Aegis M&S Verification, Validation & Accreditation At NE&SS-SS

NAVMSMO VV&A TWG
20 March 2002 Workshop

Manager, Domain & Platform M&S

navy modeling & simulation management office

NAVMSMO

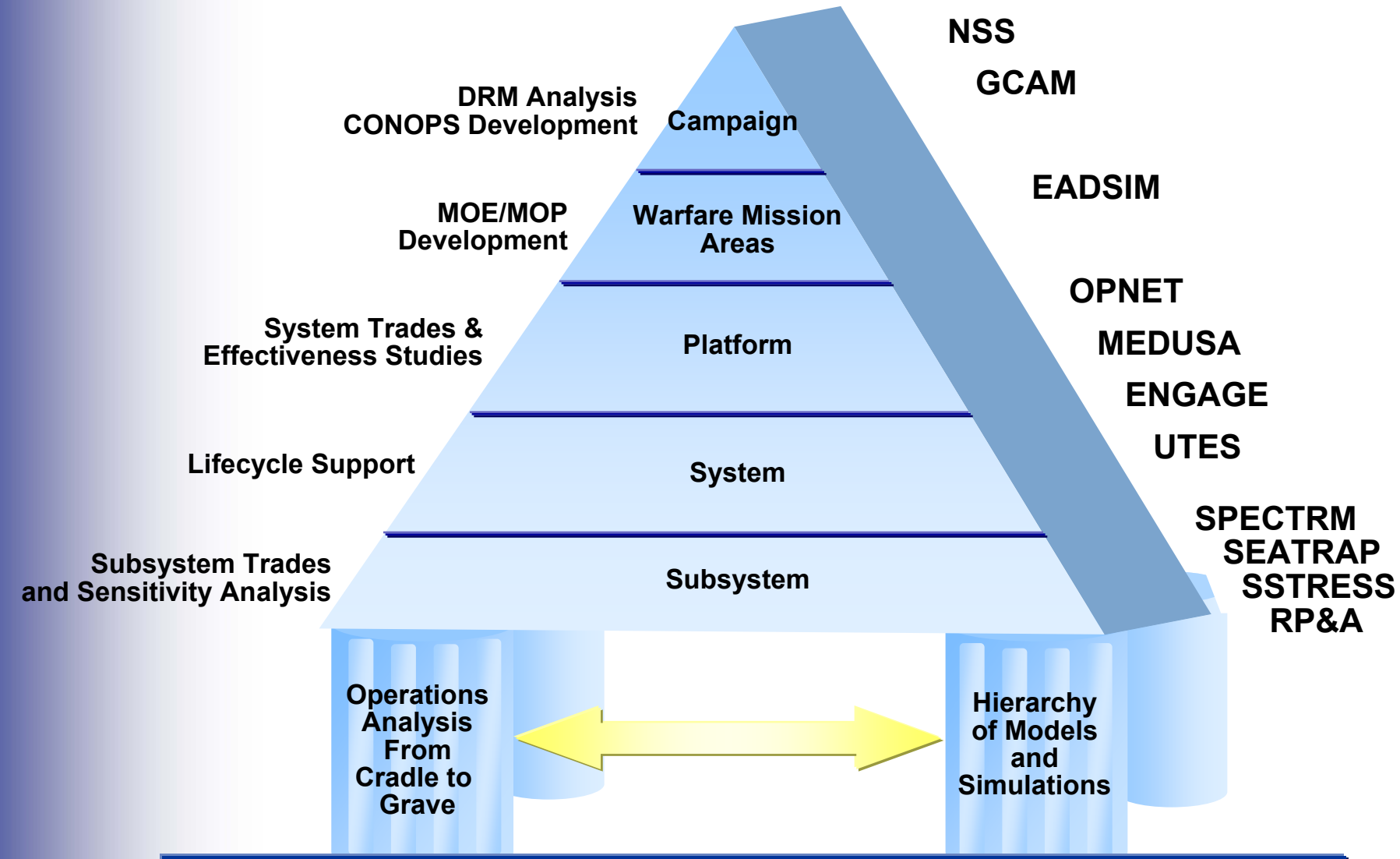
LOCKHEED MARTIN

Naval Electronics & Surveillance Systems - Surface Systems

Topics Covered

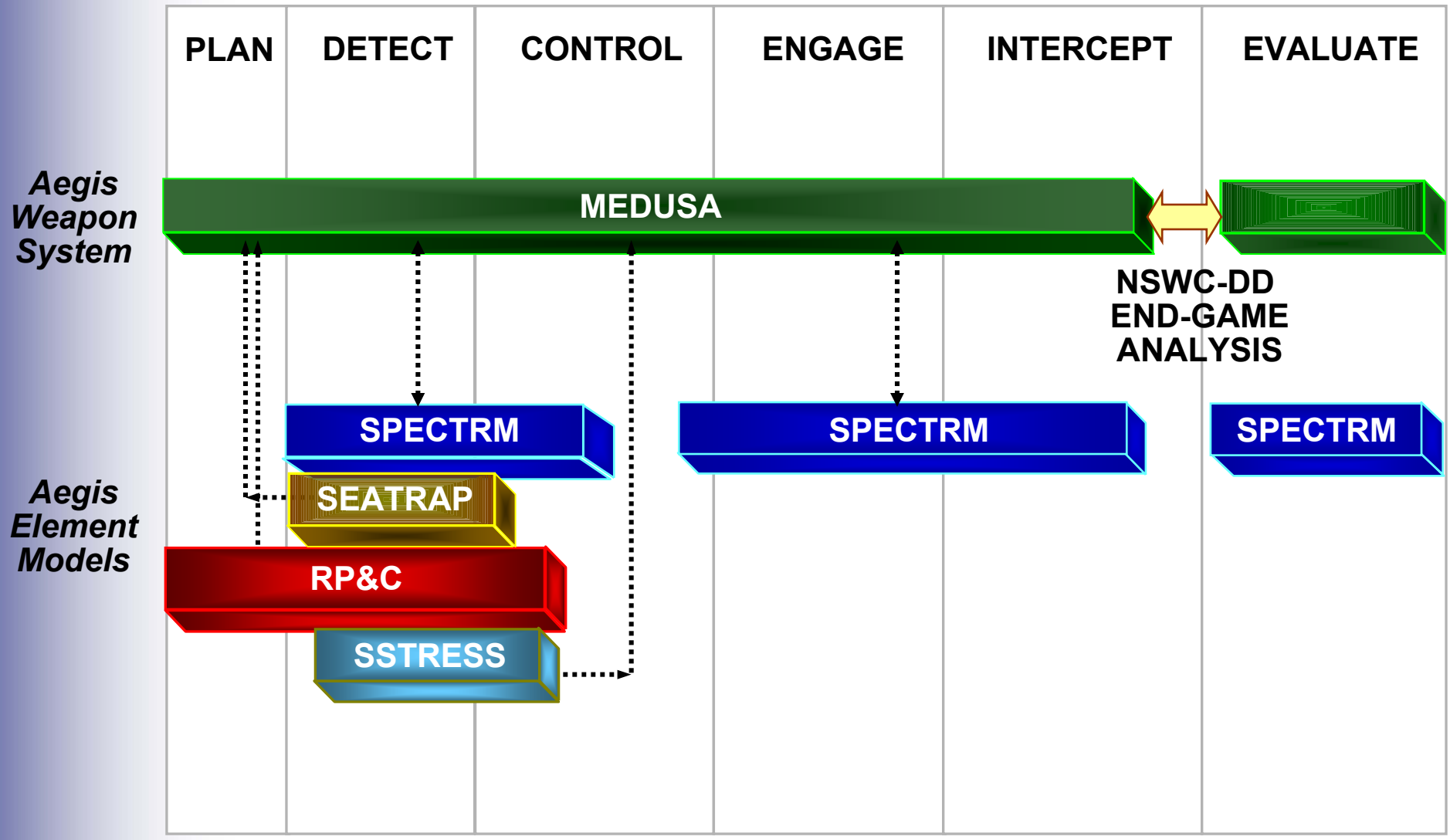
- PMS-400 Sponsored NE&SS-SS Aegis Platform and System M&S Capabilities and Usage
- Accreditation History / Process
- Tailored M&S Development and Testing Processes at NE&SS
  - Formal Software Development Process
  - Configuration Management
  - V&V Techniques
  - Sample V&V Plan Excerpts
    - Requirements Traceability
    - V&V Test Matrices
    - Acceptability Criteria
- Sample V&V Results
- VV&A Lessons Learned and Value-Added
- Conclusion and Discussion

