# Acoustic Considerations for Land Combat, Entity-based Simulation

**Michael D. Proctor, Ph.D.**
University of Central Florida
Orlando, FL
*mproctor@mail.ucf.edu*

**William J. Gerber, Ph.D.**
Dynamics Research Corporation
Orlando, FL
*wgerber@drc.com*

Acoustics is an important consideration for realistic agent behavior in land combat, entity-based simulation models. This research describes basic approaches to representing and applying outdoor sound with limited discussion of the evolving field of indoor acoustics in such simulations. Attributes necessary for acoustics representations are identified within a framework along with alternative implementation techniques. Capabilities and limitations of selected alternative techniques and algorithms are described.

**Keywords:** Acoustics, framework, entity-based simulation, DISAF

## 1. Overview and Purpose

How could soldiers conduct operations without sound and hearing? Perhaps this is a rhetorical question for some, but in land combat operations, dismounted infantry use sound as cues to events in the environment and to the presence of others. Explosions and weapons firing are but two examples of events whose occurrence often are first realized by soldiers through sound and hearing. Voices or noises associated with movement are but two examples of cues to the presence of others in the environment. Additionally, sound and hearing are fundamental to collaborative behavior among soldiers. One of the simplest illustrations is a verbal order from a fire team leader to his team. Issuing an order to a team or crew is found throughout the military and is one aspect of command and control. Hence sound also is a direct bridge from cues for events and entities to cues for command and control of other entities. Further, from a materiel acquisition point of view, sound is important as it is representative of the "perceiving first" principle of the Future Combat Systems. Sound and detection of entities will be an important part of future combat systems.

From a simulation perspective, sound and hearing complement vision and perception to make for a more realistic simulation. Cognition and perception research indicates a logarithmic rather than a linear relationship of increasing number of senses to increasing realism. Hence adding sound to a visual representation makes it four times, not just two times, as realistic [1]. As with other logarithmic relationships, the contribution to additional realism from additional senses drops off. This is illustrated in Figure 1.

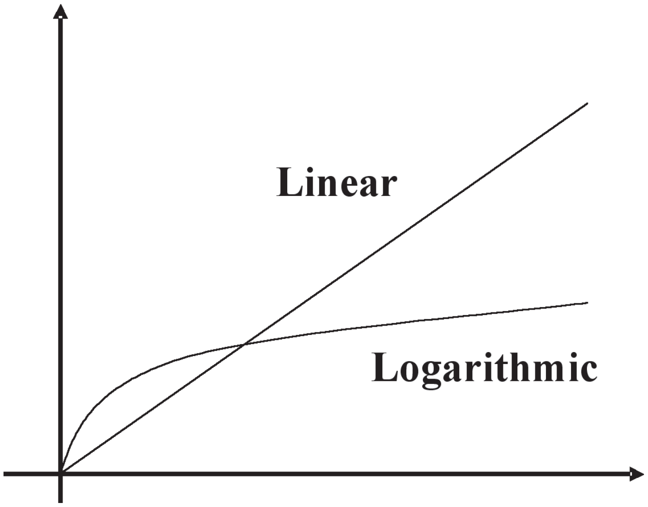

**Figure 1.** Notional illustration of the logarithmic relationship of realism (y-axis) to number of senses involved (x-axis) based on Satava and Jones [1]

Intuitively sound and hearing both are critical to entity-based, land combat operations. Sound is an essential component of the natural environment. Sound facilitates verbal communications, provides both humans and machines cues to events and other objects in the environment, enhances situational awareness, and enables an appropriate response. Due to factors such as cost, safety, environmental concerns, or materiel non-availability, simulation use in training, research and development, and concept exploration is rapidly increasing. Since invalid and/or non-accredited simulations clearly could lead to negative training, inappropriate materiel assessments, and/or false leads in concept exploration, concern immediately focuses on the suitability of the underlying models.

## 2. Research Objective and Scope

To aid in realistically and accurately simulating such operations, this research considers acoustics algorithms abstractly as well as within the context of simulations with entity/object model implementations. This paper addresses acoustic fundamentals first, followed by a detailed case study of an entity/object based simulation implementation of acoustics, specifically the Dismounted Infantry Semi-Automated Forces (DISAF) simulation model. Finally, conclusions, limitations, and recommendations for future research are provided.

