Operationalizing Directed Energy

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Evolving Directed Energy (DE) Opportunities

- Evolving threats that may be addressable by DE:
  - Guided: Rockets, Artillery, Mortars and Missiles (RAMM)
  - Proliferation of unmanned systems for both ISR and strike
  - Complex IEDs
  - Enhanced ISR capabilities
  - Asymmetric SWARM capabilities being developed
- Advancing state of the art in DE, along with the immergence of threats that are addressable by those DE capabilities, present a unique opportunity to get DE capabilities to the battlefield
- Low cost per engagement, and a deep magazine, allows the use of DE capabilities to move us to the right side of the cost curve by negating lower end threats, thereby maintaining the critical high-end KE capabilities for higher-end threats
- When an HEL weapon is deployed, platform ISR capabilities are significantly enhanced throughout the life of the DE system
- DE-related policy and legal issues are generally supportive of DE capability development and deployment

The New Paradigm

***Directed Energy Weapons*:**

It's no longer:

"It's Not If, but When?"

but is now:

"It's Not When, but How?"

Directed Energy Weapon capabilities are here today. The Warfighters and Acquisition Community need answers on how they are to be used!

Bottom Line Up Front

- DE programs come in two categories with significantly different target engagements
  - High-Energy Laser Weapons
  - High-Power Radio Frequency (High-Power Microwave) Weapons
- Historically, S&T and R&D DE programs have focused on hardware development vice lethality investigations
- Various models under development (VV&A?), fragmented lethality testing ongoing (HEL-JTO making some progress for HEL only)
- Low-level efforts to produce DE JMEM-related documentation

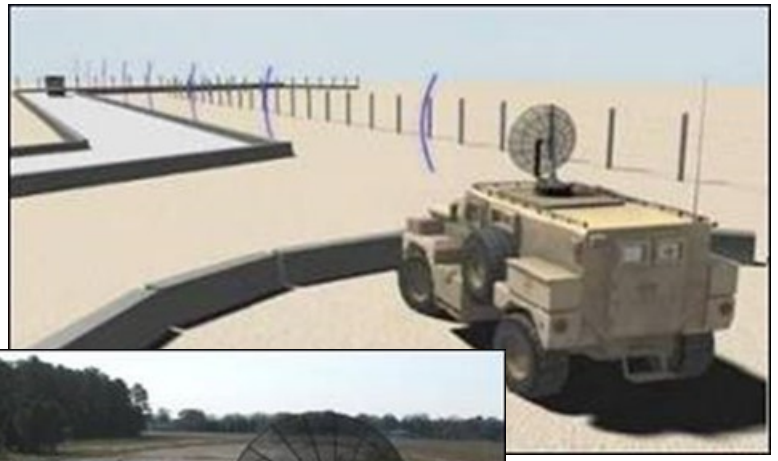
Significant focused investment required to develop "tactical" weaponeering tools that are of practical use to the mission planners and the warfighters

High-Energy Laser Weapon Missions

- Counter-Rockets, Artillery, and Mortars (C-RAM)
- Counter-Unmanned Aerial Systems (C-UAS)
- Counter-Intelligence, Surveillance, and Reconnaissance (C-ISR)
- Counter-Missile
- Reversible Counter-Personnel (dazzling)
- Vehicle/Vessel Stopping
- Airborne HEL System
  - Aircraft Self Protect
  - Infrastructure/SOF Ground Targets
  - Boost/Terminal-Phase Intercept
- Ship/Submarine HEL System
  - FIAC/FAC
  - UAS
  - Missiles
  - ISR
- Ground Based Air Defense (GBAD)
- Negation of Swarm tactics

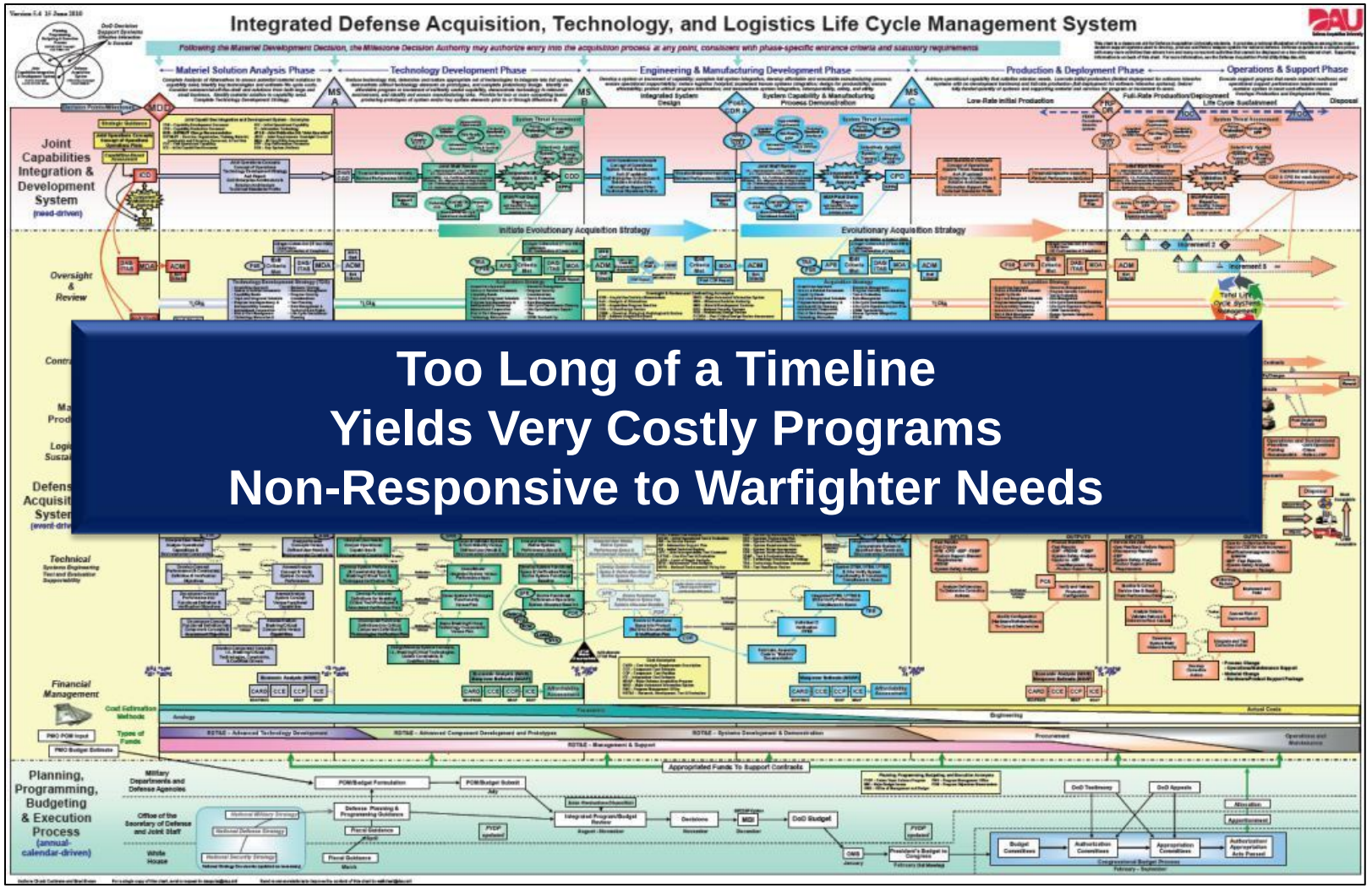
High-Power RF Weapon Missions

- Vehicle/Vessel Stopping
- Counter-Improvised Explosive Devices
- Counter-Unmanned Aerial Vehicles
- C-ISR
- Counter-Missile
- Reversible Counter-Personnel
- Airborne Electronic Attack
  - Infrastructures
  - IADS
  - Platforms
  - C4I Facilities
- Ship Self Defense
  - FIAC/FAC
  - UAV
  - Missile
- Ground-Based Air Defense (GBAD)
- Negation of Swarm tactics



