Certification by simulation for rotorcraft

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RoCS
ROTORCRAFT CERTIFICATION BY SIMULATION

The RoCS Team

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EASA
European Aviation Safety Agency

Main goal of RoCS

Produce a consolidated set of **guidelines**, agreed with the certification authority, and applicable to **helicopters and tiltrotors**, to facilitate the development of **standardized applications of flight simulation in the future certifications** in Europe. The goal is to opt whenever possible for simulation as a **Mean of Compliance** based on an ***equivalent level of accuracy**** with respect to usage of flight tests

WARNING: The definition of a standard approach will not mean that ALL certification flights CAN and SHOULD be tackled by simulation

*From CS-27/29 Subpart B. This in turn means equivalent level of risk of taking results of simulation as true

The hurdle

“No-one believes the […]* simulation, except the person who created it.
Everyone believes the flight test data except the person who measured it.”

— Anonymous (*originally it was CFD)

C R E D I B I L I T Y

Credibility of a model is the confidence in the trustworthiness of its content. There is a certain (high) probability that the model leads to results that are true.

Credibility

Requirement based Simulations

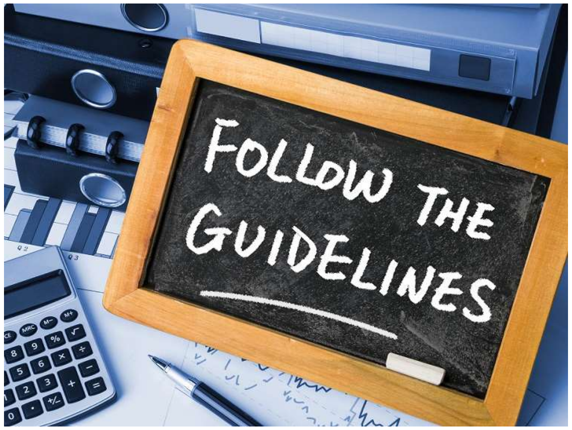
Expertise

Traceability of models & data

Objective quantifications with metrics

Guidelines as a driver

- Simulation has been already considered in a limited case-by-case basis to show compliance
- However, the requirements of simulation have yet to be investigated comprehensively, and defined in a coordinated effort
- The Guidance expands on the important concept of '**<u>sufficiency</u>**', and the various domains in which M&S is used
- We expect these guidelines to be adopted as industry-wide standard to appropriate model exchange between OEMs and part suppliers.



Extend the usage of simulation

Safety

Anticipate, reduce and prevent risks

Costs

Flight tests are expensive.

Duration

fraction of the time of a flight test. Environmental condition easily adjustable and exactly known

