The validation of models in an imaging infrared simulation

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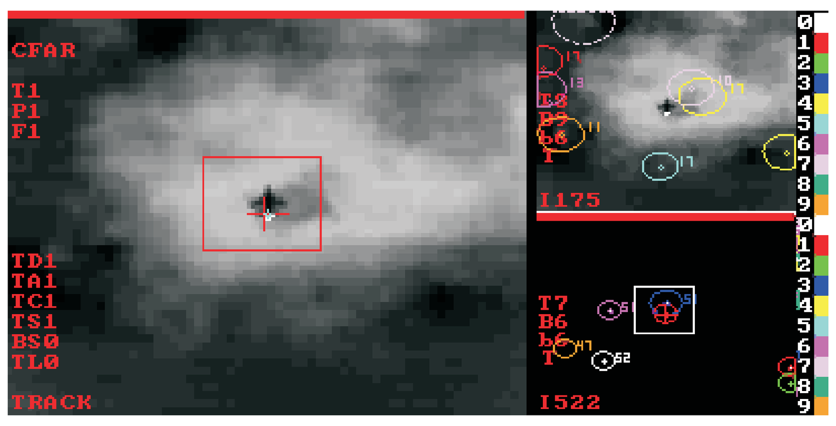
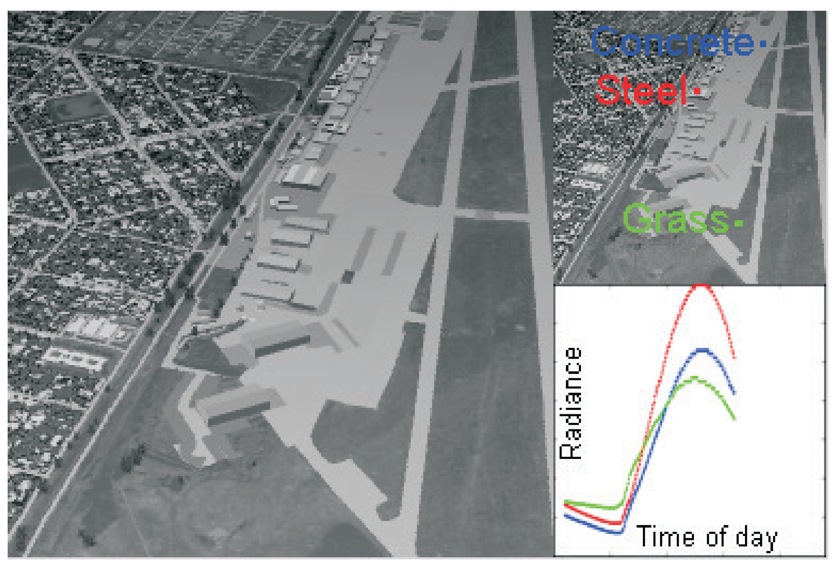




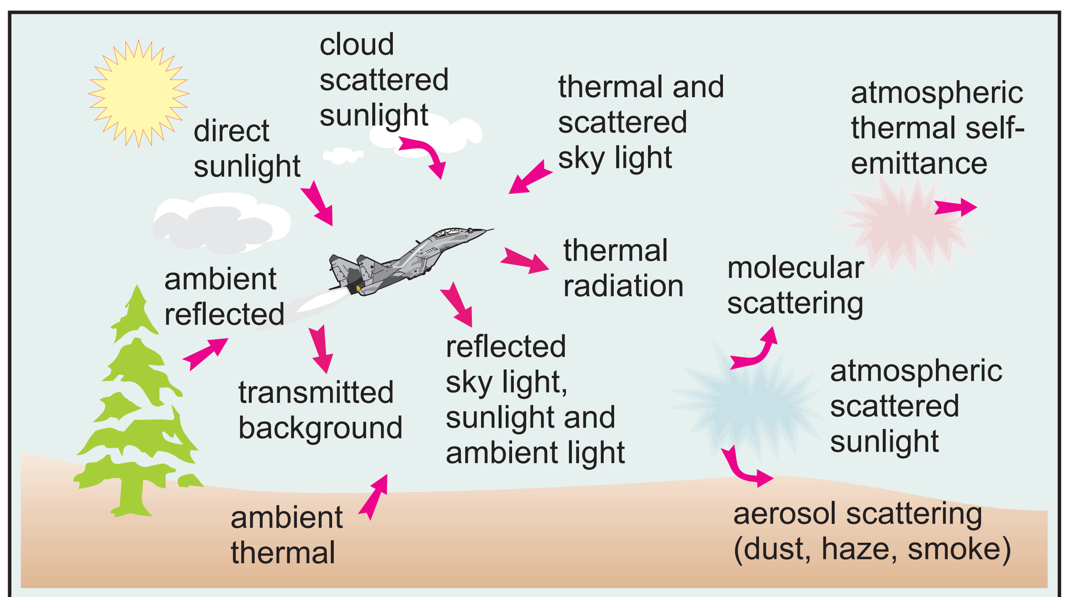
1. Problem statement: How to validate a model in a synthetic image simulation?

