Airbus Amber

Surrogate Modelling at Airbus

An Airbus Framework for Verification & Validation of Surrogate Models

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23rd of April 2025

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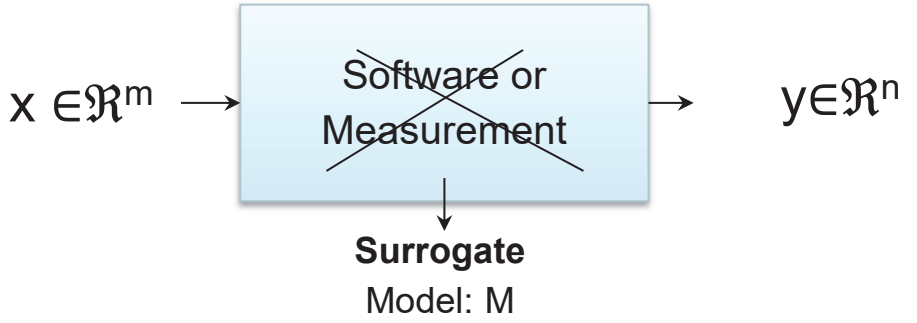
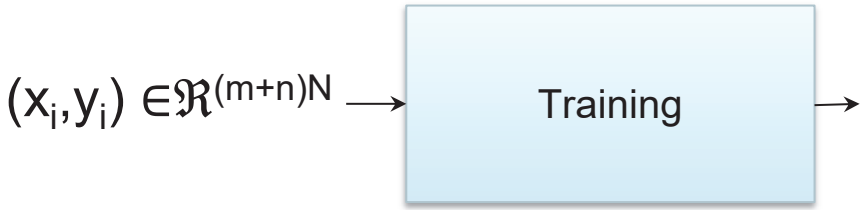
Surrogate models: What is it ?

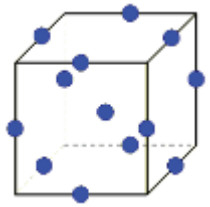
- Mathematical model linking input and output to **replace** heavier processes: simulations/tests



- Built from a grid of experimental and/or simulation data (**D**esign **O**f **E**xperiments)

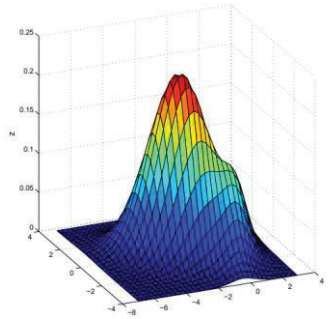


- Used
  - to accelerate simulation times for development
  - to create models from empirical/simulation data for hybrid testing
  - to export internal models for services



DOE

$$\min_{w \in \mathbb{R}^p} \sum_{i=1}^{N} \|y_i - M(w, x_i))\|^2$$



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Surrogate Factory: Main drivers

