Flight100: Rolls-Royce engagement

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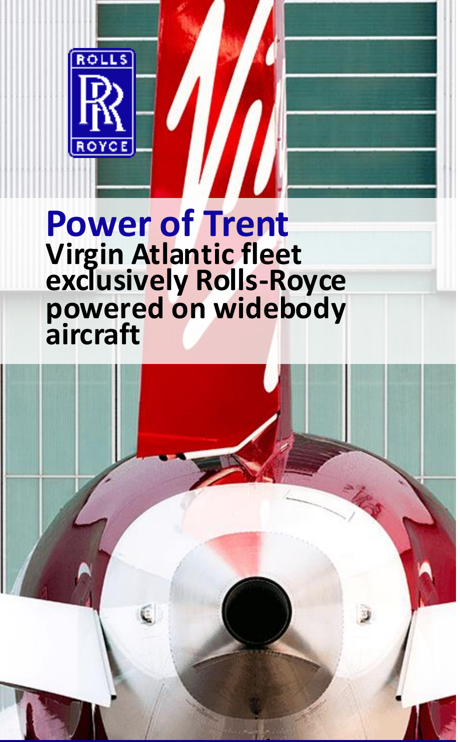
Power of Trent

Virgin Atlantic fleet exclusively Rolls-Royce powered on widebody aircraft



Rolls-Royce

Trent 1000 powered Boeing 787-9

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Trent XWB-97 powered Airbus A350-1000

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Trent 700 powered Airbus A330-300

Rolls-Royce

Trent 7000 powered Airbus A330-900

Our journey to Net Zero carbon is all about efficiency

Super-efficient gas turbines will power the majority of aircraft out to 2050.

Our approach is to maximise the efficiencies of current and future fleet and ensure they are compatible with 100% SAF.

In parallel, we research and develop options for future aircraft.

Maximise efficiency of current and future fleets	Ensure fleets are compatible with 100% SAF	Develop alternatives such as electric and hydrogen
		
Less fuel	Greener fuel	Zero-carbon energy

Aircraft installation and integration

In-service support

Manufacturing and Operations

Ensure fleets are compatible with 100% SAF

We have demonstrated compatibility with 100% SAF on our in-production Business Aviation and Civil Large engines via ground and flight testing.

There is no technology barrier to the use of 100% SAF.

virgin atlantic | BOEING | ROLLS ROYCE | ICF | RMI | Imperial College London | University of Sheffield

‘Sustainable flight is too difficult’ Challenge accepted	100% SUSTAINABLE AVIATION FUEL		virgin atlantic
	FLIGHT 100	28.11.23	

Virgin Atlantic Flight100

Project Introduction

In 2022, the UK Government launched a competition associated with delivering a transatlantic flight using 100% SAF.

£1M of government funding was allocated to support the project.

As a result of the competition, Virgin Atlantic was selected to deliver the flight using a Rolls-Royce Trent 1000 powered Boeing 787-9.

The following organisations were brought together to deliver this ground-breaking project:

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Fuel Selection Strategy

- Unlike many other recent flight demos, the intention from the outset was to only have 100% SAF on board the aircraft.
- For this to be viable meant careful fuel and fuel property selection.
- A 100% SAF drop-in solution was therefore considered the lowest risk approach.
- Hence the use of a blend of two SAF components:

  HEFA-SPK from Air BP (paraffinic, qualified blend component)

  HDO-SAK from Virent (aromatic, qualification in process in ASTM D02 committee)

- Rolls-Royce had previous engine/flight test experience with both above components.
- These were carefully blended in a ratio of approx. 88/12 to produce a 100% SAF that was a technical 'clone' of Jet A/A-1.

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Regulatory Approach

- The certification documentation for the selected airframe, engine and APU does not currently include 100% drop-in SAF as an approved fuel.

This qualification is being actively pursued within the ASTM D02 technical committee.

- Hence the flight would be undertaken on an experimental basis, supported by a 'Permit to Fly', issued by the CAA.
- The desire was always, if possible, to be able to have individuals on board the flight.
- However, the 'Permit to Fly' process typically only allows for minimal crew to be on board.
- A rigorous and robust package of work was therefore defined and delivered, the ultimate intention being to demonstrate Jet A/A-1 equivalency for the SAF blend.

