ICAO

SPECIAL SUPPLEMENT

Long-Term Aspirational Goal

Overview of Climate Goals and ICAO's Work on a Long-Term Aspirational Goal for International Aviation (LTAG)

By ICAO Secretariat

Introduction

The 2010 International Civil Aviation Organization Assembly adopted the existing global aspirational goals for the international aviation sector of 2% annual fuel efficiency improvements and carbon neutral growth from 2020. The establishment of these global goals changed the shape and the pace of the aviation response to climate change. Since then, much has happened in the aviation industry with regards to climate change action, with multiple commitments for further action from ICAO Member States and industry partners. This special supplement provides an overview of the current aviation goals related to climate, and describes the ICAO's work on the feasibility of a long-term global aspirational goal for international aviation (LTAG).

Commitments by States and Industry

In 2009, the world's major aviation industry associations, including the Airports Council International (ACI), the Civil Air Navigation Services Organization (CANSO), the International Air Transport Association (IATA), the International Business Aviation Council (IBAC), and the International Coordinating Council of Aerospace Industries Associations (ICCAIA) announced their collective commitment to reduce aviation carbon emissions by 50 per cent by 2050 compared to 2005 levels. In light of recent scientific findings and in support of the 1.5°C temperature goal, in 2021 the aviation industry had further raised their level of ambition and collectively committed to achieve net-zero carbon emissions by 2050[1], This would be supported by accelerated efficiency measures, energy transition, and innovation across the aviation sector and in partnership with governments around the world.

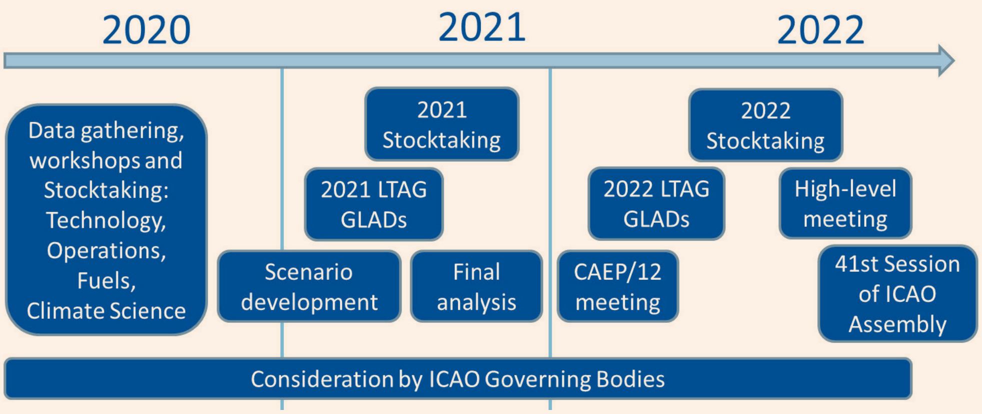
Several ICAO Member States have also committed towards the decarbonization of aviation, including 39 ICAO Member States which are signatories of the "International Aviation Climate Ambition Coalition"[2], and 37 Member States (27 EU Member States and 10 other Member States of the European Civil Aviation Conference (ECAC)), which are the signatories of the "Toulouse Declaration" in support of the goal of carbon neutrality in the air transport sector by 2050[3].

LTAG overall process

Following the request of the 40th ICAO Assembly in 2019 and in line with that momentum on climate change action, ICAO made dedicated efforts to explore the feasibility of a long-term global aspirational goal (LTAG) for international aviation, including data collection and information sharing; technical assessment of aviation CO_2 emissions reduction scenarios with analyses of costs and necessary investments; consultation and dialogues among stakeholders; and

1 Commitment to Fly Net Zero: https://aviationbenefits.org/FlyNetZero
2 International Aviation Climate Ambition Coalition: COP 26 declaration: International Aviation Climate Ambition Coalition - GOV.UK (www.gov.uk)
3 Toulouse Declaration: https://presidence-francaise.consilium.europa.eu/en/news/european-aviation-summit/

ICAO LTAG process and timeline



engagement of high-level representatives to facilitate decision. The overall ICAO process and timeline related to LTAG during the triennium is illustrated in the Figure above.

Data Collection and Information Sharing

As part of the ICAO LTAG work, the 2020 and 2021 ICAO Stocktaking events were convened in September 2020[4] and September 2021[5], respectively, for data collection and information sharing on aviation in-sector CO_2 emissions reductions. Further details on the Stocktaking Events are provided in article "ICAO Stocktaking on Aviation in-sector CO_2 Emissions reductions" in Chapter 4 of ICAO Environmental Report 2022.

Additionally, with a view to providing one single source of information that is frequently updated to access all the latest CO_2 reduction innovations for aviation, ICAO developed a series of Tracker Tools[6]. They provide the latest information on aviation CO_2 emissions reduction initiatives, and are updated from three streams – technology, operations and fuels, as well as on aviation net zero initiatives. Further information on these trackers are provided in article "ICAO Aviation CO2 Reduction Initiative Trackers" in Chapter 4 of ICAO Environmental Report 2022.

The ICAO CAEP LTAG Report

Over the last two years, the ICAO Committee on Aviation Environmental Protection (CAEP) undertook its technical work on the feasibility study on LTAG. It has focused on the attainability and readiness of aviation in-sector CO_2 reduction measures, including innovative aircraft technologies, operations and fuels, as it would be necessary to assess the in-sector CO_2 reduction potentials before considering the need and extent of any complementary measure.

The LTAG report, which was unanimously approved at the CAEP/12 meeting in February 2022, consolidates cumulative efforts of over 280 experts over nearly 2 years of intensive work. The LTAG report is available on the ICAO website[7], and includes scenarios that highlight the potential for substantial CO_2 reductions from innovative aircraft technologies, operations, and fuels, with the assessment of required costs and investments. More details on the LTAG report and its results are provided in the following articles of this special LTAG supplement to ICAO Environmental report 2022.

4 2020 Stocktaking website: https://www.icao.int/Meetings/Stocktaking2020/Pages/default.aspx
5 2021 Stocktaking website: https://www.icao.int/Meetings/Stocktaking2021/Pages/default.aspx
6 ICAO Tracker Tools website: Aviation CO_2 emissions reduction initiatives - Tracker Tool (icao.int)
7 ICAO LTAG report website: https://www.icao.int/environmental-protection/LTAG/Pages/LTAGreport.aspx

LTAG consultative process

As part of the consultative process on LTAG among ICAO Member States and stakeholders, ICAO organized the LTAG Global Aviation Dialogues (GLADs) as a series of five regional events held both in May 2021[8] and March/April 2022[9]. The goals and objective so of these events were to share information and raise awareness on the LTAG process and technical analyses, as well as to allow for the exchange of views and expectation to facilitate further LTAG work and decision-making.

The GLADs supported the well-informed deliberations at the High Level Meeting on LTAG (HLM-LTAG), held in July 2022 (more details on HLM-LTAG are provided in a dedicated article "High-level meeting on the feasibility of a long-term aspirational goal for international aviation CO2 emissions reductions" of this special supplement. The GLADs participants also exchanged views on possible building blocks for LTAG considerations, such as: scientific understanding and context, expected potential contribution of technology, operations and fuels, and the level of LTAG ambition. The participants also discussed on possible means of implementation, expected support to ICAO Member States with action plans, roadmaps, and ways of monitoring progress (more details on GLADs are provided in the a dedicated article "Global Aviation Dialogues (GLADs)" of this special supplement).

Conclusion

Aviation is moving to address its responsibilities on the climate crisis. ICAO is steadily following up on these developments, with the extensive work associated with the feasibility of a long-term global aspirational goal for international aviation. The LTAG deliberations at the ICAO 41st Assembly will be of crucial importance to consolidate the aviation's efforts towards decarbonization.

