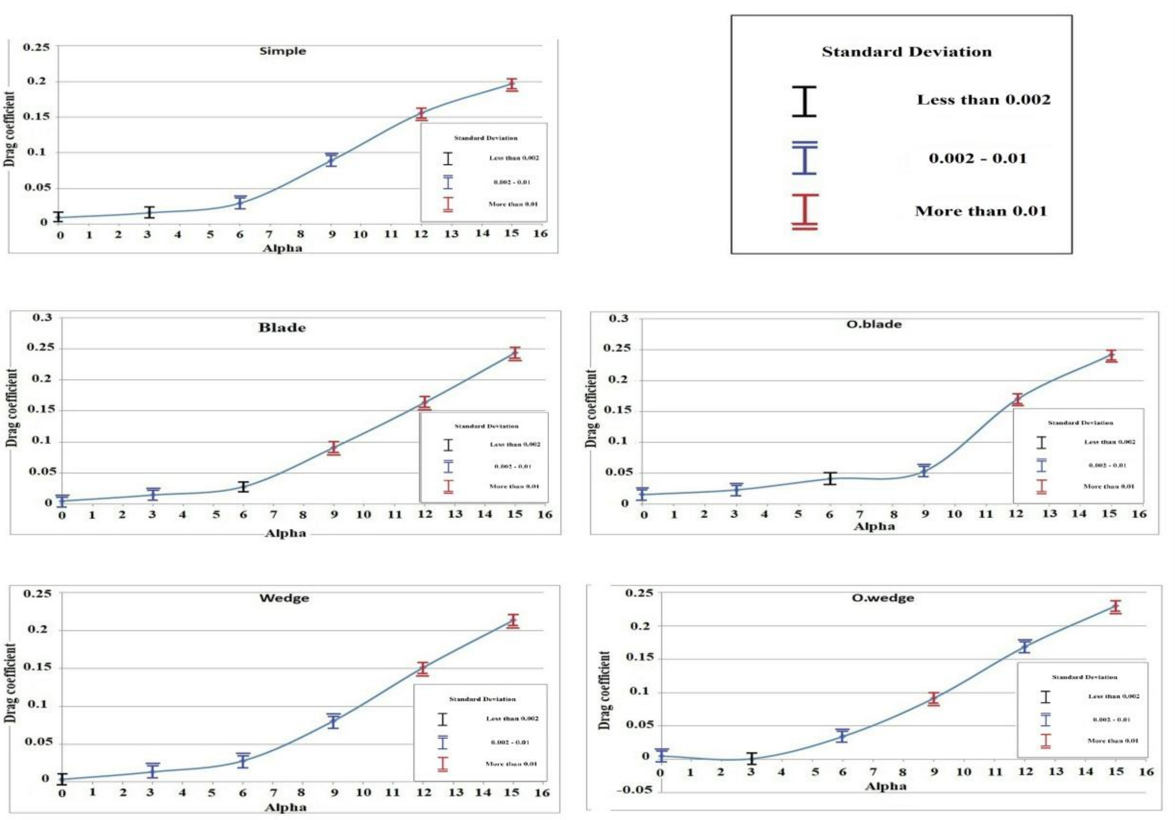

Figure 5. Standard deviation (SD) of measured drag data

FLOW VISUALIZATION

There are different methods to detect a flow in the model, including use of smoke, tuft (yarn), Chinese flower, oil strip can be named. In view of the model of the used wind tunnel and available facilities and equipment, one of these methods has to be selected. As the wind tunnel of the Research Institution of Shiraz is of closed circuit type, using smoke isn't possible for detection. So considering the equipment available in this center, using tuft was sleeted to detect flow.

Tuft is the simplest and the most common method of detection of flow on the surface. Tufts mainly are from light flexible materials; like nylon fibres that stick on the surface and flow along the flow. These tufts must be attached uniformly on the surface. The length of the tuft is very important. Such that the radius of curvature of the flow line has to be a fraction of the tuft length. The following figure shows the flow detection on the model tested in the presence of aerodynamic tools [10].

Figures 6 and 7 show the flow visualization on the model tested with the vortex generators at a 15 degree angle. According to Fig.6, in the Blended wing-body area, the tufts tend to be in the opposite direction of flow movement and this shows the flow separation phenomenon. But with the presence of vortex generators (Fig.7), the tufts are in line with the flow and fluctuate.

