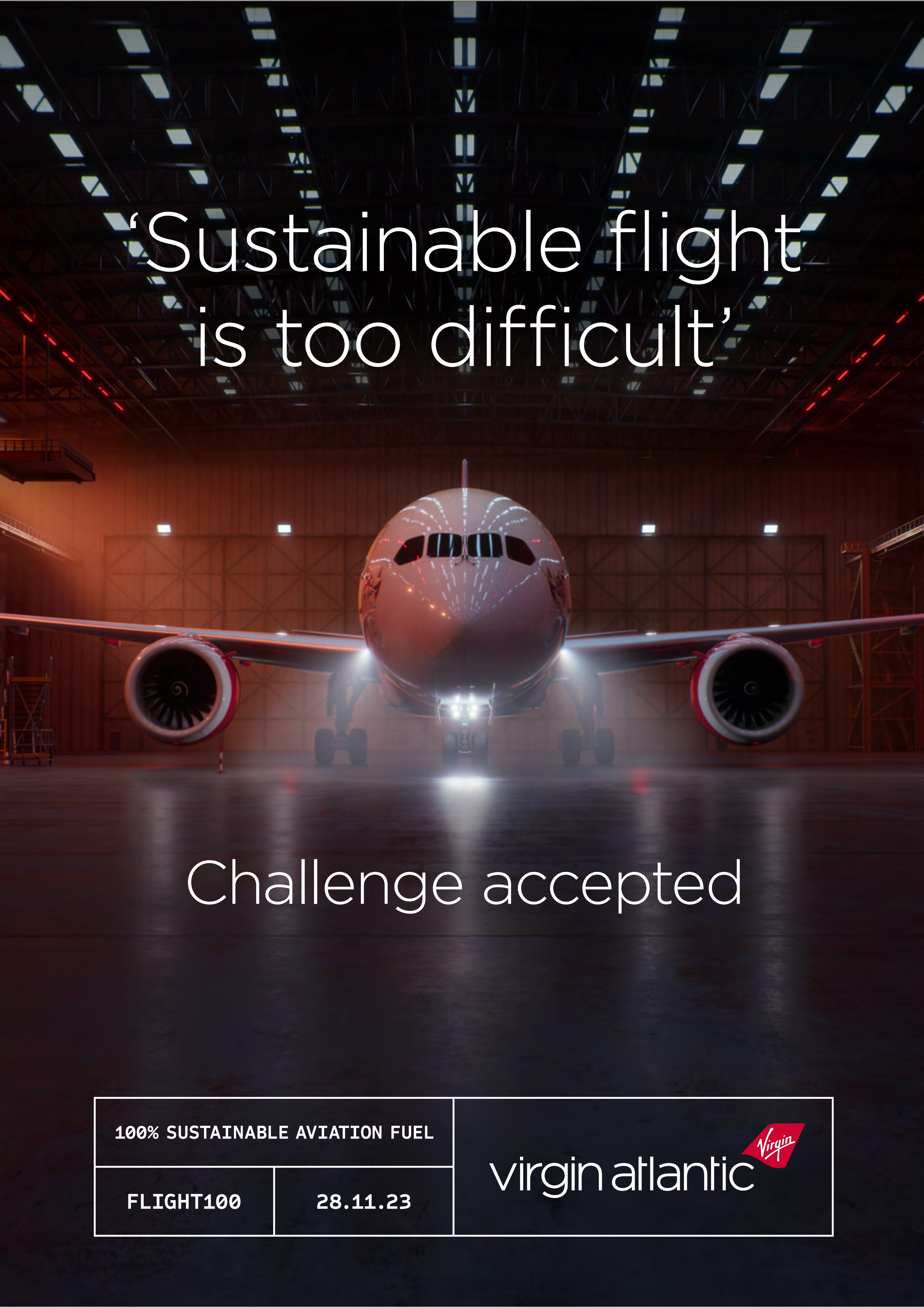

‘Sustainable flight is too difficult’

Challenge accepted

100% SUSTAINABLE AVIATION FUEL

FLIGHT100

28.11.23

virgin atlantic

Foreword

virgin atlantic
University of Sheffield
Rolls Royce
Boeing
Department for Transport
ICF
Imperial College London
ARMI

On 28 November 2023, Virgin Atlantic successfully operated the world's first 100% Sustainable Aviation Fuel (SAF) flight across the Atlantic from London to New York on a commercial aircraft. Flown on a Boeing 787-9 and powered by Rolls-Royce Trent 1000 engines.

Flight100 was more than a year in the making; following a call to action from the Department for Transport (DfT) and demonstrating that together we can achieve more than we can alone. In our Line in the Sand Manifesto, published in 2021, we set out our commitment to finding new solutions, to lead efforts to decarbonise our industry and to share any learnings or innovations Virgin Atlantic made. This same approach underpinned Flight100.

> ‘Virgin Atlantic is committed to being at the forefront of the monumental effort required to decarbonise long haul flight’

We have demonstrated that it can be done, 100% SAF flown under equivalent safety standards to every other commercial flight. No engine, airframe or fuel infrastructure modifications needed. Just 100% SAF as a full, drop-in replacement for fossil derived Jet A-1.

This report sets out the key findings from Flight100. Ranging from the carbon emission savings achieved, fuel performance vs fossil derived Jet A-1 and the wider environmental benefits that adopting SAF may deliver in the future. Since the flight we have frequently been asked ‘when are all flights operating at 100% SAF?’. The answer is we are ready, but a scale up in production of c. 100 times from where we are today is needed to meet 10% SAF by 2030. We must now see urgent action from Government, oil majors and private capital to invest in the production capacity needed to deliver a thriving UK SAF industry.

We’ve proven that if enough SAF is made, we will fly it.

Shai Weiss, CEO Virgin Atlantic

It was a privilege to be onboard Flight100 with the amazing teams that made it happen. Third time lucky for me at world record attempts across the Atlantic, having been fished out of the Atlantic in some of my previous efforts to cross the transatlantic by hot air balloon and boat. I want to thank everyone that worked tirelessly in the year leading up to the flight, not just at Virgin Atlantic but across our consortium partners. Flight100 was an example of what can be achieved through collective ambition and radical collaboration.

