Airbus Group Innovations

Uncertainty and validation: critical knowledge towards virtual hybrid testing and virtual certification

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Outline

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Use-Case: analysis of indirect lightning effects on critical systems

Natural phenomenon

Real environment

Physical understanding of the phenomena

SYSTEMS

Meters - Centimeters

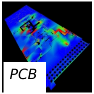
EQUIPMENTS

Centimeters - Millimeters

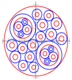
COMPONENTS

Millimeters - µmeters

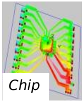
Aircraft



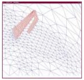
PCB



Wiring



Chip



Antenna

Multi scale modelling of the phenomena
Solving the Maxwell equations
with electronic models

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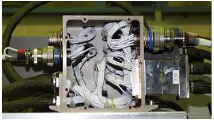
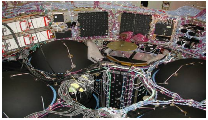
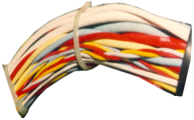
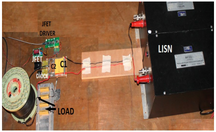
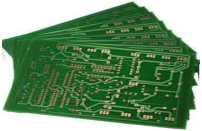
Sources of uncertainty in this use-case (1/3)

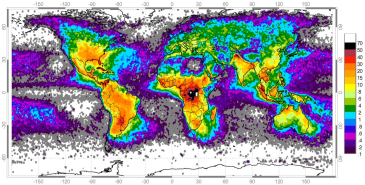





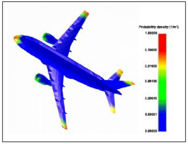


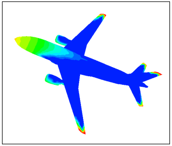

Sources of uncertainty: system design variables

- Variability linked to electrical parameters (composite materials, electrical junction, installation parameters).
- Lack of knowledge of the detailed behaviour of some electronic equipments (Printed Circuit Board, chips, ...).
- Complexity of the system definition.

Sources of uncertainty in this use-case (2/3)



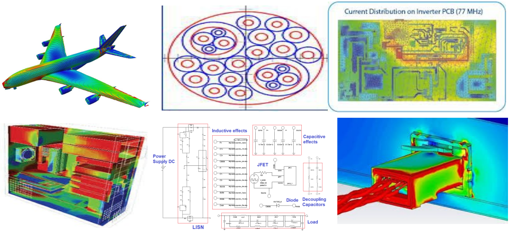




Sources of uncertainty: environmental variables

- Likelihood of occurence of a lightning strike in a given area.
- Variability of the lightning strike (current level, signal shape, ...).
- Zoning of the attachment zone on the aircraft.

Sources of uncertainty in this use-case (3/3)



Sources of uncertainty: modelling approximations

- Approximation linked to the choice of the Maxwell equation.
- Choice of the 3D numerical scheme (Finite Difference, Boundary Element Method, ...).
- Coupling with the bundles (transmission line theory, ..).
- Non linear behaviour of the electronic components in an electric circuit.

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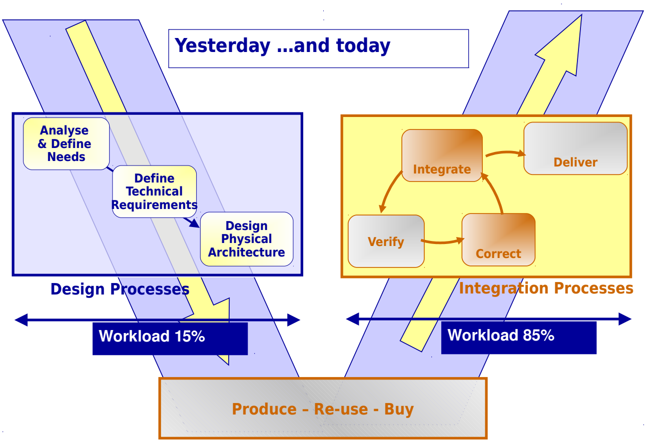
Objectives of the virtual testing during the design cycle