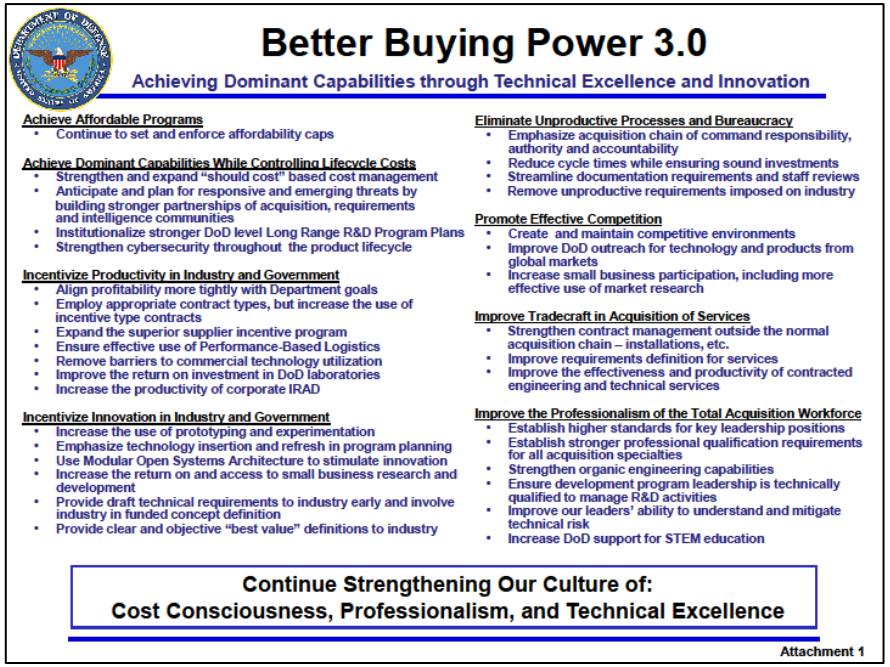
Acquisition Process

Acquisition Of Materiel Capabilities for the Warfighter



Achieving Affordable Capabilities through Technical Excellence and Innovation

- Better Buying Power 3.0: Incentivize Innovation in Industry and Government
  - Increase the use of prototyping and experimentation
  - Emphasize technology insertion and refresh
  - Use Modular Open Systems Architecture to stimulate innovation



Better Buying Power 3.0

Achieving Dominant Capabilities through Technical Excellence and Innovation

Achieve Affordable Programs
- Continue to set and enforce affordability caps

Achieve Dominant Capabilities While Controlling Lifecycle Costs
- Strengthen and expand "should cost" based cost management
- Anticipate and plan for responsive and emerging threats by building stronger partnerships of acquisition, requirements and intelligence communities
- Institutionalize stronger DoD level Long Range R&D Program Plans
- Strengthen cybersecurity throughout the product lifecycle

Incentivize Productivity in Industry and Government
- Align profitability more tightly with Department goals
- Employ appropriate contract types, but increase the use of incentive type contracts
- Expand the superior supplier incentive program
- Ensure effective use of Performance-Based Logistics
- Remove barriers to commercial technology utilization
- Improve the return on investment in DoD laboratories
- Increase the productivity of corporate IRAD

Incentivize Innovation in Industry and Government
- Increase the use of prototyping and experimentation
- Emphasize technology insertion and refresh in program planning
- Use Modular Open Systems Architecture to stimulate innovation
- Increase the return on and access to small business research and development
- Provide draft technical requirements to industry early and involve industry in funded concept definition
- Provide clear and objective "best value" definitions to industry

Eliminate Unproductive Processes and Bureaucracy
- Emphasize acquisition chain of command responsibility, authority and accountability
- Reduce cycle times while ensuring sound investments
- Streamline documentation requirements and staff reviews
- Remove unproductive requirements imposed on industry

Promote Effective Competition
- Create and maintain competitive environments
- Improve DoD outreach for technology and products from global markets
- Increase small business participation, including more effective use of market research

Improve Tradecraft in Acquisition of Services
- Strengthen contract management outside the normal acquisition chain – installations, etc.
- Improve requirements definition for services
- Improve the effectiveness and productivity of contracted engineering and technical services

Improve the Professionalism of the Total Acquisition Workforce
- Establish higher standards for key leadership positions
- Establish stronger professional qualification requirements for all acquisition specialties
- Strengthen organic engineering capabilities
- Ensure development program leadership is technically qualified to manage R&D activities
- Improve our leaders' ability to understand and mitigate technical risk
- Increase DoD support for STEM education

Continue Strengthening Our Culture of:
Cost Consciousness, Professionalism, and Technical Excellence

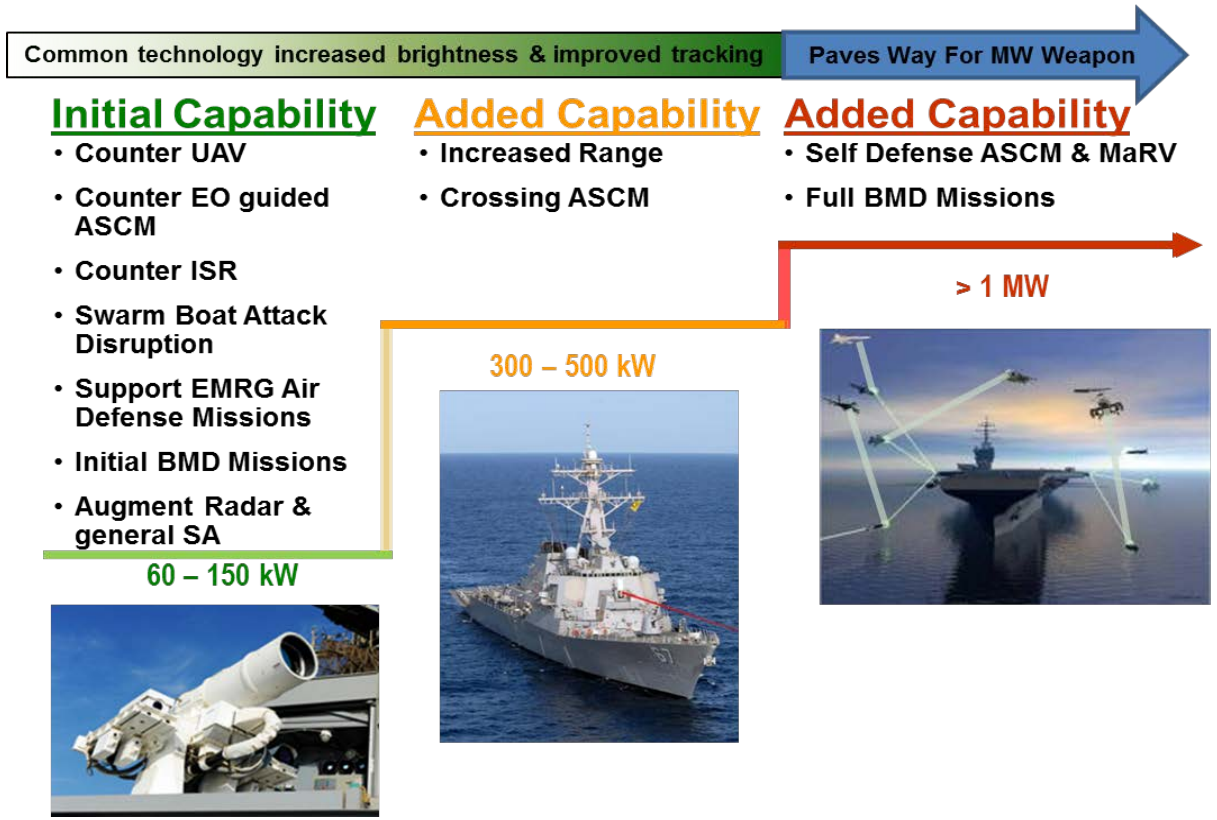
Attachment 1

Acquisition Community

- Department of Defense Acquisition Problems:
  - Acquisition costs increasing while budgets are declining
  - Acquisition timeline far exceeds Threat Evolution timeline:
    - Results in Creeping Requirements
    - Engineering Change Proposals (ECPs) increase costs
    - Joint Capabilities Integration Development System (JCIDS): attempt to control costs (addition of BBP 3.0)
- Department of Defense Desire: Affordable and Rapid Technology Acquisition
  - Desired increased use of Rapid Prototyping (LaWS, NIRF, MaxPower)
- Total Ownership Cost (TOC): Includes cost per engagement, resupply logistics, and weapon refurbishment, etc.
- Analysis of Alternatives (AoA): will still be required for all DE POR's
  - Not necessarily a direct KE vs. DE comparison (i.e. include TOC)
- Doctrine, Organization, Training, Materiel, Leadership And Education, Personnel, Facilities, and Policy (DOTmLPF-P) considerations need to be incorporated early in development

Incremental HEL Progression into the Fleet

- An incremental approach to bring HEL capabilities to the warfighter
- Insure initial capability addresses warfighter needs/gaps
- Obtain critical warfighter feedback as a result of initial fielding

