CA3ViAR: a step forward towards modelling and testing aerodynamic and aeroelastic instabilities experienced by Low Transonic Fans made of composite material

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Presented by: N. Paletta, Project Coordinator (IBK)

Co-authors: E. Vecchio (IBK), J. Gößling, M. Amer, J. R. Seume (LUH), J. Friedrichs, T. Eggers (TUBS), S. Russo, N. Natale (DREAM)

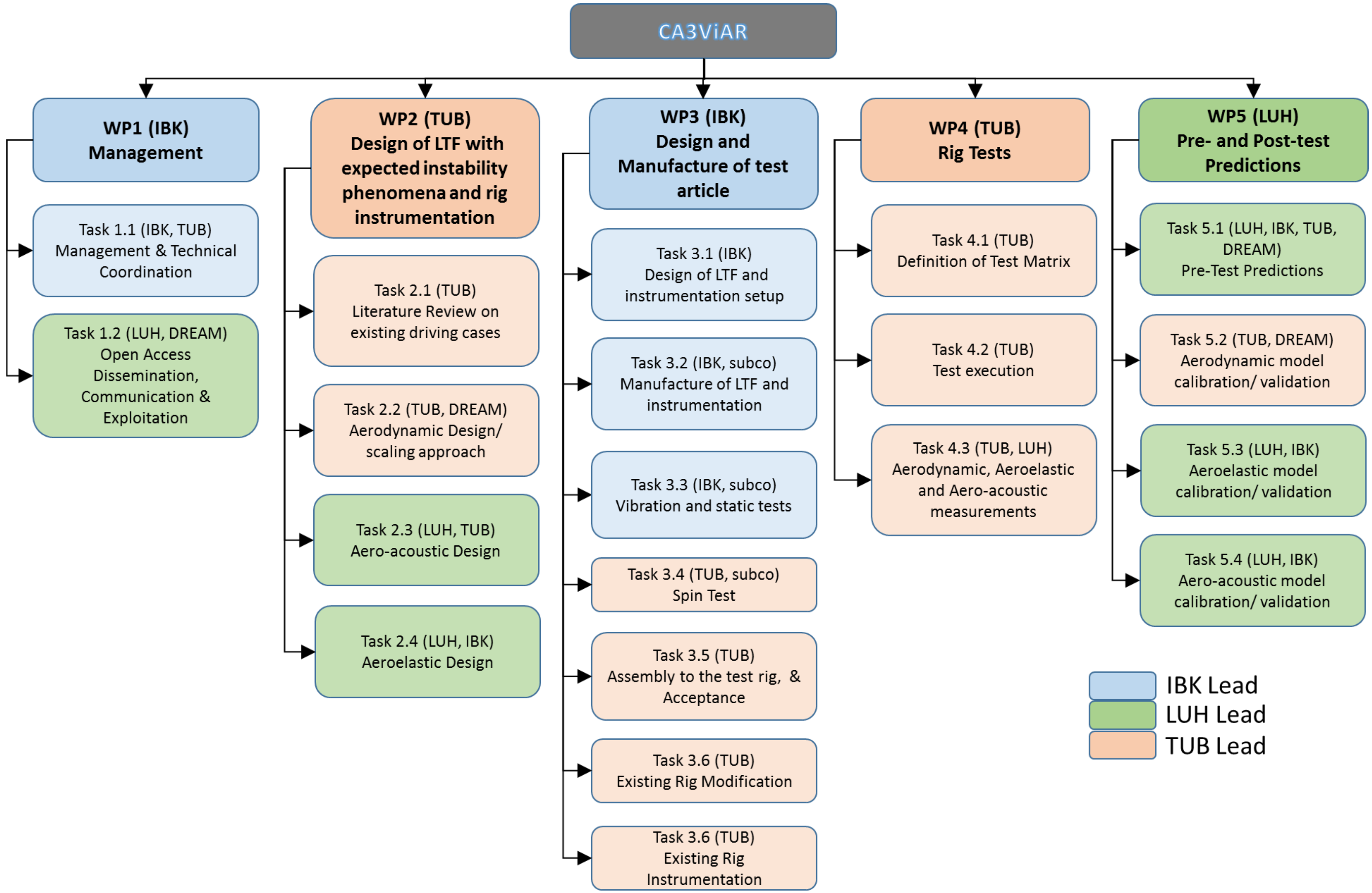
Project Objectives

- To perform a **literature review** of the main issues affecting composite **UHBR** engine fans;
- To **design a low-transonic fan** typical of a future large aircraft UHBR engine, in terms of aerodynamic shaping as well as structural design and analysis to make sure the test article can safely go close to aerodynamic and aeroelastic instabilities <u>in an expected way</u> during WT operations;
- To **design** the test article(s);
- To **manufacture** the test article(s);
- To **instrument** test articles and rigs;
- To perform **experimental tests** including fan instabilities due to off-design operation and inlet distortion;
- To perform a **final experimental-numerical assessment** for calibrating and validating numerical models;
- To provide **open access** to all the produced **models, data and documents** for other institutions for in-house developed methods validation, with the objective to establish an "open test-case" for the whole European scientific community, unique in the engine fans landscape.

