June 20-22, 2023
Vienna, Austria

SAE INTERNATIONAL

International Conference on Icing

of Aircraft, Engines, and Structures

sae.org/icing

Development of a new rotor- propeller test rig for tests under icing situation

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Presenter: F. Knöbl

RAIL TEC ARSENAL

Climatic Wind Tunnel Vienna

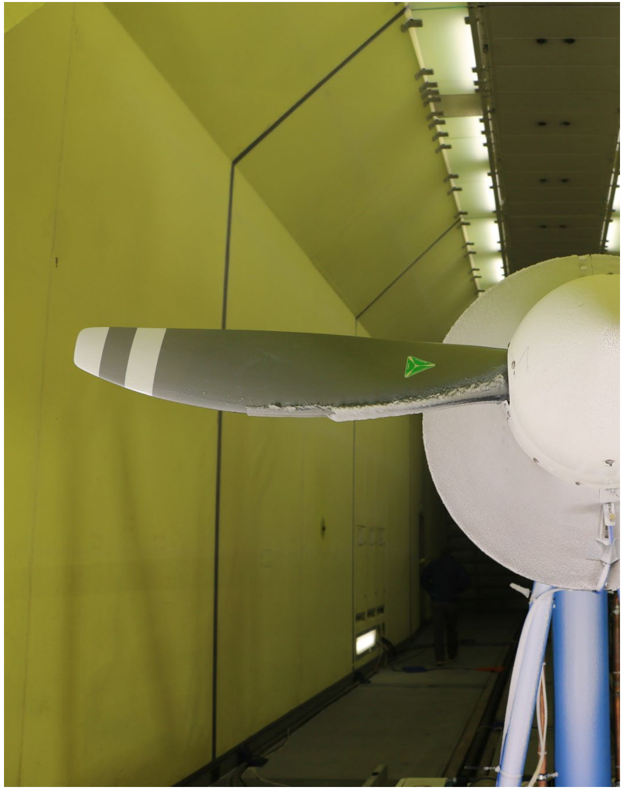
Content

- RTA - Icing wind tunnel
  (Vienna icing wind tunnel)

- Rotor- propeller test rig (PropRig)
  Overview
  shaft dynamics and passive balancer

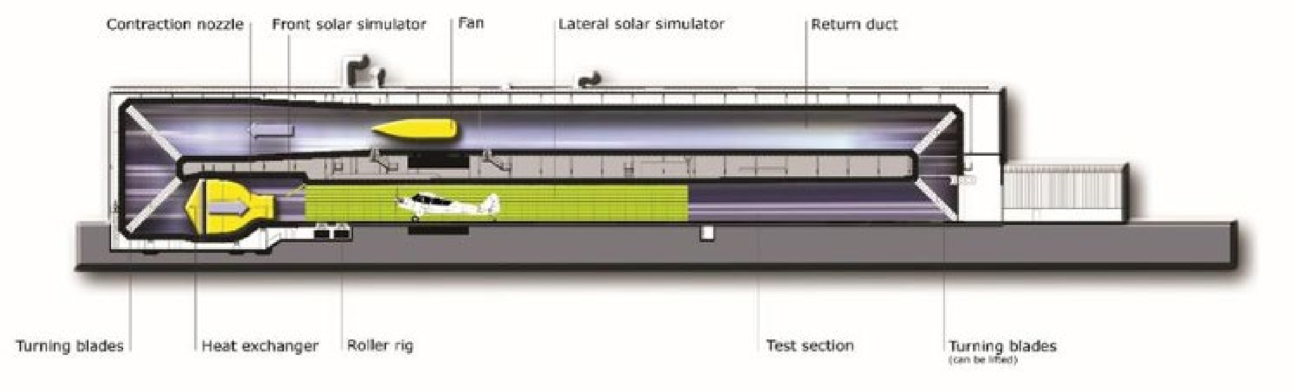
- FFG TakeOff Project JOICE
  Operation in the icing wind tunnel
  Shedding detection
  Measurements on the shaft

- Conclusion and outlook



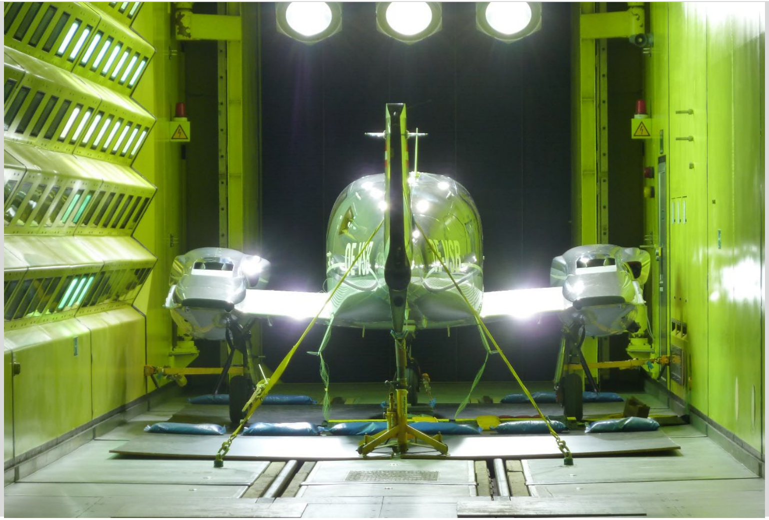
Climatic Wind Tunnel Vienna

- Two Climatic Wind Tunnels with same cross section but different test section length up to 100m
- Temperature range -45°C to +60°C humidity controlled and solar field up to 1000 W/m²
- Wind speed up to 80 m/s
- Different kind of precipitation (Snow, Rain, ground Ice and In-flight icing)



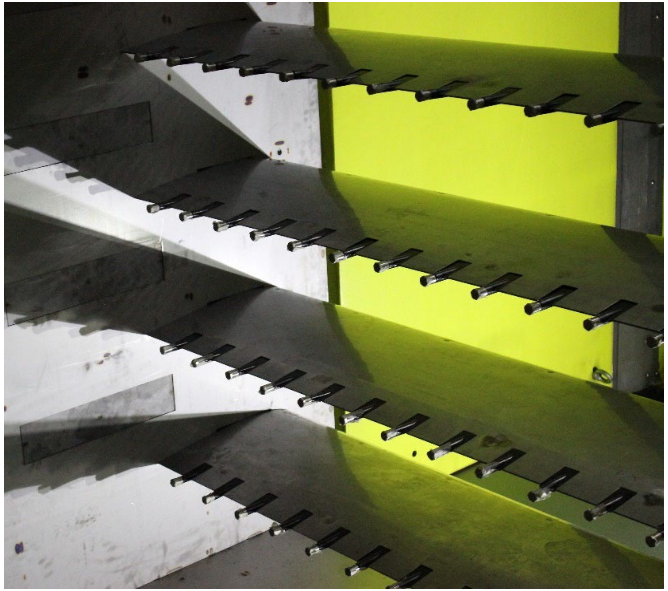
Climatic Wind Tunnel Vienna

Climatic testing in aviation

Sun radiation & heat	Cold / Hot start
	

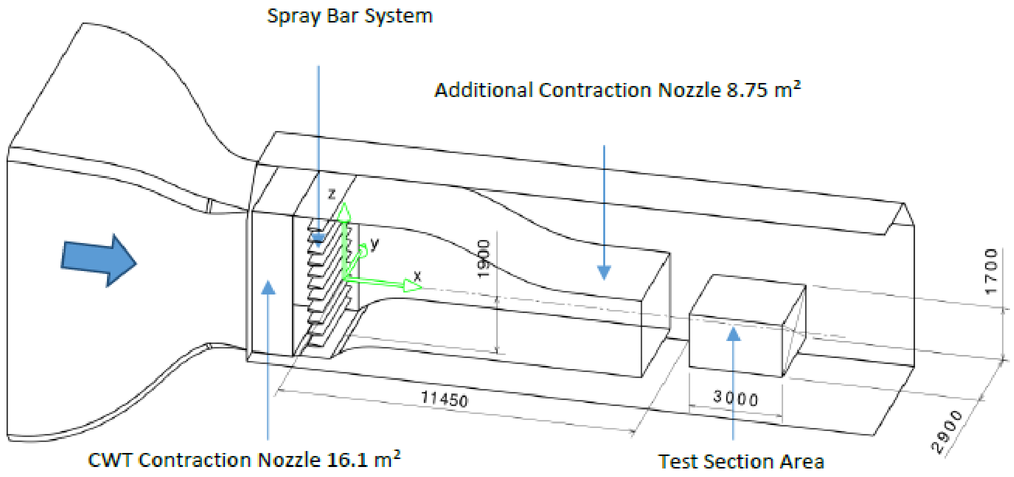
Icing Wind Tunnel Vienna

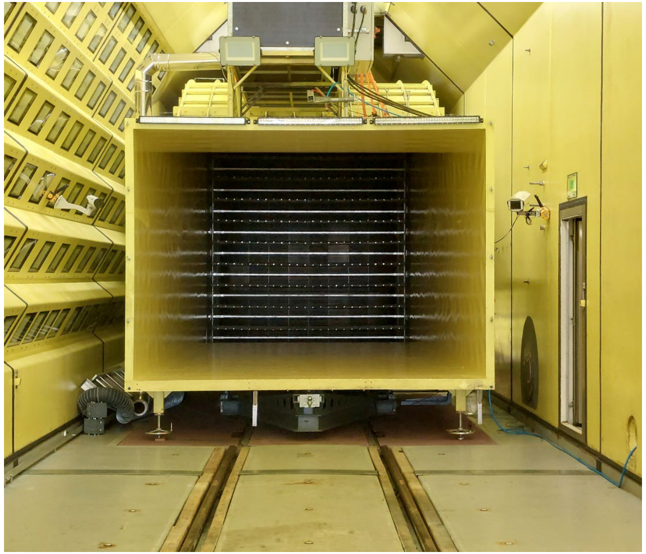
Icing Rig (mobile spray bar system)



