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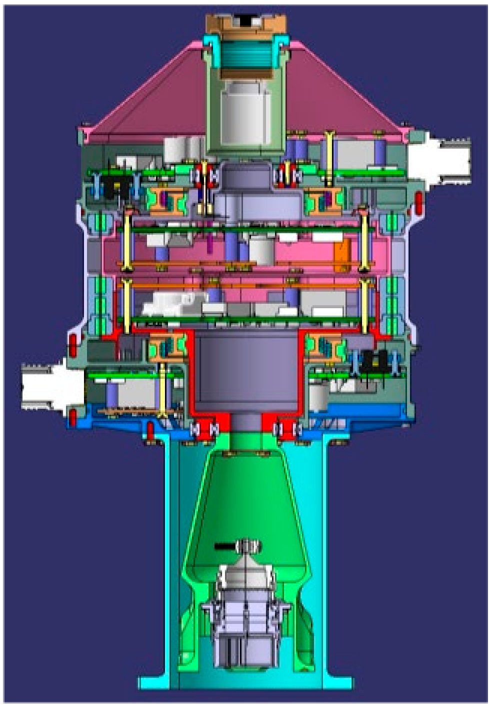
NLR-TP-2022-412 | December 2022

Contactless power and data transfer to and from rotating aircraft parts applied to a tilt rotor aircraft

CUSTOMER: European Commission



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Contactless power and data transfer to and from rotating aircraft parts applied to a tilt rotor aircraft

Problem area

Slip rings are necessary for monitoring of flight-critical electrical equipment in the prop-rotor system. Additionally, during experimental flight activities, slip rings are required to transmit instrumentation data across the rotating to non-rotating systems boundary. The slip ring is required to deliver sufficient power to the rotating system to operate the rotating portion of the slip ring and the electronic control and data management systems in the rotor. A contactless transfer is highly desired for their high bandwidth and reliability capabilities to support flight-critical signals and/or large volumes of experimental data.
The Constance project therefore enables an innovative flight critical contactless rotating power and data transfer unit (CRPDT) for demonstration on the flying Leonardo Next Generation Civil Tiltrotor (NGCTR) - Technology Demonstrator (TD). The project develops the module providing electrical power and a bi-directional data link to components mounted on the prop-rotor.
In order to meet the overall safety objectives the unit includes a dual power and data channel on each rotor including a redundant azimuth sensor. The module performance and interface are tailored to link to the flapping sensor and related flapping sensor controller developed in the Clean Sky 2 FLAPsense project. Additionally an Ethernet data channel for the Flight Test Instrumentation on the proprotor is included in the design.
Constance will enable a safe and highly reliable link to the avionics and the Flight Test Instrumentation on the proprotor.

Description of work

In the project the requirements for the module and the preliminary and detailed design of the module have been developed.

REPORT NUMBER
NLR-TP-2022-412

AUTHOR(S)
C.A.M. Rens
S.M. Bardet
P.R. Faasse
S.B. Scholten
H.W. Jentink
W.J.C.M. van Zutphen

REPORT CLASSIFICATION
UNCLASSIFIED

DATE
December 2022

KNOWLEDGE AREA(S)
Vliegtuigsysteem-ontwikkeling

DESCRIPTOR(S)
Contactless
Data transfer
Power transfer
Tilt rotor aircraft
Rotor

Results and conclusions

A contactless data transfer is highly desirable for their high bandwidth and reliability capabilities to support flight-critical signals and/or large volumes of experimental data.
Transformer technology is applied for the power transfer. The transfer technology is implemented in a small and light module for in-flight application on a tilt rotor aircraft.
Constance will enable a safe and highly reliable link to the avionics and the Flight Test Instrumentation on the prop-rotor of the NGCTR developed by Leonardo..

Applicability

Slip rings for transferring power and data commonly form the interface between a rotating environment and a stationary domain. For aerospace applications, currently only conventional slip rings, with brushes, are on the market. A few commercial wireless slip rings are available, however not designed and certified for aerospace applications. For such a flight-critical application in such harsh environment, a fault-tolerant design has to be taken into account from the start of the development. The innovative patented contactless data transfer is power efficient, high bandwidth, reliable (because no or limited wear) and with low noise through an innovative near-field transmission of electrical waves. The technology does not need the modulation of radio waves applied for far-field transmission.

GENERAL NOTE
This report is based on a presentation held at the 33rd Society of Flight Test Engineers – European Chapter (SFTE-EC) Symposium, Nurnberg, Germany, May 10-12, 2022.

