
VESTIBULAR
TRACK
INTENSITY
EXPERIMENTAL
IONIZED
FLUORIDE
WEAPONRY
PARABOLIC
RAY
THEORETICALLY
DEVELOPMENT
EFFECT
CLOUD
SUPERCONDUCTORS
SPEED
AIR
ENEMY
COHERENT
OSCILLATOR
ABSORPTION
SENTRIES
POWERFUL
HIGH
PROJECTILE
ORGAN
ABLATION
WAVE
SHUTTLE
DIRECTED-ENERGY
SHOCKWAVES
SOUND
ENCEPHALOPATHY
SEARCHLIGHT
DEATH
MIRROR
DENOTATION
ENERGY
SHOCKWAVE
FICTION
SOLDIER
OPTICAL
MISSILE
NUCLEI
WEAPON
VACUUM
MOUNT
ELECTROMAGNETIC
EXPOSURE
NEUROPHYSIOLOGICAL
LIGHT
YD
RESEARCH
UNSHIELDED
MILITARY
LETHAL
GAS
DEVELOPED
INFRARED
WAVES
ARTILLERY
HUMAN
HYDROGEN
MASER
SPACE
UNDIRECTED
ELECTRIC
LASER
RADIATION
SPECULAR
REFLECTORS
BLOOMING
BEAM
AIRCRAFT
COOLING
SYSTEM
AIM
MAGNITUDES
BALLISTIC
ORIFICES
SONIC
MICROWAVE
WEAPON
PLASMA
FREQUENCY
AMPLIFICATION
DAMAGE

1

NAVAL
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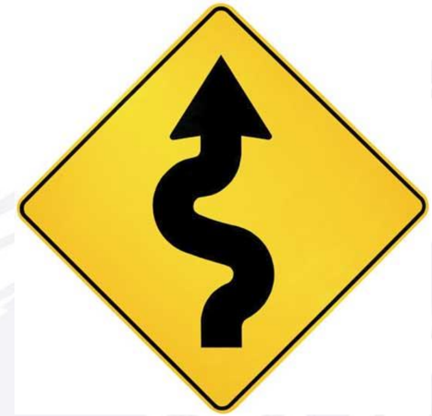
SCHOOL

Directed Energy Weapons

SEA-19B Capstone
Final Progress Review
June 06 2013

Roadmap



- Team & Organization
- Tasking & Scope Summary
- Historical Overview
- SE Process
- ➢ Modeling and Simulation
  - Method, results, and findings
- Cost Estimation
- Integration, Sustainment, Training, and Manning
- Selected Technologies Summary & Overview
- AoA
- Conclusion and Future Recommendations

Bottom Line Up Front

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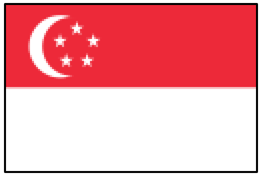
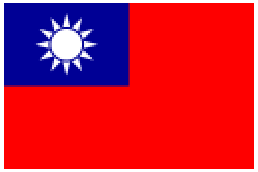
Bottom Line Up Front

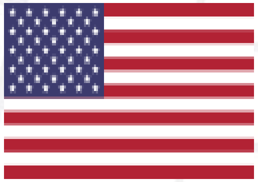
- DEW can and will be "game changing," just not in the next 4 years
- Current DEW tech levels inadequate for "one for one" weapon replacement
- Aggregate estimate for shipboard fuel cost associated with a DEW shot is less than $1
    - Compare to $800K to $3.6M AD interceptors
- Tactical Laser System (TLS) currently offers the best "bang for the buck"
- Active Denial System (ADS) has potential to fill unique capability gap for Anti-Terrorism and Force Protection
- Both TLS and ADS are significantly cheaper than other alternatives of comparable performance

Systems Engineering Team

- 23 Total Personnel
  - 6 US Navy Surface Warfare Officers
  - 1 US Army Officer
  - 1 Taiwanese Air Force Officer
  - 1 Israeli Army Officer
  - 14 Singapore military / DOD / Industry Reps







Tasking Statement

Design a family of systems or a system of systems of Directed Energy Weapons (DEW) that can be integrated with manned and unmanned forces to address a broad spectrum of missions commensurate with the needs of the U.S. Navy. Consider current fleet structure and funded programs as the baseline system of systems to conduct current missions. Develop the concept(s) of operations for the range of current and future missions that incorporate DEW, then develop alternative fleet architectures for 8 platforms, ships, manning, command and control, communications, logistics, and operational procedures to advantage DEW capabilities. Consider the potential technology gaps for both DEW and integrating DEW into Naval forces; determine a more streamlined architecture for the combined DEW – Navy forces; and identify and characterize the “gap” fillers. Iterate the task, as approved by your primary faculty advisor. Produce a coherent vision of U.S. Navy missions that incorporate DEW; identify the requirements for support and collaboration with coalition forces; and discuss the interoperability issues with these collaborative efforts. Provide a roadmap of DEW to improve the effectiveness for future Navy ships.

Tasking Statement

- Address a broad spectrum of missions commensurate with the needs of the U.S. Navy
- Consider current fleet structure and funded programs
- Consider the potential technology gaps for both DEW and integrating DEW into current and future Naval forces
- Identify and characterize the gap fillers
- Produce a coherent vision of U.S. Navy missions that incorporate DEW
- Provide a roadmap of DEW to improve the effectiveness for future Navy ships

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What is the problem?

Path to Solvency

- We recognize that shipboard weapon systems are about tradeoffs; provide equal capability or better
- Just because it works does not mean it’s useful
- We recognize the value of federal dollars already spent

DECISION
CALCULUS

✓COMPARATIVE ADVANTAGE
✓ADDED VALUE TO WARFARE COMMANDER
✓RETURN ON INVESTMENT

Within the Scope

- We will only consider DEW technologies that currently have an operationally tested prototype
- DEW must have the ability to comply with the following timeline:
  - 12 months to development of concept of operations
  - 24 months to the demonstration of operational utility
  - 36 months to initial operational capability
  - 48 months to validation of operational capability
- Consider integration with DDG-51
- Consider prototypes that are US developed
- Focus on defensive capabilities

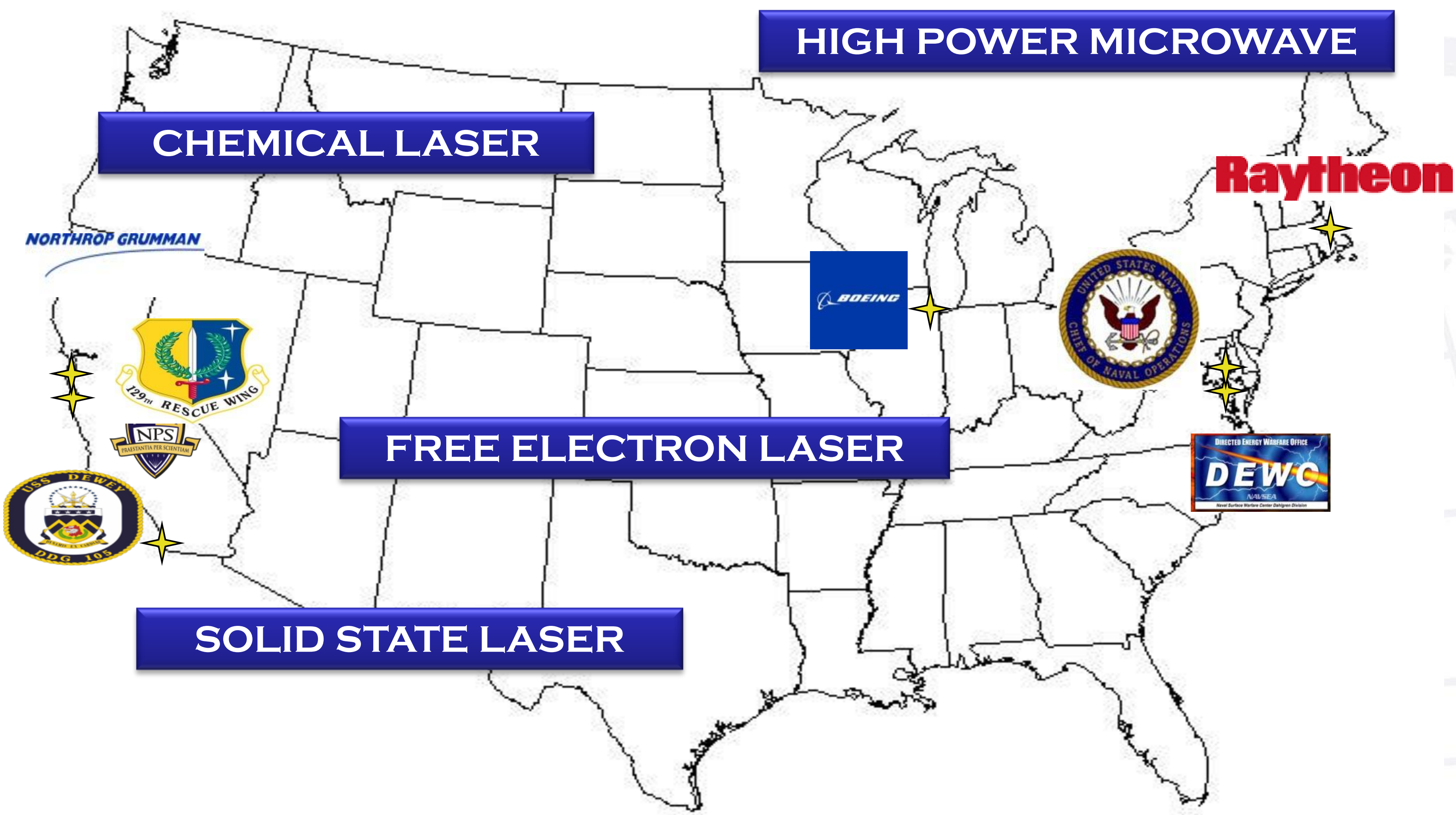
Outside the Scope

- Focus is on “Beams” not “Bombs”
- Space-based weapons
- Not looking to provide “strike” capability
- Not evaluating technologies whose purpose is to provide Ballistic Missile Defense (BMD) capability
- Not considering DEW technologies designed to be deployed on airborne platforms
- Technologies whose primary purpose is to cause unnecessary suffering or superfluous injury
- Politics surrounding the use and employment

Stakeholders

NPS and N9I are the two project stakeholders.

Potential Sources of Information

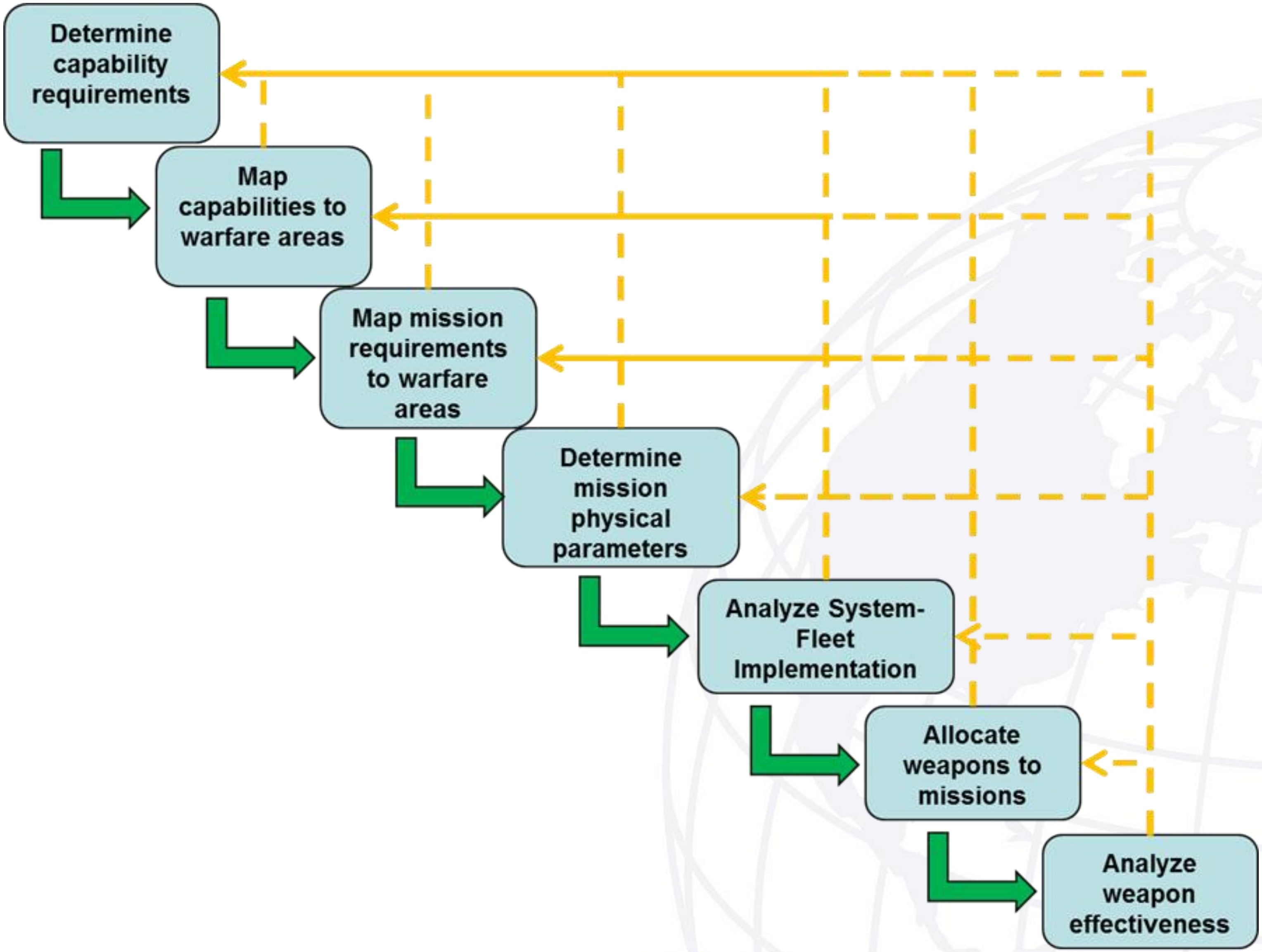


Respective company trademarks

DEW Research History

- Archimedes “death ray” (circa 200 B.C.) used against invading Roman fleet
- Nikola Tesla’s work on high frequency technologies (circa early 1900s)
- WWII German experiments (circa 1940s)
  - Proved you can make people physically sick with DEW (induce nausea and vertigo)
- Reagan’s Strategic Defense Initiative (circa 1980s)
- DEWs subject of study at NPS (circa “recent”)
  - Funded studies by professors
  - Student Capstone Project; student thesis

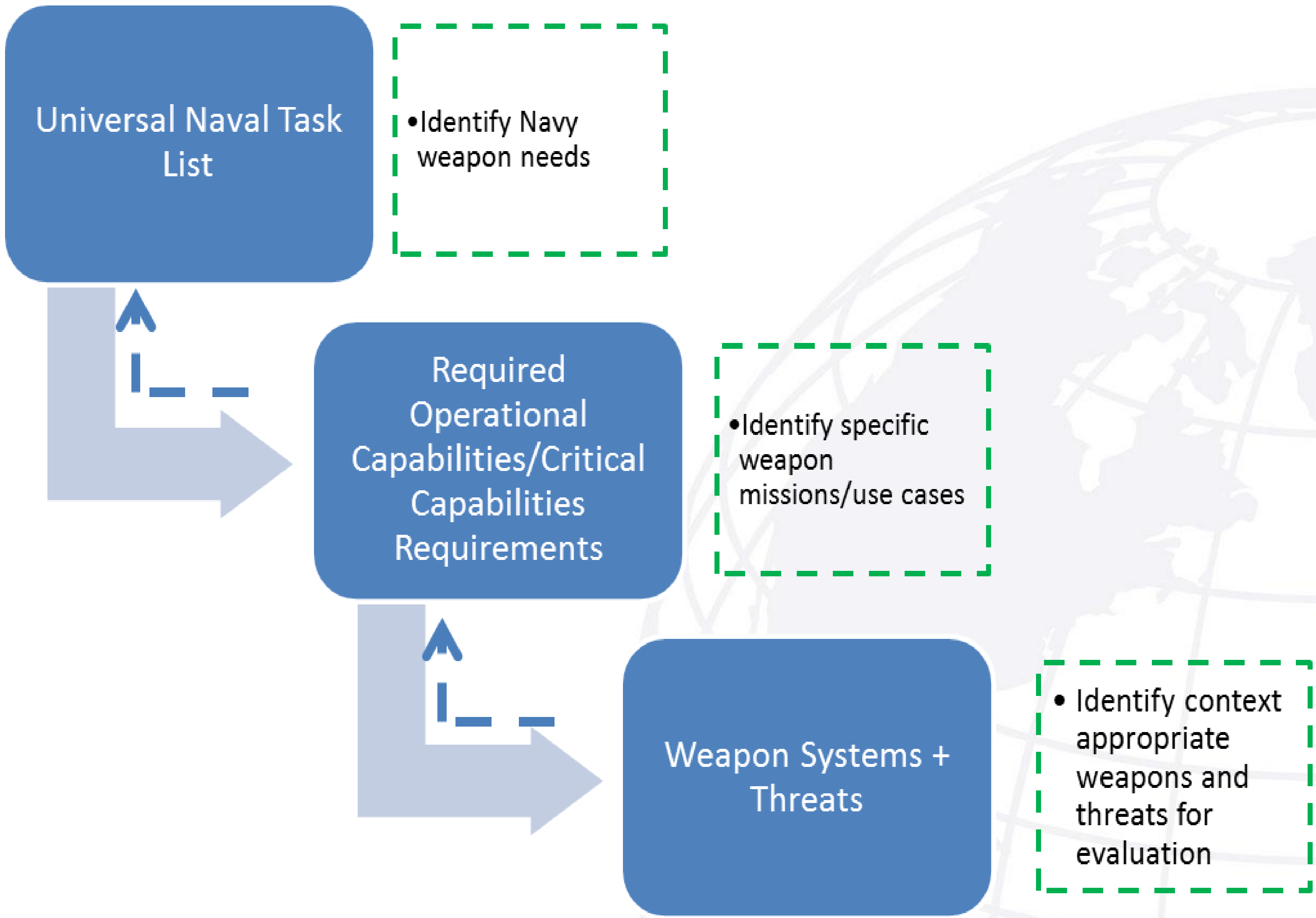
Tailored SE Process



Fractured View of Need/Mission/Weapon Integration

Warfare Area & Capability Needs	Mission Definitions	Mission Objects
UJTL	ROC	Threats
UNTL	CCR	Weapons

Needs/Mission/Weapon Mapping Method



High Power Microwave (HPM) Weapons

- What are they
  - Weapons designed to exploit parts of the electromagnetic spectrum in order to neutralize targets
- How do they work
  - HPM weapons transmit high amounts of energy via concentrated radio waves which can be used to disrupt electronic equipment and produce devastating biological effects in the use of crowd control
- Origin
  - Development began nearly 50 years ago in the technology race between East and West
- Where are we now
  - Active Denial System is the only U.S. HPM weapon with a viable, operationally tested, prototype

Active Denial System

(www.globalsecurity.com)

- ADS is a non-lethal counter-personnel directed energy weapon
- Millimeter waves penetrate up to 1/64 of an inch into skin quickly heating it up
- Burning sensation stops when target moves out of the way of beam or when the system is turned off
- Low potential for burns produced due to low levels of energy used and shallow penetration
- Deployed to Afghanistan in 2010; however, not used for political reasons

Solid State Lasers

- What are they
  - A laser that uses a gain medium that is a solid (opposed to a liquid such as in dye lasers, or a gas as in gas lasers)
- How do they work
  - Energy is pumped into a solid gain medium of rare earth elements exciting ions and producing more energy that is focused by glass or crystalline (lens) onto the target
- Origin
  - First SSL was invented in 1960
- Where are we now?
  - Several viable options available including the LaWS which will be installed on the USS Ponce in FY 2014

Laser Weapon System (LaWS)

(www.popsci.com)

- Technical Maturity: TRL 6
- Working on ASCM capability
  -Not demonstrated yet
- NAVSEA 05 Tentative Green Light
- 33 - 150 KW technically acceptable to be fitted onto DDG-51
  -All blueprints and technical drawings exist

Maritime Laser Demonstration (MLD)

(www.ndu.edu)