Icing Wind Tunnel Vienna

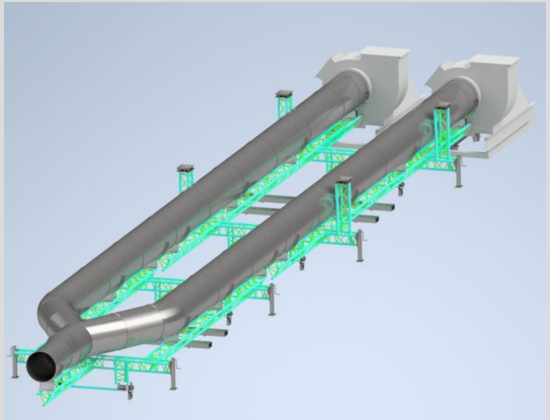
- Droplet size and LWC according to EASA CS25 – Appendix C and Appendix O from -2°C to -30°C
- Calibrated according SAE ARP 5905
- Test section area 2.9 m width 1.7 m height up to 80 m/s (155 kts)





Icing Wind Tunnel Vienna

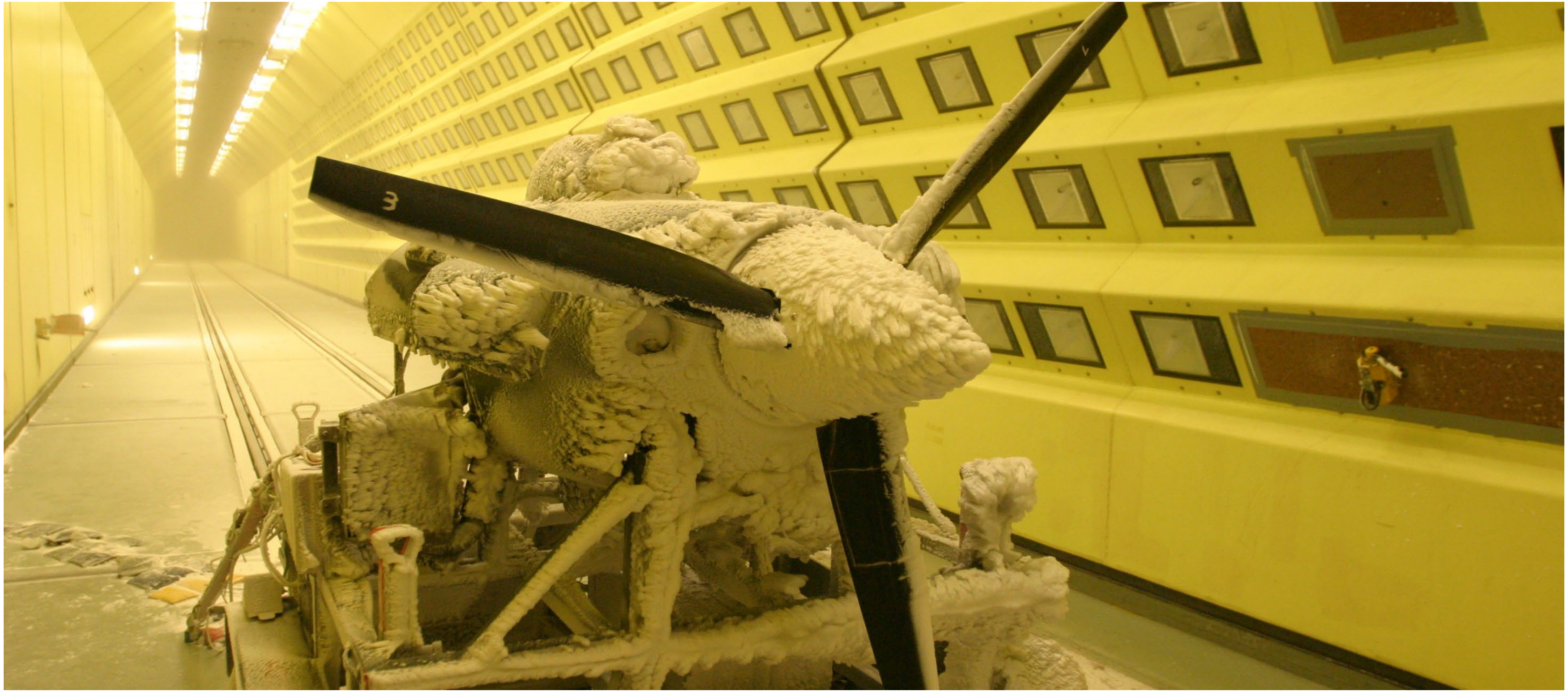
Testing equipment for the Icing Wind Tunnel

Test bench for wing sections (Force Jig)	Ventilation system for engine mass flow simulation	Propeller Rig (Prop Rig)
		

Testing equipment for the icing Wind Tunnel

Customised (UAV fuselage)	Exhaust gas system (air inlet filter with running engine)
	

Propeller Test Rig – first tests in 2013



PropRig since 2021

Specifications:

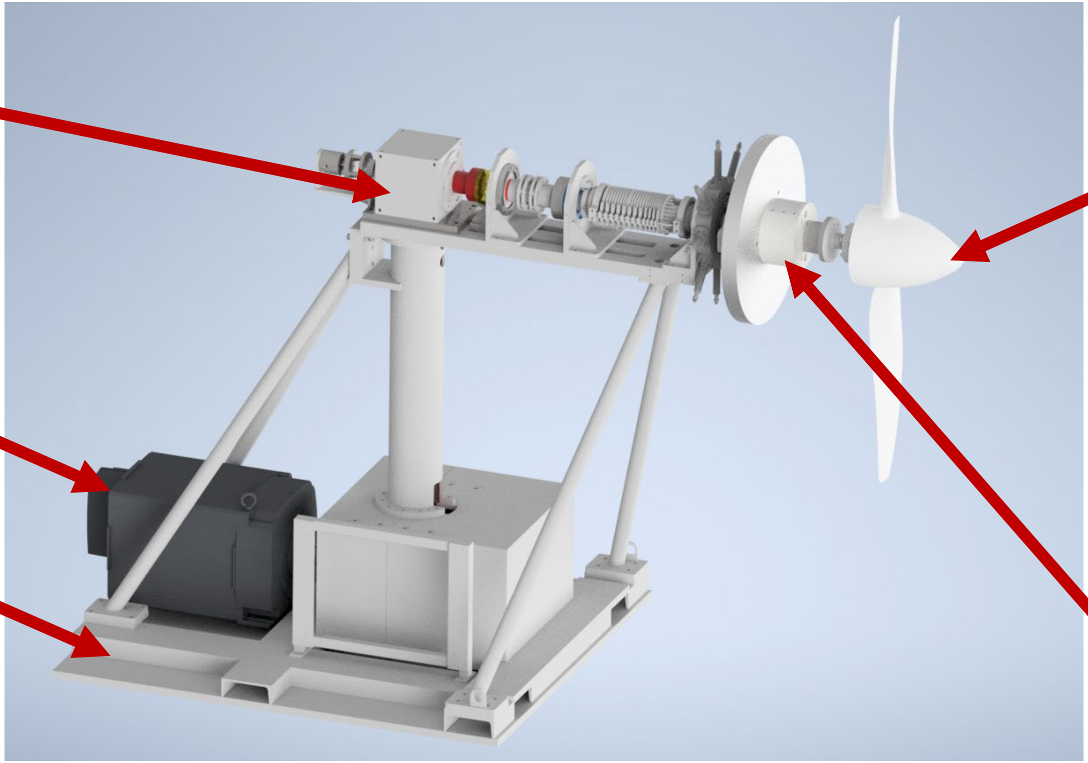
- Max rotational speed 2500 rpm
- Motor power: 90 kW (180 kW)
- Torque: 280 Nm (550 Nm)
- Can supply electrical IPS systems
- Passive balancing system

PropRig - overview

Gearbox &
Transmission

Motor

Frame

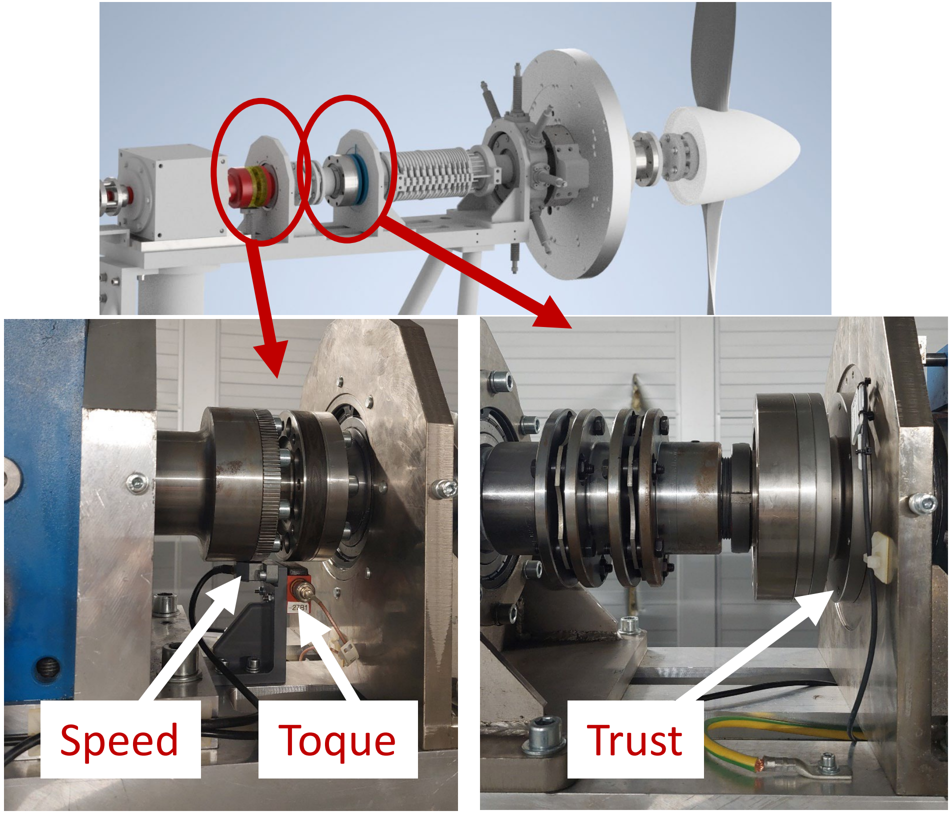


Specimen
(rotor)

