Impact of Model Plunging Motion on Wind Tunnel Wall Pressure Fluctuations

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Abstract

A series of experimental work was conducted to investigate the variation of the wall pressure time history at different locations during the test of an aircraft model in a sinusoidal plunging motion. The model used in this research was a standard dynamic model known as SDM. Dynamic data were taken at various combinations of reduced frequencies, mean angle of attack and oscillation amplitudes. Time variations of the static pressure at several locations on the wind tunnel were recorded using sensitive pressure transducers.

The results show that wall pressure oscillation is highly affected by the model motion and varies with the free stream Mach number, oscillation amplitude and frequencies as well as the model mean angle of attack.

Introduction

In contrast to the static wind tunnel testing where extensive calibrations are commonly used to account for the wall interference on the aerodynamic characteristics, in dynamic tests, there is a complicated coupling between the unsteady support and wall interference mechanisms and the conventional aerodynamic testing knowledge is not likely to account for these interference effects [1]. When the model oscillates inside a wind tunnel test section, it can communicate with the test section wall through the oscillatory air around it. In a supersonic flow regime, the unsteady shock waves emanating from the nose and other parts of the oscillating model have a major impact on the wall pressure time history and impart some additional

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oscillatory modes in to the frequency spectrum of the wall pressure fluctuations [1]. Effects of model pitching motion on the wall pressure fluctuations have been previously investigated [2]. This paper presents some of the most important aspects of the oscillating model interactions with the surrounding walls in a plunging motion. Effect of model mean angle of attack, Plunging frequency and amplitude and also free stream Mach number have been studied on the static pressure variations at several locations on the wall.

Model and Experimental Apparatus

The model considered in the present experiments was typical of a fighter aircraft called the Standard Dynamic Model (SDM) and has been used in many research centers for flow field study and verification of dynamic test rigs for several years [3-5]. It has 32 cm length and 10.34 cm semi span. Figure 1 shows this model. The experiments were conducted in Trisonic wind tunnel with a continuously open circuit and with test section dimension of $60 \times 60 \times 120\, cm^3$. The test section Mach number varies continuously from 0.4 to 2.2 via the engine RPM and different nozzle setting [6]. The wall static pressure during a sinusoidal plunging oscillation of the model was measured at several points. Both static and oscillatory data were taken at Mach numbers of 0.4 and 1.5, corresponding to the Reynolds numbers of 0.84, and 3.15×10^7 per meter respectively. The oscillation frequencies were 1.25, 2.77, 6 Hz and the oscillation amplitudes were $\pm 1, \pm 3$ and $\pm 5\, cm$.

The locations of the pressure tabs on the wind tunnel walls have been schematically shown in figure 2. Port 3 is located at the bottom of the test section wall and ports 4, 5 and 6 are on the side wall.

Results and Discussion

Figure 3 shows the pressure time histories for the port numbers 3, 5 and 6 located on the bottom and side wall of the wind tunnel when operating at M=0.4 and the model was oscillating in plunge motion at a frequency of 6.00 Hz and at an amplitude of ±5 cm.

According to this figure, the magnitude of the wall pressure at port 5 is less than the other two ports while its variations are very similar. This is due to the effects of wing tip vortices which have been convected laterally to the side wall at port 5. This has been further illustrated in Fig. 3(b) where the pressure power spectrum at ports 3, 5 and 6 has been shown in the frequency domain using discrete Fourier transform. As can be seen, the pressure power spectrums for the three ports are nearly the same and the shift in the magnitude of the wall pressure at port 5 did not influence the oscillatory modes of the fluctuations at this port on the side wall. Thus, it can be deduced that the subsonic tip vortices can affect the magnitude of side wall pressure but will not change the frequency spectrum.

For the supersonic regime, figure 4(a) exhibits a completely different behavior. The wall pressures at ports 3 and 5 are nearly constant with time but port 6, which is located downstream of the model in the wake region has considerable fluctuations, as seen from figure 4. During the model plunging motion, the shock system emanating from the nose, LEX, wing tips, empennage, etc. affects the wall pressure at this point. In fact, shock wave is the main reason for the different behavior of wall pressure at subsonic and supersonic regimes as observed in Figures 3(a) and 4(a).