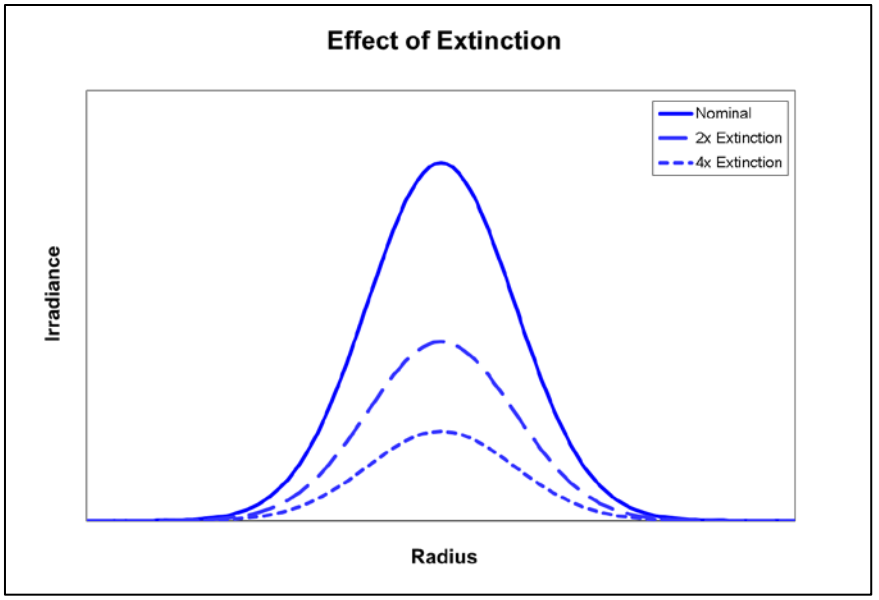


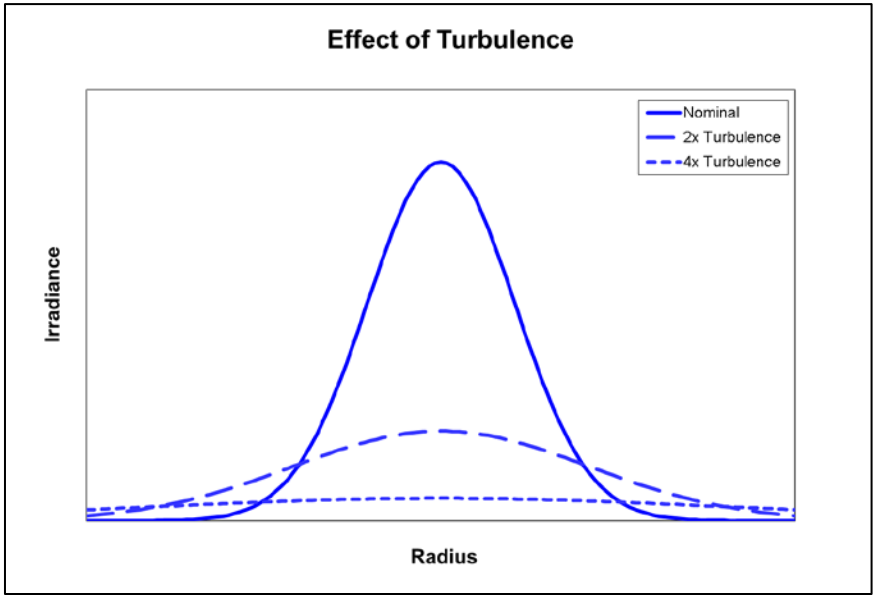
Operational Questions Related to HPRF/HEL

- Weather impact/understanding (fog, rain, snow sandstorm, etc.)
  - Ability to determine on the “tactical” level (more significant for DE)
- Atmospheric impact/understanding (aerodynamic, turbulence, extinction, utility of adaptive optics, passive treatments, etc.)
  - Ability to determine on the “tactical” level (real-time or forecast?)
- Target lethality understanding
  - Fidelity to determine Pk (need to determine HEL “time to effect,” or HPRF “duration of effect,” with high confidence)
  - Ability to perform “aimpoint selection and maintenance” (primarily HEL)
- Ability to determine weapon effectiveness
  - Ability to “tactically” perform a kill assessment
  - Ability to perform a Battle Damage Assessment (Intel function and $$?)
- Ability to perform a collateral damage estimation
  - Allows engagement of targets on Restricted Target List?
  - Need to understand collateral effects on personnel
- Size, Weight, Power, and Cooling (SWaP-C) needs to be minimized
- Consideration of adversary employment of Countermeasures to DE

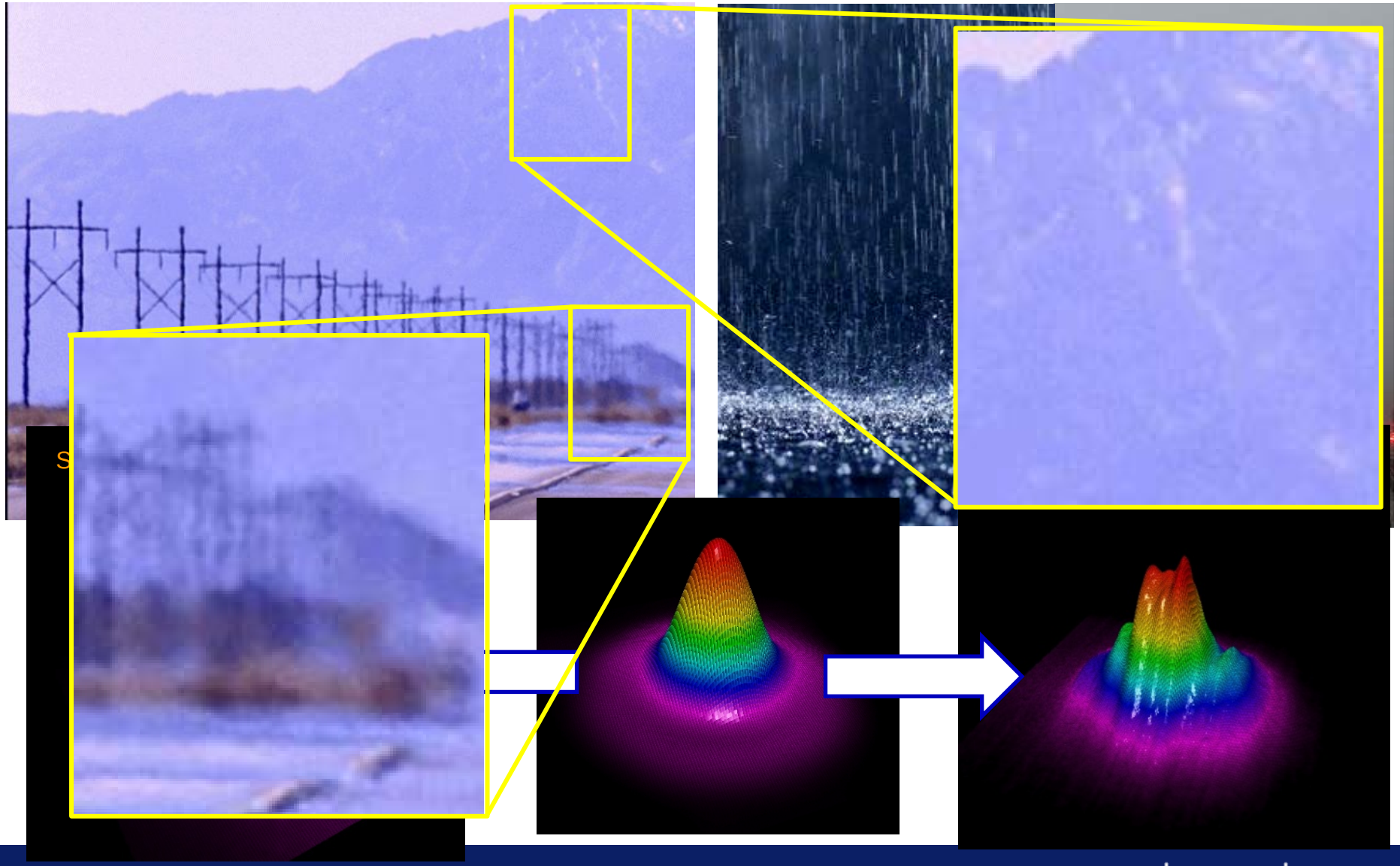
Atmospheric Effects

- How much power gets down range (i.e., transmission) is affected by the extinction due to atmospheric effects
  - Aerosols (soot, dust, etc.) and molecules (H2O, CO2 etc.) in the atmospheric can absorb and scatter the energy, thereby reducing the amount of power down range
- How well the power is focused down range is affected by turbulence (refractivity) in the atmosphere
  - Turbulence refracts the light rays off of the straight-line path
  - Refraction results in spreading of the power over of larger area therefore reducing the peak irradiance
  - Can typically be improved with Adaptive Optics