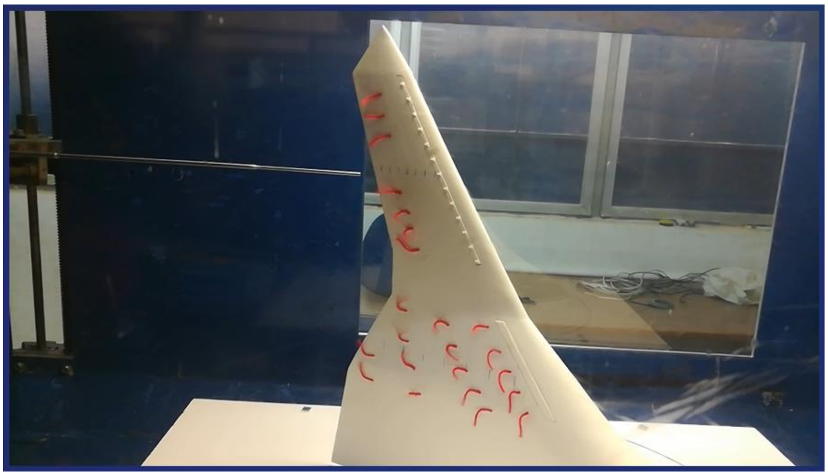

Figure 6. Model with wedge MVGs in outer wing area

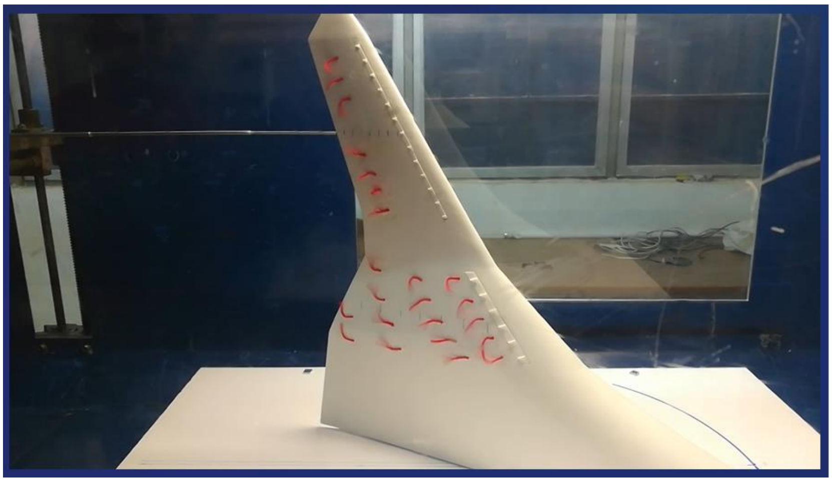

Figure 7. Model with wedge MVGs in both blended and outer wing area

FINDINGS

In this study, the focus was on aerodynamic coefficients and the model was tested in the range of angle of attack of 0 to 15° in the various cases listed in table 3. One of the studies carried out similar to the current research, is Shim and Park's [2] Research. In Shim and Park's research, has been using a blade vortex generator in the outer wing area to control flow behavior. The most important results presented in Shim and Park's research are presented simultaneously with the analysis of the results obtained in this study.

Figures 8 demonstrate variations in the lift coefficient of the UAV model tested in all cases. By increasing the angle of attack of the model, inside the boundary layer formed on the upper surface, an undesirable pressure gradient begins to form which causes, the pressure difference between the upper and lower surfaces of the model to decrease and reduces the lift coefficient. The presence of vortex generator changes the dynamics of the flow in the boundary layer, and by preventing the formation of undesirable pressure gradient increases the lift coefficient, particularly in high angles of attack. As illustrated in figure 6, the best effect on increasing the lift coefficient in various attack angles is associated with case 3, with the highest lift coefficient in this case obtained at 15° as 0.562.