These shock waves impart the oscillatory motion in the pressure time history at port 6 behind the model as seen in figure 4(a). However for port number 3 ahead of the model, no fluctuations are imparted in contrast to figure 3(a) where in the subsonic case, the fluctuations affect the upstream ports too.

For the port number 5, no fluctuation is seen in the pressure time history. This is probably due to the fact that the conical shock wave forming in the nose of the model impinges the side walls at a point located aft of the port number 5 and this port is unaffected by the pressure fluctuations caused by the unsteady shock waves. When the conical shock impinges on the side wall, it disturbs the upstream boundary layer on the wall, hence affecting the static pressure.

The pressure power spectrum shown in Fig. 4(b) for the supersonic case indicates that there are several oscillatory modes in the pressure power spectrum at port 6 while there is almost no significant jump in the frequency spectrum for the other ports. It is believed that the oscillations observed in the pressure time history of port 6 is due to the shock wave fluctuations explained earlier.

Figure 5 shows the effects of plunging amplitude of the model on time variations of wall pressure fluctuations at port 5 for two different mean angles of attacks; zero and 12 degrees. From this figure, it is clearly seen that for f= 2.77 Hz and M=1.5, plunging amplitude of the model does not change the pressure behavior significantly. Furthermore, for both cases; $\alpha=0$ and 12 degrees, the fluctuations for $H_A=\pm5$ cm are more than those for $H_A=\pm1$ cm but the mean values are the same.

However for the mean angle of attack of 12 degrees, Fig. 5(b), a significant jump in the pressure time history is observed, which is probably caused by the strong shock wave formed on the model lower surface.

In Figure 6, effects of model plunging amplitude in both subsonic and supersonic regimes on wall pressure behavior at port 6 located downstream of the model in the wake region are studied. In subsonic regime, the velocity induced by wing leading edge and also by the LEX vortices together with the wake disturbances are the main contributors to the wall pressure in this location. In supersonic regime, the aforementioned induced velocity effects are obviously replaced by the strong shock system emanating from the model components, i.e. nose, wing, LEX, etc.

From this figure, it is evident that for both cases; M=0.4 and 1.5, as the plunging amplitude increases, the magnitude of the wall pressure changes. For the subsonic case, as the model amplitude increases, the absolute value of the wall pressure increases, while for the supersonic case, the trend is different, Fig. 6(c). In the subsonic regime, the fluctuations observed in the pressure time history at port 6 is mainly due to the momentum loss through the boundary layer developed on the model. For $H_A= \pm1$ cm, the boundary layer is thin, while for $H_A=\pm5$ cm, the dissipative character of the boundary layer becomes more pronounced, thus increasing the wall pressure fluctuations. At M=1.5, however, the momentum loss in the wake region increases due to the shock-boundary layer interactions at the wall. As the plunging amplitude increases, the shock strength increases too, hence its effects on the tunnel wall boundary layer becomes more significant.

This phenomenon is clearly observed in Fig. 6(c), were by increasing the plunging amplitude, the pressure fluctuations increases and its power spectrum in Fig. 6(d) indicates several natural frequencies, while for $H_A=\pm1$ cm, the pressure power spectrum does not exhibit any significant jump, Fig. 6(b).

Figure 7 shows the effects of mean angle of attack on the wall pressure fluctuations at port number 6 in subsonic and supersonic regimes. For M=0.4, the wall pressure increases with increasing mean angle of attack and the pressure oscillations at $\alpha=12^{\circ}$ is due to the oscillatory wake effects. For M=1.5, it can be observed that the pressure fluctuations have been clearly reduced. The increase in wall pressure at point $\alpha=12^{\circ}$ illustrates the contribution of the aforementioned shock system originating from the model components.

