THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

U.S. Passenger Jets under ICAO's CO_2 Standard, 2018-2038

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Executive Summary

In 2016, the International Civil Aviation Organization (ICAO) finalized a performance standard that will mandate reductions in carbon dioxide (CO_2) intensity from new aircraft. This is the first policy to impose binding energy efficiency targets for the aviation sector. Individual countries will adopt and implement the CO_2 standard under their national aviation authority's aircraft type certification system. The standard will be enforced for all new aircraft starting in 2028; non-compliant models cannot be certified for sale in the jurisdiction area of the certification body. This paper analyzes the likely effect of the standard when implemented in the U.S., along with ways that it might be strengthened to improve its environmental benefit.

Previous ICCT work has shown that the average newly-delivered single- and twin-aisle commercial aircraft already complies with the ICAO CO_2 standard. Therefore, the standard is not expected to require manufacturers to further improve their aircraft when it is fully implemented in 2028. However, the U.S. Environmental Protection Agency (EPA) has the legal authority to apply the standard to in-service aircraft operated by U.S. airlines. This paper analyzes this potential approach, along with flexibility mechanisms like averaging, banking, and trading (ABT) and tiered standards, as a way to improve the energy efficiency of U.S. airlines.

According to this analysis, seven mainline carriers and all regional carriers, accounting for 82% of 2017 aviation demand from U.S. airlines, would already meet the CO_2 standard by 2028. Two additional airlines, representing 17% of current demand, would be able to comply via modest (less than 2%) additional fuel efficiency improvements. Only Allegiant, a carrier specializing in the use of older aircraft on minor routes, would require larger efficiency improvements to meet the 2028 standard. Therefore, it is feasible that the U.S. could apply the standard to both new and in-service aircraft starting in 2028, with periodic tightening, as a means to promote additional fuel efficiency improvements from airlines.

Introduction

In 2016, the International Civil Aviation Organization (ICAO) finalized a performance standard that will mandate reductions in the carbon dioxide (CO_2) intensity of new aircraft. This is the first standard to impose binding energy efficiency targets for the aviation sector. It will apply to new designs entering into service from about 2024 and all new commercial and business aircraft delivered starting in 2028, with a transition period for modified aircraft starting in 2023 (ICCT, 2016).

Under the standard, an aircraft type's fuel efficiency will be evaluated on ICAO's CO_2 metric value (CO_2MV) (ICCT, 2016). The MV is expressed as

$$MV = 1 / (SAR \times RGF^{0.24})$$

where SAR is the maximum specific air range, a measure of cruise fuel efficiency, and RGF is the reference geometric factor, determined by multiplying the pressurized fuselage length by the fuselage width. RGF approximates the amount of usable space in the aircraft.

Fuel efficiency targets are set as a function of an aircraft's maximum takeoff mass (MTOM)—which designates the maximum combined mass of aircraft empty weight, payload, and fuel that an aircraft can operate at—and measured at three equally weighted gross weight test points. In order to be certified under the standard and sold internationally, each aircraft/engine combination produced by a manufacturer will need to meet a CO_2MV limit assigned as a function of its MTOM. More information on ICAO's aircraft/engine certification requirement can be found in a previous paper (ICCT, 2013).

Figure 1 depicts the ICAO CO_2MVs adopted for new in-production (InP) and new type (NT) jet aircraft. New type aircraft, which represent future certifications of new aircraft/engine combination like Airbus's A321neo or Boeing 777X, are required to meet more stringent CO_2 targets because they typically incorporate more fuel efficiency technologies than new in-production aircraft. The flat area in the figure around 60 tonnes MTOM separates larger commercial jets from smaller regional and business jets. Because those latter aircraft types may have fewer fuel efficiency technologies available to them, they were offered less stringent efficiency targets under the standard.

Individual countries adopt and implement the CO_2 standard under their national aviation authority's aircraft type certification system. The standard will be enforced via a production cutoff for new InP aircraft starting in 2028, where non-compliant models cannot be certified for sale in the certification body's jurisdiction. Countries may choose to adopt the ICAO standard or impose tighter restrictions on CO_2 emissions from aircraft.