Straight from data to models

*A **user-friendly** environment with minimum development*

Easy

Surrogate Factory

Shared

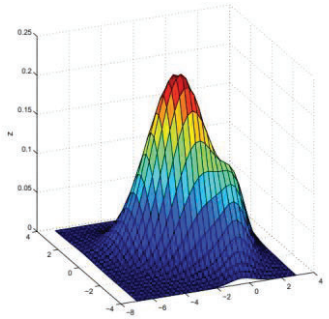
Robust

*An exchange platform for **algorithms** and **models***

*A full **V&V** process to guarantee fit-to-purpose surrogate models*

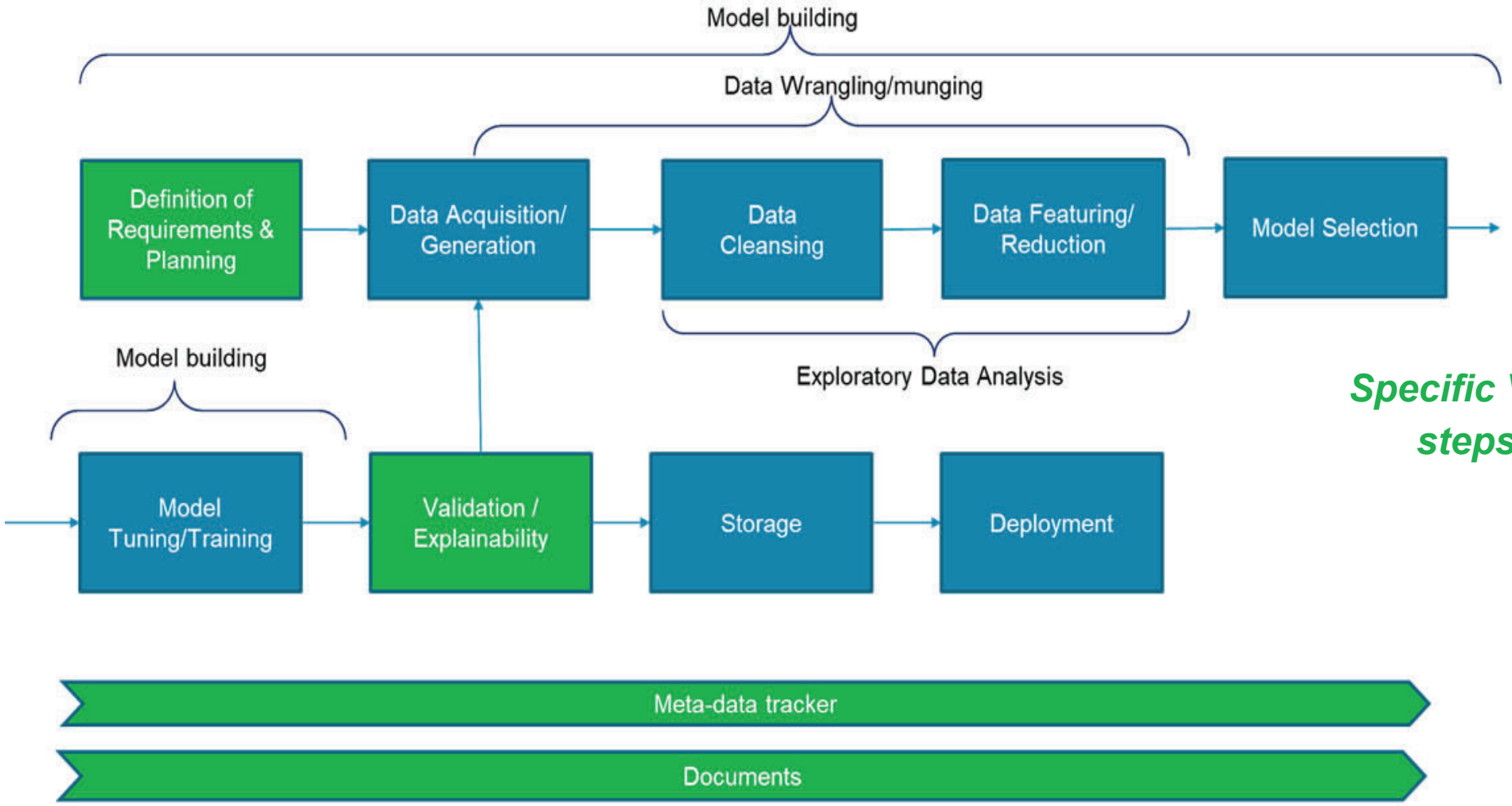
to support engineering projects:

Aero2stress, SOFIA, ...



Surrogate Factory aims at democratizing surrogate models in engineering but in a framed and guided V&V process

Surrogate Factory: An end-to-end process



Specific V&V steps

E2E process as a backbone of the Surrogate Factory, well beyond the standard Machine Learning pipeline

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Surrogate Factory: Applications

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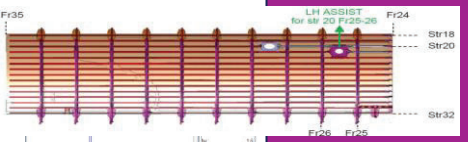
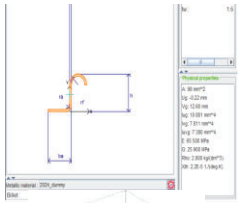
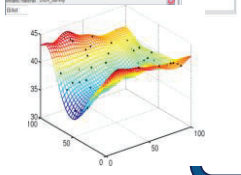
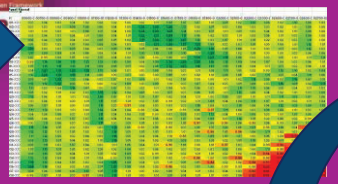
SA Fuselage Optimization



