Crusader Interior Noise Levels Due to Gun Firing

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The noise levels in the Crusader combat vehicle due to gun firing were a crew/human factors safety issue. This study reports on an engineering approach to predict noise levels in a test box subjected to gun firing conditions. An acoustic test box was designed and tested with measurements made of exterior surface pressures and interior noise levels due to large caliber gun firings. These exterior surface pressures were used to drive a finite element model of the test box to obtain box wall velocities. These wall velocities were then used as boundary conditions for a computational fluid dynamics model of the air inside the box. The resulting analytical noise levels were compared to test firing results. The comparison indicated that this approach provided a reasonable prediction of the box interior noise level. The same approach was then used to predict first order noise conditions inside a conceptual Crusader combat vehicle crew compartment.

1.0 INTRODUCTION

The muzzle blast pressure wave due to gun firing creates a concern about noise levels in the crew compartment of a combat vehicle from a human factors safety viewpoint. There have been limited studies which analytically determine noise due to explosions [1].

This study reports on an engineering approach to predict noise levels in a test box subjected to gun firing conditions. An acoustic test box was designed and tested to provide outer surface pressures and interior noise levels due to large-caliber gun firings. These outer surface pressures were used to drive a finite element model of the test box to obtain box wall responses which were then used as boundary conditions for a CFD model of the air inside the box. The CFD analytical noise level results were compared to test firing results. The comparison indicated that this approach provided a reasonable prediction of the box interior noise levels. Such an approach could then also provide an effective way to predict first-order noise conditions inside a combat vehicle crew compartment.

2.0 TEST BOX

A blast test box was constructed to provide a test platform for pressure and acoustic measurements of importance to the U. S. Army Crusader program. During ongoing gun firing tests, the test box was placed in the near-vicinity of prototype Crusader cannons. The box was part of the data collection system assembled to

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define the blast field near the cannon and provide data suitable for validation of analytical models used to predict pressure and acoustic loads associated with the Crusader design

The chosen test box design was based on estimates provided by the analytical model described herein such that the peak acoustic amplitude would be roughly the same as that predicted for the Crusader Self Propelled Howitzer in an earlier study. Further, the interior volume needed to be large enough so that acoustic measurements taken near the center of the box would not be indicative of near-wall conditions. In addition to measuring interior acoustic conditions, provisions were made to gather wall acceleration data and exterior wall surface pressures. Since surface pressures are known to be a function of the angle of incidence between the pressure wave and the wall surface normal, the mounting fixture (stand) for the box was designed to rotate and pivot to accommodate various box orientations without having to move the entire, large stand. The test box and the support stand are depicted in Figure 1.

Features of the box design relevant to the present topic are outlined in the following table.

Feature	**Parameter Value**
material of construction	aluminum
outside box dimensions	36 in x 36 in x 36 in
box wall thickness	2 in
box edge fastening	welded continuous, inside and out
support	4-point bolted on base
interior access	via hinged door (opening outward) on back wall with bolt-down closure

Table 1: Important Blast Box Design Parameters

The box with instrumentation was supported by a large, steel frame and designed to withstand the moments imparted by the blast on the box, provide for pivoting of the box relative to the gun muzzle, and mitigate significant movement of the box during firings. The box was instrumented with the sensors as outlined in Table 2.

Measurement	Transducer	Number	Mounting Provisions
exterior surface pressure	PCB 112A22	5 on 3 different walls	2 flush mounted, 2 recessed relative to outer surface for thermal isolation
interior acoustics	Larson Davis 2530/910B PCB 106M107	2 1	one mounted near center of box on an aluminum frame that was isolated from walls via shock isolaters mounted ¾ inch from inside of wall, center of front panel
acceleration	PCB 353B34 PCB 356A27 Kistler 8692B50	3 (on 3 different walls) 1 triaxal 4 (on internal microphone stands)	stud-mounted to aluminum wall at center of respective panels bolted to wall at upper left corner of front panel mounted to internal stands to monitor vibration of microphones and internal pressure gages

Table 2: Blast Box Instrumentation

Data was gathered and processed using a 32-channel Nicolet Odyssey system. Signals were acquired at a rate of 100K samples per second for each probe with analog filtering at 25 KHz. Typical results for acceleration at the center of the box surfaces under firing load are shown in Figure 2.