Conclusion

An experimental investigation was undertaken to study the effect of model oscillation on wind tunnel wall pressure fluctuation in both subsonic and supersonic flow regimes. According to the results, the pressure time history has a strong dependence on unsteady flow field around an oscillating model. When a model oscillates inside a wind tunnel test section, it can communicate with the test section walls via the oscillatory air around it. The most important phenomena in determining the unsteady wall pressure behavior are the wing and LEX leading edge vortices, the velocity induced by the wing tip vortices, the effects of wake region and finally the shock waves originating at different components of the model in supersonic flow.

References

[1] Beyer, M. E., *"Unsteady Wind Tunnel Interference in Aircraft Dynamic Experiments,"* Journal of Aircraft, Vol.29 No. 6, Nov.-Dec. 1992.

[2] Davari, A. R. and Soltani, M. R. *"On Wind Tunnel Wall Pressure Fluctuation during an Unsteady Test of a Fighter Model,"* AIAA Paper 2005-4745.

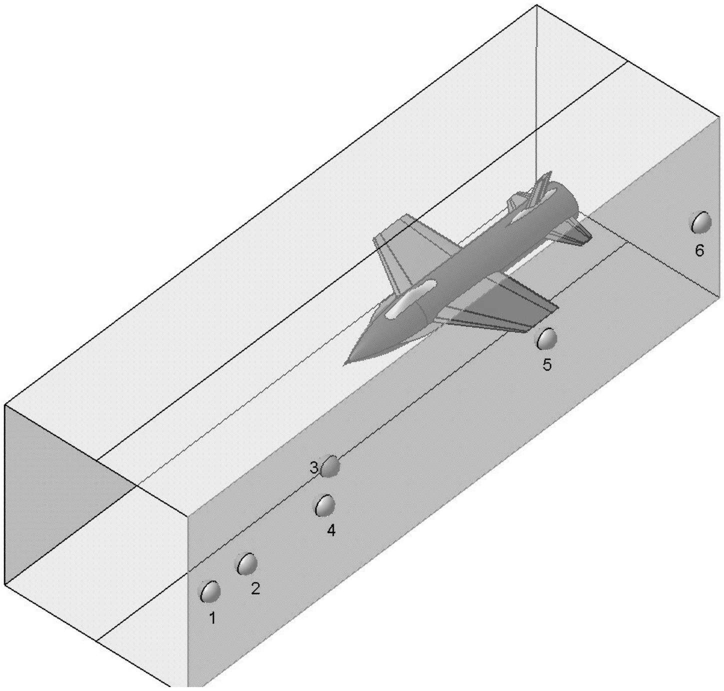
[3] Beyers, M. E., *"SDM Pitch and Yaw Stability Derivatives,"* AIAA Paper 85-1827, 1985.

[4] Schmidt, E., *"Standard Dynamic Model Experiments with the DFVLR/AVA Transonic Derivative Balance."* AGARD CP-386, May 1985.

[5] Jansson, T. and Torngren, L., *"New Dynamic Testing Techniques and Related Resultant FFA,"* AGARD CP-386 May 1985.