NE&SS-SS Modeling, Simulation and Analysis Capabilities



NE&SS Has a 25 Year Heritage of Using M&S to Develop and Test Aegis

Navy-Approved Aegis Platform & System Models Developed by NE&SS-SS

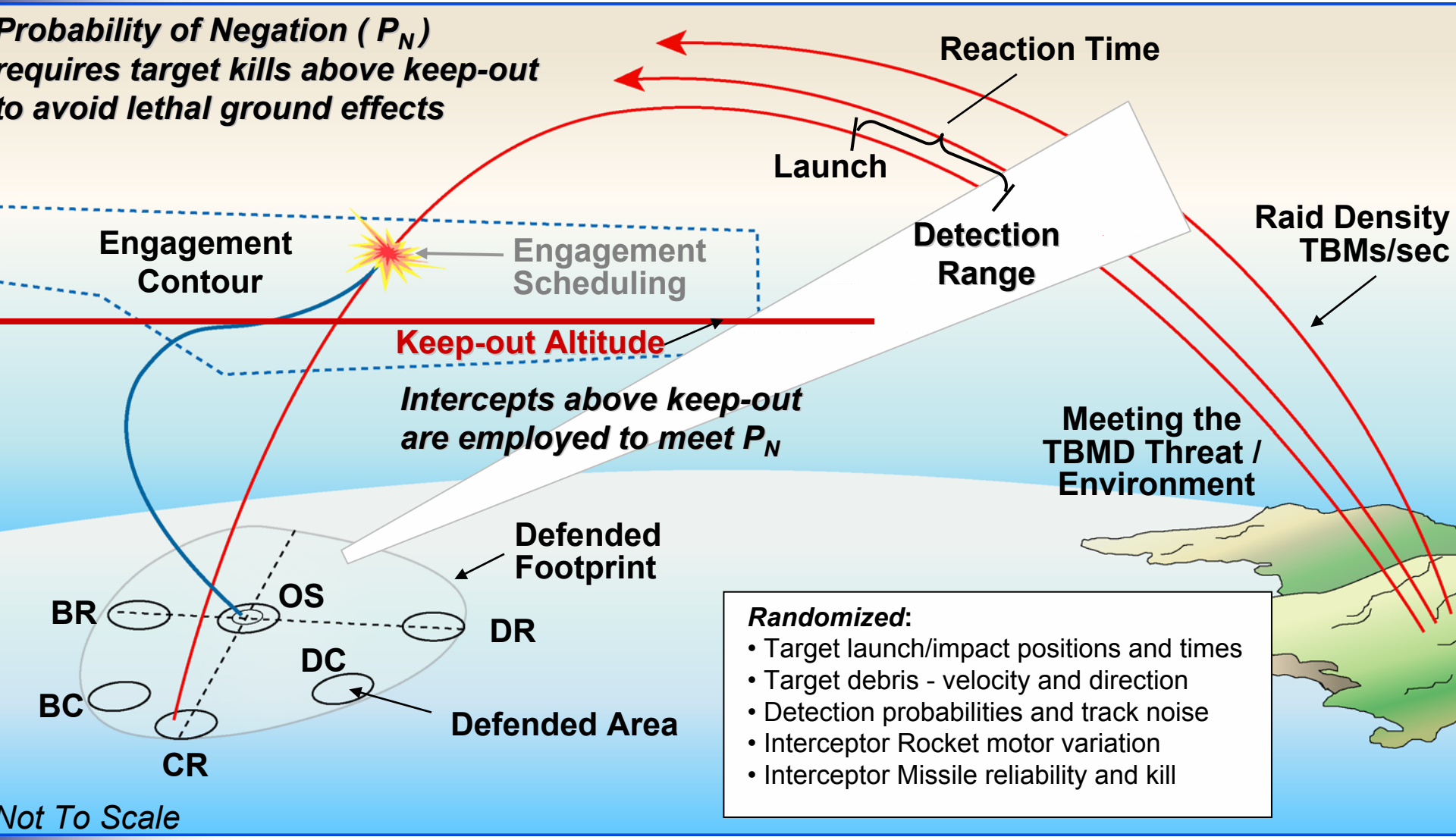


Aegis Weapon System M&S – MEDUSA

- **MEDUSA -- Multi-target Effectiveness Determined Under Simulation for Aegis**
- **A discrete event, Monte Carlo simulation of Aegis Air Defense**
- **System level model which enables A-Specification requirements performance verification of probabilistic key performance parameters**
- **Sound software development and design for accurate system representation and model stability**
- **Extensive Verification and Validation – *Accredited by PMS-400 for Area TBMD (1995, Current Effort Cancelled)***
- **Modeling is at various levels of fidelity across the detect-control-engage process**
  - **Evolves with system design – multiple versions supporting baselines**
  - **Shared code development with design engineers**
  - **Leveraged V&V and configuration management efforts**
  - **Over 200,000 lines of code contained in over 400 modules**

