Active Flow Control for High-Speed Weapon Release from a Bay

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ABSTRACT

In recent years work at the Air Force Research Laboratory Air Vehicles Directorate has focused on pursuing active flow control (AFC) devices for achieving better weapons bay control with regard to acoustic loads reduction and weapon separation characteristics than the control offered by passive devices (spoilers). This paper describes the "Long Range Strike Aero Experiment" which was a systematic study that pursued AFC actuators integrated in a 10%-scale weapons bay model representative of a Long Range Strike Aircraft configuration. Results are presented from acoustic testing, grid testing with force-balance and pressure instrumented weapon models, and drop testing. Based on these measurements, conclusions are drawn with regard to the physical processes that characterize high-speed weapon release from a bay without and with active flow control.

1.0 INTRODUCTION

The Long Range Strike Aero Experiment (LRSAe) was a program conducted from April 2002 through September 2003 by the Boeing Phantom Works under contract to the Air Force Research Laboratory (AFRL), Contract F33615-00-D-3052, D.O. 23. The objective of this work was to characterize the flow field environment and to identify the requirements of acoustic and flow enhancement devices for the safe release of weapons from a bay in the flight-speed range between Mach 2 and 4. The technology developed under this program is intended to be ultimately transitioned to the Long Range Strike Aircraft (LRSA).

Traditional weapon dispense from bays uses spoilers for modifying the bay shear layer to reduce acoustic levels within the bay and enhance characteristics of weapon departure from the bay. However, spoilers have the disadvantage of not having acceptable performance over a wide range of flight conditions, so attention at the Air Force Research Laboratory Air Vehicles Directorate has focused in recent years on pursuing active flow control devices for achieving more robust weapons bay control than that offered by passive devices. The need for enhanced weapons bay flow control is more crucial for high speed weapon release (Mach 2 to 4), and the LRSAe program has addressed this need by performing a series of experiments using advanced flow control actuators and measurement techniques to provide the needed technology.

Paper presented at the RTO AVT Symposium on "Functional and Mechanical Integration of Weapons and Land and Air Vehicles", held in Williamsburg, VA, USA, 7-9 June 2004, and published in RTO-MP-AVT-108.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **01 JUN 2004**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Active Flow Control for High-Speed Weapon Release from a Bay**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **The Boeing Company St. Louis, MO 63166**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM201999., The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**24**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

The Boeing performance on the Long Range Strike Aero Experiment drew heavily on Government furnished property made available through a DARPA program “High-Frequency Excitation Active Flow Control for Supersonic Weapons Release” (HIFEX). The HIFEX work considered simply shear layer control in a weapons bay at Mach 2.5. The LRSAe program expanded the scope of flow control for high-speed weapon release by looking at control of the weapon after it departs the bay shear layer. Moreover, the LRSAe program has tested the HIFEX shear layer control technology at higher Mach numbers (3.2 to 3.7) and provided weapon drop tests for the various HIFEX active flow control actuators.

In addition to being complementary to HIFEX, the Long Range Strike Aero Experiment was also a companion program to the AFRL “Long Range Strike Weaponization” program (LRSW). The goal of the latter ongoing program is to investigate high-speed weapon dispense techniques other than those using traditional bays (such as upward and aft ejection) and then to test the most promising concepts. The active flow control work supported under LRSAe is a concept also pursued by the LRSW work, and the experimental data base provided by LRSAe offers extensive measurements that can be used to benchmark the computational fluid dynamics codes that will be used in LRSW studies.

2.0 WEAPONS BAY MODEL AND FLOW CONTROL ACTUATORS

A 10%-scale weapons bay model (based on a representative Long Range Strike configuration) and a variety of flow control actuators were used in LRSAe testing as Government-furnished hardware from the HIFEX program. The HIFEX weapons bay model has a length of 20 inches and a width of 4 inches. In its full depth configuration it is 4 inches deep; however, an insert can be placed in the bay, which reduces the depth to two inches. The bay can be instrumented with three dynamic pressure transducers along the ceiling. five on the rear wall, and six on the upstream wall and with static pressure taps as well. Installation of the weapons bay in the Boeing Polysonic Wind Tunnel (St. Louis) is illustrated in Fig. 1.

Through its modular design, the HIFEX weapons bay can be fitted with a variety of actuators. Those made available to the LRSAe program from HIFEX work are the powered resonance tube, a jet screen, and supersonic microjets. Each of these control devices offers unique attributes for high-speed weapon release and was the subject of considerable testing in the LRSAe program.

The powered resonance tube device was developed by Boeing and the Illinois Institute of Technology [1] and has been successfully used in a variety of tests for noise suppression of free and impinging jets and for weapons bay acoustic suppression at transonic conditions. The device is based on the principle of high-frequency excitation, which departs from the conventional philosophy of exciting the shear layer only within the range of frequencies where large-scale structures are amplified. The rationale in the conventional excitation approach is to energize the large structures that in turn enhance mixing. In contrast, when frequencies that are an order of magnitude higher than the large-scale range are used, the dissipative scales are excited, which in turn can bring about large changes in the development of the large scales and the mean flow [2]. An important consequence of the high-frequency excitation is that the direct addition of dissipative scales apparently accelerates the dynamics of energy cascade across a broad range of wave numbers. In simulations involving resonant acoustics, low-frequency excitation reduces the amplitude of resonant tones by detuning the feedback loop. In contrast, high-frequency excitation destroys the organization of the initial shear layer that is necessary to sustain flow-induced resonance.

The powered resonance tube (PRT) is a simple device with no moving parts for producing acoustic levels in excess of 160 dB in a frequency range from 500 to 15,000 Hz. The device is based on a pressurized air stream from a nozzle directed into a tube with the downstream end closed off. This creates the flow resonance and the expulsion of fluid from the tube, which is injected into the shear layer to be controlled. Various parametric studies have been performed on the resonance tube to determine the optimum configuration, and it was found that a bank of powered resonance tubes (PRTB) is the most effective device. Further optimization studies were performed to look the effects of varying the diameter of the tubes, the spacing between the tubes, and the operating pressure of the devices. Figure 2 illustrates a powered resonance tube bank (8 tubes) installed in the HIFEX weapons bay model.

The jet screen is a flow control device suggested by AFRL for use in the LRSAe program. It injects pressurized air normal to the flow surface though a narrow slit upstream of the weapons bay leading edge and extending the width of the bay. The slit has a width of either 0.03 inches or 0.07 inches. The advantage of this method is that in addition to providing shear layer control, it can also provide shock control. That is, a shock can be generated upstream of the bay which extends near the weapon and turns the flow to correct the weapon attitude and prevent the weapon from striking the parent aircraft. The jet screen installed in the HIFEX weapons bay model is illustrated in Fig. 3.

The final HIFEX actuator is the supersonic microjet, a device developed at Florida A&M/Florida State University and described by [3]. Small (0.016-inch diameter) jets are embedded at the leading edge of the bay, either in the plane of the bay opening or in the front face of the bay. The inclination of the jets with regard to the surface normal was also varied, with angles of 90 degrees or 45 degrees relative to the flow. The basis for the effectiveness of the microjets is that they destroy the spanwise coherence of the instabilities generated in an open weapons bay. Figure 4 illustrates the installation of the microjets in the HIFEX weapons bay model.

3.0 LONG RANGE STRIKE AERO EXPERIMENT TESTING

The Long Range Strike Aero Experiment consisted of weapons bay acoustic testing, shock generation studies, force-and-moment grid testing with a 10%-scale MK-82 JDAM model, and MK-82 JDAM weapon drop tests. Free stream Mach numbers ranged between 2 and 3. As part of this testing, particle-image-velocimetry and high-speed video imaging systems were used to acquire data for better interpretation of the weapon release characteristics. All tests were conducted in the Boeing Polysonic Wind Tunnel (PSWT) in St. Louis, which has a 4 ft X 4 ft test section with a Mach number range from 0.3 to 5.05 and a Reynolds number range of 1 to 48 million per foot.

