Effect of Acoustic Excitation on Flow Asymmetry over Slender Body at High Angles of Attack

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Abstract
A new kind of flow control method, acoustic excitation, was applied to control flow asymmetry over a slender body at high angles of attack. Results show that acoustic excitation could improve the asymmetric behaviors as long as controlling conditions are chosen appropriately. The development of asymmetric vortices on the leeward along the model axis would be greatly affected by acoustic excitation. Moreover, the fluctuation energy in the boundary layer could be reduced.

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1. Introduction

Slender body is a widely used forebody configuration for modern advanced fighters and tactic missiles. At high angles of attack, asymmetric vortices appear usually on the leeward of the body, and large lateral force would occur, leading to severe effects on the operational performance and flight safety of vehicle. With the development of advanced vehicle, more and more attentions have been paid to the asymmetric flow involved in high-alpha slender bodies. Nowadays, research on the flow asymmetry mainly includes two aspects: one is research on the mechanism of flow asymmetry, the other is to explore effective methods to control flow asymmetry[1-5] But it is so difficult for a researcher to agree with another researcher’s opinion on the mechanism of the flow asymmetry though we have done a lot about it. So the aerodynamic field is divided in to two schools according to their thought of the mechanism at flow asymmetry. One says

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that we can understand flow asymmetry by studying the spatial instability of the flow at high angles of attack. While the other thinks flow asymmetry is induced by asymmetric flow separation and transition. Now we must find some effective methods to depress flow asymmetry, whatever the mechanism of flow asymmetry is, because we are challenged by flow asymmetry during the designing of vehicles. Many manipulating methods have been developed so far, though none of these methods is perfect enough.

In recent years, acoustic excitation was mainly applied to increase the lift and decrease the drag on airfoils. Results showed that acoustic excitation can make the energy centralized near the character frequency, which could suspend the flow separation. Then what would happen if acoustic excitation were applied to control flow asymmetry [6] And how does acoustic excitation act on flow asymmetry at high angles of attack [7] Particular study we have presented showed that acoustic excitation could change the development of the main vortices on both sides of the leeward.

2. Test Facility and Experiments

2.1. Test facility

The experiment was performed in the low turbulence level wind tunnel which is 33 meters long at Northwestern Polytechnic University. The test section is 6m long × 0.4m wide × 1m high. We can get very good flow quality and low turbulence level. The velocity ranges from 5m/s to 70m/s and turbulence level from 0.02% to 0.33%. Why we have chosen this low turbulence level wind tunnel to present this study? Results show that turbulence level will hardly affect flow quality when turbulence level is low enough (less than 0.1%), which will make other effects more effective. The results presented in this document are obtained when turbulence level is 0.02% if it is not marked specifically. The sting system at this wind tunnel allows the angle of attack to be varied from 0 to 90 deg.

2.2. Coated Test model

![Fig.1 Model and acoustic excitation mode](image)

We take a slender ogive body with a small blunt nose which is a kind of typical forebody configuration of modern fighters and missiles as our objective model. The nose fineness and the overall fineness of this model are 3.5 and 8 respectively. Seven pressure measurement sections are distributed along the model as shown in fig.1. And the right-hand coordinate system defined for the measurements is shown in Fig.1 too. The origin of the coordinate system is located at the tip of the model. The small orifices on the surface of the model are where the acoustic excitation comes from into the flow field at high angles of attack.

2.3. Test conditions

In this paper, we will mainly give the results obtained when the angle of attack is 50 deg. if it is not marked specifically because flow asymmetry is more intense when angle of attack is higher than 45 deg. while lower than 55 deg. And the angle of sideslip is kept at zero deg. constantly during the research. And the Reynolds number based on the maximum diameter of the model ranges from $0.12 \times 10^6$ to $0.22 \times 10^6$. 
3. Results

3.1. Image processing procedure Frequency of the acoustic excitation

We have obtained dynamic signals of the flow field at high angles of attack with hot-wire anemometry. Then we chose the character frequency or its harmonic frequency as the frequency of the acoustic excitation.

3.2. The effect of acoustic excitation on flow asymmetry

The effect of acoustic excitation can be affected by three parameters: location of acoustic excitation, frequency of acoustic excitation and its sound pressure level (SPL).