- Built by: Northrup Grumman
- Tech Maturity: TRL 6
- Testing Completed: April 2012
  - Tracking and setting on fire multiple, small, unmanned boat targets
- Description:
  - Mounted on Spruance-class destroyer
  - Using only ship's existing electricity
  - Integrated with ship's radar and navigation system
  - Actual maritime conditions: 8-ft waves, 25kt winds, rain & fog

Tactical Laser System (TLS)

(www.nosint.blogspot.com)

- Built by: BAE and Boeing
- Tech Maturity: TRL 7
- Testing Completed: December 2012
  - Successful engagements at thousands of meters
  - Has engaged targets over land and water
- Description:
  - High energy laser system attached to Mk 38 naval gun systems currently deployed on most surface combatants

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DEW Assumptions and Summary

System	Power	Wavelength/ Frequency	Aperture Diameter/ Area	Gaussian Waist Factor/ Antenna Constant	Antenna Efficiency
ADS	100kW	3155.7 µm	4.772 m^2	4/π	0.8
LaWS	33kW	1.064 µm	0.66 m	6.5	N/A
LaWS+	150kW	1.064 µm	0.66 m	6.5	N/A
MLD	105kW	1.064 µm	0.49 m	6.5	N/A
TLS	10kW	1.6 µm	0.3 m	6.5	N/A

Modeling and Simulation

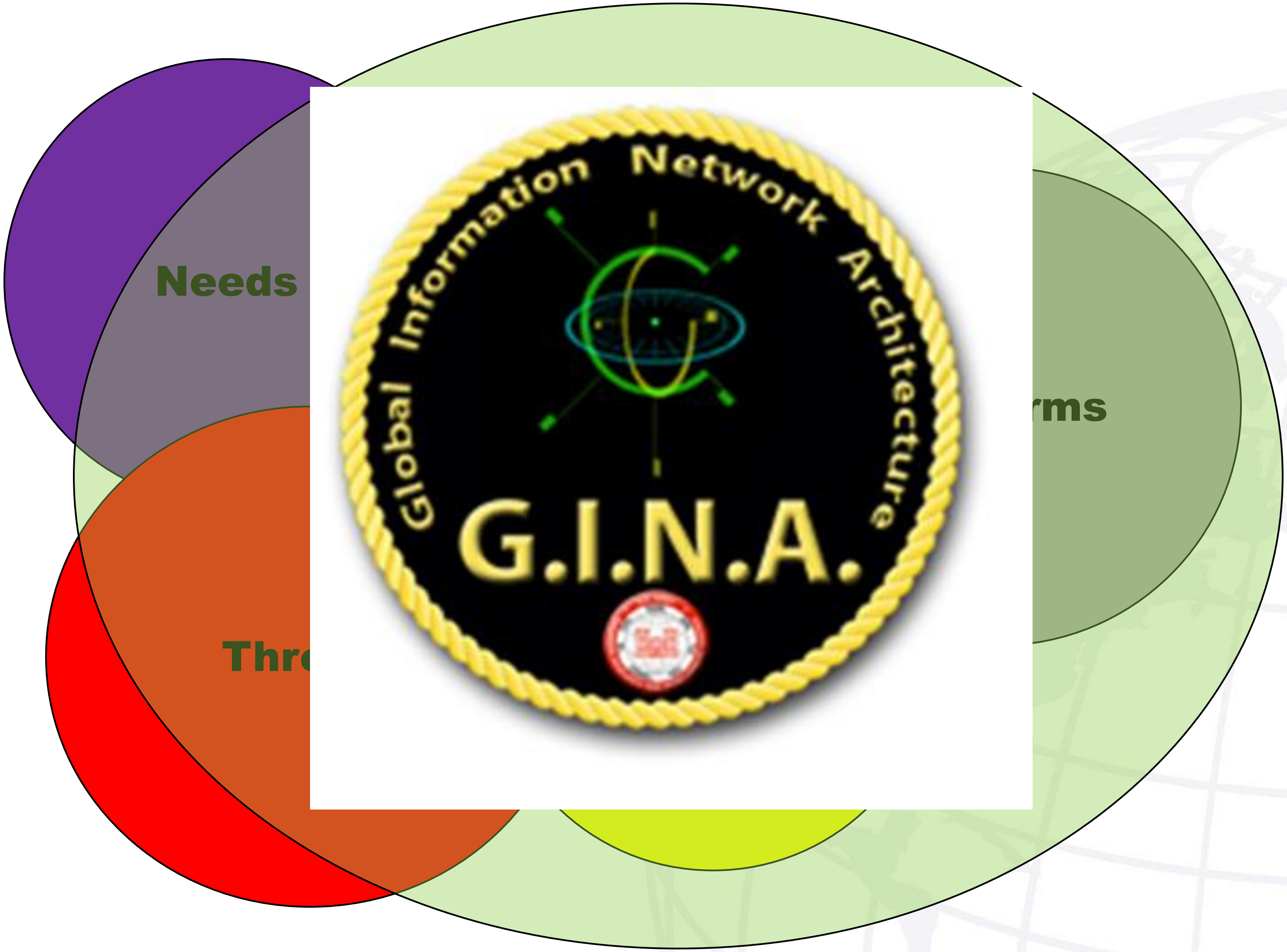
Essential Elements of Analysis

- How well do DEWs address an entire warfare area?
- What missions or set of missions is most appropriate for a DEW?
- What threat or set of threats is most vulnerable to a DEW engagement?
- How can DEWs be used in a unique or augmenting capacity?
- How do DEWs perform as compared to conventional weapons?

DEW Performance Metrics

- GINA Modeling Metrics
  - Warfare area missions success percentage
  - Mean range of first Type I Engagement, given success
  - Mean Range first Type II Engagement, given success
  - Number of threats with more with Type I Engagements than a conventional weapon
  - Is DEW's maximum range of first Type I Engagement greater than that of a convectional weapon?
  - Is the DEW non-lethal capable?
- Simulation Metrics
  - Percentage of scenarios with zero leakers
  - Best combination of weapons for maximum survivability

Problem Space Contexts

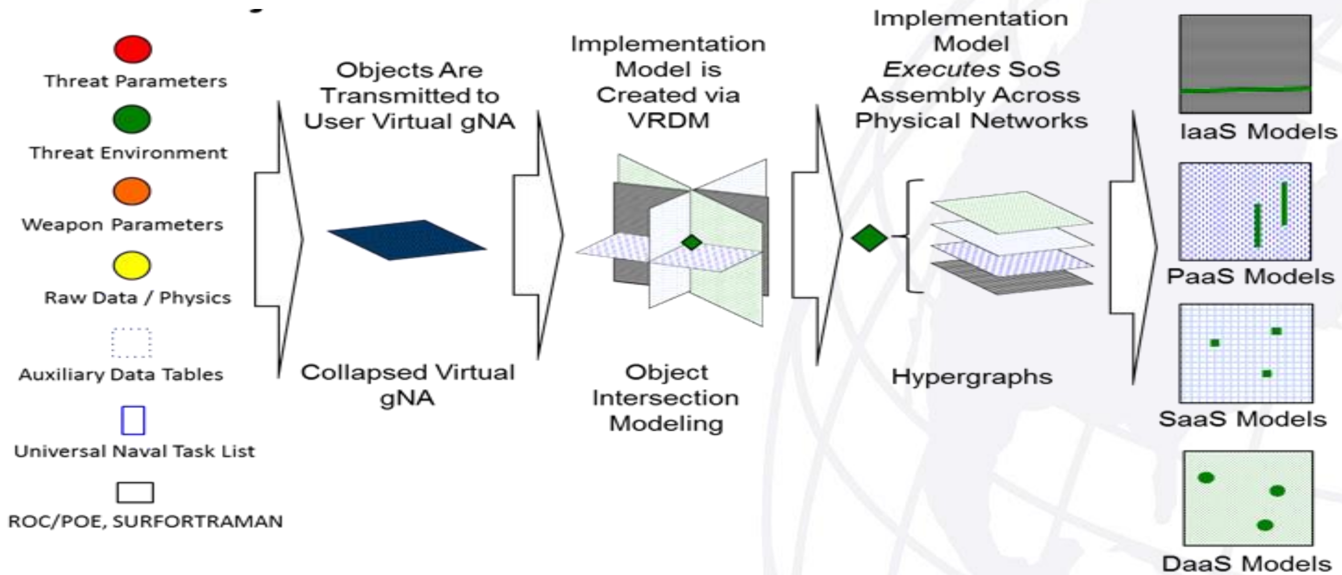


Global Information Network Architecture

- "A configurable interoperable network information object modeling environment for configuring and implementing an executable description of system of systems behavior with applications across the IT domain space"
- Developed under a collaborative research agreement by NPS and the US Army Corps of Engineers with Big Kahuna Technologies LLC
- Technical Support: Dr. Tom Anderson, USACE ERDC (TRAC Monterey) and Mr. Frank Busalacchi, Chief Technology Officer, Big Kahuna Technologies LLC

Why GINA?

Raw Data → X-Type With Metadata → Specific, Navigable X-Type Instance → Coherent GINA model → Query Outputs



GINA provides a fully customizable architecture for implementing "Supermetadata"

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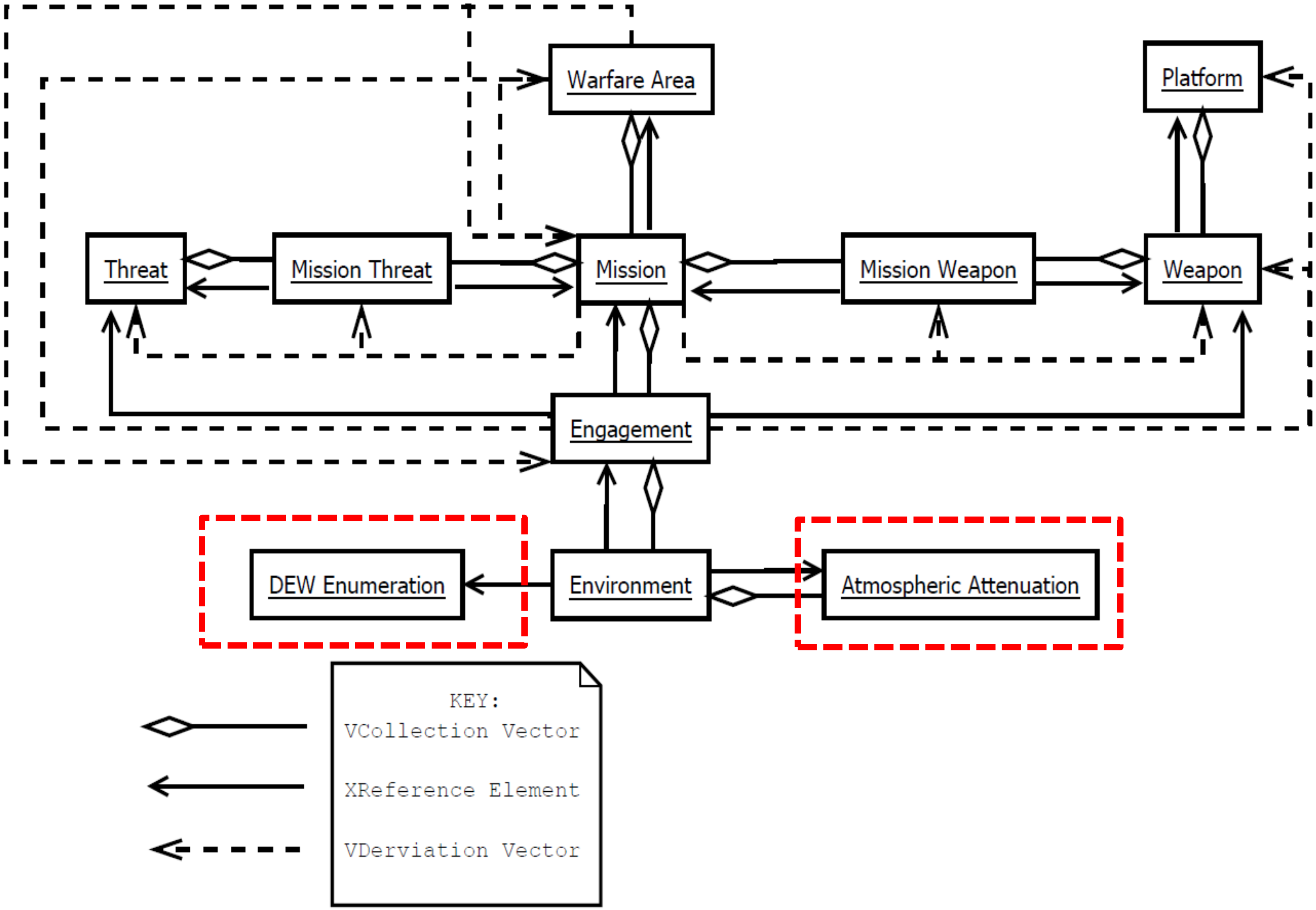
GINA Model Architecture



Under the Hood of GINA

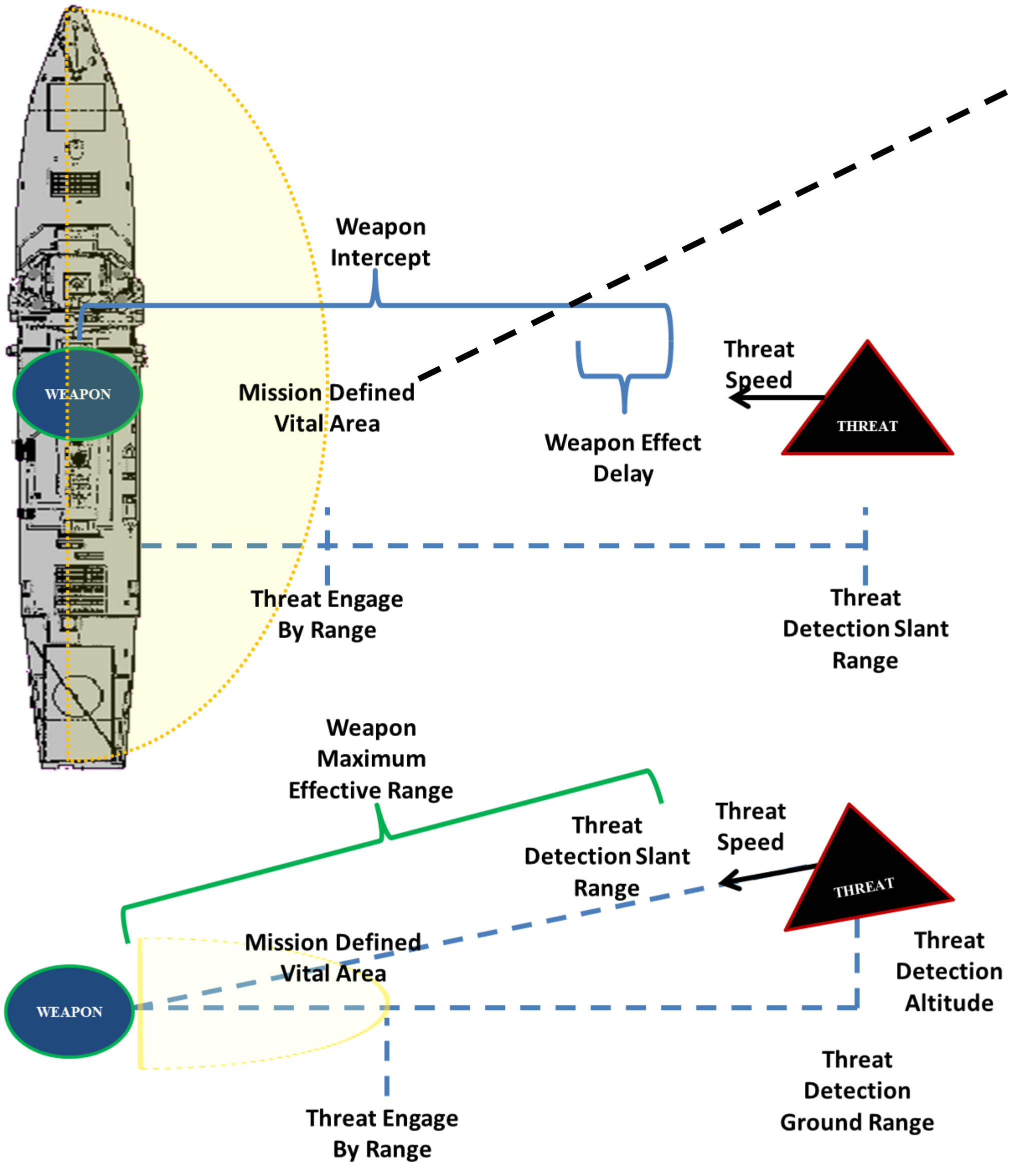
- 3 mathematical models implemented in VB.NET
- MODTRAN 5 Radiative Transfer Model
  - C# Class Wrapper for MODTRAN integration
- Custom GINA Content Manager to execute mathematical models and run MODTRAN from GINA
- Result:
  - A semantically-driven framework that allows a direct comparison of DEWs to conventional weapons in the context of a mission, warfare area, weapon platform, threat, and environment

Modeling Taxonomy

- What does it mean to model DEW performance?
  - Current combat models do not accurately address DEWs
- Required unique definitions of engagement end-state:

	Type I Engagement	Type II Engagement
LASER	Burn though threat armor	Threat armor failure under stress due to structural weakening
Microwave	Probability of death from exposure > 1%	Exposure causes the pain threshold to be reached
Conventional	Ability to intercept a threat	Not applicable

Modeled Engagement Diagram



Mission ID	VA Radius (m)
ATFP 12	50
ATFP 15	100
ATFP 4	200
ATFP 8	100
ATFP 9	500
AW 1.1	5000
AW 1.12	500
AW 1.13	5000
AW 1.2	500
AW 1.4	1000
AW 1.5	3000
AW 1.6	3000
AW 9.1	1000
AW 9.3	500
AW 9.4	1000
NCO 19.6	200
NCO 19.9	200
SUW 1.10	100
SUW 2.3	1000

Modeling HPM Performance in GINA

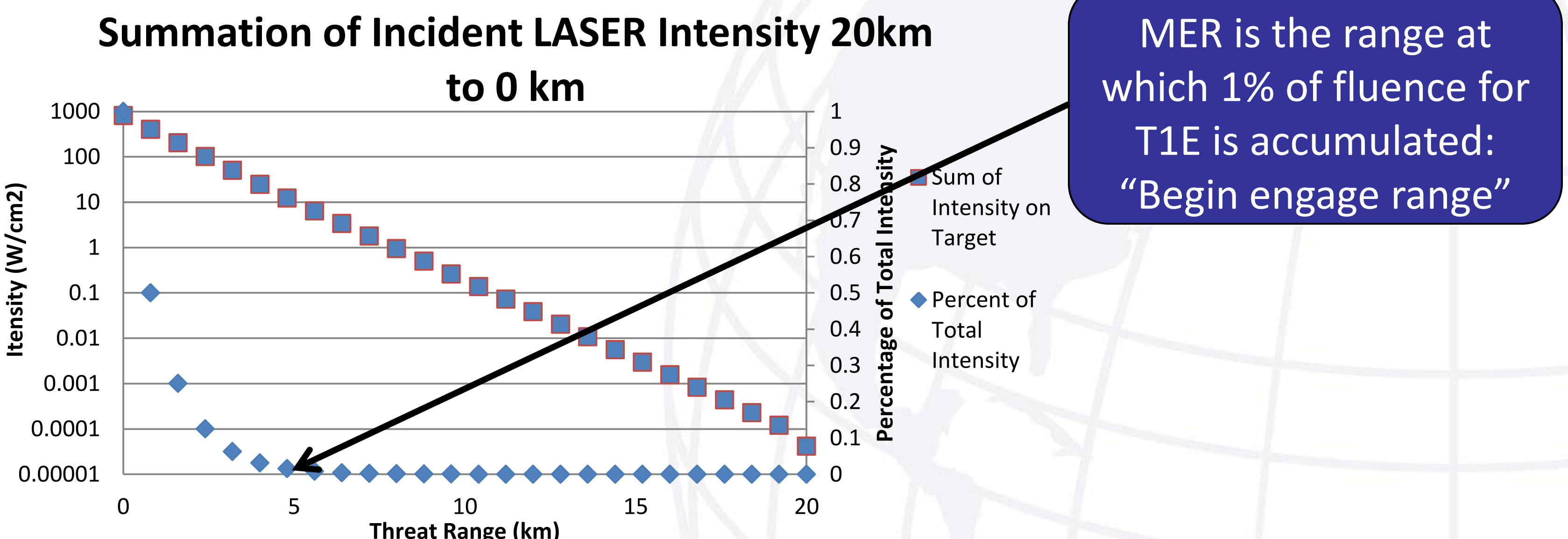
Model Parameter	Inputs and Assumptions
Determine Threat Material Properties	Assume human skin, using empirical data to determine pain and lethal thresholds: *Thermal Radiation: Physiological and Pathological Effects* (Institution of Chemical Engineers)
Calculate Intensity at Range	Atmospherics: MODTRAN Maritime Model, Absorption + Scattering, Use transmittance at detection range to estimate attenuation coefficient along entire path $$I = \frac{P_{peak} * G * T}{4 * \pi * R^2}$$ P: Power (Watts) G: Gain (dB) T: Transmittance (%) R: Range (meters)