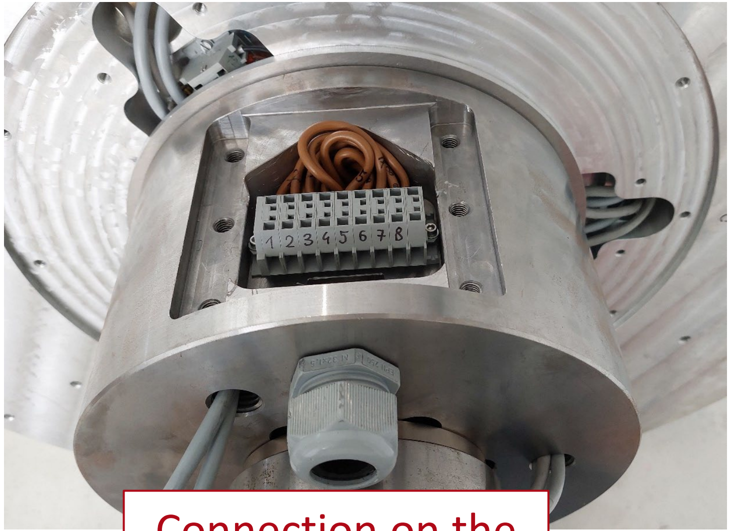
Main shaft

PropRig – main shaft measurements

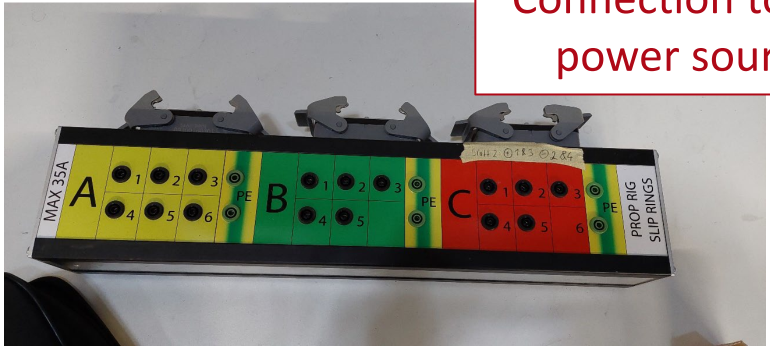
- Thrust (strain gauge)
  ± 10 kN
- Torque (strain gauge)
  ± 1 kN*m
- Speed (incremental sensor)
  0 to 3000 rpm



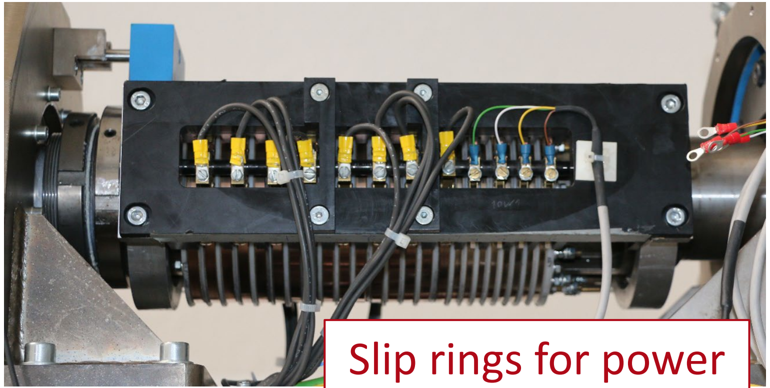
PropRig Slip rings to power IPS



Connection on the shaft to the rotor



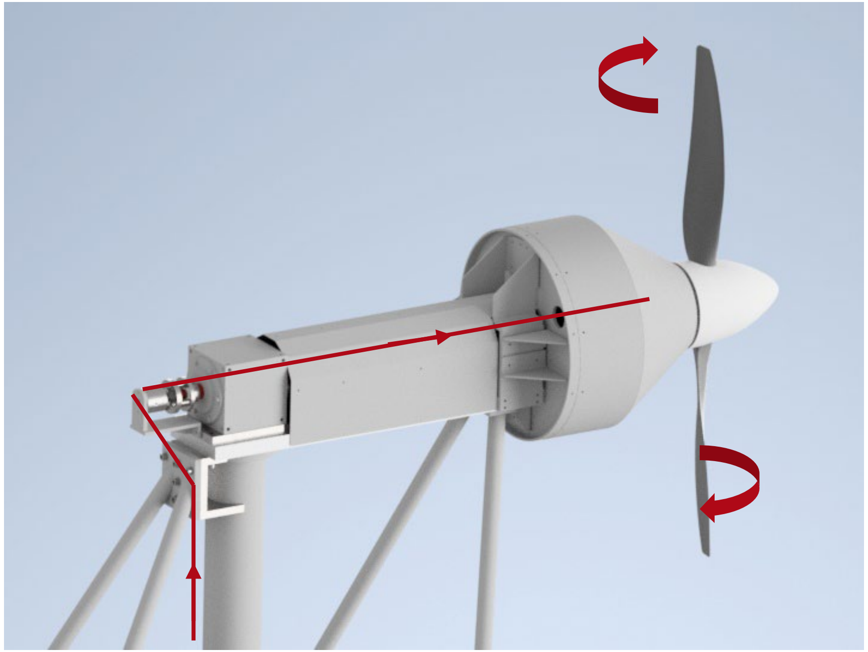
Connection to the power source



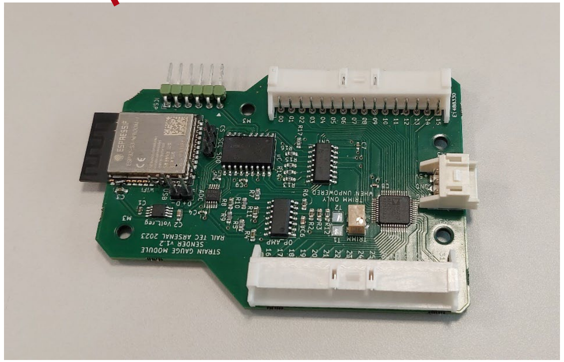
Slip rings for power transmission

PropRig Hydraulics

- Variable pitch control
- Hydraulics line though shaft
- Pressure 0 to 20 bar

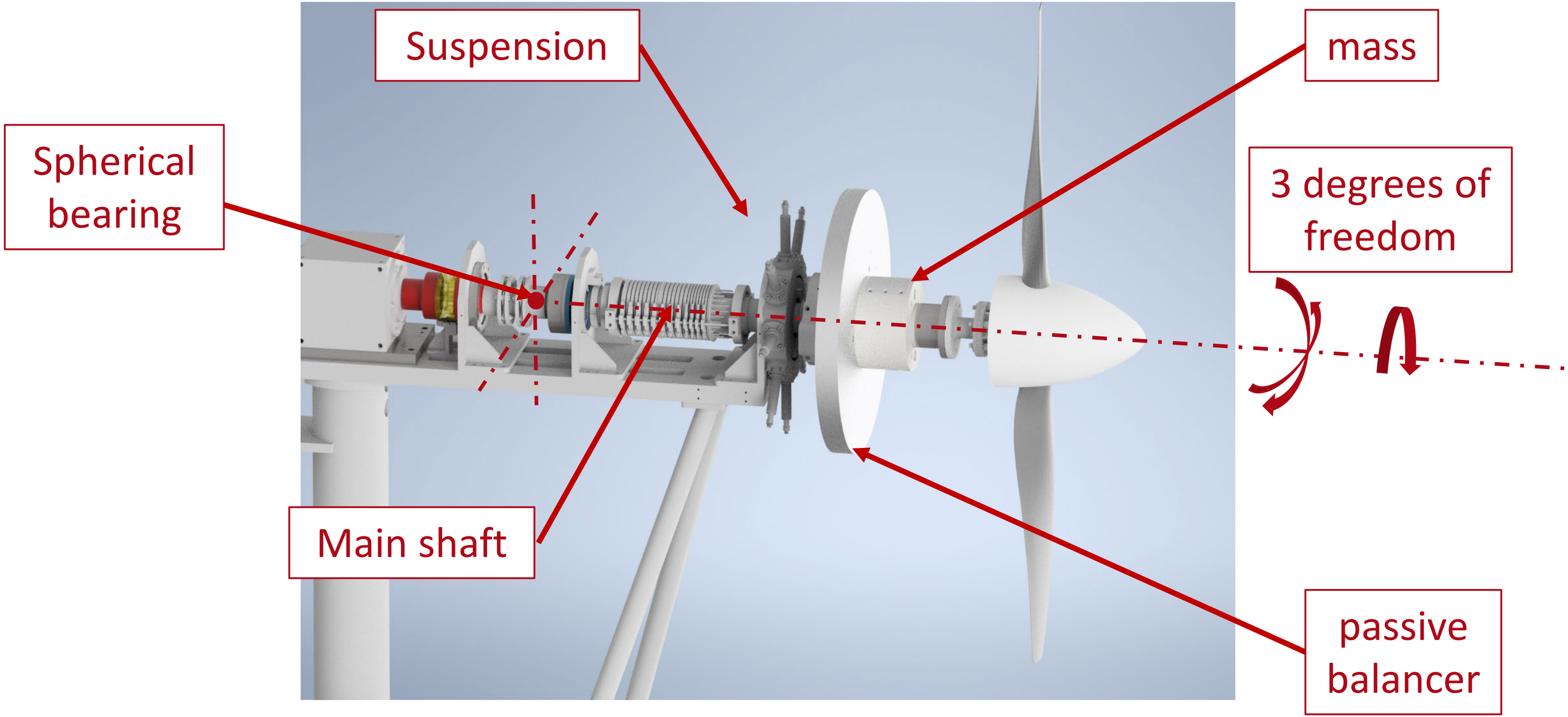


PropRig - strain gauge acquisition



- Telemetry system
- 16 channels
- 3 wire technology
- Goal: 500 Hz (10 Samples per Revolution)
- Located in the nose cone or at the back of the spinner

