Propulsion Integration Future Challenges. The Role of Wind Tunnel Testing.

National Wind Tunnel Facility Conference.

2 – 3 April 2025

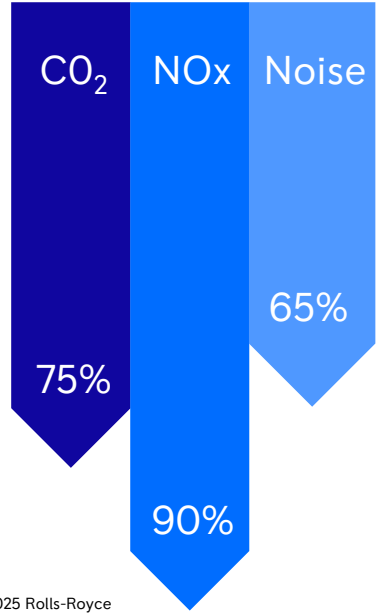
Chris Sheaf. Senior Specialist Installations Aerodynamics.

Co-funded by the European Union

Rolls-Royce UltraFan®

The challenge

ACARE Flightpath 2050 targets

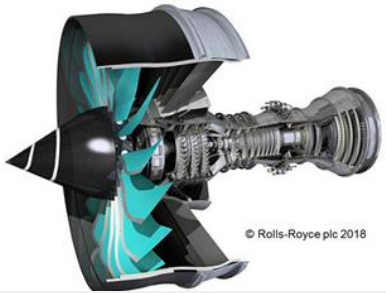


A Disruptive, Sustainable, Scalable Gas Turbine for the 2030s

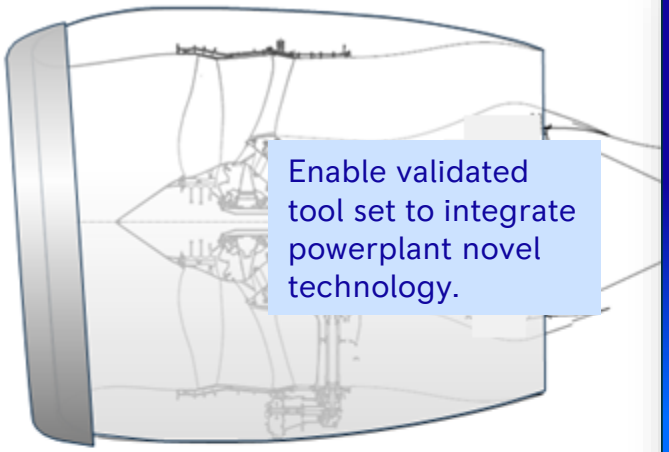
UltraFan Demonstrator. Test Bed 80

Rolls-Royce Powerplant Integration Technology

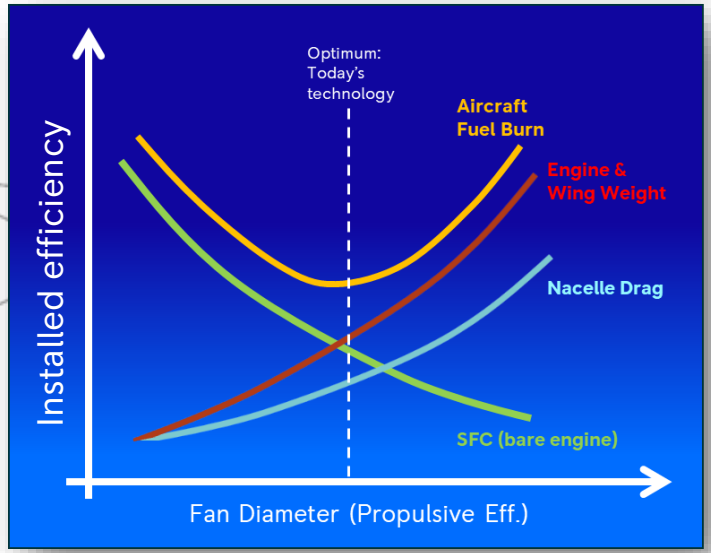
From Engine



To Installed Powerplant



Enable validated tool set to integrate powerplant novel technology.