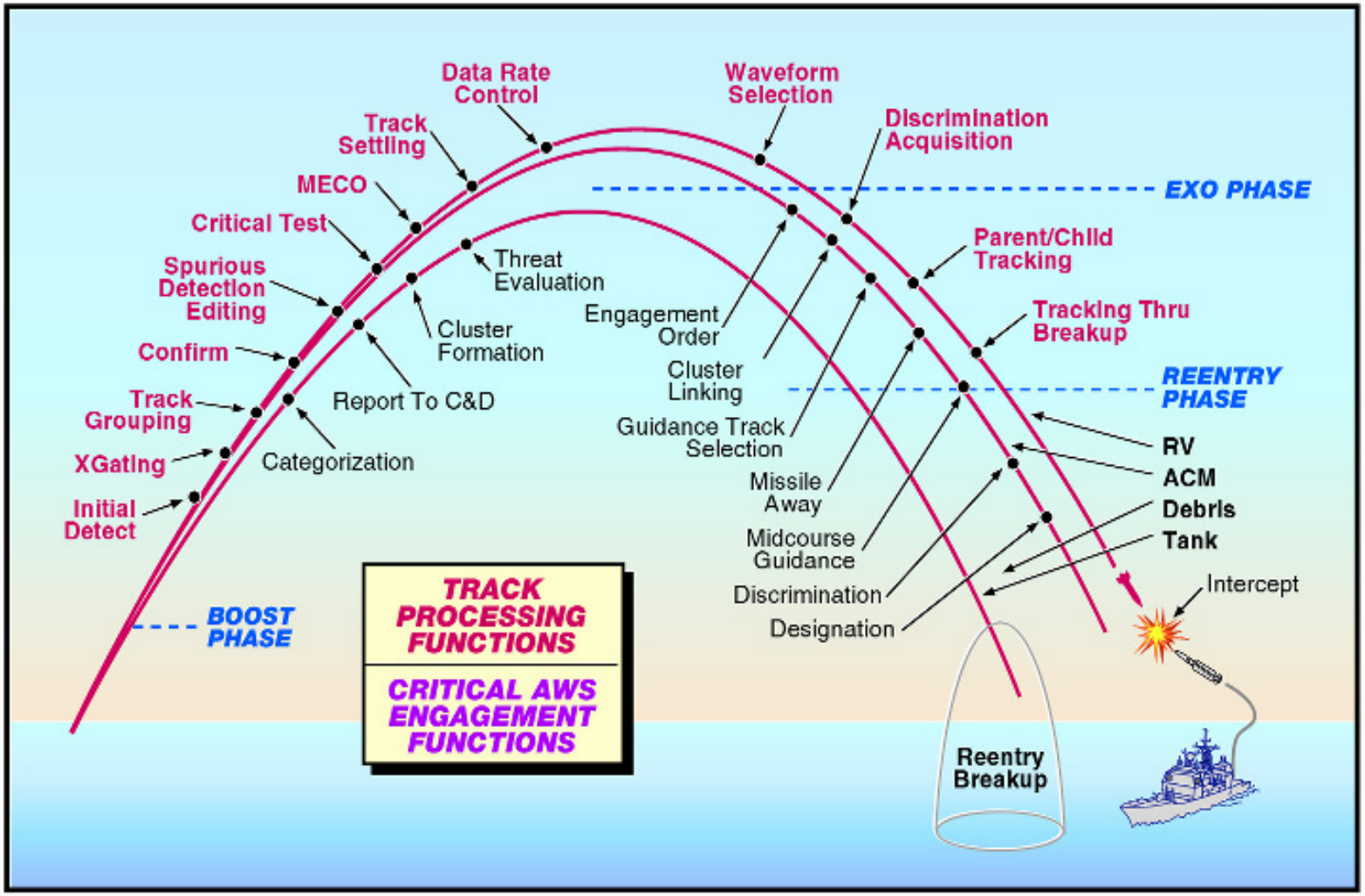
MEDUSA Has Had Over 85 Man-years of Development in Support of Aegis

MEDUSA Performance Verification Capability



MEDUSA Listed in A-Specification as Required to Conduct Performance Analysis Driven by P_N Top Level Requirement

SPY Search & Track Engagement Support Simulation

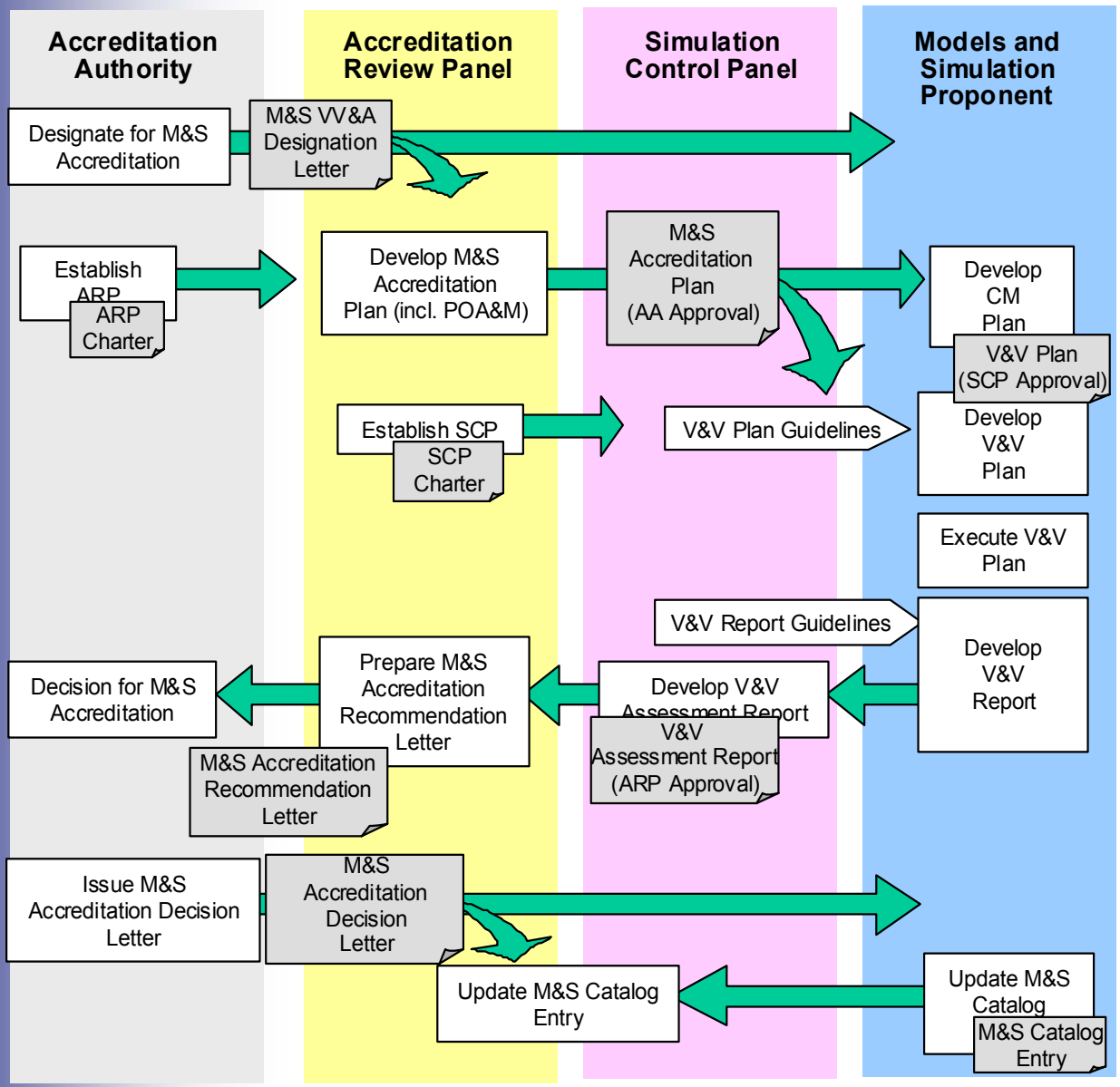


High Fidelity Radar Simulation Used to Support Design, Test and Evaluation of SPY Functionality for TBMD

Other M&S Tools Supporting Aegis

Model	Description / Usage	Features
SEATRAP SEArch and TRAnsition Program	↗ Radar Engineering Analysis ↗ Generic, non-Aegis ↗ Hi-fidelity detection & environmental models	↗ Signal to Noise (+Clutter+Jamming) ↗ Firm track range ↗ Detection probabilities ↗ Propagation Factor
SPECTRM System Performance Evaluator Comprising Target, Radar and Missile	↗ Dynamic, single-target simulation of the Aegis Weapon System ↗ Hi-fidelity WCS/MSL ↗ Aids Mid-Course Guidance Design	↗ 5 DOF Missile Emulator ↗ Tactical mid-course guidance and in-flight control ↗ WCS Filter / Missile Filter