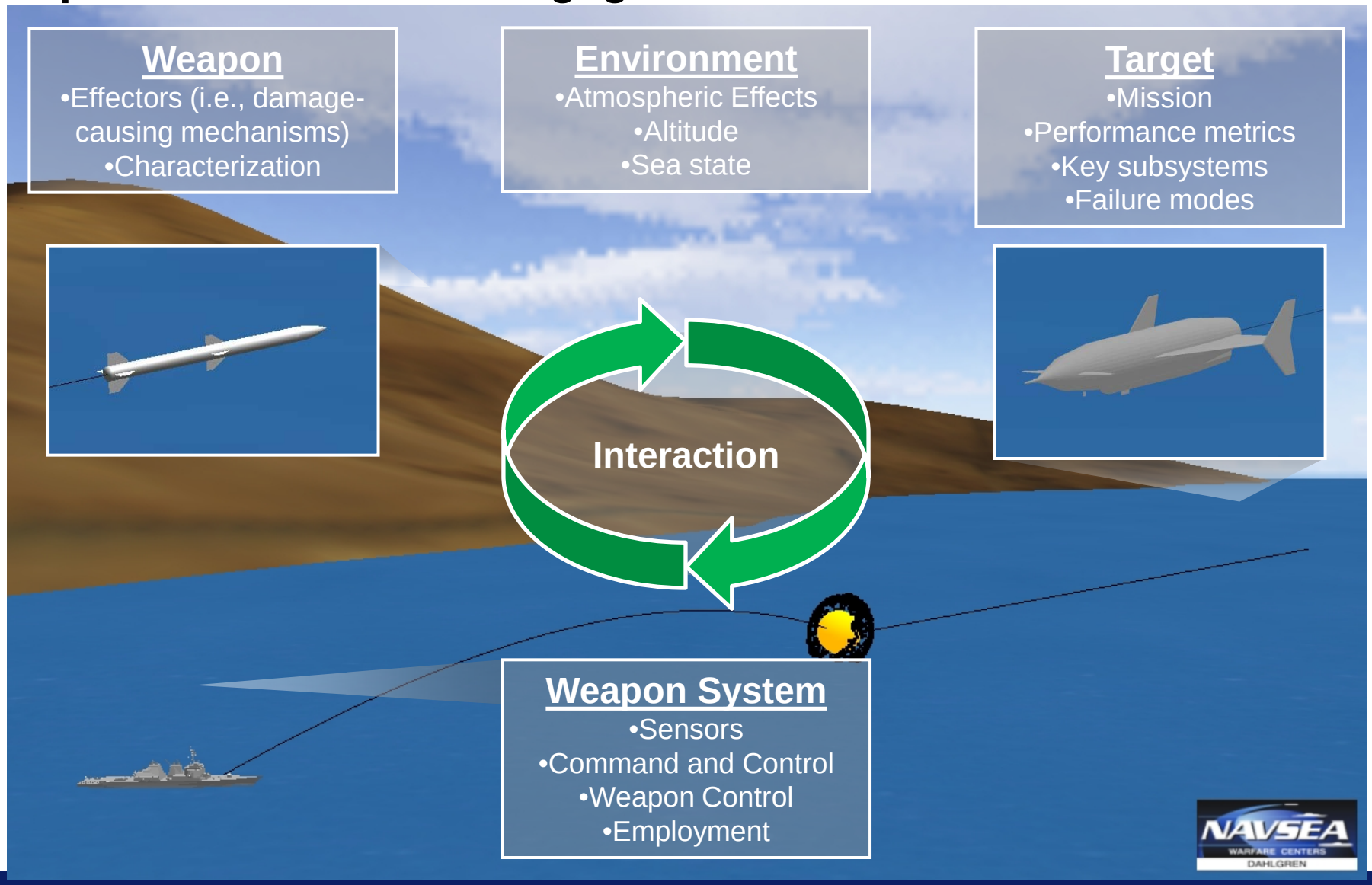
Atmospheric Effects on Power/Spot Size



Tactical Weather and Atmospheric Information

- The way that weather and atmospheric information will feed into the tactical firing solution has not been resolved
- The Predictive Approach:
  - Global Forecasting System (GFS) forecast data is available on the internet (coarse grid)
  - Navy Coupled Ocean/ Atmosphere Mesoscale Prediction System (COAMPS) can provide finer grid and more detailed aerosol forecast
- The In-Situ Approach:
  - Develop the capability to determine the atmospheric impact on the DE-capability effectiveness in real time
- Ultimately, it may require a combination of both approaches

Weapon Effects: Kinetic Engagement



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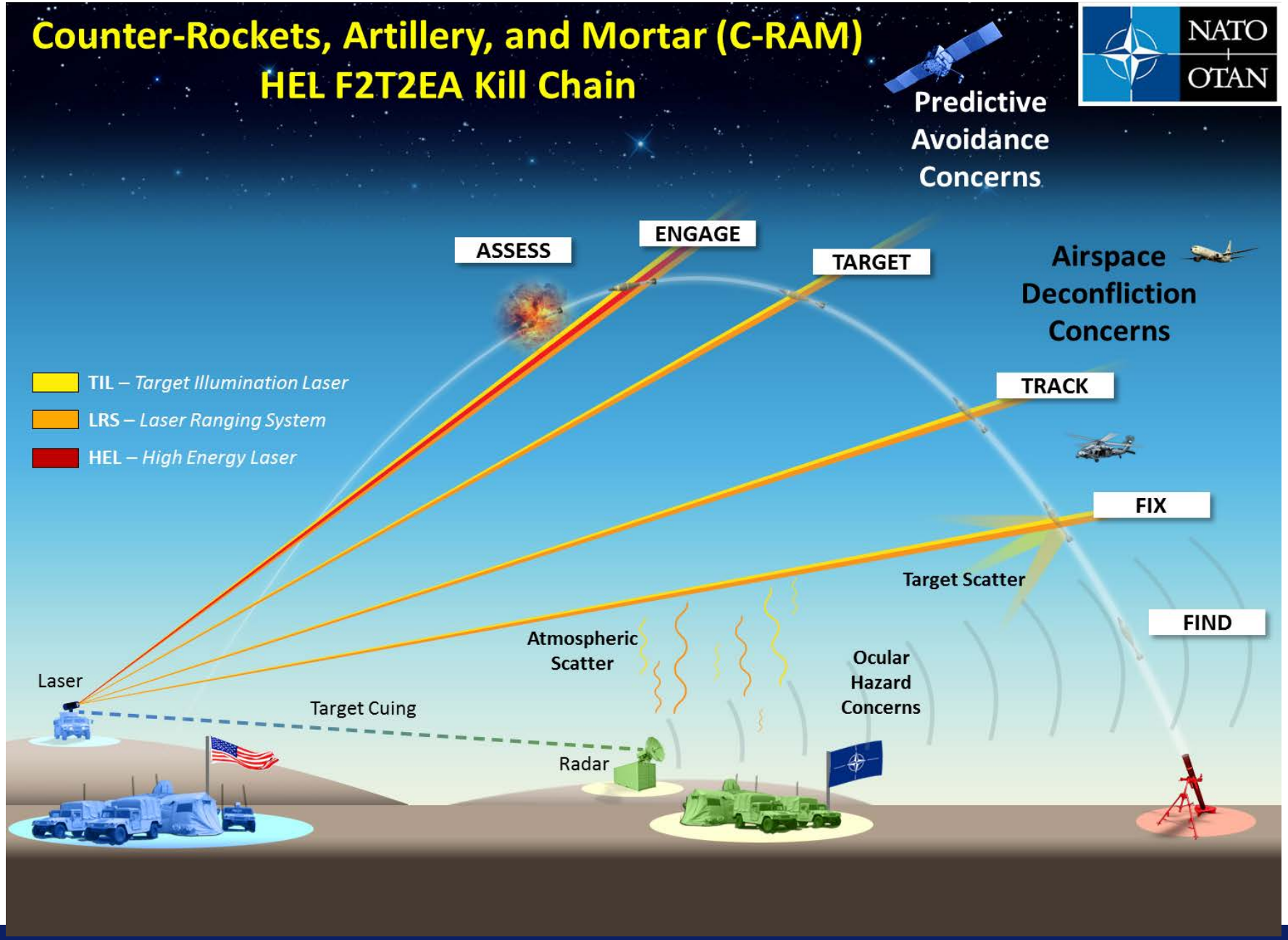
Lethality: KE vs. DE(HEL) Comparison

- Kinetic Energy Lethality:
  - We have centuries of experience and data evaluating KE lethality
  - Blast, Fragmentation, Hit-to-Kill effects are nearly instantaneous
  - Probability of Kill (P_k):

$$P_k = P_{Hit} \times P_{Damage/Hit} \times P_{Kill/Damage}$$

  - Above parameters are statistical, weapon system and weapon-target pairing dependent, complicated to determine, etc., HOWEVER, warfighters are comfortable with the answer (often found in JMEM), and use it for determining CONOPS for target engagements.
  - Example: Cruise Missile Defense
    - Missile P_k drives shot doctrine. Currently, shoot-shoot-look-shoot (S-S-L-S) puts Navy on the wrong side of the cost curve, particularly for the SM-6 missile ($4 M), vice the older SM-2 ($700k). The higher P_k of SM-6 may yield S-L-S, but still yields $8M per engagement.*

