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TRANSATLANTIC AIRLINE FUEL EFFICIENCY RANKING, 2017

Brandon Graver, Ph.D., and Daniel Rutherford, Ph.D.

THE INTERNATIONAL COUNCIL
ON CLEAN TRANSPORTATION

www.theicct.org

communications@theicct.org

BEIJING | BERLIN | BRUSSELS | SAN FRANCISCO | WASHINGTON

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AIRLINE
DATA
INC
Formerly Data Base Products, Inc.

FlightGlobal

International Council on Clean Transportation
1225 I Street NW Suite 900
Washington, DC 20005 USA

communications@theicct.org | www.theicct.org | @TheICCT

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EXECUTIVE SUMMARY

Public information on airline fuel efficiency remains scarce. Starting in 2013, the International Council on Clean Transportation (ICCT) began assessing the fuel efficiency of U.S. airlines on domestic operations for 2010, with subsequent updates for 2011 through 2016. In 2015, the ICCT compared the fuel efficiency of 20 major airlines operating in the transatlantic market, specifically nonstop passenger flights between North America and Europe. This report updates that ranking.

Figure ES-1 illustrates the fuel efficiency of the 20 carriers analyzed. Passenger-based fuel efficiency was estimated after correcting for cargo carried on passenger flights, referred to as belly freight, which increases the absolute burn of a given flight but improves the fuel efficiency per unit of mass moved. Norwegian Air Shuttle was the most fuel-efficient airline on transatlantic operations in 2017, with an average fuel efficiency of 44 passenger-kilometers per liter of fuel (pax-km/L), 33% higher than the industry average. British Airways (BA) ranked as the least fuel-efficient, falling 22% below the industry average. On average, BA burned 63% more fuel per passenger-kilometer than Norwegian. The gap between the most- and least-efficient transatlantic airlines has grown since the 2014 rankings.

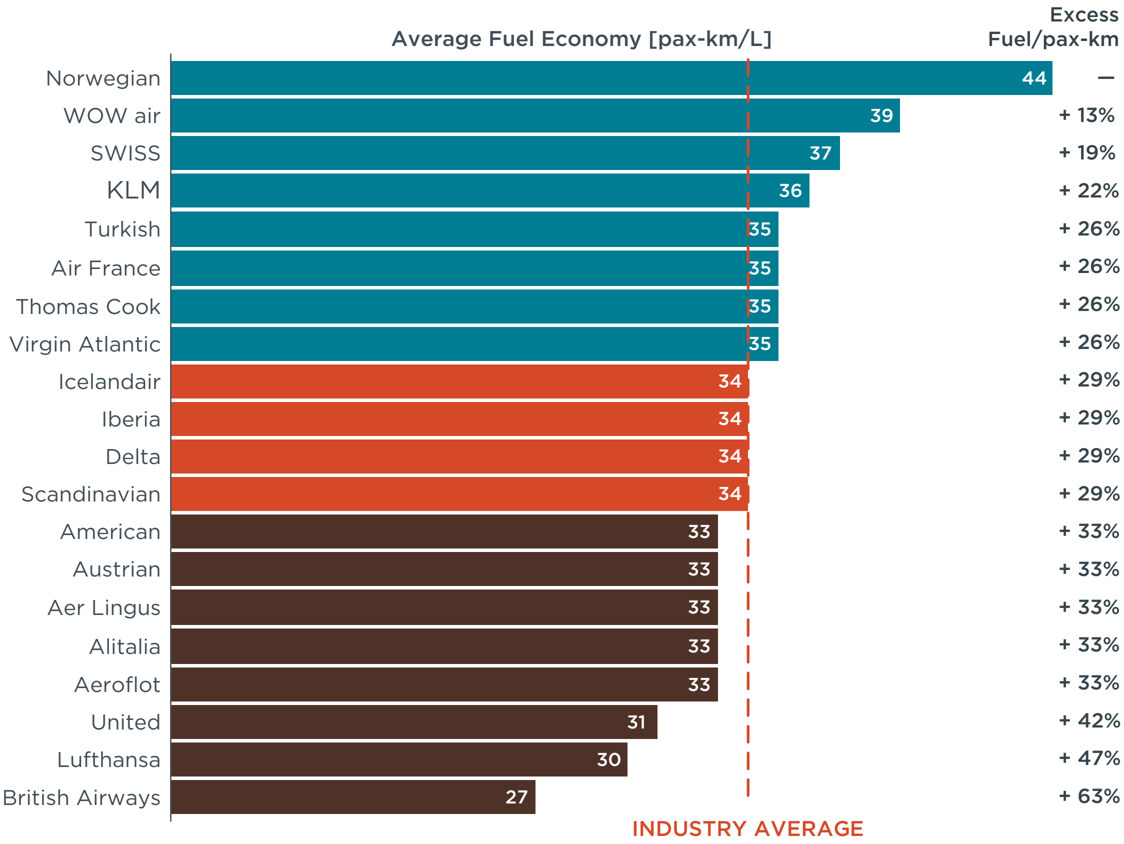

Figure ES-1. Fuel efficiency of 20 airlines on transatlantic passenger routes, 2017.

The report also assesses key drivers of the observed fuel efficiency gap across carriers (Figure ES-2). Factors investigated include aircraft fuel burn, seating density, passenger load factor, and freight share of total payload. Of these, aircraft fuel burn was found to be the most important driver overall, explaining almost 40% of the variation in airline fuel efficiency across carriers, followed by seating density, which accounted for one third of the variation. Freight share and passenger load factors were relatively less important. The importance of seating density as a driver of fuel efficiency has increased since 2014 due to the expansion of carriers like Norwegian and WOW air, which operate transatlantic flights with higher seat counts and a lower percentage of premium seats compared to competitors.

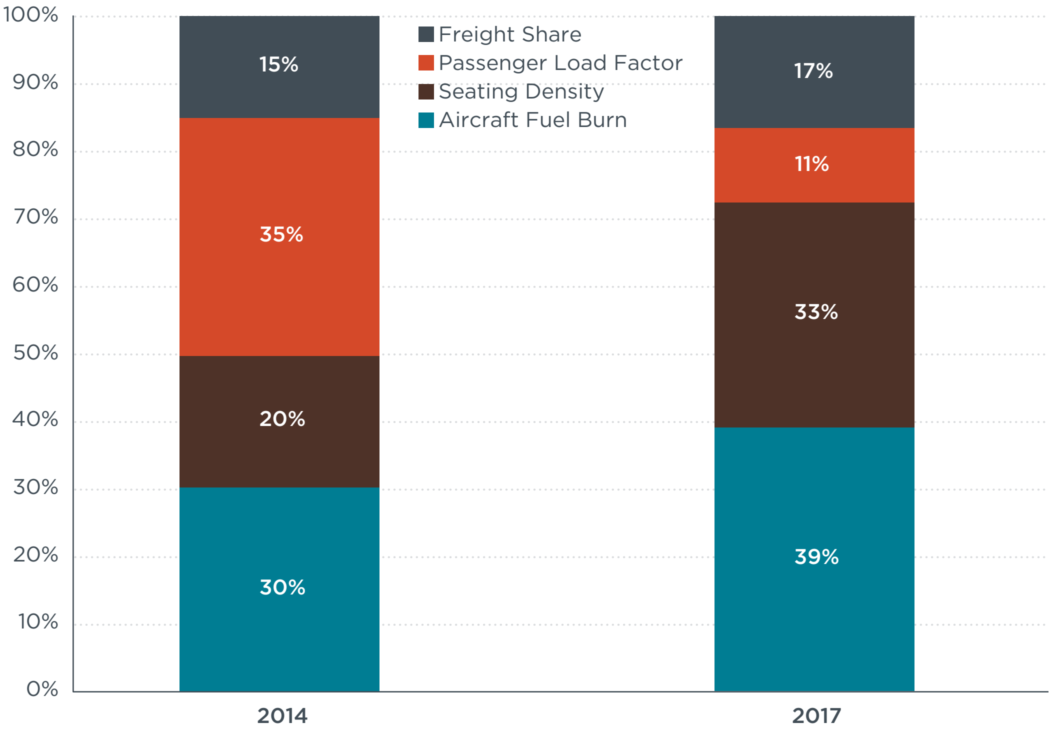

Figure ES-2. Key drivers of transatlantic airline fuel efficiency, 2014 and 2017.

Other conclusions of this work include:

- The industry average fuel efficiency improved from 33 pax-km/L in 2014 to 34 pax-km/L in 2017 after adjusting for a common modeling methodology. This improvement could be attributed to an increase in fuel-efficient aircraft. Between 2014 and 2017, the margin to the International Civil Aviation Organization (ICAO) carbon dioxide (CO_2) emission standard for the average transatlantic aircraft improved from 8% to 5%, while passenger load factor, seating density, and freight share varied very little.
- Major improvers in the ranking from 2014 to 2017 include Virgin Atlantic (30 to 35 pax-km/L) and Aeroflot Russian Airlines (30 to 33 pax-km/L). These improvements are linked to the increased use of more fuel-efficient aircraft—the Boeing 787-9 for Virgin Atlantic and Boeing 777-300ER for Aeroflot. The introduction of new supersonic aircraft, which are expected to have fuel efficiencies around 7 pax-km/L, could reverse Virgin Atlantic's efficiency gains.
- The estimated gap between the most and least fuel-efficient transatlantic airlines widened since 2014. Norwegian's average fuel efficiency increased by 3 pax-km/L, while British Airways' decreased by 1 pax-km/L. Although the fuel efficiency of

British Airways' fleet increased and average passenger load factors were similar in 2014 and 2017, the freight share of total payload and average seating density of BA's fleet fell during this time.

- There was an inverse relationship between aircraft size and fuel efficiency on transatlantic operations—as aircraft weight, or maximum takeoff mass (MTOM), increases, fuel efficiency declines. This is predominantly because aircraft with four engines are generally less fuel-efficient than those with two.