Challenging the status quo is in our DNA at Virgin. Proving that 100% SAF is operationally achievable today, with equivalent safety standards to all our other flights, was a pivotal moment but not a silver bullet. There is more work ahead to scale SAF at pace and whilst we cannot solve that challenge alone, Virgin Atlantic is committed to being at the forefront of the monumental effort required to decarbonise long haul flight.

Sir Richard Branson

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[1] *F2023 global SAF production 600m litres (0.5m tonnes) (IATA press release (Dec 23)) vs. 10% global SAF target requirement of c. 40m tonnes (WEF, Clean Skies for Tomorrow)*

Key results

100% SAF

with equivalent safety to Jet A-1

- Demonstrated operation of widebody long haul aircraft (Boeing 787-9 with Rolls-Royce Trent 1000 engines) on 100% SAF at 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 tonnes CO_2e reduction compared to standard Virgin Atlantic flight from London Heathrow to New York JFK equivalent to a 64% CO_2e reduction
- End to end lifecycle assessment completed – providing replicable framework that can be adopted across industry

+1%

in fuel calorific value vs Jet A-1

- Lab analysis indicated that Flight100 SAF also delivered a 1% improvement in energy density compared to Jet A-1
- This result would indicate a fuel burn saving of 0.35 tonnes during Flight100 vs a standard flight using Jet A1
- At 10% SAF adoption by 2030 this could reduce total UK fuel burn by 12k tonnes and 400k tonnes globally

4.4%

fuel reduction through operational efficiencies

- Flight100 deployed nine ground and flight ops efficiency initiatives avoiding 2.2 tonnes of fuel burn and 8 tonnes CO_2e
- ATM and flight path initiatives delivered 70% of those benefits – highlighting the opportunity for international collaboration across air traffic management

40%

reduction in particulates

- Flight100 SAF showed a ~40% reduction in particulate matter emissions, increasing to 70% for the HEFA component alone
- Demonstrating the potential of SAF to reduce the environmental impact of emissions beyond carbon
- Reduction in particulates is also likely to reduce the in-air creation of persistent radiative forcing contrails

0

contrails

- Flight100 verified the accuracy of contrail creation forecasting and visual monitoring observed persistent contrail formation of aircraft at lower flight path levels
- Breakthrough Energy open-source model incorporated into flight planning
- No contrails formed in flight due to higher-than-normal cruising altitude of 40,000 feet

Permit to fly and overflight approvals

100%
SAF
operating with equivalent safety to Jet A-1

Safety and security underpins everything we do at Virgin Atlantic and across the aviation industry. Flight100 was no exception. It operated at an equivalent level of safety to any other commercial service we fly. And whilst, in the air, it performed and felt like any other flight, the approval process ahead of take-off was multifaceted.

The **100% SAF** used for Flight100 was a blend of **87% HEFA-SPK**[2] sourced from the EU and supplied by Air bp and **13% SAK**[3], a SAF rich in aromatic compounds and supplied by Virent Inc. from the US.

This unique SAF blend is not approved as a qualifying fuel for use in commercial aviation by the ASTM, a leading international technical standards body for aviation fuel. The HEFA SAF component, whilst approved under the ASTM, is subject to a blend cap of 50%, meaning that it must be mixed with at least 50% Jet A-1 to be used in commercial aircraft. The SAK component is an uncertified fuel that is currently going through the ASTM technical qualification process and therefore cannot yet be used, at any volume, in any commercial service.

The nature of the SAF blend and its use at 100% required a markedly different testing and regulatory approval process compared to business-as-usual operations.

- Flight100 could not operate under the normal pre-approved Commercial Air Transport criteria;
- It required a one-off approval as a non-commercial Permit to Fly (granted by the UK Civil Aviation Authority (CAA), as a UK originating and UK airline operated flight);
- Given the transatlantic routing, overflight approvals were also required from the Irish, Canadian and American civil aviation authorities.

The Permit to Fly approval process required extensive assessment across Virgin Atlantic, our consortium partners (Boeing and Rolls-Royce) and fuel suppliers (Air bp and Virent Inc). This included fuel property analysis, engine performance testing and a wide range of technical and operational assessments. The key processes and findings are set out below in the Technical and Engineering section. All testing outputs formed part of the extensive Virgin Atlantic safety case submitted as part of the Permit to Fly application.

The Permit to Fly was issued on 3rd November 2023 with a lead approval for our Boeing 787-9 aircraft. selected for Flight100 (G-VDIA), powered by Rolls-Royce Trent 1000 engine. As a Permit to Fly approval relates to a single aircraft – Virgin Atlantic actually submitted and received two approvals (one on a backup aircraft) to hedge against the risk of aircraft-G-VDIA being unavailable (for example, any engineering or maintenance check failures pre-flight). In a similar vein, duplicate approvals were also sought and received from overflight authorities.

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[2] Hydroprocessed Esters and Fatty Acids-Synthetic Paraffinic Kerosene
[3] Synthetic Aromatic Kerosene

The overflight approvals from the Irish Aviation Authority (IAA) and Transport Canada Civil Aviation Authority (TCCAA) were received on 6th November 2023, the US Federal Aviation Authority (FAA) issued its Special Flight Authorisation (SFA) on 14th November 2023.

Early engagement with authorities and particularly the CAA was key to delivering Flight100 within the timeframe (12 months from competition award to operation). Across the consortium, we established open, transparent and collaborative information sharing following a process of technical and operational working groups, alongside senior stakeholder checkpoints. A cadence that ran for nine months to review key findings and progress against critical milestones including:

- Early definition and visibility of all technical and operational considerations required for the Permit to Fly submission;
- Key learnings from previous demonstration flights including the Virgin Atlantic and Boeing first ever commercial flight with SAF (at 5%) in 2008 through to Rolls-Royce's support of the Royal Air Force Voyager 100% SAF flight over UK airspace in November 2022;
- Real-time updates of the technical assessments and performance validations required for the use of 100% SAF in a Rolls-Royce Trent 1000 powered, Boeing 787-9 aircraft.

Included in the consortium bid to operate Flight100 was the ambition to carry observers onboard. Those with a role to play in advancing SAF adoption from a technical, operational, policy, sustainability or communication perspective. To put that ambition in the context of a Permit to Fly – normally only essential personnel (usually pilots and engineers) are approved to fly on these types of flights. On Flight100, we carried 110 essential observers as well as four tonnes of cargo. No observer or cargo carried was revenue generating; all our usual terms and conditions of carriage applied and whilst not at full load factor, Flight100 operated under comparable conditions to a commercial flight, one of our primary objectives in this project.