Main objectives

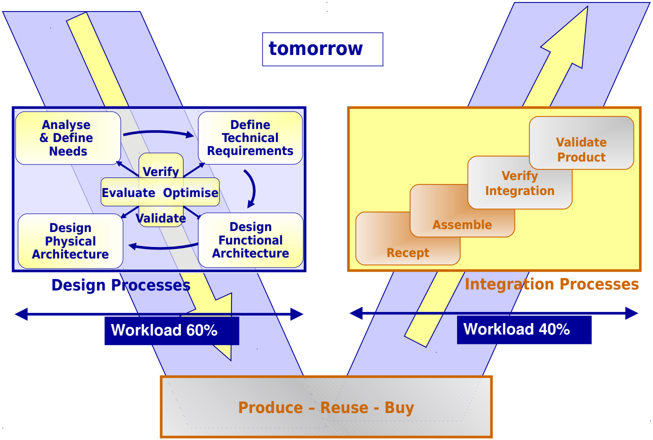
- Analysis of the technological options (aircraft architecture, EMC protection, ...) in early design or detailed design.
- Specification/analysis/impacts of the electromagnetic constraints between the different stakeholders.
- Preliminary risk assessment by simulation.
- Preparation of the real tests campaign.

Outline

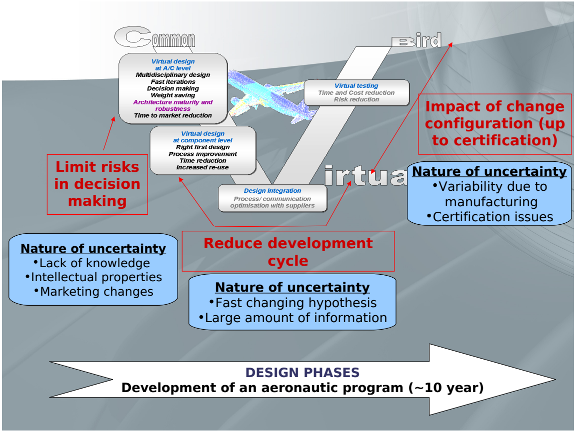
Uncertainty management in an industrial environment



Uncertainty management in an industrial environment



Modelling activities during the design phases



The “amount” of information (linked to uncertainty) and the objectives of the design evolve during the design cycle.

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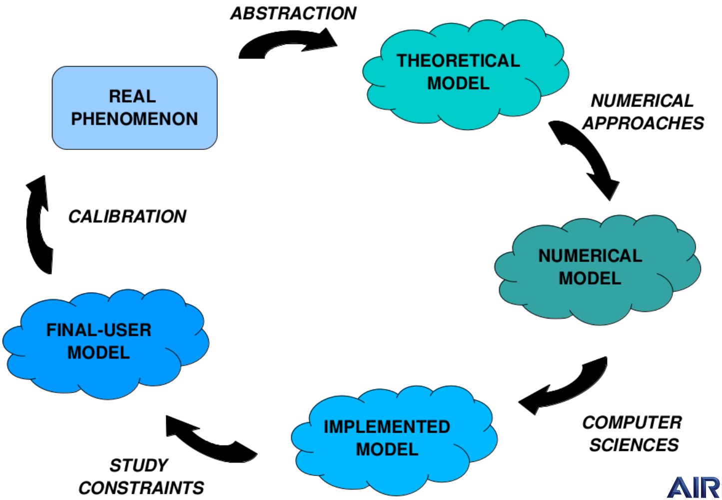
Model circle



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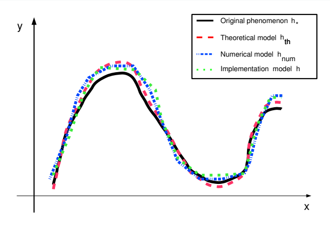
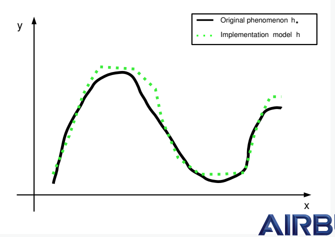
What is the nature of uncertainty in this context?

