
‘Sustainable flight is too difficult’
Challenge accepted
BOEING
Imperial College London
Department for Transport
ICF
ROLLS ROYCE
RMI
University of Sheffield
virgin atlantic

Agenda

The following topic and running order to be covered by the Flight100 Consortium during the technical session

	Session	Speakers	Time (GMT)
1	Welcome	▪ Holly Boyd-Boland Virgin Atlantic ▪ Ben Chapman – ICF	13:00 – 13:25
2	Approvals and Permit to Fly	▪ Luke Ervine – Virgin Atlantic ▪ Gareth Salt – Virgin Atlantic ▪ Gareth Norman – Virgin Atlantic	13:25 – 13:45
3	Fuel, Technical and Engineering	▪ Ian McDonald – Virgin Atlantic ▪ Alastair Hobday – Rolls-Royce ▪ Bill Griffin – Boeing	13:45 – 14:15
			Break 15 mins
4	Lifecycle	▪ Luke Ervine - Virgin Atlantic ▪ Maks Kraidelman - ICF	14:30 – 14:45
5	Operational Efficiencies	▪ Karl Corcoran – Virgin Atlantic	14:45 – 15:00
6	Non-CO2	▪ Karl Corcoran – Virgin Atlantic ▪ Mohamed Pourkashanian OBE – University of Sheffield ▪ Dr Marc Stettler – Imperial College London ▪ Joey Cathcart - Rocky Mountain Institute	15:00 – 15:20
7	Q&A	▪ Moderated by Holly Boyd-Boland	15:20 – 15:45

Key results

100% SAF Equivalent safety to Jet A-1	**0** Engine or airframe mods	▪ Demonstrated that a wide-body long haul aircraft (in this case Boeing 787-9 with Rolls-Royce Trent1000 engines) can operate100% SAF at an equivalent level of safety to Jet A-1 ▪ No modification required or made to airframe, engines or any components
64% Reduction in CO_2e	**-95 tCO_2e**	• 95 tonnes CO_2e reduction compared to standard LHR-JFK flight • End to end life cycle analysis completed – providing replicable framework that can be adopted across industry • 64% CO_2e reduction from use of Flight100 SAF blend
+1% Increase in energy	**-350 kgs** Fuel saved	▪ Lab analysis findings indicate that Flight100 SAF also delivered a 1% improvement in energy density ▪ 34.6 tonnes of fuel burnt – a saving of 0.35 tonnes vs typical flight with Jet A-1 ▪ At 10% SAF adoption could reduce total UK fuel burn by 12k tonnes and 400k tonnes globally
40% Reduction in particulates	**Likely reduction of radiative forcing contrails**	▪ Flight100 SAF ~40% reduction in particulate matter, increasing to 70% for HEFA component ▪ Demonstrating the potential of SAF to reduce environmental impact of non-CO2 emissions ▪ Reduction in particulates likely to reduce in-flight creation of persistent radiative forcing contrails
0 Contrails	**Predictive modelling accuracy verified**	▪ Flight100 verified the accuracy of contrail creation forecasting ▪ Incorporated Breakthrough Energy open-source model into flight planning ▪ No contrails formed in flight due to higher-than-normal cruising altitude of 40,000 feet
4.4% Fuel reduction through operational efficiencies	**-2.2 tonnes** Fuel savings	▪ Flight100 deployed nine ground and flight ops efficiency initiatives avoiding 8.4 tonnes CO_2e ▪ ATM and flight path efficiencies delivered 70% of benefit – highlighting opportunity for international collaboration across air traffic management

Making it happen

Structure of programme focused on the radical collaboration required to deliver change on SAF industry initiatives

Consortium workstreams

1	2	3	4	5	6
Testing & Certification – fuel, engine, airframe	Safety and regulatory approvals	Operations and flight delivery	Carbon measurement and removals	Non-CO_2 effects & fuel efficiency	Comms and stakeholder engagement
Boeing, Rolls-Royce, Virgin Atlantic	**Boeing, Rolls-Royce, Virgin Atlantic**	**Virgin Atlantic**	**Virgin Atlantic ICF**	**Imperial College, University of Sheffield, RMI**	**All Consortium**
Air BP & Virent	**CAA, FAA**	**LHR, JFK, Air BP**			**DfT**

Speakers

Program and Permit to Fly

Luke Ervine – Head of Sustainability

Luke led the delivery of Flight100 at Virgin Atlantic and across the consortium

Gareth Salt – Vice President Health, Safety and Security

Gareth led the Permit to Fly process and Virgin Atlantic's corporate safety case for Flight100

Gareth Norman – Senior Manager Compliance

Gareth led Virgin Atlantic's engagement with the CAA, FAA and other regulators to secure the Permit to Fly and overflight approvals

Fuel, Technical and Engineering

Ian MacDonald – Head of Engineering

Ian was responsible for Virgin Atlantic's fuel, engineering and maintenance workstreams for Flight100

Alastair Hobday – Associate Fellow – Fuels and Lubricants

Alastair led the fuel testing program and Rolls-Royce's assessment of engine compatibility – culminating in the issuance of the OLN

Bill Griffin – Technical Lead – EcoDemonstrator Program

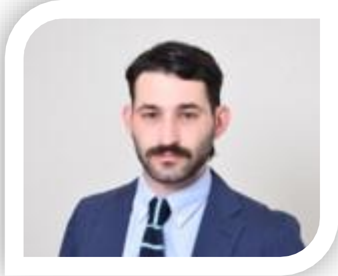
Bill led the Boeing team technical assessment of airframe interoperability and was responsible for the No Technical Objections confirmation

Speakers

Life Cycle Analysis

Luke Ervine – Head of Sustainability

Luke led the delivery of Flight100 at Virgin Atlantic and across the consortium



Maks Kraidelman – Senior Consultant ICF

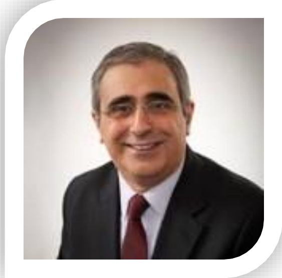
Maks worked on the lifecycle benchmarking and analysis for Flight100

Operational efficiencies

Karl Corcoran – Senior Manager, Flight Technical

Karl led Virgin Atlantic's work across operational efficiency initiatives and non CO_2 measures used in flight

Non CO_2 analysis



Mohamed Pourkashanian OBE – Head of Energy Research

Mohamed led the Sheffield team on fuel analysis testing focused on particulate emissions

Dr Marc Stettler – Lead Transport & Environment Laboratory

Marc led the project and Imperial teams in the non – CO_2 analysis and modelling with a focus on contrails

Joey Cathcart – Senior Associate

Joey led the RMI team, working with Imperial, on the model forecasting for contrail formation

Approvals and Permit to fly

Unique Blend of SAF

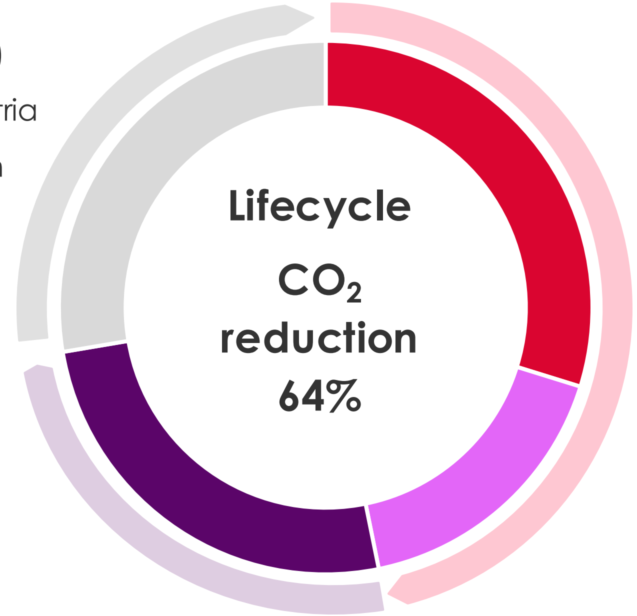
Flight 100 used a mix of 88% HEFA and 12% high aromatic SAK to achieve properties akin to Jet A-1

Renewable feedstocks

- Category 1 waste animal fats (HEFA)
  - Sourced in Portugal and Austria
- Dextrose derived from industrial corn starch (SAK)
  - Sourced in US corn belt

Conversion process

- HEFA SPK from convert feedstocks into aviation fuel
- Virent Synthetic Aromatic Compound
- Bioform process



Blending & distribution

- Blend ratio 88:12
- Fuel distribution direct into wing
- Isolated from fuel farm given off-spec nature

Fuel burn in engine

- SAF properties equivalent to ASTM
- SAK component delivers aromatics and required density

Approval Framework

Flight100 operated outside of existing commercial flight framework – requiring one off Permit to Fly

	Commercial Flight	Flight 100
Fuel	**Jet A/Jet A-1** Contains up to 50% SAF is qualified currently for use in commercial aviation	**100% SAF** *Make up : 88% HEFA / 12% SAK*
Certification	Type Certificate & Certificate of Airworthiness	**Does not meet Type certification due to proposed fuel**
Flight Routing	**ETOPS approved** Approved to 180 Minutes diversion	**ETOPS NOT Approved** *Intent to fly per ETOPS optimal routing*
On Board Observers	**Not Applicable** Commercial Flight approved for certified passenger capacity	Up to 110 essential observers critical to demonstrating capability

=

Aircraft does not comply with current regulations due to limitations of existing fuel approvals for SAF but is still capable of safe flight under defined conditions

Permit to Fly

Defines approved flight routing, Departure/Arrival points, flight profile and operation of the aircraft under defined flight conditions

Flight Conditions

Defines technical conditions and restrictions for the aircraft to operate safely under a Permit to Fly

Flight100 objective: use of 100% SAF today with equivalent level of safety and airworthiness to a commercial flight on 100% Jet - A

Approvals

Interplay across regulators to achieve full flight approvals required – with UK CAA lead through Flight Conditions & Permit to Fly

Flight Conditions

Approved by the CAA

- Technical configuration
- Flight Profile
- Essential personnel & cargo
- Return to Service

Permit to Fly

Approved by the CAA

- Categorised as an Exhibition Flight
- Resilience – back up aircraft

Overflight Approvals

Approved FAA, IAA, TCAA

- Permission to Fly - IAA
- Overflight Permission - TCAA
- Special Flight Authorisation – FAA

Flight 100 Regulatory Approach

- **Relentless focus on safety and compliance**
- **Achieve all necessary regulatory approvals – driven by analysis and testing robustness**
- **Deliver operational resilience by securing secondary approvals for alternative aircraft**
- **Collaboration with regulators – ensuring early engagement and transparency throughout process**

Permit to Fly

Core of regulatory approvals focused on demonstrating the safety case and flight specific procedures in place

Flight Conditions

Two applications per aircraft

UK Reg (EU) 748/2012 – Requirement 21.A.708

Approval of flight conditions for PtF (SRG1767)

- Purpose of Flight
- Aircraft condition requiring permit

Approval of CAA approved Flight Conditions (SRG1728b)

- Proposed Aircraft Technical Configuration
- Substantiating assessments - VAA safety and regulatory case
    - *Flight Overview Summary*
    - *Consortium Technical Assessments*
    - *VAA Technical Assessments (Eng/Ground/Flight)*
    - *VAA Risk Assessments (Eng/Ground/Flight)*
    - *Essential Observers Analysis/Definition*
    - *Nominated Postholder Approval(s)*

Permit to Fly

One application per aircraft

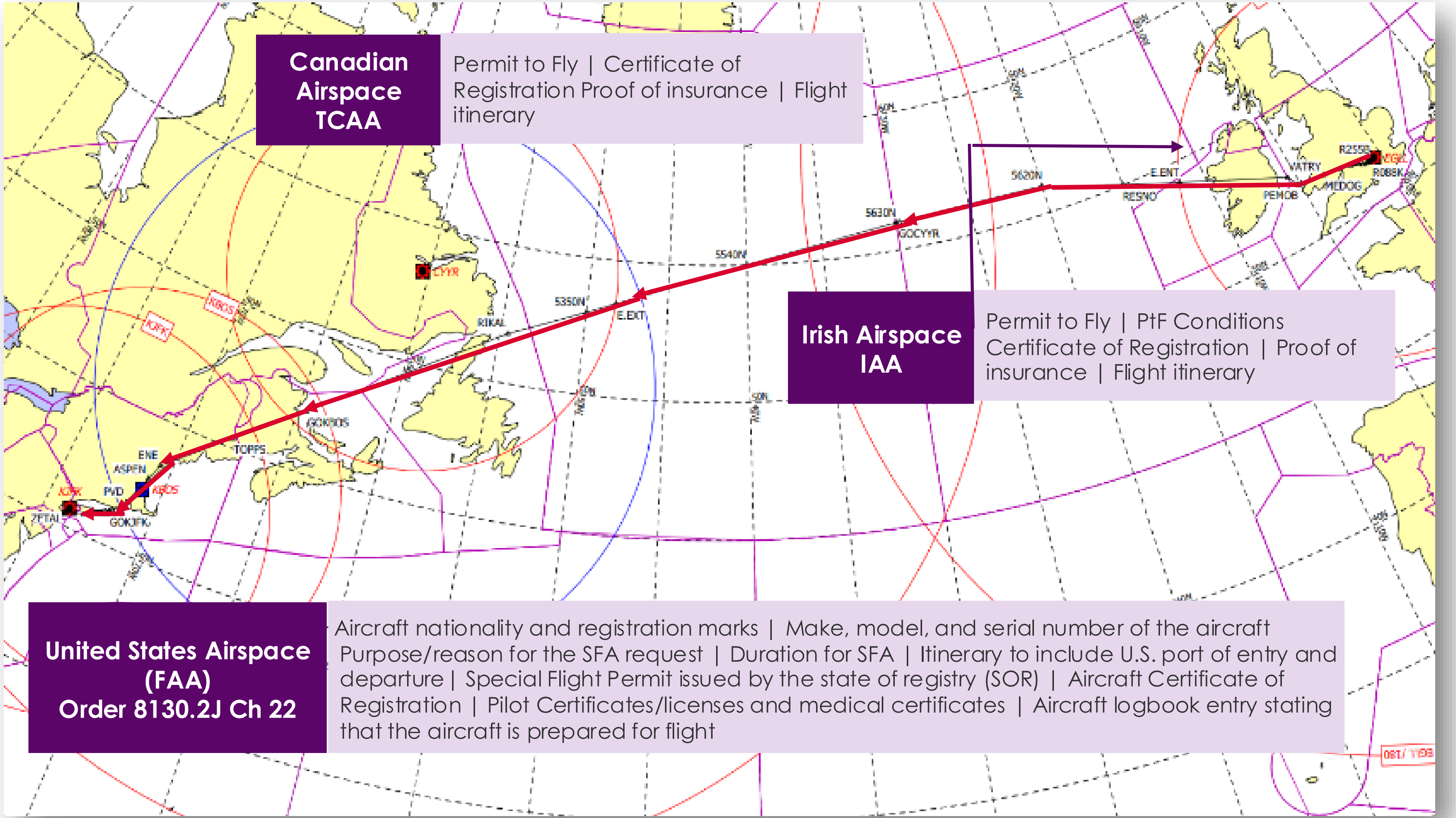
UK Reg (EU) 748/2012 – Requirements 21.A.701 & 21.A.707