The simulation system models the radiometric, geometric and kinematic characteristics of objects such that images can be compiled showing the objects from any arbitrarily chosen view point. The simulation supports objects that can move in a three-dimensional world in six degrees of freedom. Some of these objects have the ability to form images of all other objects in the scene.

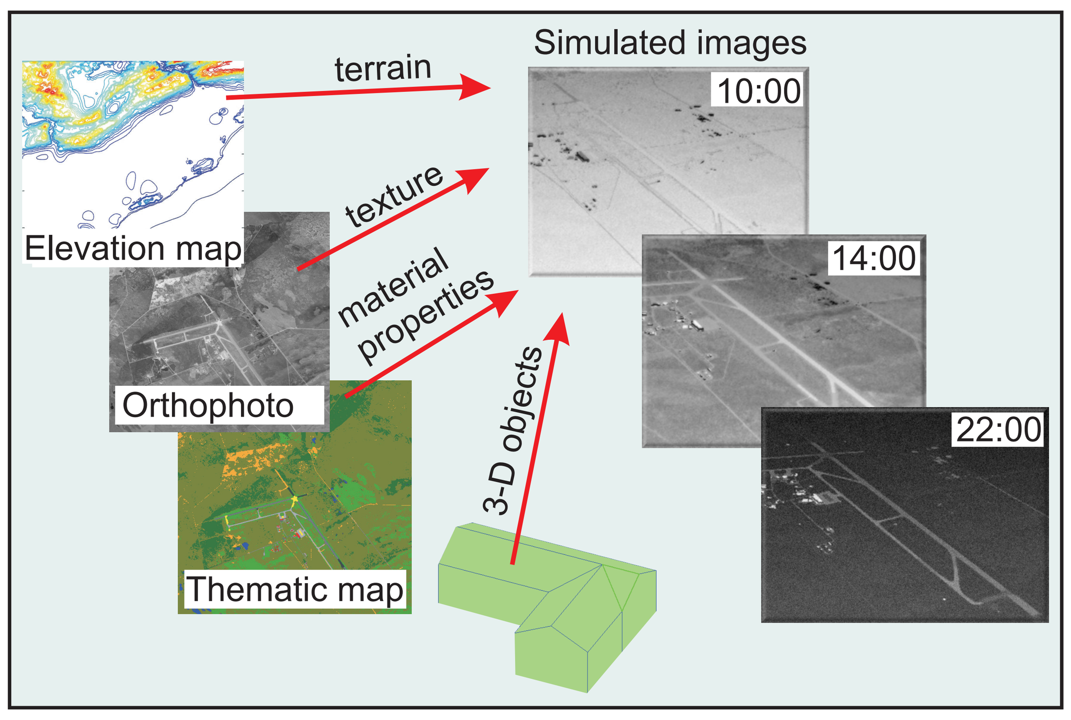
All objects in the world are modelled in terms of a wireframe geometry and radiometric characteristics.

The radiometric model includes emitted, reflected and transmitted energy. The emitted radiance of objects is determined by the object's temperature and surface emissivity. The sun radiance, sky radiance and ambient background radiance are reflected from objects in the scene.

