F-111 Generic Weapons Bay Acoustic Environment

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A wind tunnel test was conducted on a generic weapons bay model to define the acoustic environment in the bay and how it is affected by various missiles, suppressors, and flow conditions. Two different depth bays were tested. Three different missile designs were installed in the bay with the capability of putting one, two, or three in the bay at a time. One of the missiles was tested at three vertical positions to measure the effect it has while being deployed. Two leading-edge sawtooth suppressors were evaluated along with a slanted rear bulkhead. Overall levels as high as 163 dB were measured in the bay. Narrowband tones were strongly excited. The sawtooth spoilers were partially effective in suppressing the tones. In some cases the levels were amplified. The slanted aft bulkhead was very effective in suppressing the levels. The missiles generally reduced the acoustic levels in the bay, with the most reduction when a missile was partially out of the bay interacting with the shear layer. The measured levels were of high enough intensity to result in severe fatigue problems for sensitive missiles and components.

Introduction

AN aircraft weapons bay exposed to freestream flow experiences an intense aeroacoustic environment in and around the bay. Experience has taught that the intensity of this environment can be severe enough to result in damage to a store, its internal equipment, or the structure of the weapons bay itself. To ensure that stores and sensitive internal equipment can withstand this hazardous environment and successfully complete the mission, they must be qualified to the most severe sound pressure levels anticipated for the mission. If the qualification test levels are too high, the store and its internal equipment will be overdesigned, resulting in unnecessary cost and possible performance penalties. If the qualification levels are below those from flight, the store or its internal equipment may catastrophically fail during performance of the mission. Thus, it is desirable that the expected levels in weapons bays be accurately predicted.

A large number of research efforts have been directed toward understanding flow-induced cavity oscillations. References 1–14 are a small sample of the efforts addressing flow-induced cavity pressure oscillations. However, the phenomena are still not adequately understood to allow one to predict the fluctuating pressure levels for various configurations and flow conditions. This is especially true at supersonic flow speeds, where only a small amount of data are available. The objective of the current effort was to define the flow-induced acoustic levels in a generic (basic rectangular) weapons bay at both subsonic and supersonic speeds.

A 4.9% model of an F-111 aircraft with a generic weapons bay was tested at the Arnold Engineering Development Center's PWT-4T wind tunnel facility. Subsonic and supersonic Mach numbers were tested. The fluctuating pressure levels in the bay were measured with four Kulite pressure transducers. The data were reduced into narrowband spectra and then plotted to show the effects of the various test parameters. Comparisons to flight data and predictions were also performed.

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Description of Model

The wind tunnel test bed was a 4.9%-scale model of an F-111 aircraft. Figure 1 is a picture of the model, and Fig. 2 shows a sketch of the model. Figure 3 shows how the model was installed in the PWT-4T test facility. The model has a generic weapons bay installed in it. The bay had two depths and vertical or slanted rear walls. The rear walls were slanted at 48 deg. The dimensions of the bays are given in Fig. 4. The two depths resulted in cavities with length-to-depth ratios of 6.79 and 10.27. The three stores which were tested, fixed-fin AMRAAM, ducted-rocket, and folded-fin AMRAAM, are shown in Figs. 5, 6, and 7, respectively. Two sawtooth-shaped leading-edge spoilers were tested as suppression devices. They were of the same shape, but one was 0.36 in. high and the other 0.18 in. high. Filler blocks were used to vary the width of the bay. For the deep bay, one filler block was installed filling one-half of the bay, leaving room for one fixed-fin store. For the shallow bay, two filler blocks were used, one on each side of the bay, leaving room for one fixed-fin store in the center of the bay.

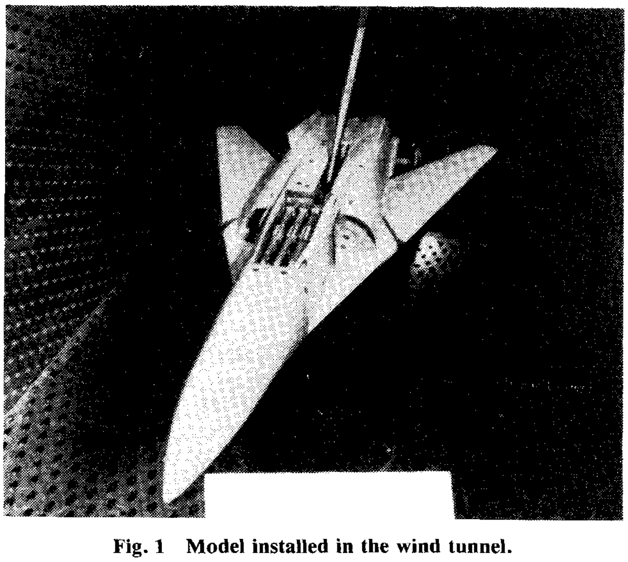


Fig. 1 Model installed in the wind tunnel.

