ICAO's Global Horizontal Flight Efficiency Analysis

By David Brain, EUROCONTROL and Nico Voorbach, CANSO

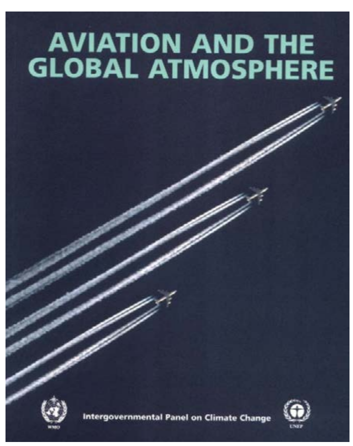
BACKGROUND

The contribution of air traffic management (ATM) operators in reducing the climate change impacts of aviation can best be achieved by enabling aircraft to fly on their optimum 4D trajectory in the climb, on-route and descent phases of flight - the optimum horizontal path from departure to destination flown at the most fuel-efficient flight level. There are several factors however that may influence whether such an optimum trajectory may be flown. One factor is safety, the number one objective in ATM with aircraft separated by different horizontal and vertical separation minima depending upon the type of airspace in which they fly. Another factor is military activity which may restrict the availability of certain airspace. Meteorological conditions such as wind speed and direction may provide more favorable flight conditions away from the most direct route. In addition, airlines may choose to minimize delay over the cost of fuel meaning that they may choose to fly on a less optimal routing to ensure that any delay is kept to a minimum. There may also be other operational, technical and economic reasons why airlines may choose not to file the most efficient flight plan.

Nevertheless, studies of flight efficiency have focused principally on measuring the efficiency of the horizontal plane by comparing the flown trajectory to a theoretical optimum, resulting in efficiency values based on a percentage up to a maximum figure of 100%. For example, an inefficiency of 10% in an aircraft profile indicates a flight profile that is 90% efficient. It is widely understood however that 100% efficiency may never be reached as some latent inefficiency will always be required to enable the aviation system to be optimized at the overall network level. This need to optimize all profiles to the extent possible will invariably mean that interactions to maintain safety, capacity, flight efficiency, and reduce environmental impacts will lead to an inherent level of inefficiency. The key is to minimize these inefficiencies to the extent possible.

Attempts to identify the base case for flight efficiency have been undertaken over the last 20 years with further attempts to measure any performance improvements undertaken at the regional level.

FIGURE 1: Aviation and the Global Atmosphere report (IPCC)



In the 1999 Intergovernmental Panel on Climate Change (IPCC) report, *Aviation and the Global Atmosphere*, it was estimated that improvements in ATM and other operational procedures could reduce aviation fuel burn by between 8% and 18%, thus implying an average flight efficiency of 82% to 92%. That study reviewed the results of available studies on the benefits of an improved ATM system attributable to the implementation of future ATM concepts. The IPCC concluded that addressing these limitations in ATM systems could reduce fuel burned in the range of 6% to 12% with the efficiency improvement to come from ATM improvements which it was anticipated would be fully implemented in the 20 years following the report. This finding assumed that the necessary institutional and regulatory arrangements would be in place by that time.

In 2008, the Civil Air Navigation Services Organization (CANSO) continued that thread of work in its report titled *ATM Global Environment Efficiency Goals for 2050*. That study estimated that the Global ATM system was already between 92% and 94% fuel efficient and that 100% ATM fuel efficiency was not achievable as some inefficiency is unrecoverable due to unavoidable operating constraints and interdependencies, such as: safety, capacity, weather, noise, and fragmentation of the airspace.

FIGURE 2: ATM Global Environment Efficiency Goals for 2050 (CANSO)

CANSO made a first attempt to break down the total efficiency levels on a regional basis and concluded that ATM efficiency varies among regions, ranging from between 89-93% in Europe, to 98-99% in Australia. CANSO also estimated that approximately 75% of the ATM inefficiency could be recovered by improved horizontal flight efficiency (HFE), and 25% by improved vertical flight efficiency (VFE).

In the 8th cycle of the ICAO Committee on Aviation Environment Protection (CAEP) the operational working group made an estimation of the baseline efficiency for all ICAO regions that were not part of the CANSO study, also breaking down the inefficiency within these regions to: horizontal flight inefficiency, vertical flight inefficiency, and delays/flow.

It was estimated that the baseline efficiency in these regions ranged from 90-93% in Africa to 93-96% in Central and South America (see Figure 3).

