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U.S. DOMESTIC AIRLINE FUEL EFFICIENCY RANKING 2010

AUTHORS: MAZYAR ZEINALI, PH.D., DANIEL RUTHERFORD, PH.D., IRENE KWAN, AND ANASTASIA KHARINA

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

www.theicct.org

communications@theicct.org

BEIJING | BERLIN | BRUSSELS | SAN FRANCISCO | WASHINGTON

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1225 I Street NW, Suite 900, Washington DC, 20005

www.theicct.org | communications@theicct.org

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EXECUTIVE SUMMARY

This report assesses and compares the fuel efficiency of airlines serving the U.S. domestic market in 2010. The analysis presented here rigorously compares the efficiency of all airlines independent of size, network structure, or type of service, with a methodology that improves upon previous efforts in four fundamental ways. First, it uses airline-reported fuel consumption data, rather than modeled estimates, to account fully for all the ways in which airlines can reduce fuel burn (e.g., aircraft technology or operational practices). Second, it develops an efficiency metric that recognizes that airlines burn fuel to provide both *mobility* (measured in terms of passenger miles traveled) and *access* (frequency of service and number of airports served), allowing an equitable comparison between airlines. Third, the efficiency metric distinguishes productive from nonproductive miles flown by identifying those airlines that operate particularly circuitous routes. Finally, the study attributes the transport service provided by and fuel consumption of affiliate carriers to mainline carriers in order to enable comprehensive comparisons across carriers' full business operations.

Figure ES-1 summarizes the principal findings of this study, comparing the relative fuel efficiency for the domestic operations of the 15 largest U.S. airlines in 2010 across each carrier's entire network. A fuel efficiency score of 1.00 corresponds to average in-use fuel efficiency for the U.S. market in the given year, with values above or below 1.00 representing airlines that fare better or worse, respectively, than the industry average. Since fuel use is inversely proportional to fuel efficiency, the fuel efficiency score can be directly linked to the amount of fuel consumed, and consequently the emissions generated, by each airline to provide a comparable level of service.

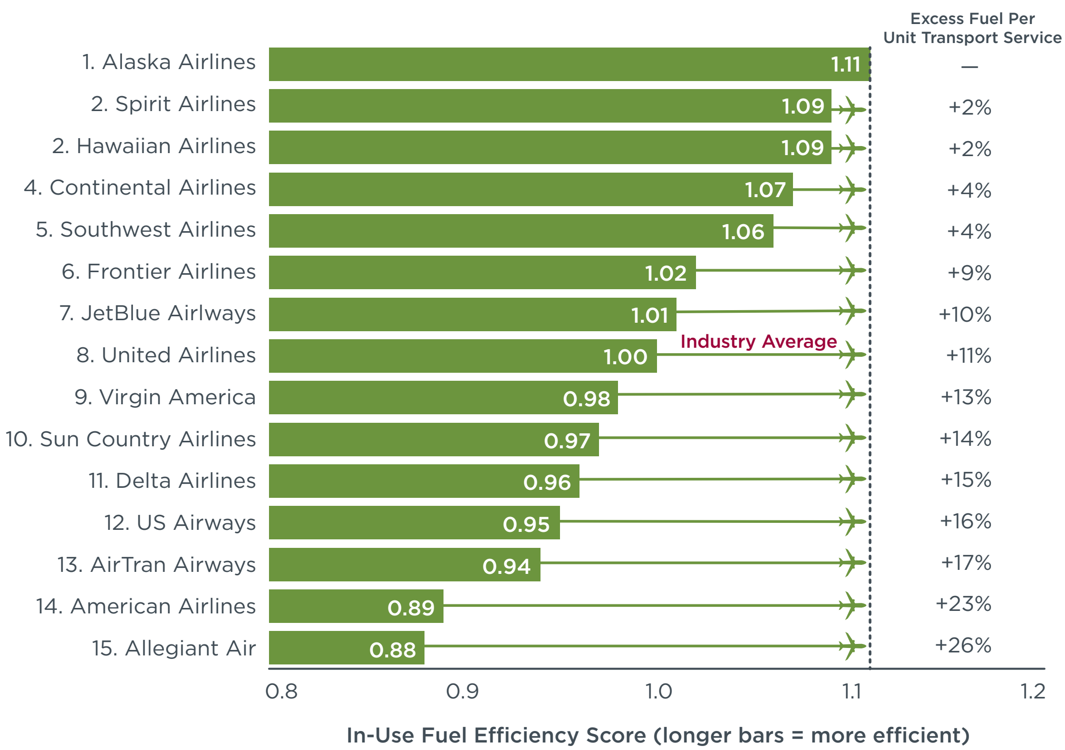

Figure ES-1. Fuel efficiency scores by airline for 2010 U.S. domestic operations (higher score means greater efficiency).

Of the carriers with above average fuel efficiency in domestic operations, Alaska Airlines (ranked first), Spirit Airlines (tied for second), and Hawaiian Airlines (tied for second) are relatively small carriers serving geographically limited markets. Continental Airlines, in fourth place, was the most fuel-efficient full-service legacy carrier (established prior to deregulation) while Southwest Airlines (fifth) was the most efficient carrier operating on a point-to-point rather than a hub-and-spoke business model. United Airlines (eighth), with a fuel efficiency score of 1.00, was equal to the average for 2010 U.S. domestic operations. Many, although not all, of the carriers with worse fuel efficiency than the industry average were, or subsequently have been, the subject of merger activity, including Delta Air Lines (11th), US Airways (12th), AirTran Airways (13th), and American Airlines (14th). The least efficient airline in this ranking, Allegiant Air, also happened to have the most profitable U.S. domestic operations during the 2009 to 2011 period.

Figure ES-1 highlights a large gap between the most and least efficient airlines serving the U.S. domestic market. The figure suggests that Allegiant would have used 26 percent more fuel than Alaska Airlines to provide a comparable level of transport service in 2010. Approximately one-third of this variation can be attributed to differences in technology alone, with the balance of the variation related to a complex set of characteristics such as seating density, operational practices (e.g., fuel loading/tankering, single-engine taxi, etc.), load factor (the number of passenger miles traveled as a percentage of seat miles available), and route circuity (the total number of passenger miles traveled divided by the number of intended, or "productive," passenger miles).

An additional analysis was performed to estimate the fuel efficiency of U.S. airlines across the ten most traveled domestic city pairs. Owing to a lack of primary airline data, this analysis relied on an aircraft performance model to estimate fuel burn. Overall, route-based fuel efficiency, as measured by passenger miles transported per pound of fuel, differed among airlines serving the same route from 9 percent to as much as 90 percent because of aircraft technology, load factor, seating density, and route circuity. Shorter trips, for example, north-south travel along the coasts, are significantly more fuel intensive on a passenger mile basis than transcontinental flights. This general finding is attributable in part to the large amount of fuel consumed during takeoff and to the use of smaller, less efficient aircraft such as regional jets on shorter routes. In many cases, because of variations in aircraft choice, seating density, route circuity, and such, an airline offering efficient flights between a major city pair may not rank well at the network level. These results highlight the need for better route- and even flight-specific data for consumers wishing to select less carbon-intensive flights for a specific trip.

Several conclusions can be drawn from this work:

1. Within the mature, competitive U.S. aviation market, there remains a large gap in fuel efficiency among airlines flying on domestic routes even at today's high fuel prices. Fuel prices alone may not be a sufficient driver of in-service efficiency across all airlines.
2. Although technology utilization is important, operational practices vary significantly from airline to airline, impacting in-service fuel efficiency. To address the energy and environmental effects of aviation, policies that facilitate and encourage efficient operations as well as technologies should be considered.

3. The most efficient airline for a given itinerary varies by city pair, with the top performer on one route not necessarily being efficient on another. Thus, route-specific data are required for consumers to make more environmentally responsible decisions.
4. Accurate, transparent data are the cornerstone for assessing the efficiency of airlines. Data in this report can help inform consumers about the relative efficiency of their air travel. Reporting requirements for more detailed data on aircraft fuel consumption would go further in supporting any future policies to improve efficiency.

1. INTRODUCTION

1.1. Background

Aircraft play a vital role in our modern economy by quickly and conveniently transporting people and goods, although at a cost of increasing petroleum demand and affecting the global climate through the production of greenhouse gases. Aircraft were responsible for approximately 2.5 percent of anthropogenic carbon dioxide (CO_2) emissions, and up to 5 percent of historical radiative forcing,[1] including non-CO_2 impacts, in 2006. Moreover, emissions from aviation are projected to increase by approximately 4 percent annually through 2050, by which time they might contribute as much as 15 percent of anthropogenic CO_2 emissions.[2] Aviation activity is currently responsible for about 10 percent of global transportation-related oil use, amounting to around 4.5 million barrels per day—and oil consumption by the aviation sector is expected to at least double by 2030.[3]

Currently, surprisingly little public information is available to policymakers, investors, and consumers about airline fuel efficiency and CO_2 emissions. Knowledge about the ways in which airlines can operate their aircraft more efficiently could be used to craft policies to reward more efficient airlines while promoting practices that reduce fuel consumption. Since the price of jet fuel accounts for a large share of operating costs, investors could use fuel efficiency data to make smarter investment decisions. Finally, business and leisure travelers are increasingly demanding better information about the carbon footprint of flights to help them select less carbon-intensive travel options.

This study presents a new methodology to assess and compare the fuel efficiency of airlines irrespective of size or business model. Two approaches have been developed. The first compares the relative efficiency of the top fifteen airlines, accounting for 99 percent of the total annual jet fuel consumed for U.S. domestic operations in 2010. The comparison is based upon the amount of fuel used to provide a given level of transport service across an airline's complete range of domestic operations. The U.S. domestic aviation market in 2010 provides an ideal laboratory for such an analysis. First, the United States is a large, mature, and diverse market, historically accounting for roughly a third of global aviation-linked fuel consumption and representing a diverse mix of full-service legacy[4] and low-cost carriers. This improves the likelihood that the conclusions drawn here will be applicable across a range of carriers and countries. Furthermore, the United States compiles a variety of information on airline operations and fuel burn, including BTS Form 41 data from the U.S. Department of Transportation's Bureau of Transportation Statistics, through which primary and modeled analysis can be conducted. Finally, 2010 provides a useful base year—post–global recession, prior to major mergers—from which future changes in fuel efficiency can be easily measured.

A second, complementary way to characterize airline fuel efficiency, one of particular interest to the flying public, is to examine the performance of airlines on the 10 most traveled U.S. domestic routes. Together, these approaches provide a complete picture of relative airline efficiency for multiple audiences and establish a benchmark year, from which changes can be gauged. The study also attempts to explain the gap between

1 Radiative forcing is defined as the change in net irradiance at the tropopause after allowing for stratospheric temperatures to readjust to radiative equilibrium. See Pachauri and Reisinger, eds., 2007.
2 Lee et al. 2009.
3 Façanha, Blumberg, and Miller 2012.
4 A legacy airline in the United States is one that had established service prior to the route liberalization permitted by the Airline Deregulation Act of 1978.

the most and least fuel-efficient airlines by assessing the importance of technology versus operational parameters (e.g., high load factor, prevalence of direct flights, etc.) in reducing fuel use.

1.2. Comparisons with Previous Airline Efficiency Evaluations

Several previous attempts have been made to compare the fuel efficiency or environmental performance of airlines (see Appendix A). Although these studies share a goal—to assess the fuel efficiency (or CO_2 intensity) of various airlines—significant differences can be found among the study methods, chosen metrics, and ultimate findings.

Previous studies have suffered from the following limitations:

1. Lack of transparent information about the data, which were frequently proprietary, and analytical techniques (e.g., "black box" modeling without detailed methodological description);
2. Failure to use real-world airline fuel consumption data for validation;
3. Simplistic metrics, such as fuel per passenger mile, that inappropriately penalize certain carriers;
4. Inability to distinguish productive from nonproductive (circuitous) passenger miles; and
5. Narrow coverage range of airline types, which ought to include low-cost carriers and regional affiliates of larger airlines.

Each of these limitations is discussed briefly below.