Description of Instrumentation and Data Acquisition

The primary measurement systems consisted of four Kulite XCQ-093-2D differential pressure transducers installed in the F-111 weapons bay by AEDC personnel. The four pressure transducers were flush-mounted inside the F-111 model as shown in Fig. 4. The main component of the data acquisition system was a Masscomp computer, which was located in the Mobile Experimental Laboratory (MEL) van (see Ref. 15). A PRM SGA-5 strain gauge signal conditioning unit was used to output the required 5 V dc excitation and 40 dB of amplification to each Kulite transducer.

The SGA-5 unit was located alongside the test section of the wind tunnel. Automatic gain changing (AGC) amplifiers were used to provide additional amplification of the data signals from the SGA-5 unit.

The AGC amplifiers were located in the MEL van. The transducers were connected to the signal conditioning equipment and tape recorder. Transducer cables were routed through the weapons bay, extending to the tail of the model into the arm of the sting. The sting supported the F-111 model (Fig. 8) and was used to change its altitude.

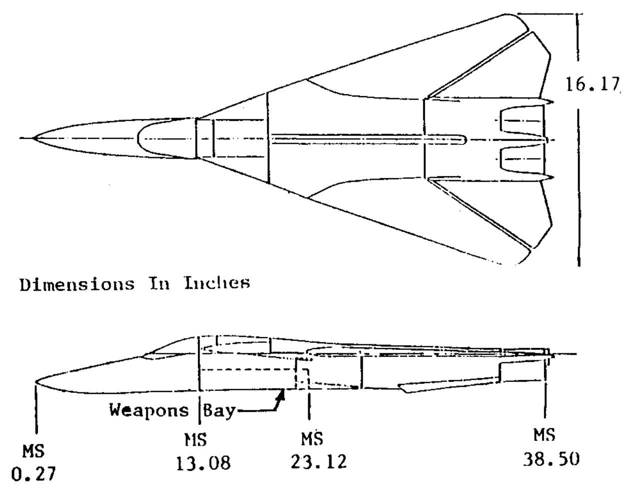


Fig. 2 Wind tunnel test model.

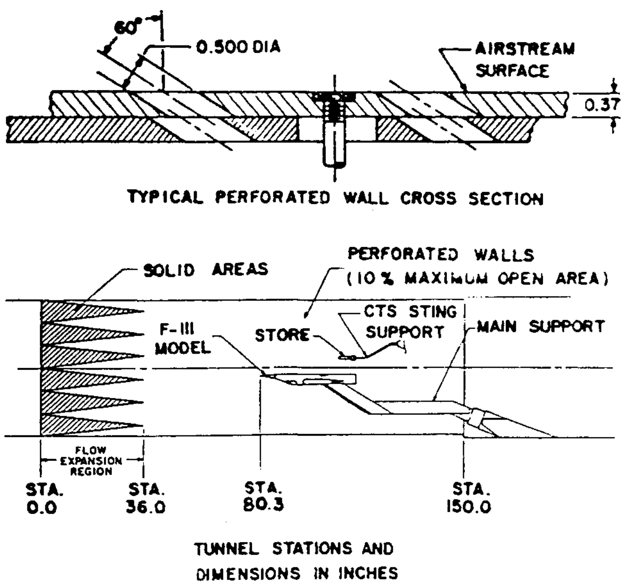


Fig. 3 Test model relative to wind tunnel.

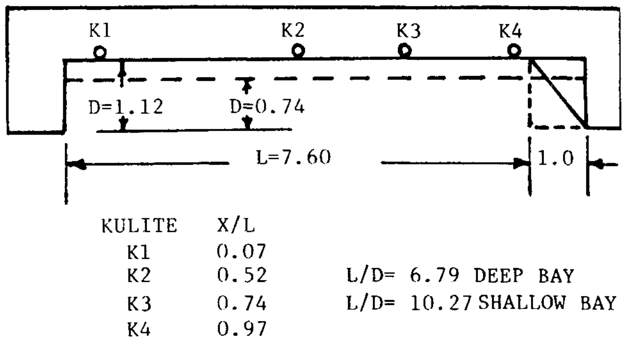


Fig. 4 Generic bay dimensions.

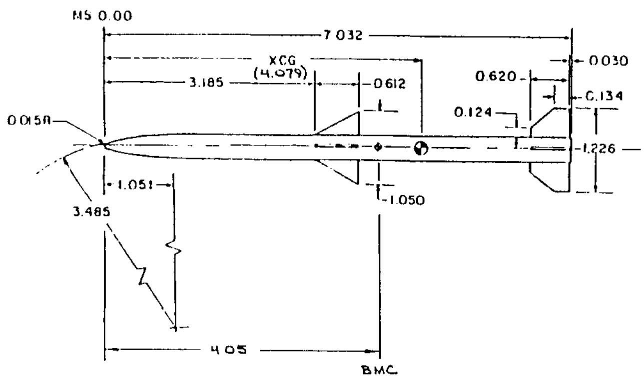


Fig. 5 Fixed-fin AMRAAM.