Objects in the scene can also be partially transparent allowing the transmittance of background radiance. These radiance components are all attenuated by the atmosphere between the sensor and the radiance source. The emitted radiance of the atmospheric path between the sensor and the scene adds to the total radiance.



$$L_{total} = [\epsilon_{obj} L_{thermal} + \rho_{obj} (L_{sun} + L_{sky} + L_{ambient}) + \tau_{obj} L_{background}] \times \tau_{atmo} + L_{path}$$



The temperature of objects heated by the sun is determined by a thermodynamic energy balance equation. Airborne objects' temperatures are determined from aerodynamic heating models.

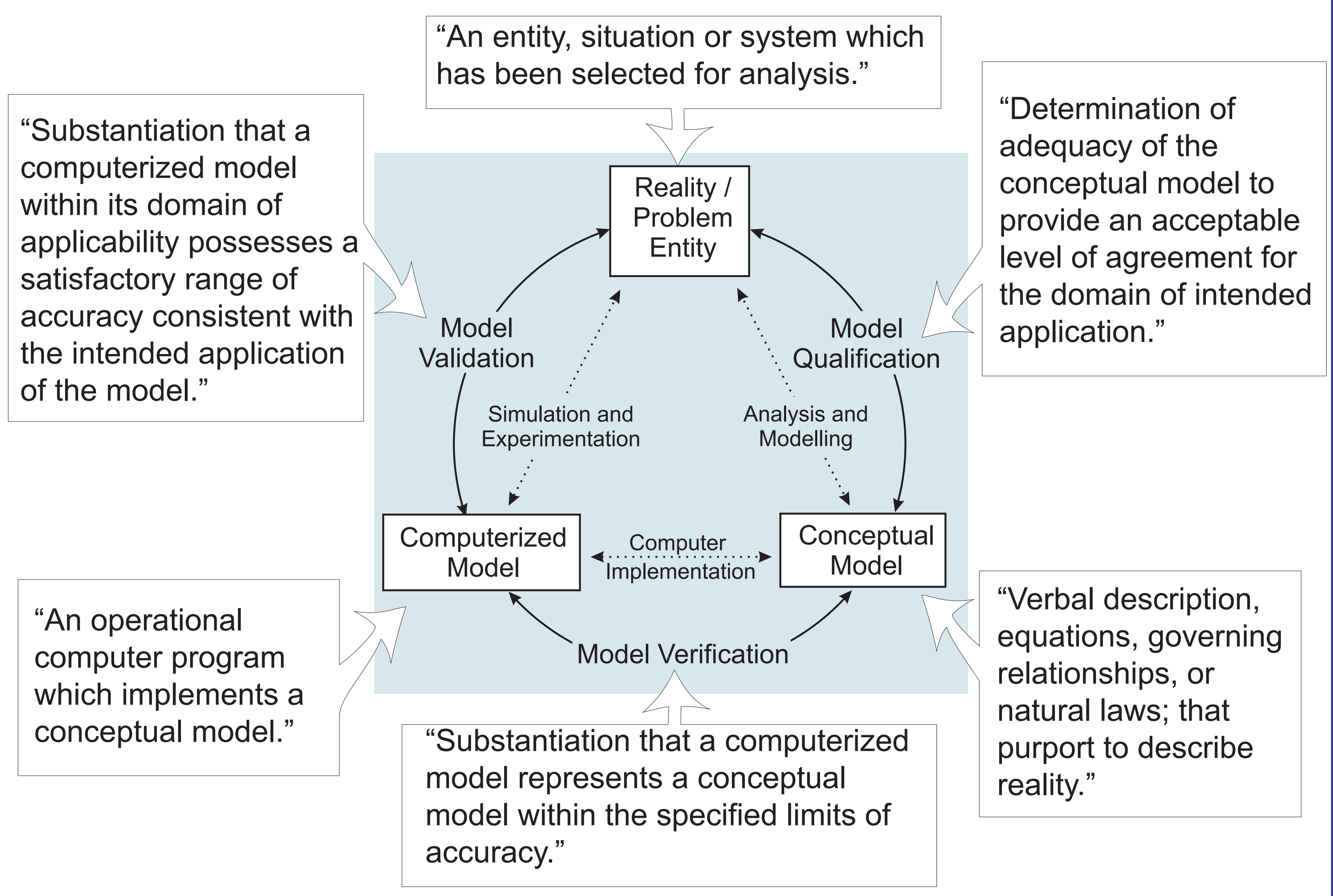
Geometry plays a crucial role in the presentation of the spatial radiometric signature in the image.