Effectiveness

Possibility to test numerous configurations easily. Possibility of repetition

REDUCTION OF THE TIME TO MARKET FOR INNOVATIONS THAT CAN INCREASE SAFETY AND SAVE LIVES

The RCbS Process

Phase 0
- Project Management

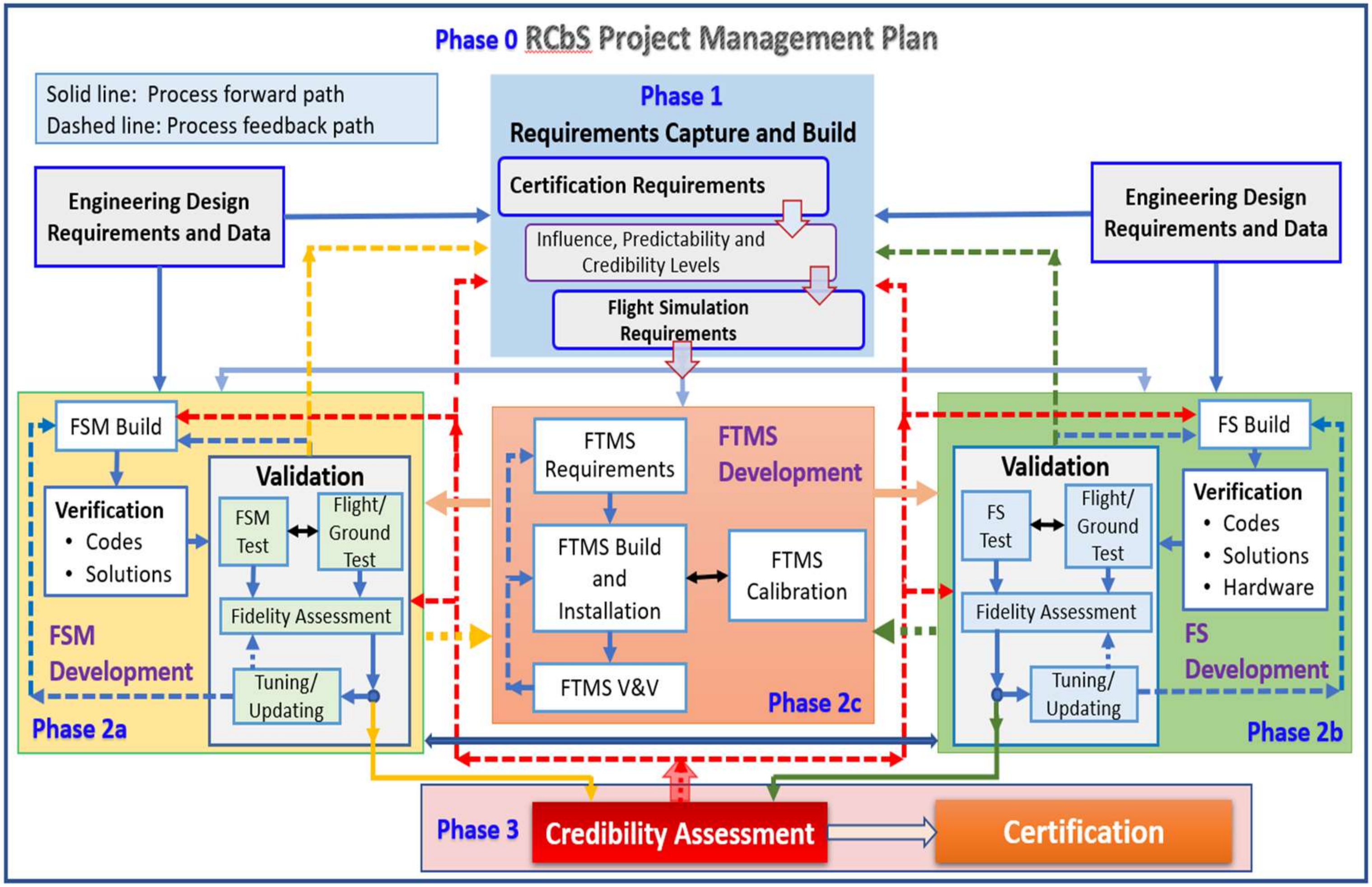
Phase 1
- Requirements Capturing

Phase 2
- Model, Simulator and Flight Test development. Fidelity, and uncertainty assessment