Technical and engineering

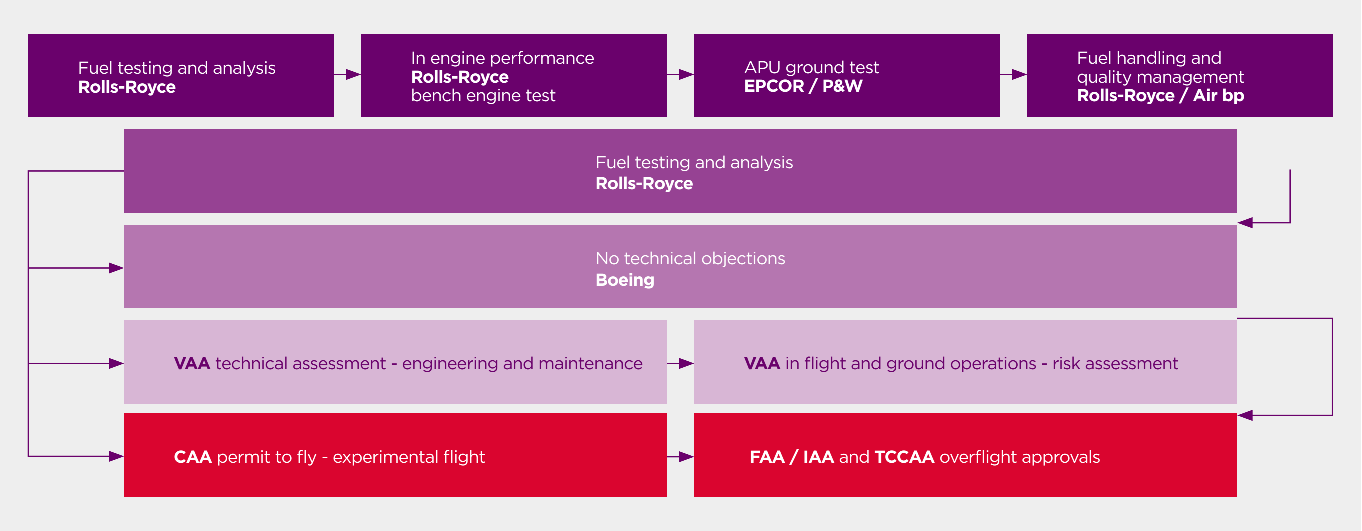
With our partners at Rolls-Royce and Boeing, the Virgin Atlantic Engineering and Maintenance team completed extensive evaluation and testing of the 100% SAF fuel in combination with both the Rolls-Royce Trent 1000 engines and the 787 aircraft and its systems. This technical evaluation, along with rigorous reviews by multiple teams across Virgin Atlantic, was reviewed and approved by the CAA, who subsequently issued the Permit to Fly.

Virgin Atlantic submitted 39 supporting documents with the Permit to Fly and overflight applications covering technical evaluations, results, methodologies and procedures that would be in place for Flight100.

The key elements included:

1. **Fuel Analysis:** the proposed SAF blend was analysed in laboratories to demonstrate equivalency to ASTM standards of Jet A-1 (see below).
2. **Ground based engine and aircraft tests:** undertaken to demonstrate the equivalent operational performance on the engine, airframe or Auxiliary Power Unit (APU)[4] systems without detrimental impact to the equipment.
3. **Fuel handling process:** developed to ensure compliance with industry best practice in order to mitigate cross contamination.
4. **Operational Limitation Note (OLN):** issued by Rolls-Royce defining engine related procedures, checks and inspections which need to be observed when using Flight100 SAF.
5. **No Technical Objection (NTO):** issued by Boeing and detailing all aspects of the hazards and mitigations assessment across the entire fuel system and all engines. In addition, the NTO defined all the maintenance requirements pre and post flight required to enable the aircraft to return to commercial service.
6. **Virgin Atlantic technical, and operational assessments:** taking account of all the above inputs to define the maintenance and engineering procedures, checks and controls before, during and post flight.
7. **Virgin Atlantic's overarching evaluation:** of all risk and effective mitigations, to ensure Flight100 operated at an equivalent level of safety to any other Virgin Atlantic flight.