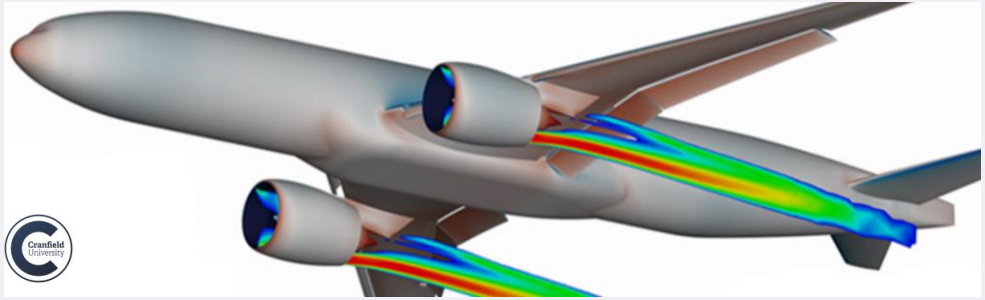
Ability to engineer low drag nacelle enabler low specific thrust cycle - enhancing sfc

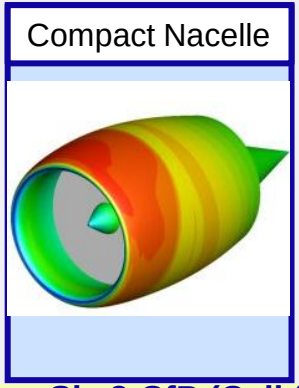
Validated Methods and Technology to work in shared new design space.

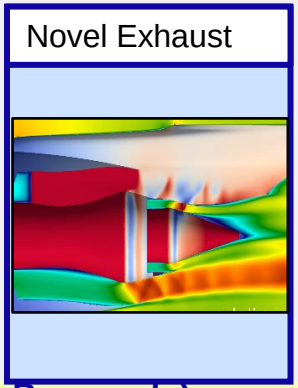
UltraFan® Powerplant Integration - Advancing Technology

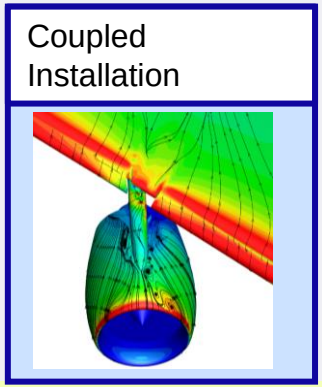
Understand New Powerplant Design Space

- Application of Advanced Design Tools to understand new ‘design space’
- Compact powerplant/nacelle necessary maximise fuel burn
- Airframe Interaction understanding – design point and off design.
- Installed performance – build understanding









Test Validation – Clean Sky2 CfP (Call for Proposals)

- Complex ‘flow physics’ needed to be understood.
- Acquisition of high-fidelity test data for methods validation.
- Open source geometry - NASA CRM aircraft, AIAA DFSRN nozzle, and NASA TRU used as baseline for models.
- Enabling publication and sharing of results.

Advancing Knowledge for UHBR Powerplant Integration

Clean Sky 2 LPA Platform 1

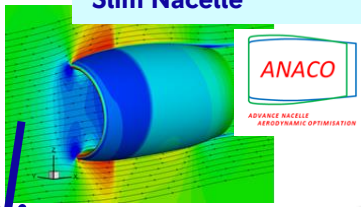
Developing UHBR Powerplant Understanding

Themes for each Project

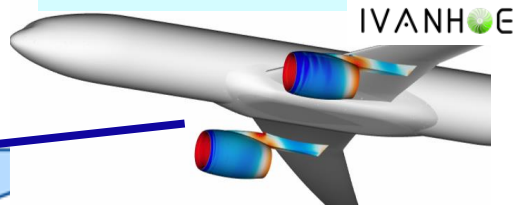
- Apply latest Numeric Design Tools
- New Highly Instrumented Test Rigs
- Investigate complex Aerodynamic Interactions
- Validate Methods post test.
- Basis for future technology development.

CfP ODIN Slim Nacelle off design windmill + jet flap noise

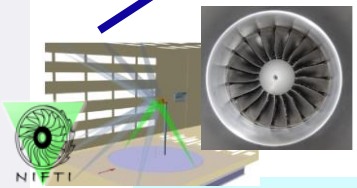
CfP07 ANACO – Short Slim Nacelle



CfP09 IVANHOE – High Speed 3-D Installed Nacelles



Advanced Powerplant design Validation



CfP09 NIFTI – PIV for intake fan rigs

CfP08 TRUflow – TRU integration methods

CfP03 AvAUNT – Jet Rig with wing- installed nozzle

Co-funded by the European Union

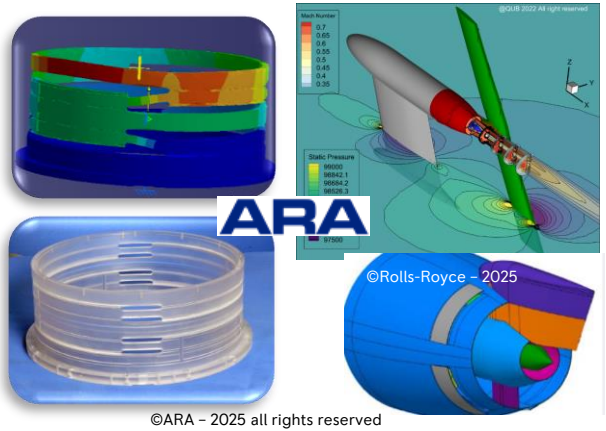
Rig validation of Advanced Adaptive Nozzles (AAN)