Accreditation Process and History



Accreditation History

- 1995 - Previously Accredited by PMS-400 for Area TBMD
  - MEDUSA
  - SEATRAP
  - SPECTRM
- 2001 - Over 100 Verification Reports generated for Baseline 6.3 Demo Accreditation (Currently On-Hold)
  - MEDUSA
  - SSTRESS
  - ACSIS
- 2003 and Beyond - Planned accreditation in support of Baseline 6.3 and 7.1 Testing
  - MEDUSA
  - SSTRESS
  - 5 SPY-1D(V) 7P1 Models

MEDUSA Formal Software Development Process

- **Controlled, Iterative Requirements Definition**
- **Design Reviews** – use of approved techniques, traceable to requirements
- **Code Reviews** – standards, constructs, variables, conventions
- **Test Plan Reviews** – Unit, Element and Integration, Regression, Verification
- **Checklists** – Official Record
- **Configuration Management** – Controlled Environment and Library of source code and related documentation and data

- Other Attributes
  - Clearly Defined Roles and Responsibilities
  - Detailed M&S Development Plans
  - User-Community and Design Engineers' Involvement

Process Ensures the Necessary Discipline is Employed to Model Development

Software Development Process: Roles & Responsibilities

- Baseline Responsible Engineer (RE)
  - Manage Project - SOW, Project Plan, Schedule
    - Plan and track development and testing of all Change Requests
    - Coordinate with System Engineering and Operations Analysis
  - Ensure policies and procedures are followed
    - Create and monitor Project Development Folder (PDF)
- Software Engineer (SE)
  - Maintain knowledge of area of responsibility & changes to tactical design. Establish working relationships with System Engineering and Analyst counterparts
  - Implement Change Requests
  - Follow Software Development Checklists
  - Follow CM Procedures
  - Update PDF

Software Development Process: Design Reviews

- Design Review Package
  - Requirements documents
  - Method of implementation using approved design techniques
- Criteria for Design Review
  - Technical Adequacy
    - Modularity, complexity, clarity of interfaces
    - Adherence to requirements
  - Understandability of Design Package
  - Use of Approved Design Techniques
    - OOD - e.g. Unified Model Language (UML)
    - Functional - flowcharts, DFDs, pseudocode
  - Degree of Completeness - step/task breakdown
  - Traceability / Consistency - mapping of requirements to functions
  - Test Plan - Unit, Element Integration, Regression testing
- Design Review Record - Satisfactory / Unsatisfactory / Not Applicable, Comments and Action Items

Software Development Process: Code Reviews

- Criteria
  - Design Review Record Action Items Complete
  - Program Modularity
  - Moderate Size of Code Aggregates
  - Limited & Appropriate Use of Global Variables
  - Language Construct Standards
  - Naming Conventions
  - Comments and Readability
  - Abstracts with Reference to Specifications / Requirements
  - Appropriate Initialization
- Code Review Record - Satisfactory / Unsatisfactory / Not Applicable, Comments and Action Items

Software Development Process: Test Plan Reviews

- Test Plan
  - Document Requirements (for SC's)
  - Test Instruction/Description
  - Expected Results
  - Actual Results
  - Pass/Fail
- Unit Test - all requirements / problems covered
- Element & Integration Test - all elements covered (including expected outputs)
- Regression Test
  - All program pathways are traversed
  - All output files are covered
  - Monte Carlo runs

Software Development Checklist

- Software Development Procedures (Change Request / Problem Report)
  - Source (requirements) listed
  - SOW reference
  - ROM incorporated into schedule
  - Engineering Load & corrections to defects
  - Develop Design & Conduct Review
  - Implement Design (successful compiling, linking & preliminary confidence testing)
  - Code Review
  - Test Plan Review
  - Testing - Unit/E&I
  - Merge applicable files
  - Regression Testing using Purify
- Check-in to Production Branch & email appropriate developers
- Update README
- Update applicable .inputs & .mdats
- Update appropriate sections of CR/PR
- Perform Regression Testing
- Note other baselines affected
- Update PDF

Iterate via Development Branch To Support Rapid Prototyping

Configuration Management

- Clearcase Versioned Object Base (VOB)
  - Provides Controlled Environment for Development, Management and Releasing
  - Controlled Library of source code, makefiles, headers, and related data and documentation stored under CM
  - Branches maintained for each baseline
    - Limited “check-in” priveleges – Project / Element Leads, CM Manager
    - Main - Formal Releases
      - Full Software Development Process applied
      - Fully Verified but Validation still required
      - Eligible for production runs (customer)
    - Development - Interim Releases
      - Reproducible (all files checked-in) but not fully “processed”
      - Problem Reports may be submitted
    - Engineering Loads
      - Built from personal views - may be incomplete or deviate from spec
      - No formal testing or process required - Not reproducible
    - Rules and Triggers to regulate and automate transactions
    - Database record of comments, transactions, history of builds
    - Labels used to indicate verification status
- Archival of all programs, libraries and data applicable to any analysis effort

Verification and Validation Processes Per Recommended Practices

- Verification Only
  - Documentation Review – compare spec requirements to M&S code
  - Formal Peer-Level Reviews / Walk-throughs

- Verification and Validation
  - Subject Matter Expert Reviews
    - Verification – Design engineers routinely participate in code reviews
    - Validation – Evaluate model performance *versus* expected results
  - Comparison to other M&S – for validation must use other ***validated*** models
  - Functional Decomposition and Testing
    - Verification – Develop stand-alone models to isolate specific functions for testing / comparison with other models, tactical system, or spec
    - Validation – Comparison with modules from the tactical system using real-world representative data / scenarios
  - Test Results – End-to-End Testing (Comparing to Tactical Systems)
    - CSEDS and other laboratories
    - Missile test flights (WSMR)
    - At sea exercises (CSSQT and others)

Our Verification Process Ensures Model Reflects Design
Our Validation Process Ensures Model Reflects Real World

Sample Requirements Traceability (Excerpt from V&V Plan)

SRD Requirement	A-Spec System Requirement	Key M&S Requirements (Accreditation Plan)	Other M&S Requirements (Accreditation Plan)
3.1.4 Erroneous Engagements	3.2.1.6.c Erroneous Engagements	3.2 MEDUSA TBM Generator 3.3 MEDUSA SPY Model	3.4 MEDUSA C&D Model 3.5 MEDUSA WCS Model 3.6 MEDUSA Missile Model
3.3.2.3 Wide-azimuth Engagements	3.2.1.10.2.c Wide Azimuth Engagements	3.3 MEDUSA SPY Model 3.4 MEDUSA C&D Model	3.2 MEDUSA TBM Generator 3.5 MEDUSA WCS Model 3.6 MEDUSA Missile Model
3.1.2 Negation Probability	3.2.1.11.2.2.a TBMD Negation Prob.	3.2 MEDUSA TBM Generator 3.3 MEDUSA SPY Model 3.4 MEDUSA C&D Model 3.5 MEDUSA WCS Model 3.6 MEDUSA Missile Model	N/A
3.1.1. Defended Footprint 3.1.1.2 Inl	3.2.1.11.2.2.b TBMD	3.2 MEDUSA TBM Generator	
3.1.1.1 Ke			or odel ile Model
3.1.1.3 Defended Areas	Defended Areas		TBM Generator A SPY Model USA WCS Model EDUSA Missile Model
3.1.3 P_{ssek}	3.2.1.11.2.2.e Single Shot Eng. Kill	3.2 MEDUSA TBM Generator 3.3 MEDUSA SPY Model 3.4 MEDUSA C&D Model 3.5 MEDUSA WCS Model 3.6 MEDUSA Missile Model	N/A
3.2.1.3 Raid Density	3.2.1.11.2.2.i TBMD Raid Density	3.4 MEDUSA C&D Model 3.5 MEDUSA WCS Model 3.6 MEDUSA Missile Model	3.2 MEDUSA TBM Generator 3.3 MEDUSA SPY Model