Figure 1. Simplified testing and technical analysis for Flight100



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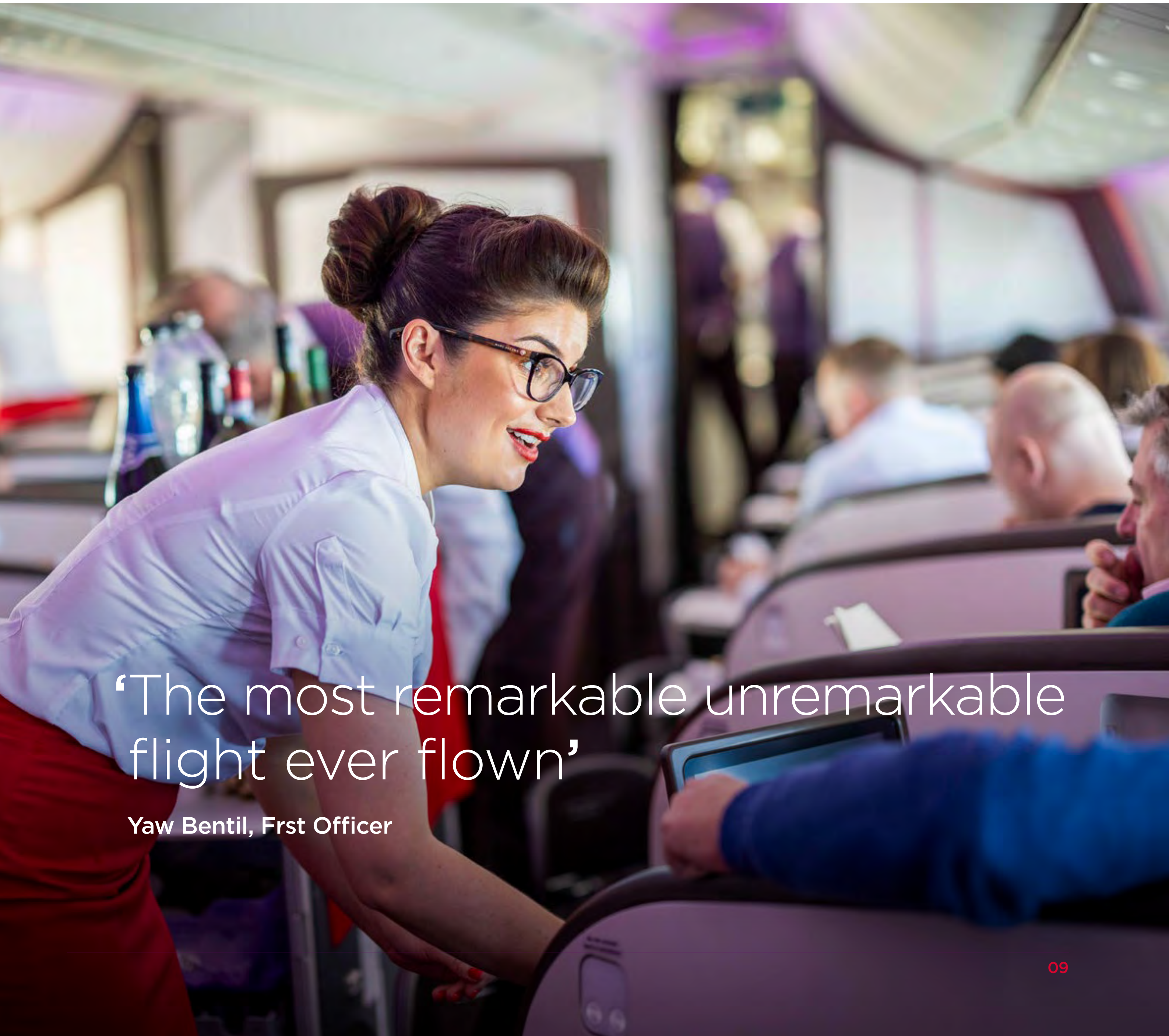
[4] *An APU is a non-engine powerplant on the aircraft used to support electrical power generation*

On the 29th of November, the day after Flight100, G-VDIA returned to commercial service from New York JFK. This followed the completion of a number of precautionary procedures including manual inspections, flight data review, as well as on the ground engine running to purge the fuel lines. In all subsequent engineering and maintenance checks on G-VDIA since Flight100 we have not observed any adverse impacts of 100% SAF use to the engine, airframe or APU.

Whilst all SAF types differ, the analysis undertaken and playbooks developed by the consortium in Flight100, demonstrate that there are types of 100% SAF capable of an ASTM equivalent standard to Jet A-1 today.



> ‘The most remarkable unremarkable flight ever flown’
>
> **Yaw Bentil, First Officer**

Fuel characteristics

The aim of Flight100 was to build on progress to date and further develop OEM, operator and regulatory experience in the practical application of using 100% SAF. At the outset of our consortium bid, we set fuel density and aromatic compound targets at a technical equivalency to Jet A-1.

The density target was 0.778 +/- 0.5 kgm^3. This equated to a proposed SAF blend mix of 88% HEFA to 12% SAK and a total aromatic concentration of 13%. The target fuel characteristics outline above reduced the risks of engine and fuel system seal degradation (which can cause fuel leakage) and removed the need for any engine or airframe modifications as part of the project.

87.3% HEFA

made from waste fats (no used cooking oil) sourced from Portugal and Austria

12.7% SAK

made from dextrose i.e. sugars from non-edible industrial corn starch, post processing with all oil, protein, and fibres eligible for animal feed going into the supply chain

The fuel mix ratios used in flight varied slightly to our test ratios of 88%/12% - adjustments were made between testing and flight to achieve the required fuel density

Figure 2. Flight100 SAF characteristics

Property	Method	Units	ASTM D7566 Annex 2	ASTM D1655 Jet A1	F100 SAF
Density of 15˚C	ASTM D4052	Kg/m^3	730-722	775-840	**777.7**
Aromatics	ASTM D1319	%(v/v)		Max 25	**13.1**
Distillation	ASTM D86	˚C			
18P					**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**
Kenematic viscosity of 20˚C	ASTM D445	cSt	<8cSt	8cSt	**5.063**
Kenematic viscosity of 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**

ASTM D7566: Synthesised hydrocarbons (SAF) fuel quality specifications
ASTM D1655: Jet A/A-1 fuel quality specifications
ASTM D4052: Defined method to determination of density, relative density and API Gravity of petroleum distillates
ASTM D1319: Defined method for determination of saturates, olefins and aromatic group types in petroleum fractions

> ‘Challenging the status quo is in our DNA at Virgin.’

As the fuel analysis summary in Figure 2 shows, the properties of Flight100 SAF were equivalent to ASTM criteria for Jet A-1. This gave the consortium confidence heading into ground testing that the SAF used should perform in line with traditional Jet A-1. In total, 6 Certificates of Analysis (CoA), confirming the technical equivalency to Jet A-1, were provided at various stages of the fuel batch production process, evidencing the conformity of Flight100 SAF with the defined properties of Jet A-1.

Ground engine test

Whilst conducted primarily as a validation exercise and not considered critical to engine flight clearance, a ground engine test took place at Rolls-Royce on the 13th July 2023, comparing engine performance using 100% SAF and normal Jet A-1. This testing profile is commonly used to evaluate engine performance and operability. Testing ran for a duration of four hours on the 100% SAF blend across four different thrust settings to replicate a complete flight sector.

Whilst minor differences in the engine response to the two types of fuels were observed – seen in Figure 3 as the dotted vs firm line in acceleration and deceleration phases – these were attributable to environmental conditions across the two days of testing – namely weather conditions and manual throttle inputs of different testers. Otherwise, the engine performance across both fuels was equivalent.

