U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND – ARMAMENTS CENTER

NDIA FFCCE – Signature Suppression Session
21 SEP 2022

Adam M. Jacob

Chairman, Joint Service Signature Suppression IPT

Joint Service Small Arms Program (JSSAP) office

21 SEP 2022

NDIA FFCCE – SIGNATURE SUPPRESSION SESSION

Background of Sound, Light, and Human Factors		
Dr. Michelle Swearingen	US Army Corps of Engineers, Engineer Research and Development Center, Construction Engineering Research Laboratory	BANG or pop: A Tutorial on Sound Propagation in the Environment
Ms. Ruth Foutz	US Army, Public Health Center	Effects of Sound on the Human Ear
Dr. David Dye	NSWC Crane	Human Eye Perception of Flash
Applied Studies in Human Perception and Operational Relevance		
Dr. Paul Fedele	US Army, DEVCOM ARL	Localization of Shooter Position Based on Weapon Signature
Mr. Tim Cler	US Army, DEVCOM ARL	Outdoor Acoustics
Mr. Lewis "Cole" Cochran	US Army, MCDID	Tactical Advantage by Sound and Visual Suppression
Technology Development and Related Studies		
Mr. Dan Baechle	US Army, DEVCOM ARL	High-Temperature Evaluation of Suppressor Covers
Mr. Ernest Bray	X2 Dev Group	Flow Through and Reverse Flow Suppressors - Advanced Designs to Address Modern Suppression Challenges
Mr. Barry Dueck Mr. Ryan Steven Glasby	SureFire Oak Ridge National Lab	Surefire's Advanced Suppressor Program - Blending Science, Technology, and Experience to bring Next Generation Signature Suppression to the Warfighter
QUESTIONS		

BANG or pop: A Tutorial on Sound Propagation in the Environment

NDIA-FFCCE Suppressor Summit

Prepared by Michelle E. Swearingen, Ph.D.

21 September 2022

U.S.ARMY

US Army Corps of Engineers®

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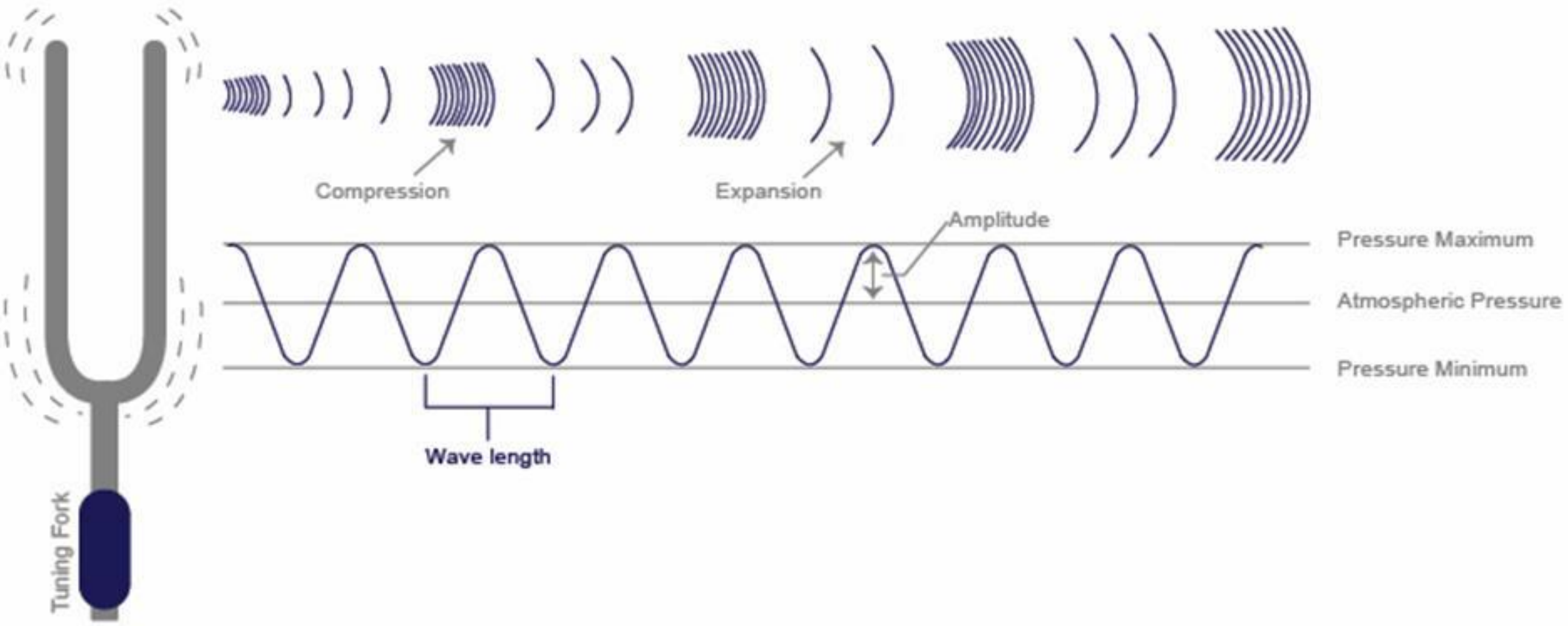
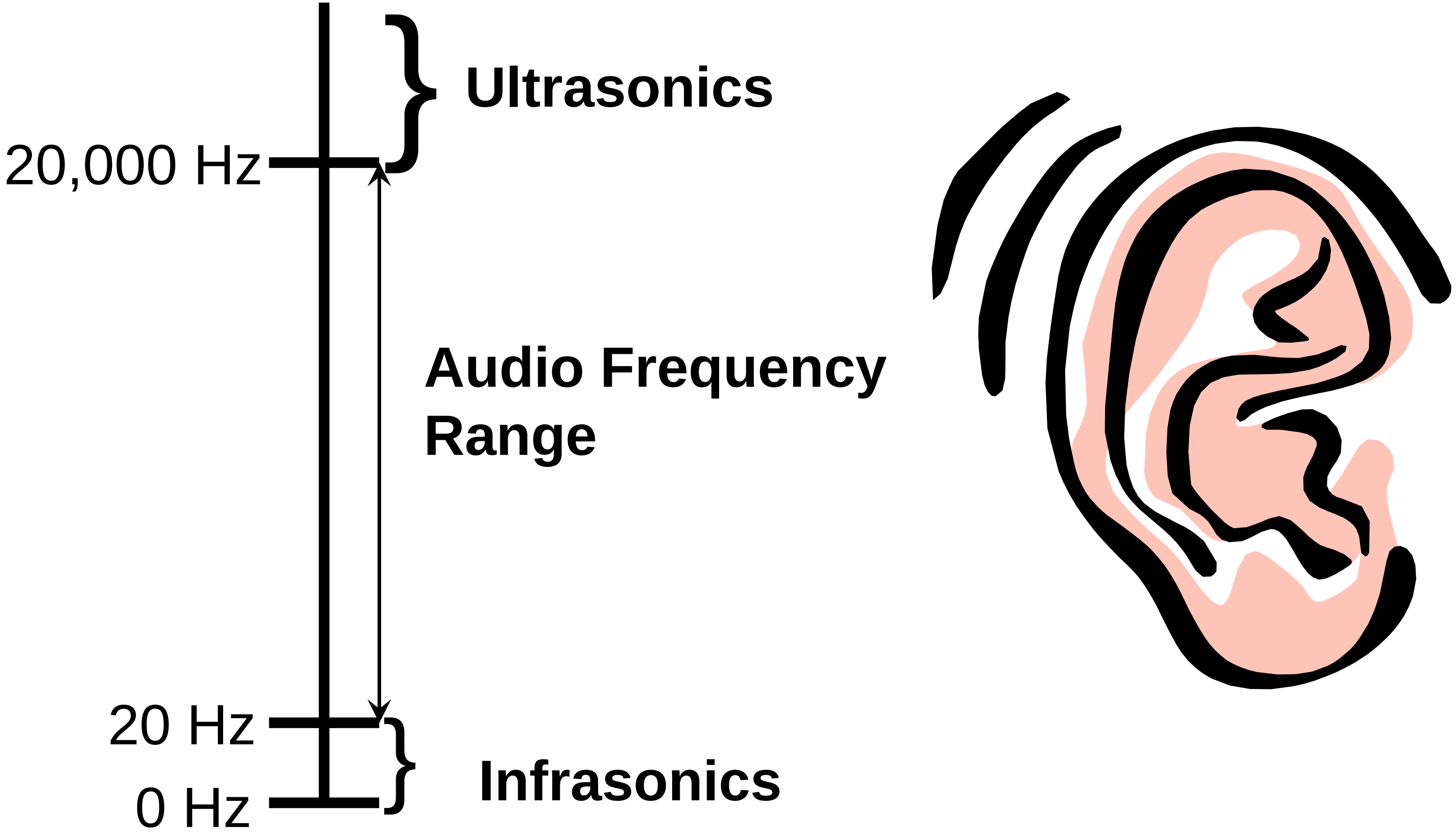
Agenda

- **Terminology**
- **Characteristics of different types of sources**
- **Ground-to-ground propagation effects**
  - **Refraction:** Temperature and wind variations increase or decrease signature propagation distance
  - **Ground Interaction/Surface Reflection:** Hard surfaces reflect signatures/soft surfaces attenuate signatures
  - **Atmospheric Absorption:** Low frequency signals less impacted
  - **Diffraction:** Large structure/terrain features block or redirect sound
  - **Turbulence Effects:** Introduces variability
- **Putting it all together**

Terminology



Hearing and Perception



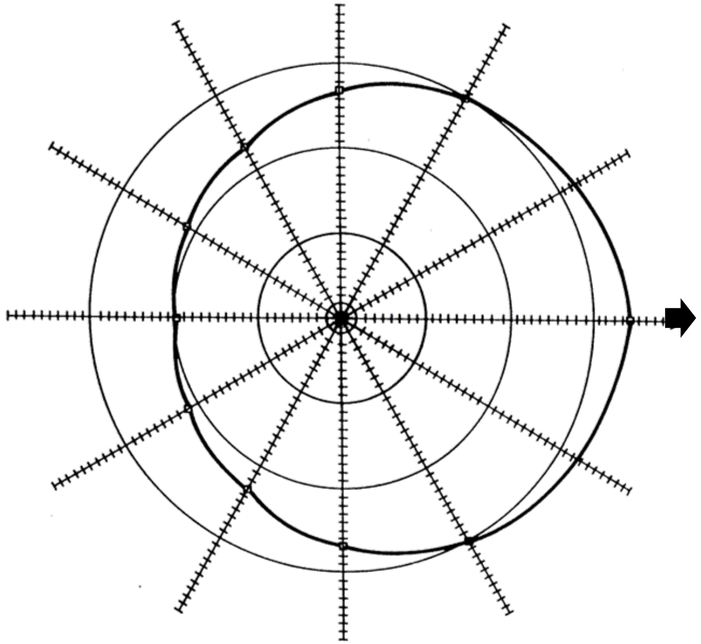
Directivity

Most sources are louder in some directions than in others; this is called directivity

Examples: loudspeaker, human voice, rifle

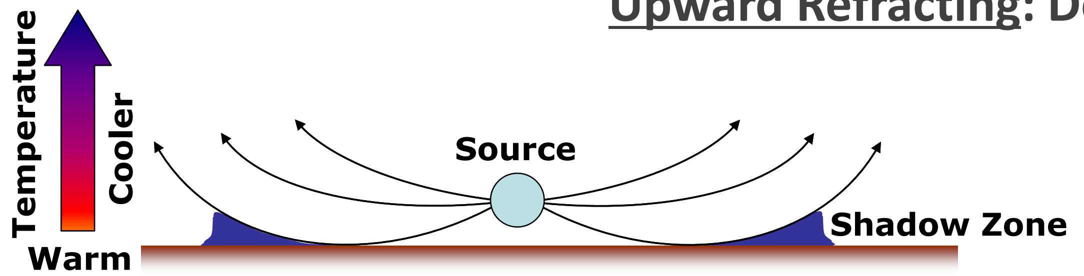
Directivity can be significant

In large weapons, it can be up to 15 dB louder in front!



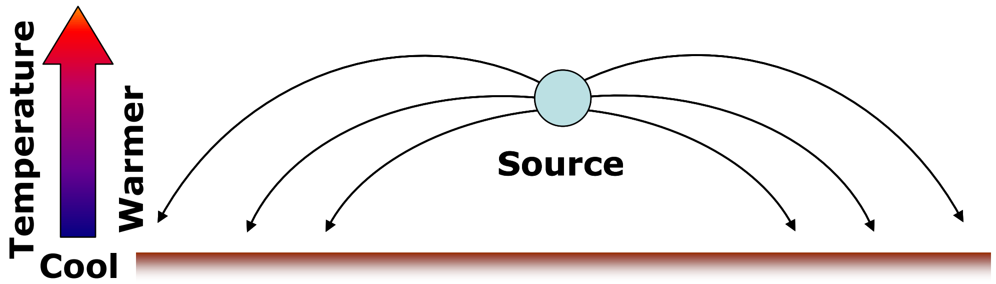
Refraction Summary

Upward Refracting: Detection ranges decreased



- Typically occurs late morning to early evening
- Temperature cools with increasing altitude
- Sound waves are bent upward
- Creates shadow zones away from source

Downward Refracting: Detection ranges increased

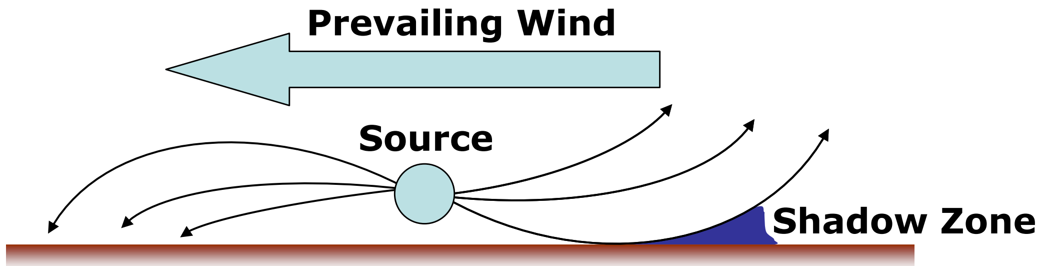


- Typically occurs early evening to mid morning and/or overcast conditions
- Temperature warms with increasing altitude
- Sound waves are bent downward
- Can propagate farther along the ground

Wind Effects: Enhanced signature propagation downwind from the source, decreased upwind

Downwind

- Bends sound downwards
- Enhances propagation along the ground
- Increases detection range



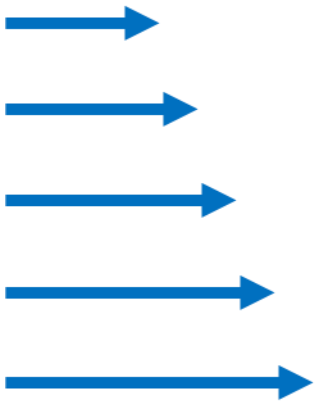
Upwind

- Bends sound upwards
- Creates shadow zones
- Decreases detection range

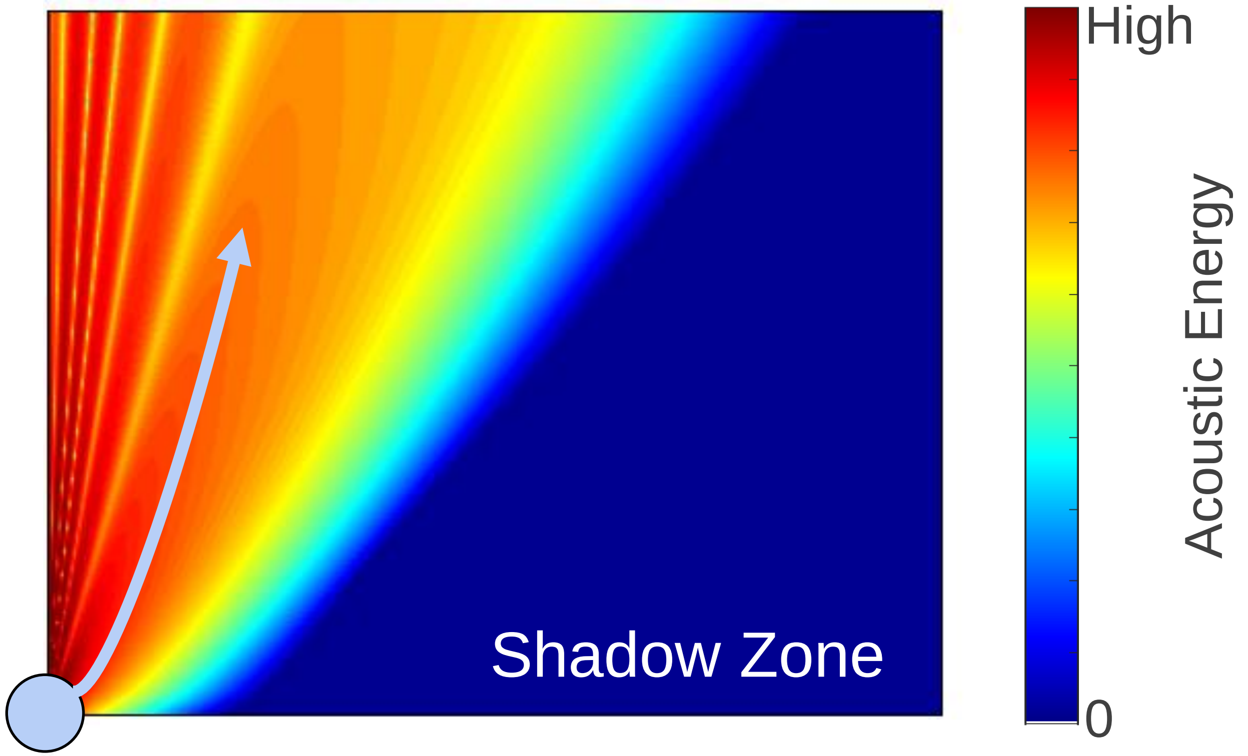
Upward Refracting

Common on bright, sunny days and upwind conditions
Example is idealized – in reality, shadow zones are not this clear-cut!

Sound Speed Profile
Decreasing



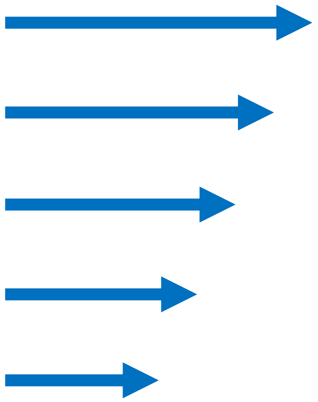
Propagation Effects



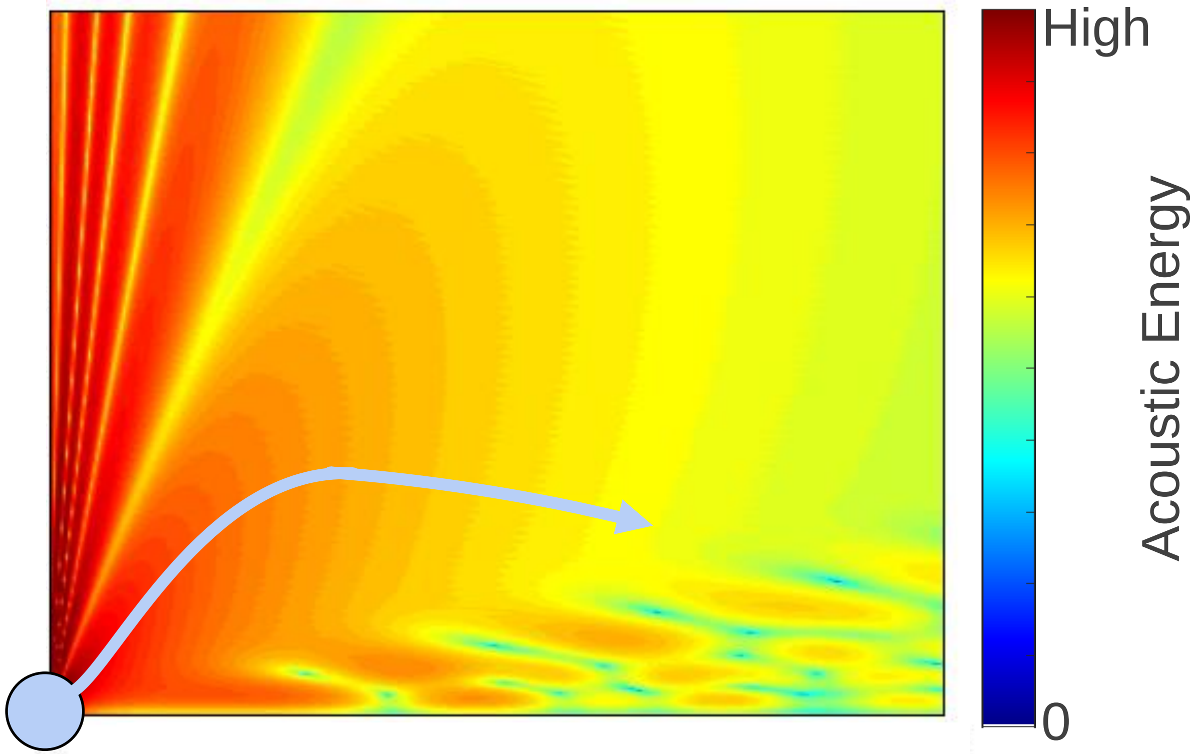
Downward Refracting

Common during nighttime, overcast, and downwind conditions

Sound Speed Profile
Increasing

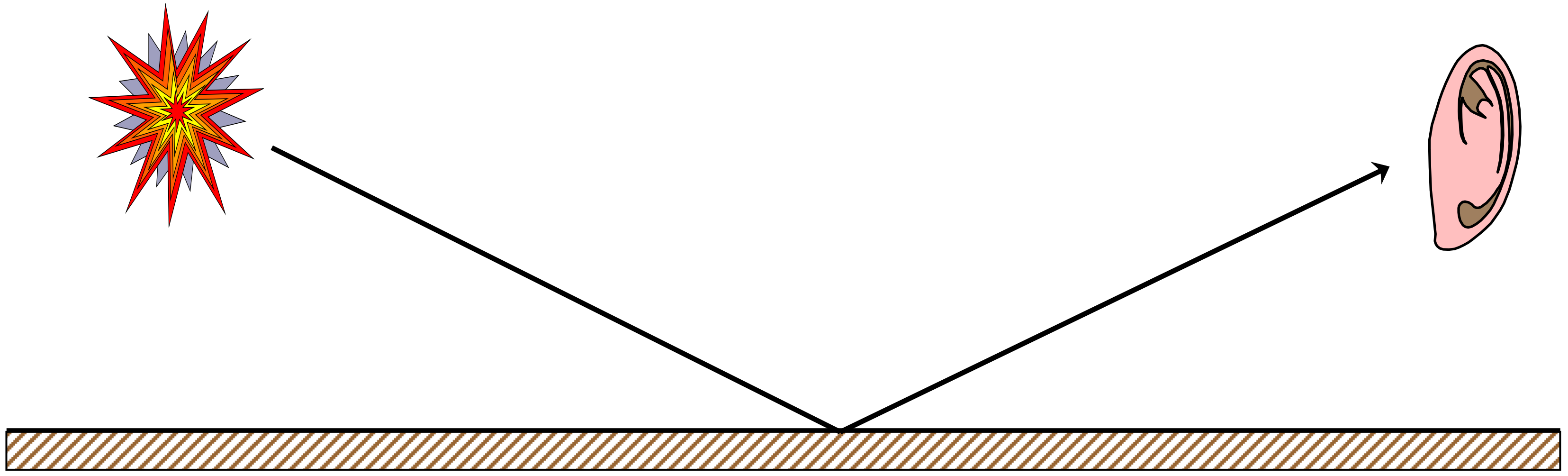


Propagation Effects



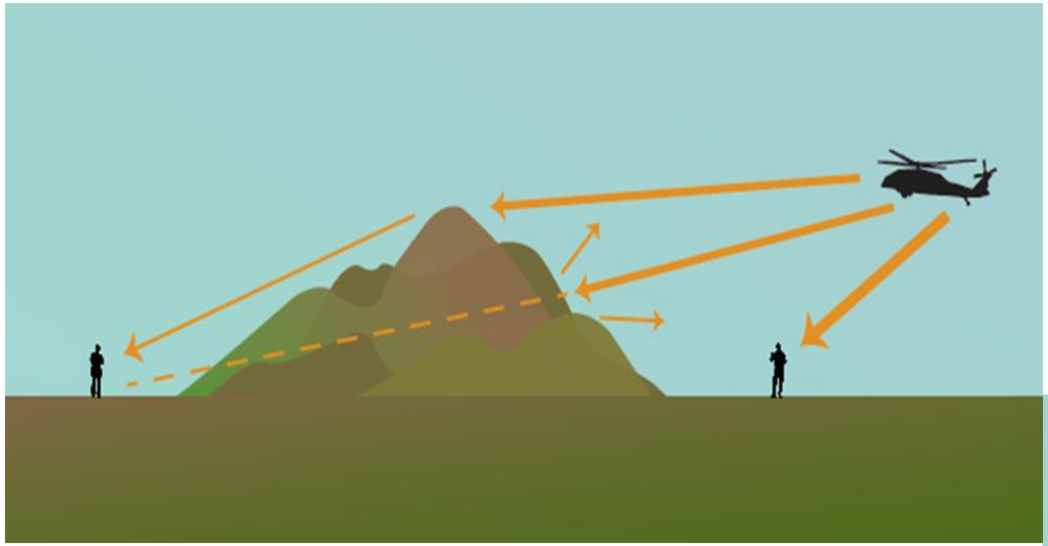
Ground/Surface Reflections

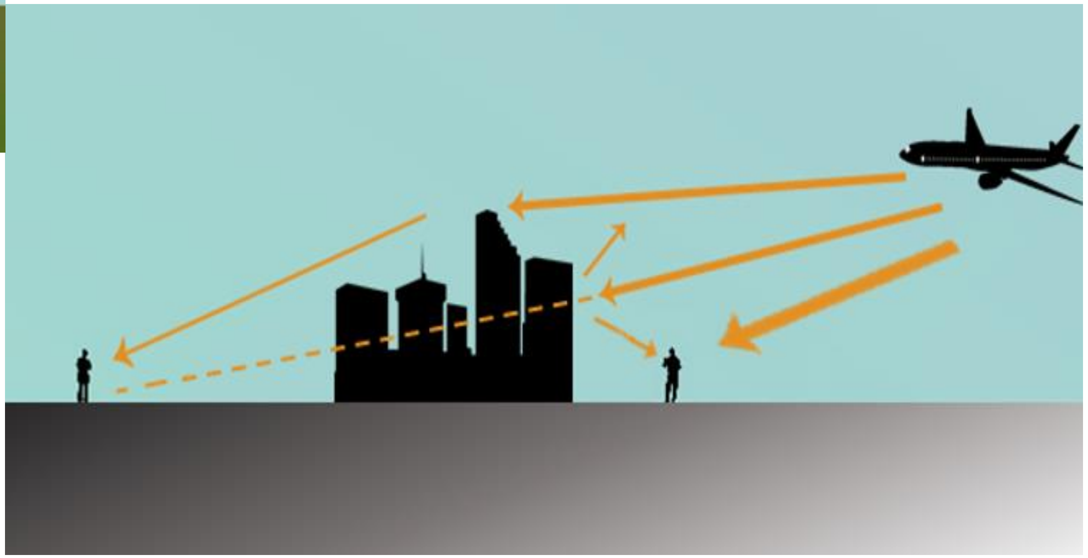
“Hard” grounds, such as water and asphalt, reflect signals with minimal attenuation.
“Soft” grounds, such as grass, snow, and forest floors, attenuate signals