Map Top Level Requirements to System Requirements to M&S Requirements

Sample Verification Test Matrix (Excerpt from V&V Plan)

MEDUSA REQUIREMENTS					VERIFICATION TECHNIQUES									
MEDUSA Accreditation Plan M&S Requirement	Element	V&V Requirement Number	Function	Fidelity Required	Subject Matter Expert Review	Comparison to Other Models	Functional Decomp & Testing	Documentation Review	Design Walk-Through	Flow Diagram Review	Code Walk-Through	End-to-End Testing	Acceptability Criteria Details
3.3 MEDUSA SPY Model													
	S	1	Hardware (Signal Processor)	M		P							In SSTRESS
	S	2	Waveform Selection Logic	H		P							In SSTRESS
	S	3	Waveform Min/Max Range	H				P					
	S	4	Pre-Dwell Scheduling Function	M				P				S	
	S	5	Real-Time Dwell Scheduling Function	M				P				S	
	S	6	Frequency Management Function	L		P							Very low Fidelity in SSTRESS
	S	7	Beam Stabilization Function	L		P							Very low Fidelity in SSTRESS
	S	8	Cueing	L	P								
	S	9	Search Management	H		P							SSTRESS
	S	10	Scan Rate Frametime	H		P							in SSTRESS
	S	11	Search Lattices (RP&A)	H		P					S		
	S	12	Individual Beam Scheduling	H		P							in SSTRESS
	S	13	Confirmation Dwell Processing	H		P							SSTRESS
	S	14	Det Probability (StoN, Radar Range,...)	M		P							TRESS
	S	15	Detection Processing Function	H		P							ESS
	S	16	Propagation	M		P							
													STRESS & tactical
	S	27	Cluster Formation	H	S	S		P	S	S	S	S	
	S	28	Cluster Linking	H	S	S		P	S	S	S	S	
	S	29	Categorization (interface with C&D)	H	S	S		P	S	S	S	S	
	S	30	Discriminiation	H	S	S		P	S	S	S	S	
	S	31	Designation (interface with WCS)	H	S	S		P	S	S	S	S	
	S	32	MECO	H		P							in SSTRESS
	S	33	Multiple Object TBM Processing	H		P							in SSTRESS
	S	34	Resource Loading (dynamic computations)	M		P		S				S	Compared,more to be done
	S	35	Missile Redirect	H		P		S				S	in SSTRESS
	S	36	C&D User Services Function	M	P								
	S	37	WCS User Services Function	M	P								
	S	38	Missile Communications Function	L	P								
	S	39	Interceptability	H	P		S	S					
	S	40	SPY - TBM Separating Targets	H	P								
	S	41	Track Noise	M	P								
	S	42	Target - separating components	L				P					Will be H for Study 3
	S	43	Target - debris	H				P					

Map M&S Requirements to V&V Requirements to Specific Acceptability Criteria

Note: Acceptability Criteria colun is to indicate additional specific criteria over and above general criteria associated with each verification technique (slide 21)

Sample Validation Test Matrix

MEDUSA Accreditation Plan M&S Requirement	MEDUSA Functional Area	Validation Requirement Number	MOP/MOE Parameters	Acceptance Criteria
3.3 MEDUSA SPY Model				
	SPY	1	Smoothed X, Y, Z position	Compares within 10% of SEG input data
	SPY	2	Smoothed X, Y, Z velocity	Compares within 10% of SEG input data
	SPY	3	Detection time	Passing T-Test, @ 95% confidence level (CL), Note 1
	SPY	4	Detection range	Passing T-Test, @ 95% CL, Note 1
	SPY	5	MECO declaration time	Passing T-Test, @ 95% CL, Note 1
	SPY	6	Transition to Track (TTT) time	Passing T-Test, @ 95% CL, Note 1
	SPY	7	Time of missile divert	Passing T-Test, @ 95% CL, Note 1
	SPY	8	Engage Quality determination time	Passing T-Test, @ 95% CL, Note 1
	SPY	9	Re-entry flag set time	Passing T-Test, @ 95% CL, Note 1
	SPY	10	Discrimination complete flag	Passing T-Test, @ 95% CL, Note 1
3.4 MEDUSA C&D Model				
	C&D	1	Smoothed X, Y, Z position	Compares within 10% of SEG input data
				input data
	WCS	5	Keep-out time to launch (KTL)	Passing T-Test, Note 1
	WCS	6	Engagement Contour Class	Passing T-Test, Note 1
3.2 MEDUSA TBM Generator, 3.3 MEDUSA SPY Model, 3.4 MEDUSA C&D Model, 3.5 MEDUSA WCS Model, 3.6 MEDUSA Missile Model				
	AWS	1	Commit time	Passing T-Test, @ 95% CL, Note 1
	AWS	2	Launch time	Passing T-Test, @ 95% CL, Note 1
	AWS	3	Intercept time	Passing T-Test, @ 95% CL, Note 1
	AWS	4	Intercept down range position (X)	Passing T-Test, @ 95% CL, Note 1
	AWS	5	Intercept cross range position (Y)	Passing T-Test, @ 95% CL, Note 1
	AWS	6	Intercept altitude (Z)	Passing T-Test, @ 95% CL, Note 1
	Note 1. Assumes CSEDS data is statistically significant. If not, MOP/MOE must fall in the interval [min, max] from 500 MEDUSA replications.			

Map M&S Requirements to V&V Requirements to Specific Acceptability Criteria

Note: Acceptability Criteria column is to indicate additional specific criteria over and above general criteria associated with each verification technique (slide 21)