We applied two different positions which is located before the main separation, as shown in Fig1, which is designated by character “B1” and “B2”.

The results shown in fig.2 and Tab1 are the effect of the acoustic excitation location on flow asymmetry. We can get different effect by interfering in the flow field only near the nose of the model. This is a hint on the mechanism of “spatial dynamic instability”, which shows that it is very important to control the incipient disturbance of the flow field at high angles of attack.

![Fig.2 Effect of acoustic position on Flow Asymmetry](image)

We can see the effect of the acoustic frequency on flow asymmetry from fig.3. But we can’t simply think that the higher the frequency is, the more obvious the effect will be. In fact, efficient frequency is located in a narrow frequency sect. When frequency located in this sect can resonate with the character frequency of the flow field, flow asymmetry will be affected.

Another important parameter that can affect the effect of acoustic excitation is the SPL. The effect of acoustic excitation is weakened when SPL is decreased from 110dB to 110dB with the same frequency, as can be seen in fig.4. SPL is a measurement of acoustic energy entering the flow field. And it must be higher than a minimum value to make the acoustic excitation dominate in the flow field because the background noise has great effect on acoustic excitation. For example, we didn’t get obvious effect when the turbulence level increased to 0.33%, which is shown in fig.6. Flow asymmetry is so complicated that it is very sensitive to many other factors besides turbulence level, such as Reynolds number and compressibility. Reynolds number has great effect on the leeward vortices at high angles of attack, which can change the character frequency of the flow field. So if we want to control flow asymmetry, we must change the acoustic parameters with different Reynolds number. Moreover, flow asymmetry will be weakened with the
increasing of compressibility, and so will the effect of acoustic excitation.

3.3. The mechanism of flow asymmetry at high angles of attack

We haven’t any break through on the mechanism of flow asymmetry. But more results show that flow asymmetry is an inviscid process in nature, The dynamic instability has sensitive response to the unpredictable micro-disturbance coming from near the nose of the model. That is to say, we can change the flow at high angles of attack by the disturbances presented from near the nose of the model.

But why flow asymmetry is so unpredictable at high angles of attack? Many people usually simply think that this is because flow asymmetry is a kind of flow behavior with strong unsteadiness. Our results show that unsteadiness is just a kind of explicit act of flow asymmetry. It is dominated by some implicit rule. This unsteadiness of flow at high angles of attack is induced by interference and extrusions between the vortices on both sides, a kind of “vortex behavior”, when they are close enough. This kind of “vortex behavior” is induced by the sensitive response to the unpredictable micro-disturbance coming from near the nose of the model because of flow instability. The relative position of vortices is always changing along with the unpredictability of the micro-disturbance as well, which will change the flow asymmetry. Main vortices will always be switching between two conditions resulting in maximum side forces with contrary directions and the same magnitude especially when the flow is absolutely instable.

4. Conclusion

The analysis above of the collected data shows that the acoustic excitation can indeed affect the flow asymmetry occurring on the high-angle slender body, and enable to obviously improve the asymmetry behaviors as long as controlling conditions are chosen appropriately. The controlling effectiveness is the most apparent under the case that the excitation location is located near the first separated flow region, and the excitation frequency approaches the inherent frequency and its harmonic frequency of the first separated flow region near the nose as well as the increasing of sound level.

Spatial dynamic instability at high angles of attack can make the micro-disturbance magnified and transmitted to the whole flow field. And the response of the main vortices to the disturbance from the nose of the model make the relative position of the two main vortices always be switching. This provides a theoretical possibility for micro-disturbance to control flow asymmetry at high angles of attack.
After the acoustic excitation is magnified, it can affect the character frequency, the velocity fluctuation energy and the relative position of the main vortices. We can infer that the acoustic excitation can affect the frequency of vortices shedding when the angle of attack is high enough and the vortex shedding frequency can’t be ignored. The results in reference 7 show that acoustic excitation can induce small-scale vortices, but we should study further that how these small-scale vortices act on the main vortices.

The acoustic excitation is a kind of active flow control method with high potentiality that can overcome the faults of traditional flow control methods. It can control flow asymmetry with low energy. Moreover, it won’t demolish the configuration of the vehicles and can be controlled continuously.

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