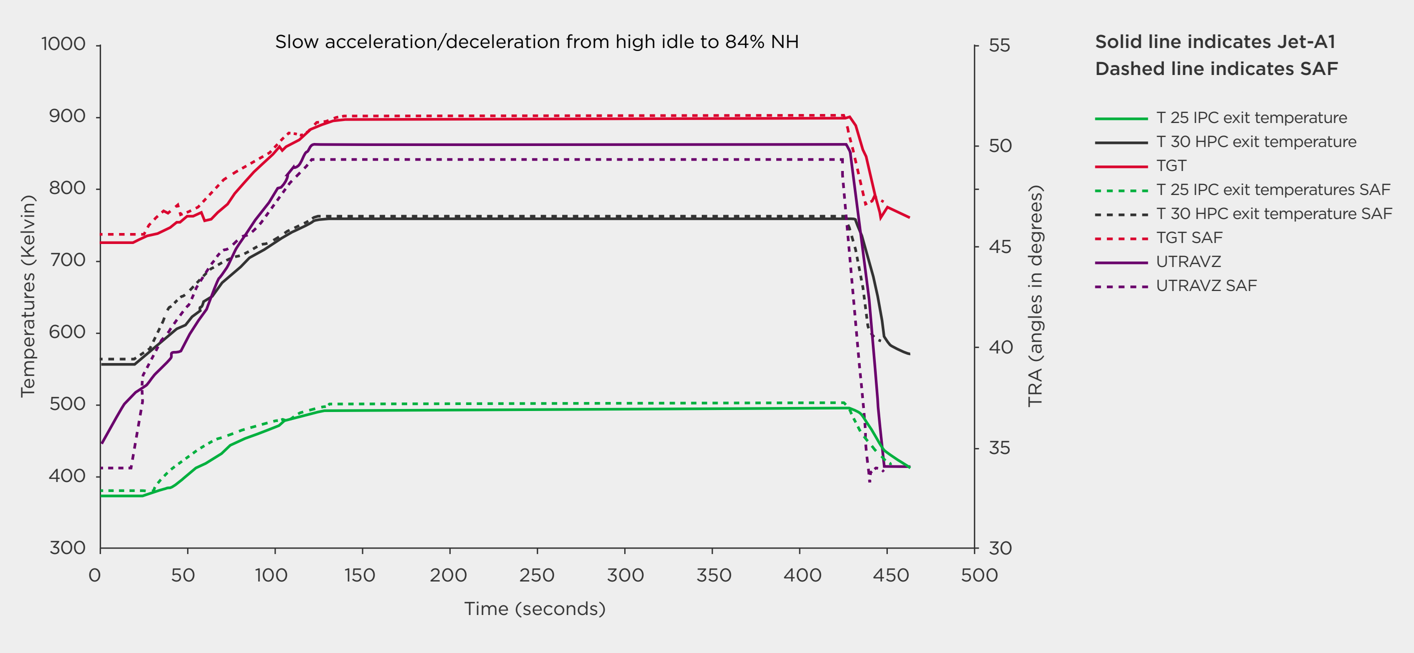
Ground APU test

An APU ground test was also conducted by our maintenance, repair and overhaul providers, EPCOR, on the 23rd September 2023 to assess how it performed on Flight100 SAF. This included a comparative operating test versus Jet A-1, in which the APU was tested first with Jet A-1 to give a baseline data set and then repeated using the 100% SAF blend. Following the SAF test, the APU was visually inspected using a borescope, a specialised camera tool that can be inserted into internal sections of the APU to look for any signs of damage or leaks.

The results of these tests confirmed that there were no identifiable adverse effects of using the Flight100 SAF blend within the APU.

In total, the Flight100 consortium operated 16 hours of engine and airframe testing using the Flight100 SAF blend.

Figure 3. Flight100 SAF performance in bench engine testing



Carbon emissions and Lifecycle Assessment

64%
reduction in CO_2e

SAF can reduce lifecycle carbon emissions by up to 70% when compared to fossil derived Jet A-1. These reductions are achieved in the upstream production process. By using renewable or carbon recycling waste products as feedstocks, instead of virgin fossil fuels, delivers a material reduction in end to end carbon emissions.

Baselining a BAU LHR to JFK flight

In order to quantify the carbon emission savings of Flight100, we worked with ICF to conduct a comparative CO_2e (end to end) Lifecycle Assessment (“LCA”). This involved a baselining exercise of 49 flights between London Heathrow to New York JFK on our Boeing 787-9s, to understand the typical carbon emission profile. The LCA included passenger journeys to the airport and cargo activities, aircraft fuel burn and the embodied emissions associated with the aircraft manufacturing and end of service.

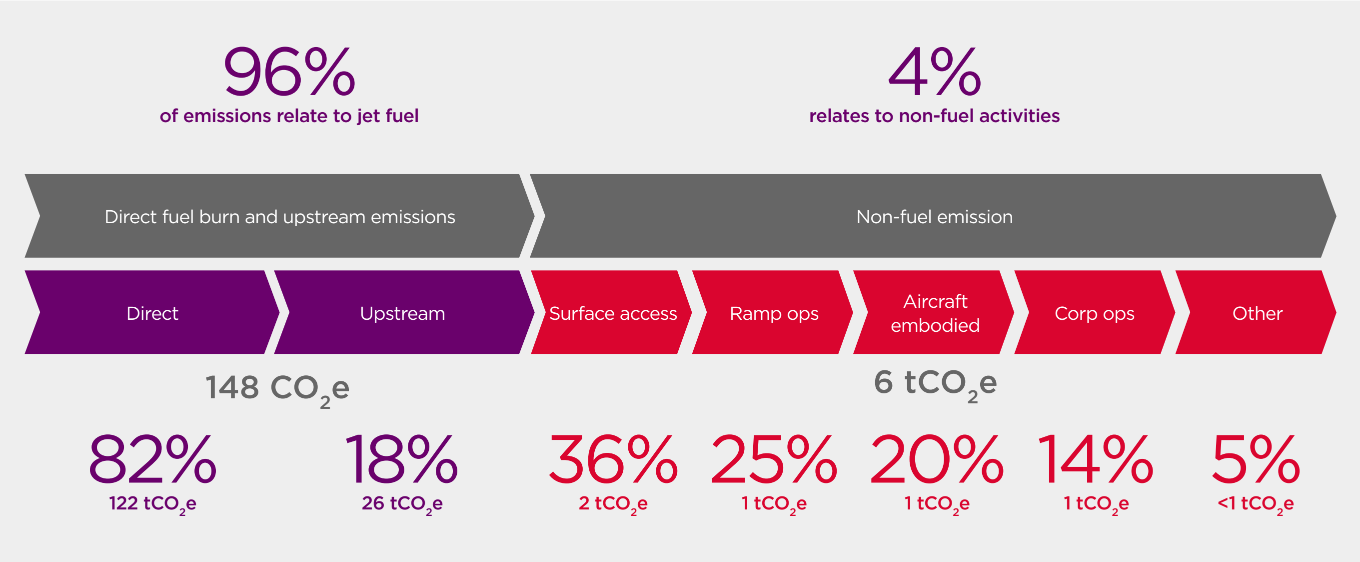
The baseline lifecycle CO_2e profile of a LHR – JFK flight on our twin-engine, fuel-efficient Boeing 787s is 154 tonnes - of which 96% relates to Jet A-1 use (including its production, transportation and use).