AvAUNT
AdaptiVe Area nozzle for Ultra-high bypass Nacelle Technology

CfP03 AvAUNT

- New rig capability: Independent dual stream jet propulsion rig for testing at ARA's Transonic Wind Tunnel
- Provide understanding of wing interaction effects.
- Rig validation data for Advanced Adaptive Nozzle (AAN) concepts
- AAN CFD simulation best practices
- AAN Thrust-Drag bookkeeping methodologies

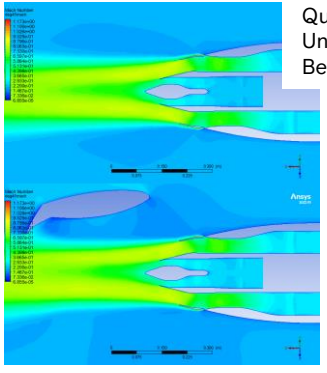
Advanced Digital Design + CFD



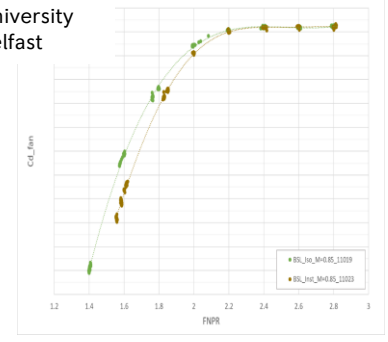
New Test Rig

Highly instrumented, high quality test & data

Post test analysis & understanding of new designs



Queens University Belfast



Co-funded by the European Union

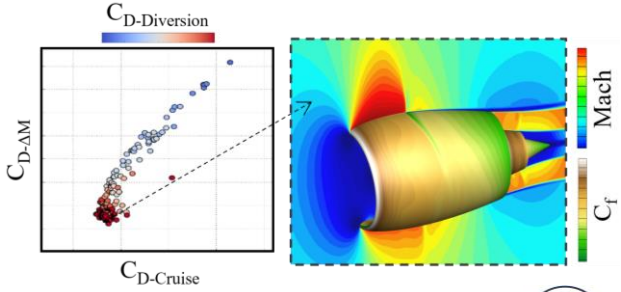
Advanced Slim Low Drag Nacelle Design and Validation Test

ANACO
ADVANCE NACELLE AERODYNAMIC OPTIMISATION

CfP07 ANACO

- Design Low Drag Nacelles M=0.80 and 0.85
- Optimisation methods for nacelle aerodynamic design
- Wind Tunnel Verification tests
- Apply high fidelity measurement
- Establish design rules

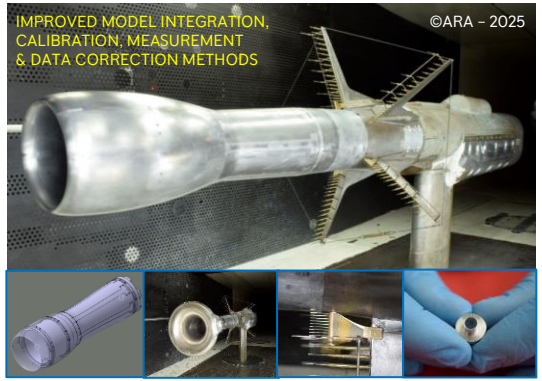
Advanced digital Design + CFD



- Multi-point, multi-objective design optimisation

Cranfield University

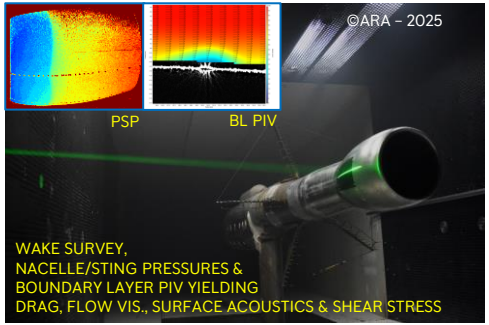
New Test Rig



ARA

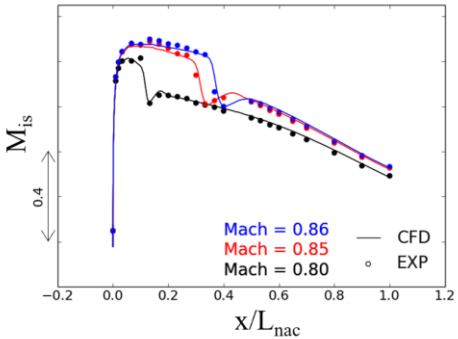
Test, high quality data, highly instrumented

