CA3ViAR

Dissemination Event #1: Design of a Composite UHBR Fan

Mechanical Design

05th September 2022

Presented by: Nicola Paletta / Jens Lindemann

Agenda

1. Introduction
2. Mechanical Design
    1. Stator Stage
    2. Rotor Stage
    3. Rotor Blade Instrumentation
    4. Test Rig Adaptation
    5. Advanced Balancing Concept
3. Final Statement

CA3ViAR Dissemination Event #1 - Mechanical Design

Introduction

The Task for the Mechanical Design

New rotor and stator stage, to be assembled to the same rig used for the INFRA project.

INFRA: metal blisk design for rotor stage

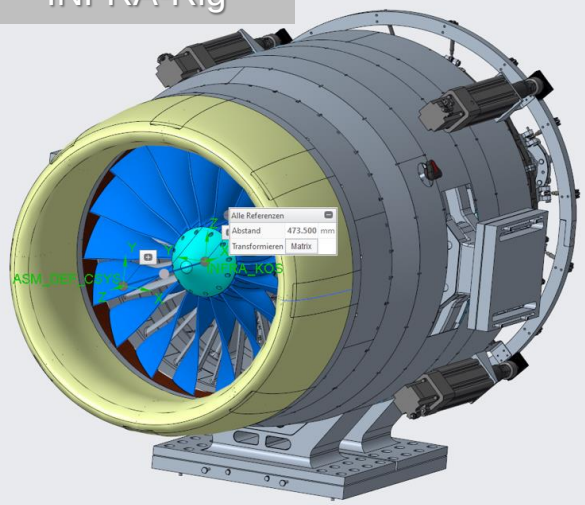
CA3ViAR: classical design approach

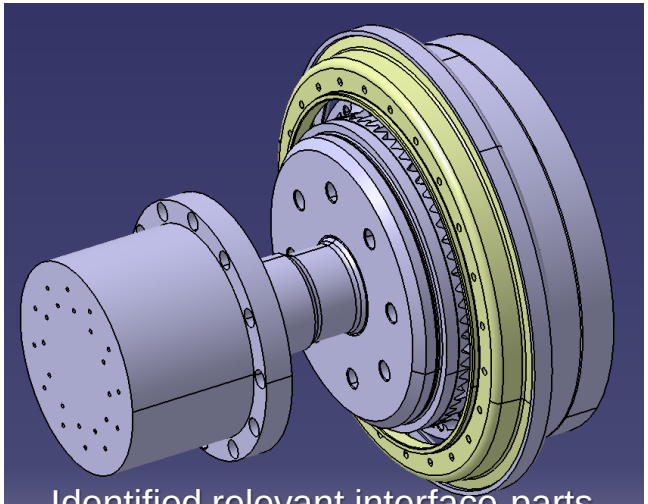
- ➢ metal slotted rotor hub
- ➢ composite rotor blades with dovetail-like foot design

Important requirement:

- Reuse as many interfaces (and parts) of the existing rig as possible (e.g. rotor shaft for the rotor stage, telemetry system…)
  - ➢ minimize design and manufacturing efforts and therefore costs

INFRA-Rig



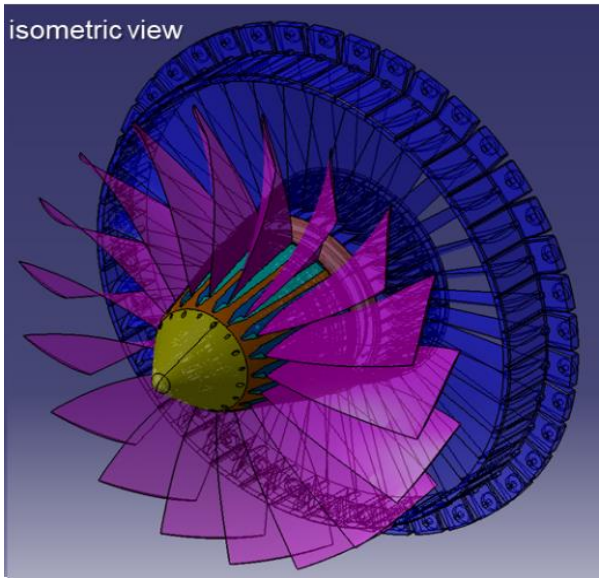


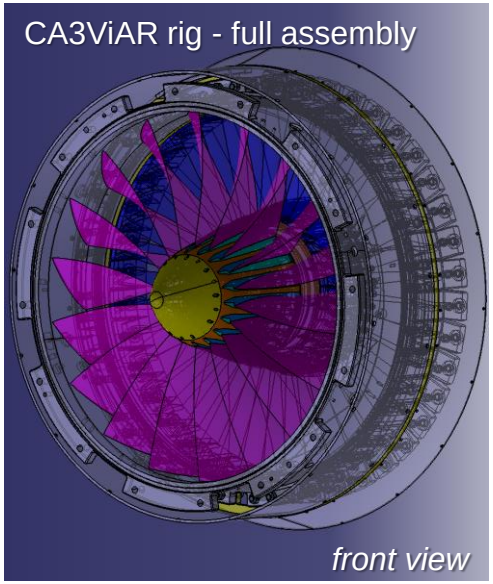
Identified relevant interface-parts from the INFRA-Rig

CA3ViAR Rig Overview

Full Assembly of Rotor and Stator Stages

- Colored parts specifically designed specifically for CA3ViAR
  (e.g., the rotor blades are in magenta, the rotor hub is in orange and the stator vanes are in blue)
- reused parts from INFRA-rig are displayed in grey color



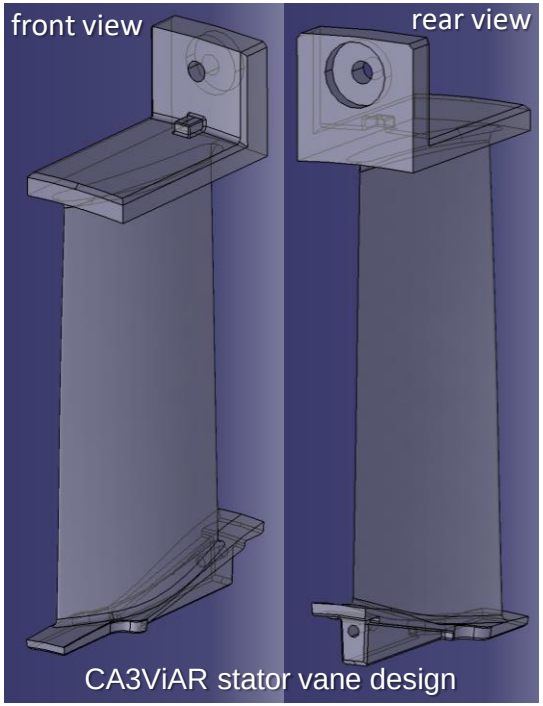


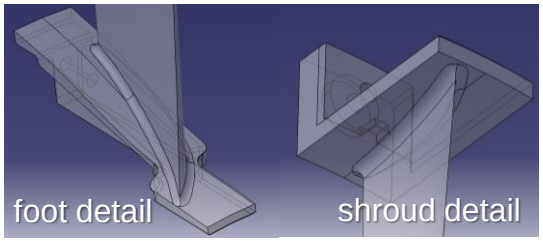
Agenda

1. Introduction
2. Mechanical Design
    1. Stator Stage
        1. Stator Vane Design Overview
        2. Stator Stage Assembly
    2. Rotor Stage
    3. Rotor Blade Instrumentation
    4. Test Rig Adaptation
    5. Advanced Balancing Concept
3. Final Statement

CA3ViAR Stator Stage

Stator Vane Design Overview



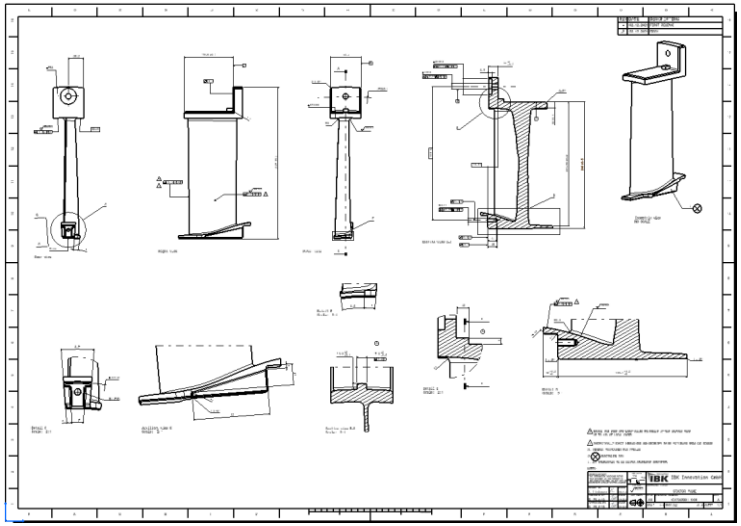


The design concept from the INFRA stator vane is kept unchanged, Only the aero-shape of the vane is update.

Keeping all the interfaces to surrounding elements

- reuse INFRA stator hub ring and stator case

Design is finalized and the drawing is released.



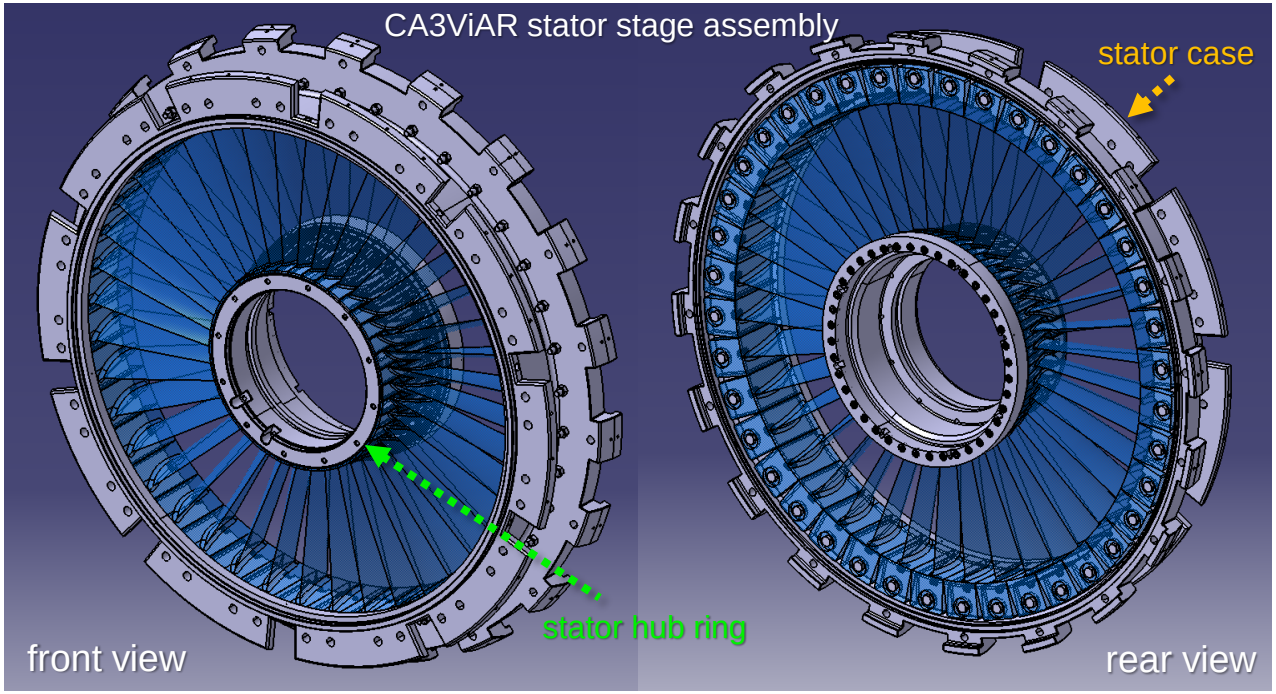
CA3ViAR Stator Stage

Stator Stage Assembly

The stator stage consist of 40 stator vanes.

The stator vane shroud is fastened to the **stator case** and the stator vane foot to the **stator hub ring** (both original INFRA parts - **grey**).

Both INFRA parts serve as interface design references and will be reused without any changes.



Agenda

1. Introduction
2. Mechanical Design
    1. Stator Stage
    2. Rotor Stage
        1. Blade Manufacturing - Hybrid Concept
        2. Notes: Rotor Blade Manufacturing Procedure
        3. Dovetail-like Foot
        4. CFPR Blade
        5. Curved Wedge
        6. Rotor Hub
        7. Retaining Ring
        8. Stator Inner Ring Cover
        9. Spinner – Nose Cone
    3. Rotor Blade Instrumentation
    4. Test Rig Adaptation
    5. Advanced Balancing Concept
3. Final Statement

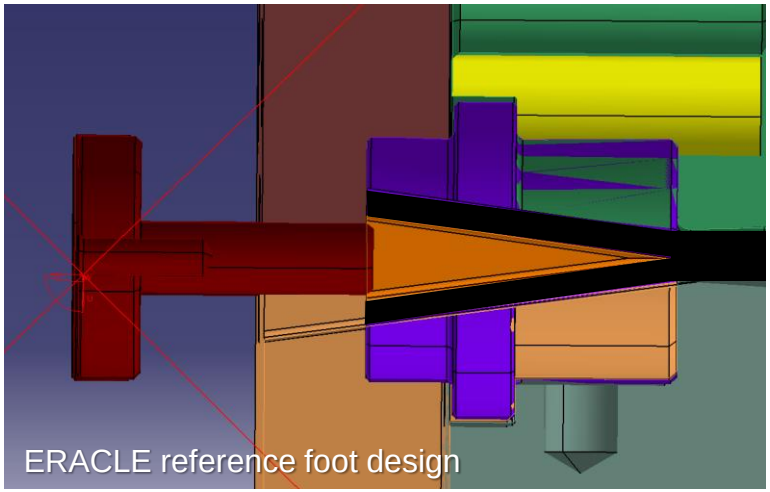
CA3ViAR Rotor Stage

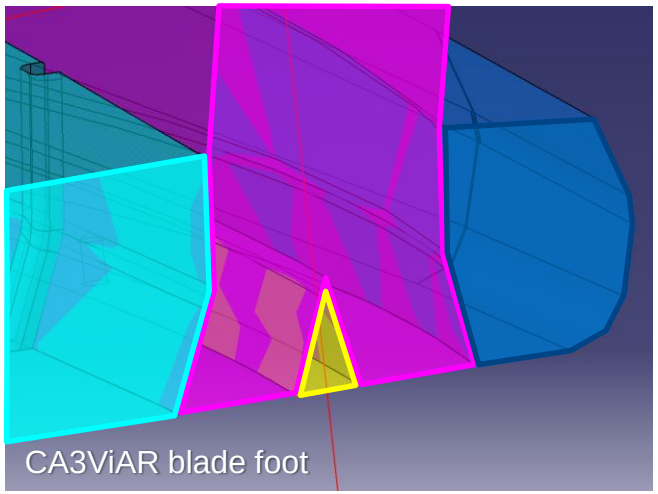
Blade Manufacturing - Hybrid Concept

The original hybrid design from the ERACLE project was taken as the initial idea for the design of the CA3ViAR blade.