Against the baseline, the use of 100% SAF was factored into this analysis for a Flight100 LCA, which demonstrated:

- The use of Flight100 SAF reduced CO_2e by 95 tonnes – a 64% reduction compared to our baseline fuel emissions. This includes not just the use of SAF but also the operational efficiencies that we implemented on the day (see operational efficiencies section below);
- A residual CO_2e impact of the flight of 65.3 tonnes (accounting for the carbon related to Flight100 SAF testing) – reinforcing what we already know – that SAF use has a material impact on lifecycle emissions but does not remove it fully.

The residual emissions of Flight100 were addressed with our partner Supercritical through biochar removals. Biochar is a form of permanent carbon removal achieved when charcoal is produced through a process of heating biomass feedstock (such as wood waste and crop residues) in the absence of oxygen (pyrolysis). Carbon removals, alongside offsets, will have a role to play for the aviation industry in achieving Net Zero 2050.

Figure 4. Emissions profile of an end-to-end LHR-JFK flight



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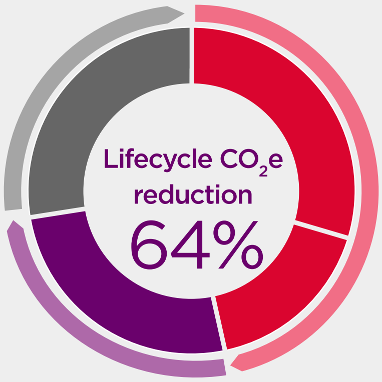
[5] CO_2e stands for carbon dioxide equivalent and is a metric used to compare the emissions of various greenhouse gases based on their global warming potential

‘Sustainable Aviation Fuel can reduce the lifecycle carbon emissions by up to 70% when compared to traditional petroleum-based fuels’

Fig 5. Flight100 SAF

Fuel burn in engine
- SAF properties equivalent to ASTM
- Aromatic content **12%**
- Density **777.7**

Blending and distribution
- Blend ratio **87.3 : 12.7**
- Fuel distribution direct into wing
- Isolated from fuel farm given off-spec nature



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
- Aromatics are mono cyclic

With a permanence that exceeds those offered by offsets, we believe that removal methodologies should be fully included into the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). Increasing the use of robust and high quality projects and processes to abate the sector’s residual emissions remains important in the years ahead.

Onboard

Virgin Atlantic has reduced the use of single use (virgin) plastics onboard by 90% since 2019. As part of Flight100 we went further, testing a number of onboard initiatives. We know that a key driver of customer perception is what they see and experience onboard and that 35% of passengers are “very concerned” about Single Use Plastic.[6]

On Flight100 we trialled two additional customer facing initiatives:

- Replacing single use plastic wraps on our blankets in Premium and Economy cabins with a paper band;
- Using multiuse rotable cups instead of our 95% recycled material single use cups in economy.

A detailed LCA was undertaken to assess the environmental impact of the trials and to better understand the trade-off between waste and emissions. The LCA found that the rotable cups and paper blanket wraps had a higher carbon footprint than the products they replaced.

- Replacing plastic cups with a rotable alternative contribute an additional 345 tonnes CO_2e per year across its lifecycle, resulting from a 5.5x increase in fuel burn due to additional weight, and the addition of washing-phase lifecycle emissions;
- Paper blanket wrap alternatives contribute an additional 217 tonnes CO_2e emissions across its lifecycle, due to increased laundering-phase lifecycle emissions.

The above findings confirm that there are a number of trade offs between regulatory frameworks, landfill avoidance and carbon emissions for onboard products. Reducing the overall environmental impact of our onboard offering remains an area of focus and there is more work to do to across our supply chain and with our customers to make sure we are making the right choices when it comes to what we serve and offer onboard.

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[6] *International Aviation Transport Association consumer survey analysis (2023)*

SAF benefits beyond carbon

+1%
in fuel calorific value vs Jet

40%
reduction in particulates

In addition to the CO_2e benefits of SAF, its use can also materially reduce other environmental impacts compared to burning fossil Jet A-1. Through Flight100 and led by Imperial College London and Sheffield University, additional testing was undertaken to better understand the Non-CO_2 impacts of SAF use.

This included:

- Analysis of particulate emissions – such as sulphur oxides (SOx), nitrogen oxides (NOx) and non-volatile particulate emissions;
- The potential interplay between particulate emissions and their impact on contrail formation.

Particulate emissions

The University of Sheffield conducted laboratory testing of Flight100% SAF through an APU as a 'proxy engine' to stimulate real-life fuel combustion, measuring both Non-CO_2 emissions and the energy content of different fuels. The APU testing was conducted using Jet A-1, 100% HEFA and the Flight100 SAF blends.

In respect of particulates, testing confirmed a reduction in both the number and size of particulate emissions. Figure 6 shows the comparative emission profile of the three fuels tested, with Jet A-1 tracked in purple, Flight100 SAF in green and 100% HEFA in red.

As can be seen in Figure 6, the results showed significant reductions in the number of particulates. HEFA SAF had a reduction in the number of particulates of 70% when compared to Jet A-1 and the Flight100 SAF blend a reduction of 40%. Flight100 SAF performance versus HEFA was due to the aromatic content required to achieve operational characteristics akin to Jet A-1 at 100% use and still had a marked reduction compared to the Jet A-1 baseline when it came to particulate emissions.

Particulate emissions are a known concern in respect of local air quality at and around airports. The adoption of SAF at scale could bring benefits for local airport communities and further work is being undertaken by Imperial College London and the University of Sheffield to assess the local air pollution impact of the reduced particle emissions observed during testing.

