6th Workshop on
Battlefield Acoustics &
NATO SET-233, HFM-285 & CCIEP Experts meetings
ISL – French-German Research Institute of Saint-Louis
October 16-17, 2018
Saint-Louis, France

Book of Abstracts
WELCOME MESSAGE

It is a great honour for us to welcome all our civil and military colleagues, industrials, researchers, engineers, and PhD students to the 6th International Workshop on “Battlefield Acoustics”. This 2018 edition is attended by 70 participants from 13 countries.

The acoustic environment of the battlefield is of major importance for military operations. Military equipment like air and ground vehicles, electric generators etc. are often significant sources of continuous noise whereas weapons such as artillery guns, mortars or small calibre weapons as used by snipers are important sources of impulse noise. Therefore, hearing protection is an important issue for personnel exposed to extreme noise levels, like aircraft crews, artillery staff or dismounted soldiers. The priority is to limit the noise exposure to an acceptable level while not impeding the perception of the acoustic environment. Beyond the simple need to be protected, the design of earplugs or earmuffs has to offer an improved intelligibility of speech transmitted by radio-communication devices.

Blast Injury is also an important source of casualties in current military operations. Comprehension of the generation of blast overpressure, propagation and injury mechanisms are very challenging topics as well as studies on personal protective equipment against blast waves.

Military systems create sounds loud enough to be detectable at a long-distance. Acoustic detection sensor systems for early warning, surveillance and tracking targets have been developed over the last years to be used in battlefield and peacekeeping operations. Acoustics offer a Non-Line of Sight, a full space coverage (360°) and an ideal complement to other detection technologies.

More precisely, the following topics will be discussed during this workshop:

- Acoustic environment in the battlefield: metrology and characterisation of such sound sources,
- Hearing protection, audio communication and situational awareness:
  - Acoustic protectors (earplugs, earmuffs, etc.), passive or electronically controlled,
  - Auditory hazard, noise regulations and hearing conservation programs in military context,
  - Enhanced speech intelligibility, 3D Audio Display, augmented and virtual hearing,
- Mechanisms of blast injuries and protective equipment,
- Acoustic detection of threats,
  - Acoustic sensors for small UAV detection, for counter-sniping, for sensor networks,
  - Influence of environmental conditions on the performance of acoustic detection and localisation systems, (including numerical models for the acoustic propagation).

All these topics are of great importance for the soldier on the battlefield and during his training, especially for the conservation of his hearing and his ability to perceive the acoustic environment. Acoustic protection devices, audio communication systems and acoustic detection of threats have been studied during the last years, but despite the protective measures, the number of reported Acute Acoustic Trauma is still too high. Actions in the medical domain, educational measures and development of new technical equipment are still of great importance to improve the protection and the operational performances of the soldiers.

New miniature electronics components and sensors allow to provide better performance at a reasonable price, including new functionalities such as real-time noise control and dosimetry, immersive audio-communications, augmented reality functions and acoustically “transparent” protection systems. Custom moulded earplugs and individualised parameters of the previously evoked functionalities are expected to be of great benefit for the users. This will provide a better fit to the physiological characteristics and will be better adapted to the scenario of use of each soldier. At the same time the digital MEMS sensors allow to envisage acoustic arrays with a quite large number of individual sensors for sound recording and display, for acoustic sources detection/localisation as well as for situational awareness purposes. These hardware trends will also have consequences on the signal processing algorithms, with simplifications due to fully digital treatment of the data, but also with an “explosion” of the number of data to be processed.

In parallel, the progress in terms of measurement devices and numerical modelling offers quite valuable tools for a deeper understanding of the physical phenomena involved.

These technical topics are quite challenging; as they are of common interest, they have the potential to initiate collaborative studies between the organisations of the participants. We hope that this workshop may encourage such cooperation to improve future protective equipment for our soldiers.

As an illustration of these cooperation needs, specific sessions linked with NATO working groups topics have been organised this year. One is the STO/HFM-285 dealing with “Speech Understanding of English language in Native and non-Native speakers/listeners in NATO with and without Hearing Deficits”. The second one is the CCIEP Team of Experts / Noise & Hearing Protection “Improving hearing protection for NATO soldiers and enhance the interoperability of the personal equipment”. Another session is linked to the NATO technical group STO/SET-233 on “Acoustic Transient Threat Detection Sensors & Signal Processing for Battlefield Situational Awareness”.

We want to acknowledge all participants who contribute to this workshop, in particular the speakers and exhibitors. We also want to thank our supporting agencies DGA and BAAINBw, the industrial sponsors, the chairpersons and the ISL staff who are all committed to the success of this event.

On behalf of the organizing committee,

P. Naz
PROGRAMME

Tuesday, October 16th, 2018

13:30   Welcome address
> ISL - Directors
13:40   Technical announcements
> P. Naz (ISL)

Chairmen: T. Weßling (BAAINBw/WTD 91) and T. Pauchard (DGA/DT)

13:45   Introduction and overview of the workshop
> T. Pauchard (DGA/DT), T. Weßling (WTD 91)

Acoustic detection & localisation

14:00   Source localization & identification with a compact array of digital MEMS microphones
> A. Ramamonjy, E. Bavu, S. Hengy et al. (ISL, CNAM)

14:20   Acoustic detection and localization of UAVs with large microphone arrays - the Austrian approach
> M. Blass, C. Amon et al. (Joanneum Research)

14:40   A modular systems approach for acoustic SUAV detection
> M. Walzer et al. (Diehl Defence)

15:00   CARAVAN, a vehicle mounted mobile sound ranging array - presentation canceled
> D.P. Cabo (Microflown AVISA)

15:20 - 16:20 Exhibition & coffee break

Common Session with NATO SET-233

Chairmen: W.C.K. Alberts (US ARL) and M. Walzer (Diehl Defence)

16:20   Sensing of impulse sounds in open environments: an overview of ISL research in the last decade
> S. Cheinet, M. Cosnefroy et al. (ISL)

16:40   Combining noise engineering and boundary element methods to model outdoor sound propagation over complex objects
> M.J. Kamrath, P. Jean et al. (CSTB, IFFSTAR)

17:00   Acoustic localization of artillery shots
> A. Dagallier, T. Weßling et al. (WTD91), S. Cheinet, P. Wey (ISL)

17:20   Automatic speech detection and bearing estimation using a microphone array
> M. Varela et al. (FKIE)

19:30   Symposium dinner

Wednesday, October 17th, 2018

Common Session with NATO CCIEP: Military noise source measurements

Chairmen: T. Pauchard (DGA/DT) and T. Weßling (BAAINBw/WTD 91)

08:30   French noise benchmark for the benefit of the hearing conservation program
> G. Blanck (DGA-TT), P. Hamery et al. (ISL)

08:50   Impulsive noise: measuring, modeling, and estimating personnel exposures
> H. Gallagher, A. Wall, C. Wagner (US-AFRL)

09:10   A new method for the standardized measurement of the acoustic parameters of stun grenades
> C. Amon, F. Graf et al. (Joanneum Research)

09:30   Auditory and non-auditory effects of impulsive pressure waves
> J. Bouillier, S. De Mezzo et al. (ISL), C. Deck et al. (UNISTRA)

09:50   Problems with repeated low-level blast exposure: The Canadian armed forces breacher study
> A. Nakashima et al. (DRDC-RDDC)

10:10   Air blast and measurement of high frequency response shock wave
> P. Briquet, B. Metz (PCB Piezotronics)

10:30 - 11:00 Exhibition & coffee break
Hearing protection, 3D audio, Noise regulations

Chairmen: U. Zölzer (UniBw) and G. Andéol (SSA/IRBA)

11:00  Acute acoustic trauma among soldiers during intense military action
       > N. Fink, N. Yehudai et al. (IDF Medical Corp)
11:20  Factors affecting objective and subjective hearing symptoms in military populations - presentation canceled
       > D.S. Brungart (WRNMMC)
11:40  Hearing protector fit-testing: from industrial plants to battle fields
       > J. Voix (ETS)
12:00  Assessment feedback of intelligent earplug, move towards battlefield dosimetry and new collaborative functionality
       > P. Hamery et al. (ISL), G. Nexer (COTRAL)
12:20  Frequency-dependent hearing protector insertion loss measured with impulses
       > C.J. Fackler, E.H. Berger, M.E. Stergar (3M)

12:40 - 14:00 Lunch

Chairmen: J. Voix (ETS) and P. Naz (ISL)

14:00  Psychoacoustic hybrid active noise control structure for application in headphones
       > P R. Benois, V. Papantoni, U. Zölzer (HSU/UniBw Hamburg)
14:20  Development of a new ANSI standard for measuring sound localization performance with hearing protection devices
       > E. Thompson (US Air Force Research Lab.)
14:40  Methods for solving front-back confusions in 3D audio headphones
       > P. Nowak, V. Zimpfer, U. Zölzer (HSU, ISL)

Common Session with NATO HFM-285: Speech intelligibility, Audio communication

Chairmen: R. Jacob (BwZKhrs) and L.R. Henry (HCE/USAf)