1. INTRODUCTION

Public information on airline fuel efficiency remains scarce. U.S. carriers report quarterly fuel burn and operations by aircraft type and market, whether domestic or international, to the Bureau of Transportation Statistics (BTS) of the U.S. Department of Transportation (DOT). Fuel burn data is not required from foreign carriers, nor are similar data sets published by governments outside of the United States. Several online carbon calculators, including from the International Civil Aviation Organization (ICAO, n.d.), ClimateCare (2017), and individual airlines (United Airlines, n.d.), can be used to estimate fuel consumed and carbon dioxide (CO_2) emissions over origin-destination pairs for passengers and air freight. These calculators do not provide carrier or flight-specific comparisons and are designed mostly to support carbon offsetting programs rather than to help consumers choose more fuel-efficient flights or carriers.

Starting in 2013, the International Council on Clean Transportation (ICCT) began assessing the fuel efficiency of U.S. airlines in its benchmark study of domestic operations for 2010 (Zeinali, Rutherford, Kwan, & Kharina, 2013), with subsequent updates for 2011 through 2016 (Kwan, Rutherford, & Zeinali, 2014; Kwan & Rutherford, 2014; Kwan & Rutherford, 2015; Olmer & Rutherford, 2017). The gap between the most and least efficient airlines on U.S. domestic operations was 26% in 2016. This led the ICCT to compare the fuel efficiency of 20 major airlines operating in the transatlantic market, specifically nonstop passenger flights between North America and Europe. For 2014, there was a 51% gap between the most and least efficient airlines flying over the North Atlantic (Kwan & Rutherford, 2015). Overall, airlines with more fuel-efficient aircraft, less premium seating, and higher passenger and freight load factors operated more fuel-efficient flights.

This report updates the previous work on transatlantic fuel efficiency using refinements from a study of transpacific airline fuel efficiency (Graver & Rutherford, 2018). According to an ICAO forecast of future airline traffic, in 2020 “Europe and Asia/Pacific will have the largest share of CO_2 emissions from international aviation with 36.6% and 31%, respectively, followed by North America with 14.8%” (ICAO, 2013). There are some notable differences between the transpacific and transatlantic markets. Whereas twin-aisle and very large aircraft are also used on transatlantic flights, more premium flight offerings are available for the Asian market, typically resulting in fewer seats on each plane.

In addition, the amount of freight transported between Asia and the United States, both in dedicated freighter aircraft and in the cargo hold of a passenger plane, dwarfs what is carried between the United States and Europe. In addition, average flight distances across the Atlantic Ocean are shorter than across the Pacific.

For the first time in the transpacific rankings, we directly integrated primary, as opposed to estimated, data of freight carriage on passenger flights into the methodology. Belly freight accounted for approximately 25% of the total payload mass moved on transpacific flights (Graver & Rutherford, 2018).

The balance of this report is structured as follows. Section 2 introduces the methodology used to estimate airline fuel efficiency. Section 3 presents and discusses the average fuel efficiency of the incorporated airlines and aircraft, and on key routes. Section 4 offers conclusions along with potential future work to refine and extend the methodology presented.

2. METHODOLOGY

In a previous ICCT study (Graver & Rutherford, 2018), a methodology was derived to estimate airline fuel efficiency on nonstop transpacific routes. An international flight schedule database and detailed operational data reported to the BTS were used to model airline fuel burn for 20 major airlines. The estimated airline fuel efficiencies were validated using activity and fuel burn data reported by three U.S. carriers. The same methodology was used in this study.

All airlines operating flights to, from, and in the United States must report operations data to the BTS. The data are made available to the public via the BTS T-100 database. We purchased T-100 International Segment data from Airline Data Inc., which completes quality assurance and control procedures on the BTS data. The T-100 data provide information on air carrier, flight origin and destination, frequency, distance, aircraft type, seats available, passenger load factors, and freight transported. Separately, fuel burn reported through BTS Form 41 financial data was used to validate the fuel burn modeling (see Appendix A). Calendar year 2017 was used in this analysis.

2.1 AIRLINE SELECTION

The 20 airlines with the greatest capacity on nonstop flights from the United States to Europe, as defined by ICAO, were analyzed. Unlike the 2014 transatlantic rankings, flights to and from Canada were excluded because operations data for those flights are not publicly available. Table 1 presents the 20 airlines analyzed in this report, along with each airline's total number of transatlantic flights, average flight length, share of available passenger seat kilometers (ASKs), share of available freight tonne kilometers (ATKs), and the prevalent aircraft used by each airline. More information on the aircraft types used in 2017 for transatlantic flights is included in Table 2.

Table 1. Airlines evaluated

Airline	Flights performed	Average flight length (km)	Share of ASKs	Share of ATKs	Most prevalent aircraft
Aer Lingus	8,844	5,888	3%	2%	Airbus A330-300
Aeroflot	3,156	8,579	2%	1%	Boeing 777-300ER
Air France	12,159	7,249	6%	5%	Boeing 777-300ER
Alitalia	4,521	7,643	2%	2%	Airbus A330-200
American	36,426	6,893	12%	13%	Boeing 777-200ER
Austrian	2,949	7,797	1%	2%	Boeing 767-300ER
British Airways	30,549	7,073	11%	11%	Boeing 747-400
Delta	45,435	6,818	14%	14%	Boeing 767-300ER
Iberia	4,420	7,034	2%	2%	Airbus A330-300
Icelandair	7,467	4,856	1%	1%	Boeing 757-200
KLM	7,055	7,649	3%	3%	Boeing 747-400
Lufthansa	21,121	7,749	10%	9%	Airbus A340-600
Norwegian	10,641	7,166	4%	4%	Boeing 787-8
Scandinavian	7,107	7,278	2%	3%	Airbus A330-300

continued

Airline	Flights performed	Average flight length (km)	Share of ASKs	Share of ATKs	Most prevalent aircraft
SWISS	7,310	7,537	3%	3%	Airbus A330-300
Thomas Cook	2,281	7,180	1%	1%	Airbus A330-200
Turkish	7,065	9,346	4%	4%	Boeing 777-300ER
United	43,214	6,805	13%	13%	Boeing 767-300ER
Virgin Atlantic	14,515	7,124	6%	8%	Boeing 787-9
WOW air	4,262	5,077	1%	1%	Airbus A321
Total	**280,497**	**7,028**	**100%**	**100%**	**Airbus A330-300**

Note: ASK = Available seat kilometers. ATK = Available tonne kilometers. Source: Airline Data Inc. (2018)

Table 2. Aircraft types used on transatlantic operations

Aircraft	MTOM (tonnes)	Typical seating capacity	Cargo capacity (m^3)	Number of engines, max. thrust	Range (km)
Airbus A318	68	107	21	2 @ 106 kN	5,750
Boeing 737-700	70	128	27	2 @ 116 kN	5,570
Boeing 737-800	79	160	44	2 @ 120 kN	5,436
Boeing 737 MAX-8	82	162	44	2 @ 130 kN	6,570
Airbus A321	94	185	52	2 @ 147 kN	5,950
Boeing 767-300ER	187	261	114	2 @ 282 kN	11,070
Boeing 767-400ER	204	296	139	2 @ 270 kN	10,415
Boeing 787-8	228	242	137	2 @ 280 kN	13,620
Airbus A330-200	242	247	132	2 @ 316 kN	13,450
Airbus A330-300	242	277	158	2 @ 316 kN	11,750
Boeing 787-9	254	290	173	2 @ 320 kN	14,140
Boeing 757-200	255	200	43	2 @ 193 kN	7,250
Boeing 757-300	273	243	62	2 @ 193 kN	6,295
Airbus A340-300	277	277	162	4 @ 151 kN	13,500
Airbus A350-900	280	325	162	2 @ 375 kN	15,000
Boeing 777-200ER	298	313	202	2 @ 417 kN	13,080
Boeing 777-300ER	352	396	202	2 @ 513 kN	13,650
Airbus A340-600	368	380	208	4 @ 249 kN	14,600
Boeing 747-400	397	416	160	4 @ 282 kN	11,250
Boeing 747-8I	448	410	176	4 @ 296 kN	14,816
Airbus A380-800	575	544	184	4 @ 311 kN	15,200

Note: MTOM = maximum takeoff mass. Sources: Airbus (2017); Airbus (2018); Boeing (1999); Boeing (2008); Boeing (2010); Boeing (2011); Boeing (n.d.)

2.2 FUEL BURN MODELING

Similar to the ICCT's previous fuel efficiency rankings (Kwan & Rutherford, 2015; Graver & Rutherford, 2018), aircraft fuel burn was modeled using Piano 5, an aircraft performance and design software (Lissys Ltd., 2017). Piano 5 requires various inputs to model aircraft fuel burn, and Table 3 contains a list of the key modeling variables and sources.

Table 3. Key modeling variables

Type	Variable	Sources
Airline scheduled flights	Route	BTS T-100 International Segments
	Aircraft used	
	Available seats	
	Departures	
	Passenger load factor	
	Freight carriage	
Airline-specific aircraft parameters	Type and count	Ascend Fleets
	Engine	
	Winglets/scimitar	
	Maximum takeoff mass	
	Seats	
Aircraft weights	Operating empty weight	Piano 5
	Passenger weight	Industry standard
	Seat and furnishings weight	ICAO default
Aircraft fuel burn	Engine thrust	Piano 5
	Drag	
	Fuel flow	
Other operational variables	Taxi time	BTS T-100 International Segments, FAA Part 121, Piano 5
	Fuel reserves	
	Flight levels	
	Speed	

The Ascend Fleets database from FlightGlobal provides comprehensive carrier fleet and aircraft specific information (FlightAscend Consultancy, 2017). This database was used to assign representative Piano 5 aircraft to each airline by matching aircraft type, use of wingtip device, engine type, seat count, and maximum takeoff mass (MTOM) as closely as possible.

For flight distance, the great circle distance for each route was adjusted upward by 4% to account for air traffic management inefficiencies over the North Atlantic, as was done in the previous transatlantic ranking. More information can be found in Appendix A of that report (Kwan & Rutherford, 2015).

