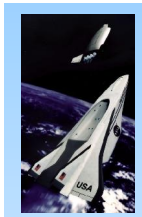

Simulation Credibility Scale* and Credibility Assessment Scale^

Unmeel B. Mehta

(Unmeel.B.Mehta@nasa.gov)

6th Simulation Credibility Workshop

8th Joint Army-Navy-NASA-Air Force (JANNAF)

Modeling and Simulation Subcommittee (MSS) Meeting

Huntsville, Alabama,December 6, 2011

*Mehta U. B., "Simulation Credibility Level," Presented at the 5th Joint Army-Navy-NASA-Air Force (JANNAF) Modeling and Simulation Subcommittee Meeting, May 14–17, 2007, Denver, Colorado; archived in CDJSC 49, CPIAC, Johns Hopkins University, May 2007.

^"Standard for Models and Simulations," NASA-STD-7009, July 2008.

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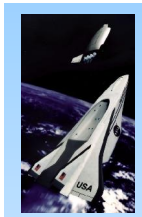

Themes

- Background
- Simulation Credibility Level (SCL) Scale
  - Reports on the credibility of a product of M&S technology, namely, a simulation result.
  - Represent milestones demarking progress towards achieving credible simulations.
- Credibility Assessment Scale
  - Assesses the rigor of the processes used to produce the simulation results and determine their favorability against key factors that affect the credibility judgment.
  - Requires extensive documentation.
- Summary

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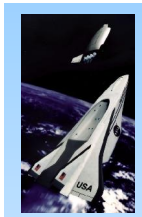
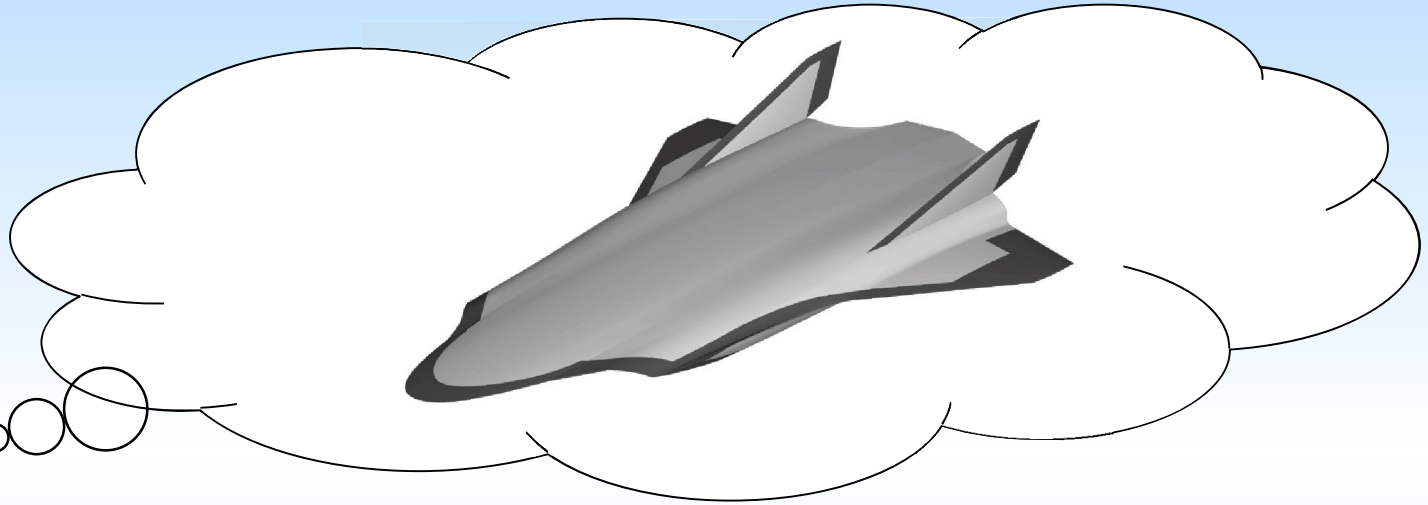
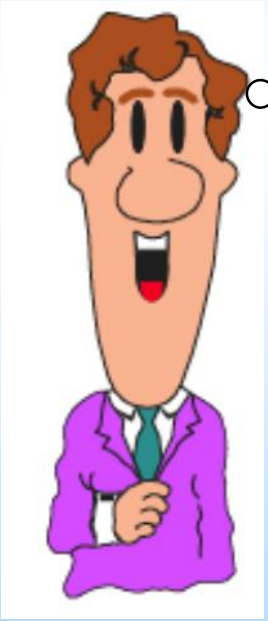


Decision-Maker's Concerns





- How accurate are simulations and test data?
- What is the level of confidence in the design based on these simulations and data?
- Are system requirements met?