The imager creates an image with exactly the same characteristics and 'defects' as would be observed by the real sensor.

When evaluating the physical reality, the conceptual model and the computer implementation we consider the accuracy and validity of the following properties:

- Geometric shape
- Radiometric signature
- Radiometric-geometric spatial distribution
- Material thermal properties
- Kinematics, aerodynamics & flight control
- Imager properties and artifacts

2. Terminology for model credibility [1]



The most widely used model for verification and validation was conceived by the SCS Technical Committee on Model Credibility [1]. This model consider three entities and three processes for transforming the information between the entities.

3. Solution: Applying the SCS model toward validation of imaging simulations

The principles behind the SCS model is simple, but it is not obvious to apply. How does one develop a holistic view of the model validity?

In our view, the three models are important, but just as important are the three processes leading from the one to the other model. We propose:

Analysis of the validity of, and confidence in, the

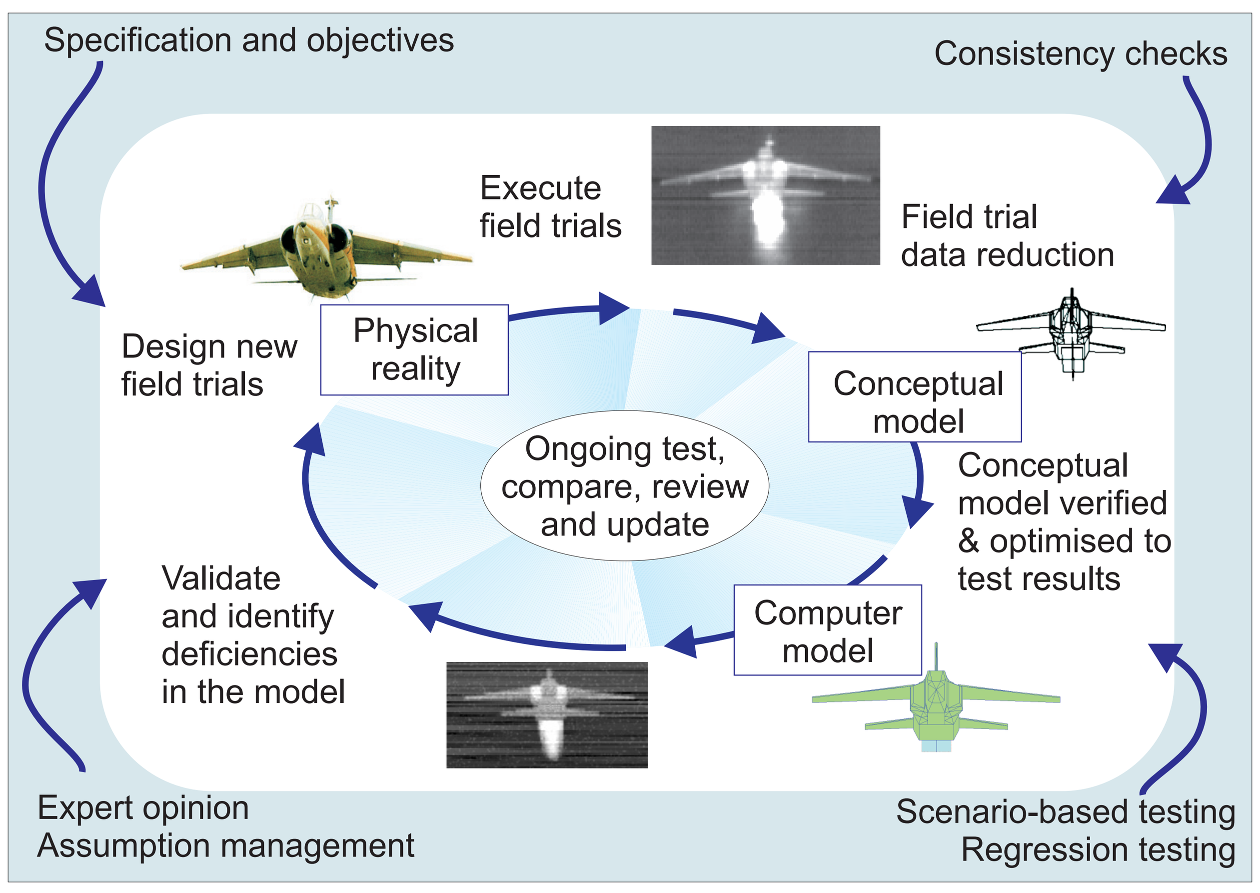
Models	Processes
Reality	Analysis and modelling
Conceptual model	Conceptual implementation
Computer model	Simulation and experimentation