15:00  NATO CSO-HFM 285 approach to improve communication quality among non-native English speakers/listeners
       > R. Jacob (BwZKhrs), L. Henry (HCE/USAf), CSO-HFM 285 members
15:20  Self-reported and measured hearing difficulties in noise in a population of normal-hearing to mildly hearing-impaired adults
       > G. Andéol, T. Fux, C. Suied et al. (SSA/IRBA)
15:40  Cartilage conduction HPD for communication during impulse noise exposure
       > J. Rosier, J. Dury et al. (ELNO/FRI), V. Zimpfer, P. Hamery (ISL)
16:00  Measuring speech intelligibility using throat microphones
       > E. Wickman, K. Bolin, O. Sundqvist et al. (FMV)
16:20  Speech Intelligibility: Ongoing creation and validation of a list of French rhyming words for MRT tests
       > V. Zimpfer, T. Fux et al. (ISL, SSA/IRBA, DGA-TT)
16:40  Predicting the intelligibility of non-native speech using the Speech Transmission Index
       > S.J. van Wijngaarden et al. (Embedded Acoustics)
17:00  Conclusion of the workshop and of the exhibition

Poster Session

Influence of TCAPS on HRTFs and on sound source localization precision
> L. Kröner, A. Garcia, V. Zimpfer (CNAM, ISL)
Analysis and reduction of frictional sounds of soldier’s uniforms
> F. Leclinche et al. (ISL, UHA/LPMT)
Method to choose the ideal size of earplug
> V. Zimpfer, G. Andéol et al. (ISL, SSA/IRBA)
Assessment of the frequency response of a solid conduction transducer based on an audiometric threshold measurement of individuals
> V. Zimpfer et al. (ISL), J. Rosier, Y. Penne et al. (ELMO)
Integrating situational awareness into hearing protectors
> S. Hengy, V. Zimpfer et al. (ISL)
Development of a cost-effective system for dosimetry of high sound pressure levels
> F. Königstein, M. Christoph (ISL)
Modelling sound propagation in complex battlefield environments
> D. Keith Wilson, M.J. Kamrath et al. (ERDC-CRREL)
Technical exhibitions with the participation of the following companies:
Acoustic detection & localisation

Chairmen:
T. Weßling (BAAINBw/WTD 91) and T. Pauchard (DGA/DT)
Source localization and identification with a compact array of digital MEMS microphones

A. Ramamonjy¹,², E. Bavu², A. Garcia², S. Hengy¹

A compact microphone array was developed for source localization and identification. The planar array consists in an arrangement of 32 numerical MEMS microphones (see Fig. 1), concentrated on an aperture of less than 10 centimeters, and connected to a computer by Ethernet (AVB protocol).

A real-time 3D direction of arrival (DOA) finding algorithm was developed (see Fig. 2). Localization is performed using the pressure and the particle velocity estimated at the center of the array. The pressure is estimated by averaging the signals of multiple microphones. Eventually high order pressure finite differences and the Phase and Amplitude Gradient Estimation (PAGE) method are compared for particle velocity estimation. A measurement campaign took place in ISL proving ground (Baldersheim) where multiple flying drones were recorded with our sensor. Results on drone detection based on the obtained dataset and binary classification techniques are presented (see Fig. 3). Their potential integration for signal enhancement on a drone detection and tracking system is discussed.

Fig. 1: Sensor prototype

Fig. 2: Real-time localisation of a simulated drone source

Fig. 3: F-scores obtained with the JRip classifier

This work has been done is in the framework of a PhD Grant supported by the Direction Générale de l’Armement (DGA).

Keywords
Acoustics, UAV, Sound, Detection, Classification, Localization

Reference
1. A. Ramamonjy, E. Bavu, A. Garcia, H. Hengy
Source Localization and Identification with a Compact Array of Digital MEMS Microphones, ICSV25, Hiroshima, JP
8-12 July 2018

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Acoustic detection and localization of UAVs with large microphone arrays - the Austrian Approach

M. Blass¹, C. Amon¹, H. Marhold², F. Graf¹

We present a holistic approach for real-time acoustic detection and localization of UAVs using microphone arrays. We describe the design of a large planar array, its construction and associated hardware. The array has a diameter of 1.5 m and consists of 31 high-quality measurement microphones (see Fig. 1).

Audio data of different UAVs was acquired in measurement campaigns using a defined procedure. Data is stored within an MPEG-7 database which handles metadata and labeling of audio segments. Labeled audio data is used to train classification algorithms to discriminate between the presence and absence of UAVs. For acoustic localization, beamforming techniques and 3D direction-of-arrival (DOA) estimation algorithms are used in combination with a simple source tracking algorithm. The localizer uses a probabilistic approach to track multiple sound sources over time. An example of the DOA estimation is shown in Fig. 2.

The system is evaluated using common classification metrics and a proposed localization error metric for different UAV types. The ground truth for classification and localization experiments are manually labeled audio segments and GPS data recorded during flights, resp. The detection and localization ranges vary based on the engine type and size of the UAV (Table 1). We outline the real-time implementation of the system and give an outlook about joint beamforming and classification.

<table>
<thead>
<tr>
<th>UAV</th>
<th>Engine</th>
<th>Distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DJI S1000</td>
<td>electric</td>
<td>140</td>
</tr>
<tr>
<td>AscTec Falcon</td>
<td>electric</td>
<td>170</td>
</tr>
<tr>
<td>X8 Custom</td>
<td>electric/jet</td>
<td>750</td>
</tr>
<tr>
<td>Schiebel S100</td>
<td>combustion</td>
<td>850</td>
</tr>
</tbody>
</table>

Fig. 1: Microphone array and hardware

Fig. 2: DOA estimation example of a single flight

Tab. 1: Maximum localization distance ranges

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A modular systems approach for acoustic SUAV detection

M. Walzer\textsuperscript{1)}, F. Kurth\textsuperscript{2)}, S. Urrigshardt\textsuperscript{2)}

At the previous workshop on Battlefield Acoustics in 2016, Diehl Defence presented a modular systems approach for adaptable acoustic reconnaissance of small aerial unmanned vehicle (SUAV). Since then, an open architecture sensor platform has been developed and tested in field trials. The sensor’s signal processing algorithms have been developed by Fraunhofer IDMT and FKIE.

The open architecture of the sensor enables adaptation and scaling in terms of both software and hardware. For easy algorithm integration and testing, the sensor features a modular software testbed. The sensor frontend platform has been designed to meet low-noise requirements and uses state of the art hardware components. Finally, this integrated sensor frontend is equipped with an open interface, which enables easy integration into higher echelon systems and easy multi-sensor network realization.

The sensor has been built up as part of a German government funded research project on drone defence. The project also addressed the development and integration of suitable signal processing algorithms for drone detection. This contribution presents the system along with basic algorithms for drone detection integrated into the systems modular architecture.

First results obtained from data acquired in systematic drone field trials are presented, indicating the feasibility of the proposed approach.

Directions for future work are illustrated both for further developments in the system framework and algorithms for drone detection, localization and classification.

Fig. 1: Testbed for modular integration of drone detection algorithms
CARAVAN, a vehicle mounted Mobile Sound Ranging Array

D.P. Cabo

Exploiting the benefits of acoustic particle velocity sensors, Acoustic Multi Mission Sensors can be used to detect and localize not only gunshots, but also transients like rockets, artillery and mortars and tonal sound sources like heavy ground vehicles.

In 2017 and 2018, various tests have been conducted at artillery ranges in, amongst others, Finland, Lithuania, the Netherlands and Germany.

The campaigns will be explained. Results will be presented on target acquisition, fire control and the monitoring of heavy ground vehicles.

The path of migration of ground based AMMSs towards vehicle mounted versions will be discussed.

Keywords
Acoustic sound ranging, Acoustic particle velocity, Microflown, Vehicle mounting system

Reference

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Common Session with NATO SET-233

Chairmen:
W.C.K. Alberts (US ARL), M. Walzer (Diehl Defence)
Sensing of impulse sounds in open environments: an overview of ISL research in the last decade

S. Cheinet, M. Cosnefroy, A. Dagallier, Th. Broglin, L. Ehrhardt

Acoustic sensing systems are used for battlefield surveillance of shots and explosions, in operational and in field trial contexts. The scenarios (ranges of 100 m to 10 km) and acoustic wavelengths (30 to 3000 Hz) imply that the sound signatures and subsequent sensing are affected by the environment.

The ISL performs R&D to characterize the propagation-induced modulations, and develop sensing algorithms or systems which mitigate them. In the Battlefield Acoustics symposium of 2016, an innovative approach was presented to address the issue in urban areas.

The challenge of open (flat, homogeneous ground) environment is rather different: some systems exist, but they feature sensitivity to poorly understood environmental effects (weather, turbulence, ground).

The presentation gives an overview of the research performed by ISL—with partners—on sensing in the open environments. It recalls findings on how the performance of existing sensing systems varies with the environment. It introduces the experimental and modeling tools developed to manage the sensitivity of shot sounds to the environment.

Finally, it demonstrates how these tools increase our understanding and prediction capability of the sensed signatures, and outline original sensing strategies based on these results.