Fundamentally, fuel efficiency metrics are ratios of the amount of "good" (e.g., persons carried times distance traveled) per unit of "bad" (fuel use or emissions impact). Fuel consumption can be measured via primary data (self-reported fuel use by airlines) or analytical approaches that estimate fuel use based upon parameters such as aircraft type, empty weight, stage length (the length of a flight), payload, speed, etc. Because the universe of parameters influencing aircraft, and therefore airline, fuel efficiency is very large, and no data set is complete, even the most sophisticated modeling approaches cannot capture the full range of operational and environmental variables that determine fuel use.

Further examples are illustrative. Table 1 provides a summary of the determinants of airline fuel efficiency arranged into four categories: the *transport services* provided by airlines, notably mobility and access; *aircraft-level parameters* such as age and maintenance practices; *operational practices* (routing, load factors, speed); and *environmental conditions* (weather and congestion). Since airlines are in the business of providing transport service, an effective metric should be able to distinguish fuel used to support mobility and access from excess fuel burned as a consequence of other conditions such as the use of older equipment, indirect routing, or lower load factors.

Table 1. Parameters influencing airline fuel consumption

Category	Parameter	Relevance to efficiency	Metric	Fuel consumption	Variation across carriers
Transport service	Mobility	Passenger and distance influences fuel burn through payload and fuel mass	RPMs	Very high	Very high
	Access	Number of flights determines fuel burn	Departures	Very high	Very high
Aircraft-level parameters	New aircraft efficiency	Reduced fuel burn/RPM and fuel burn/departure	See section 3.2	High	High
	Age	Aircraft become 1–5% less fuel efficient over time due to degradation in engine and aerodynamic performance	Age	Medium/ low	High
	Size	Gauge, use of regional jets, etc.	Floor area	Medium	Medium
Operational practices	Routing	High circuity means lower percentage of productive miles	Circuity	High	Low
	Flight length	Close match of flight length to aircraft optimum range for best fuel performance reduces fuel burn	Operated range/ optimum aircraft range	Medium/ low	Medium
	Seating density	Determines number of seats available for passengers	Seats / floor area	High	Medium
	Load factor	Determines number of passengers carried on a flight	Percentage of seats filled	High	Low
	Aircraft utilization	Greater utilization of more efficient aircraft reduces fuel burn	Activity hours/ year	High	Medium
	Fuel loading	Excess fuel carriage (tankering, etc.) affects efficiency	Excess fuel at landing	Medium/ low	Unknown
	Speed	Operating aircraft faster/slower than optimum cruise speed will increase fuel burn	Percentage of max SAR speed	Medium / low	Unknown
	Maintenance	Engine washing/fuselage painting, etc. can reduce fuel burn	Engine fuel degradation factor	Low	Unknown
	Engine utilization	Single-engine taxi can reduce ground fuel burn	Ratio of single-engine taxi time to total taxi time	Low	Unknown
	Ground time	Aircraft engine idling	Units of time per flight	Low	Unknown
Environmental factors	Congestion	Aircraft holding in the air or idling increases fuel burn	Observed delay against schedule per flight	Medium/ low	Unknown
	Weather	Increased fuel burn and higher fuel loading	Delay in units of time per flight	Low	Unknown

RPM = Revenue Passenger Miles (number of miles traveled by passengers occupying seats); SAR = Specific Air Range

Given this large list of influencing sources, no modeling approach can ever completely describe the fuel efficiency of airlines; thus, where available, having primary fuel burn data reported by the airlines to a validating third party is the sounder option. Such data, though, are not often publicly disclosed by the airlines themselves to characterize their environmental performance; instead, incomplete or selectively disclosed proprietary data often form the basis of comparisons. Typically, only the most efficient carriers will self-report, and often only for those years in which they outperform their competitors. A transparent, consistent, and primary data source is preferable for evaluating the relative efficiency of airlines on common basis.

Previous estimates of airline efficiency also tended to use simple metrics such as fuel consumption per passenger mile or per ton-mile. These metrics, while readily understandable, oversimplify the transport services that airlines provide. At their core, airlines provide two kinds of benefit to consumers: mobility and access. *Mobility* is a measure of how far a specified number of people are carried on an airline. *Access*, defined as the ability of a traveler to board or deplane an aircraft, can be expressed as the number of flights (departures) that an airline provides over a given period of time. Consumers require both mobility and access, and airlines compete in the marketplace by burning more or less fuel to provide a combination of them. A metric failing to take into account mobility and access together will therefore bias the findings in favor of airlines operating fewer, longer flights.

Previous studies also varied in how they estimated passenger miles traveled. While fliers would like to travel directly between their origin and intended destination, they are often unable to do so and must instead fly circuitous routes, either because the airline uses a hub-and-spoke model in which passengers must transfer at intermediate airports or because of indirect routing resulting from operational constraints such as weather or congestion. Miles flown beyond those of a direct route (the “great circle distance”) represent unproductive travel properly characterized as inefficient. Airline efficiency studies should capture the effects of circuity[5] and reward airlines that burn less fuel by operating more direct routes than their competitors.

Finally, comparisons of airline efficiency ideally ought to cover the full range of airlines serving a given market, including low-cost carriers and smaller affiliate airlines. Many studies to date have failed to do so. For example, a ranking by Atmosfair excluded low-cost carriers, reasoning that those carriers, which may be operating efficiently thanks to their relatively new fleets and high seating densities, increase emissions by stimulating demand among budget-conscious travelers. Furthermore, many previous surveys have not included regional carriers, which link consumers at smaller airports to the wider network of legacy airlines, in their rankings.

1.3. Structure of this Report

Chapter 2 of the report to follow describes the methodology used while explaining how the shortcomings described earlier were overcome. Chapter 3 summarizes the study’s primary findings. Chapter 4 presents conclusions and considers the implications of the work for policymakers, investors, and consumers.

5 Circuity is defined as the total number of passenger miles traveled divided by the number of intended/productive passenger miles, as defined by the great circle distance linking the origin and destination airport. A more detailed explanation of circuity is provided in Chapter 2.

2. METHODOLOGY

2.1. Methodology for Airline Efficiency Ranking

The fundamental level of analysis in this study is that of the fuel efficiency of airlines in the context of the full suite of transport services they provide over their entire networks. A key step was to develop a metric and methodology that would allow for fair comparisons across all major airlines serving the U.S. market. The methodology was developed in collaboration with Professor Mark Hansen at the National Center of Excellence for Aviation Operations Research (NEXTOR) at the University of California, Berkeley.[6]

Airlines operate under varying business models and practices, network structures, and scale in serving their customers. Each of these characteristics helps determine aggregate fuel consumption without necessarily representing a meaningful difference in efficiency. In order to rate the underlying fuel efficiency of airlines in a fair way, fuel consumed to provide a particular level of transport service must be distinguished from excess fuel burned as a result of inefficient practices. Defining the transport "service" that airlines provide allows them to be compared on a common basis without excluding any on the basis of qualitative distinctions such as business model.

Commercial passenger aircraft efficiency is defined as transport of people[7] (the desired outcome) compared with the amount of fuel used (the required input). While gauging fuel use is relatively straightforward, measuring airline transport service is less so because of the need to account for airline business models, mobility, access, and circuity. As noted in the introduction, airlines offer their passengers both mobility and access. This study accounts for airlines that utilize fewer (or more) stops to transport a passenger from origin to destination by evaluating fuel use relative to both revenue passenger miles (RPM) and the number of departures—RPMs being a measure of the mobility provided by an airline and departures serving as a proxy for accessibility. In general terms, the more RPMs an airline provides per unit of fuel, the more efficient the airline. However, travelers' ability to avail themselves of an airline's RPMs is also important, with each airline striking a unique balance between getting passengers to their final destination as directly as possible with the need to provide access to all its potential customers. Carrying more, flying further, and offering more flights—either by serving more airports or flying more frequently—all increase fuel burn. A robust methodology credits airlines for fuel consumed to supply both RPMs and departures.

At the same time, while the intention is to credit fuel used to enhance access, there needs to be a means of discounting fuel used for overly circuitous flights. Circuity is the ratio of the actual distance traveled to the intended distance of travel (i.e., the great circle distance from origin to destination); by definition, circuity is always equal to or greater than 1. A mainline carrier's circuity is estimated by taking the ratio of the total passenger itinerary miles to nonstop miles for each airline from the Bureau of Transportation Statistics' (BTS) Airline Origin and Destination Survey (DB1B) database, which provides detailed information for a 10 percent sample of U.S. domestic travel itineraries.[8]

6 A detailed report authored by Zou, Elke, and Hansen presenting the metric in full technical detail, including a comparison to alternative metrics, can be found at http://theicct.org/evaluating-air-carrier-fuel-efficiency

7 Although this study focuses on the carriage of passengers and thus uses a passenger-based metric (passenger mile), the methods presented here can likely be adjusted to include air freight as well via the use of a ton-mile metric for mobility. Since freight carriage is limited on U.S. domestic routes—nonpassenger ton-miles made up less than 3 percent of total ton-miles for the 15 mainline carriers—this study includes passenger movement only.

8 Regional carriers are included in the DB1B database under the name of their affiliated mainline airlines. Therefore, the passenger itinerary miles used for circuity calculation represent the mainline/regional composite RPMs, and the resulting efficiency is for the mainline airline combined with its affiliated regional carriers.

The greater the value of circuity, the more nonproductive miles are traveled by an airline's customers. Airlines deviate from great circle distances for an origin-destination pair for various reasons, including weather and air traffic control restrictions. However, an airline's network structure also influences its level of circuity and hence the number of nonproductive miles traveled by passengers.

Airline fuel efficiency can be compared through a frontier approach[9] that uses the best-performing airline(s) to benchmark less efficient airlines. First, an empirical mathematical model is constructed, relating productive RPMs and departures (output) to fuel use (input). For a population of airlines and a set of operations, one airline will provide the largest amount of transport service per unit of fuel or, alternatively, use the least fuel to provide a given level of service. The combination of fuel, RPMs, and departures for this airline is used to establish a minimum (the frontier) value representing the most efficient use of fuel. Figure 1 graphically illustrates the connection between transport service and fuel use, showing four hypothetical airlines and the efficiency frontier. In the figure, an airline that lies on the frontier (represented by the dotted line) is more efficient than those located above the line, with the magnitude of an airline's deviation from the frontier line corresponding to its relative inefficiency. In Figure 1, Airline 1 is the most efficient followed by Airline 2, then Airline 3, with Airline 4 being the least efficient.

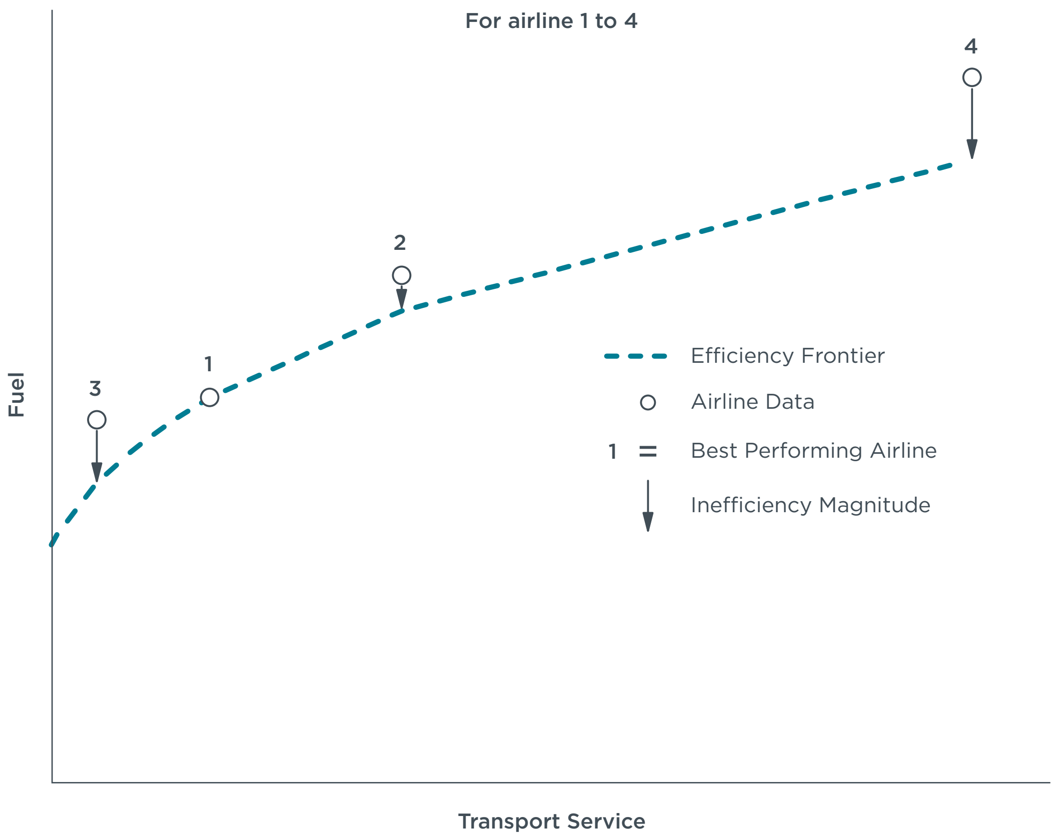

Figure 1. Frontier ranking approach

9 Kumbhakar and Knox Lovell 2000.

Mathematically, the input of an airline *i* at time *t* is related to its output through the following general function:

$$input_{it} = f(output_{it}) + \eta_{it} \qquad \textbf{[Eq. 1]}$$

or, more specifically,

$$fuel_{it} = f(RPM_{it}, dep_{it}) + \eta_{it}$$

where η_{it} represents the airline's true inefficiency. Assuming that a log-linear function best describes the data, this relationship transforms into the following specific function:

$$\ln(\text{fuel})_{it} = \beta_0 + \beta_1 \ln(\text{RPM})_{it} + \beta_2 \ln(\text{dep})_{it} + \xi_{it} \qquad \textbf{[Eq. 2]}$$

where β_0, β_1, and β_2 are the coefficients estimated from a given dataset of fuel consumption, RPMs, and departures. An ordinary least squares regression is calculated to estimate the two slopes β_1 and β_2 with an initial intercept β_0', based on which the residual ξ_{it} is calculated for each observation. In the second step, β_0' is shifted downward until it becomes β_0, defining a line for which the most efficient airline has a residual of zero, thereby lying directly on the frontier.

From the previous equation, the inefficiency measure becomes $\exp(\xi_{it})$ and is equal to $\frac{1}{\exp(\beta_0)} \cdot \frac{(\text{fuel})_{it}}{\text{RPM}_{it}^{\beta_1}\text{dep}_{it}^{\beta_2}}$, where $\frac{1}{\exp(\beta_0)}$ is a constant across observations.[10]

For 2010, the total fuel consumption, RPMs, and departures for the top 15 mainline carriers and their affiliates were characterized by the following relationship:

$$\ln(\text{fuel})_{it} = -2.066 + 0.816 \ln(\text{RPM})_{it} + 0.201 \ln(\text{dep})_{i} + \xi_{i} \qquad \textbf{[Eq. 3]}$$

The coefficients for the output variables are elasticities of the log-linear model indicating how much additional fuel would be needed to increase either mobility or access. The coefficient for RPMs indicates that for a constant number of departures a 10 percent increase in RPMs would require on average 8.16 percent more fuel. Similarly, the coefficient for departures suggests that boosting departures by 10 percent while maintaining total RPMs—for example, by moving the same number of passengers between two cities using smaller aircraft—would increase fuel consumption by about 2 percent. Based on these coefficients, mobility (RPMs) had the greatest impact on fuel consumption in U.S. domestic operations in 2010. That the sum total of these coefficients is close to one suggests that at the network level there were essentially no economies of scale for aviation efficiency in U.S. operations in 2010; that is, a doubling of output would lead to essentially a doubling of fuel burn.

With these coefficients in hand, it is possible to illustrate how the frontier approach rewards increases in transport capability but not circuity. Consider a hypothetical example for a passenger traveling between San Francisco International Airport (SFO) and New York's John F. Kennedy International Airport (JFK) (Figure 2a). An airline may provide direct service (great circle distance of 2,600 miles), or it can stop at Chicago O'Hare International Airport (ORD). Since O'Hare lies essentially on the great circle path between SFO and JFK, the circuity of each itinerary would be 1.00, meaning that the number of productive RPMs would be identical. Figure 2b presents the frontier approach depicted in Figure 1 via simplified annual operations for two airlines, one

10 See Zou, Elke, and Hansen 2013 for detailed mathematical derivations.

that provides nonstop service between SFO to JFK and another that stops at ORD. The point along the frontier with which each airline would be compared is shown in the figure. The nondirect flight, in providing the greater number of departures, would neatly offset this gain in service if it were to consume 14 percent more fuel than the nonstop flight. If it had only a 12 percent greater fuel burn than its competitor operating directly, it would be judged more efficient, or less efficient if it burned 16 percent more fuel. This example, while simplistic, highlights that the fuel burn of each airline must be evaluated relative to its unique combination of RPMs and departures because a practice that might be regarded as inefficient for a given route (an "unnecessary" layover in Chicago for a traveler flying between SFO and JFK), provides access to passengers boarding or deplaning at ORD.

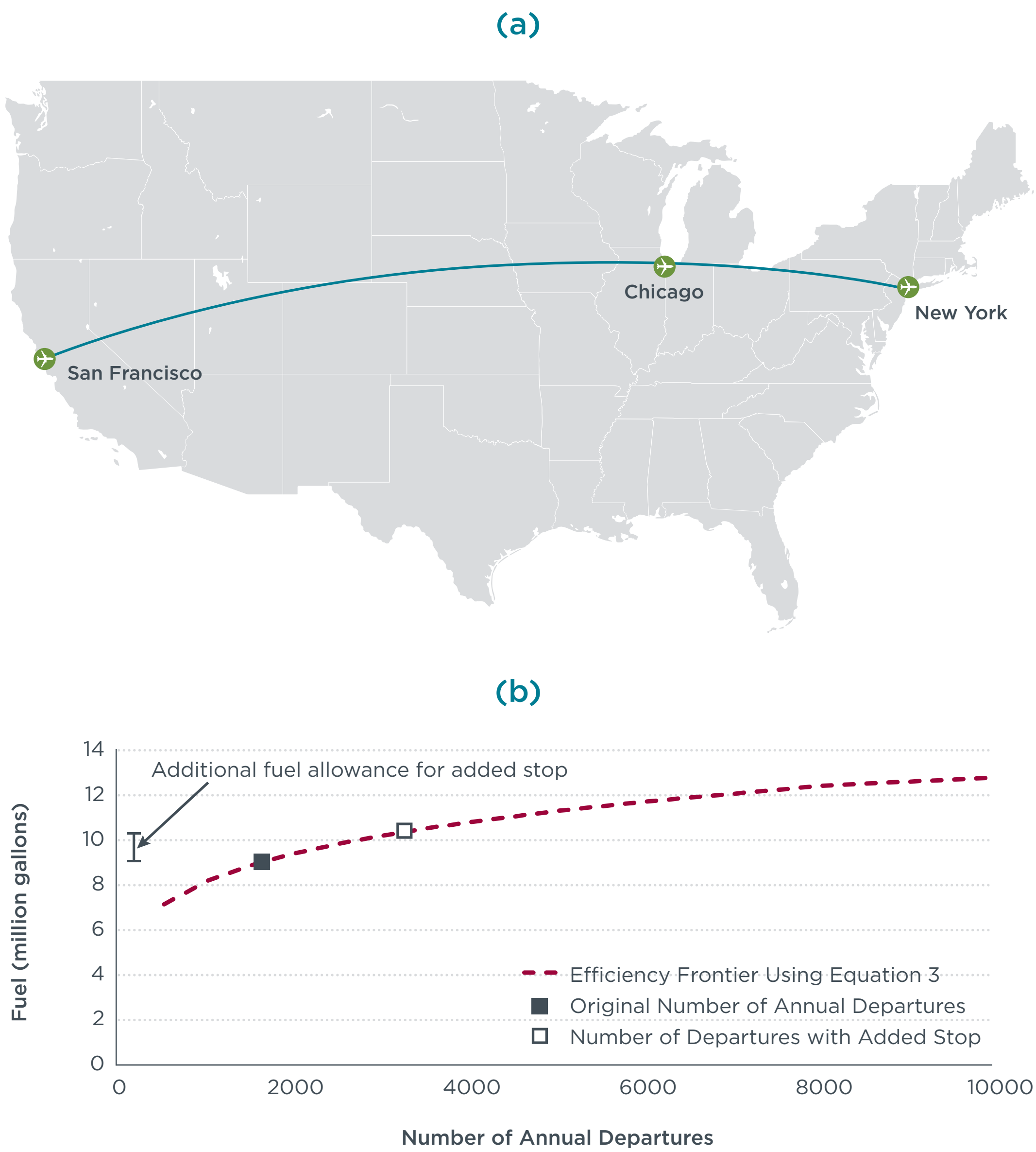

Figure 2. (a) Great circle path for SFO to JFK with a stop at ORD; and (b) Modeled annual fuel burn for efficiency frontier for constant RPM

In contrast, the frontier approach adopted penalizes circuity. Consider again a passenger traveling from SFO to JFK with a layover at ORD (Figure 3). If a passenger were instead routed through Hartsfield-Jackson Atlanta International Airport (ATL), the total distance traveled would be about 2,900 miles, or a circuity of 1.12 (2,900/2,600). A passenger traveling on a different flight with a layover at George Bush Intercontinental Airport (IAH) in Houston would fly an additional 460 nonproductive miles, for a circuity of 1.18. For the example illustrated in Figure 3, a routing through Atlanta would result in approximately 11 percent higher fuel burn than a flight connecting in Chicago, while a connection through Houston would increase fuel burn by 15 percent.[11] Because they have the same number of departures and productive RPMs, however, both operations would be judged relative to the same point on the frontier, meaning that the airline stopping in ORD would be judged to be 11 to 15 percent more efficient than the flights servicing Atlanta or Houston.

SF to Chicago to NY	2600 Miles	(---)
SF to Atlanta to NY	2900 Miles	(+11% fuel consumption)
SF to Houston to NY	3100 Miles	(+15% fuel consumption)

Figure 3. Examples of possible routes from San Francisco to New York by distance

This method also accounts for the significant number of passengers, particularly those traveling to or from smaller airports, carried by regional affiliates at the beginning or end of their journeys. Affiliations generally fall into one of three categories: (1) A regional carrier that is fully owned or controlled by a mainline operator and functions only to serve the mainline; (2) a regional airline that, although an independent company, contracts with a single mainline; or (3) a regional operator that is independent and contracts with multiple mainlines.[12] Under the first two relationships, the full fuel consumption, RPMs, and departures of a regional operator can be easily assigned to the appropriate mainline carrier. The third type of affiliate requires more analysis. Since

11 Fuel burn is modeled using Piano-5 (an aircraft performance and design tool [www.lissys.demon.co.uk]), using a Boeing 737-800 with winglets, with default operational parameters such as flight levels and reserves.
12 Truitt and Haynes 1994.

investigating all flight segments a regional carrier flies in partnership with all affiliated mainline carriers would be too time-consuming, a route analysis of flights in and out of thirty-five Operational Evolution Partnership (the Federal Aviation Administration's plan for the next generation of air transport) airports, drawing from the BTS T-100 Domestic Segment traffic database, was used to assign affiliate fuel, RPMs, and departures to mainline carriers. In general, more than 90 percent of regional carriers' total RPMs were captured using this method,[13] which provides more equitable treatment of all carriers, including those operating hub-and-spoke and point-to-point service models. The combination of mainline operators plus affiliates captures greater than 99 percent of U.S. domestic fuel consumption and air traffic for 2010. These affiliate-mainline relations, including the total share of airline RPMs carried by affiliates, are summarized in Table 2 for airlines with affiliates.