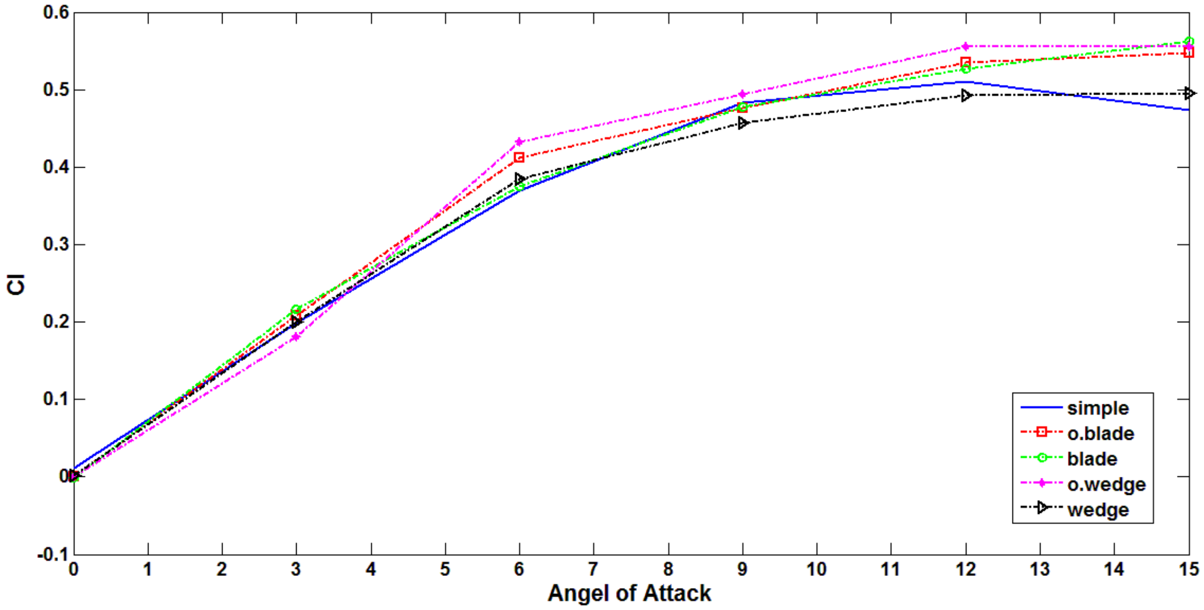

Figure 8. Variations of lift coefficient relative to the angle of attack

By comparing Fig.8 and the results presented in experiment of Shim and Park (Fig.9), we can see the same behavior in the variation of the coefficient of lift with the presence of vortex generator. Figure 9 show that, the presence of a vortex generator in the outer wing area has led to an increase in the lift coefficient at an angle of attack of 12 to 16 degrees.

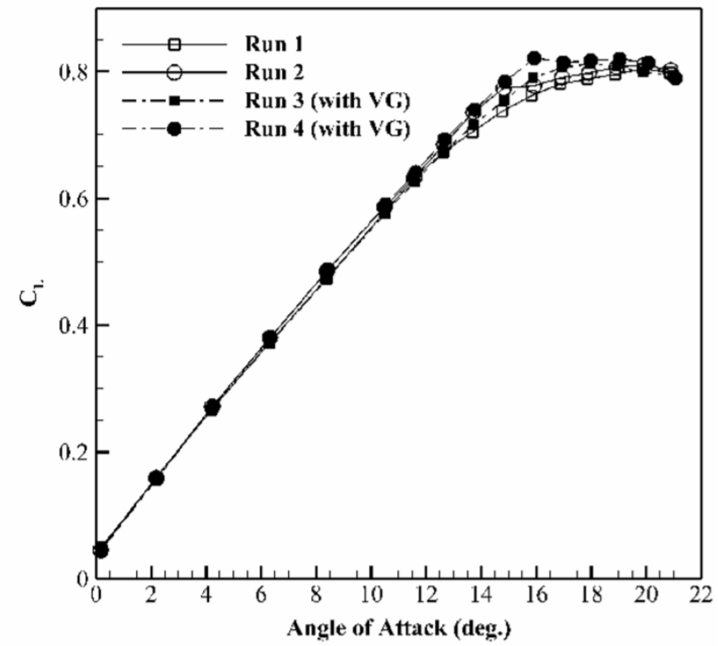

Figure9. Lift coefficient variations in Shim and Park research [2]

Figure 10 indicates that in the presence of a vortex generator, the drag has remained almost fixed at lower angles of attack in comparison to the base model (case 1), and even at 9° (cases 2 and 5) the drag rate has decreased in some cases. However, the drag has increased at the angle of attack of 15°. This increase in drag indicates that, at an angle of attack of 15°, the vortices generated by the MVGs were not strong enough to transmit energy to the near-surface flow layers. In addition, the impact of the inevitable interference drag was observed due to the presence of MVGs which has resulted in an increase in the drag and a slight decrease in the lift.