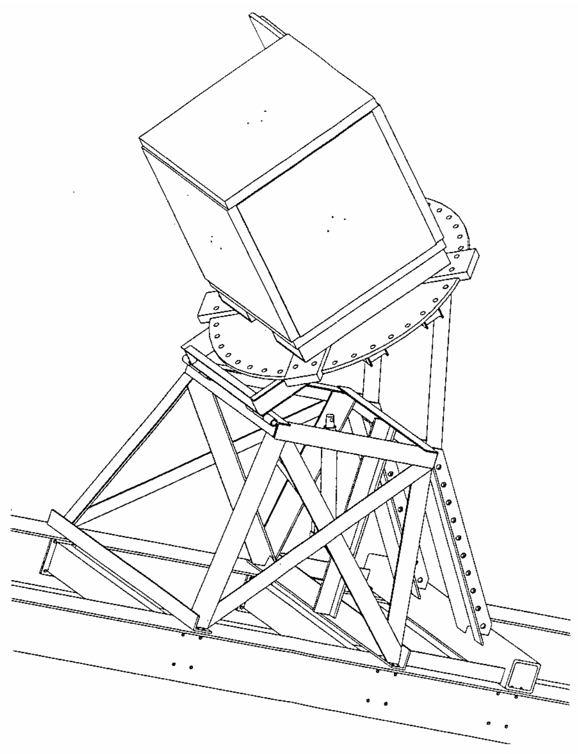

Figure 1: Test Box and Test Fixture

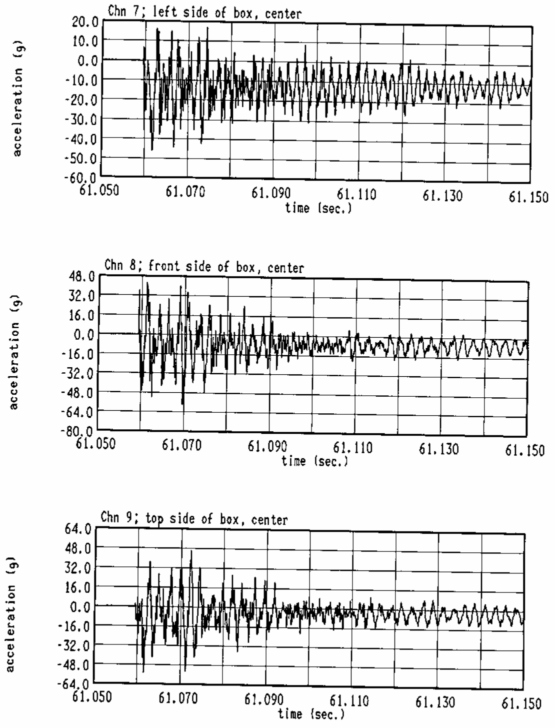

Figure 2. Test Box Center Acceleration Time Histories

3.0 EXTERNAL PRESSURE PULSES

As an incident wave impacts a solid surface, the amplitude of the reflected pressure wave at the surface can be significantly greater than the amplitude of the incident (free-field) wave. The ratio of the reflected wave and incident wave amplitudes is a function of the gas properties, the incident wave amplitude, and the angle of incidence between the wave front and the reflecting surface. In general, for an all-air pressure wave, the reflected pressure is between 2 (low incident wave pressures) to 4 (high incident wave pressures) times greater than the amplitude of the incident wave.

For the purposes of validating the methodology used to predict interior acoustic levels, the basic forcing function for estimating the displacement of the box walls was defined by the transient, reflected pressures *measured* at the box walls. That is, during this effort, no attempt was made to predict the incident wave characteristics from near-muzzle or inner-bore conditions. Also, with external, reflected pressure measurements made at only one point (at most) on a given box wall, the pressure measured at that single location (per wall) was applied uniformly to all points on that surface at any given time.

The pressure data was processed in a manner that facilitated its use by structural finite element analysis. Figure 3 is a typical time history of the reflected pressures on exterior walls of the test box.