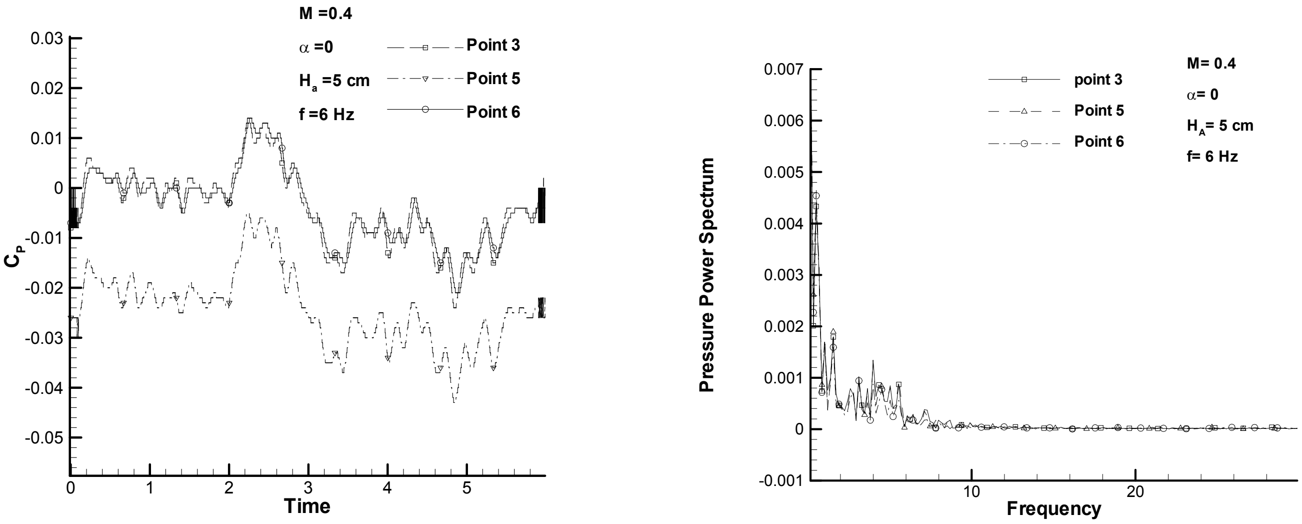
[6] Davari, A. R. and Soltani, M. R., *"Force and Moment Measurements on a Fighter Model in Heaving Motion,"* AIAA Paper 2005-0238.

Figure 1- The Standard Dynamics Model (SDM) used in the present experiments



Pressure Tabs on wall	Distance from the Nose of Model (cm)
1	73.05
2	62.75
3(at bottom of test section)	17.7
4	39.25
5	16.5
6	38.2

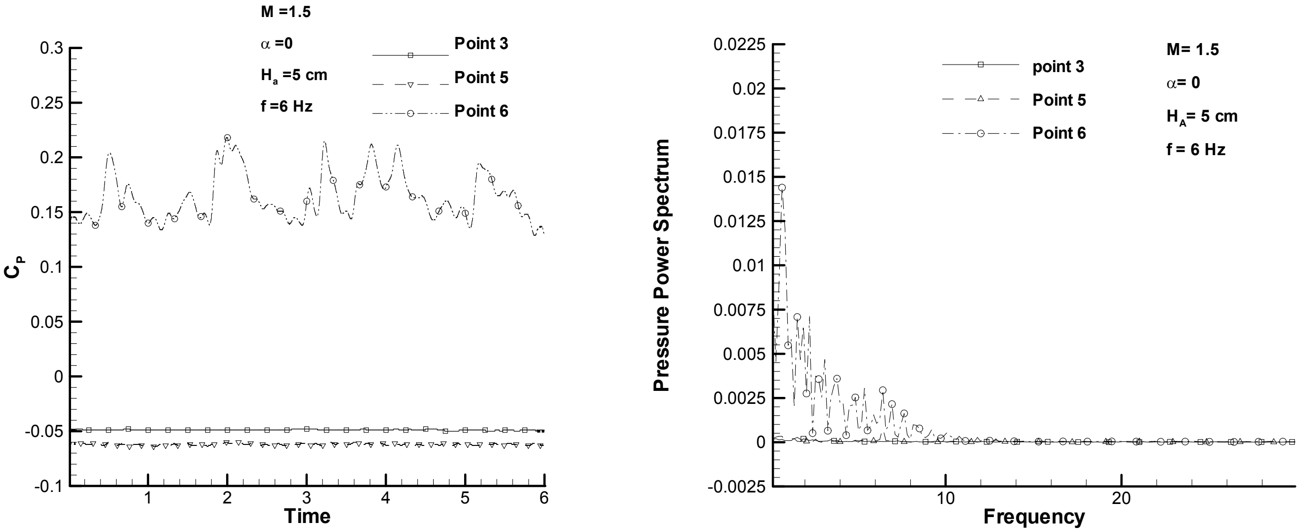
Figure 2- Schematic view of the pressure tab locations on wind tunnel walls