8 2021 GLADs website: https://www.icao.int/Meetings/2021-ICAO-LTAG-GLADS/Pages/default.aspx
9 2022 GLADs website: https://www.icao.int/Meetings/2022-ICAO-LTAG-GLADS/Pages/default.aspx

CAEP Report on the Feasibility of a Long-Term Aspirational Goal for International Civil Aviation CO_2 Emissions reductions (LTAG)

By Hajime Yoshimura (Japan), Michael Lunter (the Netherlands) and Mohammed Habib (the Kingdom of Saudi Arabia)[1]

Introduction

The 40th Session of the ICAO Assembly in October 2019 requested the Council to explore the feasibility of a long-term global aspirational goal (LTAG) for international aviation for consideration by its 41st Session (Resolution A40-18, paragraph 9). The CAEP LTAG Task Group (LTAG-TG) was established in March 2020 with the agreement of the ICAO Council to provide technical support to the Council in exploring the feasibility of a LTAG.

CAEP LTAG-TG undertook:

- **data gathering** from internal and external sources in a transparent and inclusive manner,
- **development of combined in-sector scenarios** from technology, fuels, and operations that represent a range of readiness and attainability based on the data gathering, and
- **conducted final analysis** of the scenarios to understand those **impacts on CO_2 emissions** and **cost associated with the scenarios** and **economic impacts on aviation growth, noise and air quality**, in all countries especially developing countries and the results was placed **in context of the latest consensus scientific knowledge**.

The final report from CAEP consolidates cumulative efforts of over 280 experts and provides a technical assessment of the feasibility of an LTAG.

Methodology: Overview

Figure 1 illustrates the overall methodology used for the LTAG feasibility study. The LTAG feasibility study started from the Data Gathering process, embracing Aircraft Technology, Operations and Fuels areas, which contributed to each element of the Integrated Scenarios.

On the Economic Modeling and Traffic Forecast, the Fleet Evolution was evaluated, which was fed into the CO_2 emissions modeling. Additionally, the consensus scientific knowledge on climate change formed the basis and context for the output of the analysis.

The detailed results from each subgroup of LTAG-TG will be covered in a separate subsequent articles and will cover:

- CO_2 Emissions Trends;
- Cost and Investment Estimations;
- Additional Analyses results, such as sensitivity analyses, for example;
- Results on Aviation in Context of Scientific Knowledge.

1 Hajime Yoshimura (Japan Civil Aviation Bureau), Chairperson of the Long-Term Aspirational Goal Task Group of the ICAO CAEP, and Michael Lunter (Ministry of Infrastructure and Water Management, the Netherlands) and Mohammed Habib (Delegation of The Kingdom of Saudi Arabia on the Council of ICAO), LTAG-TG Vice-Chairpersons would like to acknowledge the invaluable contribution of the 287 members of the Long-Term Aspirational Goal Task Group.

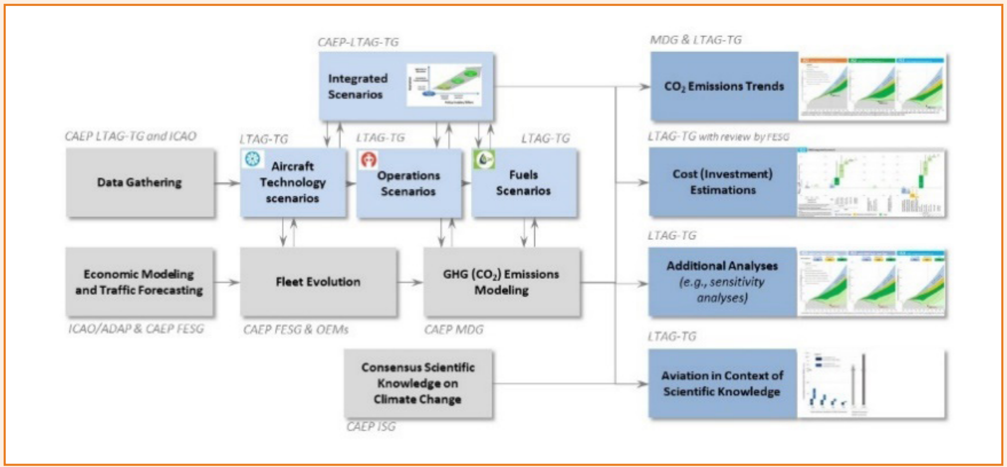


FIGURE 1: Overall Methodology used for the LTAG feasibility study

LTAG integrated scenarios

The LTAG analysis is not aimed at forecasting future emissions trends in aviation but is explicitly a scenario-based analysis. A set of scenarios (Integrated Scenarios) were developed to represent the level of effort and aspiration needed with the degree of readiness and attainability (Figure 2). With the baseline scenario numbered as zero, the Integrated Scenario 1 (IS1) represents the pathway with highest readiness level and attainability but with the lowest aspiration. While Integrated Scenario 3 (IS3) offers the highest aspiration, but requires greater efforts to attain. The Integrated Scenario 2 (IS2) is the middle path between scenarios 1 and 3.

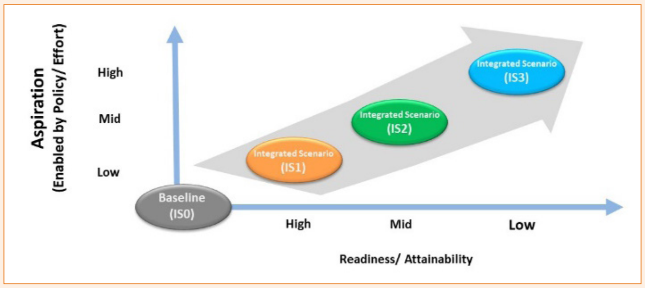


FIGURE 2: Integrated scenarios

Question 1: How could in-sector measures (i.e., technology, operations, and fuels) help reduce CO_2 emissions from international aviation through 2050 and beyond?

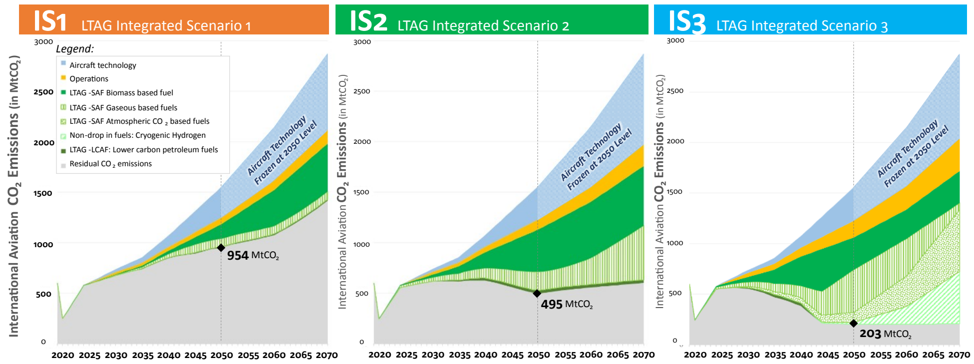
In terms of CO_2 emissions in 2050 taking into account reductions from aircraft technology, operations, and fuels, CO_2 emissions could reach from 950 $MtCO_2$ for IS1, to 200 $MtCO_2$ for IS3, equivalent to a 39–87% reduction from the baseline scenario. In terms of a breakdown, the fuels part is the biggest with 15–55% range, followed by the technology with around a 20% share, and with operations ranging from 4 to 11% (Figure 3).

For your reference, the cumulative residual CO_2 Emissions from 2020 to 2070 are also provided. These are the following points with regard to the high-level observations from the LTAG analysis:

- Scenarios show the potential for substantial CO_2 reduction, however none of them reach zero CO_2 emissions using in-sector measures only.
- There will be residual emissions despite 100% replacement of conventional jet fuel with novel fuels, due to consideration of fuels' life cycle emissions.
- As other aspects of economies reduce their emissions, the life cycle value should drop as well.
- As per the LTAG Terms of Reference, out of sector measures were not considered in the LTAG-TG analysis.

Advanced tube and wing aircraft have a clear potential to improve the fuel and energy efficiency of the international aviation system with some incremental contribution from aircraft with unconventional configurations.

