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RESEARCH PROJECT EASA.2022.C25

D-2.2 REPORT ON THE STAKEHOLDER WORKSHOPS

MODEL-SI

Digital Transformation - Case Studies for Aviation Safety Standards - Modelling and Simulation

An Agency of the European Union

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SUMMARY

This report provides a description about the presentations, briefings and feedback collected during the two workshops that occurred in April 2023 and July 2024. The first workshop introduced the MODEL-SI project, its objectives, and methodology, emphasizing both physics-based and data-driven approaches. Initial results and examples were shared. Feedback from attendees centered on AI-related questions, including its motivation, validation, uncertainty quantification, and potential for certification.

The second workshop focused on presenting mid-project results, building upon the foundation laid in the first workshop. While attendance was lower, discussions primarily revolved around AI and digital twin concepts. Key questions from the first workshop, such as the role of AI, model validation, and the project's alignment with certification requirements, were reiterated.

Overall, both workshops highlighted the importance of AI and data-driven methods in the context of eVTOL modeling and simulation, while also emphasizing the challenges associated with these approaches.

CONTENTS

ABBREVIATIONS

ACRONYM	DESCRIPTION
AI	Artificial Intelligence
CFD	Computational Fluid Dynamics
ML	Machine Learning

1. Workshop #1

1.1 Presentation

It was delivered on April 27th 2024 from Cologne (EASA and ZHAW) with stakeholders attending online. Slides and the video recording of the meeting can be found on MODEL-SI (Digital Transformation - Case Studies for Aviation Safety Standards - Modelling and Simulation) | EASA (europa.eu).

1.2 Briefing

The workshop aimed to provide a comprehensive overview of the MODEL-SI project, outlining its goals, objectives, and methodological approach. Both physics-based and data-driven techniques were presented as core components of the project. Preliminary examples presenting the successful application of these methods were also shared with attendees.

1.3 Feedback

The stakeholder invitee list was of 120 people, while around 70 people attended the workshop.

The workshop discussion was mainly on the Machine Learning (ML) approaches. For example, how to validate them, if is it possible to extrapolate, and how to deal with their non-deterministic approach. The audience raised several key questions about the project, focusing on:

- Motivation for AI: The justification for incorporating AI into the simulation, considering the complexity of eVTOL modeling.
- Execution Time: Whether execution time refers to processing per flight hour or per specific events.
- Novelty and Validation: The approach's application to simpler aircraft with existing data and the project's validation methods for the AI tools used.
- Uncertainty Quantification: How uncertainty was assessed (model vs. experimental or both).
- Related Projects: The connection between this project and the EU-funded RoCS project.
- Extrapolation Beyond Flight Envelope: The model's ability to predict beyond the tested flight conditions.
- Non-Deterministic Nature of ML: How the project addresses the inherent randomness of some ML techniques.
- Model Credibility: Whether references from ASME's VVUQ subcommittees on ML, CFD, and solid mechanics were considered.
- Acceptance for Certification: The possibility of an AI-based model being accepted for compliance demonstrations with limited flight test data.

After the workshop, a questionnaire was sent to all the stakeholders (see Annex A for questionnaire and feedback received).

Based on both workshop discussion and questionnaire answers, the main challenges seem to be related to the aerodynamic interaction between rotors, wings and tails. The resulting force is among one of the most

interesting quantities of interest, together with the shear stress. Another non-trivial topic is the interaction between the wing and the body.
Other interesting take-home messages are related to the most method used. At low-fidelity Blade Element Momentum (BEM) is used to model the rotors, whereas at high-fidelity RANS CFD with multi-domain discretization areas.

Finally, concerning flight simulations, the transition phase is the most interesting maneuver to study.

2. Workshop #2

2.1 Presentation

It was delivered on July 10th 2024 from Cologne (EASA) and Winterthur (ZHAW), with stakeholders attending online. Slides and the video recording of the meeting can be found on MODEL-SI (Digital Transformation - Case Studies for Aviation Safety Standards - Modelling and Simulation) | EASA (europa.eu).

