



## M&S at NASA

Martin J. Steele, Ph.D.

November 20, 2009

## Overview



- Constellation's Discrete Event Simulation
  - DES ?
  - Analysis
- NASA's Modeling & Simulation Standard
  - Analysis/Results Focused



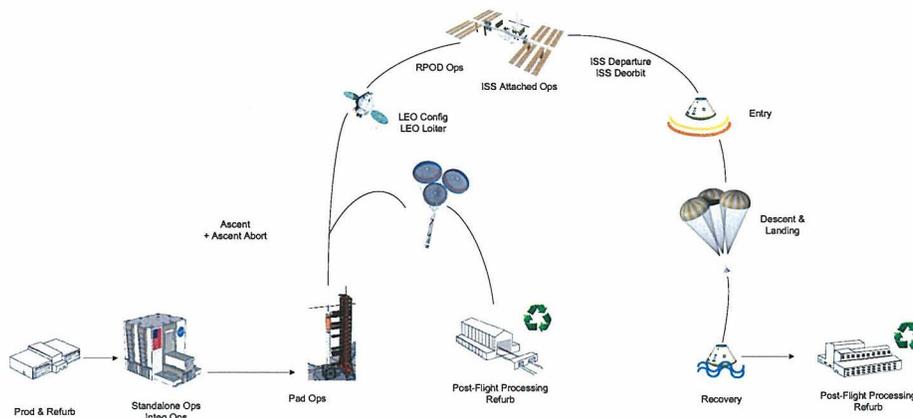
## CONSTELLATION'S DISCRETE EVENT SIMULATION

### Discrete Event Simulation

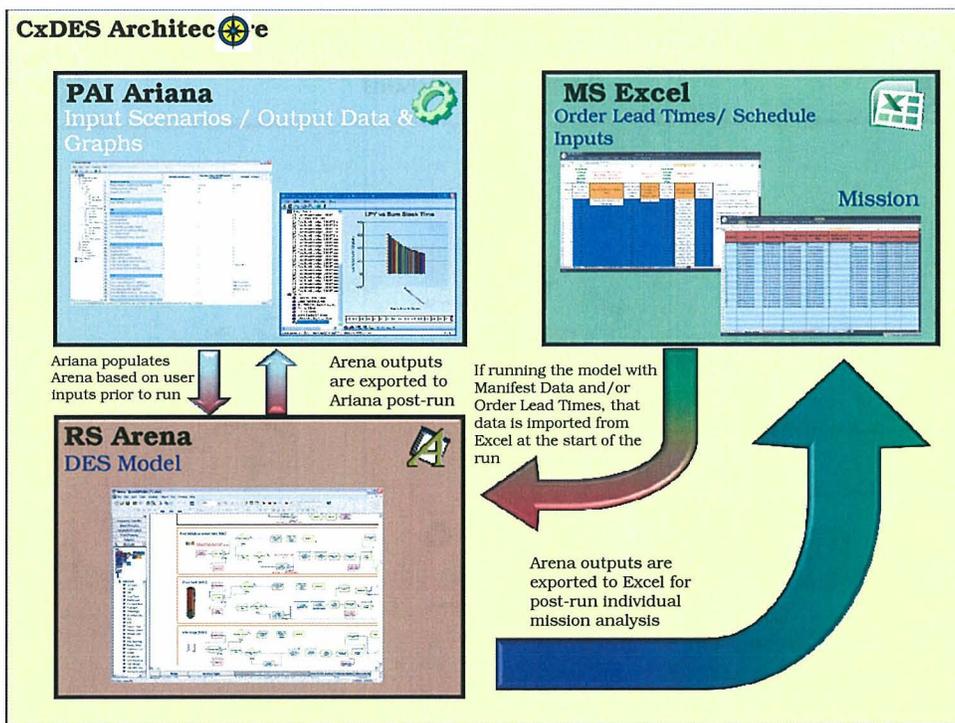


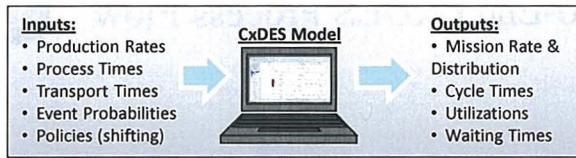
- Definition:
  - Process & System Analysis, through time-based & resource constrained probabilistic simulation models, providing insight into operational system performance.
- “Competing” types of Analysis
  - Spreadsheets
  - Scheduling Software
  - Probabilistic Risk Assessment

# Current End-to-End CxDES Process Flow



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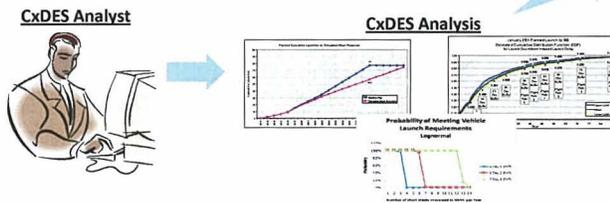