The technology wedge continues to grow after 2050 as these aircraft penetrate the fleet. Hydrogen powered aircraft would exhibit worse energy efficiency, relative to aircraft operating on drop-in fuels, noting that emissions reductions would come from life cycle emissions reductions from the hydrogen.



Metrics	IS1	IS2	IS3
CO_2 Emissions in 2050 after Reductions	**≈950 $MtCO_2$** in 2050 (*160% of 2019 CO_2 emissions*)	**≈500 $MtCO_2$** in 2050 (*80% of 2019 CO_2 emissions*)	**≈200 $MtCO_2$** in 2050 (*35% of 2019 CO_2 emissions*)
Reduction in 2050 from the Baseline	**39% total** through: Technologies - 20%, Operations - 4%, Fuels - 15%	**68% total** through: Technologies - 21%, Operations - 6%, Fuels - 41%)	**87% total** through: Technologies - 21%, Operations - 11%, Fuels - 55%
Cumulative residual Emissions from 2020 to 2070	23 $GtCO_2$ (2020 to 2050) 23 $GtCO_2$ (2051 to 2070)	17 $GtCO_2$ (2020 to 2050) 11 $GtCO_2$ (2051 to 2070)	12 $GtCO_2$ (2020 to 2050) 4 $GtCO_2$ (2051 to 2070)

FIGURE 3: Reductions in CO_2 emissions from international aviation through in-sector measures through 2050 and beyond

The overall traffic growth rate has an important impact on residual CO_2 emissions by 2050 and after.

The analysis shows there are opportunities for operations to reduce CO_2 emissions through improvements in the performance of flights across all phases of flights, including unconventional measures such as formation flying.

Drop-in fuels have the largest impact on residual CO_2 emissions driving overall reductions by 2050, being independent—to some extent—of technology and operations scenarios.

Hydrogen is not expected to have a significant contribution by 2050 (with only 1.9% of energy share in 2050) but may increase in the 2050s and 2060s if technically feasible and commercially viable.

Question 2: How do cumulative aviation emissions compare to requirements to limit the global temperature increase to 1.5°C and 2°C?

Estimated cumulative residual global anthropogenic CO_2 emissions from the start of 2020 to limit global warming to 1.5°C is 400 $GtCO_2$ at 67% probability, i.e. the international aviation share could be around 4.1 to 11.3 % of this total.

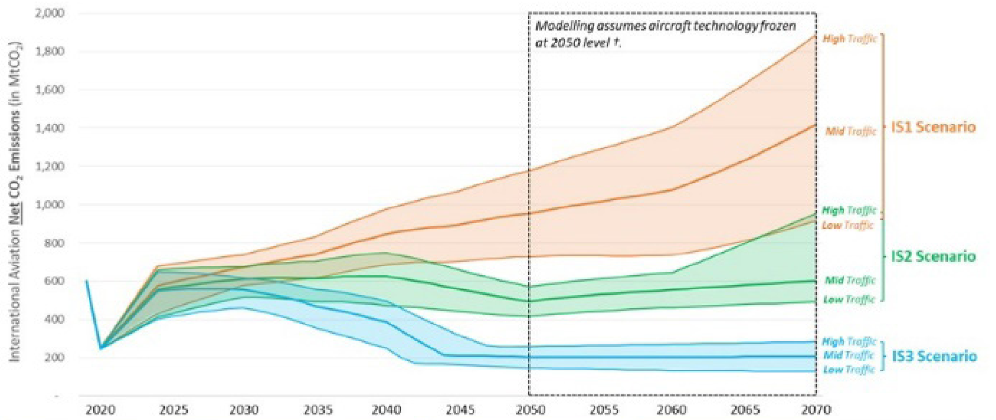
For a warming limit of 2°C, the remaining allowed global carbon emissions are estimated to be 1150 $GtCO_2$ at 67% probability, i.e. the international aviation share could range from 1.4 to 3.9% of this total.

Question 3: What investments are required to support the implementation of the in-sector measures associated with each scenario?

Costs and investments associated with the three scenarios are largely driven by fuels. Incremental costs of fuels (i.e. minimum selling price of SAF compared to conventional jet fuels) further motivates fuel and energy efficiency improvements from aircraft technology and operations. Aircraft technology and operational measures will require investments from governments and industry. More details on placing costs associated with LTAG Integrated Scenarios in context are provided in a dedicated article of this special supplement.

Question 4: What would be the impacts of various future aviation traffic levels?

Figure 4 provides CO_2 emissions in 2050 after the implemented emissions reductions from technology, operations and fuels. After 2050, the uncertainty grows



CO_2 emissions in 2050 after emissions reductions (from tech., ops and fuels)	IS1	IS2	IS3
High (traffic)	1160 $MtCO_2$	590 $MtCO_2$	260 $MtCO_2$
Medium (traffic)	950 $MtCO_2$	495 $MtCO_2$	200 $MtCO_2$
Low (traffic)	730 $MtCO_2$	420 $MtCO_2$	150 $MtCO_2$

FIGURE 4: Impact of Aviation Traffic Forecast

towards 2070, with an increasing range between high, mid and low options within the scenarios. The table at the bottom shows the CO_2 emissions remaining in 2050 following the implementation of the reduction measures.

Question 5: How sensitive are the results to scenario assumptions?

In developing the integrated scenarios, LTAG-TG recognised that there could be multiple combinations of technology, operations and fuels measures to form alternative integrated scenarios. In particular, sensitivity analysis was conducted to examine the impact of lower technology and operations improvements, coupled with high reductions from fuels.

This shows that there are multiple paths that may result in similar levels of emissions. However, in all cases, the contribution from fuels is critical to decouple the growth in international air traffic from its emissions.

Considerations regarding LTAG Options

Based on the results of the LTAG feasibility study, technical options for LTAG metrics were identified. This is not an exhaustive list and other formulations may be considered.

One type of option could use annual levels of emissions:

- The annual level of emissions, for example: 950, 500 or 200 Mt CO_2 in 2050.
- Using a reference year earlier than 2050 may not give the long-term certainty expected to be a key benefit of adopting an LTAG, while using a reference year after 2070 would be subject to increased uncertainty.
- Additional intermediate waypoints in milestone years could layout a trajectory to the emissions profile.

Another option could use cumulative total emissions:

- The cumulative total emissions from the international aviation sector: for example 23, 17 or 12 $GtCO_2$ by 2050.
- This would most closely translate into an atmospheric temperature response.

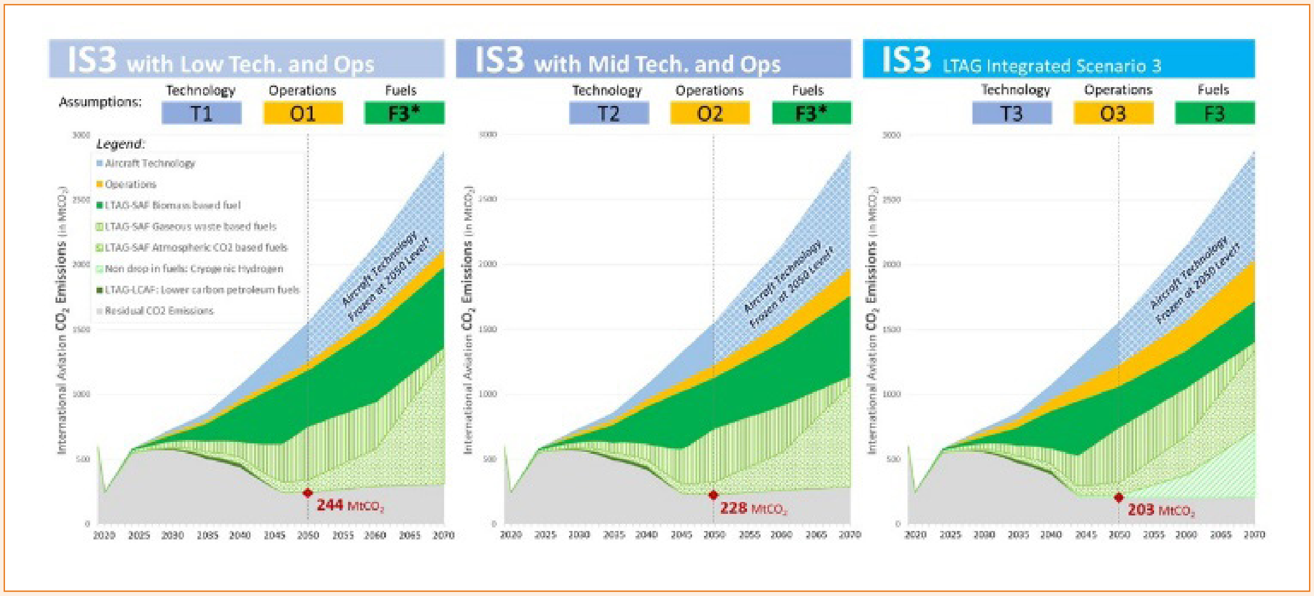


FIGURE 5: Sensitivity analysis of IS3 Scenario demonstrates the importance of fuels

