Naval Surface Warfare Center, Dahlgren Division

Sound Intensity Prediction System (SIPS) A Noise Complaint Management Tool For Explosive Operations

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SOUND INTENSITY PREDICTION SYSTEM (SIPS)
A NOISE COMPLAINT MANAGEMENT TOOL
FOR EXPLOSIVE OPERATIONS

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ABSTRACT

The Sound Intensity Prediction System (SIPS) is a range operations tool for the management of noise complaints. It is an acoustic ray tracing computer code employing weather data to determine the locations of both noise enhancements and reductions from the conduct of explosive operations. SIPS was installed at the Utah Test and Training Range, Hill Air Force Base, Ogden Utah in September 1994. Since then 2,400 tons of ordnance, at a rate of 20 tons per operation, has been demolished. There has been only one complaint, which was predicted but overlooked due to lack of experience in output interpretation.

SIPS has been employed in conjunction with the Blast Operational Overpressure Model (BOOM) to predict which areas along the Wasatch Front would become agitated by the sound generated during operations. BOOM is an empirical model based on a flat earth, and produces a generalized contour of sound intensity, while SIPS incorporates topography into the predictions. Extensive sound data were taken in populated areas between 1995 and 1997 for model comparison. Upper atmosphere weather data were collected by balloon soundings for model predictions before a decision was made for each operation. Results of the predictions and measurements over this three-year period of intense use are presented.

INTRODUCTION

On 3 November 1993, the Utah Test and Training Range (UTTR) of Hill Air Force Base (AFB) in Ogden, Utah disposed of two C-3 POSEIDON second stage rocket motors by open detonation in their Thermal Treatment Unit (TTU). The noise from the disposal generated numerous complaints in Salt Lake City, which is between 90 and 100 kilometers away from ground-zero, and the state of Utah stopped the program for 10 months. That detonation brought a great deal of visibility to the phenomenon of long range sound propagation (noise), and a keen appreciation of the refractive properties of the atmosphere.

In September 1994, the State of Utah granted a demonstration permit for the disposal of ten C-3 POSEIDON second stage rocket motors on the condition that no noise complaints were registered. A noise abatement strategy was developed by Hill AFB with the Blast Operational Overpressure Model (BOOM) as the centerpiece with contingencies to evaluate two additional models, BLASTO and Sound Intensity Prediction System (SIPS). The plan was to determine which model or combination of models would produce the greatest number of safe shot days without noise complaints bringing state involvement in the operation.

The successful completion of the demonstration resulted in the state granting a permit for the disposal of up to 85 motors per year. During the three-year period between April 1995 and October 1997, UTTR disposed of 2380 tons (TNT equivalent) or 238 POSEIDON rocket motors. The validation of the models was presented in a paper at the 1998 Global Demilitarization Symposium [1].

MODEL DISCRIPTIONS

BOOM is an empirical model developed by NSWC based on data from Mark-82 bomb drops (500 lb) and 5-inch gunfire (both projectile detonation and muzzle blast) [2]. Additional data was collected for Mark-83 bombs (1000 pounds TNT equivalent) placed by the Air Force Weapons Laboratory (AFWL) in Kirtland Air Force Base, New Mexico [3]. Since BOOM was originally designed to run on a programmable calculator, it simplifies the atmosphere to a two-point line segment of sound speed and altitude. The sound speed at ground level and the maximum sound speed at some point above the ground are used as input for a single direction. BOOM also assumes a flat earth with no terrain effects. The model’s strong points include providing a general description of sound distribution and sound level predictions in the direction of sound reductions. Figure 1 shows a typical output graph.