2.2 Briefing

The workshop aimed to provide an overview of the MODEL-SI project mid-results, outlining which methods, both physics-based and data-driven, were applied.

2.3 Feedback

The stakeholder invitee list was of 140 people, whilst circa 35 people attended the workshop. The small attendance was anticipated since the event took place in July.

The main discussion topics were on general AI/ML aspects The discussion focused on several key areas of the project:

- Digital Twin Definition: There was a discussion about the relationship between digital twins and reduced-order modeling.
- Project Motivation: The underlying reasons for EASA's involvement in the project were questioned.
- Model Fidelity and Impact: The influence of including wing and tail models on the hover case was explored, along with the impact of structural flexibility on flight mechanics.
- Training Material and Knowledge Transfer: The potential for creating training materials and sharing knowledge with EASA was discussed.
- Flight Resonance and Model Development: The importance of modeling flight resonance and the interaction between lifters with different RPMs was highlighted.
- AI and Future Outlook: The potential impact of AI on simulation and the overall project sentiment were explored.

Annex A Workshop #1

A.1 Questionnaire

MODEL-SI Workshop #1 Questionnaire

MODEL-SI workshop #1: Modeling and Simulation of digital twin eVTOL. This workshop is aimed at bringing together experts in the fleld of aerospace to discuss the latest developments and advancements in digital twin technology and its impact on certiflcation.

The questionnaire is meant to have an overview about stakeholder opinion about eVTOL aircraft development and the implications of machine learning processes in certiflcation.

1. General aircraft development: major challenges?

Tick all that apply.

- ☐ Aerodynamic prediction
- ☐ Structure prediction
- ☐ Rotor thrust prediction
- ☐ Interaction between rotors/wing/tail
- ☐ Other

2. Which are the most interesting quantities to study?

Tick all that apply.

- ☐ Shear stress
- ☐ Bending moments
- ☐ Rotor thrust
- ☐ Total aerodynamic forces
- ☐ Flutter speed
- ☐ Divergence speed
- ☐ Other

3. Most difficult eVTOL part to model

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.....
.....
.....
.....

4. Which is the most interesting eVTOL part to study

Tick all that apply.

- [ ] Rotors
- [ ] Wing/Body aerodynamics
- [ ] Moving parts (rotors/wings)
- [ ] Structure
- [ ] Electrical system
- [ ] Other

5. Which is the most interesting rotor design to study?

Tick all that apply.

- [ ] Open
- [ ] Ducted
- [ ] Fixed
- [ ] Tiltable
- [ ] more than 4
- [ ] less than 4
- [ ] Other

6. Low-fidelity: Most used method to model structures?

Mark only one oval.

- ◯ Finite Element Model (FEM)
- ◯ Ritz-Rayleigh
- ◯ Other

7. Low-fidelity: Most used method to model aerodynamics

Mark only one oval.

- ◯ Vortex Lattice Method (VLM)
- ◯ Panel methods
- ◯ Strip theory
- ◯ Lifting-Line Theory (LLT)
- ◯ Other

8. Low-fidelity: Most used method to model rotors

Mark only one oval.

- ◯ Actuator disk
- ◯ Blade Element Momentum theory (BEM)
- ◯ Multi-blades coordinates
- ◯ Other

9. High-fidelity: Most used method to model structures

Mark only one oval.

- ◯ Finite Element Model (FEM)
- ◯ Other

10. High-fidelity: Most used method to model aerodynamics

Mark only one oval.

- ◯ Reynolds-Averaged Navier-Stokes (RANS)
- ◯ Detached eddy simulation (DES)
- ◯ Delayed Detached eddy simulation (DDES)
- ◯ Large Eddy Simulation (LES)
- ◯ Other

11. High-fidelity: Most used method to model rotors

Mark only one oval.

- ◯ Embedded actuator disk in CFD
- ◯ Blade Element Momentum theory (BEM)
- ◯ Multi-domain CFD simulation (physical blade)
- ◯ Other

12. Could you provide some flight test data?

Mark only one oval.