Other impacts

The LTAG analysis also included consideration of the other impacts. Potential impacts on aviation growth were qualitatively considered, finding that an LTAG may increase operating costs and some costs may be passed on to passengers. This impact may be limited, however, and aviation will continue to deliver national, regional and global benefits.

Most significant regional variations are expected in production and uptake of fuels due to, for example, regional availability of feedstocks, renewable energy, and infrastructure.

With regard to the impacts on noise and air quality, in all scenarios, the traffic growth increased total noise and NOx emissions.

However, technology improvements typically reduced noise and emissions alongside fuel burn. Additionally, operational efficiencies may have co-benefits for noise but did not impact air quality. Another observation is that LTAG SAF and cryogenic hydrogen have co-benefits, for local air quality and contrail formation with no impact on noise.

Roadmaps for LTAG Implementation

On roadmaps, CAEP considered technical aspects of implementation without prejudging any future decisions. For monitoring of progress, State Action Plans may be used for States to report progress towards a goal, without duplicating existing processes.

If a goal were adopted, CAEP could conduct future work on possible metrics, reporting mechanisms, etc.

ICAO may need to review any goal to ensure it remains appropriate. For this purpose, a triennial review process could be considered similar to the CORSIA Periodic Review, for example. Finally, capacity building and assistance may be needed, for example:

- Workshops on measures, including understanding costs;
- Assistance on monitoring and measuring CO_2 emissions;
- An overarching training programme similar to ACT-CORSIA.

LTAG Assessment from a Technology Perspective

By Dimitri Mavris (USA), Wendy Bailey (Canada)[1]

Introduction

At the 40th Session of ICAO Assembly in Montreal, Canada, in 2019, the ICAO Council was asked to explore the feasibility of a global long-term aspirational goal (LTAG) for the reduction of carbon dioxide emissions from international aviation. The ICAO Committee on Aviation Environmental Protection established the LTAG Task Group in 2020 for this purpose. The Technology Subgroup was formed under the Task Group to assess the feasibility, readiness and attainability of technology improvements that could contribute to in-sector CO_2 reductions, and to quantify the reductions where possible.

Specifically, the Technology Subgroup assessed the potential of evolutionary technologies for airframes and propulsion systems, as well as revolutionary technologies such as non-drop-in energy sources and new aircraft configurations up to 2050.

The methodology introduced in the 2019 Independent Expert Integrated Review (IEIR) report[2] was utilized as a starting point for the Technology Subgroup's work, although there were differences in scope and timeline. The IEIR methodology focused on the interdependencies between noise, emissions, and CO_2, whereas the LTAG methodology focused on carbon dioxide emissions only. While the IEIR projections went to 2037, the Technology Subgroup extended projections to 2050 based on new technologies assessed by the Airframe, Propulsion and Advanced Concepts and Energy Storage ad hoc groups. However, to give the 2050 vehicles enough time to enter the market and have a measurable impact, the fleet assessment continued until 2070.

From a high-level perspective, the LTAG Technology Subgroup methodology involved four main steps: creation of Technology Representative Aircraft for several classes of aircraft, assessment of advanced tube and wing (ATW), assessment of advanced concept aircraft (ACA), and generation of information for the fleet-wide modeling and cost assessment.

Technology Scenarios

The Technology Subgroup identified three different technology scenarios based on technology advances for the aircraft and the infrastructure changes needed. In the first Technology Scenario (T1), only ATW aircraft would be available, and no infrastructural changes are required. In this scenario, conventional aircraft continue to improve, suggesting incremental changes in CO_2 emissions. Revolutionary concepts with the potential of introducing step changes are included under the next two scenarios. Under the second scenario (T2), in addition to introducing ATWs, unconventional airframe/propulsion concept aircraft that require limited infrastructural changes also become available. Concepts such as the truss-braced wing, boxed-wing, hybrid/blended wing bodies and unducted fans could be grouped here, as well as mildly hybrid electric aircraft. The option of non-drop-in fuels (hydrogen and battery electric) appears in the third (most ambitious) scenario (T3), as these concepts require major infrastructural changes to operate.

1 The co-Leads Dimitri Mavris (Georgia Institute of Technology, USA) and Wendy Bailey (Transport Canada) would like to acknowledge the invaluable contribution of the 102 members of the Long-Term Aspirational Goal Task Group's Technology Subgroup.

2 "Independent Expert Integrated Technology Goals Assessment and Review for Engines and Aircraft", ICAO Doc 10127, 2019. https://www.icao.int/environmental-protection/Pages/ClimateChange_TechGoals.aspx

Technology Reference Aircraft (TRA)

Using four conventional technology reference aircraft for a Business Jet (BJ), Regional Jet (RJ), Narrow Body (NB) and Wide Body (WB), the Technology Subgroup found it necessary to add a turboprop reference aircraft to serve as a foundation for studying alternative energy sources. With guidance from the International Coordinating Council of Aerospace Industries Association (ICCAIA), notional aircraft were selected for each category. These reference aircraft represent the state-of-the-art airplanes in production in 2018. The major aircraft classes, their seat capacities, and their notional reference aircraft are listed in Table 1.

Aircraft Class	Number of Seats	Notional Aircraft
Business Jet	≤20	G650ER
Turboprop	20–85	DHC Dash 8-400
Regional Jet	20–100	E190E2
Narrow Body	101–210	A320neo
Wide Body	>210	A350-900

TABLE 1: Technology Reference Aircraft by Aircraft Class

Assessment Processes

To frame the assessment of the ATWs and the ACAs for this study, the metric of interest was defined as energy intensity (change in energy consumption per unit of transport (MJ/ATK)) because it is independent of the fuel being used. This allows an easy way to compare both conventional and unconventional concepts regardless of their energy source. The uncertainties around potential performance improvements of ATWs and ACAs were captured through a three-point confidence estimation. At each timeframe, the performance improvements were estimated through three technology progress levels: lower, medium and higher.

The modeling approach for the ATW assessment used by the Technology Subgroup assessed and quantified the performance improvement of ATW for the 2030, 2040 and 2050 timeframes. Once the TRAs were selected, aircraft models were generated using the Environmental Design Space (EDS)[3] and used as the baselines to which future technologies (propulsion, system, structures/materials and aerodynamic technologies) were applied. The impacts of these technologies were then identified for the milestone timeframes for each aircraft class at three technology progress levels (lower/medium/higher) and subsequently, through the modelling and simulation tool, for each vehicle class. The vehicle level benefits were quantified with respect to the corresponding 2018 TRA.

The ACA assessment for revolutionary technologies however, required a methodology that was based on previous credible studies because the inherent uncertainties related to ACA development did not justify the use of overly precise models. The ACA assessment began with a comprehensive search of all possible ACAs in literature through published authoritative studies and information from ICAO Stocktaking Events. Concepts were qualitatively evaluated based on potential benefits to carbon emissions reductions, and technical and non-technical barriers were identified. Subject matter experts evaluated readiness, attainability, and potential benefits of these aircraft concepts. Unlike ATWs, ACAs suggest step changes in performance. The quantification of these step changes is primarily based on the publicly available authoritative studies from research organizations. The vehicle-level benefits were estimated compared to the same-year ATW at lower/medium/higher technology progress levels. Because the ACAs were considered to be at early stages of their design processes, the earliest entry into service year was projected as 2035.