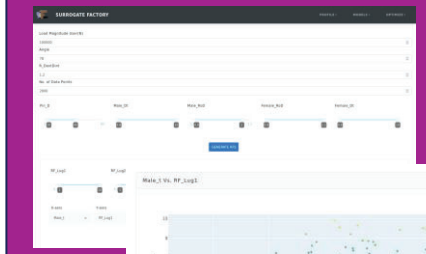


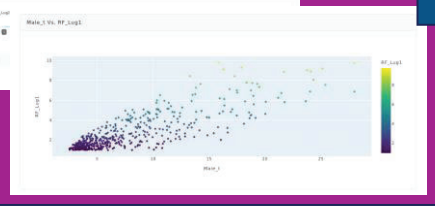


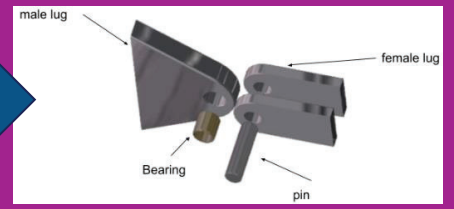


Weight and cost savings

Lugs Design Agent

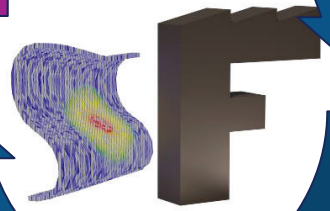






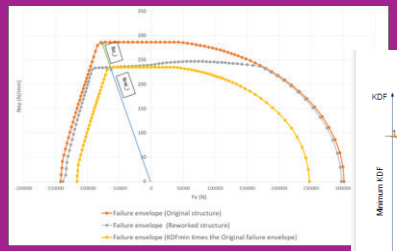
Weight and cost savings

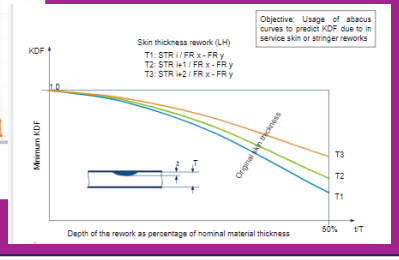
Design



Services

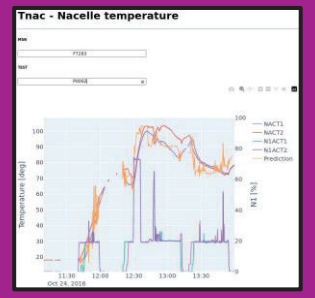
SA Fuselage repairability





Quicker answer to tech-requests, end-customer satisfaction

Virtual sensors for thermal prediction



Derisk delivery and avoid penalties, end-customer satisfaction, reduce time to certification

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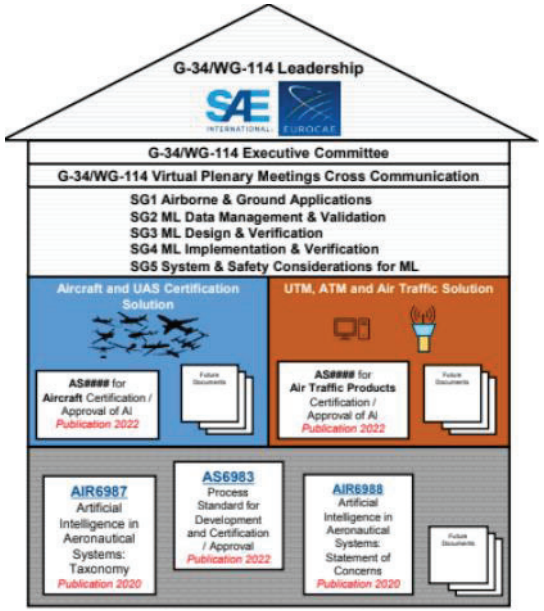
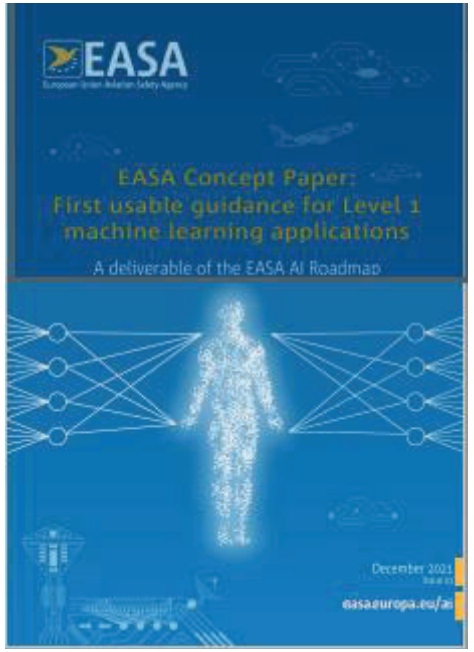
Context