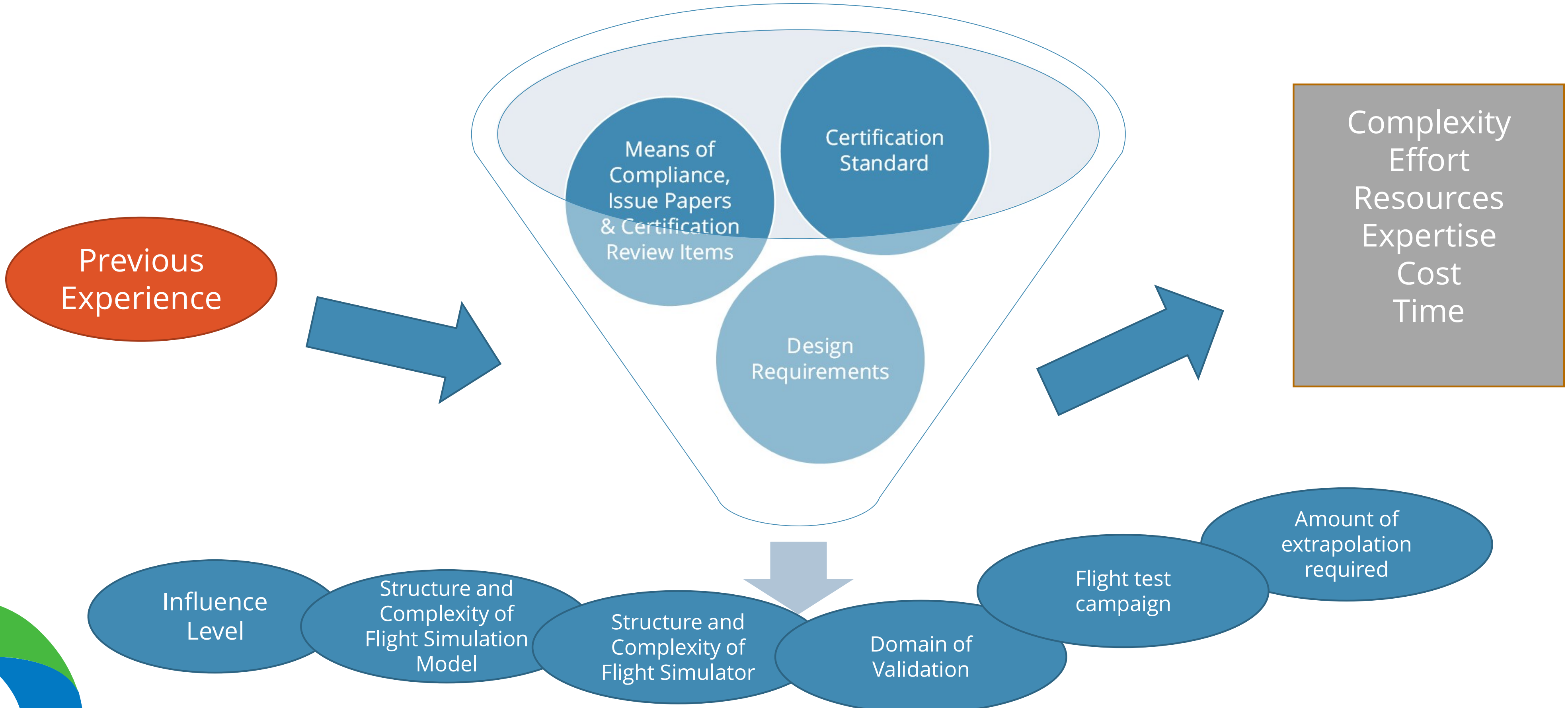
Phase 3
- Credibility Assessment

Certification Tests

The RCbS Process



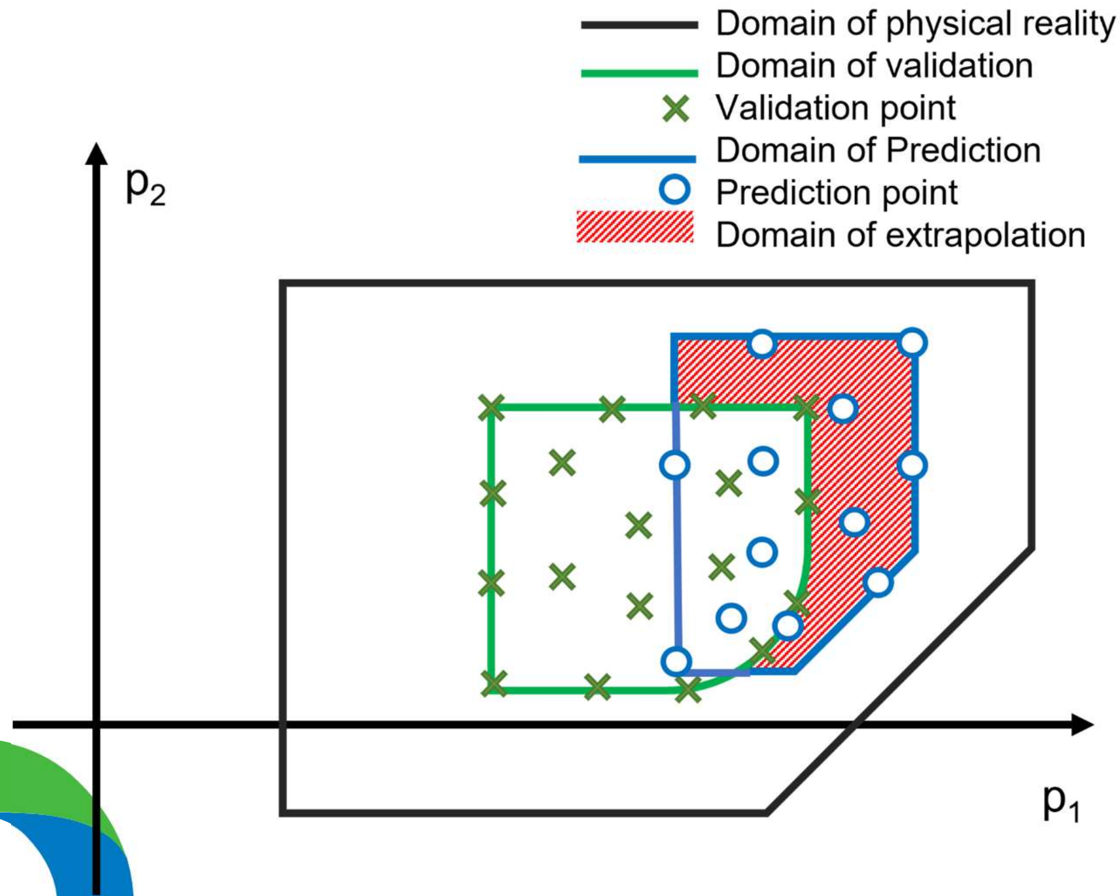
Phase 1 – Requirement Capturing



Phase 1- Influence Levels

Influence Levels		Description
I	**De-risking**	The simulation is used to develop/familiarise with flight test procedures and to obtain an understanding of possible problems, hazards, or the need for additional data gathering etc.
II	**Critical Point Analysis**	The simulation is used to explore the flight envelope to be tested for a specific ACR and to perform a down-selection of critical points to be tested in flight.
III	**Partial Credit**	The simulation is used to receive certification credit for a portion of the flight-envelope/aircraft-configuration matrix, or an aspect of an ACR (e.g. performance, human factors). Supplementary flight tests will need to be performed to obtain full credit.
IV	**Full credit**	This category is for cases where certification flight tests for a specific ACR are replaced by simulation.

Phase 1 – Domains



- **The domain of physical reality (DoR)** is the domain within which the relevant physics is captured up to the limit of accuracy required
- **The domain of validation (DoV)** is the domain within which test data are used to validate
- **The domain of prediction (DoP)** is the domain within which it is the intention to predict the behaviour of the aircraft to achieve certification
- **The domain of extrapolation (DoE)** is the portion of the domain of prediction that is outside the domain of validation

Phase 1- Predictability Levels

Predictability levels		Description
P1	**Full interpolation**	Predictions performed within the DoV, the (interpolation) errors for the quantities of interest can be estimated with high confidence
P2	**Interpolation in the DoV and limited extrapolation in the DoE**	Usage of interpolation within the DoV plus extrapolation outside DoV based on the current CS-29 and CS-27 Accepted Means of Compliance (MoC)
P3	**Interpolation in the DoV and extensive extrapolation in the DoE**	Usage of interpolation within the DoV plus extrapolation outside DoV from based on limits that do not fall in the P2 cases
P4	**Full extrapolation**	All points used in simulated tests are outside the DoV and so no direct comparison of the complete FSM with flight test data is available, e.g. failure testing.