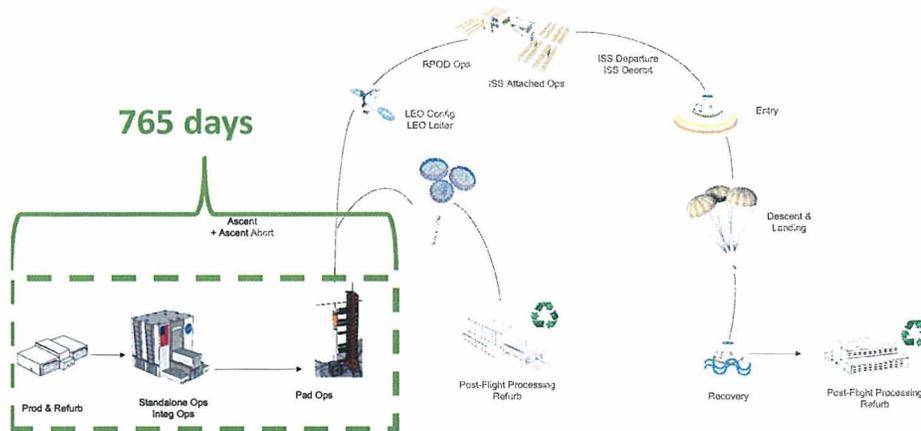
# DES Analysis Cycle

**Understanding System Performance**

- Critical Path
- Risk to Launch Rate
- Margin

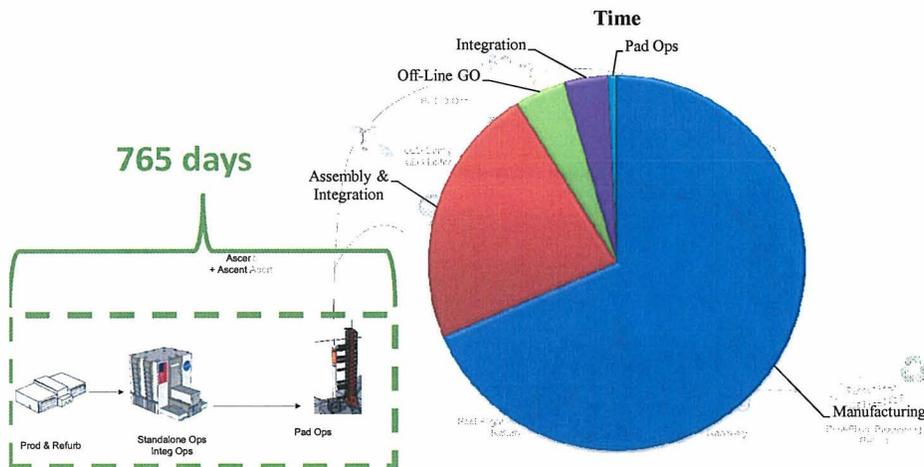


## Manufacturing through Launch Duration Comparisons





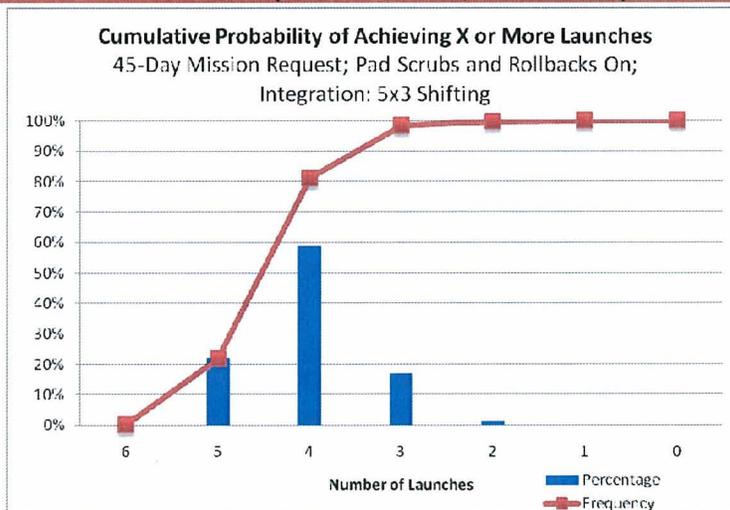
## Manufacturing through Launch Duration Comparisons



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## Ares I/Orion shall be able to launch every 45 days Baseline (With Scrubs/Rollbacks)

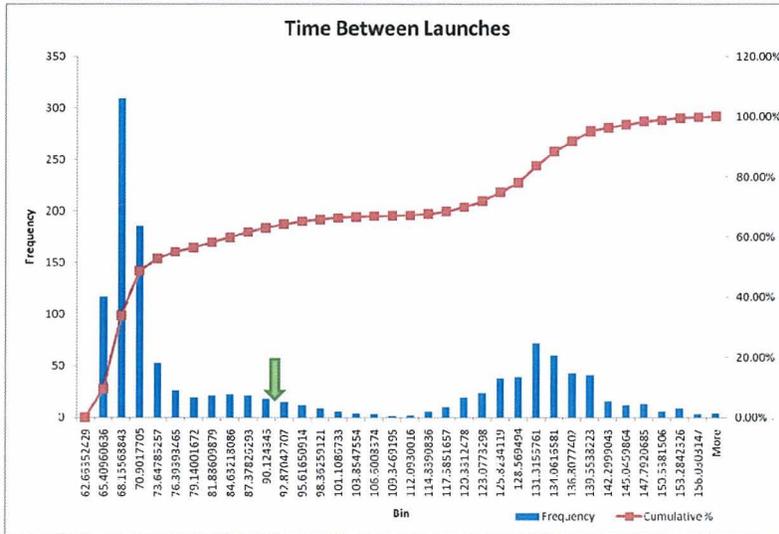


- 22% probability of 5 launches during one year
- Average of 4.01 launches per year

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Ares I/Orion shall be able to launch every 45 days  
Baseline (With Scrubs/Rollbacks)