Technical Advice Contract with EASA on-going

International standard (EUROCAE-SAE) , EASA commitment

HALO
Aero2stress
Fatigue Digital Twin
DLR
SOFIA
Cabin2Stress

Loads & stress SM projects

International initiatives for SM & AI V&V

NGSA
Confiance.ai
Trust.ai
Surrogate Factory

Need

Surrogate Models Verification & Validation Working Group

Loads/stress community

Created in September 2021

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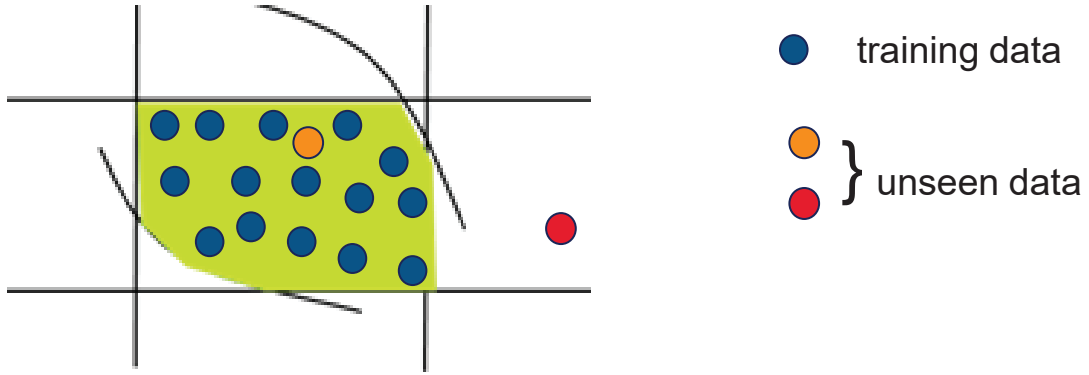
Main problematics

Sampled ODD*: Operational Design Domain



- Training data shall be **representative** (within constraints) and **complete**: Filling the ODD (Design of Experiments)
- Data should be well predicted: **Generalization**
- Data cannot be well predicted: **Robustness**

  in specific cases (strong non-linearities) some orange points can be red: needs an **error predictor**
- Continuum is never known: error is always presented as a probability

  exception when target function (ground truth) regularity is known

$$Prob(error \leq \varepsilon) \geqq 1 - \delta$$

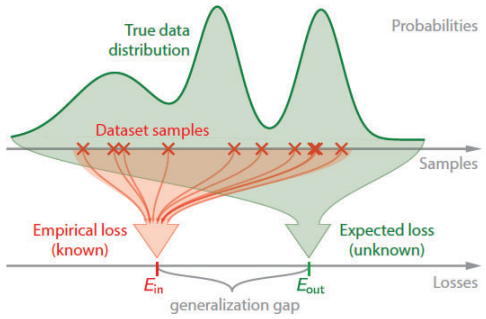
  needs good statistical estimates + pyramidal approach of the error to scrutinize the ODD

ODD*: Input Space, Design Space

High Level properties

The error is in line with the requirements over the full ODD

$$Prob(error \leq \varepsilon) \geqq 1 - \delta$$



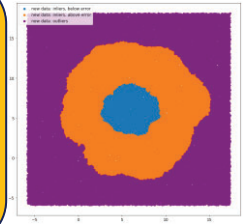
courtesy of EASA
IPC CoDANN public report

Generalization
(quantifiable guarantees theoretical/statistical)

supports

Good operational behaviour in presence of abnormal inputs

Robustness
(applicability, error prediction in operations)

