Active Control of the Flow-Induced Unsteady Loads of a Pod Wake

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ABSTRACT

Pods and externally carried stores can generate unsteady flows in their wakes with high acoustic loads capable of damaging aircraft structure. Active flow control technology has the potential to modify unsteady shedding in the wake of the pod, thereby reducing acoustic loads. In this work, an active flow control system was developed and tested on a generic pod configuration. Using open loop flow control actuation, the frequency of the acoustic loads can be modified and their amplitude reduced. In addition, wake location can also be manipulated by the active control system. A larger scale wind tunnel test on an eighth inch diameter pod with synthetic jet flow control actuators was conducted with the flow field being defined with and without the actuators operating. It was tested up to a Mach number of 0.5. Synthetic jet exit velocities in excess of 800 feet per second were achieved. As was the case for previous smaller scale pod wake control, the frequency of shedding was controlled, the location of the wake also was controlled, and the amplitude of the pressure fluctuations was reduced. Data were obtained for various actuator frequencies, amplitudes, and ejection locations on the aft end of the pod.

1.0 MODEL AND TEST SETUP

The testing configuration & half-scale model were based on a simplification of the LANTIRN pod attached to the undercarriage of an aircraft. This configuration was inverted, as shown in Figure 1, for ease of mounting in the Subsonic Aerodynamic Research Laboratory (SARL) located at Wright Patterson Air Force Base, Ohio. The pod model was thirty inches long with an eight-inch diameter hollow cylindrical body, spherical nose, and blunt end. The blunt end was a cylindrical end cap that contained the internal instrumentation. The model instrumentation was a state-of-the-art synthetic jet flow actuator whose orifices were on the cylindrical surface, near the blunt edge, as shown in Figure 2. A second model configuration was also examined, with a scoop attached to the pod, as shown in Figure 3. The pod model was mounted to a 3.5-inch high symmetrical, airfoil shaped pylon. This configuration was bolted to splitter plates, simulating the aircraft body and allowed for rake attachment. The pod model was installed at an orientation such that the centerline of the model was parallel with the flow. The pod wake test did not utilize the standard crescent-shaped sting of the SARL. Rather, as shown Figure 4, a pedestal was installed in the tunnel to serve as a mount for the entire testing configuration. Two auxiliary support legs on the rear part of the splitter plate provided additional support.

Shaw, L.L.; Smith, B.R.; Saddoughi, S. (2005) Active Control of the Flow-Induced Unsteady Loads of a Pod Wake. In *Flow Induced Unsteady Loads and the Impact on Military Applications* (pp. 8-1 – 8-14). Meeting Proceedings RTO-MP-AVT-123, Paper 8. Neuilly-sur-Seine, France: RTO. Available from: http://www.rto.nato.int/abstracts.aps.

The larger of the two splitter plates was machined to 85 inches long and 36 inches wide. The smaller, oblong splitter plate was utilized from a previous test and measured 47½ inches long and $23^{11}/_{16}$ inches wide.