Royal NLR
Anthony Fokkerweg 2
1059 CM Amsterdam, The Netherlands
p) +31 88 511 3113
e) info@nlr.nl i) www.nlr.nl

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CUSTOMER	**European Commission**
CONTRACT NUMBER	**755516**
OWNER	**NLR**
DIVISION NLR	**Aerospace Systems**
DISTRIBUTION	**Unlimited**
CLASSIFICATION OF TITLE	**UNCLASSIFIED**

APPROVED BY:		**Date**
AUTHOR	Carlo Rens	07-12-2022
REVIEWER	Henk Jentink	07-12-2022
MANAGING DEPARTMENT	Carlo Rens	07-12-2022

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CONTACTLESS POWER AND DATA TRANSFER TO AND FROM ROTATING AIRCRAFT PARTS APPLIED TO A TILT ROTOR AIRCRAFT

Carlo Rens, Carlo.Rens@nlr.nl
Michiel Bardet, Michiel.Bardet@nlr.nl
Peter Faasse, Peter.Faasse@nlr.nl
Sigurd Scholten, Sigurd.Scholten@nlr.nl
Henk Jentink, Henk.Jentink@nlr.nl
Pim van Zutphen, Pim.van.Zutphen@nlr.nl

NLR - Royal Netherlands Aerospace Centre
Anthony Fokkerweg 2, 1059 CM Amsterdam, The Netherlands
www.nlr.org

Abstract

Contactless power and data transfer is developed as an alternative to traditional slip rings with electrical connections. The contactless data transfer is power efficient, high bandwidth, reliable (because no or limited wear) and with low noise through an innovative near-field transmission of electrical waves. The technology does not need the modulation of radio waves applied for far-field transmission. Transformer technology is applied for the power transfer. The transfer technology is implemented in a module for in-flight application on a tilt rotor aircraft. A light-weight module is developed for installation in the hub of the proprotors. Additional to the data and power transfer a contactless optical sensor is integrated in the module for angular position measurement.

The development is both for integration in the aircraft avionics, e.g. measuring the flapping angle of the rotor blades and for enabling the transfer of power and data to Flight Test Instrumentation installed in the hub and on the rotor.

The power circuitry is developed in cooperation with DDC limited, partner in the Constance project and will be applied on the Leonardo Next Generation Civil Tiltrotor (NGCTR) - Technology Demonstrator (TD), Leonardo being the topic leader for the project.

Constance will enable a safe and highly reliable link to the avionics and the Flight Test Instrumentation on the rotor.

1 INTRODUCTION

Slip rings for transferring power and data commonly form the interface between a rotating environment and a stationary domain. For aerospace applications, currently only conventional slip rings, with brushes, are on the market. The technique is proven, fairly reliable and robust, but there are clear drawbacks: wear, size and compromised signal integrity due to electrical noise. A few commercial wireless slip rings are now available, however not designed and certified for aerospace applications. Flight-critical applications in harsh environments require a fault-tolerant design, flight test applications require a high reliability of the connection. The independent dual channel architecture and the reliability of the proposed wireless connection will be larger than for traditional slip rings.

On helicopters and tiltrotors slip rings are necessary for monitoring of flight-critical electrical equipment in the rotor system. Additionally, during experimental flight activities, slip rings are required to transmit instrumentation data from the rotating to the non-rotating systems domain. The slip ring is required to deliver sufficient power to the rotating system in order to operate the rotating portion of the slip ring and the electronic control and data management systems in the rotor.

A contactless transfer is highly desirable for their high bandwidth and reliability regarding flight-critical signals and/or large volumes of experimental data. The aim of the Clean Sky 2 Constance project is therefore to enable an innovative flight critical contactless power and data transfer unit, to be developed for demonstration on the flying technology demonstrator; Next Generation Civil Tiltrotor [1], at Technology Readiness Level 7 (system prototype demonstration in operational environment) which provides electrical power and a bi-directional data link to components mounted on the rotor.

2 TEST AIRCRAFT INTEGRATION

2.1 Components location on the aircraft

In the tiltrotor concept the nacelles of the aircraft will be rotated to transfer from helicopter to aircraft mode. Each nacelle houses a rotor system, which controls the pitch of the rotor blades, similar to that of a conventional helicopter. The rotor system is managed by the Flight Control System (FCS) using the measured flapping angle as a critical sensor input. The development of the flapping sensor and related flapping sensor controller are covered in the Clean Sky 2 FLAPsense program [2].