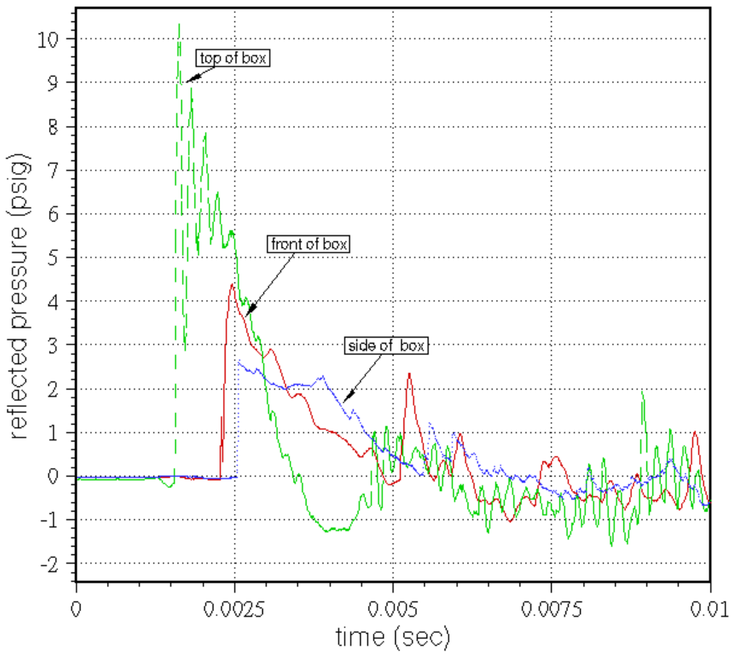

Figure 3: Typical Exterior Wall Pressure Time History

4.0 STRUCTURAL RESPONSE

A finite element model of the basic test box was created for use with the Abaqus/Explicit transient dynamic solver. This model is shown in Figure 4 and represents a half symmetry model of the test box. The loads applied to the box were exterior surface pressure time histories as defined in the previous section. Boundary conditions used were consistent with the fixture and symmetry conditions. The model is generally defined for a 6000 cps flexural frequency based on box wall geometry and assuming four one inch elements for the flexural half wave. Bending waves are assumed to dominate the response [2]. Damping was applied assuming a welded structure [3] and fundamental frequencies of the structural geometry. The damping is applied in the form of stiffness proportional damping and applies across all frequencies.

The results of interest were the time histories of the nodal velocities in the model which would be used as boundary conditions for the internal volume. A typical wall velocity contour is shown in Figure 5. This indicates the expected type of response for one instant of time for velocities in a direction normal to the front and back surfaces of the model.