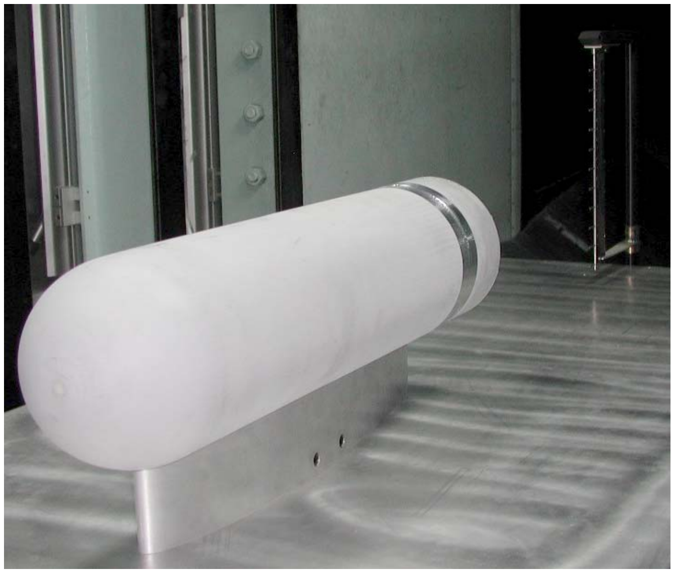

Figure 1. Pod Model Installed in Tunnel

Figure 2. Jet Orifices on Pod

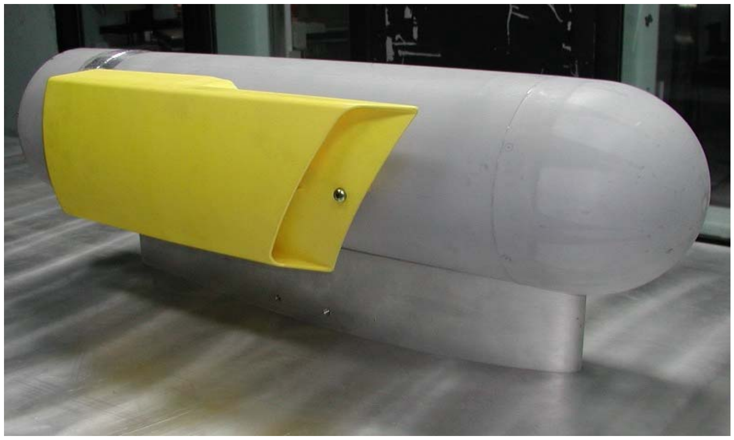

Figure 3. Model Mounted With Scoop

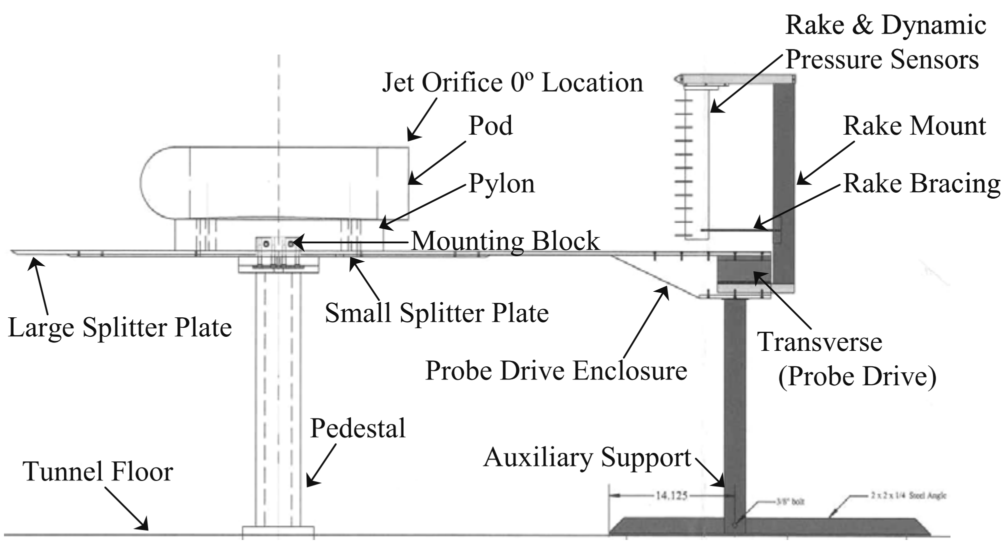

Figure 4. Testing Configuration as Installed in SARL

A dynamic pressure rake was placed aft of the model on a mechanical transverse, shown in Figure 5, to measure the wake total and dynamic pressures at various points within the probing area, shown in Figure 6. The rake mounting was designed so as to place the tips of the rake pressure probes approximately 30.4 inches, or 3.8 times the pod diameter, aft of the end of the model. A second rake configuration was used, placing the rake an additional 10.75 inches aft of the pod by use of an extension plate, as shown in right hand image of Figure 7.