A metallic **wedge** part is inserted into the **metallic foot** part, dividing **CFPR-layers** from the blade into two parts and constraining them within the foot.

During manufacturing, the autoclave pressure acts on a **plug**, pushing the against the wedge, fixing it in its position between the divided CFRP layers within the foot.


ERACLE reference foot design


CA3ViAR blade foot

→ The implementation of this principle into the manufacturing process will be presented by ADAMANT.

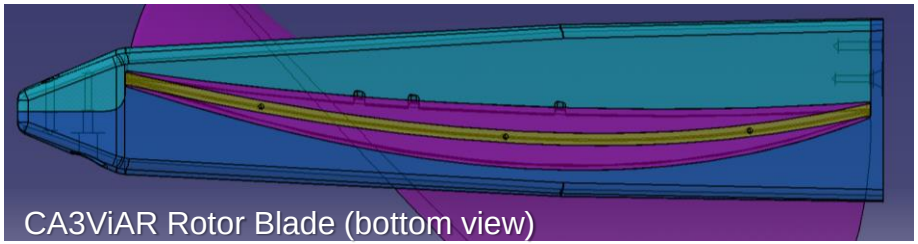
Agenda

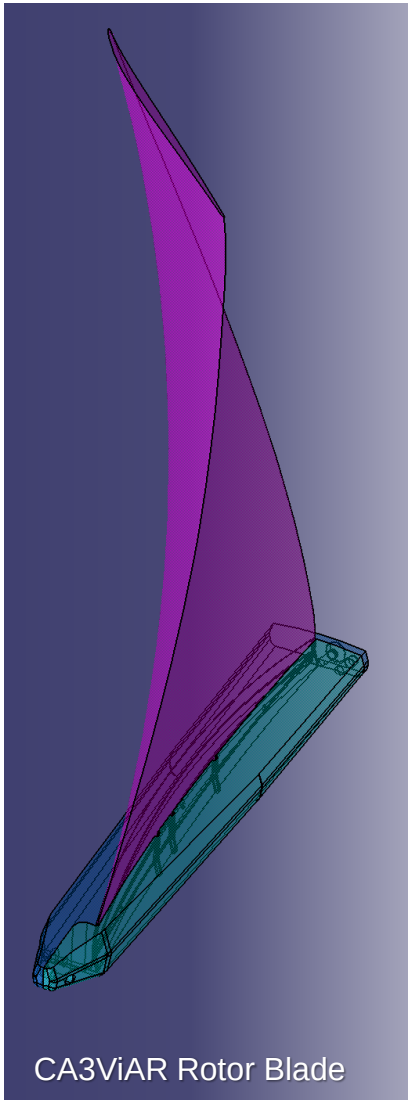
CA3ViAR Rotor Stage

Notes: Rotor Blade Manufacturing Procedure (incl. Instrumentation)

- The blade is made of CFRP & epoxy resin, manufactured by hand lay-up, using mould and counter-mould and will be cured in an autoclave
- The **suction side blade foot is placed into the mold** in a suitable housing slot, before the **CFRP plies are placed in** their respective **positions**
- At the same time a **curved wedge is put into** its desired **position** between the CFRP layers of the blade
- The **SG's and cables** are placed in their positions
- The **pressure side blade foot is fastened** to the suction side foot using screws and pins
- The **wedge** will be pushed and **kept in place** between the split CFRP-layers of the blade **by multiple plugs** placed along its length, which are loaded by the autoclave pressure
- After curing the blade will be de-molded, trimmed and inspected

➢ Further details on the SG installation procedure are given by ADAMANT.


CA3ViAR Rotor Blade (bottom view)


CA3ViAR Rotor Blade

Agenda

1. Introduction
2. Mechanical Design
    1. Stator Stage
    2. Rotor Stage
        1. Blade Manufacturing - Hybrid Concept
        2. Notes: Rotor Blade Manufacturing Procedure
        3. Dovetail-like Foot
        4. CFPR Blade
        5. Curved Wedge
        6. Rotor Hub
        7. Retaining Ring
        8. Stator Inner Ring Cover
        9. Spinner – Nose Cone
    3. Rotor Blade Instrumentation
    4. Test Rig Adaptation
    5. Advanced Balancing Concept
3. Final Statement

CA3ViAR Rotor Stage

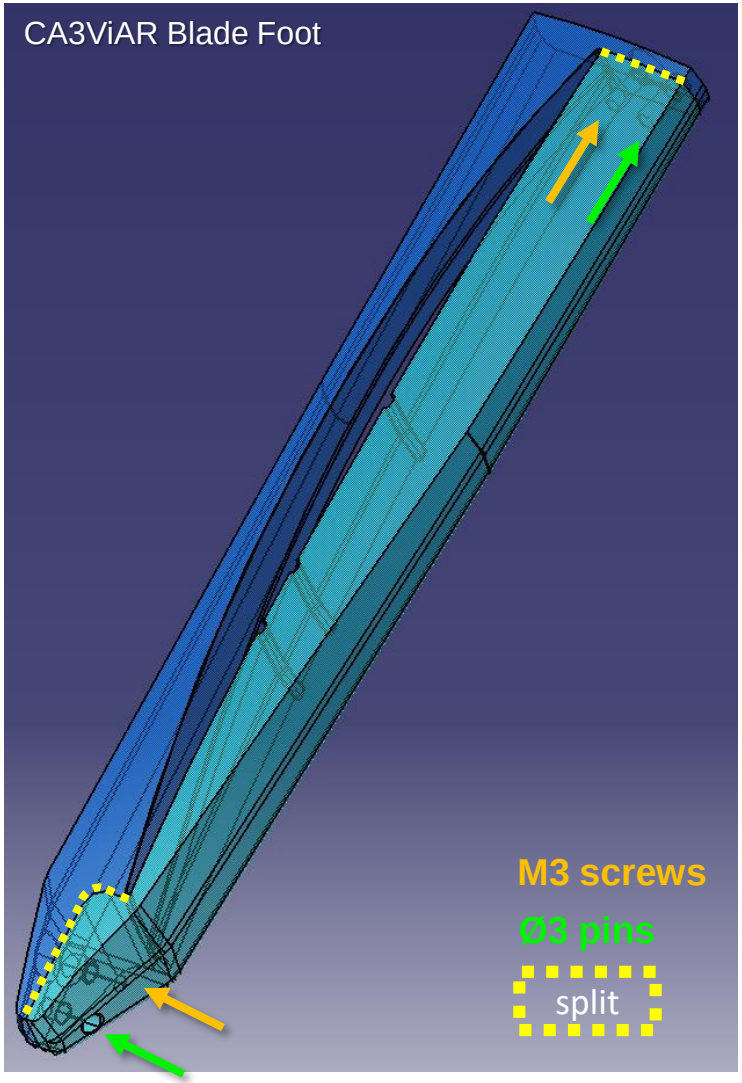
Dovetail-like Foot

The design was optimized to maximize the contact surfaces to the hub:

- Rotor blade assembly will be pushed into a slot on the hub from the rear
- Width increases from front to back (tapered design)
- Asymmetrical design, achieving optimized centred position of the opening on the upper side of the blade foot (where the CFRP blade “leaves” the foot)

<u>Optimization wrt. manufacturability:</u>

- Split design will enable much easier and more reliable approach to place the CFRP layers within the opening of the foot
- An M3 screw and two Ø3 pins are placed in the front and the back will fix assembly together



CA3ViAR Rotor Stage

Details - Split Dovetail-like Foot

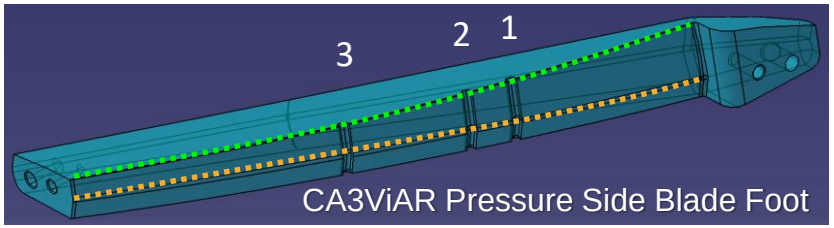
Both foot parts:

To prevent damage of the CFRP layer of the blade caused by sharp edges, a fillet is foreseen on the upper edge where the blade “leaves” the foot (**green**) and as well on the mid part of the blade foot (**orange**)

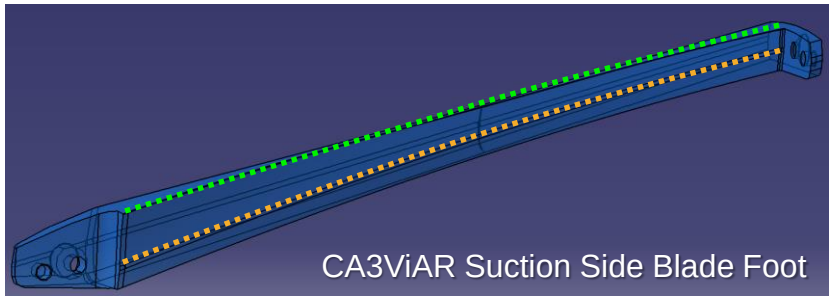
On pressure side foot:

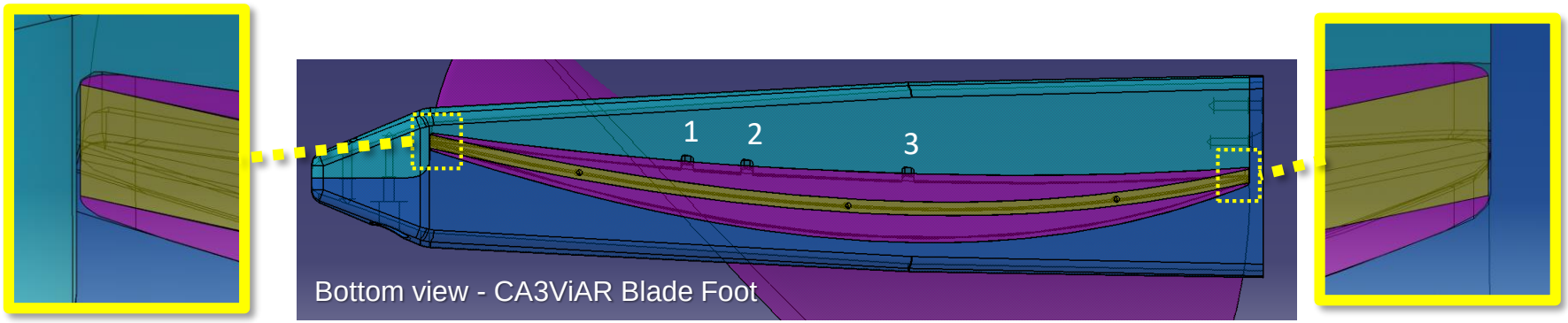
3 groves (2mmx1mm) used to route 3 Ø0.5mm cables coming from SG’s mounted on the pressure side of the blade