"Model" uncertainty

- **Reference model** h^*: Usually not accessible, expression of a natural or a complex technical object.
- **Theoretical model** h_{th}: Scientific expert activity (modelling activity, theoretical solution of a PDE system, ...), corresponding to the level of understanding and simplification of the problem.
- **Numerical model** h_{num}: Numerical solution of the theoretical model (effects of meshing, choice of a numerical scheme, truncature effects, ...)
- **Implementation model** h: Software implementation of the model on a given hardware architecture (computer accuracy, choice of coding rules, ...)

$$h^* \rightsquigarrow h$$





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What is the nature of uncertainty in this context?

Parametric input uncertainty

- For a given numerical model $h : (\mathbf{x}, \theta) \in \mathcal{X} \times \Theta \mapsto \mathbf{y} = h(\mathbf{x}, \theta) \in \mathcal{Y}$, we consider **an uncertainty attached to the input variables X modelled by a statistical law** $\mathbb{P}^*_{\mathbf{X}}$.
- In practical contexts, it is often difficult to build $\mathbb{P}^*_{\mathbf{X}}$ due to scarsity of data, heterogeneous database, lack of information on the dependency, ... As a matter of fact, one has to work with an **approximate statistical law** $\mathbb{P}_{\mathbf{X}}$.

$$\mathbb{P}^*_{\mathbf{X}} \rightsquigarrow \mathbb{P}_{\mathbf{X}}$$

Computational budget $\mathcal{B}$

- In many situations, it is difficult to compute analytically the risk measures $\rho(h(\mathbf{X}, \theta))$. Numerical methods $\mathcal{M}(\mathcal{B}, \varepsilon, h(\mathbf{X}, \theta)$ (either stochastic or not) are required using a fixed computational budget $\mathcal{B}$ for a given accuracy ε

$$\rho(h(\mathbf{X}, \theta)) \rightsquigarrow \mathcal{M}(h(\mathbf{X}, \theta), \mathcal{B}, \varepsilon)$$

How to manage all the components of the error?

Recap of the errors

1. Building of the model: $\mathcal{N}_{\mathcal{S}}(h^*, h_{th})$
2. Numerical approximation: $\mathcal{N}_{\mathcal{N}}(h_{th}, h_{num})$
3. Hardware/Software implementation: $\mathcal{N}_{\mathcal{I}}(h_{num}, h)$
4. Model paramaters uncertainty: $\mathcal{N}_{\mathcal{Q}}(\mathbb{P}^*_{\mathbf{X}}, \mathbb{P}_{\mathbf{X}})$
5. Uncertainty propagation error: $\mathcal{N}_{\mathcal{P}}(\rho(h(\mathbf{X},\theta)), \mathcal{M}(h(\mathbf{X},\theta), \mathcal{B}, \varepsilon))$

Naive form of the total error

$$\begin{aligned}\Delta \leq\ & \underbrace{\mathcal{N}_{\mathcal{S}}(h^*, h_{th})}_{\textit{Scientific Validation}} \\ & + \underbrace{\mathcal{N}_{\mathcal{N}}(h_{th}, h_{num})}_{\textit{Numerical Validation}} + \underbrace{\mathcal{N}_{\mathcal{I}}(\hat{h}, h)}_{\textit{Hardware/Software Validation}} \\ & + \underbrace{\mathcal{N}_{\mathcal{Q}}(\mathbb{P}^X_*, \mathbb{P}^X)}_{\textit{Statistical Validation}} + \underbrace{\mathcal{N}_{\mathcal{P}}(\rho(Y), \hat{\rho}_{\mathcal{B}}(Y))}_{\textit{Propagation Validation}}\end{aligned}$$