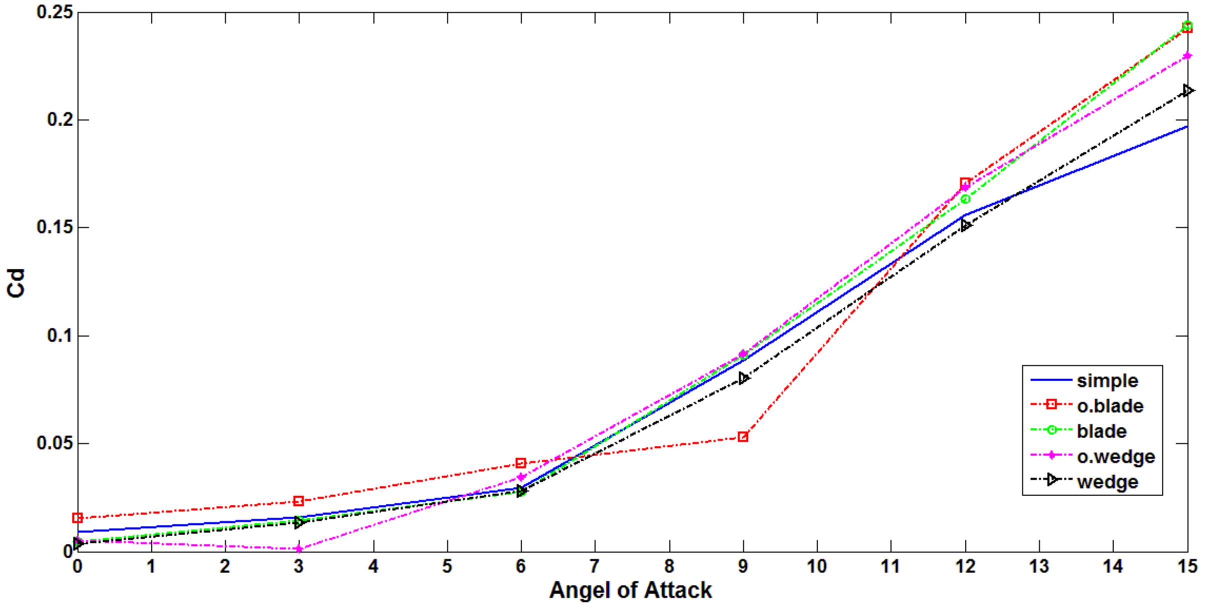

Figure10. Variations of drag coefficient relative to the angle of attack

Figure 11 shows the graph of changes in the drag coefficient in Shim and Park [2] research. The variation in the drag coefficient in the range of zero to 15 degrees in this graph also remains unchanged, compared with the model without the vortex generator. The reason for the increase in the drag at the angle of attack of 15 degrees in the present study, compared with Shim results, could be due to the presence of vortex generators in the two areas of blended wing-body region and the outer zone of the wing, which reduce the power of the vortices produced at this angle of attack by the vortex generators.

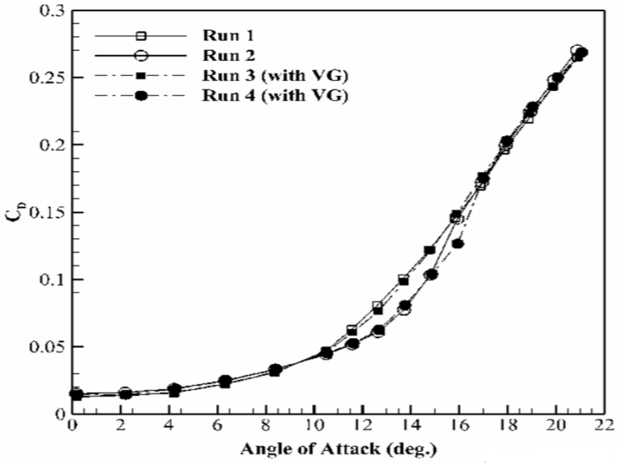

Figure 11. Drag coefficient variations in Shim and Park research [2]