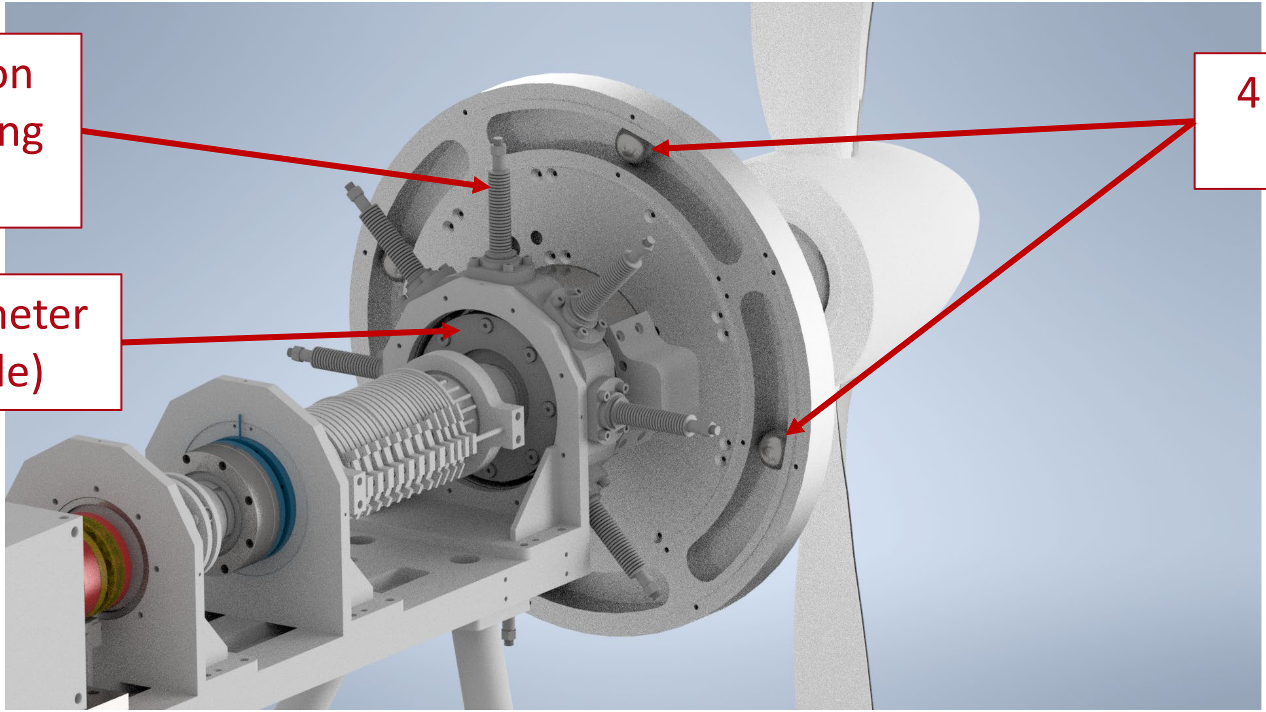
PropRig – main shaft



PropRig – passive balancer and suspension

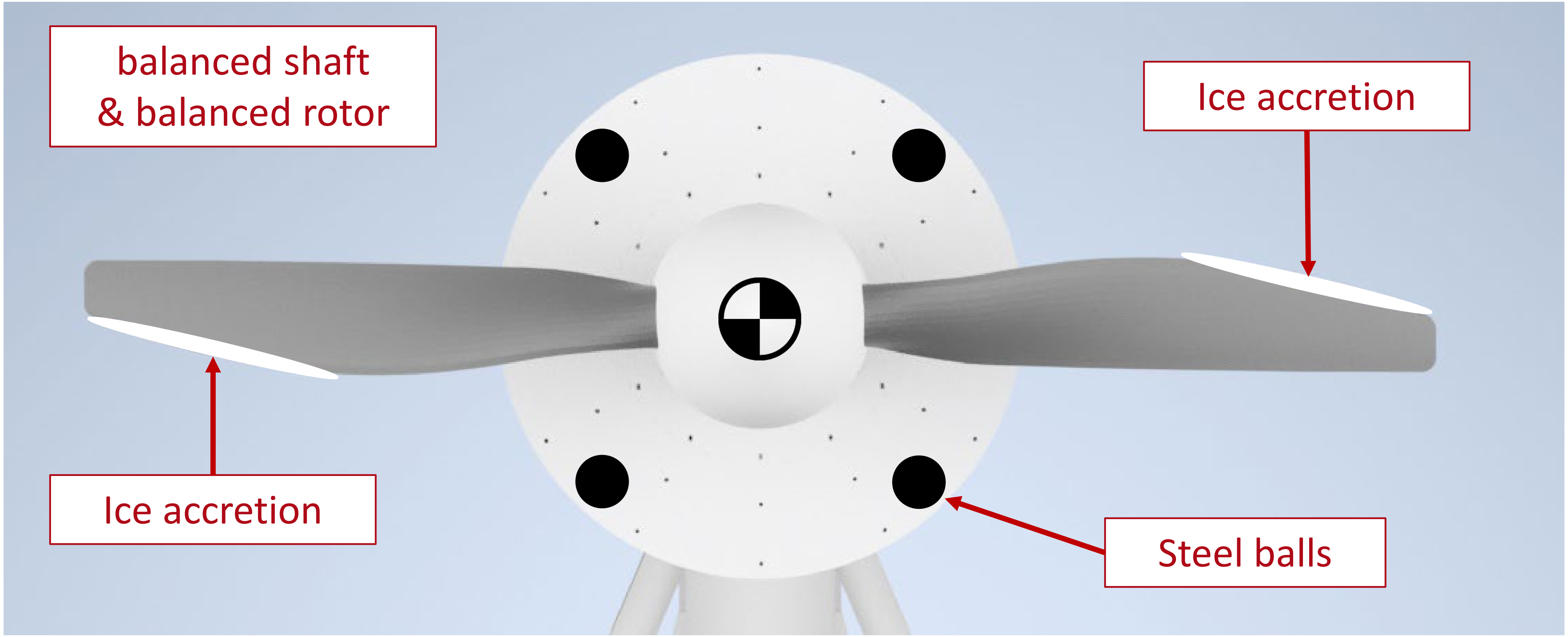
Suspension
8 disc spring
stacks

Accelerometer
(Backside)