In conclusion, previous studies on global flight efficiency by the IPCC, CANSO and ICAO have focused on horizontal flight efficiency and have traditionally focused only on those areas where data is available (e.g., North America, Europe and Australia) and not where traffic growth is at a premium (e.g., Asia and the Middle East). In the absence of data, estimations of efficiency levels to date have relied on: IATA technology

FIGURE 3: CAEP/8 IEOGG global baseline and projected efficiency levels (CAEP)

Canso Region	ICAO Region	% of global aircraft movement in 2006	Basis of Goal Setting (Sources of inefficiency covered)						Estimated Base Level Efficiency	Operational Efficiency Goals	
			Great Circle Route	Delays and Flow	Vertical Flight	Airport & Terminal Area	Wind Assisted Routes	Contingency Fuel Predictability	2006	2016	2026
World		100%	assessed	assessed	assessed	assessed	not assessed	not assessed	92-94 %	92-95 %	93-96 %
US		35%	assessed	assessed	assessed	assessed	not assessed	not assessed	92-93 %	92-94 %	93-96 %
	North America		assessed	assessed	assessed	assessed	not assessed	not assessed	92-93 %[1]	92-94 %	93-96 %
ECAC		28%	assessed	assessed	assessed	assessed	not assessed	not assessed	89-93 %[2]	91-95 %	92-96 %[3]
	Europe		assessed	assessed	assessed	assessed	not assessed	not assessed	89-93 %	91-95 %	92-96 %
Other Regions		37%	estimated	estimated	estimated	estimated	not estimated	not estimated	91-94 %	94-97 %	95-98 %
	Central America / Caribbean		estimated	estimated	estimated	estimated	not estimated	not estimated	93-96 %	94-97 %	95-98 %
	South America		estimated	estimated	estimated	estimated	not estimated	not estimated	93-96 %	94-97 %	95-98 %
	Middle East		estimated	estimated	estimated	estimated	not estimated	not estimated	92-94 %	94-97 %	95-98 %
	Africa		estimated	estimated	estimated	estimated	not estimated	not estimated	90-93 %	94-97 %	95-98 %
	Asia/Pacific		estimated	estimated	estimated	estimated	not estimated	not estimated	91-94? %	94-97? %	95-98? %

Figure 3: *Operational efficiency goals (great circle), 2016-2026.*

1 This is a direct copy of the US figures and, as a general principle, regional goals should not be applied to individual states.
2 This IPCC based estimations of the base-case matches the EUROCONTROL PRR07 report.
3 This figure extrapolated from the CANSO report is used for consistency, but may be conservative when compared to work by SESAR on 'Gate-to Gate fuel efficiency'.

assessments, congestion assumptions, and expert judgements.

CAEP GLOBAL HORIZONTAL FLIGHT EFFICIENCY STUDY – 2018

Since 2010, the above-mentioned studies were not revisited, but with the arrival of new sources of surveillance data, such as *Automatic dependent surveillance*-broadcast (ADS-B), together with modern flight tracker websites with global coverage, CAEP, in 2018, undertook the first truly global horizontal flight efficiency study using a single harmonized surveillance data source, ADS-B.

New Data Available

Flightradar24 provided four one-week sets of ADS-B global movement data for the first calendar week of each of February, May, August and November of 2017. The granularity of this movement data depended upon the phase of flight of each aircraft and varied between approximately 60 second surveillance updates for flights in the on-route phase, down to approximately 6 second updates during the climb and descent phases of flights in which small changes in both the vertical and horizontal profiles may occur.

As ADS-B data is surveillance data, it is only available where ground-based surveillance receivers are available to record it. Therefore, trajectory data is not recorded in oceanic areas and is usually missing over less densely populated areas such as deserts and northern latitudes. Figure 4 demonstrates the geographic distribution of where ADS-B surveillance was recorded in the study, indicating the presence of ADS-B receivers on the ground. Note the availability of trajectory data due to ADS-B receivers in specific locations, e.g., The Azores, Bermuda, St. Helena, and Mahe Island (Seychelles). In addition, note the relative absence of surveillance data over mainland Africa (limited number of receivers), Western China (restricted airspace) and Syria (airspace restrictions).

Data Validation

ADS-B data may be associated with numerous nuances relating to: data source, receiver reliability, and time stamp issues. Therefore, a rigorous data validation process was undertaken with the aid of a tool developed by EUROCONTROL called V-PAT. This tool contains a number of validation steps designed to weed out 'bad' data.