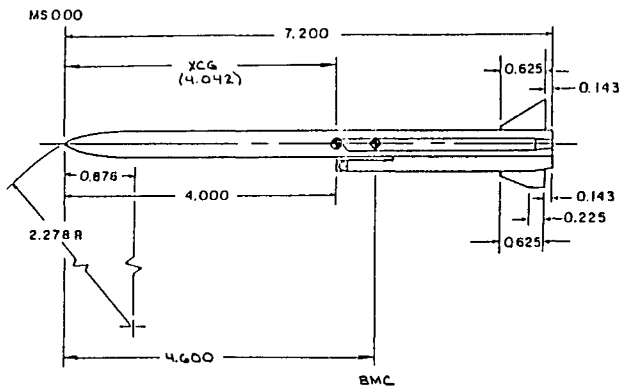


Fig. 6 Fixed-fin ducted rocket.

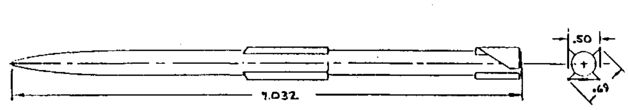


Fig. 7 Folded-fin AMRAAM.

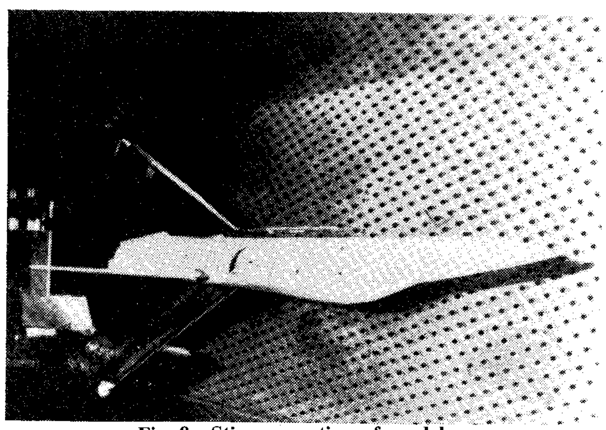


Fig. 8 Sting mounting of model.

The output from the AGC amplifiers was filtered by programmable lowpass active filters. These filters were programmed for an upper cutoff frequency of 5 kHz to prevent aliasing of the data. Gains of the AGC amplifiers were fixed when recording data for each test point and manually logged. The output from the filters was routed to an MC-500 Masscomp computer system and a Honeywell 101 magnetic recorder.

The Masscomp MC-500 computer system in the MEL van was used to acquire and process the data from the Kulite pressure transducers. The Masscomp system includes a Data Acquisition and Control Processor (DA/CP). This portion of the system contains a 16-channel multiplexer and an Analog-to-Digital (A/D) converter. The system contains software to process the acquired data into spectra and produce graphic displays. A Hewlett Packard 6-pen color plotter was used to produce final plots.

A detailed description of the Masscomp computer system and the MEL van is in Ref. 15. An IRIG-B time code signal geostationary operational environment satellite was provided by a satellite receiver located in the van.

Data acquisition was accomplished by sampling the data at approximately 16,000 samples/s with the A/D converter and storing to the Masscomp disk as well as backing up the raw data on the tape recorder. Each data record was sampled by the A/D for approximately 5 s.

Calibration

An end-to-end system calibration was performed at the test site. Each pressure transducer was excited with an acoustic calibrator that produced a sound pressure level (SPL) of 150 dB at a frequency of 250 Hz. The amplifiers in the SGA-5 unit were set at 40 dB of gain, and the AGC amplifiers were normalized during calibration so that 1 V rms = 150 dB SPL. The calibration signal for each of the four pressure transducers was recorded on magnetic tape for permanent retention. These calibrations were repeated after every weapons bay change.

Voice communications with the test operator were used to determine when the model was on test point. A visual display of the test condition (Mach number, angle of attack, etc.) was available in the van on a closed-circuit TV monitor for correlating the test point data and run numbers.

The raw data records stored on disk were processed into spectra immediately following the completion of each set of runs. This procedure provided the data necessary to establish the optimum test sequence. During the test, all four microphones were plotted on a single graph for each run. Afterwards, different test configurations were cross-plotted to show the effects of the configuration change. The Honeywell model 101 tape recorder was used to record the raw analog data in case additional processing was required.