Sound pressure of an impulse sound after its propagation over 100 m upwind (left) and downwind (right). Observations are in blue, 3D+time numerical simulations are in dashed green. Note the major effect of wind, and the match between model and observations.
Combining noise engineering and boundary element methods to model outdoor sound propagation over complex objects

M. Kamrath\textsuperscript{1)}, P. Jean\textsuperscript{1)}, J. Maillard\textsuperscript{1)}, J. Picaut\textsuperscript{2)}

Modeling vehicle sound levels in urban environments is challenging because such domains are large and complex. Noise engineering methods (e.g. ISO 9613-2) do not accurately model the complicated geometries and reference methods (e.g. the boundary element method) are too computationally expensive. However, hybridizing these approaches provides an improved compromise between accuracy and computational expense. Specifically, this hybrid approach extends the engineering methods by introducing a new attenuation term that is calculated with the 2.5D boundary element method. These boundary element calculations are only performed once and stored to mitigate the computational expense. As an example, the figure below shows a real urban scene with two different barrier types: an I-barrier and a T-barrier. The I-barrier case can be modeled with an engineering method but the T-barrier case cannot. For the T-barrier case, this hybrid approach yields improved accuracy compared to the engineering methods alone and reduced computation time compared to the reference methods alone.

![Figure showing a real urban scene with different barrier types: an I-barrier and a T-barrier.](image)

**Keywords**
Urban outdoor sound propagation, Noise engineering methods, Boundary element method

**References**
1. M. Kamrath
2. M. Kamrath, P. Jean, J. Maillard, J. Picaut, C. Langrenne,

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Acoustic localization of artillery shots

A. Dagallier¹,³, S. Cheinet¹, P. Wey¹, W. Rickert², T. Wessling², D. Juvé³

In battlefield acoustic applications, synchronous acoustic sensors are used to localize the impact point or the source position of artillery shots. The sensors record a complex combination of the various sound signals generated by the weapon, by the projectile (supersonic) motion, by the final impact, as well as the possible reflexions. For localization purposes, one has to identify and process these various contributions, taking the sound propagation effects into account (atmospheric winds, temperature gradients, ground type, topography…). In practice though, distinguishing and interpreting these various contributions turns out to be a challenge.

The Time-Matching technique, recently proposed by ISL², is used to find the TOAs in the database that best match those of the measured signals and thus recover the source and/or impact position.

On-going developments demonstrate the potential of processing the projectile’s wave in order to make the detection and localization more robust.

In this talk, a model is presented to build a database relating projectiles’ trajectories to the times of arrival (TOAs) of the sound waves at the sensors. The model combines two numerical techniques (1) ballistic calculations performed with the BALCO software¹, and (2) sound propagation simulations, which account for complex propagation effects.

Fig. 1: Example of simulation results for a projectile trajectory (black line) and associated muzzle (green surface) and supersonic projectile wave (violet). TOAs are then extracted at the sensors locations (black dots).

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Keywords
Shot localization, Time-matching, Fast-marching, Times of arrival, Sound propagation

References
1. P. Wey et al., BALCO 6/7-DoF trajectory model, 29th International Symposium on Ballistics, Edinburgh International Conference Center, Edinburgh, Scotland, 151-162, 9-13 May 2016
2. S. Cheinet et al., Time Matching Localization of Impulse Sounds in High-Building, Non-Line-of-Sight Configurations, Acta Acustica united with Acustica, Volume 102, Number 6, pp. 1118-1127(10), November/December 2016

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Automatic speech detection and bearing estimation using a microphone array

M. Varela, K. Wilkinghoff, A. Cornaggia-Urrigshardt, M. Oispuu, F. Kurth

Automatic speech detection and enhancement as well as further speech processing stages such as speaker recognition and keyword spotting are crucial for security related applications. Important application scenarios include automatic acoustic monitoring and surveillance. To approach these tasks, a real-time outdoor speech monitoring demonstrator composed of 8 randomly distributed microphones and a subsequent digital signal processing chain is being created at Fraunhofer FKIE.

Considering the challenges presented by the detection of noisy speech signals, a robust two-stage detection method using shift-ACF based F0-features\(^1\) is applied. To enhance the recorded speech in a preprocessing step, microphone array processing techniques such as beamforming\(^2\), are implemented in the demonstrator. The latter reinforce the signals sourcing from the look direction and attenuate the others. In order to achieve a highly accurate bearing and provide a full hemispherical coverage, the Crow’s Nest Array\(^2\) is used. As an outlook we propose to subsequently identify speakers by combining multiple i-vector models trained on different speech features. Finally, the performance achieved with the demonstrator is evaluated experimentally.

**Fig. 1: Flow Chart of the Experimental System**

**Fig. 2: Crow’s Nest Array: array geometry (a), and directivity pattern (b)**

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**Keywords**
Microphone array, Speech detection, Bearing estimation, Speaker recognition, Monitoring

**References**
1. F. Kurth, A. Cornaggia-Urrigshart, S. Urrigshardt
   Robust F0 estimation in noisy speech signals using shift autocorrelation, in Proc. IEEE ICASSP, 2014
2. W.-D. Wirth
   Radar Techniques Using array Antennas

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Common Session with NATO CCIEP: Military noise source measurements

Chairmen:
T. Weßling (BAAINBw/WTD 91), T. Pauchard (DGA/DT)
French noise benchmark for the benefit of the hearing conservation program

G. Blanck\textsuperscript{1)}, P. Hamery\textsuperscript{2)}, V. Zimpfer\textsuperscript{2)}, S. De Mezzo\textsuperscript{2)}

Latest evolution of noise regulations tend to integrate the characterization of the real noise dose to which soldiers are exposed. It has consequently become a top priority for existing and future systems. The goal is to propose methods to assess if soldiers are well protected for their missions. Indeed a very close attention has to be paid to human beings, who are the masterpiece at the centre of every weapon systems. A new generation of protections is starting to emerge. They are more efficient by better combining hearing protection and communication. But human beings can’t be an adjustment variable when measured levels of noise with existing systems are too high.

It is important to keep in mind that noise issues are very complex and have to be tackled from the very start. Noise takes a heavy toll on the soldiers’ health, yet the noise trauma is only the tip of the iceberg. A soldier operating in a too noisy environment is faced with great difficulties to communicate and to realize his tasks. He is therefore much less efficient.

Thus the main idea of a project between ISL and DGA is to come up with solutions to include at the right place hearing issues and noise constraints on human soldiers in armament programs. The aim is to reduce the number of noise trauma and to increase the performances of the “Human / Weapon System” pair.

\textbf{Fig. 1: Test of an earmuff with the ISL ATF}

\textbf{Fig. 2: Steps proposed to include noise constraints in armament programs}

\textbf{Keywords}

Hearing protection, Sources of noise, Armament programs

\textbf{References}

1. G. Blanck, P. Hamery, V. Zimpfer
   Proposal of a technical baseline, ISL private communication, April 2018

2. P. Hamery, G. Blanck, V. Zimpfer, S. De Mezzo
   Operational mode to assess the noise dose to which soldiers are exposed in weapons systems, ISL private communication, April 2018

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Impulsive noise: measuring, modeling, and estimating personnel exposures

H. Gallagher, A. Wall, C. Wagner

During basic military training, instructors and trainees are exposed to impulsive noise generated from military rifles on shooting ranges. It is well known that hazardous noise exposure may result in hearing loss or other hearing related disabilities. Hearing protection is typically provided to reduce the auditory risk by decreasing the level of noise at the ear. Unfortunately, hearing protection has the potential to degrade communications, is not routinely fit correctly in the ear, and at times is not worn at all. Therefore, a large percentage of trainees exit basic training with permanent hearing loss.

The objective of this study was to investigate impulsive noise measurement techniques and model personnel noise exposures with various hearing protection devices.

Impulsive noise measurements were collected in accordance with MIL-STD-1474E and ANSI S12.7 at an outdoor shooting range, Weapons Training Battalion, Quantico Marine Base, Virginia. Over 100 microphones were set up to capture M16A4 noise from single- and multiple-shooter exercises.

Fixed and roving microphones were utilized and positioned in rectangular and polar arrays at prone, kneeling, and standing ear heights.

The data were used to characterize the noise environment at the shooting range, Figure 1. A noise dose calculator was developed to estimate personnel noise exposures at all stations on the shooting range based on the number of shooters, the number of shots fired from each shooter, and the level of protection provided by a hearing protection device. The noise dose was calculated using the 100-millisecond A-weighted Equivalent Noise Level ($L_{100\text{ms}}$).

**Keywords**
- Impulsive noise
- Hearing protection
- Noise exposure
- Noise measurement

**References**
1. MIL-STD-1474E, Department of Defense Design Criteria Standard Noise Limits. 15 April 2015

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![Fig. 1: Noise contour map for single shooter at the center of the shooting range](image-url)
A new method for the standardized measurement of the acoustic parameters of stun grenades

C. Amon¹, F. Graf¹, H. Marhold², R. Wimmer²

Nowadays security forces are forced to use an approach that fulfills the principle of proportionality and minimizes the probability of causing consequential damages or injuries. Due to the fact that the manufacturer’s information on different stun grenades is not comparable, an appropriate use can hardly be assessed by the security forces. The reason for this is the lack of standardized methods for the measurement of the acoustic parameters of stun grenades.