The U.S. EPA is expected to propose a CO_2 emission standard for commercial aircraft in December 2018 (OMB, 2018). The rule is key to the U.S. meeting its goals to cap CO_2 emissions from U.S. commercial carriers at 2005 levels beginning in 2020 (U.S., 2015). As Figure 2 shows, commercial fuel usage for both domestic and international operations exceeded the 2005 peak in 2016 due to continued increases in demand, measured here as revenue tonne kilometers (RTKs). From 2009 to 2017, the number of

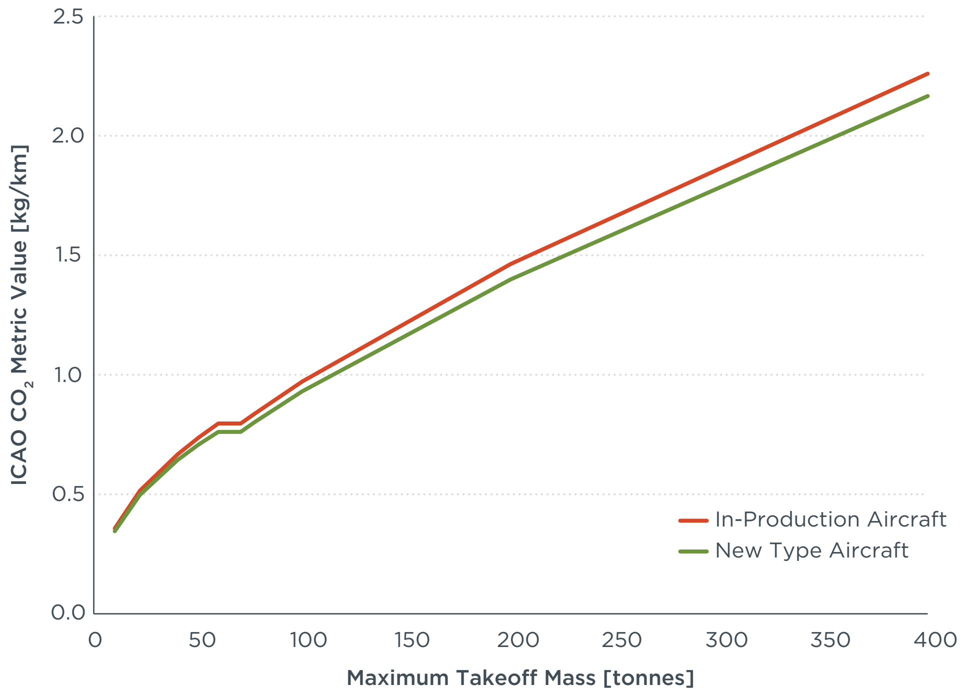

Figure 1. ICAO's CO_2 metric values, as a function of maximum takeoff mass, for jet aircraft

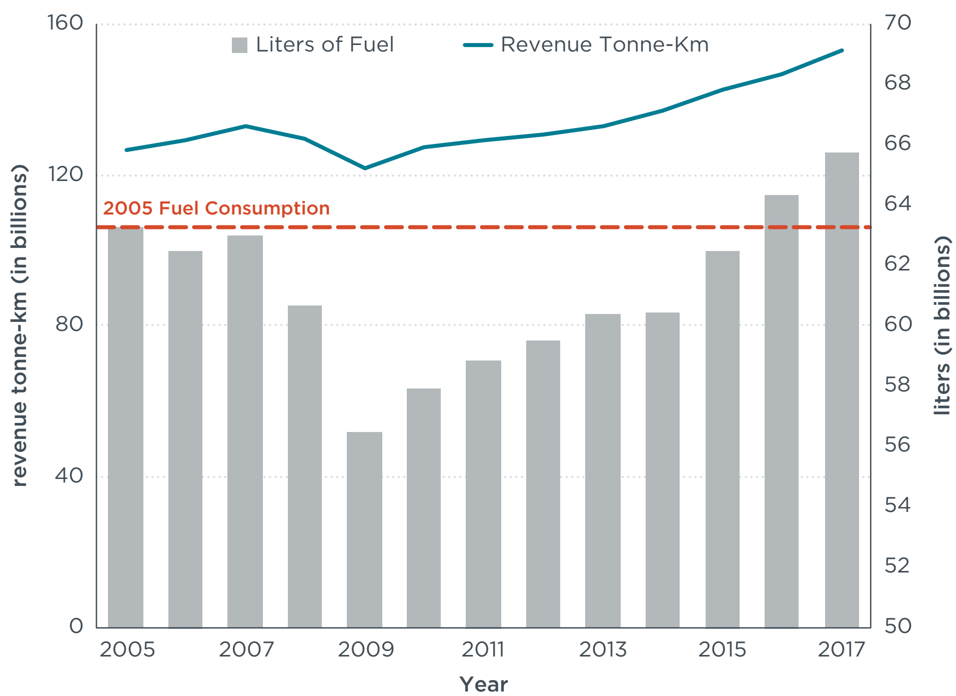

Figure 2. Revenue tonne-kilometers and fuel consumed on domestic and international operations by U.S. carriers, 2005 to 2017.