3.1 Acoustic tests

Acoustic testing in the LRSAe program was the first opportunity to test the active flow control actuators over a range of Mach numbers. Although the testing was directed to evaluating the capability of the actuators to reduce the sound pressure levels in the bay, it was also felt that reducing the flow unsteadiness would also have a beneficial effect on achieving effective weapon release characteristics as well. Therefore, the acoustic testing served as a screening of the actuators prior to the subsequent grid testing with a sting-mounted weapon for quantifying the forces and moments on the weapon in proximity to the bay shear layer.

The first LRSAe acoustic entry took place in the Boeing PSWT in June and July of 2002. The weapons bay model was tested as a shallow bay, and for this configuration only the supersonic microjets were effective in reducing the bay tones. The second LRSAe acoustic entry took place in the Boeing PSWT in October and November of 2002. In this entry the weapons bay model was tested in the deep-bay configuration, which is more representative of the bay on the Boeing Long Range Strike Aircraft. Actuators chosen for testing were three optimized powered-resonance-tube (PRT) devices, one “splash” actuator (SA, a PRT with the receiving tubes closed), two microjet devices (MJ), and one jet-screen device (JS). Air to the flow control devices was applied at various pressures. Representative results obtained with two of these devices are shown in this section.

The effect of the powered resonance tube denoted PRT1 on the acoustic levels in the bay at Mach 2.5 is shown in Fig. 5 at various locations on the trailing edge and the ceiling of the bay. The plots show the baseline (no control) levels as well as the levels with control. At all locations the device dramatically reduces the levels of the tones in the deep bay.

The ability of the microjet configuration denoted MJ1 to control weapons bay acoustic levels at Mach 2.5 is shown in Fig. 6 at the various trailing edge and ceiling positions. The microjets provided substantial reduction in the sound pressure levels. Similar reductions were also obtained with the SA and JS devices. Figure 7 shows the baseline and controlled spectra in the bay for the MJ1 microjet configuration when the free stream Mach number was raised to 3.2. Again, the actuators were effective in reducing the tones, although the levels for the uncontrolled bay diminish with increasing Mach number.

3.2 Shock Generation Tests

One objective of the LRSAe program was to purse control shock actuators as a means of adjusting the attitude of a weapon after it departs the bay shear layer. The basis of this approach is to generate a shock wave in the vicinity of the weapon, which turns the flow and modifies the weapon pitching moment. To determine the potential and efficiency of this method, the June-July and October-November 2002 LRSAe wind tunnel entries had segments devoted to shock control. In the first entry particle-image velocimetry (PIV) was used to measure the flow in the vicinity of the control shocks, and in the second entry grid testing with a weapon model containing a force balance was used to measure the control authority of the generated shock waves.

In the June-July entry, both mechanical and fluidic means were evaluated for generating the control shock. The former used pins and wedges of varying heights that could be positioned on the weapons bay model upstream of the bay. However, these devices proved to be ineffective since the generated shock was cancelled by a downstream expansion fans. The fluidic approach used the jet screen located upstream of the bay opening and was found to be an effective shock generator.

To quantify the strength of the shock wave generated by the jet screen, PIV was used in the Boeing PSWT to measure the velocity field upstream and downstream of the shock. Although a Schlieren system will show the position of the shock in the flow, it, of course, does not provide velocity levels, as does PIV. To set up an operational PIV system in a blow-down wind tunnel is a challenging task, and the LRSAe application was the first time such measurements were made. The particle-image velocimetry was performed by Integrated Design Tools, a Boeing subcontractor on the program. A major challenge was providing seeding in the blow-down facility, and this was achieved using injectors in the plenum that put seeding particles (RUSCO fluid) into the test section. Adequate seeding was achieved in the flow external to the bay. However, reflections of the laser beam off the weapons bay model caused a glare problem that prevented velocity measurements close to the bay surface. The control actuator used to generate the shock waves for the PIV measurements was the jet screen device. Figure 8 shows the PIV image of the jet screen operating at 150 psig with a Mach 2.5 free stream.

Under the HIFEX program, attempts were made to measure the velocity distribution within the weapons bay model. This was first attempted using a transparent ceiling with the recording cameras located outside the wind tunnel. Sufficient optical access was not possible with this approach. Therefore, the weapons bay model was modified to embed four short-focal-length cameras adjacent to the bay with transparent side walls. Difficulties were obtained in properly seeding the bay flow, so the measurements were not successful. Nevertheless, the LRSAe and HIFEX programs have contributed to the development of the technology for making velocity measurements in weapons bays. Such measurements are an important diagnostic tool to have when evaluating the effects of active flow control on weapons integration.

3.3 Force/Moment Model Grid Tests

Force/moment grid testing was pursued in the LRSAe program in order to see how the flow control devices that were successful in acoustic suppression modified the pitching moment on a weapon as it departed the bay. To conduct this segment of the testing, a 10%-scale MK-82 JDAM model with an installed balance was designed and fabricated. The model was positioned on a traversing arm that could be moved below the weapons bay for measurements of forces and moments on the weapon model. This approach did not allow an extensive traverse of the weapon in the streamwise or lateral positions. Moreover, there was no capability for varying weapon pitch angle. Nevertheless, the present approach did give sufficient force and moment data to make judgments regarding the effectiveness of the active flow control actuators in modifying the weapon separation characteristics from the bay.

The traversing mechanism is mounted at three x-axis (streamwise) positions along the bay. The configuration is shown in Fig. 9. The forward bay position is denoted G1; the mid-bay position is denoted G2; and the aft bay position is denoted G3. There is a single y-axis (lateral) position. A range of ten inches of motion is allowed in the z-axis (normal) direction. Travel of the traversing sting starts at a weapon home position within the bay for tunnel start-up and shut-down. The arm can be moved to multiple points along its full range of travel without pausing for data acquisition. However, the capability also exists to pause the arm at discrete positions. The traversing arm is capable of moving through a predetermined range at varying velocities to allow continuous data acquisition for 70 to 120 seconds of tunnel run time. The 10%-scale weapon model used in the grid tests was a MK-82 JDAM, also shown in Fig. 9. The model consists of a four-piece body with a nose, nose adapter, centerbody, and aftbody. In order to gain greater insight into the flow characteristics affecting the weapon, a temporary Schlieren system was set up in the Boeing PSWT to visualize the shock system associated with the weapon, bay, and fluidic actuators.

Shear-layer-control actuators used in the grid testing were those that performed the best in the acoustic testing. These included a powered resonance tube, the splash actuator, the jet screen, and a microjet array. For comparison a spoiler was also fabricated for use as a passive device. Grid testing was done at Mach 2.5 and 3.2 for the weapon external to the bay shear layer.

Figure 10 provides a representative comparison of the actuators for the grid traverse at the mid-bay (G2) position and at the Mach 2.5 condition. The baseline case shows a nose-up moment on the weapon as it passes through the bay shear layer. With the microjet actuator array, this positive Cm value is sustained. With the PRT the pitching moment is near zero down to $z = 6$ cm, and a similar result was obtained with the SA. With the jet screen initially a near-zero Cm exists, but the pitching moment increases to 0.5 before going negative. Figure 11 shows the results obtained with the microjet and PRT combined with the jet screen. Both of these combinations indicate acceptable weapon release characteristics. The spoiler provided acceptable release characteristics from the G2 position but not from the G1 position. When the free stream Mach number is raised to 3.2, at the mid-bay traverse location the baseline results show a positive Cm on the weapon as it passes through the shear layer. As for the lower Mach number case, the microjet/jet-screen and PRT/jet-screen combination show acceptable pitching moment characteristics.