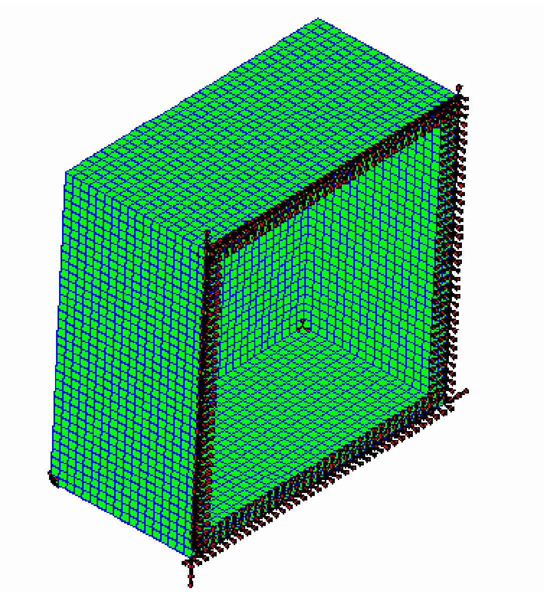

Figure 4: Box Finite Element Model

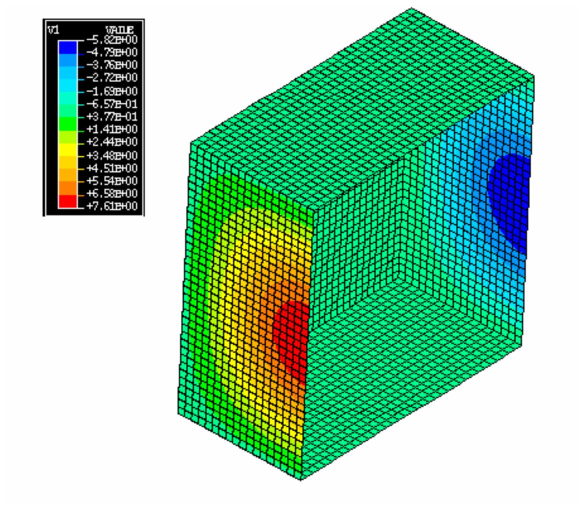

Figure 5: Typical Wall Velocity Contour

Typical results for the nodal velocity time history of several nodes along the centerline of the top surface from the middle to the side wall are shown in Figure 6. The fundamental frequency seen is comparable to that for an equivalent flat plate of the same geometry and thickness. Results such as these are saved for use in the computational fluid dynamics solution.

Figure 7 shows a comparison of SRS acceleration response spectra. The acceleration spectra for the top center of the box from the test results and the finite element solution are shown. The comparison is reasonable in terms of level and phases. Similar results were obtained for other positions on the test box.

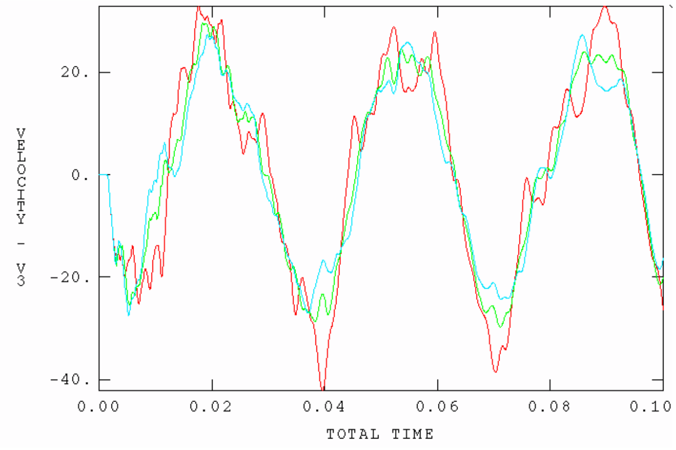

Figure 6: Wall Nodal Velocity Time History

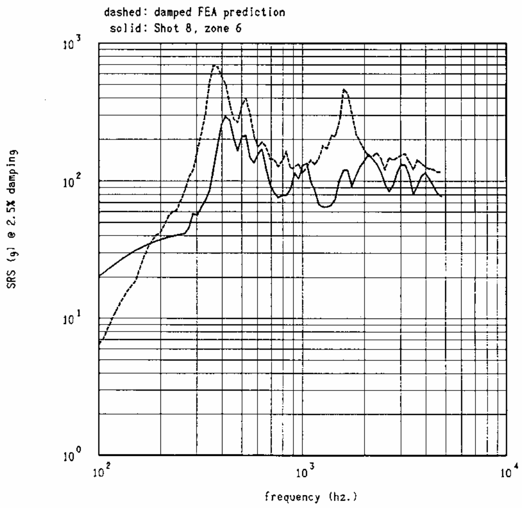

Figure 7: SRS Acceleration Comparison

5.0 CFD ANALYSIS

Point-by-point velocity time histories of the box walls as predicted by the finite element model served as the boundary conditions for the interior acoustics model. This model was developed using NPARC3D, a general-purpose computer code developed by NASA/Ames and modified by the Arnold Engineering Development Center (AEDC) for simulating viscous, turbulent three-dimensional compressible flows. The code uses a Beam and Warming finite-difference algorithm for solving, in curvilinear coordinates, the partial differential equations that govern the conservation of mass, momentum, and energy. Version 2.0 of the code was used for the analysis and Gridgen 11.0, developed by Pointwise, provided the grid-point mesh inputs to NPARC3D.

A uniform mesh geometry was selected so that the CFD domain boundaries corresponded with the FEA mesh. Based on length scale comparisons between the resulting grid and the anticipated smallest dominate acoustic wavelengths of importance, no modifications or refinements of the FEA mapping were deemed necessary at the time of the analysis. Fluid damping is possible through the low-level effects of fluid viscosity; however, no attempt was made to explicitly account for any acoustic damping that may have been provided by either the surfaces of the walls or the instrumentation mounting brackets enclosed within the space. Consequently, the duration of the acoustic event is not expected to be accurately predicted.