Decision-Maker

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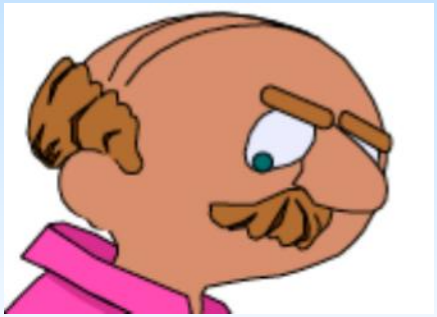
Simulation and Test Debate



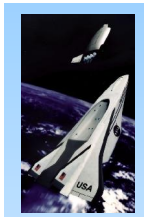
- Test data are the reality.
- Simulation models are questionable.
- Simulations are generated with many knobs.
- Simulation uncertainties are not known.

Tester
(One who conducts tests)

- Simulations represent physics.
- The data reduction procedure is questionable.
- The flow environment in the test is unknown.
- Test uncertainties are questionable.

Simulator
(One who simulates)

Both wind tunnels and CFD are *"notorious liars."*
— Paul Rubbert



Sources of Uncertainties in Simulations and Tests

Sources of Uncertainties

Simulations

- Equivalence
- Accuracy
- Isolation of Phenomena
- Extraneous Phenomena
- Modeling
- Creativity over belief

Tests

- Insufficiency of data
- Accuracy
- Isolation of Phenomena
- Extraneous Phenomena
- Creativity over belief

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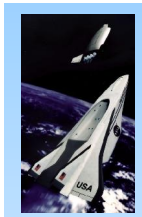


Simulation Credibility

Simulation Uncertainties

Numerics

Lack of equivalence
Lack of accuracy

Simulation Precision

Verification

Numerics Uncertainty

Physics

Isolation of phenomena
Extraneous phenomena
Modeling of phenomena

Simulation Bias

Validation

Physics Uncertainty

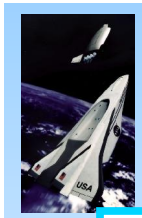
Human Traits

Human Error
Creativity
Over belief

Personal Bias

Independent Review

Certification



Simulation Credibility Scale

SCL

Simulation Certification	5	Simulations and their strengths and weaknesses are certified for making simulation-based decisions.
Validation for Prediction	4	Reality models are validated, their uncertainties are quantified, and both are certified for predictions.
Validation for Postdiction	3	Reality models are validated, their uncertainties are quantified, and both are certified for postdictions.
Simulation Verification	2	Numerical uncertainties and sensitivities are quantified and certified.
Model Verification	1	Conceptual, mathematical, and simulation models are verified and certified.