Permit to fly Application (Online Portal)

- Certification type/basis for the aircraft
- Approved Maintenance Programme.
- Who(either organisation or individual) will be issuing the aircraft the Certificate of Release to Service
- Maintenance or actions to be carried out to ensure safe flight. *(Supported by FC's)*
- Flight Plan Route (Departure/Arrival)
- Targeted Flight date range

Overflight Approvals

Three key civil aviation authority approvals required given flight path – Irish, Canadian and US



Canadian Airspace TCAA

Permit to Fly | Certificate of Registration Proof of insurance | Flight itinerary

Irish Airspace IAA

Permit to Fly | PtF Conditions Certificate of Registration | Proof of insurance | Flight itinerary

United States Airspace (FAA) Order 8130.2J Ch 22

Aircraft nationality and registration marks | Make, model, and serial number of the aircraft Purpose/reason for the SFA request | Duration for SFA | Itinerary to include U.S. port of entry and departure | Special Flight Permit issued by the state of registry (SOR) | Aircraft Certificate of Registration | Pilot Certificates/licenses and medical certificates | Aircraft logbook entry stating that the aircraft is prepared for flight

Results

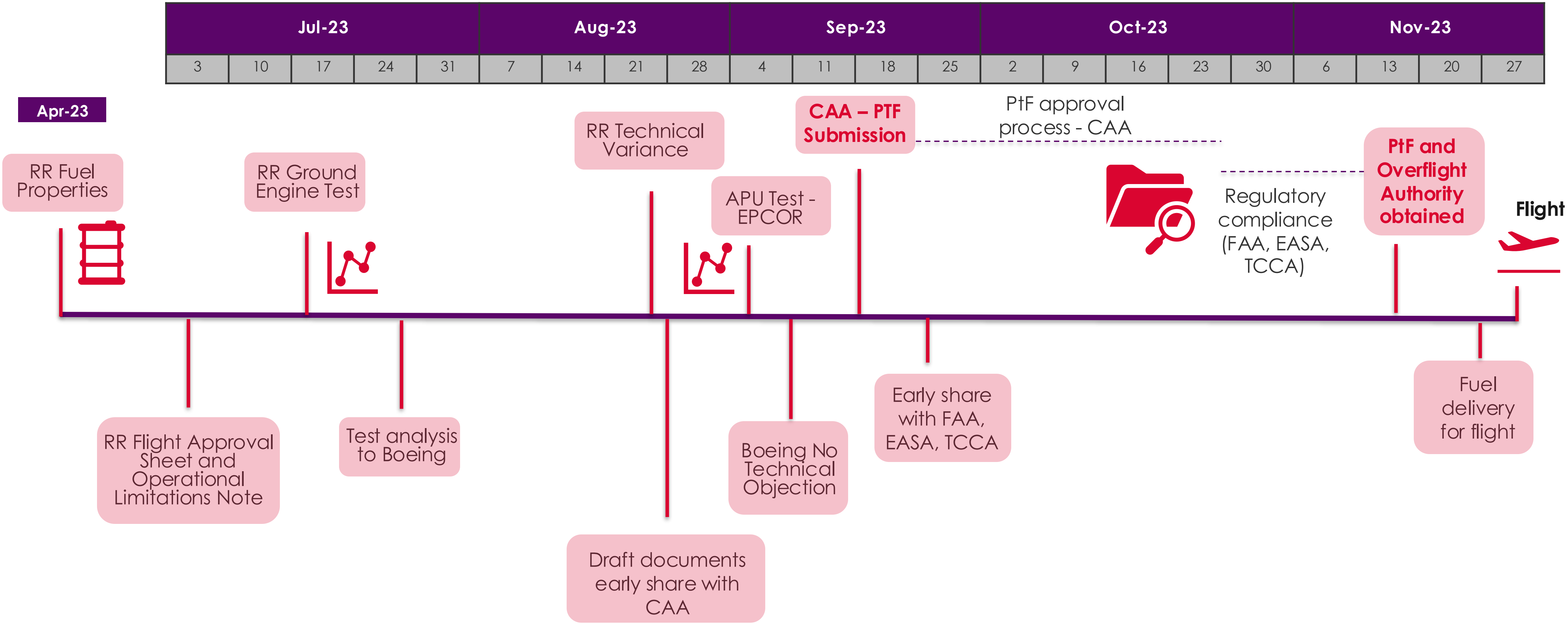
All regulatory approvals achieved pre-flight

1. **Equivalent Safety Standard of Flight100 vs commercial flights demonstrated – in approval process and operation**
2. **Common knowledge building across regulators and Virgin Atlantic – increasing experience of high SAF volume flights from a regulatory perspective**
3. **All Flight Approvals (Primary & Secondary) received ahead of flight**
4. **Whilst non commercial flight – essential observers and non commercial cargo approved – creating flight conditions more akin to commercial service**

Technical & Engineering

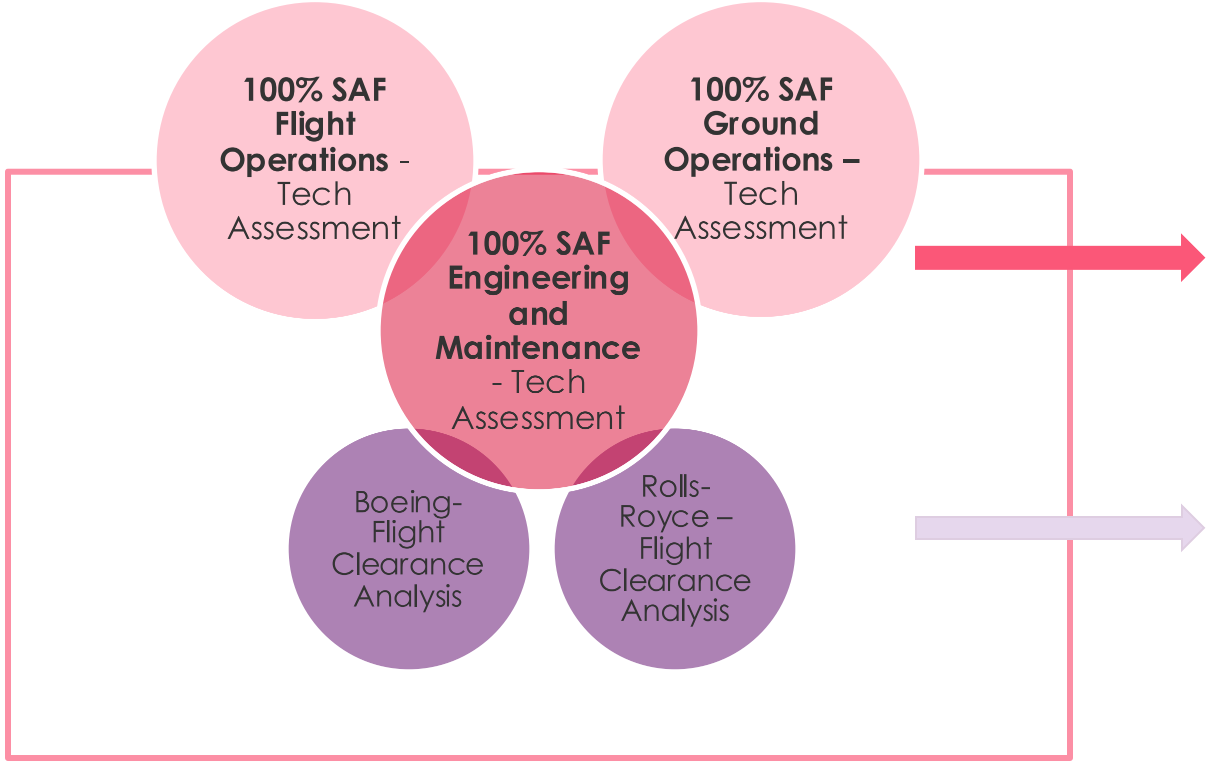
Milestone Plan

12 months in the making with many technical milestones required to support the submission to the regulators



Technical Activities

Technical assessments to support the flight involved stakeholders both internal and external to Virgin Atlantic



Virgin Atlantic Technical Report – Risks Addressed

1 – SAF maintenance activities not completed / not accomplished correctly

2 – Engines fail to perform as required / shut down / uncontrollable

3 – APU fails to perform as required / shuts down / speed not reached for generator to come online

4 – Aircraft systems do not perform as intended

References

A. Rolls-Royce Flight Clearance Overview
B. Rolls-Royce Trent 1000 SAF Ground Test
C. Rolls-Royce/AirBP Fuel handling and quality management
D. Rolls-Royce Operational Limitations Note
E. Rolls-Royce Technical Variance Document
F. Boeing No Technical Objection
G. Boeing/P&WC Eng Coordination Memo APU Operation

Fuel Characteristics

Analysis of Flight100 SAF demonstrated equivalent properties to fossil Jet-A

Fuel Selection

A 100% SAF drop-in solution was considered the lowest risk approach

Hence, the Virgin flight used a blend of two SAF components:

- ~88% HEFA-SPK from Air BP (paraffinic, qualified blend component)
- ~12% 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 blended to produce a fuel that was technically equivalent to Jet A-1

Fuel Characteristics

Extended Fuel property database established

An exhaustive suite of property testing was agreed between Rolls-Royce and Boeing

This provided further key data to substantiate fuel technical equivalence

Property	Method	Units	ASTM D7566 – Annex 2	ASTM D1655 – Jet A1	F100 SAF
Density at 15°C	ASTM D4052	Kg/m3	730-722	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 A1		86
T50-T10			15 min Jet A1		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 neat HEFA - SPK	<12 cSt for blended (<50%)	11.672
BOCLE (lubricity)	ASTM D5001	mm	Max 0.85	Max 0.85	0.67

Rolls-Royce Technical Clearance

4 hours of ground-based engine testing with an identical bill of materials to the engines flown

Rigorous engineering approach to substantiate technical viability of selected SAF

- **Engineering analysis summarised in Flight Approval Sheet**
- **Operational Limitation Note provided to Boeing and Virgin Atlantic**
- **Oversight on flight readiness through Rolls-Royce Corporate Audit team**
- **Regular engagement with Civil Aviation Authority technical specialists**

Representative Trent 1000 Ground Test

- A ground test was conducted on a Rolls-Royce Trent 1000 engine
- The Bill of Material 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
- The test was conducted as a back-to-back (Jet A-1 vs. HEFA-Virent blend) to confirm equivalence of behaviour between the two fuel types

Testing included:

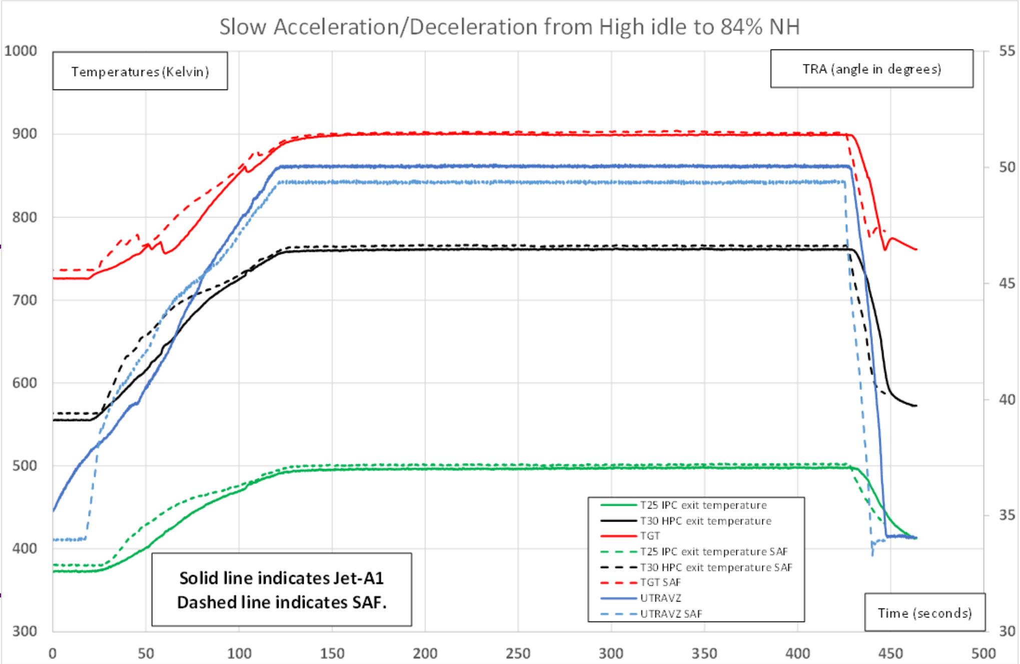
- A total of approx. 4 hours running on the SAF blend, including various relevant test points focused on starting, operability and handling