- More details shown in following slides…



CA3ViAR Pressure Side Blade Foot


CA3ViAR Suction Side Blade Foot

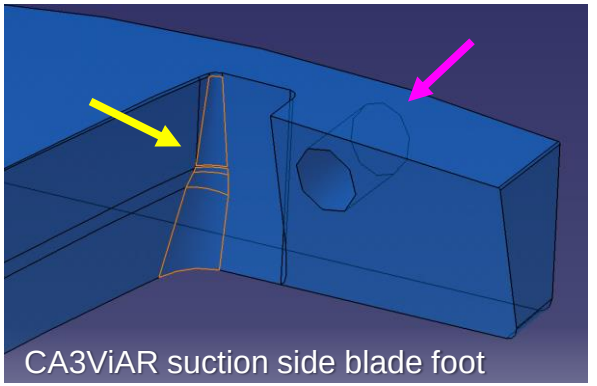


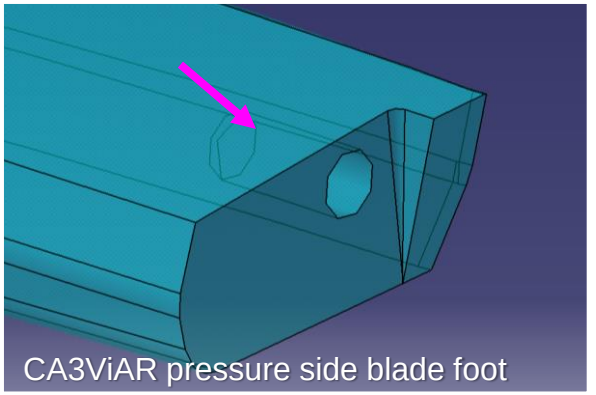
Bottom view - CA3ViAR Blade Foot

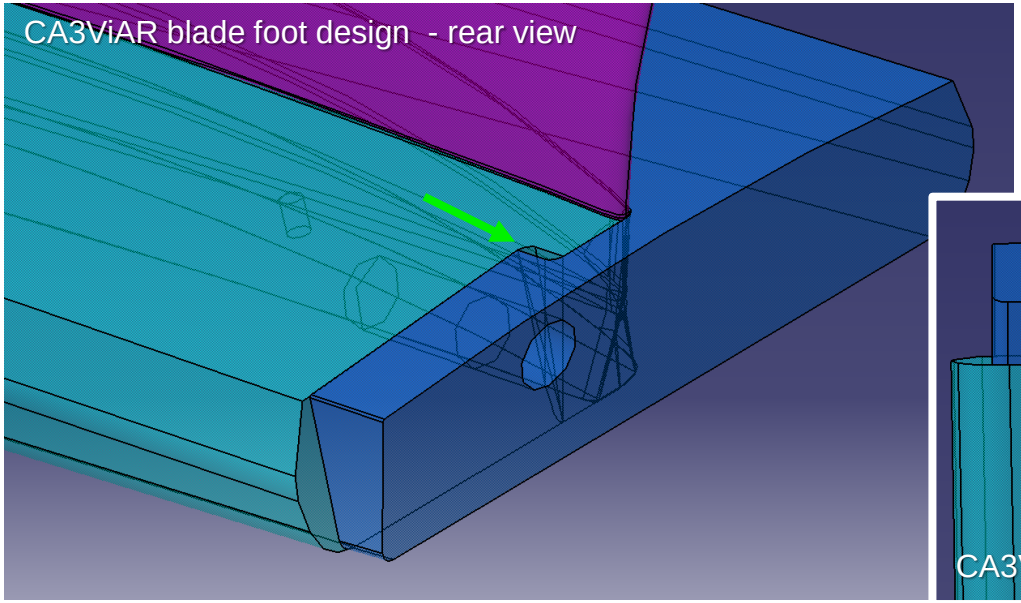
Blade Foot – Optimized Design

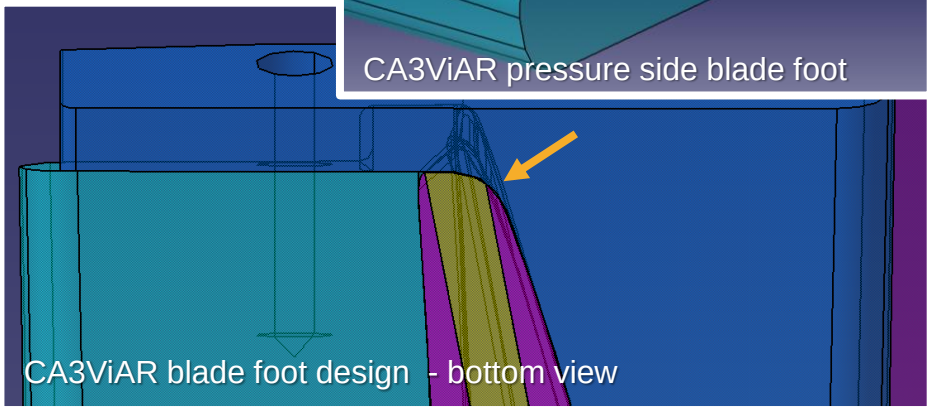
Detailed optimizations on design features

- **Variable radius fillet** created between main body and lug of the suction side foot part (0,5mm at the top; 2mm at the bottom)
  - ➢ Wedge and blade adapted accordingly to avoid a **clash**
- **Rear contact surface** between both foot parts inclined to be perpendicular to pin axis
- Small **pocket** could be filled after assembly (0,5mm)


CA3ViAR suction side blade foot


CA3ViAR pressure side blade foot


CA3ViAR blade foot design - rear view


CA3ViAR blade foot design - bottom view

Agenda

1. Introduction
2. Mechanical Design
    1. Stator Stage
    2. Rotor Stage
        1. Blade Manufacturing - Hybrid Concept
        2. Notes: Rotor Blade Manufacturing Procedure
        3. Dovetail-like Foot
        4. CFPR Blade
        5. Curved Wedge
        6. Rotor Hub
        7. Retaining Ring
        8. Stator Inner Ring Cover
        9. Spinner – Nose Cone
    3. Rotor Blade Instrumentation
    4. Test Rig Adaptation
    5. Advanced Balancing Concept
3. Final Statement

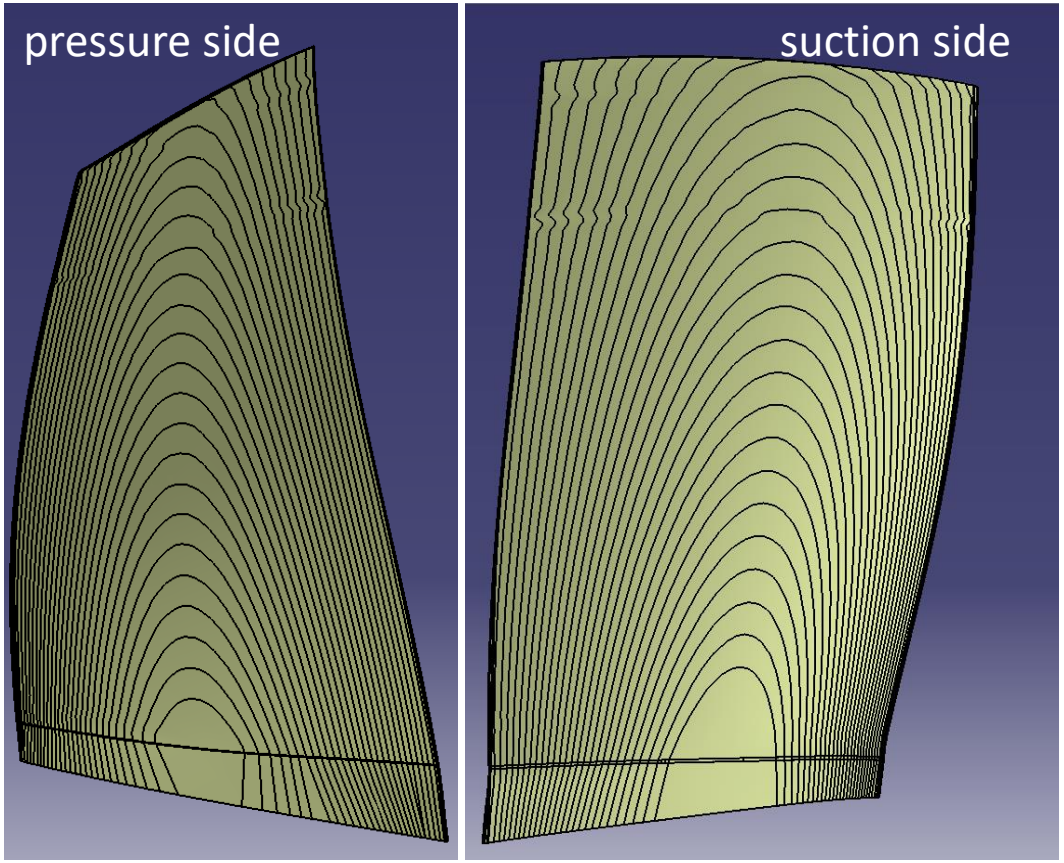
CA3ViAR Rotor Stage

CFRP Blade – Ply Book

A ply book for the CA3ViAR CFRP blade was created, containing 31 plies on the suction side and the pressure side each.

Ply #001 being the outer ply.

Ply #031 being the innermost ply.



Agenda

1. Introduction
2. Mechanical Design
    1. Stator Stage
    2. Rotor Stage
        1. Blade Manufacturing - Hybrid Concept
        2. Notes: Rotor Blade Manufacturing Procedure
        3. Dovetail-like Foot
        4. CFPR Blade
        5. Curved Wedge
        6. Rotor Hub
        7. Retaining Ring
        8. Stator Inner Ring Cover
        9. Spinner – Nose Cone
    3. Rotor Blade Instrumentation
    4. Test Rig Adaptation
    5. Advanced Balancing Concept
3. Final Statement

CA3ViAR Rotor Stage

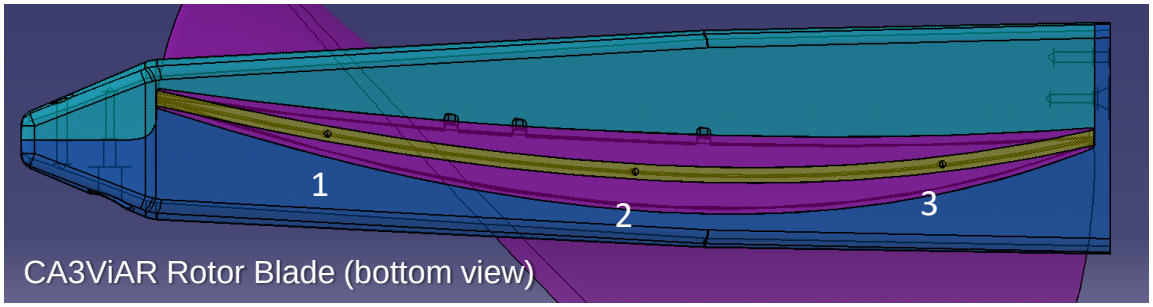
Curved Wedge

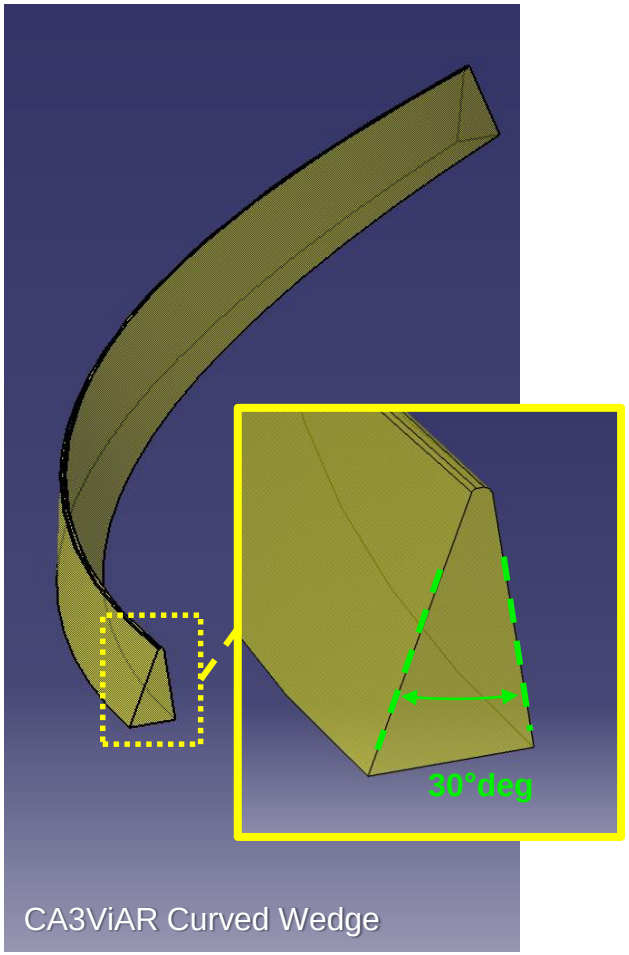
Design features of the wedge:

- Curved shape due to curvature of the blade
- Top-angle of wedge sides 30°deg
- Rounded top edge, preventing damage to CFRP layers

Added design feature:

– Three Ø1mm holes are foreseen for thermo-couples, to monitor the temperature during the curing process.





Agenda

1. Introduction
2. Mechanical Design
    1. Stator Stage
    2. Rotor Stage
        1. Blade Manufacturing - Hybrid Concept
        2. Notes: Rotor Blade Manufacturing Procedure
        3. Dovetail-like Foot
        4. CFPR Blade
        5. Curved Wedge
        6. Rotor Hub
        7. Retaining Ring
        8. Stator Inner Ring Cover
        9. Spinner – Nose Cone
    3. Rotor Blade Instrumentation
    4. Test Rig Adaptation
    5. Advanced Balancing Concept
3. Final Statement

CA3ViAR Rotor Stage

Rotor Hub – Rear Interfaces

The interfaces on the “inside” of the rotor hub on the rear were kept unchanged from the INFRA design:

- **lamellar gasket ring**
- **connection to the rotor shaft**

Additional interfaces:

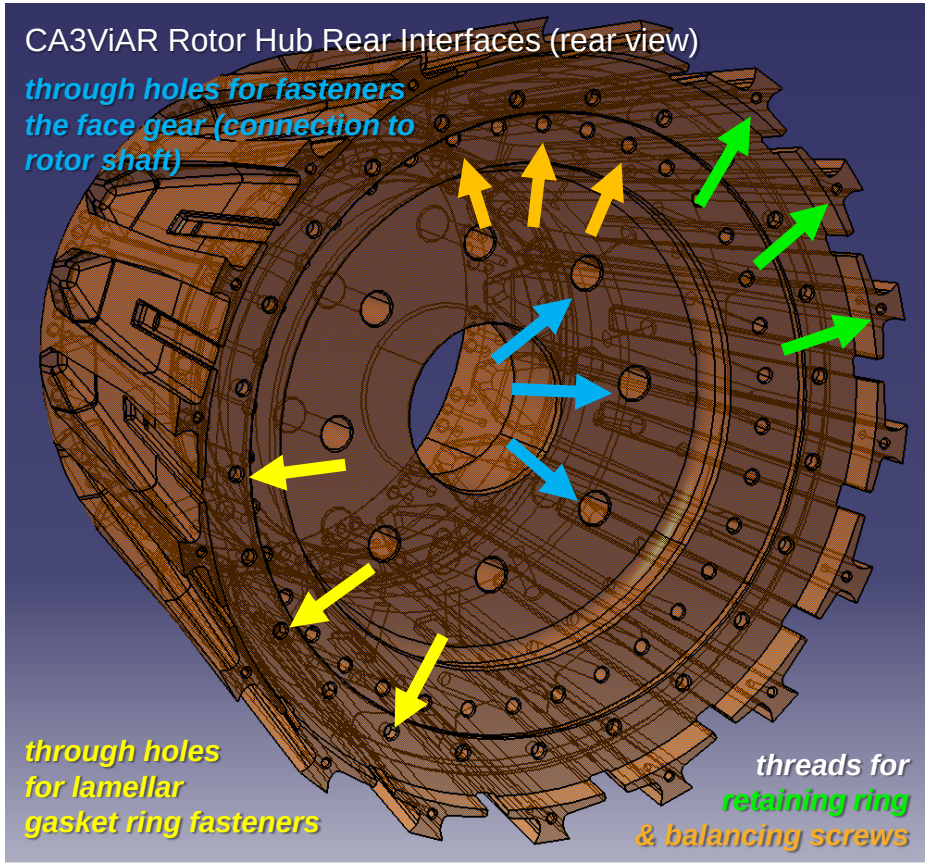
- **Retaining ring**
- **Balancing screws**