* http://cimsec.org/peeling-back-the-layers-a-new-concept-for-air-defense/15222

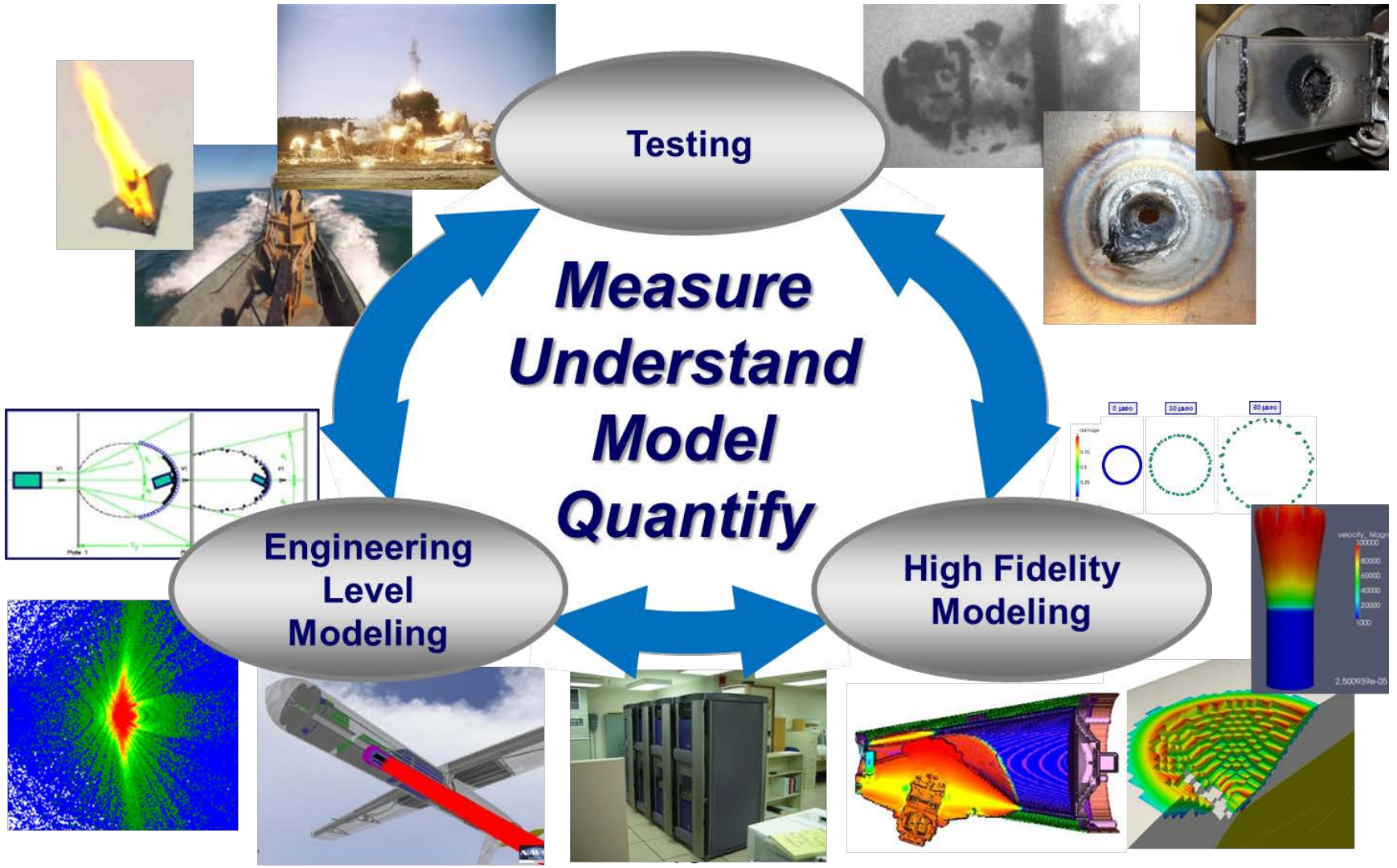

Counter-Rockets, Artillery, and Mortar (C-RAM)
HEL F2T2EA Kill Chain
NATO
OTAN
Predictive Avoidance Concerns
ASSESS
ENGAGE
TARGET
Airspace Deconfliction Concerns
TIL – Target Illumination Laser
LRS – Laser Ranging System
HEL – High Energy Laser
TRACK
FIX
Target Scatter
FIND
Atmospheric Scatter
Ocular Hazard Concerns
Laser
Target Cuing
Radar

Lethality: KE vs. DE(HEL) Comparison

- Directed Energy (HEL) Lethality:
  - Decades of disjointed experience and data evaluating DE lethality
  - Probability of HEL Kill (P`k) often considered a function of:
    1. Time (Not instantaneous)
    2. Fluence [J/cm^2] on Target
    3. Target Susceptibility
  - Operationally, Probability of HEL Kill (P`$_k$) is actually a function of:
    1. Time
    2. Propagation = *f* (turbulence, extinction, thermal blooming, etc.);
    3. Target Aimpoint Maintenance = *f* (susceptibility, selection, aspect angle=*f* (time), etc.);
    4. Range = *f* (time),
    5. HEL System Jitter, Power, Beam Quality, etc.
- To be operationally viable, complexity needs to be driven out of the kill chain, with most functions automated

A well-funded lethality program will build Warfighter confidence

Approach for Lethality Investigations



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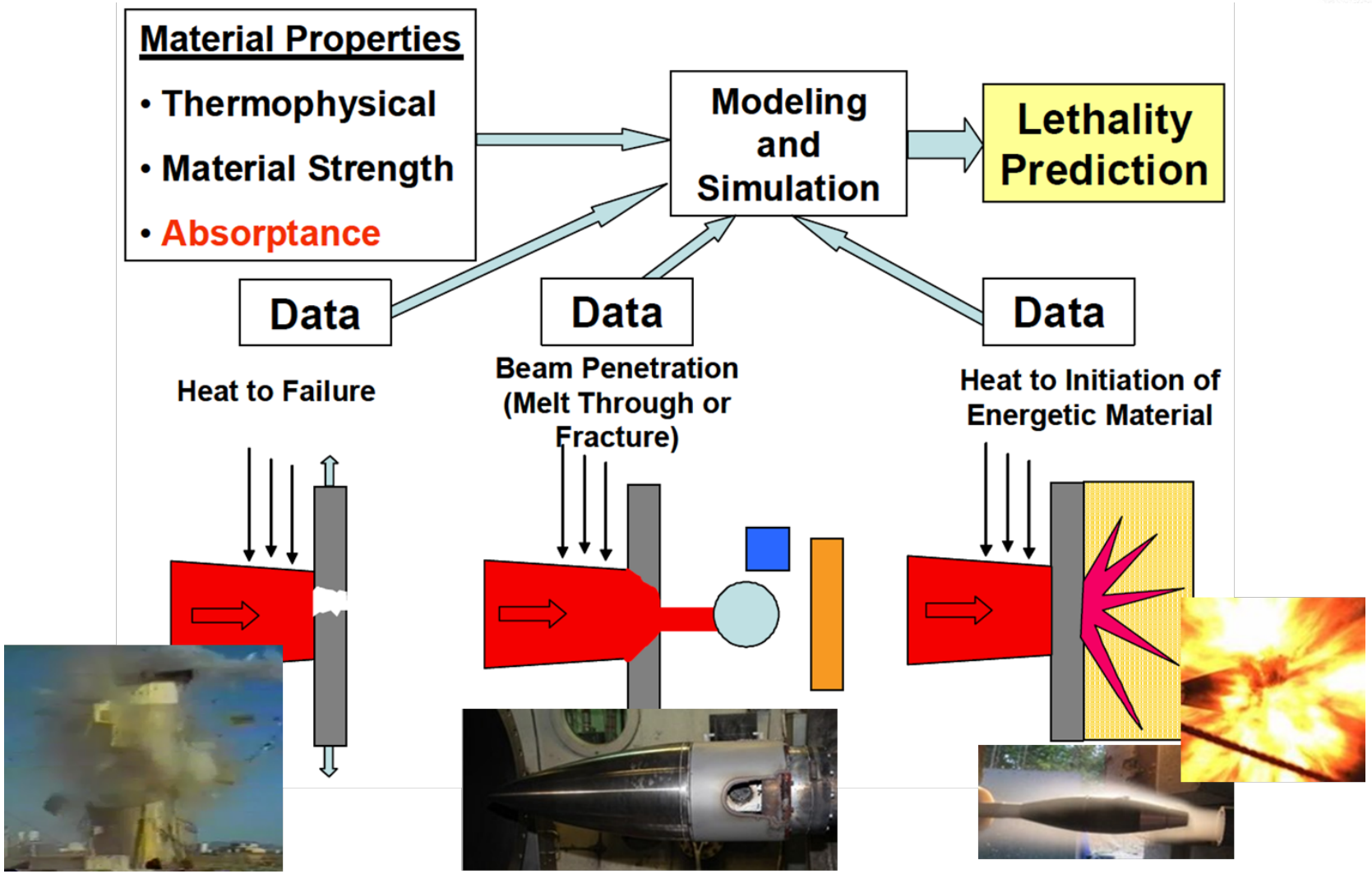
Laboratory HEL Lethality Testing