In this paper, we present a new method for the standardized measurement of the acoustic parameters of stun grenades based on the enveloping surface method. The acoustic pressure values are measured at 5 sensor positions on a hemisphere with the stun grenade installed in the center of the hemisphere’s base (see Figure 1).

Using this raw acoustic data, the room and distance independent unweighted maximum sound power level $L_{PW}$ in dB is calculated (see equation 1). $L_P$ is the measured maximum sound pressure in pascals, $Q$ is the directivity coefficient ($Q=2$ for hemispherical sound propagation) and $r$ is the distance from the stun grenade to the sensors in meters.

$$L_W = L_P + 10 \cdot \log\left(\frac{Q}{4\pi \cdot r^2}\right)$$  \hspace{1cm} (1)

Acoustic information acquired according to the proposed method ensures comparability between all types of stun grenades regarding their maximum impact sound pressure. Figure 2 shows raw sound pressure data of all 5 sensors with a peak amplitude of 174.95 dB (11182 Pascal) measured in a distance of 2 m.

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Fig. 1: Setup for the standardized measurement of the acoustic parameters of stun grenades

Fig. 2: Raw sound pressure data of all 5 sensors

The proposed method is described in a detailed measurement instruction document. We further discuss the use of other mathematical approaches based on the acquired data such as the maximum acoustic impulse and the impulse time to extend the acoustical information on stun grenades by parameters that closer fit the characteristics of the human ear when subjected to high-energy acoustic impulses.
Auditory and non-auditory effects of impulsive pressure waves

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Firing weapons from small caliber rifles to large caliber artillery guns as well as explosive charges generate an impulsive shock wave which propagates in the surrounding air and may injured soldiers who are close. The pressure waves generated by the various weapons are quite similar in shape, but the peak pressure values, time durations and frequency characteristics are quite different and are mainly related to the type and the quantity of explosive materials (or of powder). The consequences may be quite different and may affect organs such as ears, lungs...

To support the development of innovative solutions to protect soldiers, the ISL has initiated research actions in collaboration with other institutes for:
1 - threat characterisation: peak value, duration of the impulsive pressure signal,.
2 - comprehension of the injury mechanisms,
3 - development of experimental manikins and numerical models to test new protective solutions.

The recent conflicts have highlighted the fact that: noise generated by the soldier’s own weapon or by weapons of close by troops represents a source of acoustic trauma and of permanent hearing loss. In the same time, the blast waves generated by IEDs have also increase the risk of thoracic injuries.

Keywords
Pressure waves, Injury risk, Experimental and numerical models

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Fig. 1: Ideal pressure profile from the detonation of an explosive charge - Friedlander waveform

Fig. 2: Experimental ATF (a) for noise study and swine finite element model (b) for injury mechanisms understanding and evaluation (non-lethal weapons and blast threat)

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Problems with repeated low-level blast exposure: The Canadian Armed Forces breacher study

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Explosive breaching is a tactical technique in which controlled explosions are used to gain entry into closed spaces. During military breacher training courses, instructors and range staff are exposed repeatedly to low-level blasts over several weeks or months. Although range safety procedures exist to limit the levels of blast exposure, actual measurements during training have recorded exposure levels that are above the operational limits. Recent work has suggested that operators who are exposed repeatedly to low-level blasts report psychological and physiological issues, such as headaches, sleep disturbances and hearing problems.

The purpose of the current cross-sectional study was to assess the effects of long-term occupational exposure to repetitive low-level explosive blasts by comparing a sample of breaching instructors and range staff (n = 19) to age- and sex-matched Canadian Armed Forces members with no exposure to breaching (n = 19). Our comprehensive test battery included background health and occupational questionnaires, neuropsychological tests of cognition and visuomotor coordination, physiological tests of balance and tremor, blood samples for proteomic and metabolomic profiling and hearing tests to assess noise-induced hearing loss. This paper will focus on the blast measurements and hearing data.

Blast events were recorded using body-worn blast gauges. Peak pressure levels were as high as 4.9 psi, with the average peak levels being 1.7±1.0 and 2.0±0.8 psi for the two training courses, respectively. Approximately 13\% of the recorded blast events exceeded the range safety limit of 3 psi.

Our criteria for noise-induced hearing loss was having an average hearing threshold level > 25 dB HL (taken from the thresholds at 2, 3 and 4 kHz). Four of the breachers had hearing loss compared with one control. However, 12 of the breachers reported having tinnitus compared with four controls. This result was statistically significant (Mann-Whitney U = 105, p = 0.009). These results suggest that breachers experience changes in hearing function that are not detected by conventional audiometry. Moreover, our other measures indicated alterations in psychological and physiological health for the breacher group.

Our results demonstrate significant, but subtle effects of repeated low-level blast on the health and performance of breachers. This presentation will also discuss the challenges associated with future research, including the accuracy of blast exposure measurements and effectiveness of personal protective equipment.
Air blast and measurement of high frequency response shock wave

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Battlefield explosions result from a rapid energy release. One of the cause can be an intentional release of unstable chemical compounds rapidly transforming themselves to a more stable form due to a release of energy. This energy transformation results in gas formation (pressure) and intense heat (Fig. 1).

In order to characterize the time signature of a blast-pressure event, pressure transducers are required. However, the common solution does not provide relevant information to make speed time of arrival or shock wave measurements. The design of new multiple sensors on a single probe though allows that kind of measurements, which were impossible for small charge when the pressure decayed too fast.

Sniper and projectile detection systems and shooter training create high frequency shock wave. To make such measurement we could use micro sensors originally designed for time of arrival.

Fig. 1: Serie 137B Quartz, free-field, ICP\(^\text{®}\) blast pressure pencil probe, with two outputs for T.O.A

Fig. 2: Micro ICP\(^\text{®}\) pressure sensor, for high frequency velocity or T.O.A. measurements

Keywords
Explosion, Air blast, Pencil probe, Time of arrival, Shock wave

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Hearing protection, 3D audio, Noise regulations

Chairmen:
U. Zölzer (UniBw), G. Andéol (SSA/IRBA)
Acute acoustic trauma among soldiers during intense military action

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Introduction
During military actions, soldiers are exposed to various forms of potentially harmful noises. Acute acoustic trauma (ATT) results from an impact, unexpected noise ≥140 dBs which generates a high energy sound wave, which can damage the auditory system. ATT occasionally accompanies other physical injuries, but can also present as a solitary injury, and sometimes as a silent disability during battle. Factors that influence the severity of inner ear damage include distance from the noise source and its intensity, length of exposure, location (outdoors vs. indoors), worn protective means and individual sensitivity. We sought to characterize ATT among military personnel during operation “Protective Edge”, to analyze the utilization and effectiveness of hearing protection devices, and to evaluate the effectiveness of steroid treatment in early diagnosed ATT.

Methods
We retrospectively identified affected subjects who presented with ATT during the operation and 4 months afterwards (July 2014 - December 2014). Data were extracted from electronic medical charts for demographics, time and duration of ATT, worn protective means, hearing tests and any treatments given (if any).

Results
Of the 187 individuals who presented with hearing complaints attributed to ATT, 122, 39 and 25 were in duty service, career personnel and reservists, respectively, and their mean age was 21.1, 29.2 and 30.4 years, respectively. One-hundred-and-four (56%) subjects eventually had abnormal hearing tests. Hearing was significantly more impaired in unprotected subjects when compared with protected subjects, 62% (74/119) vs. 45% (30/67), p<0.05. Tinnitus was more common in 75% unprotected subjects, and vertigo was an uncommon presentation. Twenty-one subjects had received steroid treatment for ATT, which significantly increased follow-up hearing thresholds, as compared with untreated subjects (p<0.01 for 1-4kHz).

Conclusion
ATT is a common military injury, and should be diagnosed early to minimize associated morbidity. Early steroid treatment was proven to be effective in the treatment of ATT. The use of hearing protection devices in the battlefield continues to be the preferred method for preventing related hearing loss.

References

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Keywords
Acute Acoustic Trauma, Hearing loss, Noise-induced hearing loss, Steroids

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Factors affecting objective and subjective hearing symptoms in military populations

D. S. Brungart

Service members are exposed to a variety of potentially dangerous noise exposures as a part of their military duties, and these exposures can result in a multitude of possible hearing impairments. The purpose of this study was to use the results of a large-scale questionnaire administered to service members during their annual audiometric tests to identify common underlying factors that define the noise exposures and hearing symptoms of noise exposed personnel, and to attempt to identify underlying relationships between the different symptoms experienced by service members and the kinds of exposures that cause them.

Methods
A total of 2324 Service Members were recruited to participate in the study as part of their annual audiometric screening in one of six different hearing conservation clinics. Each participant completed a noise history and hearing symptom assessment consisting of up to 29 questions. The responses to these questions were recorded along with information on age, gender, and pure-tone audiometric thresholds from 250 Hz to 6 kHz in each ear. The hearing symptom portion of the assessment consisted of four items from the Tinnitus and Hearing Survey, six items from the Spatial and Sound Qualities questionnaire, a question on the use of audio-visual speech cues, a question on localization ability, and a question on sensitivity to loud sounds. A factor analysis was used to reduce these 13 questions down to seven factors.