- ◯ yes
- ◯ no

13. Most interesting maneuver to test

Tick all that apply.

- ☐ Hover
- ☐ Transition
- ☐ Cruise
- ☐ High load factor
- ☐ Descent
- ☐ Landing
- ☐ Other

14. Most important quantities to measure

Tick all that apply.

- ☐ Wing bending moment
- ☐ Wing shear stress
- ☐ Wing accelerations
- ☐ Total rotational velocities/accelerations
- ☐ Total linear velocities/accelerations
- ☐ Airdata
- ☐ Control deflections
- ☐ Other

15. Have you already developed a Digital Twin?

Mark only one oval.

- ◯ yes
- ◯ no

16. If yes, on which part of the aircraft did you develop the Digital Twin

.....
.....
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.....

17. Best machine learning method?

Mark only one oval.

- ◯ Gaussian Process
- ◯ Neural Netword
- ◯ Other

18. Gaussian processes: which method do you use?

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19. Neural network: which method do you use?

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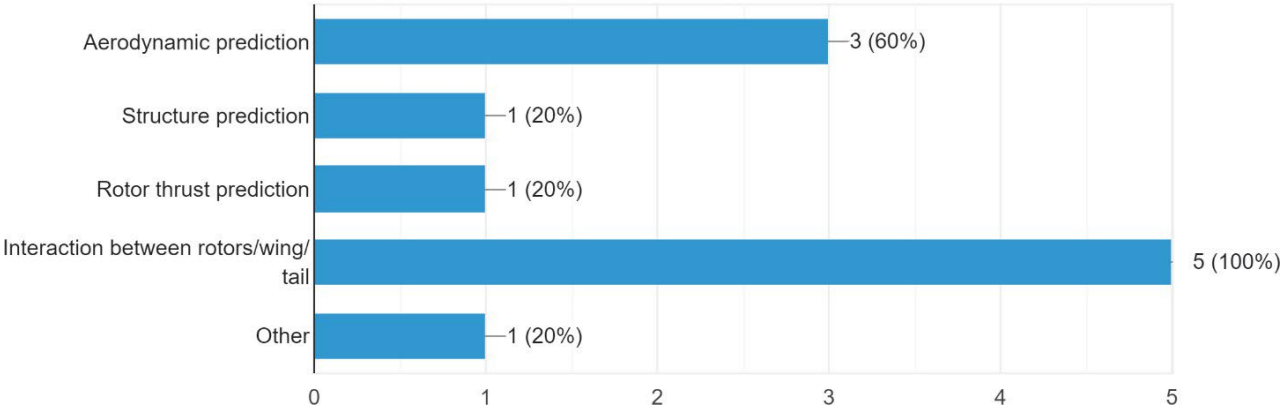
A.2 Questionnaire Answers

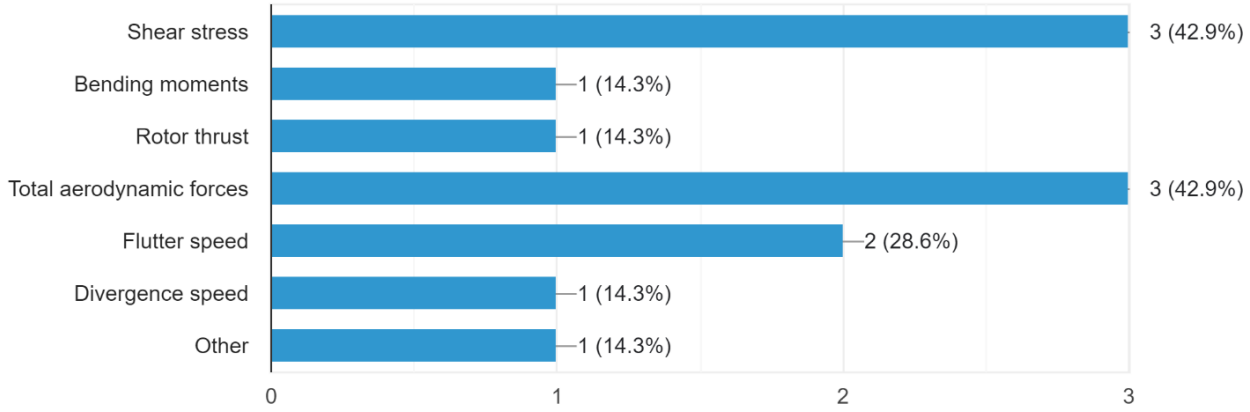
General aircraft development: major challenges?