0
SCL

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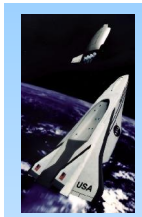
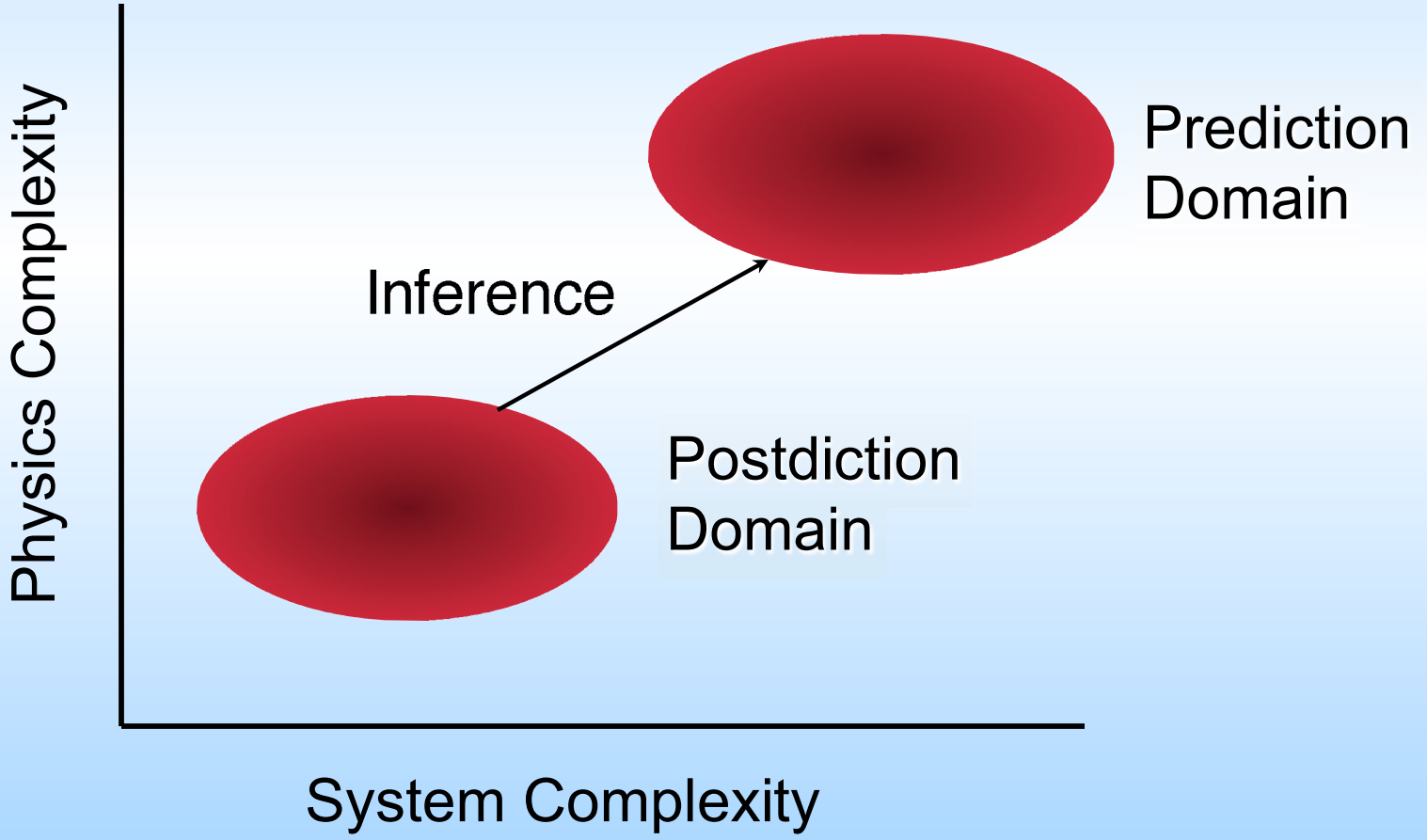


Postdiction and Prediction



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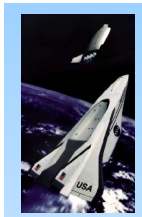

SCL 1: Model Verification - Supporting Information

- Verified
  - Simulation requirements
  - The conceptual model
  - The transformation of the conceptual model to the mathematical model
  - The equivalence of the simulation model to the mathematical model
  - The correctness of various coded phenomena individually and of complex couplings of various phenomena.
  - The correctness of simulation code

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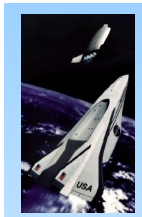
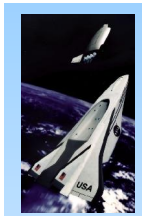


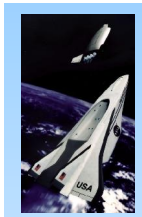
SCL 2: Simulation Verification - Supporting Information

- Numerical uncertainties
  - All relevant sources are identified.
  - A plan to manage and reduce uncertainties is developed.
  - Uncertainties and their sensitivities are quantified.
  - Levels of confidence in quantified uncertainties are estimated.
- Whether achieved uncertainties meet the requirements is determined.
- Recipes for generating simulations are developed.



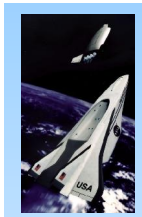
SCL 3: Validation for Postdiction - Supporting Information

- Uncertainties
  - The same supporting information as that for SCL2.
- Validation with real-world data
  - The technique of Design of Experiment is used to conduct reality tests for validations.
  - Simulations are generated before tests are conducted.
  - No reality data are used for validation without knowing their uncertainties.
  - Numerical uncertainties are appreciably smaller than reality data uncertainties.
- Recipes for generating postdictions are developed.