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Extended property database

- Laboratory blends of AirBP HEFA-SPK and Virent HDO-SAK were generated in the specified ratio.
- An ASTM D1655-type fuel specification property dataset was developed associated with the blends.
- In order to provide further evidence of technical equivalence, a more exhaustive suite of property testing was agreed between Rolls-Royce and Boeing.
- This addressed so called ‘fit for purpose’ properties, which are not necessarily called out in the ASTM fuel specification, such as:
    - 2-dimensional Gas Chromatography
    - Air release characteristics
    - Viscosity/density vs temp
    - Bulk modulus
    - Surface tension
    - Vapour pressure
    - Derived Cetane Number

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HEFA-Virent blend properties meet D1655 / JetA-1 requirements.

Fuel property summary – Flight100

Property	Test Method	Units	ASTM D7566 Annex A2	ASTM D1655 (Jet A-1)	Air BP HEFA-SPK & Virent SAK (~12% blend) Flight100
Density at 15°C	ASTM D4052	kg/m3	730-772	775-840	777.7
Aromatics	ASTM D1319	% (v/v)		Max 25	13.1
Distillation	ASTM D86	°C			
IBP					148.9
T10			205 max		173.1
T50			report		224.3
T90			report		259.1
FBP			300 max		264
T90-T10			22 min HEFA / 40 min Jet A-1		86
T50-T10			15 min Jet A-1		51.2
Kinematic Viscosity at -20°C	ASTM D445	cSt	< 8cSt	< 8cSt	5.063
Kinematic Viscosity at -40°C	ASTM D445	cSt	Not required for a neat HEFA-SPK	<12cSt for a blended fuel (<50%)	11.672
BOCLE (lubricity)	ASTM D5001	mm	max 0.85	max 0.85	0.67

Approach to technical clearance

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Abbreviations:

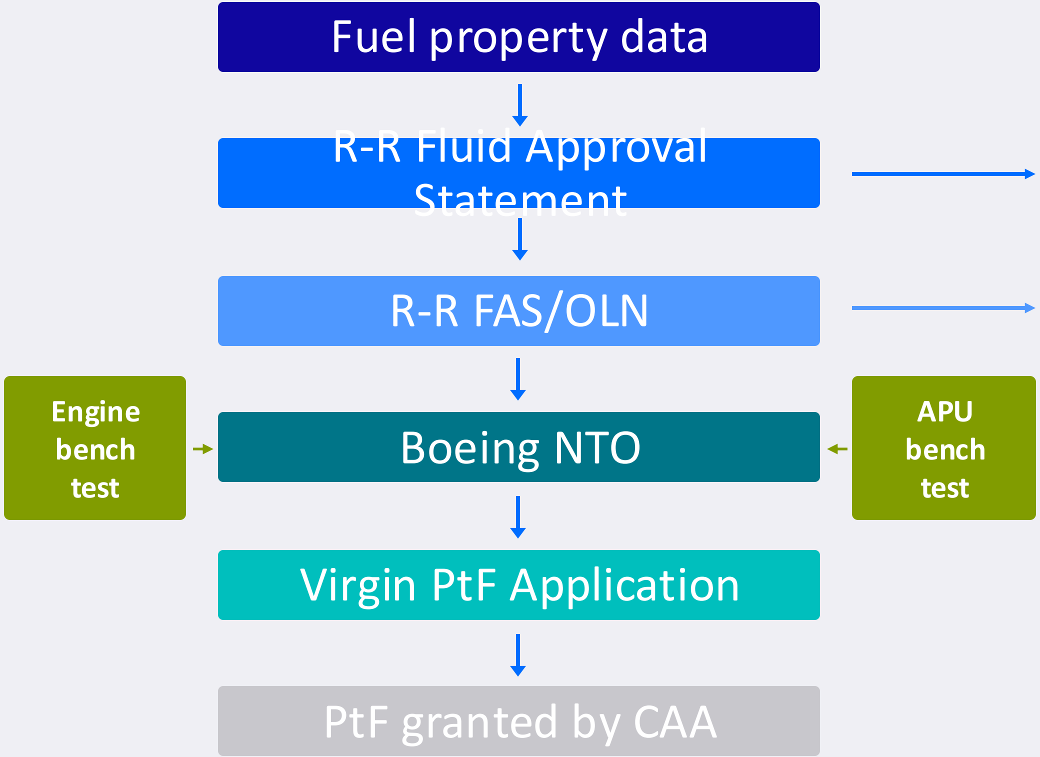
FAS – Flight Approval Sheet

OLN – Operational Limitations Note

NTO – No Technical Objection

CAA – Civil Aviation Authority

PtF – Permit to Fly



Fuel blending and quality control (simplified)