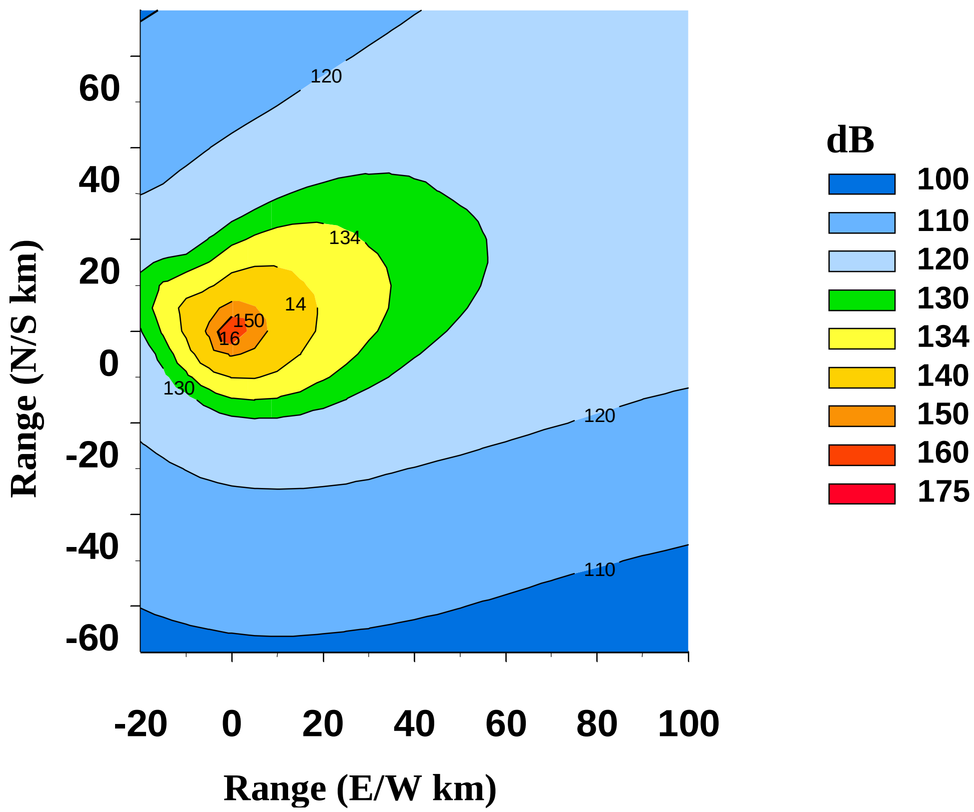

Figure 1. BOOM Flat Earth Sound Prediction

SIPS [4] is a two-dimensional ray tracing model developed by NSWC for use on the Potomac River gun range. Calculations are performed in a vertical plane defined by radial direction centered on a ground-zero. The atmosphere is divided into many stratified horizontal layers with the sound speed gradient in each layer assumed linear. Based on Fermat's Principle, sound rays are refracted through the stratified layers according to Snell's Law. Focal points are identified not just when a small group of sound rays converge on the earth's surface, but also when they share the same convergence point. Sound reduction areas, or quiet zones, are indicated when all the sound rays in a direction of interest are refracted aloft. Quiet zones are to be differentiated from shadow zones in that the latter occur when rays returning to earth arc over a particular area to create a zone of reduced sound intensity bracketed by areas of increased intensity. SIPS calculates the mean expected peak sound pressure level for a given distance and TNT equivalent charge weight by using the Ballistic Research Laboratory (BRL) curve [5]. At predicted focal points, 15 dB is added to the BRL mean expected level. If the rays return to earth without focusing a sound intensification increment less than 15 dB can be calculated by SIPS, but this is not output by the model; returning ray endpoints are simply noted on the output map in the sensitive areas. SIPS does not predict a sound intensity level for quiet zones. Terrain effects are modeled so that sound rays can be reflected, blocked or partially absorbed. The terrain maps are developed from Digital Terrain Elevation Data (DTED®) Level 1 data held by the National Imagery and Mapping Agency (NIMA). The resolution of the map is .01 degree of both latitude and longitude with the vertical resolution governed by DTED. Examples of SIPS graphical output are contained in Figures 2 through 4.