Conclusions:

- All target test points were achieved on both fuel types
- Engines performed and behaved as expected throughout all testing
- Overall performance on the 100% SAF blend was equivalent to that observed on Jet A-1slide

Rolls-Royce Trent 1000 Ground Test Results

Ground based Engine testing, comparing the SAF Blend to Jet A-1



Performance in bench engine test

- ➢ Engine performance identical between F100 SAF and Jet A-1
- ➢ Only environmental differences observed

Power of partnership

The key strategic partnership between Virgin Atlantic and Rolls-Royce was pivotal in achieving Flight 100

100%

Rolls-Royce Trent powered fleet

10 years

Rolls-Royce Trent 1000 operation

#2

Back-to-back engine tests to compare Flight100 SAF vs Jet A-1

Dozens

Of parameters monitored real time during F100

3

Rolls-Royce technical reports in support of the PtF

Leadership in SAF Flights

Flight100 represents the latest in a long history of first-of-a-kind SAF flights between Boeing and Virgin Atlantic, starting in 2008 with a 5% SAF blend

2008
First SAF test flight

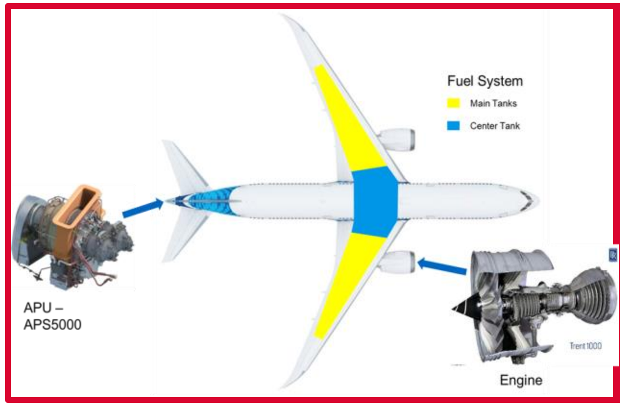
2023
First 100% SAF transatlantic flight on a commercial aircraft

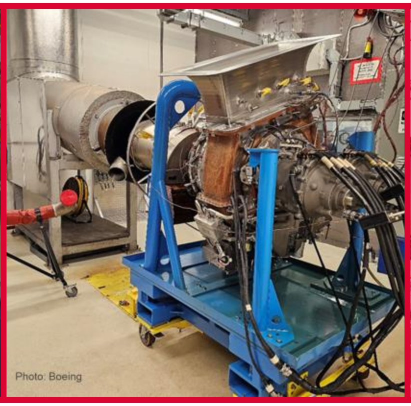
SAF → 100%

2008 2010 2012 2014 2016 2018 2020 2022 2024

Boeing Flight Clearance Progression

Analysis





Fuel Properties Assessment

Ground Test
RR Engine

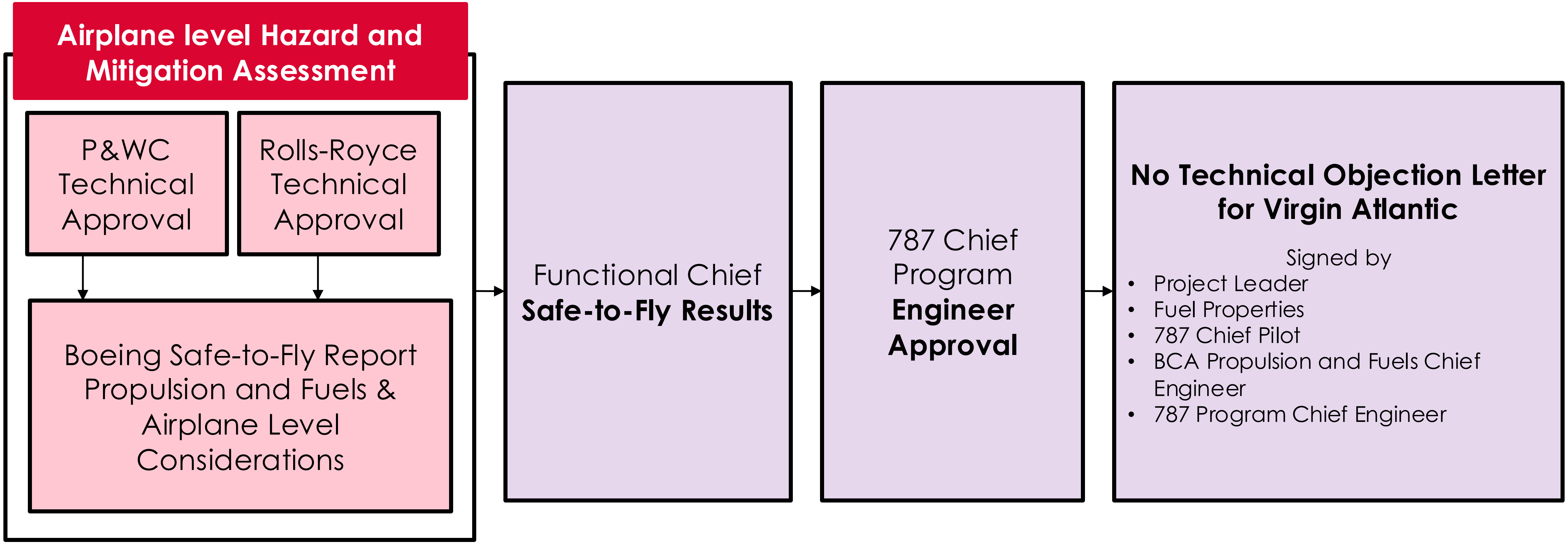
Ground Test
P&WC APU

Airplane Ground Check
High Power Engine Run + APU Run

Clearance for Dual Engine Flight
100% SAF All Tanks

Boeing No Technical Objection

Analysis



Delivery of the NTO enabled Virgin Atlantic to proceed with the CAA Permit to Fly (PtF) application

Fuel handling procedures

Robust fuel handling procedures and monitoring ensured that the fuel properties remained at a technical equivalent to Jet A-1 at each stage of the process.

✓✗ = go/no go decision VAL

A *Hand blending carried out pre batch blending to determine approach for ASTM conformity*

B *Batch and blend tests carried out to ensure density target achieved and sample for certificate of analysis*

C 46 tonnes of 100% SAF on board Boeing 787 powered by 2 x RR Trent 1000 engines

Bulk Supply HEFA SPK [87.3%]

SAK Drums [12.7%]

✓✗ A

Blending at BP Facility IoG

Blended at ratio 88:12

Lab testing at each batch stage

Recirculation

Total of 4 batches

2 x road tankers delivery into wing

B ✓✗

C **Delivery into wing**

D On-bowser pump/filtration

✓✗

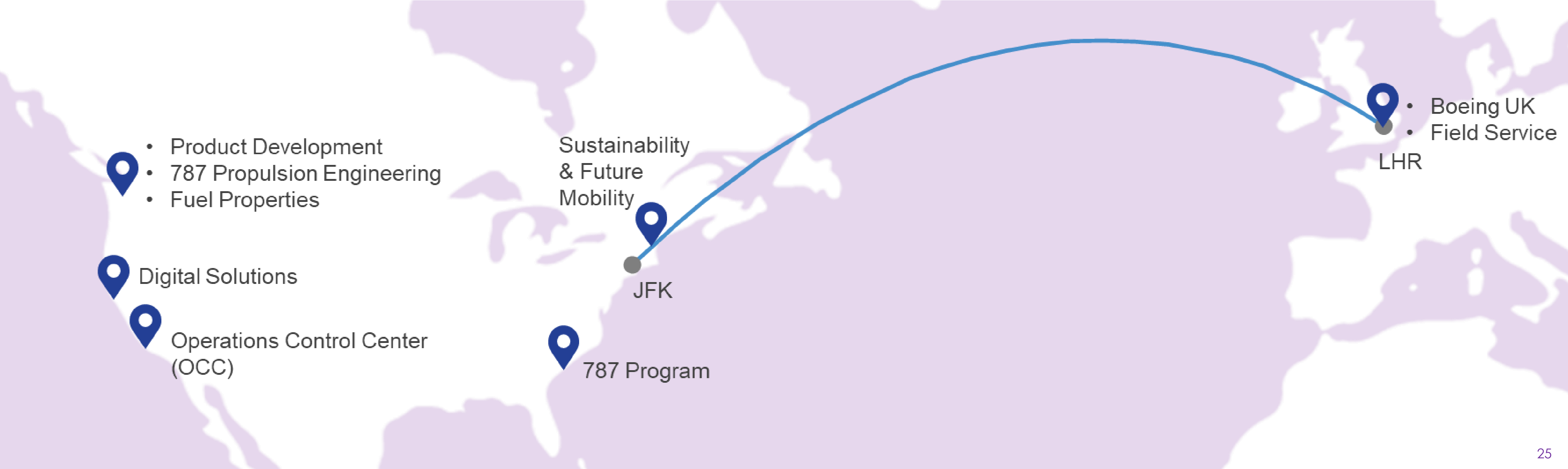
By the Numbers – Boeing

The key strategic partnership between Virgin Atlantic and Boeing was pivotal in achieving Flight 100

>75
Total Boeing personnel

6
Boeing sites

DOZENS
of parameters monitored real-time during Flight 100



Technical Activities

All of the Technical Analysis workstreams concluded with a clear framework of necessary controls

Aircraft G-VDIA

Boeing 787-9
Trent 1000 Engines

Maintenance Controls

Dedicated Virgin Atlantic Engineers to carry out all maintenance

Training Requirements reviewed

Maintenance controlled via Virgin Atlantic procedures

Health and Safety procedures in place

Fuel

Fuel production controls including Certificates of Analysis

Tank sampling for micro-biological contamination

Fuel Handling Quality Checklist

Drain and sump Jet A-1

Fuel temperature monitoring of all tanks in flight

Engine and APU

Engine and APU Ground Test

Simulator Session Engine and APU failures

Engine Oil Pump and LP Fuel Filter replacements

High Power Engine Runs and APU SAF Operation

Enhanced Engine Health Monitoring

APU operated continuously during flight

Airframe

Fuel Quantity Indication System adequate reading checked

Fuel System Operational Tests

Engine and APU fire detection and Extinguishing systems Tests

Frequent log of Fuel Temp/FL/SAT/Mach No. during flight

Return to Service

Download Flight Data logged during operation

Drain and sump SAF

Engine and APU operation on Jet A-1

Place the APU on MEL

Technical Conclusions

Post Flight 100 Technical Conclusions

1. **The Boeing 787-9 aircraft with Rolls-Royce Trent1000 engines can operate100% SAF at an equivalent level of safety to Jet A-1**

2. **Flight 100 Aircraft was successfully returned to service with zero operational disruption following the historic flight**

3. **Further substantiation for ASTM International and airframers to drive the use of SAF at 100%**

4. **Technically we are ready, operation at 100% SAF with existing engine technology is achievable**

Lifecycle analysis

Flight100 lifecycle assessment (LCA) objectives

Benchmark LHR-JFK flights to assess 100% SAF carbon savings, using removals to mitigate residual emissions to zero

0 CO_2e

Deliver a 'net zero' emissions flight

Address F100 residual emissions using UK-based carbon removals

Develop and trial a methodology to capture the full lifecycle emissions from aviation

Better understand value chain impacts and mitigation opportunities

Lifecycle assessment results

Using UK Government conversion factors and 98% primary data, baseline footprint of LHRJFK flown on 787-9 calculated