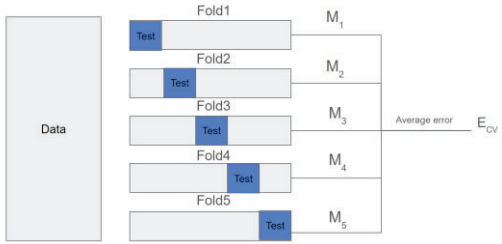


discriminator

supports

supports

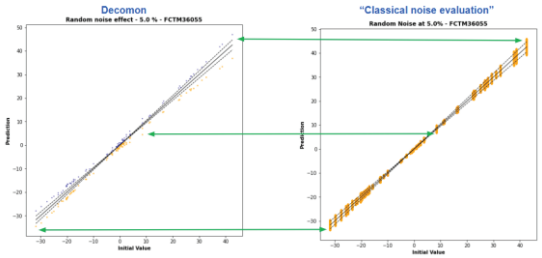
supports



Bias-Variance* Optimization
(cross-validation)

In-sample generalization
The error is stable with respect to training set

Stability
(formal, statistical)



Output not sensitive to input perturbations

*Variance: sensitivity to data particularly in presence of noise

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Airbus answer: statistical methods

Data

Training level

Feedback of new data to training: Active learning

Bias

Model scanning & Operational **applicability**

Bias

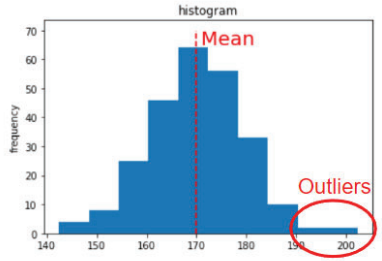
Global

Probabilistic

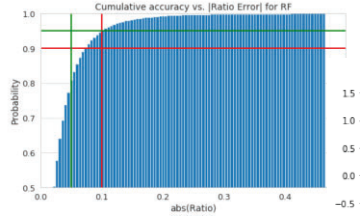
Region-wise

Pointwise

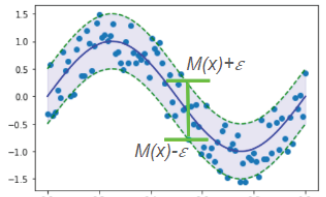
Average



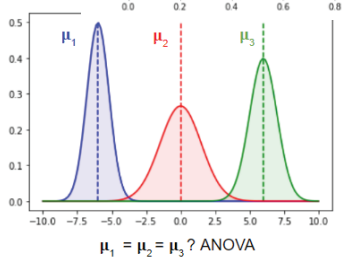
Quantile



Global CI

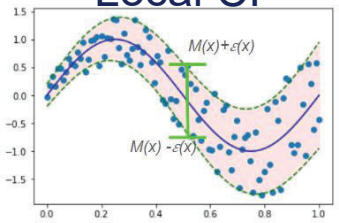


ANOVA (Analysis of Variance)



LEQ (Local Error Quantification)