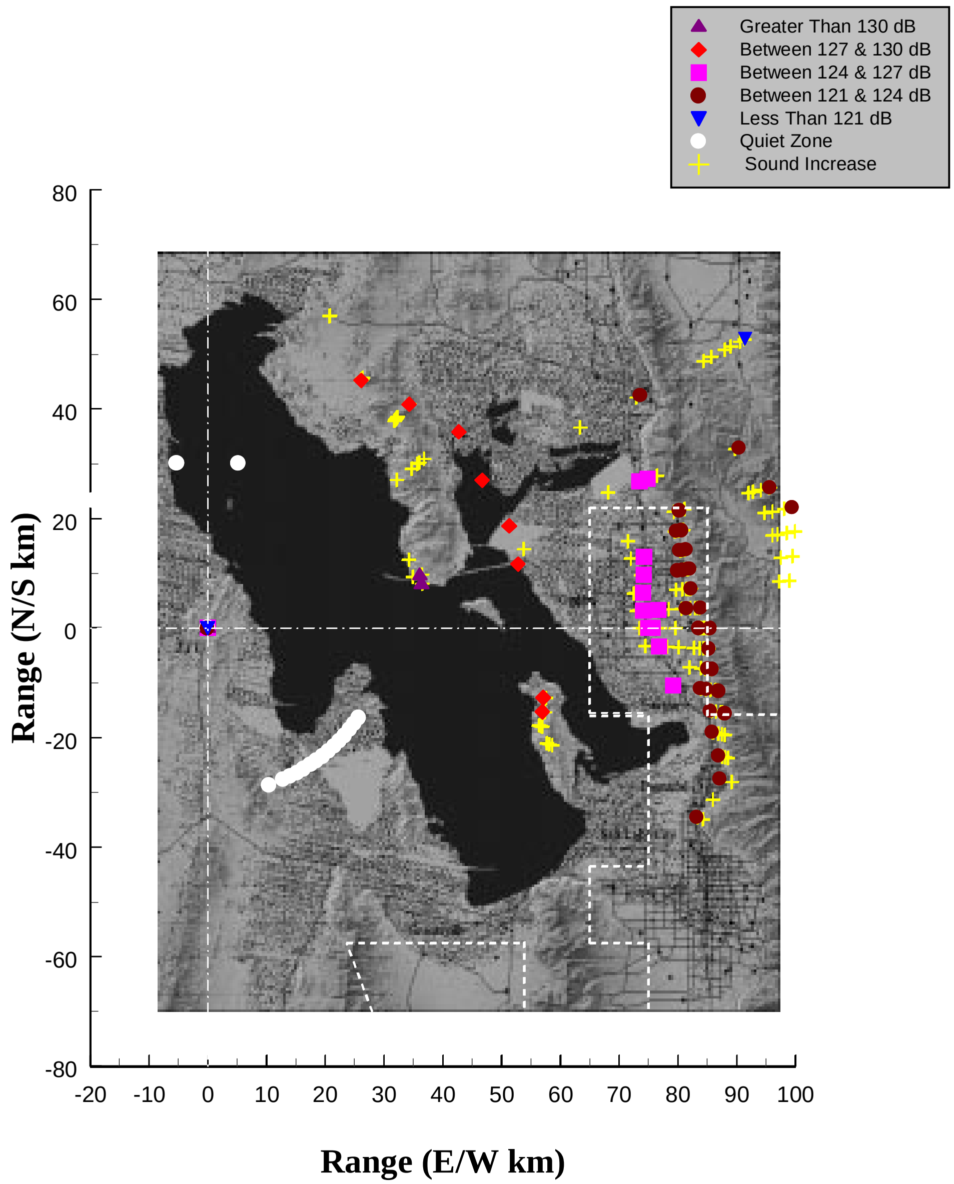

Figure 2. SIPS Ray Returns

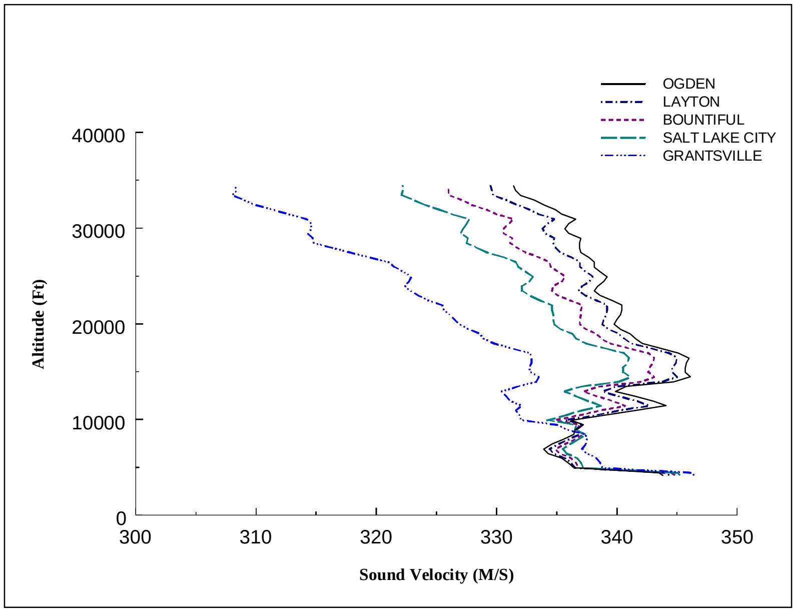

Figure 3. Sound Velocity Profile from SIPS

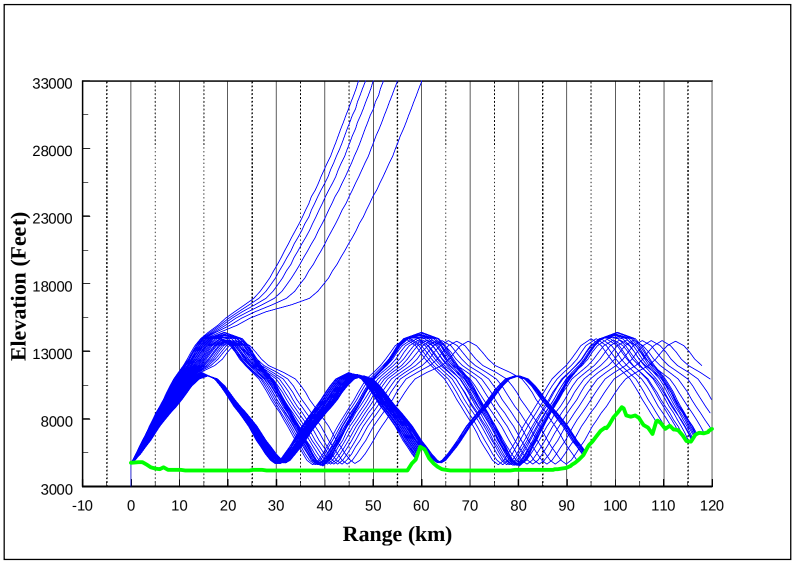

Figure 4. Ray Path from SIPS

It is interesting that the original curve fit employed by Lorenz of NSWC in BOOM closely matches the BRL curve employed by SIPS. When AFWL incorporated additional data, the curve fit remained parallel to, but rose 2.9 dB above, the Lorenz curve. The relationship between the three curves is shown in Figure 5.