These seven factors, plus an additional question on perceptual tinnitus, were subjected to a correlational analysis with 13 questions related to deployment history, exposure to continuous, small-arms, and heavy weapons noise, blast exposure, TBI history, and the frequency and duration of temporary changes in hearing.

Results
Self-reports of temporary changes in hearing were significantly more correlated with hearing symptoms than other reports of noise exposure. There were also indications of differences between the types of auditory symptoms associated with different noise exposure types.

Acknowledgements
This research was conducted in collaboration with the US Army Public Health Center. The views expressed in presentation are those of the authors and do not reflect the official policy of the Department of Army/Navy/Air Force, Department of Defense, or U.S. Government.
Hearing protection fit-testing: From industrial plants to battle fields

J. Voix

Individual hearing protection devices (HPD) are often the first line of defence against noise-induced hearing losses (NIHL) in occupational and military settings. Unfortunately, the attenuation offered by HPDs in the real world greatly differs from the laboratory ratings, for many reasons now well understood, mostly boiling down to the proper fit of a given HPD by an individual wearer. To better assess this fit and predict the effective individual attenuation, Field Attenuation Estimation Systems (FAES) have been developed over the years and are now paramount to many Hearing Loss Prevention Programs (HLPP). A new standard, ASA/ANSI S12.71, has even been recently adopted by the American National Standard Institute (ANSI) to specify how the FAES measurement uncertainty should be calculated, accounting for the fact that all FAES do not rely on the same measurement paradigms nor the same hardware.

With fit-testing being recommended for almost one decade as part of the best practices (NIOSH/NHCA/OSHA Alliance, 2008) and nowadays more and more widely adopted in industrial hearing conservation, it would be now a good time to review what currently limits its adoption for military settings. Three different areas are explored hereafter: what would make FAES technologies suitable for battlefields, what is the notion of protection sufficiency in armed forces and finally what are really the administrative measures that are available on the battlefield.

A. FAES Technologies
Subjective vs objective measurement
While psychophysical paradigms (such as hearing threshold screening, loudness balance, etc.) are widely used for FAES in civilian occupational health and safety (see list in Voix et al., 2018), their suitability for assessment on the battlefield is questionable. Objective fit-testing approaches, such as Field-MIRE (Microphone in Real-Ear), featuring one external and one internal microphone, appear to be more suitable and seem to be adopted by most commercial products. Nevertheless, several electroacoustic measurements can be made to assess the proper fit and estimate attenuation of an HPD, ranging from difference in auto-spectrum between both microphones, to transfer function assessment, to impulse response identification and possibly even involving the measurement of the transfer function between the internal miniaturized loudspeaker and the internal microphone. All these methods have inherent advantages and drawbacks in terms of processing power, hence electrical consumption, and accuracy.

In situ vs in vivo measurement
While objective fit-testing systems currently commercialized for industrial use can give an accurate “snapshot” of what a given individual is getting from his HPD in the field, or “in situ”, these systems are usually not designed for continuous measurement of the hearing protector attenuation during the whole duration of the exposure. In the case of exposure of military personnel, the continuous monitoring of the hearing protectors attenuation is key, as a periodic refit of the hearing protectors might be required. An “in vivo” measurement system could trigger such refit by notifying the wearer when suboptimal performances are being measured. A further consideration might also apply to in vivo measurement systems: when such systems use both an external and an internal microphone, not only can they monitor the fit and estimate the attenuation of the HPD, but they can also measure directly the protected exposure level of the worker, accounting for all variability in the sound field and in the HPD’s attenuation.

Continuous vs impulsive noise measurement
While many industries may have ambient noise levels that are fluctuating, these fluctuations are nothing compared to the magnitude of the impulse noise resulting from the use of firearms and explosives.

The measurement, by objective F-MIRE fit-test systems, of high peak sound pressure levels is challenging on two aspects: it requires a very large dynamic range and sufficient headroom on the external microphone data acquisition chain, and it requires a very high sampling rate to capture the true “peak” value of the incoming sound wave. Both these requirements add to the cost and power consumption of a fit-test system designed for the battlefield.

B. Protection sufficiency: what is adequate attenuation anyway?
Assuming that the technical limitations mentioned above were addressed and that a fit-test system could be designed to continuously monitor the fit of a given HPD and estimate both the HPD attenuation and the resulting protected exposure at the wearer’s ear, in both continuous and impulsive ambient sound, a critical question would remain unanswered: “What level of attenuation is required for that particular wearer?”. The underlying question being what the exposure limit should be for military noise and what the damage risk criteria are in the battlefield. Fit-testing on the battlefield can only be beneficial if safe but realistic limits and criteria are defined to protect the soldier’s ears.
C. Administrative measures: really?
The deployment of an objective in vivo fit-testing system in civilian industrial settings create some serious practical challenges to the individuals in charge of the administration of Hearing Loss Prevention Programs. For example, what to do when a given worker has reached 99% of a daily noise dose by the middle of a workshift? Fortunately, occupational health and safety regulations in most regions have already addressed that issue, at least on a theoretical basis. Simply stated, the answer is often an administrative one: the workers should be assigned to new tasks, so that the cumulated noise exposure does not exceed the permitted limit. Obviously, it is something easier to do on a factory floor than on the battlefield.
Assessment feedback of intelligent earplug, move towards battlefield dosimetry and new collaborative functionality

P. Hamery¹, V. Zimpfer¹, G. Nexer², G. Blanck³, T. Pauchard⁴, Y. Demumieux⁵

Despite the wearing of hearing protection, the number of acute acoustic trauma remains important. Machine guns, artillery, explosives and all kind of weapon systems used by soldiers especially during training exercises frequently induce hearing damage. French Army counts more than one thousand acute acoustic trauma every year. One French military personnel out of six experienced acute acoustic trauma and one out of three reported acute tinnitus after a shoot despite wearing hearing protections (1). Nowadays, passive earplugs with nonlinear attenuation (level dependent) are increasingly used in Armies: they protect against impulsive noise while keeping contact with the useful sound environment. Nevertheless when they are in “open position” they do not protect against continuous noise.

In this way, ISL acoustic team was a pioneer with the well-known impulse filter of the combat arms earplug (2) and always continue to lead the way in last decade by developing intelligent earplugs. However, to reduce the number of acute acoustic trauma, it is obvious that noise attenuation should be maximized by taking care of the well-fitting of earplugs. This is the reason why ISL and the French Company Cotral Laboratory, specialized in high quality custom molded earplugs initiated a partnership to realize 30 prototypes of an intelligent earplug for assessment in military environment. This study is financially supported by French government (DGA) in a project named BANG (Bouchon Auriculaire de Nouvelle Génération).

The control box of the BANG prototype (Figure 1) contains the intelligence of both the processing and diffusion algorithms for input and output sound signals. This box is connected in one way to the ear via the custom molded earplug (Figure 2) and to the communication equipment of the soldier in other way.

Main functionalities of BANG are: i) high-quality passive protection, ii) active noise reduction, iii) reproduction of the sound environment at a controlled level (talk-through system, see Figure 3), iv) check-up of the correct insertion of the protection during switch-on procedure, v) sound recording directly within the ear canal. Other functionalities will soon be integrated in BANG. One of them is the capability to realize in situ dosimetry during professional activities.

The discussion will focus on the results of the “in the field” tests realized this year with soldiers selected by STAT (combined with the FELIN system). This will be the occasion also to speak about the dosimetry aspect and the Industrial/Military duality needs which are not always the same but very alike. In the near future, one important capability of BANG will be to use the microphones inserted in the custom molded earplugs (doublet right/Left ears) to improve acoustics detection of noises in the battlefield.
Keywords
Hearing protection, Dosimetry, Intelligent earplug

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Specialized hearing protection devices (HPDs) intended to minimize the impact on auditory situational awareness often allow low-level sounds to reach the ear relatively unattenuated. At the same time, such HPDs typically provide attenuation of high-level impulse sounds. The first standard test method to quantify level-dependent attenuation with impulses was developed for the 2010 revision to ANSI/ASA S12.42. This standard defines impulse peak insertion loss (IPIL) as the difference in the peak sound pressure level of an impulse, measured at the ear-simulator microphone of an acoustical test fixture (ATF), with and without an HPD in place. Since IPIL is based on the time-domain peak reduction, the measurement strongly depends on the spectral content of the impulse noise source and the spectral characteristics of the HPD’s noise reduction.