5 responses



Which are the most interesting quantities to study?

7 responses



Most difficult eVTOL part to model?

3 responses

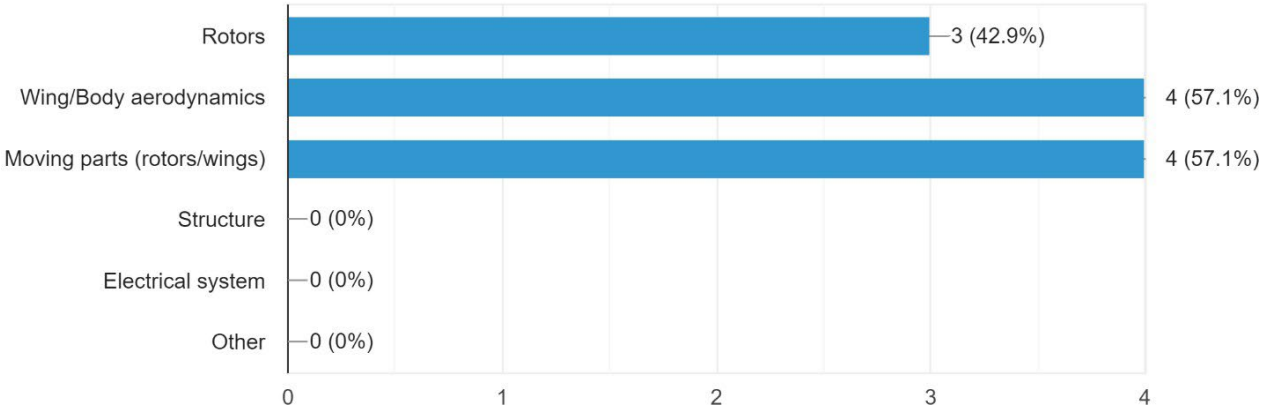
Wing/ Body

wing-propeller interaction at high AoA, fuselage effects of non-classical fuselage shapes

Rotors and their interactions

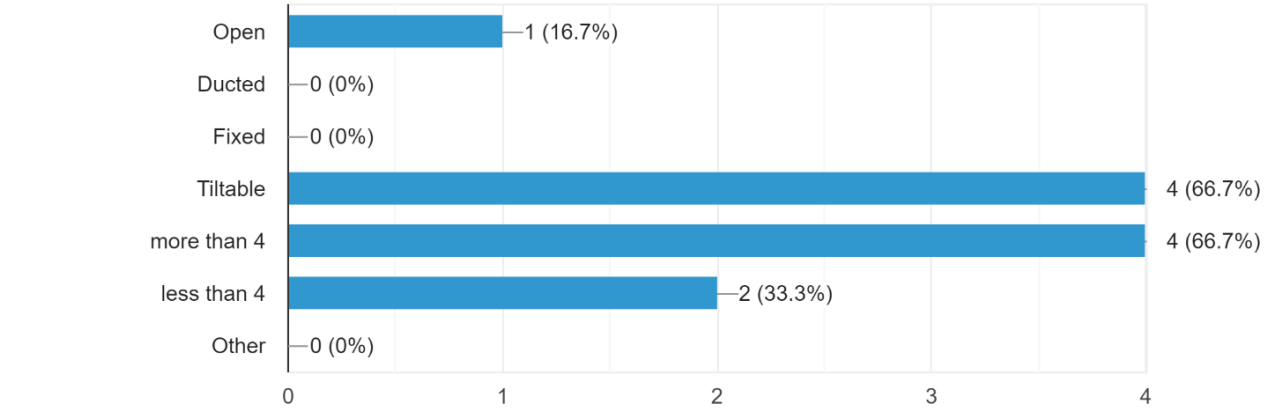
Which is the most interesting eVTOL part to study?