Test Procedures

The Mobil Experimental Laboratory (MEL) van was situated just outside of the 4T test section building, and all of the instrumentation wiring was connected between the MEL van and test section patch panel. After all connections were made and the system checked out, an end-to-end calibration was made on each of the four Kulite transducers and recorded on tape. When the test started and the wind tunnel was on condition, the tunnel operator in the control room would tell personnel in the MEL van and a record would be taken. The data from each record were stored on FM tape and simultaneously digitized. The digitized data were stored in the Masscomp computer. Reduction of the data into narrowband (8 Hz) spectra was started immediately. The results from all 29 model configurations were reduced. The angle of attack of the model was changed and another data record was taken and analysis started. Store position was varied and records were made for each one. Mach number was also varied with data taken at each one. After data were obtained for all desired angles of attack, store positions, and Mach numbers, the tunnel was shut down and a model change was performed. During the model change, all of the previously analyzed data were plotted. At the end of the acoustic testing, a post-test calibration was made and recorded on tape.

Discussion of Results

Dynamic pressure data were recorded from the four Kulite transducers located in the model. Data were obtained for each of the configurations tested at Mach numbers from 0.7–2.0. Data were recorded for angles of attack from − 4 to + 16 deg and for three store positions: in-bay, one-half out, and just outside the bay. The data were reduced into narrowband (8 Hz) spectra from 0 to 5 kHz, and the spectrum from all four Kulites were plotted on one graph. A total of 315 graphs were made, one for each record. Specific trends and configuration effects are presented in the following section.

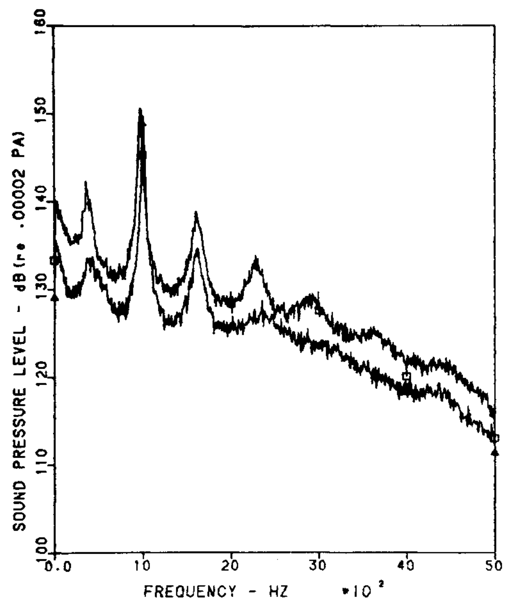


Fig. 9 Effect of spoilers 1 and 2 for deep bay at Mach number 0.9 with 48-deg rear wall; □ = no spoiler, X = spoiler 2, Δ = spoiler 1.

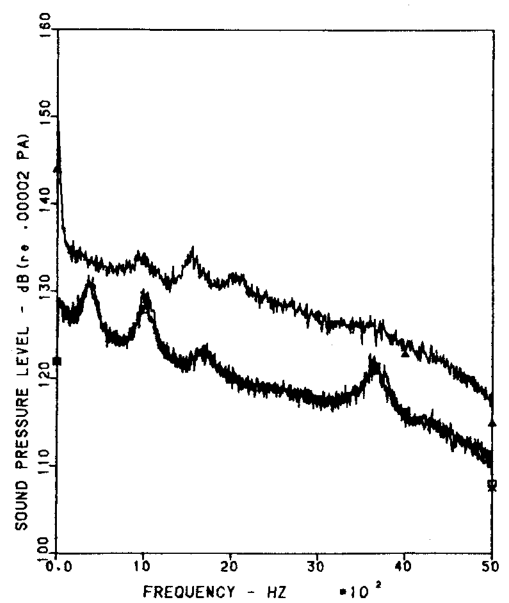


Fig. 10 Effect of spoilers 1 and 2 for deep bay at Mach number 1.2 with 48-deg rear wall; Δ = no spoiler, X = spoiler 2, □ = spoiler 1.

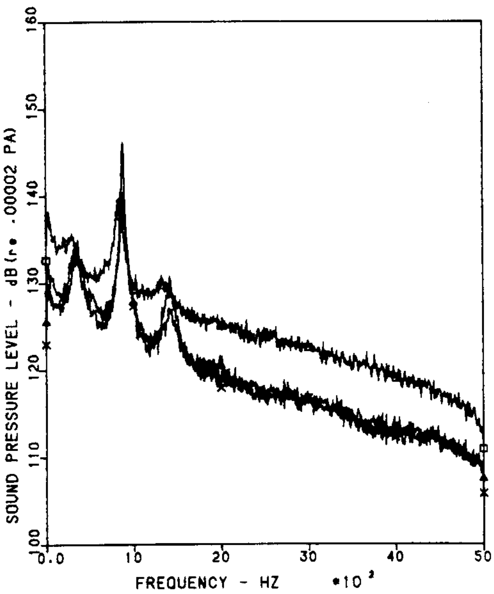


Fig. 11 Effect of spoiler 2 for deep bay at Mach number 0.9 with 90-deg rear wall; □ = no spoiler, Δ = spoiler 2.