ARA



Post Test analysis, new design rules and understanding

Cranfield University



Long-range cruise drag reduction ~9%

Excellent agreement between CFD and experiments

PSP – Pressure Sensitive Paint
PIV – Particle Image Velocimetry
BL- Boundary Layer

Co-funded by the European Union

▪ Thrust Reverser High fidelity Measurement –Feasibility

Co-funded by the European Union

Images ©TRUflow consortia

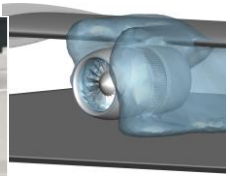
ARA

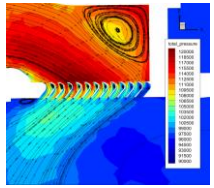
The University of Manchester

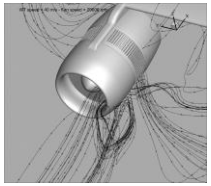
RUAG

CfP08. TRUflow

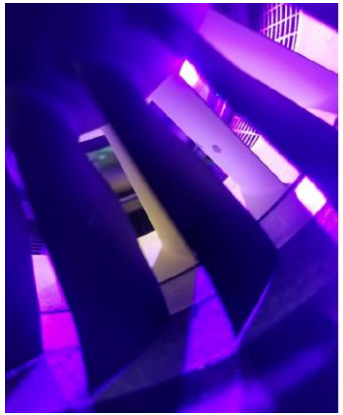
- Rig test validation for close coupled TRU. High fidelity TRU flow measurements.
- ▪ New test rig capability.
- ▪ Application of high fidelity measurement of internal and external flow, with powered fan.
- ▪ Develop TRU new CFD modelling for rapid analysis.

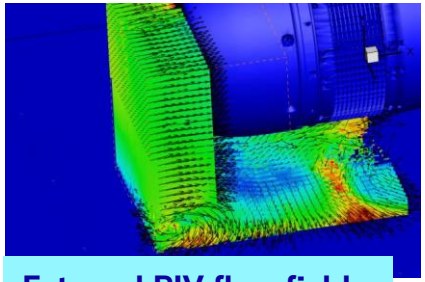






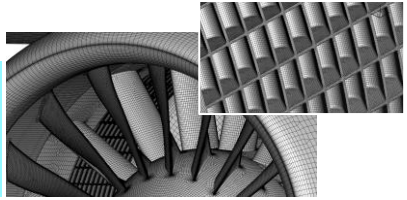
Highly instrumented powered model test. NASA 'open source' TRU design

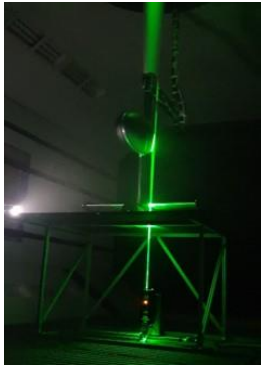


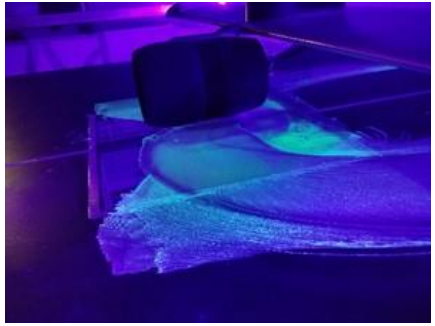


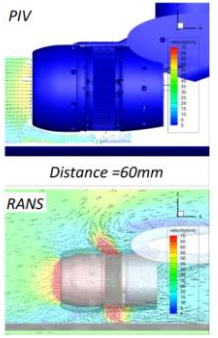
External PIV flow field in Reverse

PSP measurement on LP system. Internal PIV with Fan









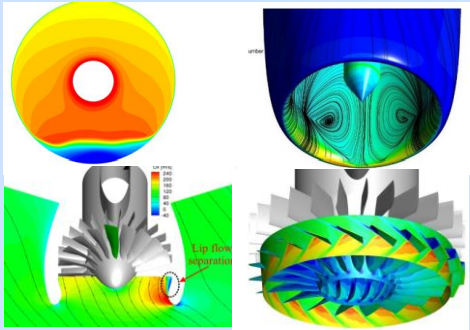
PSP – Pressure Sensitive Paint
PIV – Particle Image Velocimetry