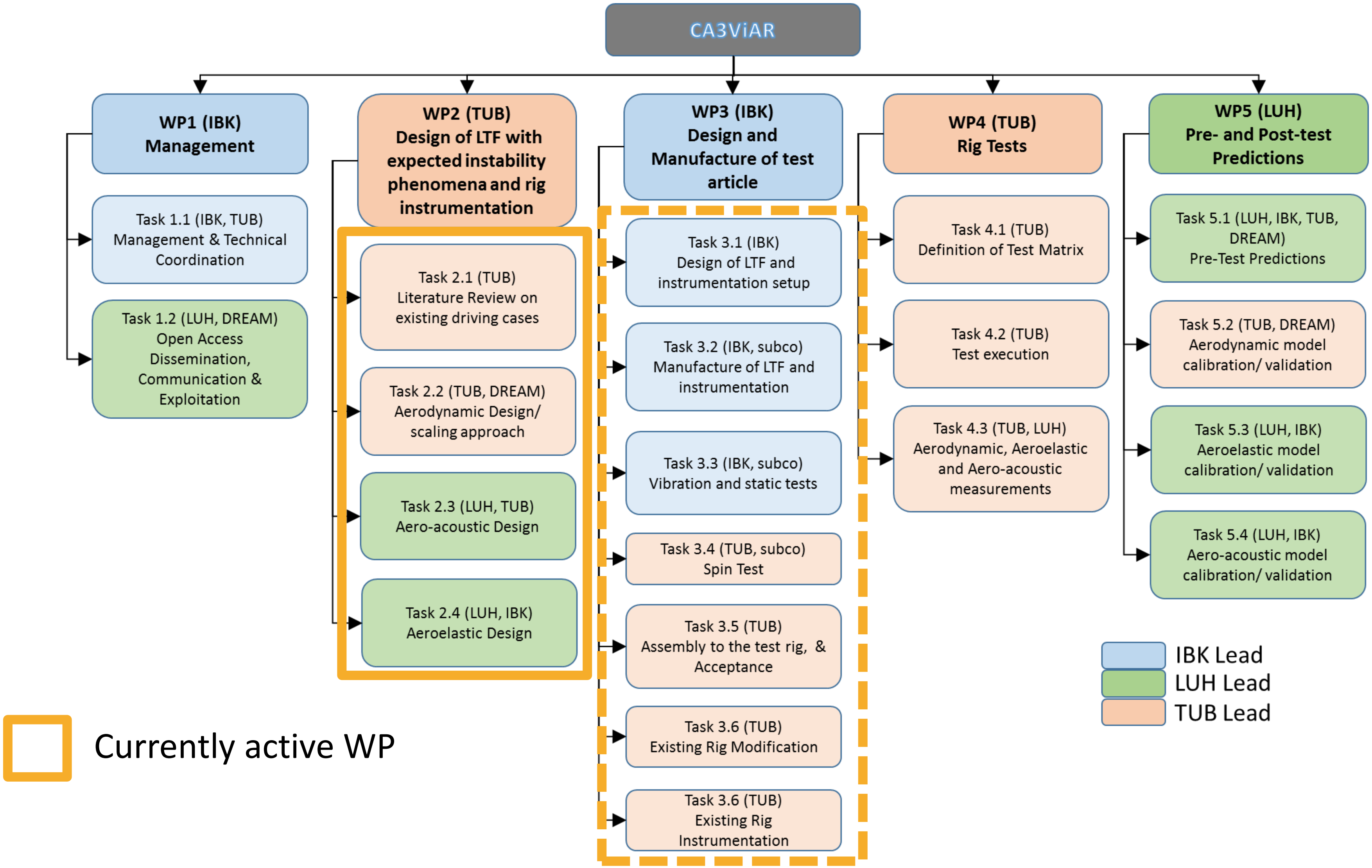
Project Partners

- **IBK →** Project Coordination, support to Low Transonic Fan (LTF) aeroelastic design, test article design Leader and manufacture responsible
- **TUBS →** requirements management, LTF aerodynamic design and scaling approach, rig modification and instrumentation, management of WT tests
- **LUH →** LTF aeroelastic and aeroacoustic design, support to WT test measurements, pre/ post-test predictions
- **DREAM →** Support to LTF design and post-test predictions (CFD)

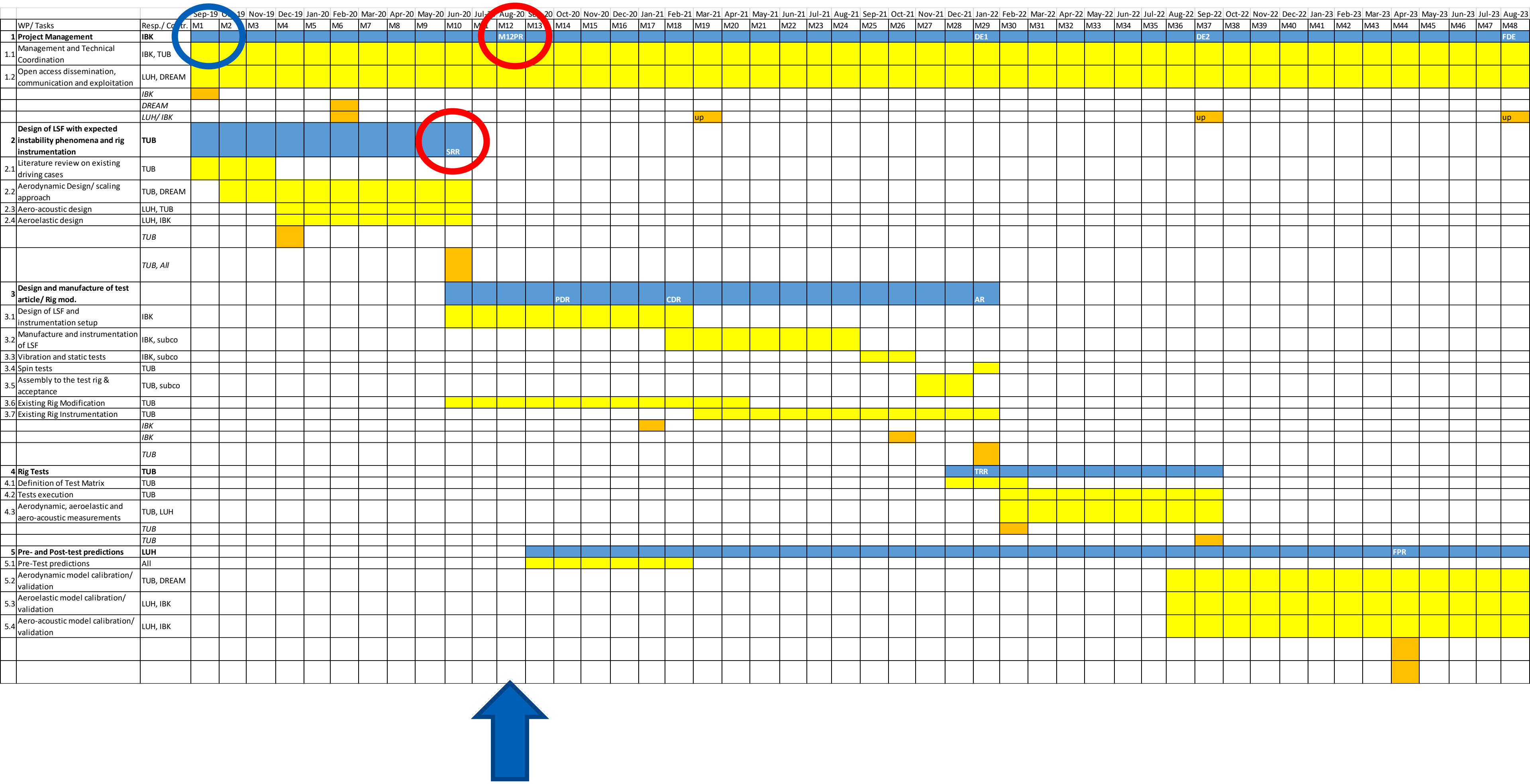
Project Implementation – Work Package Breakdown



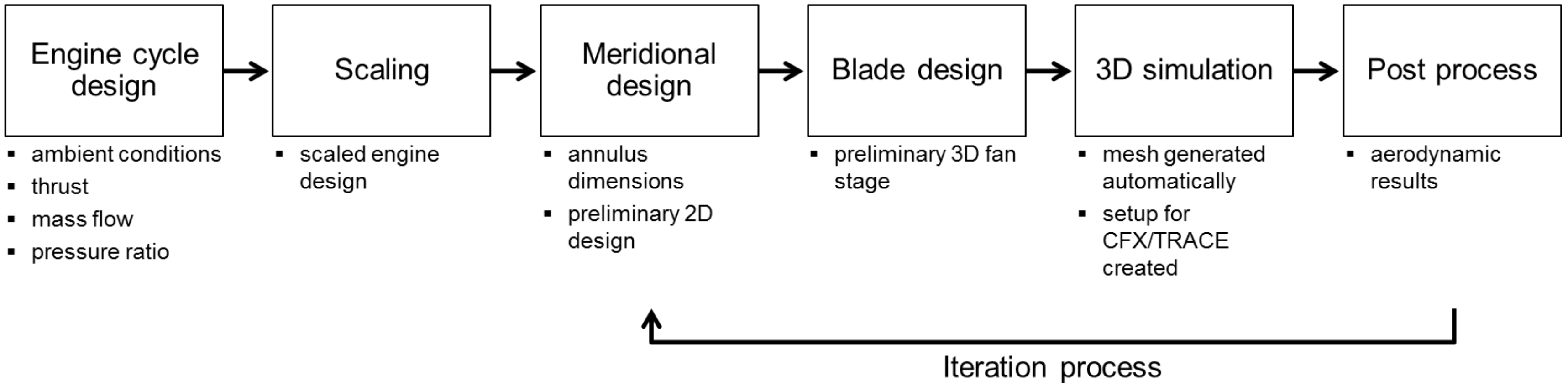
Project Implementation – Work Package Breakdown