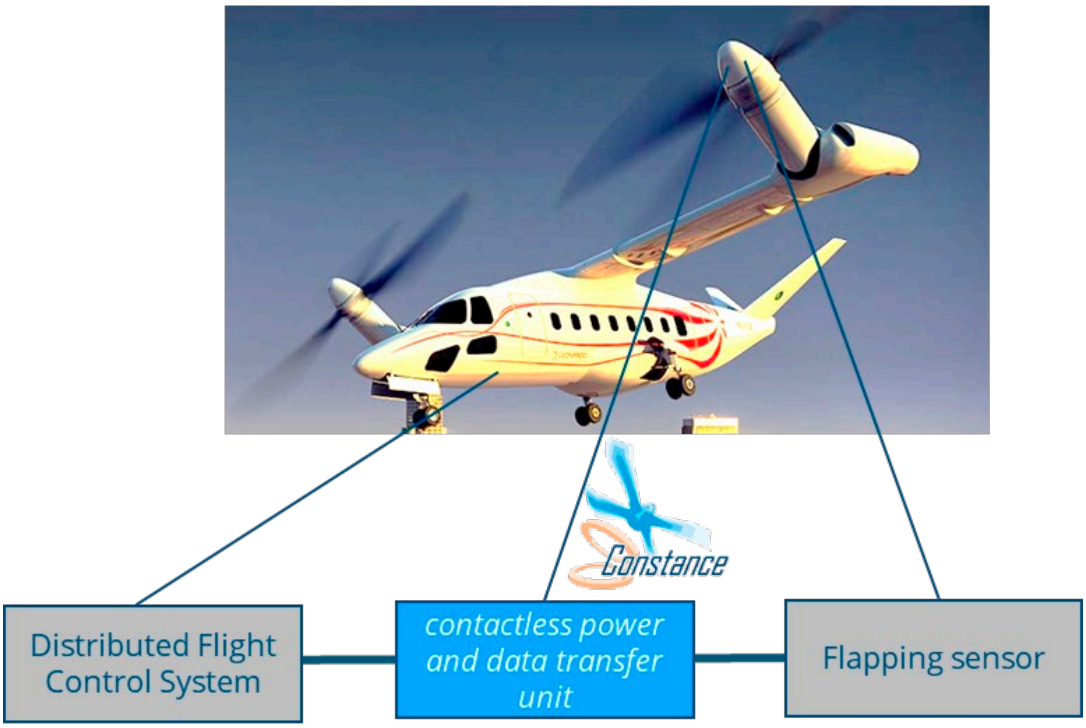


Figure 1 Constance module on Leonardo NGCTR

2.2 Component description

The contactless power and data transfer system Constance on the Next Generation Demonstrator provides the connection between the Flapping sensor system and the FCS on both rotors. Constance will be installed on each collective head, through a dedicated adapter. Environmental and reliability requirements are defined according the conditions of this location. The three main functions of Constance are i) deliver sufficient power to the electronic components on the rotor; ii) provide data transfer between the rotor system and the Flight Control System (FCS) and Flight Test Instrumentation (FTI), and iii) provide the azimuth signal to the flapping sensor controller to synchronize the measured flapping angle with the rotation angle.

The Constance shipset for the NGCTR will consist of two dual Contactless Rotating Power and Data Transfer (CRPDT) subassemblies, one for each collective head. In order to meet the overall safety objectives the dual CRPDT assembly will contain a dual independent power and data ARINC 429 downlink channel on each rotor, including a dual azimuth sensor. Further, one CRPDT unit is capable to provide an additional 100Mbit/s Ethernet communication channel for the Flight Test Instrumentation (FTI) Data Acquisition Station (DAS) and the non-rotating parts of the FTI (bottom channel in Figure 2).

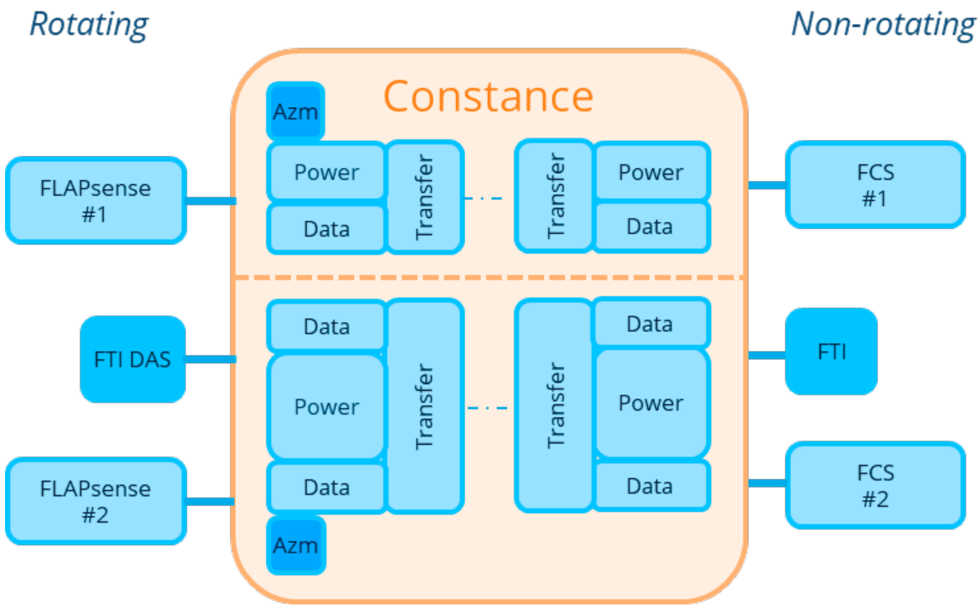


Figure 2 Constance dual CRPDT context diagram

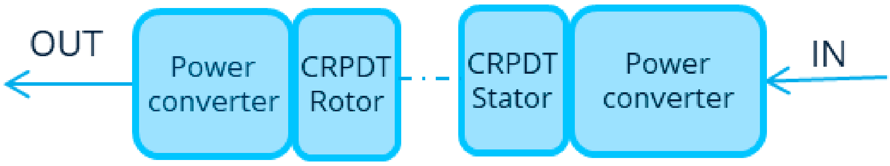
Constance provides a contactless transfer of data and power which can be operated at all rated rotational speeds without any wear or thermo-mechanical stress as opposed to the case when traditional contact (brushed) slip rings are used.