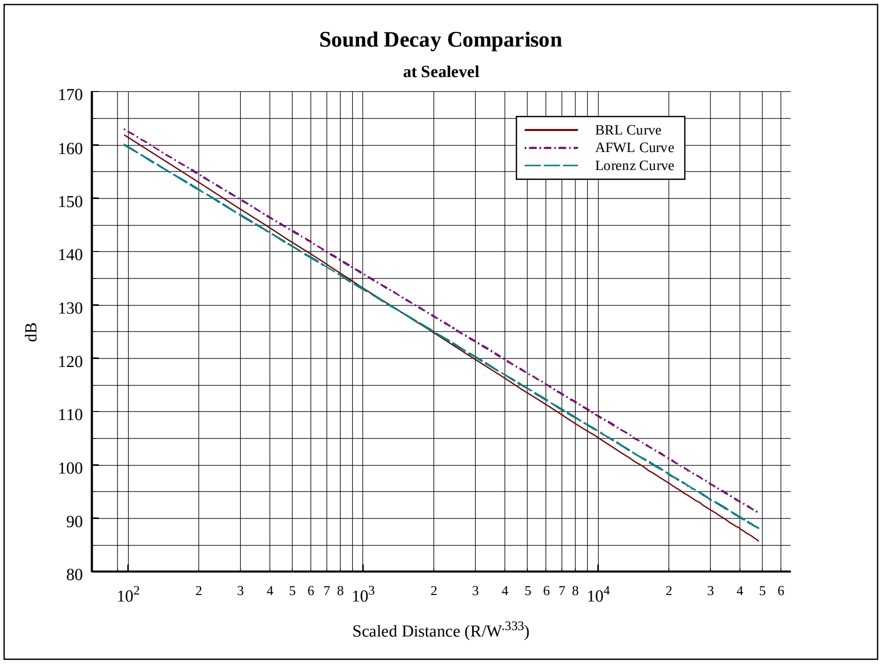

Figure 5. Comparison of Sound Decay Curves

MODEL OPERATIONAL USE

UTTR employs a conservative approach to noise complaint management for two reasons. First, the state of Utah suspended operations for ten months when a C-3 operation was conducted on a particularly bad sound propagation day and no prediction model was in use. This event led to the realization that a shutdown could happen again if noise complaints are received by the state. Second, the operational permit for the disposal of C-3 POSEIDON second stage motors allows for a maximum of 85 motors per year. Therefore, the sense of urgency to conduct operations and reduce the inventory is somewhat decreased. For these reasons, a set of procedures has been developed in terms of when and how each step of the operation is accomplished.

A normal operations day requires the launch of at least three weather balloons for sound propagation modeling. The flights provide temperature and wind velocity data to an altitude of 30,000 feet above ground level (AGL). The first balloon is launched at approximately 0830 to establish a baseline for the day's weather. This balloon informs the operations manager if weather conditions exist that will improve or are apt to cause cancellation of operations for the day. Typically, a temperature inversion at low level altitude improves during the day, while high wind velocity aloft is not likely to diminish. High wind velocities aloft usually define the approach of a weather front or a jet stream shift capable of directing sound energy to sensitive areas.

If the potential for an operation is confirmed by the initial weather balloon, additional balloons are launched at one- to two-hour intervals. These launches continue until the "GO" criteria either has been met or the operations manager cancels operations for the day.

OPERATIONAL "GO/NO-GO" CRITERIA

The "GO/NO-GO" criteria for UTTR has evolved as confidence in the sound propagation models increased and the attitude of the receptors toward noise became better known. Note that the receptors, Wasatch Front communities, are at ranges of between 65 and 100 kilometers (km) from ground-zero and that the equivalent TNT charge weights of the ordnance preclude physical damage to people or structures.

When operation restarted in September 1994, the "GO" criterion was very strict in that no increased sound energy could be directed toward the populated regions of the Wasatch Front. The decision was based solely on the output of the BOOM program as it was specified in the state operations permit. As confidence grew, and there were no complaints, the criterion was modified such that the BOOM prediction could not exceed 134 dB, 100 Pascals, at a range of 30 km. SIPS was also being executed during this time frame but the prediction was employed more to confirm the BOOM result. Solely employing the BOOM model resulted in the project's only registered complaint over the three-year period. One questionable operation was also conducted when focusing was predicted on Hill AFB. In both cases, SIPS predicted sound focusing for the operation in the area of the complaint, but the resolution of the weather data (1000 feet) was not fine enough to raise an alarm.

These two incidents resulted in a revision to the "GO" criterion and a refinement of the input weather data. The raw weather data is now divided into 500-foot increments that include all significant weather elevations. This layer thickness allows for a higher ray trace resolution. When the ray trace resolution increased, focus conditions could be plainly seen at the complaint location. The prediction of the complaint revised the "GO" criterion so that two conditions must be met:

1) BOOM prediction of less than 100 Pascals at 30 kilometers in the direction of populated areas.
2) SIPS predictions of no focus conditions within the populated areas.

This two-pronged criterion has been employed since June 1996 with no complaints being registered against the operation.

PROGRAM TRACK RECORD

The performance period being reported on covers April 1995 through October 1997. This represents three years of disposal operations at UTTR. During this period 171 operations were attempted, in that personnel and equipment were on site ready to proceed. The number of operations can be broken down for analysis purposes into the following categories, shown graphical in Figure 6:

1) Operation conducted with no adverse consequences
2) Operation canceled for non-sound related reasons
3) Operation canceled due to sound predictions
4) Ill-advised Operation (conducted with complaint)