Results

The assessment processes explained previously were performed for each of the five aircraft classes. All the classes exhibited similar trends and progress, with slightly different magnitudes of improvement over time. Table 2 shows the energy intensity changes for the medium progress level only. The changes in the energy intensities of future aircraft were calculated relative to TRAs. The TRAs are represented by 100%, and the energy intensity changes of ATWs and ACAs are either above or below 100%. For all ATWs, continuous but incremental improvement in energy intensity is expected. The earliest projected entry-into-service (EIS) year for ACAs is 2035. For WB, the EISs

3 Kirby, M. and Mavris, D., "The Environmental Design Space," 26th International Congress of the Aeronautical Sciences, Anchorage, Alaska, 14–19 September 2008.

Aircraft Class	2018 TRA	Tech Scenario	Advanced Tube and Wing			Tech Scenario	Advanced Concept Aircraft		
			2030	2040	2050		2035	2040	2050
Turboprop	100%	T1	88.0%	82.2%	79.2%	T2	76.5%	-	71.3%
						T3	85.1%	-	79.2%
Regional Jet	100%	T1	93.5%	85.9%	82.2%	T2	80.6%	-	73.9%
						T3	103.0%	-	94.5%
Narrow Body	100%	T1	89.2%	81.1%	75.8%	T2	76.6%	-	68.2%
						T3	97.8%	-	87.2%
Wide Body	100%	T1	90.6%	78.0%	72.2%	T2	-	70.2%	65.0%
						T3	-	-	72.2%
Business Jet	100%	T1	90.5%	84.8%	80.1%	T2	83.2%	-	76.1%
						T3	-	89.0%	84.1%

TABLE 2: Energy Intensity Changes Relative to 2018 TRAs for All Classes (Medium Progress)

for T2 and T3 aircraft are later than other classes. It was decided that the NB or RJ would serve as a pathfinder for such technologies and then these technologies would be applied to WB. For BJ T3 aircraft, however, the EIS year has a five-year lag because flex-fuel concept is at an earlier stage in its development. Comparing the ATW values with ACA values, it can be seen that ACAs suggest step changes in performance. Similar to ATWs, ACAs are also expected to make steady improvements after they enter the market. While T2 aircraft will most likely have less energy intensity to perform the same missions, T3 aircraft may require more energy and may not fly as far as the TRA. This is due to the potential increase in aircraft size and/or weight. This increase may not be considered as a drawback if it allows a significant carbon emissions reduction through the use of cleaner energy.

Key Findings

Potential improvements for ATWs in smaller categories such as TP, BJ and RJ are lower than those of larger aircraft (NB and WB). This is due to lower benefits achievable via technology infusions and to the shorter mission ranges. It was found that CO_2 reductions may be feasible in the ranges of approximately 30 to 40% in 2050, relative to 2019.

ACAs were considered to be possible by 2035 and onward with near-term applications for smaller aircraft. Larger aircraft will take more time to develop but will have a greater impact on carbon reduction. ACA alternate airframes and propulsion concepts, with or without alternative energy, could happen by 2035 and may yield a 10–15% energy intensity reduction compared to the same year ATWs. It is important to note that alternative energy solutions are highly dependent on the availability of energy infrastructure. Both electrified aircraft propulsion and hydrogen-fueled aircraft are examples of evolutionary and revolutionary technologies that can contribute to CO_2 reductions. However, the carbon reduction possible from electrification is highly dependent on the carbon intensity of the local electrical grid, while the carbon reductions from hydrogen will be highly dependent on the carbon intensity of the production method used for hydrogen.

For long term CO_2 reduction goals to be achieved, the Technology Subgroup's analysis demonstrates that action needs to be taken as soon as possible to accelerate reductions, and that large-scale demonstrations and investments in technology will be required. In the case of non-drop-in energy, substantial changes to the energy infrastructure available to aviation is also required.

LTAG Assessment from a Operations Perspective

By David Batchelor(EU) and Muayyed Al Teneiji (UAE)[1]

Introduction

This article highlights the results from the LTAG-TG Operations sub group, which was tasked to identify and evaluate existing, foreseen, and innovative in-sector measures in the area of operations that could potentially contribute to reducing CO_2 emissions from international civil aviation, and to develop and analyse in-sector scenarios of operations that represent a range of readiness and attainability.

LTAG-TG OPS SG Methodology

The methodology established an overall approach based on three phases: data collection, data analysis, and outputs to be delivered subsequently to feed the scenarios development. In addition to these three phases, the sub-group undertook additional work to develop its input to the Sample Problem. This took place after completing the data collection phase and before embarking on the data analysis.

Phase 1 – Data collection: A literature review of the information and data sources on current, foreseen and innovative measures to reduce aviation in-sector CO_2 emissions. Data sources reviewed included both internal ICAO documentation and external ICAO documentation (i.e., ICAO/ENV stocktaking questionnaires, library of documents, videos prepared by the Secretariat, additional information provided to the sub-groups by its Members). Gaps were identified and the required information was found to fill them. All measures identified during the literature review were listed in a master excel spreadsheet, and were then subject to a thorough review to ensure that measures were categorized correctly and that no measures were duplicated.

Many of the measures identified during the data collection phase had been captured in the work undertaken in the CAEP/11 WG2 environmental assessment of the Global Air Navigation Plan – Aviation System Block Upgrades (GANP-ASBU), which had assessed ASBU blocks 0 and 1 in 2019. This data had included operational improvements (OI) for the years 2028, 2038 and 2050 for Horizontal Flight Efficiency (HFE), and CAEP was also considering Vertical Flight Efficiency during the time that feasibility report was being prepared. This previous analysis, which served as the baseline, had created 53 rule of thumb fuel saving benefits to be expected from the generic implementations of 31 operational measures and estimated the expected fuel and CO_2 savings based on the planned implementation plans of ICAO States between 2015 and 2025. Table 1 below lists the 31 operational measures already assessed by CAEP.

✓ Remote Tower ✓ Enhanced MET information ✓ Flexible use of airspace ✓ Flex routes ✓ Free Route Airspace ✓ User Preferred Routings ✓ Space-based ADS-B surveillance ✓ Datalink En-route ✓ Datalink Departure Clearance ✓ FF-ICE Planning Service ✓ Continuous Descent Operations ✓ Continuous Climb Operations ✓ PBN STARs ✓ PBN SIDs ✓ Flight-based Interval management ✓ Ground-based Interval Management ✓ ATFM	✓ Short-Term ATFCM Measures ✓ Advanced FUA (ATFM / Airspace Management) ✓ RNP-AR approaches ✓ Airport – Collaborative Decision Making ✓ Wake Vortex Re-categorization ✓ Time-Based Separation ✓ Arrival Manager ✓ Extended Arrival Manager ✓ Terminal Flight Data Manager ✓ Advanced – Surface Movement Guidance and Control System ✓ PBN approaches (Radius to Fix) ✓ PBN to xLS approaches ✓ GBAS CAT I/II/III ✓ Multi-segment approaches / glideslopes

TABLE 1: List of Operational Measures assessed by CAEP

1 The co-Leads David Batchelor (SESAR 3 Joint Undertaking, EU) and Muayyed Abdulla Al Teneiji (UAE General Civil Aviation Authority) would like to acknowledge the invaluable contribution of the 79 members of the Long-Term Aspirational Goal Task Group's Operations Subgroup.

As a result of its data collection exercise, the OPS sub-group identified a number of operational measures additional to those assessed by CAEP. These additional measures are listed in the Table 2 below.