Diffraction/Terrain Effects

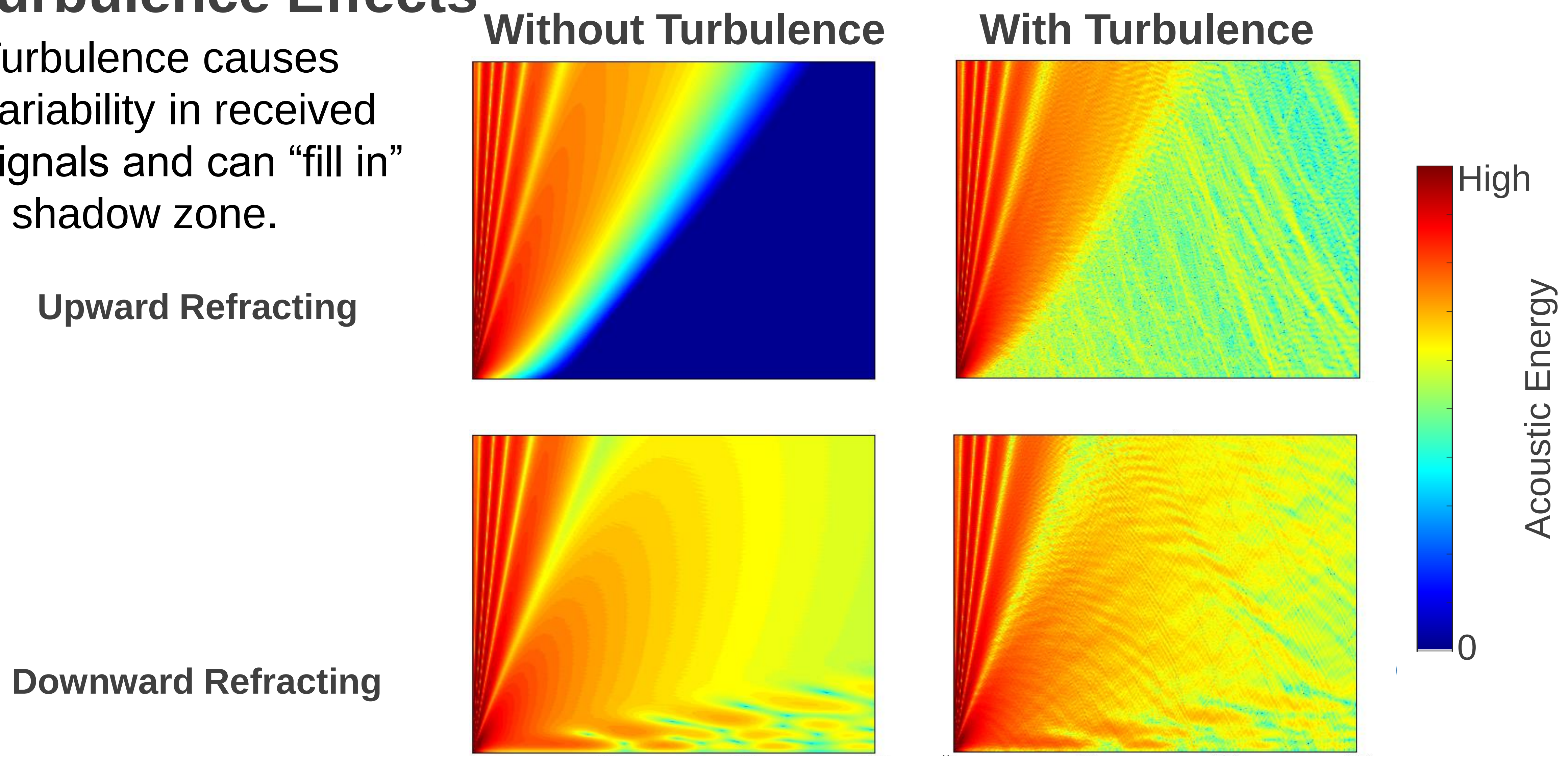
- Large structures and terrain features can block and redirect signals





Turbulence Effects

Turbulence causes variability in received signals and can “fill in” a shadow zone.



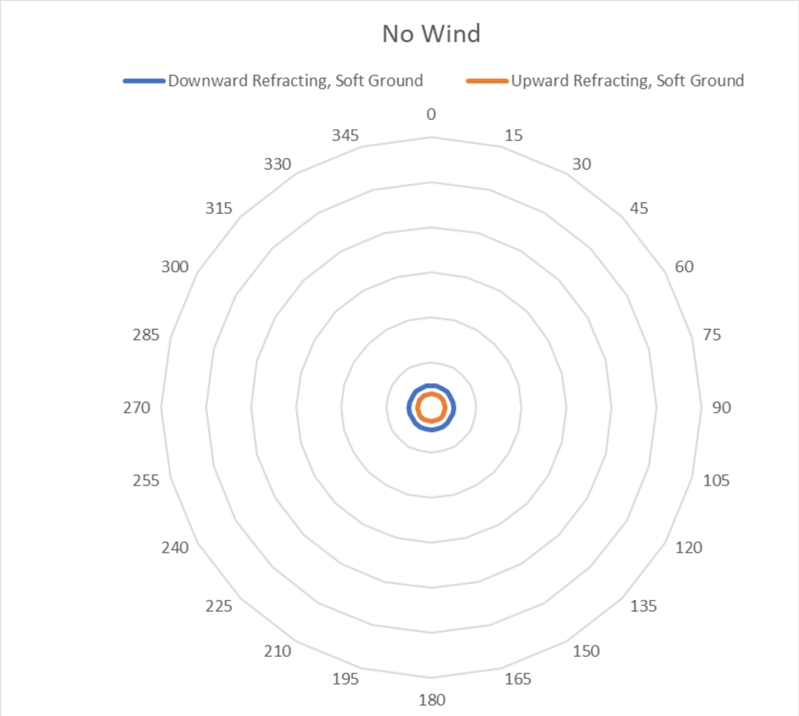
Putting it all together…

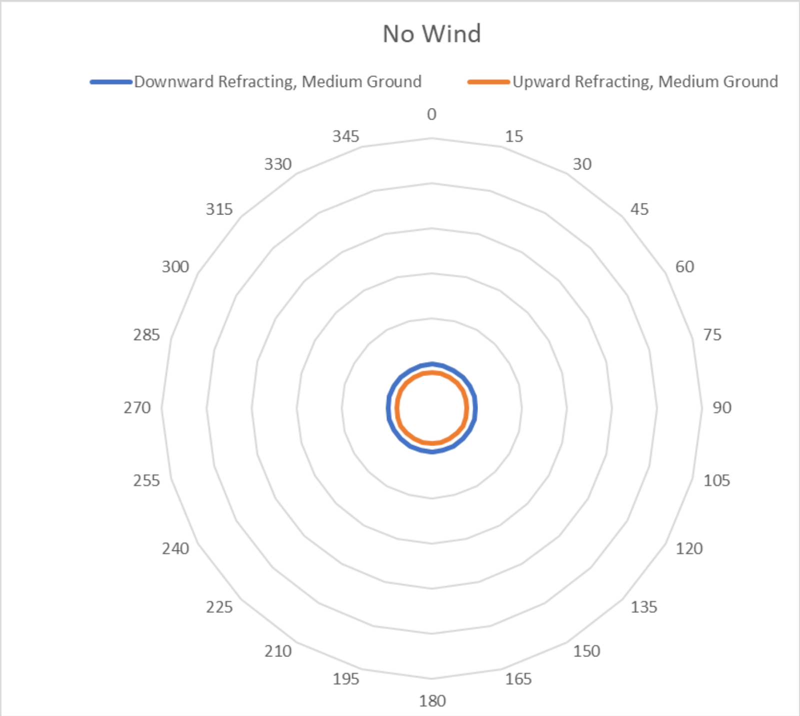
Simplified examples to show coupled effects

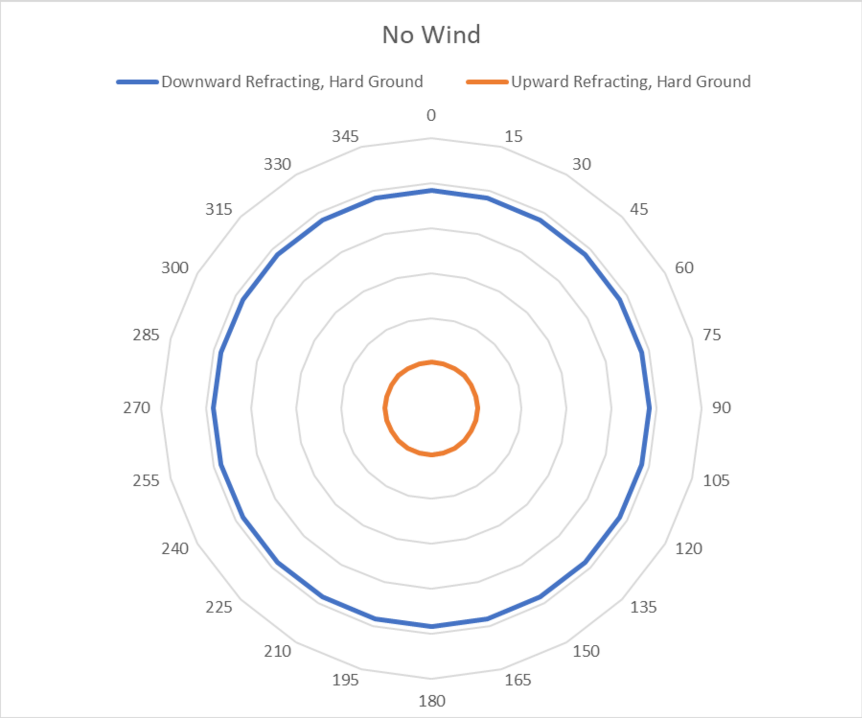
- Upward and Downward refracting temperature profiles
- With and without wind
- Three ground impedance values (soft, medium, hard)
- Atmospheric absorption included
- Turbulence not included
- Source is in the center

Temperature Only (no wind)

- Downward Refracting
- Upward Refracting







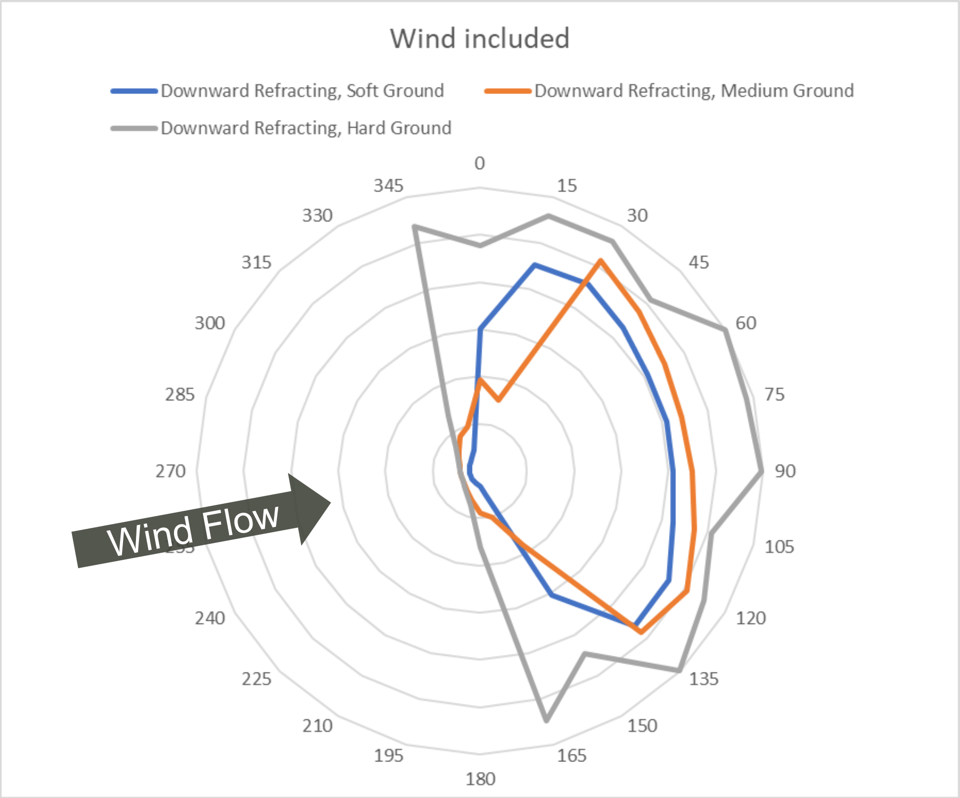
Soft Ground (Grass)

Medium Ground (Sand)

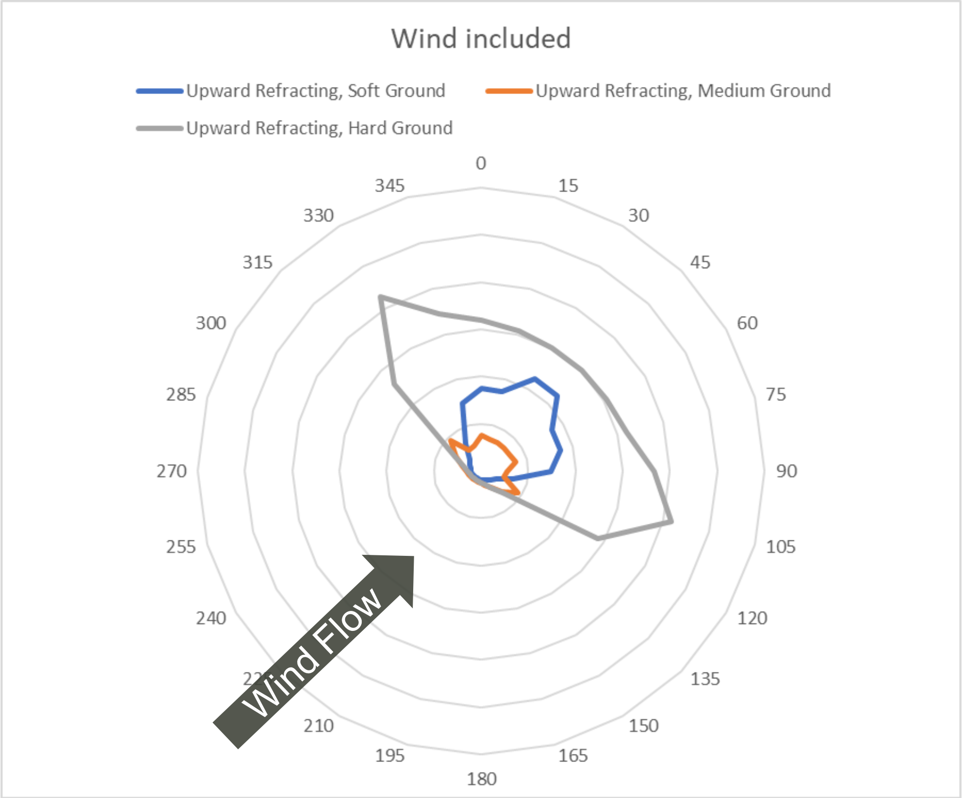
Hard Ground (Asphalt)

Wind Included

- Soft Ground
- Medium Ground
- Hard Ground



Downward Refracting (night)



Upward Refracting (day)

Additional Questions?

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Army Futures Command

Effects of Sound on the Human Ear

Ruth Foutz

21 September 2022

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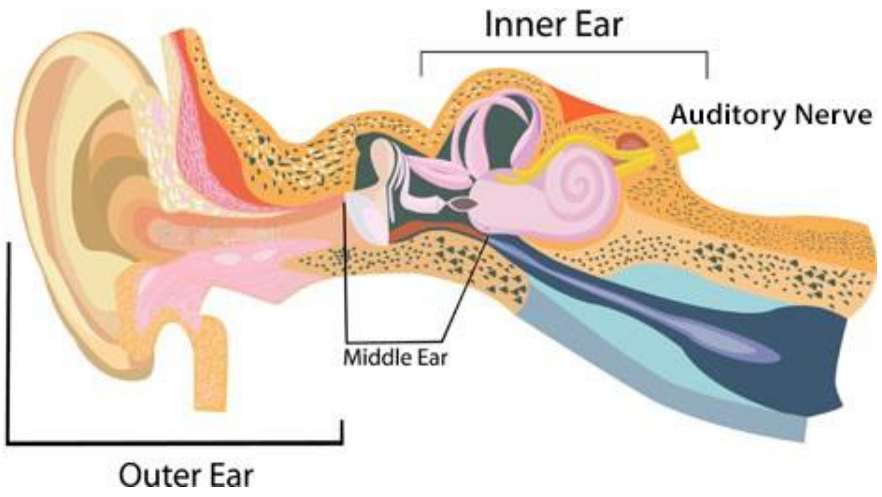
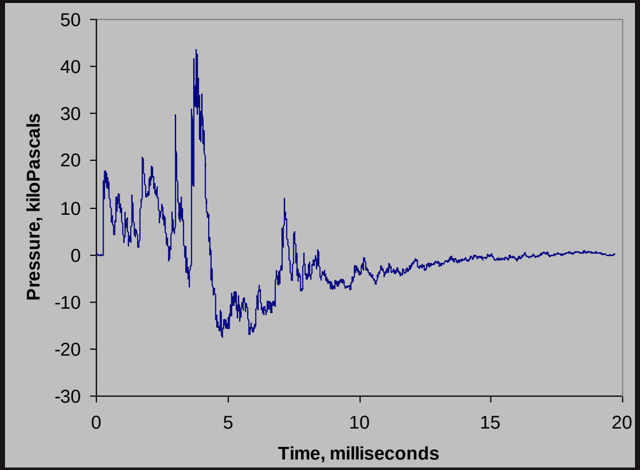
JOURNEY OF SOUND TO THE BRAIN



ACOUSTIC ENERGY–IMPULSE NOISE

Action Level per DA Pamphlet (DA Pam) 40-501 and Military Standard (MIL-STD) 1474E is impulse noise at or above

140 dBP



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IMPULSE NOISE EFFECTS ON THE EAR

Normal Hair Cells   Damaged Hair Cells

Human Eye Response to Flash

Dr. David F. Dye, david.f.dye2.civ@us.navy.mil

CAPT Duncan McKay, USN
Commanding Officer

Dr. Angela Lewis, SES
Technical Director

NSWC Crane Small Arms Signature Laboratory

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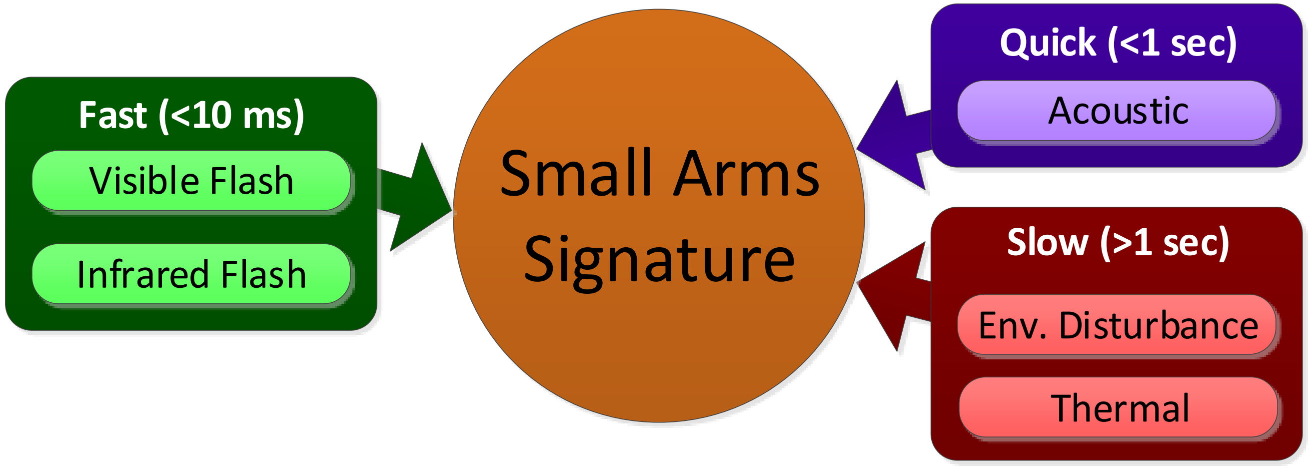
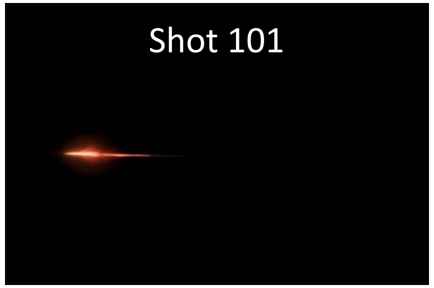
Small Arms Weapon Signatures

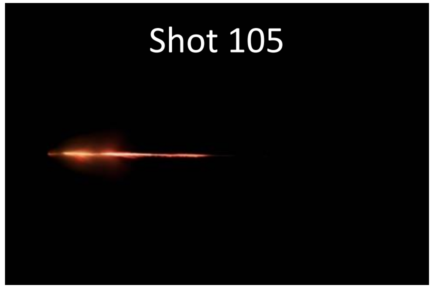


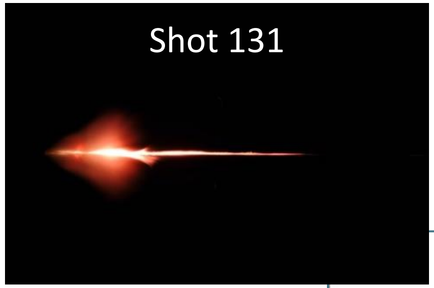
Signature Type	Day			Night		
	Shot Fired	Shooter Position	Track Shooter	Shot Fired	Shooter Position	Track Shooter
Flash, Visible				Eye	Eye	
Flash, Infrared	Imager	Imager		Imager	Imager	
Acoustic	Ear, Mic.	Ear, Mic.		Ear, Mic.	Ear, Mic.	
Environmental Disturbance	Eye	Eye				
Thermal (Infrared)		Imager	Imager		Imager	Imager
Low Concern, Medium Concern, High Concern						