Phase 1 Influence and Predictability Matrix for an ACR – typical layout for example ACR

ACR		Predictability levels with Confidence Ratio			
		P1: Interpolation only	P2: Exensive interpolation in DoV Limited extrapolation in DoE	P3: Limited interpolation in DoV Extensive extrapolation in DoE	P4: Full extrapolation in DoE
Influence Levels	I1: Derisking				
	I2: Critical Point Analysis				X
	I3 Partial Credit		X		
	I4 Full Credit				

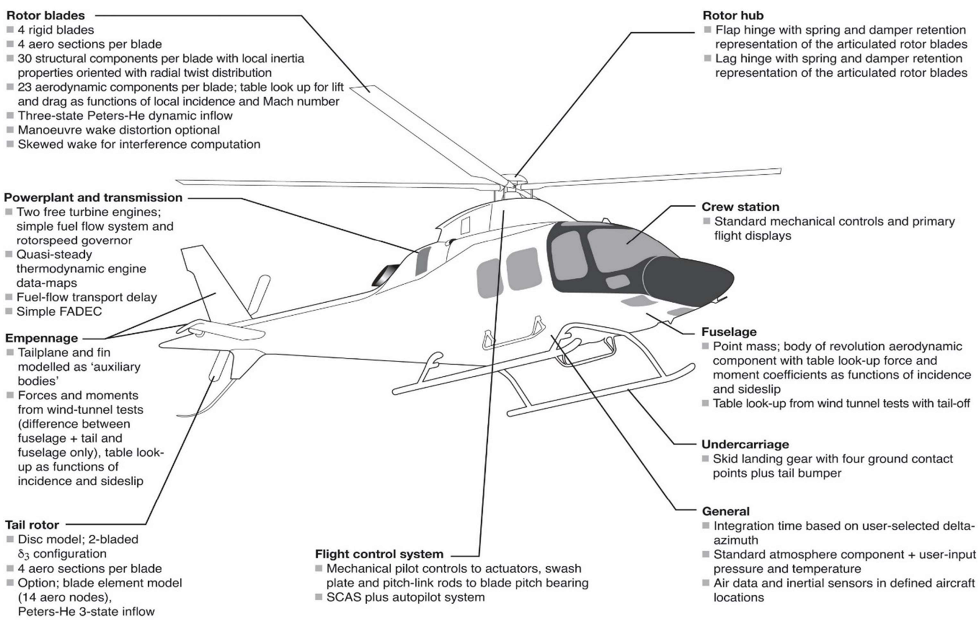
4 influence levels: I1-I4
4 predictability levels: P1 – P4

Relevant to decide:

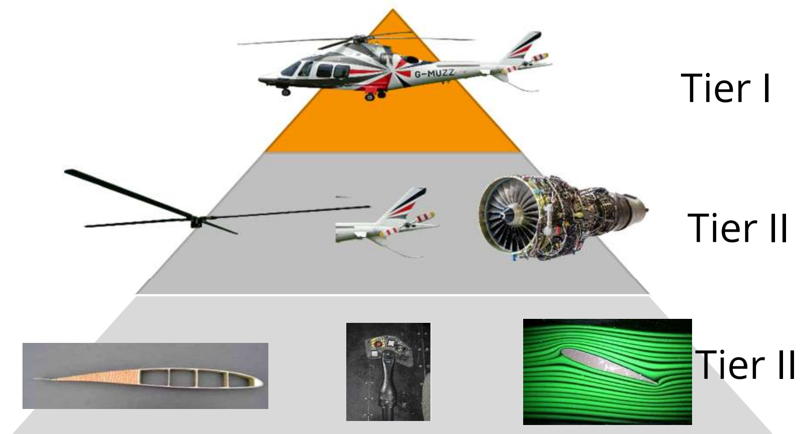
- Complexity of the model
- Validation domain and fidelity
- Flight Test data required

*ACR Applicable Certification Requirements

Phase 2 – Flight Simulation Model



Building Block Approach



The integrated components of a typical FSM

Data Pedigree

For every data used in the FS, FSM and FTMS it is necessary to keep trace of:

1. **Nature**: measured, inferred by measured data, taken from literature, decided based on engineering judgment or experience, extracted by design requirements.

2. **Range of uncertainty**: defined as measurement uncertainty, or inferred uncertainty, or engineering judgment (with explanation of the source). This element is essential to perform the tuning of the model, the assessment of uncertainty of the output.

3. Any **modification** occurred during the development must be **traced and reported**, so that it will be always possible to return to previous values.

The data must include all numerical parameters used to develop numerical models (physical constants, sampling/integration times, grid characteristics….).

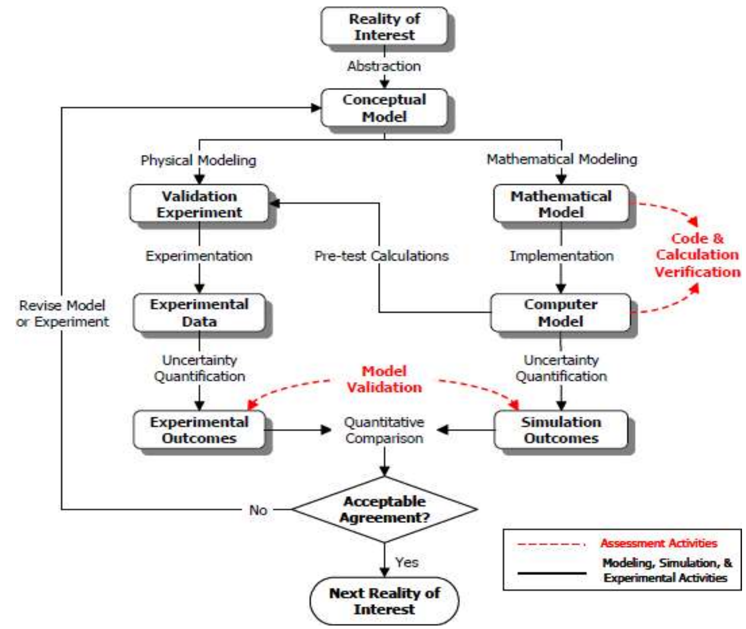
Phase 2 – V&V

Verification: is the model solving the equations right?