International passenger flights carry both passengers and freight, so the fuel burn of individual flights must be apportioned between passengers and freight based on mass. The average payload per flight was estimated using Equation 1 for each airline-aircraft-seat count-distance flight group given the reported number of departures, available seats, passenger load factor, and freight carriage. The industrywide standard mass for a passenger and luggage of 100 kg is used (ICAO, 2017). Changes in aircraft weight due to an aircraft type having multiple seating configurations were incorporated into the modeling by adjusting the default number of seats in Piano, assuming 50 kg per seat.

$$payload\ [kg] = \left(\frac{seats}{departures}\right)(load\ factor_{pax})\left(\frac{100kg}{pax}\right) + \left(\frac{freight[kg]}{departures}\right) \tag{1}$$

In the 2014 ranking, actual freight carriage from the T-100 International Segments dataset were not used for the non-U.S. carriers, but instead were modeled as a function of aircraft cargo capacity by volume (Kwan & Rutherford, 2015). This method could either under or overestimate the amount of freight carried by an airline and aircraft, which could affect fuel efficiency estimates. In the 2016 transpacific rankings, it was observed that freight share was the major driver in the fuel efficiency rankings (Graver & Rutherford, 2018). Therefore, in order to make comparisons between the 2014 and 2017 transatlantic rankings, airline fuel efficiencies for 2014 were recalculated based on T-100-reported freight carriage. More information can be found in Appendix B of this report.

Default Piano 5 values for operational parameters such as engine thrust, drag, fuel flow, available flight levels, and speed were used because of the lack of airline- and aircraft-specific data. Cruise speeds were set to allow 99% maximum specific air range. Taxi times were set at 34 minutes, as estimated by T-100 International Segments data for transpacific flights by the three U.S. carriers (Bureau of Transportation Statistics [BTS], U.S. Department of Transportation, 2018). This is equal to the average taxi time used in previous transatlantic and transpacific rankings (Kwan & Rutherford, 2015; Graver & Rutherford, 2018). Fuel reserves were set for a 370 km diversion distance, 10% mission contingency fuel to account for weather, congestion, and other unforeseen events, and 45 minutes at normal cruising fuel consumption, corresponding to U.S. Federal Aviation Administration's *Operations Specification B043* (FAA, 2014).

2.3 FUEL EFFICIENCY CALCULATION

The fuel efficiency of each flight was calculated using the method developed for the ICCT's previous transpacific ranking (Graver & Rutherford, 2018). The average fuel efficiency for each airline (represented by index *a*) was calculated using a bottom-up approach.

After modeling each unique airline-aircraft-seat count-distance-payload flight group, represented by index *i*, the total fuel consumption for the full set of nonstop transatlantic flights flown by each of the 20 airlines was calculated according to Equation 2.

$$fuel\ [L]_a = \sum_i (fuel\ [L]_{a,i})(departures_{a,i}) \tag{2}$$

Aircraft fuel use is proportional to the total payload mass transported. For passenger flights that also carry cargo, or belly freight, payload is calculated as the total mass of passengers and freight per flight. Belly freight, while increasing the absolute burn of a given flight, improves the fuel efficiency of an airplane per unit of mass moved because the airframe is loaded closer to its maximum payload capability. The ratio of payload-distance to fuel burned for each airline was used as a starting point for the average fuel efficiency metric. This was then converted to the passenger-based metric, passenger-kilometers per liter of fuel (pax-km/L), using the passenger weight factor, as shown in Equation 3.

$$pax \times km/L_a = \frac{\sum_i (payload\ [kg]_{a,i})(distance[km]_{a,i})}{(fuel\ [L]_a)(100kg/pax)} \tag{3}$$

The resulting fuel efficiencies for the 10 aircraft types operated by U.S. airlines were validated using Form 41 fuel burn data, as described in Appendix A.

3. RESULTS

This methodology allows for comparison of transatlantic fuel efficiency at the airline, aircraft, and route level. Section 3.1 presents the overall fuel efficiency results. Section 3.2 relates the overall results to the aircraft types, and Section 3.3 explains the findings in terms of key drivers of fuel efficiency, including aircraft fuel efficiency, seating capacity, passenger load factor, and freight carriage. Sections 3.4 and 3.5 provide context for individual airlines and select routes.

3.1 AIRLINE COMPARISONS

The average fuel efficiencies in pax-km/L of 20 airlines operating transatlantic routes in 2017 are shown in Figure 1. The orange bars indicate the industry average fuel efficiency of 33 pax-km/L. Norwegian Air Shuttle was the most fuel-efficient airline with an average fuel efficiency of 44 pax-km/L, 33% higher than the industry average. Another low-cost carrier, Iceland's WOW air, ranks second. British Airways (BA) was the least fuel-efficient carrier at 30% below the average. In 2017, BA burned on average 63% more fuel per passenger-kilometer than Norwegian. This gap is 17 percentage points higher than that seen on 2014 transatlantic flights based on a common modeling methodology (see Appendix B).

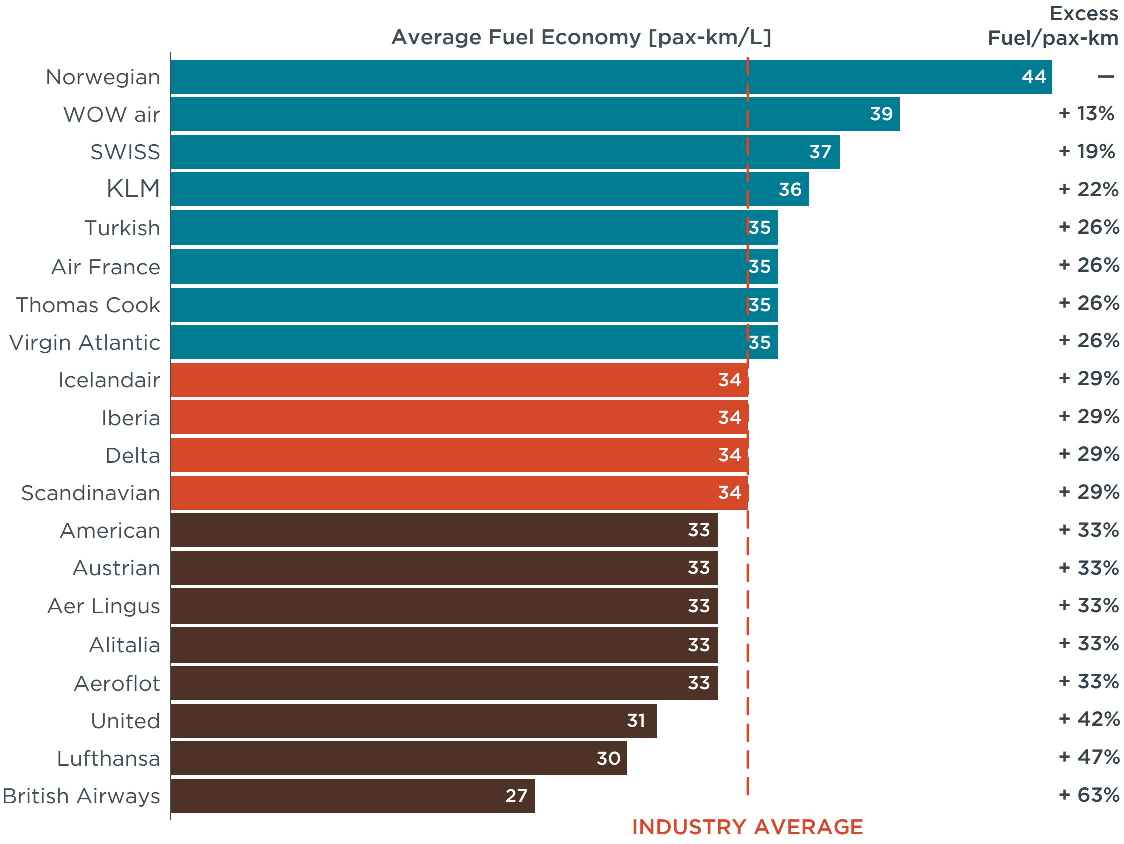

Figure 1. Fuel efficiency of 20 airlines on transatlantic passenger routes, 2017.

Three airlines are new to the rankings—WOW air, Thomas Cook Airlines, and Austrian Airlines—replacing Air Berlin, Air Canada, and US Airways. Air Berlin ceased operations in October 2017 and was excluded from analysis. Air Canada was omitted due to a lack of Canadian operations data (see Appendix B). US Airways ceased operations in October 2015 when it merged with American Airlines.

The three worst-performing airlines—United, Lufthansa, and British Airways—accounted for one out of every three ASKs between the United States and Europe of the airlines analyzed. The top 10 airlines in the rankings combined had a fewer number of ASKs.

Some patterns in the fuel efficiency by country carrier can be seen. The U.S. carriers had differing fuel efficiencies, with Delta and American at the industry average, and United below average. Delta provided the most capacity, at 14% of all ASKs, followed by United and American at 13% and 12%, respectively. All four Nordic airlines analyzed—Norwegian, WOW air, Icelandair, and Scandinavian Airlines (SAS)—had average fuel efficiencies at or higher than the industry average. With BA ranked at the bottom, Thomas Cook and Virgin Atlantic were the most fuel-efficient carriers from the United Kingdom, each with an average fuel efficiency 8 pax-km/L higher than BA.

3.2 AIRCRAFT-SPECIFIC ANALYSIS

Figure 2 compares the average fuel efficiency for each aircraft model operated to the transatlantic average of 33 pax-km/L. The Airbus A330 family of aircraft was the most widely used on transatlantic routes in 2017, accounting for 25% of all flights. Its fuel efficiency averaged approximately 1 pax-km/L better than the industry average. The Airbus A350-900 and Boeing 787 Dreamliners, in contrast, were notably more fuel-efficient with average fuel efficiencies at or above 40 pax-km/L.