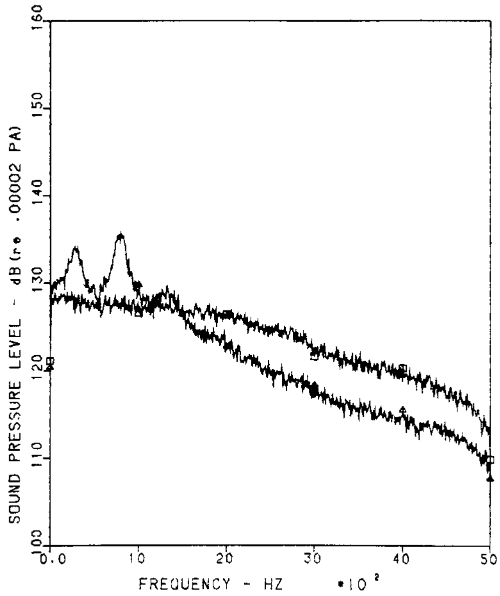


Fig. 13 Effect of spoiler 2 for shallow bay at Mach number 0.9 with 48-deg rear wall; □ = no spoiler, Δ = spoiler 2.

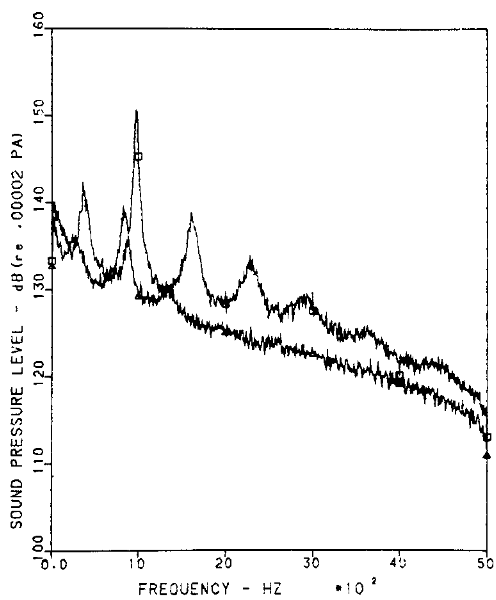


Fig. 12 Effect of 48-deg rear wall for deep bay at Mach number 0.9; □ = 90 deg, Δ = 48 deg.

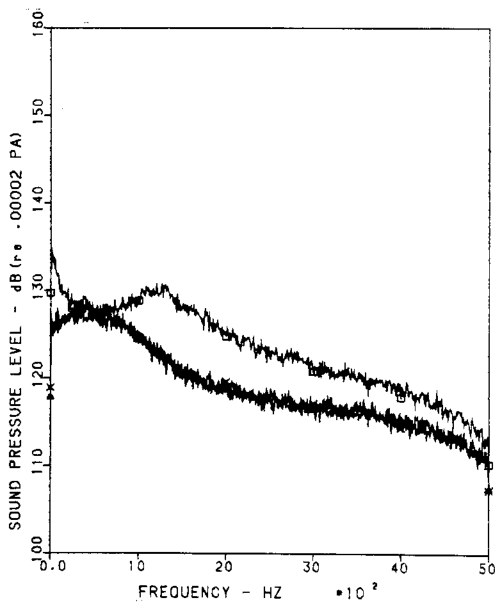


Fig. 14 Effect of spoilers 1 and 2 for shallow bay at Mach number 2.0 with 90-deg rear wall; □ = no spoiler, Δ = spoiler 2, X = spoiler 1.

Suppression Effects

The two sawtooth spoilers and slanted rear wall were tested to determine their effectiveness in suppressing the flow-induced acoustic levels. The suppression effects for both spoilers as compared to the no-spoiler case are shown in Fig. 9 for the deep bay and Mach number 0.9 with 48 deg rear wall. Both spoilers increase the amplitude of mode 2 (near 800 Hz) but reduce the amplitude of the broadband level. Modes 1 and 3 (near 300 and 1400 Hz) are affected very little. At Mach number 1.2 (Fig. 10), the levels are seen to be suppressed at all frequencies. Different suppression characteristics were observed for the vertical rear wall. Since both spoilers were equally effective, only spoiler 2 was tested in most subsequent tests. Figure 11 presents the 90 deg rear wall results for Mach number 0.9 for only spoiler 2. At Mach number 0.9 mode 2 was not affected, but modes 1 and 3 were reduced by 5–7 dB. However, at Mach 1.2, mode 2 was suppressed 12 dB, mode 1, 10 dB, and mode 3, about 2 dB. It should be noted that the 90 deg rear wall resulted in the highest levels in the bay. Simply slanting the rear wall 48 deg suppressed the levels significantly, as seen in Fig. 12 for Mach number 0.9. Modes 2 and 3 were suppressed 12 dB, and mode 1 was suppressed 8 dB. Similar results were observed at Mach number 1.2. A decrease in frequency of mode 2 is clearly noted in Fig. 12. The cause of decrease is that the shear layer stagnation point now occurs further downstream on the slanted rear wall, resulting in a longer distance from the leading edge. Since the frequency is inversely proportional to this distance, a lower frequency results.