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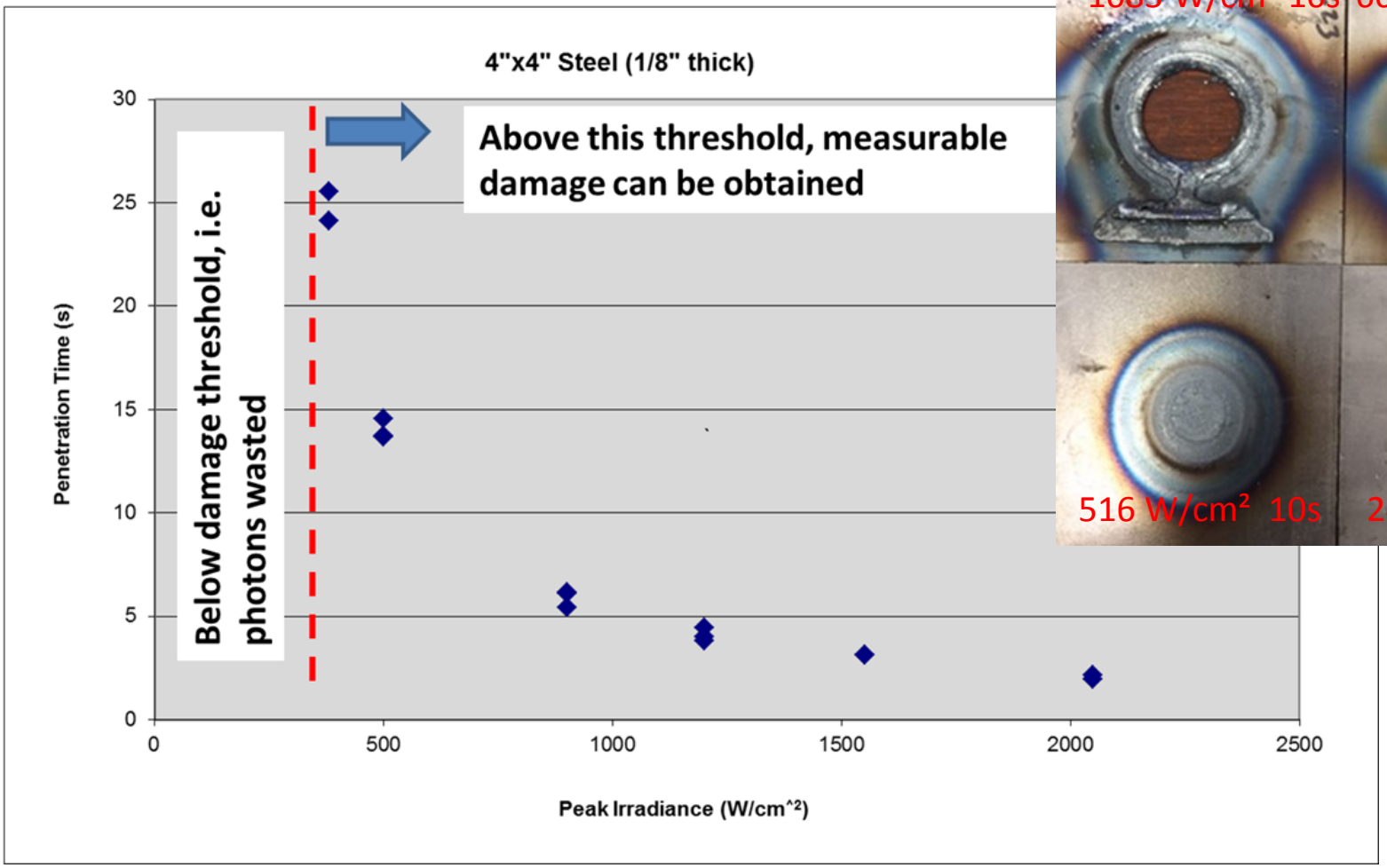
Material Irradiance Curve



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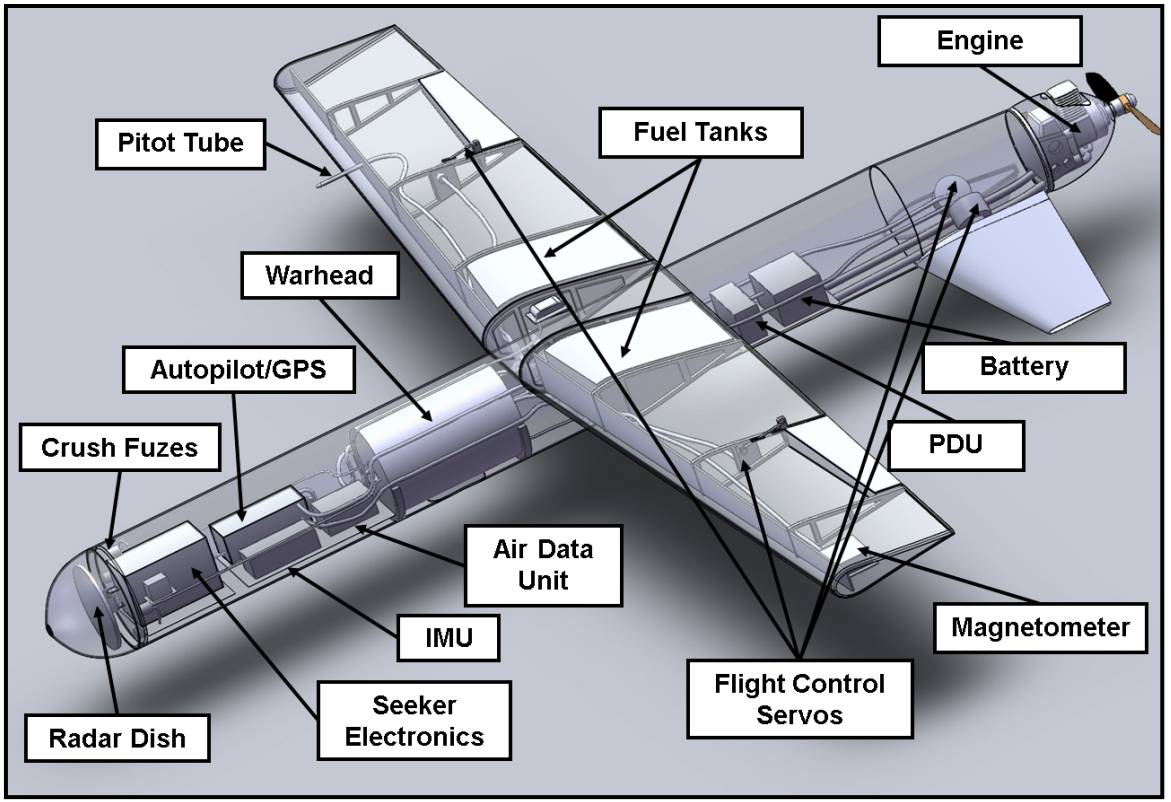
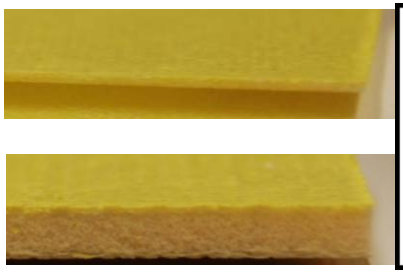
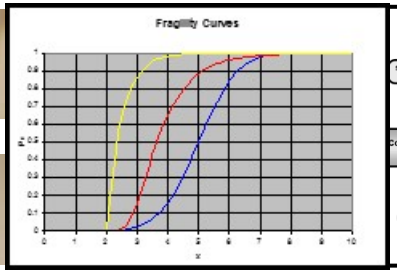
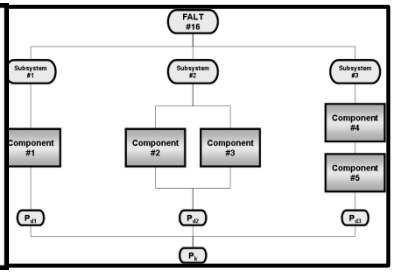
Target Vulnerability Characterization

- Work with intelligence agencies to understand target's mission/functions
- Work with program sponsors to understand the mission objectives of the DE or KE weapon
- Based on this understanding, a Failure Modes Effects Analysis (FMEA) is performed
- The result of the FMEA process is a target vulnerability characterization
  - Target geometry model
  - Component properties
  - Damage criteria
  - Failure Analysis Logic Tree (FALT)