Modeling HEL Performance in GINA

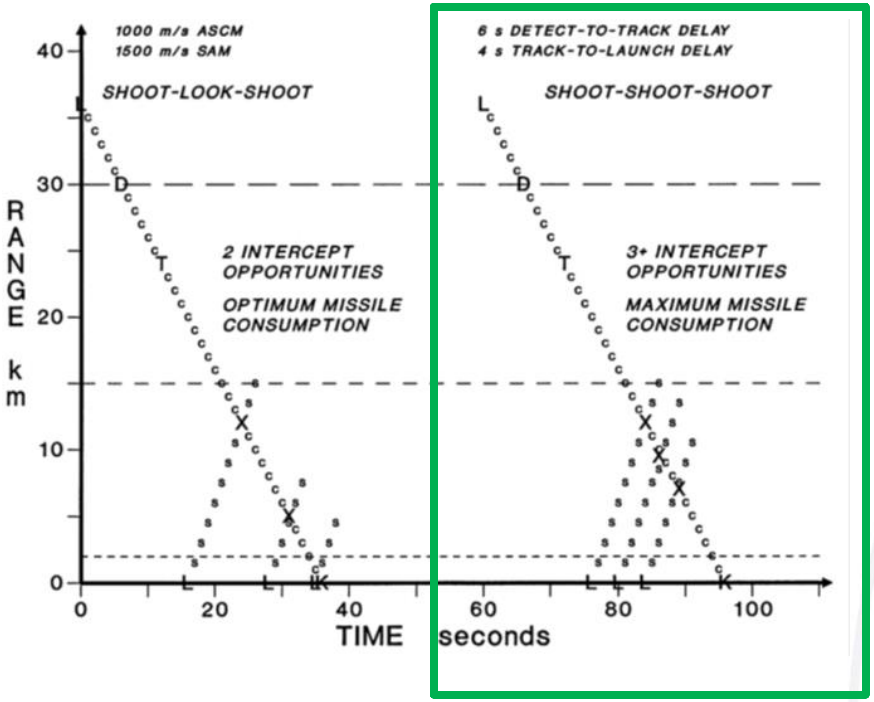
Model Parameter	Inputs and Assumptions
Determine Threat Fluence for T1E	Density, Thickness, Specific Heat, Melting Temperature, Ambient Temperature, Latent Heat of Fusion, Reflectivity
Determine Threat Fluence for T2E	$F = \frac{Fluence\ for\ Type\ I\ Engagement}{6}$
Determine Intensity at Range	• Beam:coherent, spherical, Gaussian • Atmospherics: MODTRAN Maritime Model, Absorption + Scattering, Use transmittance at detection range to estimate attenuation coefficient along entire path • Ignore jitter and use a 1/3 conical spreading approximation, assume adaptive optics work $I_{pk} = \frac{4 * P * e^{-\alpha * (\frac{R}{1000})}}{\pi * ({W_0}^2 + R^2 * \varphi^2)}$ P: Output power (Watts) α: Attenuation Coefficient (km^{-1}) W_0: Beam waist (meters) R: Range (meters) φ: Full angle beam divergence (1/e power point) (Radians)

GINA Outputs for LASER

- Number of Type I Engagements possible
- Number of Type II Engagements possible
- Range of first Type I Engagement
- Range of first Type II Engagement
- Maximum effective range:



Modeling Conventional Weapon Performance in GINA



- Time, speed, distance to intercept calculation
  - No drag or acceleration
- If weapon can reach the threat before threat reaches Vital Area: success
- Single delay between shots assumed
- Guns are modeled as bursts of rounds

Conventional Assumptions

Weapon Designator	Weapon Name	Weapon Speed (m/s)	Weapon Max Effective Range (m)
MK 15	Close-In Weapon System	1113	1490
MK 38 Mod 2	25mm Bushmaster	1100	2460
MK 54	5 Inch/54 Cal. Deck Gun	808	15000
RIM-66 MR	SM-2 Block III Medium Range	1191	166680

GINA Conventional Outputs

- Number of Type I Engagements possible
- Range of first Type I Engagement
- Maximum effective range

- *Type II Engagements are N/A*

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Modeled Threat Assumptions

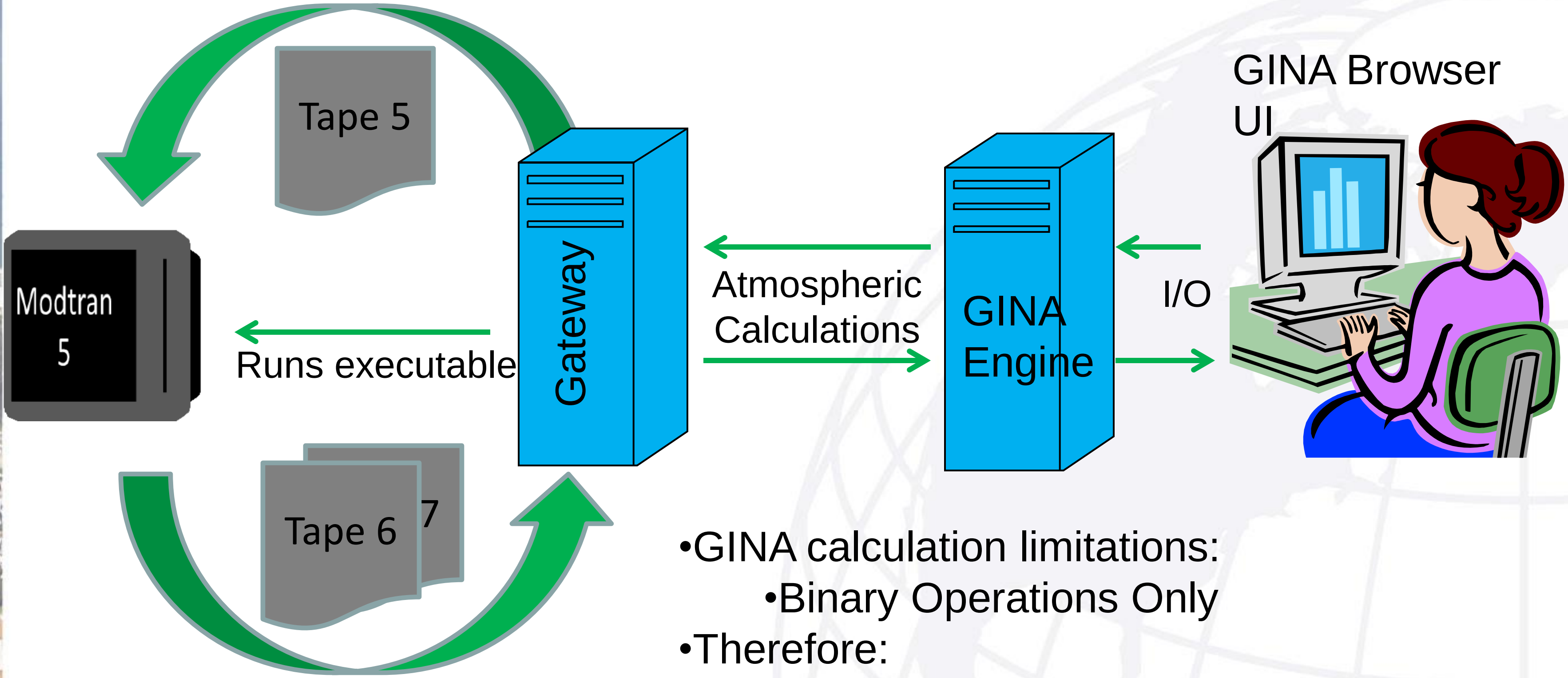
Designator	X-type Name	Armor Material	Speed (m/s)
Cessna	Cessna 150	Aluminum	49
FAC	Aluminum Boat	Aluminum	23
Iranian UAV	Ghods Ababil Ababil-T	Aluminum	103
MiG-29	Fulcrum	Aluminum	666
FIAC	Fiberglass Boat	Fiberglass	23
Person	Running 5 mph	Skin	2
AS-11	Kilter	Stainless Steel	1167
C-802	Saccade	Stainless Steel	266
PC	Boghammer	Stainless Steel	9
F-14	Tomcat	Titanium	555
Dhow	Dhow	Wood (oak)	4

Atmospheric Modeling

Modtran5

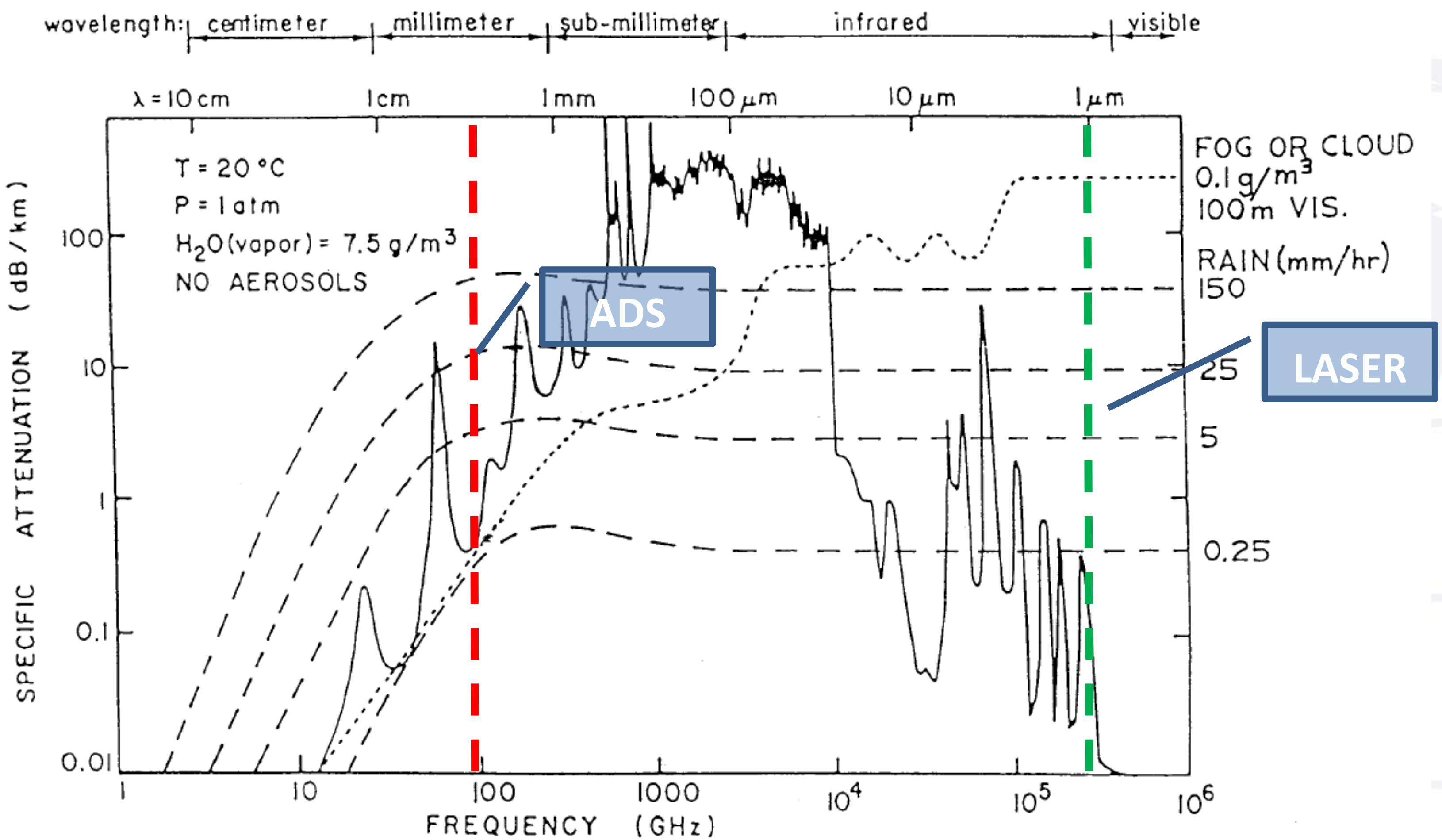
- Readily available to the project team
- Validated model for radiative transfer estimation for use by DoD
- Included U.S. Navy maritime atmospheric model by default
- Covers both LASER and microwave regions in one model
- Provided necessary transmittance inputs for mathematical models

GINA-MODTRAN 5 Integration

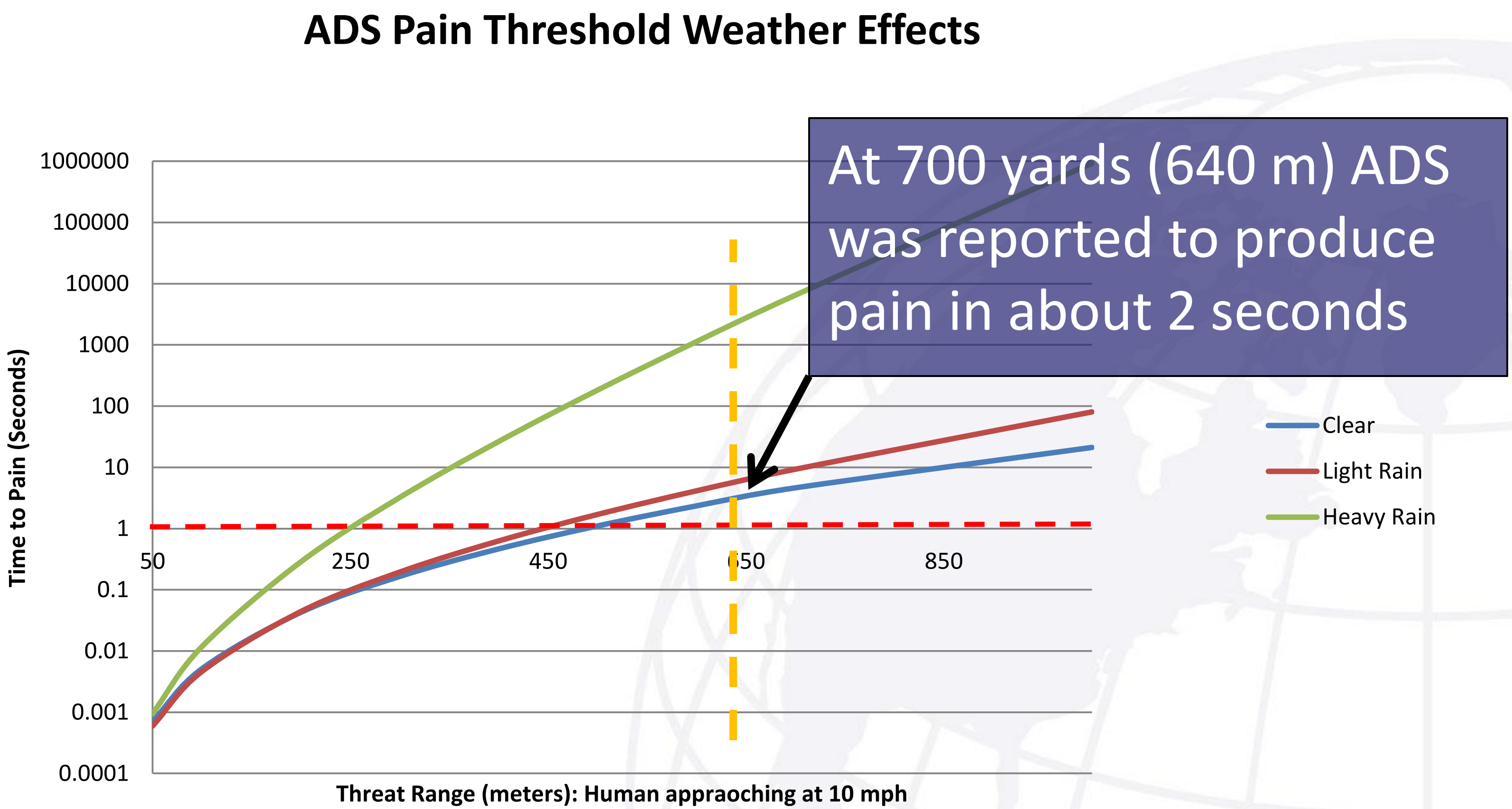


- GINA calculation limitations:
  - Binary Operations Only
- Therefore:
  - Invokes custom content manager to be developed by GINA engineers and the .NET Class gateway developed by the project team