Recent work has shown that an alternate frequency-domain analysis of S12.42 impulse measurements yields better agreement between measurements of the same HPD when tested with impulse noise sources having different spectral content. This paper presents frequency-dependent insertion-loss measurements on several HPDs, measured with both an acoustic shock tube (low frequency) and an AR-15 (higher frequency) impulse source. We compare these impulse measurements to insertion loss measured on an ATF with lower-level pink noise and measured on humans with the standardized real-ear attenuation at threshold procedure. Finally, the current activities of the working group revising the S12.42 standard are reported on, including its direction in adopting a spectral analysis method.
Hearing protection, 3D audio, Noise regulations

Chairmen:
J. Voix (ETS), P. Naz (ISL)
Psychoacoustic hybrid active noise control structure for application in headphones

P.R. Benois1), V. Papantoni2), U. Zölzer1)

Psychoacoustic active noise control aims to decrease the perceived loudness and annoyance of the acoustic noise present in the environment. In order to achieve this, the frequencies to which the human ear is more sensitive are attenuated with higher priority. An implementation of such a control system based on FeLMS and noise weighting curves has shown to effectively improve the pleasantness of the residual noise. However, although it produces attenuation within the critical frequency region, the high frequencies are partially amplified and the low frequencies remain almost unaltered. In this paper, a hybrid structure is proposed for the application in active noise control headphones, which extends the attenuation capabilities of the feedforward control structure with a classical feedback controller.

The feedback controller is designed to attenuate the residual error in the low frequency region, thus partially compensating the limitations of the original structure. A realtime FPGA implementation of the proposed hybrid control structure is presented and its performance is evaluated based on the analysis in frequency domain and based on psychoacoustic objective metrics, which are calculated from measurements made on a headphones prototype.

The evaluation of the measurement results shows that the passive attenuation provided by the headphones materials plays a dominant role in the pleasantness of the overall system. Nevertheless, the implemented ANC structures contribute to a further reduction of loudness and roughness. Among the evaluated control structures, the proposed structure shows the best results in attenuation and psychoacoustic objective metrics, which is consistent with the qualitative pleasantness experienced when using the prototype.

Keywords
ANC headphones, Hybrid control, FeLMS, Psychoacoustics

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Development of a new ANSI standard for measuring sound localization performance with hearing protection devices

E.R. Thompson

An important aspect of auditory situation awareness is the ability to localize sounds in one’s environment. Often, this ability is greatly diminished when wearing a hearing protection device (HPD), including the ability to determine whether a sound source is in front of or behind the listener [1-3]. Recently, some HPDs have been developed that are claimed to preserve, or even enhance, sound localization performance when they are worn. Until now, there has not been a standardized procedure for measuring sound localization performance that could be used to validate the claims. A working group of the American National Standards Institute (ANSI) through the Acoustical Society of America (ASA) has recently developed a new standard for measuring the impact of head-worn devices, including hearing protection devices (HPD), on sound localization performance. This standard describes four methods, which provide different information about sound localization with sources on the horizontal plane. Method 1 uses an array of eight loudspeakers arranged in four pairs around the subject, and is intended to be a rapid, inexpensive test that provides a coarse impression of the impact of a device on sound localization. Method 2 uses an array of 36 loudspeakers, obscured from view of the subject, to measure localization error as a function of azimuth, when wearing a device.

Method 3 demonstrates an operational impact of impaired sound localization ability by using an aurally-guided visual search task [3]. Method 4 uses a 180-loudspeaker array to measure sound localization acuity with and without a head-worn device. The methods will be presented in detail, along with some data collected using the methods.
Methods for solving front-back confusions in 3D audio headphones

P. Nowak¹,², V. Zimpfer¹, U. Zölzer²

Human natural listening is based on the localization of sound sources using two ears. In the horizontal plane mainly the interaural time difference (ITD) and the interaural level difference (ILD) are used to localize a sound source. In addition, monaural spectral cues as well as characteristic peaks and notches inside the frequency spectrum give information for vertical localization. Head-related transfer functions (HRTFs) summarize all these aspects. In binaural synthesis through headphones, level and time differences can be introduced respectively to the left and the right channel in order to offer the possibility to shift a source to one of the sides. Additionally, HRTFs can be used to filter the two channels in order to add information about the elevation and to create a complete 3D space for the virtual sources. However, uncertainties in the perception whether a virtual source is located in the front or in the back of the subject are still one of the main problems of binaural synthesis.

In order to improve the localization ability and to reduce the front-back confusions, different strategies to individualize the used HRTFs and/or the headphone equalization are investigated [1]. Moreover, a shelving filter can be used to increase the natural effect of the monaural spectral cues [2].

Hence, the filter has to amplify high frequencies for frontal directions and attenuate them for back directions. Often front-back confusions are counted and analyzed during listening tests in the full azimuthal plane. In contrast to this, here, only two sources, i.e. one in the front and one at the rear, are taken in order to target on the basic problem of front-back confusions rather than evaluating additional errors in the perceived angle of arrival.

In this work, different methods for solving front-back confusions are evaluated in a listening test with different setups, including the usage of different headphone types, headphone equalization, and additional shelving filtering of the used HRTFs. Furthermore, two real speakers are taken as a reference in the listening test.

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Common Session with NATO HFM-285: Speech intelligibility, Audio communication

Chairmen:
R. Jacob (BwZKrhs), L.R. Henry (HCE/USAF)
NATO CSO-HFM 285 approach to improve communication quality among non-native English speakers/listeners

R. Jacob\textsuperscript{1)}, L.R. Henry\textsuperscript{2}) and CSO-HFM 285 members

Background: Hearing is critical to the performance of NATO forces and is integral to situational awareness and verbal communications. Acoustic communications (verbal/speech) is a critically important ability for soldiers to perform their tasks. Misunderstandings and miscommunications can cause fatal accidents or lead to errors in decision making. Within NATO coalitions, communications take place between native and non-native English-Speakers and English-Listeners. Non-native language communication between speakers and listeners with even the best of language skills can be difficult, and variations in the levels of language training, environmental noise, and adjunct of communication gear can make reasonable speaker/listeners unable to effectively communicate.

Noise Induced Hearing Loss (NIHL) is commonly caused by exposure to excessive noise levels in the military environment and these noise levels can cause irreversible damage. Regular exposure to noise levels over 85 decibels (dB) can cause hearing loss and hearing related disabilities such as tinnitus. Exposure to extremely loud noise can increase the risk of sudden or immediate hearing loss. Harmful noise levels do not always cause pain and injury is often initially not noticeable with no reaction from the exposed. By the time an individual realizes their hearing is impaired (e.g. sounds become muffled, distorted, or poorly perceived) it can be too late to intervene. On a personal level, auditory dysfunction may directly impact safety, career progression, and quality of life.

Objectives: The HFM-286 technical group will provide recommendations for assessing communication quality in international settings as well as recommendations for noise exposure and health risk assessment. In particular, the group will be actively engaged in the development of standards for acoustic communication based on a soldier’s linguistic and hearing abilities, while maintaining the needed hearing protection. NATO must therefore analyze the risks, and identify, mitigate, and minimize potential threats to communication that will optimize NATO Forces abilities to exchange information without errors. Notwithstanding, optimal hearing protection (to include protection from impulse noise) must be maintained.

Keywords
Speech intelligibility, Non-native english speakers/listeners, Noise induced hearing loss

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Self-reported and measured hearing difficulties in noise in a population of normal-hearing to mildly hearing-impaired adults

G. Andéol, T. Fux, C. Suied, A. Moulin

Speech in noise performance differ widely among the military population (normal-hearing to mildly hearing-impaired adults). However, it is unclear whether speech in noise performance measured in tests is related or not to the listener’s subjective assessment of his/her own speech in noise abilities.

In the present study, speech in noise performance was measured with the French version of the Oldenburg Matrix test (namely the Framatrix), and the French language version of Noble and Gatehouse’s Speech, Spatial and Qualities of hearing questionnaire (SSQ) was used for the self-report measure. One hundred listeners participated, aged from 18 to 50 (mean = 34 ± 7).

Pure-tone audiometry was evaluated per octave from 125 Hz to 12.5 kHz in both ears of each subject. The Matrix test consist in sentences presented in a voice shaped noise, in free field, using an adaptive procedure to identify the 50% threshold. Three consecutive tests were performed for each subject and the best threshold of the three was considered. The SSQ scores were calculated on the full scale and subscales, and using the new 15 items SSQ short-form (15iSSQ).

There was no significant correlation between low and mid-frequencies hearing thresholds and the SSQ score, or the Matrix test thresholds. However, the SSQ scores decreased significantly as high frequency thresholds (HFT i.e. the average of 4-8-12.5 kHz thresholds) increased. Matrix test SNR threshold decreased significantly with decreasing HFT and decreased significantly with increasing SSQ scores, and SSQ speech scores. However, the variance in SSQ scores and SSQ speech scores explained by the Matrix test seemed to be low. Those results reflect listeners’ difficulties to self-report their own speech in noise abilities.
Cartilage conduction HPD for communication during impulse noise exposure

J. Rosier¹, J. Dury¹, Y. Pène¹, V. Zimpfer², P. Hamery², G. Blank²

For military environment, Hearing Protection Device (HPD) with integrated communication system is increasingly used. These devices must provide to soldiers communication facility and efficient protection against high level of noise for both steady and impulse noise exposure.

HOPLITE is a new Tactical Communication Headset based on Cartilage Conduction technology (see figure (1)). Its transducers foster sound propagation through ear cartilages rather than auditory canal. As a result, earplugs can be used to reduce noise disturbances without interfered with useful sounds.