SCL 4: Validation for Prediction - Supporting Information

- The appropriateness of models and numerics is reassessed and justified, and limitations identified.
- Methods are developed and justified to quantify uncertainties in the prediction domain.
- Uncertainties
  - The same supporting information as that for SCL2.
- The technique of Design of Experiment is used to conduct simulations for validation with circumstantial evidence.
- Whether uncertainties meet the requirements is determined.
- The conceptual model is validated.
- Recipes for generating predictions are documented.



SCL 5: Simulation Certification - Supporting Information

- The acceptability of simulations is justified.
- The certification authority is also provided
  - Simulations along with their relevant uncertainties and confidence levels
  - Previous certifications and previous outcomes of reviews at lower SCLs are also provided.

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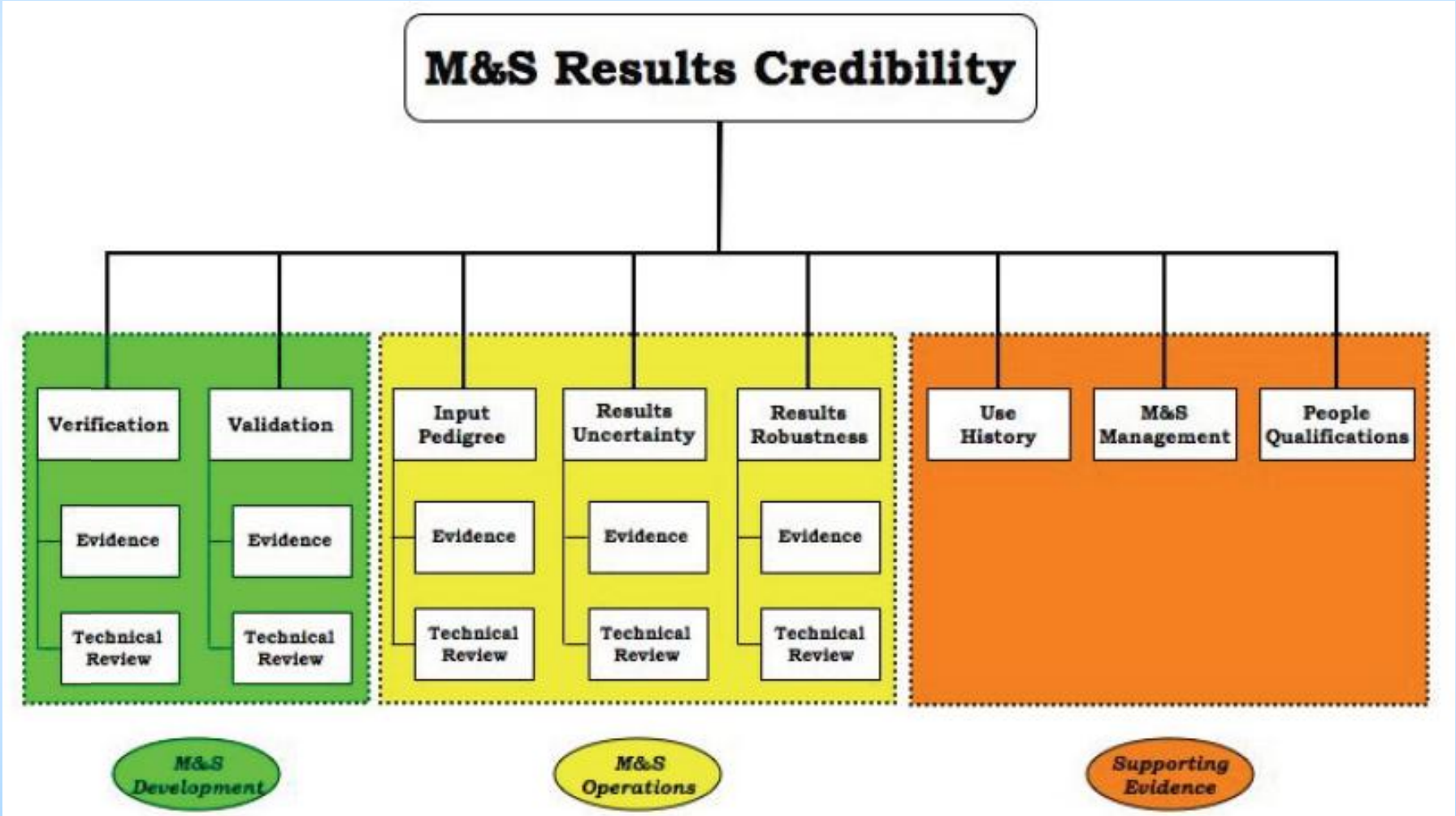
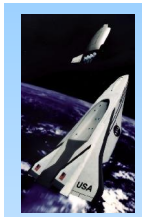
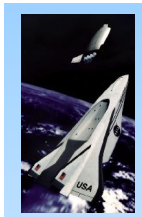
Credibility Assessment Scale