Figure 5. Aft View of Transverse Used for Pressure Rake

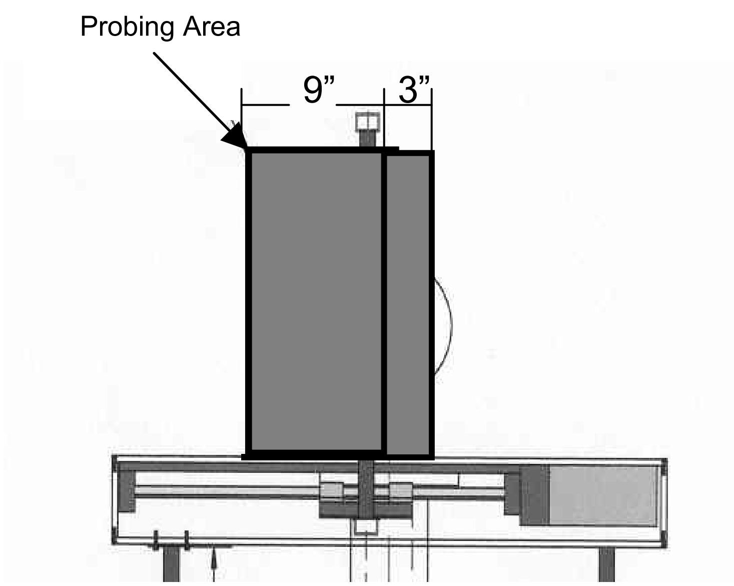

Figure 6. Rake Probing Area

Figure 7. Comparison of Pressure Rake at Nominal & Extended Positions

Two GE designed (proprietary) synthetic jets, known as DBSJ, were used in this experiment. Each DBSJ was connected to three holes, each hole having an exit diameter of 3mm. The actuators were run at 850Hz and bench top hot wire velocity measurements conducted at the exit of each hole showed peak values of the order of 250 m/s. A sample of these results is shown below in Figure 8. Different sizes of the DBSJ have been used successfully in a variety of applications, e.g Boundary-layer separation control & LED cooling.