passenger jet aircraft in operation increased by 11%, the amount of RTKs flown increased by 26%, and total fuel burned increased by 16%. Fleet average fuel efficiency improved by 8% over the same period.

The analysis below shows how implementing the ICAO standard would affect the U.S. airline industry over the next 20 years and considers alternate approaches to increase the industry's contribution to U.S. climate protection goals.

Methodology

For our analysis, aircraft fuel burn was modeled using Piano 5, an aircraft performance and design software (Lissys Ltd., 2017). Piano 5 produces estimates of the CO_2MV based on airline-specific aircraft parameter inputs. 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, and MTOM as closely as possible. The percent difference between the aircraft MV and the ICAO standard was then quantified.

A U.S. airline jet fleet projection prepared by ESG Aviation Services in June 2017 was used to estimate which aircraft types will be used by airlines through 2038. We adjusted this projection based on fleet management decisions made by airlines after the projection was prepared. For example, our analysis reflects the decision by Hawaiian Airlines to cancel their order for Airbus A330-800 aircraft and purchase Boeing 787-9 Dreamliners instead (Hawaiian Airlines, 2018). Turboprop aircraft are not included in this analysis as all are expected to meet the ICAO standard.

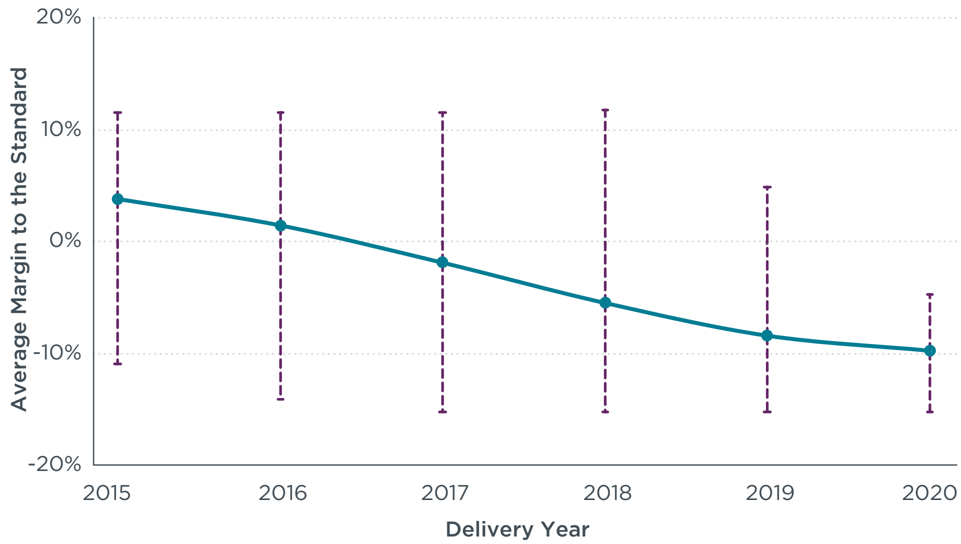

Figure 3. Projected average margin to ICAO's CO_2 standard by delivery year, 2015 to 2020, aircraft greater than 60 tonnes MTOM. Source: ICCT, 2017.

The fleet average margin to the ICAO CO_2 standard was calculated by multiplying the number of each aircraft type in service in a particular year by the percent difference between the aircraft MV and the ICAO standard, and weighted by MTOM. Projections on the number of departures and RTKs for each aircraft type are not available and not included in this analysis.

Near Term Global Aircraft Deliveries

As recommended by ICAO, the CO_2 standard would apply to new aircraft deliveries only. Since manufacturer production lines change over time, one way to understand the impact of the ICAO standard is to consider how the MV improvements required relate to the projected performance of future deliveries. Figure 3 presents the year-by-year average margin to the standard for projected deliveries of new commercial aircraft greater than 60 tonnes globally (ICCT, 2017).