In addition to the above finding, an improvement in energy density of the Flight100 SAF as compared to Jet A-1 was also observed in energy measurement tests. The increase in calorific value of up 1% validates existing academic work and suggests there are two potential benefits of SAF use that are not necessarily accounted for in how industry thinks about adoption today:

1. Less fuel is potentially required for the same distance flown using SAF. Alongside the lab based results on SAF energy density we also observed a reduction in fuel burn on Flight100. A total of 34.6 tonnes of SAF was used between London Heathrow and New York JFK whereas an equivalent flight (in the same conditions) on Jet A-1 would have used 34.95 tonnes.
2. Used at the same volume as Jet A-1, SAF may deliver incremental reductions in CO_2e emissions above and beyond fuel LCA savings due to the improved energy output. Although the margin of that gain is comparatively small at 1%, it represents an additional saving of ~1 million tonnes CO_2e in the context of global SAF target of 10% by 2030.

Contrails

As with local air quality, the reduction in particulates can also have a positive impact on contrail formation. Contrails, or condensation trails, are clouds formed when water vapor from aircraft exhaust condenses and freezes around small particles in the cooling exhaust plume. These ice clouds can persist for hours (persistent contrails) and can contribute to climate forcing[7] by trapping heat in the atmosphere.

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[7] *Climate forcing is a broad term that refers to an any external factor that can cause an imbalance on the Earth's energy balance, which affects the global climate system*

> ‘We’ve proven that if enough SAF is made, we will fly it.’

Figure 6. SAF effects on aircraft nvPM emissions

Particulate size and distribution in ground APU testing

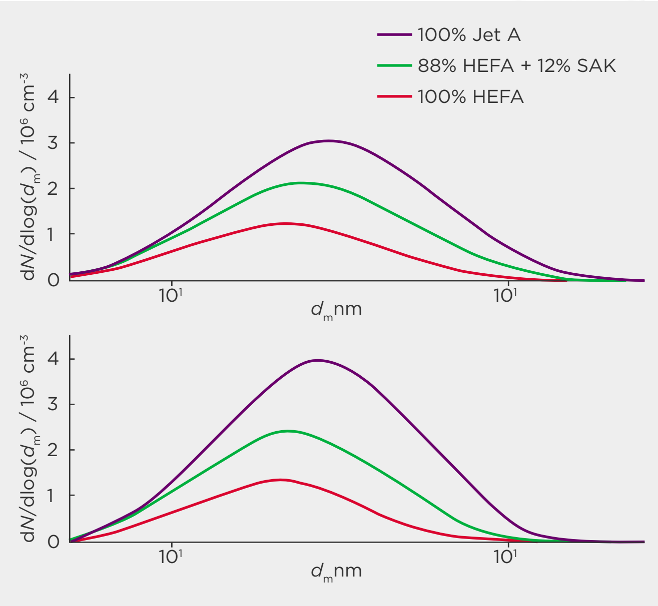
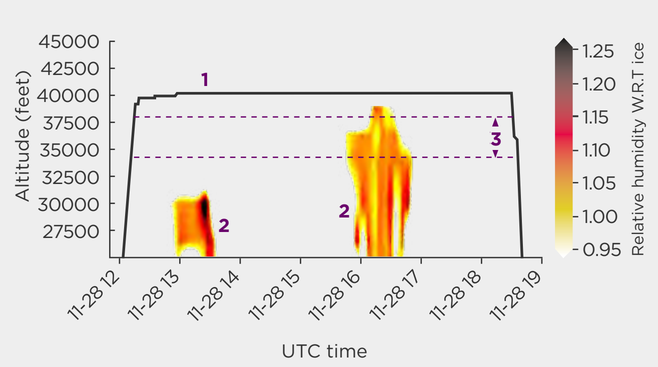


Figure 7. Forecast contrail model and Flight100 flightpath



1 Shows F100 flight path and altitude

2 Shows forecast areas conducive to contrail formation - ice supernatural 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

More research is needed on the extent to which aviation induced radiative forcing contributes to climate warming and there is focus across industry, academia and the Jet Zero Council in this area.[8] Particulate studies, referenced in the above section carried out by the University of Sheffield and supported by Imperial College London, have shown that Flight100 SAF reduced non-volatile particle emissions by 40% relative to fossil Jet A-1. These results, along with model simulations, suggest that utilisation of 100% SAF could materially reduce the formation of persistent contrails and their radiative effects.[9]

Contrail forecasting and mitigation

Figure 7 shows the flight path of Flight100 which, given the lighter load factor and aircraft weighting, operated at 40,000 feet compared to the standard cruising altitude of between 35,000-38,000 feet. Compared to the Imperial College London forecast of persistent contrail formation, Flight100 flew above areas identified as possible formation zones.

The predictive model we deployed, using the state-of-the-art contrail cirrus prediction analysis (CoCiP), accurately identified where persistent contrails were likely to form on the day of Flight100. Observations were made from onboard Flight100 using a new visual identification process (PIREP) developed by RMI, which confirmed the formation of persistent contrails below the flight path as forecast by the software (see inset picture, figure 7). Flight100 was one of many flights that have used this form of visual reporting of contrails, helping Imperial College London to validate and improve accuracy of predictive models for identifying where persistent contrails could form.

Imperial College London will use the contrails findings in support of ongoing work to evolve the use of weather-based models to predict contrail formation. This will facilitate operational interventions (such as flight re-routings and a targeted use of SAF by route, time of day etc.) to minimise persistent contrail formation.

[8] *Example research groups include i) Jet Zero Council Non-CO$_2$ Task Finisher Group, ii) Contrail Impact Task Force, led by RMI*

[9] *Radiative forcing is a subset of climate forcing and is specific to changes in the balance of incoming and outgoing radiation at the top of the earth’s atmosphere. Effects include both heating (positive radiative forcing) and cooling (negative radiative forcing) of the atmosphere*

‘There was no perceivable difference in the performance and flight handling of G-VDIA on 100% SAF compared to any of the other Boeing 787 flights I have operated’

Captain Jon Walker, Flight Commander on Flight100

Operational efficiencies

4.4%
fuel reduction through operational efficiencies

Whilst the primary focus of Flight100 was to demonstrate the safe operation of 100% SAF, we also sought to further optimise and build on existing efficiency measures that can reduce fuel burn as part of business-as-usual operations, on the ground or in the air.