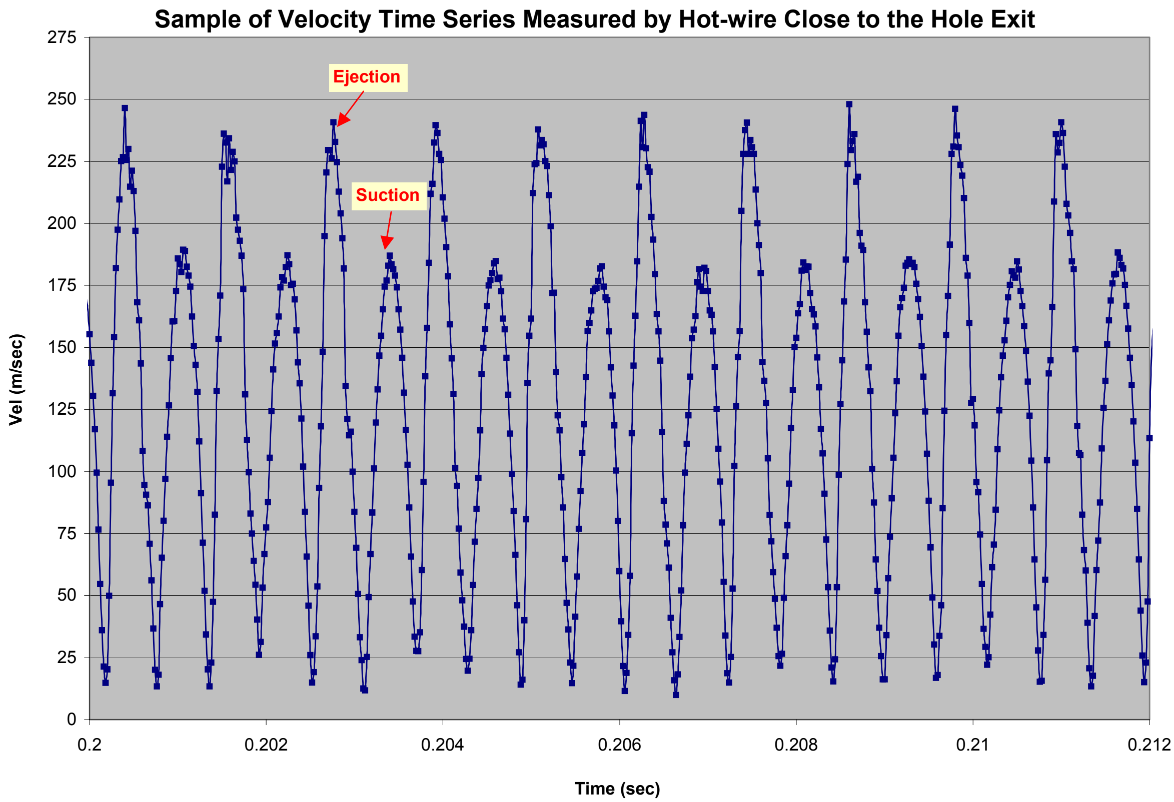

Figure 8. Hot Wire Results for the Synthetic Jets

2.0 TEST RESULTS

Dynamic pressure spectra were recorded for all of the transducers at all of the lateral positions shown in Figure 6. The probe was positioned at 1.5 inch increments over the region shown. A spectrum from one of the most affected positions is presented in Figure 9 for the baseline with the synthetic jet off and the other one for the synthetic jet on. The synthetic jet actuator was operating at 850 Hertz and the air speed was Mach 0.5. The 850 Hertz actuation tone is clearly visible in the spectra as well as the suppression at the shedding frequency near 220 Hertz. There is a 10 dB reduction at the shedding frequency but the shedding frequency is reduced somewhat when the actuator is on. The broadband levels are also reduced 3-5 dB. This amount of suppression is not achieved at all locations since the shedding turbulence is being moved by the flow control actuators. Thus, one must look at the total area to characterize the net suppression from the control actuators.