Sample General Acceptability Criteria

Primary V&V Techniques	Acceptability Criteria
Subject Matter Expert Review (applies to verification and validation)	Model sufficiently characterizes corresponding system functionality as verified by formal, documented review with system engineer, which may consist of design/code walk-throughs, flow diagram reviews, symbolic debugging, and comparison of model output with system engineer's expectations.
Comparison to other models and simulations (applies to verification and validation)	Demonstrated concurrence of results of controlled testing of equivalent function in another independently verified model, factoring in differences in the models' required fidelity. Acceptance criteria may be explicit, i.e. model results pass a statistical hypothesis test at some confidence level, symbolic outcome is identical, etc.; or acceptance may be sufficient concurrence for intended use via subject matter expert review of model outputs.
Functional Decomposition and Testing (applies to verification and validation)	Demonstrated concurrence of results where extracted function is tested in stand-alone mode and compared against measured outputs from other verified models or from tactical measurements (CSEDS). Acceptance criteria involves explicit concurrence, i.e. model results pass a statistical hypothesis test at some confidence level with the measured data from other models and simulations or from tactical data.
Documentation Review (applies to verification)	Requirements met as illustrated by formal review of model functionality (code, flow diagram, or other models and simulations, design documentation) versus requirements documentation (e.g. design spec, model change request).
Design Walk-Through (applies to verification)	Design matches expectations as demonstrated via formal review between model proponent and intended user (similar to documentation review but requires involvement of intended user).
Flow Diagram Review (applies to verification)	Model flow matches corresponding system flow as demonstrated by cause-effect graphing, control analysis, data flow diagrams, structural analysis, procedural flowcharts, pseudo-code, etc. (note - this may be part of Documentation Review, Design / Code Walk-Through techniques as well)
Code Walk-Through (applies to verification)	Code-level implementation is acceptable as determined via detailed review by model proponent of algorithms for efficiency, correctness, completeness and adherence to coding standards. If function is emulated this review may involve comparison with design spec and/or tactical code.
End-to-End Testing (applies to verification and validation)	Standard testing of model version is required prior to release and verifies at a high level that MEDUSA matches expected system behavior.

Criteria for Identifying Candidate Stand-Alone Models (Functional Decomposition)

- Value-added to sponsoring Program Office and Navy in demonstrating system meets requirements
- Equivalent V&V not possible with end-to-end runs or other methods
  - Is I/O already available in current files?
  - Can the debugger be used to inject values and compare output?
- Fidelity / Compatibility with CSEDS and Workbench Data Analysis Suite
- Complexity of interface and interdependency with other functions
  - Can function be called with minimal overhead and no code changes?
- Size of module (SLOC) - can this be captured at a higher level? Are multiple layers warranted?
- Other uses - value-added as an analysis tool, debugging tool, ...