The measured Insertion Loss (IL) attenuation levels for both double protection from 150 to 190 dB Peak Impulse noise exposure, are presented in the figure (3). The IL Level is defined as difference between acoustic level at the tympanic membrane with the hearing protector and the acoustic level without the protector. Insertion Loss attenuation versus frequency is representative of attenuation performance of the device and is used to evaluate the shot numbers authorized during noise exposure.

For soldiers, the impulse noise levels can reach sound pressure levels ranging from 145 to 190 dB Peak (Amrein & Letowski, 2012) [1]. Performances of the HOPLITE with two kind of earplugs were evaluated: CAE 3M manufactured by 3M and BIL-SOM 303 manufactured Howard Leight. Trials were realized on artificial test fixture (see figure 2) with explosives charges.

Coupled with earplugs, Hoplite users can communicate in harsh environment with impulse noises. A large variety of passive earplugs, from foam type to custom moulded earplugs can be used. The performances of the double protection will depend on the chosen earplugs.

**Fig. 1**: HOPLITE a new tactical cartilage conduction Headset (manufactured by ELNO)

**Fig. 2**: Insertion Loss of HOPLITE used in double protection with CAE 3M and BILSOM 303 earplugs for Impulse Noise Exposure

**Keywords**
Impulse noise exposure, Hearing double protector, Communication headset

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Measuring speech intelligibility using throat microphones

E. Wickman, K. Bolin, O. Sundqvist, F. Green et al.

Contact microphones, especially throat microphones, have been developed for use in a complex environment, where high background noise is evident in order to improve the speech intelligibility of communication systems. Throat microphones pick up vibrations from the skin surface where they are in contact and are less sensitive for background noise than standard microphones.

The performance evaluation of throat microphones, regarding speech intelligibility, compared to other type of microphones have historically been made by test persons, examining and subjectively rating the communication devices in question. This study examines the possibility to use the objective method STI to assess the speech intelligibility and thus enable a comparison between different microphone types in various noise environments. The aim of the study was to examine the relationship between speech signals and head and neck vibrations and investigate if an STI test signal may be transformed to vibrations and thereafter used to record speech intelligibility for a chosen contact microphone.

22 men and women participated in this study, where the test persons read about 20 phrases according to Hagerman’s “Sentences for testing speech intelligibility in noise”. Contact vibrations were measured from the various microphone positions while reading those test sentences. Frequency responses were calculated for all microphone positions. The study reveals that the frequency response of the neck may be approximated as a second order low-pass filter with a cut-off frequency of about 300 Hz that attenuates speech signals with higher frequencies.

Experiments were also made to measure the STI value of a throat microphone with data from the experiments. However, the results pointed out several problems that need to be addressed before a STI-method can be applied successfully.

Beyond the scope of this study, the results may also be used to study the relationships between vibration characteristics on different locations on the throat and head and speech signals. Furthermore, suggestions on how the performance of contact microphones may be improved are included.

Fig. 1: Experimental setup and instrumentation for the study of relationship between speech signals and contact vibrations

Keywords
Speech intelligibility, Contact microphones, Vibration

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Speech Intelligibility: Ongoing creation and validation of a list of French rhyming words for MRT tests

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Military standards describe how speech intelligibility must be assessed in radio communication systems \cite{MIL-STD-1472G}. That assessment is vital to prevent errors of communication and potential accidents. The modified rhyme test (MRT) \cite{Articulation-testing methods} is the most popular behavioural test of speech intelligibility in military context. MRT is helpful for osteophonic systems because predictive tests such as the speech transmission index cannot be used. Osteophonic systems are currently widely used in the French Army (FELIN system).

The assessment of those osteophonic systems in operational context and the development of new systems require to create a French version of the MRT. The French MRT was designed on the same principles as the original MRT: two speakers, monosyllabic words, closed set of six alternatives differing according to the first or the final consonant. The validation of the French MRT focused on the effect of SNR on correct scores, and the absence of a learning effect.

The figure above shows that the effect of SNR on correct scores in French MRT is similar to the original MRT. Our new MRT can therefore be used for future tests of new and existing communication systems in the French Army.

Keywords
Modified Rhyme Test (MRT), French language, Speech-in-noise, intelligibility

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Predicting the intelligibility of non-native speech using the Speech Transmission Index

S.J. van Wijngaarden, J.A. Verhave

Non-native perception and production of speech almost universally results in a reduction in speech intelligibility when compared to “normal,” fully native, speech communication. Causes for the observed reduction in intelligibility have been traced back to various linguistic and phonetic phenomena associated with non-native speech, such as distortions in phoneme space, unusual intonation, limited understanding of grammar and limited vocabulary [1]. Not just differences in the (native) language backgrounds of talkers and listeners contribute to the diversity in non-native speech encountered in practice; non-native perception and production also varies between individuals [2,3]. As a result, the numerous scientific studies aiming to increase our understanding of non-native speech processing are extremely diverse. Fortunately, the details of second-language speech production and perception do not need to be fully modelled (or in fact understood) in order to be able to predict how non-nativeness impacts speech intelligibility.

Populations of talkers/listeners can be categorised into proficiency categories that predict the impact of non-nativeness on the intelligibility of speech [2]. Based on self-reported proficiency levels or the outcome of a linguistic proficiency test, subjects are categorised into one of 4 categories (native proficiency and 3 levels of non-native proficiency). Within each category, a wide variation in terms of non-native production and perception irregularities is observed. However, the overall level of speech intelligibility (as measured with sentence intelligibility tests) is consistent within each category (see Fig.1). In other words, self-rated proficiency or linguistic proficiency tests are sufficient to predict the impact of non-nativeness on speech intelligibility without any consideration regarding the precise production and perception process involved.

For non-native subjects to achieve the same level of speech intelligibility as native subjects, the overall quality of the communication channels needs to be higher [4]. In other words, the lower the average non-native proficiency level is across the target population, the better the communications channels need to be in order to achieve satisfactory intelligibility. For each of the 4 proficiency categories, adjusted qualification criteria for the Speech Transmission Index (STI) have been established. E.g., for a “normal” population, IEC-60268-16 considers the minimum for “fair” intelligibility to be reached at an STI of 0.45 or higher. For severely accented speech, the same criterion (hence the same level of intelligibility) is achieved at an STI of 0.56 or higher. An adjusted table of qualification criteria for non-native speech based on [4] is currently part of IEC-60268-16 as an informative Annex (see also table I below).

Other recent developments regarding the STI, such as the development of a specific test signal that can be used with narrow-band Voice Coding systems (STIPA-VC), have reinforced the usefulness of the STI for military communications channels. Objective performance criteria can now be set that can be objectively verified with commercially available test equipment, and that take into account that the population using the equipment is partially non-native.

<table>
<thead>
<tr>
<th>STI label</th>
<th>Standard STI (Cat. I)</th>
<th>Cat. II (mild accent)</th>
<th>Cat. III (moderate accent)</th>
<th>Cat. IV (severe accent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>bad - poor</td>
<td>0.30</td>
<td>0.32</td>
<td>0.34</td>
<td>0.36</td>
</tr>
<tr>
<td>poor - fair</td>
<td>0.45</td>
<td>0.49</td>
<td>0.52</td>
<td>0.56</td>
</tr>
<tr>
<td>fair - good</td>
<td>0.60</td>
<td>0.66</td>
<td>0.71</td>
<td>0.79</td>
</tr>
<tr>
<td>good - excellent</td>
<td>0.75</td>
<td>0.85</td>
<td>0.91</td>
<td>&gt; 1</td>
</tr>
</tbody>
</table>

Table 1: Relation between STI and qualification labels for non-native talkers differing in degree of foreign accent. The text “>1” indicates that an STI greater than 1 would be required, meaning that this qualification cannot be reached.

Fig. 1: Sentence intelligibility as a function of speech-to-noise ratio for four arbitrary non-native talkers (one in each of 4 proficiency groups). Curves for other talkers from the same groups are closely matched [2]
Keywords
Speech intelligibility, STI, Non-native speakers

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Poster Session
Localizing sound sources is a major skill which serves humans to orientate them in daily life. The localization process is based on the inter-aural level difference (ILD), the inter-aural time difference (ITD) and spectral cues of the incoming sound. Spectral cues are introduced by the individual shape, resp. geometrics, of the auricle. The way how sound is filtered by the auricle is described by the angle and frequency dependent head-related transfer function (HRTF). The brain is trained to the HRTF during a human’s lifetime, allowing an unambiguous identification of sound source positions. Wearing earplugs, hearing aids or tactical communication and protection systems (TCAPS) modifies the geometrics of the auricle. These geometric modifications lead to important changes of the HRTF, but do not affect the ILD and the ITD. The listener’s brain cannot adapt instantaneously to the modified HRTF, which results in a less precise sound source localization. The major error type is due to front-back confusions by listeners. To pave the way towards a new generation of TCAPS which are intended to preserve the listeners natural spectral cues, three different models of TCAPS (BANG by Cotral&ISL, QuietPro by Nacre, and Z111 by Z-TAC) are analysed regarding sound source localisation capabilities and how they modify the HRTF. For this HRTF measurements of a dummy head are done in an anechoic chamber during four scenarios: dummy head without TCAPS, dummy head wearing once BANG, once QuietPro and once Z111. Sound source localization tests are conducted in a listening chamber with subjects in the same four scenarios, as the HRTF measurements of the dummy head are done. Based on the results from the HRTF measurements and the localization test concepts for a prototype of new generation TCAPS are illustrated.