- Average is 91.35 days between launches

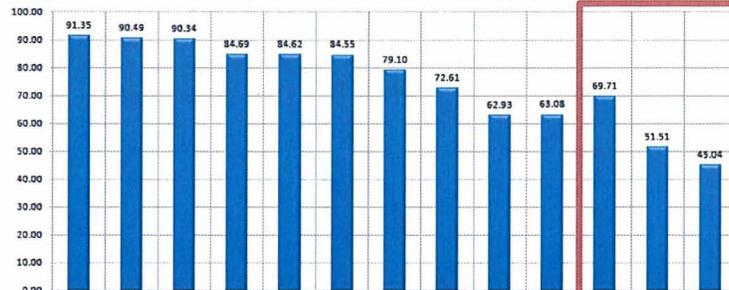
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Ares I/Orion shall be able to launch every 45 days  
Baseline (No Scrubs/Rollbacks)



Launches/yr: 4 4 4 4.3 4.3 4.3 4.6 5 5.8 5.8 5.2 7.1 8.1



Baseline Integration Schedule	X										X		
6,3 Integration Schedule		X										X	
7,3 Integration Schedule			X	X	X	X	X	X	X	X			X
Orion time available for integration				X	X	X	X	X	X	X			
Fwd Assy Manufacturing Facility Capacity Increase				X	X	X	X	X	X	X			
RPSF Capacity Increase					X					X			
ARF-Fwd Assy Capacity Increase									X	X			
Aft Skirt inventory Increase						X		X	X	X			
All FHE are ready to integrate when needed											X	X	X

- Change in Integration Shift Schedules

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## Conclusions



- 2 & 4 Launches per Year possible with Baseline Assumptions
- $\approx$  90% of Cycle time is in Manufacturing & Assembly
- Dependencies to 45-day launch-to-launch cycle:
  - Integration & Pad Shifting Policy
  - FHE readiness for Integration
    - Manufacturing
    - Assembly
    - Off-Line Ground Ops
  - Aft Skirt quantity (of reusable FHEs)
- 1-time 30-day launch-to-launch cycle not possible using current model data

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## Future Work



- Input Data Refinement
  - Level 3 Projects Data
- Automate Chart Production
- Refine Analyses
- Logic for minimum launch spacing
- Adjust manufacturing start time based on system behavior (manage ETE Cycle Time)
- Shelf Life of FHEs
- Lunar SRR

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## NASA'S MODELING & SIMULATION STANDARD (NASA-STD-7009)

### Thoughts to Discuss



- M&S Practices
- Reporting to Decision Makers
- Credibility discussion
  - V&V, VV&A
- Placarding results

## Why a New Standard?



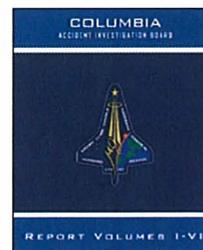
- Why Aren't Software Standards Enough?
  - Don't cover **models** developed only **in hardware**
    - With simulations carried out as an exercise using the hardware models
  - M&S use is **focused towards** understanding a system for the purpose of **decision making**

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## Why NASA? / Why Now?



- Feb 1, 2003
- Resulting Columbia Accident Investigation Board (CAIB) developed set of **Recommendations, Observations, & Findings (R-O-Fs)**
  - Directed towards the Space Shuttle Program
  - Some were related to Models & Simulations



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## Findings of Shuttle Accident Investigations Related to Modeling & Simulation



- Operating a model outside known limits
  - Conditions are outside known limits
- Model Operator
  - Training
  - Experience
- Assumptions Communicated
  - Also, Abstractions
- Model Management
  - Maintenance
  - Support
  - Configuration Control
- Data V&V (I & O)
  - Model Verified with Real Data
  - Model Data is Current
  - Sensitivity Analysis Performed

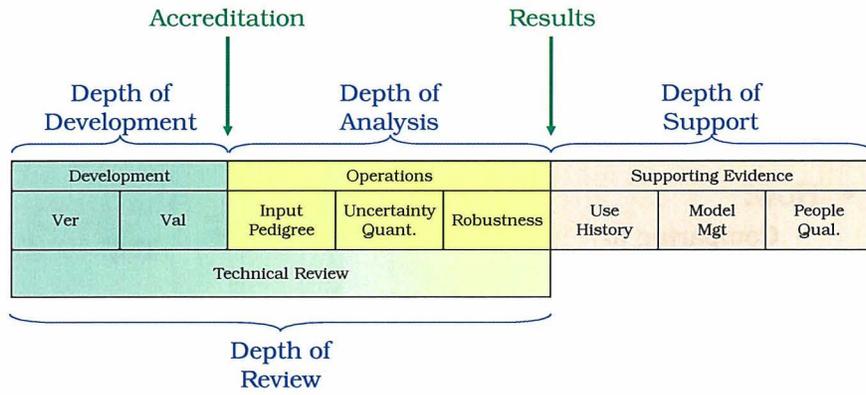
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## Basic Ideas



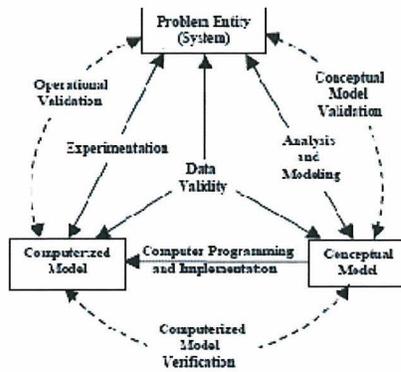
- Documentation of M&S Activities (Sections 4.1 – 4.6)
- Credibility Assessment (Section 4.7 & Appendix B)
- Reporting to Decision Makers (Section 4.8)
  - M&S Analysis Results
  - A statement on the uncertainty in the results
  - Credibility of M&S Results
  - Identify
    - Unfavorable outcomes
    - Violation of assumptions
  - Unfavorable Use Assessment
    - Difference Between V&V & Use Assessment



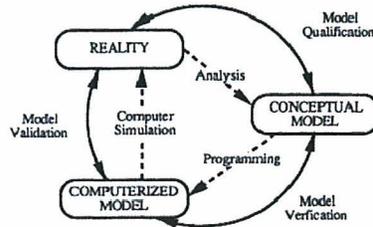


Use Assessment	
Fidelity	Within Validated Domain

## V&V Foundation



© Sargent, R. G. (c. 1980).