Baseline = 153.74 tonnes CO_2e

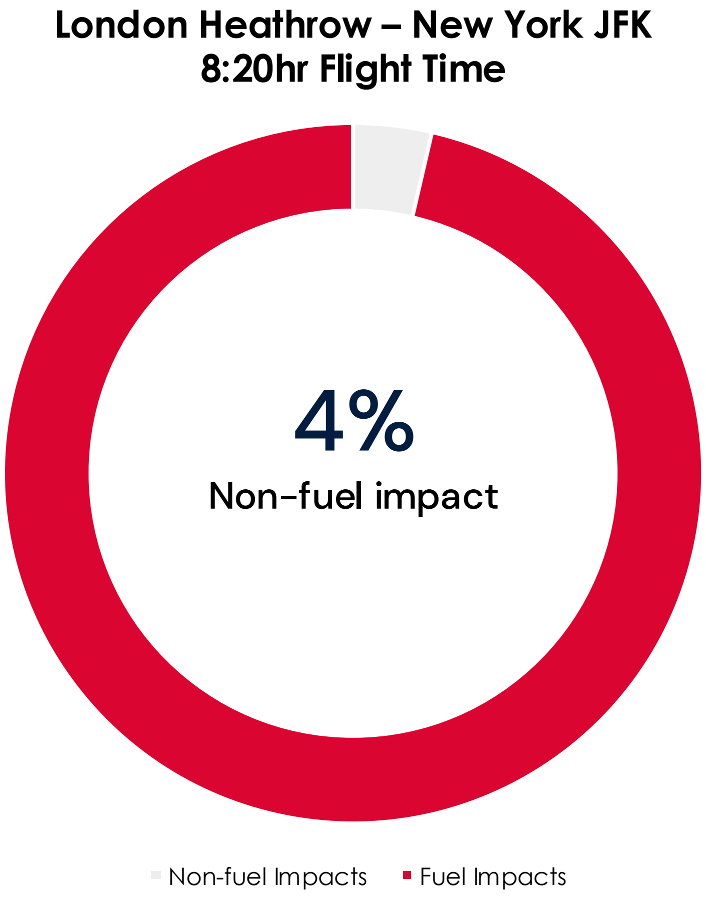
96%
Of emissions relate to jet fuel

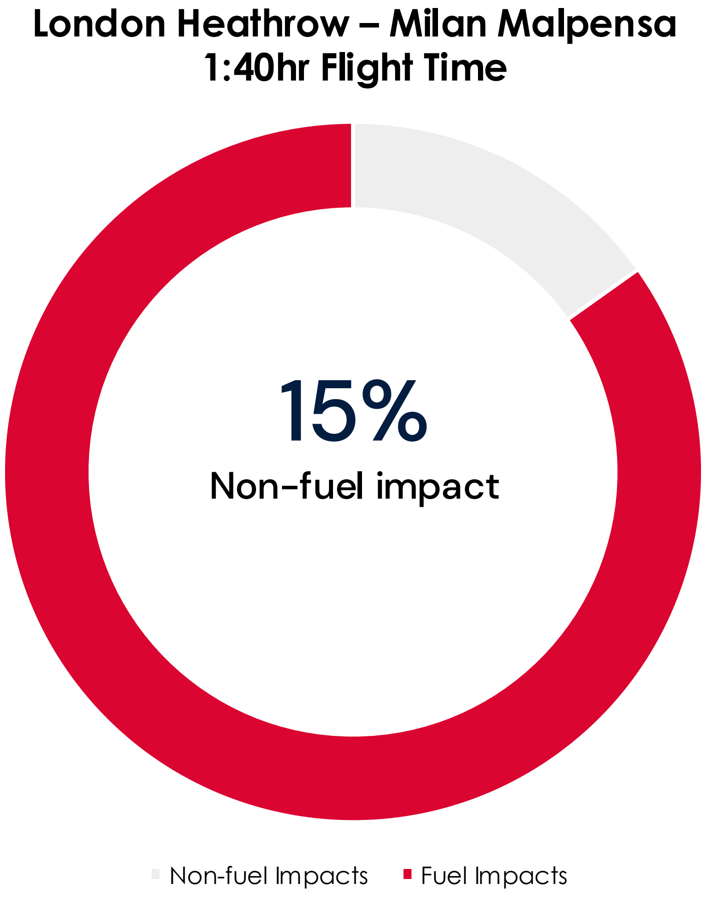
4%
Relates to non- fuel activities

Direct fuel burn and upstream emissions		Non-fuel emission				
Direct	Upstream	Surface access	Ramp Ops	Aircraft Embodied	Corp. Ops	Other
148 CO_2e		6 tCO_2e				
82%	**18%**	**36%**	**25%**	**20%**	**14%**	**5%**
122 tCO_2e	26 tCO_2e	2 tCO_2e	1 tCO_2e	1 tCO_2e	1 tCO_2e	< 1tCO_2e

LCA discussion & industry implications

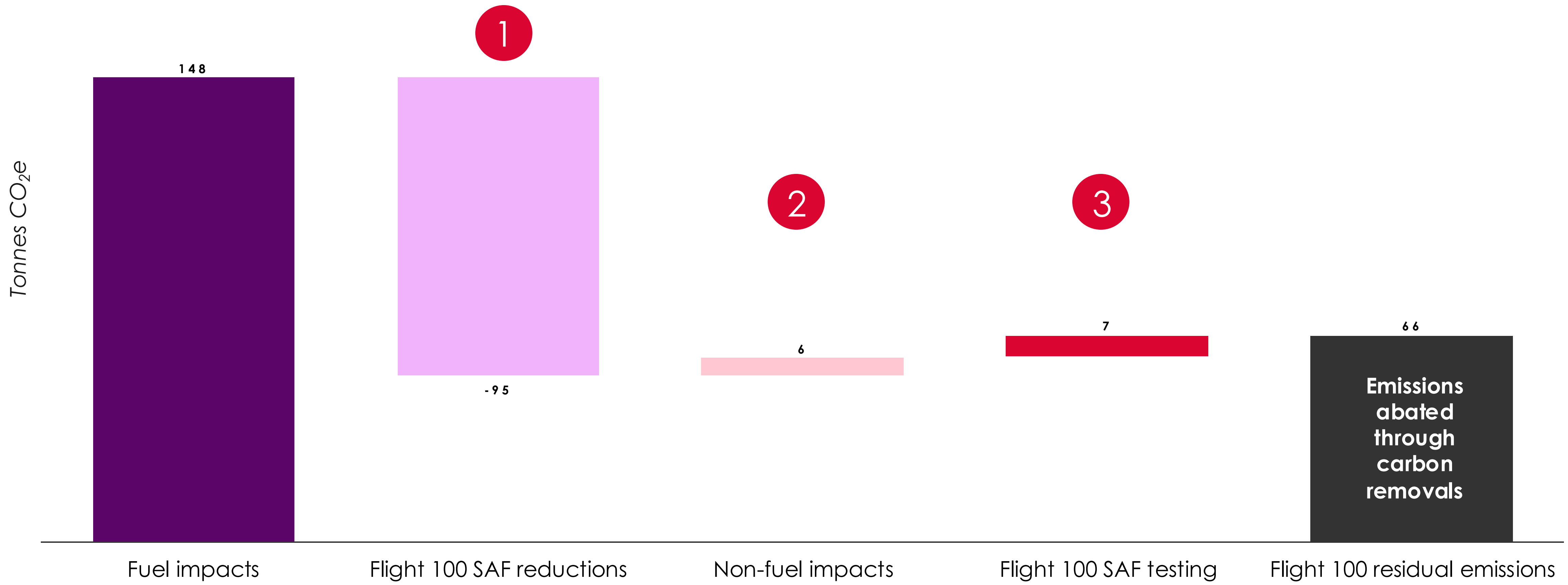
The variability of non-fuel impacts highlights a broader opportunity for industry-wide decarbonisation





Flight100 LCA results

Following the use of 100% SAF, Flight100 residual emissions impact was assessed at 66 tonnes CO_2e that could not be mitigated through in-sector measures



Flight100 carbon removals

UK-based biochar project selected after rigorous vetting, ensuring high quality, durable and long-term removals credits used to mitigate remaining unabated 66 tonnes CO_2e, with additional co-benefits for UK agriculture

Biochar

Charcoal produced by pyrolysis, using waste biomass, removing carbon from atmosphere

Charcoal sequesters stable carbon when mixed into soils

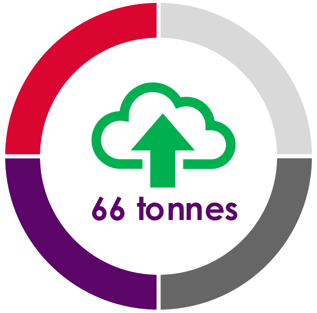
Agricultural co-benefits, improving water retention and soil fertility

Certified permanence of 100 years, but can sequester carbon up to 1,000s years

Vetting process

Supercritical

- Only 11.5% biochar projects pass Supercritical vetting
- Vetting requirements incl. no significant harm, additionality, durability, co-benefits, future potential
- Alignment with Oxford principles for Net Zero carbon offsetting



Selection criteria

Vetting	Puro certification
2023 vintage	**UK-based project**

Carbon Hill biochar, Wales

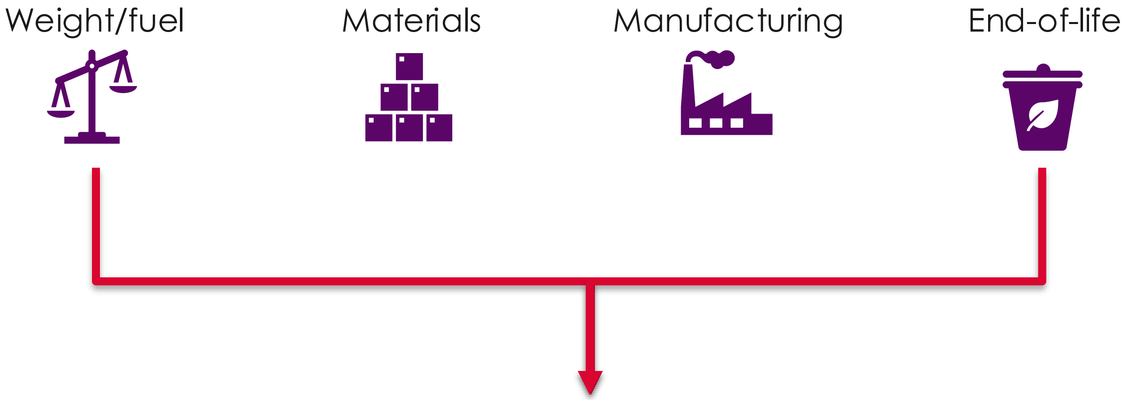
- Family farm, near our Swansea customer centre
- Hedgerow cuttings and local garden waste feedstock
- Innovative pyrolysis system, producing biochar with minimal emissions
- High pyrolysis temperature (800°C) and high H:Corg ratio ensures durable biochar (~1,000 years)

Flight100 LCA – Onboard services

A testbed for innovation onboard – a dedicated LCA was undertaken measuring impact of F100 trial of single use plastic alternatives in Economy and Premium cabins

SUP cups replaced with multi-use alternative

Plastic blanket wraps replaced with paper band



Additional CO_2 emissions resulting from increased weight and washing.

Divert **>33 million SUP items** (156 tonnes) from landfill and incineration

Additional CO_2 emissions resulting from increased laundering.

Divert **>6 million SUP items** (13 tonnes) from landfill and incineration

Approach

LCA review

Review of existing LCA methodologies

Lifecycle mapping

Identify impacts throughout flight lifecycle

Data collection

Value change stakeholder engagement

Lifecycle impact assessment

Quantification of baseline flight emissions

Flight100 analysis

Flight100 impacts & 100% SAF analysis

Carbon removals

Residual emissions mitigation w. Biochar

Flight100 LCA Takeaways

Net-zero
Mitigating aviation CO_2e must be viewed as a shared responsibility

Carbon removals
Support for UK-based removals in aviation decarbonisation and policy

Data
Granularity, collection and allocation challenge requires streamlining to support future flight LCAs

Methodology
Established replicable LCA framework for the industry

Operational Efficiencies

Operational Efficiencies Objectives

1. Demonstrate collective impact of existing fuel efficiency initiatives in place across the Virgin Atlantic BAU operation
2. Trial emerging technologies / efficiency solutions to evaluate potential impact for future deployment
3. Highlight and quantify the fuel and carbon inefficiencies across air traffic congestion – to identify biggest opportunities for improvement

Key results

9 Ground based and in-flight fuel efficiency initiatives were a focus point for delivering firther CO2 reductions beyond the use of SAF

2,191 kgs

Initiative-led Fuel Reduction

4.4%

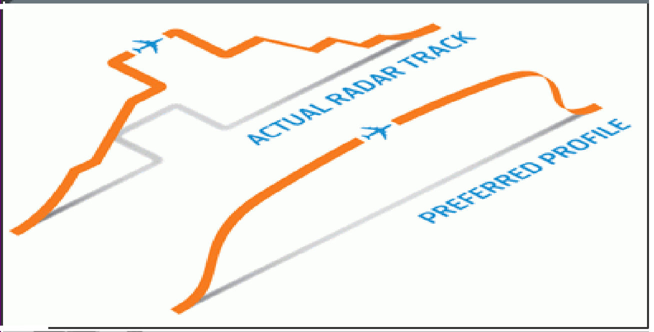
8,413
kgs CO_2e

Versus same flight without initiatives

48.7 Mil kgs

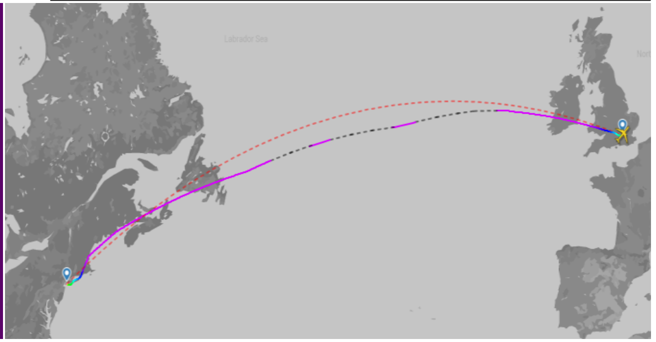
60.6 Mil litres

4.4% scaled to 2023 fuel burn data



3,928
London Buses

24
Olympic Swimming Pools

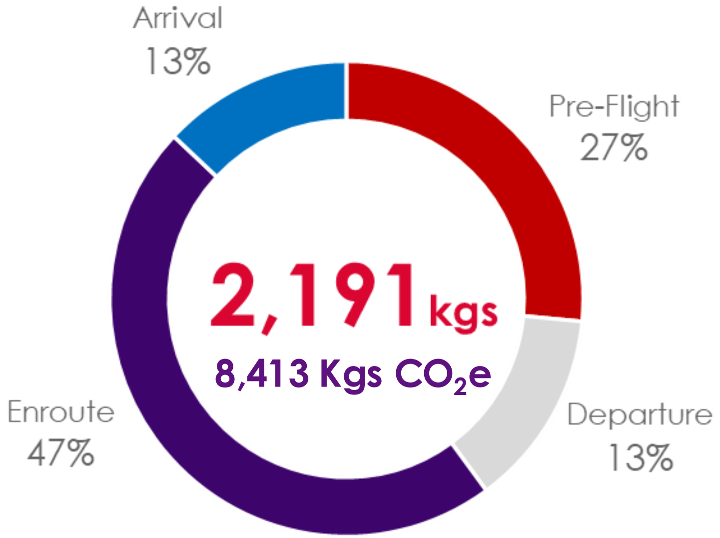


Initiatives Breakdown

70% of fuel savings related to opportunities relating to Air Traffic Management – demonstrating the opportunities that exist for airspace modernisation