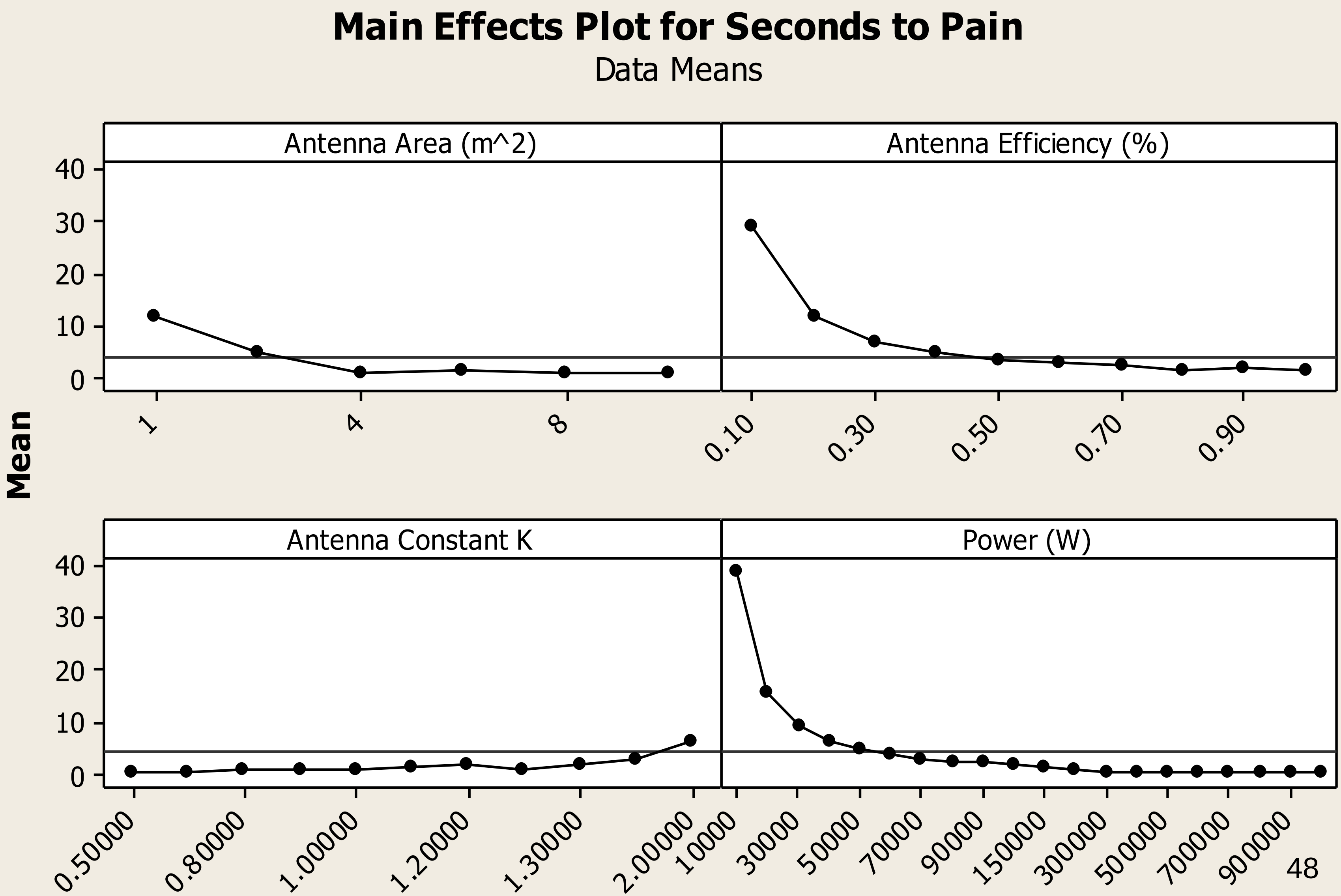
Atmospheric Analysis



Microwave Model Validation

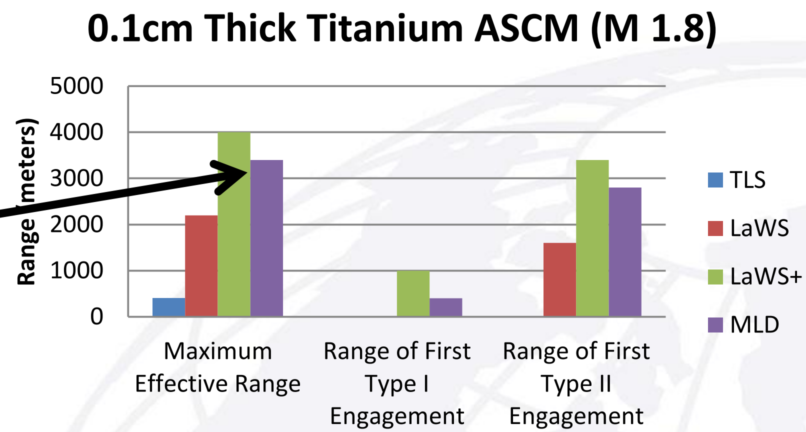


Microwave Model Sensitivity

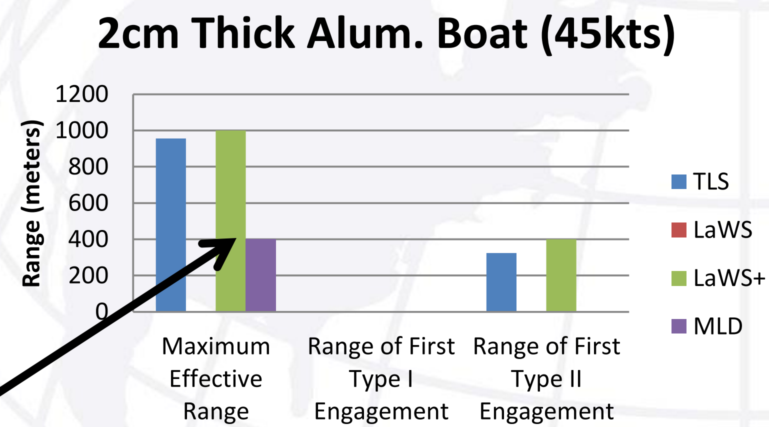


LASER Model Validation

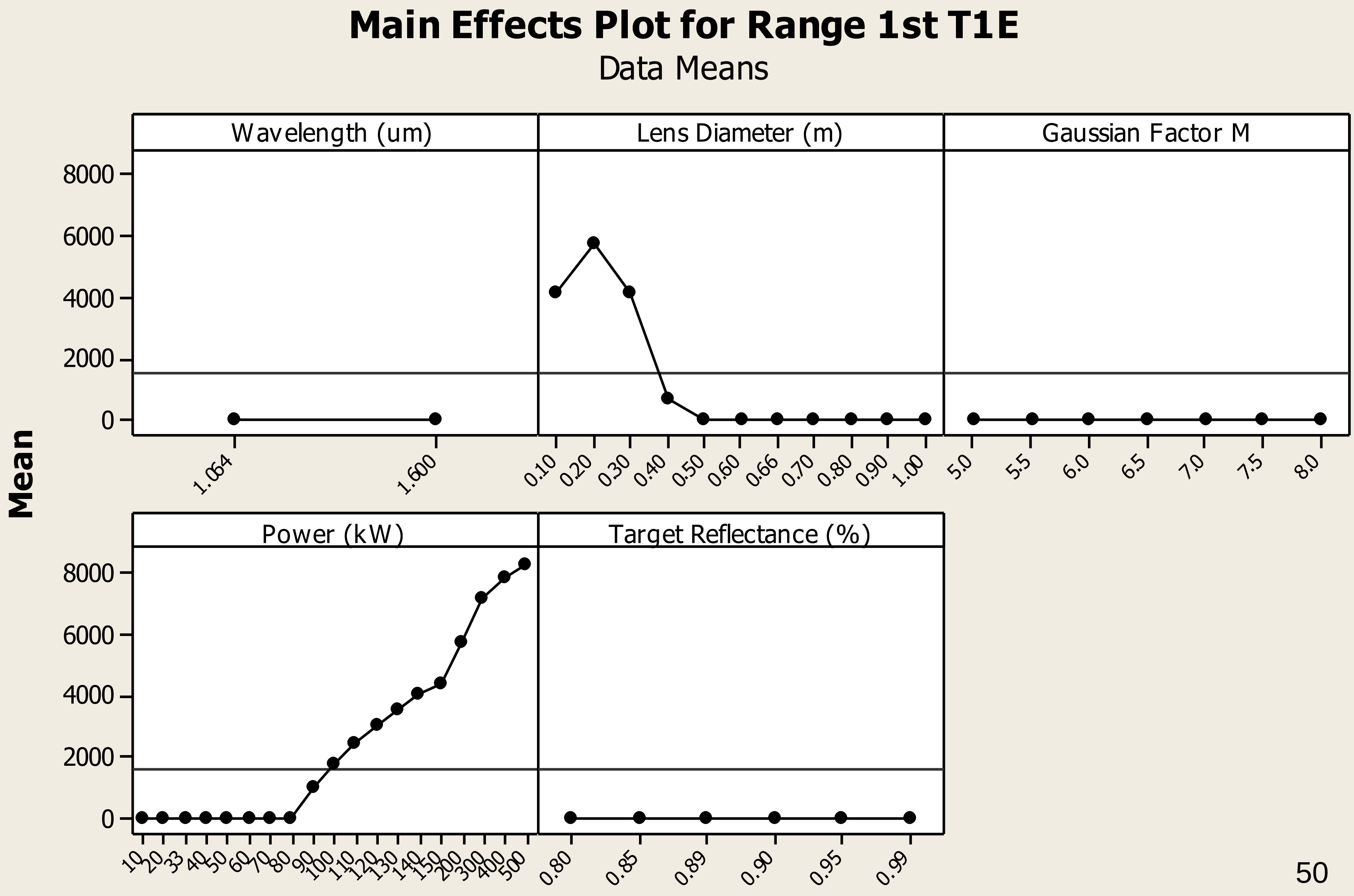
- MLD reported to be effective at kilometers not meters



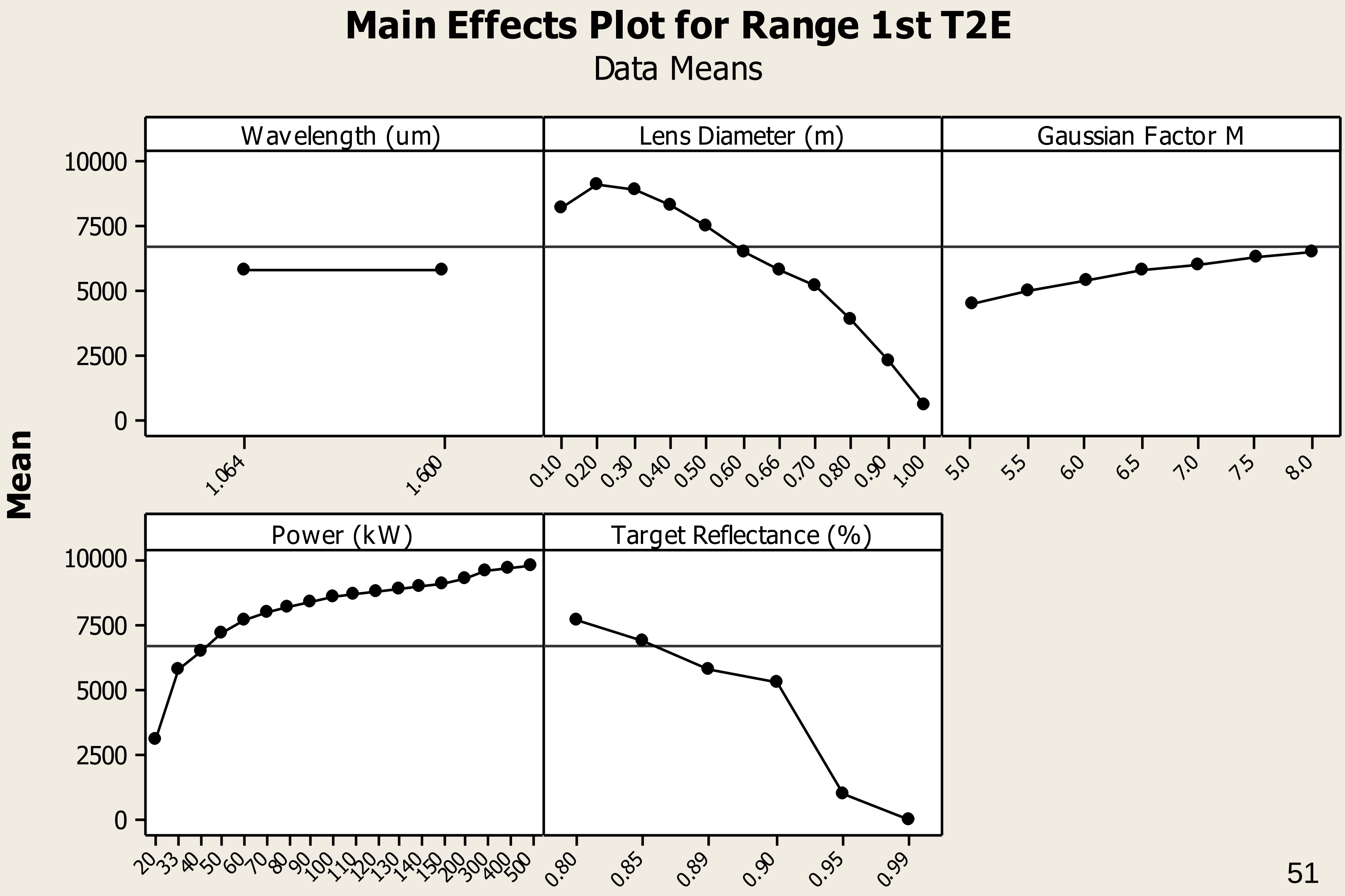
- MLD burns boat engine housing (range not disclosed), but appears to be close to the MER calculated by the model



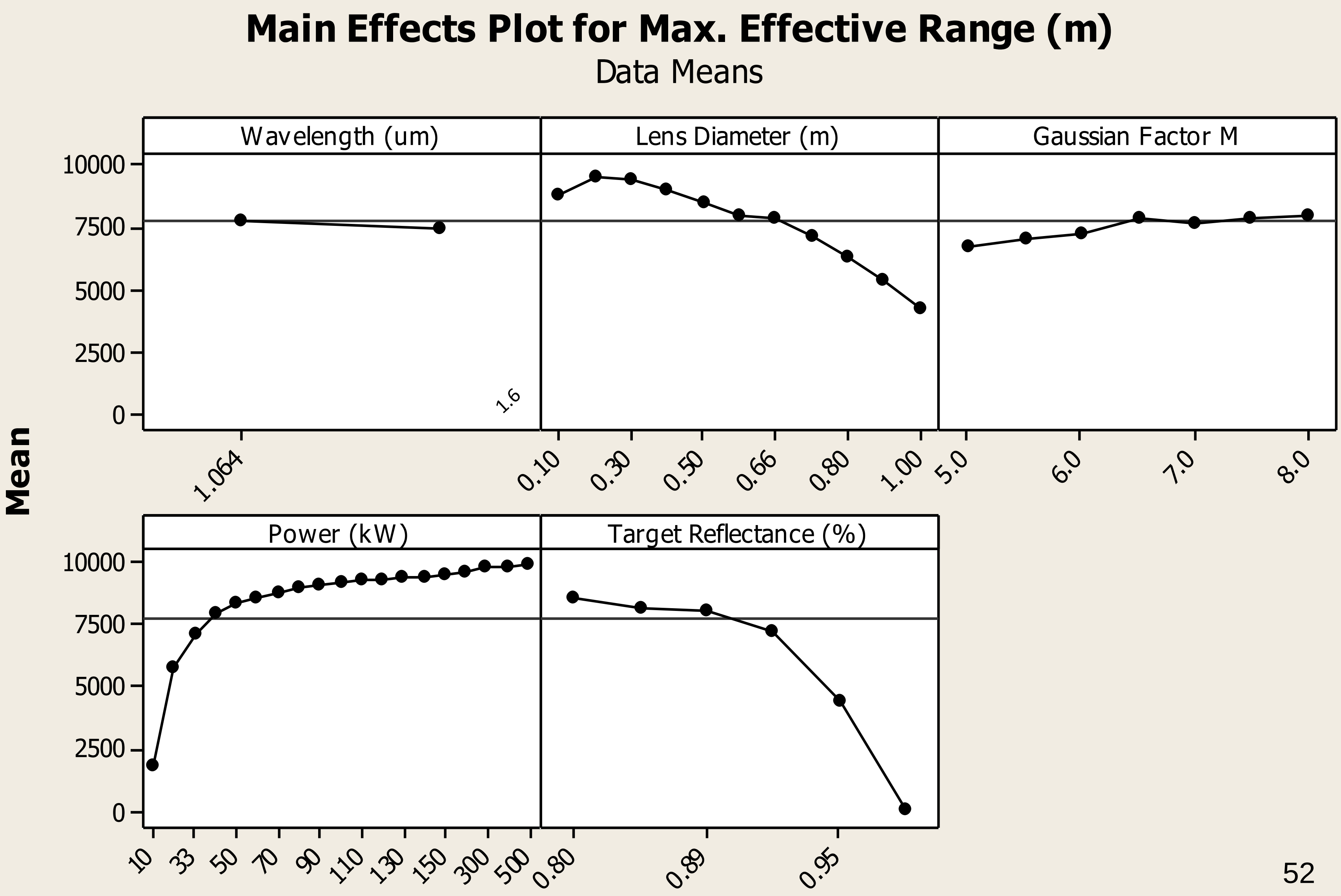
LASER Sensitivity Cont.



LASER Sensitivity Cont.



LASER Model Sensitivity



GINA Experimental Design

- Full Factorial: 1008 potential engagement combinations
- Partial Factorial
  - Mr. Bill Glenny of CNO's SSG suggested narrowing the scope to FAC/FIAC and ATFP as primary areas of interest
  - Used UNTL to scope analysis:
    - Scoped to 212 possible engagements
  - Randomized remaining combinations to be executed on a time permitting basis
  - Ultimately ran 337 engagements in the model

Mission	Mission Threats
SUW 1.10	3
AW 1.2	3
ATFP 12	1
NCO 19.6	2
ATFP 15	1
ATFP 9	2

GINA Results and Analysis

Back | Previous Form

Select Engagement

New

Mission ID	Threat Desig	Weapon Desig	Environment
ATFP 15	FIAC	ADS	Marine, Light Rain, Mid Latitude
ATFP 15	FIAC	ADS	Marine, Moderate Rain, Mid Latitude
ATFP 15	FIAC	MK 38 Mod 2	Marine, Heavy Rain, Mid Latitude
ATFP 15	FIAC	MK 38 Mod 2	Marine, Light Rain, Mid Latitude
ATFP 15	FIAC	MK 38 Mod 2	Marine, Moderate Rain, Mid Latitude
ATFP 15	FIAC	MK 38 Mod 2	Marine, Clear, Mid Latitude
ATFP 15	FIAC	MLD	Marine, Clear, Mid Latitude
ATFP 15	FIAC	MLD	Marine, Heavy Rain, Mid Latitude
ATFP 15	FIAC	MLD	Marine, Light Rain, Mid Latitude
ATFP 15	FIAC	LaWS	Marine, Clear, Mid Latitude
ATFP 15	FIAC	MLD	Marine, Moderate Rain, Mid Latitude
ATFP 15	FIAC	TLS	Marine, Clear, Mid Latitude
ATFP 15	FIAC	TLS	Marine, Heavy Rain, Mid Latitude
ATFP 15	FIAC	LaWS	Marine, Light Rain, Mid Latitude
ATFP 15	FIAC	TLS	Marine, Light Rain, Mid Latitude
ATFP 15	FIAC	LaWS	Marine, Moderate Rain, Mid Latitude
ATFP 15	FIAC	LaWS	Marine, Heavy Rain, Mid Latitude
ATFP 15	FIAC	TLS	Marine, Moderate Rain, Mid Latitude
ATFP 4	Person	ADS	Marine, Moderate Rain, Mid Latitude
ATFP 4	Person	ADS	Marine, Light Rain, Mid Latitude
ATFP 4	Person	ADS	Marine, Heavy Rain, Mid Latitude
ATFP 8	FIAC	LaWS	Marine, Light Rain, Mid Latitude
ATFP 8	FIAC	LaWS	Marine, Moderate Rain, Mid Latitude
ATFP 8	FIAC	MLD	Marine, Moderate Rain, Mid Latitude
ATFP 8	FIAC	ADS	Marine, Heavy Rain, Mid Latitude

Select Page: 1 2 3 4 5 6 7 8 9 10 ...

Enter Engagement Parameters for Analysis

Save | Delete

Mission ID:	ATFP 15
Environment Description:	Marine, Light Rain, Mid Latitude
Threat Designator:	FIAC
Threat Detection Altitude (meters):	1.0000
Threat Detection Ground Range (meters):	700.0000
Weapon Designator:	ADS
Wavelength:	0.00316
DEW Power (W):	100000
Laser Lens Diameter:	
Laser M:	
Microwave Antenna Area m2:	4.772
Microwave Antenna Constant:	1.273239545
Microwave Antenna Efficiency:	0.8
Density g/cm3:	0.026
Thickness cm:	2.5
Mass Per Area g/cm2:	0.065
Temp at MSL K (Ambient):	288.15
Melting Temp . K:	1394.15

Query Results

Atmospheric Attenuation	DEWMaximum Effective Range	DEWMaximum Tactical Range	Mission ID	Number Of Hard Kills Possible	Number Of Soft Kills Possible	Threat Designator	Threat Detection Altitude _m	Threat Detection Ground Range _m	Vital Area Radius _m	Weapon Designator	Weapon Type
0			ATFP 15	15	0	FIAC	1.0000	700.0000	100	MK 38 Mod 2	CONV
0			ATFP 15	15	0	FIAC	1.0000	700.0000	100	MK 38 Mod 2	CONV
0			ATFP 15	15	0	FIAC	1.0000	700.0000	100	MK 38 Mod 2	CONV
0			ATFP 15	15	0	FIAC	1.0000	700.0000	100	MK 38 Mod 2	CONV
0			ATFP 9	2	0	Iranian UAV	500.0000	1000.0000	500	MK 15	CONV
0			ATFP 9	2	0	Iranian UAV	500.0000	1000.0000	500	MK 15	CONV
0			ATFP 9	3	0	Iranian UAV	500.0000	1000.0000	500	MK 38 Mod 2	CONV
0			ATFP 9	3	0	Iranian UAV	500.0000	1000.0000	500	MK 38 Mod 2	CONV
0			ATFP 9	3	0	Iranian UAV	500.0000	1000.0000	500	MK 38 Mod 2	CONV
0			ATFP 9	3	0	Iranian UAV	500.0000	1000.0000	500	MK 38 Mod 2	CONV
0			ATFP 9	3	0	Iranian UAV	500.0000	1500.0000	500	MK 15	CONV
0			ATFP 9	7	0	Cessna	500.0000	1500.0000	500	MK 15	CONV
0			ATFP 9	7	0	Cessna	500.0000	1500.0000	500	MK 15	CONV
0			ATFP 9	7	0	Cessna	500.0000	1500.0000	500	MK 15	CONV
0			ATFP 9	7	0	Cessna	500.0000	1500.0000	500	MK 15	CONV
0			ATFP 9	7	0	Cessna	500.0000	1500.0000	500	MK 15	CONV
0			ATFP 9	12	0	Cessna	500.0000	1500.0000	500	MK 38 Mod 2	CONV
0			ATFP 9	12	0	Cessna	500.0000	1500.0000	500	MK 38 Mod 2	CONV
0			ATFP 9	12	0	Cessna	500.0000	1500.0000	500	MK 38 Mod 2	CONV
0			ATFP 9	12	0	Cessna	500.0000	1500.0000	500	MK 38 Mod 2	CONV
0			AW 1.1	0	0	C-802	5.0000	5000.0000	5000	RIM-66 MR	CONV
0			AW 1.1	9	0	F-14	1000.0000	10000.0000	5000	RIM-66 MR	CONV
0			AW 1.1	19	0	Iranian UAV	100.0000	7000.0000	5000	RIM-66 MR	CONV
0			AW 1.12	6	0	AS-11	5.0000	10000.0000	500	RIM-66 MR	CONV
0			AW 1.13	3	0	AS-11	5.0000	9000.0000	5000	RIM-66 MR	CONV