✓ Dynamic Sectorization ✓ Reduced Extra Fuel On-board ✓ Best Practices in Operations Minimizing Weight ✓ In-Trail Procedure (ITP) ✓ Airline Fuel Management System ✓ Optimized Runway Delivery Support tool and Reduced Pair-Wise Weather Dependent Separation between Arrivals ✓ Electrical Tug Detachable Aircraft Towing Equipment	✓ Support for Optimized Separation Delivery and Reduced Pair-Wise Weather Dependent Separation between Departures ✓ Formation Flight ✓ Geometric Altimetry and RVSM Phase 2 ✓ Global Air Traffic Flow Management ✓ Satellite Based VHF for oceanic/remote areas ✓ APU Shut Down ✓ MAINTENANCE - difference between maintenance and modification to aircraft, technology related

TABLE 2: List of Operational Measures considered by CAEP

Phase 2 – Data Analysis: For the data analysis, the same methodology as that was used previously by ICAO CAEP in its assessments of individual operational measures was utilized. This involved the development of so-called "Rules of Thumb" for each individual operational measure not already included in the CAEP Global Air Navigation Plan – Aviation System Block Upgrades (GANP-ASBU) assessment and conduct a detailed analysis of each of these measures. The objective of the "Rule of Thumb" for each measure was to identify its potential contribution to CO_2 emissions reductions.

In addition to determining the potential contributions to CO_2 emissions reductions, the sub group also made estimates of the likely costs associated with implementation of these measures. The summary information is included in the Attachment A of the ICAO LTAG Report Appendix M4[2].

For the operational measures already assessed by CAEP, the LTAG-TG OPS sub-group updated the baseline to take into account the following sources of inefficiency, and operational measures to address these sources of inefficiency, the final three of which were new and additional to previous work performed:

- **Horizontal flight inefficiency** - the comparison between the length of a trajectory and the shortest distance between its endpoints;
- **Vertical flight inefficiency** - the flight can't reach its optimum cruising level during the flight nor the flight is kept at a suboptimal flight level during the climb or descent phase;
- **Ground operations inefficiency** - typically infrastructure-related measures that can reduce emissions at taxiway or the gate, i.e. such as semi-autonomous tow-truck (taxibot);
- **Innovative flight inefficiency** - achieved through implementation of new operational measures in the medium term, i.e. notionally from 2038, such as formation flying;
- **Advanced flight inefficiency** - results from the introduction of advanced concept aircraft into the fleet, such as blended wing body (BWB) aircraft. It is possible that these aircraft will have different performance characteristics from conventional aircraft, e.g. in terms of speed, altitude etc.

Phase 3 – Outputs for the LTAG-TG Scenario Development sub-group (SDSG): After development of "Rules of Thumb" for each individual additional operational measure and update of the baseline which was previously established in CAEP, a high-level description of the operations scenarios was prepared. Based on the scenarios fuel savings, readiness level and associated cost related to each individual operational measure were estimated. These outputs were feed into the integrated scenarios developed by the Scenarios Development sub-group (SDSG).

2 https://www.icao.int/environmental-protection/LTAG/Documents/ICAO_LTAG_Report_AppendixM4.pdf

LTAG Operations Scenario Descriptions

The LTAG-TG OPS sub-group then prepared a high-level description of the operations scenarios to feed into the integrated scenarios developed by the SDSG. Three scenarios were proposed — conservative, medium, and aggressive. These scenarios were constructed according to different rates at which the five above categories of measures were assumed to be implemented. The three scenarios are summarised here and in Figure 1 below:

Operations Scenario 1 (O1)

O1 represents the low or conservative end of the range of potential CO_2 emissions reductions from operations. In this scenario, there is a low rate of ASBU element deployment to optimise Horizontal Flight Efficiency (HFE), Vertical Flight Efficiency (VFE) and Ground Flight Efficiency (GFE).

Operations Scenario 2 (O2)

O2 represents the middle of the range of potential CO_2 emissions reductions from operations. In this scenario, there is a medium rate of ASBU element deployment to optimise HFE, VFE and GFE, and low rate of operational measure deployment to optimise IFE and AFE.

Operations Scenario 3 (O3)

O3 represents the high or aggressive end of the range of potential CO_2 emissions reductions from operations. In this scenario, there is a high rate of ASBU element deployment to optimise HFE, VFE and GFE, and medium rate of operational measure deployment to optimise IFE and AFE.

Results and Key Findings

Based on the assumptions on rate and extent of implementation of operational measures for O1, O2 and O3 scenarios fuel efficiency improvements from operational measures were estimated. Figure 2 below shows the average fuel efficiency improvements from operational measures across 2035, 2050 and 2070.

	Operations Scenario 1 (O1)	Operations Scenario 2 (O2)	Operations Scenario 3 (O3)
2035	3%	4.5%	7%
2050	5%	8%	13%
2070	6%	11%	16%

FIGURE 2: Average Fuel efficiency improvements from operational measures across LTAG-TG integrated scenarios

Analysis conducted by LTAG OPS sub group showed that there would be regional variances in implementation of operational measures however; there are opportunities for operations to reduce CO_2 emissions through improvements in the performance of flights across all phases, including unconventional measures such as formation flying.

	LTAG-TG Scenarios		
Baseline	O1 Scenario Low CO_2 reduction from Operations	O2 Scenario Mid CO_2 reduction from Operations	O3 Scenario High CO_2 reduction from Operations
No emissions reductions from operations after 2025 (implementation of ASBU blocks 0 and 1)	Conservative assumptions about rate and extent of implementation of operational measures, based on reduced/slower investment in ground and airborne systems and technologies. Low rate of ASBU element deployment to optimize HFE, VFE and GFE.	Emissions reductions and operational efficiencies in line with existing "Rules of Thumb" developed by WG2 and new "Rules of Thumb" developed by LTAG OPS for new measures. Medium rate of ASBU element deployment to optimize HFE, VFE and GFE. Low rate of operational measure deployment to optimize IFE and AFE.	Aggressive assumptions about rate and extent of implementation of operational measures, based on higher/accelerated investment in ground and airborne systems and technologies. High rate of ASBU element deployment to optimize HFE, VFE and GFE. Medium rate of operational measure deployment to optimize IFE and AFE.

FIGURE 1: Summary of LTAG-TG operations scenarios

LTAG Assessment from a Fuels Perspective

By James Hileman (USA) and Matteo Prussi (Italy)[1]

Introduction

This article describes this work done by the LTAG-TG Fuels sub group, which was tasked to develop emissions reductions scenarios from the use of different types of fuels up to 2070.

For that, the Fuels sub-group gathered and analysed data from various internal and external sources — in a constant relation with the most relevant stakeholders — which were then used to support the definition of fuel classifications, methodology development, and assessments of readiness and attainability. Based on these definitions, the expert group developed projections of fuel volumes and CO_2 emission reductions for three scenarios with increasing ambition, which represent varying levels of introduction of both drop-in and non-drop-in fuels that could reduce the life cycle GHG emissions from aviation. All the work is described in detail in Appendix M5 of the LTAG report.[2]

Fuel classification

The assessment considered three high-level fuel categories, as follows:

- Sustainable aviation fuels (LTAG-SAF): drop-in fuels produced from renewable or waste resources;
- Lower carbon aviation fuels (LTAG-LCAF): drop-in fuels produced from petroleum resources, which demonstrates a well-to-wake carbon intensity of <80.1 gCO_2e/MJ (i.e. >10% reduction in life cycle emissions vis-à-vis conventional jet fuel); and,
- Non-drop-in fuels: fuels that require changes to existing and legacy airframes and fueling infrastructure (i.e. electricity and cryogenic H_2). They are not compatible with current aircraft and engine architectures, and have unique safety and performance considerations.

Various types of fuels were included in these three categories, depending on the carbon source in the fuel feedstock; these are described in Table 1.