This research also may be used as a reference for acoustic modeling for the military simulation community. The research provides insight into the capabilities and limitations of various acoustic algorithms for simulating entity-based, land combat operations. Algorithms may support binary or stochastic implementations of computer-generated entities or provide interval data for humans participating in a virtual environment. General entity-based, land combat operation applications include all those currently envisioned for DISAF, OneSAF Testbed Baseline (OTB), and the follow-on OneSAF Objective System (OOS). This research is not intended to replace a needs analysis for specific training applications or a requirements analysis for specific materiel developments. Nor is it intended to be an "unfettered," "unfocused," or "unbounded" "pursuit of high fidelity" model as some might think such efforts [2]. Rather this research provides primarily a scientific framework for acoustics in simulation and supports that framework with a case study. This framework provides future modelers a perspective on the potential gains to simulation that acoustics offer for entity-based, land combat operations. The case study provides insight on impacts and shortcomings that acoustics has had on a major existing application.

The following discussion of DISAF, OTB, and OOS is provided as way of further explicit description of the entity-based, land combat context in which the acoustic models will be used, essential features needed to support that use, and which of those features are included.

First, the primary emphasis in DISAF is to develop tactical behaviors for individuals through squad level operations. Specifically, how a soldier at a squad level of operations moves and conducts himself on the battlefield. Efforts have been made to allow an immersed soldier to not only interact with, but control Dismounted Semi-Automated Forces (DISAF) and it's computer generated entities. An immersed soldier now has the ability to command a fire-team to respond to such orders as: Move Out; Move to Objective Point; Get in Wedge; Commence Fire; and Cease Fire, either by giving a gesture or voice command [3,4].

Secondly, OneSAF Testbed Baseline (OTB) is platform independent software for integration, test, and user feedback of technology developments for the OneSAF objective system (OOS). OTB version 2.0 is available by subscription. OOS is intended to be a composable, next generation computer-generated force that will represent a full range of operations, systems, and control process from entity up to battalion level, with variable level of fidelity that supports all M&S domain applications with an emphasis on human-in-the-loop and no human-in-the-loop [5,6].

## 3. Acoustic Fundamentals and Definitions

The purpose of this section is to review fundamental acoustic algorithms used to represent the science of sound so as to give perspective on the suitability of existing approaches for auditory stimulus of agents in entity/object-based models. Davis and Anderson [7] describe objects as entities wherein "'physics-level' engagements occur" (p. 8). A detailed discussion of acoustics is beyond the scope of this research. Selections of representative algorithms are not intended to be limiting, but are possible approaches based on acoustics that take into consideration possible computational limitations of real-time simulation applications. Selected aspects of acoustics discussed below represent fundamental approaches for speed of sound in air, attenuation of sound in outdoor settings, representation of sound in enclosures, and perception of sound by agents.

The science of acoustics strengthens the realistic representation of sound in combat models. Sound differs from visual line-of-sight in a number of ways. First, as explained further below, geometric spreading, refraction, diffraction, and reflection of the sound wave results in non-linear and long-distance perception in the real world. Second, sensors, such as the human ears, support omni-directional perception rather than just the field of regard perception, as is the case of visual sensors. Third, sound is temporal whereas vision may allow for multiple detection opportunities. On the other hand, sound impinges on the human ear thus providing an alerting and sometimes startling stimulus. Vince, Stuart, and Sherman and Craig [8,9,10], provide more discussion on the interaction of sound and humans in simulation. Agent representation of a human in simulation would draw on these same characteristics.

### *3.1 Speed and Refraction of Sound in Air*

Propagation of sound from a point source may be modeled as a wave front that expands in a spherical manner from the source. Mathematically the speed of that sound wave in air can be found in most text books. One source is Speaks [11]:

$$S = \sqrt{(E/\rho)}$$

where S is speed, E refers to elasticity of the medium and ρ refers to density of the medium. Typically for entity-based simulations this formula can be simplified. The speed of sound at 0ºC is 331m/s and increases with temperature because an increase in temperature decreases air density. The increase in speed in air occurs at a rate of approximately 0.61 m/s for each 1º C [11].

Refraction of the symmetric wave occurs when the wave front is transmitted into a different medium. Portions of the front may incur speed changes as the temperature of the medium changes. Temperature and wind speed changes are important causes of refraction resulting in sound shadows and sound focusing. Figures 2, 3, and 4, which are based on [12], artistically illustrate in two dimensions some possible refractions of sound by increasing wind speed at higher altitudes, decreasing temperature with altitude under still air conditions, and increasing temperature with temperature inversion.