Radiometric Flash Measurement

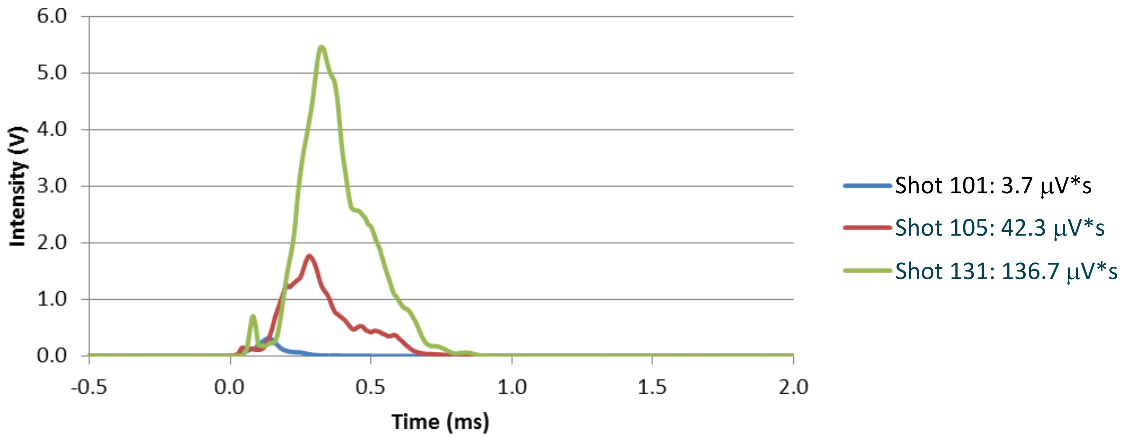
Old Method: Comparing Pictures

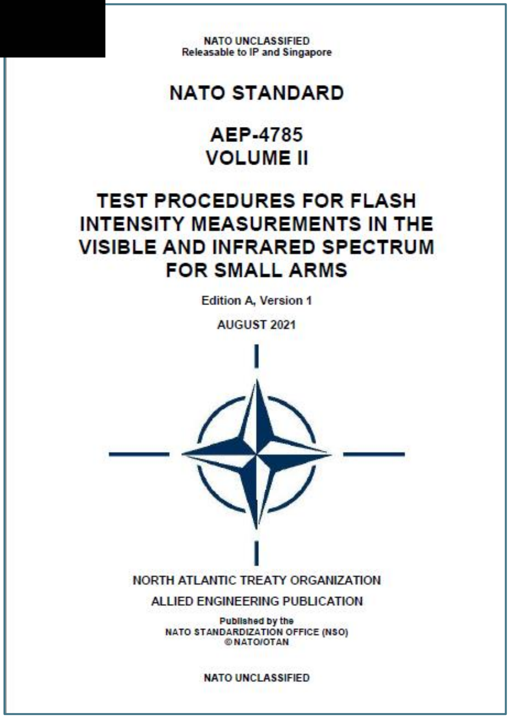






AEP-4785 Method: Radiometric Measurement

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NATO STANDARD

AEP-4785
VOLUME II

TEST PROCEDURES FOR FLASH INTENSITY MEASUREMENTS IN THE VISIBLE AND INFRARED SPECTRUM FOR SMALL ARMS

Edition A, Version 1

AUGUST 2021

NORTH ATLANTIC TREATY ORGANIZATION
ALLIED ENGINEERING PUBLICATION

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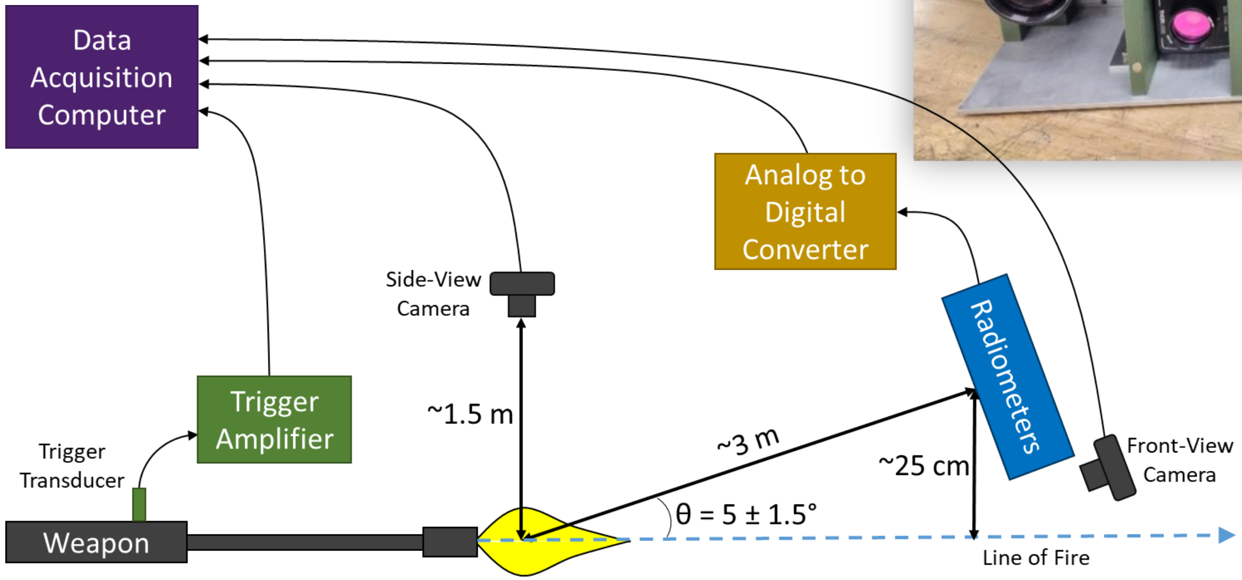
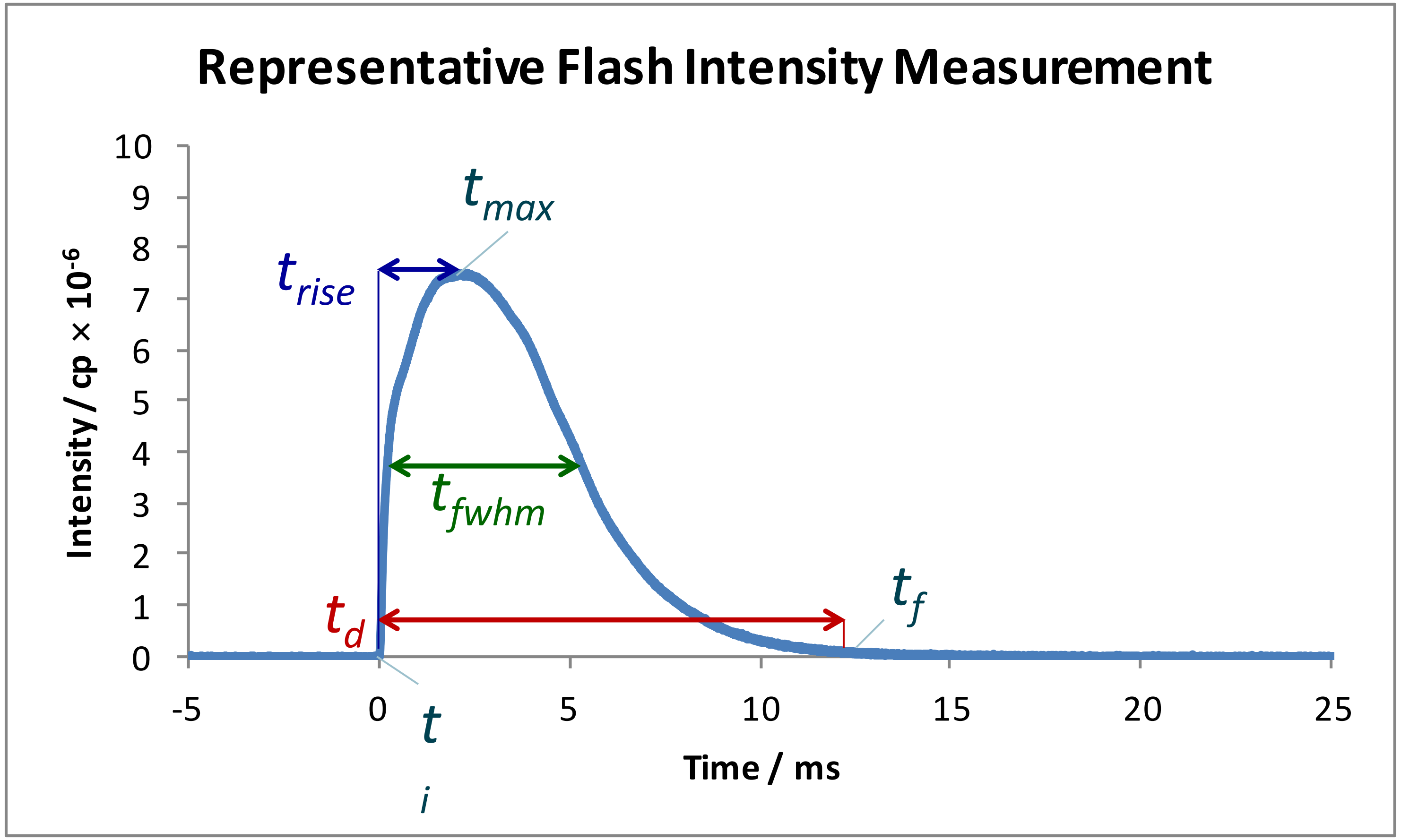
Flash Signature

NSWC Crane's Integrated
Flash Characterization Array

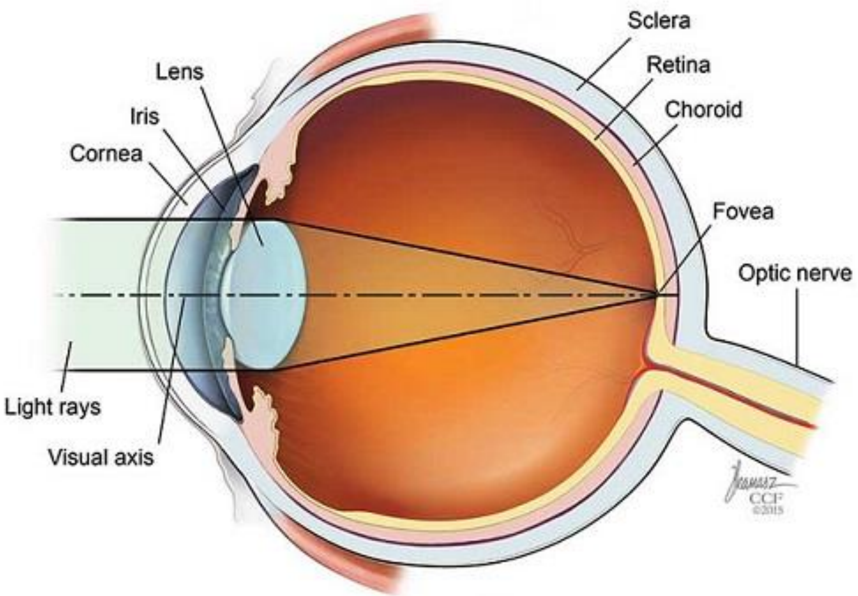
- Simultaneously collects flash in multiple spectral bands
- Images flash from front & side



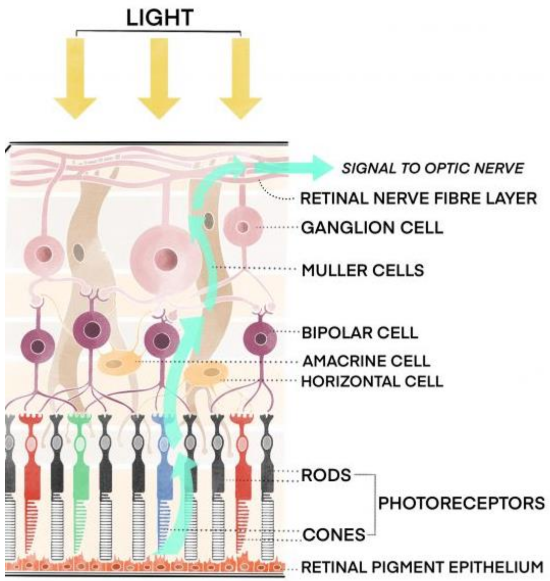
Which Measurements Matter?

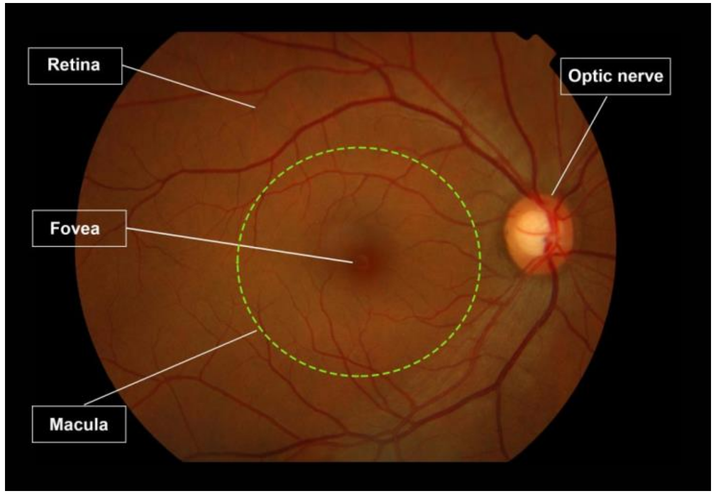


Anatomy of the Human Eye

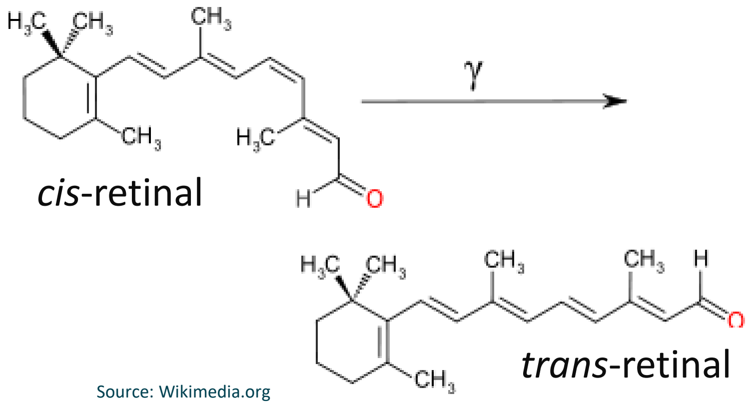


Source: https://www.magrabi.com.sa/blog/faq-about-farsightedness/





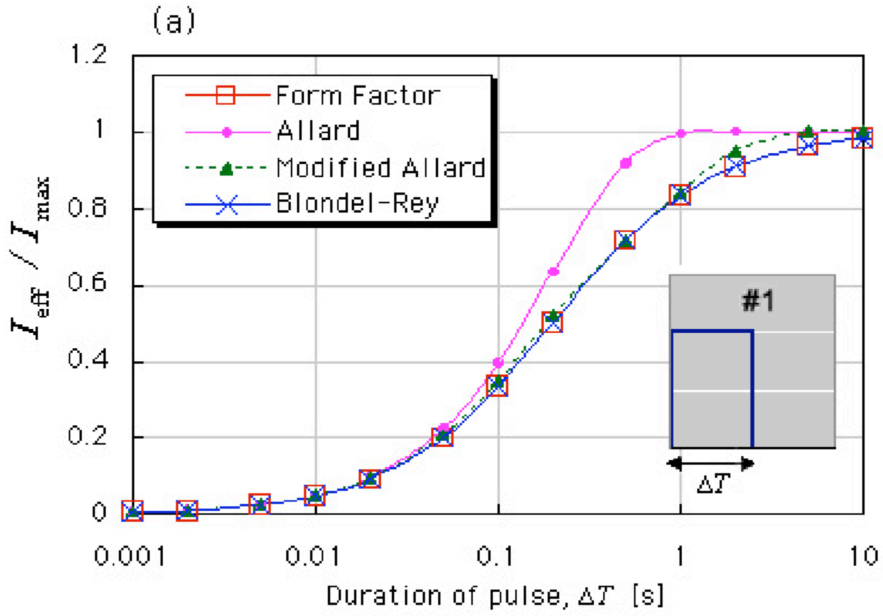
Source: https://gene.vision/retina/



Source: Wikimedia.org

Eyes as Photon Integrators

- For weapon flash timescales, all major models agree: brightness is proportional to the integrated flash energy.
  - Multiple human tests confirm these models
- Chemical reason: it takes time to convert *trans*-retinal to *cis*-retinal

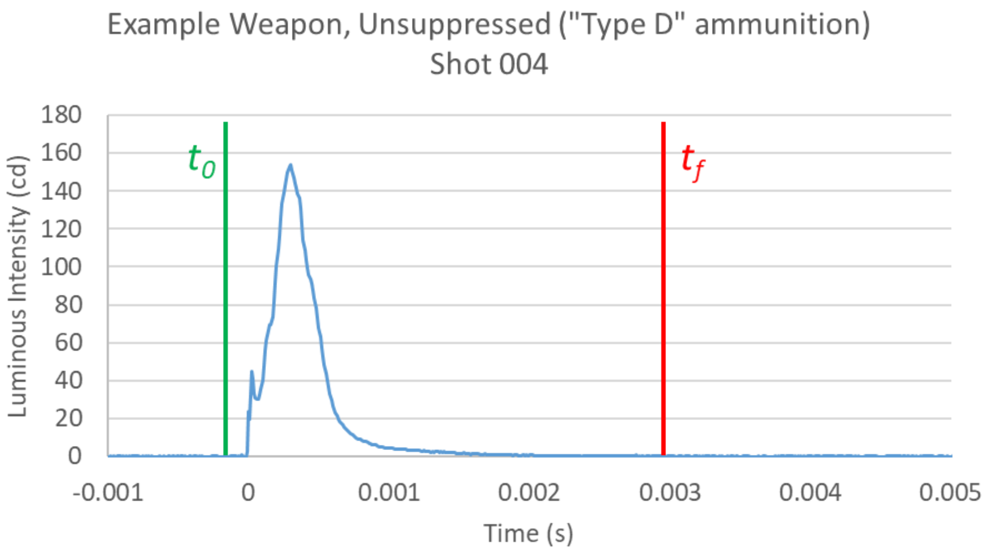


Source: Ohno, Couzin, & Dennison, NIST White Paper, "Modified Allard Method for Effective Intensity of Flashing Lights"

Flash Signature

NATO AEP 4785 Flash Measurement Methodology:

1. The visible and IR emission from a flash is measured by an array of radiometers.
2. Instantaneous luminous intensity (I_v) is integrated over the duration of the flash to give luminous energy (Q_v, reported in millicandela seconds).
3. **Luminous energy is proportional to perceived brightness.**



$$Q_v = \int_{t_0}^{t_f} I_v(t)\, dt$$

Detectability is Linked to Contrast

- Detection of a point source is dependent on contrast with the background
- For detection of muzzle flash, some basic rules of thumb can be used for detection thresholds.
  - 100% detection: contrast ratio of 10:1
  - 50% detection: contrast ratio of 2:1

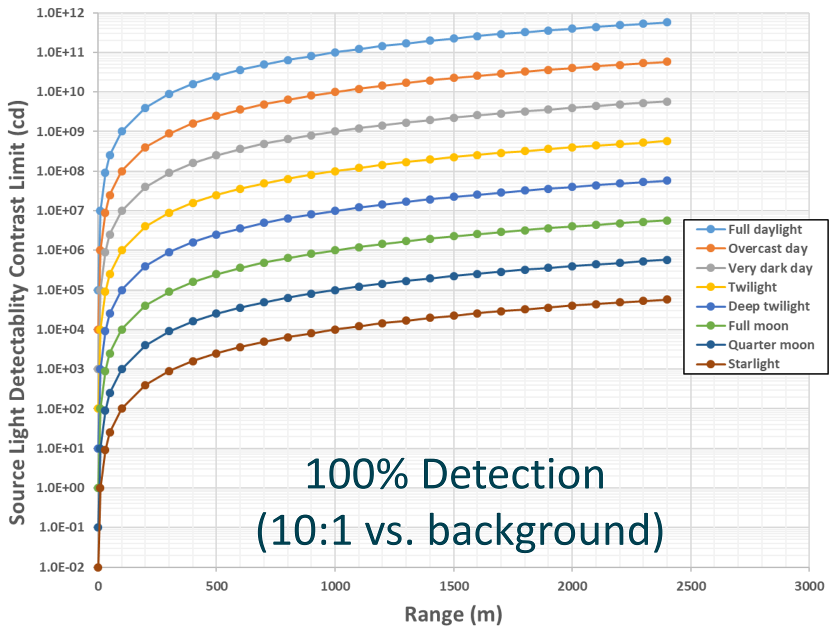
Slide courtesy Daniel Cler, CCDC – Armaments Center

Common Illuminance Background Levels

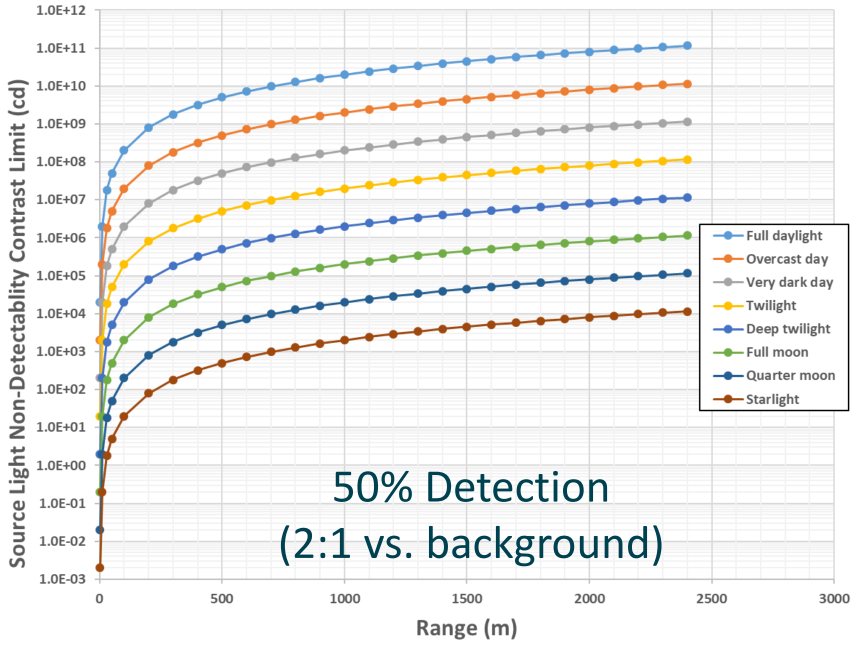
Lighting condition	Foot-candles	Lux
Full daylight	1,000	10,000
Overcast day	100	1,000
Very dark day	10	100
Twilight	1	10
Deep twilight	0.1	1
Full moon	0.01	0.1
Quarter moon	0.001	0.01
Starlight	0.0001	0.001

Source: https://en.wikipedia.org/wiki/Illuminance

Detectability is Linked to Contrast



- Detection probability models can be constructed using established rules of illuminance at the observer vs. distance



- Studies to correlate theoretical with empirical observational data are planned at Crane

Conclusions

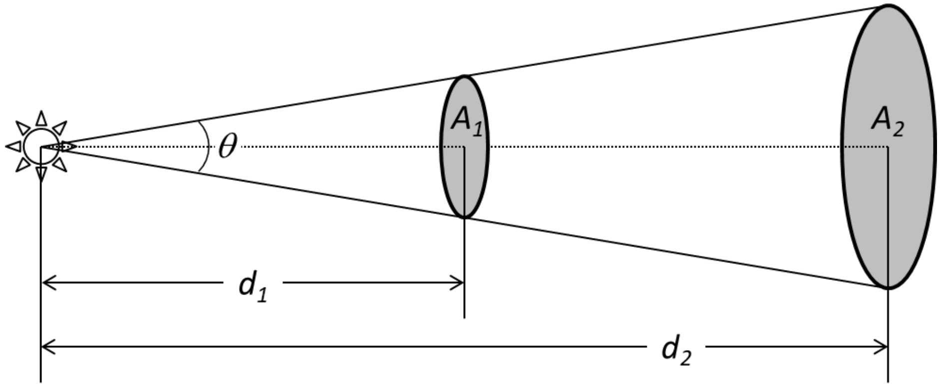
- AEP-4785 Flash Measurement methods utilize luminous energy as a “brightness” metric
  - Chosen based on physiology of the human eye
  - Works well for many electronic sensors as well

- Measurement of perceived flash brightness will allow use in environmental contrast models
  - Goal is to provide probability of detection models to decision makers

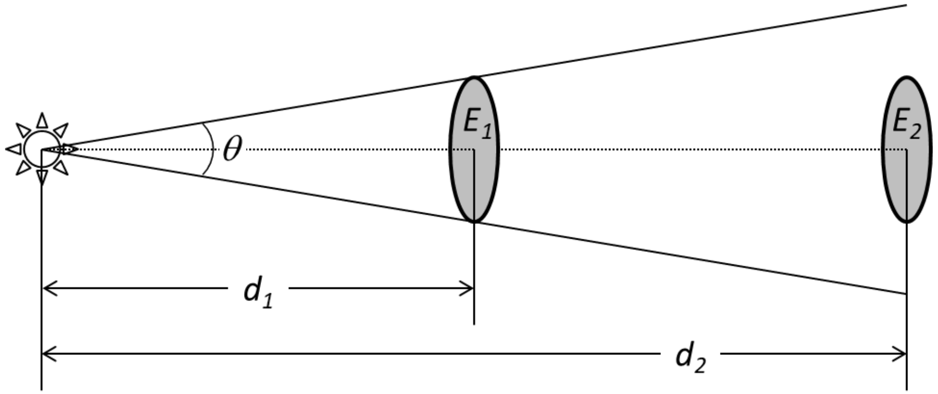
Questions?