▪ Coupled Intake/Fan PIV for Rig Test in large tunnels

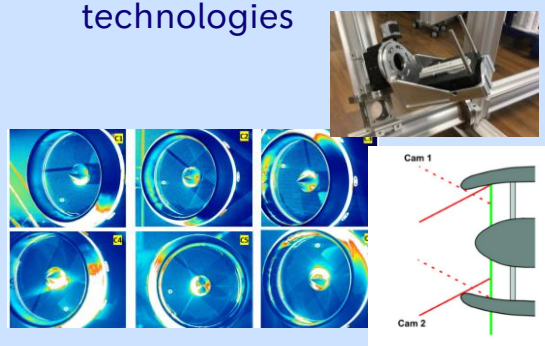
CfP09 NIFTI

- TRL6 non intrusive PIV measurement capability for Fan/Intake rigs
- Industrialise high productivity PIV for Fan rigs in large wind tunnels.
- Productionise post processing of fan compatibility metrics

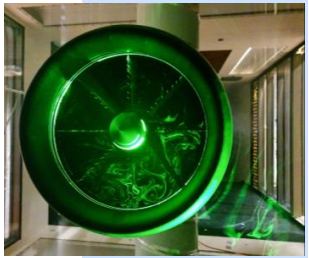
Advanced digital Design + CFD

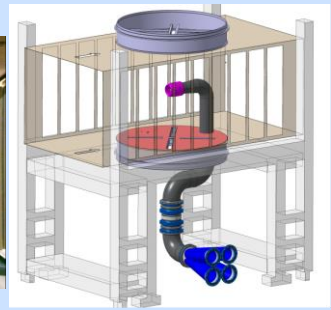


New measurement technologies

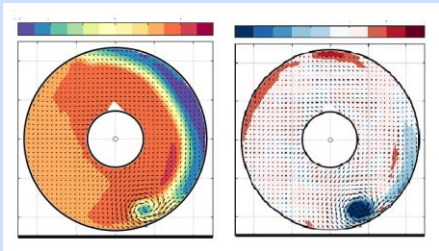


Test, high quality data, highly instrumented





Post Test analysis new design rules and understanding



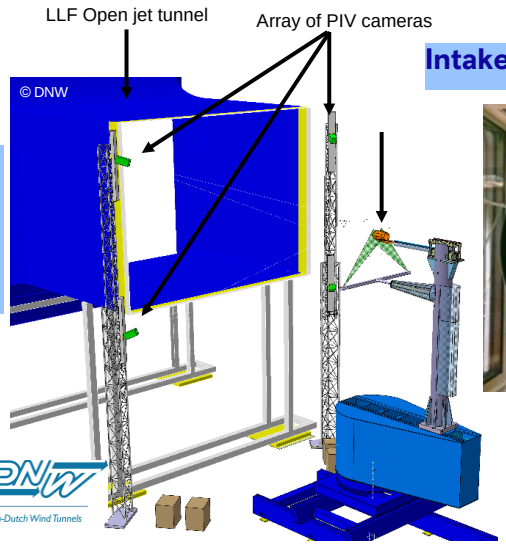
Co-funded by the European Union

▪ Non-Intrusive Flow distortion measurements in a Turbofan Intake - NIFTI

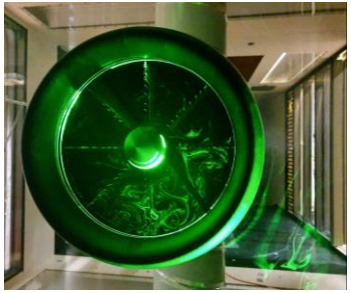
Enabling full annulus SPIV of a coupled intake and Fan in an Industrial Wind Tunnel

Key Achievement

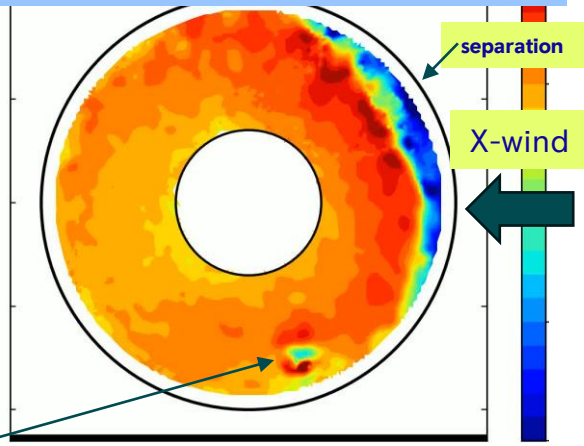
- **NIFTI Programme achieved measurement and data processing of full annulus PIV with a rotating fan**



Intake test with rake system



Measured data full annulus 15Hz image



Ground vortex

Intake and TPS powered fan

PIV significantly enhances knowledge of flow field and interactions.