Positive values represent fuel efficiency worse than required under the standard, while negative values indicate fuel efficiency performance better than required. Error bars on the graph represent the 10^{th} and 90^{th} percentile aircraft delivered in a given year, weighted by MTOM. As the margin moves from positive to negative on the y-axis, the fleet average fuel efficiency increases.

As the graphic shows, the average newly delivered single and twin-aisle commercial aircraft was expected to comply with the standard in 2017, more than a decade before the binding InP aircraft requirement takes effect. Less efficient models, represented by the 90^{th} percentile efficient aircraft (upper error bar), would fail the standard through 2019. Beginning in 2020, eight years before the standard takes effect, the average new aircraft delivered is expected to over-perform the standard by approximately 10%. This is due to the introduction of many new aircraft designs over the next five years (e.g. Airbus A220, A320neo, and A330neo; Boeing 737 MAX and

777X; Embraer E-Jet E2) that pass the standard with a substantial margin.[1]

The key takeaway from Figure 3 is that ICAO's CO_2 standard is not expected to promote additional improvements in energy efficiency if applied to new aircraft as recommended in 2028. This is because the average newly delivered single- and twin-aisle commercial aircraft already complies with the ICAO CO_2 standard, so manufacturers will not be required to further improve their aircraft.

Other research highlights that current improvements in fuel efficiency are unlikely to reduce emissions on an absolute basis due to an increase in demand. In a recent ICCT analysis, the overall efficiency of U.S. domestic airline operations improved by 3% from 2014 to 2016 on a revenue passenger-mile (RPM) per gallon of fuel basis (Olmer & Rutherford, 2017). Over the same period of time, RPMs increased by 10%, and fuel use by 7%. Based on our fleet projection, we expect continued fuel efficiency improvements in aviation, although not quickly enough to offset an increase in overall demand.

U.S. Passenger Airline Fleet

The ICAO global CO_2 standard would only apply to new aircraft delivered starting in 2028. As shown above, new aircraft scheduled for delivery to U.S. airlines in the future will meet the ICAO standard by approximately 10%. A reduction of CO_2 emissions could instead be achieved by applying the standards to in-service fleets. Because the average aircraft operating in US fleets is between 11 to 13 years old (Kwan 2014), the standard could promote the retrofit or retirement of in-service aircraft.

1 Note that this analysis doesn't take into account the proposed Boeing New Midsize Aircraft (NMA) that both Delta Air Lines and United Airlines have announced interest in and expect to place a sizeable number of orders for. This aircraft could be the first to be certified as a new type under ICAO's CO_2 standard.

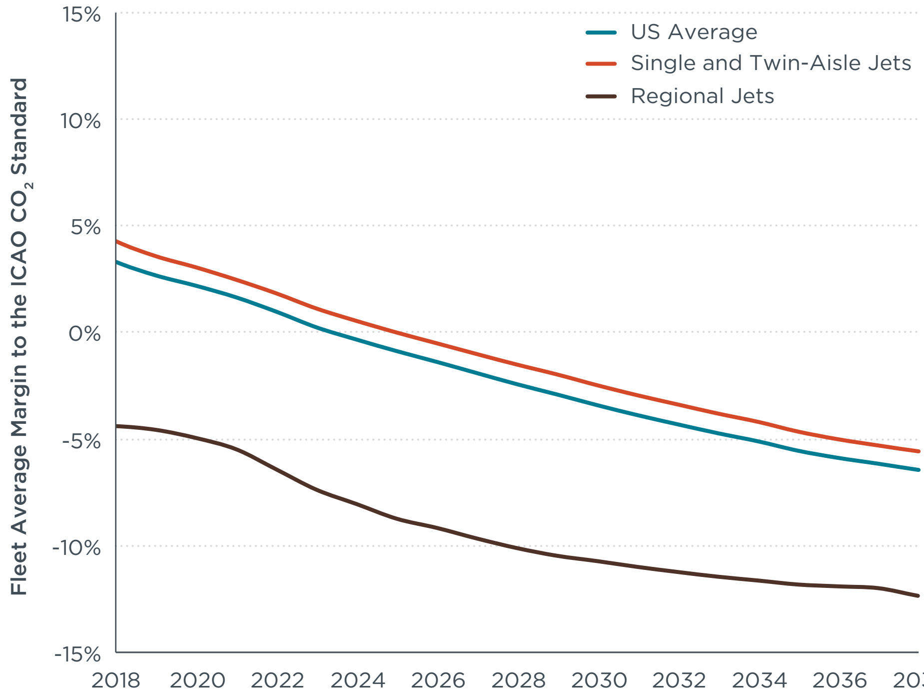

Figure 4. Average margin to the ICAO CO_2 standard for jet aircraft in the U.S. passenger airline fleet, 2018 to 2038.