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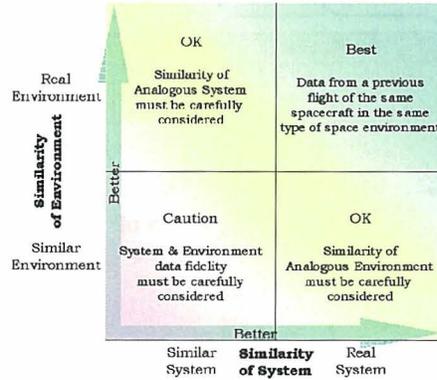
# Verification & Validation



## Verification

- Structure
- Flow
- Fidelity
  
- How:
  - Comparing to Conceptual Model
  - Entity (Code) Tracing
  - Primitive Tests (All 1's)
  - Min/Max Value Tests

**Validation:** "... determining the degree to which a model or a simulation is an accurate representation of the real world ..."



# Input Pedigree



## Input:

- **Source**
  - Notional
  - Subject Matter Expert
  - Applicability to current problem
    - **Referent** Quality relative to current problem
      - Referent System
      - Referent Environment
  - **Authoritative Data**
  
- **Quantity of Source Data**

## Input Form:

- What's the character of your analysis?

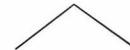
- Average



- Uniform



- Triangular



- Estimated PDF (from min, mode, 95%)

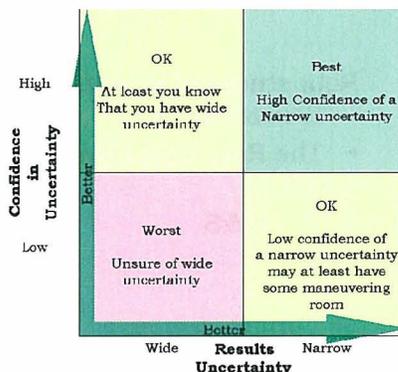
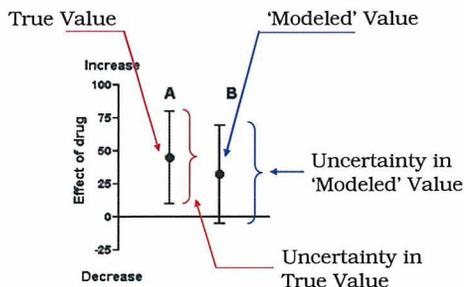


- PDF from adequate real-world data

# Accuracy & Uncertainty



## Accuracy:



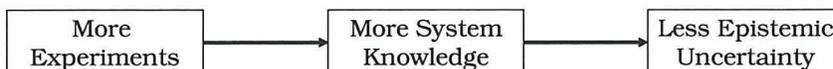
## Uncertainty:

- Types
- Sources
- 'Size' (i.e., how big)
- How Confident
- Epistemic
  - Reducible
  - Subjective
  - Model Form
  - Assumptions
  - Abstractions
  - Incomplete Information
- Aleatory
  - Irreducible
  - (Natural) Variability
  - Inherent
  - Stochastic

# Uncertainty



- 2 Types
  - Epistemic
    - Reducible
    - Subjective
    - Model Form
    - Lack of Knowledge
    - Incomplete Information
  - Aleatory
    - Variability
    - Irreducible
    - Inherent
    - Stochastic
- Uncertainty Occurrences
  - Parameters of the model
  - Accuracy of the model
  - Sequence of possible event
- Parametric Uncertainty
  - Aleatoric
  - Stochastic Parameters
- Model Form
  - Epistemic
  - Model Structure/Selection
- Why M&S Results may not be correct
  - Variability
  - Uncertainty
  - Error
- Methods
  - Representation
  - Aggregation
  - Propagation
  - Interpretation of Results

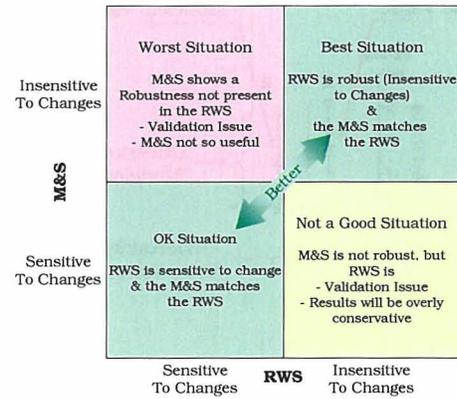


## Robustness



### Robustness of Results, i.e., Sensitivity of:

- The Real World System (RWS)
- The M&S



## Use History & Management



### Use History:

- Similarity of Uses
  - Analogous Systems
  - Exact Systems
- Length of Time in Use
  - Just Developed
    - Just Updated
  - Long-Term Successful Use

### M&S Management:

- Models & Data under Configuration Control
- Models are
  - Maintained
  - Sustained

# People Qualifications & Tech Review

## People Qualifications:

- Education
- Training
- Experience
  - In M&S
  - With the Modeled (Real World) System
- Use of Recommended Practices