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Drums of HDO-SAK from USA

Bulk supply of HEFA-SPK at BP Isle of Grain facility

Samples taken upon receipt and quality confirmed prior to blending

Batch blended at BP Isle of Grain facility

Recirculate

Full specification test to ASTM D7566 Table 1&2 and 'Top-up' tests to demonstrate Def Stan 91-091 compliance conducted

Ensure density target is achieved.
Sample for CoA certificate

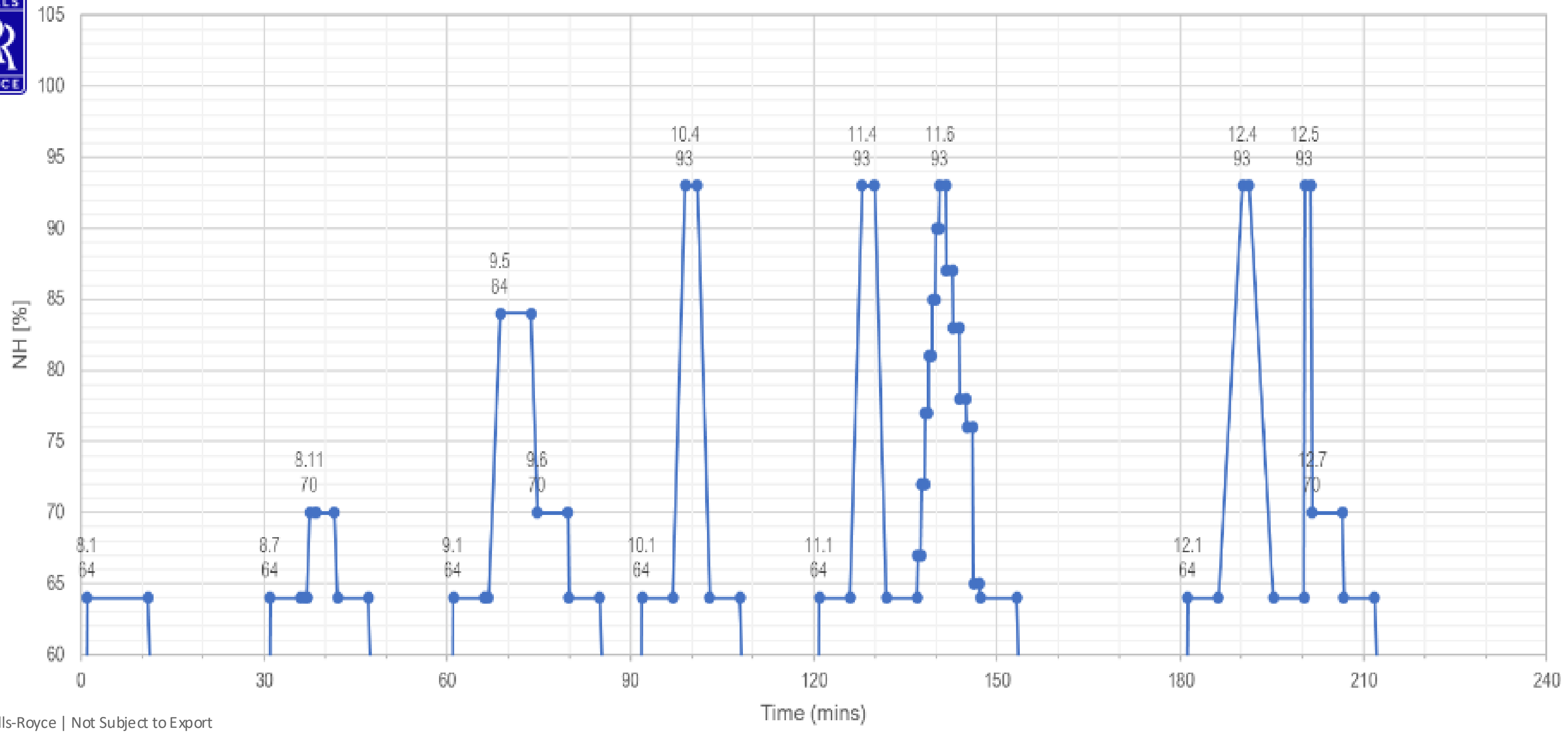
Road tanker(s) for transfer to LHR

Delivery into wing via on-bowser pump/filtration

52 tonnes of 100% SAF on board aircraft

Engine Ground Test Overview

- A ground test was conducted on Trent 1000 PkC experimental engine 10150/8.
- The Bill of Material (BoM) for the asset was demonstrated to be equivalent to that of a production engine such as that fitted to the Virgin fleet.
- The engine test was conducted primarily as a validation exercise, and was not considered critical to engine flight clearance.
- This was due to the technical similarity of the fuel to Jet A/A-1, plus significant previous positive test experience with SAF across multiple products.