POC: Dr. David F. Dye,
david.f.dye2.civ@us.navy.mil

Light and Distance



- Radiant or luminous intensity (*I*) describes the light emitted by a source
  - Independent of distance to the source
  - Units are Watts per steradian (W/sr) or candela (cd)



- Irradiance (*E*) describes the light projected onto a surface
  - Decreases as a function of d^2
  - Units are W/m^2 or cd/m^2
  - Radiometers can ONLY measure irradiance

Radiometry vs. Photometry Terminology

SI Radiometry Units

Quantity	Photopic Equivalent	Symbol	SI Unit	Unit Symbol	Notes
Radiant Energy	Luminous Energy	Q_e	joule	J	energy (W · s)
Radiant Flux	Luminous Flux	Φ_e	watt	W or J/s	radiant energy per unit time, also called radiant power
Spectral Power		$\Phi_{e\lambda}$	watt per meter	$W \cdot m^{-1}$	radiant power per λ
Light Emitted by a Source					
Radiant Intensity	Luminous Intensity	I_e	watt per steradian	$W \cdot sr^{-1}$	power per unit solid angle
Spectral Intensity		$I_{e\lambda}$	watt per steradian per meter	$W \cdot sr^{-1} \cdot m^{-1}$	radiant intensity per spectral wavelength range (Δλ)
Radiance	Luminance	L_e	watt per steradian per square meter	$W \cdot sr^{-1} \cdot m^{-2}$	power per unit solid angle per unit projected source area
Spectral Radiance		$L_{e\lambda}$	watt per steradian per meter^3	$W \cdot sr^{-1} \cdot m^{-3}$	commonly measured in $W \cdot sr^{-1} \cdot m^{-2} \cdot nm^{-1}$
Radiant Exitance / Emittance	Luminous Emittance	M_e	watt per square meter	$W \cdot m^{-2}$	power emitted from a surface
Spectral Radiant Exitance / Emittance		$M_{e\lambda}$	watt per meter^3	$W \cdot m^{-3}$	power emitted from a surface per Δλ
Radiosity		J_e	watt per square meter	$W \cdot m^{-2}$	emitted plus reflected power leaving a surface
Spectral Radiosity		$J_{e\lambda}$	watt per meter^3	$W \cdot m^{-3}$	emitted plus reflected power leaving a surface per Δλ
Light Incident on a Surface					
Irradiance	Illuminance	E_e	watt per square meter	$W \cdot m^{-2}$	power incident on a surface, also called radiant flux density
Spectral Irradiance		$E_{e\lambda}$	watt per meter^3	$W \cdot m^{-3}$	commonly measured in $W \cdot m^{-2} \cdot nm^{-1}$
Radiant Exposure	Luminous Exposure	H_e	joule per square meter	$J \cdot m^{-2}$	also referred to as fluence
Radiant Energy Density	Luminous Energy Density	ω_e	joule per meter^3	$J \cdot m^{-3}$	

SI Photometry Units

Quantity	Radiometric Equivalent	Symbol	SI Unit	Unit Symbol	Notes
Luminous Energy	Radiant Energy	Q_v	lumen second	lm · s	units are sometimes called talbots
Luminous Flux	Radiant Flux	F_v	lumen (= cd · sr)	lm · s	Also called luminous power
Light Emitted by a Source					
Luminous Intensity	Radiant Intensity	I_v	candela (= lm/sr)	cd	SI base unit for light measurements
Luminance	Radiance	L_v	candela per square meter	cd/m^2	Light emitted by an area of a large object
Luminous Emittance	Radiant Emittance	M_v	lux (= lm/m^2)	lx	used for light emitted from a surface
Light Incident on a Surface					
Illuminance	Irradiance	E_v	lux (= lm/m^2)	lx	used for light incident on a surface
Luminous Exposure	Radiant Exposure	H_v	lux second	lx · s	
Luminous Energy Density	Radiant Energy Density	w_v	lumen second per meter	$lm \cdot s \cdot m^{-3}$	
Luminous Efficacy		h	lumen per watt	lm/W	ratio of luminous flux to radiant flux
Luminous Efficiency		V			also called luminous coefficient (unitless)

Source: https://en.wikipedia.org/wiki/radiometry

U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND ARMY RESEARCH LABORATORY

Localization of shooter position based on weapon signature

Research and modeling-based considerations of human factors benefits for Soldiers from applications of small arms suppressors

Controlled by: US Army
Controlled by: DEVCOM ARL Internal
CUI Category: Public Release
Distribution/Dissemination Control: A
POC: Paul Fedele (410) 278-5984

Paul D. Fedele
Research Physical Scientist DB04
US Army DEVCOM Army Research Laboratory

Approved for Public Release: distribution unlimited

Localization of shooter position based on weapon signature

Potential Soldier benefits from small arms suppressors

Need –

The enemy can too quickly localize shooter position and too accurately return direct fire.

Solution –

Increase Soldier stealth against unaided human detection by using suppressors to reduce visible muzzle flash and auditory muzzle blast.

Soldier stealth – model human localization of shot position based on weapon fire signature.

All material is available in ARL Technical Report 9277, August 2021
Approved for public release: distribution unlimited

Localization of shooter position based on weapon signature

Visual Flash Detectability Threshold Research

Dark Condition Detection Baseline

Flash Visibility Measurements

Early Work

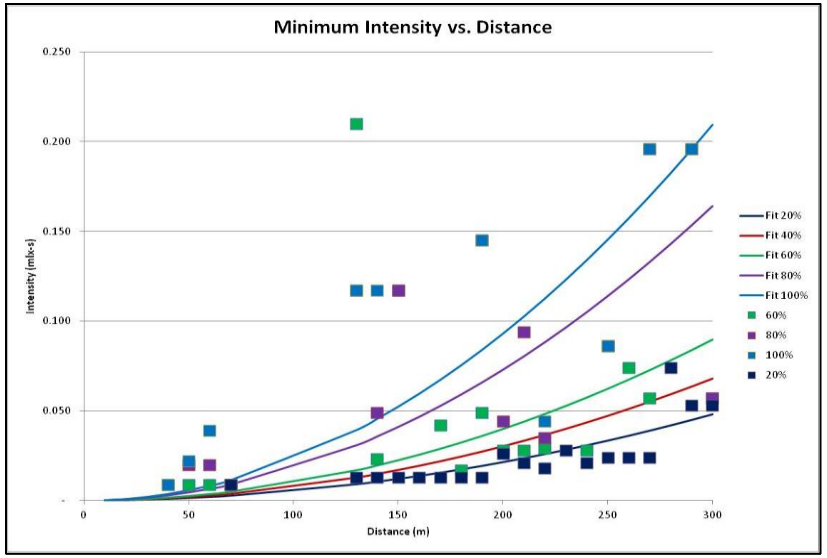
Hecht, S., Shlaer, S., & Pirenne, M. H. (1942). Energy, quanta, and vision. *The Journal of general physiology, 25*(6), 819-840.

Minimum photopic energy - 3.84 to 10.44 10^-7 mlux.s

Recent Work

Hennage, John (c2012). Unpublished Data, Aberdeen Test Center, APG, MD

Minimum photopic energy - 8.74x10^-7 mlux.s



Data is scattered – there are outliers.
Goal is NOT to prove line is quadratic.
Goal is FIT single parameter parabola to half of the subjects. (Green Line)

Final model will include adjustment for primary wavelength and daylight conditions. Spatial resolution based on 20/20 vision: 1 minute of arc for source spatial extent, Barton formula.

<u>Very low levels can be seen when dark adapted.</u>
<u>Operational values being determined.</u>

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Localization of shooter position based on weapon signature

Visual Flash Detection

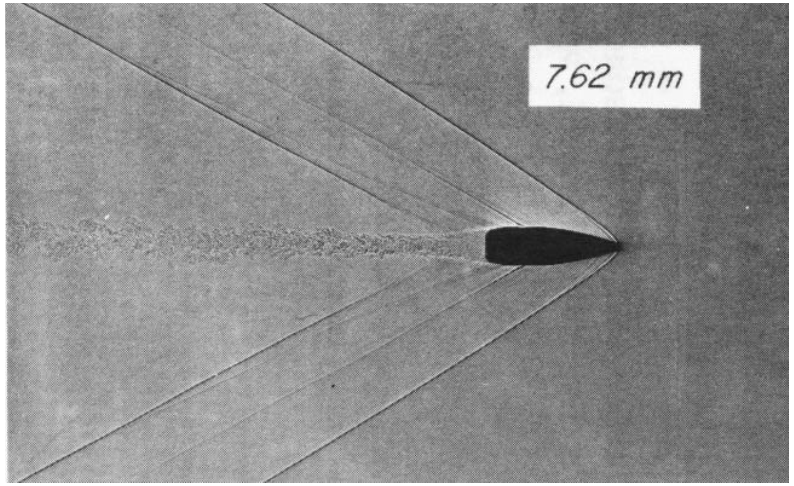
- Human visual detection of muzzle blast luminance
  - Based on total time-integrated luminance
    - Luminance is the total perceived brightness: radiation integrated over all wavelengths, weighted by standard human-perceived brightness – basically ‘visible’ wavelengths.
    - Units: milli-lux.seconds.
    - Thresholds adapted to total darkness are low: ~ 1E-5 mlux.s.
    - At threshold, flash time-envelope and color influences are small.
    - Field data is needed - background illumination (contrast and visual noise) influences for specific small arms configurations and environments.

Flash standard measurement methods - Dr. David Dye, US NSWC, Crane.

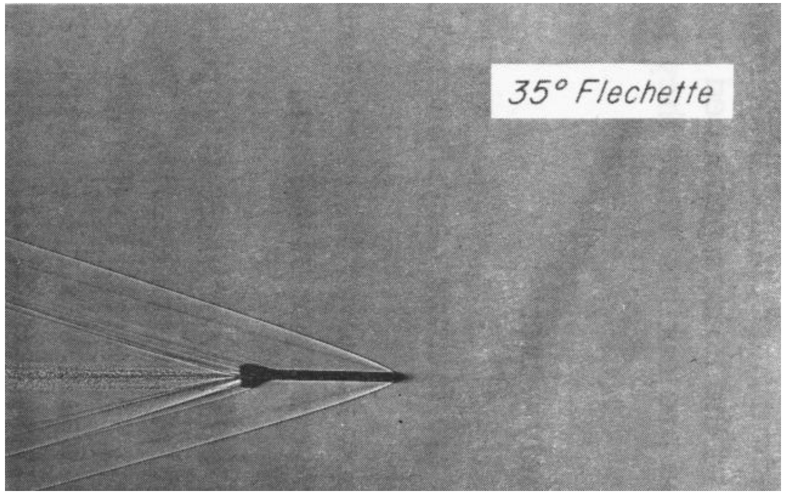
Localization of shooter position based on weapon signature

Auditory Stimuli - Ballistic Crack Waveforms and Muzzle Blast

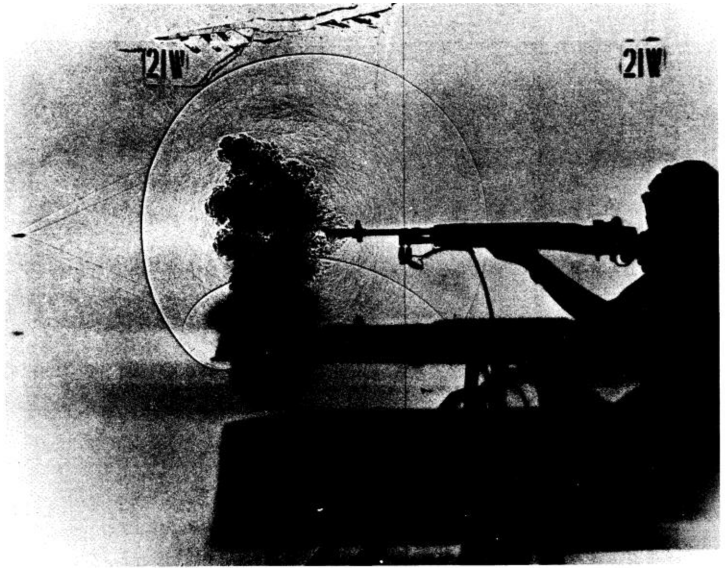
1)



2)



3)



Example Waveform Pictures

1) 7.62 mm Bullet N-Wave ~ 1.5c
2) 35° Flechette ~ 3c
3) Combined muzzle blast & bullet N-wave

Garinther, G., & Moreland, J. (1966). Acoustical considerations for a silent weapon system: A feasibility study. *Aberdeen Proving Ground, Maryland, USA*.

Localization of shooter position based on weapon signature

Research on Auditory Impulse Detection

Law of the First Arriving Wave Front

Sound is localized on the direction of arrival of the first wave front.

1. Lindemann, W. (1986). Extension of a binaural cross-correlation model by contralateral inhibition. II. The law of the first wave front. *The Journal of the Acoustical Society of America, 80*(6), 1623-1630.
2. Bishop, C. W., London, S., & Miller, L. M. (2012). Neural time course of visually enhanced echo suppression. *Journal of neurophysiology, 108*(7), 1869-1883.
3. Blauert, J., & Braasch, J. (2005). *Acoustic communication: The precedence effect.* Paper presented at the Forum Acousticum.

Precedence Effect

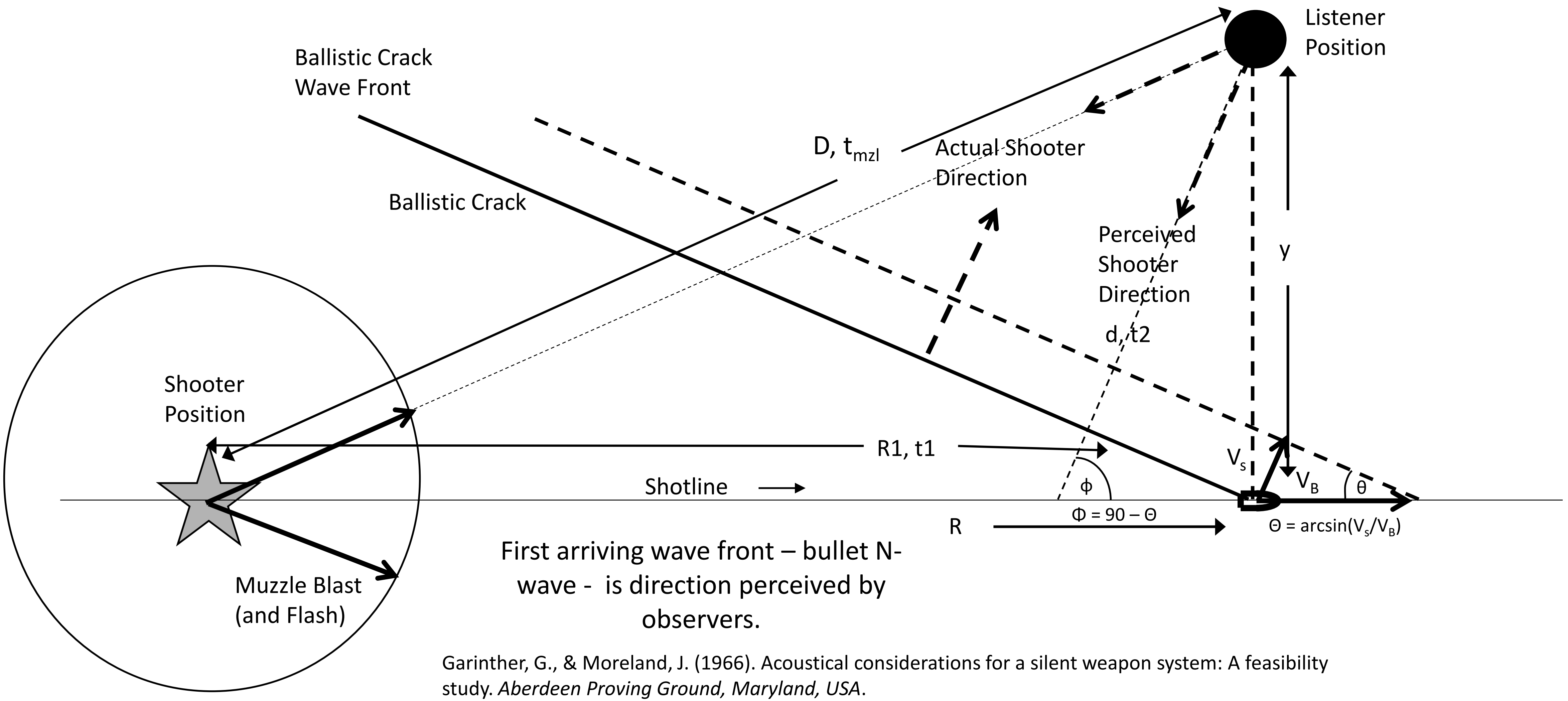
First-arriving sounds have perceptual ‘precedence’. Echo sounds are suppressed in the inner ear and in the brain, to support perception of sound source toward the direction of the first arriving sound.

1. Wallach, H., Newman, E. B., & Rosenzweig, M. R. (1949). A precedence effect in sound localization. *The Journal of the Acoustical Society of America, 21*(4), 468-468.
2. Divenyi, P., & Blauert, J. (1987). On creating a precedent for binaural patterns: When is an echo an echo? *Auditory Processing of Complex Sounds*, 146-155.
3. Divenyi, P. L. (1992). Binaural suppression of nonechoes. *The Journal of the Acoustical Society of America, 91*(2), 1078-1084.
4. Brown, A. D., Stecker, G. C., & Tollin, D. J. (2015). The precedence effect in sound localization. *Journal of the Association for Research in Otolaryngology, 16*(1), 1-28.

Issue: Perception of real-environment stimuli (echoes) versus laboratory stimuli (clean clicks)

Localization of shooter position based on weapon signature

Auditory Stimuli Geometry – Bullet N-Wave and Muzzle Blast

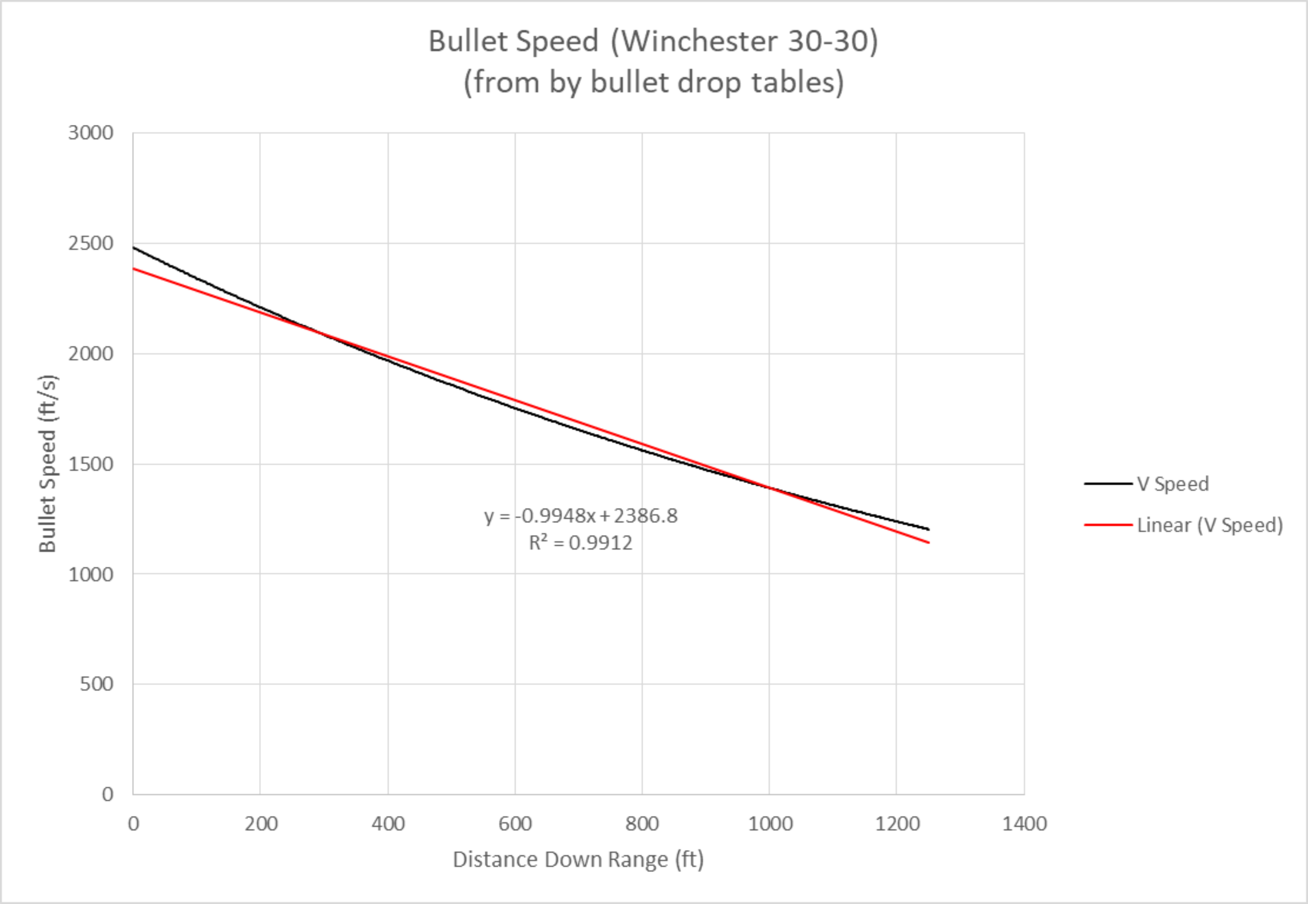


First arriving wave front – bullet N-wave - is direction perceived by observers.

Garinther, G., & Moreland, J. (1966). Acoustical considerations for a silent weapon system: A feasibility study. *Aberdeen Proving Ground, Maryland, USA*.

Localization of shooter position based on weapon signature

Bullet Trajectory Approximation – Linear Velocity Decrease with Distance

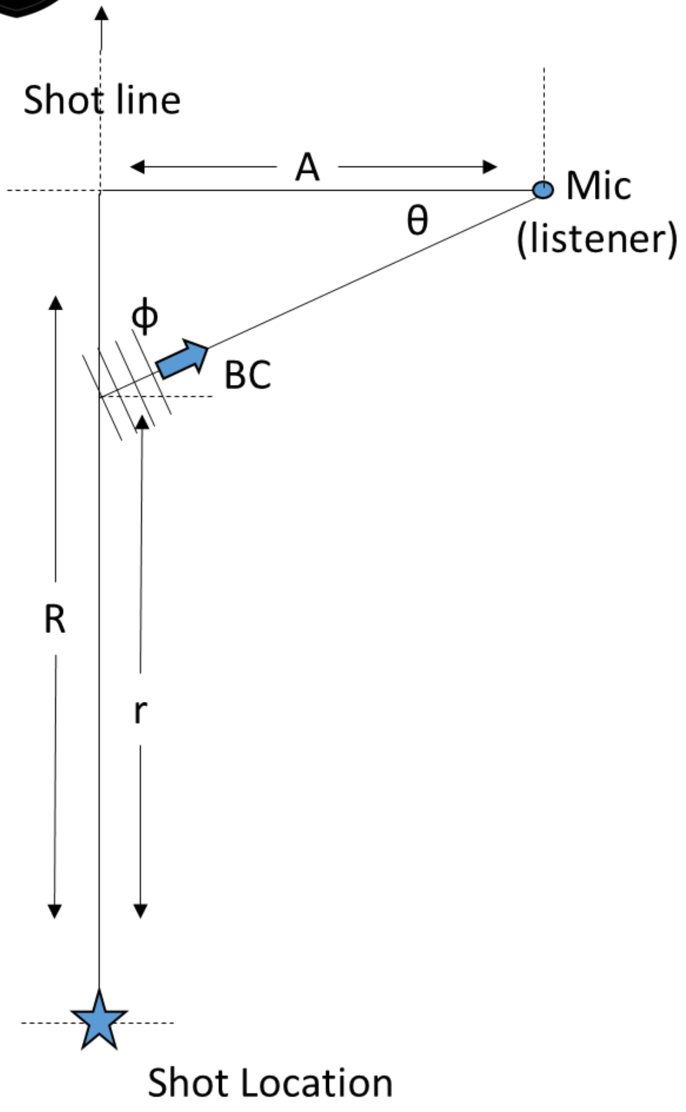


For bullet crack calculation, bullet speed versus range approximated by linear relation.

$$V(r) = V_0 - \alpha r$$

Localization of shooter position based on weapon signature

Auditory Stimuli Bullet N-Wave Arrival Direction



Variational Method

Approximate bullet speed linearly with range

$$V(r) = V_0 - \alpha r$$

Time to release of BC

$$t_1 = \frac{r}{V_0 - \frac{\alpha}{2} r}$$

Time BC reaches (R, A) down- across- range

$$t_2 = \frac{\left[(R-r)^2 + A^2\right]^{1/2}}{c}$$

Total arrival time of BC is

$$t_T = t_1 + t_2$$

Differentiate wrt r, set to zero, and obtain

$$r = R - \frac{A}{\left[\left(\frac{V_0}{c}\right)^2 \left(1 - \frac{\alpha r}{2V_0}\right)^4 - 1\right]^{\frac{1}{2}}}$$

Start with α = 0; iterate r to convergence.

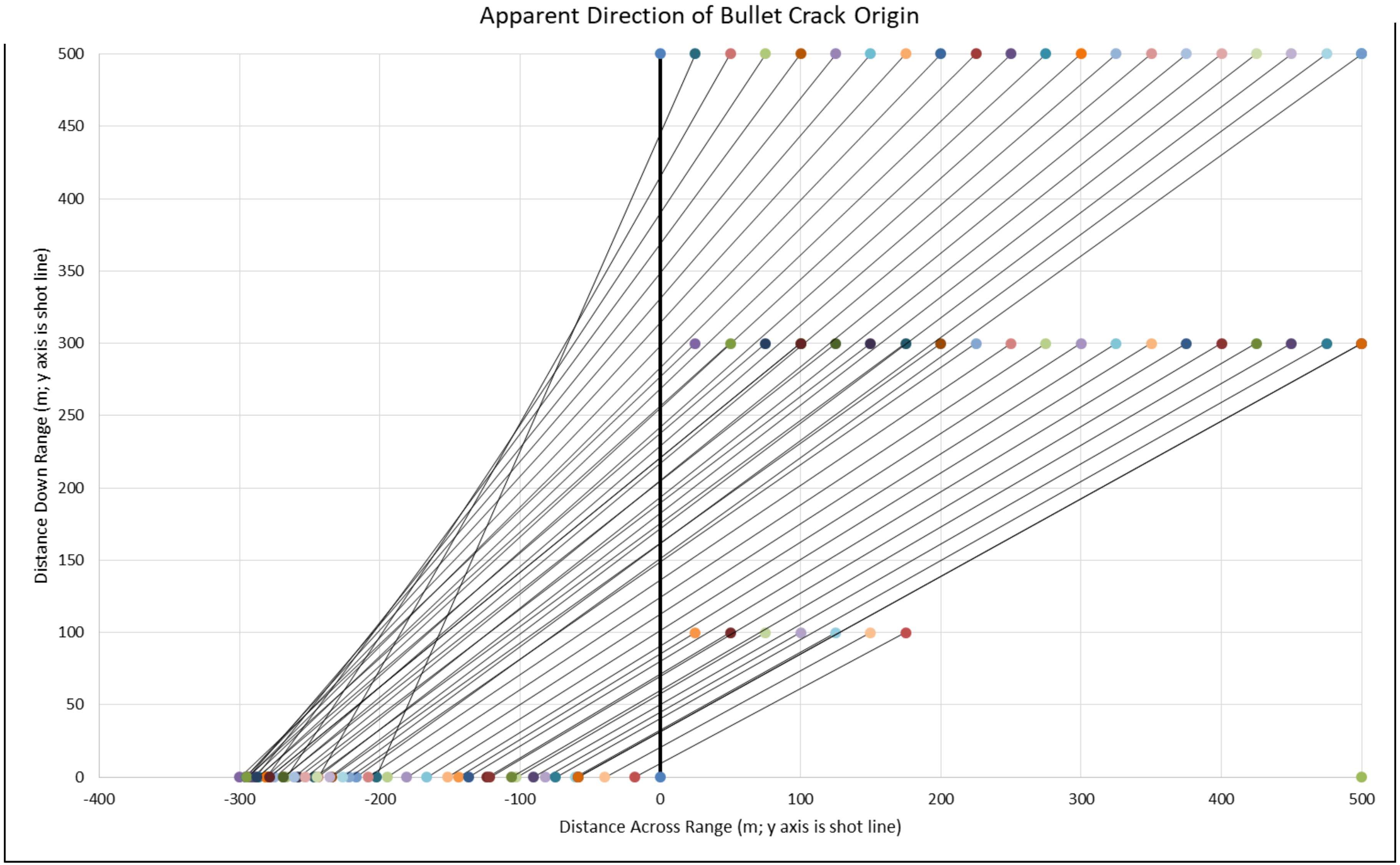
Example – Win 30-30

V_0 = 756 m/s
(α = 0.9948 s^{-1})

	R (m)	400
	A (m)	100
	r first (m)	349.0985
	Tan(Theta)	0.509015
	Theta	26.97676
	Phi	63.02324
	r second	281.3911
	r-3	306.4368
	r-4	298.6842
	r-5	301.2338
	r-6	300.4113
	r-7	300.6783
	r-8	300.5918
	r-9	300.6199
(final)	r-10	300.6108
	Tan(Theta)	0.993892
	Theta	44.82449
	Phi	45.17551
view: x=0	intercept	-302.458

Localization of shooter position based on weapon signature

Auditory Stimuli Bullet N-Wave Arrival Direction



More detailed modeling, ARL Blast-Crack Model: Gregory S Oberlin, CIV USARMY DEVCOM ARL (USA)

Localization of shooter position based on weapon signature

Observations from Research, Modeling, and Previous Field Studies (1966)

People hearing a ballistic crack often mistake it for muzzle blast.