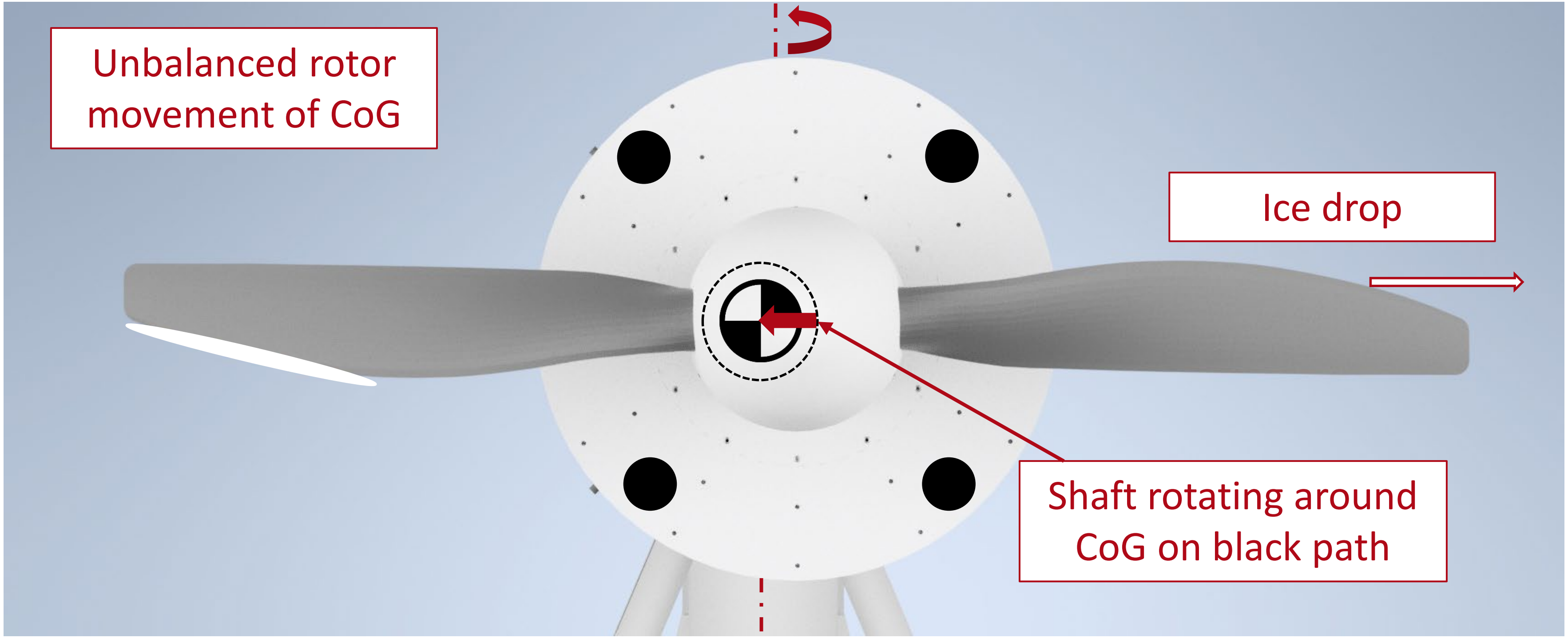


4 Steel balls
(0.5 kg)

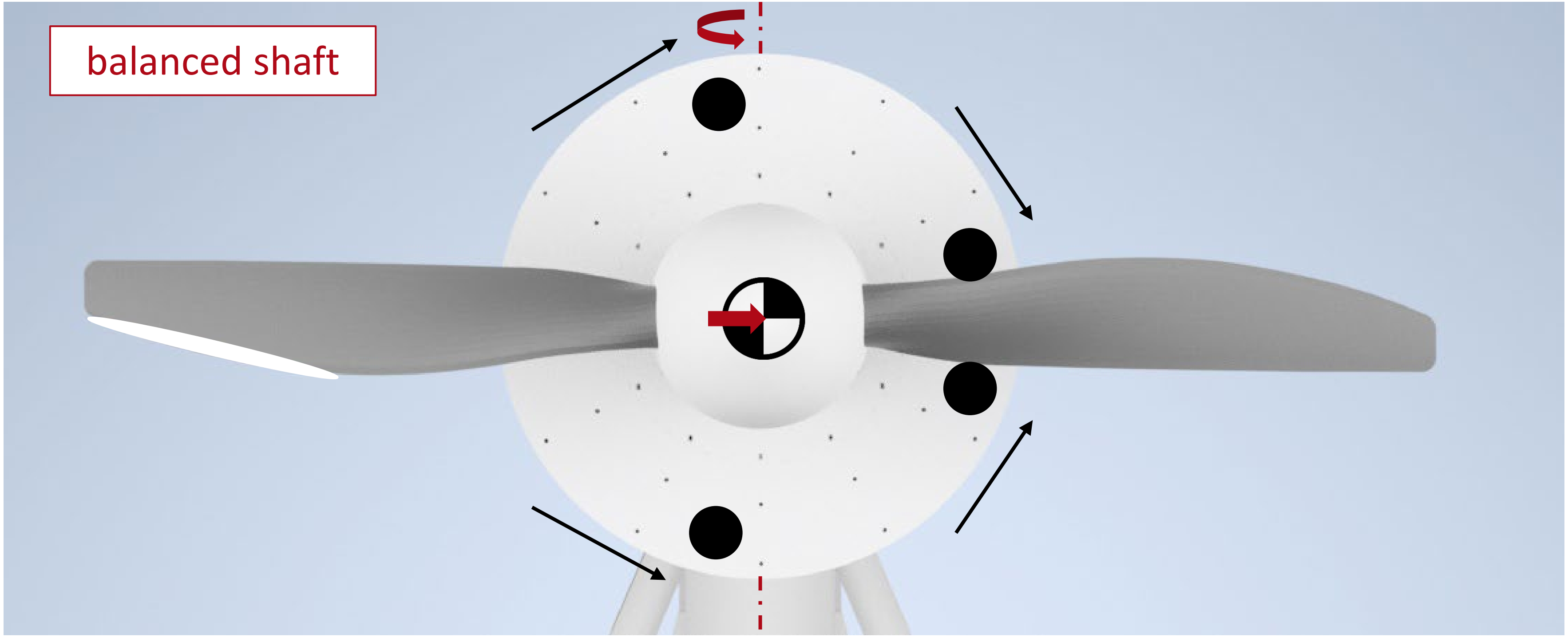
PropRig – passive balancer



PropRig – passive balancer



PropRig – passive balancer



PropRig - Main shaft dynamics

- Analytical description of the system
- x_b, y_b, φ, $\psi_{1 \text{ to } 4}$ … 7 degrees of freedom

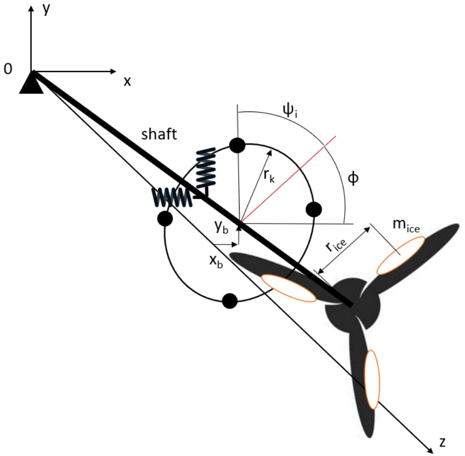
$$\ddot{x} = \frac{m_k}{4m_k + M_w} \sum_{i=1}^{4} \Big((\ddot{\varphi} + \ddot{\psi}_i) r_k \cdot \sin(\varphi + \psi_i) + (\dot{\varphi} + \dot{\psi}_i)^2 r_k \cdot \cos(\varphi + \psi_i) \Big) - \frac{c_x \cdot \dot{x} + k_x \cdot x - f_x(t)}{4m_k + M_w}$$

$$\ddot{y} = \frac{-m_k}{4m_k + M_w} \sum_{i=1}^{4} \Big((\ddot{\varphi} + \dot{\psi}_i) r_k \cdot \cos(\varphi + \psi_i) - (\dot{\varphi} + \dot{\psi}_i)^2 r_k \cdot \sin(\varphi + \psi_i) \Big) - \frac{c_y \cdot \dot{y} + k_y \cdot y - f_y(t)}{4m_k + M_w}$$

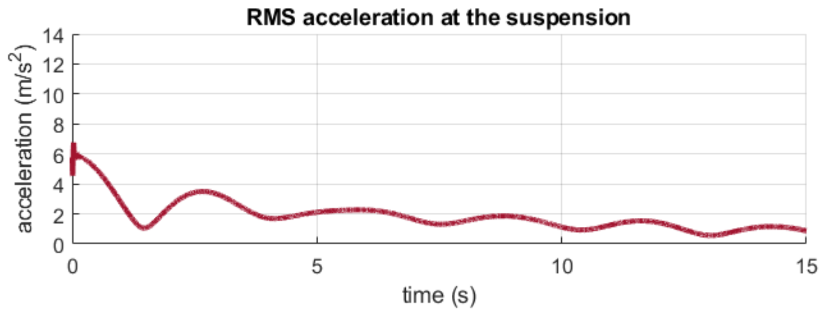
$$\ddot{\psi}_i = \left(\ddot{\varphi} \frac{R}{r} - \frac{m_k}{Izz}(A + B) - \frac{C_k}{I_{zz}} \dot{\psi}_i \right) \frac{r^2}{R^2}$$

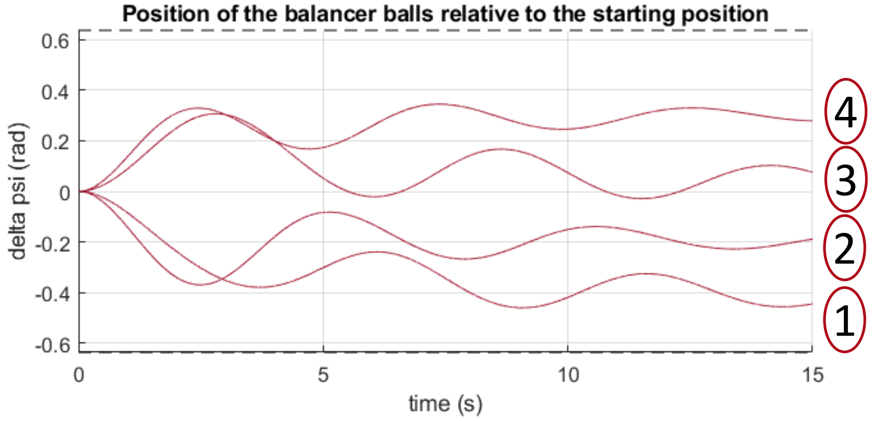
$$\begin{aligned} A = & \ddot{y} \cdot r_k \cdot \cos(\varphi + \psi_i) - \dot{y} \cdot r_k \cdot \sin(\varphi + \psi_i)(\dot{\varphi} + \dot{\psi}_i) \\ & - \ddot{x} \cdot r_k \cdot \sin(\varphi + \psi_i) + \dot{x} \cdot r_k \cdot \cos(\varphi + \psi_i)(\dot{\varphi} + \dot{\psi}_i) \end{aligned}$$

$$B = \dot{y}(\dot{\varphi} + \dot{\psi}_i) r_k \cdot \sin(\varphi + \psi_i) + \dot{x}(\dot{\varphi} + \dot{\psi}_i) r_k \cdot \cos(\varphi + \psi_i)$$

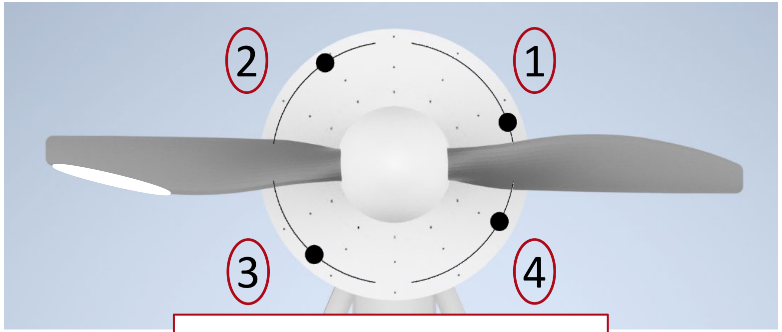


PropRig Passive Balancer - simulation



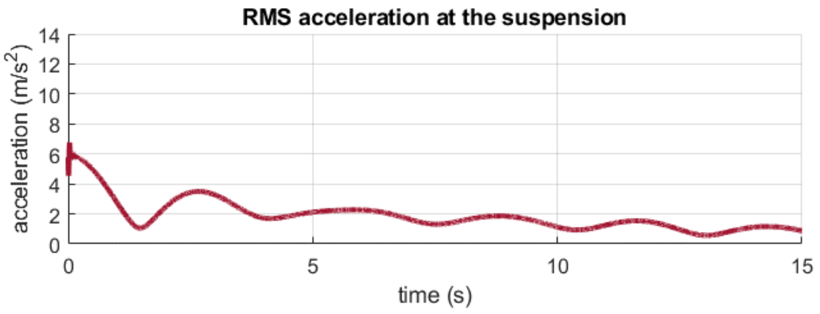


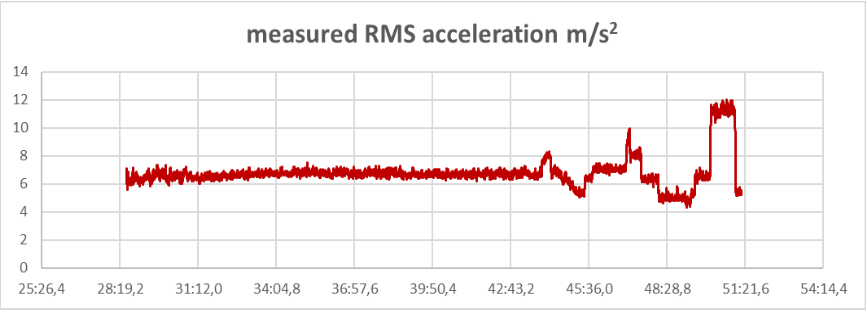
- Behaviour after shedding of 44 g*m of ice
- Balancing operation takes several seconds
- Balls oscillate in the racetracks