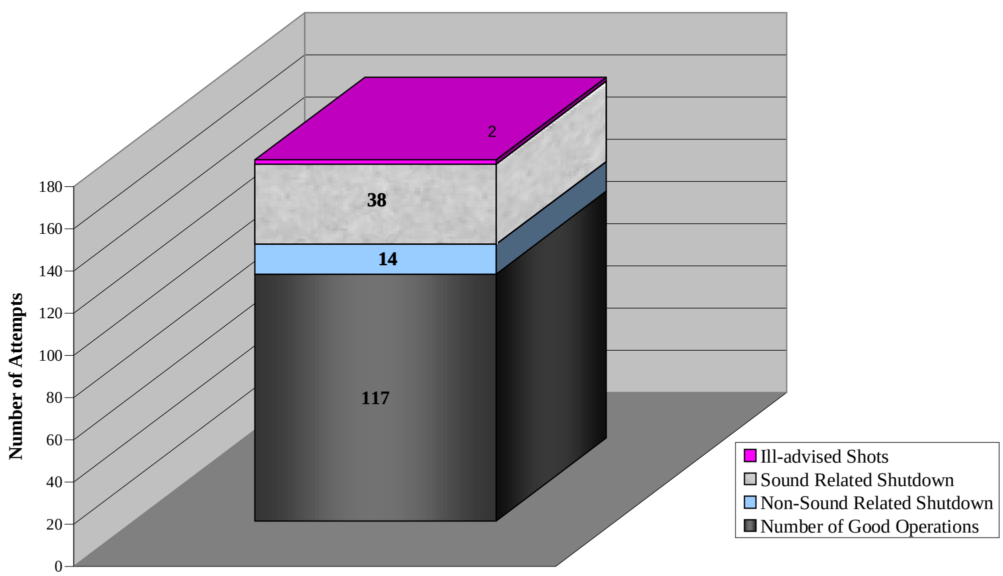

Figure 6. Summary of UTTR Operations (1995-1997)

There were 171 operations attempted during this reporting period; 117 were conducted with no adverse consequences to the project. Either, there was no sound propagated to the populated areas, there were quiet zones, or the sound levels were too low to annoy the population. These conditions constitute the perfect times for an operation. As would be expected the months with the most stable weather produce the greatest number of good days. This trend is shown in Figure 7 which contains the monthly summary of operations at UTTR.

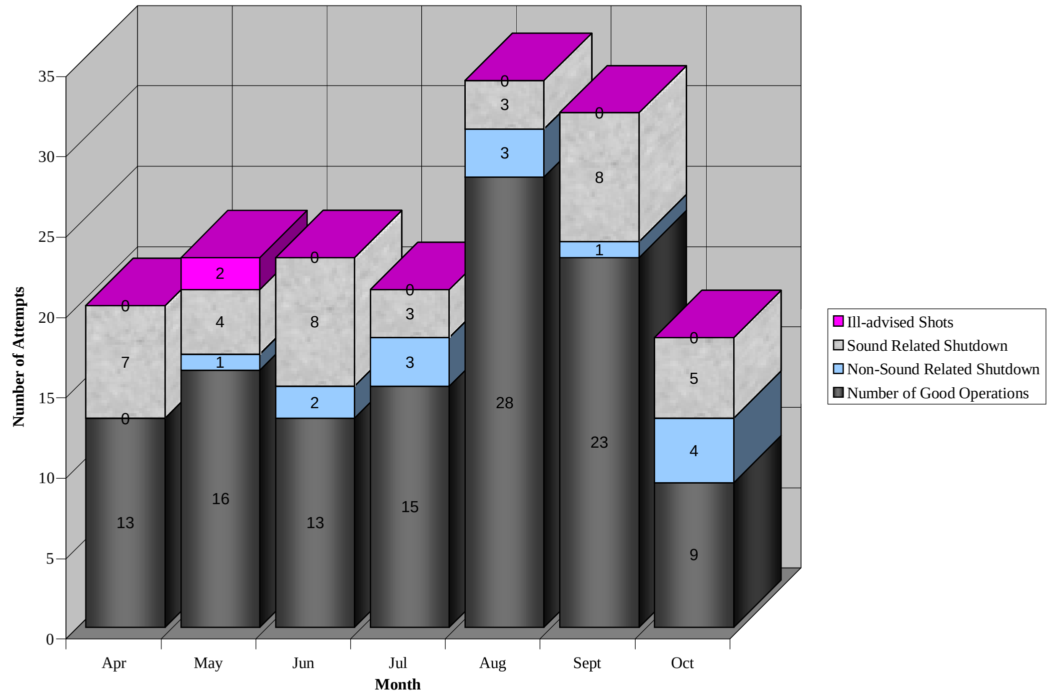

Figure 7. Monthly Summary of UTTR Operations

Fourteen operations were canceled for non-sound related reasons. The majority of these cancellations were safety related, such as approaching thunderstorms with lightning, and gusting surface winds higher than allowable for safe crane operation. In addition, in June 1996 the state instituted a clearing index requirement for dust and smoke. This requirement caused the cancellation of some operations that met the sound propagation "GO" criterion.