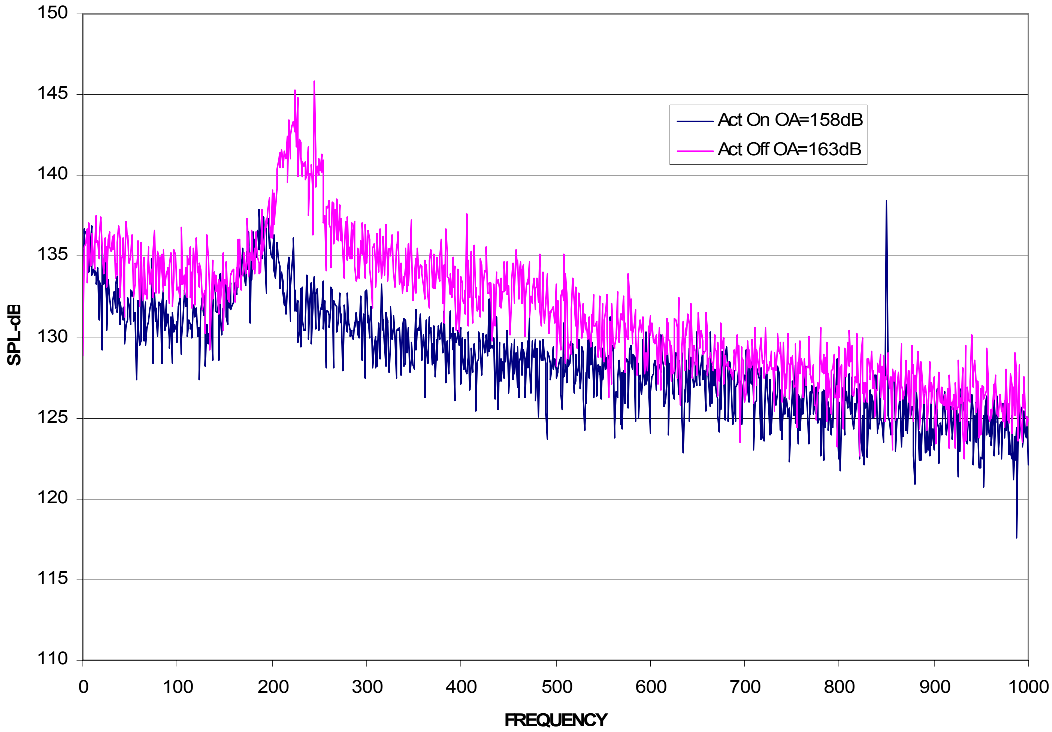

Figure 9. Typical Spectra Showing Suppression for Mach 0.5

To asses the affect on the levels over the entire area, contour plots of the OASPL at the traverse plane were obtained. Figure 10 shows the pressure contours for two configurations, with and without the scoop on, for both cases of actuator on and off. The top two show that the region of highest dynamic pressure levels is greatly reduced and not just moved while the bottom two show that installing the scoop negates this suppression.