7 responses



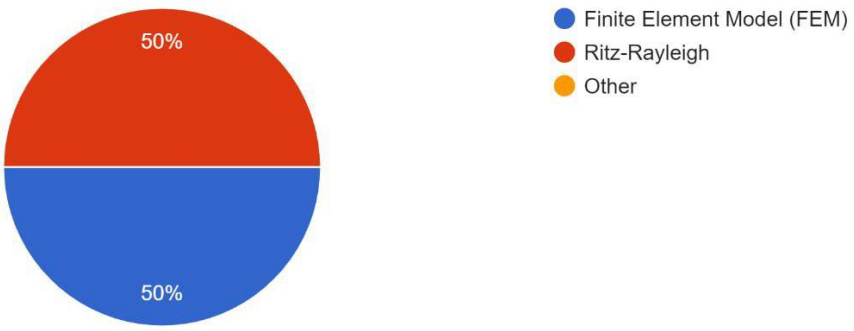
Which is the most interesting rotor design to study?

6 responses



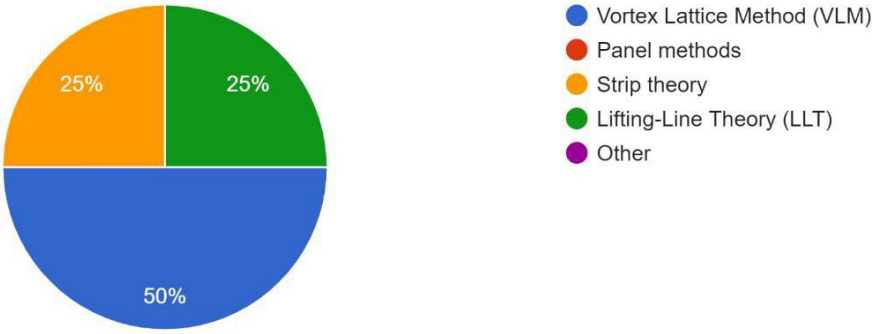
Low-fidelity: Most used method to model structures?

4 responses



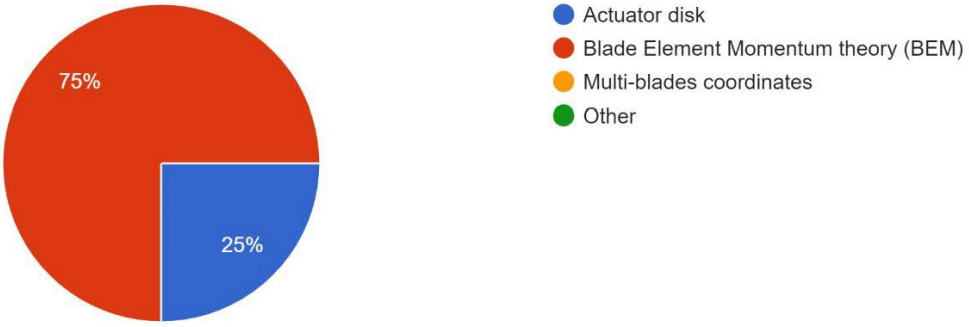
Low-fidelity: Most used method to model aerodynamics