The effects of the spoilers for the shallow bay were investigated, and the result for spoiler 2 is shown in Fig. 13 for Mach number 0.9. Generally, the flow-induced levels in a shallow bay are lower than those in a deep bay. The modal tones are not excited for the shallow bay, but at Mach number 0.9, when spoiler 2 is added, the modal frequencies are excited, as seen in Fig. 13. At Mach number 1.2, the increase of the modal frequency amplitudes is only 3–4 dB. Similar results were observed for spoiler 1. The shallow bay was also tested at Mach number 2.0. Figure 14 shows the effectiveness of both spoilers for Mach numbers 2.0 with a 90 deg rear wall. Both spoilers reduce the levels at almost all frequencies.

Door Effect

The F-111 bifold weapons bay doors were tested to see their effect on the acoustic levels. Figure 15 shows that the doors can increase the modal frequency levels but do not significantly affect the broadband levels. At Mach number 0.9 (Fig. 15), the amplitude of mode 2 was increased 11 dB, and at Mach number 1.2 it was increased 5 dB. Most tests were performed with the doors on.

Mach Number Effect

Mach numbers from 0.7 to 2.0 were investigated. Figure 16 shows spectra for Mach numbers 0.7, 0.9, 1.2, and 2.0. Modal frequencies were observed to increase with Mach number. These frequencies can be predicted using the modified Rossiter equation given by

$$f_m = \frac{Mc}{L}\left(m - \alpha\right)/\frac{M}{(1 + 0.2M^2)^{1/2}} + 1.57 \qquad (1)$$

where M = Mach number, c = speed of sound, m = 1, 2, 3, and α = constant which varies with L/D. Using $\alpha = 0.57$ (see Ref. 16), the predicted frequencies for Mach 0.9 are: $f_1 = 295$ Hz, $f_2 = 980$ Hz, $f_3 = 1667$ Hz, and $f_4 = 2352$ Hz, and the second modal frequencies at the other Mach numbers are:

Mach number 0.7	$f_2 = 819$ Hz
Mach number 1.2	$f_2 = 1197$ Hz
Mach number 2.0	$f_s = 1712$ Hz.

The predicted values are shown in Fig. 16. The solid lines are the first four modes for the Mach 0.9 spectrum, and the dashed lines represent the different Mach numbers for mode 2. The predicted values agree reasonably well except at Mach number 2.0. The predicted value is 1712 Hz, while the measured value is about 1550 Hz.

Effect of Stores

Stores can be put into a bay without affecting the acoustic levels. However, if the stores interact with the shear layer, they greatly reduce the flow-induced acoustic levels. Figure 17

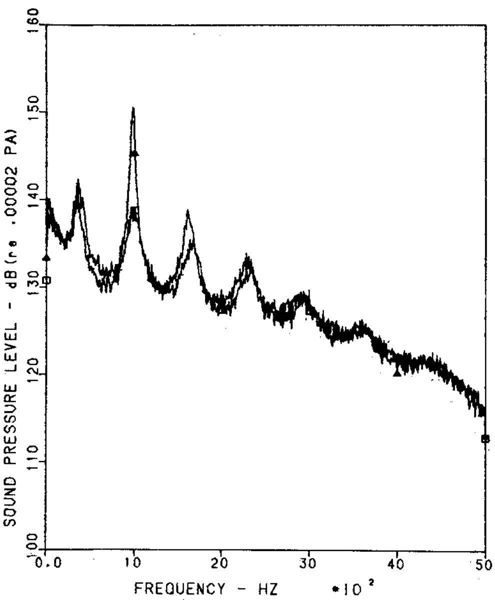


Fig. 15 Effect of bifold doors for Mach number 0.9; □ = no doors, Δ = doors on.

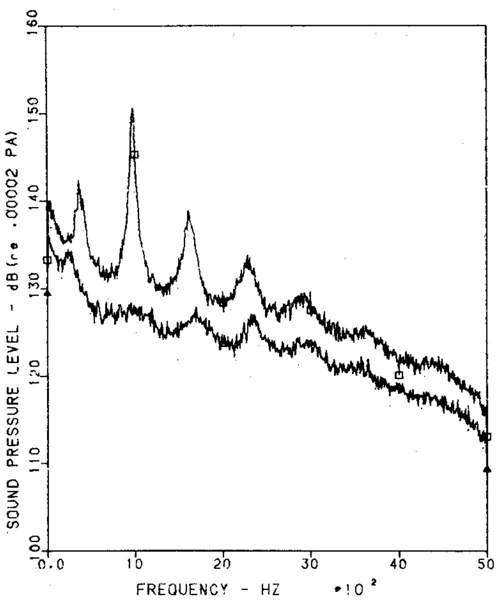


Fig. 17 Effect of two AMRAAM stores in the bay; Δ = empty, □ = two stores.