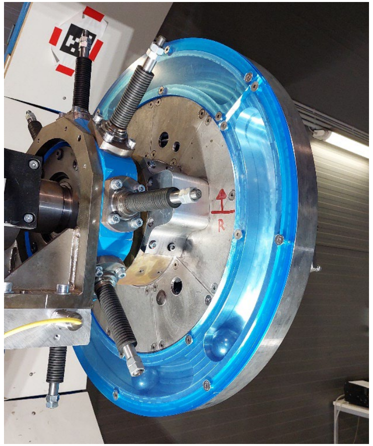
Simulation result

PropRig Passive Balancer - validation

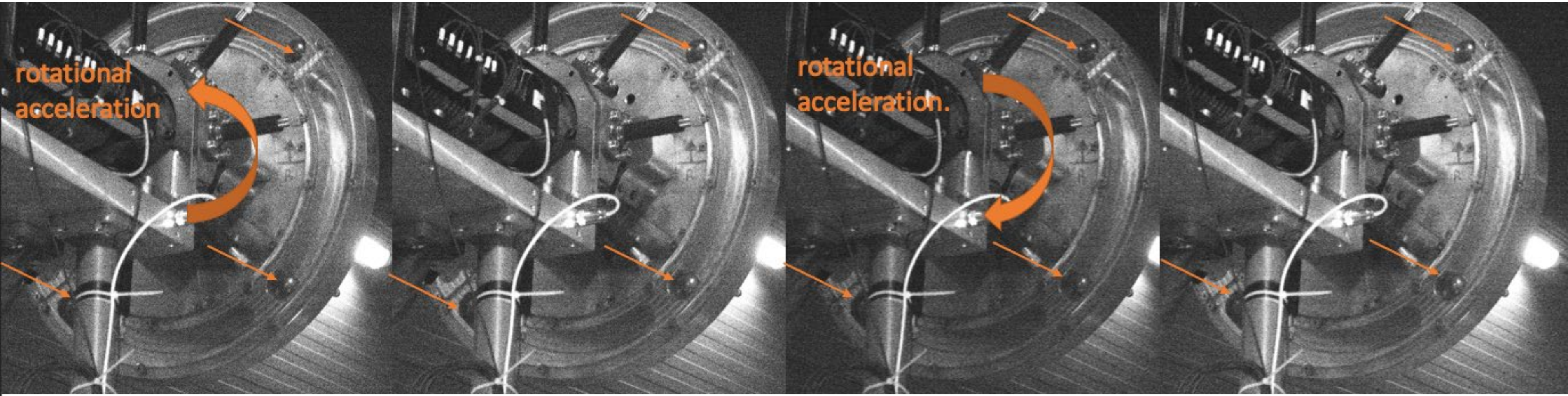




- No change in the acceleration for small imbalances
- Installation of window glasses to investigate the balls movement



PropRig – Passive Balancer



1500 rpm
Balls at max position
since acceleration

1800 rpm
Balls stay at same position
also, with residual imbalance

1500 rpm
Balls stay at same position
also, after deacceleration

1000 rpm

- Balls should have left their positions
- Check for possible imprints

PropRig – Passive Balancer

Advantages:

- Reduction of loads introduced to the frame (mobile test bench – no specific foundation)
- Low frequency of resonance (~360 rpm)
- no higher modes of the main shaft in the speed envelope (2^{nd} order at 120 Hz)

Disadvantages:

- Complex kinetics
- Disadvantage for aerodynamics due to the size of the balancer

Austrian funded In-flight Icing Flagship FFG TakeOff Project JOICE

- **The Austrian In-flight Icing Flagship Project JOICE**
- **Technical "TOP-Level-Goals" of JOICE:**
- Provision of comprehensive numerical and experimental simulation methods for the development of ice protection systems in CS-25 Appendix C, O and snow icing conditions
- Demonstration of highly energy-efficient hybrid ice protection systems for UAV and small and medium-sized aircraft for inadvertent flight in icing conditions
- Development/extension of a comprehensive experimental 2D and 3D validation data base for numerical ice accretion simulation tools in Appendix C, O and snow icing conditions

Austrian funded In-flight Icing Flagship FFG TakeOff Project JOICE

PROJECT PARTNERS

FH JOANNEUM Luftfahrt / Aviation

AAC aerospace & advanced composites

AeroTex GmbH

ATT

AIT AUSTRIAN INSTITUTE OF TECHNOLOGY

eologix sensor technology

FACC

TU Graz Graz University of Technology

JOANNEUM RESEARCH DIGITAL

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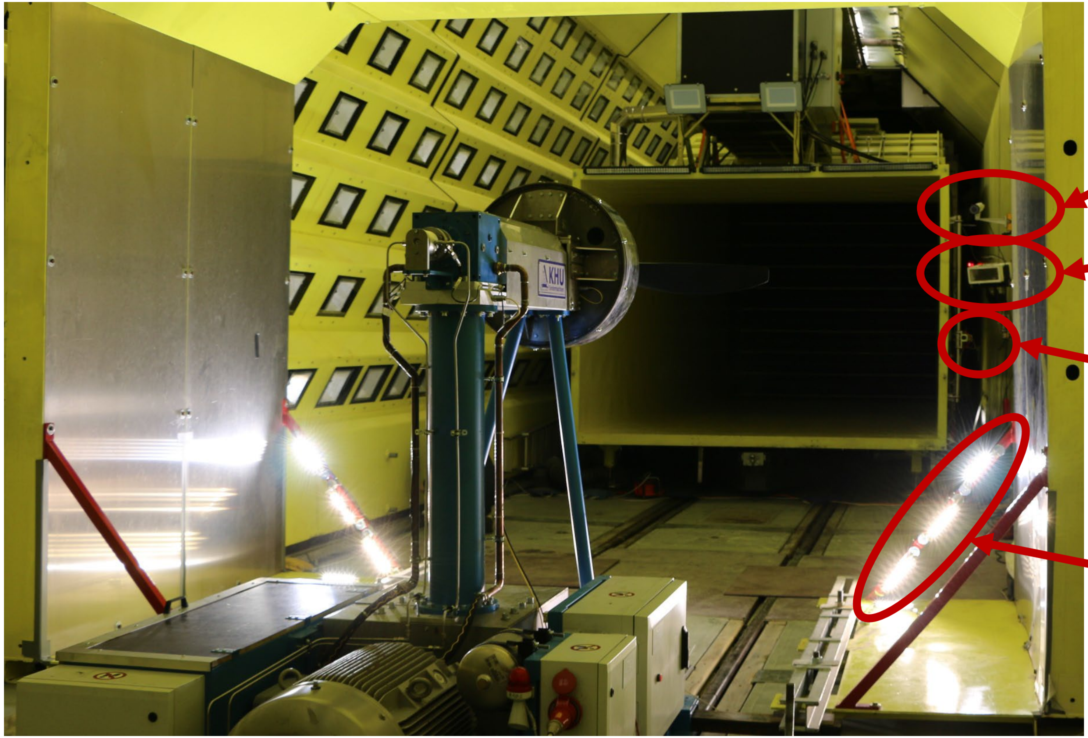
DOWTY

PropRig– Icing Wind Tunnel setup

PropRig– Icing Wind Tunnel setup



Observation camera

AIIS High speed camera

Camera synchronized with shaft position

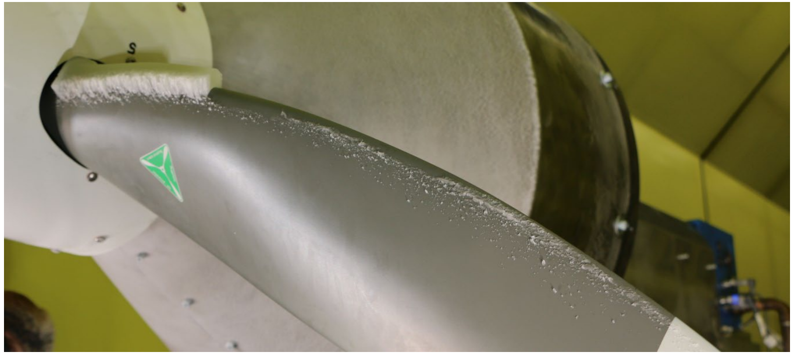
Lighting (constant light for HS camera)

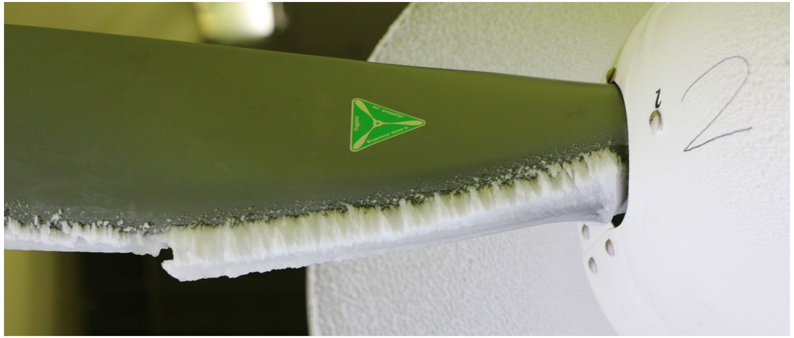
PropRig – test with commercial propeller without IPS

Propeller: MT MTV15B

Conditions:

- Temperature range -5 °C to -20 °C
- Wind speed 24 m/s to 31 m/s
- MVD 20 µm, LWC 0,31 to 0,8 g/m^3
- Test time up to 10 minutes
- Prop speed up to 2000 rpm

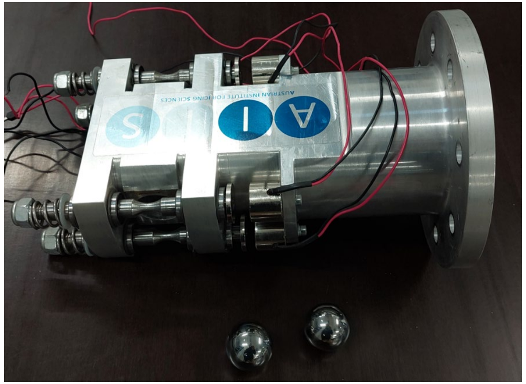




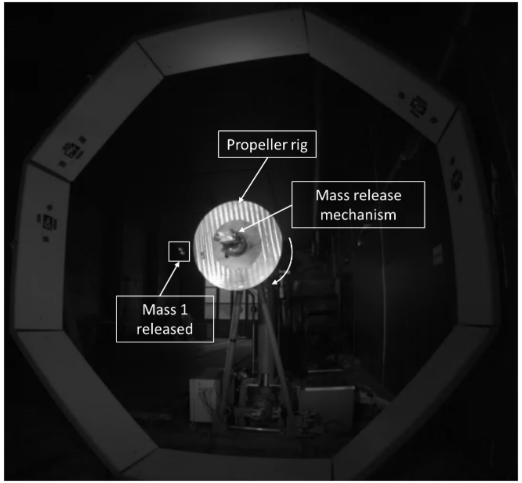
PropRig – Camera synchronized with shaft position