FIGURE 4: Screen shot of the average flight movements over a 7-day period of FR24 data using hexagonal bins (August 2017)

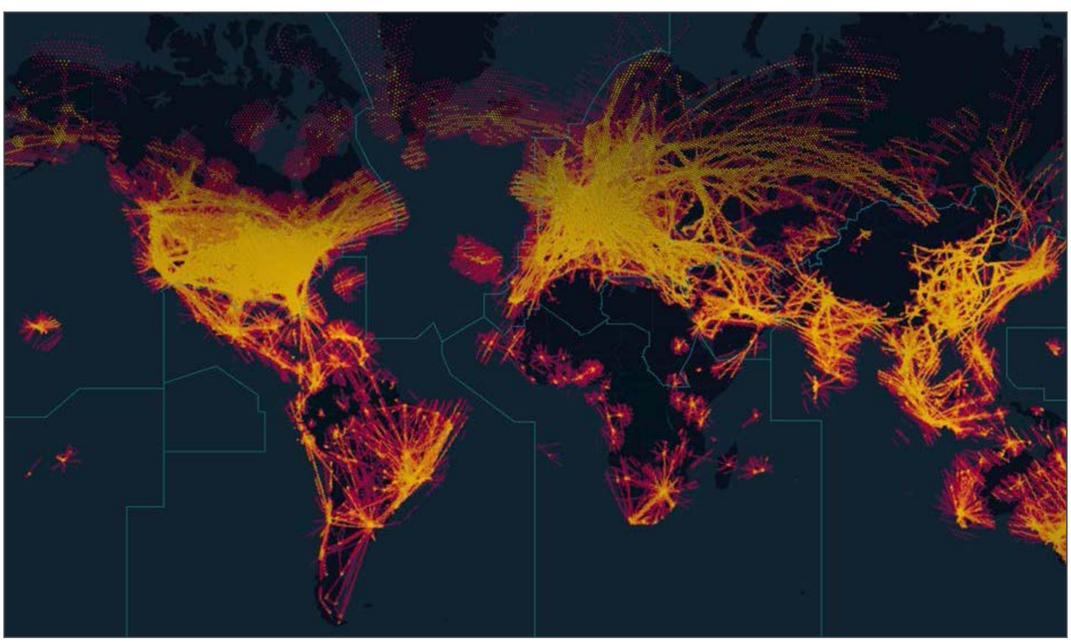
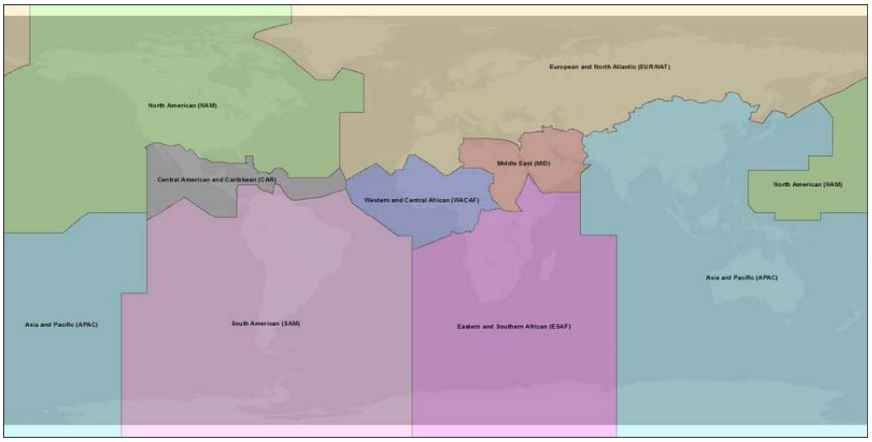


FIGURE 5: ICAO region definitions



The first validation step identified flights with missing departure or destination airports or flights that were outside the scope of the analysis such as: gliders, ground movements, flights with a cruising level of below FL100, and flights with a total number of trajectory points below a selected threshold. The second step used user-defined parameters to exclude flights with missing, incomplete, or corrupt data. The third step identified any trajectory points which exceeded additional user-defined parameters so that trajectories could be smoothed out, and any potential erroneous trajectory points or those with speeds that were out of tolerance eliminated.

Study Methodology

To identify a relevant horizontal flight efficiency methodology to use in the analysis, a literature review was undertaken of available resources relating to the measurement of flight efficiency including: scientific studies, reports, conference papers, websites, and available presentations. These sources were reviewed to select the most appropriate methodology and metric to use. The one methodology that was widely established and considered appropriate for study purposes, and thus subsequently chosen for the analysis, was the mathematical tool at the core of the European Performance Scheme's methodology to calculate 'achieved distance'[1] . This tool is used on an annual basis for the European measurement of horizontal flight efficiency (HFE) in EU/US HFE comparison studies. This performance indicator is a variant of KPI05[2], a potential performance indicator presented in the ICAO Global Air Navigation Plan (GANP) 2016, and is also consistent with the methodologies used by the previous CANSO and CAEP studies to measure horizontal flight efficiency.