(Garinther G, Moreland J. Acoustical considerations for a silent weapon system: a feasibility study. Army Research Laboratory (US); 1966.)

Suppressors will not attenuate bullet ballistic crack, but …

Arrival direction of the ballistic crack is not from the shot location.

Direction is from across the shot line.

Direction bends back as bullet slows down further down-range.

Ballistic crack, echoes, and muzzle blast suppression make it more difficult to localize shot position based on the auditory muzzle blast.

Auditory direction misperception can provide a basis for improving Soldier stealth.

Localization of shooter position based on weapon signature

Directions for on-going field studies

Behavioral Validation of Perception Models

Flash visibility validation trials

- Multiple flash locations
- Weapon muzzle flashes and flash simulator flashes
- Night (dark) and day (light) conditions
- Suppressed and unsuppressed weapons

Auditory localization validation trials

- Trained and untrained observers
- Day (light) trials and night (dark) trials
- Multiple shot locations with ballistic crack design
- With and without false-flashes

Field behavior data is needed to adjust and validate research models.

Military tactical advantage analysis – L. C. (Cole) Cochran, USA MCDID CDD S&T, Ft. Benning.

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Localization of shooter position based on weapon signature

Questions?

Potential Soldier benefits from small arms suppressors

Presented material is available in ARL Technical Report 9277, August 2021 Approved for public release: distribution unlimited

Report also addresses concepts for

- Auditory Communication
- Auditory Environmental Awareness
- Hearing Damage Risk
- Potential Marksmanship Influences

U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND –
ARMY RESEARCH LABORATORY

Outdoor Acoustics

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Daniel L. Cler
Aerospace Engineer
DEVCOM – Armaments Center
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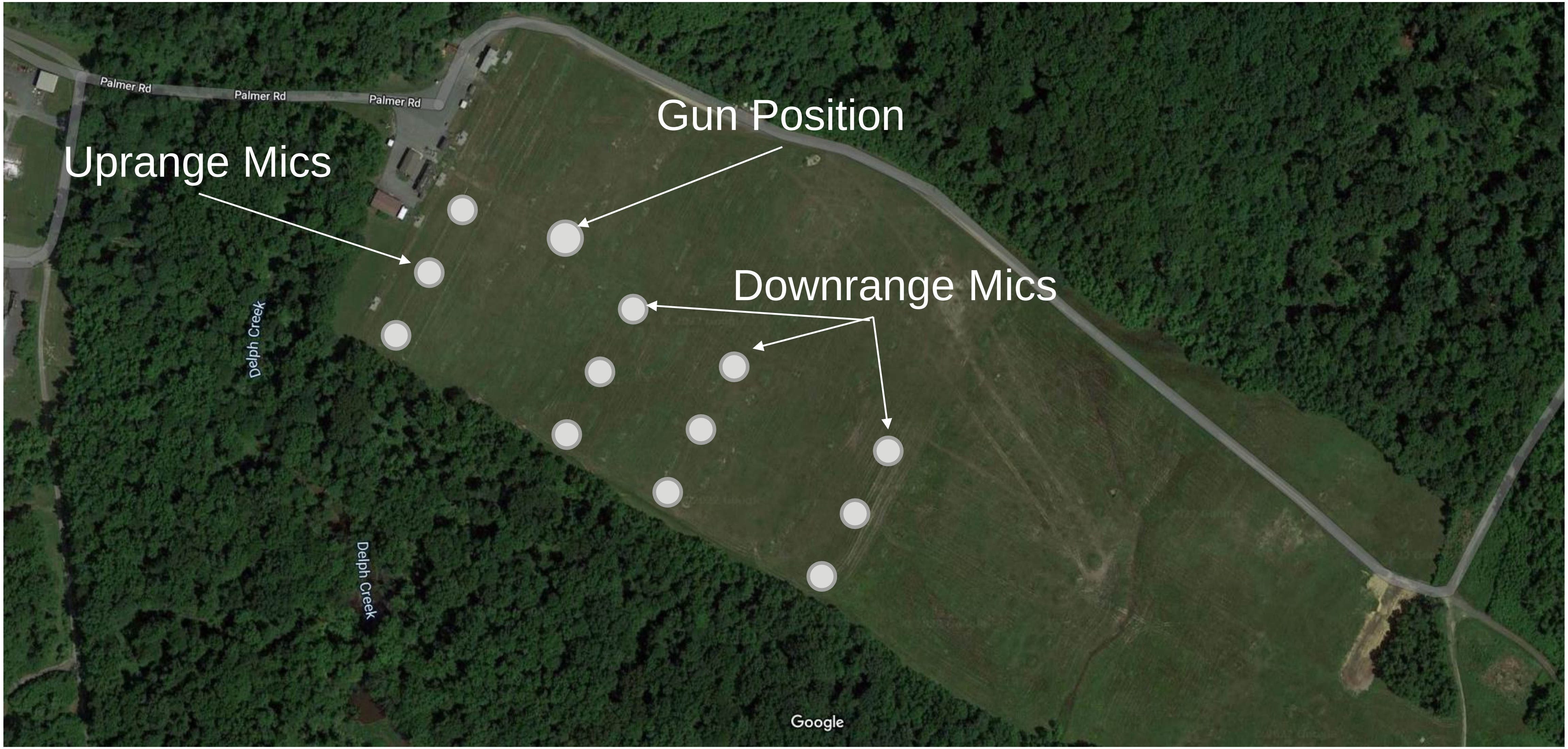
Armaments Technology & Evaluation Division
Weapons Science & Technology Directorate

BACKGROUND

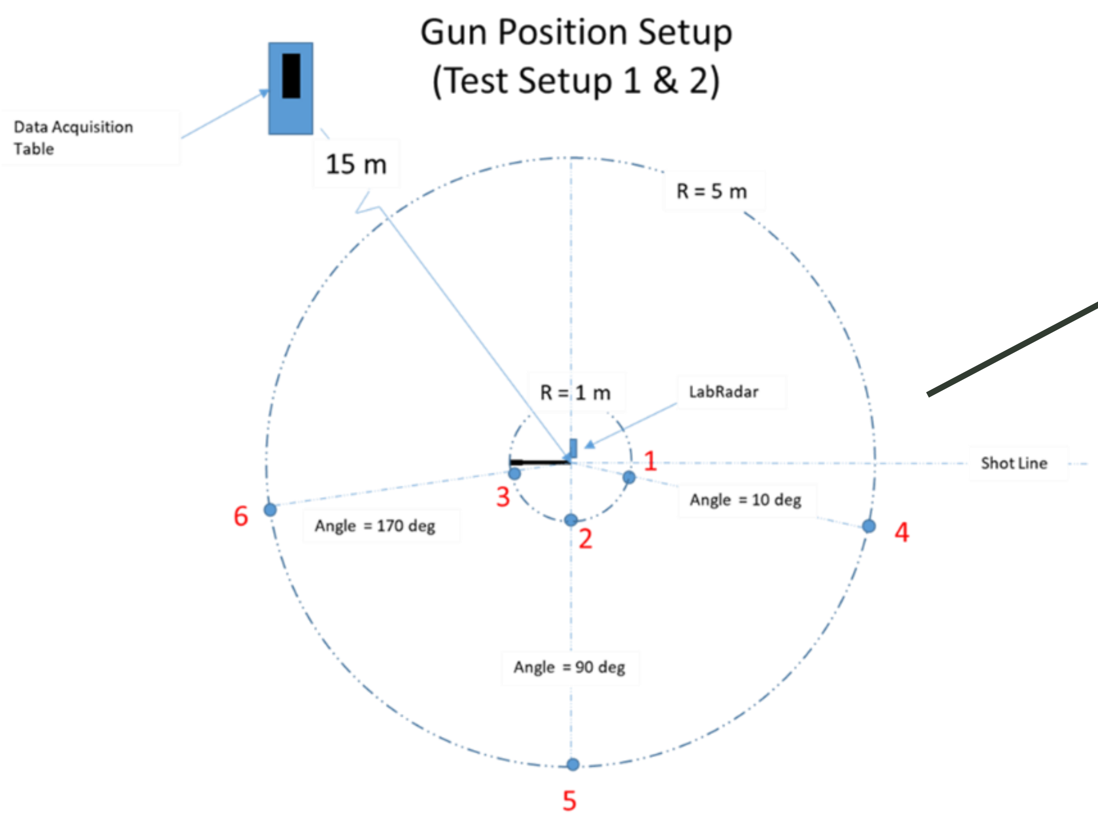
- **Purpose:** Assess the near field and far field acoustics of small caliber weapons, suppressors and ammunition in a large, outdoor open field for application to detection models and other needs.
- **Location:** Army Research Lab, M-Range, APG, MD
- **Field Size:** 200 m x 600 m
- **Weapons:** Various
- **Muzzle Devices:** Suppressed and Unsuppressed
- **Instrumentation:**
  - *Microphones* - PCB microphones near gun and down range up to 400+ m from gun
  - *Data Acquisition* - Separate gun location and downrange location, NI Field DAQ, data acquisition systems time synced over a directional Wi-Fi network

ARL M-RANGE - GOOGLE MAPS

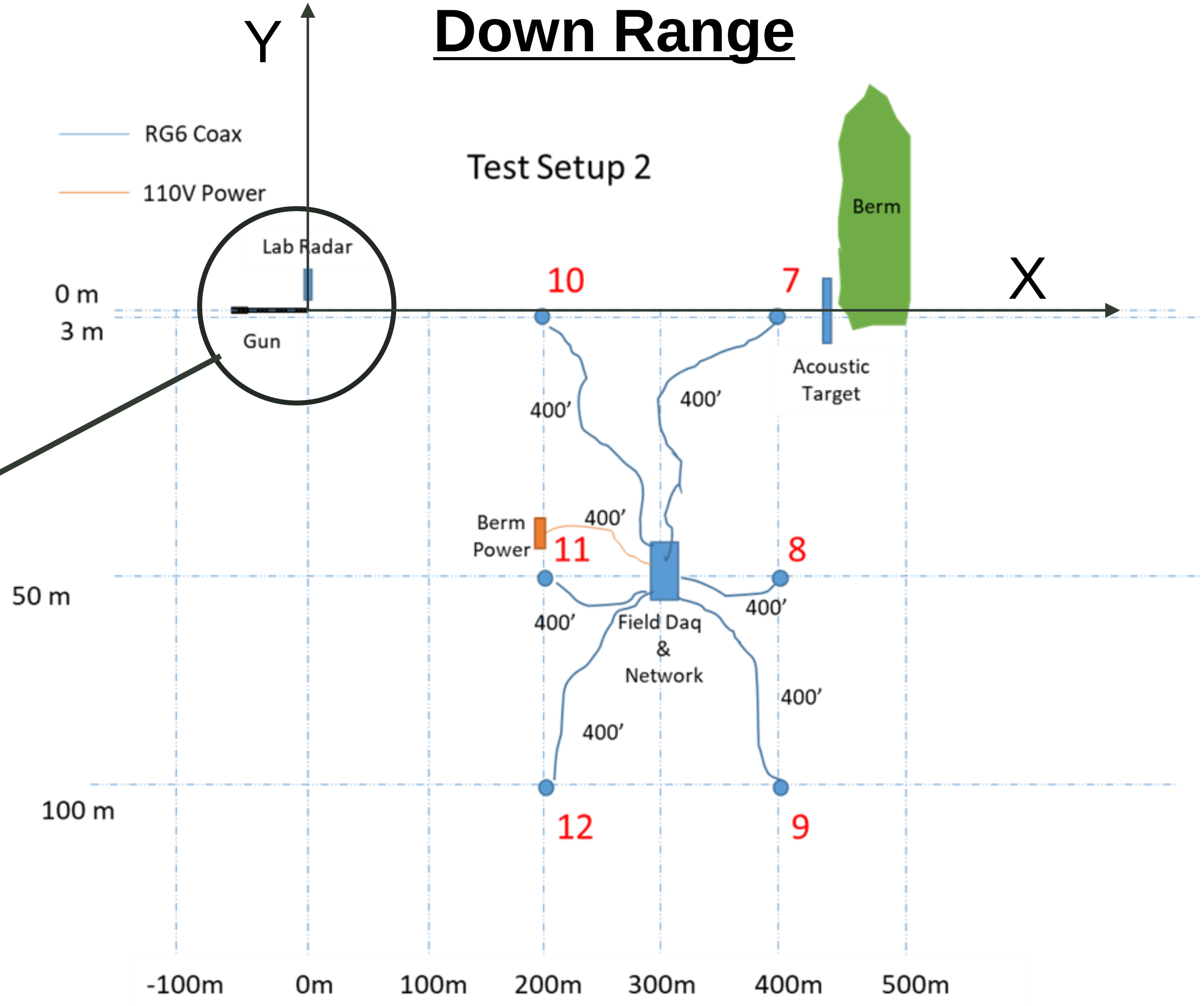


NEAR FIELD AND DOWN RANGE MICROPHONE LOCATIONS

Gun Location



Down Range

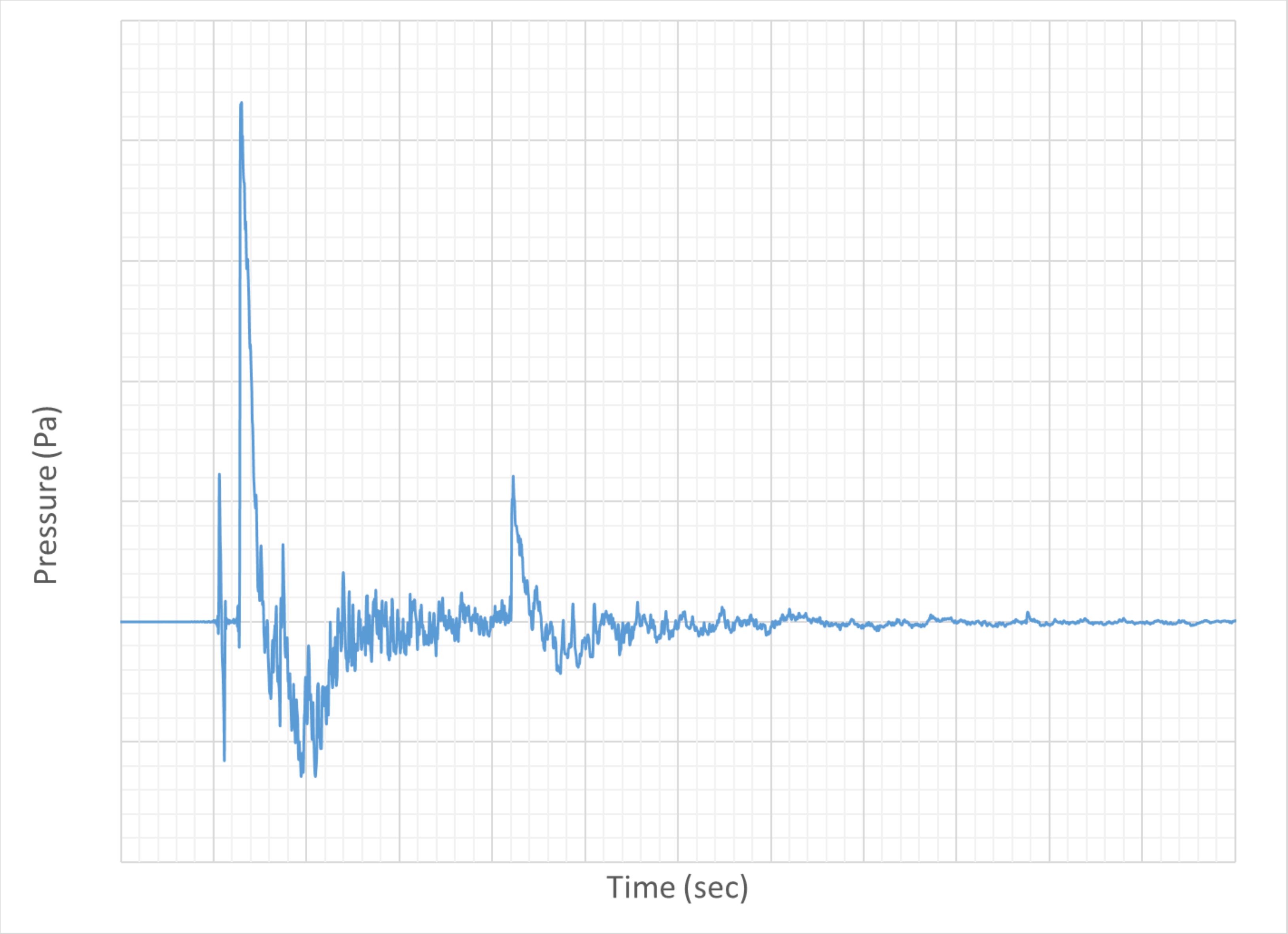


MICROPHONE SETUP

Gun Location

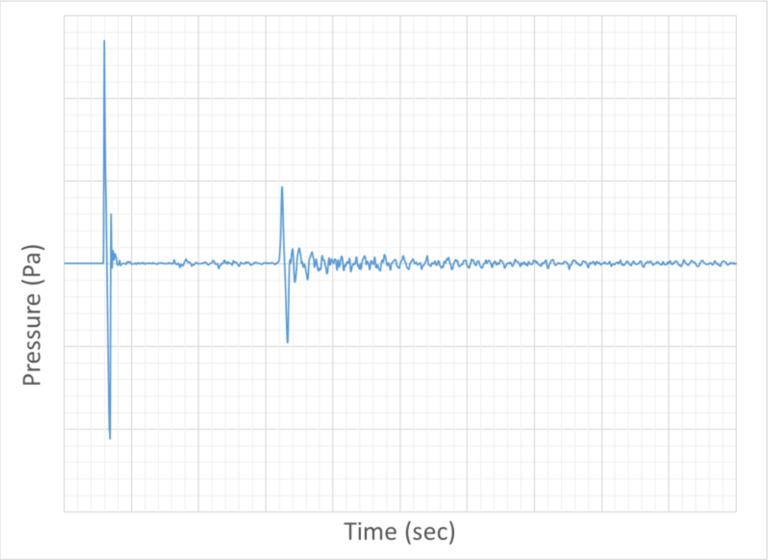
Down Range

GUN LOCATION EXAMPLE
PRESSURE AT 1M FROM GUN – 10 DEGREES OFF SHOT LINE

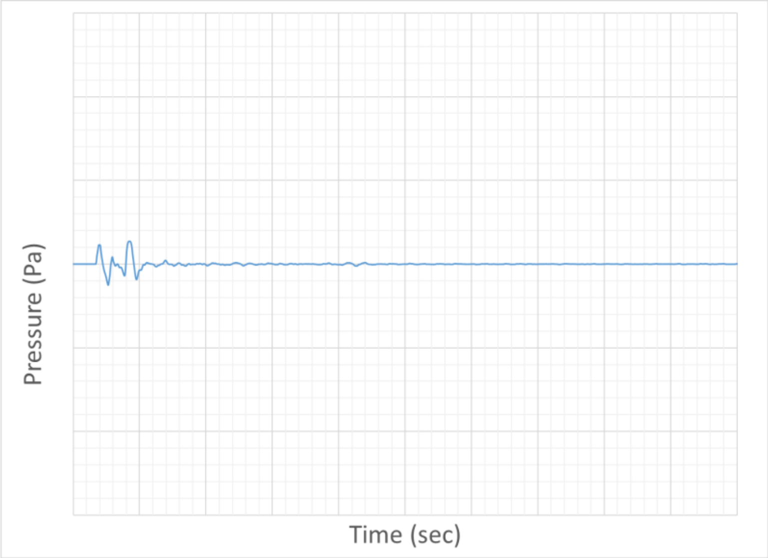


DOWN RANGE EXAMPLE BALLISTIC CRACK COMPARISON

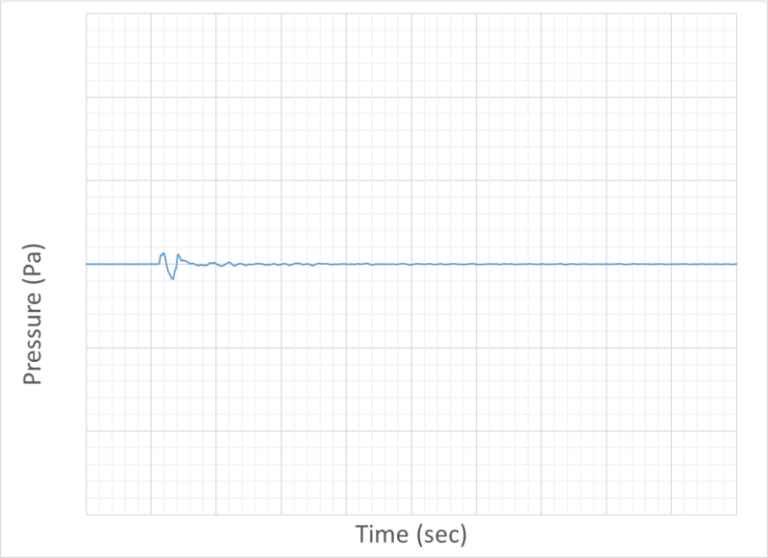
+200m, -3m



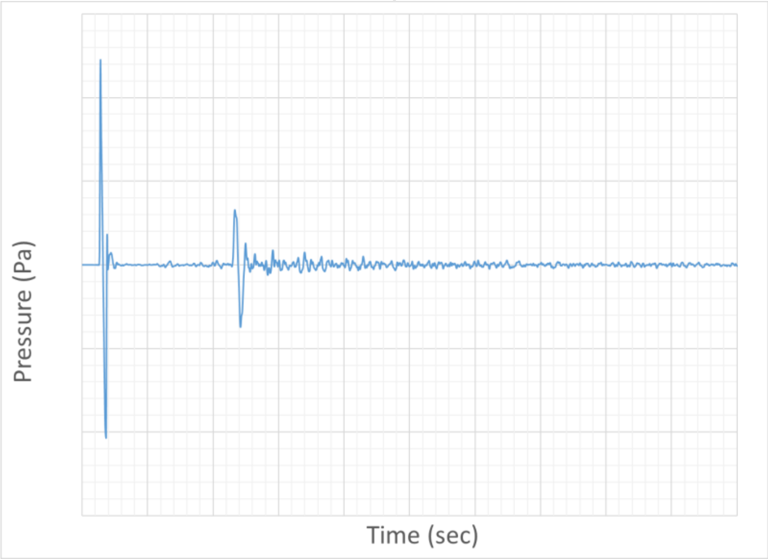
+200m, -50m



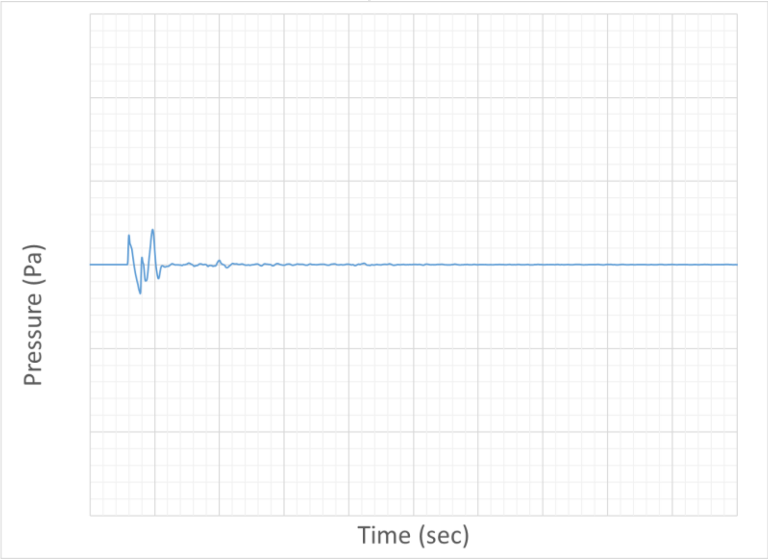
+200m, -100m



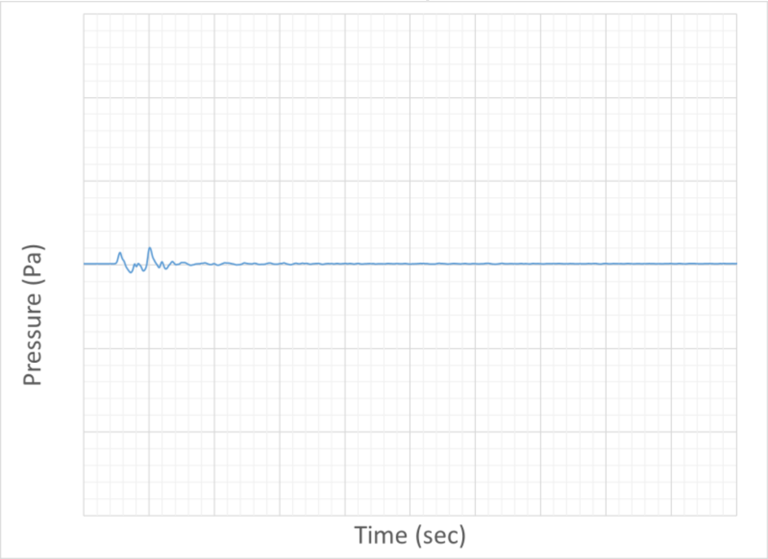
+400m, -3m



+400m, -50m



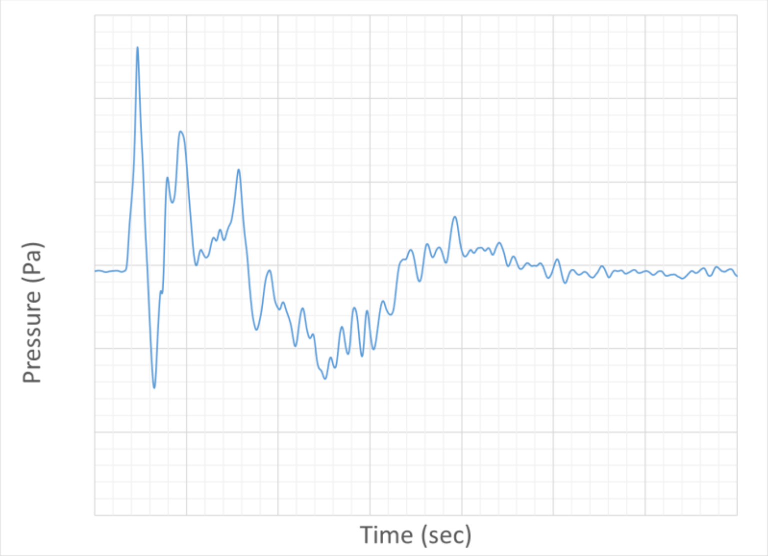
+400m, -100m



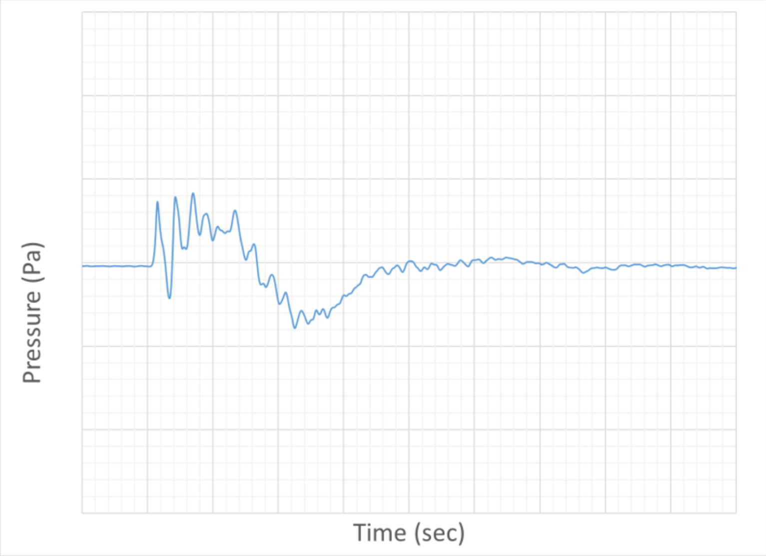
DOWN RANGE EXAMPLE

MUZZLE REPORT COMPARISON (SCALE - 20X LOWER THAN BALLISTIC CRACK)