Local CI



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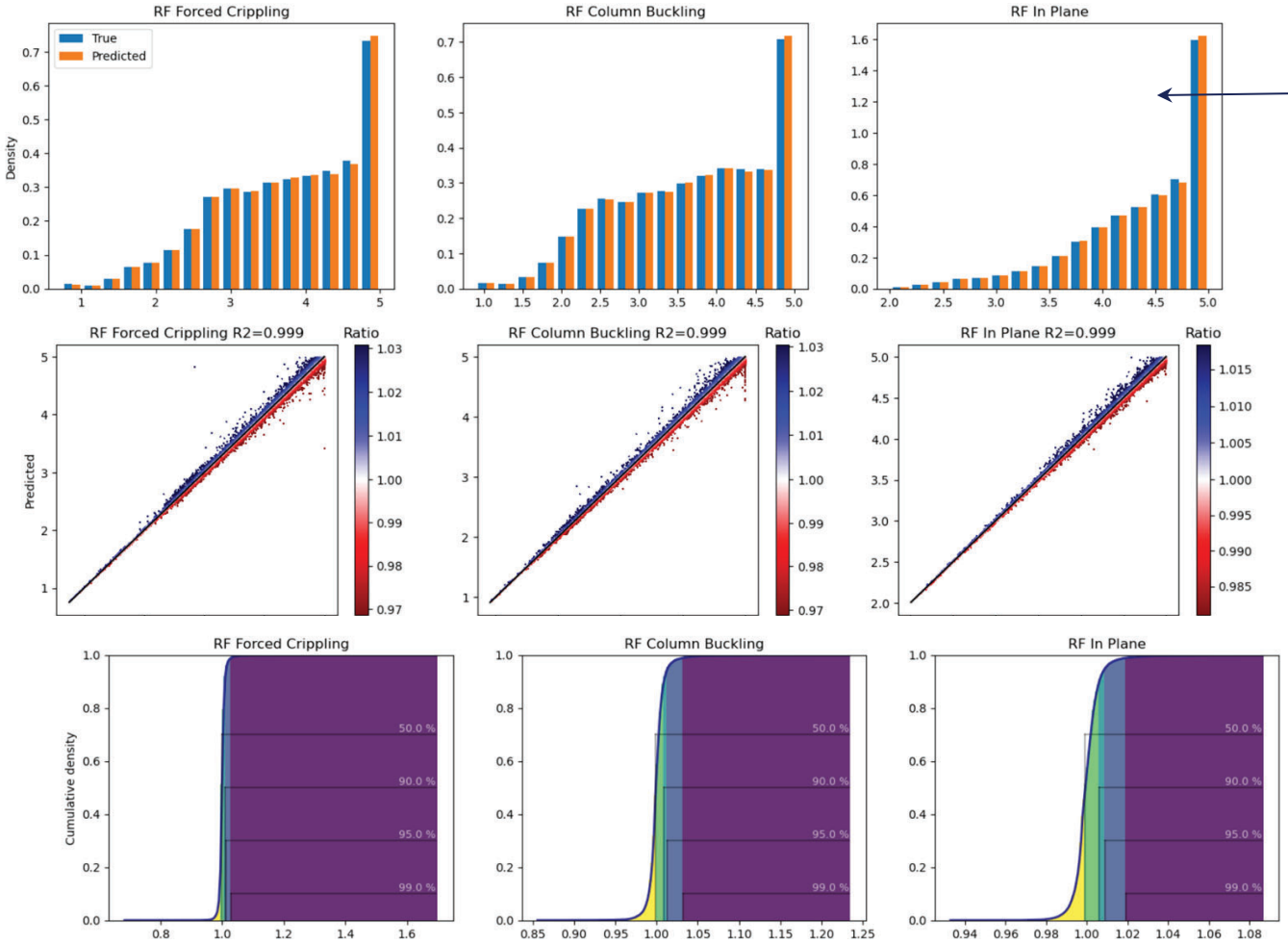
Pyramidal error analysis (2) - Global & Probabilistic

A321 XLR S18



N-Dimensional distribution comparison between prediction and true values are identical (distance correlation test)
Marginal distributions comparison between prediction and true values are similar

$R^2 > 0.99$
Tested on 832499 Calculation points and load case.

Statistically converged quantiles (Wilson Score)

	Percentile 90%	CI (95 %)	Percentile 99%	CI (95 %)
RF Forced Crippling	$1.01^{1.01}_{1.01}$		$1.03^{1.03}_{1.03}$	
RF Column Buckling	$1.01^{1.01}_{1.01}$		$1.03^{1.03}_{1.03}$	
RF In Plane	$1.01^{1.01}_{1.01}$		$1.02^{1.02}_{1.02}$	
RF Net Tension	$1.01^{1.01}_{1.01}$		$1.01^{1.01}_{1.01}$	
RF Pure Compression	$1.01^{1.01}_{1.01}$		$1.03^{1.04}_{1.03}$	
RF Shear Panel Failure	$1.01^{1.01}_{1.01}$		$1.03^{1.03}_{1.03}$	

No goodness of fit, used **non-parametric statistics**
No outliers on error ratio distributions for any output variable

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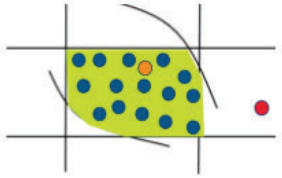
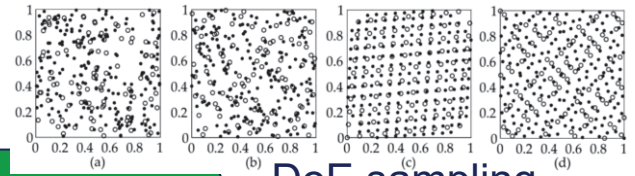
Data Quality Requirements