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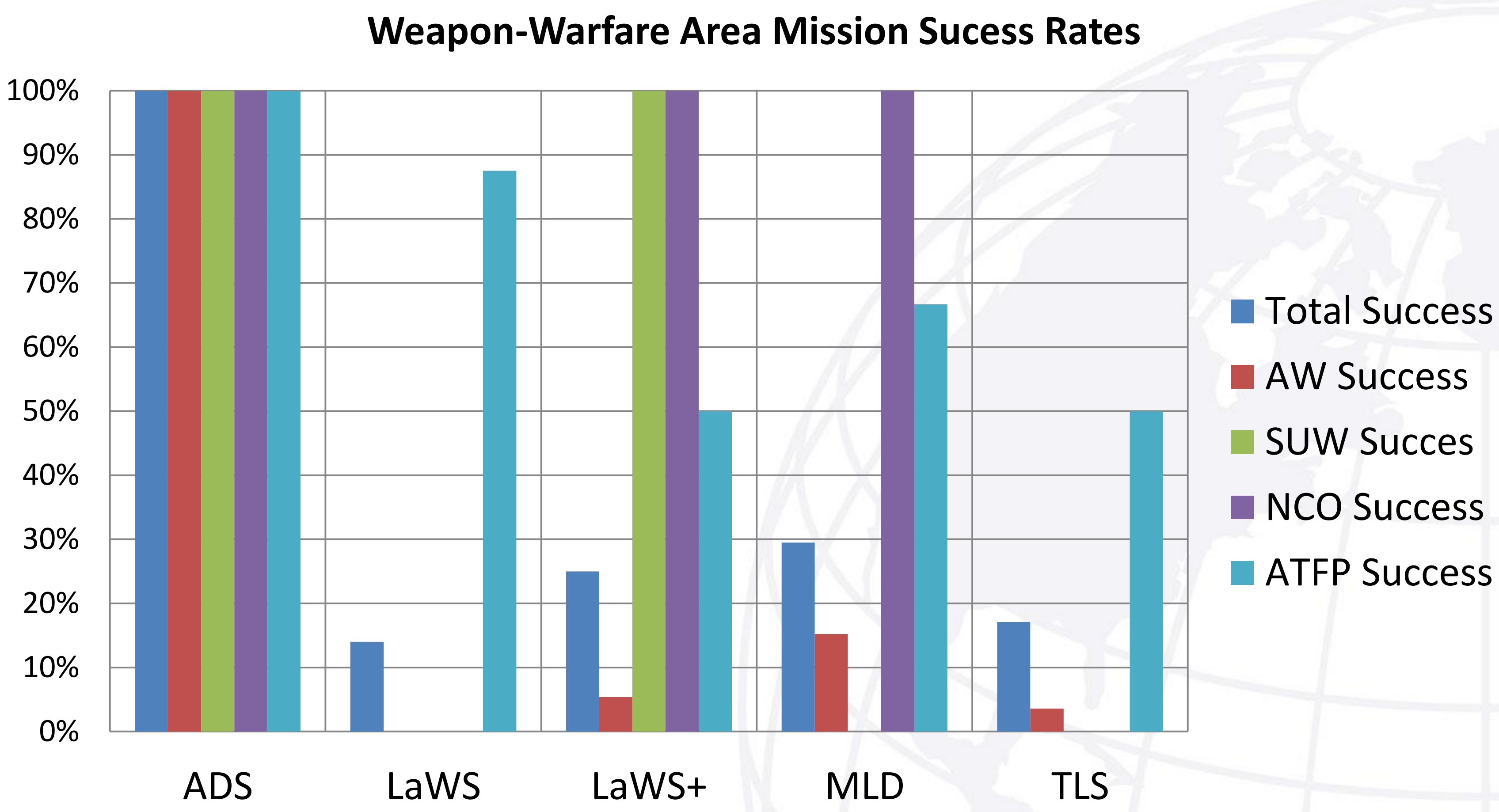
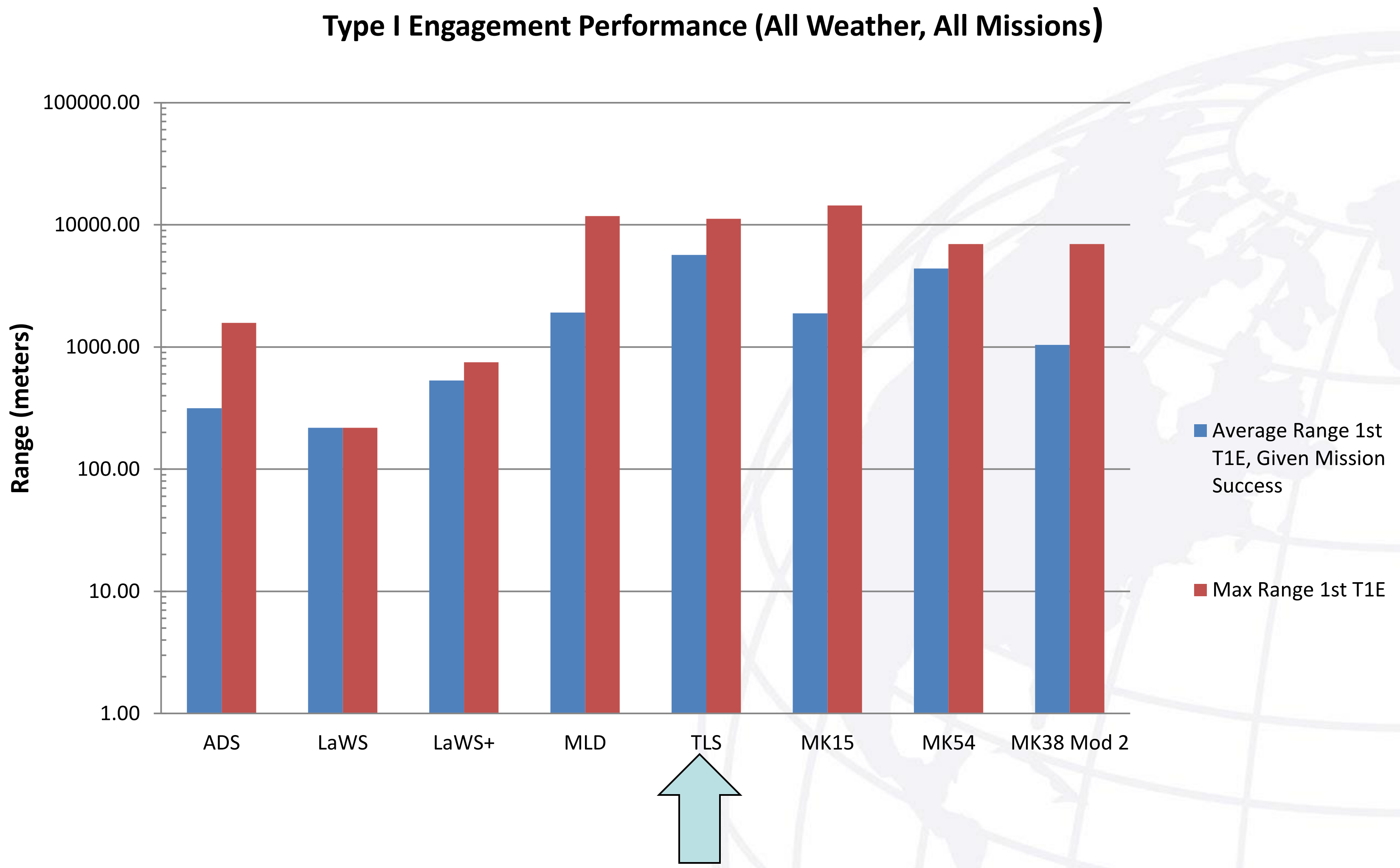
Total Results