3.4 Drop Tests

The LRSAe grid tests provided useful insights into how the active flow control actuators affected the weapon separation characteristics as reflected by the weapon pitching moment. However, a more definitive measure of the benefits of flow control was desired, so drop tests were conducted in the Boeing PSWT in which MK-82 weapon models were dispensed from the bay. This testing took place over two entries, one in December 2002 and one in March 2003. The first entry focused on only release from the forward and mid-bay positions at Mach 2.5 and consisted of 12 drops. The second entry focused on Mach 3.2 release from all bay positions. The results from both of these tests demonstrated the robustness of the model-scale flow control approach as a means of achieving high-speed weapon dispense from a bay.

One issue that arises in weapon drop tests is how to scale the weapon so that model scale results can be used to interpret full-scale results. Light scaling was used in the LRSAe testing, where the relative importance of weapon weight is decreased compared to the aerodynamic and ejector forces. As a result of this, with regard to similarity variables the weapon will tend to be closer to the aircraft for a longer time than would be experienced in flight. For this reason, the light scaling is conservative. That is, if safe separation occurs with a light-scaled weapon model, then a safe separation with the full-scale weapon is essentially certain. In the LRSAe portions of the drop testing, all weapon models were light scaled. For the drop tests the 10%-scale MK-82 JDAM models were fabricated by the stereo-lithography process and contained 7075-T6 aluminum parts and Mallory 1000 weights. An ejector system was installed in the weapons bay for the drop testing could be located at any of the three weapon release stations. The ejector is a spring-based system operated with a burn bolt. Various springs are available in order to set the ejector force variations.

To record the weapon trajectories, the Boeing subcontractor Instrumentation Marketing Corporation (IMC) provided high-speed (1000 to 2000 frames/sec) video imaging of the weapon drops. In acquiring the video images, two different approaches were used. The first was direct illumination, in which target markers were placed on the weapon to allow accurate definition of the weapon dynamics during the release using IMC software (such information as weapon center-of-gravity trajectory and pitch angle). The second approach was recording Schlieren images of the weapon drop, which had the advantage of showing the complex shock system in the flow. However, in this approach the target markers are not visible, so the weapon trajectories and pitch angle had to be constructed using identifiable geometric characteristics of the weapon in applying the analysis software.

The first drop test entry took place in the Boeing PSWT in December 2002 and considered twelve MK-82 JDAM models dispensed from the forward and mid bay positions. Confirming the grid test results, the drop tests showed that all actuators (powered resonance tube, splash actuator, and jet screen) provided a clean release of the weapon from the forward and mid bay positions (aft release was not tested). The microjet array alone was ineffective.

The second drop test entry took place in the Boeing PSWT in March 2003. Its objective was to check the robustness of the flow control actuators, to determine if additional weapon stabilization was required, and to minimize the actuator mass flow consumption to meet the bleed flow limitations of the aircraft propulsion system. The drop tests conducted at Mach 2.5 (HIFEX program) and 3.2 (LRSAe program) showed that a "tandem actuator" provided the best weapon separation characteristics at both Mach numbers. The tandem system consisted of a microjet array at the bay leading edge and another at the jet screen position. Figure 12 shows sequences from the controlled departure at Mach 3.2. Without flow control, the weapon model returned to the bay at both positions and at both Mach numbers. Acceptable weapon departure was achieved without control at the aft bay position for both Mach numbers. The flow rates required by the tandem system fell within the limit obtained by scaling down the aircraft bleed flow availability. Therefore, the tandem microjet array was selected as the actuator of choice for the high-speed weapon release problem.

3.5 Pressure-Instrumented Model Grid Tests

In July 2003 a grid test with a pressure-instrumented MK-82 JDAM model was conducted in the Boeing Polysonic Wind Tunnel. The goal of this test was to acquire pressure data on the weapon model as it passed through and below the HIFEX weapons bay model shear layer to explain the processes that occur without and with flow control.

For the baseline or no-control case, a violent buffeting condition is created in the weapons bay by the motion of the amplifying large-scale structures that are convected in the shear layer at a Mach number of 1.25 for the Mach 2.5 free stream condition. While having no appreciable effect on the trajectory of the weapon model while it is inside the bay or passing through the shear layer, this condition produces a strong nose-up moment while the weapon is in the near-field region. The tentative explanation for the baseline behavior lies in considering the large eddies in the shear layer as a wavy wall moving at the convection Mach number 1.25 with respect to the shear layer structures. It is proposed that the system of waves moves at Mach 1.25 relative to the shear layer structures. These waves traverse the essentially stationary weapon model, creating an increasingly strong pressure footprint on the rear portion of the weapon model because the structures grow with streamwise distance through vortex pairing. Therefore, the shocks generated by these structures increase in the streamwise direction. These conclusions are supported by the detailed static and dynamic pressures acquired by dynamic pressure transducers distributed over the length of the weapon model (Fig. 13). With control applied, the structures and shocks they generate are suppressed. This results in clean departure of the weapon model from the bay as observed in the wind tunnel drop tests.

4.0 SUMMARY

The Long Range Strike Aero Experiment has provided an extensive database for validation of prediction methods that will be applied in evaluating weaponization concepts for the Long Range Strike Aircraft. This database includes acoustic spectra, grid force-and-moment model data, particle-image-velocimetry data, high-speed weapon release videos and photogrammetric results, and grid pressure-instrumented model data.

The program, in conjunction with the DARPA program "High-Frequency Excitation Active Flow Control for Supersonic Weapons Release", has demonstrated at model-scale the safe weapon release from a conventional bay at Mach numbers from 2.5 to 3.2. This approach has been shown to have a robustness that is not found with a conventional spoiler at the conditions tested.

The active flow control technology originating from the LRSAe and HIFEX programs will ultimately be tested at full scale in 2005 at the Holloman AFB High Speed Test Track under HIFEX funding. Such a test would be a preliminary step toward a flight test demonstration of the active flow control high-speed weapon release concept.

5.0 ACKNOWLEDGMENTS

The authors acknowledge the contributions of the following individuals in the execution of the "Long Range Strike Aero Experiment" program: Dr. Andrew W. Cary (The Boeing Company) for developing weapon scaling relations and analysis of weapon drop imaging data; Drs. Ganesh Raman, Farrukh S. Alvi, and Anuradha Annaswamy (Waveflows) for wind tunnel test support and data analysis; and Dr. Luiz Lourenco (Integrated Design Tools) for particle-image-velocimetry measurements.

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[3] Elavarasan, R., Alvi, F. S., Shih, C., and Garg, G., "Active Control of Supersonic Impinging Jets Using Microjets", AIAA Paper 2000-2236 (2000).

Figure 1: 10%-Scale HIFEX weapons bay model installed in Boeing Polysonic Wind Tunnel