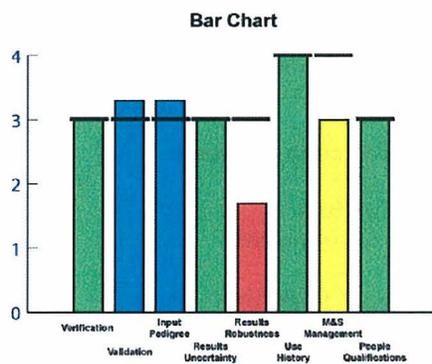
## Technical Review:

- When accomplished
  - During M&S Development
  - During M&S Operations

Development		Operations		
Ver	Val	Input Pedigree	Uncertainty Quant.	Robustness

- Qualifications & Independence of the 'Peer' Review Group:
  - Self
  - Internal Organization
  - External
  - Non-Expert to Expert
- Level of Formalism
  - Planning
  - Documentation

# Sample Report Formats



This briefing is for status only and does not represent complete engineering data analysis

## Scope of the M&S Standard



- Standard covers the use of M&S affecting:

Critical Decisions { • Human Safety  
• Mission Success } As defined by each Program

**Sample Risk Matrix**

M&S Results Influence	5: Controlling	(G)	(Y)	(R)	(R)
	4: Significant	(G)	(Y)	(R)	(R)
	3: Moderate	(G)	(Y)	(Y)	(R)
	2: Minor	(G)	(G)	(Y)	(Y)
	1: Negligible	(G)	(G)	(G)	(G)
		IV: Negligible	III: Marginal	II: Critical	I: Catastrophic
Decision Consequence					

## Models / Modeling



### Modeling Aspects:

- Incidents (events, activities)
- Lifecycle (phases)
- Functions

### Model Dynamics

- Social
- Physical
- Environmental
- Economic
- Organizational
- Infrastructure
- Other (e.g., Engineering Processes)

### Model Representations:

- Conceptual
- Mathematical
- Dynamic
- Programming Paradigms
- Analytical Techniques

### Interaction Methods:

- Live
- Virtual
- Constructive

### Uses / Objective:

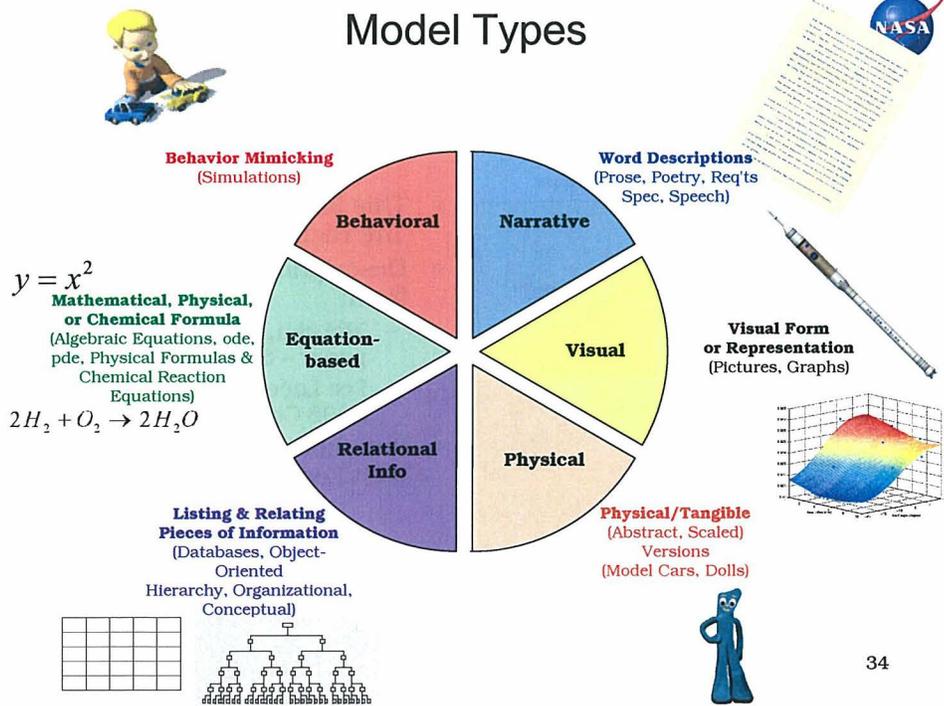
- Decision Support
- Planning
- Analysis
- Systems Engineering
- Training / Gaming
- Performance Measure
- Component / Module