There are two outlier aircraft in this analysis: (1) a British Airways Airbus A318, and (2) an SAS Boeing 737-700. The BA A318 is configured with 32 business class seats and is used for weekday service between New York-JFK and London-City. SAS wet-leased the 737-700 from PrivatAir, which owns the aircraft and provided the flight crew for flights between Boston and Copenhagen from March 2016 through October 2017. The aircraft was configured with 20 business class seats and 66 economy class seats.

Excluding the A318 and 737-700, there is a general trend with respect to aircraft size: a decrease in fuel efficiency as MTOM increases. The largest aircraft require more than two engines for propulsion and, as seen in Figure 2, aircraft with four engines are generally less fuel-efficient than those with two. It is important to note that variations in passenger load factors and freight carriage could affect the magnitude of difference in fuel efficiency.

Figure 2. Fuel efficiency of aircraft types used on transatlantic routes, 2014 and 2017.

3.3 DRIVERS OF TRANSATLANTIC AIRLINE EFFICIENCY

Table 4 summarizes key airline operational parameters, including passenger load factor, freight share, premium seating share, overall seating density,[1] and relative fuel burn of the aircraft operated[2] for 2017 nonstop transatlantic carriers in order of efficiency. As shown in the table, the share of belly freight as a share of total payload varied greatly across carriers, from 2% for Thomas Cook to 34% for SWISS, compared with an average of 21%. Relatively smaller were differences in passenger load factors, from 75% to 88%, and aircraft fuel burn, from -8% to +13% of ICAO's fuel efficiency standard. Average seating densities ranged from 0.75 seats/m^2 for British Airways to 1.58 seats/m^2 for WOW air, ranking second to freight share in terms of variation across carriers.

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[1] As measured by seats per square meter (m^2) of Reference Geometric Factor, or RGF. RGF is a close proxy for the pressurized floor area of an aircraft. It was developed by the International Civil Aviation Organization as a means to assess aircraft fuel efficiency. See ICCT (2013) for further details.

[2] As measured by margin from the International Civil Aviation Organization's fuel efficiency or CO_2 standard, which established an internationally agreed means of assessing and comparing aircraft efficiency. Negative values indicate the use of more fuel-efficient fleets, while positive values indicate more fuel-intensive aircraft. See ICCT (2017) for details.

Table 4. Airline operational parameters

Rank	Airline	Passenger load factor	Freight share of total tonne-km	Premium seating share	Overall seating density (seats/m²)[a]	Aircraft fuel burn[b]
1	**Norwegian**	85%	7%	9%	1.36	-8%
2	**WOW air**	84%	4%	3%	1.53	+3%
3	**SWISS**	81%	34%	22%	0.89	+2%
4	**KLM**	88%	32%	10%	0.91	+12%
T5	**Turkish**	83%	25%	12%	1.01	+2%
T5	**Air France**	88%	20%	14%	0.92	+3%
T5	**Thomas Cook**	88%	2%	15%	1.34	+1%
T5	**Virgin Atlantic**	78%	30%	11%	0.99	+5%
T9	**Icelandair**	83%	7%	11%	1.37	+7%
T9	**Iberia**	82%	20%	12%	1.08	+4%
T9	**Delta**	83%	18%	13%	1.08	+5%
T9	**Scandinavian**	75%	31%	15%	0.96	+4%
T13	**American**	77%	25%	13%	1.01	+3%
T13	**Austrian**	79%	21%	12%	1.10	+5%
T13	**Aer Lingus**	83%	9%	9%	1.19	+3%
T13	**Alitalia**	85%	19%	8%	1.04	+2%
T13	**Aeroflot**	83%	12%	10%	1.09	+2%
18	**United**	75%	21%	15%	1.02	+6%
19	**Lufthansa**	82%	24%	18%	0.87	+10%
20	**British Airways**	82%	23%	25%	0.75	+13%
Industry Average		**81%**	**21%**	**14%**	**1.01**	**+5%**

[a]As measured by seats per square meter or RGF. See footnote 1 for details. [b]As measured by the average margin of aircraft to ICAO's CO_2 standard. See footnote 2 for details.

A multivariate regression model was developed to relate overall airline fuel efficiency to technological and operational parameters, or drivers, including aircraft fuel burn, seating density, passenger load factor, and freight share of total payload. This is the same approach as taken in the previous transatlantic rankings (Kwan & Rutherford, 2015). The Shapley method was used to quantify the relative importance of each driver to fuel efficiency, with the results shown in Figure 3. Note that the 2014 results have been recalculated after adjusting for a common modeling methodology using actual air freight carriage, as described in Appendix B.

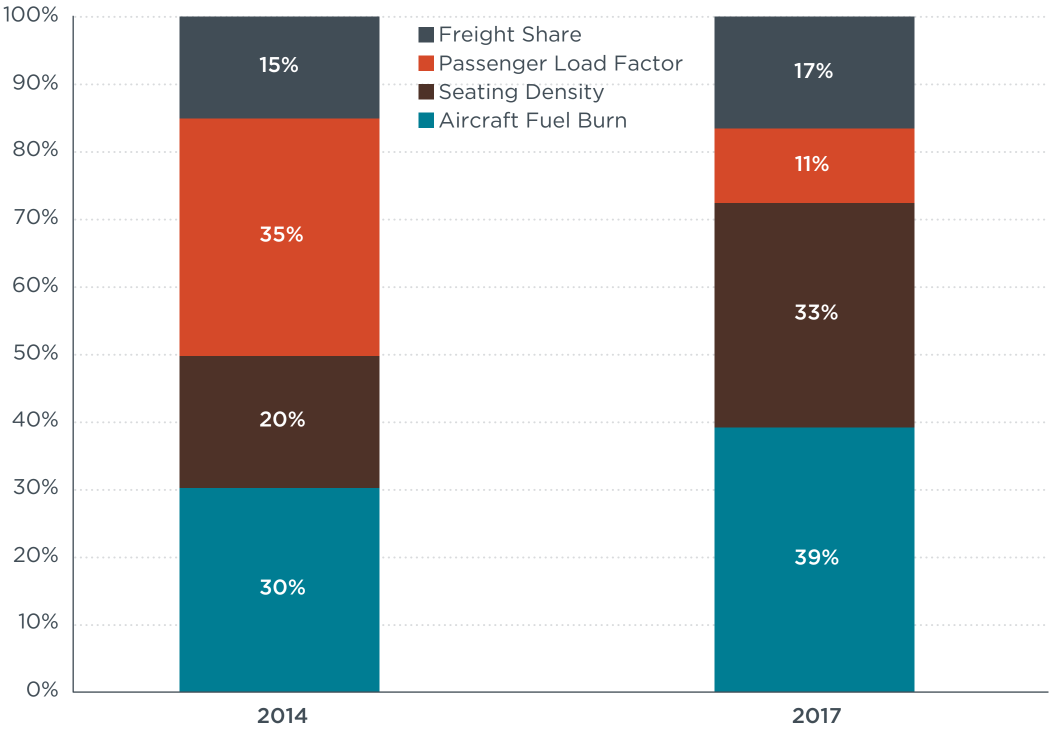

Figure 3. Key drivers of transatlantic airline fuel efficiency, 2014 and 2017.

In order of decreasing importance, the key drivers to transatlantic airline fuel efficiency in 2017 were aircraft fuel burn, seating density, freight share of total payload, and passenger load factor. Aircraft fuel burn was the most important of these, explaining almost 40% of the variance across carriers. Bootstrapping analysis indicates significant overlap in the 95% confidence interval for all four estimated drivers: aircraft fuel burn, 4%~61%; passenger load factor, 3%~38%; freight share, 9%~39%; and seating density, 16%~54%. Nonetheless, it can be concluded that aircraft fuel burn was the most important driver of transatlantic fuel efficiency in 2017. The importance of seating density as a driver of fuel efficiency has increased since 2014 because of the expansion of carriers like Norwegian and WOW air, which operate transatlantic flights with higher seat counts and a lower percentage of premium seats compared to competitors.

One of the biggest changes in the transatlantic market between 2014 and 2017 was an increase in operations from European low-cost carriers and the further utilization of newer aircraft. In 2014, Norwegian had a small footprint in the United States, accounting for approximately 1% of all transatlantic capacity, but its fleet of Boeing 787 Dreamliners generated the highest fuel efficiency. While still flying 787s, Norwegian provided 4% of capacity in 2017, with its transatlantic ASKs increasing nearly quadrupling. WOW air started flying between Iceland and the U.S. in 2015, and claimed approximately 1% of 2017 capacity across the North Atlantic.

Figure 4 compares the percentage of the total transatlantic market capacity provided by aircraft type for 2014 and 2017. Data points to the left and above of the diagonal line indicate a higher percentage of capacity available in 2017 compared to 2014, while data points below and to the right indicated a lower percentage of capacity available in 2017 compared to 2014. The Dreamliner used to provide 2% of all capacity in the transatlantic market, when combining the 787-8 and 787-9 variants. Fast forward to 2017, where the 787 provided 10% of capacity. In contrast, capacity provided by the Boeing 747 dropped from 16% in 2014 to 12% in 2017.