Project Implementation – Time schedule



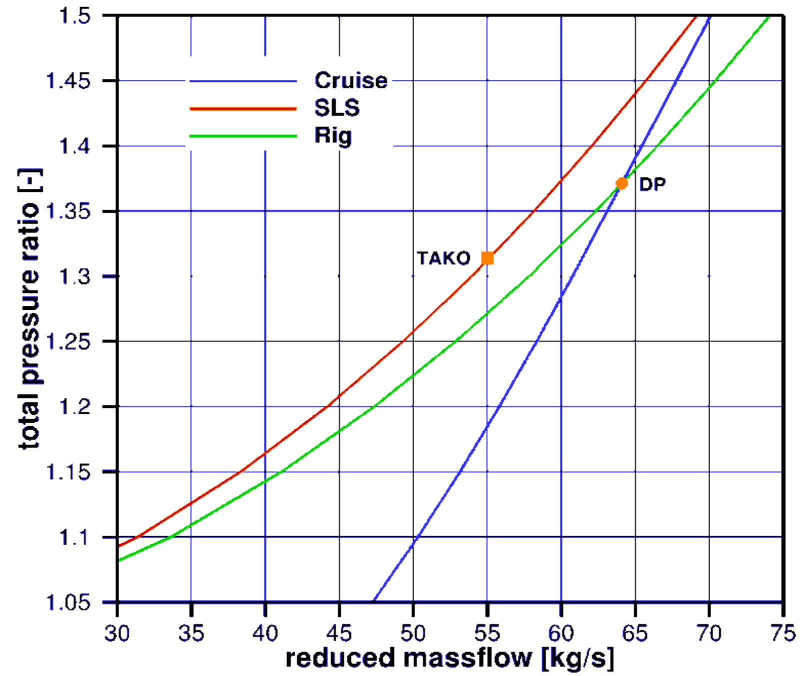
Project Results – Aerodynamic Design

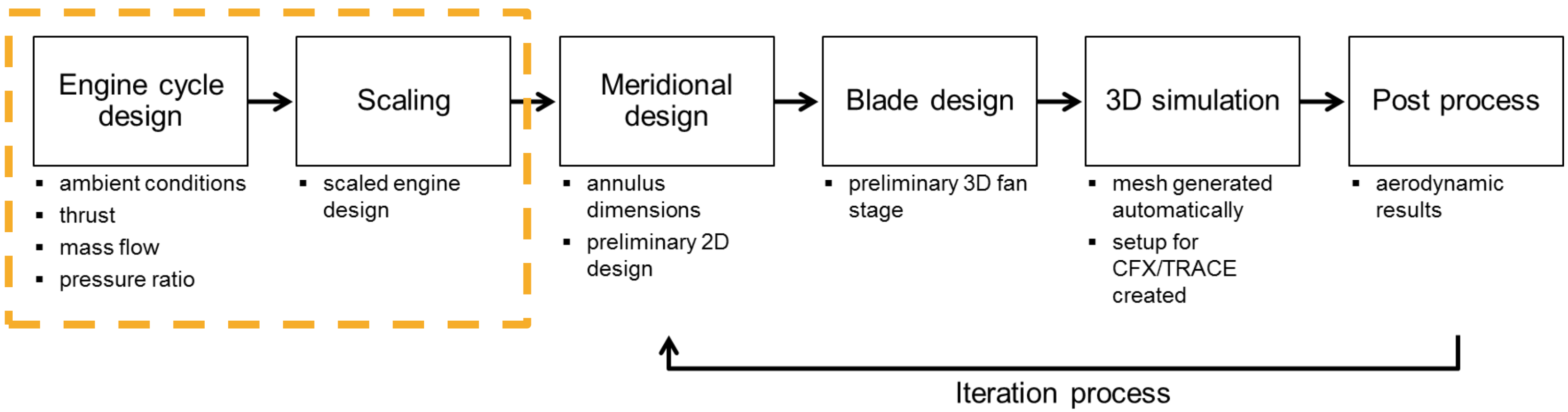


- The choice of parameters is based on orders of magnitude of **current engine designs**.
- Following the design process, the resulting thermodynamically based dimensions **are scaled to the final INFRa rig dimensions**.
- **Geometrical and Mach similarities** are ensured.