The two single CRPDT subassemblies are composed of identical Printed Circuit Boards (PCBs). Although the functionality of the top channel lacks the Ethernet communication, the PCBs can be exchanged. Furthermore, the dual Constance unit can be installed on the Left Hand or Right Hand side of the aircraft. The interchangeability of LRUs and SRUs contributes also to cost effectiveness. The application of flex PCBs for the connection of the Strip Lines eases installation, eliminates (expensive) connectors, and improves the reliability. Where possible the design incorporates standard parts and components to be cost effective.

3 WIRELESS TECHNOLOGY APPLIED

3.1 Electrical power transfer

The power will be transmitted from the stator to the rotor in a contactless manner. For this purpose, a special transformer design has been developed with a split magnetic core: half of it stationary, the other half rotating. The transformer operation is completely independent of the rotational speed and will also operate normally if the rotor is stationary.



#	IN	OUT	Power	Remark
1	28 V_{DC}	28 V_{DC}	140 W	Flapsense #1
2	28 V_{DC}	28 V_{DC}	224 W	Flapsense #2 & FTI DAS

Figure 3 Electrical power transfer

The power link provides two independent Eurocae ED-14 / RTCA DO160 [3] compliant power channels at 28VDC of 5 and 8 A respectively.

The magnetic core material of the special transformer is organized in a toroidal shape, with both the primary and secondary windings following a tangential path with respect to the axis of rotation. The magnetic core material enables the magnetic field to stay within the transformer (and thus prevent interaction with the other channel). The segmented magnetic core material is mounted such, that it can withstand the centrifugal force of the rotor.

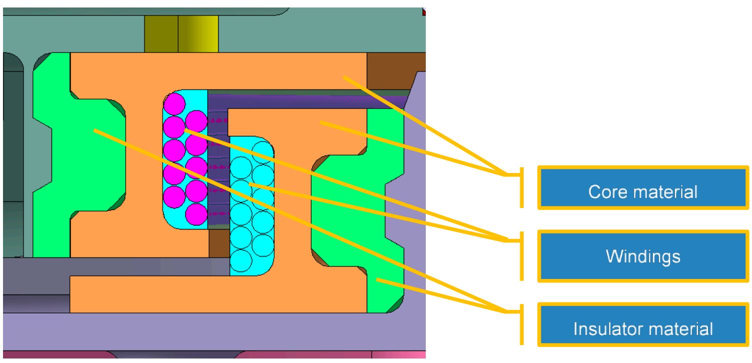
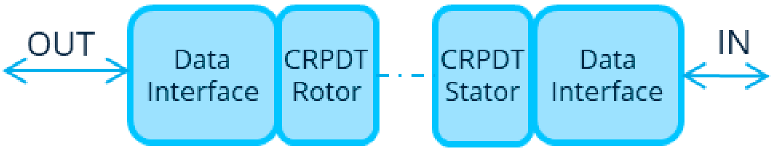


Figure 4 Cross section transformer

In the rotating domain, the windings are powering the Power Rotor Converter. The power output board uses a simple level convertor with a bus driver to generate $28V_{DC}$. The output is ED-4 / DO160 [3] compliant and incorporates safety measures to protect avionics on the rotor hardware for over and undervoltage and for over currents.

3.2 Data transfer

The single CRPDT provides an ARINC 429 communication downlink for transmission from the FLAPsense controller to the FCC. In a dual Constance unit, one side is capable to provide an additional 100 Mbit/s Ethernet communication channel. The transmission of the signals between the rotating and the static domain uses Strip Line antennas.



#	Type	IN	OUT	User
1	ARINC 429	RX	TX	FCS #1
2	ARINC 429	RX	TX	FCS #2
3	Ethernet	100 Base-TX	100 Base-TX	FTI

Figure 5 Data transfer

Contactless data transfer is required mono-directional for the ARINC 429 and bi-directional for the Ethernet communication link. The data transfer towards the rotor is accomplished by driving a circular transmission line on the stator with the desired signal, and placing a second transmission line in close vicinity on the rotor. With the broad sides of these transmission lines facing each other, there is near-field coupling between the two and a signal wave is induced in the rotor transmission line as a result. This coupling constitutes the deterministic, real-time signal transmission. It takes place in base band, not modulated on an RF carrier.

Signal transmission from the rotor to the stator is established in the same manner. Having the up and down link in different compartments reduces the possibility on crosstalk between the lines. Again, a special mechanical construction is required to ensure integrity at high rotational speed.