Validation: are we solving the right equation? Is it an accurate representation of the real world as determined by a referent?

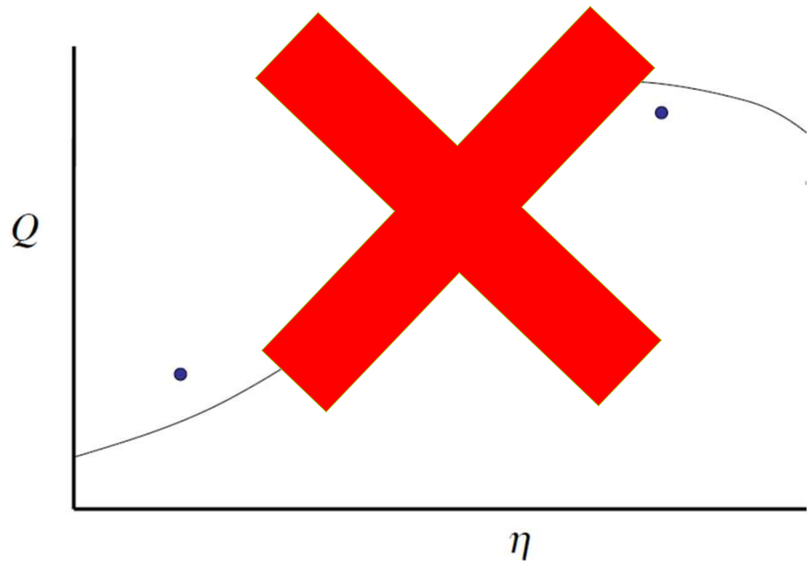
Referent, i.e.

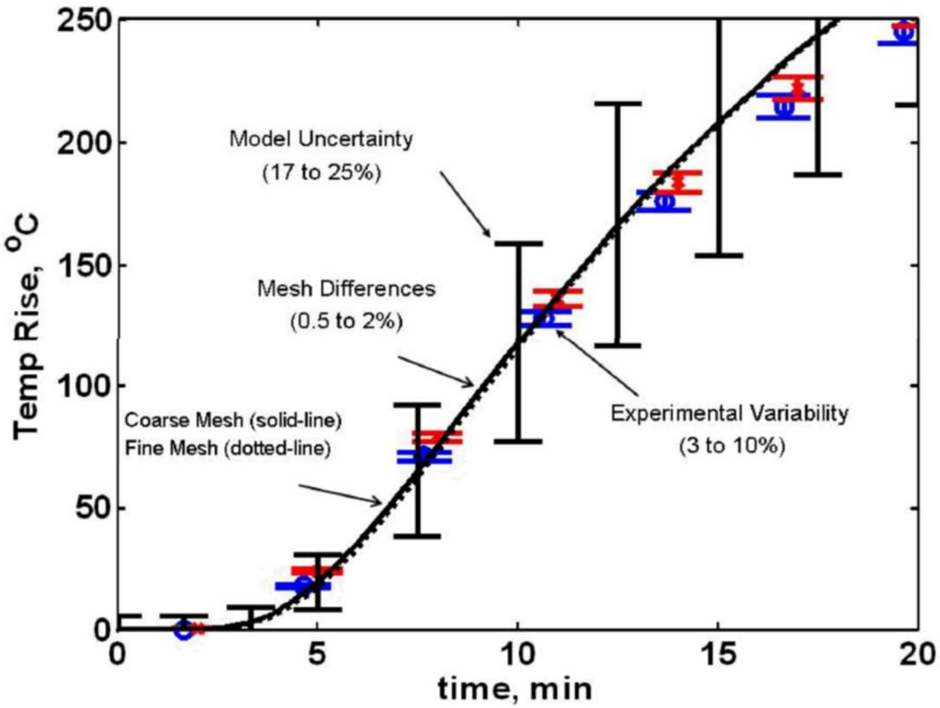
- experimental data on the aircraft of interest
- experimental data on similar aircraft
- other, more sophisticate (and validated) models
- engineering judgment



A model cannot be proved to be "valid." One can only demonstrate to a group of peers that there is no evidence that invalidates its predictions.