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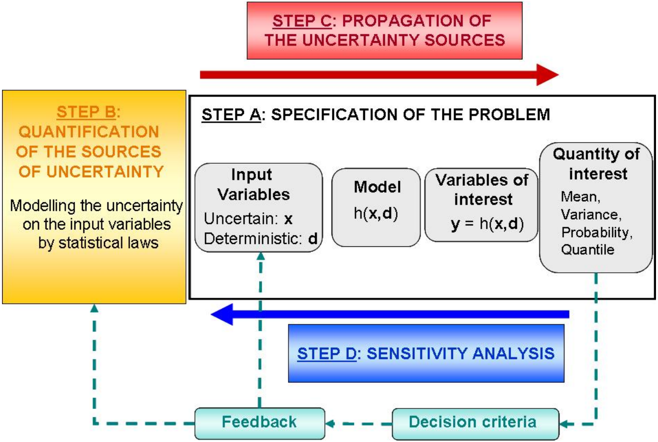
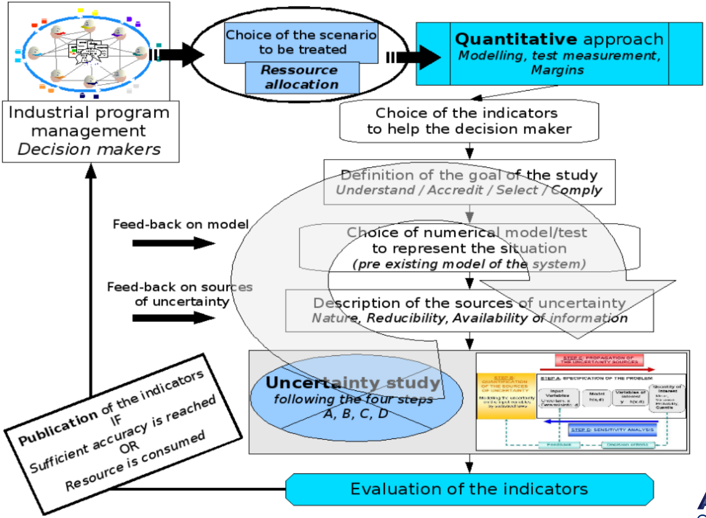
How to manage some components of the error?



Specific process for uncertainty analysis



Standards and tools

Example of Credibility Scoring – With Factor Weighting (NASA HRP Implementation)

Credibility Assessment Factors	Evidence			Technical Review		Factor Score	Weighted Subfactor Score	Overall Score	Sufficiency Threshold
	Score*	Weight+	Threshold*	Score*	Threshold*				
1 Verification	2	0.20	3	2	3	2	0.40	1.75	2.54
2 Validation	2	0.25	2	2	3	2	0.50		
3 Input Pedigree	2	0.10	3	2	3	2	0.20		
4 Results Uncertainty	0	0.10	2	0	3	0	0.00		
5 Results Robustness	2	0.10	2	2	3	2	0.20		
6 Use History	1	0.15	2	N/A	N/A	1	0.15		
7 M&S Management	2	0.05	3	N/A	N/A	2	0.10		
8 People Qualifications	4	0.05	3	N/A	N/A	4	0.20		

* Maximum = 4; where 0=insufficient evidence and 4=highest fidelity/rigor achievable

+ Minimum = 0.05, maximum = 0.25 and sum of all weights must equal 1.0

*Threshold: The required score agreed to by the end-user/customer and M&S provider to achieve sufficient confidence in the M&S for intended use

Subfactors	Weight
Evidence	0.7
Technical Review	0.3

Legend	
(blue)	CAS Score > Threshold *Exceeds credibility requirements*
(green)	Threshold ≥ CAS Score ≥ (Threshold-0.5) *Ready for use*
(yellow)	(Threshold-0.5) > CAS Score ≥ (Threshold-1.0) *Use with caution*
(red)	CAS Score < (Threshold-1.0) *Use not recommended or to be used with EXTREME CAUTION by subject matter experts only*

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Outline

Challenges

Applicative challenges

- Formalization of use-cases for problems at system level
- Formalization of mathematical problems in terms of uncertainty with coupled models

Challenges

Numerical problems

- **Uncertainty propagation** more or less intrusive: new codes to build with HPC capabilities
- **Model reduction**: best HPC strategy to build a surrogate model
- **Inverse method**: extensive use of initial model for a stochastic optimization problem
- **Domain decomposition under uncertainty**: propagate uncertainty and couple reduced model or reduce and propagate uncertainty on coupled model ?
- **To extend the panoply of model**: To refine the numerical resolution of a problem