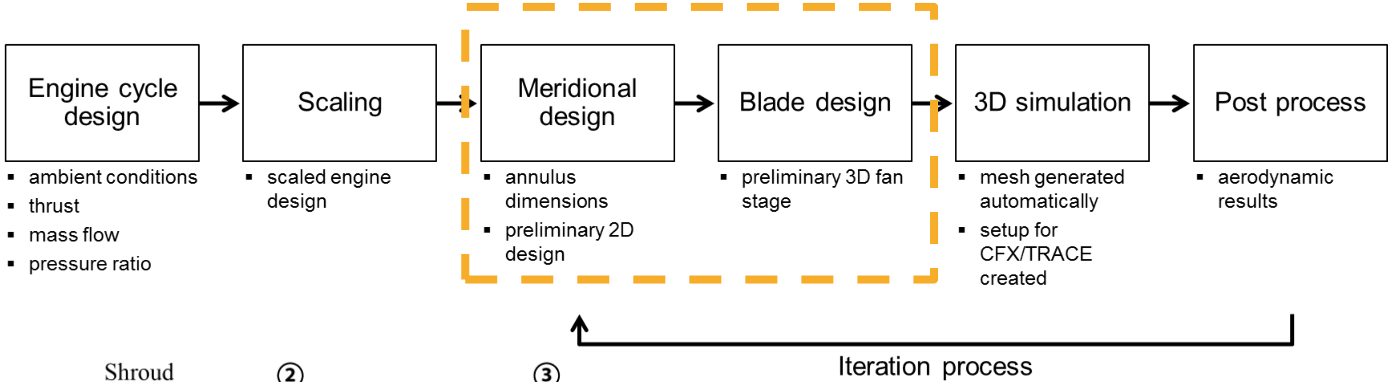
Project Results – Aerodynamic Design

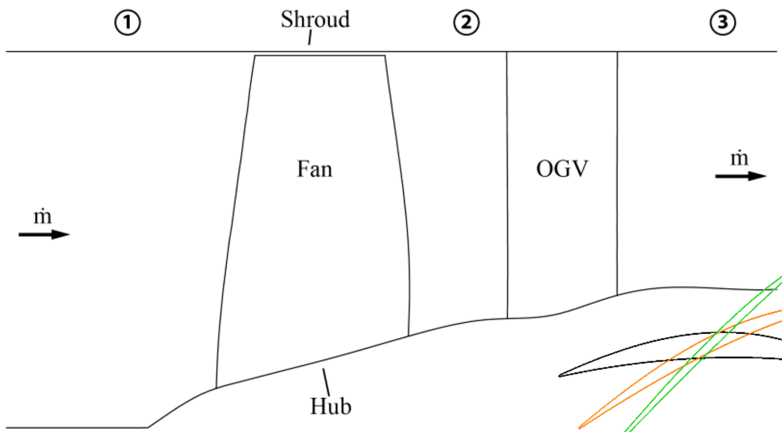
Design Parameter	Design (full scale)	Rig	Rig
Operation point	Cruise H=10.700 km Ma=0.78	Cruise H=0km Ma=0	TAKO H=0km Ma=0
Bypass ratio	17	17	17
Inlet Mach number Ma_{ff}	0.62	0.62	0.52
Poly. efficiency η_{poly} [-]	0.89	0.89	0.89
Fan total pressure ratio π_t [-]	1.37	1.37	1.32
Hub-to-tip ratio	0.26	0.26	0.26
Fan tip radius $[m]$	1.093	0.325	0.325
Fan tip speed U_G	295	295	275
Speed fan n_{Fan} $[^{1}/_{min}]$	2576	8667	8095
Mass flow $\dot{m}$ $[^{kg}/_{s}]$	272.24	63.39	57.15

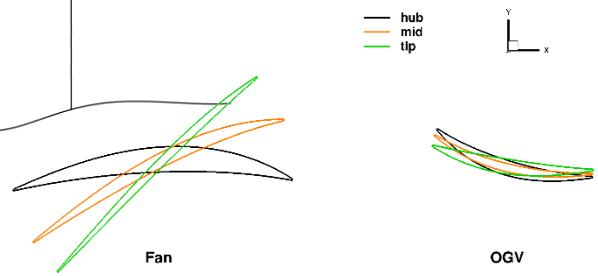


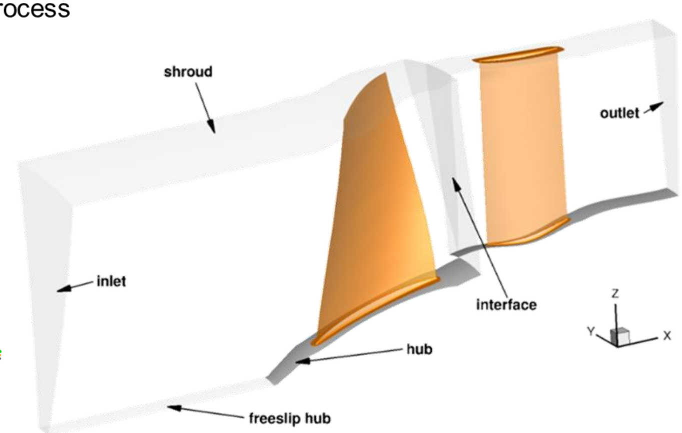


Project Results – Aerodynamic Design





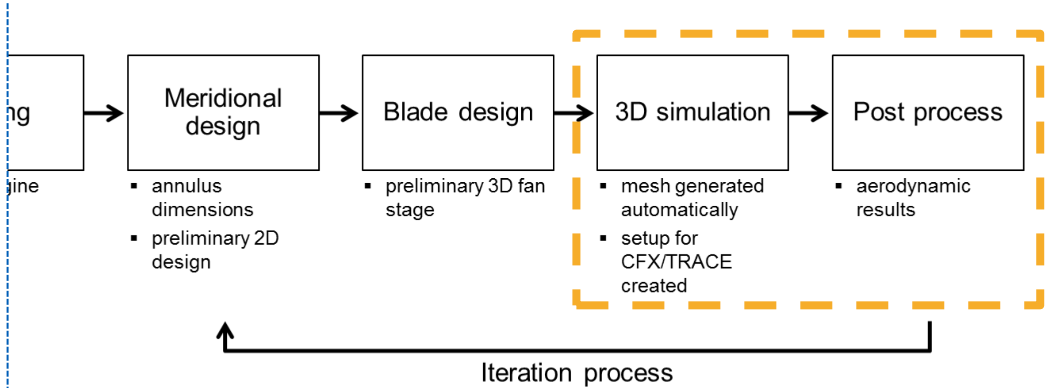


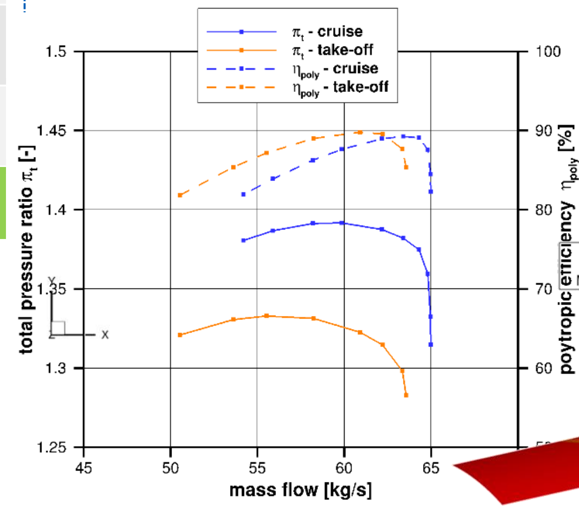


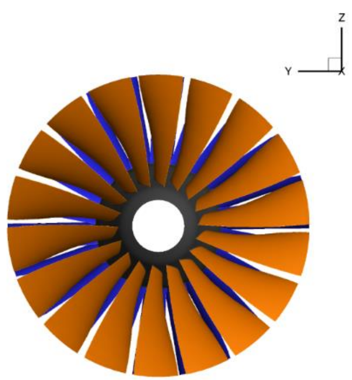
- The hub and shroud contour are defined by the **geometrical constraints imposed by the existing INFRa rig**.
- For the radial load distribution, the vortex theory, published in **NASA-SP-36** is used.
- In total, the fan stage consists of **18 rotor blades and 40 stator vanes**