At the end of 2017, 88% of all global active jet aircraft were for passenger airline use and 25% were registered in the U.S. (Greenslet, 2018). From 2009 to 2017, the number of passenger jet aircraft in operation increased by 11%, the number of RTKs flown increased by 26%, and the amount of fuel burned increased by 16%. The average fuel efficiency of the fleet improved by 8% over the same period.

The fleetwide fuel efficiency of U.S. airlines relative to ICAO's CO_2 standard for InP aircraft was assessed via the methodology described above. Figure 4 depicts the U.S. airline fleet-average margin to the ICAO standard for regional, single-, and twin-aisle jets; turboprops are not included.

As shown in the figure, regional jets in the U.S. airline fleet already comply with ICAO's CO_2 standard. On average, the single- and twin-aisle jets in the U.S. airline fleet are expected to comply with the standard around 2026. The fleet average of all U.S. jets, including regional jets, complies with the ICAO standard by 2024.

While the U.S. jet fleet, on average, will meet the ICAO CO_2 standard in 2024, that is not the case for individual airline fleets. Figure 5 shows the fleet average margin to the ICAO standard for ten U.S. mainline carriers.[2] Based on our projection, the fleets of four airlines will achieve the global CO_2 standard by the end of 2023 on average: United, Hawaiian, Frontier, and Spirit. Allegiant Air, which preferentially buys used rather than new aircraft, does not meet the ICAO standard because it is expected to continue to operate a fleet of used Airbus A319s and A320 with current engine options. All other airlines' fleets would meet the standard by the end of 2030 through expected fleet renewal.

By 2028, seven of the ten carriers analyzed—American, Delta, Frontier, Hawaiian, JetBlue, Spirit, and United – will have fleets that were, on average, in compliance with the ICAO CO_2 standard. Both Alaska and Southwest Airlines will need modest fuel efficiency improvements, while Allegiant Air will need substantial improvements.

The relative fuel efficiency of the airlines is related to the underlying fleet of aircraft they operate. The effect of the ICAO CO_2 standard on a specific aircraft model will depend not only on the MTOM, but also other factors, such as the engine type and utilization of retrofit wingtip technologies. Table 1 shows the estimated MVs of key aircraft types utilized by U.S. airlines that could fail the standard. A positive value indicates exceeding the standard and would require additional improvements in order to be used in 2028 under an in-service standard.[3]

2 We focus on mainline carriers here because the fleet projection did not break down aircraft by regional carrier, just all regional aircraft in use by U.S. carriers. However, a majority of the regional aircraft currently utilized already comply with the ICAO CO_2 standard.

3 Most new aircraft being delivered in 2018 pass the InP standard by approximately 10%. See ICCT (2017) for a full list of affected aircraft with their expected margin to the standard.