Sample Verification Report Template

I. References

II. Overview of Function

III. Variable Passed

IV. V&V Methodology

V. Model (Mathematical)

VI. Assumptions/Limitations

VII. Comments

VII. Functional Diagram

IX. Code

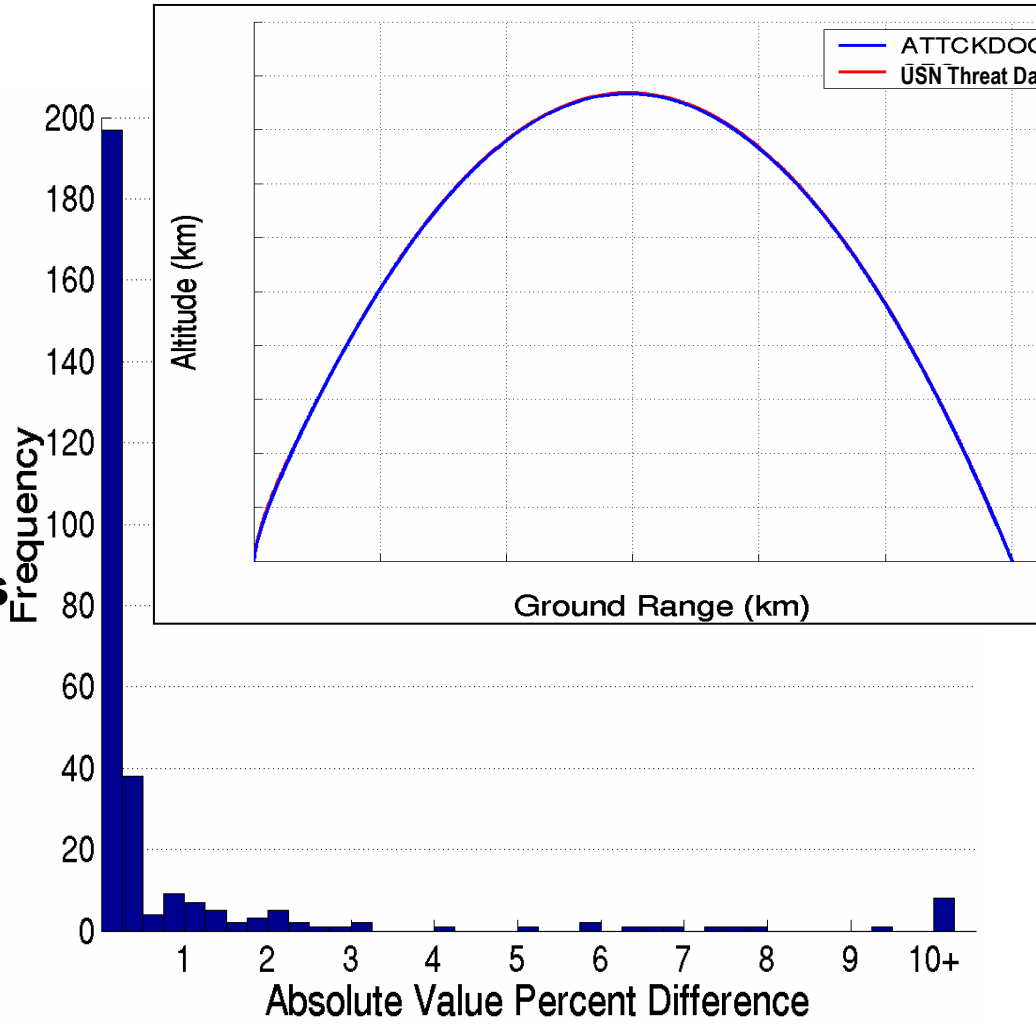
X. Test Programs

XI. Data Analysis

XII. Output/Plots

Sample Validation Comparison
MEDUSA Threat Model (ATTCKDOG)vs. SEG

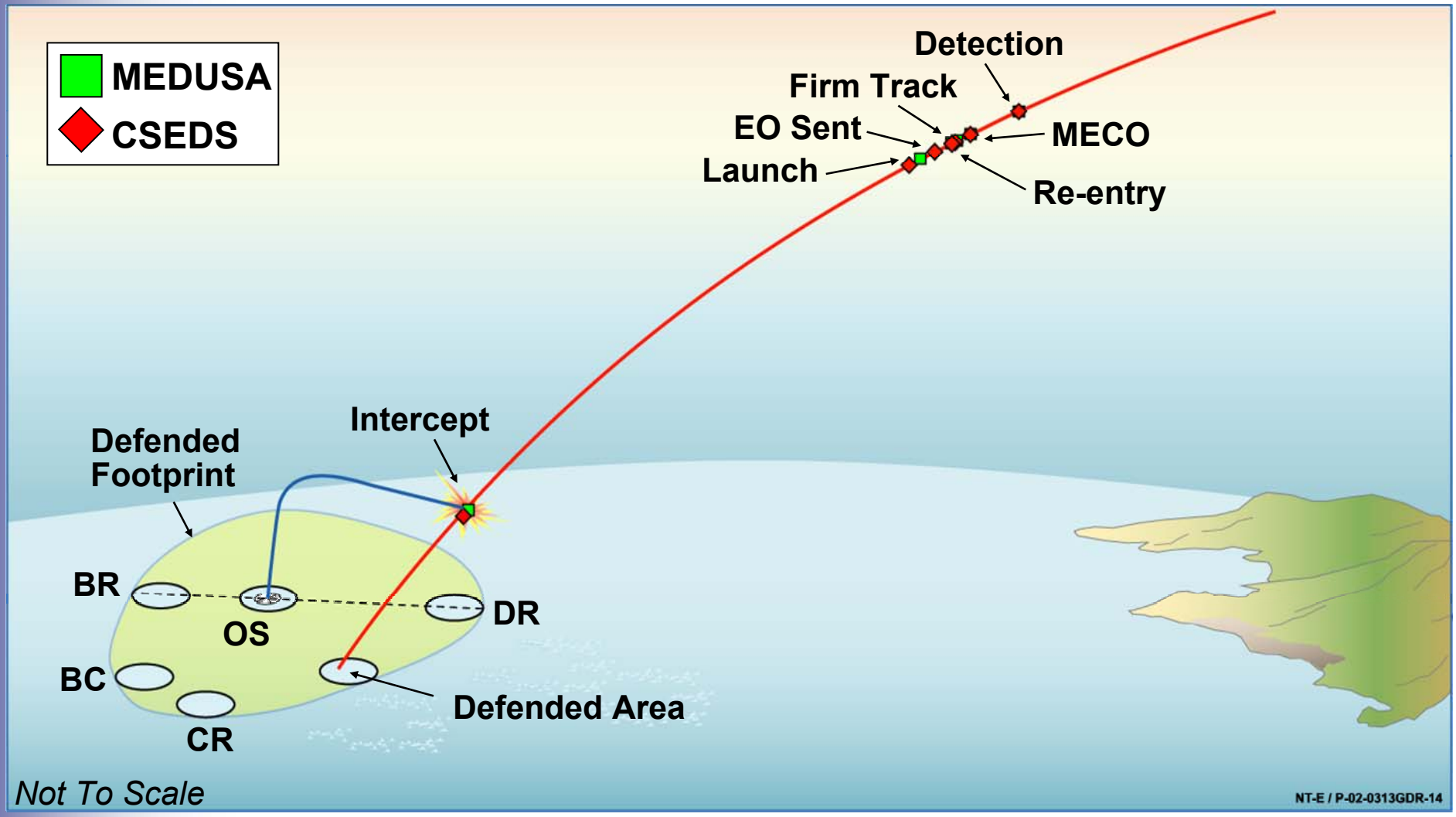
- Critical trajectory parameters are within 0.5% of SEG data (Navy Approved Threat Definition)
- 95% within 5.0% of SEG data (VV&A Criteria)
- MEDUSA runs with both ATTCKDOG and U.S. Navy Data - K-S test shows differences indistinguishable from statistical fluctuations
  - Event timelines similar (detection range, intercept altitude, salvo spacing)
  - Differences in P_N are within 1 sigma for all threats



Extensive Comparisons Conducted to Provide Necessary V&V Testing for PV Studies with Statistical Confidence

Sample Timeline Validation

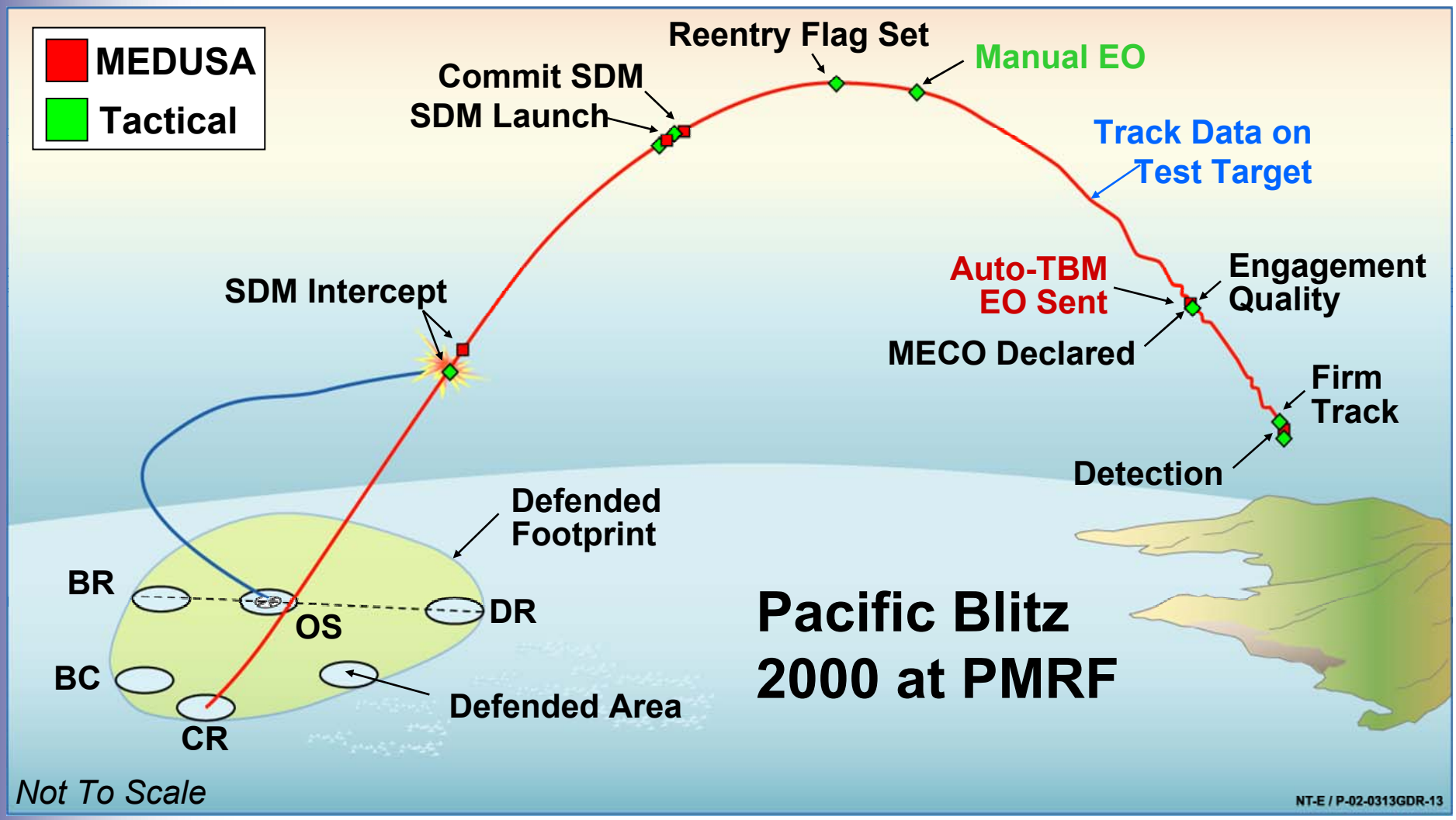
MEDUSA versus CSEDS (Tactical) Comparison



MEDUSA Initial Validation Against CSEDS Provides Excellent Preliminary Comparisons

Tactical Post-Test-Event Comparisons

Aegis Linebacker TBMD Live Event Engagement Timeline



Post-Event MEDUSA Comparison with Tactical Test Event Data is Virtually Identical