13 Zou, Elke, and Hansen 2013.

Table 2. Mainline-affiliate revenue passenger miles distribution[a]

Mainline carrier	Affiliated carriers	Apportioned RPMs (millions)	% RPMs carried by affiliates
American	American	77,263	
	American Eagle	7,802	
	Executive	264	
	Chautauqua	172	
		Total 85,501	**10%**
Alaska	Alaska	18,733	
	SkyWest	14	
	Horizon	2,451	
		Total 21,198	**12%**
Continental	Continental	41,410	
	Colgan	537	
	CommutAir	151	
	Chautauqua	537	
	ExpressJet	7,136	
		Total 49,771	**17%**
Delta	Delta	92,707	
	Pinnacle	4,668	
	Compass	2,337	
	Atlantic Southeast	5,187	
	Freedom	315	
	Comair	3,126	
	SkyWest	4,031	
	Chautauqua	494	
	Shuttle America	405	
	Mesaba	3,416	
		Total 116,686	**21%**
Frontier	Frontier	6,407	
	Chautauqua	120	
	Republic	1,598	
		Total 8,125	**21%**
United	United	57,317	
	Colgan	81	
	Trans States	747	
	Atlantic Southeast	428	
	GoJet	1,627	
	SkyWest	8,261	
	Shuttle America	2,674	
	ExpressJet	1,057	
	Mesa	1,143	
	Republic	81	
		Total 73,416	**22%**
US Airways	US Airways	43,864	
	PSA	1,696	
	Piedmont	518	
	Colgan	54	
	Trans States	89	
	Chautauqua	327	
	Mesaba	97	
	Mesa	2,559	
	Republic	3,493	
	Air Wisconsin	1,963	
		Total 54,660	**20%**

a Table adapted from Zou, Elke, Hansen 2012.

The overall merits of the method developed for this study, as contrasted with a typical RPM-based approach, are summarized in Figure 4. As indicated, the transport service metric used in the frontier approach, combined with corrections for circuity and accounting for regional airlines, credits fuel used to provide expanded access for consumers, distinguishes fuel used for productive miles from that wasted in flying circuitous routes, and includes the fuel from affiliated operators typically ignored in studies of this kind. These advantages allow for the equitable comparison of all operators independent of business type: low-cost carriers, legacy carriers, hub-and-spoke operators, and point-to-point airlines.

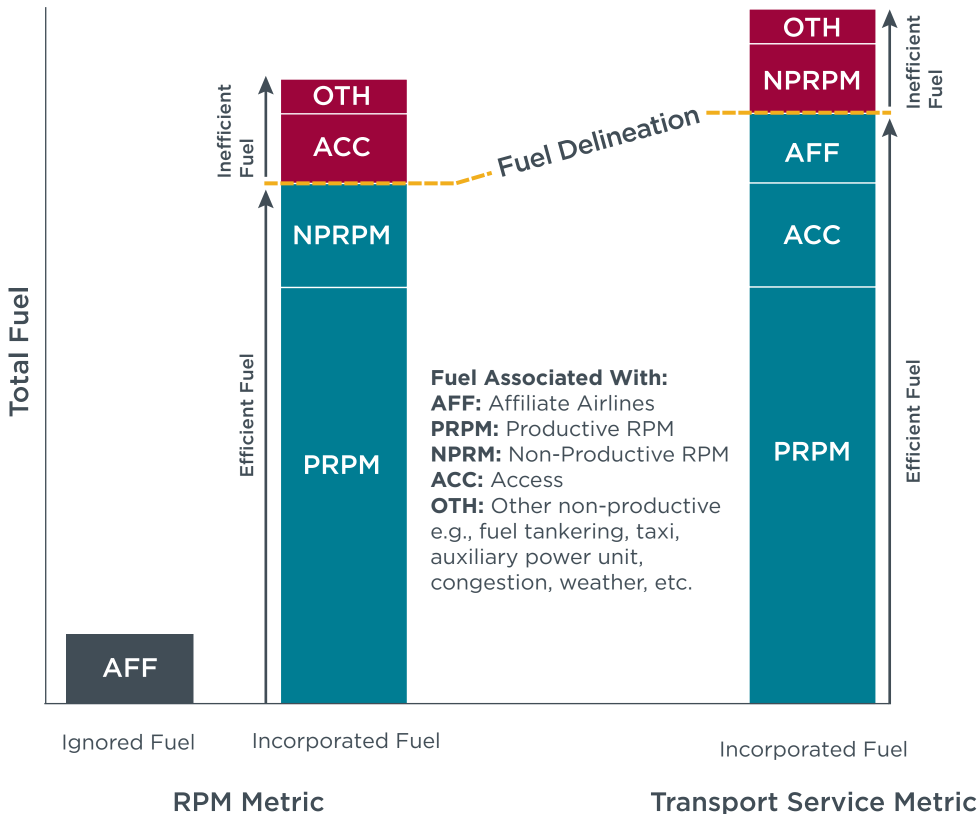

Figure 4. Schematic representation of a typical RPM metric contrasted with this study's metric

2.2. Route-Specific Evaluation

A complementary comparison of airlines across common routes was also performed. This approach is more useful to a traveler seeking information about fuel efficiency, and therefore CO_2 emissions, to help guide a purchasing decision. For several reasons, a simple ratio of passenger miles to fuel burn was used in lieu of the multivariate approach outlined above. First, airlines do not currently report actual fuel burn by route, meaning that a frontier analysis linking RPMs and departures to empirical fuel burn cannot be pursued. Second, the RPM-based metric recognizes that, at the level of a given route, access is already a primary screen for a consumer, either in the form of an airport served or an appropriate departure time. In this case, the level of access provided by an airline over its entire network is of secondary concern. Thus, assuming that a consumer has access to all the flights he or she requires, a simpler passenger mile/fuel burn metric is appropriate.

A detailed methodology for the route-based analysis is provided in Appendix B on this paper. Route-specific airline efficiency was evaluated for the top ten origin-destination city pairs. Based on the methodology developed in Breuckner, Lee, and Singer,[14] major metropolitan areas ("metroplexes") and their corresponding airports were identified, and a list of the ten most frequented city pairings was developed (Table 3). For these top ten routes and the associated airports listed in the table, airline-specific operational values, including the aircraft types flown, passenger load factors, and average taxi time, were isolated from BTS T-100 data. These airline-specific values were used to model the fuel consumption of each origin-destination airport combination for a given metroplex pair using the Piano-X model.[15] All flights (or routes) for a metroplex pair for an airline were averaged on a passenger-weighted basis to generate an average fuel per passenger value for that city pair.

Table 3. Top 10 U.S. city pairs by passenger count, 2010

Rank	Route	Passengers (millions)
1	Los Angeles–San Francisco	6.47
2	Miami–New York	4.77
3	Los Angeles–New York	3.91
4	Chicago–New York	3.12
5	Boston–Washington, D.C.	2.90
6	New York–Orlando	2.79
7	New York–San Francisco	2.73
8	San Diego–San Francisco	2.33
9	Las Vegas–San Francisco	2.16
10	Atlanta–New York	2.11

14 Brueckner, Lee, and Singer 2013.
15 Piano-X is an aircraft emissions and performance model developed and distributed by Lissys, a British analytical software firm. See http://www.lissys.demon.co.uk/

3. RESULTS

This chapter summarizes the key findings of this study. It also investigates some of the reasons why airline efficiency varies, which yields the relative scores of carriers included in the analysis.

3.1. Airline Efficiency Scores

Figure 5 summarizes the 2010 in-use efficiency scores for the U.S. domestic operations of the 15 airlines included in this study. Each airline's fuel efficiency score (green bars) measures the relative transport service provided per unit of fuel consumed, normalized by the average fuel efficiency of all 15 airlines. Thus, airlines with a score greater than 1.00 are more efficient (consume less fuel per unit output than the industry average), while those with scores below 1.00 consume more fuel per unit of transport service. Since fuel efficiency is inversely proportional to fuel consumption, the fuel efficiency score can also be used to estimate how much fuel an airline would burn to provide a hypothetical level of service compared to its most efficient competitor. This value (in percentage terms) appears in the rightmost column of the graph.

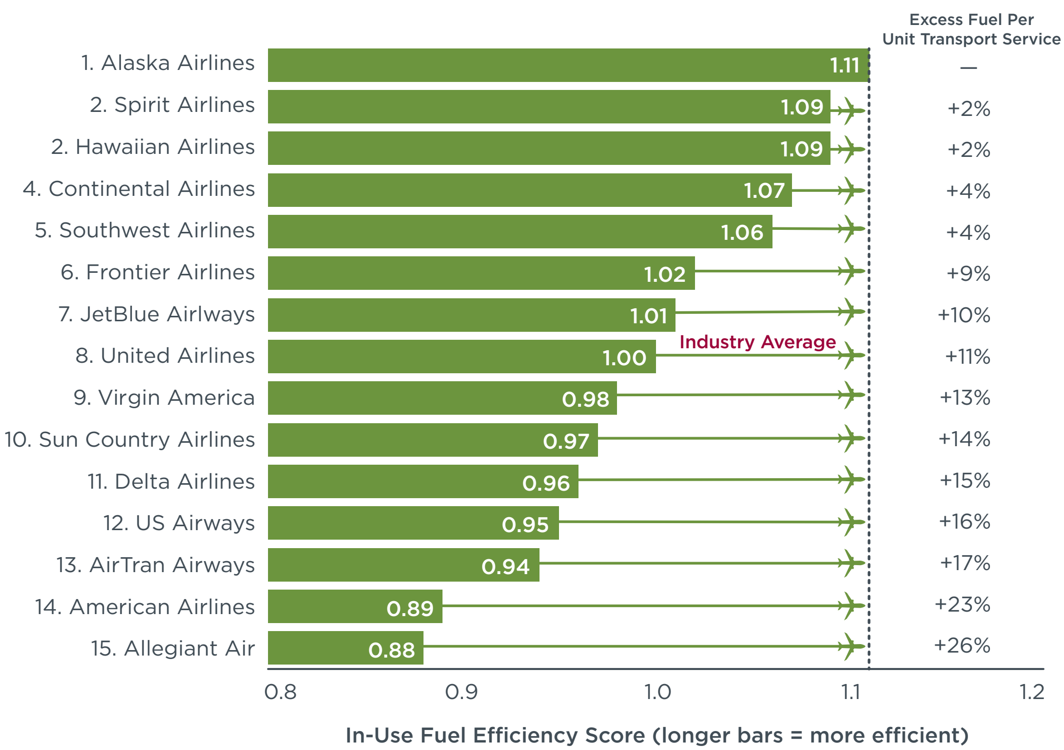

Figure 5. Fuel efficiency scores by airline for 2010 U.S. domestic operations (higher score means greater efficiency).

As the figure indicates, Alaska Airlines and Hawaiian Airlines, two relatively small carriers serving predominately West Coast markets, ranked first and tied for second with fuel efficiency scores of 1.11 and 1.09, respectively. Spirit Airlines, an ultra-low-cost carrier based in Florida, tied with Hawaiian for second. In terms of fuel consumption per unit output, these top performers are separated by only 2 percent; meaning that, for an equivalent unit of transport service, Alaska Airlines used about 2 percent less fuel than Spirit or Hawaiian in 2010. Continental Airlines, in fourth place, was the most fuel-efficient full-service legacy carrier, while Southwest Airlines (fifth) was the most efficient carrier operating on a point-to-point rather than a hub-and-spoke business model. Southwest was followed by Frontier Airlines and JetBlue Airways, two carriers that operate mainly Airbus A320 family aircraft out of hubs in Denver and New York, respectively. United Airlines, a full-service carrier that announced it would merge with Continental in 2010, came next with a fuel efficiency score of 1.00, or the average for U.S. domestic operations in that year.

Many, although not all, of the carriers with fuel efficiencies below the industry average were, or subsequently have been, the subject of merger activity. The domestic operations of Delta Air Lines, by several measures the world's largest carrier, ranked 11th in this study in 2010, the year it integrated fully with the former Northwest Airlines. AirTran Airways (13th), was purchased by Southwest Airlines in 2011 and currently operates as an affiliate of that larger airline. At the end of 2013, US Airways (12th) is expected to merge with American Airlines (14th), following the latter's 2011 Chapter 11 bankruptcy. In ninth place with a fuel efficiency score of 0.98 is Virgin America, which operates Airbus single-aisle aircraft on primarily coast-to-coast routes, followed by Sun Country (10th), a low-cost carrier based in Minneapolis. The least efficient airline in this ranking, Allegiant, is a low-cost carrier targeting secondary airports, with limited competition from the other airlines in this survey.

Several conclusions can be drawn from Figure 5. The first and most significant is that there was a 26 percent gap between the fuel consumption of the domestic operations of the most (Alaska Airlines) and least (Allegiant Air) efficient airlines serving the U.S. market in 2010. This gap is larger than what might be expected in a mature aviation market during a period of high fuel prices. As will be expanded upon in the following section, a portion of the efficiency gap can be explained by differences in technology across each airline's fleet, with the balance a function of operational practices, including variations in load factor, seating density, route circuity, use of a single engine for taxiing, fuel loading/tankering procedures,[16] airport congestion, etc. Owing to the large number of variables, as well as the limited data provided by airlines about operational practices, the individual influence of each variable on the efficiency score of an airline cannot be isolated at this time.