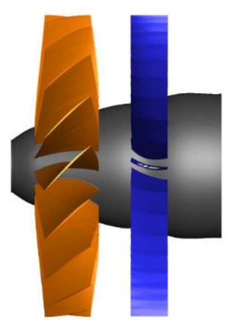
Project Results – Aerodynamic Design

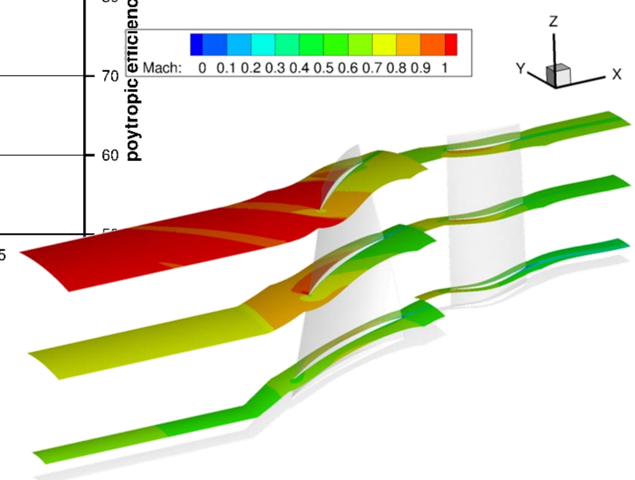
	$\dot{m}$	π_t	η_{poly}	$\Delta\dot{m}$	$\Delta\pi_t$	$\Delta\eta_{poly}$
Design target	**63.4 kg/s**	**1.37**	**89.2%**			
Case 125	**63.4 kg/s**	**1.33**	**85.5%**	**+0%**	**-2.9%**	**-4.1%**
Case 126	**63.4 kg/s**	**1.35**	**89.1%**	**+0%**	**-1.4%**	**-0.1%**
Case 128	**63.4 kg/s**	**1.30**	**84.1%**	**+0%**	**-5.1%**	**-5.7%**
Case 129	**63.4 kg/s**	**1.32**	**84.4%**	**+0%**	**-3.6%**	**-5.4%**
Case 131	**63.4 kg/s**	**1.35**	**88.7%**	**+0%**	**-1.4%**	**-0.6%**
Case 132	**63.4 kg/s**	**1.38**	**89.3%**	**+0%**	**+0.7%**	**+0.1%**





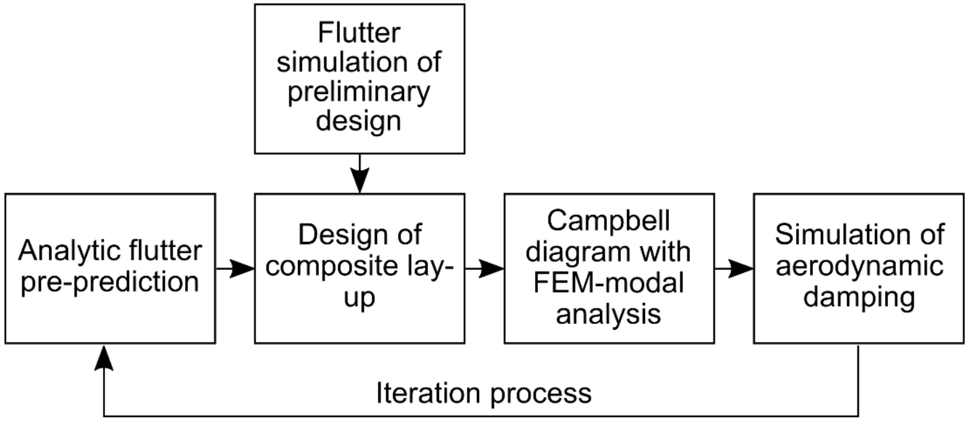


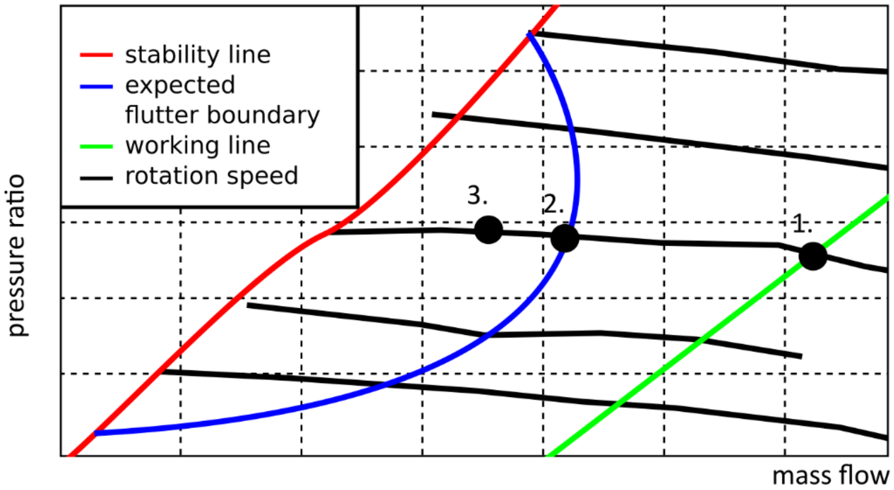




Project Results – Aeroelastic Design and analysis

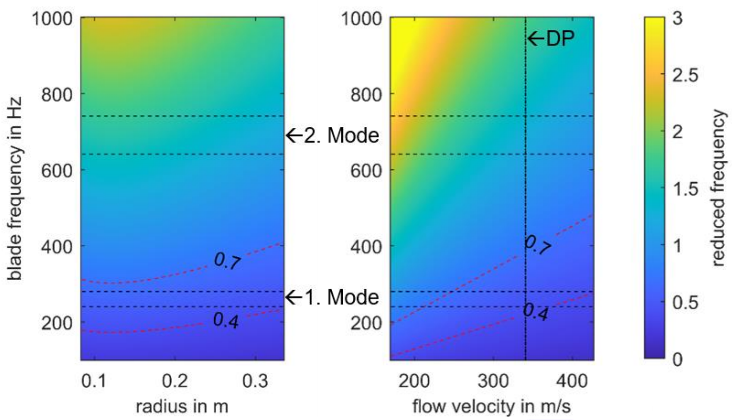
- Based on **first analytic flutter pre-predictions**, a set of different blade layups with different materials is designed.
- The **eigenfrequencies and mode shapes** of the different layups are computed.
- The resulting eigenfrequencies are plotted in a **Campbell diagram**, which allows the estimation of operating points prone to forced response.
- The resulting mode shapes and eigenfrequencies are used for the **3D-Flutter simulations**. A dependency of different structural-dynamic parameters on the aerodynamic damping at different operating points is derived and considered for the next iteration process.
- The final objective is to design **the flutter stability map** for aeroelastic characterization and to execute the experiments