This methodology creates a spatial analysis of the flight segment and calculates a radius around each departure airport and arrival airport between which the measurement is calculated. The methodology was adapted to the data type (ADS-B), data availability (typically over continental airspace) at hand and ICAO regional boundaries (as opposed to the normal entry/exit into European airspace).

The achieved distance was calculated for all flights for which surveillance data was recorded. In the absence of surveillance data between two points of a trajectory (above a certain distance threshold), no efficiency was recorded as the HFE methodology assumes a minimal efficiency for that part of the trajectory in the non-surveilled area which would not be zero (the so-called interface inefficiency). In cases where a flight consisted of two or more segments e.g., a flight from Birmingham, UK to New York City (which had two separate trajectory segments on either side of an 'unsurveilled' segment over the Atlantic Ocean), the achieved distance was calculated for each individual segment. This is because the methodology is designed to measure the horizontal flight efficiency of individual segments by default.

1 https://ansperformance.eu/methodology/horizontal-flight-efficiency-pi/
2 KPI05 refers to the 'actual on-route extension' which compares the actual on-route distance flown compared to a reference ideal distance.

Therefore, it is important to highlight that the HFE analysis measures only the HFE values for those segments of global trajectories that can be recorded by ADS-B receivers.

Following analysis of each individual flight with the achieved distance methodology, the horizontal flight efficiency was assessed for each ICAO region. This was achieved by incorporating a map file (see Figure 5) into the calculations of the methodology which allowed the creation of individual intersection points where each trajectory segment crossed a regional boundary which, in turn, allowed the achieved distance of each flight to be calculated per region.

In order to develop results that would be representative of an entire one-year period, the horizontal flight efficiency results for the four weeks of data were extrapolated to be representative of 2017 as a whole. This was achieved by aligning with existing CAEP assumptions for the extrapolation of data.

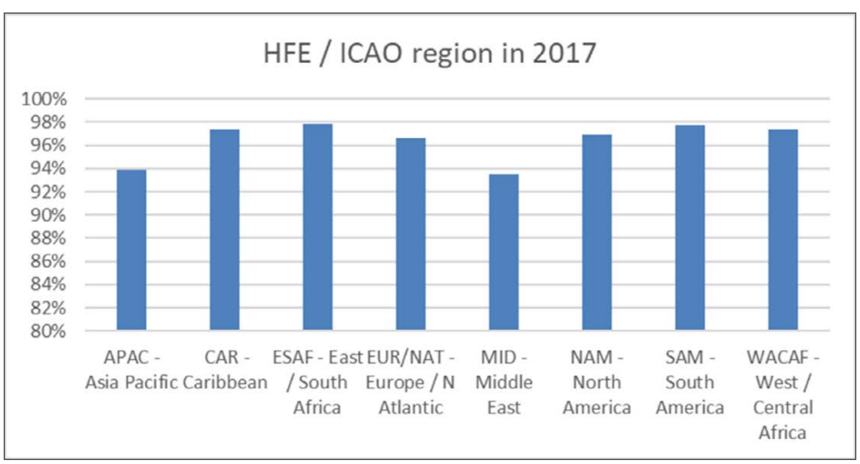
A final validation of results was undertaken. This was necessary because analyses of large traffic samples such as those in this global horizontal flight efficiency study (as large as 100,000+ flights per day), may lead to a small number of erroneous trajectories still not being identified. To combat this issue and in alignment with the same process undertaken during the calculation of the achieved distance KPI in Europe (and proposed as the HFE KPI in the GANP), the top 1% (the highest) of achieved distance values and the bottom 1% (the lowest) of achieved distance values were ignored from the final calculations.

Final Results

The purpose of this analysis was to calculate global horizontal flight efficiency, broken down to the ICAO regional level, for each and every ICAO region, using a harmonized single source of surveillance data. It is important to recognize that while the methodology has been used in the past for various analyses, this study was the first of its kind to use a new global data source, and a global-based analysis, with the potential limitations of using a single parameter to estimate different traffic flow efficiencies on a global level.