Second, Figure 5 offers evidence in support of the proposition that the metric developed for this study can provide equitable treatment of airlines regardless of their business models and sizes. For example, fuel efficiency scores for low-cost carriers (Alaska, AirTran), legacy carriers (Continental, US Airways), hub-and-spoke carriers (Spirit, American), and point-to-point carriers (Southwest, Allegiant) can be found both above and below the industry average. This suggests that the frontier methodology described above indeed enables an inclusive, apple-to-apple comparison across divergent airlines.

16 Airlines have varying procedures for determining the amount of fuel to be loaded for a given flight. For example, an airline may choose to load more fuel than required (known as tankering) in order to reduce turnaround time at the flight's next stop. This results in a heavier aircraft than need be, which in turn causes additional fuel burn.

3.2. Determinants of Airline Efficiency

Given the large variety of factors influencing airline fuel efficiency, it is not possible to explain definitively why the airlines included in this survey are ranked as they are. Some initial observations can be made, however. All things being equal, one would expect that airlines operating newer aircraft would tend to be more fuel efficient, both because these are more technologically advanced and because they presumably have had less time for their performance to degrade; therefore, they function closer to their original specifications. For example, airframe pitting over the life of an aircraft impairs aerodynamic performance, undermining fuel efficiency, while aircraft engines can wear down as they age, particularly if they are poorly maintained.

Figure 6 presents the fuel efficiency scores of the fifteen mainline carriers in this study as a function of their average aircraft age. In this case, the trend line slopes downward because as the average age of an airline's fleet increases, its overall efficiency tends to drop. Although five of the seven most efficient airlines are located in the upper left quadrant in the figure, corresponding to newer fleets and higher efficiency scores, there is significant scatter in the relationship between aircraft age and efficiency. Carriers such as Hawaiian and Southwest have high efficiency scores despite operating relatively older fleets, while carriers such as Virgin and AirTran operate newer equipment yet score below average in terms of overall efficiency. The least efficient airline in this study, Allegiant Air, has a particularly old fleet (with an average age exceeding 20 years) of McDonnell Douglas aircraft first developed in the late 1970s.

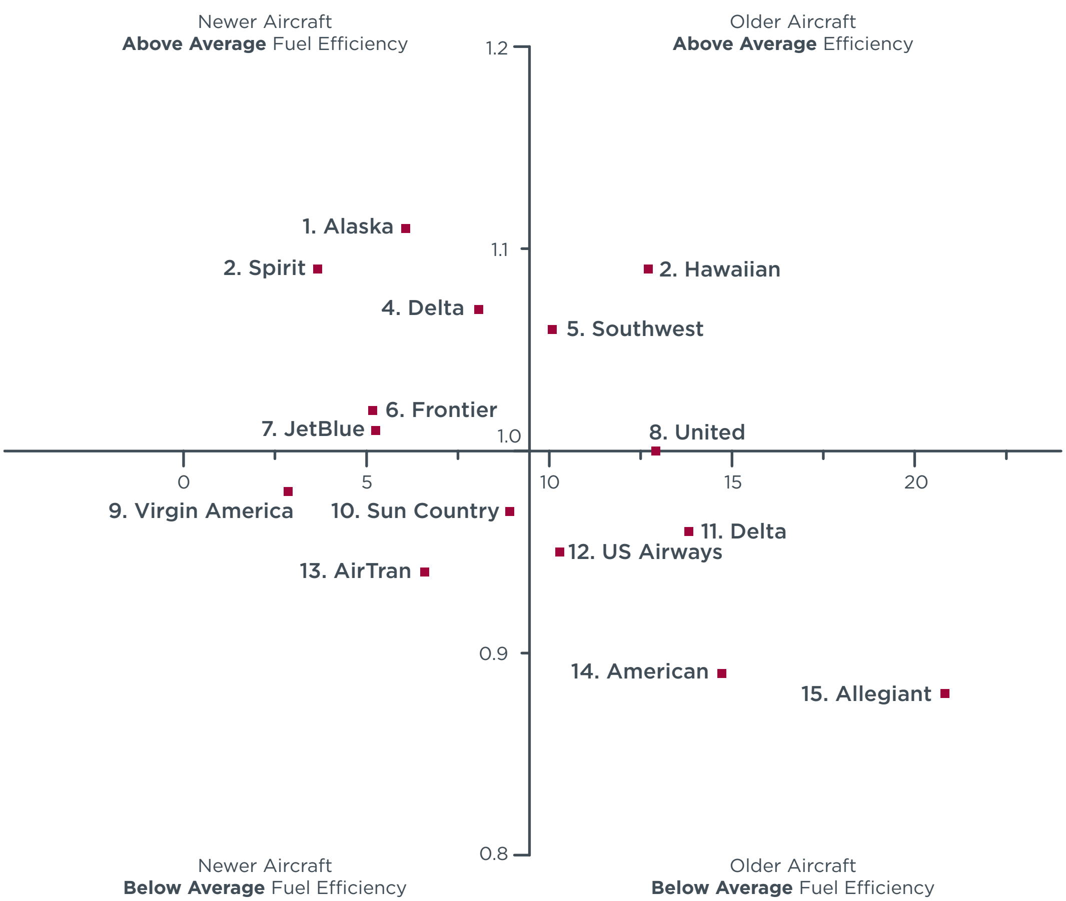

Figure 6. In-use fuel efficiency score (y-axis) versus average aircraft age (in years, x-axis)

Aircraft age alone might not be the best indicator of technology level. Furthermore, since the fuel efficiency of an aircraft varies as a function of its mission, it can be difficult to distinguish the underlying fuel efficiency of the equipment from the way in which it is used. That being said, it is useful to consider how technology utilization, that is, the technology level of aircraft deployed by an airline to serve its combination of missions, is linked to the airline fuel efficiency scores shown in Figure 5. In this case, care must be taken to distinguish differences in technology utilization from "pure" operational practices, including load factor, seating density, and cycle hours (a cycle is one takeoff and one landing together) tallied per year by aircraft type, that arise from how an airline uses a given airplane on a given route. In this way, the variance in the fuel efficiency score attributable to technology utilization alone could be tested independently of operational parameters.

A Technology Utilization Score (TUS) was developed to examine how much of the variance seen in airline fuel efficiency can be attributed to differences in technology utilization alone. The TUS applies the fuel consumption coefficients derived via the frontier methodology outlined in Chapter 2 and thus has identical measurement units as the airline fuel efficiency score but with modeled fuel burn, RPMs, and departures based upon ideal missions for each aircraft type utilized. In order to isolate technology utilization from operational practices, industry average values were used for all modeling variables save aircraft type and stage length, including seating density, load factor, cycle hours per year, taxi time, and fuel reserve carried per flight.[17]

Figure 7 presents each airline's fuel efficiency score versus its Technology Utilization Score. Each metric is normalized to the average airline (efficiency score) or fleet (TUS), with a score of 1.00, whereas high scores represent better values for both. Airlines in the upper right quadrant have higher fuel efficiency scores and utilize more efficient technology, while airlines falling in the lower left quadrant score poorly on both metrics. A clear pattern is displayed, with four of the five top airlines falling in the upper right quadrant, meaning that they were above average in efficiency and utilized a relatively advanced fleet in U.S. domestic operations in 2010. Since the TUS is derived from fuel burn as determined by "ideal" flights under industry average operational practices, the influence of nontechnological practices and developments, including seating density, load factor, maintenance, and environmental conditions, leads to the scatter from the mean regression line.

17 To generate each airline's TUS, fuel burn, RPMs, and departures for each aircraft type flown by a mainline carrier and its affiliates was modeled. Fuel burn was estimated using representative Piano-X aircraft and an "ideal" average mission for each airline, applying industry average values for seating density and load factors, and Piano-X default mission rules and reserve assumptions, by aircraft type. RPMs and departures were estimated using the Piano-X outputs, combined with average cycle/hours per year (3,020 cycle hours/year for single-aisle aircraft and turboprops; 4,250 cycle hours/year for twin-aisle planes). The TUS for each airline *j* was estimated by summing up the fuel burn, RPMs, and departures for the *i* aircraft types it uses and raising each to the coefficients derived from the frontier analysis:

$$TUS_j = \frac{\sum_i Fuel_i}{(\sum_i^n Dep_i)^{0.201} * (\sum_i^n RPM_i)^{0.816}}$$

Each airline's TUS was then normalized to the average 2010 airline for display in Figure 7.

Figure 7. In-use fuel efficiency score (y-axis) versus normalized Technology Utilization Score (x-axis)

Technology utilization clearly helps explain differences in the fuel efficiency scores among individual airlines, as can be seen by the positioning of Alaska Airlines and Allegiant Airways, which have the highest and lowest TUS scores, respectively. Alaska's fleet consists overwhelmingly of Boeing Next-Generation 737 aircraft with entry into service dates near 2000 or newer. These aircraft utilize technologies such as high-bypass-ratio CFM56-7 engines and winglets to reduce fuel burn. Alaska's affiliate Horizon also operates a large number of turboprop aircraft, which benefit from very high engine propulsive efficiencies, on many routes. In contrast, Allegiant, on its routes in 2010, exclusively operated McDonnell Douglas MD-80 series aircraft, which entered into service in the early 1980s and use less efficient, low-bypass-ratio engines, with no winglets.

Figure 7 can also be used to estimate how much differences in technology utilization among airlines can explain the divergence in their overall fuel efficiency. Overall, technology is estimated to be responsible for approximately one-third of the variation in fuel efficiency between airlines (R^2=0.36). Airlines that have invested in more fuel-efficient aircraft—with technologies such as winglets, high-bypass-ratio engines, and lighter airframes—and deploy those aircraft on routes to provide appropriate RPMs and departures burn less fuel at both the aircraft and aggregate airline level. Because of the large number of additional variables at play, as well as significant interdependencies between them, a full examination of the sources contributing to airlines' fuel efficiency is beyond the scope of this study but will be considered in future updates as appropriate data are made available.

3.3. Airline Efficiency and Profitability

In addition to the technology proxies developed above, each airline's fuel efficiency score was also compared against its profitability to investigate the relationship between market performance and airline efficiency. Since fuel accounted for approximately 35 percent of total aircraft operating expenses in 2010 for the 15 airlines in this study,[18] one might expect that operating more efficient aircraft would correlate with greater airline profitability. In fact, no clear correlation between profitability and fuel efficiency was found (Table 4). As evidence, Allegiant Air, the lowest-ranked airline in our study, had the most profitable U.S. domestic operations between 2009 and 2011. A variety of business-related concerns, including market competition (Allegiant, for example, tends to fly routes for which other airlines show little interest, giving it pricing power), labor contracts, fuel price hedging, and strategies for generating ancillary revenue such as premium services and sales, among others, temper the relationship between fuel costs and profitability.

Table 4. 2010 in-use fuel efficiency ranking and 2009–11 profitability for U.S. domestic operations

Rank	Airline	3-year average profit margin (%)[a]
1	Alaska Airlines	11.3
2	Spirit Airlines	12.6
	Hawaiian Airlines	5.8
4	Continental Airlines	-10.1
5	Southwest Airlines	5.3
6	Frontier Airlines	-2.7
7	JetBlue Airways	5.5
8	United Airlines	1.4
9	Virgin America	-3.1
10	Sun Country Airlines	1.7
11	Delta Airlines	9.4
12	US Airways	3.2
13	AirTran Airways	3.7
14	American Airlines	-4.3
15	Allegiant Air	13.5

a Financial data from U.S. Department of Transportation, Bureau of Transportation Statistics, 2013. Negative values designate a loss.