Simultaneous display and evaluation of all evaluations.

The critical properties of the image simulation models are evaluated by one or more of the following techniques:

- Animation and operational graphics (*observe images*)
- Comparison with other models (*e.g. prior knowledge*)
- Degenerative stress testing (*vary model parameters*)
- Extreme condition testing (*test at limits of model parameters*)
- Expert opinion & Turing tests (*"if it behaves like x, it must be x"*)
- Regression testing (*compare with previous results*)
- Comparison with historical evidence (*compare with other data*)
- Confirming internal consistency (*compare against mathematics*)
- Analysing parameter sensitivity (*compare against physics*)
- Validating of predictions versus reality (*measurements*)

The outcome of all these analyses provides quantitative and qualitative results, which are drawn on a polar plot for evaluation.



A key strength in our approach is the repeated process of measurement, data analysis, model building, software implementation and evaluation. Deficiencies in the model are detected and corrected with each iteration.

Since each of the three models and three processes are monitored, a long term growth in quality and confidence is achieved.

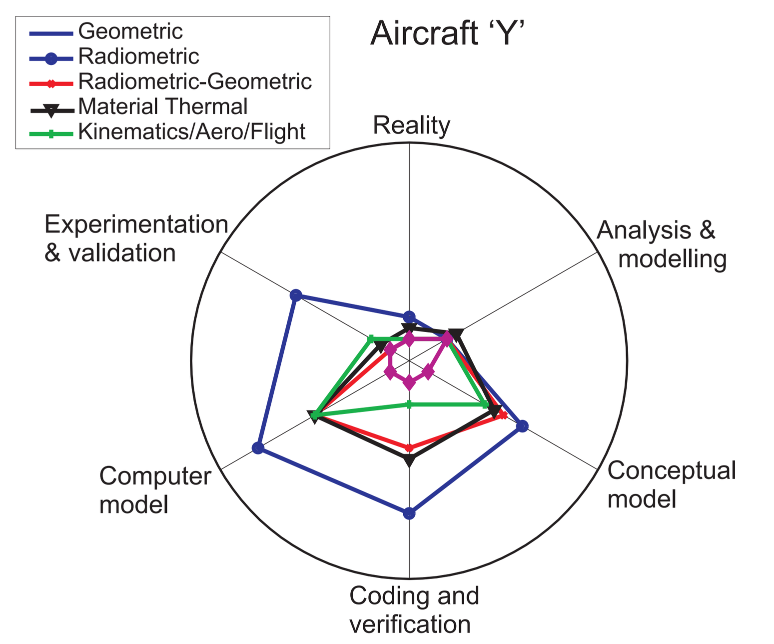
All the above take place in the context of a structured systems engineering approach and a disciplined software engineering approach. In both these approaches, quality documentation is highly valued.

4. Example and Conclusion

The confidence values are determined on a scale of [0..10] and the three model and three process confidence results are depicted in the same polar plot. These graphs are very effective and powerful in conveying the confidence in the model.

