Effect of synthetic jet actuator location on the aerodynamic performance of backward-facing step

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ABSTRACT – The present paper studied the effectiveness of synthetic jet actuator in altering the aerodynamic characteristics of a backward-facing step under the influence of the jet position. The 2D, compressible, unsteady Reynolds-averaged Navier-Stokes (URANS) equations were solved to estimate the aerodynamic drag and lift forces of the step. For the single jet cases, the best location is placing the actuator at the separation point. Such optimal setting can produce up to about 26% and 23% drag and lift reductions, respectively. Furthermore, when comparing to the single actuator case, the use of two actuators has shown higher reduction in drag. However, it is relatively less effective in regard to lift reduction.

1. INTRODUCTION

Active flow control (AFC) is a technique used to improve the aerodynamic performance of vehicles or fluid devices. Unlike passive control which requires the modification of the shape of the original geometry such like mounting a spoiler (e.g. [1-3]), an active flow control method requires the expenditure of energy and control loop. Studies have shown that synthetic jet actuator (SJA) is an effective device for AFC in wide range of applications. These include improving the total pressure losses of a compressor [4], lift augmentation in wing [5], and separation suppression of bluff-body flow [6].

The bluff-body configuration used is a rounded backward-facing step which resembles the rear section of many objects or devices found in practice such as air intake, the roof end of road vehicle, etc. Thus, it is relevant to many applications. A study has shown that the use of SJA at low-frequency forcing can produced 54% reduction in the separation length [6]. However, the effect of location of the SJA has not been considered despite many studies have shown its significance in affecting the effectiveness of the SJA performance [7-8]. Although these studies were on wing model, the same may apply to the backward-facing step. Therefore, the objective of the present study is to identify the influence of location of SJA on the performance of SJA in the case of backward-facing step.

2. METHODOLOGY

2.1 Computational domain and meshing

The rounded backward-facing step used in the study of Dandois et al. (2007) is adopted to model separated flows that are relevant to aeronautical and road vehicle applications. A 2D domain is used. The upstream extent from the step is $5h$ while the downstream is about $9h$ (see Figure 2.1). The top edge is $6h$ from the upper side of the step. The total height and length of the domain are $7h$ and $16h$, respectively.

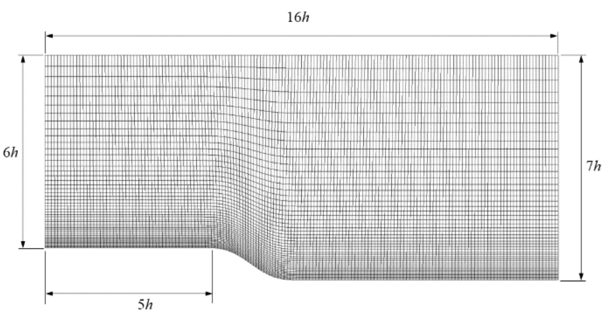

Figure 2.1 Computational domain, numerical cells, and dimensions

As shown in Figure 2.1, the structured, quadrilateral cells used throughout the domain. Finer cells were located near the bottom edge which represents the solid surface including the backward-facing step. In total, there were 8100 cells.

2.2 Numerical and physical settings

The mainstream flow was set at 0.3 Mach number. The stagnation pressure and temperature were 20011 Pa and 283 K, respectively. The outlet boundary was assigned as pressure outlet at zero-gauge pressure. The ideal gas law was used to model the fluid density with the fluid specific heat and thermal conductivity equal to 1006.43 J/kg.K and 0.0242 W/m.K, respectively. The two-coefficient Sutherland equation was used to model the fluid viscosity.

The commercial CFD solver ANSYS Fluent 16 was used to solved the compressible unsteady Reynolds-averaged Navier-Stokes (URANS) equations. Meanwhile, the Spalart-Allmaras model was used to model the kinematic eddy turbulent viscosity. Mass conservation is preserved by solving the continuity equation. The time step size used was 0.0001 second.

Transpiration boundary condition was used to model the synthetic jet actuator for all the controlled cases. The velocity of the jet is defined by $V_{\text{jet}} = V_{\max}\cos(2\pi f t)$ where, the actuation frequency f is equalled to 720 Hz, and the amplitude of the synthetic jet velocity $V_{\max}$ is equalled to 50 m/s. The velocity ratio VR is about 0.5. The width of the orifice is 3.33 mm.

The locations of the actuator in each controlled case are as summarized in Table 2.1. These locations are chosen in reference to the separation and reattachment locations obtained from the uncontrolled case.

Table 2.1 Composition of Ink Loading

Case	Description of SJA location
1	Uncontrolled flow; No SJA
2	At separation point
3	$0.5h$ upstream of the separation point
4	$0.5h$ downstream of the separation point
5	At both the separation and reattachment points

3. RESULTS AND DISCUSSION

3.1 Results of drag coefficient C_d

The mean values of C_d of all cases are as summarized in Table 3.1. As presented, among the single jet cases, the most effective position is at the separation point. The corresponding drag reduction is about 17.6%. The next best location is at $0.5h$ downstream of the separation point. Placing the actuator at $0.5h$ upstream of the separation point has not yielded any significant improvement.

Comparing to the single jet cases, the use of two jets has shown better result. The recorded reduction is about 26%.

Table 3.1 Mean aerodynamic coefficients of all cases and their respective percentage reductions in reference to the uncontrolled case

Case	C_d	ΔC_d [%]	C_l	ΔC_l [%]
1	0.00595	-	0.0172	-
2	0.00490	-17.65	0.0134	-22.09
3	0.00590	-0.84	0.0132	-23.26
4	0.00532	-10.59	0.0168	-2.33
5	0.00440	-26.05	0.0144	-16.28

3.2 Results of C_l

From Table 3.1, it is evident that all the controlled cases have generated lower C_l than the uncontrolled case. Case 2 has exhibited the largest reduction. This is followed by case 3, and subsequently case 5, while case 4 has the lowest C_l reduction. Apparently, the two actuators case did not seem more effective than the single effective case in C_l reduction.

4. SUMMARY

The present study investigated the effectiveness of synthetic jet actuator in altering the aerodynamic characteristics of a backward-facing step under the influence of the jet position by a URANS method. The results indicate that the SJA is able to produce up to about 26% and 23% reductions in both the C_d and C_l, respectively.

The jet position has strong influence on its effectiveness. In regard to drag, the best location is found to be at the separation point. As for lift, the actuator locations at $0.5h$ upstream and at the separation point have shown comparable results, and are the best among all cases.

The use of two actuators is found to be more effective than single actuator in drag reduction, but not as good in C_l reduction.

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