(a) Pressure time history

(b) Pressure power spectrum

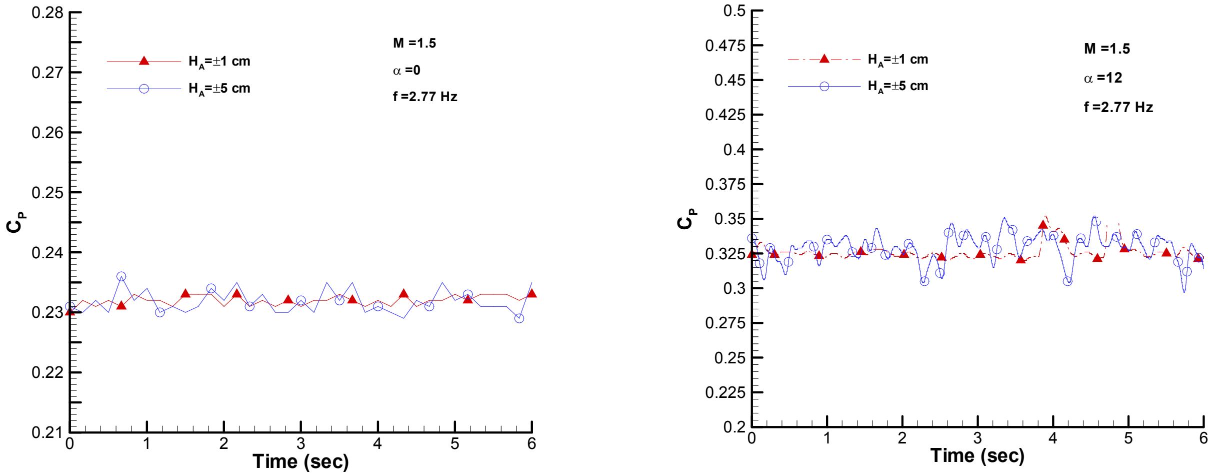
Figure 3-Pressure fluctuation at different ports on wind tunnel wall, M=0.4