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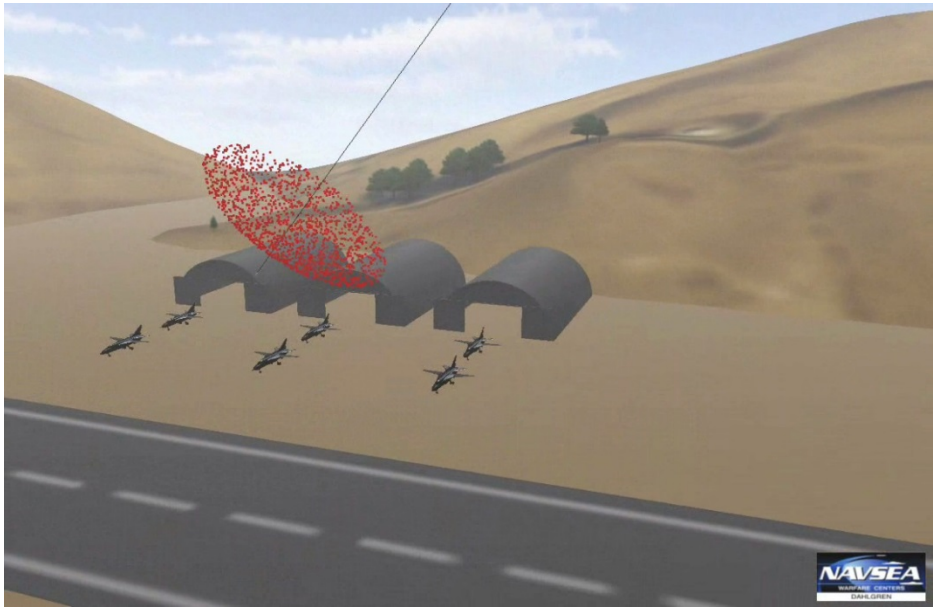
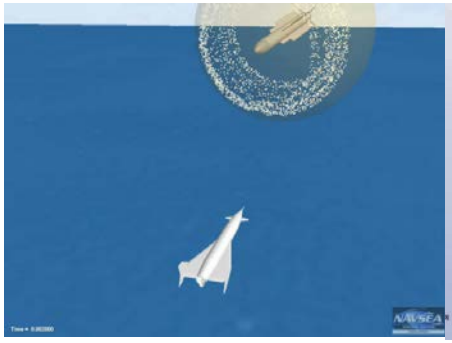
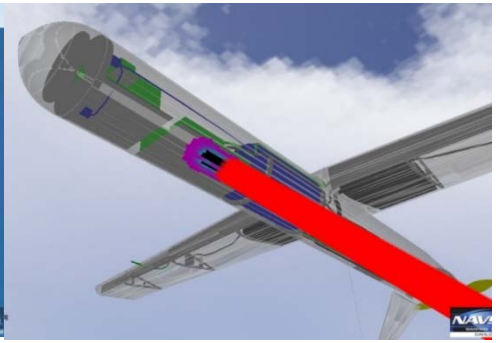
Effectiveness ToolBox (ETB) Introduction

- The Effectiveness ToolBox (ETB) is a scene-centric, time-based lethality / engagement-level model which provides a common framework for lethality and effectiveness analysis for various types of weapon systems
  - Missile systems
  - Indirect fire gun/missile systems
  - Direct fire gun systems
  - Directed energy systems
- VV&A
  - Accredited for use on ONR Railgun program (2009)
  - Accreditation underway for ONR SSL-TM program (2016)
  - Accreditation underway for AEGIS BMD Sea-Based Terminal program (2016)







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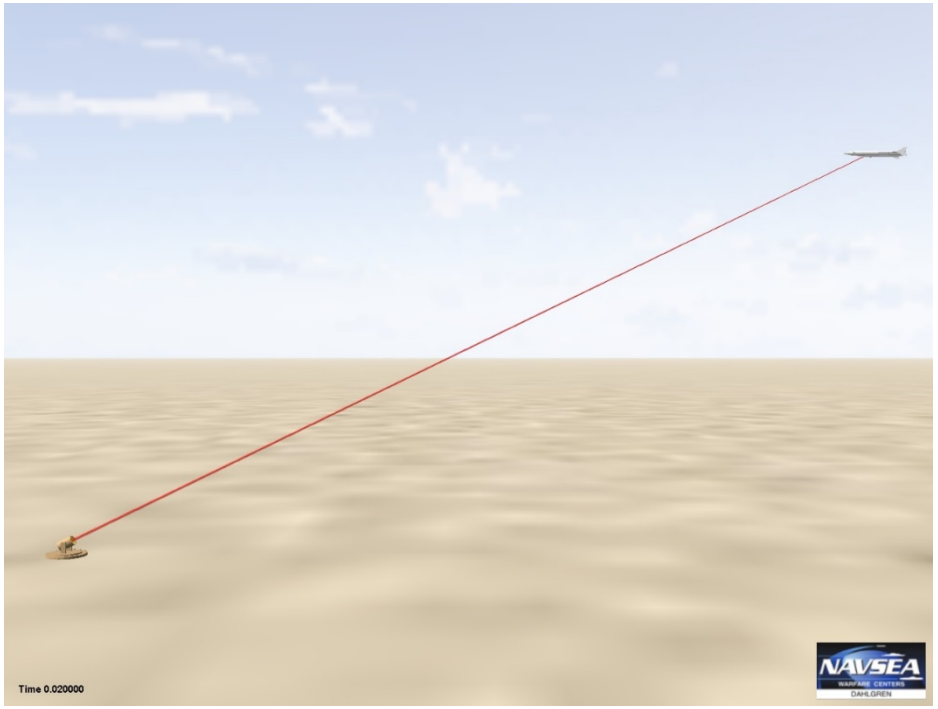
Laser Propagation

- ETB uses the High Energy Laser Consolidated Modeling and Engagement Simulation (HELCoMES) for laser propagation calculations
  - Sponsored by the HEL Joint Technology Office (JTO)
- HELCoMES calculates the propagation of a laser using scaling law techniques based on
  - Scenario type
  - Laser weapon parameters
  - Atmospheric properties
- At each time step, ETB calls HELCoMES based on the engagement geometry



HELCOMES
HIGH ENERGY LASER CONSOLIDATED MODELING & ENGAGEMENT SIMULATION

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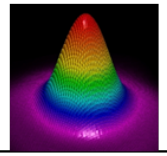
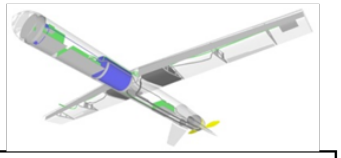
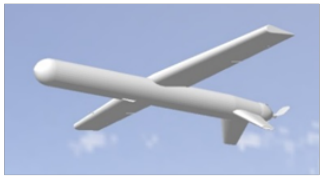
Navy Vulnerability-Module (VM) Approach



Beam Data
Peak Irradiance
Spot Size



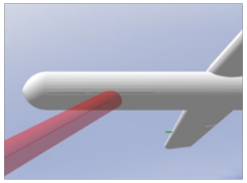
Target Data
Geometry Model
Component Properties
Damage Criteria
FALT



Atmospheric Data
Turbulence
Absorption / Scattering
Wind

Target Data
Position
Velocity
Orientation

Weapon Data
State
Laser
Characterization

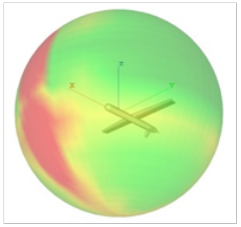


Encounter Data
Aimpoint
Azimuth / Elevation
Irradiance / Spot Size

Effectiveness ToolBox (ETB)

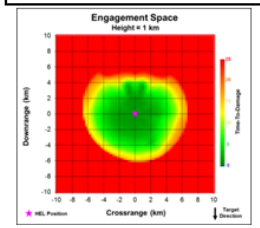
Vulnerability Module (VM)

Effectiveness ToolBox (ETB)



Vulnerability Data
Aimpoint
Azimuth / Elevation
Irradiance / Spot Size

Lethality Results
Time-to-Kill



Engagement Results

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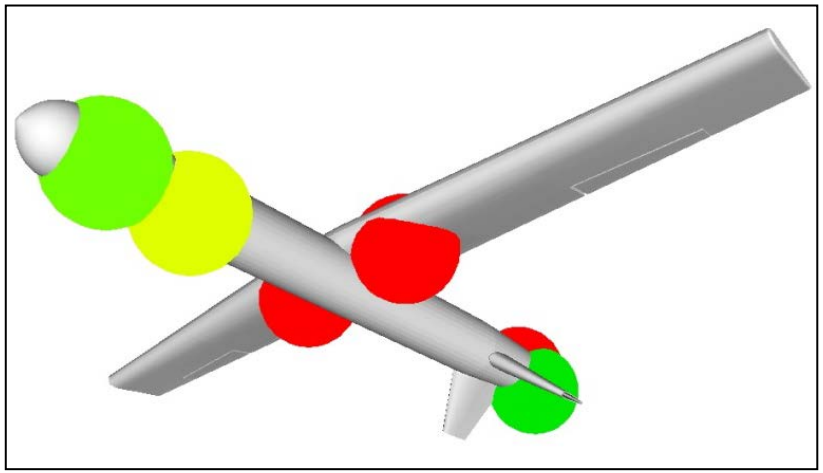
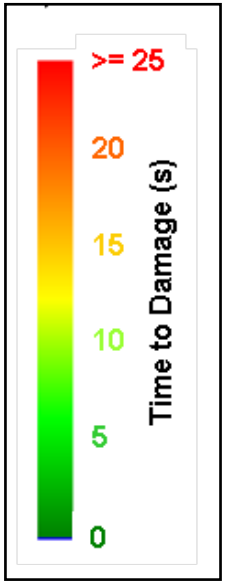
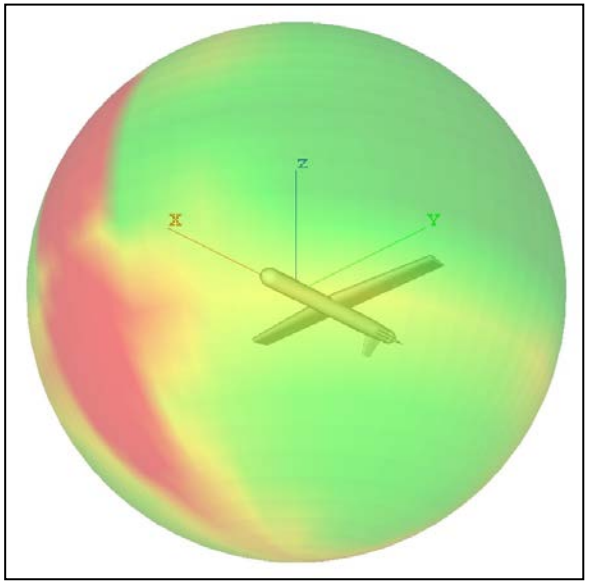
VMViewer