➢ see following slides

Interfaces/Clashes to surrounding parts:

- stator inner ring cover

➢ see following slides



CA3ViAR Rotor Stage

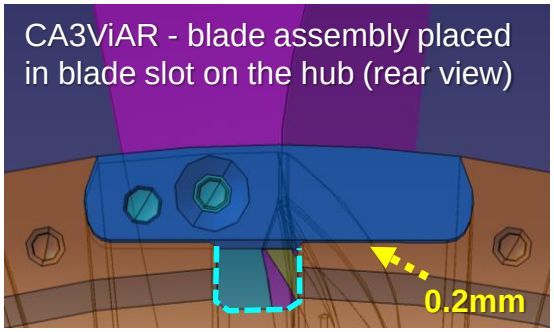
Blade Slot

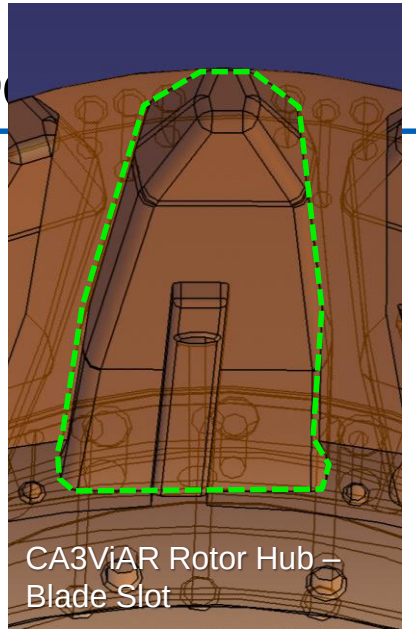
The rotor blade assembly will be pushed into the slot on the hub from the back.

A retaining ring will fix the blades in the desired position

- see following slides

A gap of 0.2mm is kept between the bottom of the foot and the surface of the slot to have some free play to push the blade into the slot without clamping.



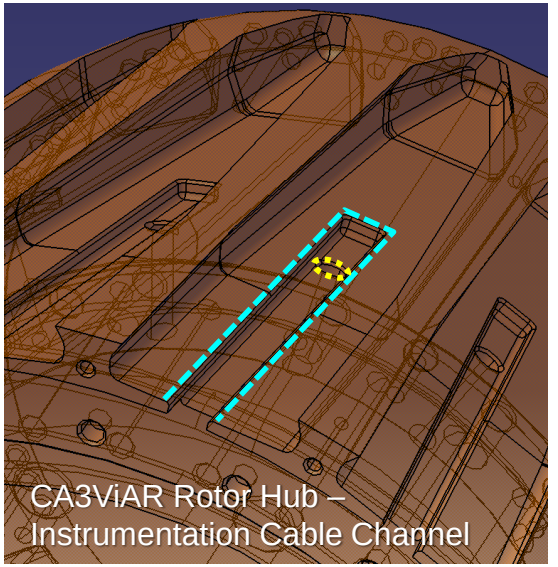


Instrumentation Cable Channel

To be able to push the assembled blade into the **blade slot** on the rotor hub without damaging the 9 wires belonging to the SG's, a **channel** is foreseen where the wires can be placed.

All 9 cables will then be routed through one **hole** (Ø5mm diameter; perpendicular to the bottom of the blade slot), leading into the area behind the telemetry box, to which all SG cables will be attached to.

- More detailed information on the instrumentation will follow in upcoming slides



CA3ViAR Rotor Stage

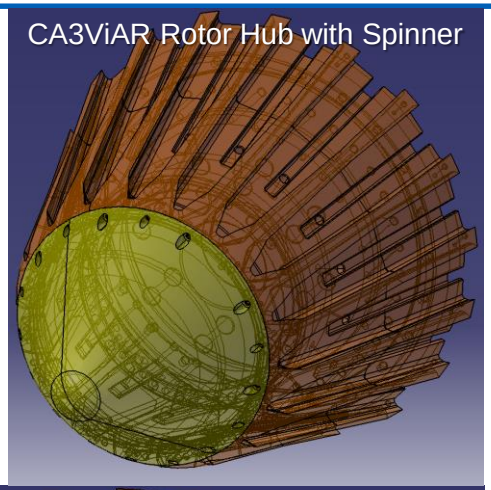
Rotor Hub – Balancing Concept

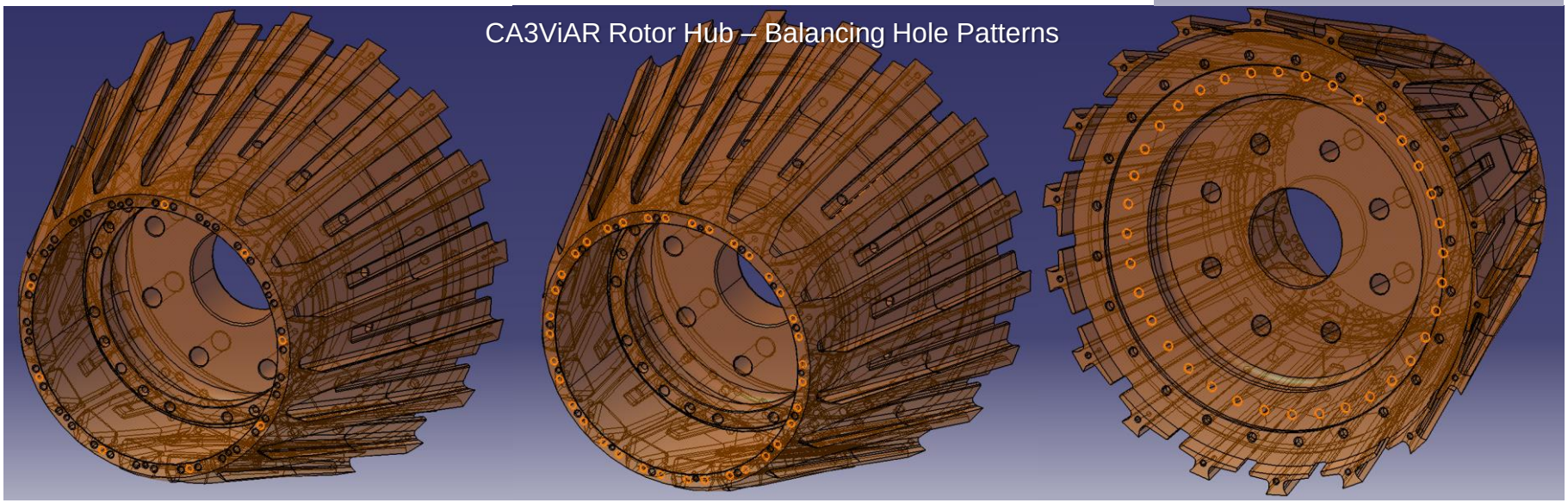
The same balancing procedure as in INFRA will also be used for CA3ViAR.

Headless screws can be put in place in multiple positions in the front and the back of the hub (highlighted **orange** hole patterns).

44 positions are accessible when the CA3ViAR rotor is fully assembled.

36 positions in the front are only accessible when the spinner is dismounted.





Balancing screws M4x15 (max.) (8X)
(accessible when spinner is mounted)

Balancing screws M4x8(max.) (36X)
(**not** accessible when spinner is mounted)

Balancing screws M5x40(max.) (36X)
(accessible when spinner is mounted)

Agenda

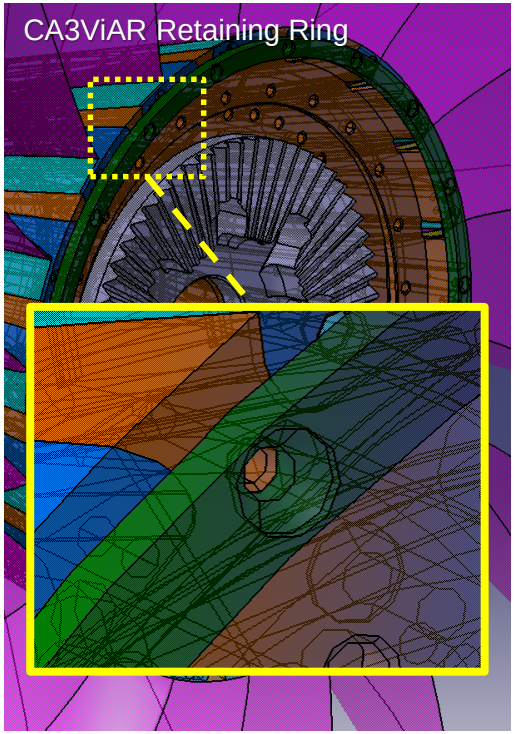
1. Introduction
2. Mechanical Design
    1. Stator Stage
    2. Rotor Stage
        1. Blade Manufacturing - Hybrid Concept
        2. Notes: Rotor Blade Manufacturing Procedure
        3. Dovetail-like Foot
        4. CFPR Blade
        5. Curved Wedge
        6. Rotor Hub
        7. Retaining Ring
        8. Stator Inner Ring Cover
        9. Spinner – Nose Cone
    3. Rotor Blade Instrumentation
    4. Test Rig Adaptation
    5. Advanced Balancing Concept
3. Final Statement

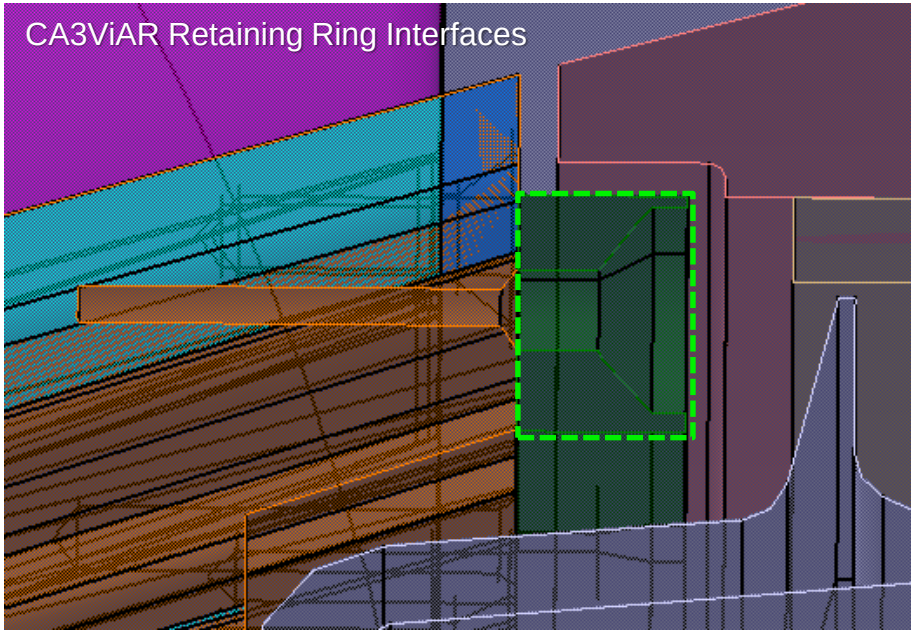
CA3ViAR Rotor Stage

Retaining Ring

The retaining ring will **constrain the rotor blades in position** within the blade slots on the hub.

18 countersunk screws are used to fasten and constrain the retaining ring on the back of the rotor hub.





The dimensions of the retaining ring were chosen to be able to **fit into the available space behind the rotor hub**.
The only change to existing surrounding parts due to the retaining ring will be on the inner radius of the **stator inner ring cover** (next slide).

Agenda

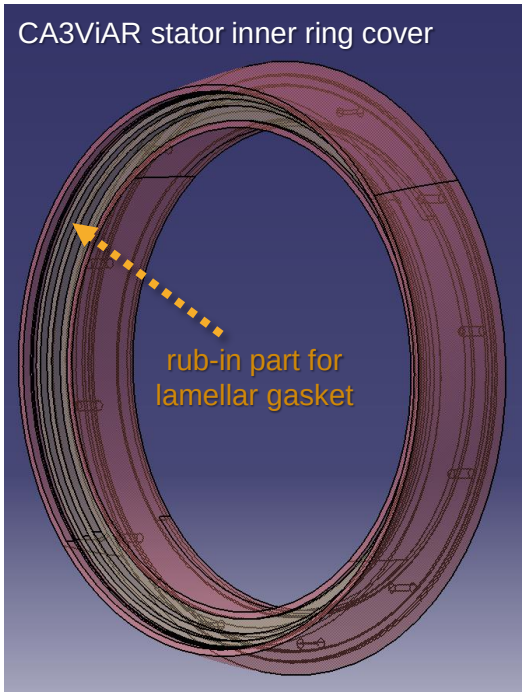
1. Introduction
2. Mechanical Design
    1. Stator Stage
    2. Rotor Stage
        1. Blade Manufacturing - Hybrid Concept
        2. Notes: Rotor Blade Manufacturing Procedure
        3. Dovetail-like Foot
        4. CFPR Blade
        5. Curved Wedge
        6. Rotor Hub
        7. Retaining Ring
        8. Stator Inner Ring Cover
        9. Spinner – Nose Cone
    3. Rotor Blade Instrumentation
    4. Test Rig Adaptation
    5. Advanced Balancing Concept
3. Final Statement

CA3ViAR Rotor Stage

Stator Inner Ring Cover

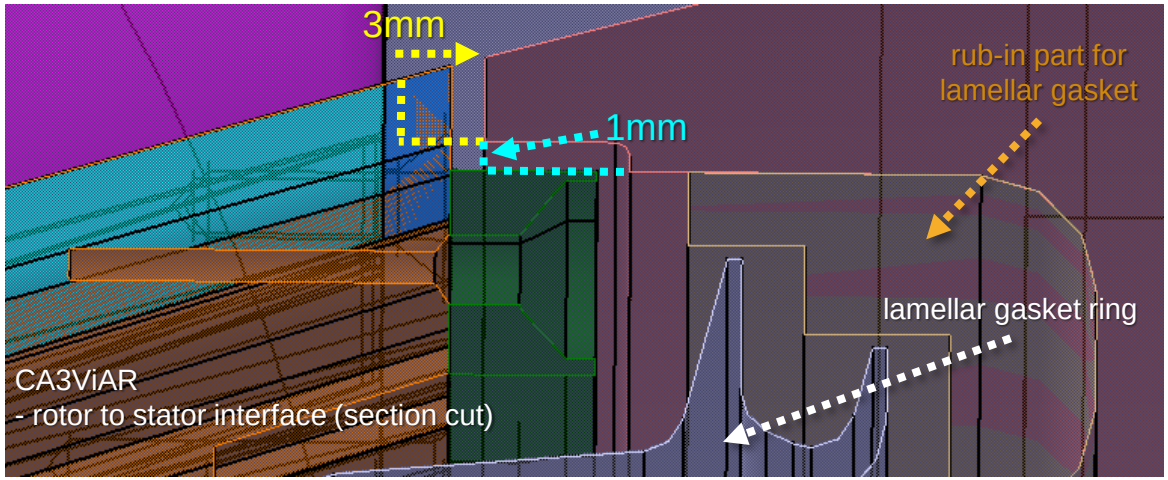
The basic design is kept unchanged from the INFRA design.