Furthermore, newer, technologically advanced aircraft cost more to purchase than used equipment that burns more fuel, allowing airlines to profit from operating less efficient equipment on certain routes. For example, Delta Air Lines recently announced that it would replace a large number of its older aircraft with MD-90 and Boeing 717 aircraft rather than with newer and more fuel-efficient aircraft such as Boeing Next-Generation

18 U.S. Department of Transportation, Bureau of Transportation Statistics 2013.

737s.[19] Delta is expected to save around $1 billion through the purchase of MD-90s alone, which is about 10% cheaper to operate per seat than the Boeing 737s. This example highlights what are in some cases the skewed incentives of the commercial aviation market: the purchase of newer, more fuel-efficient jets might make little sense when older ones are available at a significant discount because the fixed cost of state-of-the-art aircraft might not be offset by the projected fuel savings.

3.4. Route-Based Analysis

In addition to these observations about airlines operating fleetwide, the fuel efficiency of individual airlines serving common routes can be compared. Full results for the 10 city pairs analyzed in this study, which accounted for 1.6 million metric tons of jet fuel and 5 million metric tons of CO_2 emissions in 2010, are presented in Appendix C. Because for individual routes there is a presumption that access to an appropriate flight is a prerequisite for consideration by a consumer, in this case the efficiency of each airline is compared on a simple passenger mile/fuel metric that does not take into account the number of departures it provides between cities.

The route-specific results summarized in Appendix C demonstrate that high fuel efficiency scores do not necessarily translate into more efficient flights on all routes. Consider flights between Atlanta and New York City (Table 5). Although both AirTran and Delta Air Lines rank below average in overall efficiency (Figure 5), on this specific route they operate efficient flights because Atlanta serves as a major hub for both, leading to more direct flights in larger aircraft. Together, the two airlines move approximately three-quarters of all passengers between Atlanta and New York. Other airlines, in contrast, serve this route with smaller aircraft and will often have a layover at their own hub. For example, Spirit Airlines is estimated to offer the least fuel-efficient service on this route despite having the second-most efficient U.S. operations on average. The majority of Spirit's flights are nondirect (more than 55 percent of flights have at least one stop), meaning that approximately 30 percent of the RPMs flown between the two cities are circuitous and therefore categorized as nonproductive by this method.

Table 5. Atlanta-New York fuel efficiency by airline

Rank	Airline	Fuel efficiency (passenger miles/ lb. fuel)	Relative fuel burn	Passenger share[a]
1	AirTran	8.6	-----	17%
2	Delta	8.5	+1%	67%
3	US Airways	7.8	+10%	3%
4	Continental	6.7	+28%	8%
5	American	6.2	+39%	4%
6	Spirit	5.8	+48%	1%

a The percentage of passengers carried as a fraction of total passengers on the route.

19 Carey 2012.

In another example, Virgin America is judged to be the most efficient airline operating between Los Angeles and New York (Table 6), despite being ranked ninth in efficiency overall. Virgin began operations in 2007, with a focus on serving high-traffic routes between East Coast and California airports. Thus, although Virgin flies between only a small number of airports with lesser frequency, providing limited transport service in the aggregate, it is able to serve its core destinations efficiently. Similar findings, wherein the relative rankings of airlines operating between a specific city pair in 2010 deviated from their macro-level fuel efficiency scores, were observed for many of the remaining eight city pairs.

Table 6. Los Angeles-New York fuel efficiency by airline

Rank	Airline	Fuel efficiency (passenger miles/ lb. fuel)	Relative fuel burn	Passenger share
1	Virgin America	12.0	-----	12%
2	JetBlue	12.0	+0%	18%
3	Continental	11.9	+1%	18%
4	United	11.4	+5%	9%
5	US Airways	10.9	+10%	2%
6	Delta	10.7	+12%	16%
7	American	8.9	+35%	25%

Figure 8 presents the average passenger miles traveled per pound of fuel for the top ten city pairs, along with a graph showing the relationship between trip length and fuel intensity. Fuel efficiency, as measured by passenger miles transported per pound of fuel, differed among airlines serving the same route from 9 percent to as high as 90 percent. As indicated, shorter-distance routes are more fuel intensive—for example, flying from San Francisco to Los Angeles, at approximately eight passenger miles per pound, requires 1.6 times as much fuel as to fly from San Francisco to New York (13 passenger miles per pound). Greater deviations are seen generally on longer routes because more distant city pairs are linked via a greater diversity of aircraft types and flight paths due to layovers. Shorter trips, such as north-south coastal flights that are generally less than 800 miles, are significantly more fuel intensive than transcontinental flights on a fuel-per-passenger-mile basis.

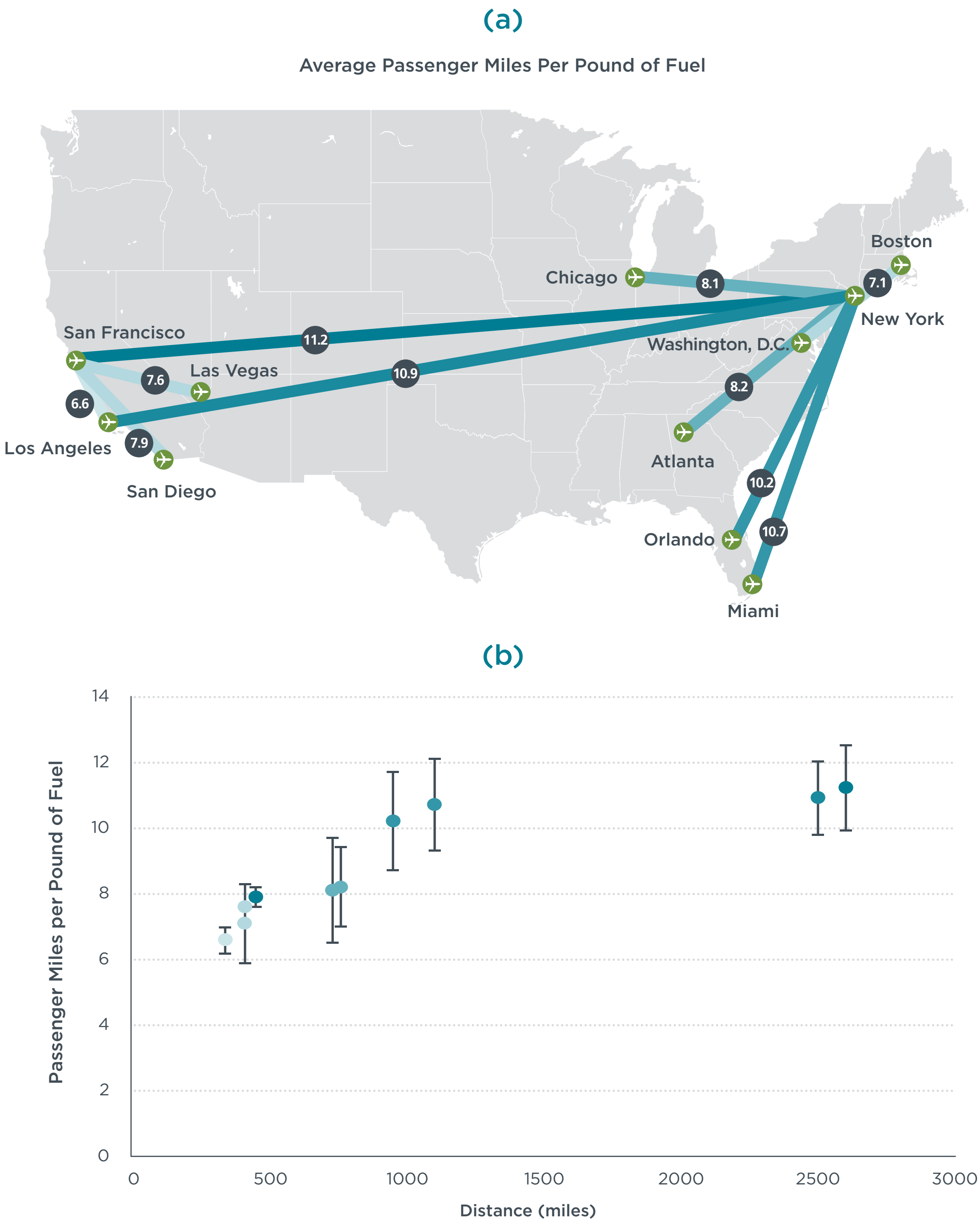

Figure 8. (a) Average fuel efficiency for the top 10 U.S. domestic metroplex routes in 2010. (b) Average passenger miles per pound of fuel as a function of distance (error bars represent one standard deviation from the mean value).

In general, the differences between airlines are driven by considerations such as aircraft choice (e.g., regional jet versus single aisle), technology (previous generation or newer aircraft), the level of nonproductive miles traveled (circuity), and seating density, among others. To fully understand these city pair differences, more detailed data from airlines are required.

4. CONCLUSIONS AND NEXT STEPS

This study developed a new methodology to compare the fuel efficiency of airlines serving the domestic U.S. market. It examined airline efficiency comprehensively at the network level, as well as on a route-specific level. The efficiency of airlines was evaluated relative to both the mobility (amount of passengers flown times the distance traveled) and access (frequency of departures) they provide, to distinguish productive miles flown from excess mileage resulting from circuitous flights and to incorporate the transport services and fuel use of regional affiliates into those of the relevant mainline carriers. Our findings indicate that there was a 26 percent gap between the fuel efficiency of airlines serving the domestic market in 2010. A gap of this size in the mature U.S. market suggests that the relationship between fuel efficiency and airline profitability is far from straightforward. Fixed equipment costs, maintenance costs, labor agreements, and network structure can all sometimes exert countervailing pressures against the tendency for high fuel prices to drive efficiency improvements. This goes some way toward explaining how Allegiant Airways, the least energy-efficient airline in 2010, had the most profitable domestic operations between 2009 and 2011.

Given the large number of variables influencing the fuel efficiency of airlines, it is not possible quantitatively to distinguish the underlying reasons why each airline is ranked where it is. In general, both aircraft average age and how much advanced efficiency technology is utilized seem to supply some explanatory power for the variations in fuel efficiency between airlines. Approximately one-third of the variation in fuel efficiency between airlines can be attributed to differences in the utilization of advanced aircraft efficiency technology. Airlines that have invested in more fuel-efficient aircraft, with technologies such as winglets, high-bypass-ratio engines, and lighter airframes, burn less fuel. Other influences on airline fuel efficiency include circuity, seating density, load factor, and the matching of aircraft capability to operational mission.

Even larger differences in fuel efficiency—in some cases, as high as 90 percent on a passenger mile per pound of fuel basis—were modeled for airlines across individual city pairs. Interestingly, airlines that were the most efficient overall did not necessarily transport a given passenger more efficiently between cities, owing to differences in aircraft types used and excess fuel burn resulting from indirect routing. These findings suggest that consumers aiming to reduce their environmental footprint would gain from a closer look at the fuel efficiency of individual flights rather than that of airlines overall.

This study is a first step toward providing consumers, researchers, and policymakers with better information about airline efficiency and CO_2 emissions. The analysis will be updated annually, and more robust causal conclusions will be drawn as the fuel efficiency scores of individual airlines change over time—for example, when new aircraft types enter the fleet, when underperforming airlines go bankrupt or are absorbed by others, or when operational practices change. Expansion of the frontier analysis methodology to international operations will shed greater light on the technologies and operational practices that affect aviation efficiency.

Unfortunately, few consistent standards exist to compel airlines to disclose publicly comprehensive data on fuel use and aircraft operation, particularly outside of the United States. While companies typically view such figures as proprietary, more complete and accurate data would help policymakers make sounder decisions about this highly complex industry. Analogies can be made to many other businesses. For example, consumers are able to make better purchasing decisions about automobiles and electric appliances based on fuel efficiency labels. Nothing of the sort is available to airline passengers today, and this is an information gap that the report and other ongoing ICCT initiatives aim to help fill.

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APPENDIX A: REVIEW OF PREVIOUS AIRLINE EFFICIENCY EVALUATIONS

Table A1 summarizes the salient characteristics of previous airline efficiency rankings.