- The test was conducted as a back-to-back (JetA-1 vs. HEFA-Virent blend) to confirm equivalence of engine behaviour between the two fuel types.



Engine test profile

Trent 1000 PkC ESN 10150/8 Test Bed 58, Derby, July 2023

Testing included: Start/Idle/Bleed valve toggle, Mid power slow accel/decel, High power slow accel/decel, Stepped accel/decel, Slam accel/decel.

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Engine testing – Derby, July 2023

Engine Ground Test Summary

- All target test points were achieved on both fuel types.
- A total of approx. 4 hours running was completed on the SAF blend.
- Overall performance on the 100% SAF blend was equivalent to that observed on Jet A-1.
  - Very minor differences in engine response attributable to weather conditions and manual throttle inputs were noted.
- Data was shared with the UK CAA to demonstrate acceptable engine capability on the subject fuel type.
- The results of the testing were ultimately provided as an input to the Boeing NTO document.

![Rolls-Royce logo]

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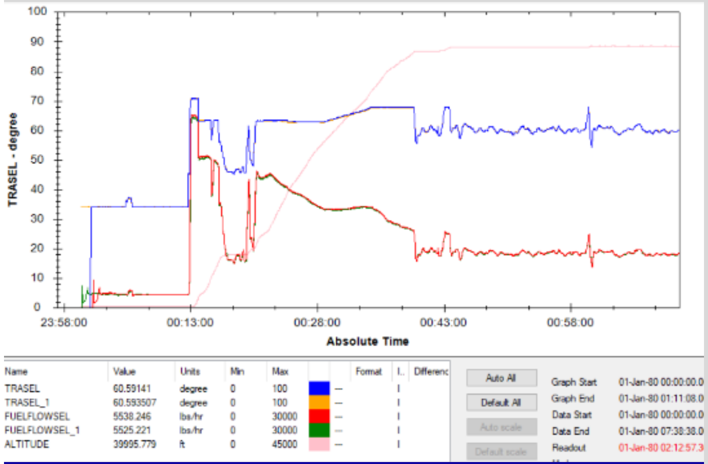
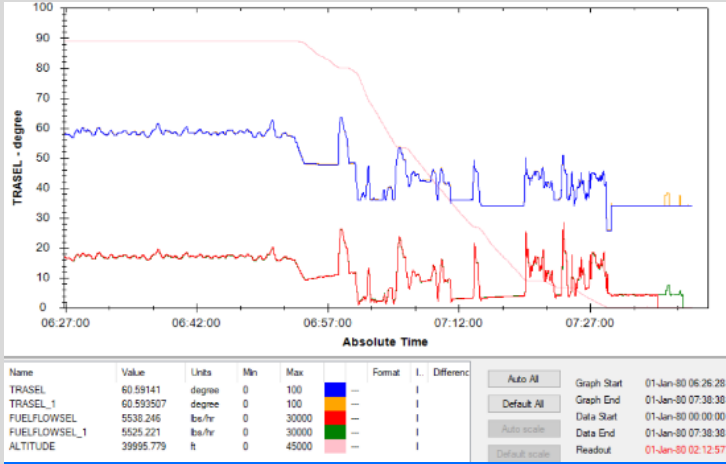
Ground test results:

Fuel flow/Throttle Resolver Angle (TRA) vs. time for JetA-1 and HEFA-Virent-blend