- CRM intake with DLR 10.2” fan diameter.
- 6-camera S-PIV.
- 1,000 snapshots / 15 Hz in velocity.
- ~18,000 vectors across plane.

This work is being carried out under NIFTI project. NIFTI has received funding from the Clean Sky 2 Joint Undertaking (JU).

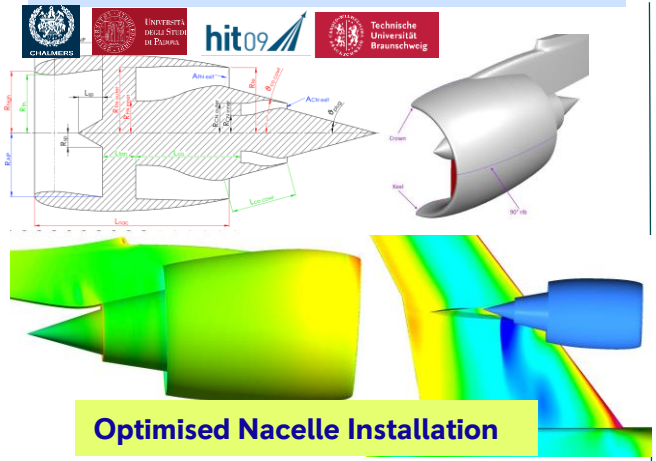
Close Coupled Installed Powered Nacelles

IVANHOE

CfP09 IVANHOE

- Develop / validate understanding of close coupled nacelles
- Validation data for 3-D installed tool
- Understanding of UHBR nacelle cruise & high lift integration
- CRM Aircraft Model.
- New UHBR TPS simulator

Advanced digital Design + CFD

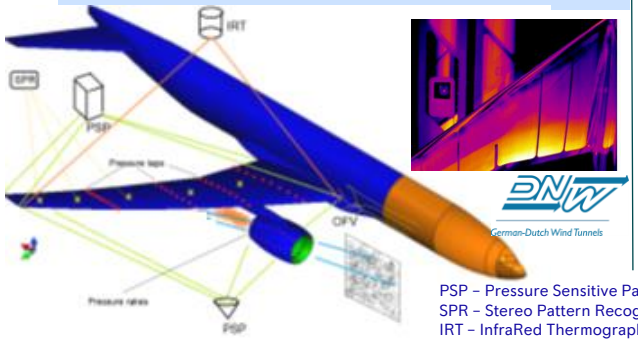


Optimised Nacelle Installation

Model in Rig DNW Transonic Tunnel

½ CRM Aircraft Model and Powered UHBR nacelle

Highly Instrumented Model

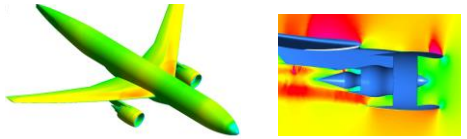


PSP – Pressure Sensitive Paint
SPR – Stereo Pattern Recognition
IRT – InfraRed Thermography
BL – boundary layer

Wing & nacelle pressures, Kulites, BL transition

New design understanding UHBR Installation

SPR Structural Deflection under aero loads



CFD analysis of 'true shape' enabled

Co-funded by the European Union

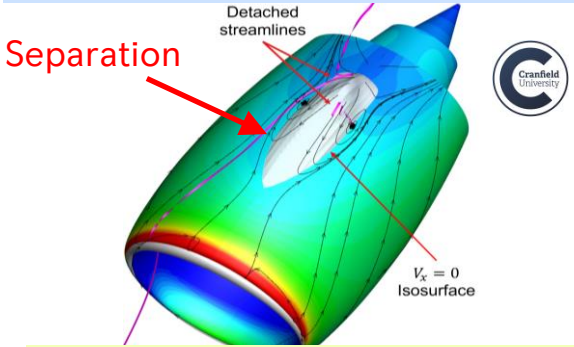
ODIN Off Design Installed Nacelle

CfP11 ODIN

- Nacelle optimisation including off design conditions
- Nacelle section rig
- Build CFD understanding of installed nacelles under high lift conditions

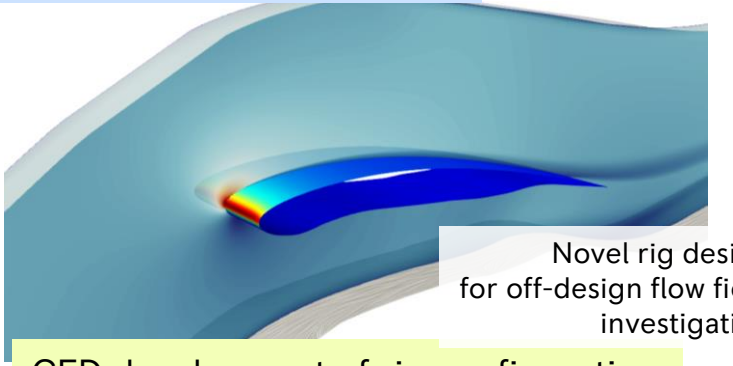
PSP – Pressure Sensitive Paint
LDA - Laser Doppler Anemometry