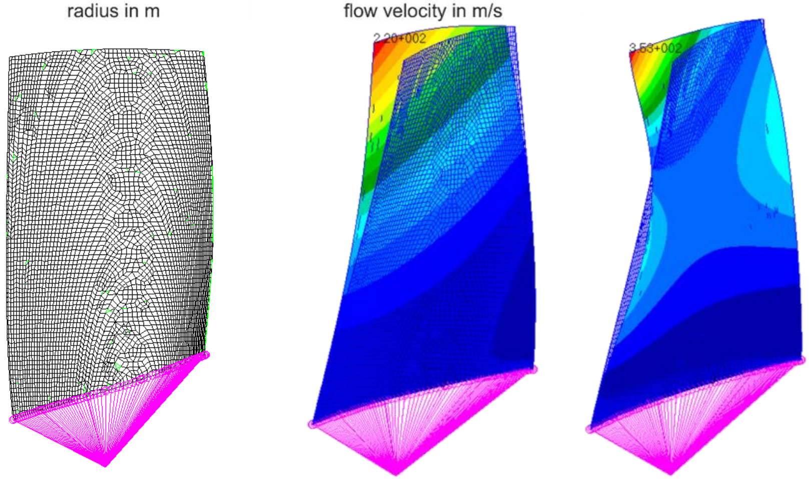


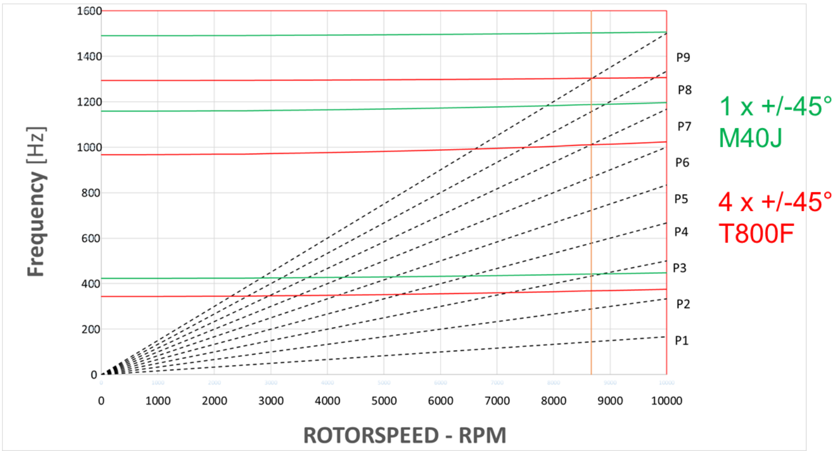
Project Results – Aeroelastic Design and analysis

- Depending on level “0” analysis (analysis of reduced frequency, twist-to-plunge ratio, aeroacoustic waves), a set of different layups are designed.
- The CFRP blades currently result in very high frequencies, different solutions to lower the frequencies are under investigation (hybrid composites, added masses, low modulus fabrics)



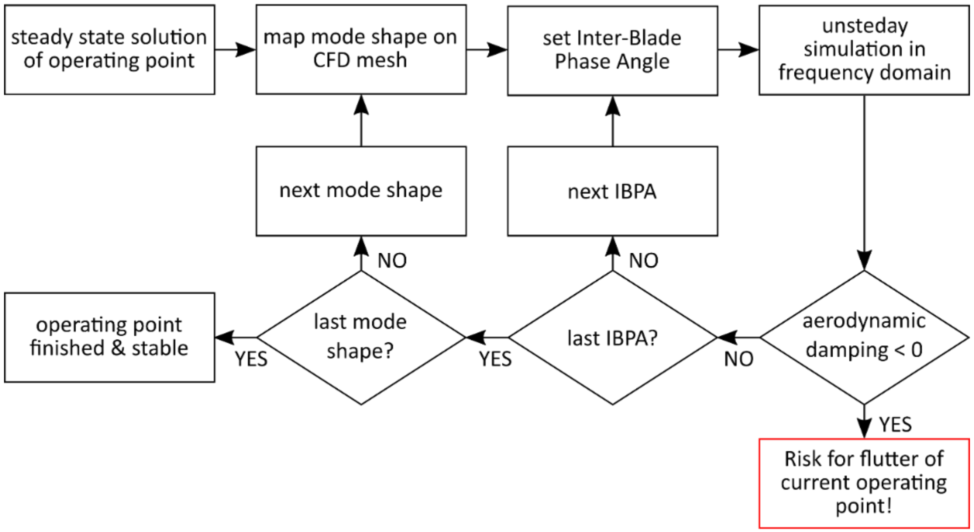
	ER432 – M40J			ER432 - T800		
	[1 x +/- 45°; 0_{48}]s	[2 x +/- 45°; 0_{46}]s	[4 x +/- 45°; 0_{42}]s	[1 x +/- 45°; 0_{48}]s	[2 x +/- 45°; 0_{46}]s	[4 x +/- 45°; 0_{42}]s
1° Bending [Hz]	423	414	379	381	372	343
1° Torsion [Hz]	1491	1522	1414	1373	1387	1293

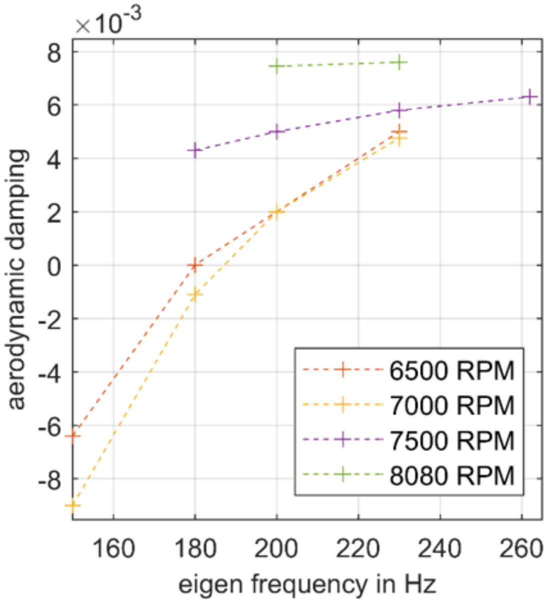


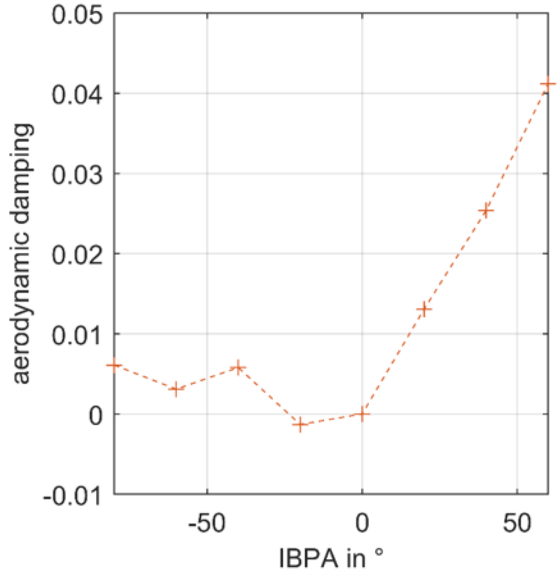


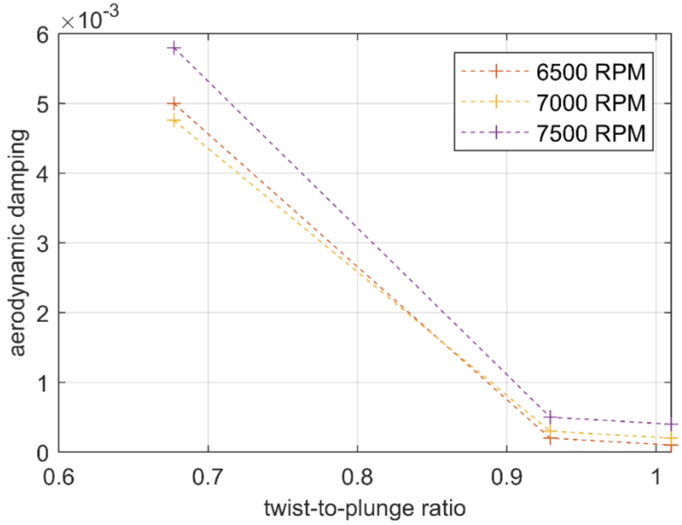
Project Results – Aeroelastic Design and analysis