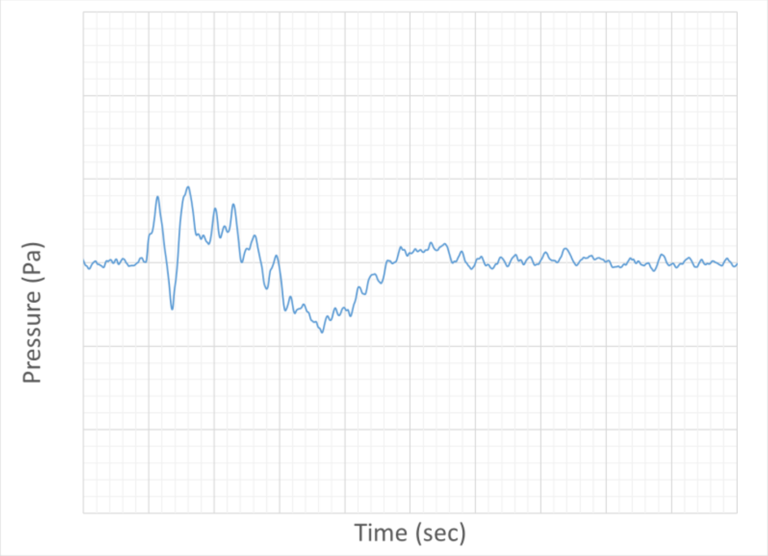
+200m, -3m



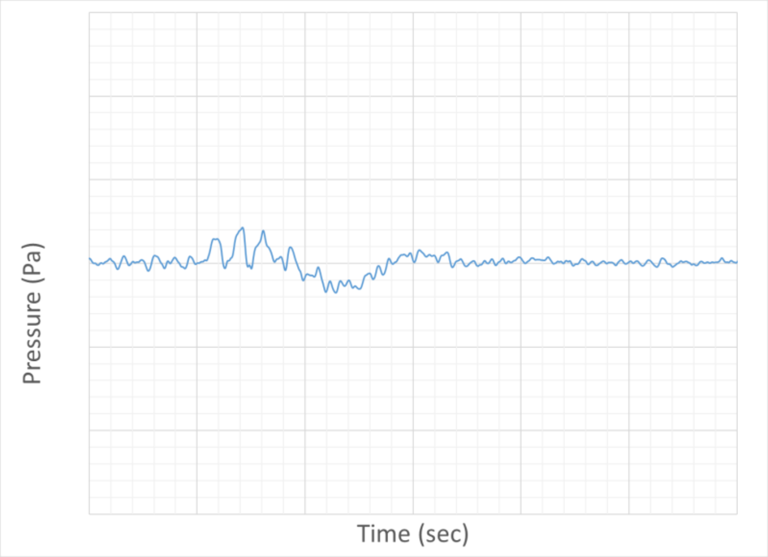
+200m, -50m



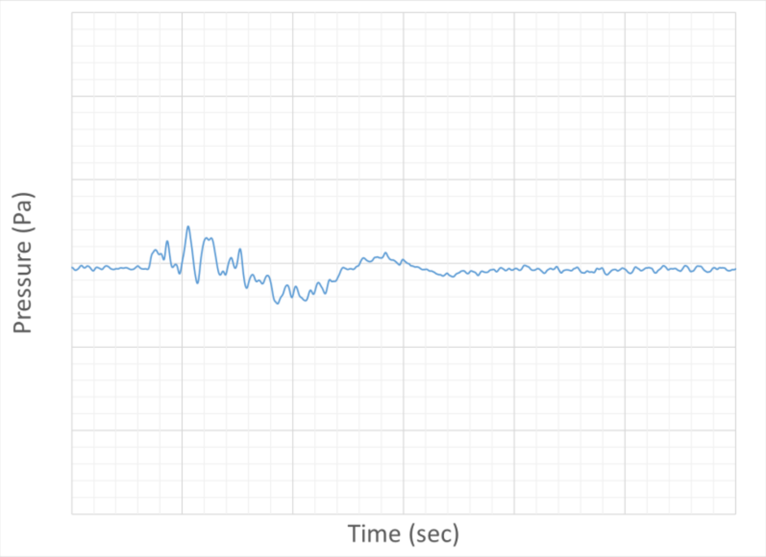
+200m, -100m



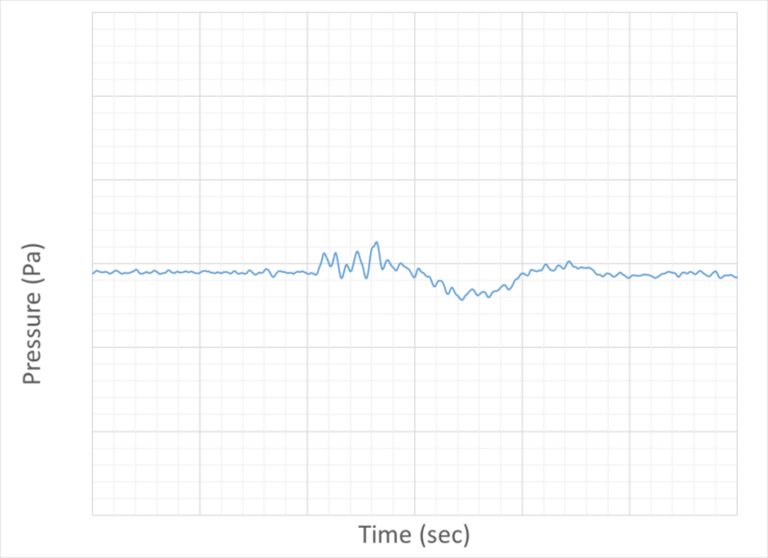
+400m, -3m



+400m, -50m



+400m, -100m



CONCLUSIONS

- Time syncing down range and near gun data systems is difficult.
- Ballistic crack is order of magnitude higher pressure than muzzle report at 200 m or farther down range
- Significant delay (0.3-0.5 sec) in time was observed between ballistic crack and muzzle report (thump) at 200-400 m
- Type of testing has limited application but can help assess detectability of weapons at various locations
- Test provides measurements that help to validate the “Crack and Thump Technique” discussed in M14 / M14A1 Rifles – FM23-8 Rifle Marksmanship

Infantry Platoon and Squad Tactical Advantage (Signature Management)
Enabling Capabilities Assessment Process (ECAP)
21 September 2022

Author: Mr. Cole Cochran, MCDID
Briefer: Mr. Adam Jacob, JSSAP

Tactical Advantage ECAP Background

- **What is ECAP:** Enabling Capabilities Assessment Process (ECAP) uses operationally informed systems engineering based analysis to examine current or projected capability gaps, decompose components of solutions, identify potential solution sets, and compare these needs to existing and projected technologies. *Minimizes Professional Military Judgement (PMJ)*
- ECAP initiated to provide analysis to explore S&T approaches to the creating tactical advantage problem.
- Previous, on-going and planned work by JSSAP provided valuable insight for desired future capabilities that assisted, but did not restrict the analysis.
- ECAP analysis took 9 months to complete (Nov 21-Sep 22).
- Threshold and Objective measures for some decomposition elements still need identification.
- Conducting surveys to provide more understanding of weighting of decomposition elements, and “tactical advantage” on-going.

Who was on the ECAP CCWS Team?

Regular participants:

- JSSAP
- SRD
- ARL
- CDD OE
- Armaments Center
- ERDC
- Soldier Center
- SL-CFT
- USAMED Public Health Center

Problem Statement

How do Infantry and Weapons squads reduce or optimize weapon system signatures in order to gain tactical advantage against a near peer threat in all environments in 2028, and 2035 and beyond?

What is "tactical advantage?" In order to gain tactical advantage via weapon signature reduction is defined in three ways:

1. Longer time to locate the firing weapon by the person being fired upon results in more time to engage and cause casualties. This encompasses at least three elements: Supersonic wave, muzzle blast - sound made by the firing of the round, and light (visible and other) made by muzzle blast - the firing of the round.
2. Increased ability to command and control friendly forces.
3. Reduced hearing loss both short and long term to the Soldier.

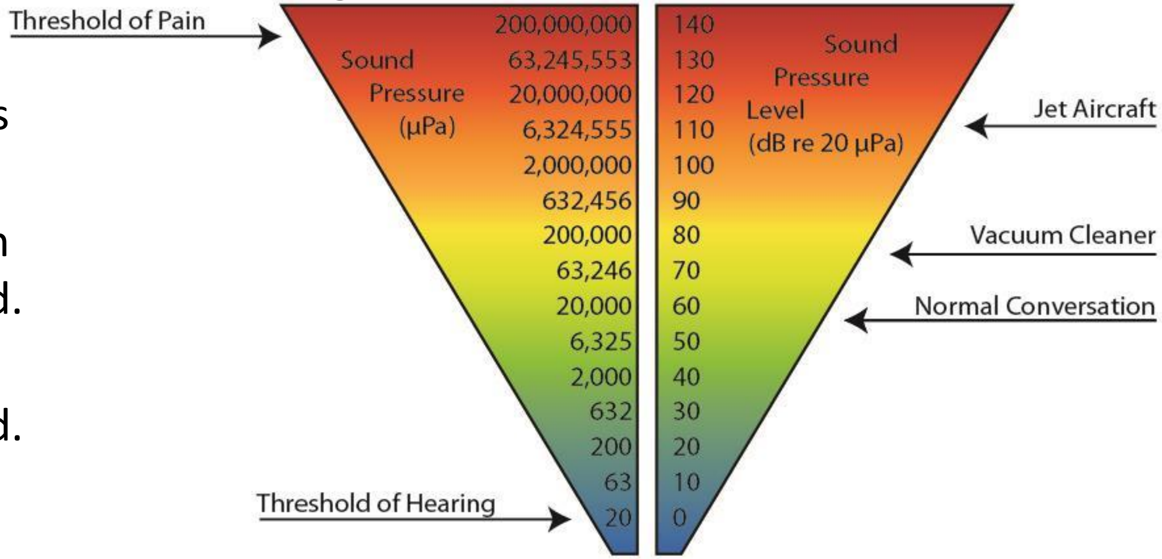
Considerations are: Environmental conditions: jungle, wooded, urban, desert, wind, night or day (unaided and aided).

Infantry Platoon weapons – M4, M249 (SAW), M240, XM5 and XM250 (Next Gen Squad Weapon and Automatic Rifle)

Sound pressure levels

- We actually 'hear' things in decibels (which is pressure).
  - 0.000,000,003 psi = 0 dB
  - 0.03 psi = 140 dB
- A 10 dB increase is perceived as twice as loud.
- In real life, people generally can detect a 3 dB change in a sound.
- In a laboratory, someone can detect a 1 dB change in a sound.
- Single event (single shot fired): 140 dB Peak
- Steady state noise: 85 dBA steady level for 8 hours
- Automatic and multiple weapons fire presents a more difficult problem to analyze because it potentially combines single event noise and steady state noise

Logarithmic scale



Example: Automatic weapon firing for 1 minute at 112 dBA is the threshold for damage to an unprotected ear

Analysis

- Developed understanding of the technical and medical aspects for supersonic crack, pressure/sound created by muzzle blast, and flash created by muzzle blast
- Able to identify <140 dB peak as the threshold for Soldier hearing damage
- <140 dB peak for muzzle blast is challenging @ 1m from the weapon
- <85 dBA as the threshold for Soldier hearing loss from steady-state noise
- Not able to determine if multiple firing events constitutes >85 dBA threshold problem
- Reduction of visible and IR flash are the most important factors in creating tactical advantage
- C2 of the unit is a close second important consideration – this includes Soldier SA
- Acoustic signature is less important than flash, difficult (but not impossible) to reduce to hearing safe levels
- Future Squad and Platoon weapons will increase the challenge because of a change in ammunition configuration
- Standardized methodology for sound and flash exist, however improvements for consistent application and methodology are on-going
- Correlation between standardized measurements and operational capability has not yet been established

Decomposition Categories and Sub Elements

- **Signature Reduction/visible light and across EM Spectrum** (37.4%)
  - Flash (visible)
  - Flash (Infrared)
  - Thermal signature Black-body radiation
  - Disturbed earth/ground
  - Heating of weapon connected devices interfering with target acquisition
- **Command and Control of Unit** (35.9%)
  - Unit leaders effectively communicating verbally
  - Unit leaders effectively communicating visually
  - Soldiers able to detect location of incoming fires
  - Soldiers able to monitor external environment for SA
- **Noise Reduction/Acoustic Signature (Ability to Locate Source of Fire)** (15.8%)
  - Supersonic crack
  - Subsonic noise
  - Muzzle blast
  - Bullet impacting downrange
  - (can noise be produced that cause enemy confusion?)
- **Reduce Hearing Loss** (7.5%)
  - Single event
  - Repetitive event
- **Other** (3.4%)

Conclusions and Recommendations

- Initial analysis leads to the conclusion that signature suppression provides tactical advantage: increases Soldier lethality and survivability, increases C2, and reduces hearing loss
- Operational context is needed to measure the necessary reduction of sound and flash to judge tactical advantage
- Surveying Soldier experience to confirm/modify weighting and measuring tactical advantage is important – lots of Soldier experience in combat with these technologies
- Industry provided suppressor technology can meet current the threshold requirements for both sound and visible flash decomposition elements
- Correlation between standardized measurements and operational capability are needed in order to inform emerging and future signature requirements
- Combined dB peak and dBA in an operational environment needs study
- Further work to provide hearing protection that does not interfere with C2 and Soldier/leader situational awareness is needed

U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND – ARMY RESEARCH LABORATORY

High-Temperature Evaluation of Suppressor Covers

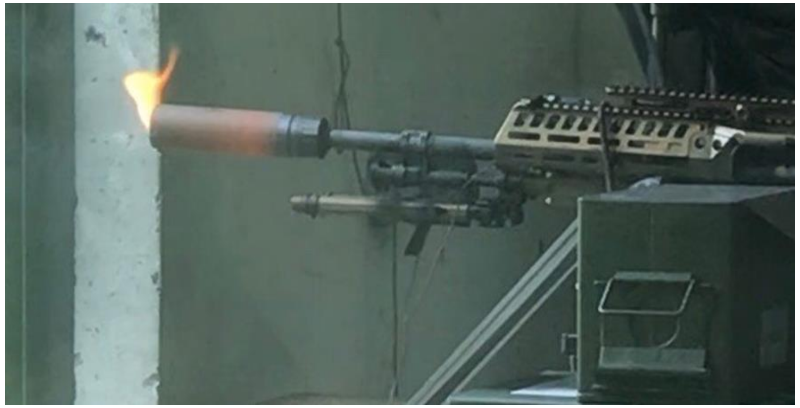
Dan Baechle, daniel.m.baechle.civ@army.mil, 410-306-0721

Composite & Hybrid Materials Branch

19 SEP 2022

Objective

- **Next Generation Squad Weapon will feature suppressor by default**
- **Suppressor gets extremely hot, can cause mirage, burns, toxic fumes**
- **Investigate commercial & ARL-developed suppressor covers for potential use**

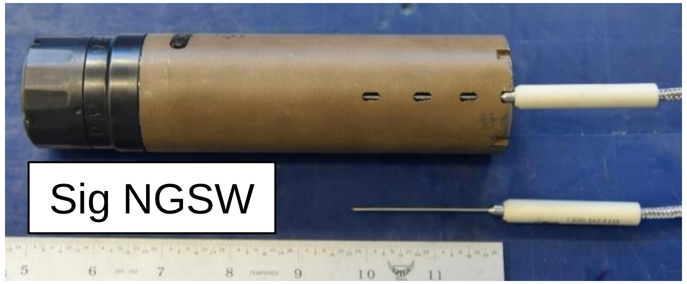


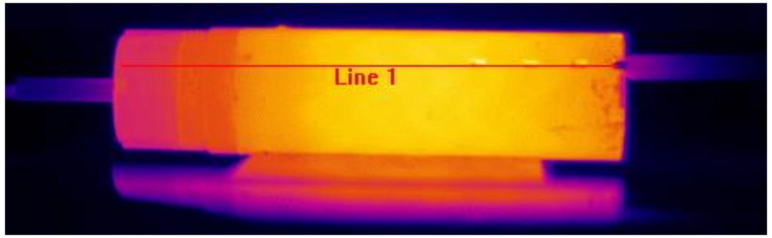
XM250

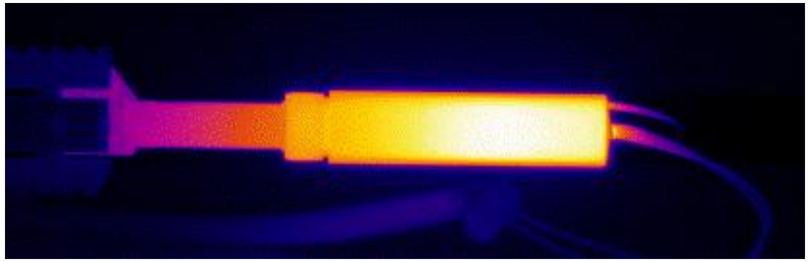
XM5

Heat Simulator

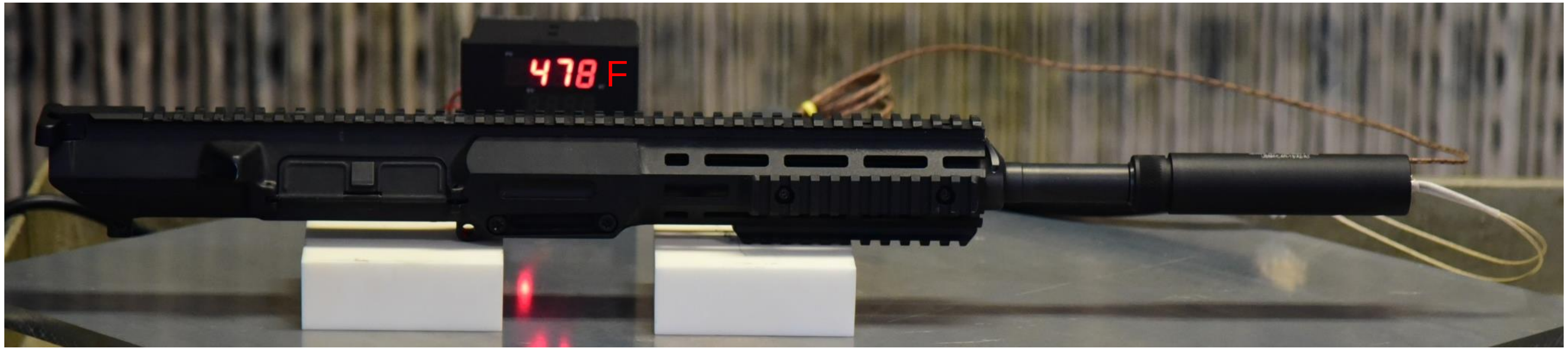
- Closed-loop system can heat suppressor & barrel separately
- Cartridge heaters: 0.247” diameter, up to 7” long, 600 W
- Thermocouple inserted into suppressor



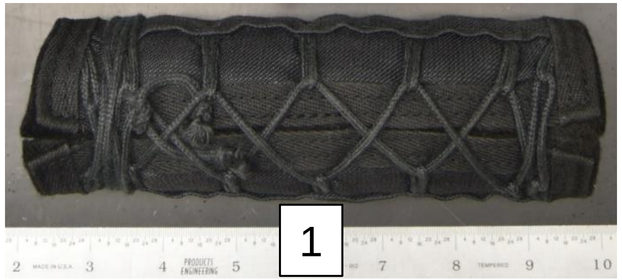


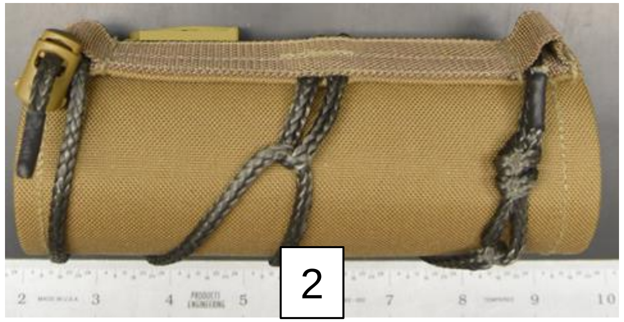


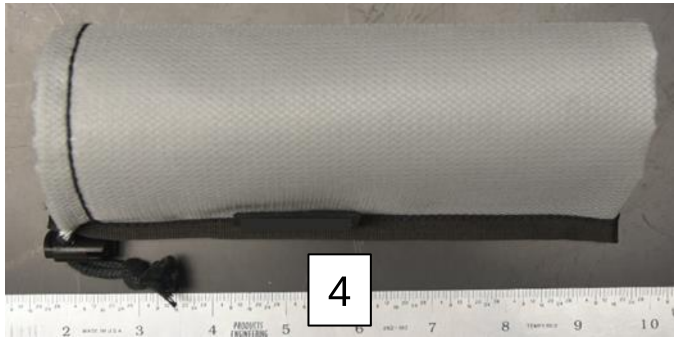
Rapidly test different thermal solutions on different weapon systems without ammo, range time



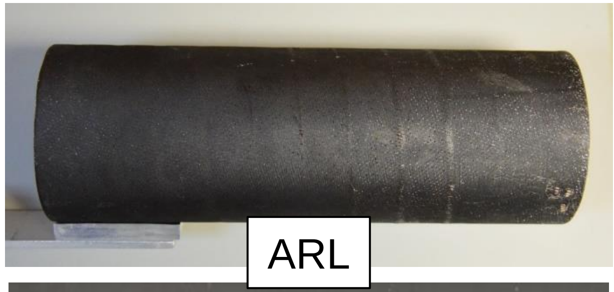
NGSW Candidate Covers

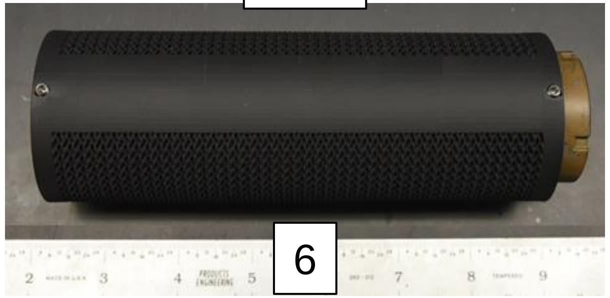






Manufacturer	Mass (g)
1	43.5
2	213.0
3	112.9
4	61.3
5	219.7
6a	103.0
6b	76.2
6c	60.8
ARL	212*
ARL 3	145**