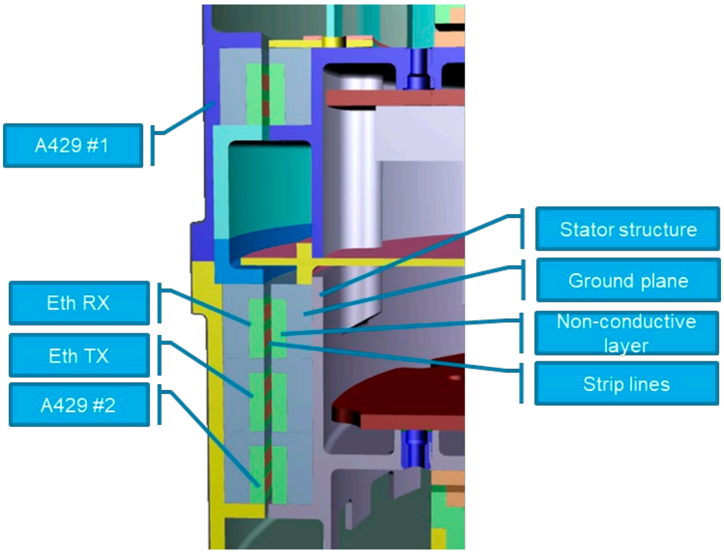
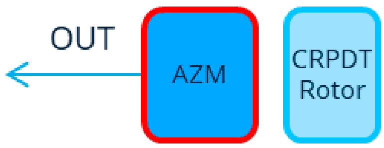


Figure 6 Cross section of the Strip Lines

The rotor data interface contains the ARINC 429 receiver circuitry that converts the ARINC 429 signals into Strip Line signal format. The stator ARINC 429 transmitter interface described here takes care of the inverse conversion of Strip Line signals to ARINC 429 format. The signal converters are all 'simple circuits', meaning no complex hardware or software is required to transfer the data. In a similar way the Ethernet signals are transformed into signals, suitable for the contactless data transfer system. The signal format of the 100 Base-TX Ethernet lines are according MLT-3 encoding (Multi-Level Transmit). Both rotor and stator boards contain an Ethernet interface, which consist of a controlled and protected connection to the Ethernet Switch/Port on the tiltrotor and a bi-directional level convertor to the Strip Lines.

3.3 Angular position sensing

Each CRPDT unit contains an azimuth sensor to synchronize the measured flapping angle with the rotation angle. Through an optical sensor the angular position of the rotating part relative to the stationary part is detected.



#	IN	OUT	Pulse	Remark
1	Excitation	Signal	24p	Flapsense #1
2	Excitation	Signal	24p	Flapsense #2

Figure 7 Angular position sensing

The target of the azimuth sensor will be an integral part of the stator structure. The target consists of 23 teeth and one missing gap. The 23 positions provide an azimuth signal each 15°. The centre of the missing gap provides the 1p starting position

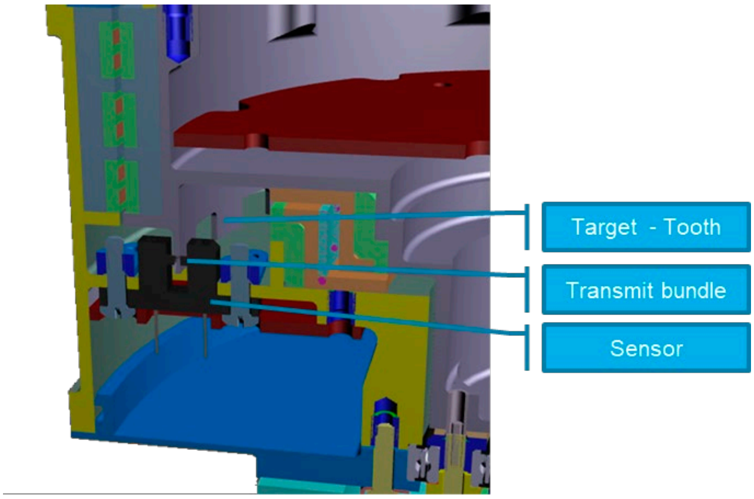


Figure 8 Azimuth transfer

3.4 Mechanical design

In order to meet the overall safety objectives Constance consists of a dual channel, a CRPDT, on each rotor. Both CRPDTs, each containing a power transfer, data transfer and azimuth sensor, have a dedicated compartment, which are segregated through a mechanical barrier.

Constance will be installed on each collective head where mechanical failures are considered catastrophic. Therefore (safety) features are implemented to mitigate the mechanical risks:

- The unit has its own bearings to ensure smooth running and a continuous air-gap.
- Redundant bearing sets, including detectable shear pins. The shear pins will indicate bearing failure.
- Sealed housing to protect against ingress of dirt and moisture.
- A desiccant breather, to prevent overpressure of the housing and prevent ingress of moisture.

4 CONSTANCE MODULE

4.1 Assembly

The design of the Constance unit has been finalised and some details given below.