- First high-fidelity analysis using the modal shape calculated with an isotropic material (steel) **by varying the frequencies confirm the expected trends**.
- Aerodynamic damping has been calculated depending on **IBPA** for different **natural frequencies**, **rotational speed** and **twist-to-plunge** ratios



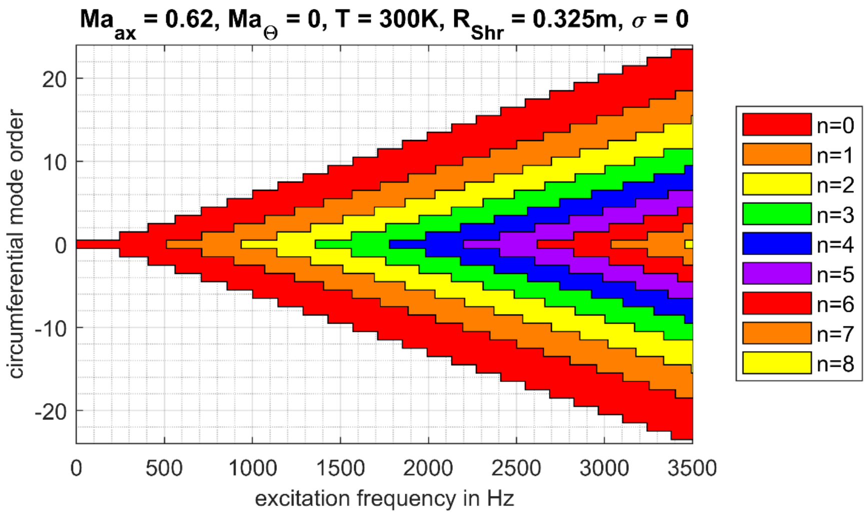


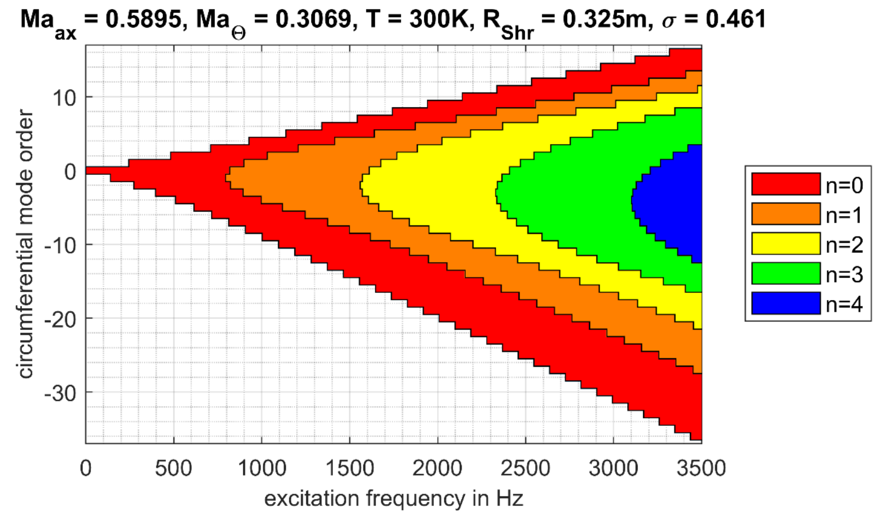




Project Results – Aeroacoustics

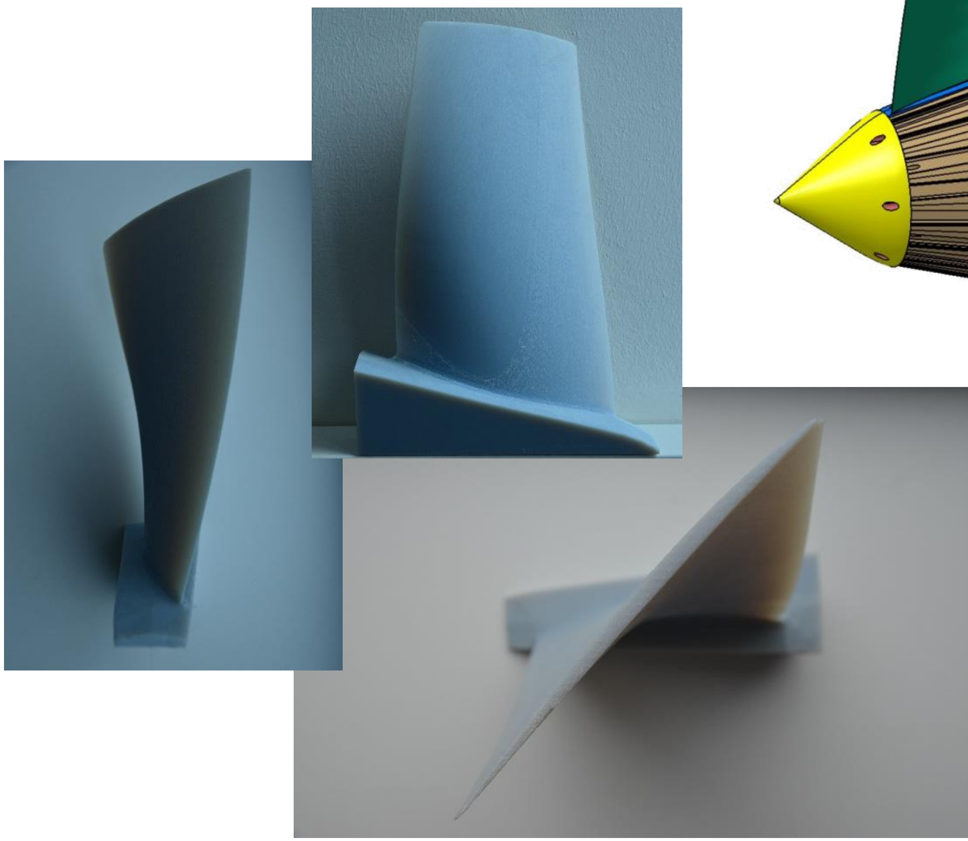
- The aeroacoustics of the fan is analysed by **computational aeroacoustic (CAA)** simulation
- The simulation is performed with TRACE Harmonic Balance in the frequency domain
- The mesh needs to be refined compared to the one for aerodynamic simulations (25-40 nodes per wavelength of the acoustic modes investigated)
- Based on the simulation results, the acoustic field induced by the rotor and rotor + outlet guide vane (OGV) interaction is analysed and compared to the analytical solution
- The first step for the aeroacoustic analysis is done by analytical investigation of the acoustic modes propagating inside the intake and behind the rotor. This is done by calculating the cut-on frequency of each mode.
- Aerodynamic investigations for CAA simulations are still ongoing