Unclassified

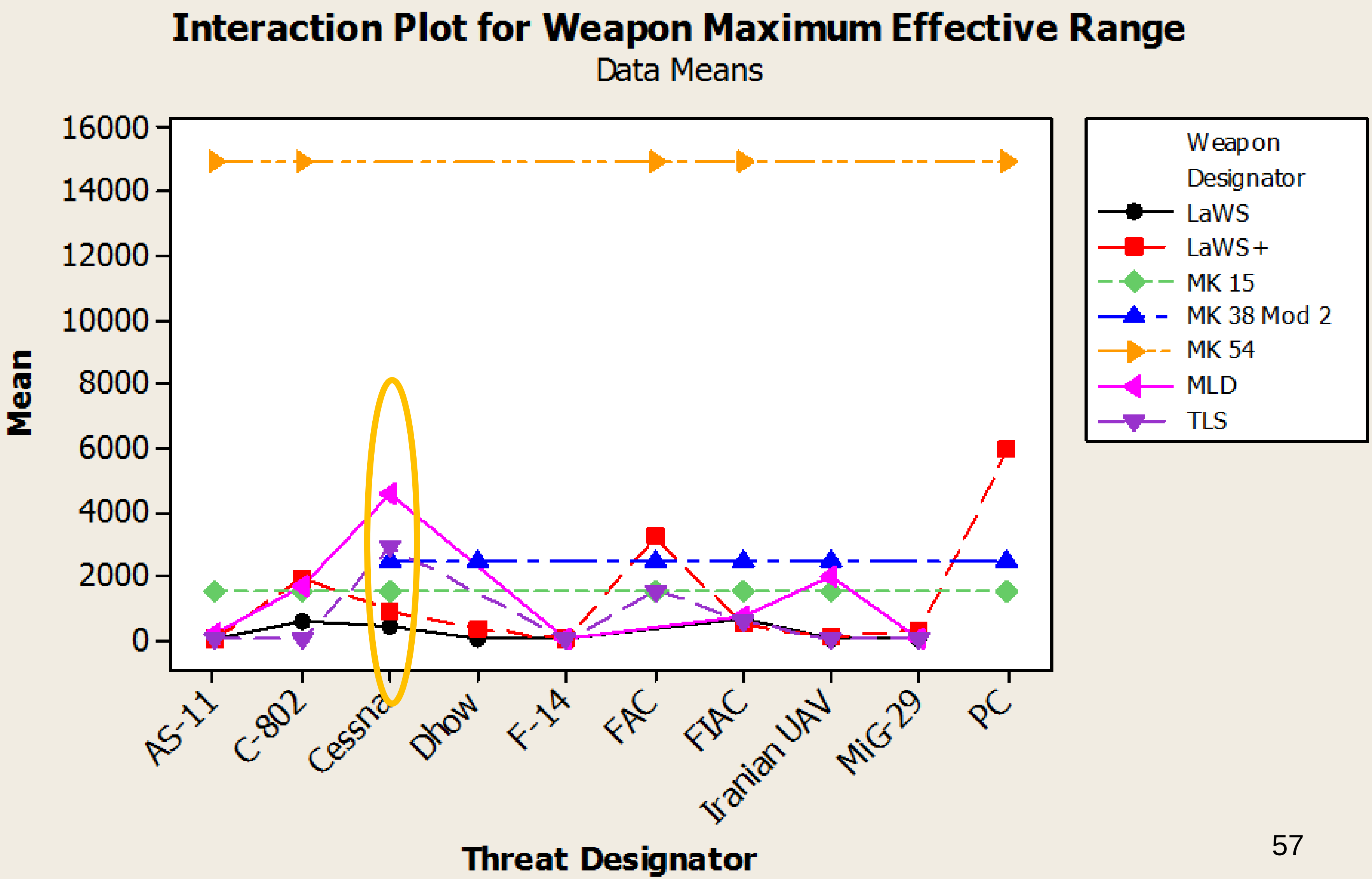
Warfare Area Results



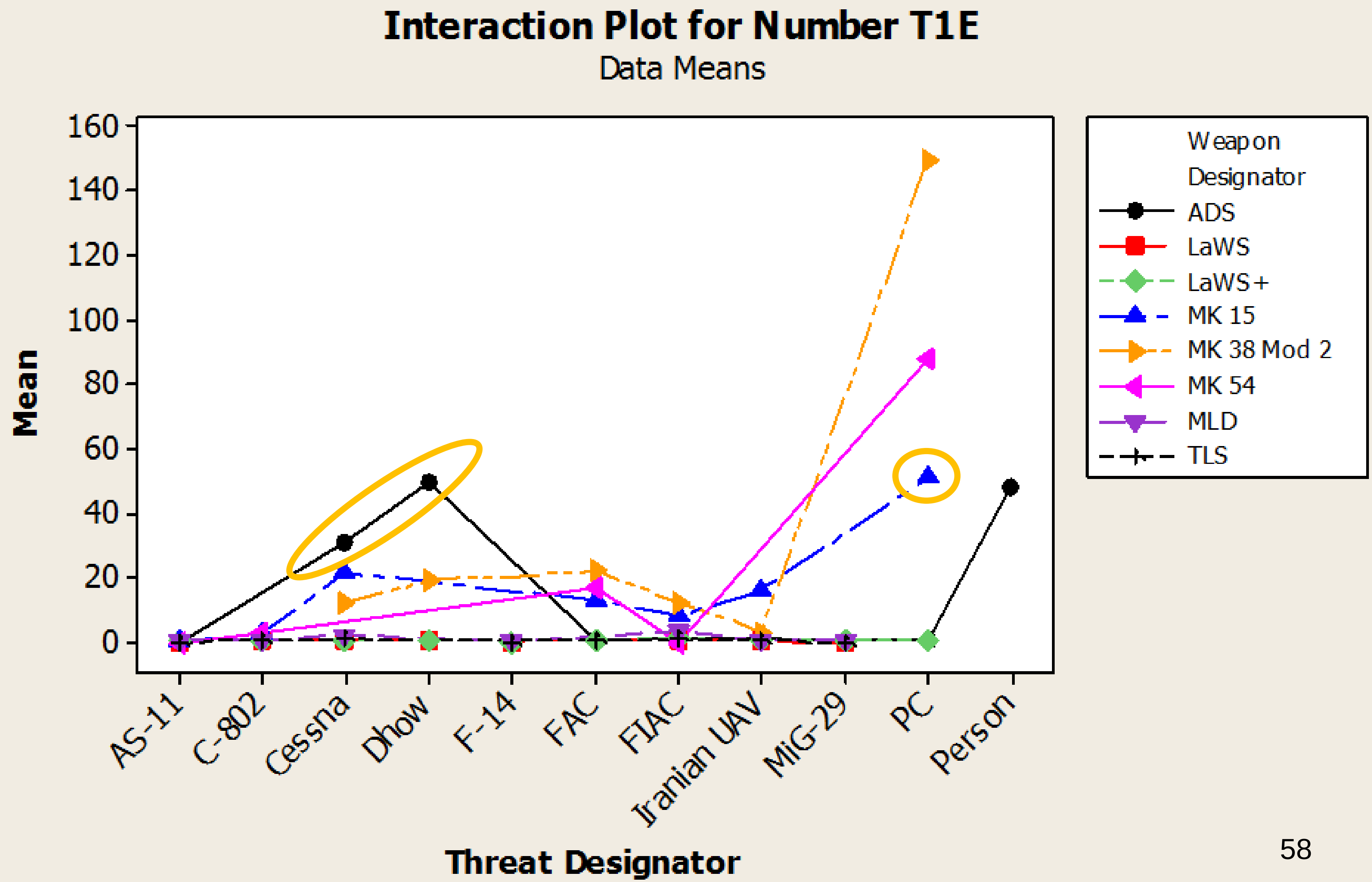
Type I Engagement Comparison



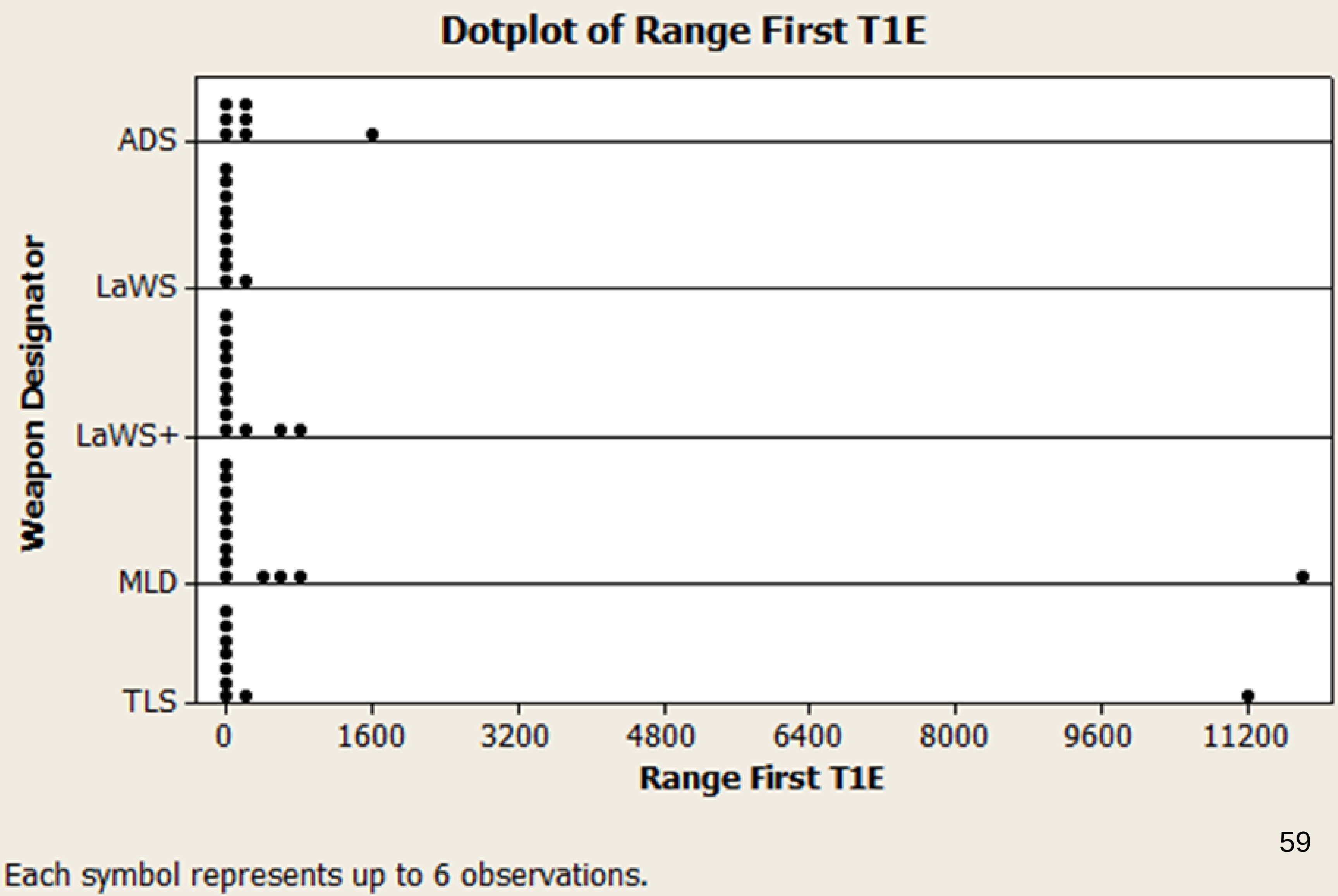
MER Comparison



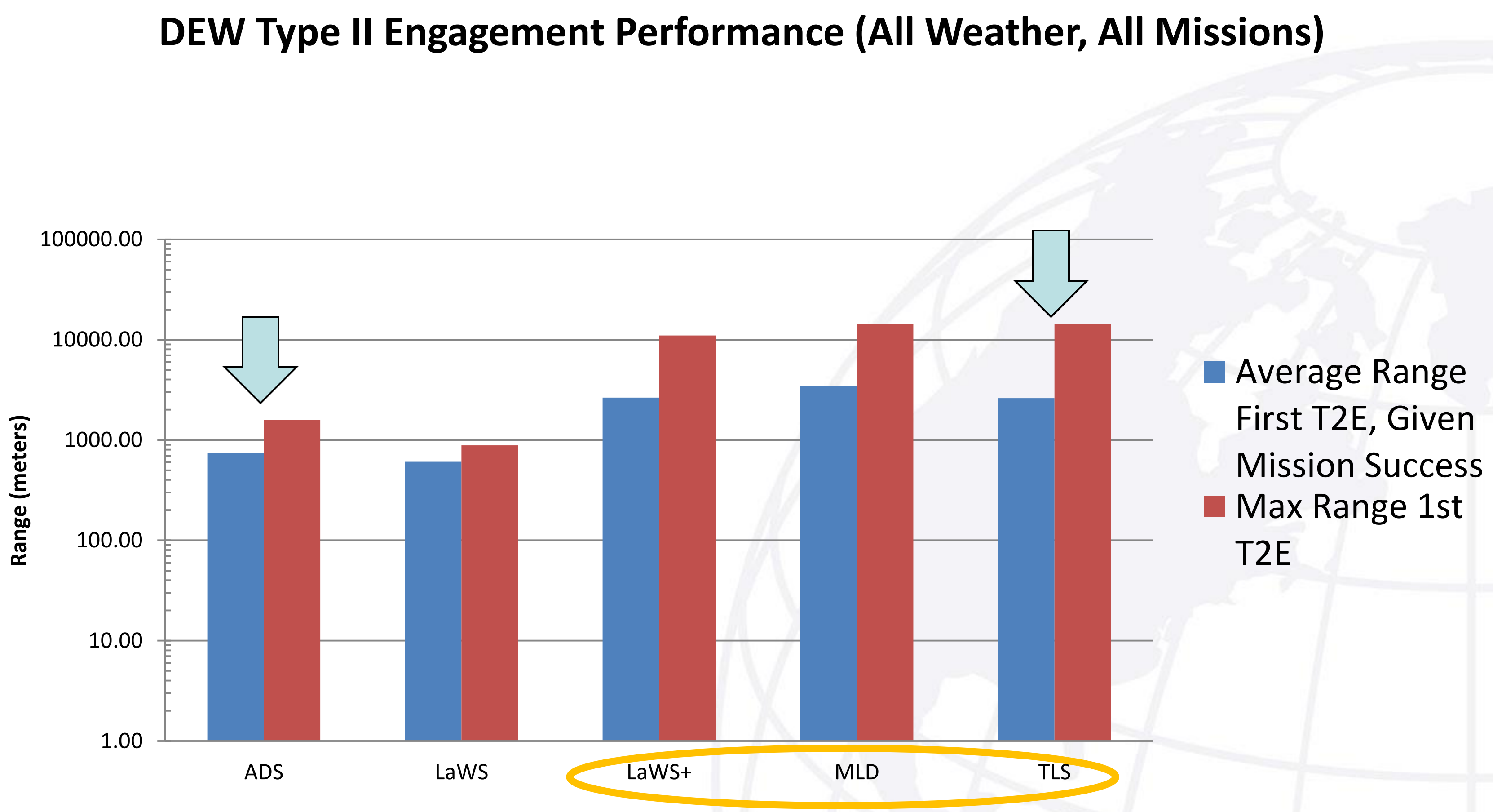
Type I Re-Engagement Analysis



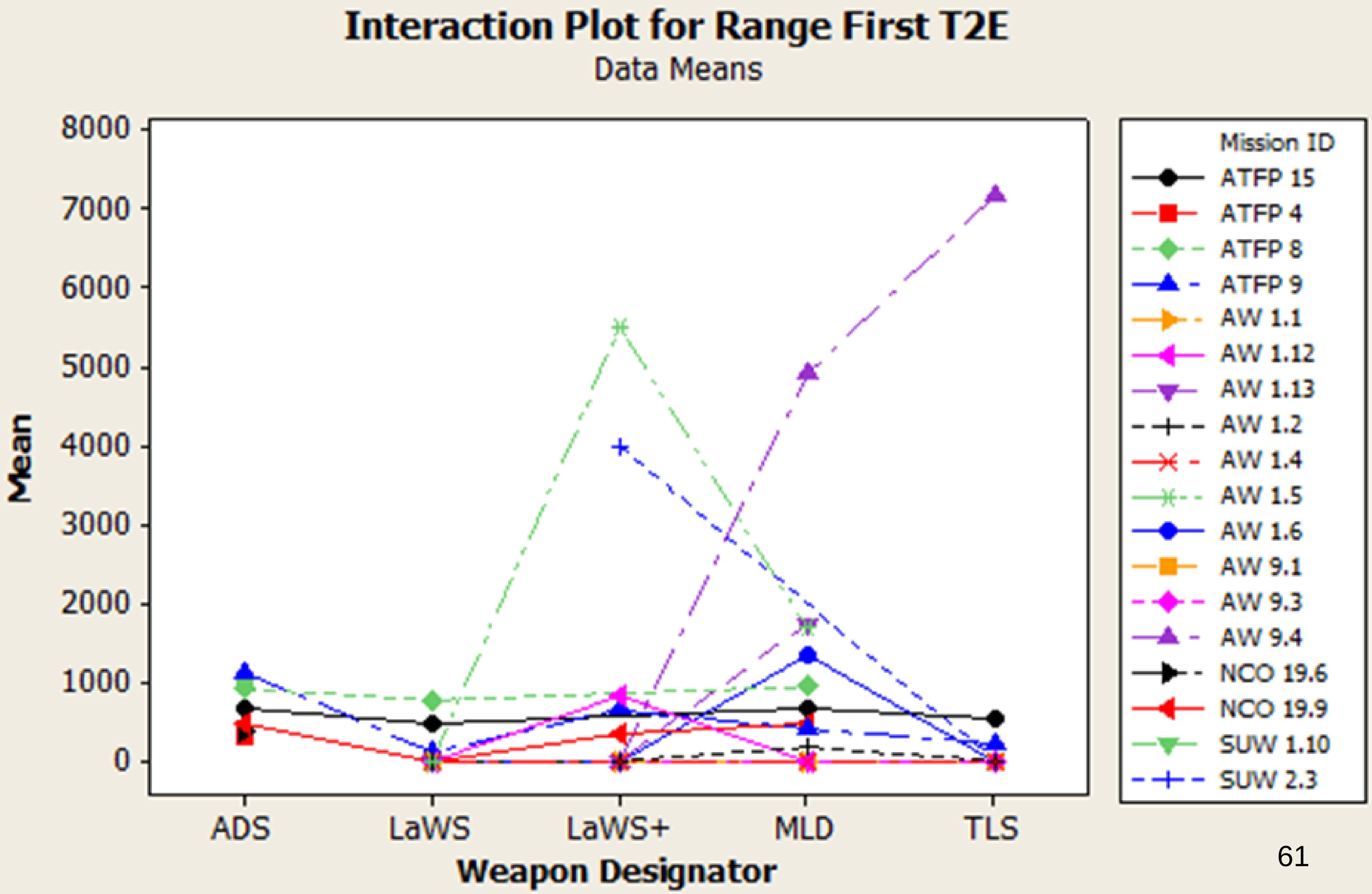
Type I First Engagement Ranges



Type II Range Comparisons



Type II Mission Analysis



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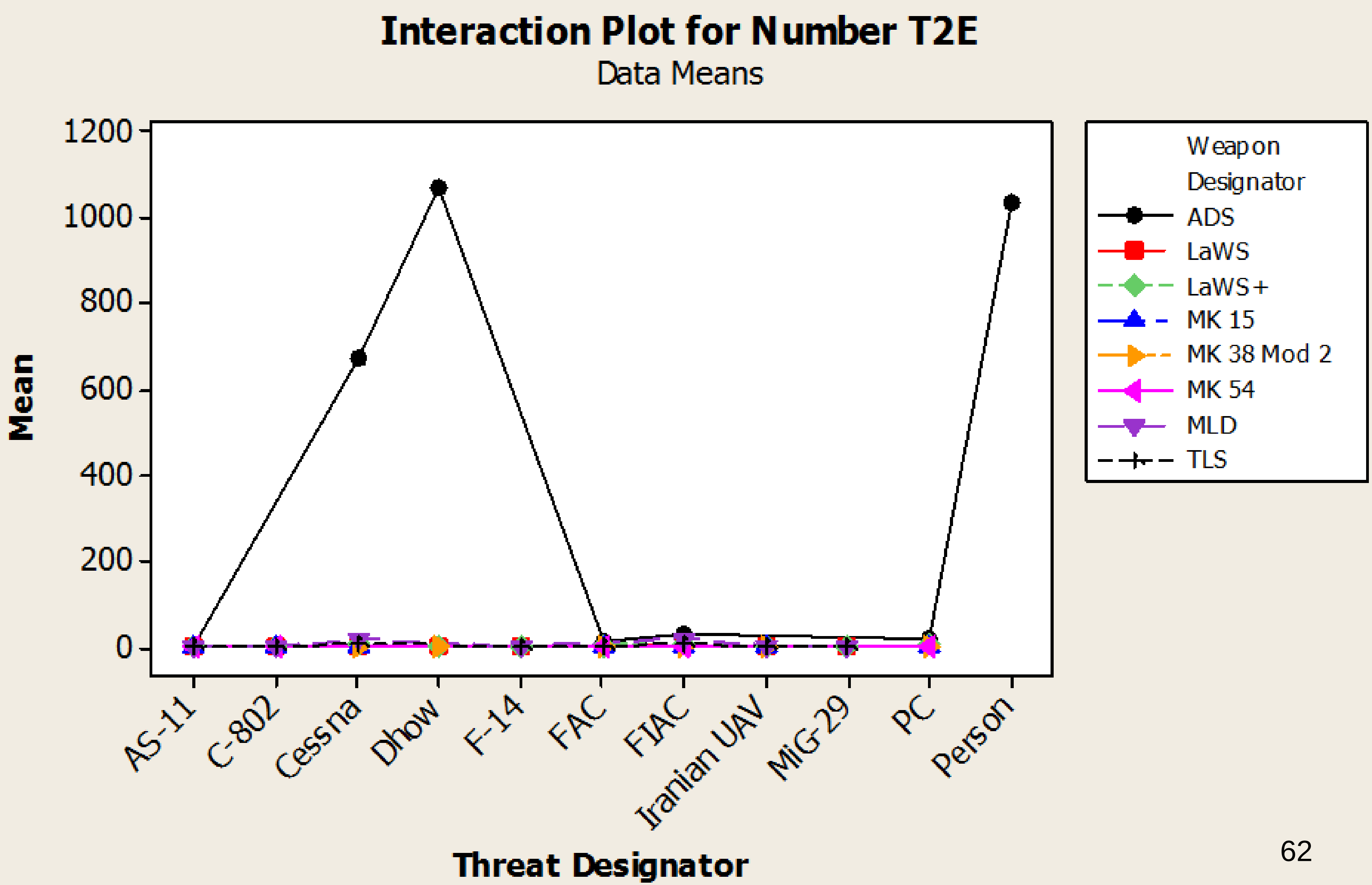
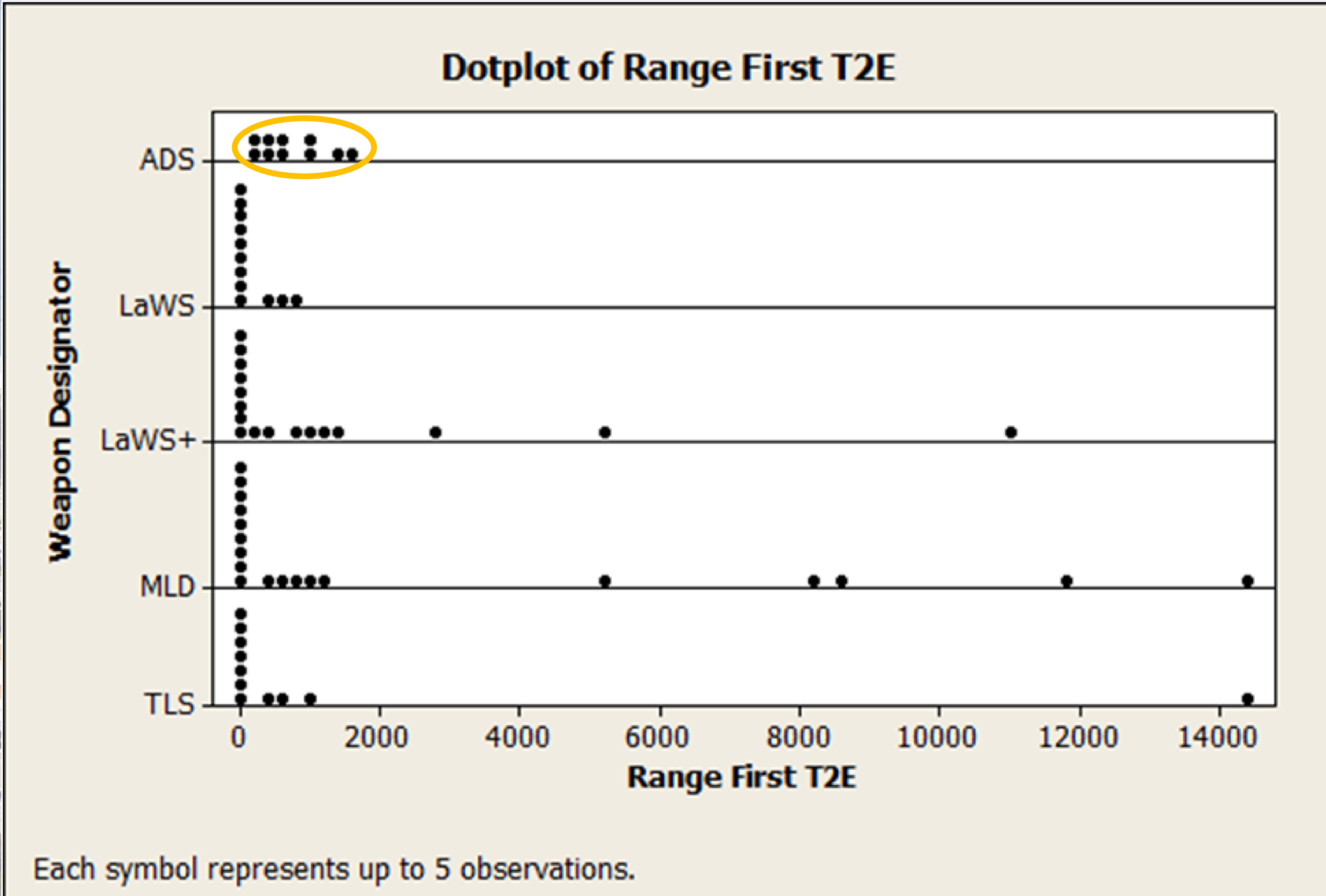
Type II Re-Engagement Analysis



Type II First Engagement Ranges



GINA Modeling Summary

- The TLS was effective against ATFP threats and showed comparable performance to the LaWS and LaWS+ in most scenarios
- The most consistent best all around performer was the ADS
- For LASER, the MLD was the best overall performer due to the combination of its relatively high power and small aperture

Simulation

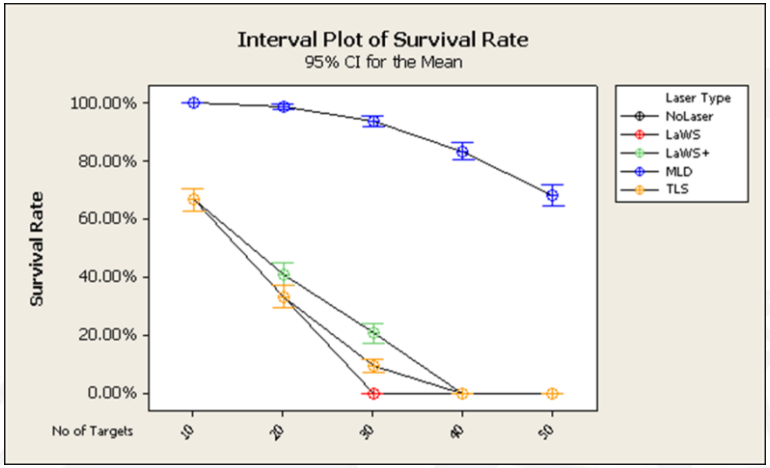
- 2 Simulations:
  - MANA
    - First to use MANA to simulate DEWs
    - Unique adaptation of MANA
  - Monte Carlo in Excel
    - Ship survivability
    - Weapon combinations
- Simultaneous time on top missile attacks, FAC/FIAC attacks, and LSFs/UAVs
- Only LASERs

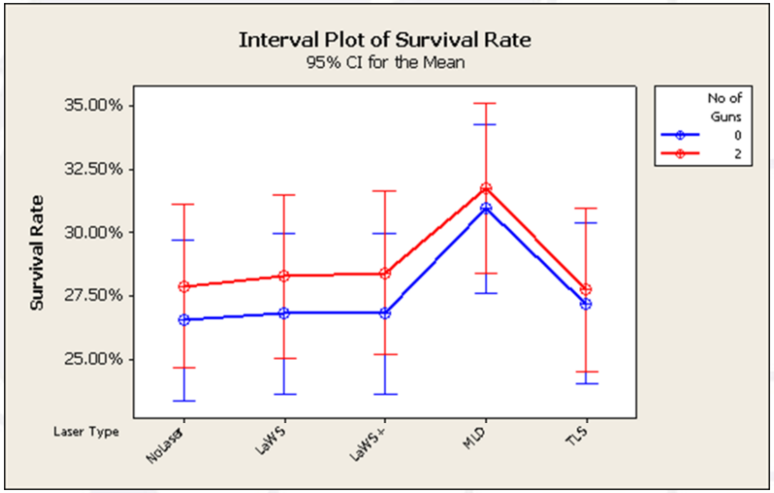
Monte Carlo Simulation

- Binomial trials based on rate of fire, effective range, and an assumed $P_{k|\text{“hit”}}$
- Factor Combinations for scenarios:
  - Missile attack (5 STOT ASCMs)
  - FAC/FIAC attack
  - Number of threats
  - CIWS mounts (0, 1, or 2)
  - Missile launchers (0, 1, or 2); assuming 1 launch per launcher at a time
- Assumptions based on MIT LPD-17 design project for realistic/unclassified P_k values for conventional weapons

Monte Carlo Results

- FAC/FIAC
  - MLD's high power and small aperture make it top performer
  - TLS out performs LaWS due to Small aperture and high BQ
- Missile Attack
  - MLD is only marginally effective compared to the other LASERS
  - TLS is on par with LaWS/LaWS+