Thirty-eight operations were canceled due to the predictions of the sound propagation models. The exact reason for the cancellation would have depended on the "GO" criteria of the time but all of the cases showed excessive sound energy being directed toward populated areas.

Two operations were conducted which should not have been. There was one registered complaint in the North Ogden area as discussed earlier and the questionable operation where the Hill AFB public affairs office notified the press. This particular operation was one of three events heard at Hill AFB and the Ogden area. There was a sonic boom from a military aircraft and a detonation from a mining operation within minutes of the UTTR operation. Therefore, it is not clear which of the three events focused on Hill AFB because exact timing was not available.

While two operations posed a problem, valuable information for the project was obtained. A sound pressure level threshold for complaints along the Wasatch Front was determined. This level was found to be in the 120-125 dB range with a sharp cracking characteristic rather than rumbling. The complaint event also showed that the thickness of each atmospheric layer is important. If the layer thickness approaches ten times the blast wavelength, resolution decreases dramatically. A better approach is to have the thickness approximately five times the wavelength, or about 500 feet. This layer thickness produces a better distribution of ray returns making output interpretation easier.

INDEPENDENT EVALUATION

A contract was let by Hill AFB for an independent evaluation of the sound prediction models for UTTR during the 1996 and 1997 operation seasons. The role of the evaluator was to determine which prediction model was best suited for use at UTTR. During the evaluation period additional information was gathered which aids in explaining the phenomena associated with long range sound propagation. It is not often that a consistent charge weight can be detonated over a range of weather conditions and data collected of analysis purposes. Reference 6 documents the contractor's efforts.

One of the assumptions within sound propagation models is that the weather is horizontally consistent. In order to evaluate the assumption corresponding weather data was taken at UTTR and Salt Lake International Airport. The weather data at the airport was gathered by the National Weather Service (NWS) with the same system as UTTR. Four sets of data were collected at the sites separated by 65 kilometers with The Great Salt Lake between them. Analysis of the data was accomplished by comparing sound velocity profiles at the two sites. These profiles, though not a prefect match, followed the same trend with any variations being attributed to wind speed variations. The NWS data typically contained a greater number of small wind shears then did UTTR. Considering that it takes between four and five minutes for sound to propagate over this range, the horizontally consistent weather assumption seems valid.

The final recommendation of the evaluation was to employ a hybrid BOOM-SIPS model at UTTR. This approach remains conservative but provides a consistent means of predicting when sound energy from an open detonation may affect the installation's neighbors.

CONCLUSION

The BOOM and SIPS models continue to be run separately at UTTR but work is underway to combine them into one code. Uniting the codes will allow the strong points of each to be employed to produce predictions of higher accuracy. For example, the empirical part of BOOM can be used to provide an estimate of the sound pressure level in quiet zones. The ray tracing techniques of SIPS are thwarted when used in quiet zones because all the rays are sent aloft, but SIPS can use pairs of returning rays to calculate sound intensification factors on the ground. BOOM provides a good general idea of sound distribution because its output is easily presented as contour plots. SIPS provides more detail by showing ray interactions with terrain, the effects of reflection on water, definite focal points, and it makes use full use of all the weather data. Future work on SIPS includes three-dimensional ray tracing and the effects of reflections on terrain, and an empirical two-parameter study to see if a BOOM resolution enhancement is possible.

The wealth of data collected during the evaluation will require time for a complete analysis to be accomplished. This data however should provide the means to greatly increase the accuracy of long range sound prediction. Many questions remain. Does sound decay at a lesser rate over water? How much sound reduction to expect from the terrain surrounding ground-zero? Does a three-dimensional model provide any advantages? The hybrid BOOM-SIPS is not perfect but, one noise complaint in three years leads to a realization that it can be employed as an effective noise complaint management tool.

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