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Challenges

HPC needs

- **HPC outside my resolution process**
  - Monitoring of the simulation on a heterogeneous grid
  - Best use of the HPC resources by knowing the performances of one run of the simulation model: what is the memory required? What is the best number of processors to run my computation of simulation model?
  - Fault tolerant architectures
- **HPC inside my resolution process**
  - Parallelization of some numerical steps inside the supervisor (Open TURNS like)
  - Development and use of new aleatory objects: random processes, random fields, ...
  - Open source algebra library
  - A priori/a posteriori estimation of errors
  - Fault tolerant architectures
  - Huge database manipulation

Other CHALLENGES

CULTURAL challenges

Engineers ARE NOT USED to express the uncertainty in their domain. By the way, only a few of them are trained on the subject !

- Problem to build the probabilistic criteria
- Quantification of the sources of uncertainty

A strong effort is required in basic training and professional training.

TECHNOLOGICAL challenges

The simulation tools are not adapted to evolve towards this revolution !

- Development of new algorithms
- Automatization of the computational workflow
- Is the computational budget compatible with the probabilistic criterion? Development of high performance computations capabilities.

CERTIFICATION challenges

The uncertainty management process has to be compatible with certification issues (legal responsability, safety issues, ...)

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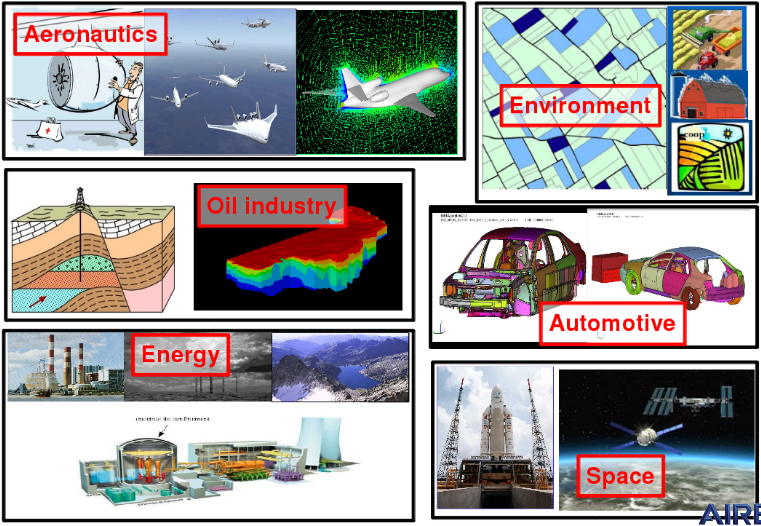
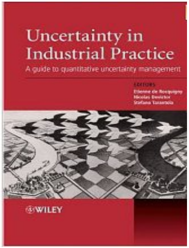
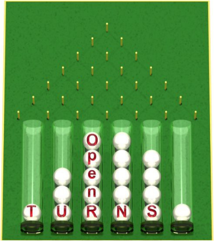
A multi sector concern



Existing initiatives and groups





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UM environment

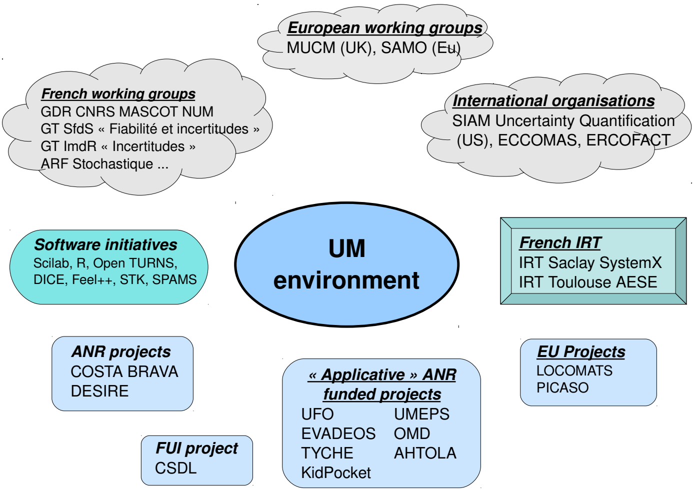

Figure: On-going initiatives in UM that I know... See for example MASCOT-NUM or MUCM