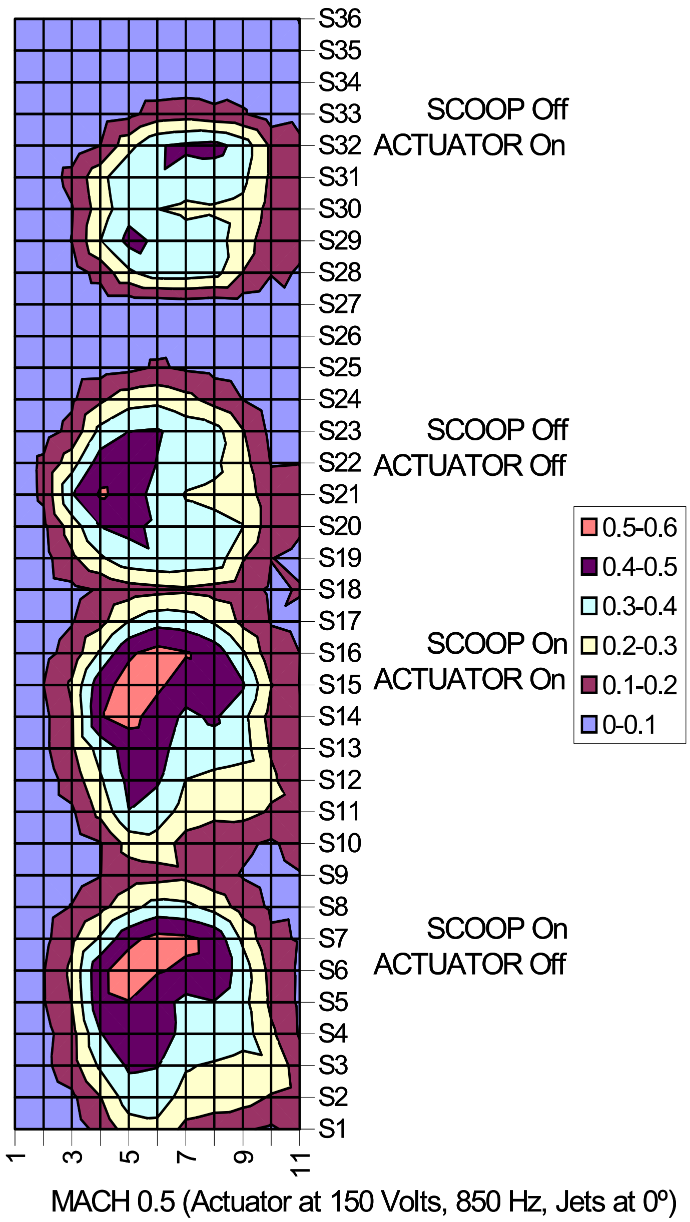

Figure 10. Overall SPL Equal Level Contours With/Without Air Scoop

The location of the synthetic jets had an impact on the effectiveness of controlling the wake. They were tested at four locations to determine the optimum location. Figure 11 presents the results for the four positions and it is clearly seen that the zero degree position, opposite the splitter plate, is the optimum position. It is believed that being in close proximity of the splitter plate strongly influences the robustness of the actuators. As noted in Figure 10, just adding an air scoop even cancels this performance. It remains to be seen if another position of the jets with the air scoop on will be more effective. Since the full-scale pod will be flight tested with the scoop on, a full-scale wind tunnel test is scheduled to evaluate the jet location sensitivity with and without the scoop installed.

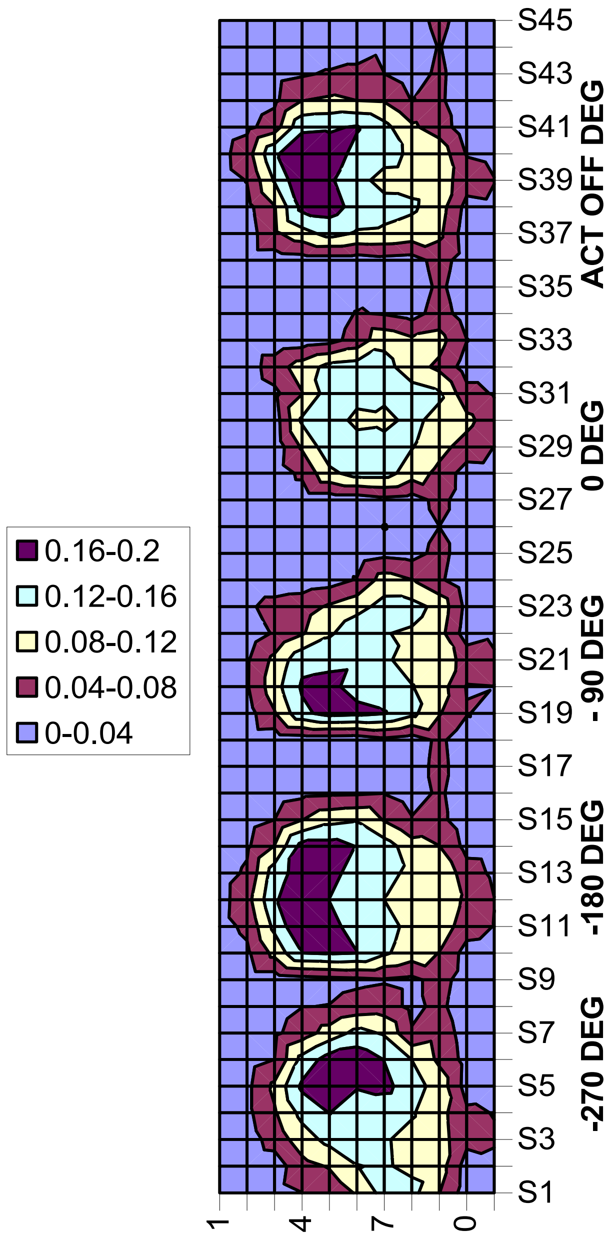

Figure 11. Overall SPL Equal Level Contours for the Four Jet Positions of 0, 90, 180, and 270 Degrees for Mach Number 0.3, 850 Hertz, 150 Volts.