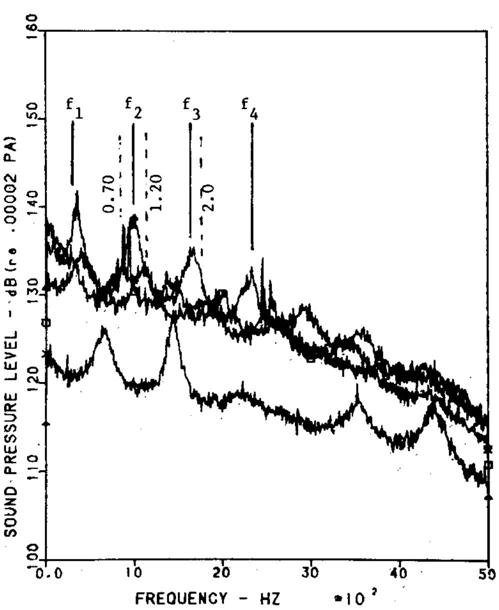


Fig. 16 Effect of Mach number; Δ = Mach number 2.0, X = Mach number 1.20, Δ = Mach number 0.9, □ = Mach number 0.70.

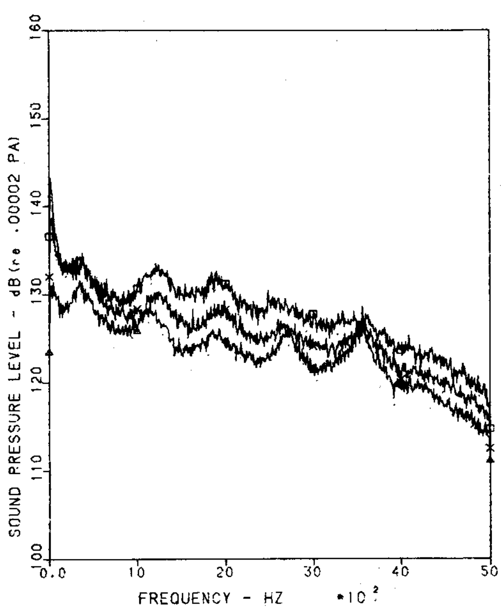


Fig. 18 Effect of store position; X = in, Δ = half out, □ = out.

shows the effect of two AMRAAM stores in the bay at 0.9 Mach. The mode-2 amplitude is suppressed more than 20 dB. At 1.2 Mach it is suppressed 15 dB. It can be concluded that the stores interact with the shear layer and stabilize the free shear instabilities, resulting in the modes not being excited (Ref. 3).

Effect of Store Position

Acoustic data were obtained for the store at three depth positions: 1) fully in the bay, 2) halfway out of the bay, and 3) just out of the bay. A typical result is shown in Fig. 18. Two AMRAAM stores were in the bay with only the right store being moved in and out for these data. The one-half out position resulted in the lowest level because the store fully suppressed the shear layer instabilities in this position. The highest levels occurred when the store was out of the bay and not interacting with the shear layer. These results also show that when the store is in the bay, it is interacting somewhat with the shear layer because the levels increase when it is out of the bay. These same trends were observed for both subsonic and supersonic speeds, deep and shallow bays, and for the different stores tested.

Effect of Type of Store

Three different stores were tested: AMRAAM, Folded-Fin AMRAAM, and Ducted Rocket. There were only slight differences between the spectra considering measurement repeatability. This was the case for all of the comparisons between the different stores.

Effect of Slot in Rear Wall

In order to bring the stores out of the weapons bay, a slot in the rear wall was necessary for the sting. This slot was about 40% of the width of the rear wall. Since the shear layer impinges on the rear wall, removing part of it will certainly affect the noise generation mechanism. This is shown in Fig. 19 for the case of two AMRAAMs in the bay with the slot both open and filled in for 0.9 Mach. When the slot is filled in, the levels of modes 2 and 3 increased 8 dB. At Mach 1.2, the increase was about 5 dB. Thus, all of the measured levels, for at least modes 2 and 3, will have to be increased by this amount to account for the effect of the slot.

Comparison to Flight Data and Prediction

A spectrum from the deep bay configuration, which is close to the F-111 bay configurations, was compared to F-111 flight data and a predicted spectrum. The flight data were taken from Ref. 17, and the following prediction equations and Fig. A are found in Ref. 4:

Modal frequencies:

$$f_m = \frac{Mc}{L}\left(m - \alpha\right) \Big/ \frac{M}{(1 + 0.2M^2)^{1/2}} + 1.57 \qquad (2)$$

Normalized modal-frequency amplitudes:

$$20 \log (P_2 \max/q) = 25 \operatorname{sech} [2(M-1)] - 3.3\, L/D - 27$$

$$20 \log (P_1 \max/q) = 20 \log (P_2 \max/q) + 1.5\, L/D - 13$$

$$20 \log (P_3 \max/q) = 20 \log (P_2 \max/q) - 13\, M + 9 \qquad (3)$$

Longitudinal variation:

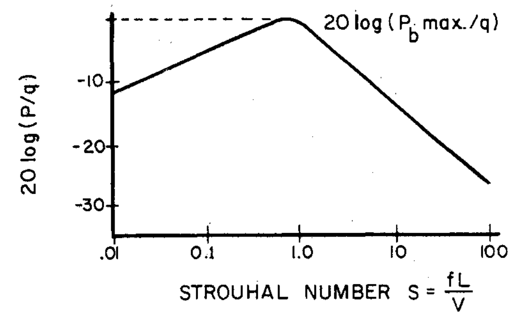
$$20 \log (P_m/q)_{X/L} = 20 \log (P_m \max/q) - 10\,[1 - |\cos\alpha_m\, X/L| + (0.33\, L/D - 0.6)(1 - X/L)] \qquad (4)$$

$\alpha_1 = 3.5$ rad
$\alpha_2 = 6.3$ rad
$\alpha_3 = 10.0$ rad

Maximum normalized broadband amplitude:

$$20 \log (P_b \max/q) = 20 \log (P_2 \max/q) + [3.3\, L/D - 28 + 3(1 - L/D)(1 - X/L)]\,[1.2 - 0.4M] \qquad (5)$$

Normalized broadband shape (Fig. A):



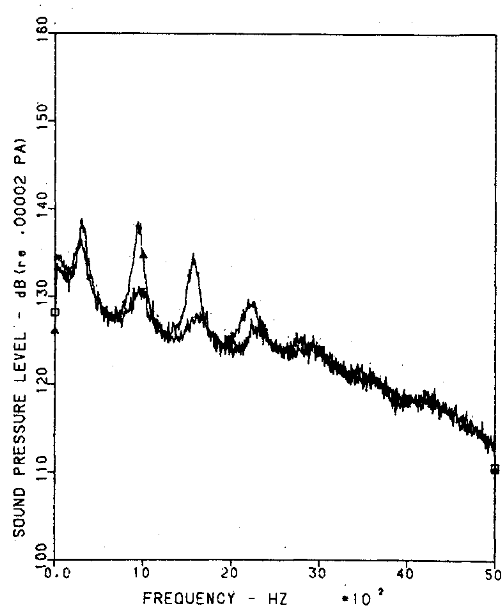


Fig. 19 Effect of slot in rear wall; Δ = no slot, □ = slot.

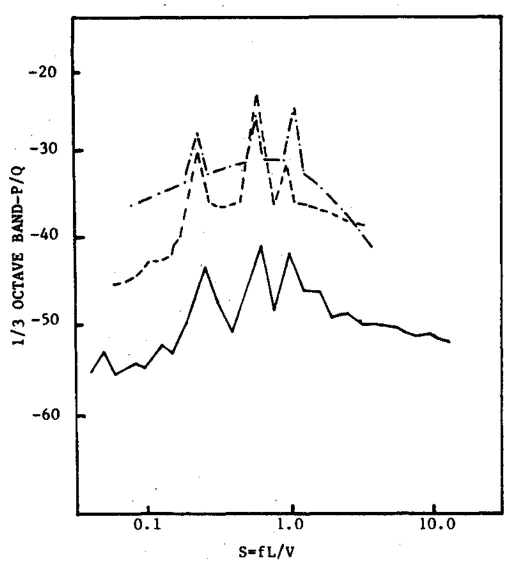


Fig. 20 Comparison of predicted and measured data; —— flight, ------ wind tunnel, - · - predicted.

Figure 20 shows all three spectra. The levels are normalized to freestream dynamic pressure. The wind tunnel spectrum and the predicted spectrum agree very well, but the flight spectrum is more than 15 dB below the other two. The reason for the difference between the flight data and the other two is believed to be the small variation in configuration and the scale size of the model. A small difference in bay geometry can significantly affect the levels. The size of the model has been shown (see Ref. 18) to very significantly (15 dB) affect the flow-induced levels in the bay.

Summary and Conclusions

A wind tunnel test on a 4.9% F-111 generic weapons bay model was performed in the AEDC PWT-4T facility, and the acoustic levels in the bay were measured. Two different depth bays, three different store shapes, doors, and filler blocks, and three different suppression devices were tested. Overall levels from 130–163 dB were measured. Levels this high can easily result in structural damage to the aircraft or to the sensitive stores in the bay. The two leading-edge spoilers tested were not very successful in suppressing the levels; in many cases they actually increased the levels. However, the 48 deg slanted rear wall was shown to be very successful in suppressing the levels. The addition of stores was shown to lower the levels. The slot in the rear wall (for the sting to travel in) significantly lowered the modal frequency levels. The measured levels must be adjusted to account for this effect. The corrected levels are considered to be representative, but conservative, of levels that will be generated in full-scale aircraft with the same bay configuration.

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