Moreover, the changes in the lift to drag ratio are shown in figure 12 for all cases. Figure 12 indicates that the highest lift to drag ratio has been achieved in the range of the angle of attack of 3 to 6° for all cases. As it can be observed, the maximum lift to drag ratio in cases 3, 4, and 5 is more than 1. However, this ratio is less than 1 for case 2. Given the graphs depicted in this figure, it can be concluded that the presence of MVGs simultaneously in the BWB area and the outer wing area has a better effect on increasing the lift to drag ratio. It can also be claimed that the wedge vortex generator had a more desirable effect compared to the blade type.

By comparing the graph depicted in figure 10 with the previous studies [2], the overall positive impact of the MVG on the increase in the lift to drag ratio can be observed.

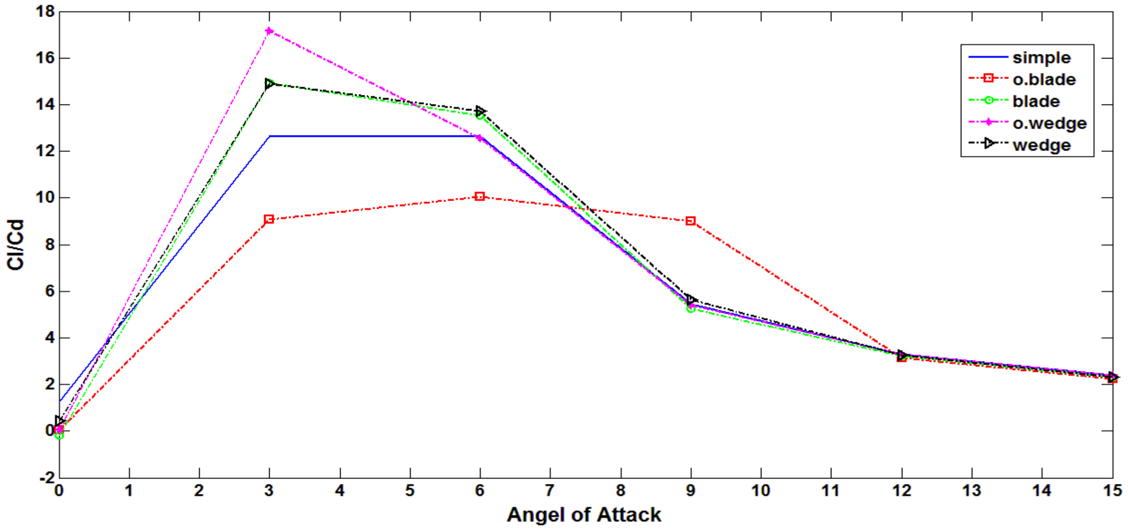

Figure 12. Variations of lift to drag ratio against the angle of attack

The variations of the pitching moment coefficient have been illustrated in figure 13. Comparison of figure 11 with the previous studies [2, 3], amongst the pitching moment coefficient results of Shim research (Fig.14), clearly indicates the strengthening of static stability in all cases of the presence of a MVG on the model.