1 Pre-Flight	2 Departure	3 Enroute	4 Arrival
~581 kgs	~294 kgs	~1,031 kgs	~285 kgs

PRE	Optimal Stand Allocation	Optimised Potable Water Loading	Priority Departure
DEP	Continuous Climb Operations (CCO)	Climb Cost Index Optimisation	
ENR	ANSP Supported Efficient Routing	Reduced Contingency Fuel	Cost Index Re-Optimisation
ARR	Continuous Descent Arrival (CDA)	ATC Priority	Reduced Engine Taxi-In (RETI)



Key Takeaways and Next Steps

Collaboration
Fuel efficiencies cannot be achieved in silos. They require radical collaboration across industry and beyond

Innovation
The low hanging fruit is gone. Future efficiencies will demand an innovative and creative approach

Perception
Leverage behavioural science to motivate and empower pilots to take impactful fuel efficiency decisions

Regulation
Through effective regulation, investment, and incentivisation, Government and industry can build a progressive and sustainable sector

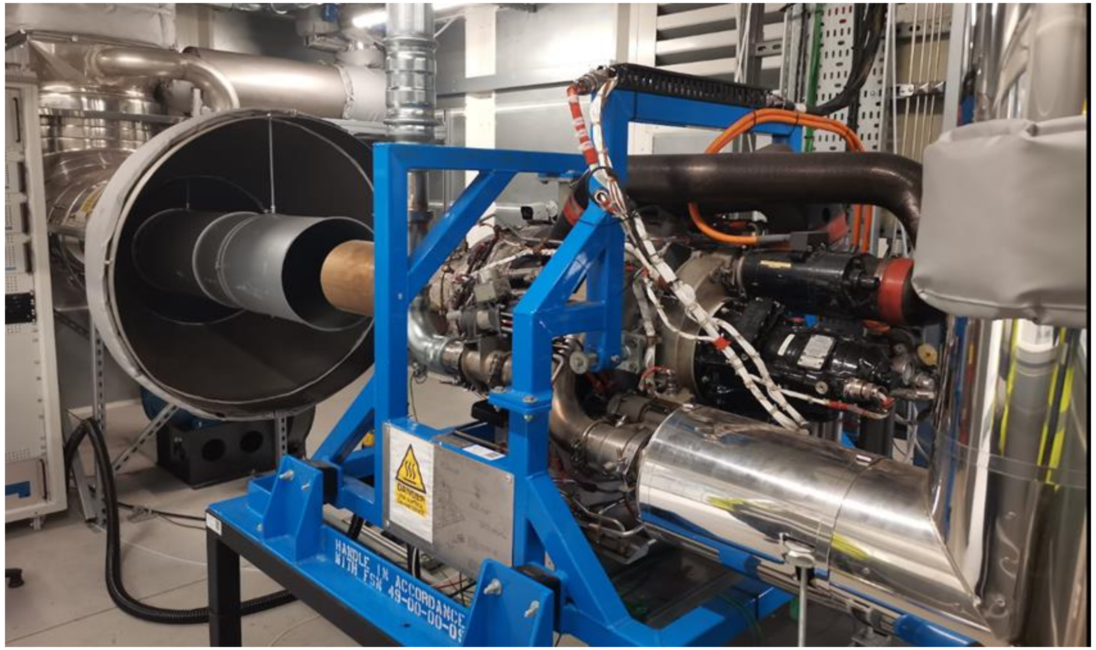
Non CO_2

virgin atlantic

Sustainable Aviation Fuels Innovation Centre

The impact of Flight-100 fuel on emission performance in an auxiliary power unit (APU)

The Sustainable Aviation Fuels Innovation Centre (SAF-IC) is the UK's first centre to develop, test, validate and certify zero-carbon and sustainable aviation fuels all in one location.

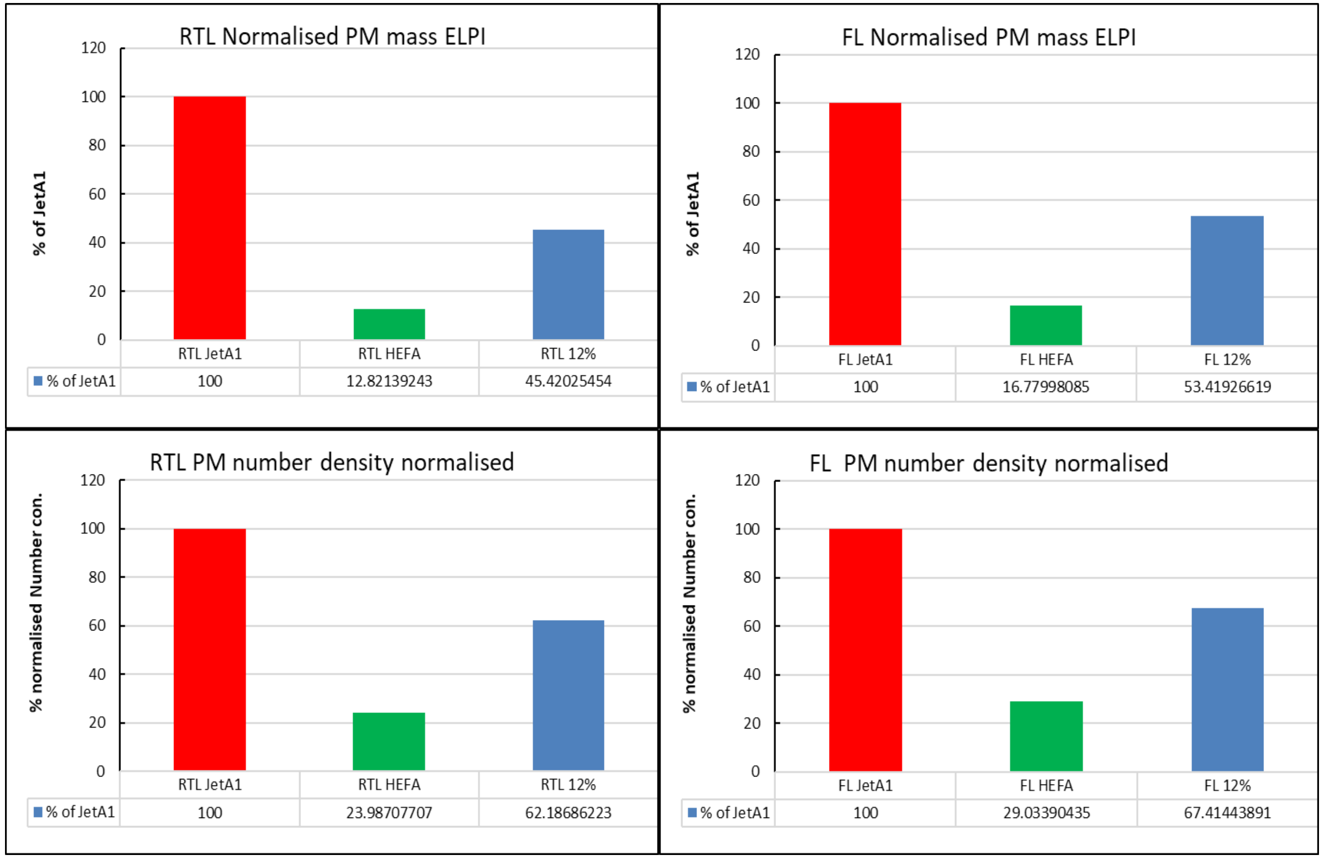


Honeywell 131_9A APU was deployed to test the fuels at two different loading conditions

The 131-9 APU, found in Boeing 737-600/-700/-800 and Airbus A319/20/21 aircrafts, serves as a versatile self-contained power unit

Non-CO_2

Flight100 SAF testing resulted in a reduction in particulates, with potential benefits for local air quality around airports and in the reduction of persistent contrails



Normalised data from the LII-300 and ELPI representing % reduction of nvPM (mass and number) from APU test at low load and full load conditions.

The APU testing revealed a marked reduction in both the number and mass of particulate emissions when using Flight-100 fuel (HEFA-SAK) and the HEFA component compared to conventional Jet A-1

Reduction on low load in comparison to full load

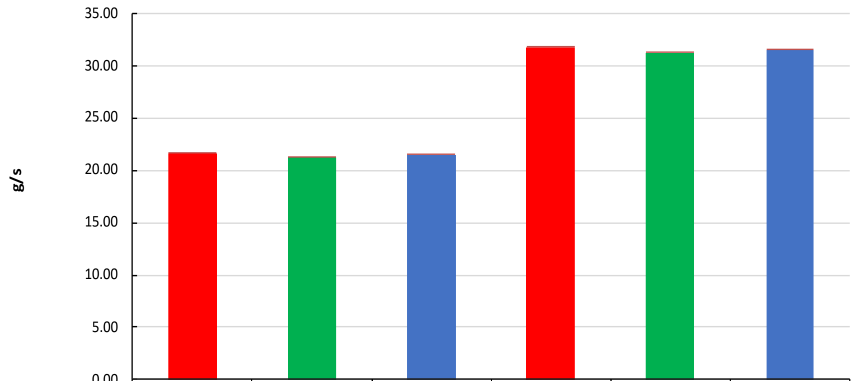
Flight100 SAF generated **40% less particulates** vs Jet A-1

The pure HEFA component generated 70% less particulates compared to that of Jet A-1

Aviation Fuel Consumption

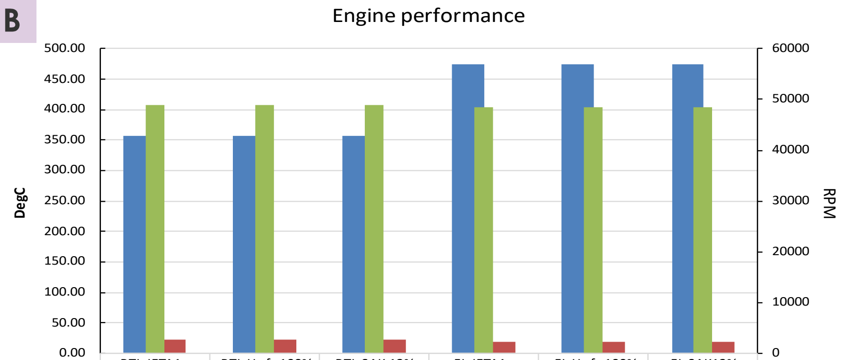
Lab results indicated that the SAF used for Flight100 had a 1% higher energy density compared to Jet A-1

A



	RTL JETA1n	RTL Hefa 100%	RTL SAK 12%	FL JETA1n	FL Hefa 100%	FL SAK12%
Fuel Flow std	0.04	0.03	0.04	0.04	0.04	0.06
Fuel Flow	21.62	21.25	21.46	31.84	31.24	31.52

B



	RTL JETA1n	RTL Hefa 100%	RTL SAK 12%	FL JETA1n	FL Hefa 100%	FL SAK12%
AV. EGT	357.25	357.12	357.54	475.30	473.62	474.45
InletTemp:1	22.02	22.07	22.18	19.13	19.29	19.28
N1RPM	48798.92	48799.24	48798.98	48363.59	48363.30	48363.65

Flight-100 Fuel (HEFA & SAK) having a higher energy density than conventional jet fuel, an increase of 0.95% to 2.2% in fuel efficiency was observed during APU ground engine test

Subject to confirmation in aircraft engine, not only will this increase the range of an aircraft, but it will also decrease its hourly fuel burn figure

This, in turn, will reduce the emissions produced from an aircraft during its mission