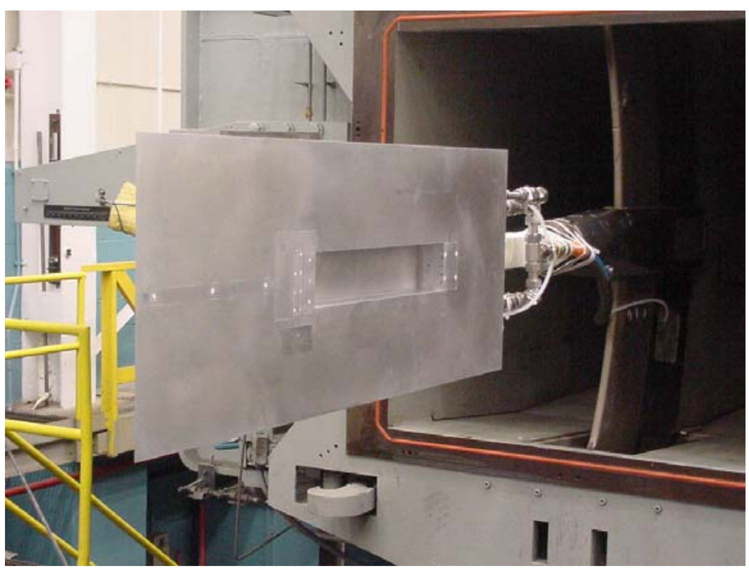


Figure 2: Powered resonance tube bank located upstream of the HIFEX weapons bay

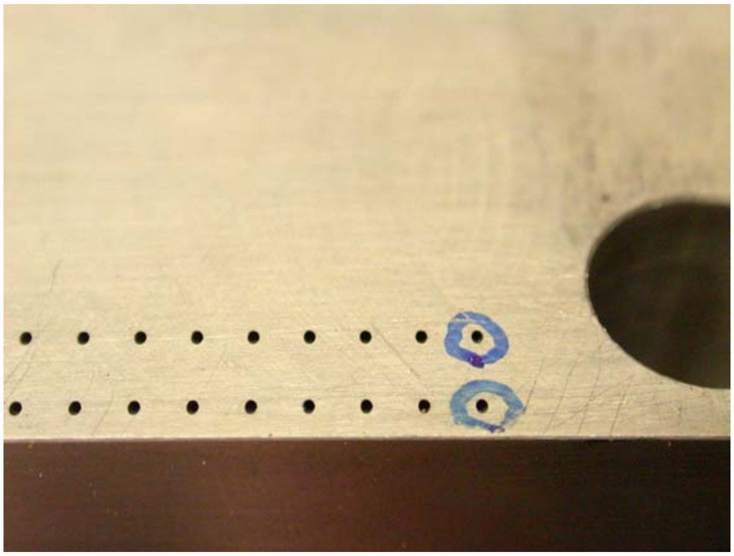


Figure 3: Jet screen slot (0.030 inch x 4 inches) located upstream of the HIFEX weapons bay

Figure 4: Microjet arrays located upstream of the HIFEX weapons bay

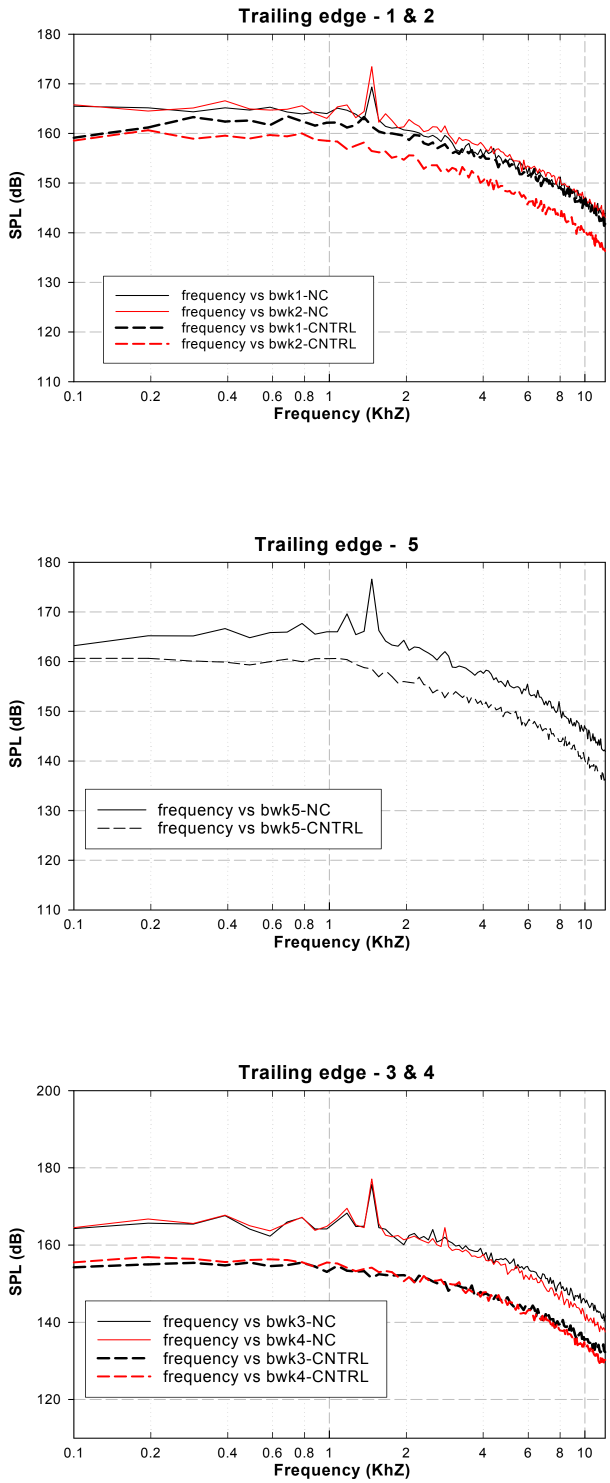
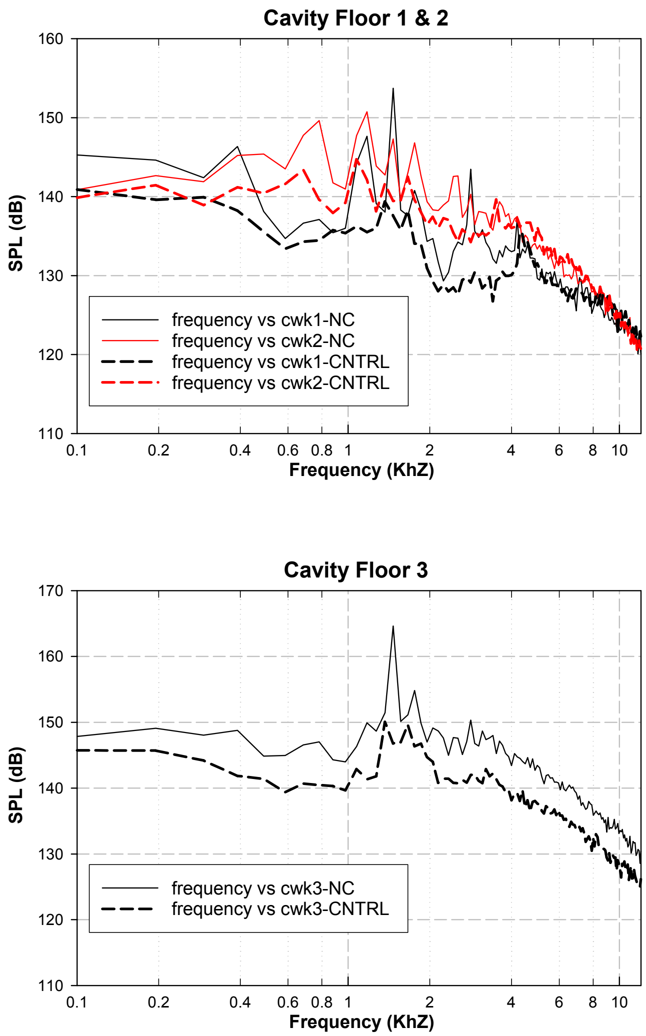


Figure 5: Effect of powered resonance tubes (PRT1) on sound pressure levels in the HIFEX weapons bay (Mach 2.5)