Flight100 delivered 2.2 tonnes of fuel savings through nine in-flight and ground-based fuel efficiency initiatives. Building on Virgin Atlantic's existing practices and deploying new initiatives to reduce fuel burn and emissions.

Whilst the individual fuel saving figures of these initiatives are comparatively small compared to fleet transformation and SAF levers, in total they represent a 4.4% reduction in overall fuel burn. If scaled to Virgin Atlantic's annual operations from LHR to JFK they represent 4,700 tonnes of fuel savings (18,000 tonnes of CO_2e).

For most airlines, Jet A-1 isn't just the biggest source of emissions, it is also the biggest cost too. Over the course of 2023, Virgin Atlantic saved approximately 7,500 tonnes of jet fuel (28,800 tonnes of CO_2e) through our fuel efficiency program initiatives. In Flight100, the nine initiatives deployed reflect our ambition to constantly work with OEMs and industry experts to improve efficiency.

The initiatives deployed during Flight100 can be broken down into different staging categories across pre-flight, departure, enroute, and arrival.

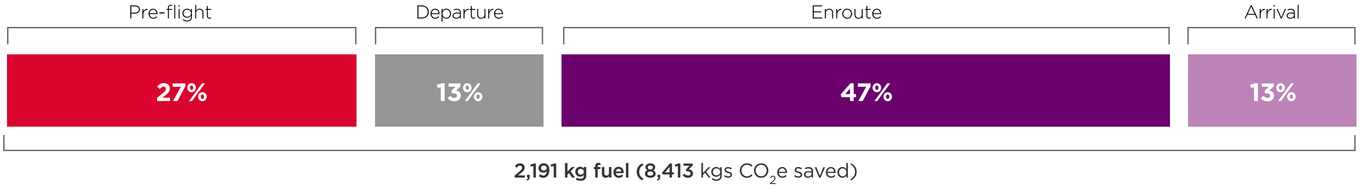
Unsurprisingly, a key outcome of Flight100 was the opportunity to drive fuel efficiency by working closely with Air Traffic Management across each stage of flight. In total, ATM controlled or influenced activities delivered 70% of the fuel efficiency gains, for example, decreased taxi time, continuous climb and descent and optimised flight path routing. Working in close collaboration with route planning teams, Boeing and both local and international air traffic managers, Flight100 was subject to prioritisation both at the airports and in the sky and it should be acknowledged that there is a high likelihood that a trade off or increase in emissions outside of the project may have occurred as a result. The project nonetheless highlights the potential that can be achieved and the need for continued research and collaboration in this space.

Ultimately, the findings point to an important and long talked about opportunity for decarbonisation - Airspace Modernisation. As a fundamental pillar within the UK Government's Jet Zero strategy which aims to create a Net Zero UK aviation industry by 2040, airspace modernisation can play a vital role through increased interactions between air traffic managers and operators wanting to operate more sustainably and realise operational efficiencies.

Figure 8. Initiatives deployed

Pre Flight	Departure	Enroute	Arrival
Fuel and weight reduction	Continuous climb operations	Direct routing	Continuous descent arrival
Reduced taxi time	Climb cost index optimisation	Reduced contingency fuel	Air Traffic Control priority
Reduced APU		Cost index optimisation	Reduced engine taxi-in
-581 kg fuel	-294 kg fuel	-1,031 kg fuel	-285 kg fuel

Figure 9. Fuel reduction from operational efficiency initiatives



What next?

Flight100 was undoubtedly an example of UK Government and industry leadership to accelerate progress toward Net Zero 2050. While Flight100 successfully demonstrated the viability of 100% SAF, the immediate priority must be to ensure the availability and affordability of supply so that more airlines can use more SAF in the near term.

Virgin Atlantic has committed to 15% net reduction in total CO_2e emissions, including 10% SAF by 2030 and 40% net reduction in total CO_2e emissions by 2040. Since Fight100 the UK Government has also confirmed its SAF mandate for the UK, targeting 10% SAF by 2030, and 22% by 2040.[10]

Our call to action

Flight100 was always intended to be a call to action. Highlighting that the key challenge ahead is not operational but one of availability and supply: if enough is made we can fly it. Although progress has been made since Flight100, there is more to do in this Parliament and the next – the role that Government investment and policy must play is not yet finished.

Our ask		Progress to date
Remove the proposed cap on HEFA, which would limit its use to ~15% of mandate volume.	🟩	The UK Government announced its SAF mandate on 25 April, including a HEFA cap from 2027/28, which progressively reduces volumes over time to 71% of the mandate in 2030, and 33% in 2040.
Underwrite and fund a Revenue Certainty Mechanism to de-risk investment, ensure UK SAF production and preventing consumers being penalised with excessive pricing.	🟨	The UK Government published a consultation on a Revenue Certainty Mechanism on 25 April. UK Government remains committed to 'industry funding' rather than using the strength and certainty of its balance sheet to underwrite the RCM.
Legislate for the introduction of the SAF mandate.	🟨	On 25 April the UK Government signalled its intention to pass secondary legislation making the mandate effective from January 2025.

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[10] *UK SAF Mandate*

Additional action required

> ‘Although progress has already been made since Flight100, there is more to do in this Parliament and the next’

A commitment by all political parties to introducing a Revenue Certainty Mechanism by 2026 in their General Election manifestos
There is global consensus across all published roadmaps that SAF needs to make the single biggest contribution to Net Zero 2050, accounting for >40% of emission reductions. There must now be political consensus here in the UK to implement a Revenue Certainty Mechanism by 2026 – whatever the colour of government – ensuring there is no further delay in securing the significant benefits of a domestic SAF industry.

Ensure availability of feedstocks for SAF producers
A UK SAF industry will require certainty over the availability of feedstocks, many of which are waste streams, such as household municipal waste. Some of these streams are used for other purposes today, such as incineration for local electricity generation. Ensuring that these feedstocks are available for SAF producers is critical to ensure certainty for producers.

Accelerate the delivery of airspace modernisation
The CO_2e savings achieved through efficiency initiatives implemented on Flight100 resulted in 2.2 tonnes of jet fuel saving, or 4.4% of overall fuel burn, of which 70% was the result of improved airspace routing. This demonstrates the significant benefits of enabling airline operational efficiencies. Accelerating the delivery of Airspace Modernisation would allow these CO_2e savings to be realised by all airlines more quickly.

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