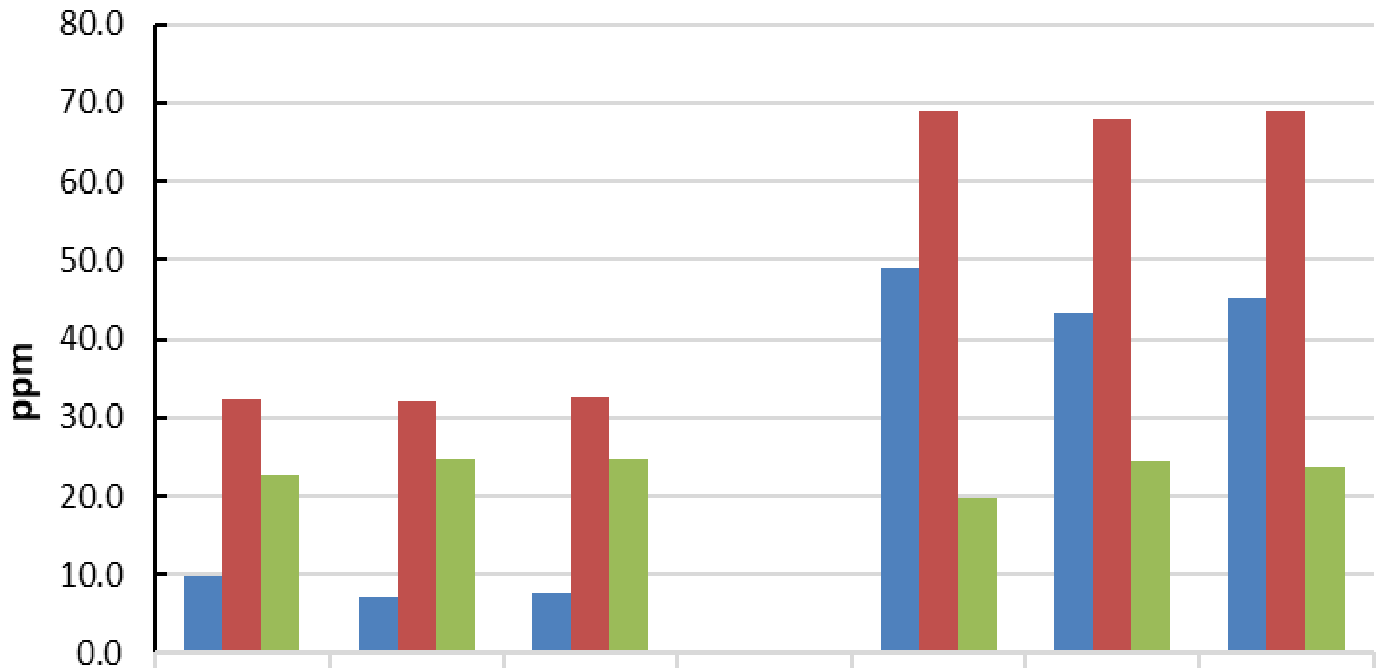
350kg of fuel was saved during Flight100 as a result of the higher energy density. This could save up to 400,000 tonnes of jet fuel globally based on a 10% SAF target by 2030

A *The fuel flow and standard deviation for the three fuels, Jet A-1, HEFA and SAF at two loading conditions (RTL & FL) with SD*

B *Figure 19 EGT, inlet temp and rpm for the three fuels, jet A-1 HEFA & SAK at two loading conditions (RTL & FL)*

Non-CO_2

The impact of Flight100 fuel on emission performance in an auxiliary power unit (APU)



	RTL JETA1	RTL HEFA	RTL SAK 12%		FL JETA1	FL HEFA	FL SAK12%
NO	9.8	7.2	7.8		49.1	43.4	45.1
NOX	32.4	32.0	32.5		68.9	67.9	68.9
NO2	22.7	24.8	24.7		19.8	24.6	23.7

Byproducts of combustion gases from aviation fuel, composed mainly of CO2, NOx, SOx, and water vapor

The APU experiments show that no significant change of NOx emissions for Flight-100 Fuel was observed.

However, EFNOx (in terms of NOX generated per trip) reduced by 1.5%.

Variation on NO/NO2 ratio requires further investigation

Key results

Testing HEFA and HEFA-SAK blends against standard JetA1 fuel in a Honeywell 131-9A APU showed clear environmental advantages

Emission Reductions:

1. HEFA and the HEFA/SAK blend demonstrated significant reductions in both particulate number and mass concentrations compared to the conventional JetA1 baseline
2. Reduction in NOx (EFNOx) and Soot (EFsoot) Emission index compared to conventional jet fuel.

Particulate Matter Analysis

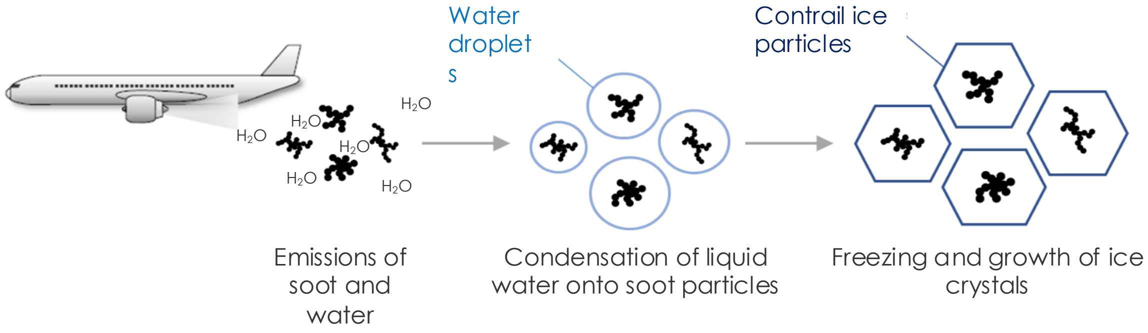
1. The LII300 results indicated that HEFA and the HEFA/SAK blend particulate matter have an increased active soot surface area compared to those of JetA1.

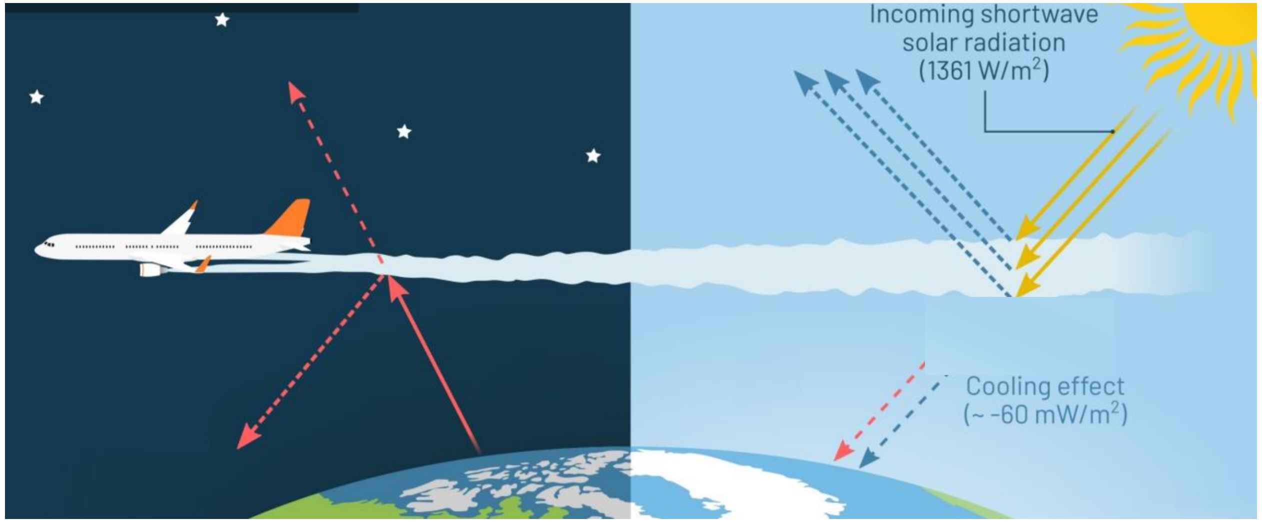
Fuel Consumption (by mass)

1. Evidence from the study suggests that when using HEFA and the HEFA/SAK blend, there was a 2.2%-0.95% improvement in fuel consumption (by mass)
2. These findings underscore the importance of considering not only emissions but also fuel consumption (by mass) when evaluating alternative aviation fuels.

What are contrails?

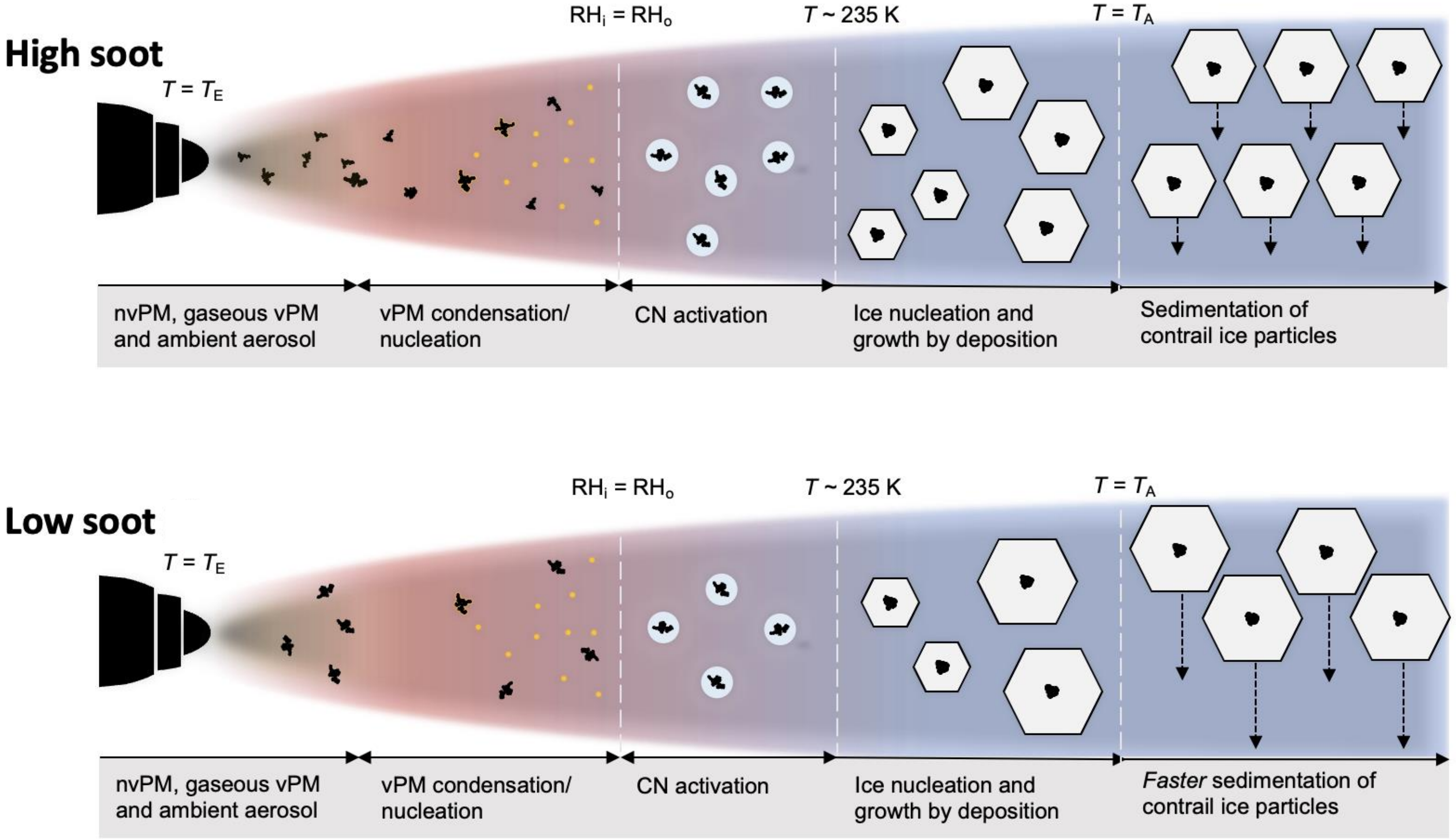
Contrails are line-shaped ice clouds formed when water vapour condenses and freezes on emitted soot particles.





How does SAF affect contrails?

SAF reduces the number of contrail ice particles, which reduces the contrail lifetime and climate effect.



Shorter lifetime and smaller RF

Contrail modelling workflow

Determining where contrails may form requires several models and accurate input data.