Fig. 1: Sketch of measurement set for sound source localization test
Analysis and reduction of frictional sounds of soldier’s uniforms

F. Leclinche1,2, V. Zimpfer1, D. Adolphe2, E. Drean2

The generated noise by fabric-to-fabric friction in the frame of military applications is essential to be studied in order to improve acoustic stealth or estimate the ageing of the garment. Indeed, when a person is moving or walking, sounds are generated by the friction under arms or between legs. The sound properties of fabrics depend on many parameters like the weave patterns or the surface roughness. In case of garments, the surface of fabric will be modified through the repeated washing process and its natural wear. Thus, these modifications provide different fabric friction sounds. The aim of this study is to analyze the influence of ageing on fabric friction sound.

For this purpose, two sets of fabrics have been used. One is composed of samples, which are worn out thanks to Martindale abrasion tester. The second set are worn out through washing many times (50 washes). The raw sample and the sample washed 50 times are presented in figure 1.

For each sample, three groups of parameters such as acoustic, sensory and mechanical properties of the fabric have been measured. The acoustic parameters, especially the total noise level, has been measured using an experimental device which simulates the human arm motion during walking. Moreover, raw frictional sounds have been studied using a Fast Fourier Transform (FFT) analysis. Thanks to the Kawabata Evaluation System, the mechanical properties have been obtained. Afterwards, a sensory panel dedicated to hearing sense has been used for the audition evaluation of fabric friction sounds. In order to find relationships between all these parameters, a statistical analysis has been done. Some interesting correlations have been found especially between the total noise level and the wear’s degree of samples (fig. 2). A relationship between some compression parameters and the fabric’s ageing has also been highlighted.

Fig. 1: (a) raw sample and (b) sample washed 50 times

Fig. 2: Noise level according to the fabric’s ageing

Keywords
Friction noise, Ageing effects

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Method to choose the ideal size of earplug

V. Zimpfer¹, G. Andéol² et al.

The latest version of the Earplugs used by French Armed Forces has been designed to provide a greater efficiency (Fig. 1). This earplug uses a triple-flange design and is sold in three sizes (small, medium and large) in order to allow an optimal fit. Choosing the size of the earplug for every individual user is the major problem towards getting adequate protection: how to choose this optimum size?

Three methods have been examined during the current study:
Method 1: assessing how tympanometry tips fit in the ear canal.
Method 2: commercial device verifying earplug attenuation in situ.
Method 3: detection of acoustic leaks at low frequencies with an instrumented earplug (Fig. 2).

The first objective of this study is to compare these three different methods. The tests were conducted with 106 soldiers and took place in the 4th Regiment of the Foreign Legion for two days. Each soldier was tested with the three methods, in a different order.

Fig. 1: S3M™ Combat Arms™ Earplug / 3 sizes

The results show that there is no evident correlation between the size prognosticated by method 2 or 3 and the tip size (method 1). We note that only for 24% of the subjects all the methods give the same size.

The method 3 is good compromise: it is easy of use, rapidly and cheap. Acoustic leak has been successfully detected with method 3 and validated by REAT measurements. It has shown to be a valuable help to choose the size of the earplug providing an optimized acoustic attenuation. The users have also noticed that it is an excellent educational tool to allow them to train to put correctly earplugs.

Keywords
Earplug size, Hearing protection, Acoustic leak

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Assessment of the frequency response of a solid conduction transducer based on an audiometric threshold measurement of individuals

V. Zimpfer¹, J. Rosier², Y. Penne² et al.

The sound transmission to the auditory organ by solid conduction (through bone or cartilage) is a physical phenomenon related in several previous works. Headbands using solid conduction allow users keeping open ears and so listening their sound environment. The audio quality of solid conduction headphone is conditioned by the choice of the transducer.

This study deals with the sound perception of a solid (bone or cartilage) conduction headphone. More specifically, it proposes a methodology to estimate solid conduction transducers behaviour by measuring subjective hearing threshold (audiometry). Two screening audiometry tests are necessary:

1) with the reference headphone and an audiometric measurement system to obtain the threshold hearing of the subject,
2) with the solid conduction transducer.

The audiometric measurements allow to determine the frequency response of the transducer at the threshold of hearing \( H \):

\[
H_{(dB)} = N_s_{(dB)} - A_1_{(dB)} - A_2_{(dB)}
\]

\( N_s \) is the sound level for a threshold of hearing related to the curve of iso-sonie

\( A_1 \) corresponds to the difference between the hearing threshold with the reference headphones and the one with the transducer to be tested (in order to cancel the hearing losses of the subject),

\( A_2 \) is a corrective term related to the amplification made by the audiometer.

Fig. 1: Frequency response for two types of solid conduction transducers obtained on 7 subjects

The figure represents the frequency response obtained for both transducers. The frequency response at hearing threshold is a tool allowing to estimate the real efficiency of transducers with solid conduction technology.

**Keywords**

Bone conduction transducer, Auditory

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¹ French-German Research Institute of Saint-Louis (ISL)
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This poster presents the latest work on hearing protectors developed in the French-German research institute of Saint-Louis. This new generation of hearing protection devices has been specifically designed to maintain an efficient protection against transient (weapon) and continuous noise while providing a better perception of the acoustic environment. Spatialized communication and warning messages provide an intuitive feedback of the information transmitted to the user. In addition, sound environment reproduction at a controlled level, and active noise reduction algorithms for enhanced continuous noise attenuation performance are integrated. Sound recorded directly in the ear canal (underneath the physical protector) is used for voice transmission, real time dosimetry, and source detection and localization.

In order to improve the acceptance of the hearing protection device by the user, various numerical filters have been designed. An evaluation with a group of listeners was performed in order to determine the filters giving the “most natural” perception. In parallel, a study of the source localization when using the inner microphones of the protectors has been initiated. For these tests the earplugs were fit into the ear canals of an artificial head. The experimental protocols and first results are discussed.

**Keywords**
Acoustics, UAV, Sound, Detection, Classification, Localization

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Development of a cost-effective system for dosimetry of high sound pressure levels

F. Königstein, M. Christoph

The noise exposure of a soldier during his training/shooting period is currently estimated by summing each of the individual theoretical noise contributions due to the use of the weapons/equipment planned to be used during the exercise. The difficulty is for considering multiple soldiers in a joint manoeuvre, with simultaneous shots of mortars and small arms, being at variable distances from the weapons etc. In such a case, the theoretical noise dose is difficult to estimate and a potential solution is to use a personal noise dosimeter. Such a device will allow to monitor individually and in real time the noise exposure of each soldier, limiting the risk of overexposure. However, the dosimeters that are presently available are not rated for the sound pressure levels occurring during weapon firing. This is due to the fact that there are no commercially available microphones that fulfil simultaneously the requirements of cost-effectiveness, high maximum sound pressure level and dynamics.

This poster presents a low-cost system based on two sensors operating in parallel (Fig. 1): an electret microphone for the low levels (good signal up to 160 dBpeak) and a pressure sensor for the high levels (tested between 160 and 190 dBpeak). Example of measured signals are given in Fig. 2 and 3).

Keywords
Acoustic dosimeter, High sound pressure level, Weapon noise

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Modelling sound propagation in complex battlefield environments

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Accurate modelling of signals in battlefield settings is important for mission planning and situational awareness, because it improves detection, identification, and vulnerability assessments. The U.S. Army Corps of Engineers has developed a framework for simulating various signals (e.g., acoustic, seismic, visible, infrared, and radio frequency) using physics-based modelling, called Environmental Awareness for Sensor and Emitter Employment.¹,² EASEE can model signals from moving or stationary targets and includes spectral and directivity effects for many common sources. It also incorporates an algorithm for optimal sensor selection and placement. The software incorporates an XML interface to support web services development, and can be integrated into a variety of command and control (C2) and geographic information systems (GIS).

For acoustics, EASEE includes a library of small-arms fire, ground vehicle, and aircraft acoustic signatures. It provides several different propagation models of varying fidelity (e.g., impedance plane, wedge diffraction, parabolic equation methods, Nord2000, and machine learning algorithms) so that users can customize the physical accuracy and computation cost to the application. If desired, complex terrain and 3D weather forecasts can be included in calculations. It models the response and directivity of sensors such as microphones. Finally, EASEE provides multiple outputs including the overall signal power, octave-band power, and detection probability. EASEE has been utilized in many applications, including aircraft audibility, detection of handheld radio transmissions, counter UAS in urban environments, and mesoscale infrasound propagation.

Keywords
Signal propagation, Sensor performance, Tactical decision aids

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6th workshop on Battlefield Acoustics & NATO SET-233, HFM-285 & CCIEP Experts meetings
October 16-17, 2018, ISL, Saint-Louis, FR

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We wish you a pleasant meeting!