6.0 BOX TEST AND ANALYSIS RESULTS

In Figure 8, a graphical comparison is made between the measured acoustical data (near the box center) and the results predicted by analysis.

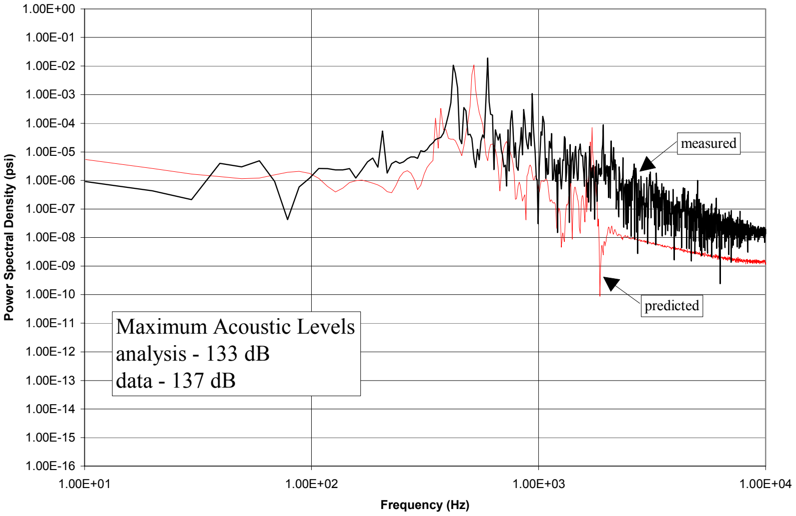

Figure 8: Power Spectral Density Comparison Between Measured and Predicted Interior Box Noise Levels

The graph depicts the power spectral density distribution for the predicted and measured results for frequencies ranging from 10 Hz to 10000 Hz. Further, the peak acoustic levels (in dB referenced to 20 μPa) for both the predicted and measured data are given. Generally, the analytical method yielded a peak acoustic level that agrees well with the measured peak level. Also, the peak power spectrum of the simulation and the measured data occur within the same frequency range of 400 Hz to 700 Hz. Further, the spectral comparison demonstrates that the frequency characteristics of the box-center simulation results agree well with the measured data; only at the higher frequencies (i.e., > 2000 Hz) does the predicted frequency deviate from the measured data frequency distribution. Those higher frequencies do not seem to significantly contribute to the peak acoustic levels as demonstrated in Figure 9. That graph shows the peak acoustic level for the measured and predicted waves with various amounts of low-pass filtering, as defined by the cut-off frequency on the ordinate. For cut-off frequencies above 2000 Hz, the peak acoustic levels are insensitive to the cut-off frequency.

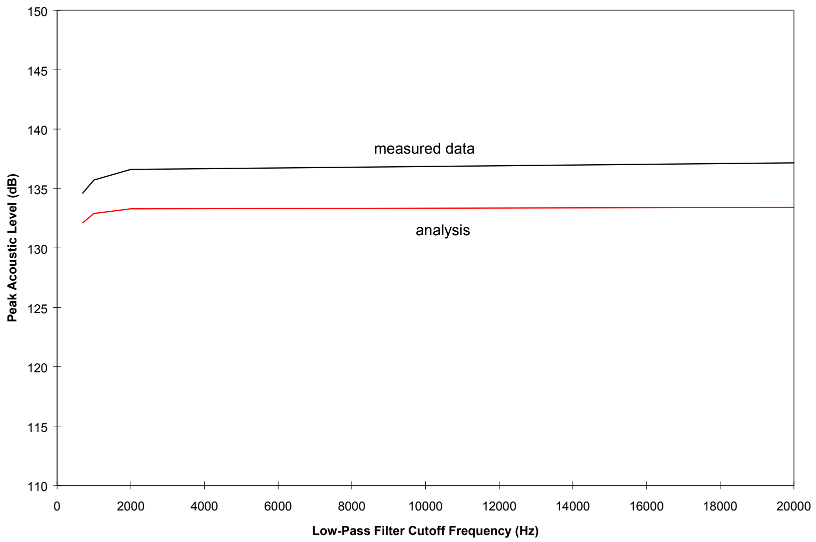

Figure 9: Effect of Filtering and Signal Frequency Content on Peak Interior Noise Levels.