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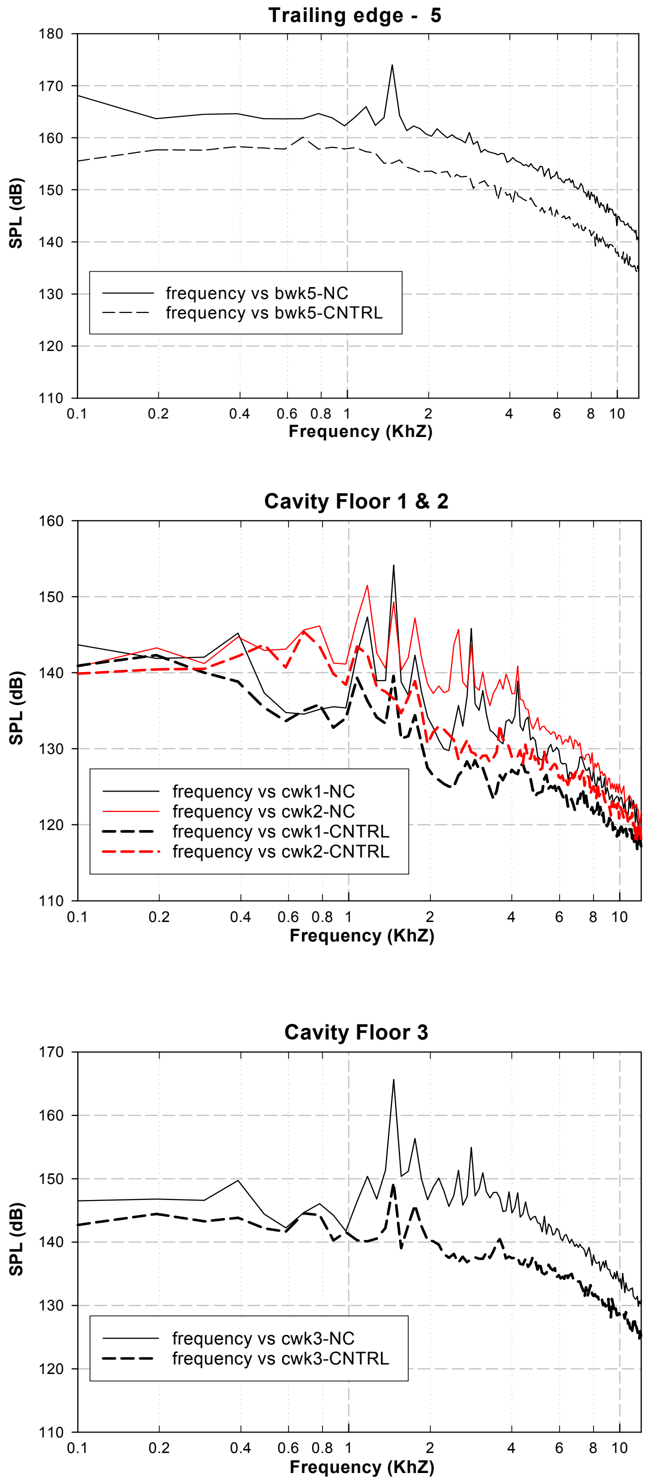


Figure 6: Effect of Microjets (MJ1, 100 psig supply pressure) on sound pressure levels in the HIFEX weapons bay (Mach 2.5).

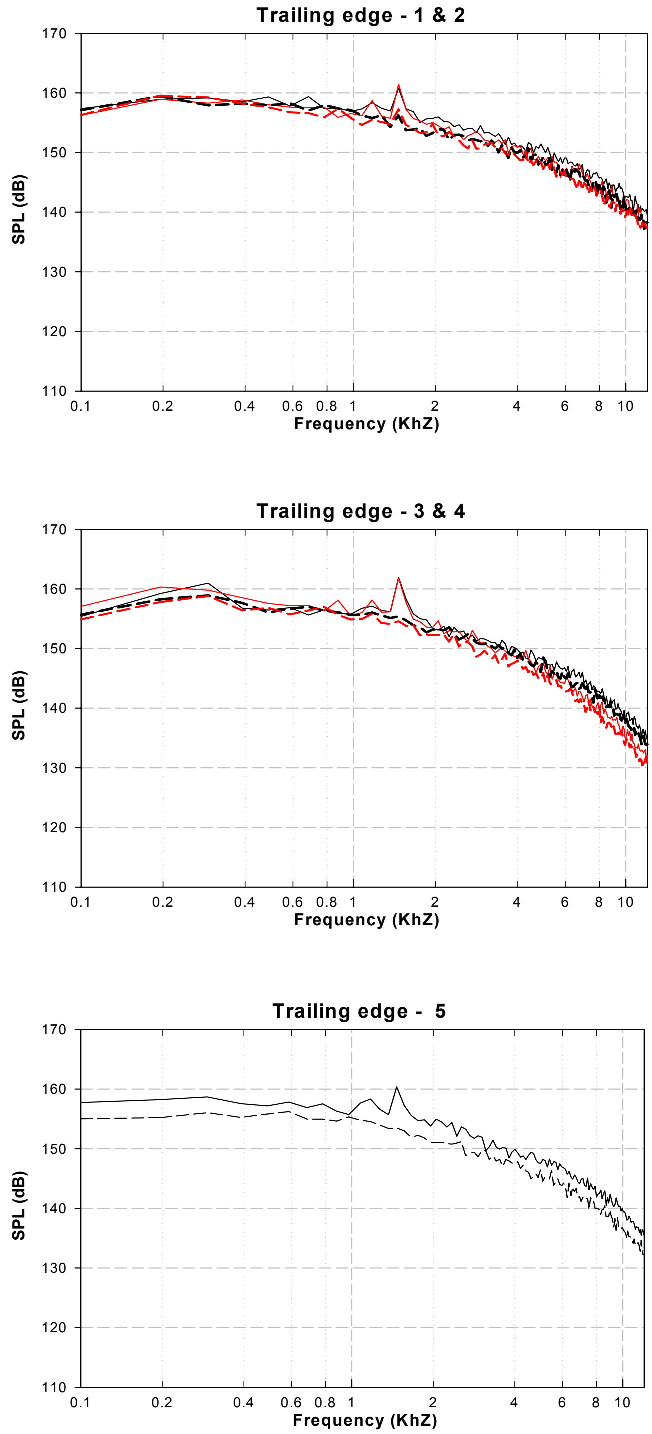
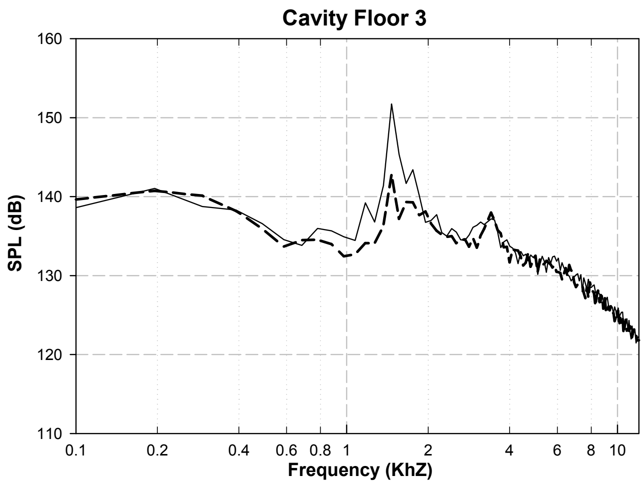
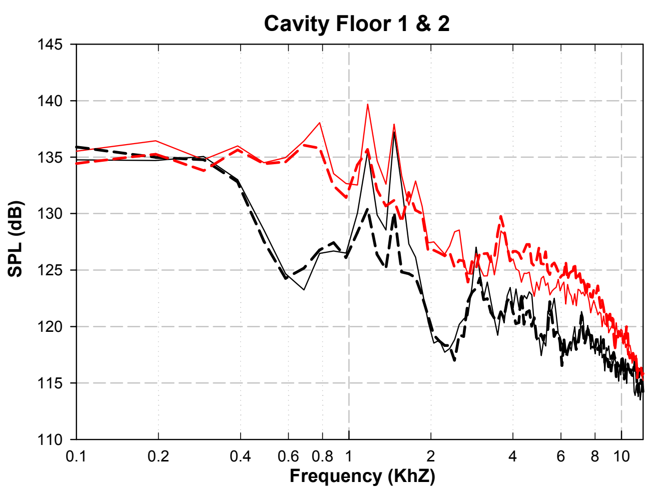