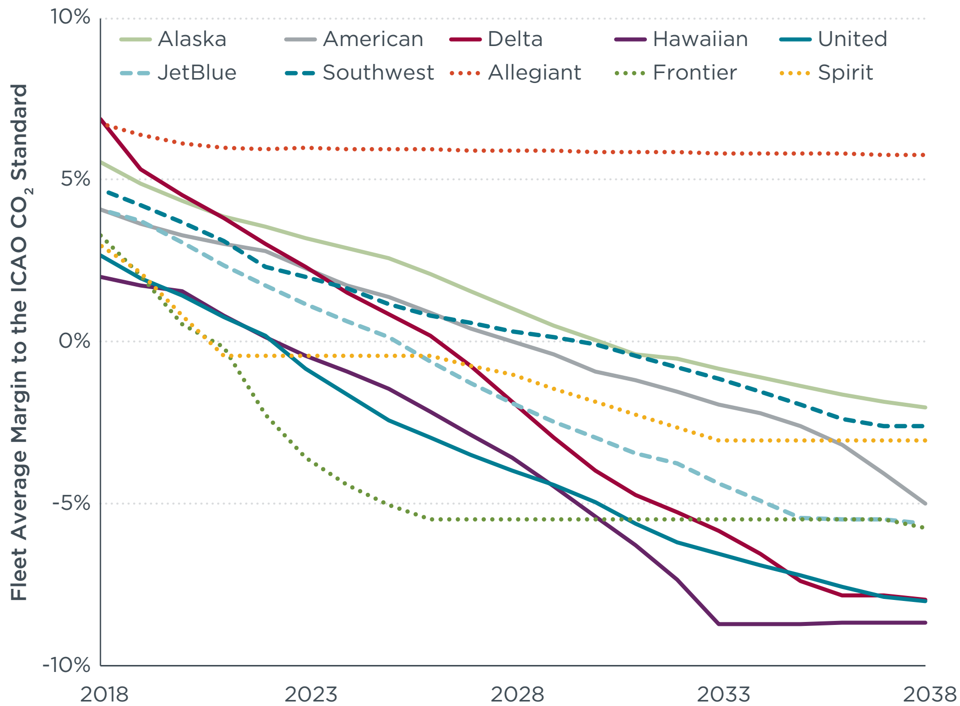

Figure 5. Average margin to the ICAO CO_2 standard for jet aircraft in the fleet of U.S. mainline carriers, 2018 to 2038.

Airlines with fleets that are less efficient than required under an simple "pass/fail" in-service standard have several options to achieve compliance. First, less efficient aircraft could be retrofit to reduce (improve) their MVs. Wingtip devices like winglets, along with performance improvement packages for engines, typically offer 3 to 5% reductions. If larger reductions are required, the airlines could choose to sell or retire older aircraft in favor of the newer designs that meet the standard. As a final option, airlines operating older aircraft types close to the standard, for example many Airbus or Embraer aircraft in Table 1, could have their certified MTOMs reduced as a strategy. This "paper" MTOM change would serve to decrease the effective range of the aircraft while providing a small margin to the standard.[4]

Policy Implications

The U.S. is expected to propose greenhouse gas emissions standards and test procedures for aircraft in 2018. Promulgation of a standard at least at the same stringency levels as the ICAO standard is necessary in order for U.S. manufactured aircraft and engines to be sold worldwide. Airlines

4 See ICCT, 2017. A "paper" change in MTOM artificially constrains the maximum takeoff mass of the aircraft and therefore its payload, range, or a combination of the two. Such an aircraft would presumably be used on shorter flights and potentially fewer hours per year, indirectly reducing emissions. As a rule of thumb, a 10% reduction in MTOM increases an aircraft type's margin to the standard by about 2%. Other options, for example crediting sustainable alternative jet fuel (AJF) use as a compliance option, could be adopted by EPA but are beyond the scope of this paper.

Table 1. Example in-service aircraft failing ICAO's CO_2 standard

Manufacturer	Aircraft Type	Exceedance†	Airlines Operating Aircraft Type at End of			
			2025		2035	
Airbus	A319	3% to 8%	Alaska Allegiant American	Delta Spirit United	Alaska Allegiant	United
	A320	-1% to 4%	Alaska Allegiant American Delta	Frontier JetBlue Spirit United	Alaska Allegiant Frontier	Spirit United
	A321	1% to 6%	American Delta Frontier	Spirit JetBlue	American Delta Frontier	JetBlue Spirit
	A330-200	-1% to 3%	Hawaiian		—	
	A330-300	-2% to 3%	Delta		—	
Boeing	737-700/ER	4% to 12%	Southwest		Southwest	
	737-800	2% to 12%	Alaska American Delta	Southwest United	Alaska American	Southwest United
	737-900/ER	5% to 10%	Alaska Delta	United	Alaska Delta	United
	767-300ER	10% to 15%	Delta Hawaiian	United	—	
	767-400ER	7% to 12%	Delta	United	—	
	777-200ER/LR	1% to 9%	American Delta	United	American	United
	777-300ER	1% to 6%	American	United	American	United
Bombardier	CRJ 701ER/LR	0% to 5%	Various Regional Airlines			
Embraer	E170	-2% to 6%	Various Regional Airlines			
	E175	-2% to 6%	Various Regional Airlines			
	E190	0% to 9%	JetBlue		—	

†Source: ICCT, 2017

for America, an airline industry association, has publicly voiced support for the ICAO CO_2 standard (A4A, 2018).