	Fuel Category	Fuel Name	Carbon source in fuel feedstock
Drop-in fuels	LTAG - Sustainable Aviation Fuels (LTAG-SAF)	Biomass-based fuel	Primary biomass products and co-products
		Solid/liquid waste-based fuels	By-products, residues, and wastes
		Gaseous waste-based fuels	Waste CO/CO_2
		Atmospheric CO_2-based fuels	Atmospheric CO_2
	LTAG - Lower Carbon Aviation Fuels (LTAG-LCAF)	Lower carbon petroleum fuels	Petroleum
Non drop-in fuels	**Fuel Category**	**Fuel Name**	**Carbon source in fuel feedstock**
	Non drop-in fuels	Electricity	Not applicable
		Liquefied gas aviation fuels (ASKT)	Petroleum gas, "fat" natural gas, flare gas, and propane-butane gases
		Cryogenic hydrogen	Natural gas, by-products, non-carbon sources

TABLE 1: Fuel categorization

1 The co-Leads James Hileman (Federal Aviation Administration, USA) and Matteo Prussi (Politecnico di Torino, Italy) would like to acknowledge the invaluable contribution of the 120 members of the Long-Term Aspirational Goal Task Group's Fuels Subgroup.

2 LTAG Report, Appendix M5, Fuels: https://www.icao.int/environmental-protection/LTAG/Documents/ICAO_LTAG_Report_AppendixM5.pdf

Description of Fuels scenarios

The Fuels sub group developed a high-level methodology to define three fuel deployment scenarios (F1/F2/F3), to reflect low/mid/high potential levels of emissions reductions, which also represent different levels of readiness and attainability. These fuel deployment scenarios, which are described in Table 2, were developed to be aligned with the corresponding scenarios developed by the Technology and Operations sub groups. For non drop-in fuel, the main input of F1/F2 and F3 were the assessments performed by the TECH group, in terms of technologies penetration. For more details please refer to Appendix M3 of the LTAG report.[3]

Fuel production analysis

With the defined scenarios, potential fuel volumes and associated emissions reductions were developed for each fuel category. In some of the Scenarios, the combined projected technical production potential for LTAG-SAF and LTAG-LCAF exceeded total expected aviation fuel demand. In order to meet the expected total fuel demand, the volumes of fuels was constrained, and fuel categories prioritised:

- For F1, the scenario prioritization emphasized low cost GHG reduction, and fuels were ordered by minimum selling price (MSP).
- For F2, selection prioritized cost effective GHG reduction, using marginal abatement cost, expressed in \$/kg CO_2reduced.
- For F3, the emphasis was on maximizing GHG reductions, and the fuel LCA values were used as ordering criterion: the lower the LCA value the higher the prioritization.

Fuels were prioritised according to the above mentioned criteria, until reaching the expected aviation fuel demand or when all projected fuel volumes were exhausted, whichever occurs first. For the latter case, remaining expected aviation fuel demand was met with conventional jet fuel use.

The figure 1 shows the fuel use projections for LTAG-LCAF, LTAG-SAF, cryogenic H_2 (LH2), and conventional jet fuel, based on mid traffic forecasts for each of the F1, F2 and F3 fuel deployment scenarios.

	LTAG-TG Scenarios		
	Fuel Scenario 1 (F1) Low GHG reduction from Fuels (LTAG-SAF and LTAG-LCAF)	**Fuel Scenario 2 (F2)** Mid GHG reduction from Fuels (LTAG-SAF and LTAG-LCAF)	**Fuel Scenario 3 (F3)** High GHG reduction from Fuels (LTAG-SAF, LTAG-LCAF and non-drop-in fuels)
Scenario Development	**Emphasize low cost GHG reduction → select fuels by Minimum Selling Price**	**Prioritize cost effective GHG reduction → select fuels by Marginal Abatement Cost**	**Maximize CO_2 reduction → select fuels by Lifecycle Value**
Approved Fuel Use	ASTM Intl approves use of alternative jet fuels at **blend levels above 50%.**	ASTM Intl approve **use of 100% Synthesized Jet Fuel in existing aircraft and engines** without any modification.	
Ground Transportation and Electrification	**Ground transportation and aviation have level playing field** with respect to alternative fuel use.	**Electrification of ground transportation** leads to increased availability of SAF.	**Economy-wide deep decarbonisation.** Extensive electrification of ground transportation and widespread availability of renewable energy.
Incentives	**Low incentives** for LTAG-SAF/LTAG-LCAF production.	**Increased incentives** lead to **reduced LTAG-SAF/LTAG-LCAF fuel cost** for users.	**Large incentives lead to widespread use** of low GHG fuels for aviation.
Fuel Availability	Using waste gases (CO/CO_2) and variety of feedstocks (e.g., oilseed cover crops) for LTAG-SAF.	**Widespread use of waste gases** and increased feedstock availability for LTAG-SAF. **SAF production exceeds jet fuel demand**	**Widespread use of atmospheric CO_2 for LTAG-SAF** and maximum LTAG-SAF feedstock availability. **SAF production exceeds jet fuel demand**
			Sufficient H_2 exists to enable use of cryogenic H_2 fuel in aircraft. Infrastructure developed to enable use of non-drop-in fuels at airports around globe.

TABLE 2: LTAG Fuels scenario descriptions

3 LTAG Report, Appendix M3, Technology: https://www.icao.int/environmental-protection/LTAG/Documents/ICAO_LTAG_Report_AppendixM3.pdf

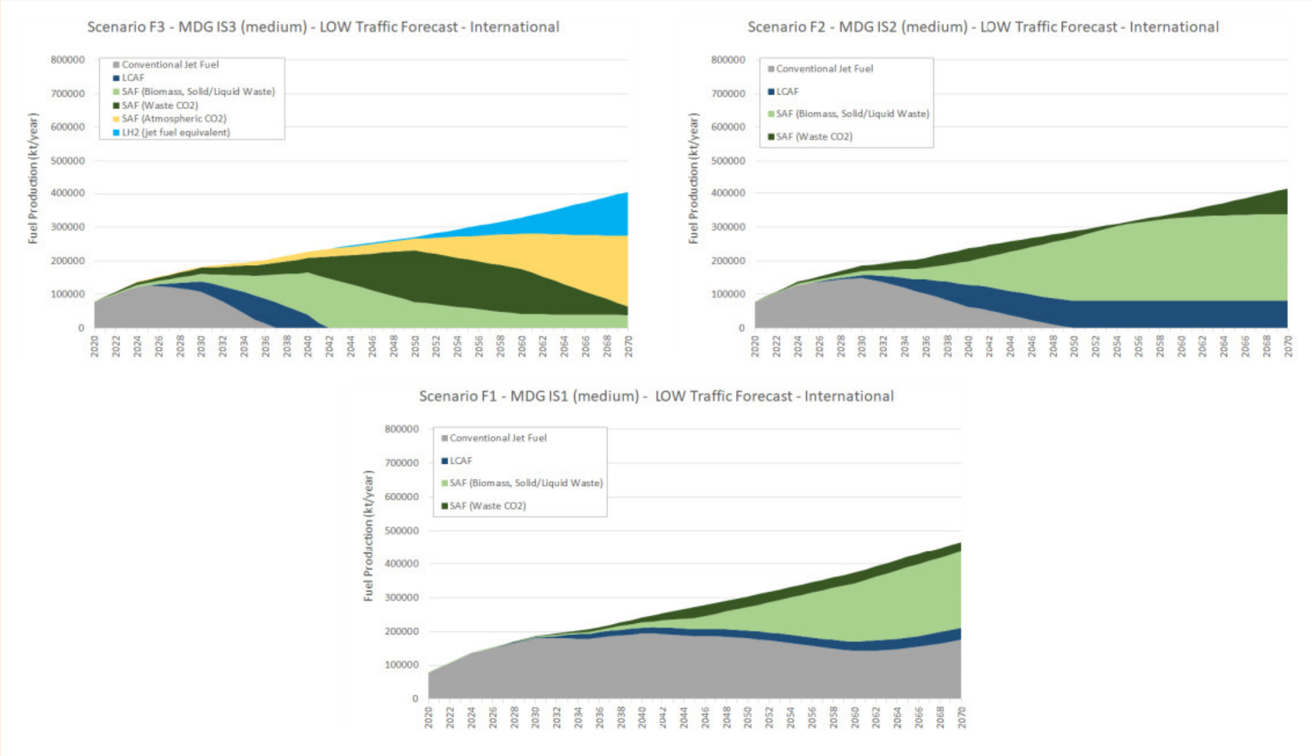


FIGURE 1: Fuel use projections for F1, F2 and F3 based on mid traffic forecasts

Emissions reduction analysis

Based on the fuel production projections for the F1, F2 and F3 fuel deployment scenarios, and the calculated life cycle assessment (LCA) values for each of the fuel categories, the potential GreenHouse Gases (GHG) saving was evaluated. This value was used to determine an overall Emissions Reductions Factor (ERF) for each of the fuel deployment scenarios across 2035, 2050, and 2070, as reflected in Table 4 below. The ERF expresses the perceptual reduction in the GHG emissions, compared to baseline constituted by the conventional fuel; this reflects the effects the use the LTAG-SAF, LTAG-LCAF, and non-drop in fuels, in accordance with projected fuel volumes and aviation fuel demand.