ODD definition
Distribution

Conformity incl. Representativeness



DoE sampling

Completeness

→ Build the right model (generalization)

Traceability

Metadata

→ Use the right model (robustness)

Availability, Timeliness, Accuracy, Integrity, Interpretability, Consistency, Precision

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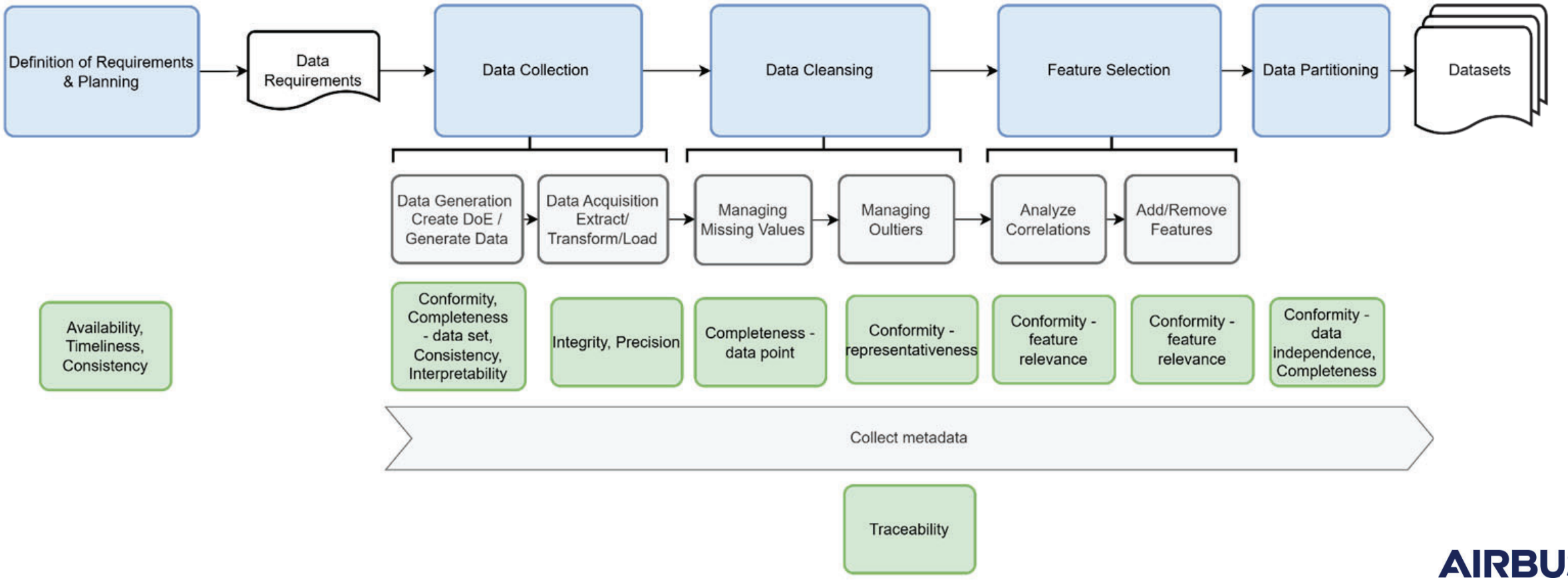
Airbus answer: A qualified data management process (Surrogate Factory)

- Most of the Data Quality Requirements satisfied **by qualification of tools and process** following the below recommended workflow



SM V&V status

- Internal report available as a referential for Surrogate Model Verification & Validation
- Checklist and documentation contents under review with EASA
- Github library implementation to materialize the checklist in terms of recommended Means of Compliance

Contents

Way forward

- Implementation of Surrogate Factory in a custom AWS/SageMaker environment (2025)
- Completion with V&V steps (2026)

- Finalize acceptance of EASA for SMV&V as a MoC* for Surrogate Models at Airbus (2025)

- Support running (HALO/Fatigue Digital Twin) and future projects for certification

- Extension to other Machine Learning Models like Computer Vision

- Support EUROCAE-SAE WG114-G34 in standard ARP6983 adaptations (unsupervised learning, reinforcement learning etc.)

*Means of Compliance

Thank you

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