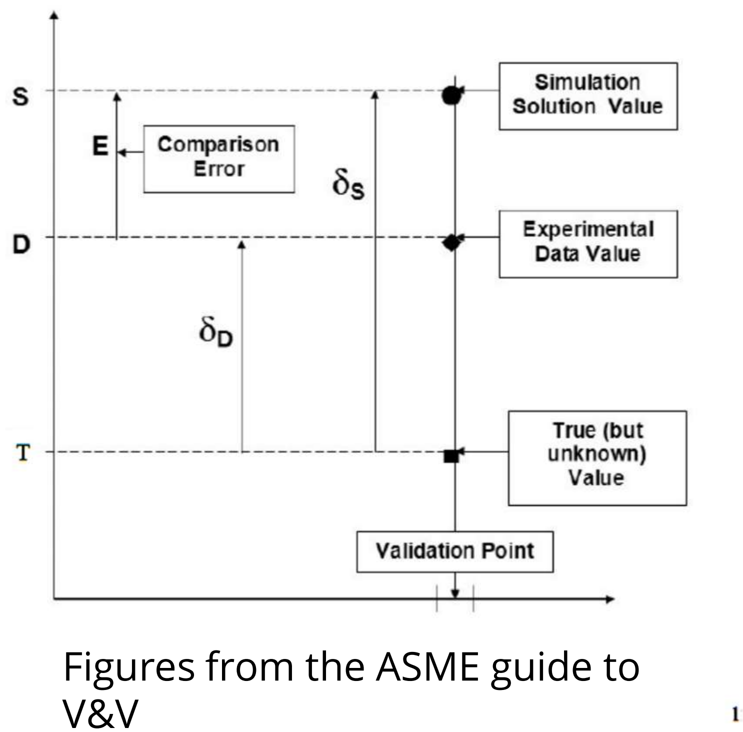
Validation





We need to quantify and show in our graphs ERRORS and UNCERTAINTIES

Validation approach



Figures from the ASME guide to V&V

δ_D Experimental error
δ_S Numerical error
$E = S - D$ Comparison Error
All errors measured used the validation metrics defined

$$E = (S - D) = T + \delta_S - (T + \delta_D) = \delta_S - \delta_D$$

What we see as an error is the combination of the experimental and simulation error

Validation approach

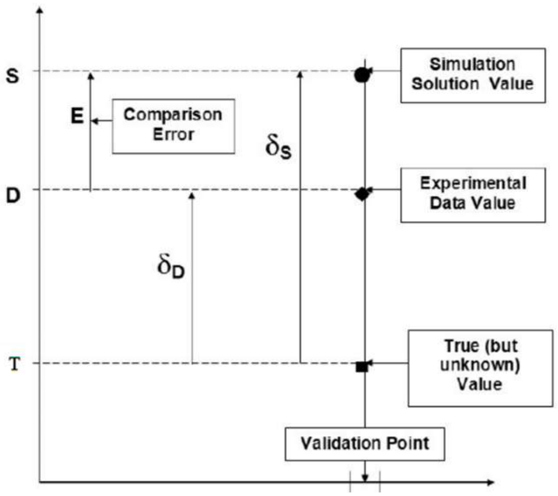


Figure from the ASME guide to V&V

$$\delta_S = \delta_{model} + \delta_{input} + \delta_{num}$$

$$\delta_{model} = E - (\delta_{input} + \delta_{num} - \delta_D)$$

$$\delta_{model} \in [E - u_{val}, E + u_{val}]$$

with $u_{val} = \sqrt{u_{num}^2 + u_{input}^2 + u_D^2}$

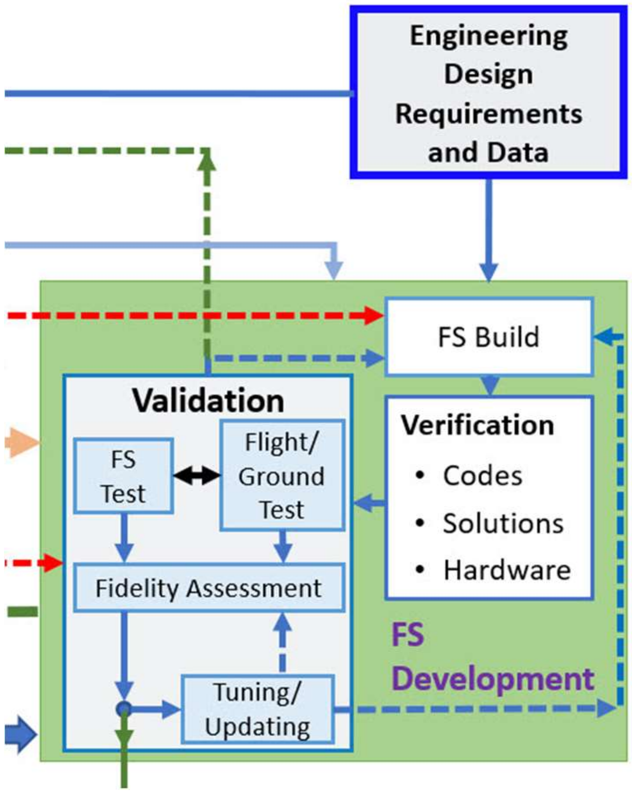
3 sources of Uncertainties: Numerics, Inputs, Experiments

In the DoE extrapolation of the error and uncertainty structure should be performed

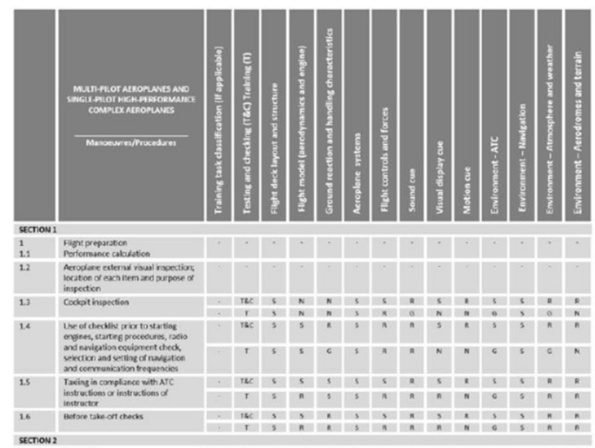
If $|E| >> u_{val}$ **the model error is larger than the uncertainty** and so some **modifications must be applied** to reduce the error, i.e $\delta_{model} \approx E$