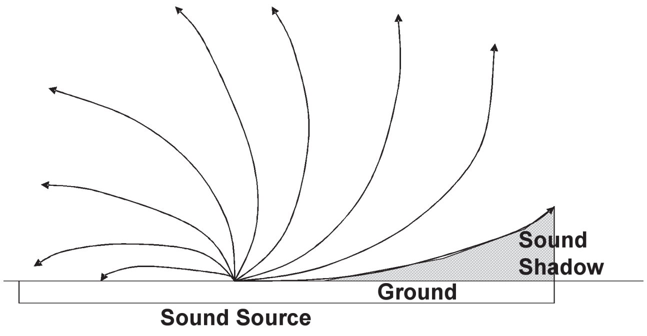

**Figure 2.** Artistic representation of the refraction of sound in air as wind speed increases with altitude [12]

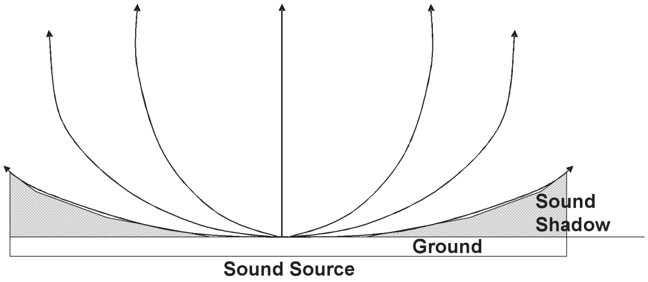

**Figure 3.** Artistic representation of the refraction of sound in air with normal temperature decrease and an increase in altitude [12]

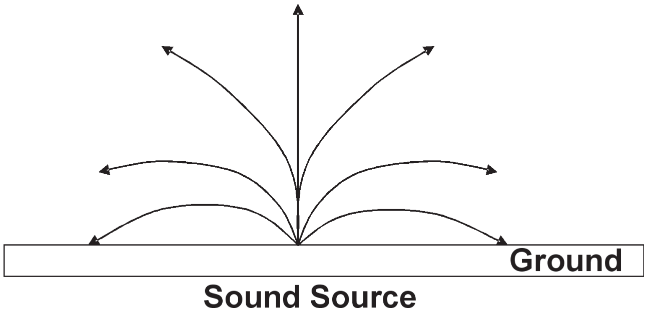

**Figure 4.** Artistic representation of the refraction of sound in air with increasing temperature and an increase in altitude as occurs during a temperature inversion [12]

### *3.2 Attenuation of Sound Level in an Outdoor Setting*

One source for mathematical representation of attenuation of sound level in outdoor settings as measured in decibels is provided by Sutherland and Daigle [13] as:

$$A_t = A_s + A_a + A_e$$

where $A_t$ represents total attenuation, $A_s$ attenuation due to geometric spreading, $A_a$ attenuation due to atmospheric absorption, and $A_e$ attenuation due to other effects. Other effects include attenuation due to the ground and its features such as foliage, refraction by a non-homogeneous atmosphere, diffraction and reflection by barriers, and scattering or diffraction due to turbulence [13]. Only symmetric and uniform attenuation due to geometric spreading and atmospheric absorption will be addressed at this point.

#### 3.2.1 Attenuation Due to Geometric Spreading

Sutherland and Daigle [13] express attenuation by geometric spreading as:

$$A_s = 20g \log_{10} (r/s)$$

where g is one for spherical wave propagation from a point source, r is the distance of the receiver from the source, and s is the distance from the source at which the reference sound level being attenuated is measured, typically a unit distance value, e.g., one meter. This formula can be simplified for entity-based, land combat models since the doubling of the distance from the source results in an approximate 6 dB loss. Major deviations of this formula may occur when non-uniformity of the atmosphere is considered or when the sound source is something other than a point.

#### 3.2.2 Attenuation Due to Atmospheric Spreading

Sutherland and Daigle express attenuation by atmospheric absorption as:

$$A_a = \alpha r$$

where $\alpha$ is a tabled attenuation coefficient expressed in decibels per meter based on temperature, humidity, and frequency. Sutherland and Daigle provide one such table (p. 308). r is the path length. Attenuation due to atmospheric absorption at long distances and for high frequencies is usually much greater than losses due to geometric spreading. Pre-calculation and tabling of these values can minimize computation load through table lookup during entity-based model execution.