4 responses



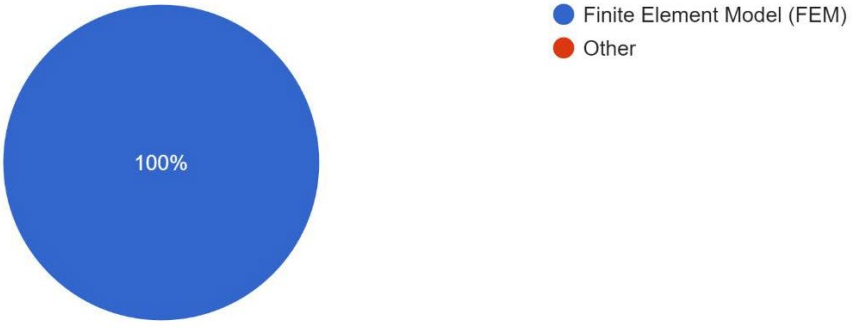
Low-fidelity: Most used method to model rotors

4 responses



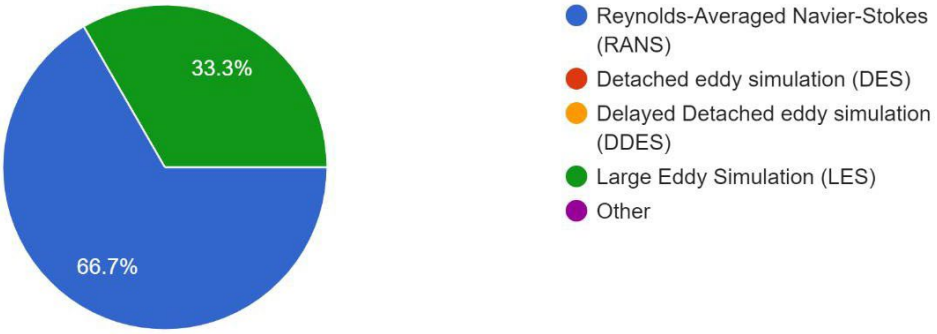
High-fidelity: Most used method to model structures

3 responses



High-fidelity: Most used method to model aerodynamics

3 responses

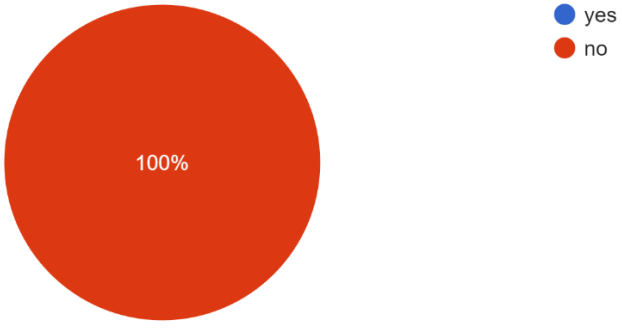


High-fidelity: Most used method to model rotors

4 responses

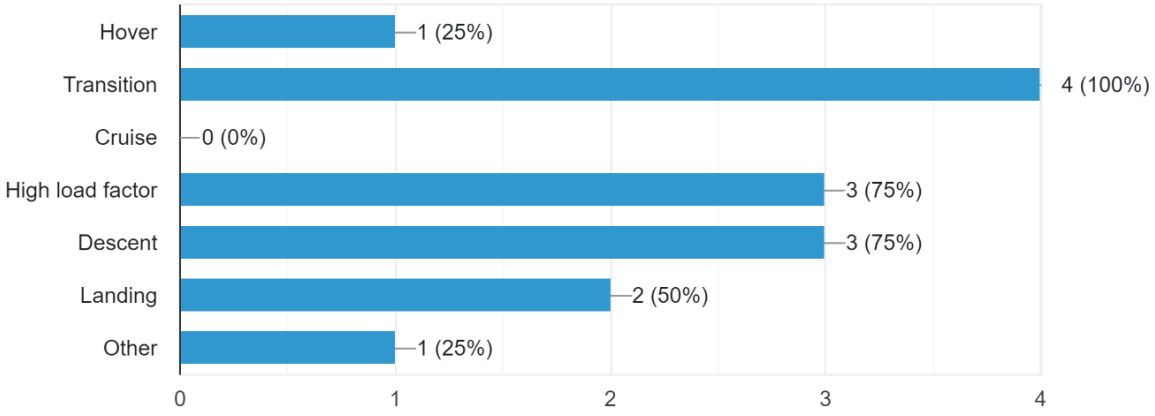
Could you provide some flight test data?