Figure 7: Effect of Microjets (MJ1, 100 psig supply pressure) on sound pressure levels in the HIFEX weapons bay (Mach 3.2)





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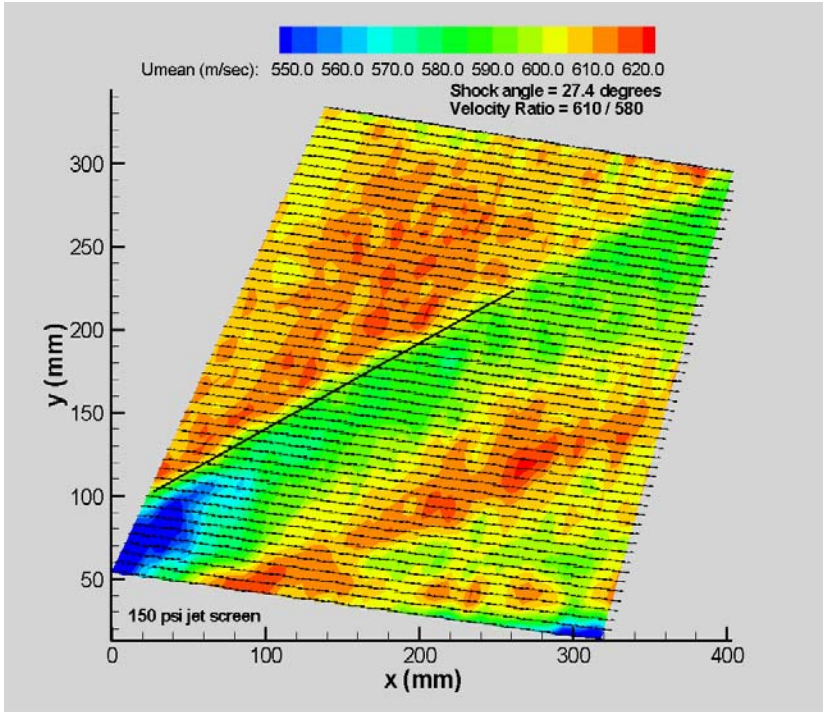


Figure 8: Velocity field in vicinity of HIFEX weapons bay with jet screen operating at 150 psig (Mach 2.5)

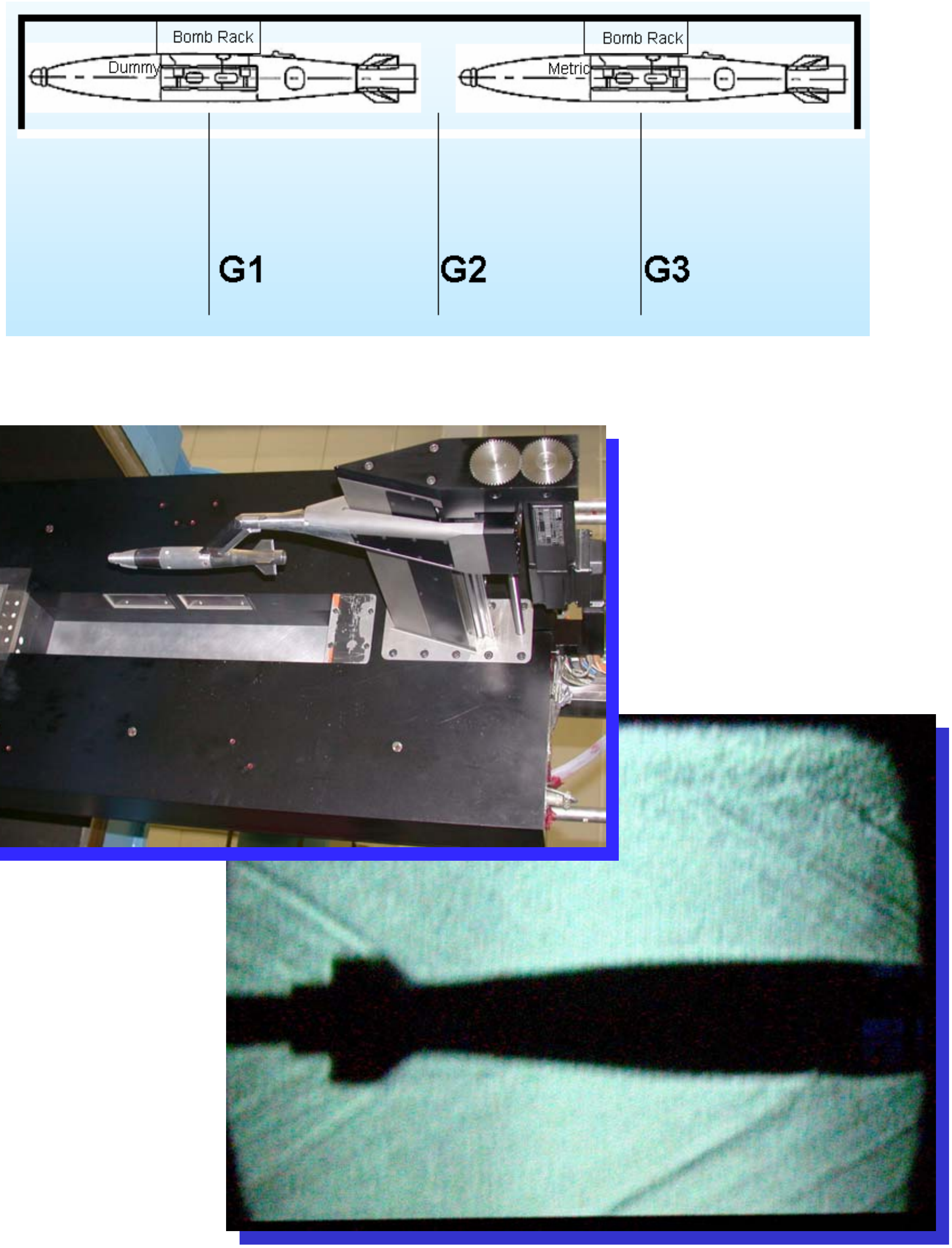


Figure 9: Arrangement of HIFEX weapons bay and MK-82 JDAM models for grid testing in the Boeing Polysonic Wind Tunnel