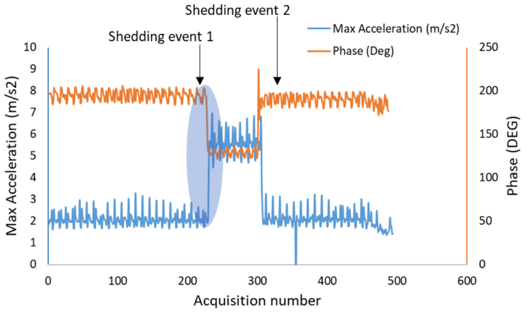
High speed camera triggering (by partner AIIS)

- With AIIS as part of Austrian funded FFG TakeOff JOICE project
- Device to eject masses of known weight
- When mass is released acceleration & and phase profile changes
- Enables camera trigger



Shedding unit from AIIS





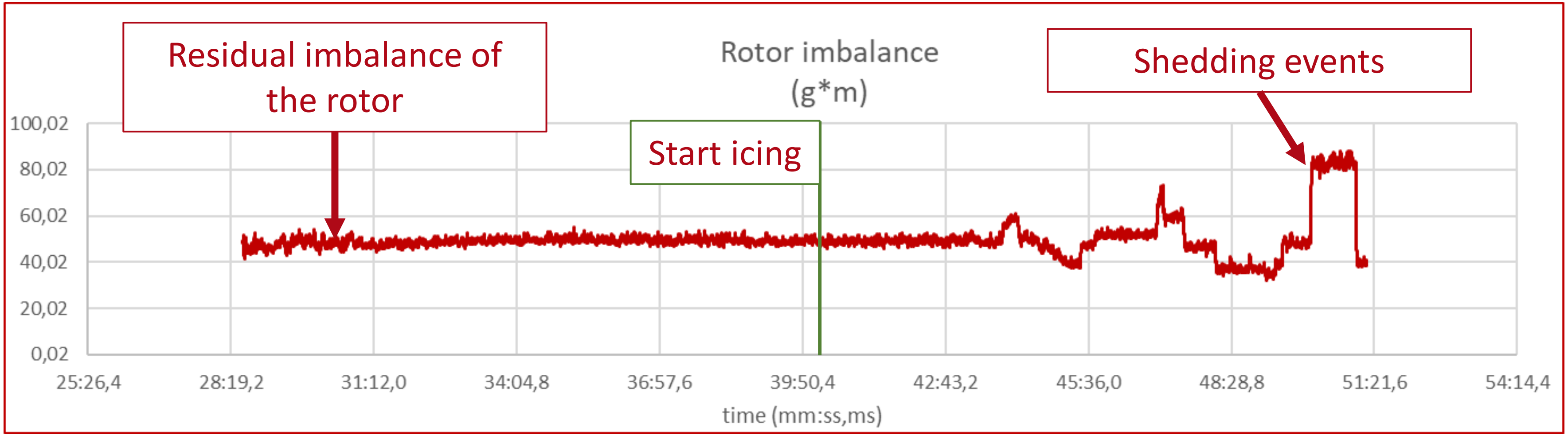
Camera trigger

High Speed Camera Recordings (by partner AIIS)

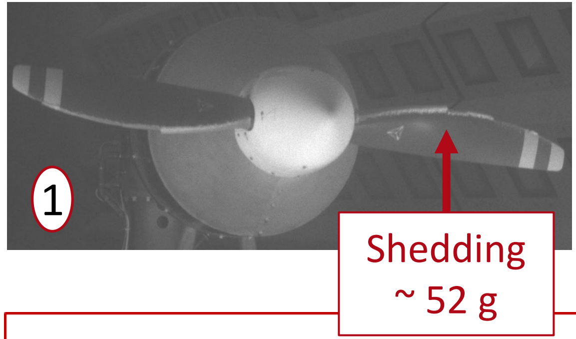
Evaluation of the acceleration measurement on the shaft

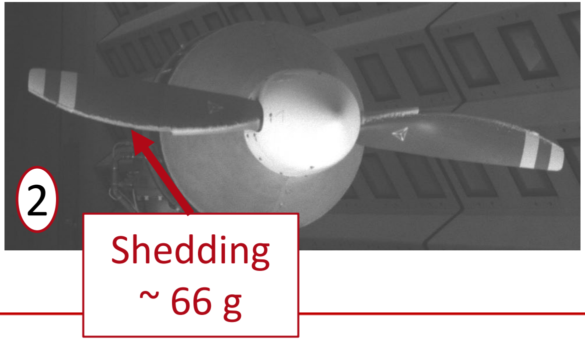
- Reduced mass of the shaft in the propeller plane (~91 kg)
- Calculation of imbalance & ice mass on the blade

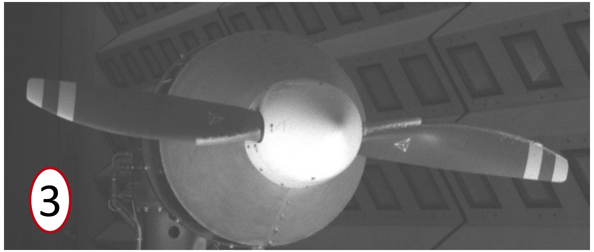
$$Imbalance = \frac{a_{rotor}}{\omega^2} * m_{shaft\_reduced} \qquad m_{ICE} = \frac{Imbalance}{r}$$