### 3.3 Sound in Enclosures

Structures affect the transmission of sound. Tables are widespread in the literature that document acoustic transmission loss through absorption by architectural materials. In one such table, transmission loss due to wall types does vary from 30 dB to 50 dB [14]. Transmission loss due to other architectural materials such as floors, ceilings, windows, and doors also varies and can be accessed through a table look up. Additional considerations include reflection of sound off surfaces and diffraction of sound through openings. Further, structure-borne sound can be transmitted along structures and re-radiated [14].

### 3.4 Perception of Sound

Perception of sound by humans or their simulation agent equivalents introduces the field of psychoacoustics. Psychoacoustics is the science of human and animal psychological response to sound and covers hearing threshold, loudness, masking, localization, binaural hearing, ageing effects, etc. [15]. This includes but is not limited to understanding of why constant sound drops out of our awareness while unexpected change draws attention. Further, psychoacoustics considers auditory scene analysis where we discriminate between sounds and associate objects with those sounds. Additional considerations for agent perception of sound include how reflected and diffracted sound waves can reduce the ability of a listener to locate a sound source. Intelligibility of speech also is adversely affected not only by transmission loss but by reverberation of sounds. Conversely, sound also can aid in determining movement of a sound producing entity through the Doppler effect. For illustrative purposes, hearing threshold and masking, localization and binaural hearing, and auditory perception and warning signals will be discussed below.

#### 3.4.1 Hearing Threshold and Masking

The human auditory system is sensitive to huge ranges of sound intensity — from 0 dB to the threshold of pain, 140 dB [14] — and frequency differences — from 20 Hz to 20 kHz [8]. Masking of sound due to noise such as louder sounds and/or lower frequency sounds can obscure auditory perception. Absolute thresholds depend on frequency, bandwidth, and duration of the signal [16]. Interference of a signal by a masking sound may decrease the perceived loudness, discrimination, or audibility of that signal. The masking ability of noise has been characterized by various schemes to include the Articulation Index and the Speech Interference Level [14]. Non-simultaneous auditory masking may occur by the onset of a brief masker either before or after a signal [16].

#### 3.4.2 Localization and Binaural Hearing

Under field conditions a listener can not presume to know exactly where a sound is coming from. Localization is the psychoacoustic phenomenon by which a listener can determine the direction and distance from which a sound emanates [10]. Localization cues are inter-aural sound level difference, inter-aural time perception difference, pinna filtering, reflection/reverberation, and Doppler effect or shift [9]. Figure 5 illustrates the Doppler effect

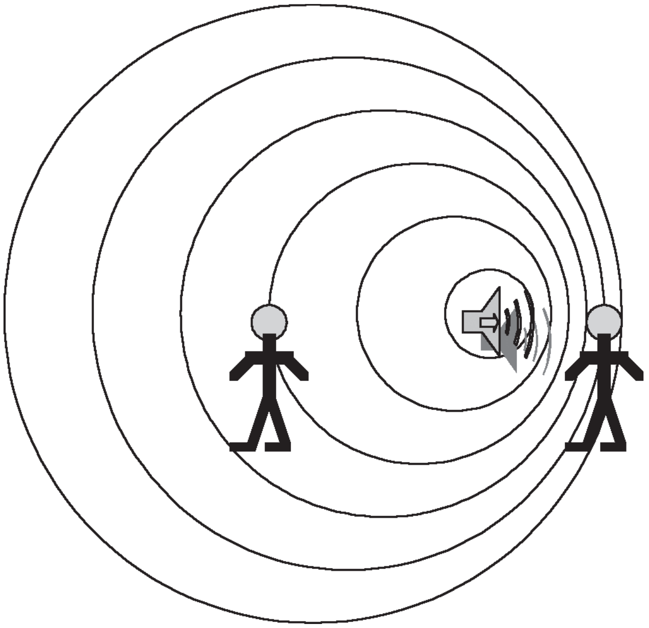

**Figure 5.** Illustration of sound wavelength compression/expansion of an approaching/departing sound source

with the compression of the wavelength from a sound source as it moves toward an individual (shown on the right) and expansion of the wavelength as the sound source moves away (shown on the left).

Mathematically the maximum and minimum perceived frequency change due to the Doppler effect may be found in Speaks [11] as:

$$f' = f*(s/(s-s_s))$$

where $f'$ is the altered (perceived) frequency, $f$ is the frequency produced by the source, s is the speed of the sound wave, and $s_s$ is the speed of the moving source.