A polar plot has the important property that the area 'within' the curve is indicative of strength or value. Smaller areas represent less confidence and larger areas better confidence.

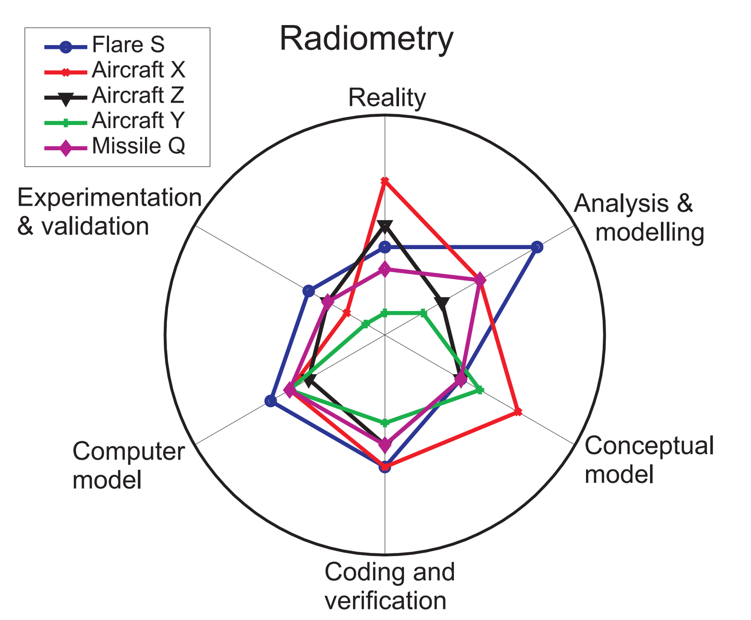
Consider Aircraft 'Y' in the following example:



- Poor quality measured/reality data
- Good conceptual and computer model
- Well tested implementation
- Verified against other, similar, real world targets

This aircraft is an adversary-owned aircraft. We have no measured information on this aircraft, we have intelligence information and scientific estimates.

By grouping the critical parameters differently, the modelling team's capability can be assessed. In the following example the 'Radiometric' parameter is considered across a number of different models. This group has intermediate skills in the execution of most elements, but are poor in their ability to validate by experimentation.



The methodology outlined here serves to analyse and visually display confidence results, supporting a validation process of an image forming simulation. The principles and execution of this method is simple, but it yields surprisingly good results for little effort.

The method described here plays a critical role in the validation of our infrared imaging simulation systems.

REFERENCES

[1] S. Schlesinger, *et.al.*, SCS Technical Committee on Model Credibility: Terminology for Model Credibility, Simulation, Vol. 32, No. 3, pp. 103– 104, 1979.

[2] R. G. Sargent, Verification and Validation of Simulation Models, Proc 1998 Winter Simulation Conference Vol 1, D. J. Medeiros *et.al.* Ed., pp. 121–130, 1998. www.ejbrm.com

[3] P. L. Knepell & D. C. Arangno. Simulation Validation (A Confidence Assessment Methodology), IEEE Computer Society Press, 1993.

[4] J. C. Refsgaard *et.al.*, Modelling Guidelines - terminology and guiding principles, Advances in Water Resources, Vol 27, No 1, January 2004, pp. 71-82(12), Elsevier.

[5] N. Oreskes, et.al., Verification, Validation, and Confirmation of Numerical Models in the Earth Sciences, Science, Vol 263, Number 5147, 4 February 1994, pp. 641 - 646. Elsevier.

[6] D. E. Thompson, Verification, Validation, and Solution Quality in Computational Physics: CFD Methods applied to Ice Sheet Physics, NASA Ames Research Center, Mail Stop 269-1, Moffett Field, CA 94035-1000.

[7] I. S. Irobi et.al., Correctness criteria for models validation – A philosophical perspective, Department of Computer Science & Computer Engineering (IDT), Malardalen University, Sweden.

[8] M. S. Martis, Validation of Simulation Based Models: A Theoretical Outlook, The Electronic Journal of Business Research Methods, Volume 4, Issue 1, pp 39 -46, 2006

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