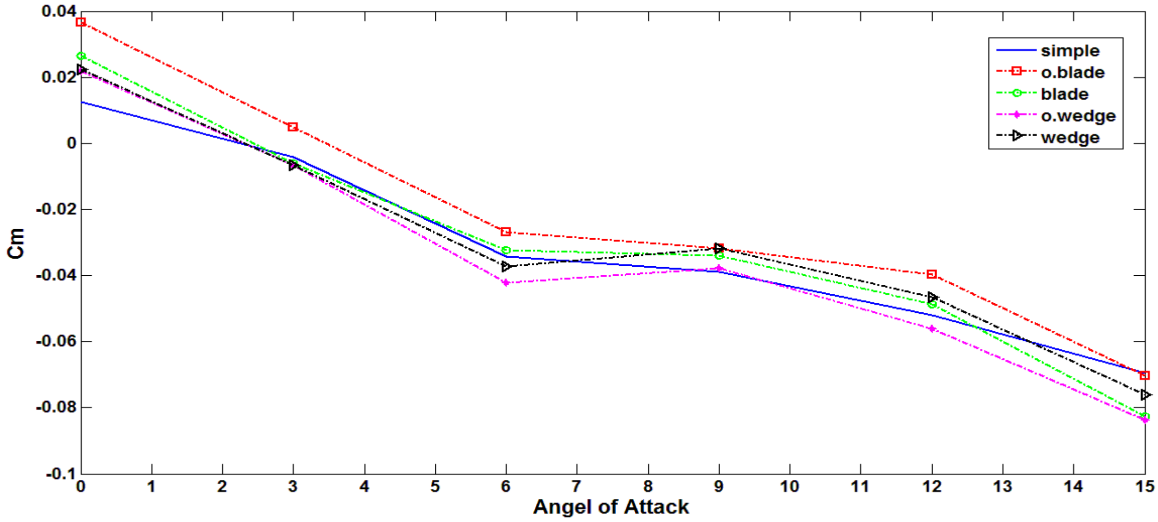

Figure 13. Variation of pitching moment coefficient of the tested BWB-UAV model

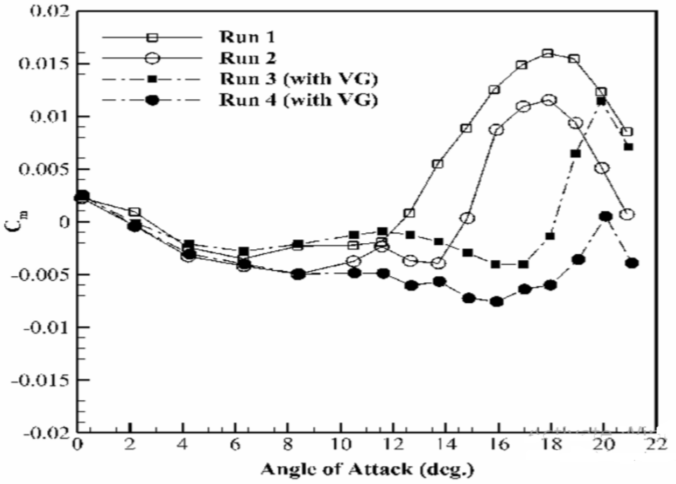

Figure 14. Pitching moment coefficient variations in Shim and Park research [2]

Due to the limitations in the design and construction of the model, it was not possible to create holes on the model body to measure static pressure. On the other hand, using a pitot tube to measure static pressure had a significant error. Therefore, by measuring the total pressure distribution along the chord, only the starting position of the separation was estimated. The total pressure distribution was measured along the chord and at an angle of 12 degrees.

As shown in Fig.15, without the presence of a vortex generator, the flow separation starts at about 0.34c in the blended wing-body area. But with the presence of vortex generators on the model, the separation of the flow was postponed. Also as shown in Fig.16, without the presence of a vortex generator, in the outer wing area, the flow separation is clearly seen at about 0.9c. The presence of vortex generators in this area prevented the flow separation from trailing edge.