A rub-in part that is integral to the metallic part (inserted into a groove on the metallic part), serves as the counterpart for the lamellar gasket ring mounted to the rotor hub.



Adaptation due to rearward shifted axial position of the CA3ViAR blade:

- The **outer lip** was shorted by 3mm, to keep the same gap dimension between the rotor hub and stator inner ring cover wrt. the INFRA design



Adaptation to avoid a clash with the retaining ring:

- Removed **material** on the inner radius of the lip

Agenda

1. Introduction
2. Mechanical Design
    1. Stator Stage
    2. Rotor Stage
        1. Blade Manufacturing - Hybrid Concept
        2. Notes: Rotor Blade Manufacturing Procedure
        3. Dovetail-like Foot
        4. CFPR Blade
        5. Curved Wedge
        6. Rotor Hub
        7. Retaining Ring
        8. Stator Inner Ring Cover
        9. Spinner – Nose Cone
    3. Rotor Blade Instrumentation
    4. Test Rig Adaptation
    5. Advanced Balancing Concept
3. Final Statement

CA3ViAR Rotor Stage

Spinner – Nose Cone

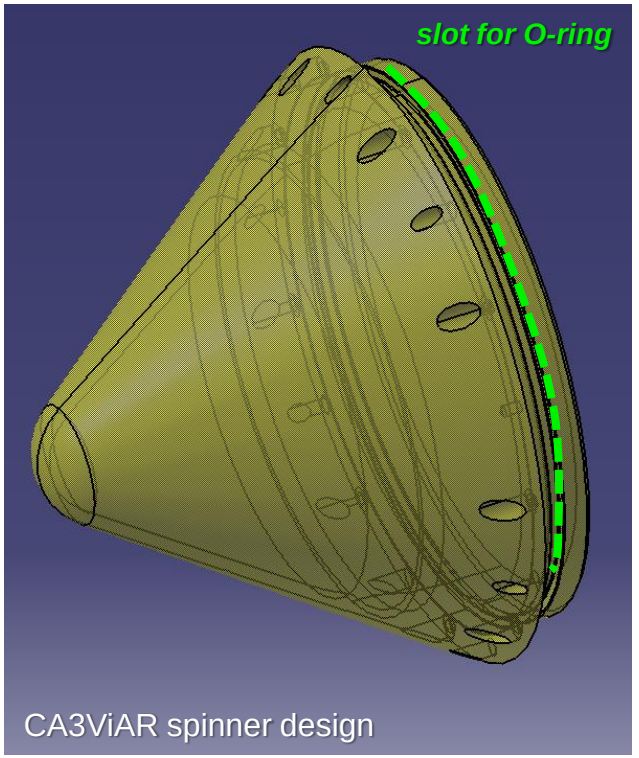
The spinner design principles from INFRA project were adapted to the needs of CA3ViAR.

9 Cylindrical headed screws are used to fasten the spinner to the hub.

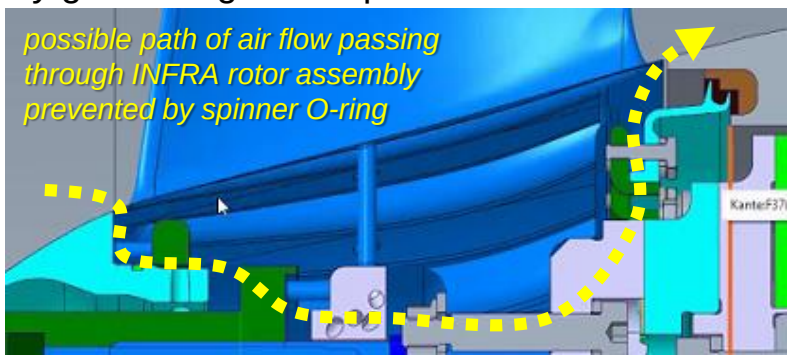
8 through-holes are foreseen in the respective positions to be able to access the headless balancing screws from the outside, without having to remove the spinner.

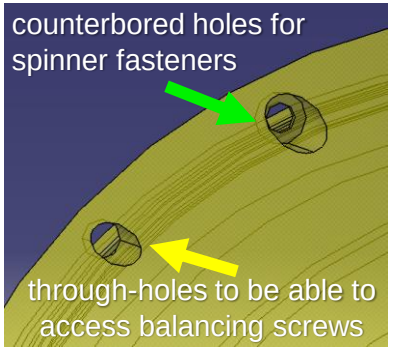
1 pin is implemented to take any shear loading and fix the radial position of the spinner wrt. the hub (balancing).

An O-ring at the hub/spinner interface will prevent any airflow through the hub, potentially disturbing aerodynamics at the rotor to stator interface, by generating flow separation in front of the stator stage.



CA3ViAR spinner design





Agenda

Rotor Blade Instrumentation

Strain Gauge Placement Analysis

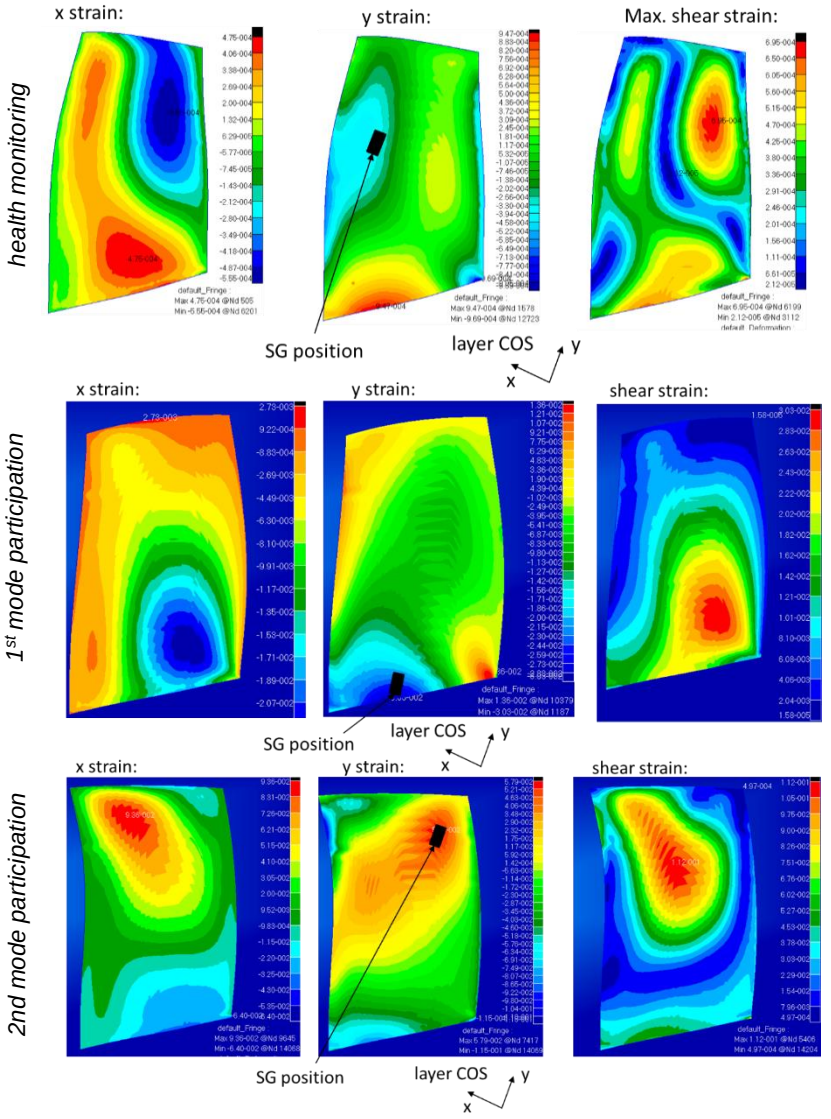
Three positions for strain gauge placement have been identified to allow health monitoring of the blade during operation considering deformation under loading as well as the first 2 eigenmodes.

<u>Health Monitoring Criterion:</u>

- maximum strain on the external ply at the design load condition

<u>Blade Deformation Criterion:</u>

- maximum strain on the external ply in two conditions of pure vibration with in turn 1st and 2nd mode shapes



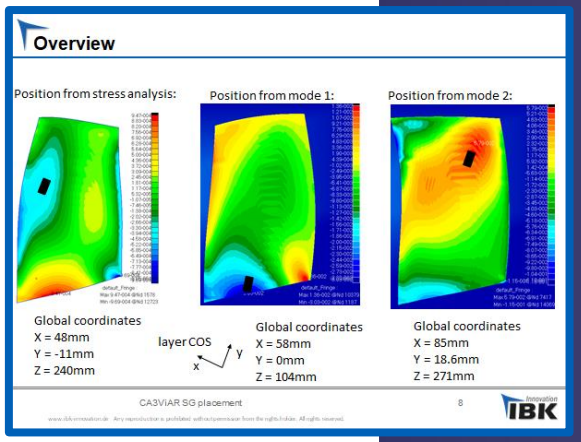
Agenda

CA3ViAR Dissemination Event #1 - Mechanical Design

Rotor Blade Instrumentation

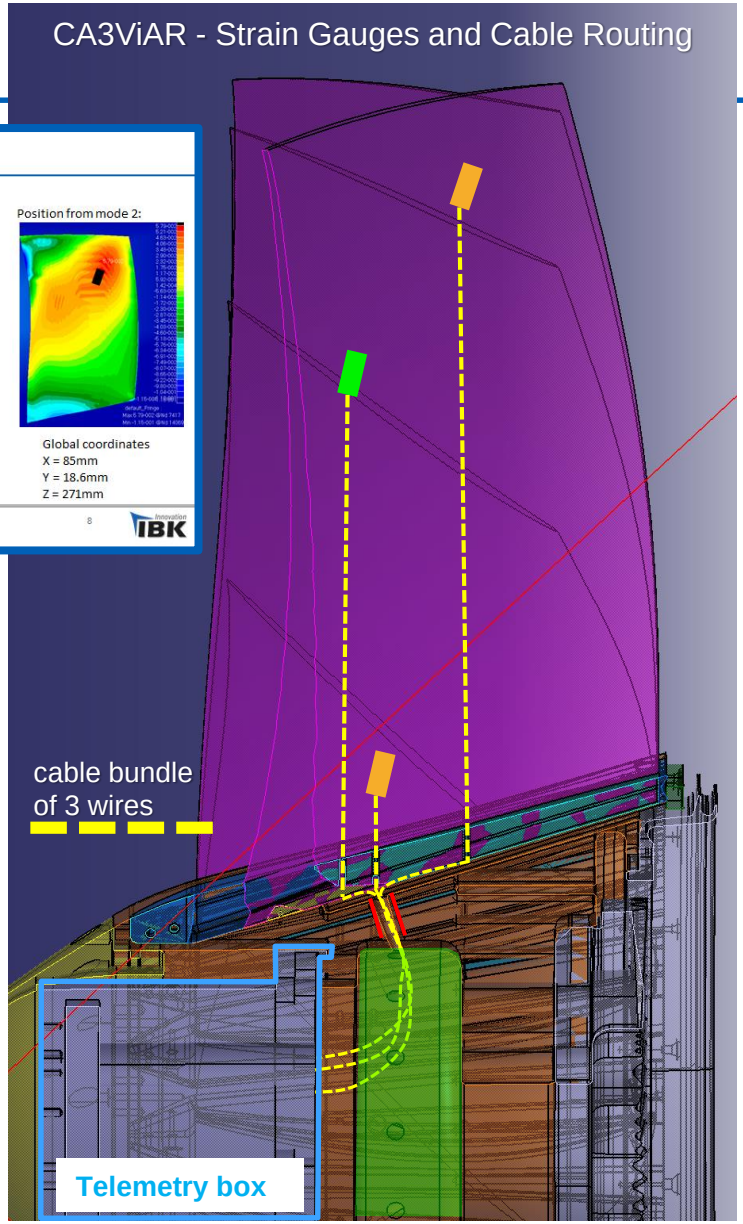
Strain Gauges – Installation

According to FE calculations and modal analyses, SG positions were identified in most critical areas.