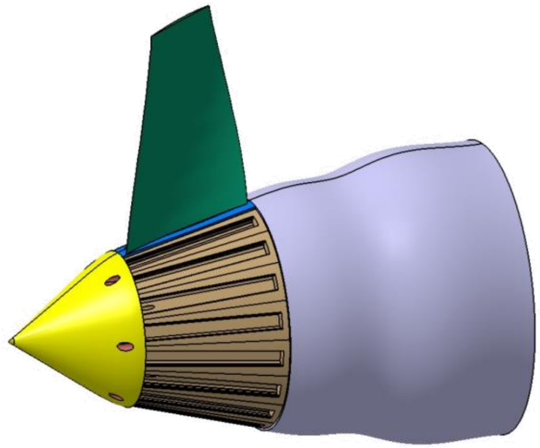


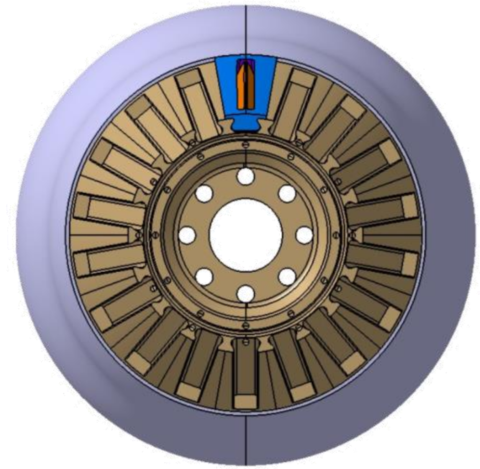


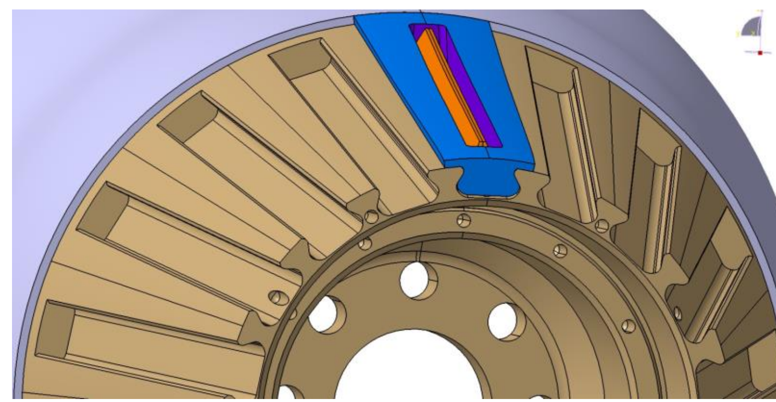
Conceptual design of test article and rig modification

- Concept studies of test article already started
- The test article aeroshape has been printed with a rapid prototype ALM machine



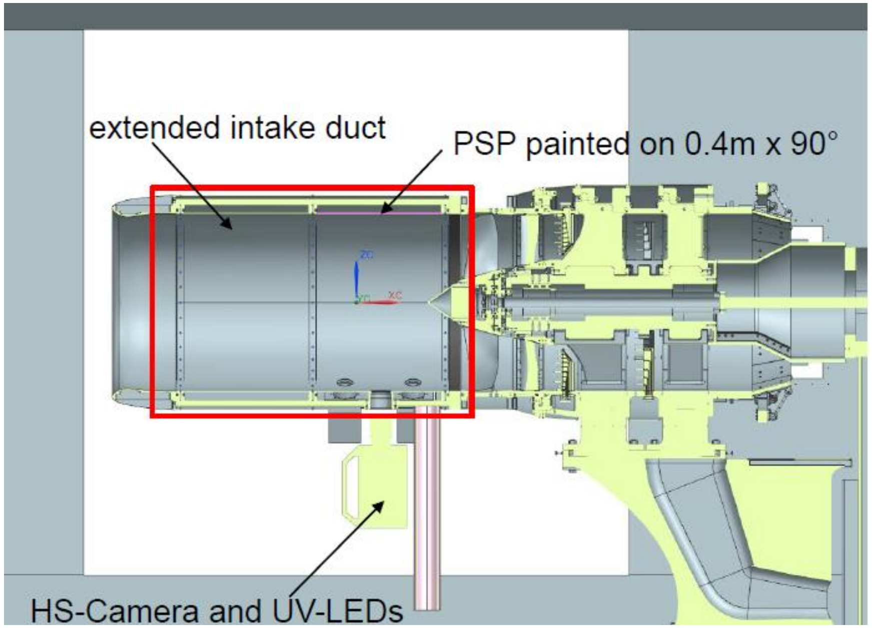


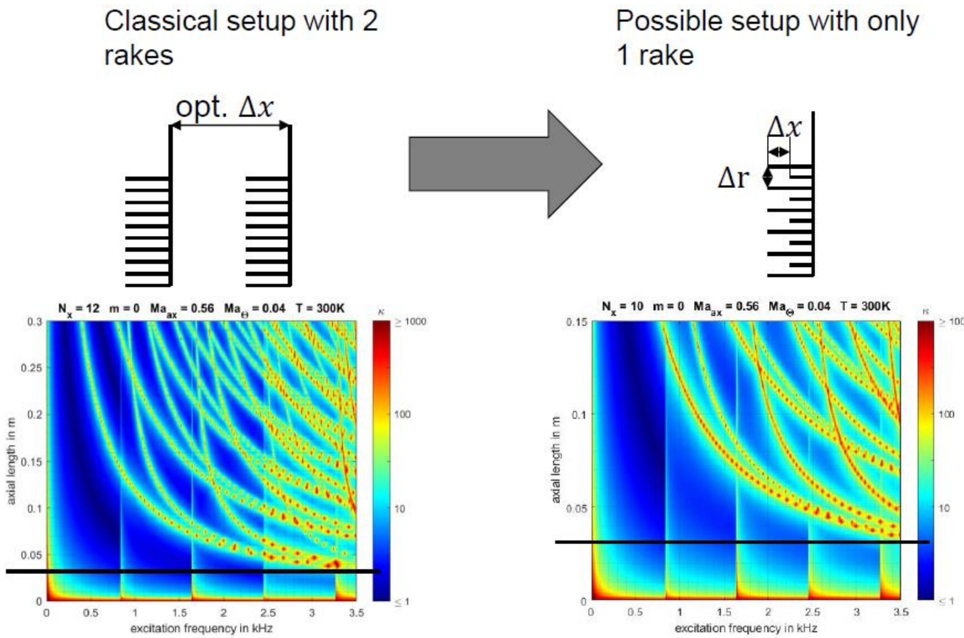




Conceptual design of test article and rig modification

- 0.8 m of inlet axial length must be painted with PSP to extract acoustic modes up to 3 kHz with an acceptable error
- As a consequence, a **special intake for the Acoustic PSP measurements** is required
- The design of the extended intake is going to be completed
- For acoustic measurements behind the stator, only one rake can be placed in axial direction. A setup using **one rake** has been conceived, with similar expected errors as a conventional two-rake design





Ongoing activities and way forward

- Completion of dynamic design and aeroelastic analysis
- Agreement on **High-level requirements** inside the Consortium, finalization of LTF design deliverable
- **System Requirement Review** with External Experts Advisory Board
- **PDR** and final selection of **subco** for blade manufacturing
- **CDR** and start of manufacture
- Test article **Manufacture** and rig modification
- **Test Campaign** execution (PTF)
- Post-test analysis and calibration of numerical methods

Q&A

https://www.ca3viar-project.eu/

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