The analysis above demonstrates that ICAO's CO_2 standard, as written, will not promote additional fuel efficiency in the aviation sector. An in-service standard, applied to airlines rather than manufacturers, may be appropriate. This analysis suggests that an in-service standard enforced around 2028 at ICAO's recommended stringency would incentivize some airlines to retrofit or renew their fleets. Additional action could be sparked by setting an emission standard that declines over time in tandem with anticipated fleet improvement, such as requiring additional 1% reductions in MV annually after 2028.

There are at least three options for implementing an in-service standard. One would be to apply the standard as a pass/fail requirement (a "phase out") for individual aircraft types. This is consistent with existing environmental type-certification in most countries. Aircraft not able to meet the CO_2 intensity targets would not be eligible to operate at U.S. airports. An alternative approach would be to set a fleet average standard that each airline would meet on an average basis across its entire in-service fleet.[5] A hybrid approach would establish multiple tiers of pass/fail performance (e.g. Tier 1 as the current CO_2 standard, Tier 2 as 5% below that, and Tier 3 as 10% below) and require an airline to shift a certain percentage of

5 In its most sophisticated approach, this could entail a full averaging, banking, and trading (ABT) approach. Banking of overcompliance for future use may be useful for airlines given the long useful life of their equipment, while trading of overcompliance credits could help address the problem of the least capable airline, in this case Allegiant, by allowing it to continue to use older aircraft if it compensates by paying more efficient airlines.

its fleet to a higher fuel efficiency tier over time. This would be similar to the approach FAA used in enforcing the Chapter 2 noise phaseout of aircraft in the 1990s (United States General Accounting Office, 2001).

Table 2 summarizes these three options, along with the major advantages and disadvantages of each.

The classic pass/fail phaseout would be easy to implement as part of current type certification. Disadvantages of the approach are its poor flexibility, higher compliance costs, difficulty in updating, and inability to reward airlines with higher fuel efficiency than the minimum requirement. A declining fleet average standard would address many of these shortcomings, but at the cost of added complexity and the need to benchmark airlines as part of the system.[6] A tiered standard blends the advantages of these two systems in a way that may be of interest to policymakers, but higher tiered stringency levels would need to be established before the system could take effect.

Conclusion

This paper analyzed potential options for the implementation of ICAO's CO_2 standard for new aircraft in the U.S. As shown, the average newly delivered single- and twin-aisle commercial aircraft already complies with the ICAO CO_2 standard. Therefore, the standard is expected to have no effect on new aircraft fuel efficiency when fully enforced in 2028.

An alternative is to apply the standard to in-service, rather than new, aircraft beginning in 2028, with additional tightening over time. According to this analysis, on average, seven mainline carriers and all regional carriers, which account for 82% of 2017 aviation demand, would already meet the CO_2 standard that year, with two additional airlines, representing 17% of current demand, able to comply via modest (less than 2%) additional efficiency improvements. Only Allegiant, a carrier specializing in the use of older aircraft on minor routes, would require larger efficiency improvements to meet the 2028 standard. Flexibility mechanisms like fleet averaging and tiered standards could allow airlines to devise least-cost compliance options.

Table 2. Options for implementing the CO_2 standard on individual airlines

Approach	Regulatory Target	Classification: Advantages	Classification: Disadvantages
Pass/fail phaseout	In-service aircraft	Easy to implement Best matched to current type certification	Inflexible Higher compliance cost Static – difficult to update Can't credit overcompliance
Declining average fleet standard	Airline	Highly flexible Lowest compliance cost Dynamic: can be tightened easily over time Can credit overcompliance Can be matched with fines	Added complexity Requires initial benchmarking of airlines
Tiered standard with fleet requirements	Airlines via in-service aircraft	Ease of implementation Dynamic Medium flexibility and compliance cost Can credit overcompliance Can be matched with fines	Medium complexity Requires multiple stringency levels

6 As an example, a regulator would need to decide whether to require all airlines to meet the same fleet average CO_2MV in the target year, to reduce their average CO_2MV by a set percent each year, or something in between. The required fuel efficiency improvement of each airline would vary depending upon this decision.

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