- **Every blade** is instrumented with one **SG** to monitor maximum stress
- **Six blades** will be instrumented with **two additional SG's** to detect the modal participation of the 1st & 2nd natural modes
- All SG's will be **installed on the pressure side** of the blade for minimal influence on the aerodynamic performance

➢ Selected SG-installation strategy presented by ADAMANT

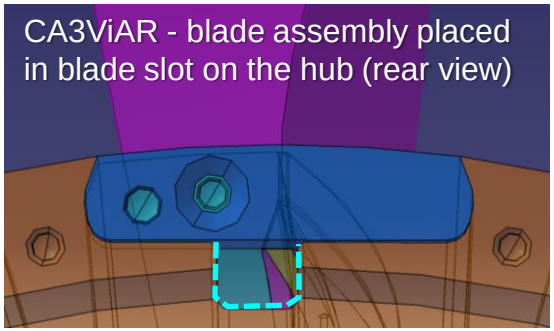


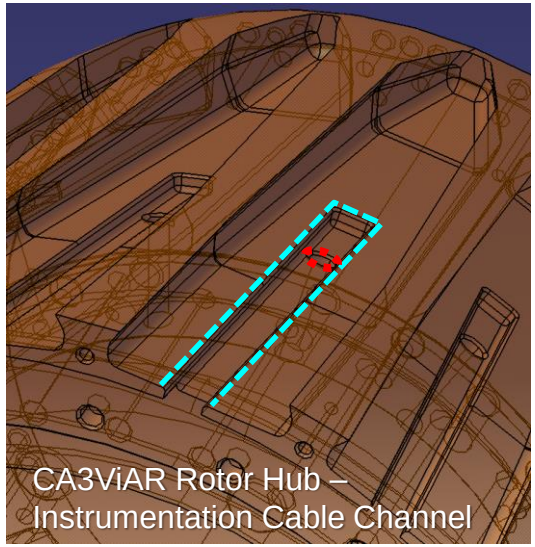
CA3ViAR Dissemination Event #1 - Mechanical Design

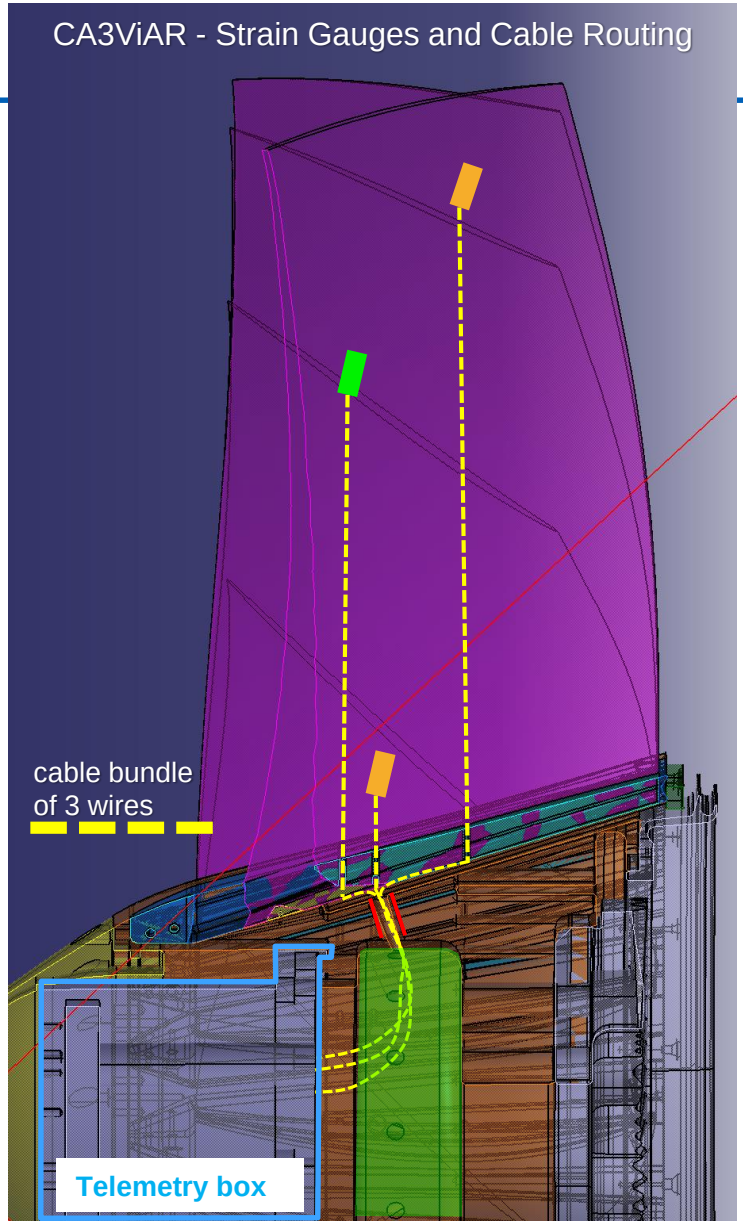
Rotor Blade Instrumentation

Strain Gauges – Cable Routing

- The **cables** are routed straight downward **following the blade shape** until they leave the bottom of the blade foot.
- **Grooves** in the respective positions are foreseen on the inside of the **pressure side foot part** to prevent damage during the assembly of the blade.
- All cables follow a **channel** on the bottom of the blade slot of the hub, enter a Ø5mm **hole** pointing into the **area** inside of the hub, where they are connected to the **telemetry box**.


CA3ViAR - blade assembly placed in blade slot on the hub (rear view)


CA3ViAR Rotor Hub – Instrumentation Cable Channel



CA3ViAR Dissemination Event #1 - Mechanical Design

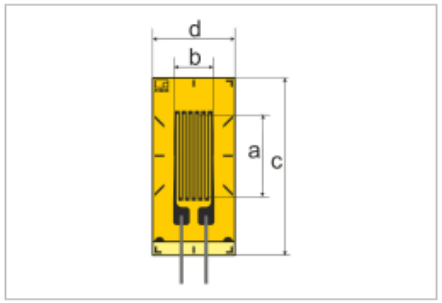
Rotor Blade Instrumentation

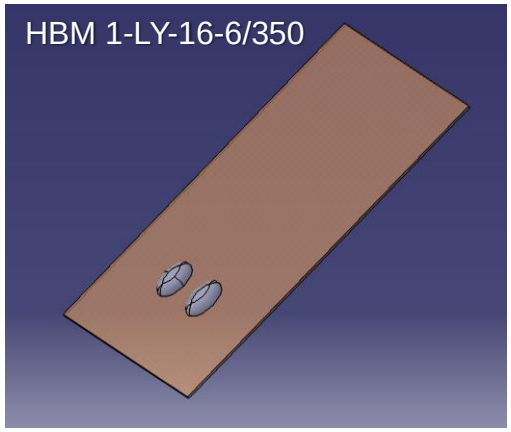
Strain Gauges – Selection

The CAD design for the SG's had to be done manually from the officially available data sheets, since the manufacturer was not able to provide an original CAD model.

1-LY16-6/350 HBM shop Made for Experts

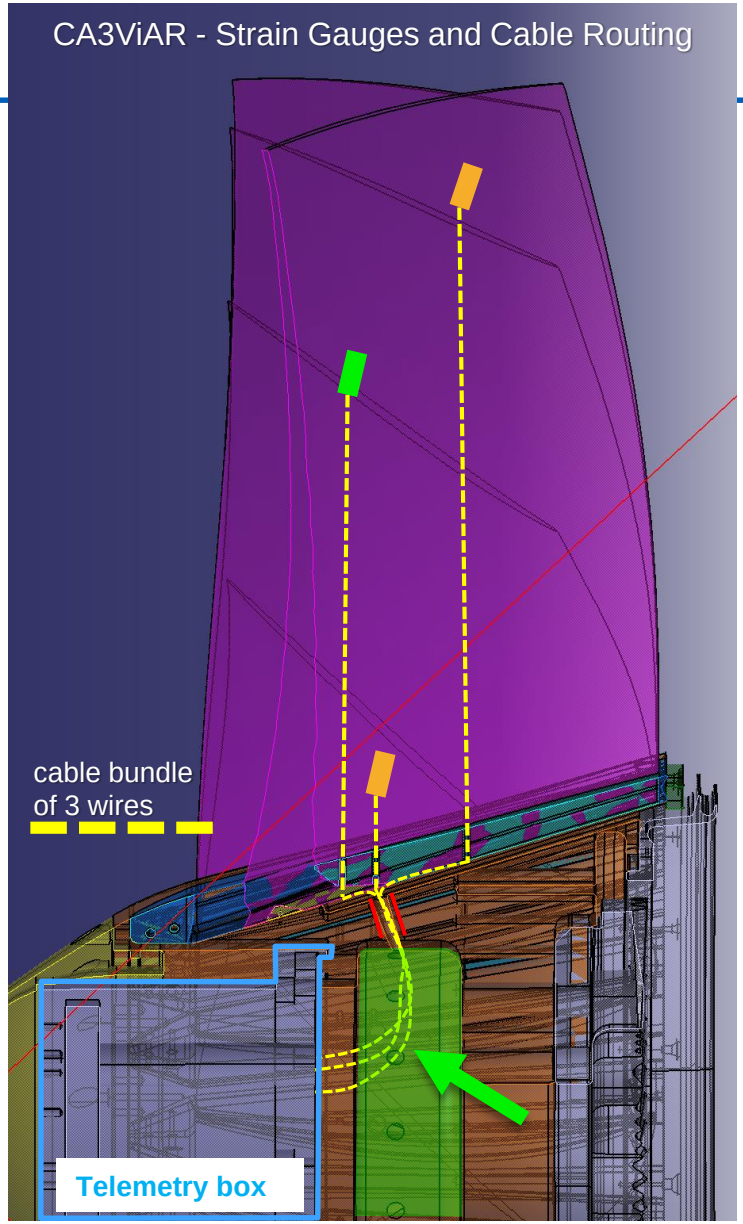
DMS 6/350 LY16





Strain Gauges – Cable Routing through Hub to Telemetry

To retain the SG-cables **within the hub**, leading them from the **hole** in the hub to the **telemetry box**, retaining parts will be used for that purpose which will be mounted in the hub (next chapter).



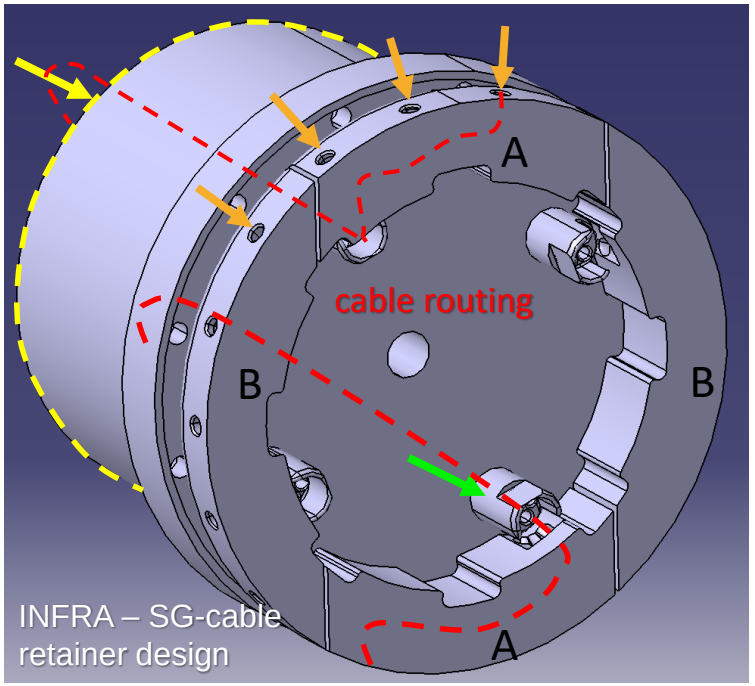
Agenda

Rotor Blade Instrumentation

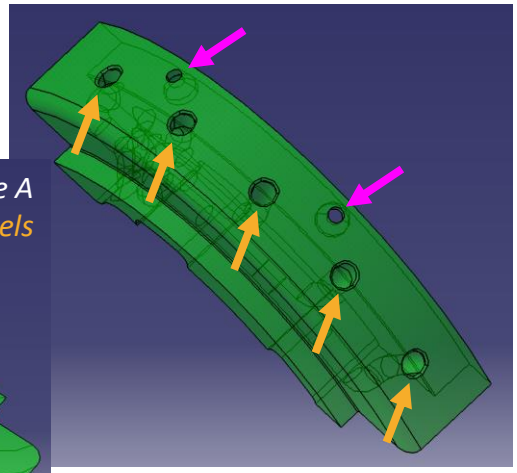
Strain Gauge Cable Retainers

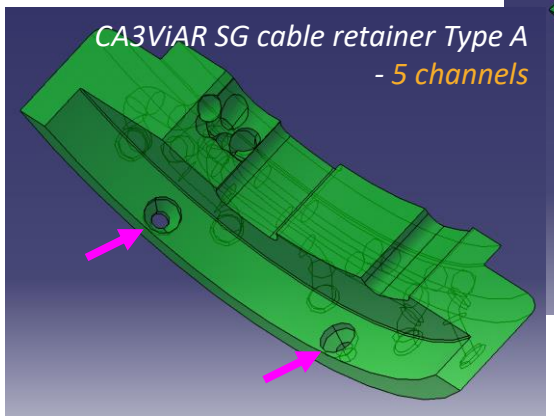
Following the design concept from the INFRA project, 3D printed parts (A & B types), with cable channels inside of it, will be used as retainers, **routing** the cables from the **holes in the hub** to the **cable guiding tubes** that lead the cables through to the front of the **telemetry box**, where the cables will be connected to it.

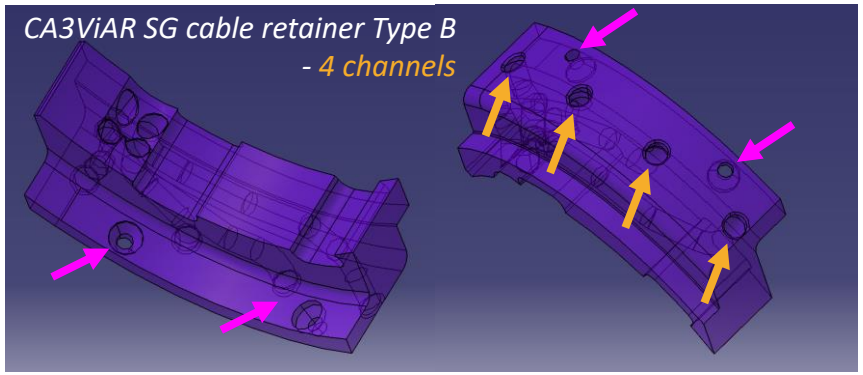
The retaining parts will be fastened with 2 **screws** to the hub in radial direction.