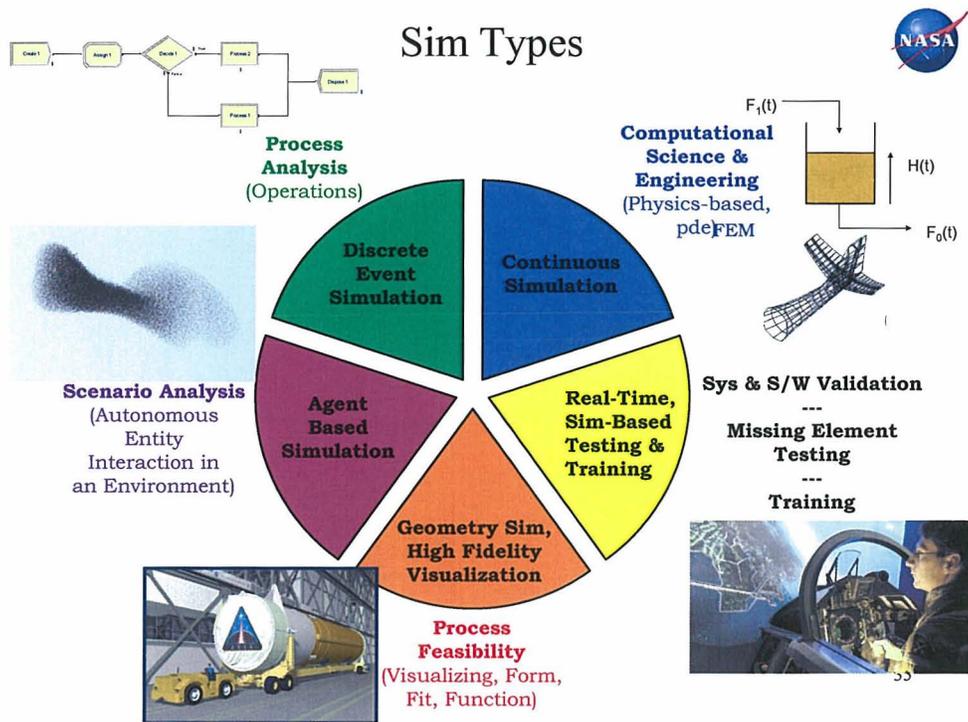
# Questions to Ask



- Type of Analysis
- Level of Detail
- Type of M&S
- Application S/W
- Uncertainty
- Use History
- Config Mgt
- V&V Domain/Range
- Analysis Domain/Range

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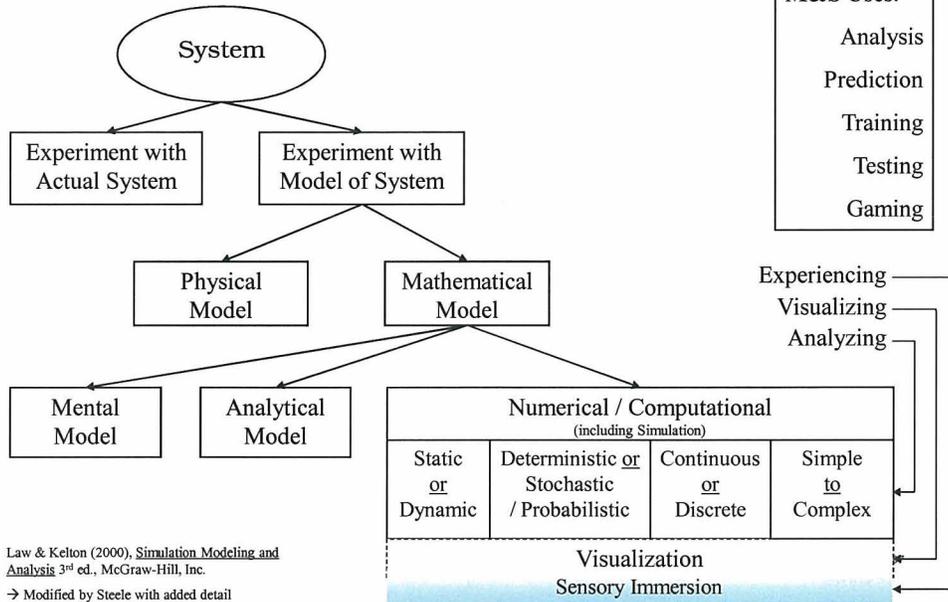
### Military View of M&S (from an 'Interaction Modes' perspective)

	Real System	Simulated System
Real Operator	<b>Live</b>	<b>Virtual</b>
Simulated Operator	This is currently not defined, but leaves room for <b>Autonomous / Robotic</b> systems operating in a real environment	<b>Constructive</b>

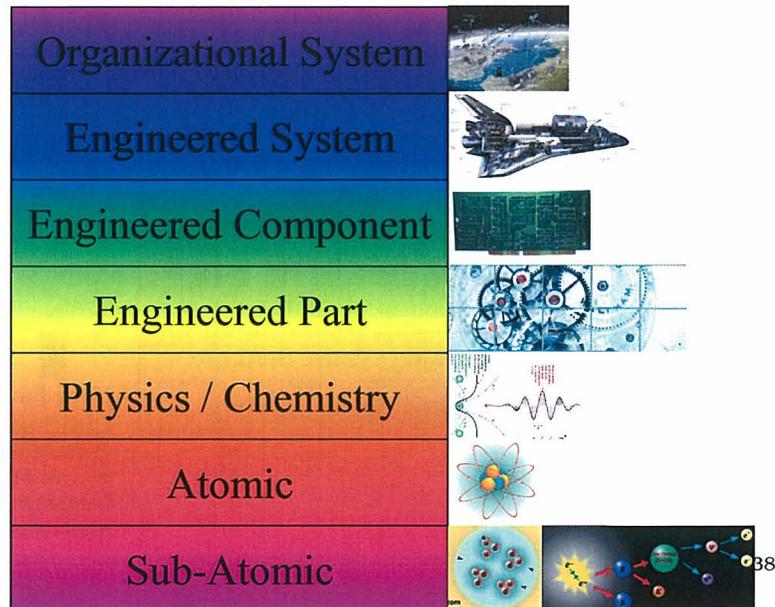
- This looks at M&S from an 'Interaction Mode' perspective
- Description of categorization from:
  - McLean, et al. - Taxonomy paper - SISO 2008
  - Lee Lacey (DRC) - OneSAF 2008 Conference
- Pink box is from conversation with Lee Lacey (DRC)