If $|E| \leq u_{val}$ **the model error is within the noise level**. You can reduce the error by tuning and then try to reduce the uncertainty, if necessary

Phase 2b - Developing a Flight Simulator for RCbS

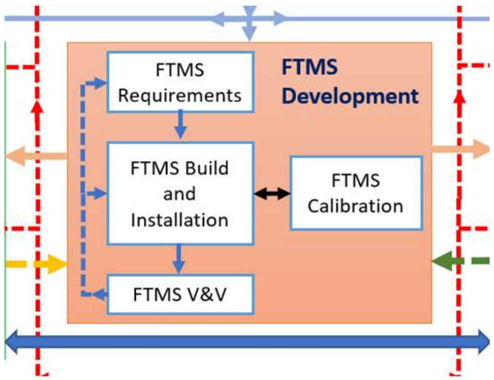


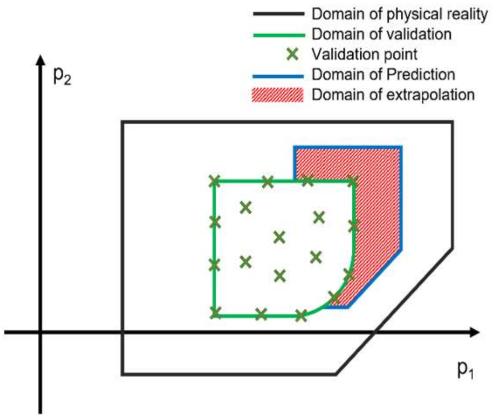
- The features should provide a pilot with **sufficient cueing environment necessary to undertake an ACR** identified in the requirements capture phase
- Notice of Proposed Amendment (NPA) 2020-15 - Update of the flight simulation training device requirements, EASA (2020)
- A Robust and Comprehensive V&V process is critical to success



	MULTI-PILOT AEROPLANES AND SINGLE-PILOT HIGH-PERFORMANCE COMPLEX AEROPLANES Manoeuvres/Procedures	Training task classification (If applicable)	Testing and checking (T&C) Training (T)	Flight deck layout and structure	Flight model (aerodynamics and engine)	Ground reaction and handling characteristics	Aeroplane systems	Flight controls and forces	Sound cue	Visual display cue	Motion cue	Environment - ATC	Environment – Navigation	Environment – Atmosphere and weather	Environment – Aerodromes and terrain
SECTION 1															
1 1.1	Flight preparation Performance calculation	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2	Aeroplane external visual inspection; location of each item and purpose of inspection	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.3	Cockpit inspection	-	T&C	S	N	N	S	S	R	S	R	S	S	R	R
		-	T	S	N	N	S	R	G	N	N	G	S	G	N
1.4	Use of checklist prior to starting engines, starting procedures, radio and navigation equipment check, selection and setting of navigation and communication frequencies	-	T&C	S	S	R	S	R	R	S	R	S	S	R	R
		-	T	S	S	G	S	R	R	N	N	G	S	G	N
1.5	Taxiing in compliance with ATC instructions or instructions of instructor	-	T&C	S	S	S	S	S	R	S	R	S	S	R	R
		-	T	S	R	S	S	R	R	R	N	G	S	R	R
1.6	Before take-off checks	-	T&C	S	S	R	S	S	R	S	R	S	S	R	R
		-	T	S	R	R	S	R	R	R	N	G	S	R	R
SECTION 2															

Phase 2c Flight Test Measurement System Development for RCbS - Quality

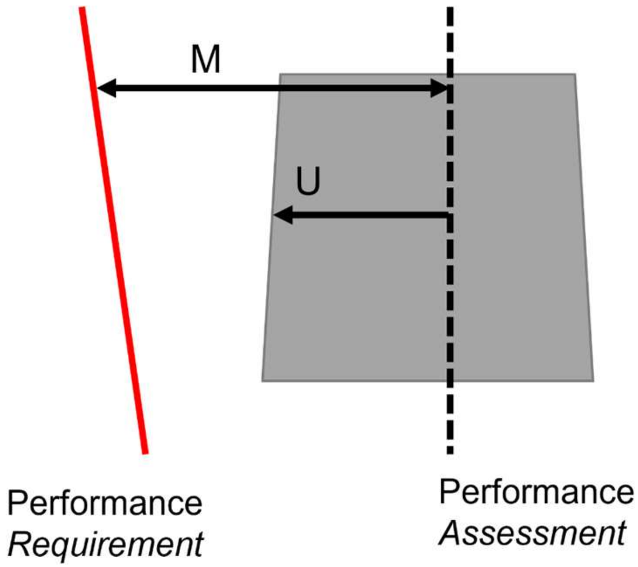




- Quality FT data critical to the accurate definition of the **validation domain**
- Focus of development is to **produce data for use by flight simulation experts in FSM and FS validation**

Confidence for Predicting a Performance Margin

(e.g. control margin, stability margin, response margin)