INFRA – SG-cable retainer design



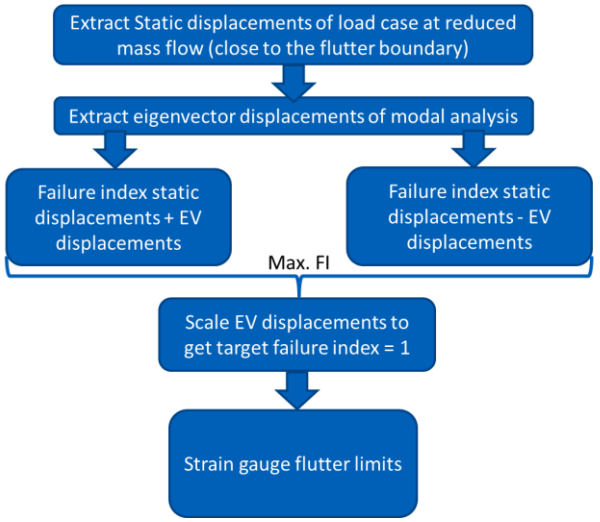




Agenda

Rotor Blade Instrumentation

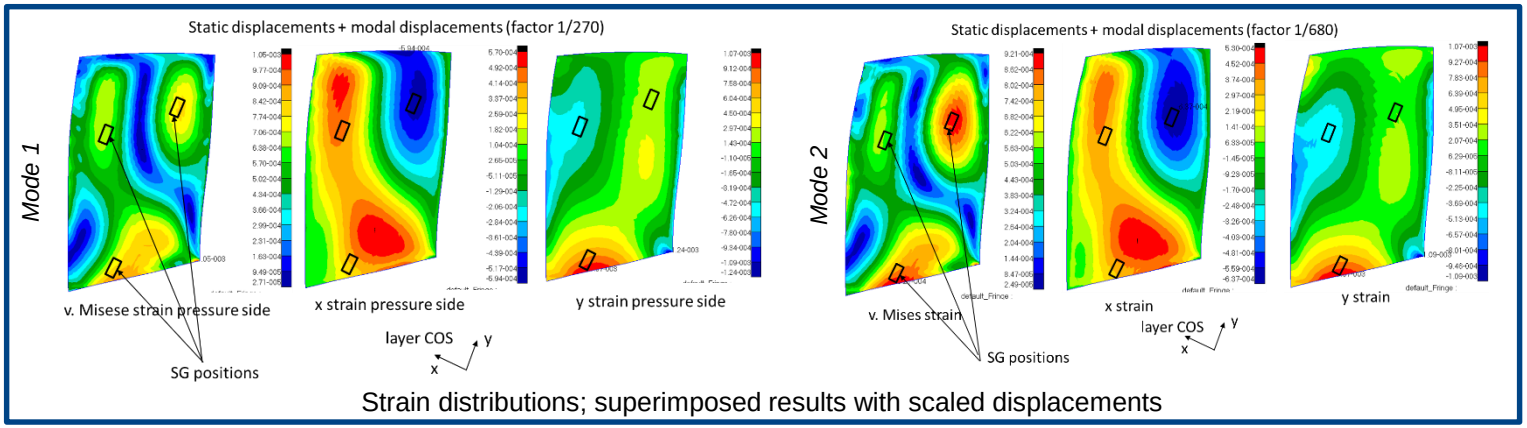
Strain Gauge Measurement Limits for Save WT Operations



The numerical procedure (see diagram):

- Superimposing the displacement of the load condition close to the flutter boundary at max rotational speed with in turn the displacements of mode 1 and 2 scaled to obtain the maximum allowed failure index (equal to 1).
- The SG measurements registered by applying the numerical procedure with mode 1 and 2 are the limit SG measurements in case of flutter, involving in turn one of the two first modes, and ensuring continuous monitoring of blade structural safety

Results for the 2 modes, with the strain distribution in the two cases, and the scale factor applied to the modal shapes to obtain a unitary failure index:



Strain distributions; superimposed results with scaled displacements

Agenda

1. Introduction
2. Mechanical Design
    1. Stator Stage
    2. Rotor Stage
    3. Rotor Blade Instrumentation
    4. Test Rig Adaptation
    5. Advanced Balancing Concept
3. Final Statement

Test Rig Adaptation

Why?:

In hot shape:

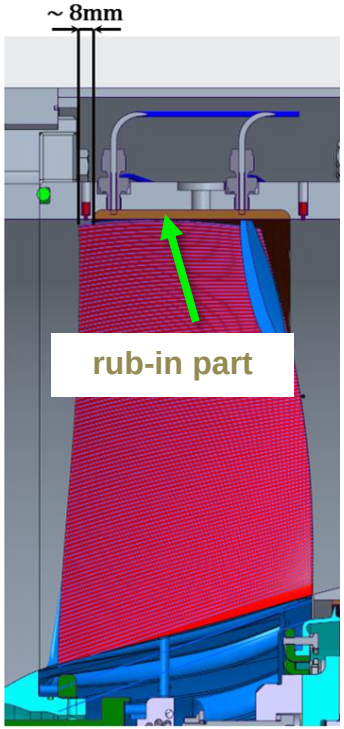
Due to the lean introduced to the CA3ViAR rotor blade design, the **forward upper blade tip is exceeding the limitation of the rub-in part** of the fan case by ~8mm wrt. its original configuration.

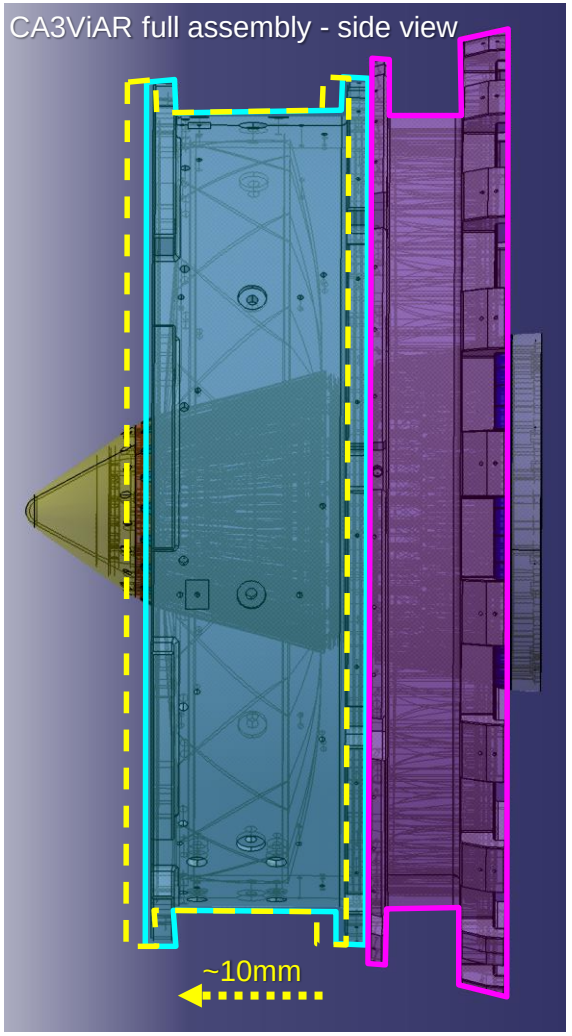
The rub-in part is an integral part of the fan case.

Solution:

A **distance ring** will be implemented **between** the **fan case** and the **stator case**, **positioning** the rub-in part centered wrt. the blade tip chord.

- The original fan case can still be used without modification.



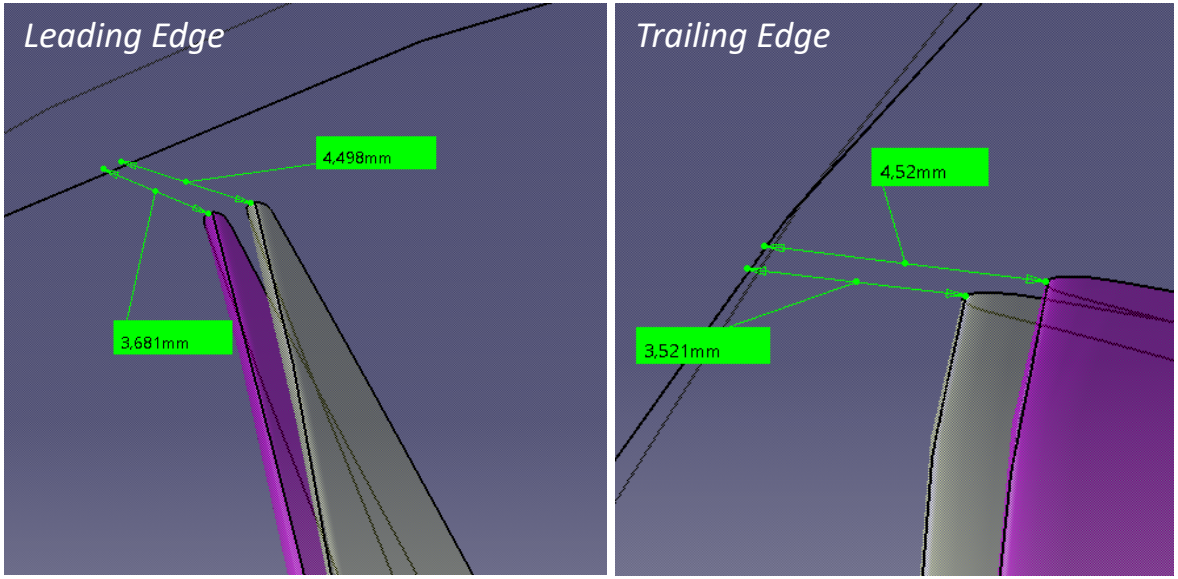


Test Rig Adaptation

Fan Stator Distance Ring

For an optimal centred position of the rub-in part wrt. the blade tip chord, a thickness of 12,5mm for the distance ring was identified.

The distances from the blade LE & TE to the front and rear limit of the Rub-In is shown in the pictures (**cold shape**; **hot shape**).

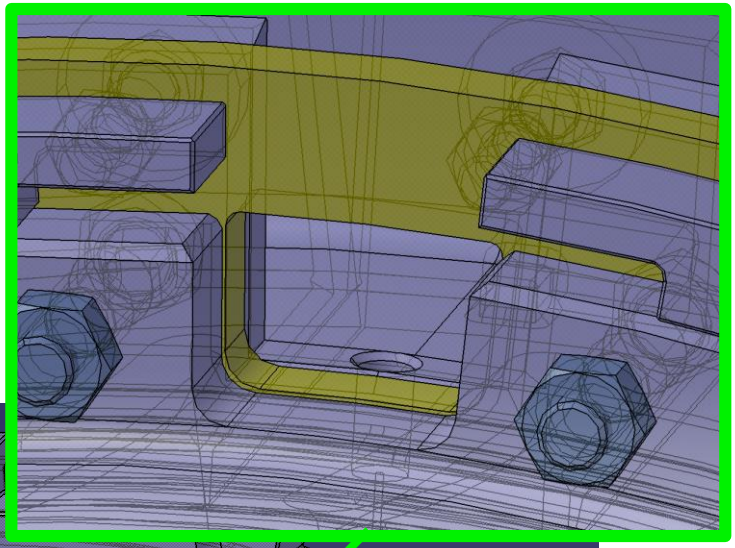


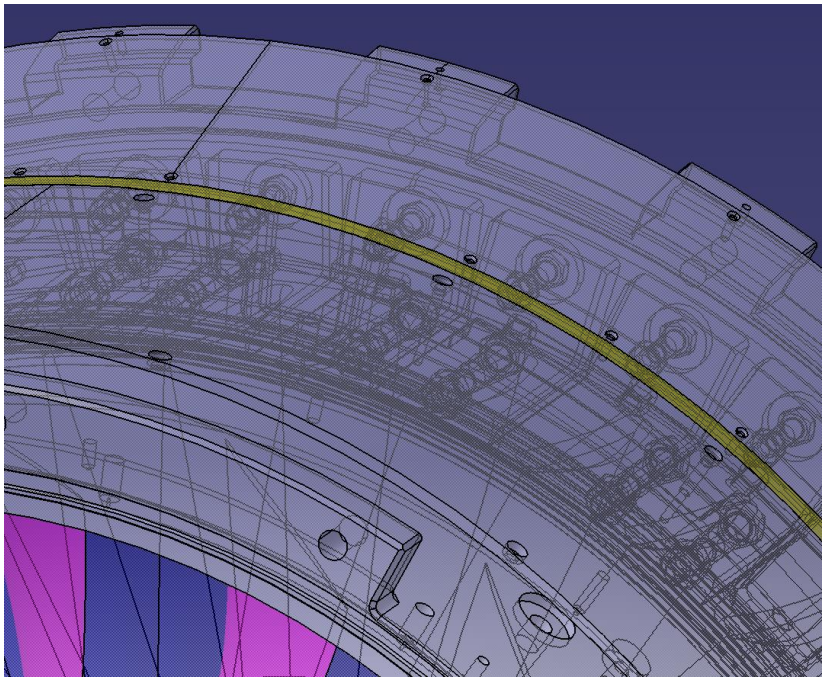
Test Rig Adaptation

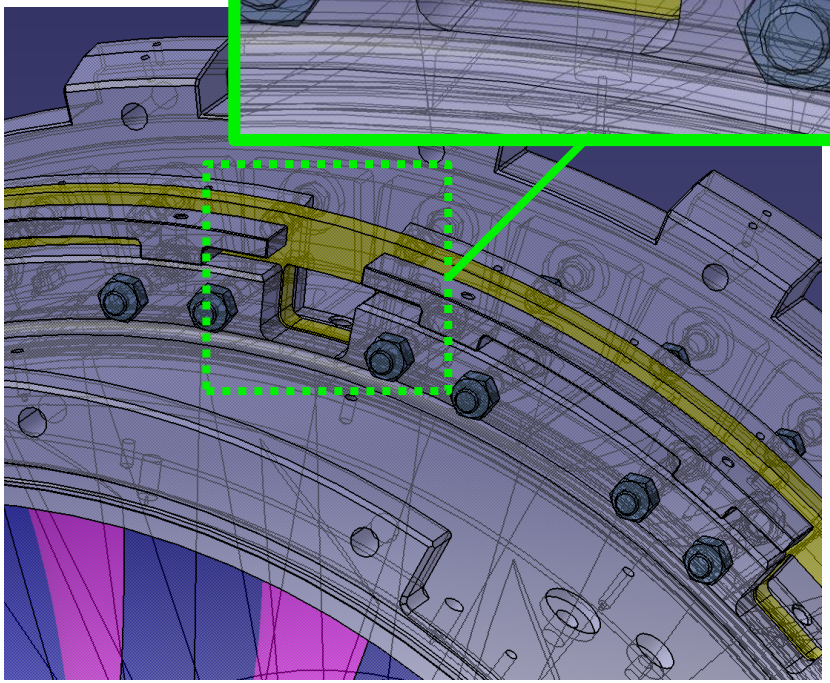
Fan Stator Distance Ring

The thickness of the distance ring was set to 12,5 mm.