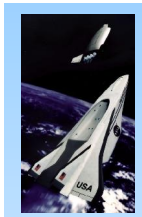
Key Aspects of Credibility Levels

Level	Verification	Validation	Input Pedigree	Results Uncertainty	Results Robustness	Use History	M&S Management	People Qualifications
4	Numerical errors small for all important features.	Results agree with real-world data.	Input data agree with real-world data.	Non-deterministic & numerical analysis.	Sensitivity known for most parameters; key sensitivities identified.	De facto standard.	Continual process improvement.	Extensive experience in and use of recommended practices for this particular M&S.
3	Formal numerical error estimation.	Results agree with experimental data for problems of interest.	Input data agree with experimental data for problems of interest.	Non-deterministic analysis.	Sensitivity known for many parameters.	Previous predictions were later validated by mission data.	Predictable process.	Advanced degree or extensive M&S experience, and recommended practice knowledge.
2	Unit and regression testing of key features.	Results agree with experimental data or other M&S on unit problems.	Input data traceable to formal documentation.	Deterministic analysis or expert opinion.	Sensitivity known for a few parameters.	Used before for critical decisions.	Established process.	Formal M&S training and experience, and recommended practice training.
1	Conceptual and mathematical models verified.	Conceptual and mathematical models agree with simple referents.	Input data traceable to informal documentation.	Qualitative estimates.	Qualitative estimates.	Passes simple tests.	Managed process.	Engineering or science degree.
0	Insufficient evidence.	Insufficient evidence.	Insufficient evidence.	Insufficient evidence.	Insufficient evidence.	Insufficient evidence.	Insufficient evidence.	Insufficient evidence.
	M&S Development		M&S Operations			Supporting Evidence		



Level Definitions

Level	Verification Evidence	Validation Evidence
4	Reliable error estimation methods are used to quantitatively assess numerical errors. These estimates show that the errors are small from test suites, which exercise all important algorithms, all important features and capabilities, and all important couplings (physics, modules, etc.) of the full computational model.	M&S results compare favorably for the real-world system at validation points by comparison of M&S results to an acceptable referent, which is measurements on the real-world system.
3	Some formal method is used to assess numerical errors associated with unit testing with significant coverage of the code.	M&S results compare favorably for problems of interest at validation points by comparison of M&S results to an acceptable referent, which is experimental measurements on problems of interest.
2	Favorable results from unit and regression testing of key features of the computational model.	M&S results compare favorably for unit problems at validation points by comparison of M&S results to an acceptable referent, which is either experimental measurements or higher-fidelity M&S results.
1	Favorable evidence of verification for conceptual and mathematical models.	M&S conceptual and mathematical models compare favorably with "general problem" and "textbook" referents.
0	Insufficient evidence.	Insufficient evidence.



Roll-Up Of Sub-Factor Score

Subfactor	Subfactor Weight	Assessed Score	Weighted Score	Factor Score
Validation Evidence	0.7	3	2.1	**3.3**
Validation Technical Review	0.3	4	1.2	

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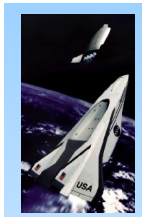
Roll-Up of Factor Scores to Overall Score

Factor	Factor Score	Overall Score
Verification	3	1.7
Validation	3.3	
Input Pedigree	3.3	
Results Uncertainty	3	
Results Robustness	1.7	
Use History	4	
M&S Management	3	
People Qualifications	3	



Summary

- Simulation Credibility Level (SCL) Scale
  - The focus is on simulation result.
  - Assesses simulation credibility vis-à-vis the quantitative requirement on the result.
  - Á la TRL, SCL demarks progress towards achieving the most credible simulation.
- Credibility Assessment Scale
  - The documentation burden and the credibility assessment are the two main shortcomings of this approach.
    - The focus is on processes.
    - Uses Analytical Hierarchy Process for roll-up of credibility score.
    - Decouples validation from verification.

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