(a) Pressure time history

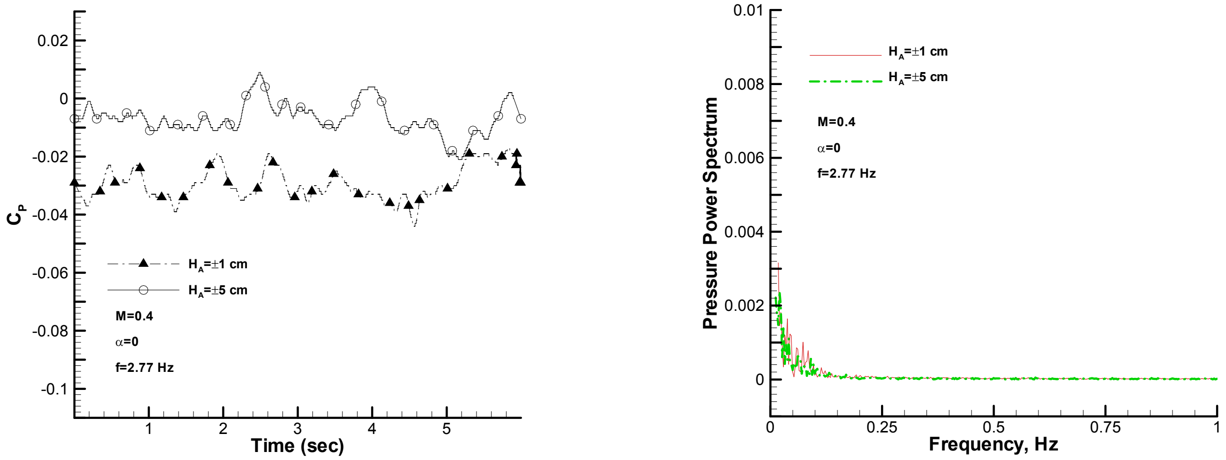
(b) Pressure power spectrum

Figure 4-Pressure fluctuation at different ports on wind tunnel wall, M=1.5

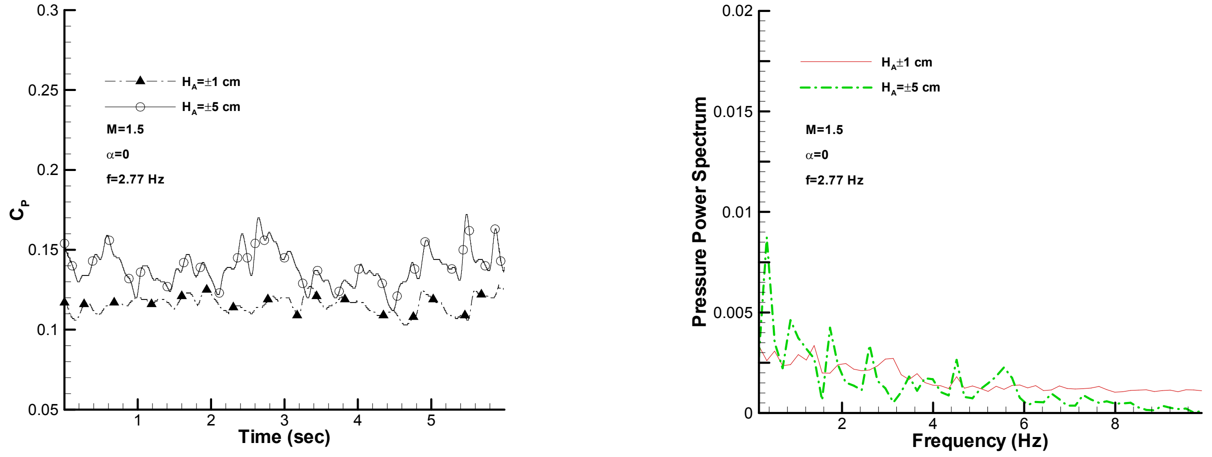


(a) $\alpha=0^{o}$ b) $\alpha=12^{o}$

Figure 5-Effects of model plunging amplitude on pressure fluctuation at Port 5.