7.0 CRUSADER APPLICATION

The reasonableness of the results for the test box analyses provides the confidence necessary for application to a more realistic situation. Hence, the structural analysis of a conceptual Crusader crew compartment follows the same procedure as the analysis of the test box. The half symmetry finite element model used to represent the Crusader crew compartment is shown in Figure 10. It corresponds to a simplified geometry which includes the essential plate structure with no attempt to model details. The wall thicknesses and material definitions correspond to proposed concept design conditions.

The structural model provided the boundaries for the simplified representation of the interior crew cab space. Among the simplifications were the lack of interior structures and components such as equipment, seats, and the crew members themselves. Further, the interior walls were approximated as purely reflective to acoustic waves with no inherent absorption or attenuation qualities. Thus, the predicted duration is governed by the structural attenuation and the weak viscous damping in the fluid. Peak acoustic levels were estimated within the space defined by the structural model. These levels are graphically depicted in Figure 11.

In the Crusader design, the crewmen's heads are located near the back of the crew space where the acoustic levels are predicted to be below 140 dB. Only near the front of the space in the wedge-shaped sponson area are the levels predicted to be above 140 dB.

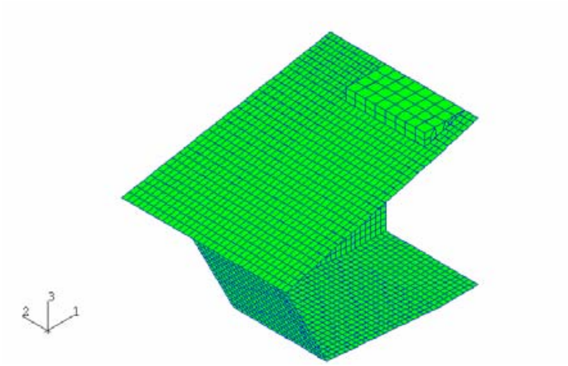

Figure 10. Crusader crew compartment model

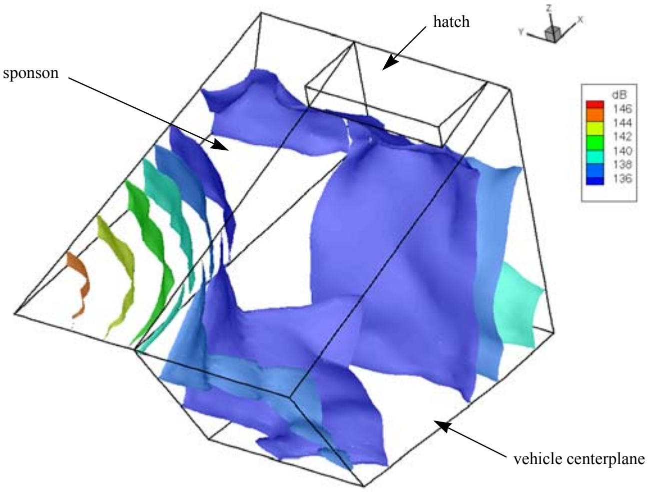

Figure 11: Peak Acoustic Levels Predicted for Crusader Crew Space

8.0 CONCLUSIONS

A method has been developed which makes possible the prediction of acoustic levels within an enclosure when pressure histories on the outer surface of the enclosure are given. The methodology employs standard computational tools with inputs based on reflected pressures on the outer surface. In the validation cases considered (of which only one is given in this paper), the comparison between predicted and measured interior acoustic levels appear reasonable both in terms of peak level and spectral content. Because the interior acoustics model did not account for wall attenuation of interior reflected waves, the duration of the acoustic event may not be accurately represented.

The method was applied to the design of the U.S. Army self-propelled howitzer program, Crusader. Using the best available design and gun blast information, the projected peak acoustic levels in the vicinity of the crew members was expected to be below 140 dB.

9.0 REFERENCES

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3. Gibson, W. O. and Austin, E. M., “Analysis and Design of Damped Structures”, *Finite Elements in Analysis and Design*, 1993, Volume 14, page. 337.