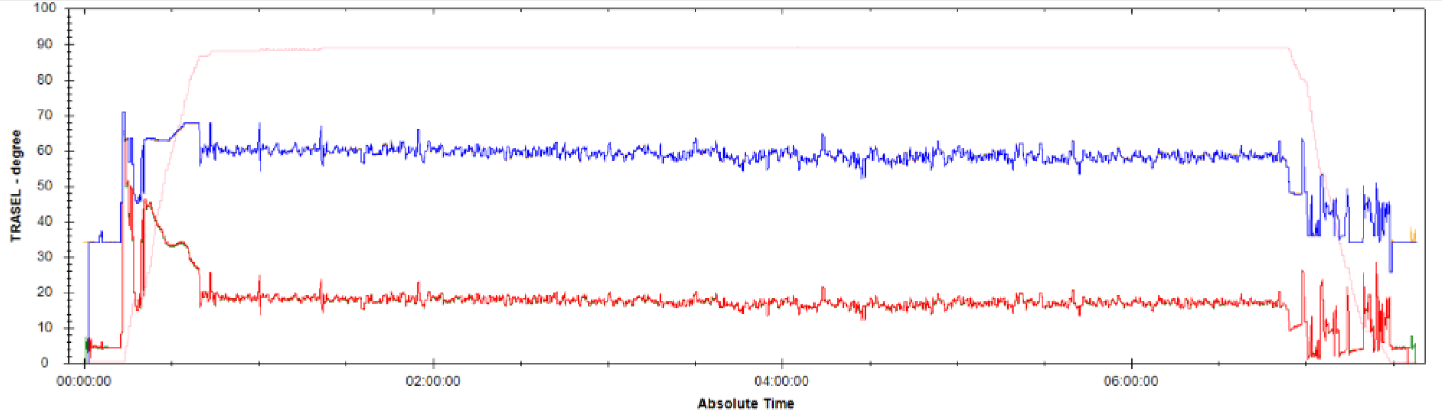
Overall performance on the 100% SAF blend was equivalent to that observed on Jet A-1.



Take-off/cruise



Descent/Landing



Whole Flight

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Return to Service Actions:

Given that the flight was undertaken on an experimental basis, action was required to return the aircraft to a revenue service condition. Rolls-Royce issued a Technical Variance to instruct engine relevant actions.

Key steps included:

Post-arrival into JFK, the aircraft was defueled as much as practicable.

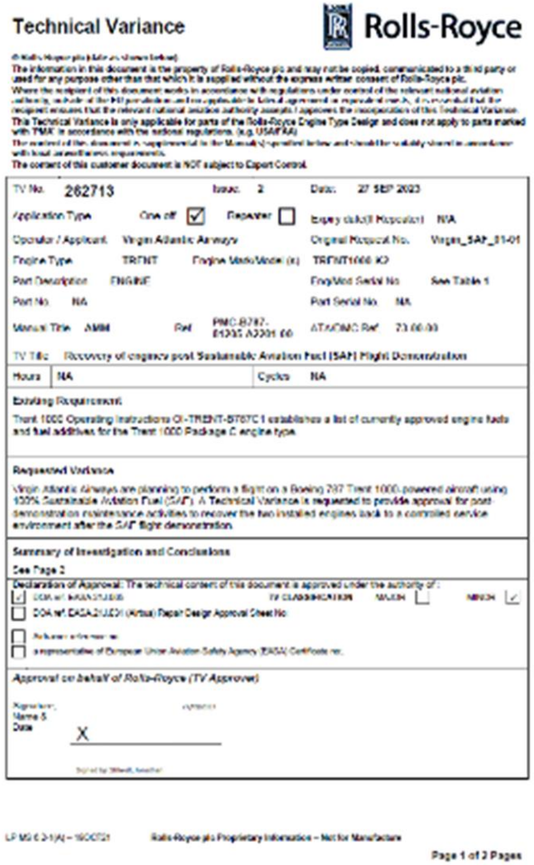
Engine and APU inspections were carried out to confirm acceptable condition.

Aircraft was refuelled with fuel meeting D1655 Jet A requirements.

Engines and APU were operated for a specified period to purge lines of any residual SAF fuel blend.

Aircraft returned to service as per normal procedures.

The aircraft returned to LHR the following day on a revenue flight, with no issues reported.



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Conclusions/Lessons learned

- Delivery of a project with such complexity is challenging and requires significant commitment and resources.
- With the right level of technical rigour and diligence, extraordinary things can be done
- A typical permit to fly would only permit skeleton crew - we were ultimately granted approval to have 100 observers on board.
- Fuel supply immaturity means those logistics need careful consideration assessment.
- Shipping, blending, testing, quality assessment, delivery to aircraft, defueling etc..
- Aircraft flew back the following day on Jet A fuel, proving the agnostic capability.
- Potential for long distance flight on 100% SAF has now been realised.