Confidence Ratio: ***CR = M/U***

A classification of level of confidence to satisfy the requirements

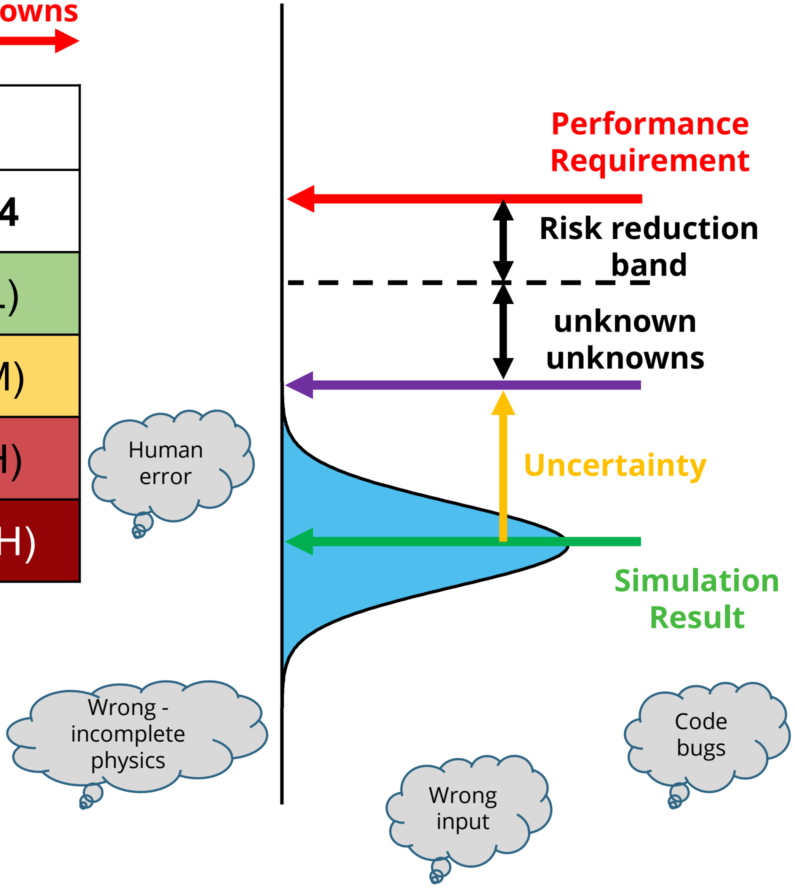
1.0 < CR	Low confidence (L)
1.1 < CR	Medium confidence (M)
1.25 < CR	High confidence (H)
1.4 < CR	Very High confidence (VH)

- M is the margin, or the generalised ‘distance’, between the quantified performance requirement and the FSM prediction
- U is the uncertainty within a certain level of probability

Phase 3 Safety-Confidence Ratio

Potential Effect of Unknown unknowns →

RCbS ACR	Influence levels	Predictability levels with Confidence Ratios			
		P1	P2	P3	P4
Risk ↓	I1	(L)	(L)	(L)	(L)
	I2	(L)	(L)	(M)	(M)
	I3	(L)	(M)	(H)	(H)
	I4	(M)	(M)	(H)	(VH)



Summarizing...

Will RCbS be a piece of cake? **NO**

Initial application likely to require significant investment, and it may not fully payback in the short-term especially for OEMs with a lot of experience in flight testing

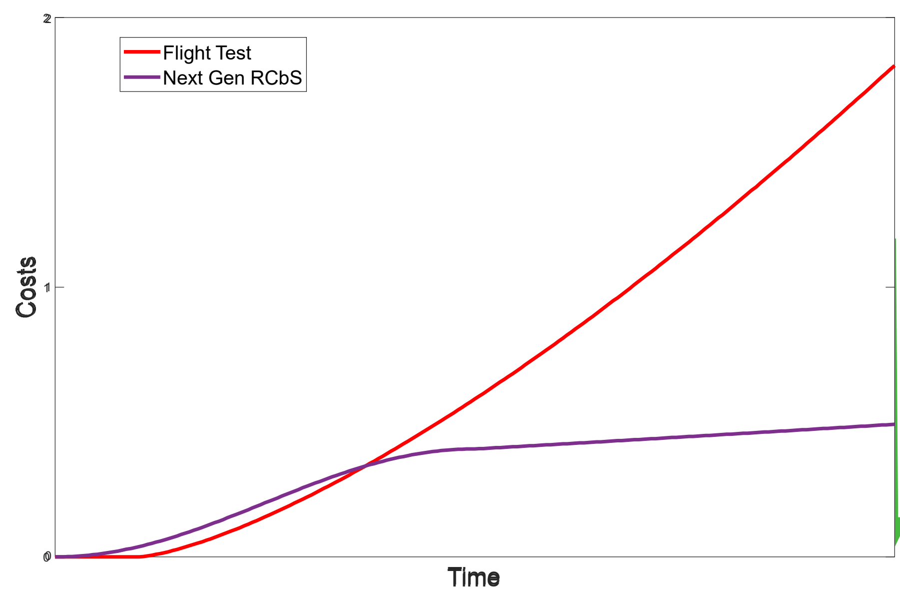
HOWEVER

Helicopters are long life-cycle programs and so, the RoCS Team believe RCbS may be rewarding in the long run

AW109 first flight 1971

↓

AW109 Trekker 2014



Cert. of Mk II

The way forward

- ✓ RoCS Guidance in its current form is only a first step in this direction.
- ✓ Input from the rotorcraft community, and in particular early industry adopters of the RCbS process, is necessary to improve and consolidate the concepts (and thresholds) that are included in the first draft of the Guidance.
- ✓ A workshop to better understand the application is planned for tomorrow. Virtual participation possible
- ✓ A copy of the guidelines for public consultation is available on the project website: www.rocs-project.org/guidelines/
- ✓ Provide feedback @ rocs.project@gmail.com

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