Modeling Laser with MANA

- Adapted MANA's kinetic energy weapons model for LASER analysis
  - Determine time for a Type I Engagement at a set of static ranges
- Convert deterministic data to probabilistic:

$$\rightarrow \quad P_k(r) = \frac{N}{s \times t_k(r)}$$

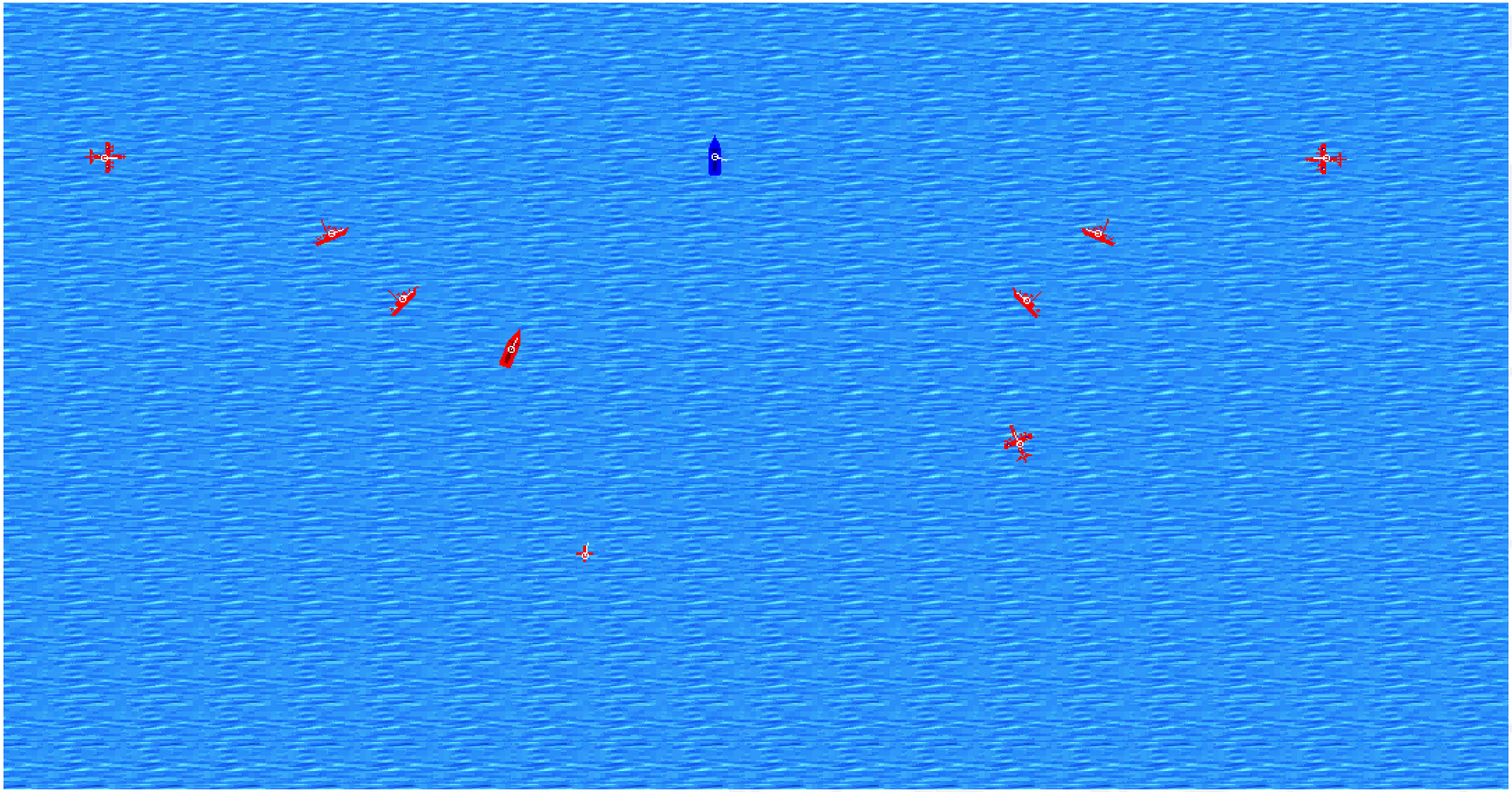
- N: Target life point, S: # "shots" per sec, t: seconds required for Type I Engagement at a specific distance
  - Example: DEW requires 5 sec for a T1E at 1 km, and N = 100, S = 100, t = 5 sec. Then, Pk = 0.2 per shot
- Assume that even after long interruptions the target will "remember" that it already received a given amount of energy

MANA Results

- Suggested that LASERs are part of a defense in depth CONOPS augmenting crew served weapons
- Suggested that 1 LASER weapon could successfully engage:
  - 2 to 3 FAC/FIAC
  - 3 to 5 LSF/UAVs
  - 1 to 2 sub-sonic ASCMs

MANA SIMULATION (Coordinated Attack)

- LaWS+ Against 1 Subsonic ASCM, 3 UAVs, and 5 Boats



Cost Estimation

Cost Estimation Assumptions

- There are a LOT of unknowns!
- Assumptions:
  - Total Life Cycle Cost Estimate would be a waste of time due to high degree of uncertainty
  - Estimating an implementation cost of a single unit is feasible
  - Federal dollars expended to date are "sunk"
  - DDG-51 class integration assumed due to short time requirement
    - Power, cooling, weight, and space requirements supported by platform
  - Total hardware cost is proportional to laser power (linear fit assumed for hardware)
  - Cost factors for aggregate shipboard electronics distributions are applicable to DEW

Cost Estimation Methodology

1. Cost estimation "scenarios" developed
   - DEW systems similar, but different
   - Permutations to the cost estimate necessary
   - 4 scenarios or cost "vignettes" utilized
2. Determined baseline costs from trusted published references
3. Identified applicable WBS cost sub-elements
4. Decomposed actual cost figures with respect to various cost factors using historical statistics
5. Use cumulative inflation to calculate inflated cost of for FY13

Methodology presented here is greatly oversimplified!

Baseline Figures & Cost Factors

System	Baseline Figure	Remarks	Company
Active Denial System (ADS)	$7.5M	Cost plus award fee contract to design, fabricate, and test	Raytheon
LaWS	$28.1M	Development funding data	Raytheon
Maritime Laser Demonstration	$98M	Indefinite delivery/indefinite quantity contract ceiling value	Northrop
Tactical Laser System	$2.8M	Prototype development contract	BAE

COST FACTORS:

- Design 15.8%
- Hardware 19%
- Contractor Support 29.5%
- Government Support 25.9%
- Software 5.3%
- Integration 4.5%

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ADS Estimate

Objective: To derive the cost estimate of deploying two units of Active Denial System (ADS) onboard a DDG-51 class ship.

COST FACTORS	SENSITIVITY ANALYSIS (95% CONFIDENCE)		
	MINIMUM	MIDDLE	MAXIMUM
DESIGN (15% original design)	$ 138,670	$ 210,438	$ 282,205
HARDWARE (2X contract HW)	$ 1,905,964	$ 3,374,104	$ 4,842,243
CONTRACTOR SUPPORT			
- Support Equipment	$ -	$ 204,222	$ 801,433
- Tools & Test Equipment (T&TE)	$ -	$ 142,068	$ 372,905
- Training	$ -	$ 17,758	$ 51,242
- Data	$ -	$ 106,551	$ 334,394
- Other	$ -	$ 159,826	$ 477,784
GOVERNMENT SUPPORT			
- System Engineering / Program Management (SE/PM)	$ -	$ 2,246,443	$ 6,433,722
- Test & Evalution (T&E)	$ -	$ 45,298	$ 240,604
SOFTWARE	$ 91,503	$ 470,599	$ 849,694
INTEGRATION	$ 399,565	$ 399,565	$ 399,565
	$2,535,702	$7,376,870	$15,085,791

LaWS+ Estimate

Objective: To determine and estimate the upgrade and shipboard installation cost of the Laser Weapon System (LaWS) from its current 33kW output to 150 kW (+).

COST FACTORS	SENSITIVITY ANALYSIS (95% CONFIDENCE)		
	MINIMUM	MIDDLE	MAXIMUM
HARDWARE (4.54X contract HW)	$14,527,015	$ 25,716,992	$ 36,906,970
CONTRACTOR SUPPORT			
- Support Equipment	$ -	$ 684,884	$ 2,687,704
- Tools & Test Equipment (T&TE)	$ -	$ 476,441	$ 1,250,582
- Training	$ -	$ 59,555	$ 171,848
- Data	$ -	$ 357,331	$ 1,121,433
- Other	$ -	$ 535,996	$ 1,602,307
GOVERNMENT SUPPORT			
- System Engineering / Program Management (SE/PM)	$ -	$ 7,533,725	$ 21,576,288
- Test & Evalution (T&E)	$ -	$ 168,600	$ 806,896
SOFTWARE	$ 306,867	$ 1,578,211	$ 2,849,555
INTEGRATION	$ 1,339,991	$ 1,339,991	$ 1,339,991
	$16,173,873	$38,451,727	$70,313,573

NAVAL POSTGRADUATE SCHOOL

MLD Estimate

Objective: To derive the cost estimate of integration and installation of the Maritime Laser Demonstration (MLD) onboard DDG-51 class ships.

COST FACTORS	SENSITIVITY ANALYSIS (95% CONFIDENCE)		
	MINIMUM	MIDDLE	MAXIMUM
HARDWARE	$11,412,101	$ 20,202,700	$ 28,993,299
CONTRACTOR SUPPORT			
- Support Equipment	$ -	$ 2,445,590	$ 9,597,278
- Tools & Test Equipment (T&TE)	$ -	$ 1,701,280	$ 4,465,588
- Training	$ -	$ 212,660	$ 613,635
- Data	$ -	$ 1,275,960	$ 4,004,422
- Other	$ -	$ 1,913,940	$ 5,721,532
GOVERNMENT SUPPORT			
- System Engineering / Program Management (SE/PM)	$ -	$ 26,901,490	$ 77,044,791
SOFTWARE	$ 1,095,765	$ 5,635,490	$ 10,175,215
INTEGRATION	$ 4,784,850	$ 4,784,850	$ 4,784,850
	$17,292,716	$65,073,960	$145,400,610

TLS Estimate

Objective: To determine the estimated cost of installing and deploying two Tactical Laser Systems (TLS) on DDG-51 class ships.

COST FACTORS	SENSITIVITY ANALYSIS (95% CONFIDENCE)		
	MINIMUM	MIDDLE	MAXIMUM
DESIGN (15% original design)	$ 45,128	$ 68,484	$ 91,839
HARDWARE (2X contract HW)	$ 620,265	$ 1,098,048	$ 1,575,831
CONTRACTOR SUPPORT			
- Support Equipment	$ -	$ 66,461	$ 260,813
- Tools & Test Equipment (T&TE)	$ -	$ 46,234	$ 121,356
- Training	$ -	$ 5,779	$ 16,676
- Data	$ -	$ 34,675	$ 108,823
- Other	$ -	$ 52,013	$ 155,487
GOVERNMENT SUPPORT			
- System Engineering / Program Management (SE/PM)	$ -	$ 731,069	$ 2,093,752
SOFTWARE	$ 29,778	$ 153,149	$ 276,519
INTEGRATION	$ 130,032	$ 130,032	$ 130,032
	$825,204	**$2,385,943**	**$4,831,129**

Integration

(www.educollaborators.com)

Shipboard Integration

	(2)TLS	LaWS	MLD	(2) ADS
Weight	2,000 lbs.	10,000 lbs.	20,000 lbs.	20,000 lbs.
Input Power	151.62 kW	400 kW	520 kW	400 kW
Cooling	Self-Contained	86 Tons	120 Tons	Self-Contained
Coverage	Nearly 360°	180°	180°	Nearly 360°
Combat Systems	No	Yes	Yes	No

Although the current AEGIS destroyer can support each of the four systems, an analysis of the current capability shows that as the power levels of these lasers are increased in the future, the DDG-51 platform must also be upgraded to account for the additional power and cooling requirements.

Sustainment Overview

Technology	Materials	Supply Chain Management	Operational Unit Support	Sustaining Engineering	Disposal
HPM	Number of units procured will be based on available platforms; some parts may be stored on ship however critical components will be held at depot level facilities	Weapons support provided by Naval Supply Systems Command Weapons Systems Support (NAVSUP WSS)	POC for supply support concerns along with call centers for troubleshooting and having technicians travel to ship for repair when needed	Perform technical tasks to ensure continued operation of a system which includes conducting major repairs at depot level facilities and having Inspections to evaluate performance standards; use of built in test equipment to ensure proper operation	Considers when, where, and how to get rid of the system
SSL	Number of units procured will be based on available platforms; some parts may be stored on ship while others such as optics will be at facilities due to level of cleanliness required	Weapons support provided by Naval Supply Systems Command Weapons Systems Support (NAVSUP WSS)	POC for supply support concerns along with call centers for troubleshooting and having technicians travel to ship for repair when needed; optics may have to be repaired off ship	Perform technical tasks to ensure continued operation of a system which includes conducting major repairs at depot level facilities and having Inspections to evaluate performance standards; use of sensors to detect laser firings	Considers when, where, and how to get rid of the system

Sustainment

- Materials
  - Requirements
    - Initial Needs/Projections
  - Personnel
- Supply Chain Management
  - Procurement
  - Distribution
  - Software
- Sustaining Engineering
  - Depot Level Support
  - Performance Standards Analysis for Continued Use
- Operational Unit Support
- Disposal

Materials and Supply Chain Management

- Material involves developing supply requirements, storing components needed for repair and replacement, and providing personnel for warehouse functions
  - Number of units acquired will be based off of number of available platforms
  - Considerations made for operating in marine environment include protective coverings, stabilizers, and lubricants
  - Minor components stored on ship and major components stored at facilities
- Supply chain managements includes the procurement and distribution of materials
  - Weapons support provided by Naval Supply Systems Command Weapons Systems Support (NAVSUP WSS)

Sustaining Engineering, Operational Unit Support, and Disposal

- Sustaining Engineering involves performing technical tasks to ensure continued operation of a system (Providing Depot Level support)
  - Major repairs conducted at depot level facilities
  - Inspections held to evaluate performance standards
- Operational unit support includes providing POC for supply support concerns
  - Call centers for troubleshooting
  - Technicians may travel to ship for repair
- Disposal considers when, where, and how to get rid of the system

Training

- Analogy Method using CIWS
- Differences in training requirements are negligible between the 4 systems.
- All systems would have a similar training pipeline
- Assumptions were made based on SME experience

A-School	C-School	OJT/PQS	Specialized Training
30 Weeks	36 Weeks	As Required	As Required

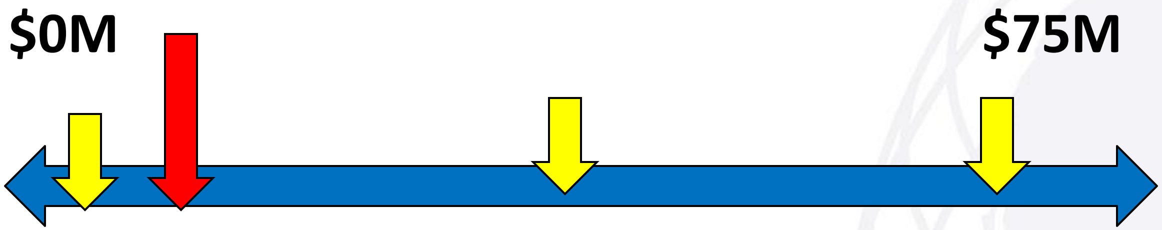
Manning

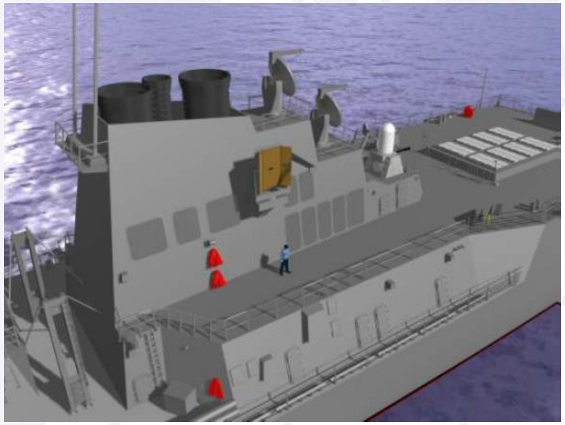
- EDVR and Projected Maintenance Requirements were used in manning projections
- FC is the Optimal Rate
- Assumptions were made based on SME experience

	Number of Additional Personnel Required?	NEC Required
LaWS & LaWS+	1-2	Yes
TLS	1-2	Yes
MLD	2-3	Yes
ADS	3-4	Yes

ADS Tech Summary

- **Integration:** ADS will likely be installed as two separate systems
  - Will add approximately 20,000 lbs.
  - Requires 200 kW of electrical power to operate and includes its own cooling
  - Operates independently from each other and the Ship's Combat System.
  - Provides nearly 360 degrees of combined coverage
- **Cost:**

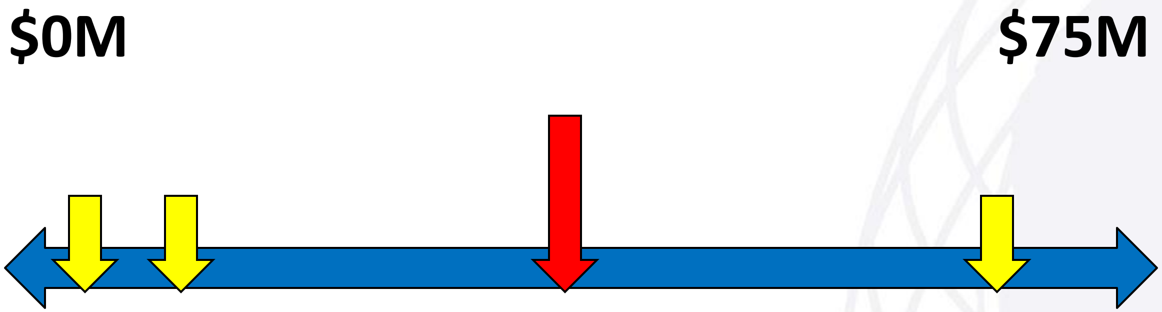




- **Performance:**
  - Only DEW with 100% effectiveness against all threats modeled against
  - Pierside ATFP applications against personnel and LSFs show the greatest potential for success
  - FAC/FIAC can be effectively engaged with multiple opportunities for re-engagement

LAWS & LAWS+ Tech Summary

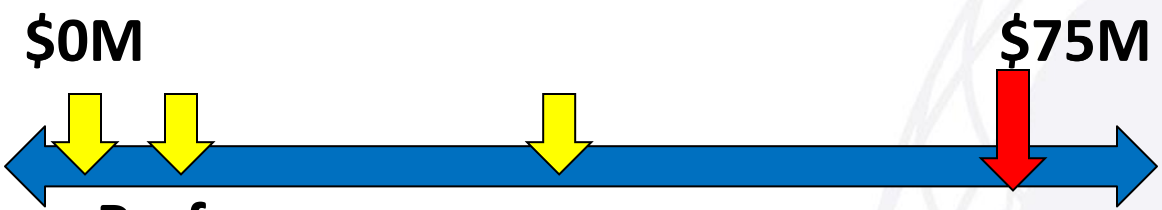
- **Integration**: Will likely be co-located on an existing CIWS mount
  - Will add approximately 10,000 lbs.
  - Requires 400 kW of electrical power to operate
  - Requires 86 Tons of cooling to remove the waste heat
  - Requires integration into the Ship's Combat Systems
- **Cost:**



- **Performance**:
  - Best against lightly armored ATFP threats like LSFs/UAVs
  - Ineffective against missiles
  - Large aperture reduces potential gains from higher power levels

MLD Tech Summary

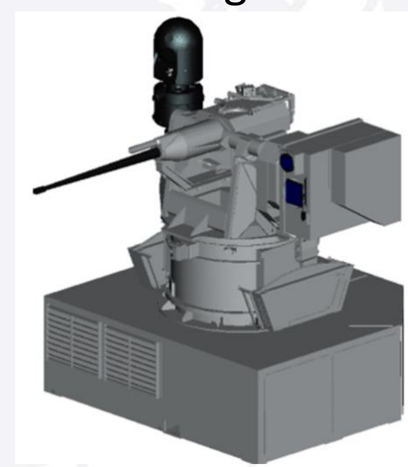
- **Integration:** The MLD is the largest and most complex of the 4 systems
  - Will add approximately 20,000 lbs.
  - Requires 520 kW of electrical power
  - Requires 120 Tons of cooling provided by the ship
  - Requires several inputs from the ship’s Combat Systems to perform DTE
- **Cost:**



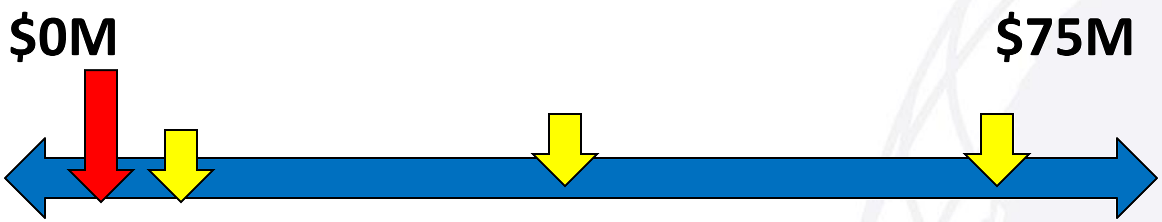
- **Performance:**
  - Best LASER overall: smaller aperture than LaWS and higher power than TLS
  - Effective against ATFP, FAC/FIAC, and LSF/UAV threats
  - Potentially able to augment current close-in missile defense systems to conserve ammunition and missiles while increasing shipboard survivability

TLS Tech Summary

- **Integration:** The TLS will have the smallest footprint to the ship. 2 systems will be added to the MK 38 Mod 2
  - Will add approximately 2,000 lbs.
  - Requires 150 kW and each system provides it own cooling
  - Each system will operate independently and will not be integrated in the Ship's Combat Systems



- **Cost:**



- **Performance:**
  - Small aperture and high beam quality make up for low power
    - Increasing power from 10 kW to 20 or 30 kW would see a marked increase in performance
  - Effective against lightly armored ATFP and LSF/UAV threats
  - Potentially able to augment current close-in missile defense systems to conserve ammunition and missiles while increasing shipboard survivability