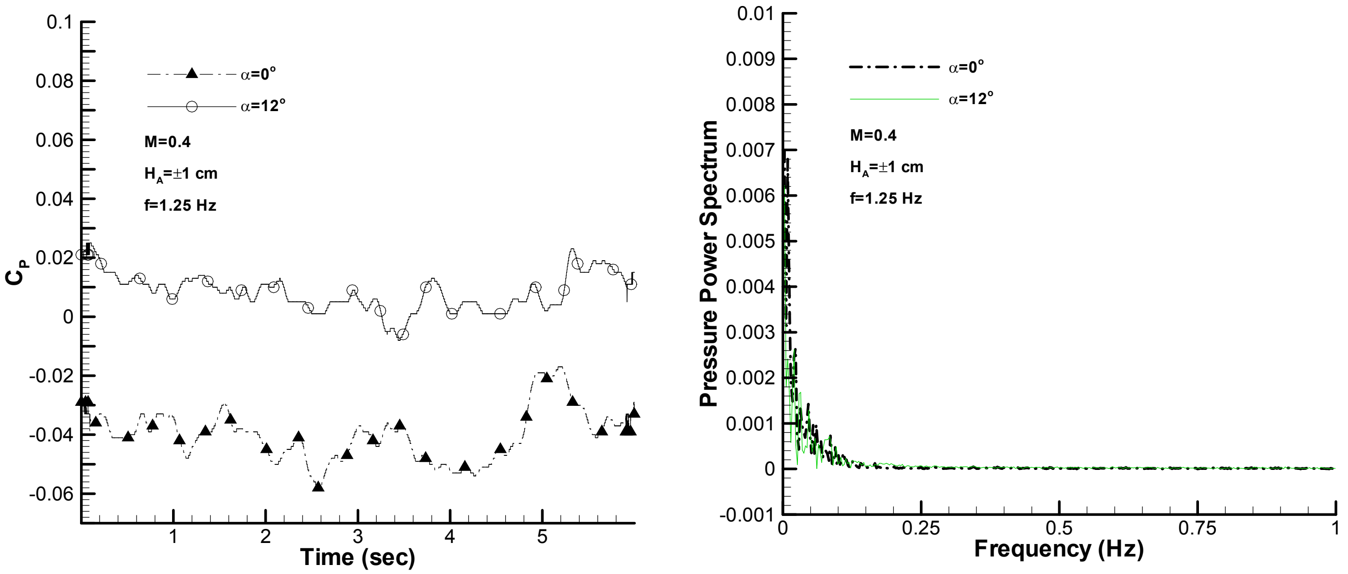


(a) Pressure time history at M=0.4 (b) Pressure power spectrum at M=0.4



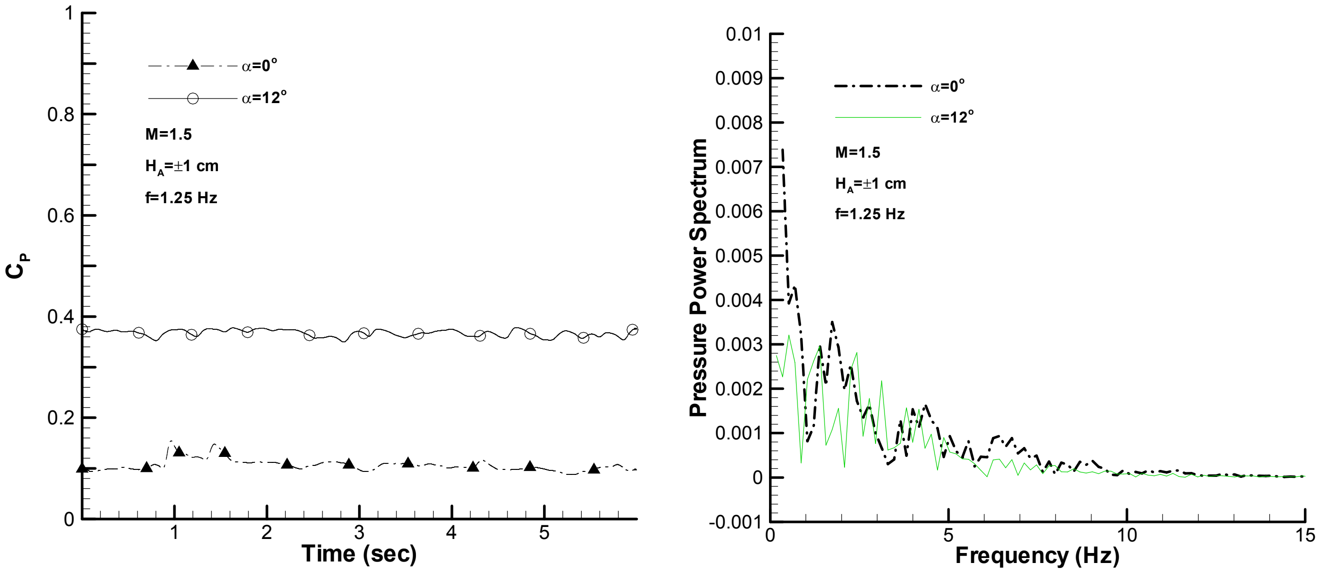
(c) Pressure time history at M=1.5 (d) Pressure power spectrum at M=1.5

Figure 6-Effects of model plunging amplitude on pressure fluctuation at Port 6.



(a) Pressure time history at M=0.4

(b) Pressure power spectrum at M=0.4



(c) Pressure time history at M=1.5

(d) Pressure power spectrum at M=1.5

Figure 7- Effects of mean angle of attack on pressure fluctuation at port 6.