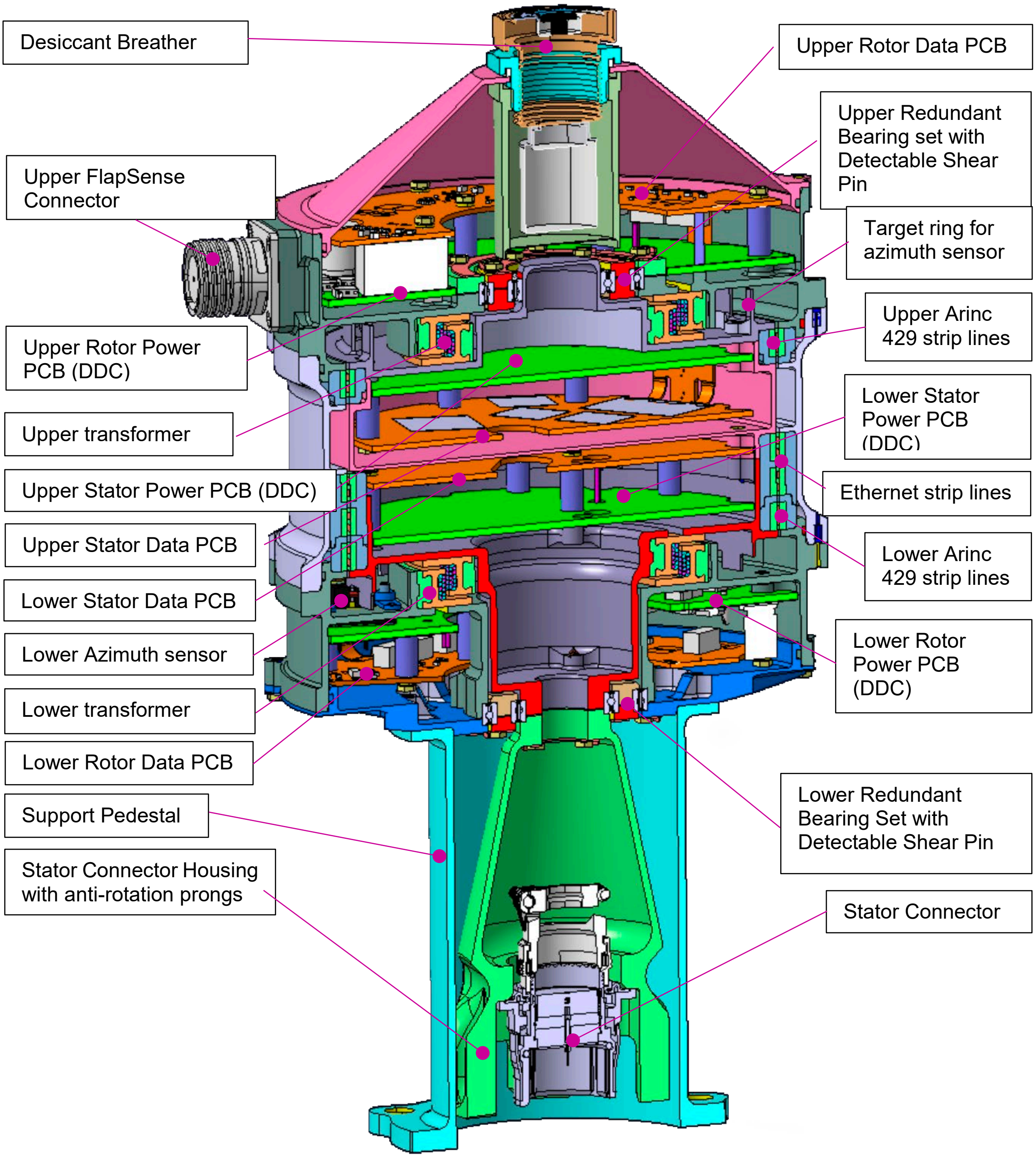


Figure 9 Constance module design

Status of the development of the Constance module is that requirements have been defined and a design for the module complying to requirements has been finalized.

Boards for the electrical parts of the module have been manufactured and tested. A qualification model of the complete module is being manufactured.

In Figure 10 the castellation of the target for the azimuth sensor is clearly visible, as well as the stator ring of the transformer. Next to the stub shaft for the bearings, a shear pin is visible. The shear pin will shear if the primary seizes and the backup bearing takes over. The shearing of the shear pin is detected in a status signal for the module.