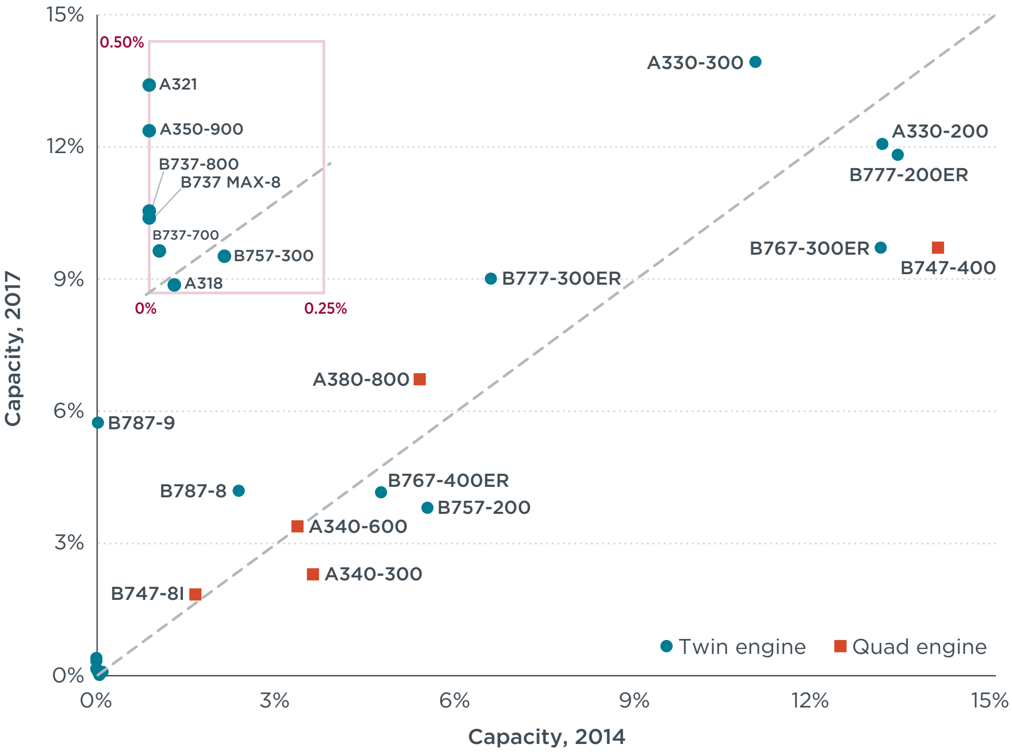

Figure 4. Comparison of transatlantic market capacity provided by each aircraft type, 2014 and 2017.

As observed in the previous transatlantic and transpacific rankings, seating configuration, or seating density, also influences airline fuel efficiency. The seating densities on transatlantic operations were generally higher than for transpacific operations, with lower share of premium seats—first and business class—on transatlantic flights. Assuming that premium seats are, on average, 1.8 to 2.7 times as carbon-intensive as economy seats (Bofinger & Strand, 2013), this could be one explanation for why average fuel efficiency for transatlantic operations at 34 pax-km/L was higher than for transpacific operations at 31 pax-km/L.

But even among carriers in the transatlantic market, the number of seats on the same aircraft model varies. For example, six of the carriers in this study operate the Boeing 787-9 across the North Atlantic. Boeing has characterized the normal two-seating class configuration for this Dreamliner variant as 290 seats (Boeing, 2018). Norwegian has the highest seating density with 344 seats, while British Airways has the lowest seating density with 216 seats.

This helps explain why airlines with densely-packed fuel-efficient aircraft—Norwegian (Boeing 787s) and WOW air (Airbus A321)—were more fuel-efficient overall than other carriers. The increase in fuel-efficient aircraft since 2014 could be a contributing factor to the industry's average fuel efficiency increase of 1 pax-km/L. The average transatlantic fleet would have failed ICAO's CO2 standard for new aircraft by 8% in 2014, but only by 5% in 2017. Passenger load factor, seating density, and freight share varied very little.

3.4 AIRLINE-SPECIFIC ANALYSIS

The aircraft used, seating density, passenger load factor, and freight carriage are key determinants of airline fuel efficiency. This section outlines how the fuel efficiency of each airline could be adjusted by improvements in these parameters.

Norwegian Air Shuttle (1st: 44 pax-km/L), the sixth-largest low-cost carrier in the world and most fuel efficient transatlantic airline in our 2014 ranking, retains its crown. Norwegian is a 4-Star rated airline by Skytrax, a consultancy that reviews and ranks global airlines and airports (Skytrax, n.d.). The airline used Boeing 737-800, 737 MAX 8, and 787 Dreamliner aircraft to fly between 14 U.S. airports and 12 European destinations.

Norwegian has orders for 30 Airbus A321LR aircraft, eight of which are scheduled to be delivered in 2019. The carrier has announced that these 220-seat aircraft will be first used on flights between London and the U.S. East Coast and Midwest, hinting at Detroit, Minneapolis, and Philadelphia (Flight Dashboard, 2018a).

WOW air (2nd: 39 pax-km/L), an Icelandic low-cost carrier, is new to the ranking. The airline started serving North America in 2015, and currently serves 12 U.S. airports from its hub at Keflavík International Airport. In 2017, the airline served only eight American airports using Airbus A321 and A330-200 aircraft. WOW air is set to lease four Airbus A330-900neos, and has hinted that the aircraft's flight range could allow it to fly from Keflavík to Honolulu, Hawaii (Kaminski-Morrow, 2017a).

Swiss International Air Lines (3rd: 37 pax-km/L), the national airline of Switzerland and subsidiary of the Lufthansa Group, remained in third position, but increased its fuel efficiency by 2 pax-km/L from the adjusted 2014 values (Appendix B). The Skytrax 4-Star airline used Airbus A330-300, A340-300, and Boeing 777-300ER aircraft between seven U.S. airports and Zürich and Geneva. SWISS had better than average freight share and aircraft fuel burn, average passenger load factor, but below average seating density. This payload management strategy of combining high premium seat share with high freight carriage is similar to that used by All Nippon Airways on fuel efficient transpacific operations (Graver & Rutherford, 2018). SWISS recently announced that it will receive two additional 777-300ERs in 2020 for route growth (SWISS, 2018). The capacity of the 777 (340 seats) is greater than that of the A330 (236 seats) and A340 (219 seats). Therefore, the direct replacement of an Airbus aircraft with the Boeing aircraft is not prudent, and consolidation of multiple flights per day on smaller aircraft (e.g. Zürich-Miami, Zürich-New York JFK) to a single flight on a larger aircraft is not possible without decreasing total capacity.

KLM Royal Dutch Airlines (4th: 36 pax-km/L), the flag carrier of the Netherlands and subsidiary of the Air France-KLM Group, currently services 10 U.S. airports from Amsterdam. KLM has announced the retirement of its Boeing 747s, which were the most often used aircraft on transatlantic operations, in 2021. The flights flown with the 408-seat 747s could easily be replaced by the carrier's Boeing 777-300ERs with the same number of seats. However, the carrier's Airbus A330-200s, which have the same number of seats as the 268-seat combination passenger-freight 747s, would not be able to handle the same amount of payload. The Skytrax 4-Star airline will take delivery of eight Boeing 787-10s, starting in 2019, and 7 Airbus A350-900s, starting in 2021. These fuel-efficient aircraft, if used for transatlantic operations, would be favorable in future rankings. The A350s could be a suitable replacement for the 747 combination aircraft with respect to payload capacity.

Turkish Airlines (T-5th: 35 pax-km/L), the flag carrier of Turkey, bettered its 2014 adjusted fuel efficiency by 2 pax-km/L. The Skytrax 4-Star airline used Airbus A330-300 and Boeing 777-300ER aircraft, which had better than industry average aircraft fuel burn and seating density, to serve nine U.S. airports from its hub at Istanbul Atatürk Airport. It has placed orders for 25 Airbus A350-900s and 25 Boeing 787-9s, with deliveries for both scheduled to begin in 2019 (Flight Dashboard, 2018b). Assuming an equal number of seats and payload, if Turkish Airlines replaces all of its A330 flights with 787s, its fuel efficiency could improve to 38 pax-km/L.

Air France (T-5th: 35 pax-km/L) is the flag carrier of France and subsidiary of the Air France-KLM Group. The Skytrax 4-Star airline served 12 U.S. destinations from its hubs at Paris-Charles de Gaulle, as well as between Paris-Orly and New York-JFK. Average fuel efficiency for the carrier increased 2 pax-km/L since 2014 after adjusting for freight due, in part, to the addition of the Boeing Dreamliner to its fleet. The French carrier has 11 Boeing 787-9 deliveries outstanding, which will be used to replace its Airbus A340-300s, as well as orders for 21 Airbus A350-900s. Replacing all A340 transatlantic flights with Dreamliners would only increase Air France's fuel efficiency to 36 pax-km/L due to the limited number of flights flown with the Airbus aircraft.

Thomas Cook Airlines (T-5th: 35 pax-km/L), one of the biggest leisure airlines in the United Kingdom, is new to the fuel efficiency ranking. The carrier used primarily Airbus A330-200 aircraft with above-industry average passenger load factor and seating densities for year-round service to Las Vegas and New York-JFK and seasonal service to six other U.S. airports. Increasing the amount of freight transported would increase average payload and, therefore, fuel efficiency. However, this may not be a realistic expectation for a leisure carrier. New, fuel-efficient aircraft may be needed to improve overall transatlantic fuel efficiency.

Virgin Atlantic Airways (T-5th: 35 pax-km/L), served 11 U.S. airports from hubs at London-Heathrow, London-Gatwick and Manchester, as well as seasonally between Orlando and Belfast and Glasgow. The Skytrax 4-Star airline increased its adjusted 2014 fuel efficiency by 5 pax-km/L and rose 11 spots from the previous transatlantic rankings due to its acquisition of efficient Boeing Dreamliner aircraft starting in late 2014. The 787-9 is now the most prevalent aircraft used between the United Kingdom and United States by the carrier, accounting for one-third of all flights. Additional changes are in store for the carrier's fleet. Virgin Atlantic's president, Sir Richard Branson, stated that the Airbus A350-1000's environmental credentials were a "genuine factor" when deciding to replace the inefficient Boeing 747s and Airbus A340s in the fleet with the aircraft (Flight Dashboard, 2016).

In its annual sustainability report, the airline states that fuel and carbon efficiency is its number one environmental policy, with aircraft fuel use accounting for nearly all of its direct carbon emissions (Virgin Atlantic Airways, 2018). Virgin's potential reintroduction of supersonic flights across the North Atlantic (Burgess, 2017) could degrade its recent fuel efficiency gains, as highlighted below.