Flight trajectories

Aircraft-engine assignment

Aircraft performance

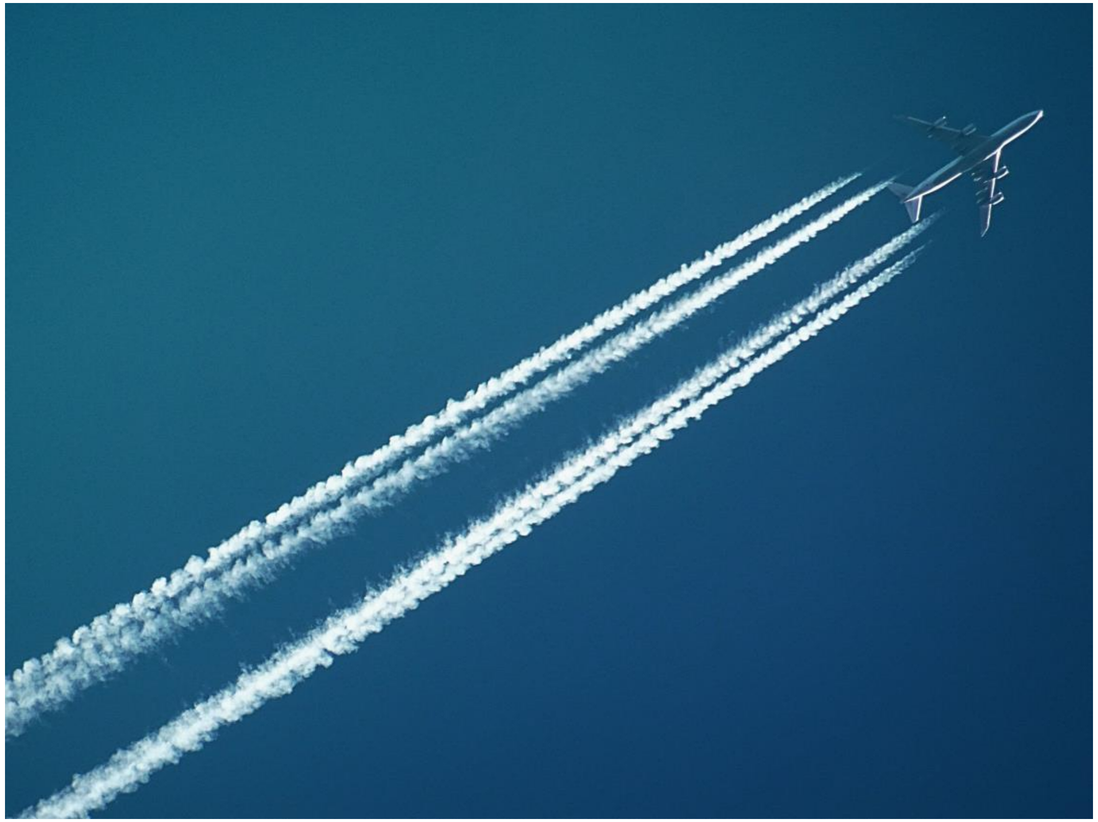
- Fuel consumption,
- Aircraft mass,
- Propulsion efficiency

Particle number emissions

- Meteorology
- Fuel properties

CoCiP contrail model

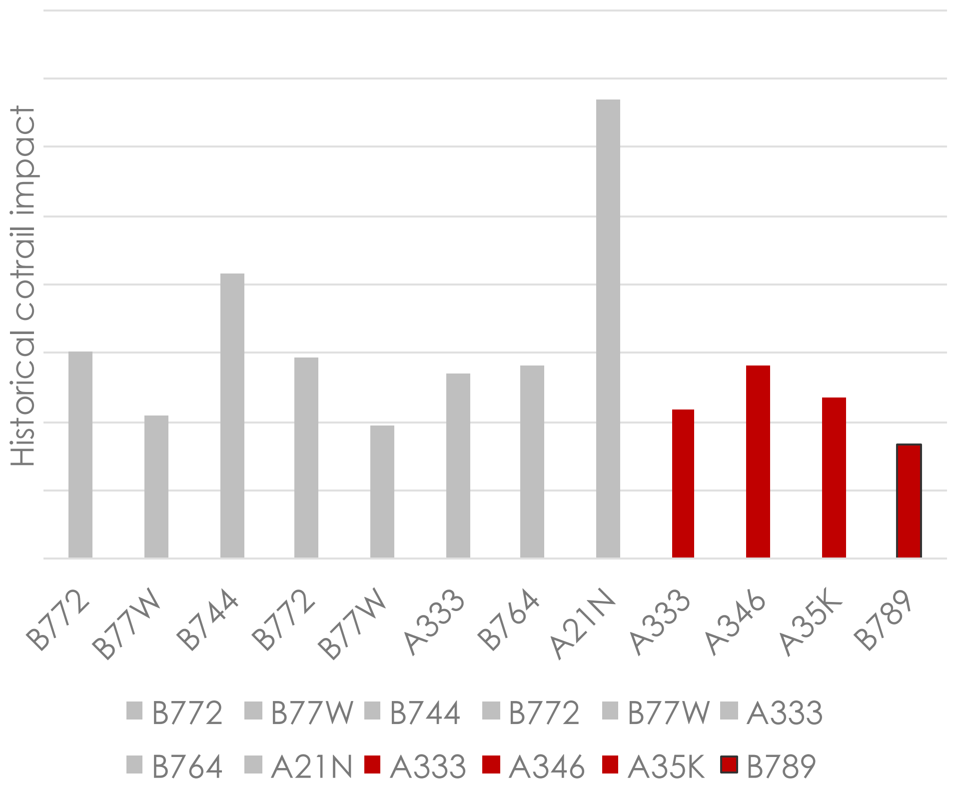
- Formation, properties, lifetime, climate forcing



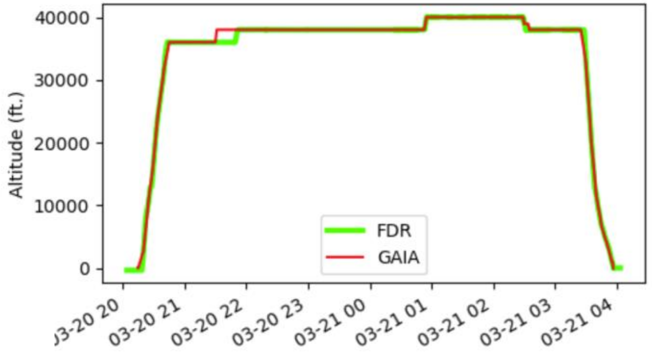
Baselining historical flights

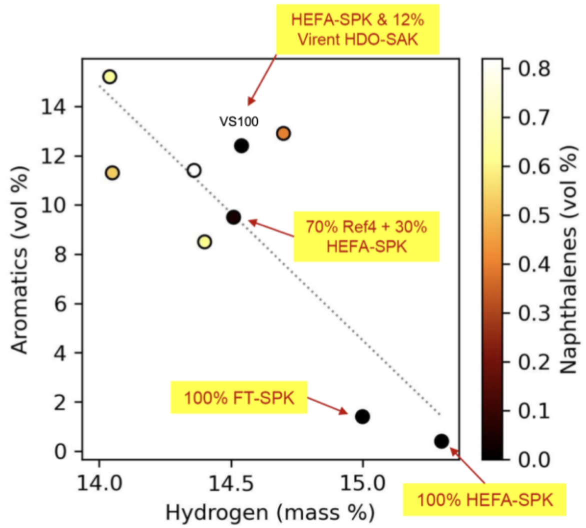
The B787 typically has lower contrail impacts than other aircraft. Accurate flight and fuel data is important.

Different contrail impacts for different aircraft and airlines due to aircraft characteristics, engine emissions and operations



Data from aircraft more accurate than our source of ADS-B



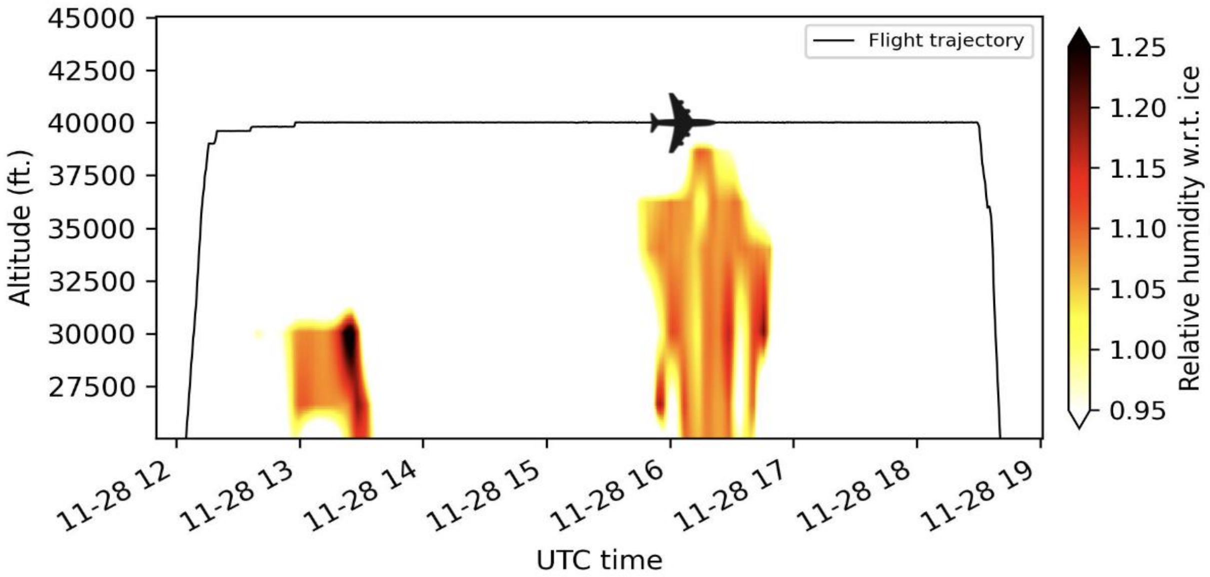


VS100 fuel fell within the range of other published studies w.r.t. hydrogen and aromatic content

Pre-flight contrail forecast and mitigation

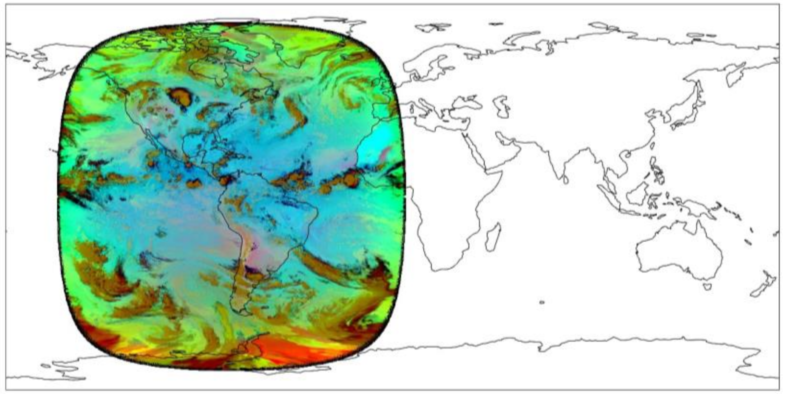
Contrail forecast provided by Imperial and Breakthrough Energy following design and process feedback from VA.

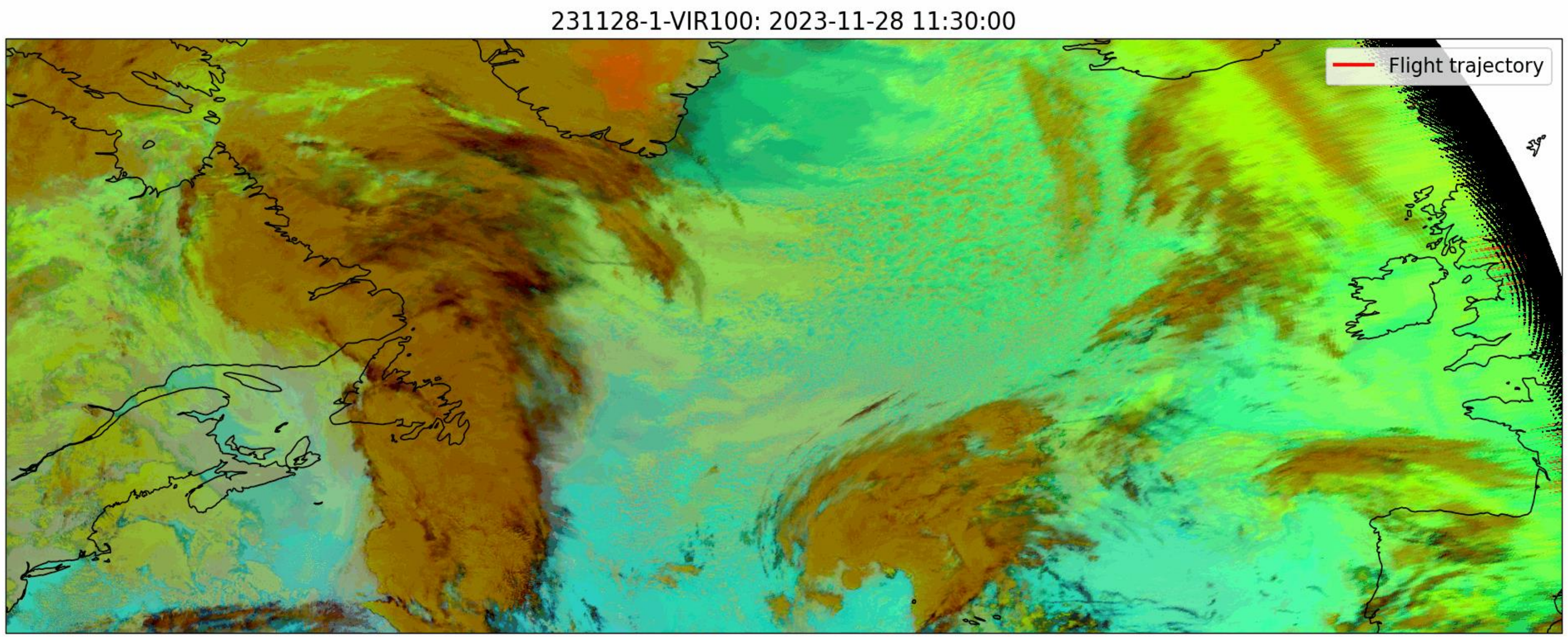
1	Contrail forecast was considered in flight planning
2	Contrail modelling predicted that Flight100 would not create any persistent contrails
3	No action to avoid contrails taken in flight plan.



Satellite observations of Flight100

Geostationary satellite images confirmed that Flight100 did not form persistent contrails.