Table A1 Previous studies of airline efficiency or CO_2 intensity

Source	Metric	Data/Modeling Source	Pros	Cons
Wall Street Journal	Available seat miles/gallon of fuel	• U.S. Department of Transportation (DOT) Bureau of Transportation Statistics (BTS) 2009 data • Geographic scope: U.S. carriers • Last analysis year: 2010	• Uses primary data and actual reported fuel consumption	• Uses total seats available and does not calculate or account for actual number of passengers flown
Greenopia	Score of 0–5 "Greenopia leafs"	• Airlines' annual reports; other publicly disclosed documents • Geographic scope: U.S. carriers • Most recent update: 2012 (recurring)	• Rating based on life-cycle weighting of environmental impact of fleet age, fuel consumption practices, carbon offsets, green building design, recycling programs, etc.	• Qualitative assessment • No transparency in methodology • Metric cannot be translated into CO_2 emissions or fuel consumption
Atmosfair	Efficiency Points (0 to 100) by flight length (short, medium, long)	• Uses DOT 2010 data; International Civil Aviation Organization (ICAO) data: Traffic Flight By Stage (TFS), Aircraft Engine Emission Databank, Air Transport Intelligence (ATI) • Coarse modeling using ICAO Carbon Emissions Calculator • Most recent update: 2012 (recurring)	• Uses primary data sources on airline aircraft and operations • Several parameters analyzed, including city pair and distance, type of aircraft, engine type, winglets, seating, cargo capacity, passenger capacity utilization	• Fuel consumption values are modeled, not actual data • Metric cannot be translated into CO_2 emissions or fuel consumption • Limited set of airlines (no low-cost carriers, regional jets, etc.)
Brighter Planet	Lbs. of carbon dioxide equivalent per passenger mile	• Uses DOT data; ICAO's TFS; Brighter Planet's own CM1 flight carbon and energy model performance • Last Analysis year: 2010	• Uses primary data sources • Takes into consideration aircraft model, seating density, load factor, freight share, and distance	• Fuel consumption values are modeled, not actual data • Use of non-CO_2 scaling factor,[29] which is controversial among atmospheric scientists
ICAO Carbon Calculator	Kg CO_2 per passenger per flight	• Uses airlines multilateral schedules database (AMSD); ICAO's TFS; EEA's EMEP/CORINAIR Emission Inventory Guidebook (EIG); and modeled data from Piano (Lissys) • ICAO traffic data: analyzed and updated on an annual basis	• Uses information on flight profile, specific aircraft, passenger load factor, cargo, etc.	• Limited number of routes for emissions calculations • Does not use air-carrier-specific information on fuel burn, passenger load factor, aircraft configuration, etc. • Aircraft type and seat configuration matching is limited and may underestimate actual emissions • Fuel consumption information for newer aircraft types and technology not yet available in database

20 Uses global warming potential to convert greenhouse gases to a common scale. See http://brighterplanet.com/entries/7-units_and_measures

In 2009, the *Wall Street Journal* published a fuel efficiency ranking[21] of major airlines using U.S. Bureau of Transportation Statistics (BTS) data and the simple metric of available seat miles per gallon of fuel. This metric presents two significant drawbacks. First, it does not distinguish between airlines flying a large number of empty seats from those that operate their aircraft mostly full and thus does not reward airlines with superior operational practices, in this case, those with higher passenger load factors.[22] Furthermore, it oversimplifies the services that airlines provide, leading to biased results. For example, one airline may rank highly on this metric because it operates mostly coast-to-coast direct service; however, this service is of limited value to the travelers that cannot access the airports served. As a result, this type of metric inappropriately compares airlines providing different levels of access (usability) resulting from many different modes of operations (e.g., regional carrier versus hub-and-spoke carrier).

In another study, Greenopia attempted to rate qualitatively various corporations, including airlines, based on how “green” they are.[23] Each airline was given a ranking from one to five “green leaves” based upon the content of their annual reports and other self-reported activities the authors considered to be environmentally friendly, including their fuel conservation practices, opportunities to purchase carbon offsets, and recycling procedures. Little transparency was provided regarding the methodology used to assign scores to each airline.

The Atmosfair Airline Index study assigns every airline a score between 0 and 100 efficiency points (EPs). To determine an airline’s EPs, the CO_2 per load-kilometer was first modeled for each flight using various assumptions, including distance, type of aircraft, engine specification, presence or absence of winglets, seating, cargo capacity, passenger capacity utilization, and freight load. Second, the CO_2 per load-kilometer is compared to the best-case flight, which is determined using the International Civil Aviation Organization (ICAO) carbon calculation method. Third, the EPs of an airline’s individual routes were compiled to determine an overall efficiency score representing how close the airline comes to the optimum performance (100 EP), based upon the best aircraft and engine combination, maximum seat density, and maximum passenger load factor, according to the ICAO calculation method.

Airlines were categorized into seven efficiency classes, from A (most efficient) to G (least efficient), for three flight-distance classes: short (<800 km), medium (between 800 and 3,800 km), and long (>3,800 km). The study’s authors chose to exclude low-cost carriers because they felt that their low prices stimulated demand that would otherwise not exist: “Since avoidance comes before optimization in a perspective of environmental economics, these passengers would need to avoid these flights in the first place. It is hence difficult to compare low-cost and other carriers on one level in the Airline Index, without distorting the desired steering effect.”[24] Thus, by design, the Atmosfair approach ranks only legacy airlines.

In 2010, Brighter Planet published an airline ranking using carbon dioxide equivalent per passenger mile as its metric for fuel efficiency.[25] The ranking incorporates characteristics

21 McCartney 2010.
22 In fact, this particular metric rewards flying empty seats because increasing the number of passengers carried adds weight, thereby increasing fuel burn.
23 See Greenopia n.d.
24 See Atmosfair 2011.
25 Brighter Planet uses a multiplier of two on determined emissions to account for warming beyond the impact of carbon dioxide, and it reports this value as carbon dioxide equivalent, or CO_{2e}.

such as aircraft size, seat class and pitch (the distance between seats in subsequent rows), engine type, fuel efficiency, capacity, freight payload, and revenue to calculate the fuel efficiency scores for an airline based upon BTS T-100 Domestic Segment data and ICAO databases as references.[26] Fuel burn scores were calculated using flight data and "fuel use coefficients," which were determined by fitting a third-order polynomial equation to the European Environment Agency (EEA) aircraft fuel consumption data.

Moreover, various sources have utilized the ICAO Carbon Emissions Calculator.[27] This tool estimates the CO_2 generated per passenger for a user-defined airport pair and seating class. The emissions calculator draws from a database consisting of various sources, notably the ICAO Traffic by Flight Stage (TFS) and the EEA's EMEP/CORINAIR Emission Inventory Guidebook (EIG), which provides values for fuel burn at discrete mission distances [fuel/km] for 50 equivalent aircraft types. The aircraft type is obtained from published schedule flights serving each airport pair. The proportion of fuel allocable to carrying passengers is determined using traffic and operational data to obtain passenger load factors and passenger-to-cargo ratios, both of which are averaged on a regional or "route group" basis. The inputs to the fuel burn calculation include the city pair, great circle distance, passenger load factors, passenger-to-cargo ratio, fuel/km for each aircraft model, and number of economy seats. Average fuel burn for a flight is weighted by the frequency of departure for each equivalent aircraft type. The final metric value is calculated as follows:

CO_2 per passenger = 3.157 * (total fuel * passenger-to-freight ratio)/(number of economy seats * passenger load factor). Where multiple passenger classes exist, a multiplicative cabin class factor is applied to adjust the CO_2 per economy passenger.

In addition to these rankings, some airlines characterize their own efficiency by providing aircraft fuel consumption figures or CO_2 emissions directly on their websites.[28] These evaluations are based on highly aggregated proprietary data with little transparency, making it difficult to compare a particular airline's score to those of its competitors. For example, airlines tend not to include fuel consumption for their affiliated regional carriers, omit route-specific results, and do not report detailed information on takeoffs, landings, miles traveled, or passengers moved. These limitations prevent a consistent comparison between airlines.

26 Kling and Hough 2010.
27 See International Civil Aviation Organization 2010a.
28 United Airlines 2012; Virgin America 2008.

APPENDIX B: METHODOLOGY FOR ROUTE-BASED ANALYSIS

The fuel efficiency of 15 mainline airlines was analyzed at the route level for city pairs in five steps. First, the ten most important domestic city pairs based on passenger count were identified. Second, BTS Airline Origin and Destination Survey (DB1B Coupon) and T-100 operational data[29] were used to allocate passengers to representative flights. Third, marginal airlines—that is, carriers transporting less than 1 percent of passengers for a given city pair—were identified and excluded so as to reduce outliers. Fourth, the fuel consumption of each flight was modeled using Piano-X, an aircraft emissions and performance model developed by Lissys. Fifth, the passenger fuel intensity of all possible routes linking each city pair were weighted by the number of passengers the airline carried on a specific route to estimate a single passenger fuel intensity for each airline and city pair.

In the first step, BTS data were used to identify the most important U.S. domestic routes. First, significant origin-destination (OD) pairs were identified, where O is the first and D is the last airport in a full itinerary. Table B1 below shows the top 10 most traveled OD pair routes.

Table B1 2010 Passenger counts for the top 10 U.S. origin-destination airport pairs

Rank	Route	2010 Passengers (millions)[a]
1	LAX-JFK, JFK-LAX	2.32
2	SFO-LAX, LAX-SFO	1.89
3	ORD-LGA, LGA-ORD	1.74
4	SFO-JFK, JFK-SFO	1.64
5	ATL-LGA, LGA-ATL	1.45
6	FLL-LGA, LGA-FLL	1.42
7	HNL-OGG, OGG-HNL	1.38
8	LAS-SFO, SFO-LAS	1.23
9	MCO-PHL, PHL-MCO	1.12
10	MCO-EWR, EWR-MCO	1.10

a The original DB1B passenger count is a 10 percent sample and therefore is multiplied by ten for an estimated annual passenger count.

Ranking only a single airport pair between two major cities (e.g., LAX to LGA) could favor airlines with hubs at those particular airports because of a large number of direct flights between those airports, even if other airlines operate efficient flights between other airports serving the same city pair. In order to cover a wider range of competing airports in a region where people choose to travel, a concept advanced by Brueckner, Lee, and Singer,[30] that of a multi-airport metropolitan area, which here is called a metroplex, was used to identify major metropolitan areas and the airports that serve them (Table B2).

29 The Bureau of Transportation Statistics (BTS) Air Carrier Statistics (Form 41 Traffic) T-100 Domestic Segment provides flight-specific information including carrier, nonstop origin and destination (OD) airport pair, departures occurring, passengers, available seats, payload, service class, and aircraft type on a monthly basis. The Airline Origin and Destination Survey (DB1B Coupon) provides data on a 10 percent sample of airline tickets from reporting carriers. The dataset contains specific information such as operating carrier, origin airport, destination airport, hub airport, passenger count, and itinerary distance, among others.

30 Brueckner, Lee, and Singer 2013.

Table B2 Metroplexes and corresponding airports[31]

Metroplex	Airports			
Atlanta	ATL			
Boston	BOS	MHT	PVD	
Chicago	ORD	MDW		
Dallas	DFW	DAL		
Denver	DEN			
Detroit	DTW	FNT		
Honolulu	HNL			
Houston	IAH	HOU		
Kahului	OGG			
Las Vegas	LAS			
Los Angeles	LAX	BUR	LGB	SNA
Miami	MIA	FLL		
New York	LGA	EWR	JFK	
Orlando	MCO	SFB		
Philadelphia	PHL			
Phoenix	PHX			
San Francisco	SFO	OAK	SJC	
San Diego	SAN			
Washington, D.C.	DCA	IAD	BWI	

An initial list of 22 candidate city pair routes, as defined by metroplexes, was subsequently narrowed down to the ten most traveled routes. For each metroplex-pair, $i - j$, all corresponding OD airport pairs were found via all combinations of i's airports (i_1, i_2, i_3, ...) with j's airports (j_1, j_2, j_3, ...). For example, San Diego–San Francisco would consist of the following OD pairs: SAN-SFO, SAN-OAK, SAN-SJC, SFO-SAN, OAK-SAN, and SJC-SAN. The total number of passengers traveling from i to j and the reverse direction, j to i, was figured to be the sum of passengers on all corresponding OD pair combinations. The final results are shown in Table B3.[31]

Table B3 Top 10 U.S. city pairs by passenger count in 2010

Rank	Route	Passengers (millions)
1	Los Angeles–San Francisco	6.47
2	Miami–New York	4.77
3	Los Angeles–New York	3.91
4	Chicago–New York	3.12
5	Boston–Washington, D.C.	2.90
6	New York–Orlando	2.79
7	New York–San Francisco	2.73
8	San Diego–San Francisco	2.33
9	Las Vegas–San Francisco	2.16
10	Atlanta–New York	2.11