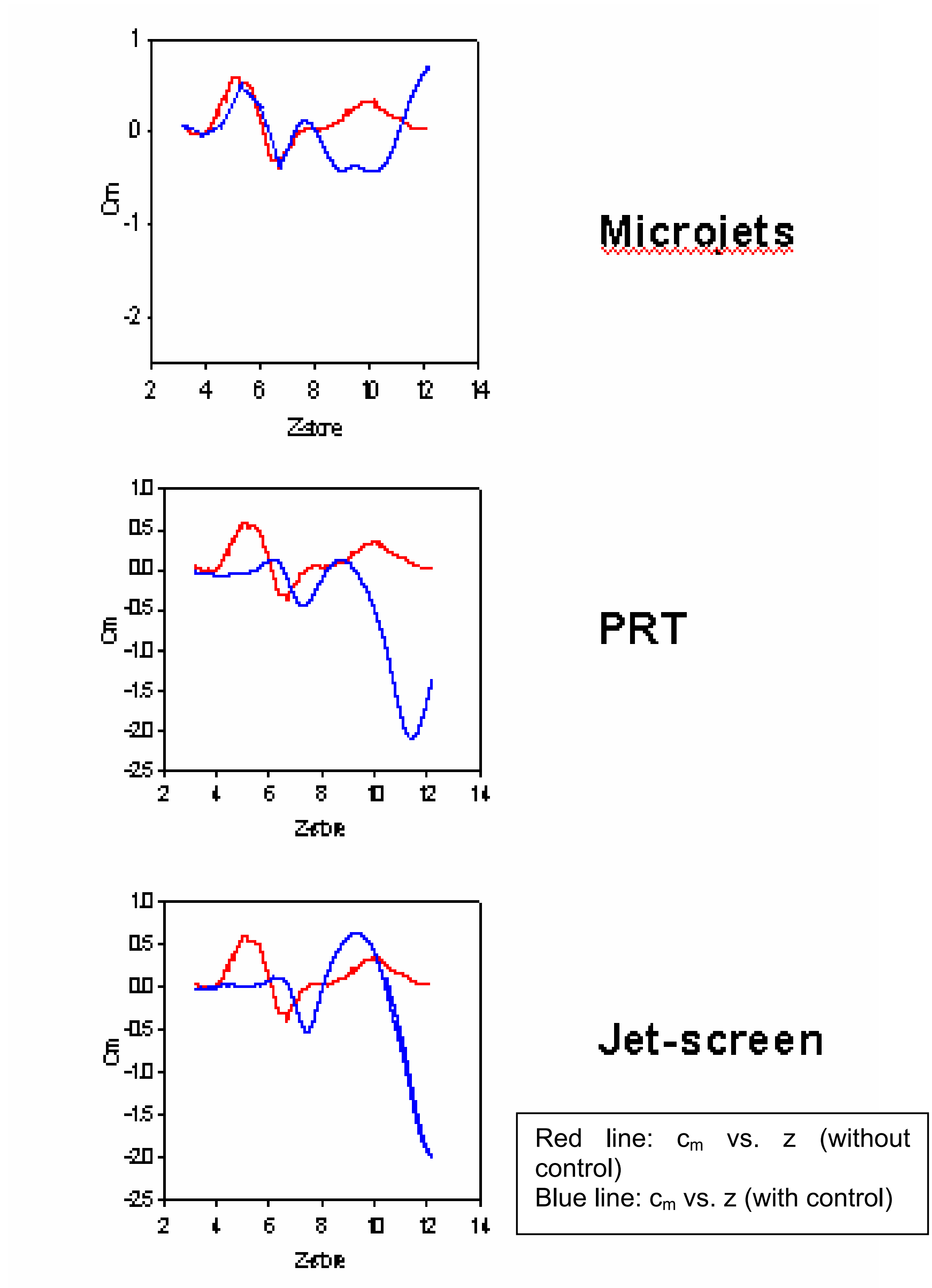
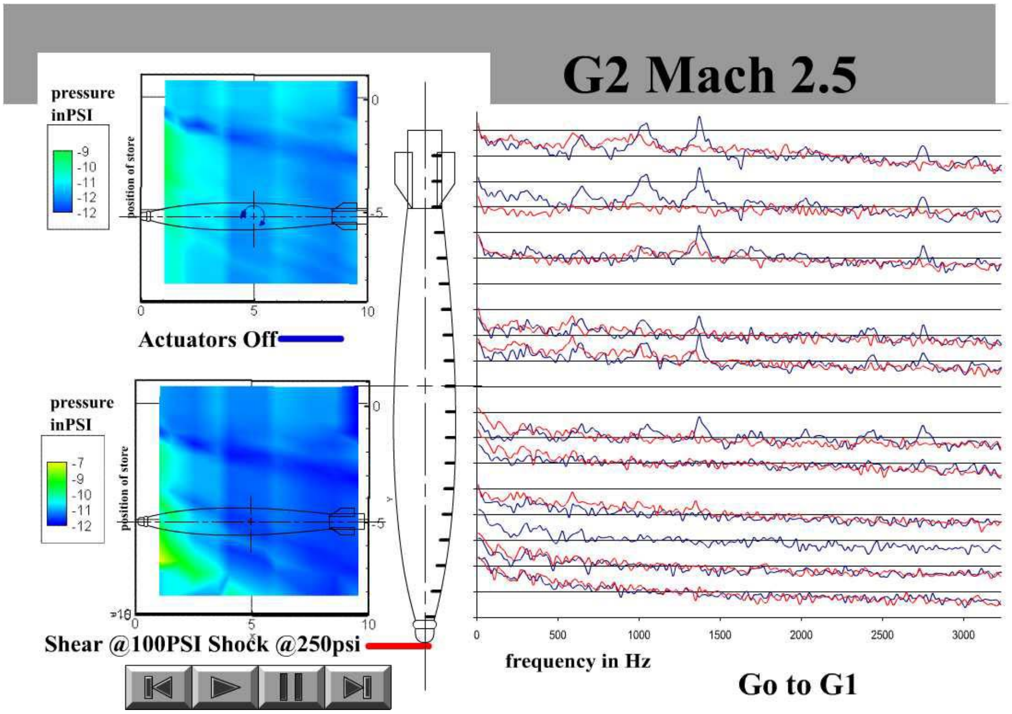


Figure 10: Pitching moment vs. weapon location for mid-bay position at Mach 2.5 (MJ, PRT, and JS actuators)



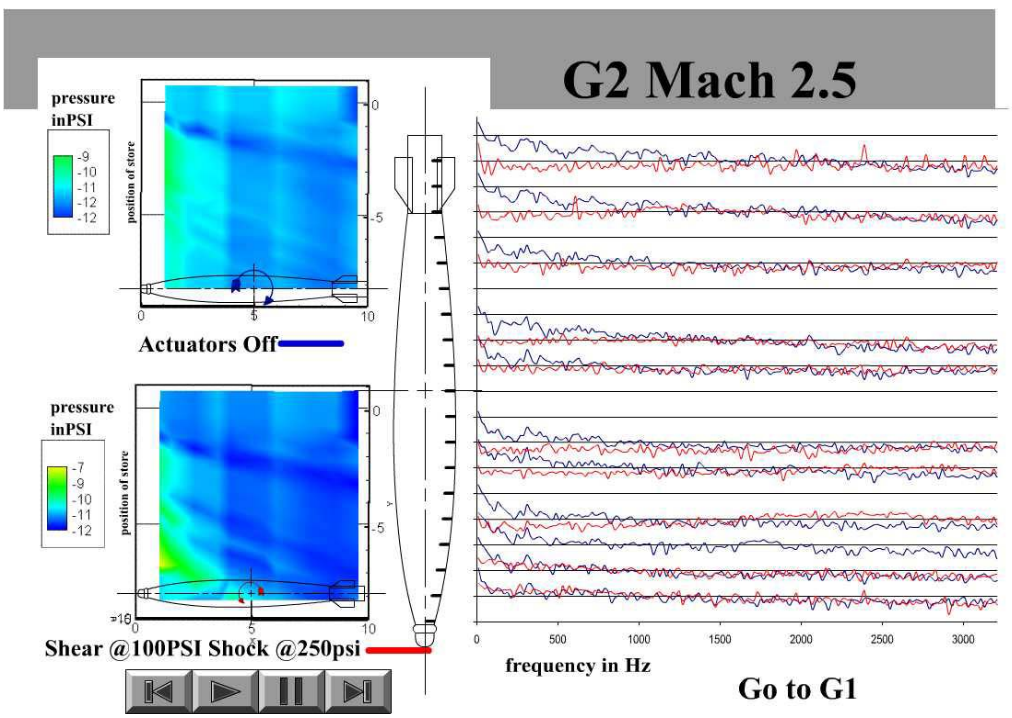


Figure 11: Dynamic pressures recorded on weapon model in mid-bay grid survey (top: weapon in initial grid position; bottom: weapon at grid position before encountering actuator-generated shock)