Icelandair (T-9th: 34 pax-km/L), Iceland's largest airline, served 18 U.S. destinations from its hub at Reykjavik's Keflavík International Airport. It used a variety of narrow- and wide-body Boeing aircraft, from the 737 MAX 8 to the 767-300ER. Icelandair is scheduled to take delivery of six more 737 MAX 8s and seven MAX 9s through 2021. On average, 83% of the 183 seats on Icelandair's Boeing 757-200 are filled each flight. Those 153 passengers could be accommodated with the 172-seat MAX 9s to be introduced to the fleet. The average flight between the United States and Iceland on its 757-200 has a fuel efficiency of 32 pax-km/L. Carrying the same payload and flying the same distance, the MAX 9 could have a fuel efficiency of 41 pax-km/L.

Iberia (T-9th: 34 pax-km/L), the flag carrier of Spain and a subsidiary of International Airlines Group, served six U.S. airports from its hub at Madrid-Barajas. The Skytrax 4-Star airline operates an all-Airbus fleet, using the A330-200, A330-300, and A340-600 on transatlantic routes. The carrier has an order for 16 Airbus A350-900 aircraft, which has a similar seating capacity as its current A340-600s. Switching the A340s with A350s on transatlantic flights would increase Iberia's fuel efficiency to 39 pax-km/L.

Delta Air Lines (T-9th: 34 pax-km/L), a U.S. legacy airline and the second-largest carrier in the world, served 24 European destinations from 13 U.S. airports. The airline provided the most capacity in the transatlantic market, using predominantly Boeing 767-300 and Airbus A330 aircraft. Delta has a number of wide-body aircraft on order—17 A350-900s will join the eight currently in the fleet by 2022, and 25 A330-900neos will replace the older 767-300ERs in the fleet starting in 2020. The A330-900neos, which are based on the current A330-300s with 293 seats, will be significantly larger than the 214-seat 767-300ERs. Therefore, estimating fuel efficiency based on replacing one aircraft with another with either the same payload or the same passenger load factors and freight share could give wildly different interpretations.

Scandinavian Airlines (T-9th: 34 pax-km/L), the flag carrier of Sweden, Norway, and Denmark, served seven U.S. airports from its hubs at Stockholm-Arlanda, Oslo, and Copenhagen. As mentioned previously, the PrivatAir wet-leased Boeing 737-700 operated only through October 2017, and was then switched over to the Airbus A330s. The limited number of 737-700 flights (418) did not have a significant impact on the carrier's overall average fuel efficiency. SAS has eight A350-900 aircraft on order, with options for another six. These aircraft will have 300 seats (Scandinavian Airlines System, 2018), more than both the A330-300s and A340-300s in the fleet. Assuming that payload remains constant, replacing the A340s on transatlantic flights with the A350s would increase the carrier's overall fuel efficiency to 36 pax-km/L. If the A350s were used on all transatlantic flights, SAS's fuel efficiency could improve to 39 pax-km/L.

American Airlines (T-13th: 33 pax-km/L), the largest carrier in the world by revenue passenger kilometers (RPKs), served 19 European destinations from nine U.S. airports using a variety of Airbus and Boeing aircraft. American recently announced the cancellation of the Airbus A350-900 orders it inherited from its merger with US Airways, and the purchase of 22 Boeing 787-8s and 25 787-9s. The airline will replace its Boeing 767-300ERs with the 787-8s, and its Airbus A330-300s and older Boeing 777-300ERs with the 787-9s. Replacing all the 767-300ER and A330-300 flights with its corresponding Dreamliners would increase American's fuel efficiency to 34 pax-km/L.

Austrian Airlines (T-13th: 33 pax-km/L), the flag carrier of Austria and subsidiary of the Lufthansa Group, is new to the rankings. The Skytrax 4-Star airline operates Boeing 767-300ER and 777-200ER aircraft on its transatlantic flights from Vienna. The carrier does not have any plans for changing its current wide-body fleet (Hofmann, 2018). Austrian's aircraft fuel burn, passenger load factor, and freight share are all at the industry average, with its seating density slightly above the industry average. This explains the slightly better than industry average fuel efficiency. The carrier could increase its fuel efficiency by increasing the number of passengers or amount of freight transported.

Aer Lingus (T-13th: 33 pax-km/L), the flag carrier of Ireland and a subsidiary of International Airlines Group, served 12 U.S. airports from airports in Dublin and Shannon. The Skytrax 4-Star airline will be receiving eight Airbus A321LR that have a range that could reach the U.S. East Coast from Ireland. If the Irish carrier replaced the Boeing 757-200 aircraft used for service to Hartford, Boston, Newark, New York-JFK, and Washington-Dulles with the A321LR, its fuel efficiency would increase to 34 pax-km/L.

Alitalia (T-13th: 33 pax-km/L), the flag carrier of Italy, served Boston, Chicago-O'Hare, Los Angeles, Miami, and New York-JFK from Rome, and New York-JFK from Milan. The airline, which has had financial difficulties as of late, uses Airbus A330-200 and Boeing 777-200ER aircraft and has no wide-body aircraft on order. The average passenger load factor was above the industry average, while average freight share, seating density, and aircraft fuel burn were slightly lower than the industry average. Therefore, in order to make large increases in overall fuel efficiency, which currently is at the industry average, Alitalia would have to purchase new, fuel-efficient aircraft.

Aeroflot – Russian Airlines (T-13th: 33 pax-km/L), the flag carrier of the Russian Federation, served Los Angeles, Miami, New York-JFK, and Washington-Dulles from Moscow's Sheremetyevo International Airport. The Skytrax 4-Star airline uses Airbus A330-200, A330-300, and Boeing 777-300ER aircraft on its transatlantic routes. The Russian airline has ordered 325-seat Airbus A350-900 aircraft, which will replace its 302-seat A330-300 aircraft (Jasper, 2017). Making this switch would have little effect on Aeroflot's fuel efficiency since only one-quarter of transatlantic operations are with the A330-300.

United Airlines (18th: 31 pax-km/L), the U.S. legacy airline and third-largest carrier in the world, served 23 European destinations from its six mainland U.S. hubs. United used an all-Boeing fleet, ranging in size from a 757-200 to 747-400, on transatlantic flights. The 747 was retired from the airline's fleet in October 2017 and is typically replaced with the Boeing 777-300ER. The carrier ordered 45 Airbus A350-900 aircraft, which it will use to replace a majority of its Boeing 777-200ERs (Russell, 2018). The carrier's passenger load factor was 5 percentage points lower than the industry average. Replacing the 747 and 777-200ERs with the 777-300ER and A350-900, respectively, and increasing the overall transatlantic passenger load factor to the industry average could increase United's overall fuel efficiency to 35 pax-km/L.

Lufthansa (19th: 30 pax-km/L) is the largest airline in Europe, when combined with the subsidiary airlines of the Lufthansa Group, and is the continent's only Skytrax 5-Star airline. The carrier served 20 U.S. destinations from its hubs at Frankfurt and Munich, as well as between Düsseldorf and Newark, using a variety of aircraft with between 236 seats (Airbus A330-300) and 509 seats (Airbus A380-800). A majority of the flights between Germany and the United States are flown on Airbus A340 (both -300 and -600 variants) and Boeing 747 (both -400 and 8i variants) aircraft. The German carrier has orders for 17 additional A350-900s, as well as 20 Boeing 777-9s. If Lufthansa were to fly A350s instead of its A340s and 777-9s instead of its 747s on its transatlantic operations in the future, assuming the same average payload, its fuel efficiency could improve to 38 pax-km/L.

British Airways (20th: 27 pax-km/L), a Skytrax 4-Star airline and subsidiary of International Airlines Group, served 25 U.S. destinations from its hubs at London-Heathrow and London-Gatwick, as well as other airports in the United Kingdom and

Ireland. BA flew more than half of its departures on inefficient Boeing 747 and Airbus A380 aircraft, leading to an average aircraft fuel burn 8 percentage points higher than the industry average. These aircraft also have a lower seating density compared to the rest of the industry. One unusual route, the Airbus A318 flown between London-City or Shannon and New York-JFK, did not have a significant impact on the carrier's overall average fuel efficiency due to the limited number of flights (535).

The airline plans to retire all 747s from its fleet by 2024 (Kaminski-Morrow, 2017b). Willie Walsh, the CEO of International Airlines Group, has stated that he is interested in obtaining additional A380s (Harper, 2018). Although larger airplanes with more premium seating may conjure up feelings of luxury travel, they do not help the airline's environmental performance. BA does operate fuel-efficient Boeing 787 aircraft on transatlantic routes, with average fuel efficiencies at or above the industry average.

3.5 ROUTE COMPARISONS

In addition to these high-level results, we selected five routes with the most airline competition as case studies to evaluate how aircraft, passenger load factor, and freight carriage affect fuel efficiency.

New York-London. The transatlantic route with the most airline competition was between New York and London. For this analysis, we combined three New York area airports—JFK, Newark, and Stewart—and three London area airports—Heathrow, Gatwick, and City—because differences in flight distance would have a negligible effect on fuel efficiency. In 2017, six airlines completed 21,646 flights between the two cities, or nearly 8% of all transatlantic flights.

The effect of aircraft type on fuel efficiency is clearly visible in the results, as shown in Figure 5. Norwegian, which flew nearly all Boeing 787 Dreamliners, was the most fuel-efficient airline on the route. It's competitors burned 33% to 78% more fuel per passenger-km than Norwegian. On the other end of the spectrum, British Airways used the Airbus A380 on two-thirds of its flights and had the worst fuel efficiency.

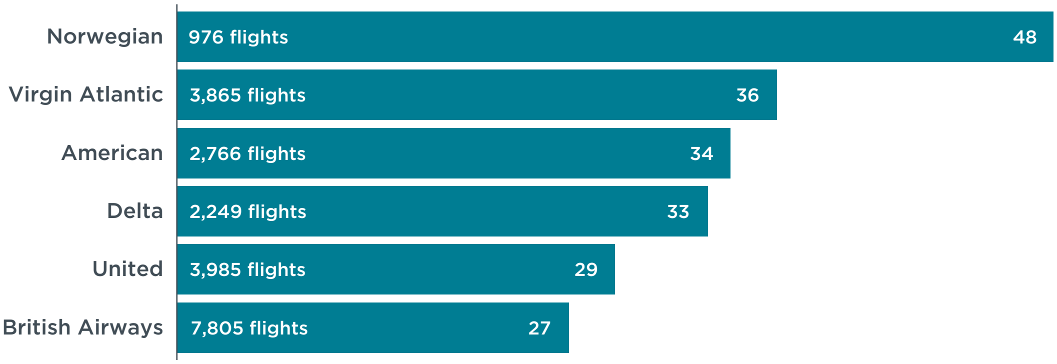

Figure 5. Fuel efficiency (pax-km/L) for airlines serving New York-London routes.