In essence, sounds from an approaching object will be perceived with an increased pitch, i.e., a shorter wavelength. A pitch drop occurs as $s_s$ takes on a negative value when passing the listener and then the sounds from the receding object will be perceived with a decreased pitch, i.e., a longer wavelength.

### *3.4.3 Auditory Perceptual Learning and Warning Signals*

Auditory perceptual learning is one dominant factor that determines a listeners' ability to detect, discriminate, and identify complex sounds [17]. Stimulus uncertainty adversely influences detection and discrimination thresholds obtained through learning. Thus training involving repeated issuance of commands between team leaders and team members may increase the auditory perception of those commands by the team members. Further, audibility of warning signals is guaranteed when 6–10 dB above threshold in laboratory conditions and 16–22 dB in field conditions. Warning signals exceeding 30 dB above threshold may engender a startled response from the listener [17].

## 4. Sound as a Cue to Agent Behavior in an Entity-based Model

While non-real-time simulations exist that have highly regarded acoustic representations, one rapidly emerging simulation for Army-wide applications that crosses training, research and development, and concept exploration applications may be found in the OneSAF Testbed Baseline. Therefore the OneSAF Testbed Baseline is an appropriate case for study. While the first version of the OTB did not incorporate sound, a closely related simulation, called Dismounted Infantry Semi-Automated Forces or DISAF, did [18]. Since the DISAF sound-related algorithms will be added to the next version of the OTB, the inclusion of those algorithms is assumed in remaining comments on the OTB. The appropriateness of OTB synthetic environment and agent behaviors is significant, as it already has provided both a synthetic environment and the synthetic entities in which the performances of combat systems of the future have been evaluated. In addition, the OTB should lead to future training environments for Army combat personnel as well as provide an environment to explore concepts about future doctrine and materiel.

Given the potential influence of OTB on the full spectrum of future activities, this research investigates the initial state of the acoustic synthetic environment and pseudo-psychological processing of acoustical events by agents that inhabit the synthetic environment. The results provide insight into OTB from an acoustic perspective affording acoustic researchers a departure point for proposed enhancements. Deficiencies in the state of acoustic modeling or behaviors in a synthetic environment like OneSAF Testbed Baseline modeling may seriously undermine the validity of any simulation outcome where sound plays an important part. This can be recognized in a situation where a human is immersed in the synthetic environment and participates with computer generated agents. For example, consider a virtual synthetic training scenario in which shots are fired. A participating human may respond to the sound by taking cover. Unless a participating computer-generated agent can likewise detect and respond to the sound by taking cover, the result will be an unfair fight, with a possible negative training outcome in a training environment. Similar examples may be found in other training, research and development, and concept exploration applications. We wish to avoid these potential problems.

## 5. Acoustical Representation in DISAF

The DISAF source code provides insights into existing stand alone approaches to establishing an acoustical environment and agents with the capability to process acoustical events. While DISAF, OTB, and OOS support High Level Architecture (HLA) and Distributed Interactive Simulation (DIS) applications, federated approaches to acoustic representation is beyond the scope of this research. A summary of the DISAF algorithms with respect to the acoustic algorithms is found in Table 1 at the end of this section.

### *5.1 Existing Sound Generation and Degradation*

Examination of DISAF source code revealed that acoustic capability provides for generation of sound due to movement of entities and gunfire. Sound generation due to movement was modeled on a maximum sound level in dB at maximum speed (both read in for each vehicle type) with a linear decrease to 0 dB at 0 speed. Sound generated due to gunfire was based on a fixed value for each munitions type (also read in). The listening agent would process the sound at its next period of listening, which was at 500 msec intervals (read in), but only for vehicles within a maximum range of its hearing (read in as 1,000 meters). While there was no time delay implemented to account for the speed of sound and the distance between the sound generation entity/gunfire location and the listening agent, the level of sound was decreased logarithmically based on distance using the formula $20*\log_{10}(\text{distance})$. Additionally, the sound level was decreased by up to 10 dB more, proportionate to the amount of obscuration of line of sight (LOS) between the two locations [19]. The sound source was given a large specific size (10 meters by 10 meters) for determining the proportion of obscuration so that small obstacles near the sound source would not block much sound. The fraction of obscuration was determined using the visible LOS function with the acoustic sensor location as the eye point location and the sound source location as the LOS function target location. The minimum threshold sound that could be heard was 5 dB (read in). Sounds also were masked below a level 30 dB (read in) below the loudest sound received at the listening agent's location from other vehicle movements/gunfire. However, the listening agent's own generated sound was not considered in determining the maximum sound to use for masking other sounds. There were no overt behavior responses due to the listening agent's receipt of sound, but the Graphical User Interface (GUI) situational awareness display for the listening agent, if selected by the user on the GUI, would indicate which other entities could be heard and when they could be heard.