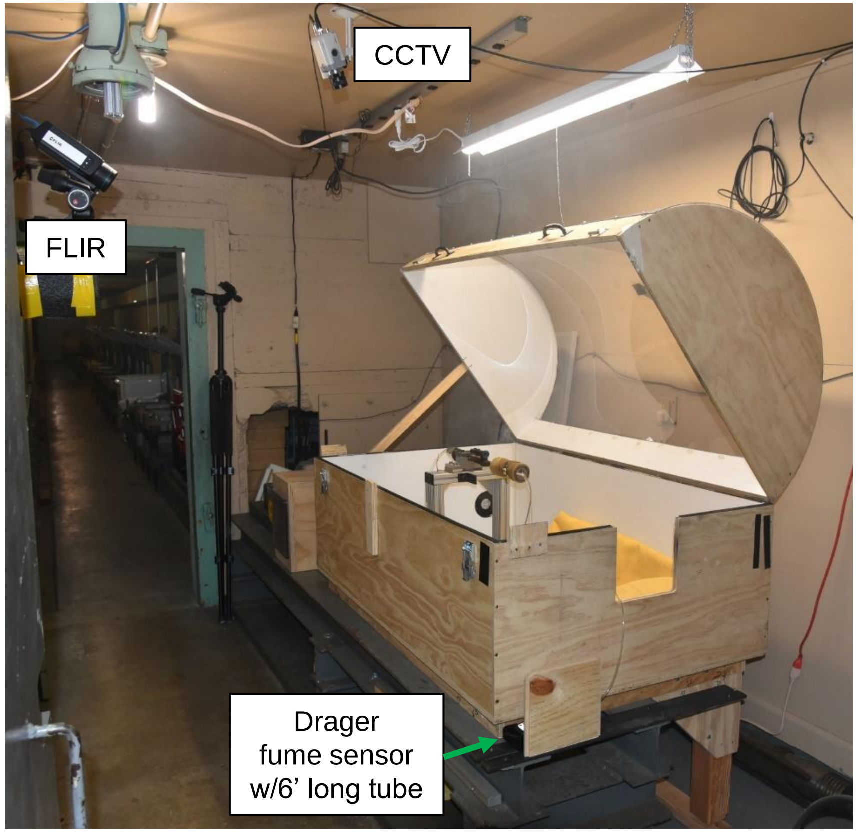




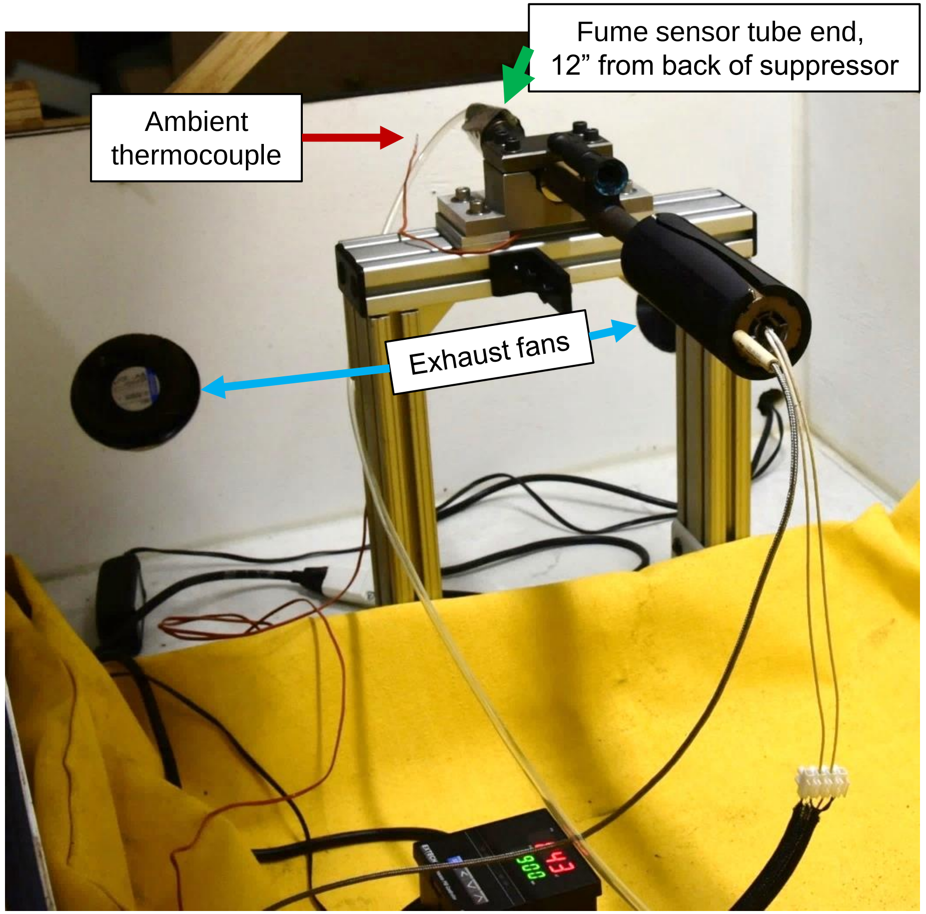
Broke apart
during heat up

To fit AR: *229g, **172g, since longer mounting arm is needed.
Design is not yet optimized.

Test Setup



- **Fans create ~1mph flow under suppressor when box closed**

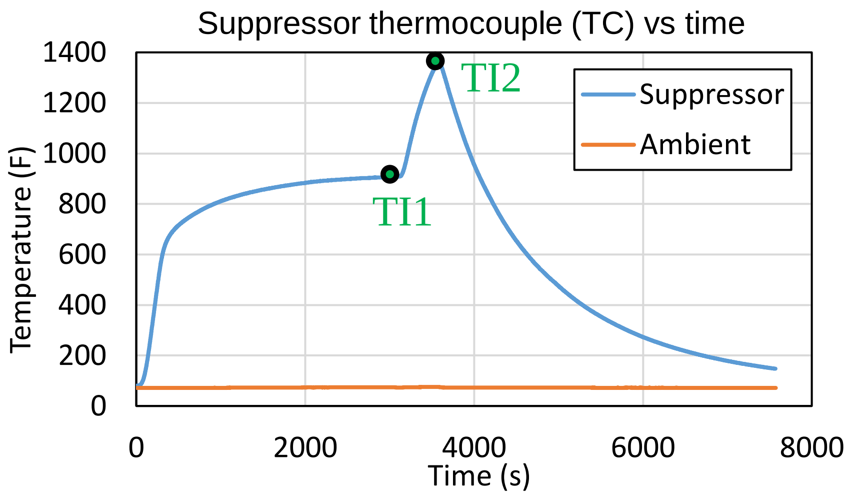


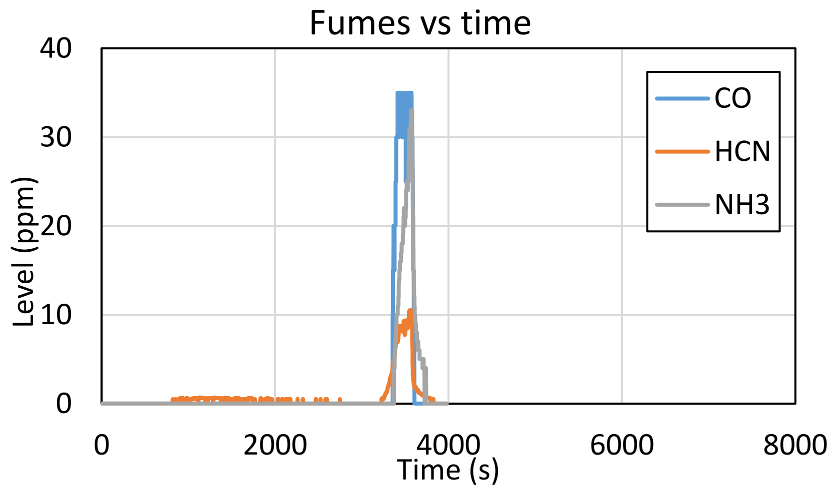
- **Drager records fumes for duration of test**
- **FLIR 655sc, 58" from suppressor**

Procedure

- **Determined heat levels that produce 500 F and 900 F with bare suppressor**
  - 500 F = "Mid power", 900 F = "High power"
- **Apply those heat levels to suppressor with each cover**
- **Record suppressor internal temperature (TC), cover external temperature (FLIR), fume levels**
- **FLIR thermal images at Mid power (TI1) and High power (TI2)**
- **Stop test if 1350 F reached, or if cover catches fire**
- **Record cool-down time**

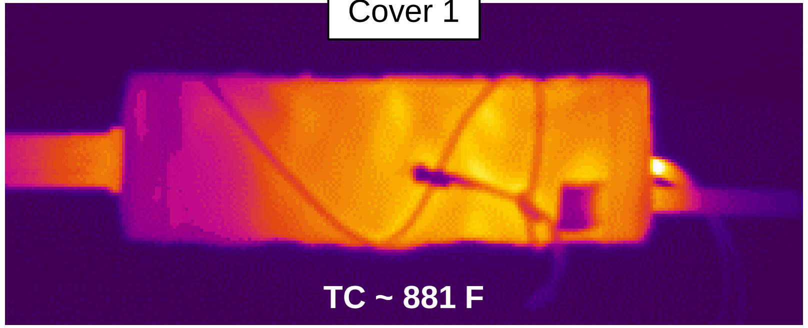
Example temperature & fume data

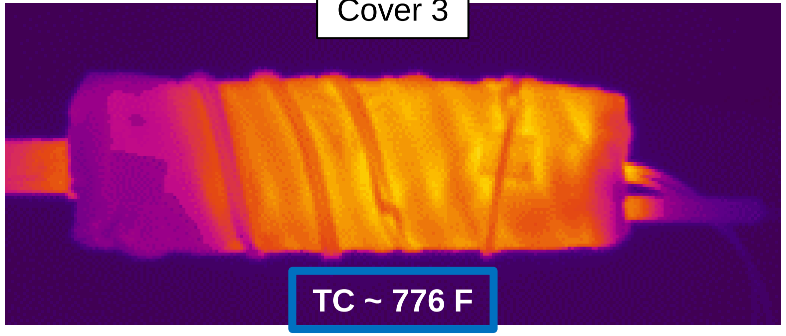


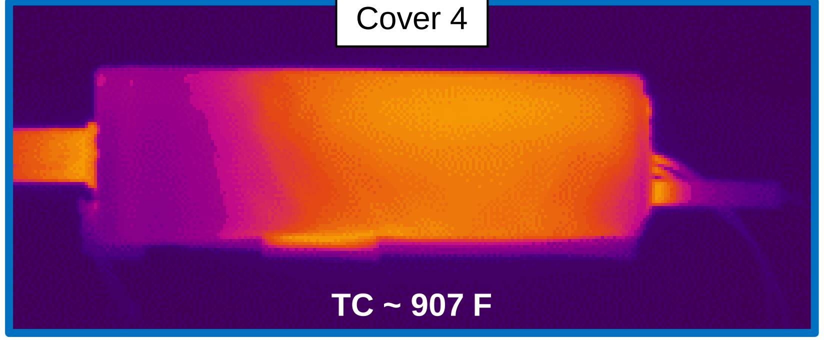


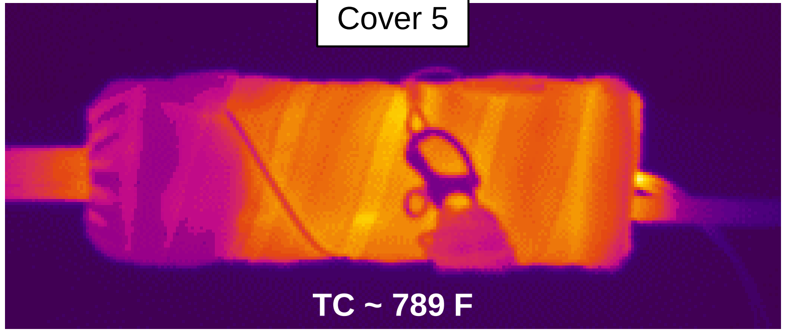
Constant Power: Mid-level

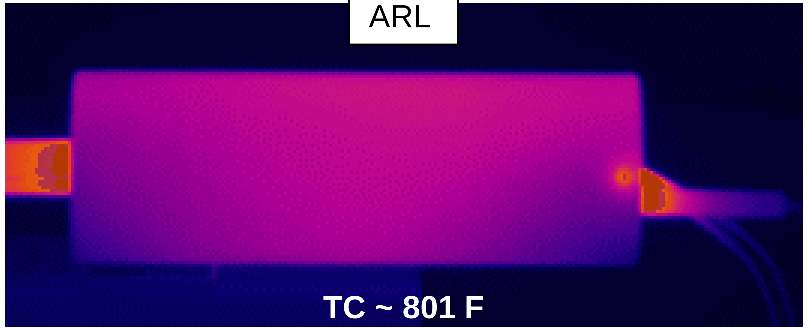
Power set to recreate 500F without any cover.



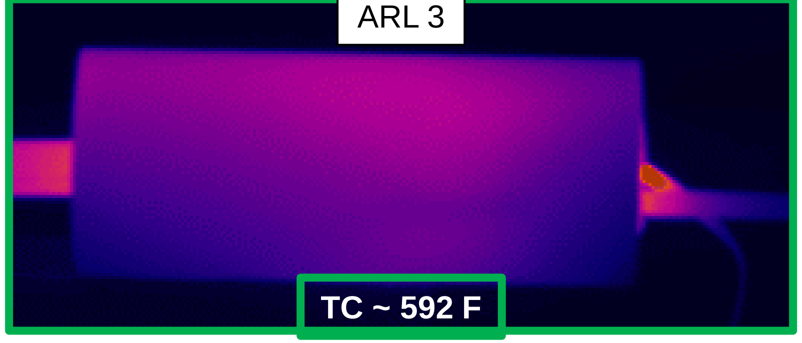








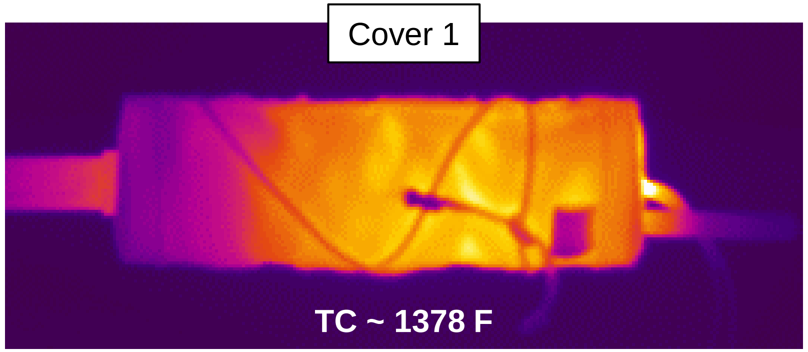
ARL exterior 98-123F cooler (avg) than commercial covers

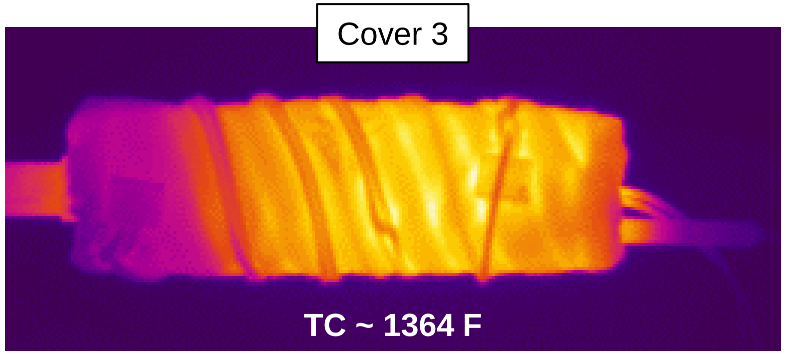


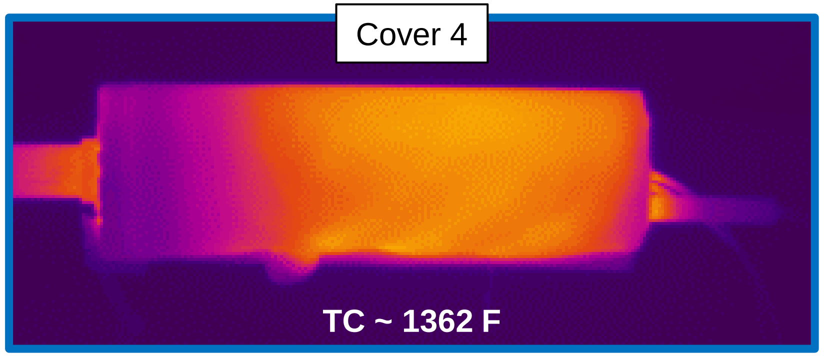
ARL3 exterior 130-163F cooler (avg) than commercial covers

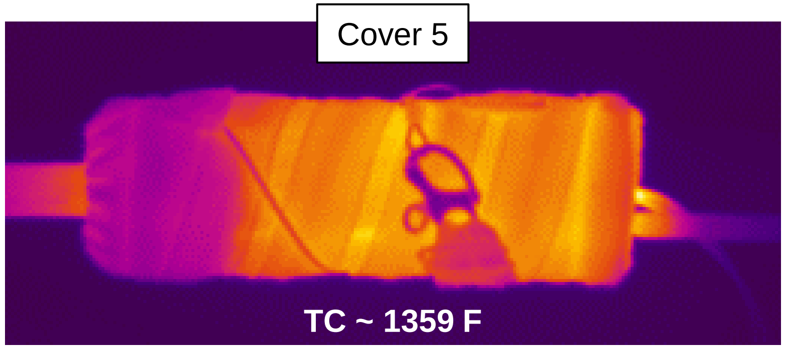
Constant Power: High-level

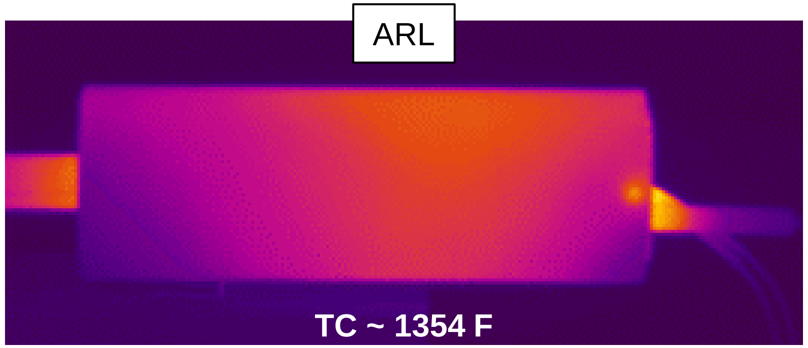
Power set to recreate 900F without any cover. Shut off power at 1350F



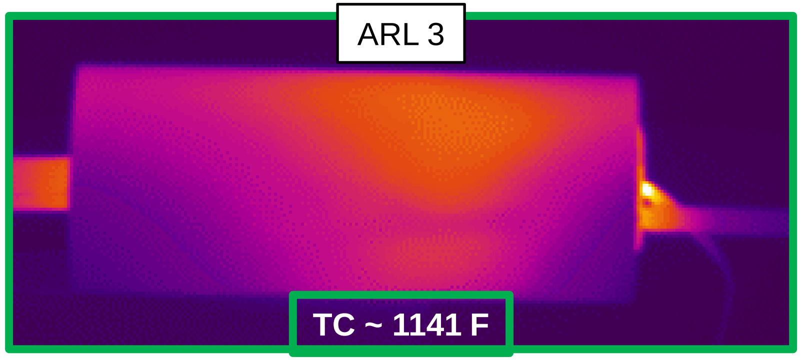








ARL exterior 97-175F cooler (avg) than commercial covers



ARL3 exterior 111-188F cooler (avg) than commercial covers

Results

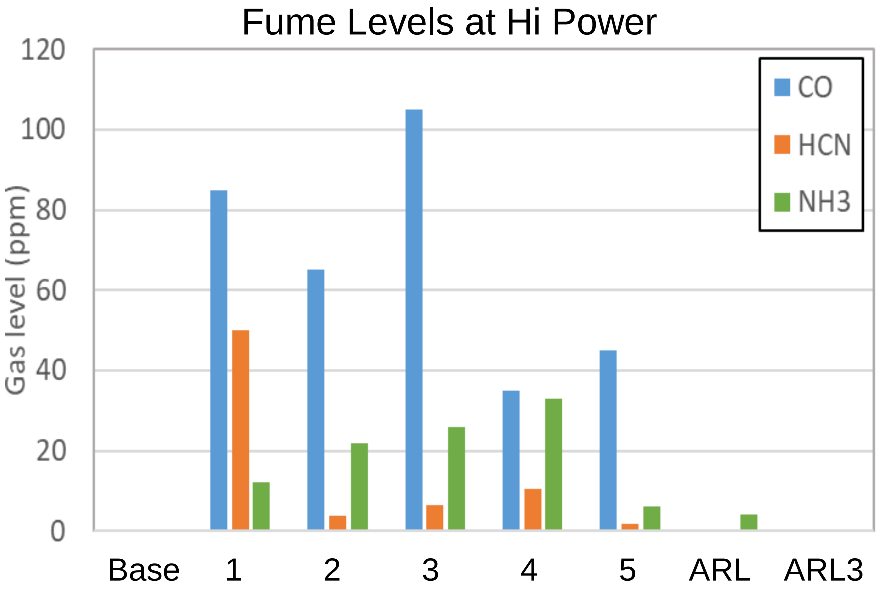
Condition	Mid power Max TC Temp (F)	Hi power Max TC Temp (F)	Mid power (ppm) CO	Mid power (ppm) HCN	Mid power (ppm) NH3	Hi power (ppm) CO	Hi power (ppm) HCN	Hi power (ppm) NH3	Cool to 160F from hi-power
Baseline	501.3	904.5	0	0	0	0	0	0	22m36s
1	881.4	1378.6	0	3.6	0	85	50*	12	56m9s
2	~~746.4~~	1358.2	0	1.3	0	65	3.9	22	N/A
3	776.5	1364.0	0	0	1.5	105	6.5	26	58m2s
4	907.5	1362.2	0	0.5	0	35	10.5	33	62m25s
5	789.6	1358.8	0	0	0	45	1.9	6	57m44s
ARL	801.5	1354.3	0	0	0	0	0	4	59m1s
ARL 3	592.5	1141.0	0	0	0	0	0	0	39m8s

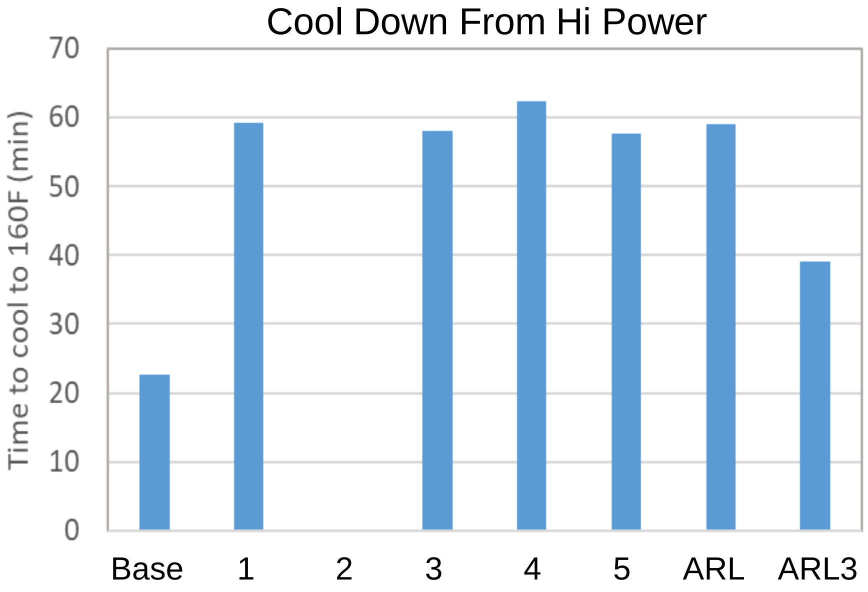
Test stopped before max temp

*1 maxed out HCN sensor

Best

Best commercial





Conclusion & Future Work

- **Demonstrated heat control system for small arms testing**
- **Best cover will depend on priority of weight, fumes, $$, ext & int temps**
- **Test commercial cover similar in design to ARL's**

ARL cover
- **Improve design for thermal management**
- **Durability testing**
- **Live fire testing; likely with 7.62 mm surrogate rifle**

ARL suppressor covers on Sig NGSW weapons

SOLVING WEAPONS SUPPRESSION CHALLENGES

WITH

MULTI-FLOW PATH FLOW-THROUGH

AND

REVERSE FLOW DESIGNS

X2 DEVELOPMENT GROUP, LLC

ERNIE BRAY – CEO

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NDIA

FUTURE FORCE CAPABILITIES CONFERENCE 2022

DEV GROUP

CURRENT WEAPONS SUPPRESSION ISSUES

- Most suppressor designs are driven by consumer market dynamics and considerations = Performance for military applications is often compromised
  1) "One size fits all" – consumer suppressors must work on a wide array of weapons and ammunition. Optimized for none – compromised on all
  2) Extreme emphasis on decibel reduction at the expense of *all* other metrics
  3) Lack of required design and engineering expertise
  4) 100+ years of trapping designs and simple flow – coax bypass designs (follow the leader)
     Email me for whitepaper: "*The Coaxial Suppressor: Evolution, Design Analysis and Prior Art 1890's to The Present" -- by Neil R. Parker*
  5) Designs and manufacturing engineering not focused on meeting military suppression requirements
  6) Many military goals and requirements go unmet