4 responses



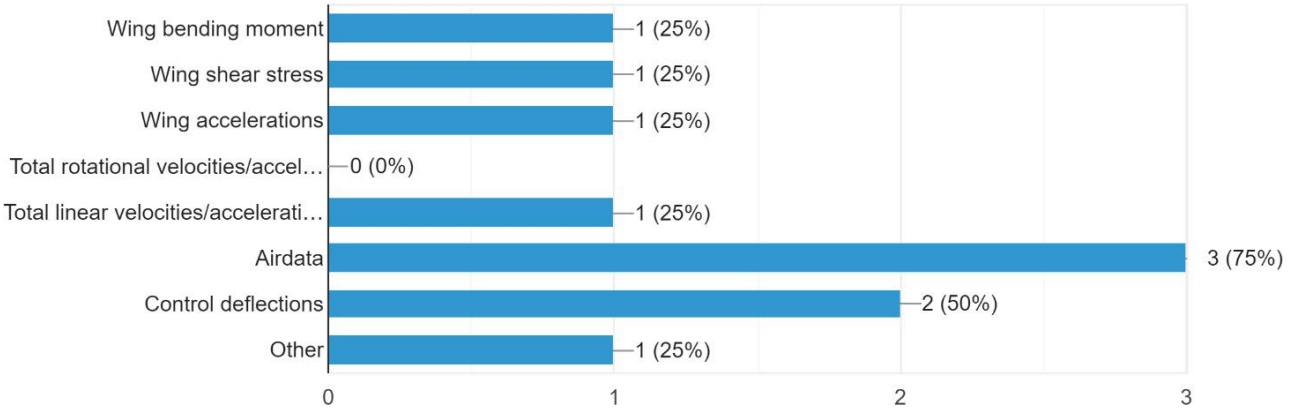
Most interesting maneuver to test

4 responses



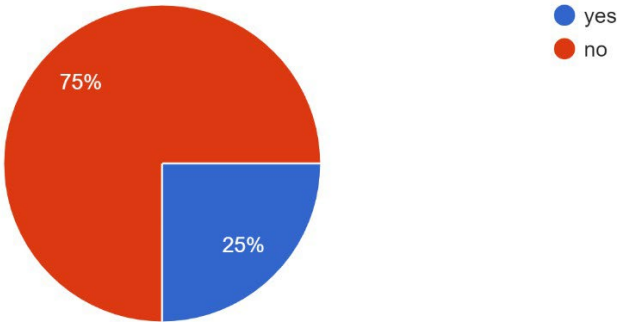
Most important quantities to measure

4 responses



Have you already developed a Digital Twin?

4 responses



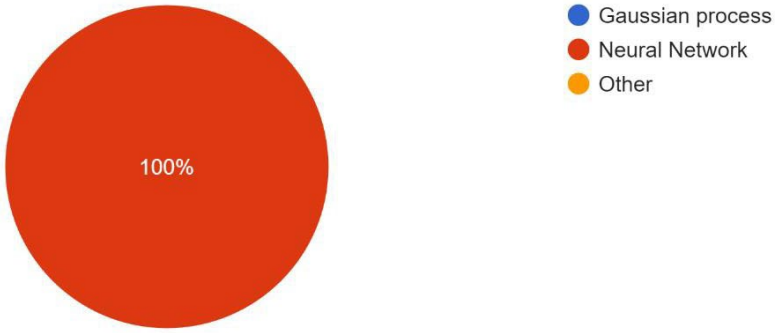
If yes, on which part of the aircraft did you develop the Digital Twin

1 response

Not of an aircraft part, but of a vertical windmill, to identify the loads acting on the main shaft of the windmill and to estimate the potential yield time for presciptive maintenance

Best machine learning method?

2 responses



Gaussian processes: which method do you use?

1 response

none

Neural network: which method do you use?

2 responses

RNN

none

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