The results shown in Figure 6 reveal that horizontal flight efficiency levels in 2017, based on the data studied, vary between 94% and 98%, compared with those estimated by CANSO (92%-94%) in 2008 and CAEP (91%-94%) in 2009. It should be noted however that the efficiencies assessed in both of those studies included an analysis of both horizontal and vertical flight efficiency. As a cross-check, it should be noted that the HFE value for 2017 calculated by the European performance scheme 'achieved distance' methodology was 97.3%. It should also be noted that in this analysis, the EUR/NAT region includes the former Soviet Union States and the North Atlantic airspace (where surveillance data exists).

FIGURE 6: Horizontal flight efficiency results per ICAO region in 2017



In conclusion it would seem that the regional and global HFE values seem aligned with previous studies. This is of course, dependent on what levels of vertical flight efficiency another study using the same data source would find. There are two distinct outliers in the results: the MID and APAC regions. It was not the aim of the study to identify the reasons for regional efficiency levels but it is quite clear that ongoing political instability in the former has contributed to more inefficient routings. Causes for inefficiency in the APAC region are not so obvious but could be linked to large areas of inaccessible airspace (i.e., military areas) or non-optimal airspace structure, or transfer of control points between countries.

To determine the percentage of global air traffic movements that were included in the analysis (and thus assess the percentage of global movements covered by ADS-B surveillance), a comparison was made between the number of movements analyzed in the study per ICAO region (i.e., movements of ADS-B equipped aircraft) and the number of departure and arrival movements detailed in the ICAO Common Operations Database (COD). Based on a comparison between the study and the number of movements in the COD (extrapolated from 2015), it was estimated that globally, the percentage of movements covered by ADS-B surveillance was 68% with the following regional breakdown (Table 1). It should be emphasized that these figures do not represent the % of ADS-B equipped aircraft.

TABLE 1: Movements covered by ADS-B surveillance per ICAO region.

	per departure (%)	per arrival (%)
APAC	84	84
CAR	46	45
ESAF	41	41
EUR/NAT	85	85
MID	95	96
NAM	48	48
SAM	54	54
WACAF	35	36

CAVEATS AND QUALIFICATIONS

ICAO considers it important that the correct messages are passed with these results. Accordingly, the following paragraphs contain a few provisos that need to be taken into account when considering the findings detailed in the article above.

This study assessed global horizontal efficiency. HFE should not be confused with ATM efficiency as HFE may encompass inefficiencies driven by non-ATM factors such as safety, traffic demand, winds, and airspace availability. ICAO considers the HFE assessment as the first step in assessing global flight efficiency.

Since HFE in on-route airspace was estimated as relative to a theoretical optimum, routing restrictions that may have been applicable at the time of flight were not directly addressed. Such routing restrictions may include factors such as convective weather, constraints from other nearby airport flows, or air traffic flow measurement measures. ICAO also agrees with previous studies that state that the air traffic system will always require some latent inefficiency that is very difficult or impossible to remove, in order to enable the system to successfully function while capacity-driven inefficiencies may be embedded in the baseline.

It should be noted that limitations exist related to the use of minimum route lengths (great circle) as an indicator of fuel efficiency and CO_2 emissions. For example, flights across specific airspaces such as the North Atlantic, or between certain city pairs such as Australia and New Zealand, may benefit from wind-assisted routes. Consequently, with strong winds, particularly where jet streams exist, the most fuel-efficient route (i.e., shortest time) is often longer than the great circle distance. It is understood e that wind–assisted routes are more likely to occur in those airspaces where current ADS-B surveillance is not available and thus outside of the analysis. However, the level of analysis does not allow the isolation of only non-wind assisted routes.

In this analysis, there was a general assumption made that those flights equipped with ADS-B are representative of the efficiency of global movements. In addition, data gaps prevented this analysis from addressing any potential differences in HFE for the operations not using ADS-B surveillance, or in those parts of ICAO regions with insufficient ADS-B coverage. The average movement coverage across the ICAO regions ranged from 35% to 95%. Therefore, in regions with lower levels of ADS-B surveillance or equipped fleets, the results were based on a smaller dataset.

ICAO would like to emphasize that this study should be viewed as the first of a multi-step process on the path to identifying global flight efficiency. Further steps would also need to address such factors as: vertical flight efficiency, the relationship between HFE and VFE, efficiency in terminal airspaces and on airport surfaces around the world, as well as trying to fill those data gaps that were identified in this analysis.

It is recommended that global flight efficiency values be regularly updated. Future availability of global space-based ADS-B surveillance data may provide a source of global data that can support a regular update, or address some of these steps in the multi-step process. In addition, normalizing for demand growth and other non-ATM factors would be other additional steps that could be proposed to isolate benefit opportunities associated with future ATM improvements.

ICAO is currently following up on this study with an assessment of global vertical flight efficiency.