Advanced digital Design and CFD



Robust isolated nacelle design

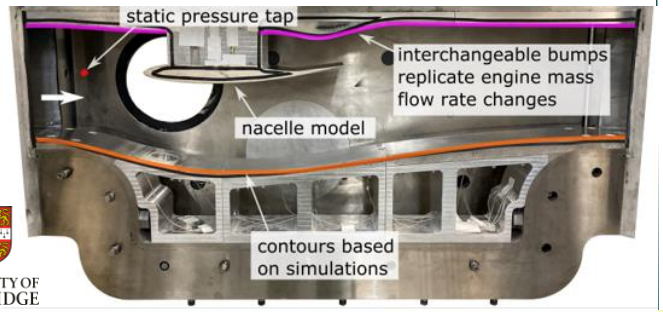
New Test Rig Design



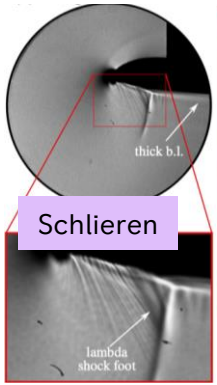
Novel rig design for off-design flow field investigation

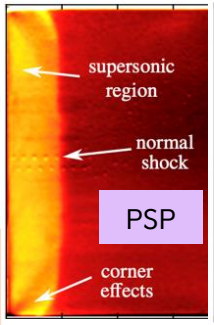
CFD development of rig configuration

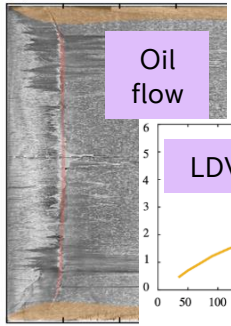
Test, highly instrumented novel rig

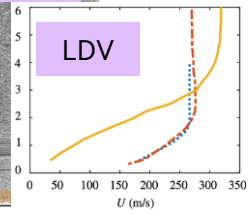


High Fidelity Flow Measurements Complex flows









UNIVERSITY OF CAMBRIDGE

Conventional instrumentation, high-speed Schlieren, PSP, infra-red camera

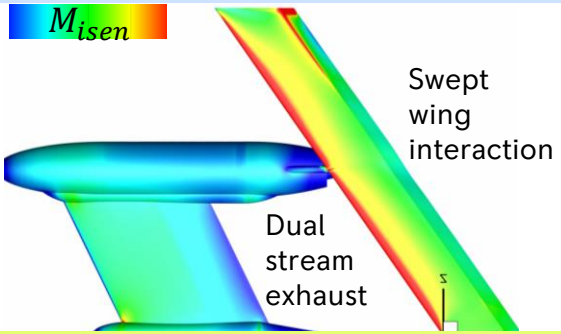
High fidelity CFD validation data

ODIN Off Design Installed Nacelle

CfP11 ODIN

- Nozzle suppression at windmill
- Build CFD understanding of installed exhausts
- Jet Flap interaction test – calibrate CAA acoustic analysis