# Analysis Methods

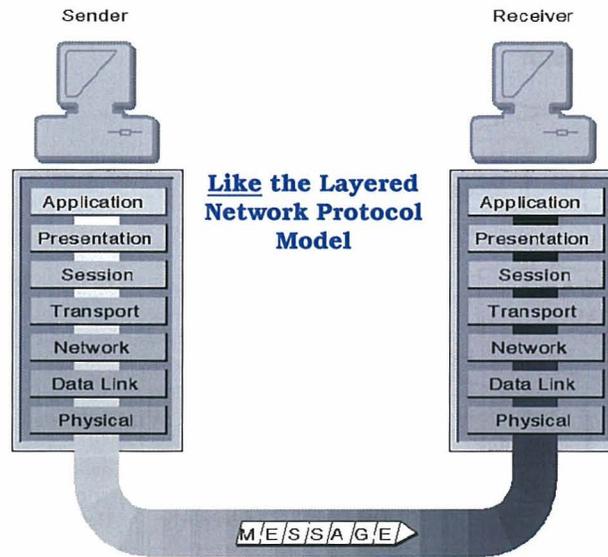


# Level of Detail





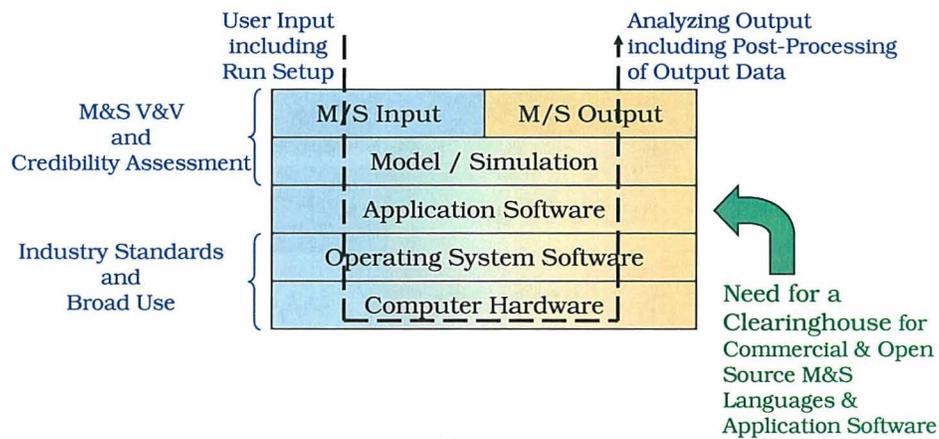
# Network Layered Protocol Approach



08E-SIW-076

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# Layered M&S View (Influences in M&S Results)



08E-SIW-076

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# BACKUPS

## Martin's Response

'Measured' Value = M&S Result

Comparing Values that have Uncertainty



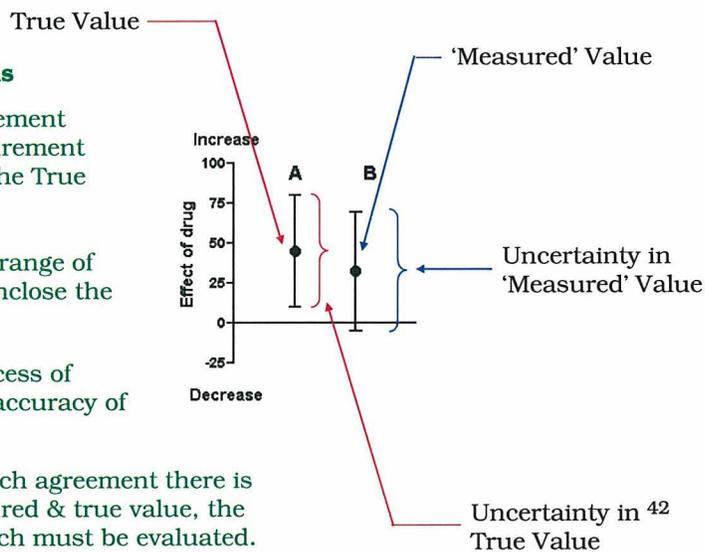
### Short Definitions

**Accuracy** – Agreement between a measurement (M&S Result) & the True Value

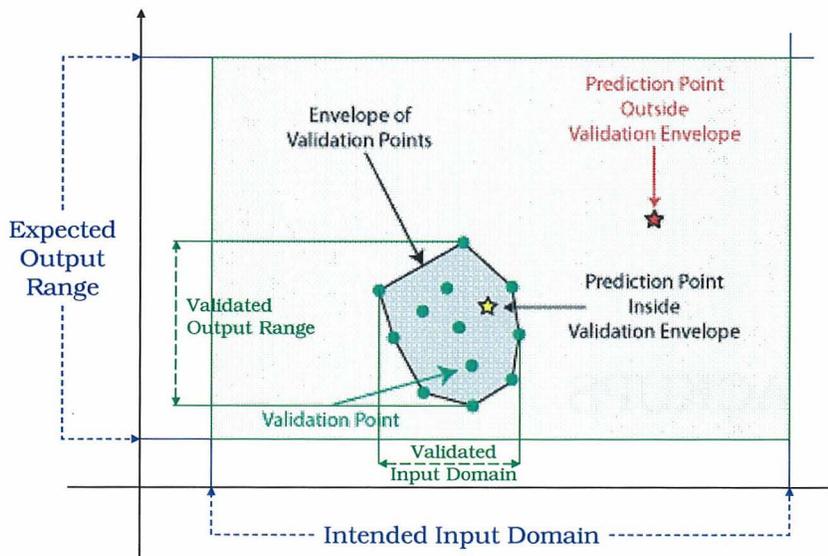
**Uncertainty** – A range of values likely to enclose the True Value

**Validation** – Process of determining the accuracy of a M&S

To know how much agreement there is between a measured & true value, the uncertainty of each must be evaluated.