### *5.2 Potential Sound Input: Message Traffic Protocols and Limitations*

Other participants (such as humans or other simulators) in a DISAF simulation are accommodated through message traffic between participants. For example, an M16A2 small arms weapons firing from a broadcasting agent to a receiving agent is accomplished with a Fire Data Unit. The receiving agent, not associated with any specific vehicle, captures the Fire Data Unit sent by the broadcasting agent along with its content. Included in the content is the ID of the firing agent, the firing location, the munitions used, and the time tag for when it was sent. The receiving agent immediately processes the information (except for the time tag), using the projectile type to obtain the sound level from data files read in at initialization. It creates and fills in a fire event structure using the firing ID, location, munitions information, and sound level. It then computes the maximum range at which the sound level can be heard and creates a list of all vehicles within that range of the firing location, excluding the firing vehicle. Finally, it iterates through the vehicle list and adds the fire event structure to each listening agent vehicle's fire event queue for later use in its next processing cycle.

Although the task addressed only small arms weapons firing, the existing protocols are likewise sufficient for the listening agent to process standardized simulated sounds produced by movement of vehicles, including individual combatants. Sound is standardized typically with set values, as stated earlier, for maximum sound at the maximum speed. There is no provision for "silent running" or contrastingly, for "excess noise." Further, the acoustic algorithms do not provide for voice, clanging of metal, or other such cues that Agents might use to focus their attention. The Entity State data unit, which includes entity ID, vehicle type, location, speed and a time tag, provide the information needed via message traffic for standardized sound. The Entity State data unit is normally passed to other agents and simulations. The listening agent uses the state information (current speed and location) from each broadcasting vehicle's model and the read in data for the broadcasting vehicle (the maximum speed and the maximum sound at maximum speed) to determine whether it could hear the movement sound level.

### *5.3 Identified Acoustic Degradation Deficiencies*

The masking effects of sound produced by movement and gunfire of the listening agent are not currently considered by the code. There is a proposal to include these sounds in this list for determining the maximum sound received. Since the maximum sound level is used as the basis for masking sounds at levels more than 30 dB below that maximum sound heard, without this addition, a moving listening agent could be shown erroneously as detecting sounds that should be blocked by its own sound of movement. Similar to movement sound, the sound of gunfire by the listening agent also is not currently accounted for though there is a proposal to add it to the sound list as well.

The DISAF code does not currently account for the speed of sound, thus the arrival time of sound at listening agents is not accurate. Given that the DISAF only processes sound out to 1,000 meters from a listening agent and that the DISAF operates at a 500 milliseconds update rate, the maximum error possible in the system is up to 2.5 seconds early through 0.5 seconds late. An algorithm is being developed to use existing time tags to properly order acoustic events. A new, separate list would have to be maintained for each listening agent that would include each sound event and the expected time for arrival of the sound. Each time a movement sound is generated and processed, the expected time of arrival would be calculated based on the distance between the generated sound location and the current vehicle location and a sound event would be created and added to the list. The same calculations and new events would be made for the sound generated by Fire events as well. For ground vehicles, the speed of the listening agent would be considered negligible compared to the speed of sound, so the time of arrival of the sound would be calculated only once based on the current locations and stored with the sound event. For high speed aircraft, the time of arrival could be recalculated at each time tick, but that would be more computationally expensive. In any case, the degraded sound, degraded due to distance and obscuration, would have only to be calculated at the time the event would be processed as having arrived. To determine what the listening agent would hear, the list of sound events would be processed based only on those that would have arrived since the last time the events were processed. For determining masking due to the loudest sound, the maximum sound also would be based only on the sound events being processed as arriving together. Once a sound event has been processed as arriving, it would be removed from the list.

For the simplest model, a constant value for the speed of sound, such as 331.45 meters/second at standard temperature and pressure with 0% humidity, would be read in. For higher-fidelity models, variations due to temperature, humidity, and the effect of wind could be considered.

Although not implemented in the DISAF, a framework for sound due to gunfire is included. If implemented, the standardized sound would be handled similarly to that of gunfire. The information needed would, in that case, be provided by the existing protocols used to transmit detonation data.