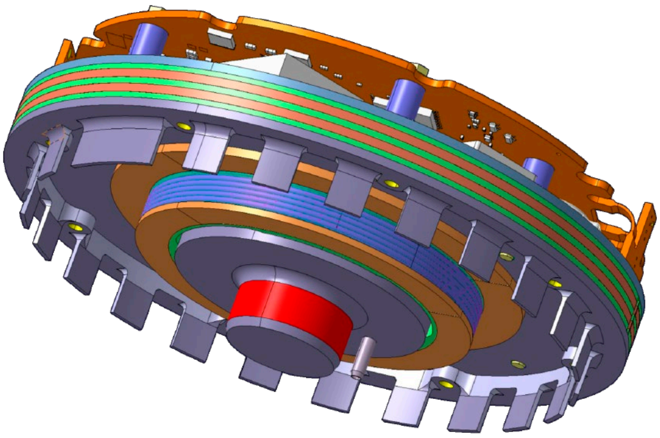


Figure 10 Upper Stator assembly

In Figure 11 the stacked printed circuit boards and the redundant bearings are visible.

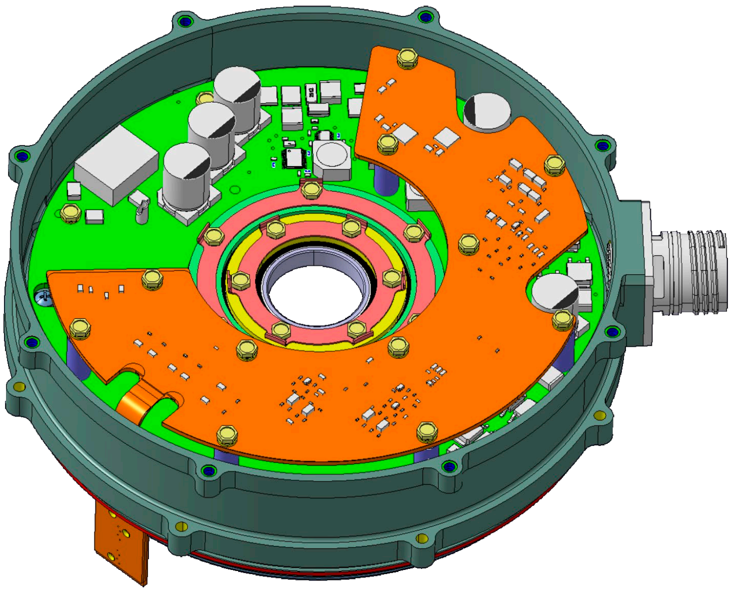


Figure 11 Upper Rotor assembly

4.2 Testing

Rotating testing with the qualification model will be performed on a test bench together with the FLAPsense unit. The test bench simulates the rotor hub to create the require sensor inputs for the Flapping sensor system. Different flapping angles can be set for simulated target surface.

Like in the operational configuration Constance will provide the power and data transfer and the required azimuth input to the controller.

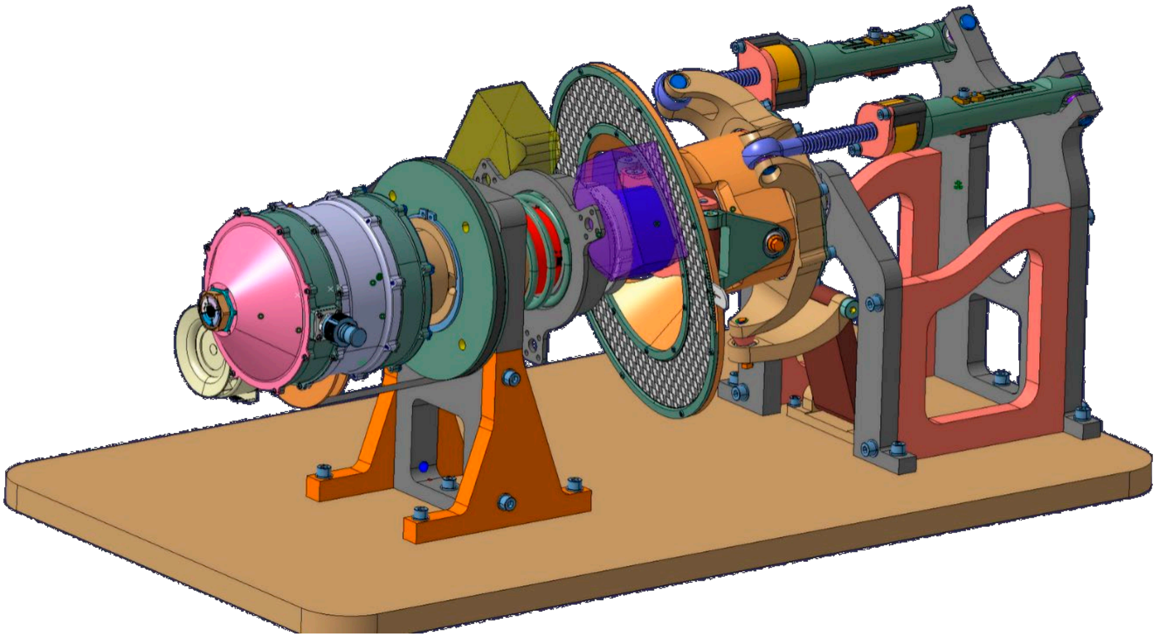


Figure 12 Rotating ground test bench for the Constance module (front) connected with the FLAPsense sensor and a simulated target surface that can be tilted

4.3 End-Product

Constance will enable a safe and highly reliable link to the avionics on the rotor. Key features of Constance are listed in Table 1.