31 Portions of the table are derived from Brueckner, Lee, and Singer 2013.

In the second step, T-100 operational data by individual airline, OD pair, and aircraft type were used to allocate passengers to representative flights. Individual itinerary routes from the DB1B dataset were first grouped into their corresponding city pairs, followed by quantification of emissions on a route basis. Two data sources were used to distribute passengers to specific routes and aircraft: DB1B data to determine the routes and total passengers an airline flew between each city pair and T-100 data to distribute passengers to aircraft on an itinerary route. First, the origins and final destinations of flights by each airline (the seller of the ticket) were extracted from the DB1B coupon data. Flights with more than one layover were excluded from the analysis because inclusion of additional stops would greatly increase the modeling burden with little benefit (more than 99 percent of passengers were captured by the nonstop and single-layover flights). For airlines with several itinerary routes where one or both flight legs were not recorded in BTS traffic data because they were carried on regional affiliates, other data sources, including airline websites and the Official Airline Guide (OAG)[32], were used to assign passengers. The goal for including regional affiliates was to account for 99 percent of the passengers from DB1B sampling. Many of the itinerary flight legs listed in the DB1B dataset did not exist in the T-100 dataset, presumably because they were flown by affiliated regional carriers that transport the mainline carrier's passengers on its aircraft.[33]

These affiliate flights were assigned in order of the lowest fraction of passengers accounted for by BTS data. An index of "missing flight legs" was created from each itinerary route associated with a city pair. 2010 OAG U.S. domestic data, which have information on both the published carrier (the carrier that sells tickets) and the operator (the carrier that flies the passengers), were used. The data retrieved from the OAG database included mainline carrier, regional affiliate(s), OD pair, aircraft type/variant, seat configuration, and the number of departures for the specific set. Using these data, carrier-OD pair sets that were missing in the BTS dataset could be identified. Since OAG and BTS list carriers and aircraft types differently, OAG and BTS name versions were matched as well with aircraft in Piano-X, an aircraft performance and emissions database that contains more than 400 commercial aircraft types calibrated via real-world operations data,[34] for modeling purposes. Some databases are more specific than the others, and in the case of ambiguity, the most frequent aircraft variant used by a carrier on a given particular OD pair was estimated using a database from Ascend, a consultancy.[35]

To avoid double counting and potential misallocation of passengers to the regional flight(s), a check was performed to confirm that a regional affiliate operates for only one particular mainline carrier for a given OD pair. In cases where a mainline carrier employs multiple regional affiliates to operate a single OD pair, the estimated number of passengers carried is assigned to each regional affiliate. This estimated value is obtained by multiplying the number of departures, seat configuration, and average load factor. The average load factor is obtained from the T-100 dataset for specific aircraft type/variant and OD pair.

The specific aircraft each passenger flew on needed to be deduced, as it was not provided by the DB1B data. T-100 traffic data were used to determine each flight leg

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32 The Official Airline Guide (OAG) is a source for flight schedules, flight status, and aviation data. Information is available at http://www.oagaviation.com/

33 Code sharing is another common practice in commercial aviation—as a result, it is not possible to account for all the passengers sampled in DB1B data without considering code sharing. However, incorporating regional affiliates alone expanded coverage to 99 percent of all passengers, so including code sharing was judged to be unnecessary.

34 Information is available at http://www.lissys.demon.co.uk/PianoX.html

35 For example, one carrier operates ERJ-135, ERJ-140, and ERJ-145 aircraft, while the dataset lists only "ERJ 135/140/145" as a general term.

of an itinerary route, what aircraft types were flown, and the proportion of passengers flown on each aircraft type based upon the assumption that the distribution of passengers among aircraft types was the same as that of the passengers sampled from DB1B. For airlines with a flight leg not recorded in BTS and having more than one affiliate, the OAG distribution of available seats was used to allocate passengers. Where sufficient data were not available from T-100, 2010 OAG data were used to determine the origin-destination airport pair, aircraft type, and departures undertaken by regional carriers for their mainline partners.

In the third step, carriers carrying less than 1 percent of passengers (relative to those carriers among the 15 mainline that did fly) on a given route were identified and excluded from further analysis. In several instances, carriers flying less than 1 percent of passengers had zero direct flights because they had limited routes sampled for that metroplex pair and thus disproportionately poor fuel efficiency. Those marginal carriers were treated as outliers and excluded from the rankings. On average, 98 percent of all passengers carried between modeled cities were retained.

In the fourth step, Piano-X was used to model the fuel consumption for each flight. Piano-X aircraft are generally specified by aircraft type/series/variant, engine type or variant, range type, winglet or no winglet, and maximum takeoff weight; sometimes, the model's jets approximate actual aircraft operated by a given carrier. Ascend Online's historical Fleets database,[36] which provides comprehensive carrier fleet and aircraft-specific information, was used to assign each unique carrier-aircraft group in the BTS data a representative Piano-X aircraft based on the greatest count in the fleet.[37]

Parameters from several different datasets were used to model the fuel burn of individual flights in Piano-X. T-100 traffic data were categorized into unique "carrier–OD pair–aircraft type" groups in the form of a lookup table. The relevant operational values for each carrier–OD pair–aircraft type group used for emissions modeling included the number of passengers, fraction of passengers flying an aircraft type, seats, load factor, average taxi time per flight, and average payload per flight (220 lbs. for a single passenger plus baggage). Operating-empty weights (OEW) and fuel burn per taxi minute by aircraft type were obtained from the Piano-X database.

The fuel burn per flight for each carrier–OD pair–aircraft type group in the lookup table was modeled using Piano-X via several inputs: average payload, distance between origin and destination airports, average taxi times, modified OEWs based on the average seat configuration in T-100, and approximate weight per aircraft seat values. For all aircraft, model default values were used for thrust, drag, fuel flow, takeoff/approach/taxi minutes, and available flight levels (altitude), while cruising speed was set at 99 percent specific air range (ratio of true air speed to gross fuel consumption), with allowances of 370 km diversion distance, 30 minutes' holding time, and a 5 percent mission contingency fuel rule.

In the final step, the passenger fuel intensity of all possible unique routes linking each city pair was weighted by the number of passengers the airline carried on a specific route to estimate a single fuel intensity for each airline and metroplex pair. As an

36 Information is available at http://www.ascendworldwide.com/

37 For example, American Airlines was determined to have 44 Boeing 767-300ER aircraft and 14 Boeing 767-300ER winglet aircraft in its 2010 fleet. This study made the assumption that where BTS designates aircraft type, "Boeing 767-300/300er" for American Airlines, American's mission would be modeled with the aircraft variant of higher count, Boeing 767-300ER.

example, assume that airline *i* has two routes associated with metroplex pair *j*, route *x(a)*: a direct flight with flight leg *a* and n_x passengers, and route *y(b,c)*: a single-layover flight with flight legs *b* and *c* and n_y passengers. The total fuel burn associated with each route *x* and its flight leg *a* is calculated as

$$fuel_{xa} = \#flights_{xa} * [block\_fuel\_per\ flight_{xa} + taxi\_fuel\_per\ flight_{xa}]. \qquad \textbf{[Eq. 1]}$$

The fuel burn per passenger is calculated by dividing total fuel for route *x* by its number of passengers, n_x. Finally, the fuel intensity for airline *i* serving metroplex pair *j* is calculated as the average of the fuel burn per passenger value for all routes weighted by the number of passengers moved:

$$Pax\_FI_{ij} = \left(\frac{fuel_{xa}}{n_x}\right) * \frac{n_x}{n_x+n_y} + \left(\frac{fuel_{ya} + fuel_{yb}}{n_y}\right) * \frac{n_y}{n_x+n_y} \left[lbs.\ fuel\ burn \,/\, passenger\right]. \qquad \textbf{[Eq. 2]}$$

Using these passenger fuel intensities, airlines were ranked from lowest to highest on the metric of passenger mile per pound of fuel for each metroplex pair. Full results are presented in Appendix C.

APPENDIX C: CITY PAIR RESULTS

Table C1 Los Angeles–San Francisco fuel efficiency by airline (340 miles)

Rank	Airline	Fuel efficiency (passenger miles/ lb. fuel)	Relative fuel burn	Passenger share
1	JetBlue	7.1	-----	9%
2	United	7.0	+1%	13%
3	American	6.8	+4%	4%
4	Virgin America	6.6	+8%	8%
5	Southwest	6.4	+11%	65%
6	Delta	6.0	+18%	1%

Table C2 Miami-New York fuel efficiency by airline (1,100 miles)

Rank	Airline	Fuel efficiency (passenger miles/ lb. fuel)	Relative fuel burn	Passenger share
1	Spirit	11.9	-----	10%
2	JetBlue	11.6	+3%	30%
3	Continental	11.1	+7%	17%
4	American	10.4	+14%	23%
5	Delta	8.9	+34%	19%
6	US Airways	8.5	+40%	1%

Table C3 Los Angeles-New York fuel efficiency by airline (2,500 miles)

Rank	Airline	Fuel efficiency (passenger miles/ lb. fuel)	Relative fuel burn	Passenger share
1	Virgin America	12.0	-----	12%
2	JetBlue	12.0	+0%	18%
3	Continental	11.9	+1%	18%
4	United	11.4	+5%	9%
5	US Airways	10.9	+10%	2%
6	Delta	10.7	+12%	16%
7	American	8.9	+35%	25%

Table C4 Chicago-New York fuel efficiency by airline (730 miles)

Rank	Airline	Fuel efficiency (passenger miles/ lb. fuel)	Relative fuel burn	Passenger share
1	Southwest	9.9	-----	7%
2	United	8.9	11%	27%
3	JetBlue	8.8	13%	6%
4	American	7.9	25%	38%
5	Continental	7.8	27%	10%
6	Delta	5.3	87%	12%

Table C5 Boston-Washington, D.C. fuel efficiency by airline (410 miles)

Rank	Airline	Fuel efficiency (passenger miles/ lb. fuel)	Relative fuel burn	Passenger share
1	Southwest	8.1	-----	35%
2	United	7.7	5%	7%
3	AirTran	7.1	14%	13%
4	JetBlue	7.0	16%	22%
5	US Airways	5.9	37%	18%
6	American	5.3	53%	1%
7	Delta	5.0	62%	4%

Table C6 New York–Orlando fuel efficiency by airline (950 miles)

Rank	Airline	Fuel efficiency (passenger miles/ lb. fuel)	Relative fuel burn	Passenger share
1	JetBlue	11.1	-----	46%
2	Continental	10.9	2%	24%
3	American	8.5	31%	3%
4	Delta	8.5	31%	22%
5	US Airways	8.2	35%	2%
6	AirTran	7.7	44%	3%

Table C7 New York–San Francisco fuel efficiency by airline (2,600 miles)

Rank	Airline	Fuel efficiency (passenger miles/ lb. fuel)	Relative fuel burn	Passenger share
1	Continental	13.1	-----	18%
2	JetBlue	11.9	8%	15%
3	United	11.5	12%	19%
4	Virgin	11.0	17%	13%
5	Delta	10.7	21%	16%
6	US Airways	10.4	24%	2%
7	American	8.9	45%	17%

Table C8 San Diego-San Francisco fuel efficiency by airline (450 miles)

Rank	Airline	Fuel efficiency (passenger miles/ lb. fuel)	Relative fuel burn	Passenger share
1	United	8.3	-----	12%
2	Southwest	7.9	5%	77%
3	Virgin	7.6	9%	11%

Table C9 Las Vegas–San Francisco fuel efficiency by airline (410 miles)

Rank	Airline	Fuel efficiency (passenger miles/ lb. fuel)	Relative fuel burn	Passenger share
1	United	8.1	-----	13%
2	Virgin	7.7	5%	17%
3	Southwest	7.6	7%	61%
4	US Airways	7.1	14%	9%

Table C10 Atlanta-New York fuel efficiency by airline (760 miles)

Rank	Airline	Fuel efficiency (passenger miles/ lb. fuel)	Relative fuel burn	Passenger share
1	AirTran	8.6	-----	17%
2	Delta	8.5	1%	67%
3	US Airways	7.8	10%	3%
4	Continental	6.7	28%	8%
5	American	6.2	39%	4%
6	Spirit	5.8	48%	1%

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