AoA Method

- Conduct a value analysis from the point of view of the 3 project stakeholders
  - Operator/user, exploratory developer, and system developer
  - Includes performance, integration, cost, and schedule
- Remove cost from the analysis for CAIV analysis
- Prototype component scores taken from Integration and Cost sections

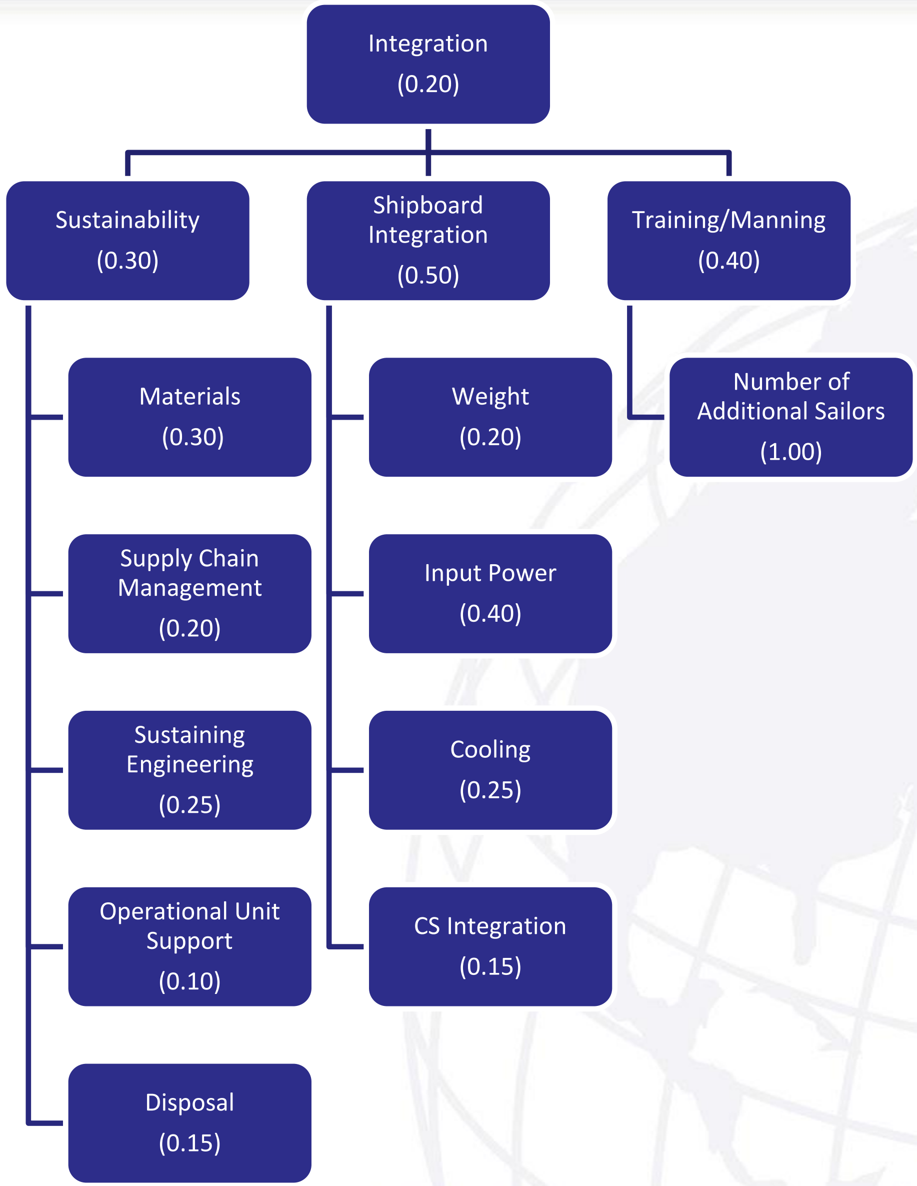
AoA Top Level

- Overall
  - Operator/User
    - Performance/Schedule (0.75)
    - Integration (0.20)
    - Cost (0.05)
  - Exploratory Developer
    - Performance (0.55)
    - Cost/Integration (0.35)
    - Schedule (0.10)
  - System Developer
    - Performance (0.33)
    - Schedule (0.33)
    - Cost/Integration (0.33)

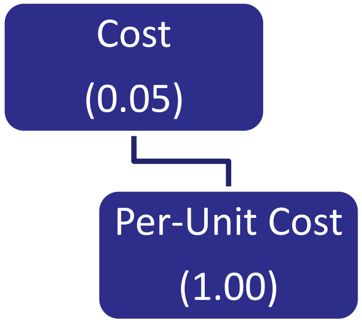
Operator AoA In Depth

- Performance (.75)
  - Mean Range 1st T1E (.10)
  - Mean Range 1st T2E (.15)
  - NCO Mission Success (.05)
  - More DEW vs Conventional Engagements (.10)
  - ATFP Mission Success (.15)
  - Max DEW Range > Conventional (.10)
  - SUW Mission Success (.10)
  - Non-Lethal Capable (.20)
  - AW Mission Success (.05)

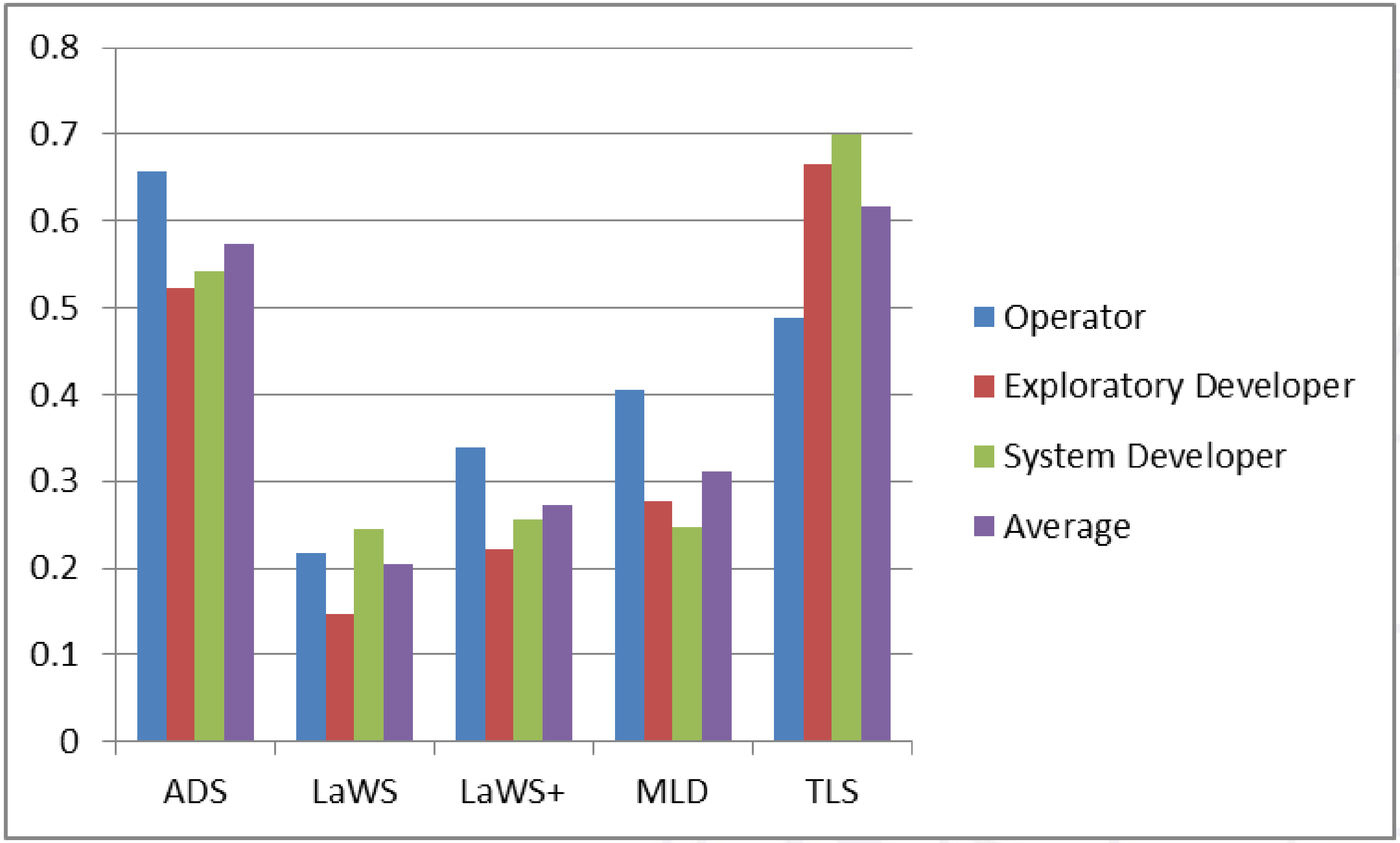
Operator AoA In Depth



Operator AoA In Depth

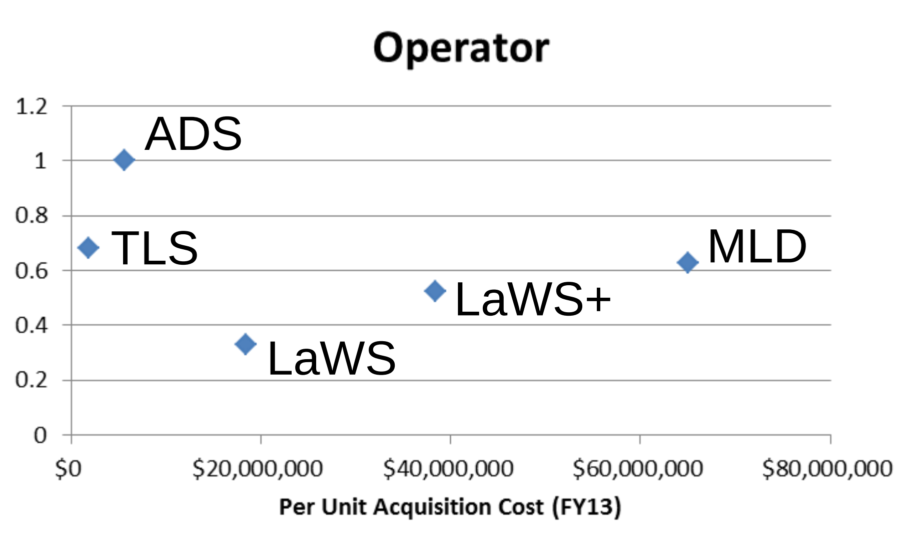


AoA Results



0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
ADS
LaWS
LaWS+
MLD
TLS
Operator
Exploratory Developer
System Developer
Average

CAIV


Operator
1.2
1
0.8
0.6
0.4
0.2
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ADS
TLS
MLD
LaWS+
LaWS
$0
$20,000,000
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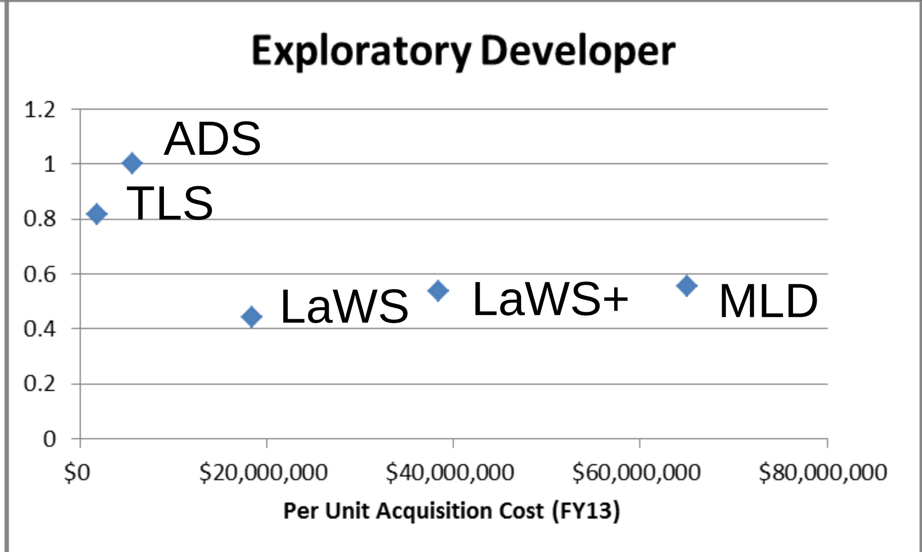
$60,000,000
$80,000,000
Per Unit Acquisition Cost (FY13)


Exploratory Developer
1.2
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0.2
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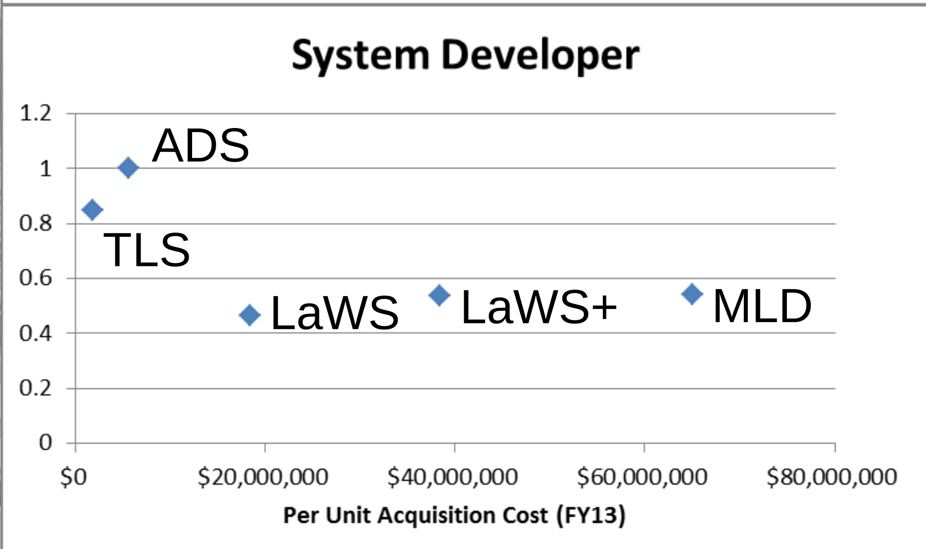
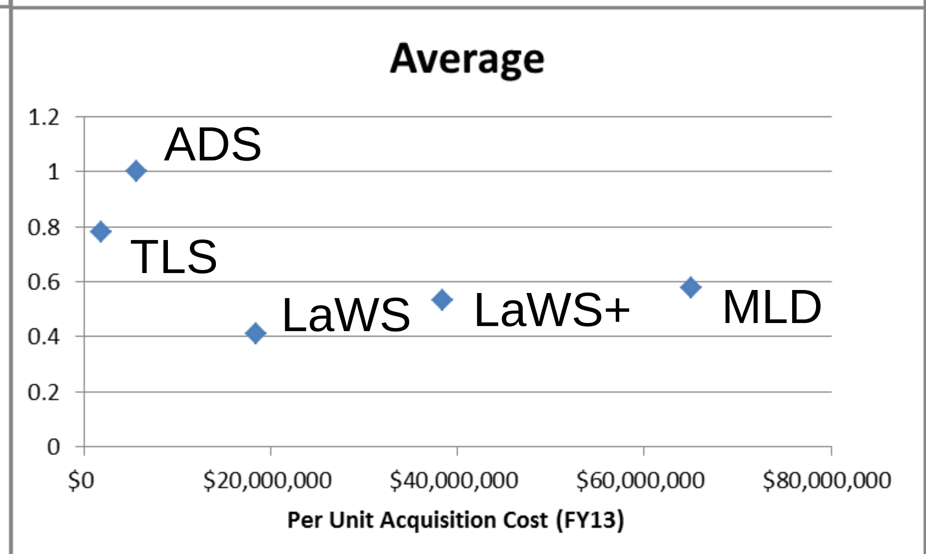
ADS
TLS
LaWS
LaWS+
MLD
$0
$20,000,000
$40,000,000
$60,000,000
$80,000,000
Per Unit Acquisition Cost (FY13)

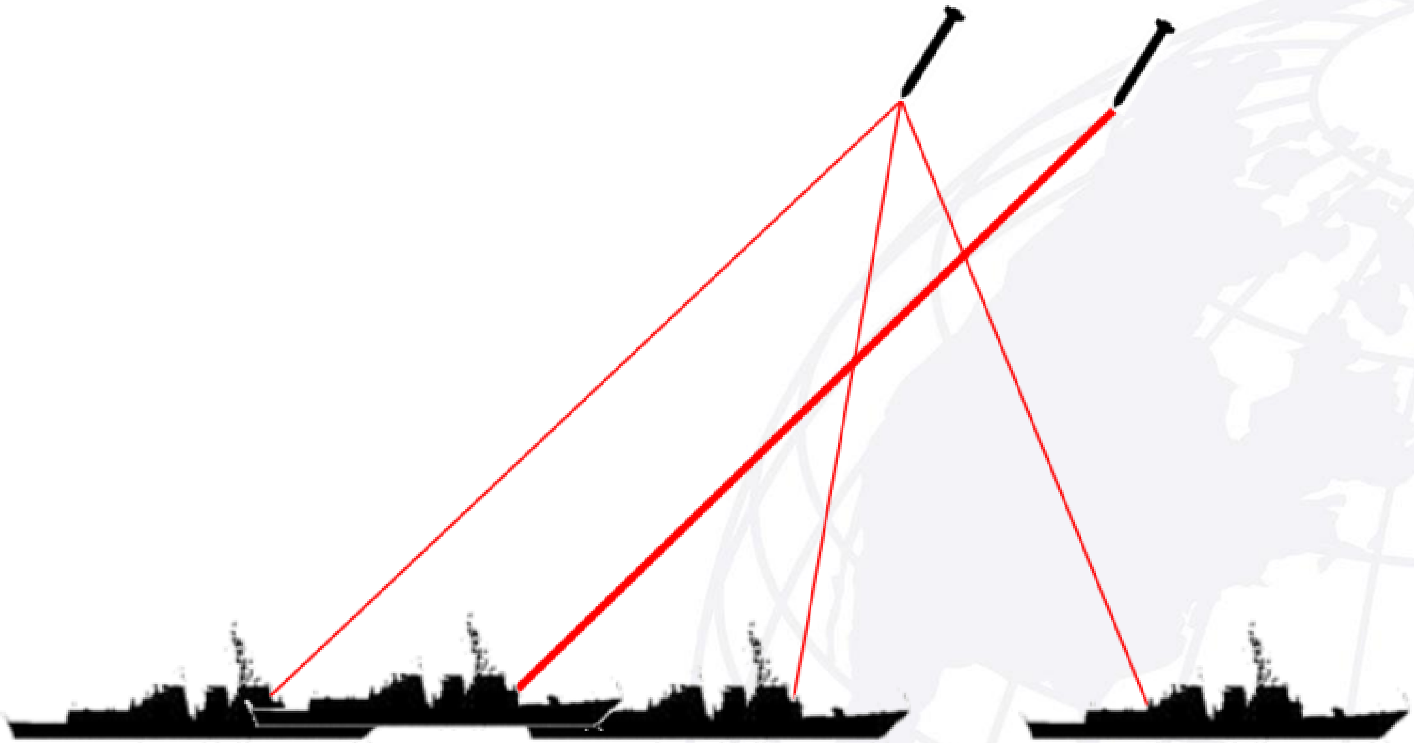

System Developer
1.2
1
0.8
0.6
0.4
0.2
0
ADS
TLS
LaWS
LaWS+
MLD
$0
$20,000,000
$40,000,000
$60,000,000
$80,000,000
Per Unit Acquisition Cost (FY13)


Average
1.2
1
0.8
0.6
0.4
0.2
0
ADS
TLS
LaWS
LaWS+
MLD
$0
$20,000,000
$40,000,000
$60,000,000
$80,000,000
Per Unit Acquisition Cost (FY13)

Conclusion

- Raw output power is not the determining factor
- TLS provides the most “bang for the buck”
- ADS fills a unique gap for AT/FP
- TLS and ADS are significantly cheaper than LaWS, LaWS+ or MLD
- TLS and ADS could both be installed for less than the cost of LaWS, LaWS+ or MLD

CONOPS



The Future

Future Recommendations

- Analyze feasibility of "stacking" TLS and compare to MLD/LaWS individual units
- Feasibility of TLS on organic shipboard aircraft
- Derive future requirements via mission-based analysis with GINA
- Add a cost X-type to the GINA model
- Use actual validated combat model to evaluate the conventional weapon performance
- Operational Availability

Questions ?