The full-scale application of the synthetic jets will be to control the dynamic loads on the ventral fins on an F-16 aircraft. The ventral fins are located further aft of the pod then the location tested in the current test. However, a second rake position located an additional pod diameter aft of the forward position was tested. This position is shown in Figure 7. It was anticipated the region of unsteadiness would grow in size at a location further downstream and possibly the effectiveness of the flow control actuators may decrease. A comparison of the effectiveness of the synthetic jets at the aft location is shown Figure 12. It is very evident that the actuators are still effective at that position

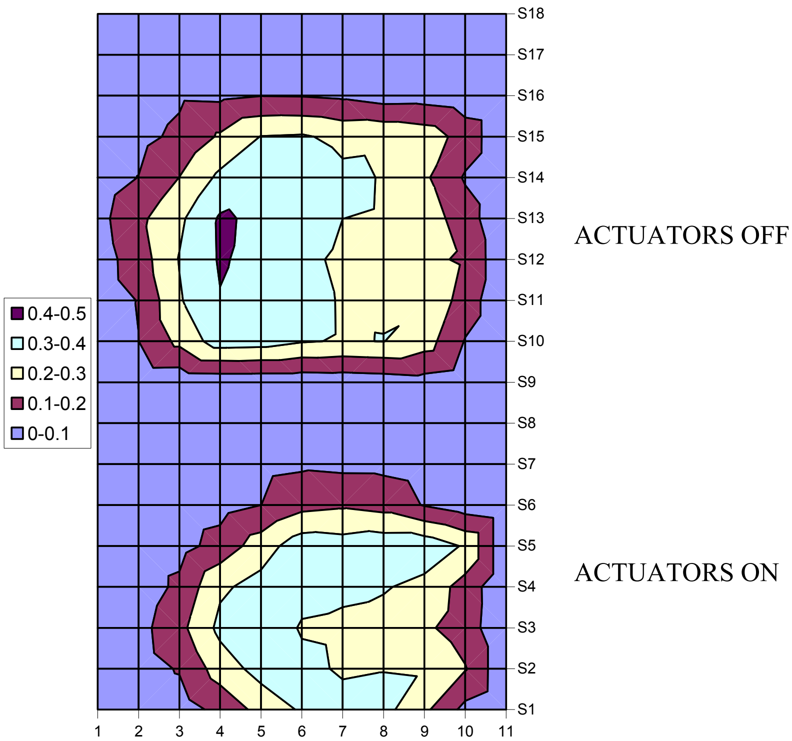

Figure 12. Comparison of Jets On/Off at Aft Rake Location for Mach Number 0.5, Synthetic Jets at 0 Degrees, and No Scoop

It is know that the excitation frequency affects the effectiveness of the synthetic jets in controlling the down stream wake of the pod. Figure 13 shows this effect for frequencies between 700 and 850 Hertz. As the frequency is decreased from the optimized 850 Hertz, the effectiveness also decreases. The region of higher fluctuating pressures continues to expand as the frequency decreases. It was also observed that as the frequency is increased above the optimum design frequency of 850 Hertz, the region of higher fluctuating pressures again increases. The reason for this trend cannot be attributed to frequency alone since the output of the actuators diminishes when it is driven at any frequency other than the optimized design frequency.

3.0 CONCLUSIONS

A test was conducted to evaluate the effectiveness of synthetic jet active flow control actuators in suppressing the wake from a pod. It has been demonstrated that the location of the down-stream wake can be controlled and the intensity of the fluctuating pressures in the wake can be suppressed with a synthetic jet at the trailing edge of the pod. The frequency of shedding can also be controlled. Effective control was demonstrated up to a speed of Mach 0.5. However, it was shown that effective flow control was significantly affected by the location of the actuators and rather or not an air scoop was installed on the side of the pod. The most effective flow control was for the jets located at the zero degree position. The air scoop essentially cancelled all flow control effectiveness.

4.0 REFERENCES

1. B. Maines, B. Smith, A. Cunningham, J. Jordan, and L. Shaw, "Establishing Bluff Pod Wake Characteristics for Flow Control," AIAA-00-2555, June, 2000.