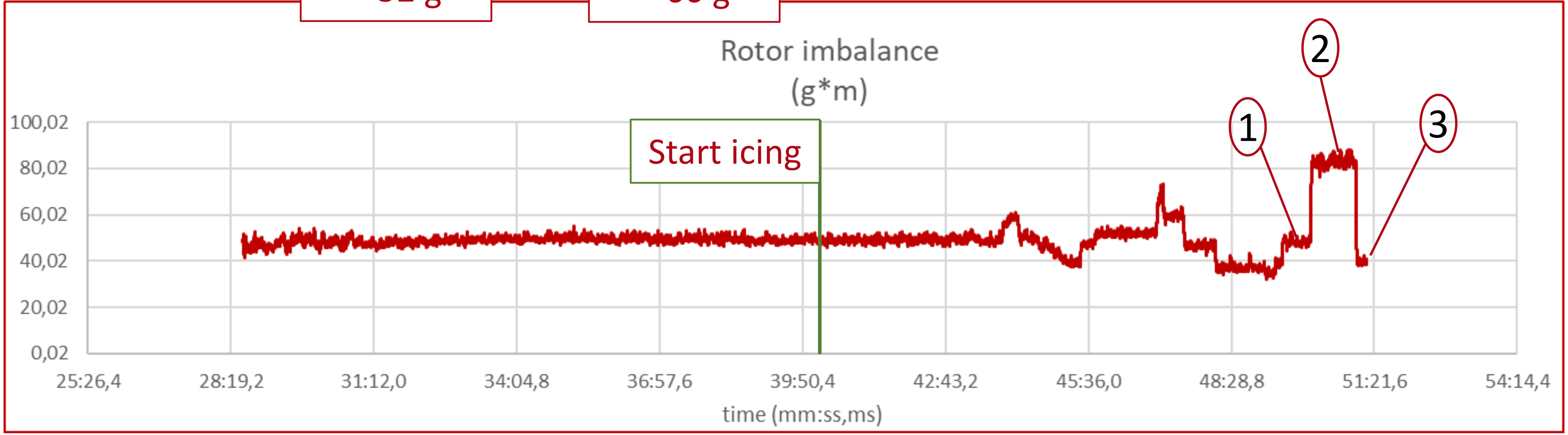


Evaluation of the acceleration measurement on the shaft



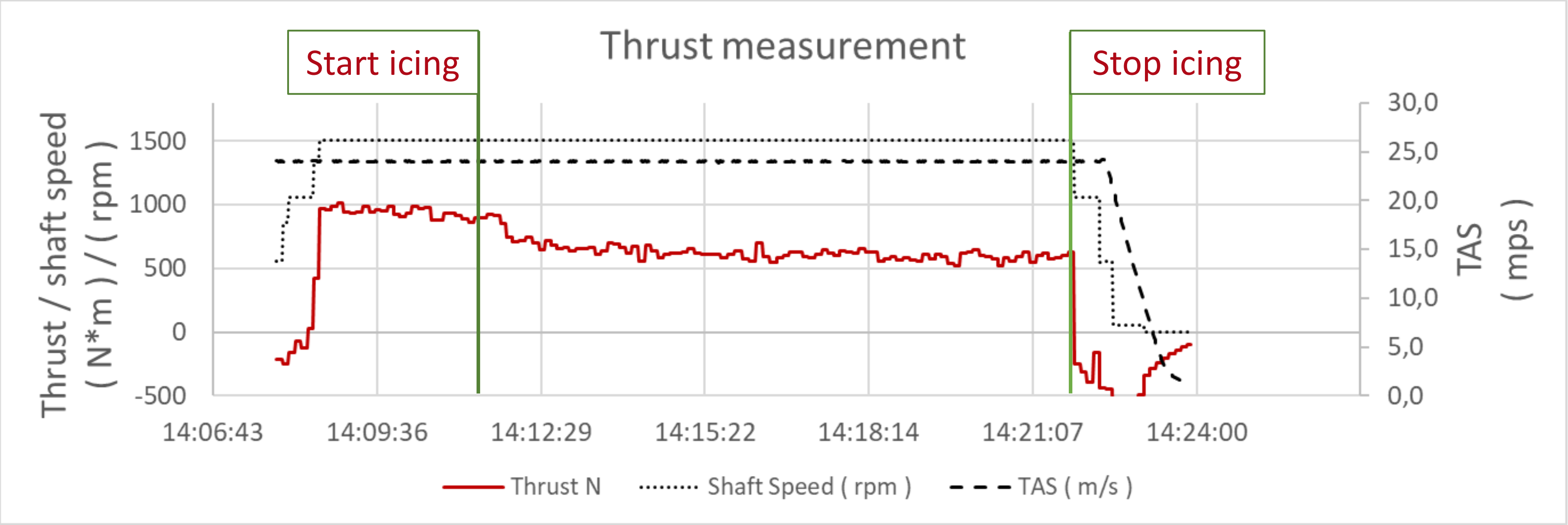






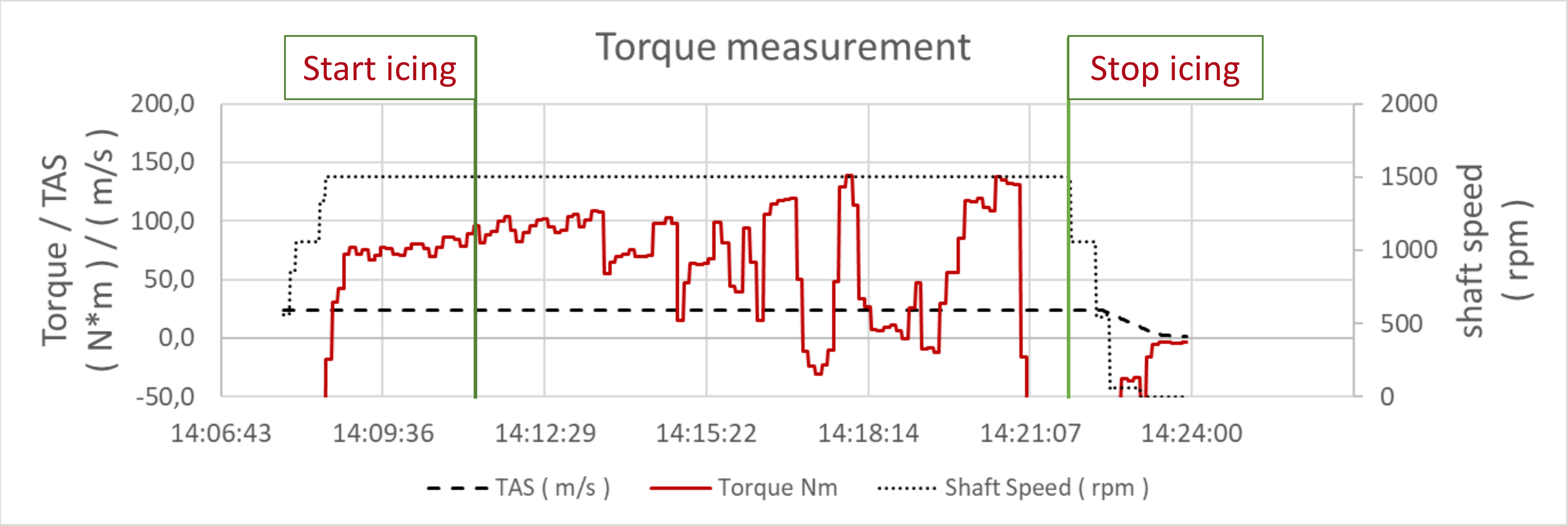
Thrust evaluation

- Reduction of thrust by ~ 30 % due to ice accretion
- about constant when shedding started



Thrust evaluation

- Increase of torque by ~ 30 % due to ice accretion
- Inconsistent after shedding started
- Investigation of oscillations in the power transmission intended



Conclusion and Outlook

Conclusions:

- Icing tests and test evaluation conducted
- Identification even of small shedding events possible to provide a trigger signal
- Thrust measurement reasonable

Outlook:

- Test rotors with IPS
- Calibration of thrust and torque
- Improvement of balancer racetracks and validation of the simulation
- Improvement of the lighting conditions
- Commissioning of strain gauge measurement

Relevant Publications and Links

- [1] European Aviation Safety Agency (EASA), “Certification Specifications and Acceptable Means of Compliance for Large Aeroplanes CS-25, Appendices C and O,” Amendment 22, November 2018.
- [2] Ferschitz, H., Wannemacher, M., Bucek, O., Knöbl, F., Breitfuß, W., “Development of SLD Capabilities in the RTA Icing Wind Tunnel,“ SAE Int. Journal of Aerospace, 10(1):2017. Available at: https://saemobilus.sae.org/content/2017-01-9001/
- [3] Breitfuß, W., Wannemacher M., Knöbl Florian, Ferschitz H., ‘Aerodynamic Comparison of Freezing Rain and Freezing Drizzle Conditions at the RTA Icing Wind Tunnel’, in. International Conference on Icing of Aircraft, Engines, and Structures, pp. 2019-01–2023. Available at: https://doi.org/10.4271/2019-01-2023.
- [4] Puffing, R., Hassler W., Neubauer T., Kozomara D., Ferschitz H. (2019) ‘Aerodynamic Assessment of Complex 3D Ice Shape Replications’, in. International Conference on Icing of Aircraft, Engines, and Structures, pp. 2019-01–1936. Available at: https://doi.org/10.4271/2019-01-1936.
- [5] Lammers, K., van.t.Hoff S., Ferschitz H. Wannemacher M. (2018) ‘HELICOPTER ENGINE AIR INTAKE ICING WIND TUNNEL CERTIFICATION TEST’. Available at: https://www.rta.eu/images/stories/pdf/Fachartikel/Helicopter_Engine_Air_Intake_Icing_Wind_Tunnel_Certification_Test.pdf .
- [6] Kozomara, D., Neubauer T., Puffing R., Bednar I., Breitfuß W., (2021) ‘Experimental Investigation on the Effects of Icing on Multicopter UAS Operation’, in AIAA AVIATION 2021 FORUM. AIAA AVIATION 2021 FORUM, VIRTUAL EVENT: American Institute of Aeronautics and Astronautics. Available at: https://doi.org/10.2514/6.2021-2676 .
- [7] JOICT Austrian In-flight icing research venture 2020+, see https://www.project-joice.com/
- [8] 3-D scan Technology provided by Austrian Institute for Icing Sciences (AIIS), see https://www.aircraft-icing.com/
- [9] Ice- Genesis Creating the next generation of 3D simulation means for icing, see https://www.ice-genesis.eu/page/en/publications.php
- [10] RTA Climatic Wind Tunnel Vienna publication see https://www.rta.eu/en/expertise/professional-publication
- [11] RTA Climatic Wind Tunnel Vienna research see https://www.rta.eu/en/expertise/r-d-projects

Thank you for listening

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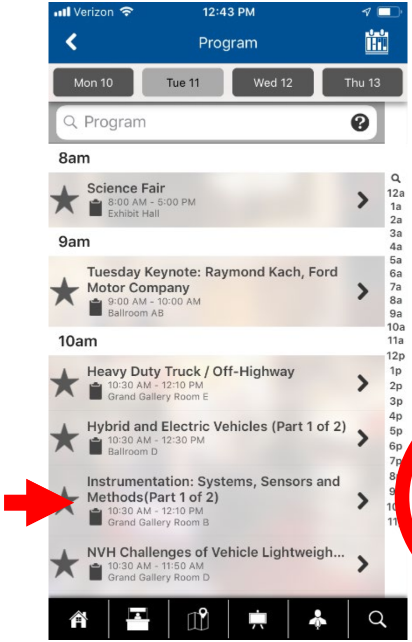

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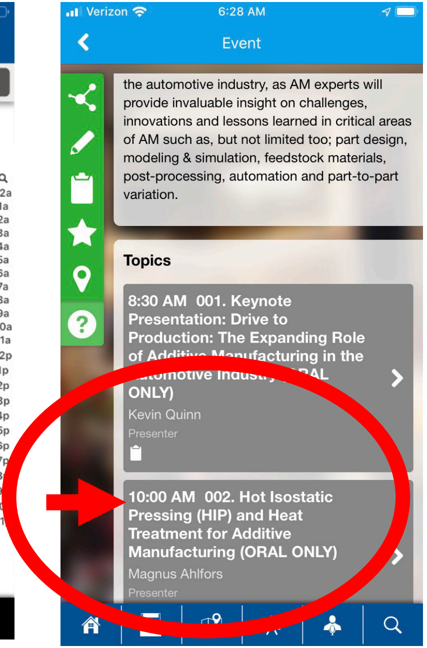
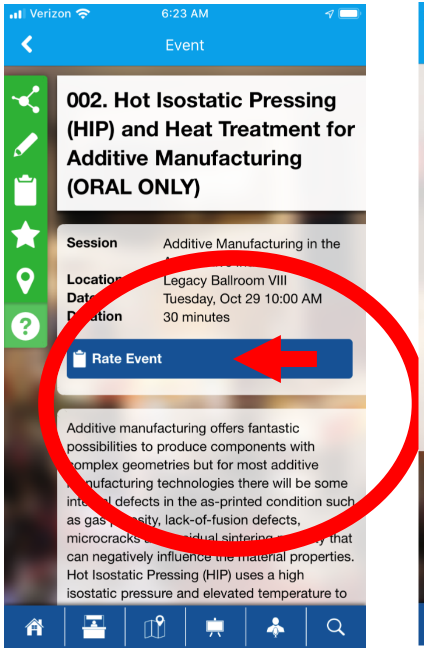
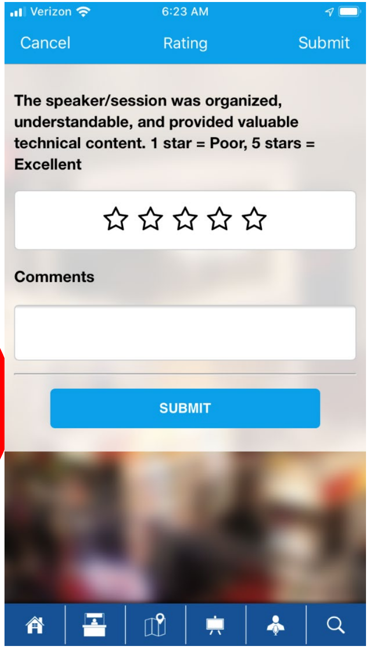


2. Click on individual presentation



3. Click on “Rate Event” button



4. Rate speaker