### *5.4 Agent Behavior Response*

The agent behavior response should be located in the finite state models that determine the agent's actions based on its environment. Currently, actions are based, in part, on the situational awareness of the model of the agent. That situational awareness in DISAF currently arises from the visual and aural sensors. The situational awareness processing is controlled by a mental model of detected entities. Information stored for the mental model is "location visible," "location known," and "location unknown." The first case is when the vehicle is sensed with the visual sensor; the second when sensed with the aural sensor only; and the third when previously, but not currently, sensed by either sensor and the vehicle is not at its last known location. Parametric data entries include time periods in milliseconds for retaining the previously sensed, but not currently sensed vehicles on the mental model lists. After the sensing time limits expire without the target vehicle being sensed, the target vehicle is removed from the lists. Along with the mental model, also stored are the sensor acquisition level the sensor used to detect, and the target vehicle's last position, velocity, appearance, and priority.

Currently in the DISAF code, no overt behaviors are based on the acoustic sensing. However, the location sensed by the aural sensor assumes absolute position certainty. Since the human acoustic resolution in absolute direction is actually in the 20 to 30 degree range, the behavior responses likely should involve shifting the visual sensor's focus of attention to more accurately detect the precise location of the sound source visually. If the source of the sound could be interpreted as an immediate threat, e.g., gunfire or an approaching enemy vehicle, a reactive behavior of seeking cover or returning suppressive fire might be more appropriate. The reduced resolution of aural location could be handled within the specific task behaviors as needed without attempting to corrupt the aurally-sensed position of the vehicle/gunfire within the subroutine, libvspotter, that determines it.

| Acoustic Aspect Categories | DISAF Capabilities |
|---|---|
| Speed of sound | Not considered. Instantaneous perception is assumed with time-delay introduced only by the 500 millisecond (2Hz) processing schedule for sound. |
| Refraction | Not considered. Wind speed and temperature gradients have no effect. |
| Geometric spreading attenuation | Represented as -20 $\log_{10}$ (distance) decibels, where distance is in meters and the decibel level of the sound being attenuated is assumed as being measured at one meter from the source location. |
| Atmospheric absorption attenuation | Not considered. Also, does not distinguish between the frequencies of sound. |
| Enclosures or intervening structures attenuation | Attenuation due to blockage is considered. The sound source is assumed as a 10 meter by 10 meter square with the attenuation calculated as -10 decibels multiplied by the fraction of the sound source that is blocked by considering direct line-of-sight from the point of reception by the listener to the sound source. No considerations are made for absorption variations due to blocking materials, for reflections off surfaces, for diffraction through openings, or for re-radiation after structure-borne transmission. |
| Hearing threshold and masking | Minimum hearing threshold is read in as 5 decibels. Masking of sounds more than 30 decibels quieter than the loudest sound level being processed at the current 500 millisecond processing interval is represented. No consideration is made for the frequency of the sounds, where lower frequency sounds might mask higher frequency sounds. Additionally, sound produced by the movement of the entity or by its own gunfire is not considered for masking of other sounds. Finally, a distance threshold of 1,000 meters is used such that sound is not perceived if its source is beyond that distance. |
| Localization and binaural hearing | Precise localization of the entity producing sounds that are heard is assumed, but the movement speed and direction of the sound source, such as might be perceived due to the Doppler effect, is not considered. |

**Table 1.** DISAF acoustic capabilities

## 6. Summary, Conclusions, and Future Research

The DISAF does:

- Provide a low-fidelity model of sound generated due to movement based on vehicle type and speed, i.e., sound level is directly proportional to the vehicle speed where the maximum sound occurs at maximum speed, with those two parameters determined by vehicle type, and zero sound occurs at zero speed.
- Provide a model of sound generated due to gunfire based on munition type.
- Provide for simplistic degradation of sound.
- Decrease sound logarithmically with distance, i.e., -20 dB * $\log_{10}$ (distance).
- Decrease sound up to 10 dB due to amount of obscuration of line-of-sight.
- Mask sounds more than 30 dB below the maximum sound heard.
- Mask sounds that are less than 5 db.
- Use a maximum range for hearing of 1000 meters.
- Process sound at minimum intervals of 500 milliseconds.