Los Angeles-London. There was greater competition for most fuel-efficient airline between the two film and television meccas. Norwegian, Virgin Atlantic, and United flew Boeing 787-9s on the route. The average payload transported made the difference. Norwegian's aircraft accommodate 344 passengers, had an average passenger load factor of 93% and average payload of 37 tonnes. Virgin Atlantic's seat 264 passengers, averaged 80% filled, but with freight averaged nearly 35 tonnes. United's 252-seat Dreamliners were 77% occupied, transported nearly 31 tonnes, and had an average fuel efficiency of 42 pax-km/L. However, a majority of the carrier's flights between Los Angeles and London-Heathrow in the first quarter of 2017 were operated using Boeing 777-200 aircraft with seats that were only 44% filled. This dragged down United's overall fuel efficiency.

Again, British Airways was least efficient, using the Airbus A380 on nearly 80% of flights.

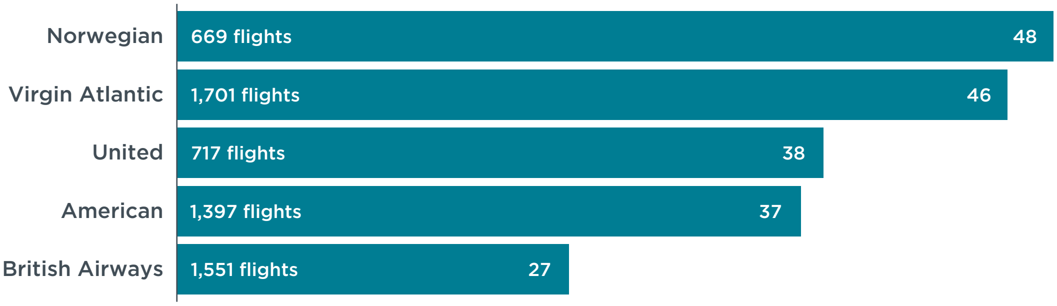

Figure 6. Fuel efficiency (pax-km/L) for airlines serving Los Angeles-London routes.

New York-Paris. A wide variety of aircraft is used between the New York-area airports and the two Paris airports—Charles de Gaulle and Orly—from the single-aisle Boeing 757-200 to the very large Airbus A380. Norwegian was the only carrier to consistently use the fuel-efficient Dreamliner in this market, and was substantially more efficient than its competitors as a result. While Air France used its A380s on this route, they accounted for less than one-third of total flights. Instead, most flights were performed with Boeing 777 aircraft.

Figure 7. Fuel efficiency (pax-km/L) for airlines serving New York-Paris routes.

In addition to overall in the transatlantic market, for the three routes above, Norwegian was the most fuel-efficient carrier. A further analysis was conducted to see if this was true for all routes on which the carrier flew. Norwegian was the most fuel-efficient on 28 of the 29 routes where it had competition with at least one other airline, only trailing Virgin Atlantic on the Seattle-London route.

New York-Reykjavik. Air traffic between the United States and Iceland has increased rapidly since 2014 due to the introduction of WOW air and the expansion of Icelandair to new American cities. Both airlines offer free stopovers, allowing tourists with a round-trip ticket to break up one of their transatlantic itineraries and visit Iceland for no additional fee. Because of Iceland's proximity to both North America and Europe, all airlines can operate single-aisle aircraft on the routes. There is minimal freight carriage, so nearly all payload consists of passengers.

In 2017, three airlines operated between New York-area airports and Keflavík International Airport. WOW air, and its 89% occupied Airbus A321 aircraft, was the most fuel-efficient carrier. Icelandair used a variety of Boeing aircraft—757-200s, 757-300s, and 767-300ERs—that were 84% filled. As previously mentioned, Icelandair's fuel efficiency on this route could increase by the introduction of the Boeing 737 MAX aircraft. On average, 83% of the seats in Delta's Boeing 757-200s were filled.

In 2018, United added seasonal service between Newark and Reykjavik with Boeing 757 aircraft.

Figure 8. Fuel efficiency (pax-km/L) for airlines serving New York-Reykjavik routes.

These route-based analyses can be compared with findings of other resources for benchmarking airline fuel efficiency. For example, as part of its CO_2 calculator, ICAO estimates the average total fuel burn per flight using a fuel consumption formula derived from fuel burn data reported by U.S. airlines to BTS (ICAO, 2017). The total fuel burn on a route is the weighted average of fuel burn by each aircraft type on the route, based on flight frequency.

Emissions estimates provided by the ICAO CO_2 calculator are not useful for selecting individual carriers or routes and may deviate significantly from the fuel burn of best and worst carriers operating on a given route. For example, ICAO estimates total fuel use of between 80 and 109 tonnes for a roundtrip flight between New York and London, depending on origin and destination airports. The ICAO carbon calculator does not include fuel burn estimates for the New York Stewart – London Gatwick route served by Norwegian or the New York JFK – London City route served by BA. According to our methodology, United had the lowest fuel burn per roundtrip at 55 tonnes, followed by Delta (58 t), Norwegian (70 t), American (87 t), Virgin Atlantic (89 t), and British Airways (93 t).

The ICAO carbon calculator uses average passenger load factors and passenger-to-freight factors in the calculation of total fuel burn. For the Europe-North America route group, it is assumed that 82% of aircraft seats are filled and that nearly 80% of total payload is due to passengers (ICAO, 2017). This study is in agreement with those figures, with a passenger load factor of 81% and a passenger-to-freight factor of 79% for the 20 airlines analyzed.

4. CONCLUSIONS AND NEXT STEPS

4.1 CONCLUSIONS

There is a wide gap of 63% between the fuel intensity of industry leader Norwegian Air Shuttle and bottom-ranked British Airways on transatlantic operations. This gap is wider than was observed on transatlantic routes in 2014. The two main drivers of this were aircraft fuel burn and seating density, which combined explain nearly 75% of the variation in transatlantic fuel efficiency. Two low-cost carriers—Norwegian, with its very efficient Boeing 787 Dreamliner fleet, and WOW air, with its densely-packed Airbus A321-200 aircraft—topped this fuel efficiency ranking.

A general trend observed is the fuel burn per passenger kilometer increases on transatlantic routes as the aircraft size and weight increase. Airlines that predominantly use very large aircraft—Lufthansa and British Airways—had the lowest overall fuel efficiency on transpacific flights. This is largely because aircraft with four engines have generally higher fuel burn per passenger than those with two. This, combined with the fact that fuel is typically the single largest operational expense for airlines, helps explain the industry-wide trend of retiring aging Boeing 747 aircraft and the sluggish market for the superjumbo Airbus A380 (Goldstein, 2017). Only British Airways is bucking this trend by wanting to purchase more A380s.

More generally, we see that carriers with very different combinations of aircraft, passenger load factor, freight carriage, and seating configuration operate with similar fuel efficiency. Four airlines averaged 35 pax-km/L—Turkish, Air France, Thomas Cook, and Virgin Atlantic. Although Air France and Virgin Atlantic performed flights with inefficient Airbus A380s and Boeing 747s, they also used fuel-efficient Dreamliners. Thomas Cook used mostly Airbus A330-200 aircraft, which have industry-average fuel efficiency. But given the higher seating density and passenger load factors, the British leisure carrier had better than average fuel efficiency.

ICAO has established a long-term, aspirational goal of increasing the fuel efficiency of international flights by 2% annually (ICAO, 2016). The introduction of more fuel-efficient wide-body aircraft, such as the Airbus A350 and the Boeing 787, can contribute to achieving this goal. As the demand for air travel increases, more new aircraft will be purchased. Models like the A350 and 787, as well as models under development like the A330neo and 777X, eventually will come to dominate the global airline wide-body fleet. All other things being equal, airlines operating aircraft with lower fuel burn tend to be more efficient, but operational parameters such as payload carried are also important and should be tracked.

Some groups, such as the Virgin Group and the supersonic jet startup company, Boom, believe that there is room for other aircraft types in the transatlantic market besides new, fuel-efficient wide-bodies. In 2016, Branson announced that Virgin Atlantic has the options on the first 10 Boom aircraft produced (Neate, 2016). An assessment of the environmental performance of new commercial supersonic aircraft was recently completed. That study (Kharina, McDonnell, & Rutherford, 2018), which used Boom's anticipated design as a representative aircraft for modeling, concluded that the efficiency of a new commercial SST operating between London and New York would be about 7 pax-km/L (Kharina, McDonnell, & Rutherford, 2018). Given the carrier is currently tied for fifth place in the rankings at 35 pax-km/L, the addition of supersonic aircraft to

Virgin Atlantic's fleet would degrade the carrier's fleet average fuel efficiency and their standing in future rankings would slump.

The UN's International Civil Aviation Organization (ICAO), which acts as the de facto regulator of commercial aviation worldwide, has adopted an aspirational goal for airlines to improve their fleet fuel efficiency by 2% annually. While ICAO has developed a fuel efficiency standard for new aircraft (ICCT, 2017), it has not yet adopted mandatory policies to boost efficiency in the existing fleet. CO_2 reductions through ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) are likely to be met through carbon offsetting, not improved aircraft efficiency or alternative fuels (Pavlenko, 2018). Fuel prices alone, while important, have been found to be an inconsistent driver of aviation fuel efficiency (Kharina & Rutherford, 2015). Additional policies to promote emission reductions from the in-service fleet will likely be needed if industry is to meet its long-term climate goals.