2. Smith, B. R.; Cunningham, A. M. Jr.; Shaw, L. L., "Active Control of a Pod Wake," AIAA 2002-3067, St. Louis MS, 24-27 June 2002

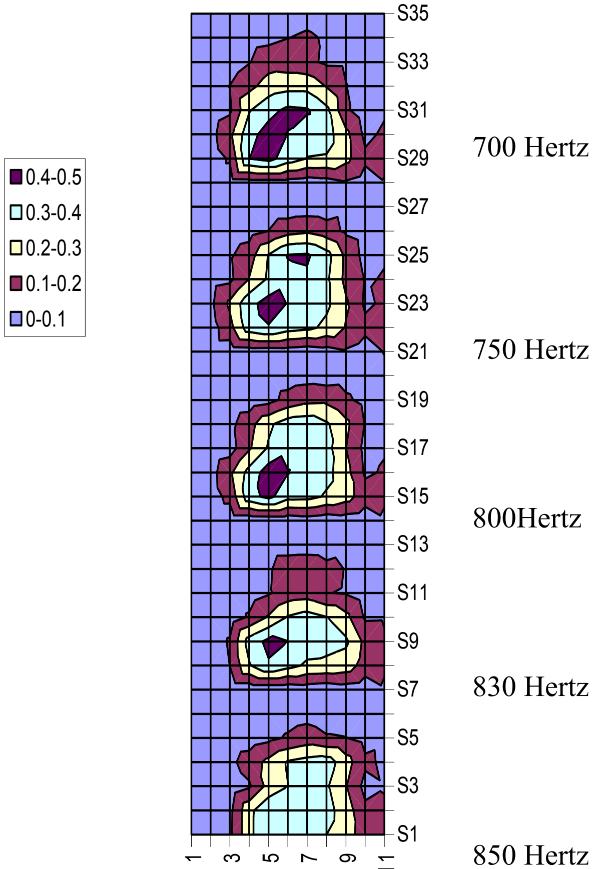

Figure 13 Comparison of Actuator Frequencies 850, 830, 800, 750, 700 Hertz for Mach Number 0.5 and 150 Volts Excitation

SYMPOSIA DISCUSSION

REFERENCE AND/OR TITLE OF THE PAPER: 8

DISCUSSOR'S NAME: D. Pitt
AUTHOR'S NAME: L. Shaw

QUESTION:
You showed loss of effectiveness of the jets with the installation of the air scope on the pod. Do you think that a stronger jet or a jet operating at a different frequency would improve matters?

AUTHOR'S REPLY:
I think we need a more powerful jet. We are testing the pod and scoop in the Lockheed tunnel with positive mass flow instead of synthetic jets.

DISCUSSOR'S NAME: A. Cenko
AUTHOR'S NAME: L. Shaw

QUESTION:
Did you use CFD to predict the effects of the synthetic jets?

AUTHOR'S REPLY:
A limited amount of CFD analysis was used in the small scale study leading to the mid-scale tests.

DISCUSSOR'S NAME: S. Zan
AUTHOR'S NAME: L. Shaw

QUESTION:
Do the jets blow normal to the free stream or into the base? What drove the choice of 850 Hz for the jet frequency when the flow is excited at the 150 to 200 Hz?

AUTHOR'S REPLY:
The jets blow normal to the flow. 850 hertz was chosen because of limitations of the synthetic jets. Also, past research has shown that an excitation frequency of 3 times the shedding frequency is most effective.

DISCUSSOR'S NAME: C. Petiau
AUTHOR'S NAME: L. Shaw

QUESTION:
Does your system play at the good frequency for the structure response? It seems it is not reduced at 200 hertz.

AUTHOR'S REPLY:
The actuator has an optimized design frequency but can be operated at other frequencies with reduced output. Flow control can be optimized with the correct actuator frequency. Structural response will be most affected if the dynamic loads are reduced at the structural resonance frequency.

DISCUSSOR'S NAME: P. Erbland
AUTHOR'S NAME: L. Shaw

QUESTION:
Was Lockheed able to predict the loss in effectiveness of the synthetic jet when the inlet was added? Were geometric modifications considered as a fix to the wake shedding problem (boat tail designs)?

AUTHOR'S REPLY:
Lockheed did not attempt to predict the effect of the air scoop. Geometric modifications were investigated in the earlier small scale studies.