DEV GROUP

ZERO BACK-PRESSURE SUPPRESSION™

QUANTUMFLO TECHNOLOGY™

WEAPONS AND MISSION FOCUSED PERFORMANCE METRICS

- Suppressor should be benign and not negatively effect weapon's operational reliability without requiring gas regulation for suppressed operation
- ***It doesn't matter how quiet a suppressor is, if reliability, muzzle flash, toxic gas, thermal signature etc. metrics aren't met***
- **KEY SUPPRESSION METRICS:**
  1) Backpressure and Blowback = Operational Reliability and Toxic Gas Blowback
  2) Flash Suppression
  3) Point-of-Impact (POI) Shift
  4) Consistent performance across service life (Carbon loading and erosion)
  5) Thermal Signature
  6) Size and Weight
  7) Service life and user serviceability (100k plus rounds)

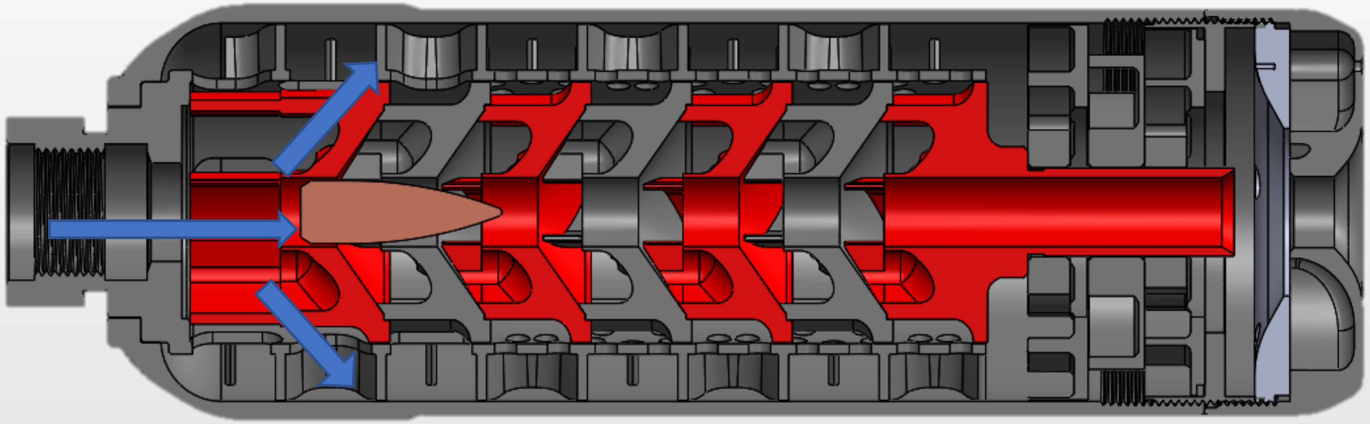
SUPPRESSORS SHOULD BE WEAPONS OPTIMIZED WITH MISSION-DRIVEN PERFORMANCE METRICS

- **LEGACY TRAPPING DESIGNS:**
  - Have high pressure differentials – gases are accelerated during blow-by up to several mach. This *increases heat and wear significantly!*
  - Lack of circumferential flow cores and efficient bypass flow leads to *rapid carbon loading*
  - Need to be *longer and heavier to achieve a high level of sound reduction*
  - Few are optimally effective in both *subsonic and supersonic flow regimes*
- **ADVANCE FLOW DESIGNS must adhere to core suppression and flow dynamics principals:**
  - Effectively expand, slow and cool gasses = High degree of thermal and suppression efficiency
  - Optimal balance of open volume and metal heat transfer surfaces
  - Gas flow efficiency = *Use of flow directing structures* to efficiently direct gasses and balance pressure
  - Optimize initial pressure blowdown, use progressive gas clamping and minimize pressure stacking to meet the weapons system and mission requirements

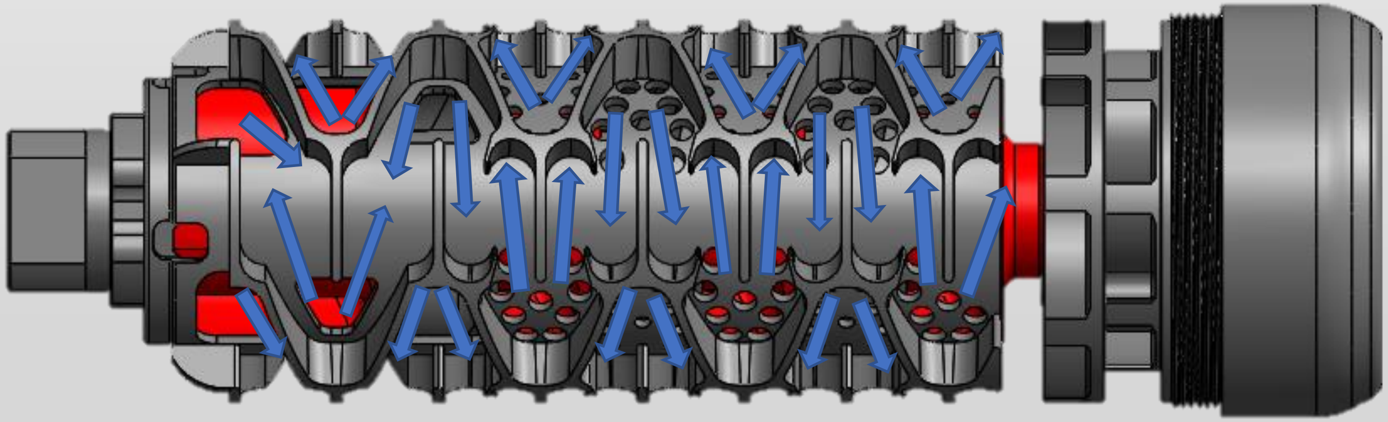
OPTIMIZING SUPPRESSORS FOR WEAPONS SYSTEMS AND MISSION REQUIREMENTS

- Multi-Flow-Path™ and Reverse Flow™ = Designed to meet these optimization challenges
- Blowdown must be matched to:
  - *Operating system, barrel length, ammunition, exit pressure, gas volume and un-burnt propellant*
  - *With sufficient blowdown, an active scavenge effect is possible = reduced weapons cleaning*
  - *Multiple controlled flow paths required to optimize/balance blowdown and sound signature*
- Multi-Flow-Path™ allows for highly flexible gas clamping = progressive and variable clamping
  - *Tailor sound signature to mission requirements- Multiple exit flows reduces sound signature*
  - *Flash Suppression: Distributed gas flow exit timing reduces the chances of Mach disks forming outside the suppressor – Combined with end cap venting can virtually eliminate all flash*
  - *Use of flow directing elements move gasses through the desired flow paths.*
  - *Allows suppressor to be equally efficient in subsonic flow regimes in the same suppressor*
  - *Pressure stacking can be effectively managed and kept within reasonable operating parameters*

Multi Flow Path Examples: X2 ORION™ Suppressor

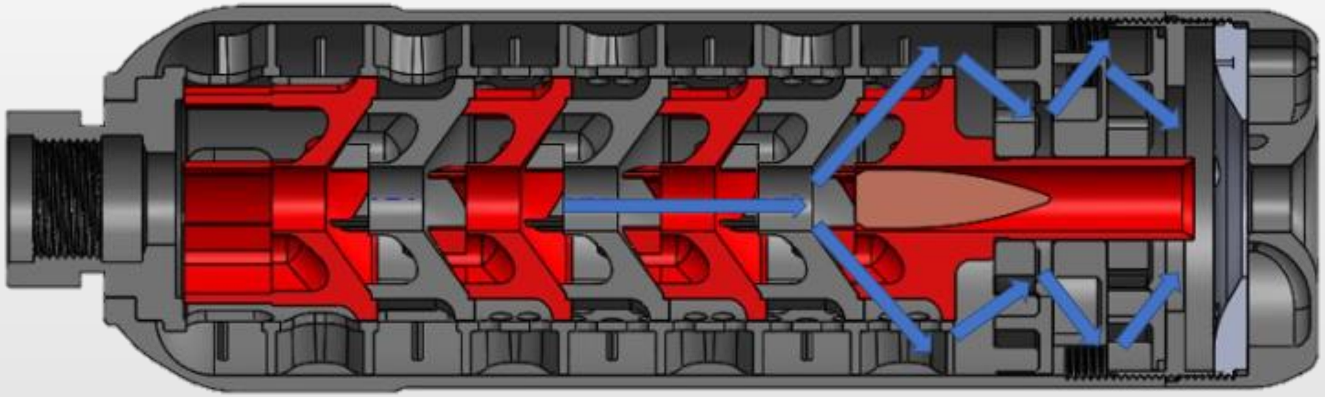


Above: Extended bore of the flow director creates a longer high-pressure zone, diverting gasses into the coax flow paths. Core has circumferential flow. Flow director spacing, direction of rotation and bore length (HP zones) are all variables for optimization.



Above: Multiple outer chamber fluid pathways (4) can have different levels of clamping structures. Time and distance of travel. Gas expansion volume. Amount and location of, inner and outer chamber fluid communication variables, etc.

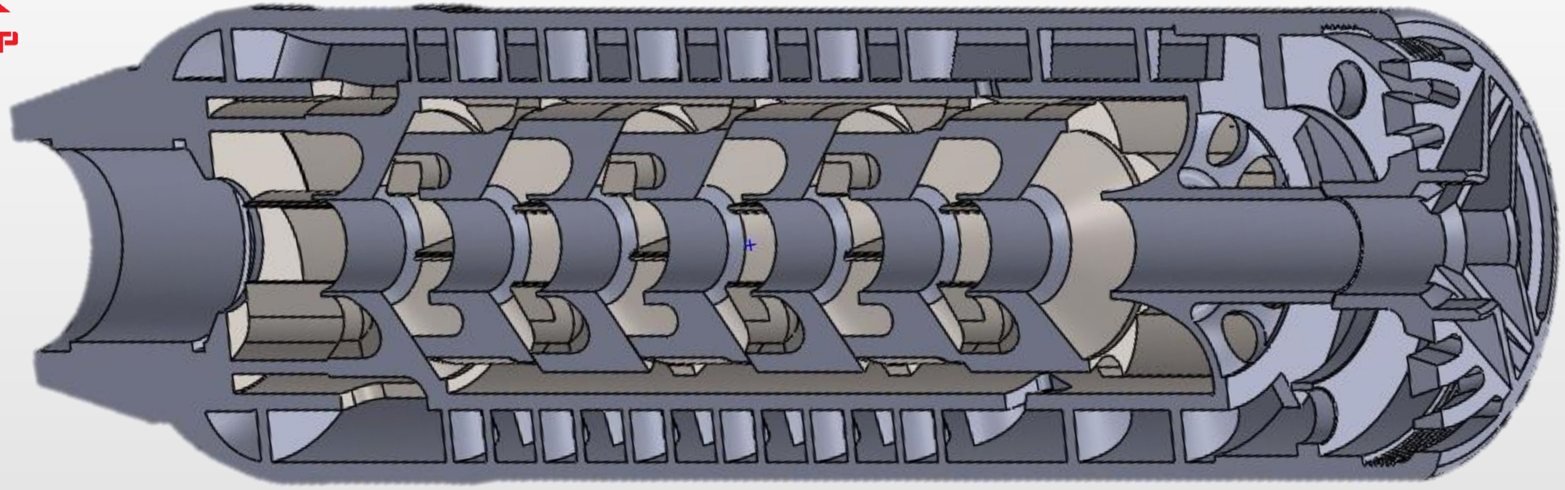
Multi Flow Path Examples X2 ORION™ Suppressor



Above: Flow Diversion Tube provides prolonged high-pressure zone directing gasses to circumferential exits, reducing flow velocity. Separate pressure zone in endcap with different venting options for weapons and mission requirements

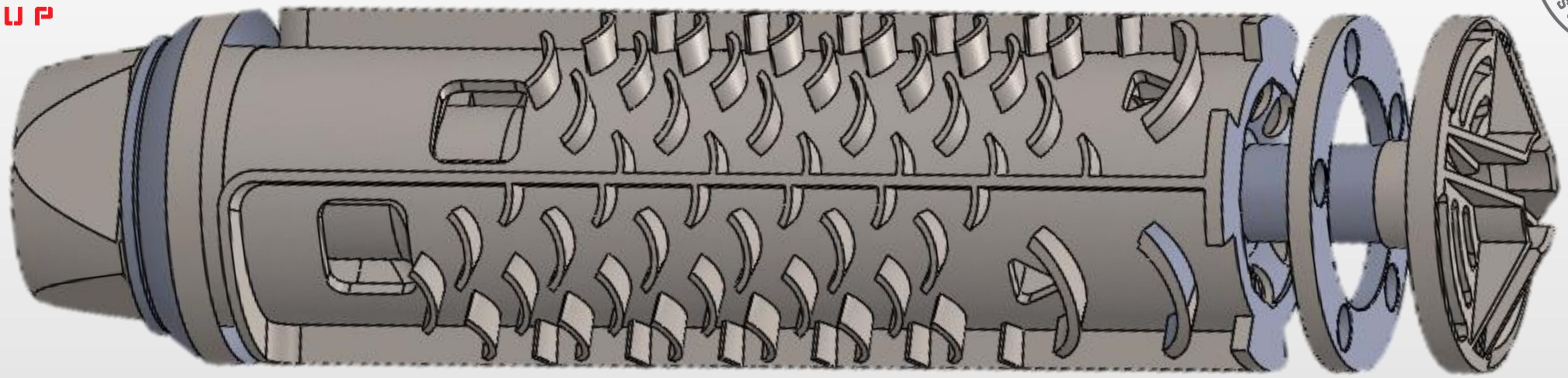
Highly modular CNC machined design. Provides flexible platform for weapons and mission optimization. Core flow rate, flow director spacing, bore HP zones, clamping, inner and outer chamber communication, outer chamber fluid paths, end cap, etc. are all customizable. Rapid prototyping

M2A1 50 BMG High-Flow X2 ORION™ Suppressor

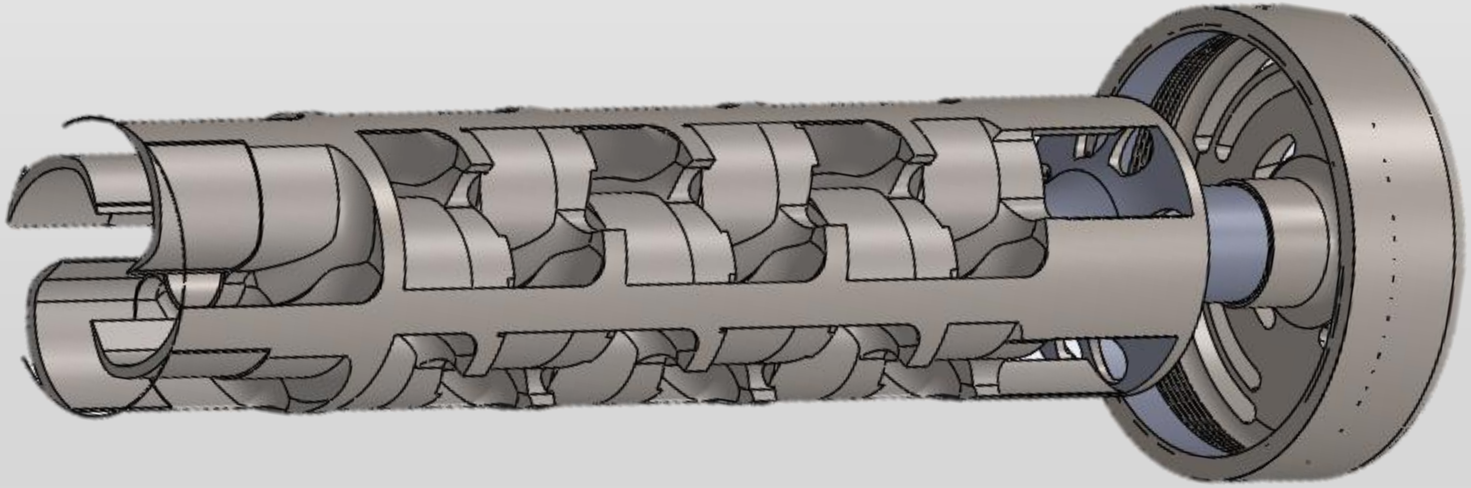


- Very high flow-rate to eliminate backpressure & blowback on bursts
- Reduce pressure stacking during sustained fire
- High-Flow Hemicycle Array™ in coax flow paths = Delivers high gas flow turbulence w/ minimized resistance
- Flow directors in core provide circumferential flow path = Prevents pressure build-up & high velocity blow-by
- Flow director spacing optimized to accommodate SLAP / SLAP-T rounds
- Design allows suppressor to be purged of oxygen to reduce or eliminate first-round pop and flash
- Multiple flow-paths, varied gas flow exit timing, and end-cap vectored exit flow = Help sound reduction and flash suppression by reducing chances of external Mach disk formation and secondary flash
- Maximized thermal efficiency = reduced thermal signature and rapid cooling
- High flow-rate design resists carbon loading and performance degradation. Can be mfg. in serviceable format

M2A1 50 BMG High-Flow X2 ORION™ Suppressor



Above: Hemicycle flow pathways provide high flow turbulence with consistent flow rate and no trapping



Above: Flow directors in core have a circumferential flow-path to prevent pressure buildup and accelerated gas blowby

THERMAL EFFICIENCY AND ACTIVE SCAVENGE
EXAMPLE: X2 ARTEMIS-X™ SUPPRESSOR

Left: ARTEMIS after 60rds @ 1 round per sec firing sequence. Less than 10° temp variance end-to-end. Cool-down time to 90° approx. 12min. 14 traditional design suppressors hit 300° in approx. 20rds and nearly 600° at 60rds w/ cool-down approx. 30-40min. Right: Ruger asked X2 to test if we could get 100rds through the 57 pistol (5.7x28mm) without pistol ceasing to function. Most suppressors tested stopped in less than 40rds. ARTEMIS is at 2060rds without cleaning, and still going… Increased operational reliability through rapid blowdown scavenge effect. Note:135-137db comparable or better than other suppressors tested.

"X2 REVERSE FLOW™"

PINNACLE OF ADVANCED SUPPRESSOR DESIGN

- **TRADITIONAL TRAPPING DESIGN** suppressors achieve sound reduction through 1) length, 2) added volume and structures = longer drain times at lower pressures
- **"X2 REVERSE FLOW™" DESIGN** achieves *maximum sound suppression in shorter, lighter suppressors*
  - Outer coax chamber divided into front and rear sections – can be adjusted for desired attributes
  - *80+ percent of gases reversed into outer coax fluid pathways at the distal end* by extended high pressure zone Flow Diversion Tube and laminar flow gas turnarounds
  - Multiple reverse flow pathways can have different lengths, volume and restrictive structures
  - Each pathway re-diverts gases forward and exits gases into the endcap chamber at different time intervals where the endcap diffuses those exit flows
- Reverse Flow has *longer drain times* and *lower pressure exits than suppressors 3"- 4" longer*
  - Longer drain times at lower pressures also help with *flash reduction*
- Proximate end portion of outer coax chamber provides volume for initial blowdown = *reduced backpressure*. Purge ports in blowdown chamber purge core to *reduce first round pop and flash*
- Suppressor core has circumferential flow paths to *eliminate pressure buildup* and accelerated blow-by

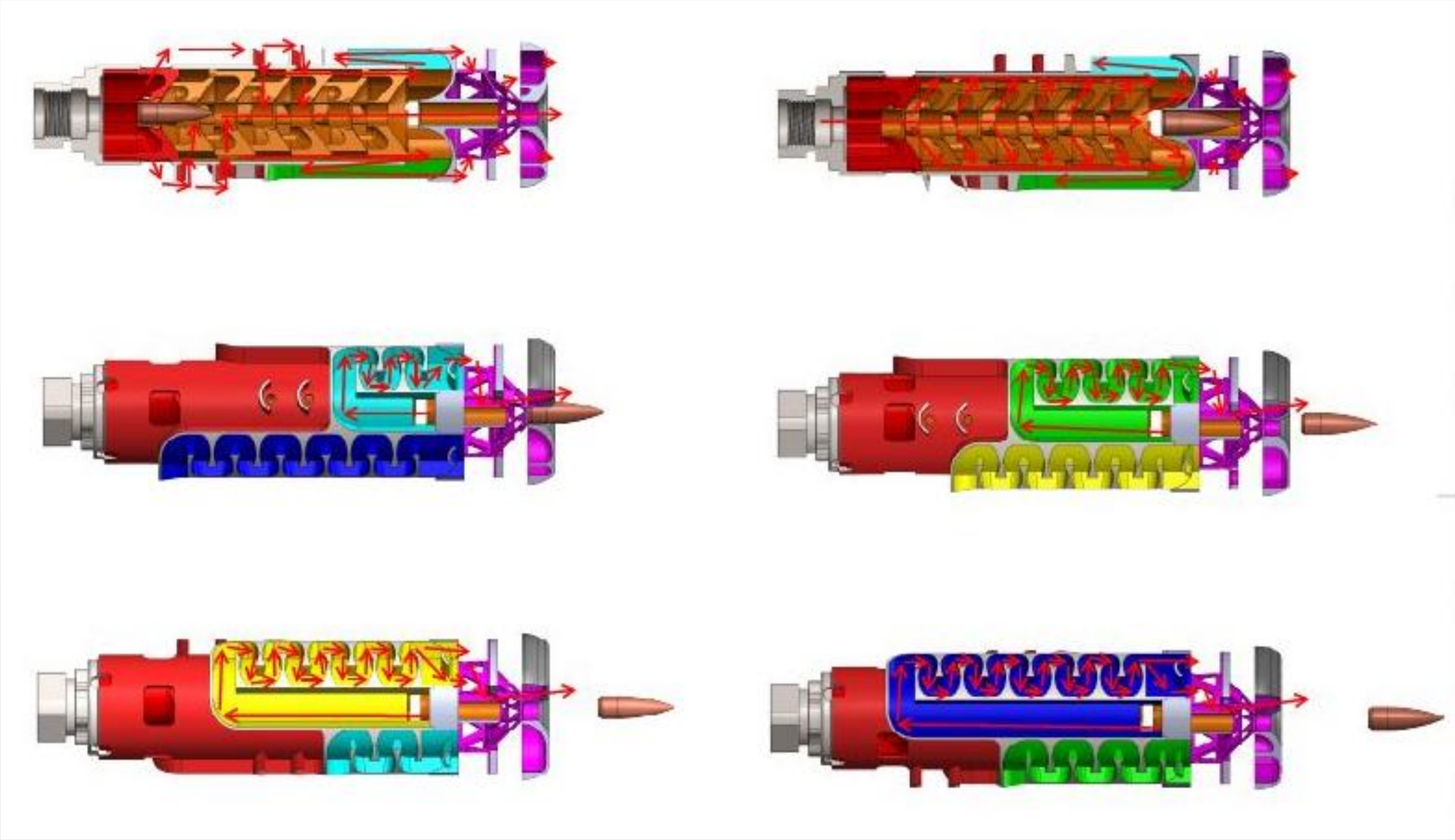
"X2 REVERSE FLOW™"

PINNACLE OF ADVANCED SUPPRESSOR DESIGN

Coax outer chamber divided into rear pressure zone for initial pressure blowdown and back pressure reduction. Front has one or more reverse flow pathways. Length, volume and exit segment structures are all variables for exit flow timing. = Long drain time with staggered, lower pressure exits. Reverse Flow pathways vent into a separate endcap pressure chamber where exit flows are diffused.

"X2 REVERSE FLOW™"

PINNACLE OF ADVANCED SUPPRESSOR DESIGN



MANUFACTURING OF COMPLEX - ADVANCED FLOW DESIGNS ISSUES AND SOLUTIONS

- **Advanced Manufacturing Technology** and *specific expertise using it* are *critical* components in achieving full potential and desired performance metrics of advanced flow designs
- **Popular consensus is that advanced flow designs need to be 3D Printed.** ***This is wrong!***
  - Typically, the more complex the flow design, the more incompatible it is with 3D printing
  - Carbon loading is a major issue = More complex flow pathways ***will carbon load more quickly***
  - As critical flow-paths carbon load, ***performance can exponentially decrease***
  - ***Performance degrades across a shorter service life (often in an unpredictable manner)***
  - As pathways plug and volume decreases, ***backpressure and blow back increase*** = ***degradation of weapon's operational reliability and increased toxic gas blowback***
  - ***Sound levels increase*** as volume decreases, ***POI shift likely*** as weight increases, ***muzzle flash increases***
- **Advanced Flow Designs** can be fully CNC machined and deliver:
  - **Service life in excess or 100K rounds** with minimal or no service
  - Designs can be **user serviceable** and, if desired, **mission configurable**
  - Manufacturing **costs can be comparable to 3D printing** (or even less…)
  - More **design flexibility**, such as mixed metals. Inconel, stainless steel, titanium and aluminum, etc. can be combined in one suppressor to **achieve optimal metrics**

MANUFACTURING OF COMPLEX – ADVANCED FLOW DESIGNS EXAMPLES:

- Left: X2's ORION™ suppressor. Fully CNC machined. Inconel first flow director, grade 5 titanium all other parts. Highly modular and fully user serviceable. Production costs nearly the same as 3D printing.
- Right: 5.56mm ORION with 14k + rounds. No carbon loading and no bore erosion. (other detailed pics available)

CONCLUSION

- AVAILABLE FOR PRIVATE BRIEFINGS
- X2's PROPRIETARY PRODUCT TECHNOLOGIES INCLUDE:
  - *THREE GRANTED SUPPRESSOR PATENTS WITH FIVE PENDING (3 ON TRACK 1)*
  - *PRIORITIES TO JAN 2016 (3) JAN 2019 (3) and Apr. 2022 (2)*
  - *6 SMALL ARMS TECHNOLOGY PATENTS AND 4 PENDING (non-suppressor)*
- ADVANCED MANUFACTURING PROCESS ENGINEERING & TURN-KEY IMPLEMENTATIONS
- **X2's BUSINESS MODEL** = *PARTNERING, JOINT VENTURES, TECHNOLOGY LICENSING*

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CAGE:8MHQ1

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