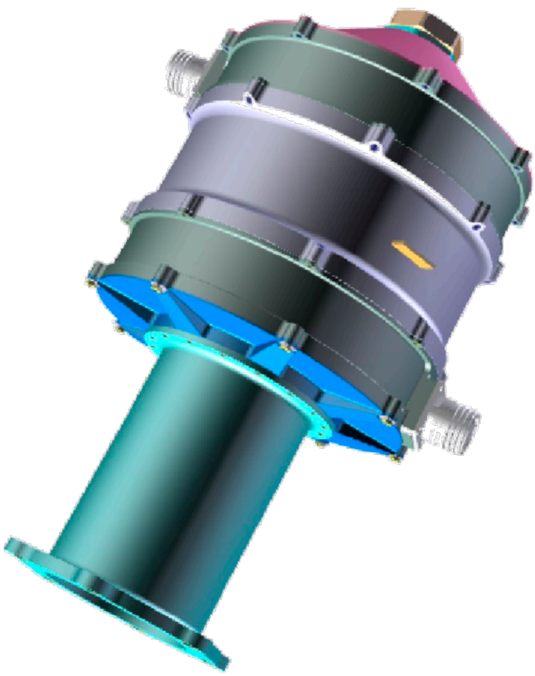


Figure 13 Constance module

Table 1 Constance features

Feature	Figures	
Power transmission	Power channels	2
	Input voltage (stator)	28V_{DC}
	Output voltage (rotor)	28V_{DC}
	Output power	Channel 1: 140W (5A) Channel 2: 225W (8A)
Data transmission	Avionics bus	2 channels
		Rotor: 2x ARINC 429 RX
		Stator: 2x ARINC 429 TX
	FTI bus	1 channel
		100base-T4 Ethernet
Azimuth sensor	Azimuth channels	2
	Target	24p
	1p detection	included
	Sensor type	Optical
	Sensor location	Rotor
Interface	Rotor connection	D38999
	Stator connection	D38999, Blind-mate
	Rotational speed	up to 750 rpm
	Weight	4 kg
	Contactless transfer	
	ED-4 / DO-160 compliant	
Safety	Fault tolerant (dual channel)	
	Simple hardware and no software	
	Safety features to withstand harsh environment on the rotor head • Redundant bearing sets including detectable shear pin • Segregated compartments • Sealed cover	

5 RELATED TECHNOLOGY DEVELOPMENTS

The technology was originally developed for applications in the wind tunnel, including scaled Contra-Rotating Open Rotor (CROR) testing [4]. For this wireless slip ring technology NLR holds a patent [5].

The experience with the wireless contact modules from the wind tunnel testing have been exploited to build the Constance module that has to comply with in-flight requirements.

The technology is currently under development for a new wind tunnel program Clean Sky 2 SA^{2}FIR [6]. For this application the contactless power and data transfer technology is combined with a high-end rotating data acquisition system interfacing over 100 strain gauge and acoustic sensors. The system will be rotated at 16.000 rpm and will have an 1 Gbps Ethernet data interface.

6 CONCLUSIONS

A contactless transfer is highly desirable for their high bandwidth and reliability capabilities to support flight-critical signals and/or large volumes of experimental data.

Constance will enable a safe and highly reliable link to the avionics and the Flight Test Instrumentation on the prop-rotor of the NGCTR developed by Leonardo.

7 REFERENCES

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[2] F. Boden, J. Lange, F. Philipp, H.W. Jentink, R. Ponza, L. Broome, S. Day, “Development of a contactless measurement system for real time monitoring of a proprotors flapping angle – Part one.” ETTC 2021– European Test & Telemetry Conference, online, 15 – 16 June 2021

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[5] Contactless Power and Data Transfer patent numbers:
EU : EP2875512, US : 9,812,255, Canada : 2,879,466

[6] Clean Sky 2 Large Passenger Aircraft Platform 1 SA2FIR (Simulation of Aerodynamic and Acoustic Fan Integration) test rig D13 demonstrator (SA^{2}FIR). https://www.clean-aviation.eu/clean-sky-2/key-demonstrators/uhbr-short-range-integration

8 ACKNOWLEDGEMENTS

This project has received funding from the Clean Sky 2 Joint Undertaking under the European Union’s Horizon 2020 research and innovation programme under grant agreement No 755516.

This work has been performed in cooperation with DDC limited, partner in the Constance project and Leonardo, the topic leader for the project.

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For more information visit: **www.nlr.org**

Postal address
PO Box 90502
1006 BM Amsterdam, The Netherlands
e) info@nlr.nl i) www.nlr.org

Royal NLR
Anthony Fokkerweg 2
1059 CM Amsterdam, The Netherlands
p) +31 88 511 3113

Voorsterweg 31
8316 PR Marknesse, The Netherlands
p) +31 88 511 4444