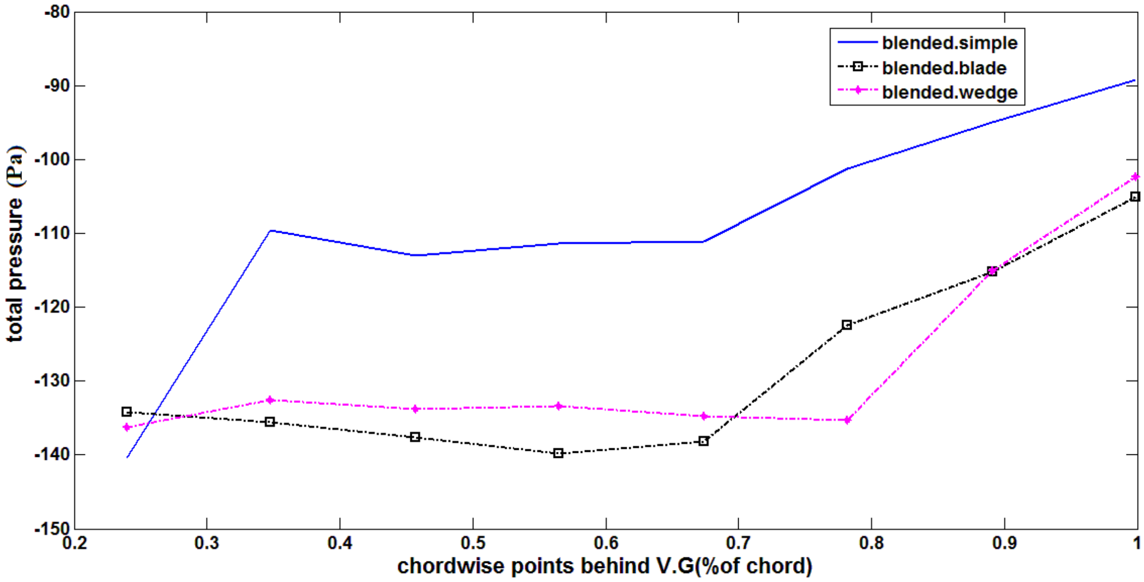

Figure 15. Chord wise distribution of the total pressure, behind the micro vortex generators, with an angle of attack of 12 degrees in the blended wing-body area

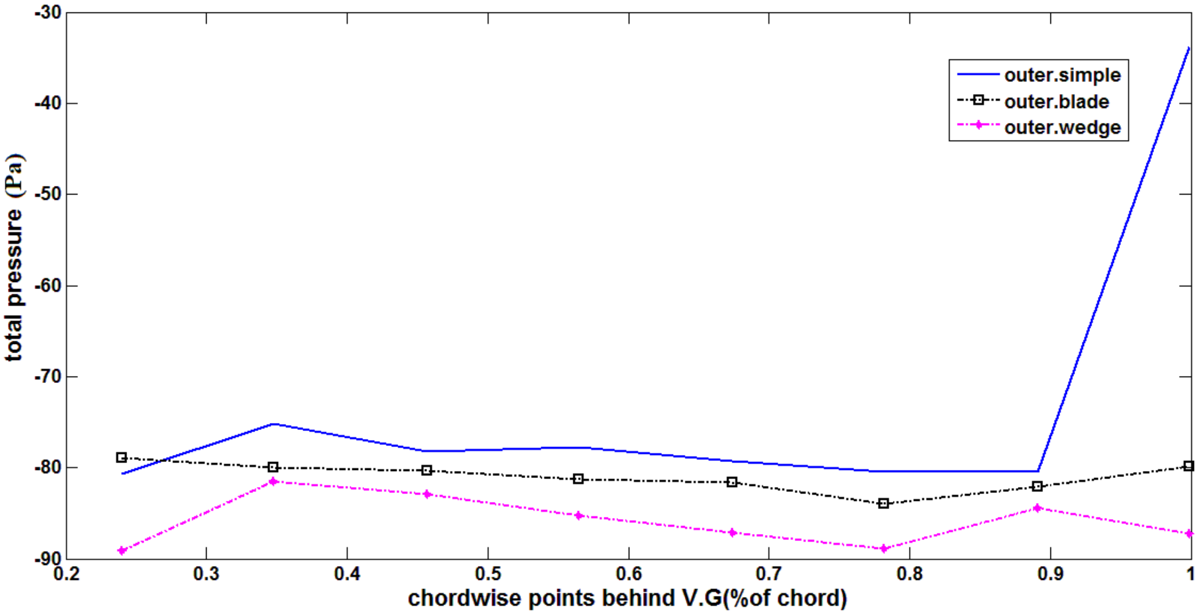

Figure 16. Chord wise distribution of the total pressure, behind the micro vortex generators, with an angle of attack of 12 degrees in the outer wing area

CONCLUSION

In this study, the effect of MVG on the aerodynamic performance of a base model of a UAV with BWB configuration was examined. This investigation was performed experimentally at a speed of $18 m/s$ and at the angle of attack range of zero to 15°. In these tests, the lift, drag, and pitching moment coefficients were measured, and the effect of different cases, type, and position of the MVGs on the model was compared with each other in terms of the angle of attack. Taking into account the findings and the analyses carried out, the MVGs generally increased the lift and thus the lift to drag ratio, in addition to strengthening the static stability. But most importantly, the presence of MVGs caused the flow separation to be delayed in the BWB area and is eliminated in the wing outer area. Eventually, from among the four cases specified, it can be claimed that case 3 was accompanied with better results.

Finally, it should be noted that comparison of other situations of MVGs and their other types can greatly contribute to the improvement of aerodynamic performance and control of the flow separation on this type of aircraft configuration.

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