- VMViewer tool developed to assist analyst in understanding the data contained in a HEL Vulnerability Module (VM)
- Two modes:
  - Aimpoint Selection Mode: displays all aimpoints in the VM and their associated time-to-damage based on attack azimuth and elevation (camera view) and laser beam conditions (peak irradiance and spot size)
  - Aimpoint Data Mode: displays time-to-damage for all attack directions for a single aimpoint given laser beam conditions
- The color in the display indicates the time-to-damage







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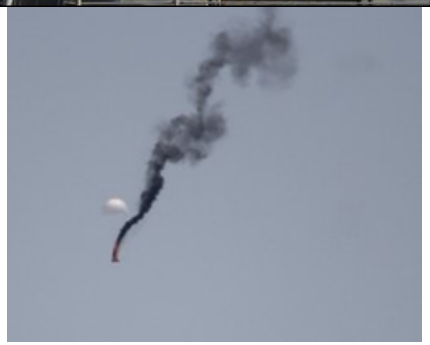
Recent Lethality Test Using LaWS



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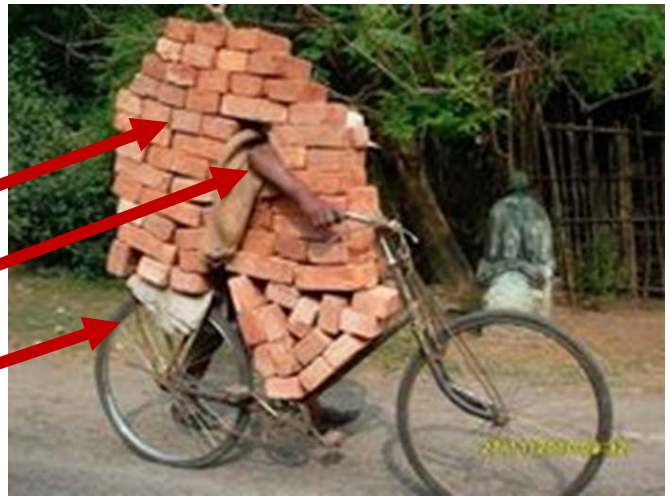
Tactical Targeting Decision Aids

- Directed-Energy (DE) (non-kinetic) capabilities will need to be integrated with conventional Kinetic-Energy (KE) weapons to meet commanders' objectives
- Tactical warfighters, targeteers, and weaponeers use the KE Joint Munitions Effectiveness Manual (JMEM) to determine the type and number of weapons to employ against a target
- Current status of the tools and effectiveness data that is needed to develop a DE JMEM is incomplete, but improving for HEL
- Need to move from a simulation environment into the tactical
- Current "Battle Staffs" are already heavily Tasked

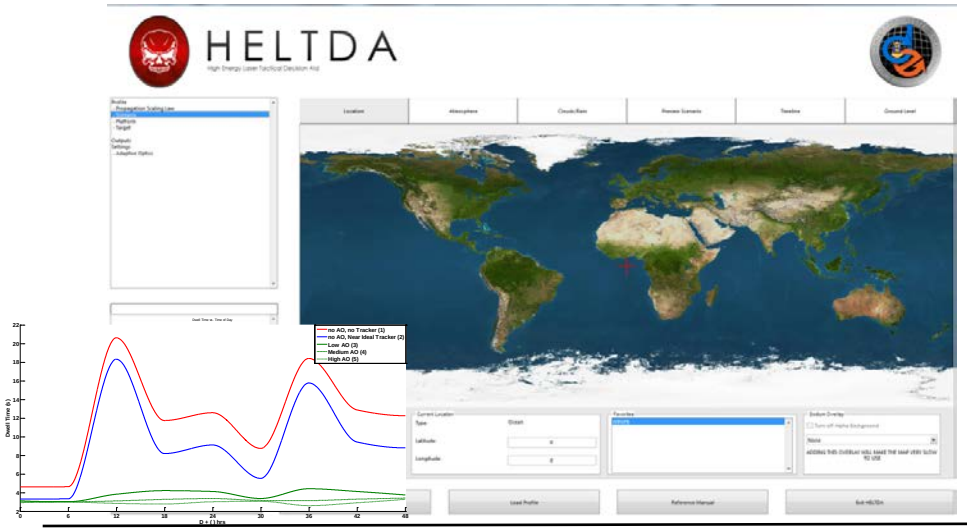
Near Full Capacity

- **Current Tasking**
- **Battle Staffs**
- **Support Infrastructure**



Must minimize additional workload!

High Energy Laser Tactical Decision Aid (HELTDA)



Description

Mission planning tool for joint command center, DE battery commander, fire / weapons control officer. "Wrapper" for HELEEOS / LEEDR engines to nowcast / forecast atm effects and predict DE performance for typical mission ops vignettes. Optimize DE order of battle near real-time, in any environment, anywhere on the globe. Extensible to DE fire control systems. (Beta)

Used For: Mission and Service field demo planning, post ops mission analysis, wargames

Limitations: Needs additional operator input and vetting; currently only accesses NOAA weather for gridded numerical data

DE Capability: Integrated

Level of Experience to make best use of: basic understanding of DE effects, employment and operations

POC: Dr. Steven Fiorino / **AFIT - CDE**

Distribution: Complete user agreement, access MZA repository via AFIT POC

Distribution Restrictions: Distribution C

Who is currently Using: All Services and limited industry

HELTDA Status

- HELTDA is the closest thing to a HEL JMEM tool in the community; however, further development required
- HELTDA currently only has a simple fluence calculation for lethality
  - NSWCDD developed VM Viewer and associated DLL, along with ETB under development
  - Desire for AFIT to integrate ETB to allow the development of a tactical decision aid
- HELTDA currently uses Global Forecasting System (GFS)
  - GFS forecast data is available on the internet (coarse grid)
  - Navy Coupled Ocean/ Atmosphere Mesoscale Prediction System (COAMPS) can provide finer grid and more detailed aerosol forecast
  - Ultimately, in-situ atmospheric characterization may be required
- HELTDA is built on High Energy Laser End to End Operational Simulation (HELEEOS) and The Laser Environmental Effects Definition and Reference (LEEDR)
  - Needs to run very fast if used for a fire control application

Still Does Not Provide Decision Aid for KE/DE Mix

Operational Readiness Level (ORL)

- Goes beyond the typical TRL, MRL, IRL construct to assess the viability for tactical employment
- Assess the state of maturity of the capability, matched to the host platform and mission, AND the ability to “tactically” answer the Operational Questions/Issues
- Should be used to help focus investment decisions on supporting operational capabilities that are beyond the DE weapon system
- A “Green” ORL means the DE capability is matched to the host platform, the mission, and the warfighter has all of the necessary tools for tactical employment

Operational Readiness Level (ORL)

MISSION	DE System	Operational Questions*						ORL
		Weather	Atmosphere	Lethality	Aimpoint	SWaP-C	Kill Assessment	
1. Aircraft Self-Protect	HEL X							
Manpads		2	2	3	3	2	2	2.33
Air-to-Air Missiles		3	3	2	3	1	3	2.50
Surface-to-Air Missiles		1	2	1	2	1	3	1.67
2. Ship Self Defense	HEL Y							
C-UAV Platform		2	2	3	2	3	3	2.50
C-UAV ISR		2	2	2	3	3	1	2.17
C-FIAC		2	1	2	3	2	3	2.17
C-Missile (Head On)		1	1	1	3	1	3	1.67
C-Missile (Side Shot)		2	1	3	2	2	3	2.17
3. Ship Self Defense	HPRF Z							
C-UAV Platform		3	3	2	3	2	3	2.67
C-FIAC		3	3	2	3	3	3	2.83
C-Missile		2	3	1	3	1	2	2.00

* All values are for demonstration purposes only.

Wrap-Up

- “Tactical” weaponeering tools that are of practical use to the mission planners and warfighters are REQUIRED
- Increased funding required for DE JMEM development to build on successful previous endeavors
- Increase to HEL-JTO budget required to focus on answering “Operational Questions” (beyond the scope/responsibility of individual programs)
- Require DoD-Level Program Office to answer HPRF “Operational Questions” (primarily a weapons effectiveness/kill assessment thrust)
- Need to develop a framework to address coalition-force employment of DE weapons, and all interoperability issues for employment
- Need to address DE countermeasures as potential adversaries continue to develop DE capabilities