The DISAF does not:

- Differentiate between "stealthy" or "noisy" movement.
- Provide for the generation or processing of aural cues, e.g., talk by personnel, clanging metal that might occur when a weapon is dropped, track clangs, detonations, etc.
- Provide for the speed of sound, essentially assigning an immediate arrival rate at every listening agent. Given a limited 1,000 meter sound listening distance and a 500 millisecond processing tick, a sound arrival error of up to 2.5 seconds early through 0.5 seconds late can occur. This could allow for moving out of the way of an incoming projectile if a cover reaction were implemented.
- Provide a situational awareness model of active agents that accurately models human behavior in response to sound.
- Provide move to cover behavior in reaction to sound.
- Provide directing/cueing of visual sensors.
- Consider movement sounds/gunfire by listening agent itself in determining maximum sound for masking.

This research performs two essential advances to the science of sound in the entity-based simulation environment. First, this research identifies and categorizes as a framework fundamental acoustic algorithms appropriate to modeling sound in entity-based simulation. Secondly, this research discusses a current implementation of sound in a widely used military simulation. Both advances contribute to a foundation of acoustic in military simulation literature. Pressing future research on indoor settings may build on this framework. Future research should expand on the categories and algorithms identified as well as discussion of the suitability of implementation variations. HLA and DIS compatibility of OTB and OOS enable acoustic effects to impact a federation. Future research may build on this foundation presented here to include federated, server-based acoustic modeling. A possible advantage to a federated approach includes but is not limited to a very detailed acoustic model of some aspect of the simulation.

## 7. References

[1] Satava, R.M., S.B. Jones. 1997. Virtual Environments for Medical Training and Education. *Presence,* Vol. 6, No. 2, 139-146.

[2] Chandrasekaran, B. J.R. Josephson. 1999. Cognitive Modeling for Simulation Goals: A Research Strategy for Computer-Generated Forces. *Proceedings of the Eight Conference on Computer Generated Forces and Behavioral Representation*. Orlando, FL: SISO, 117-126.

[3] PEOSTRI. 2003. Virtual Reality Individual Simulation. http://www.peostri.army.mil/E-DIR/ES/IST/VRIS/home.jsp.

[4] Miller, William. 2002. Dismounted Infantry Takes the Virtual High Ground. *Military Training Technoloy*. Kerrigan Media International, Inc., Vol. 7, No. 8.

[5] PEOSTRI. 2003. Command Forecast. http://www.peostri.army.mil/BRIEFINGS/BRIEFS/FORECAST/forecast016.jsp.

[6] PM OneSAF. 2003. One Semi Automated Forces (OneSAF) Users Conference Brief. http://www.onesaf.org/users%20conference%20jfl.ppt.

[7] Davis, P. K., R.H. Anderson. Improving the Composability of DoD Models and Simulations. 2004. *The Journal of Defense Modeling and Simulation Applications, Methodology, Technology*, Vol. 1, No. 1, 5–17.

[8] Vince, John. 1995. *Virtual Reality Systems.* New York: Addison Wesley.

[9] Stuart, Rory. 1996. *The Design of Virtual Environments*. New York: McGraw-Hill.

[10] Sherman, W.R., A.B. Craig. 2003. *Understanding Virtual Reality*. Morgan Kaufman Publishers.

[11] Speaks, C.E. 1999. *Introduction to Sound: Acoustics for the Hearing and Speech Sciences (3rd Edition)*. Singular Publishing Group, Inc.

[12] Crocker, M.J. Introduciton. *Handbook of Acoustics (ed. M. J. Crocker)*. New York: John Wiley & Sons, Inc., 3-9.

[13] Sutherland, L.C., G.A. Daigle. 1998. Atmospheric Sound Propagation. *Handbook of Acoustics (ed. M. J. Crocker)*. New York: John Wiley & Sons, Inc., 305-329.

[14] Prout, J.H., G.R. 1991. Bienvenue. *Acoustics for You (2nd Edition)*, Krieger Publishing Company.

[15] Morfey, C. 2001. *Dictionary of Acoustics*. Academic Press.

[16] Buus, S. 1998. Auditory Masking. *Handbook of Acoustics (ed. M. J. Crocker)*. New York: John Wiley & Sons, Inc., 1147-1165.

[17] Watson, C.S., G.R. Kidd. Perception of Complex Waveforms. *Encyclopedia of Acoustics (ed. M. J. Crocker)*. John Wiley & Sons, Inc., 1521-1534.

[18] DISAF Version 9.4. 2002. U.S. Army PEO-STRI, Orlando FL.

[19] Proctor, M., W. Gerber. 2004. Line-of-Sight Attributes for a Generalized Application Program Interface. *The Journal of Defense Modeling and Simulation Applications, Methodology, Technology,* Vol. 1, No. 1, 43-57.