VV&A Lessons Learned

- Underestimated Cost and Schedule Impacts
  - Formal S/W Development Process relatively new and additional VV&A documentation was costly
  - Unanticipated model and tactical issues uncovered due to extensive V&V testing
- Improved execution / training needed – technical writing skills, design & code reviews and development of adequate test plans
- Use of automated test tools and scripts proved highly beneficial for repeated V&V testing and regression testing
- The need to better coordinate V&V testing with M&S development is critical – delays in V&V schedule mostly attributed to both tactical and model functionality not being available on-time to begin testing
- Accreditation Authority needs to work with other programs sponsoring M&S development to ensure functionality to be accredited is in-place well in advance of accreditation review
- Lead time for accrediting functionality yet to be developed is critical (i.e. at least 2 years prior to Operational Testing)

VV&A Value-Added

- Supplements Formal S/W Development Process
  - Improved discipline
  - Increased documentation / traceability / metrics
  - Helps position for SEI/CMM goals
  - Improved quality of product
- Functional Decomposition supports modular (more reconfigurable) design and facilitates post-event analysis
- Higher confidence in stability and accuracy of M&S tools, which is critical as the need to be interoperable in a distributed simulation environment grows
  - Cleaner and more standardized interfaces which support migration to HLA and other efforts to integrate tools / objects
- Significant model and tactical system problems / issues are uncovered through the accreditation process
- Reduction in Live Testing Requirements and higher confidence in using M&S in areas of capability that cannot be tested easiy on the range or in the laboratory

Conclusion and Discussion

- Lockheed Martin NE&SS-Surface Systems has a 25 year heritage of providing modeling and simulation support to the Aegis Program
- PMS-400-sponsored M&S tools developed by NE&SS-SS experience a high degree of verification and validation testing and some have been exposed to the accreditation process
- The VV&A process has improved the quality of the M&S products at NE&SS as well as the framework and processes that support them
- Formal accreditation is still not established as an integral part of the life cycle process, and much work needs to be done to <u>align program schedules and finances to support this requirement</u>

NE&SS-SS is Prepared With the Tools & Processes to Support The Navy's Growing VV&A Requirements

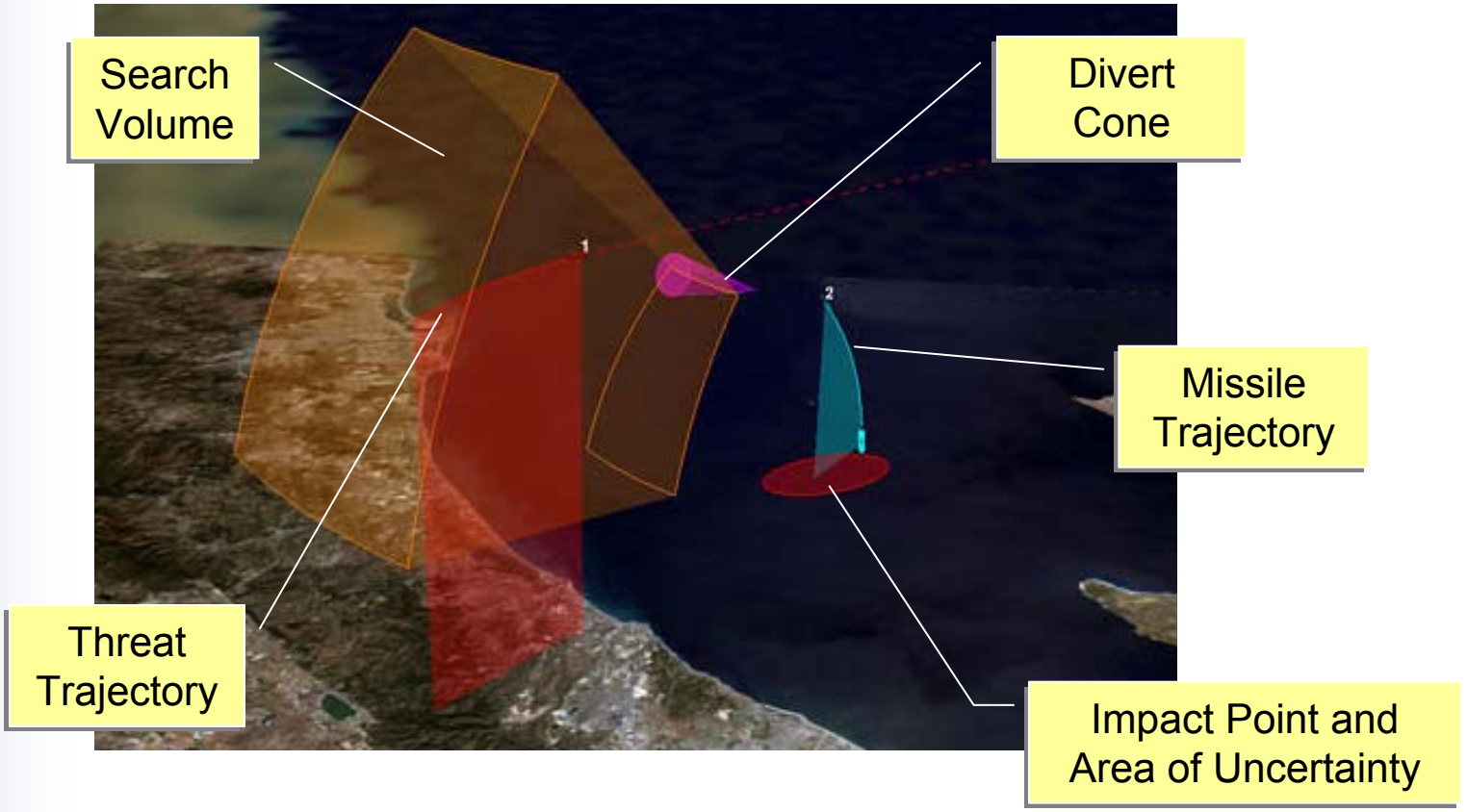
Backup Slides

MEDUSA Functionality

- SPY
  - TBMD Search Lattices from Prototype RP&A
  - TBMD & AAW Track Noise / Filtering
  - HS / AHS (AAW)
  - MTI / STC / TIP (AAW)
  - RPO Propagation Model
  - Resource Loading
  - Critical Track Processing
  - MECO Logic
  - Characterization and Discrimination
- Missiles
  - TBMD - SM-3, SM-2, Blk IV & IVA (SPECTRM equivalent missile model)
  - Interoperability with Raytheon SM-3 HIL/CIL
  - MK 72, MK 104, & MK137 rocket motor variation
  - AAW - SM-2 Family, ESSM
- Environment - Chaff, Land and Sea Clutter
- Target Model (Unitary and Separating)
- C&D
  - TBMD & AAW Track Filtering
  - Interceptibility
  - Footprint Doctrine
  - Area of Uncertainty (AOU)
  - PEQ & EQ Queue Processing
  - Characterization
- WCS
  - Engageability & Engagement Volumes (all missiles)
  - Mid-Course Guidance
  - Ballistic Intercept Prediction
  - Missile Selection Logic
  - Launch Scheduling
  - Illuminator Scheduling
  - TBMD & AAW Track Filtering
  - Spaced Salvo / Multi-Salvo Logic
- VLS
  - Independent Launchers
  - Inventory
  - Timing / Processing

MEDUSA is a High Fidelity Representation of AWS as Required by U.S. Navy to Support Performance Verification and System T&E

MEDUSA / Infoscene Visualization in Support of TBMD Analysis for U.S. Navy



Visualization illustrates critical factors throughout engagement sequence:

- **Extent of the search volume for detection**
- **Variation in impact point prediction and effect on doctrine qualification**
- **Intercept geometry and the ability for interceptor to divert**