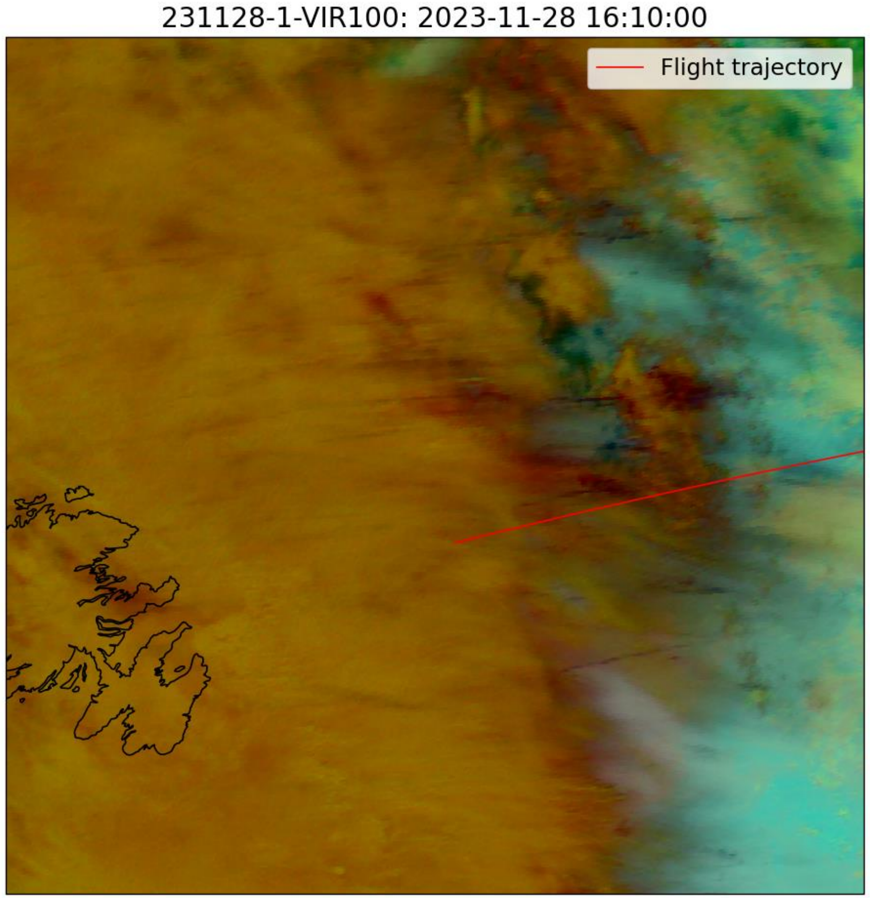


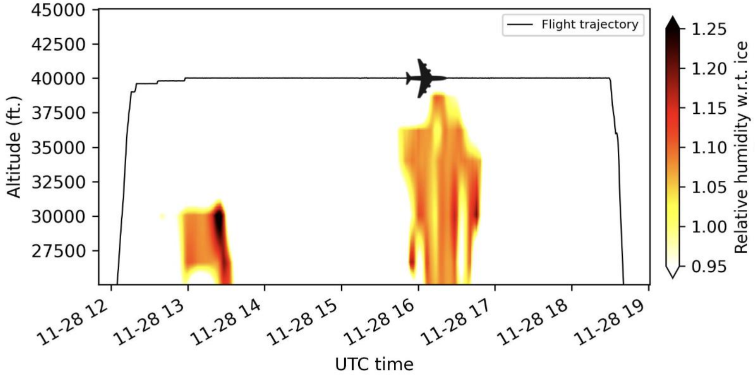
Modelling suggests that VS100 avoided ice supersaturated regions due to its high cruising altitude (FL400)

No persistent contrails were observed in satellite images

Verification with satellite

Satellite images agreed with on-board observations of contrails at lower flight levels.





Contrails observed on-board VS100

Faint blue lines can be identified from the satellite image, supporting the formation of persistent contrails at lower flight levels

Lessons Learned

Value of incorporating contrail forecasting into flight planning demonstrated

1 **SAF effects on contrails on engine particulates -** accounted for in contrail impact modelling

2 **Contrail forecast and flight plan incorporated in Flight100 plan** - developed process with Virgin Atlantic & modelling predicted no contrail formation, therefore no action needed

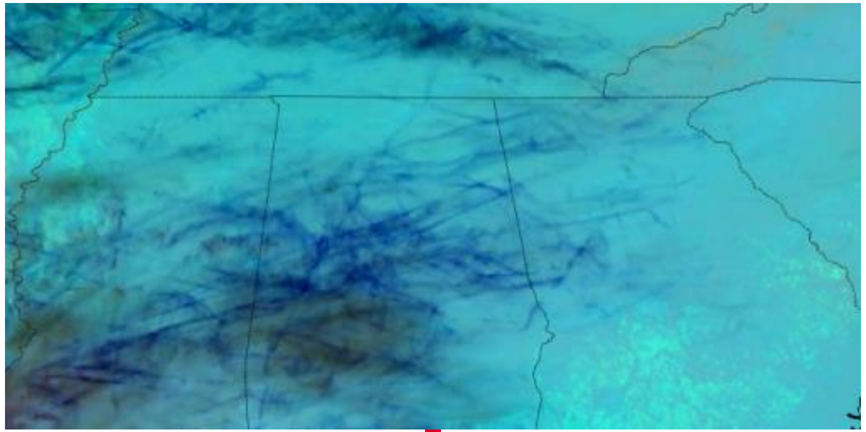
3 **Contrail observations - s**atellite images used to show that no persistent contrails formed from Flight100 but some contrails at lower flight levels observed

Contrails Observation

In addition to ground and satellite imagery, inflight contrail observations may improve contrail modeling

Ground Observations

Satellite Observations



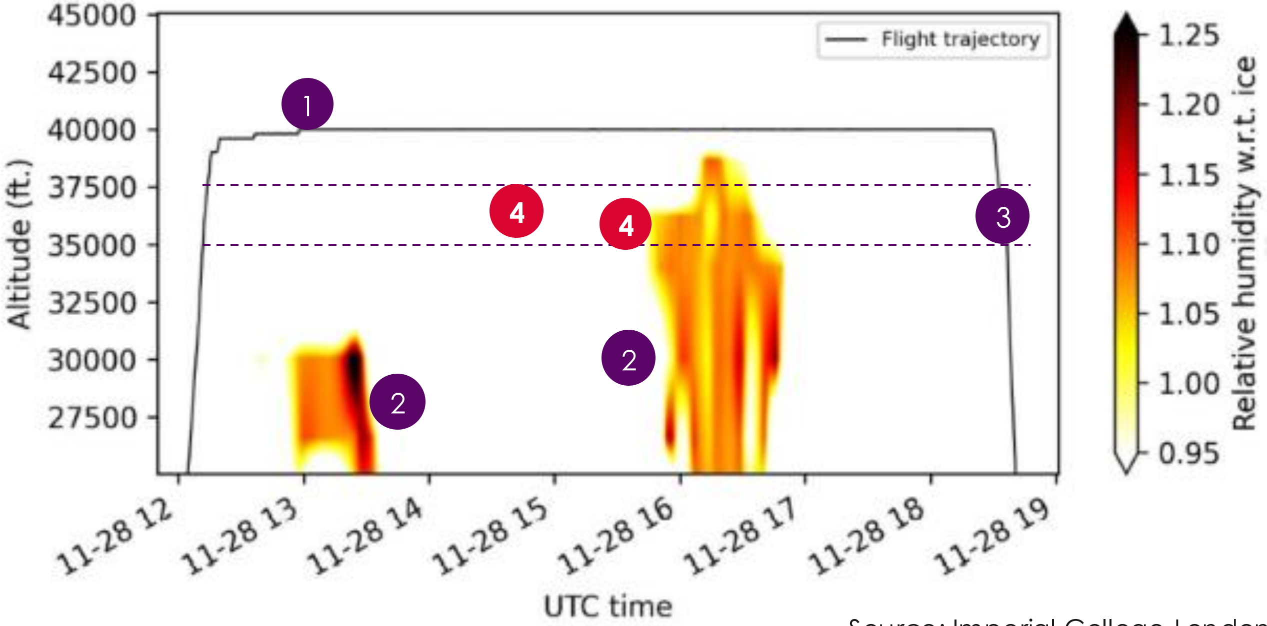
Inflight Observations

Contrail Prediction Calibration

Contrails Observation

Contrails formed by other aircraft were observed in forecast formation regions along the Flight100 route

Forecast of areas likely to produce persistent contrails



Source: Imperial College London

Source: Imperial College London

1 *Shows F100 flight path and altitude*

2 *Shows forecast areas conducive to contrail formation – ice supersaturated regions*

3 *Shows indicative "normal" cruising altitude with commercial operation i.e. higher load factor / cargo*

4 Observed contrails from flights operating at lower altitude vs F100

Contrails Observation

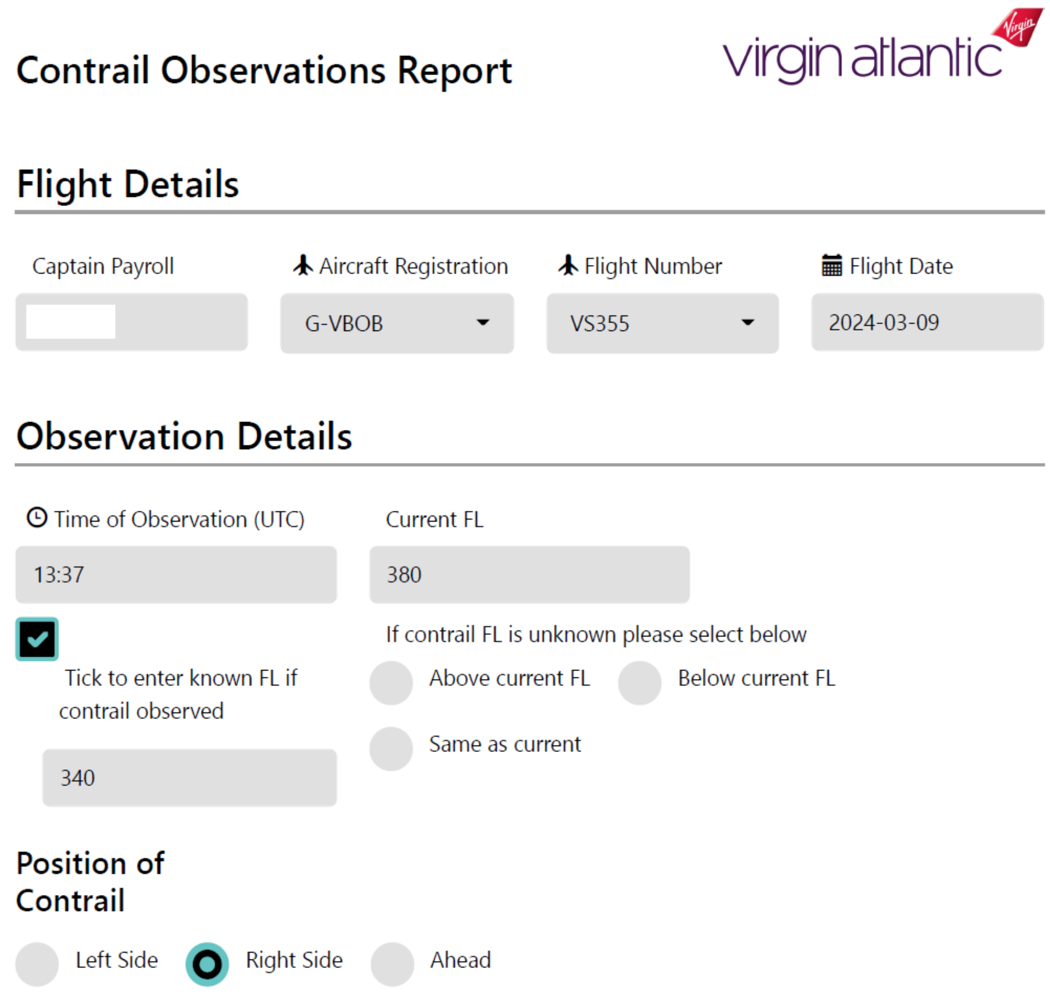
Virgin Atlantic trialled inflight Pilot Report eform procedures to report contrail formations

Flight Details

- Flight number
- Aircraft Registration
- Flight date
- Flight Captain

Observation Details

- Current flight level of reporting a/c
- Flight level of contrail observed
- Position of contrail relative to reporting a/c
- Time of observation



Lessons Learned

Virgin Atlantic research has now provided over 200 observation reports to further develop accuracy of contrail forecasting predictions

1. **~200 observations made since November 2023** – Optimistic that the observation process will be increasingly useful as it is expanded to additional routes

2. **Easy to use and replicable process** – eform developed using in-house resources. Basic inputs make the form easy to complete with limited initial training required

3. **Additional training for increased accuracy may be useful** – Perceptions of contrail persistence may vary, resulting in false positive observations

Contrail avoidance

For Flight100 the Virgin Atlantic team deployed manual workarounds to incorporate forecasting – more to be done to streamline adoption and impact operationally

Flight 100

- Flight planning for Contrail avoidance via manual process – Manually manipulating vertical profile to avoid areas displayed by the forecast
- Limitations on extra fuel burn
- To upscale avoidance the process needs to be more streamline
- Note on OFP to alert crews of any avoiding action

Next Steps

- Contrail avoidance could be viewed in a similar way to avoidance of turbulence and weather if we are able to accurately predict
- Virgin Atlantic trial planning flights using contrail avoidance information with the CAE flight planning software and Breakthrough Energy forecast modelling
- Trial will be on specific sectors with only vertical avoidance being completed
- Limitation on the extra fuel burn required to avoid contrails
- More extensive briefing material for flight crew on contrail areas
- Continue building database of pilot reports to be used for forecast validations

Q&A

Summary report available on our website – virginatlantic.com

Email us at: Flight100@fly.virgin.com