4.2 NEXT STEPS

Regarding future work, we will continue to work with DOT and our data provider to ensure that airlines report accurate operational data for use in subsequent airline fuel efficiency rankings. We will continue to seek data to support the inclusion of routes to and from Canada in future rankings. Future updates to the transatlantic rankings will help evaluate changes in fuel efficiency due to new aircraft types, such as the Airbus A321LR. Finally, assuming widespread cooperation from ranked airlines, our methodology could be shifted from a modeling approach to one in which primary fuel burn data from all carriers are analyzed to encompass the full range of operational measures that affect airline fuel efficiency.

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APPENDIX A: MODEL VALIDATION

The methodology described in Section 2 was validated using fuel burn data reported to the BTS by American Airlines, Delta Air Lines, and United Airlines for each aircraft type operating on transatlantic flights (BTS, 2018). The average fuel efficiency for each aircraft type was calculated directly from these data and compared with the modeled fuel efficiency. The uncertainty introduced by modeling fuel burn with Piano using standardized assumptions for operating parameters could be assessed. A total of 23 airline-aircraft type combinations were included in the model validation analysis, shown in Figure A-1.

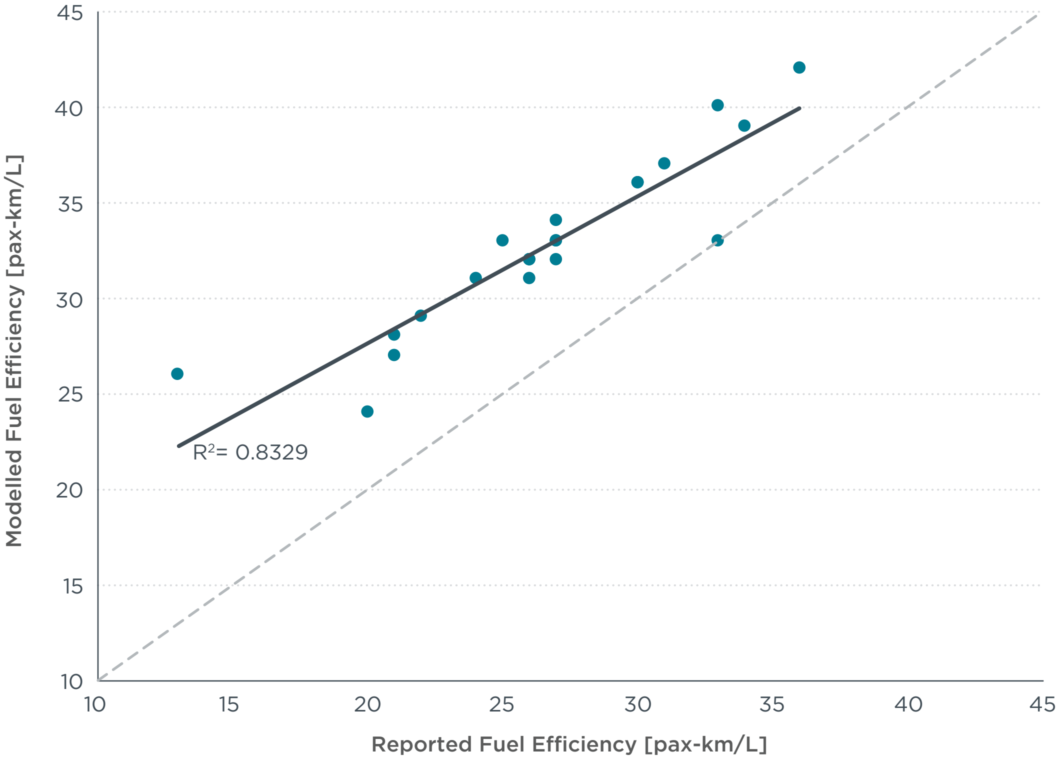

Figure A-1. Airline-reported versus modeled fuel efficiency.

In addition to this high level validation, PIANO modeled fuel efficiency was compared to reported fuel efficiency for several airlines. Modelled values were found to be within 1% of actual values for the two airlines investigated.

These validation results suggest that our modeling approach is robust and appropriate for the purpose of comparing the relative fuel efficiency of transpacific operations. Although the model overestimates fuel efficiency compared with reported fuel burn data on the order of 20%, a good linear fit (R^2 of 0.83) was observed. These validation findings are broadly consistent with those reported in the Intergovernmental Panel on Climate Change's report, *Aviation and the Global Atmosphere*.[3] This indicates that changes to the modeling parameters are unlikely to lead to major shifts in the rankings.

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[3] "The assumption of great circle flight paths results is an underestimate of distance flown. A combination of factors [e.g., deviation from great circle distance, delay, engine deterioration, etc.] results in systematic underestimation of total fleet fuel burned by 15%-20% for domestic operations." (Intergovernmental Panel on Climate Change, 1999)

APPENDIX B: ADJUSTED 2014 TRANSATLANTIC FUEL EFFICIENCY

A common methodology is needed to make direct comparisons between the 2014 and 2017 transatlantic airline fuel efficiency rankings. The 2014 ranking included Air Canada, requiring that the fuel efficiency of flights between Canada and Europe be estimated. Aircraft fuel use is proportional to the total payload mass transported. The mass of freight per flight for non-U.S. carriers was modeled as a function of aircraft cargo capacity by volume due to the lack of Canadian flight operations data.

Recent studies (Graver & Rutherford, 2018) have highlighted belly freight carriage as a key determinant of passenger airline efficiency. This update was improved by incorporating actual, as opposed to estimated, belly freight into the fuel efficiency calculation. This excluded Air Canada from the ranking due to the lack of data.

In order to directly compare the 2014 and 2017 results, we corrected fuel efficiencies for 2014 flight operations based on T-100 International Segments data for all airlines in the previous ranking. For Air Canada, the estimated average fuel efficiency of 33 pax-km/L was maintained. Figure B-1 depicts the adjusted 2014 transatlantic airline fuel efficiency ranking.

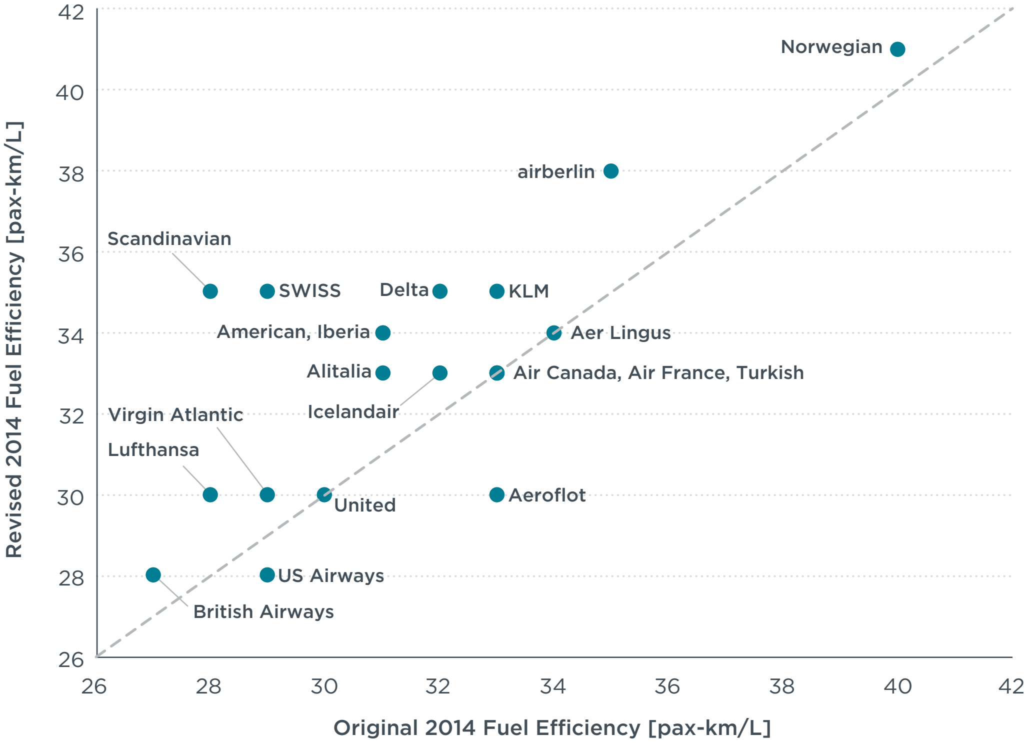

Figure B-1. Adjusted fuel efficiency of 20 airlines on transatlantic passenger routes, 2014.

Although the overall trends held, some differences exist between the previously reported and adjusted 2014 airline average fuel efficiencies linked to better data on freight carriage:

- The average fuel efficiency for Swiss International Air Lines (SWISS) increased from 29 pax-km/L to 35 pax-km/L. The modeled average freight share of payload was 17%, while T-100 data indicate an actual freight share of 33%.
- The average fuel efficiency for Scandinavian Airlines (SAS) increased from 28 pax-km/L to 35 pax-km/L. The modeled average freight share of payload was 13%, while T-100 data indicate an actual freight share of 30%.
- The average fuel efficiency for Aeroflot Russian Airlines decreased from 33 pax-km/L to 30 pax-km/L. The modeled average freight share of payload was 21%, while T-100 data indicate an actual freight share of 11%.

In addition to adjustments in airline average fuel efficiency, two improvements were made in the statistical analysis of fuel efficiency drivers. First, actual, rather than estimated, freight carriage was used. Second, the method of determining the average aircraft fuel burn for each carrier's fleet was refined. In the 2014 analysis, which was performed before ICAO's CO_2 standard was finalized, the margin to ICCT's own efficiency reference line was used to estimate the fuel burn of each airline's fleet. The standard line adopted by ICAO in 2016 was different than what was used for the 2014 transatlantic analysis. In order to make direct comparisons between the 2014 and 2017 drivers of transatlantic airline fuel efficiency, the margin to the metric value was recalculated for 2014 operations, using the ICAO-adopted reference line.

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www.theicct.org

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