The hole patterns on the distance ring fit exactly the patterns on the stator case and fan case.





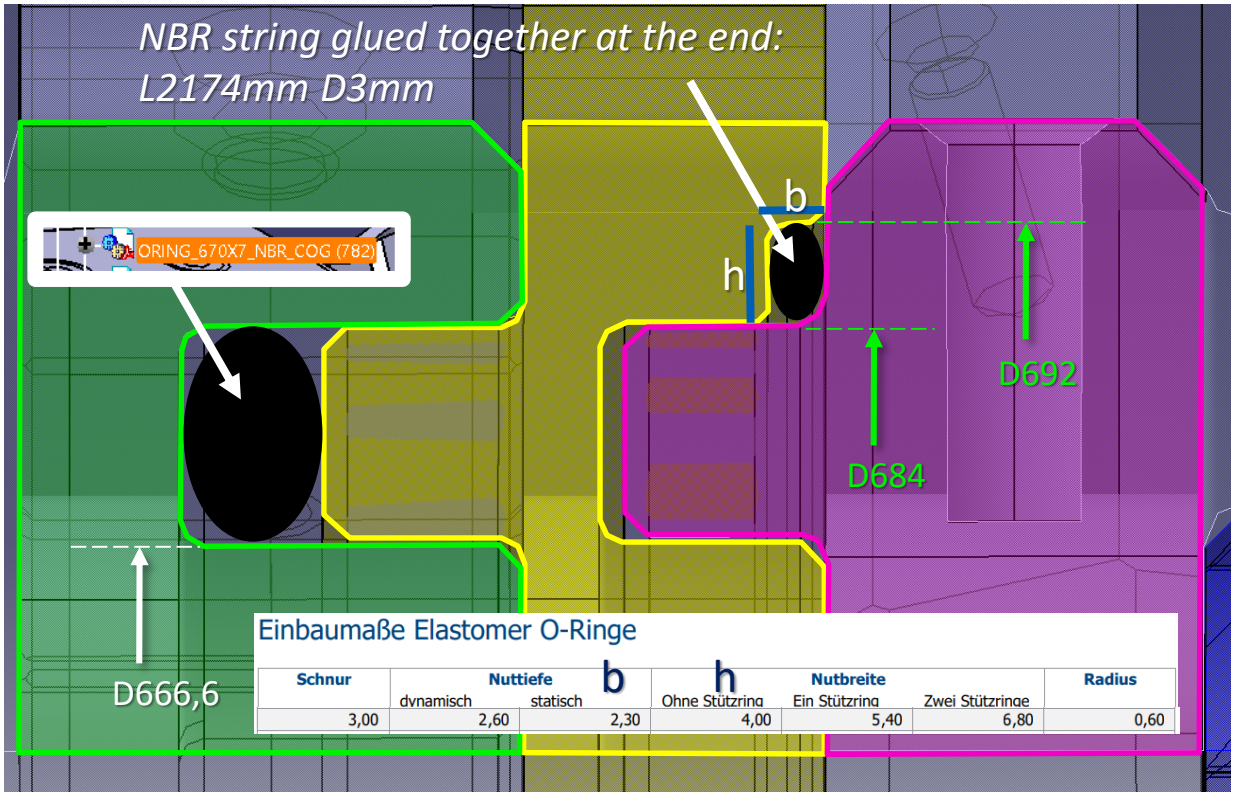


Fan Stator Distance Ring

Revised Sealing Concept

A NBR string with a diameter of 3mm will be cut to a length of 2174mm. The ends will be glued together to form an specific O-ring sealing between the stator case and the distance ring.

The sealing concept between the distance ring and the fan case will be reused from the INFRA rig, using the same OTS O-ring sealing.



arcus
Dichtelemente arcus GmbH

Agenda

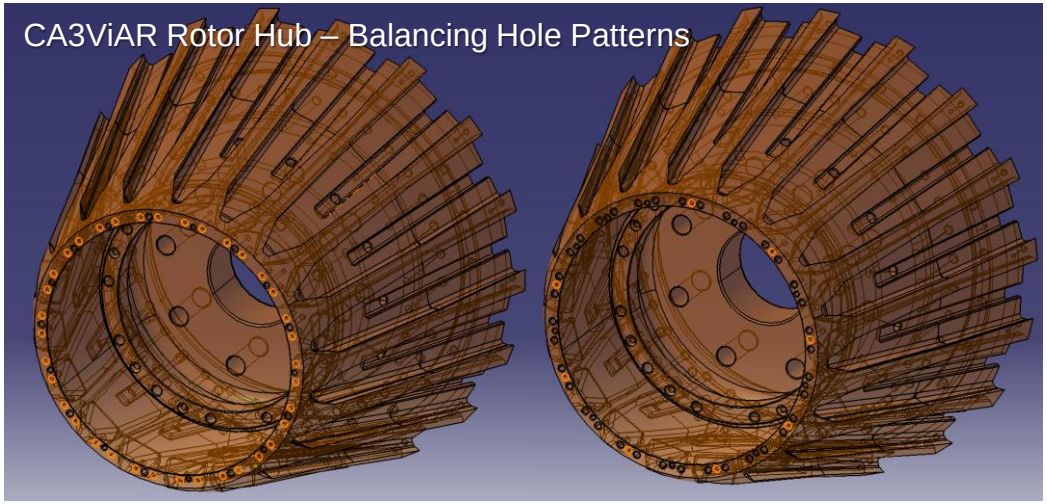
1. Introduction
2. Mechanical Design
    1. Stator Stage
    2. Rotor Stage
    3. Rotor Blade Instrumentation
    4. Test Rig Adaptation
    5. Advanced Balancing Concept
3. Final Statement

CA3ViAR Dissemination Event #1 - Mechanical Design

Advanced Balancing Concept

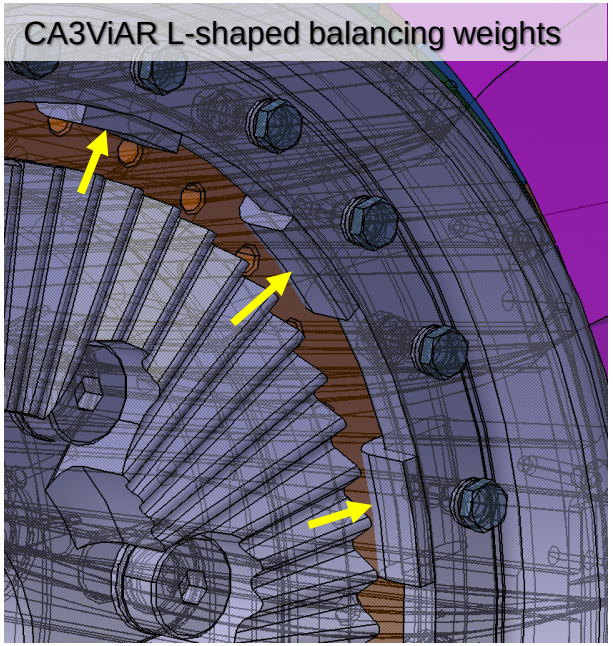
Following the balancing concept from the INFRA project, **L-shaped balancing weights** can be mounted with every second screw that fastens the lamellar gasket ring to the hub.

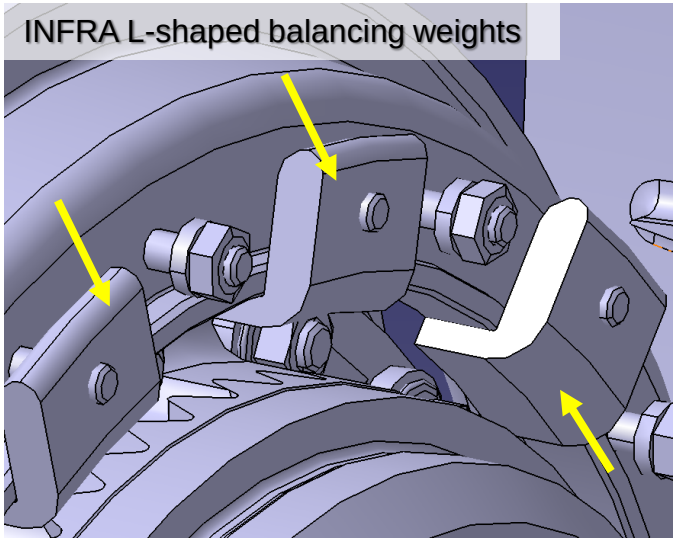
Using these weights, will enable to follow critical points of the known INFRA balancing concept.

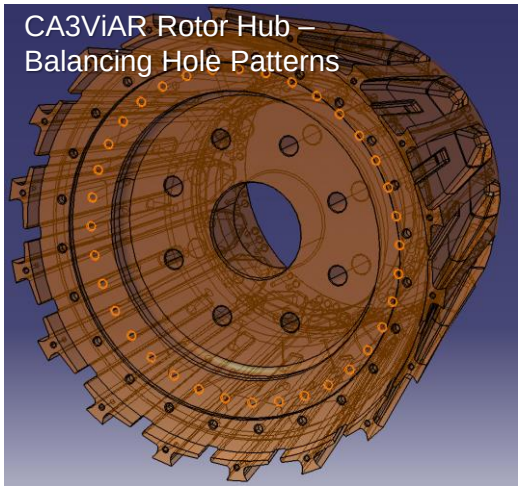


Balancing screws M4x8(max.) (36X)
(***not*** accessible when spinner is mounted)

Balancing screws M4x15 (max.) (8X)
(accessible when spinner is mounted)







Balancing screws M5x40(max.) (36X)
(accessible when spinner is mounted)

Agenda

1. Introduction
2. Mechanical Design
    1. Stator Stage
    2. Rotor Stage
    3. Rotor Blade Instrumentation
    4. Test Rig Adaptation
    5. Advanced Balancing Concept
3. Final Statement

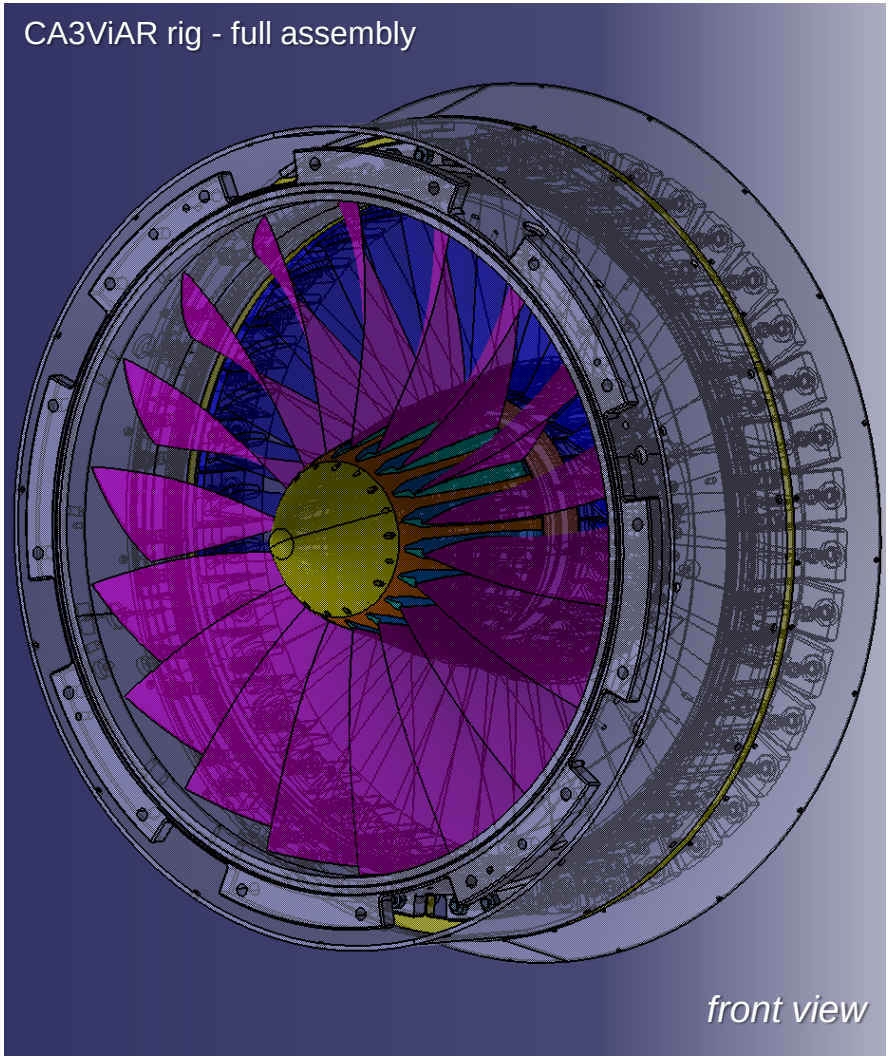
Final Statement

Construction Drawings

All the construction drawings have been released.
Assembly drawings in preparation

Manufacturing

Test article parts are being manufactured



Thank You For Your Attention