Advanced digital Design and CFD



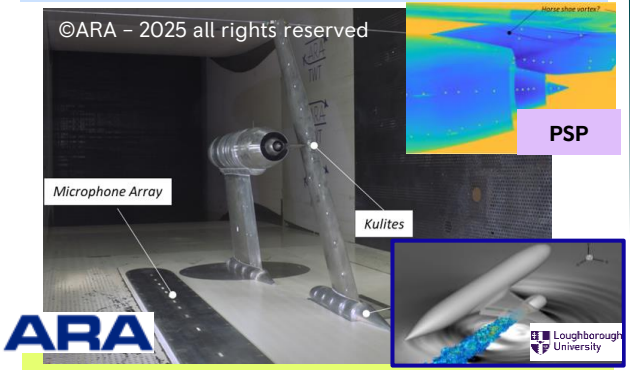
CFD analysis of exhaust at off-design

Use of new exhaust test rig

Dual stream jet rig in the transonic wind tunnel

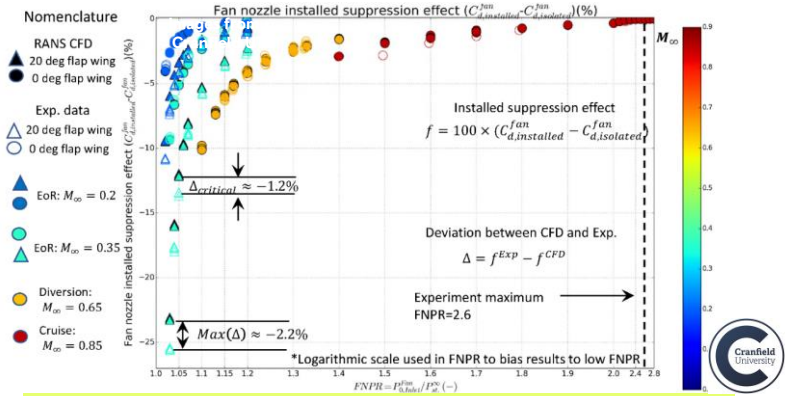
Improve pressure control for off-design operation

High value experimental data



Acoustic & nozzle suppression measurements

Post test analysis, new understanding



Fan nozzle suppression installed vs CFD

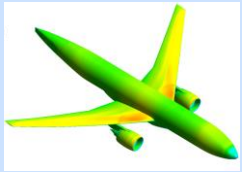
PSP – Pressure Sensitive Paint
CAA – computational aero acoustics

Powerplant Integration – Future innovation activity/opportunities

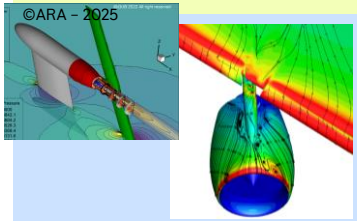
- Significant Opportunities for future testing.
- Understanding of new design space
- High Fidelity data acquisition
- Data for validating new tools and methods
- Developing and maturing new technology.

Installed UHBR powerplant testing

- High Speed / High Lift

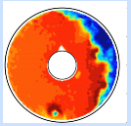


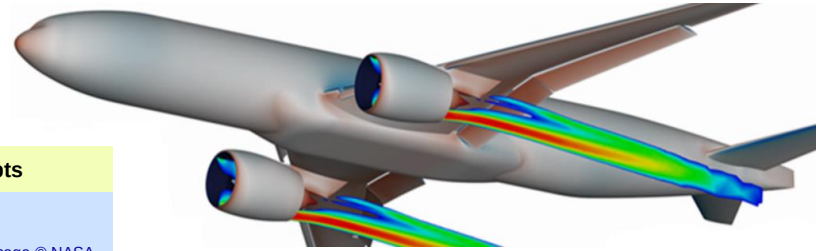
Novel Enhanced Installations



PIV enhancements

High fidelity complex flow measurement





Future Integrated Propulsion

Advanced future concepts

New Airframe Concepts

Next gen aircraft

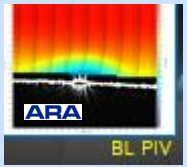
Image © NASA – publicly released

34th Congress of the International Council of the Aeronautical Sciences ICAS

Wöhler et al.

High Fidelity Data

Advanced measurements



Fundamental Flow Understanding

Mid TRL testing
Novel Physics/
New technology data

Acknowledgement

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CfP03 AvAUNT

AvAUNT
AdaptiVe Area nozzle for Ultra-high bypass Nacelle Technology

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THE QUEEN'S UNIVERSITY OF BELFAST
United Kingdom

ROHR AERO SERVICES LIMITED
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CfP07 ANACO

ANACO
ADVANCE NACELLE AERODYNAMIC OPTIMISATION

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CfP08 TRUflow

TRUflow

RUAG

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CfP09 NIFTI

NIFTI

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CfP09 IVANHOE

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HIT09 SRL
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UNIVERSITA DEGLI STUDI DI PADOVA
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CfP11 ODIN

ODIN
Off-Design Installed Nacelles

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Cambridge University
United Kingdom

Loughborough University
United Kingdom

Co-funded by the European Union

CleanSky2 Project links

Provides:-

- Detail overview of Project objectives and achievements
- Project dissemination activity.
- List of published conference and journal papers

CleanSky2 CfP Project Consortia Web Site Links

AvAUNT – Advanced Adaptive Nozzles

http://www.avaunt.info/

ANACO – Advanced Compact Nacelle

http://www.anaco-project.net/

TRUflow – TRU flow measurement and CFD methods

https://www.truflow-project.com/consortium/

NIFTI – Intake Full Annulus PIV with Fan

https://www.dnw.aero/news/nifti-consortium

https://www.cranfield.ac.uk/research-projects/nifti

IVANHOE – Installed Nacelle

https://projectnetboard.absiskey.com/website/ivanhoe

ODIN – Off Design Installed Nacelle

https://odin-project.info/home/about-odin/