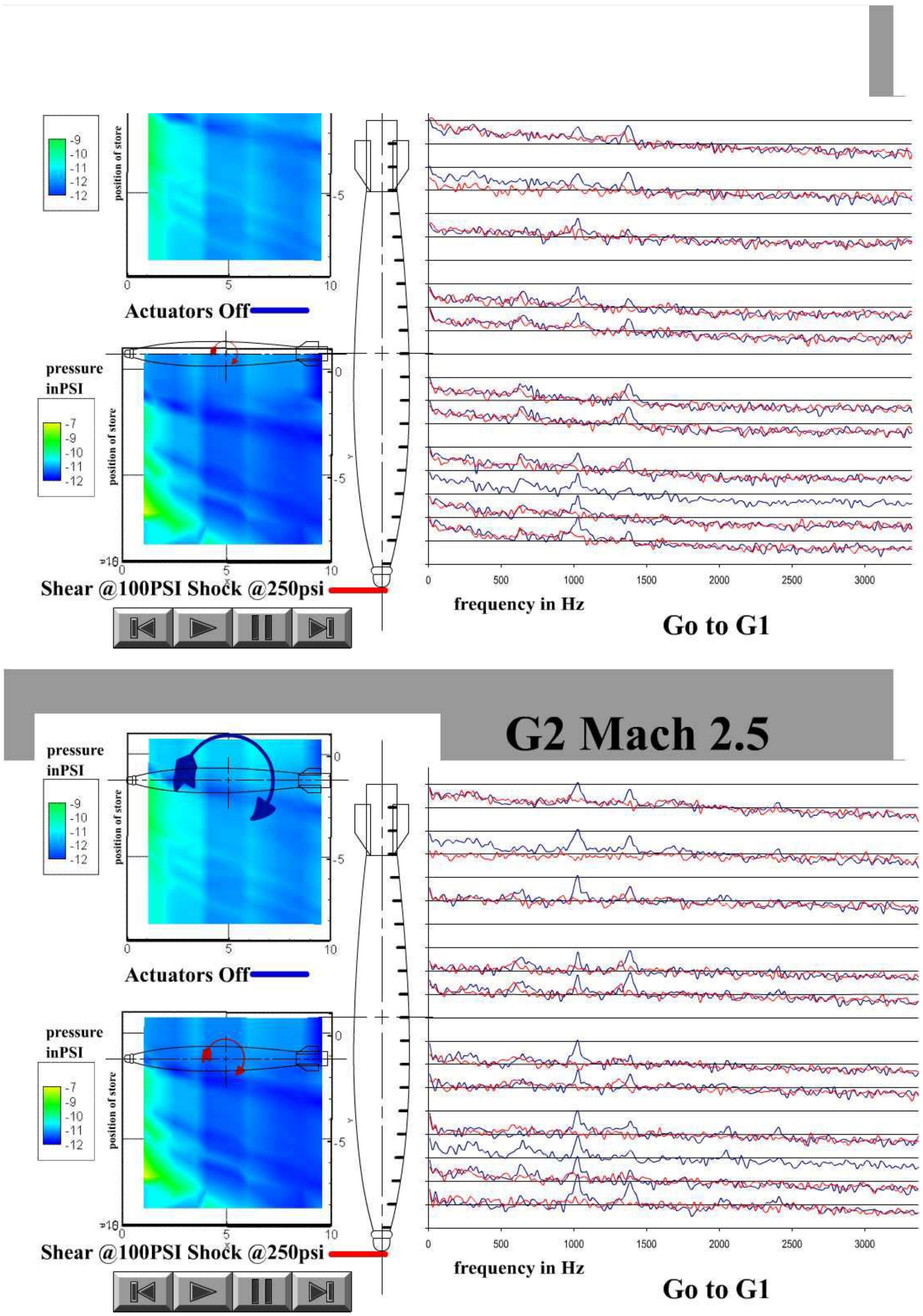


Figure 11 (continued): Dynamic pressure recorded on weapon model in mid-bay grid survey (top: weapon at grid position during passage through actuator-generated shock; bottom: weapon at grid position after clearing actuator-generated shock).

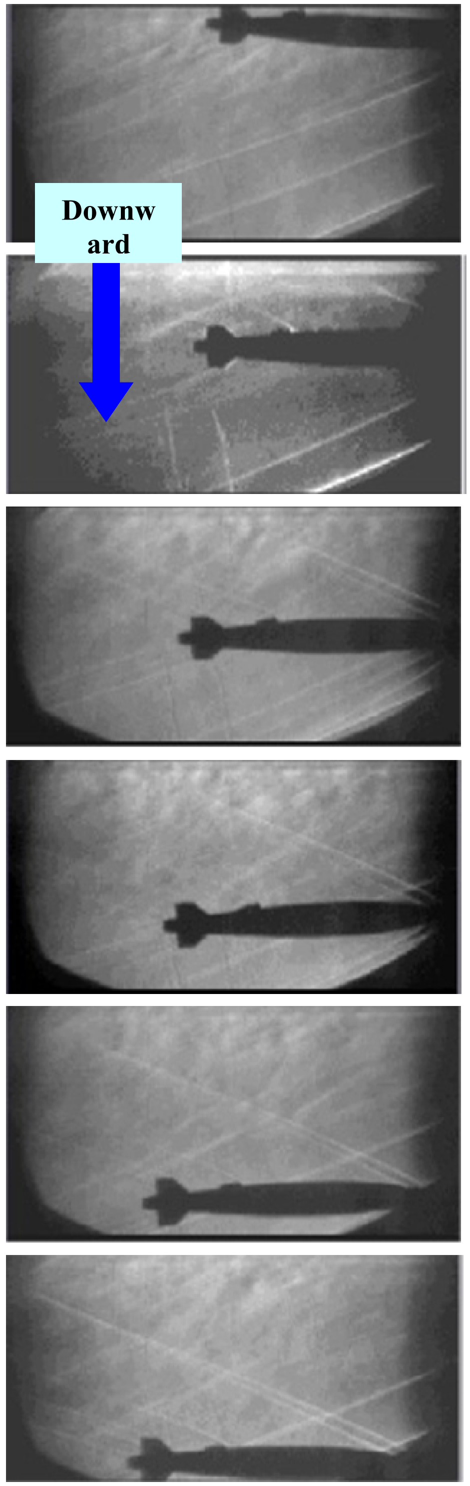


Figure 12: Sequence of high-speed video images for controlled release of MK-82 JDAM model from the mid-bay position at Mach 3.2

DISCUSSION EDITING

<u>Paper No. 30:</u> Active Flow Control for High-Speed Weapon Release from a Bay

Authors: Dave Schwartz ,Valdis Kibens and William W. Bower

Speaker: Dave Schwartz

Discussor: Stephen Perillo and Eddie Roberts

Question: How high of an ejection velocity did you try and did you try an asymmetric setting?

Have you investigated the effects of pitch rate or attidude on stores hitting the shear layer?

Speaker's Reply: Ejection velocities were meant to match the full-scale end-of-stroke velocities of a Mk-82 released from a B1-B.

Ejector bias was set to ensure horizontal release with no angular velocity. This was for simplicity. It is important to remember that this technology is still very early in its development.

As above, practical limits prevented us from varying pitch and pitch rate. This will be explored as the technology matures.

Discussor: Ronald Deslandes

Question: Don´t you think that the drop test results are too pessimistics, because you are neglecting more than 90% of the gravitation contribution (89,2m/s2)?

Speaker's Reply: The difficulties of high-Mach separation are not unique to my 10%-scale results. Full-scale problems have been observed on the F-111 in the past. Even external release is dangerous above Mach 2. Rail-launched missiles from the SR-71 (YF-12) recontacted the aircraft.

Even if we were being overly conservative, it only shows that we are able to solve difficult problem. If we can enhance separation in the light-scaled case, we can be even more confident about the full-scale case.

Discussor: M. Tutty

Question: The F-111 has been releasing stores for over 40 years with B61 etc. Is consideration being given to the design of better shapes than the extremely poor GBU-38 shape which replicated the even worse Mk-82 Loop shape.

Speaker's Reply: AFRL must respond to customer requirements, which include the

Mk-82, even for future bomber designs. This model was closer because it should be a very common loading and because it should be a very common loading and because of Boeing´s ownership of the JDAM. We hope to expand our weapon selection in future tests.

Air vehicles´ sister directorate, the Munitions Directorate, would be responsible for new store designs