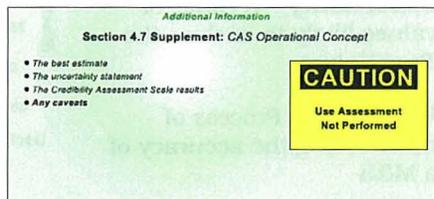
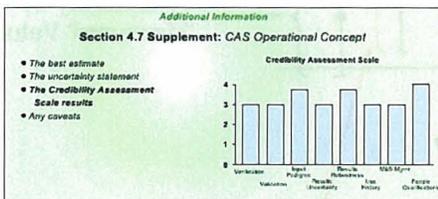
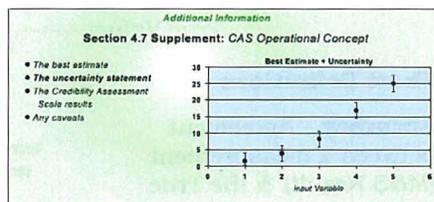
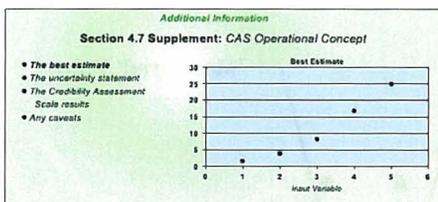
### Use Assessment



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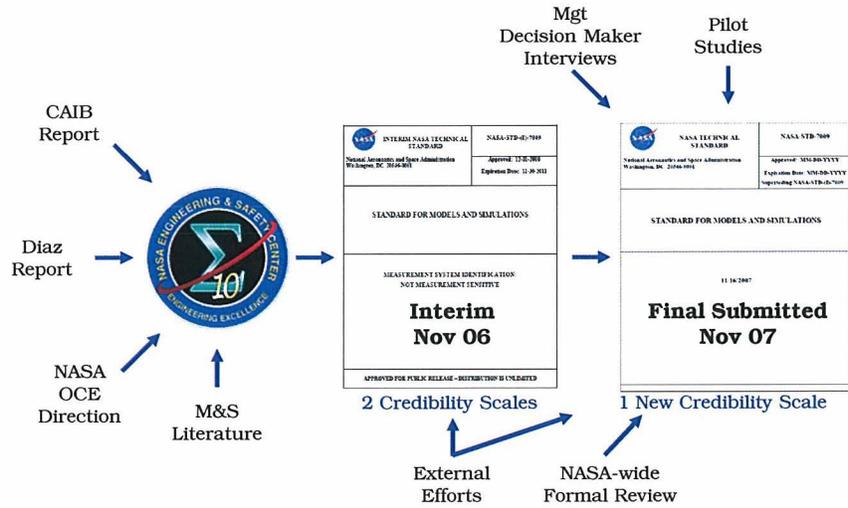
**Note** – this is a 2-dimensional example of a potentially multi-dimensional input domain & multi-dimensional output range

### Information Reported to Decision-makers



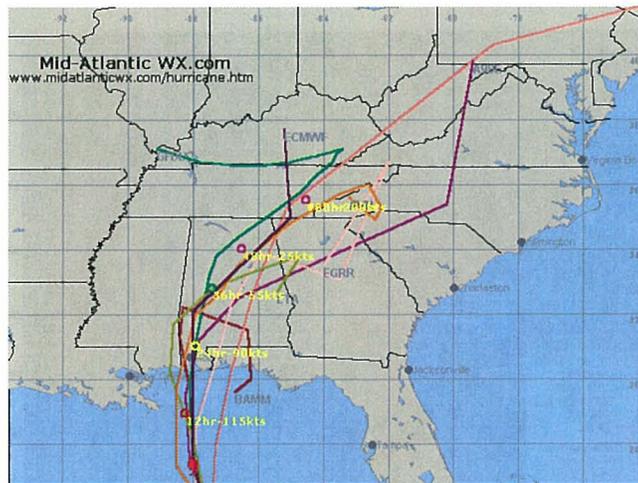
This briefing is for status only and does not represent

# Development Progression



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# Something to say about models:



Hurricane Ivan Track Prediction Models

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Something to say about models:



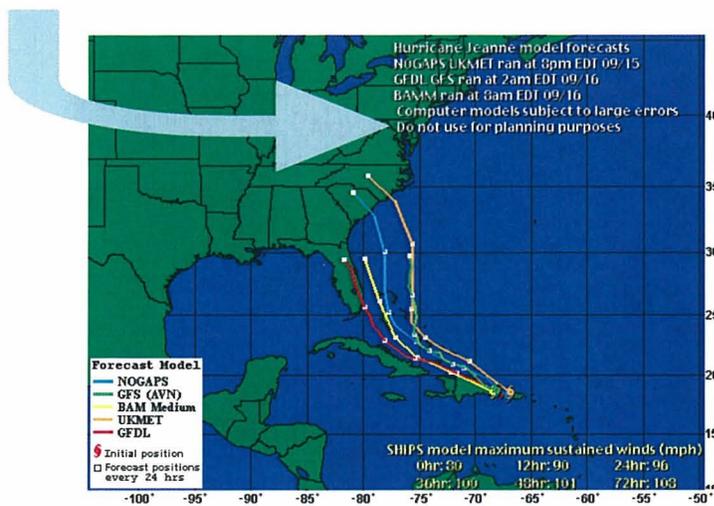
- **Model Map Display from the Mid-Atlantic WX.com (shown on previous page)**

**IMPORTANT!** This map does **\*NOT\*** represent the OFFICIAL FORECAST TRACK! Although the "official track" may be included, this is not a product of the Tropical Prediction Center/The National Hurricane Center.

This map is a graphic representation of computer generated projected tracks. This information is EXPERIMENTAL and subject to extreme fluctuations. It is provided for informational purposes only. Do not rely on this information!

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Jeanne, Sept 16, 2004 – Track Prediction



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