Key findings

The analysis carried out shows that the technical potential for the LTAG-SAF may exceed aviation demand for the F2 and F3 scenario. The benefit, in terms of GHG savings, potentially associated with the use of LTAG-SAF, LTAG-LCAF and non drop-in fuels range from 20% (F1) to 81% (F3) in 2050, and could reach the value of 90%, in 2070 (F3).

	F1	F2	F3
2035	5%	20%	37%
2050	20%	56%	81%
2070	28%	66%	88%

TABLE 4: Emissions Reduction Factors for the fuel mix under F1, F2 and F3.

Costs and Investments Associated with Long-term Aspirational Goal Integrated Scenarios

By Philippe A. Bonnefoy (USA)[1]

Introduction

Each long-term aspirational goal (LTAG) Integrated Scenario (IS) is defined by a combination of sub-scenarios for aircraft technologies, operations improvements, and use of fuels with lower life cycle emissions values that result in an overall emissions reduction by 2050 and beyond. The implementation of these aircraft technology, operations and fuels measures will require investments and result in costs to stakeholders involved in the operation of international aviation.

The LTAG Task Group (LTAG-TG) estimated costs and investments associated with each LTAG Integrated Scenario. While results are provided at the global international aviation level, CAEP also considered regional breakdown of costs and investments when data was available. A separate article of this supplement also provides broader information on placing costs associated with LTAG Integrated Scenarios in context.

Approach and methodologies

Costs and Investments Estimation Approach

Historically, CAEP conducted some cost analyses as part of aircraft technology standard setting processes and separate analyses on costs associated with market-based measures. This LTAG-TG study is the first integrated and comprehensive costs and investments assessment across aircraft technology, operations, and fuels measures.

The objective of the LTAG-TG cost and investment assessment was not to estimate the total operating costs or investments required to run the international aviation system through 2050. Using a *scenario minus baseline* approach, the costs and investments associated with aircraft technology, operations, and fuels measures were isolated for each LTAG Integrated Scenario to the extent possible quantified. The analysis results in incremental costs and investments against a "baseline" scenario defined as LTAG Integrated Scenario 0 (see LTAG scenario article for details).

Scope of cost (investment) estimations

The costs and investments associated with LTAG-TG Scenarios are characterized and driven by:

- **LTAG-TG Integrated Scenarios and measures:** Costs and investments are driven by the portfolio of technology, operations, and fuels measures. Figure 1 shows the scope of the cost elements considered by the LTAG-TG, including the costs and investments that were quantified and those that were acknowledged as potentially relevant and assessed qualitatively.
- **Stakeholders:** As shown in Figure 1, costs and investments span multiple stakeholders, including ICAO Member States (i.e., governments), suppliers and manufacturers (i.e., original equipment manufacturer OEMs, fuel suppliers), and operators (i.e., airports, ANSPs and airlines).

1 The Lead Philippe A. Bonnefoy (BlueSky Consulting, USA) would like to acknowledge the invaluable contribution of the 40 members of the Long-Term Aspirational Goal Task Group's Cost Subgroup.

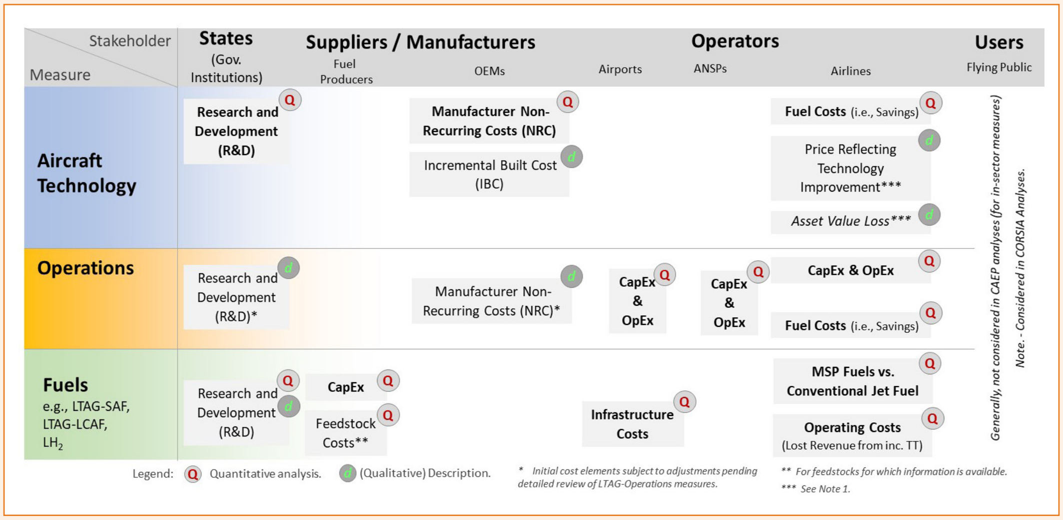


FIGURE 1: Costs and investments elements considered by the LTAG-TG

- **Aviation Sector Scope:** Given ICAO's remit, the LTAG-TG cost analysis focused on international aviation. It is therefore not a global analysis that would include domestic aviation.
- **Temporal dimension:** The cost estimation analysis captures when costs would be incurred, or investments required to deliver the associated measures. Costs and investments estimates were limited to 2020–2050-time horizon given the level of uncertainty in units costs or prices beyond 2050.
- **Geographical distribution:** Given that the LTAG would be a global goal for international aviation, costs and investments were estimated for the entire international aviation sector. When data was available, CAEP also estimated regional level costs and investments.

Aircraft Technology Costs and Investments:

Future aircraft technology developments as captured in the T1, T2 and T3 scenarios depicted in the LTAG-TG Technology section, are expected to require investments from OEMs in the form of:

- Non-Recurring Costs (NRC) which capture the fixed costs associated with developing the technology improvements that deliver fuel and CO_2 emissions reductions. It does not include additional production costs e.g., material, labour, or other recurring costs, and
- Research and Development (R&D) support from States (i.e., governments) to aerospace research institutions towards the development of technologies and commercial aircraft.

The LTAG-TG developed a model to generate bottom-up estimates of aircraft manufacturer non-recurring costs and research and development support from governments. The model uses aircraft fleet entry scenarios aligned with the LTAG Technology scenarios. Based on these scenarios, for each potential future aircraft program/family, a non-recurring cost was estimated. This non-recurring cost depends on the characteristic of the aircraft program/family, such as derivative aircraft, conventional configuration (e.g., advanced tube and wing ATWs) or unconventional drop-in powered aircraft or hydrogen powered aircraft. Forward looking non-recurring cost estimates also include escalation factors that reflect the continuously increasing aircraft development costs resulting from increasing aircraft system complexity, certification, etc. which were calibrated based on historical data. The temporal distribution of the non-recurring costs was also modelled and determined by the entry into service of the first aircraft type in the family. Costs associated with developing potential subsequent variants are also included based on a stochastic approach.

Fuel costs or savings resulting from the operations of aircraft types exhibiting the technology improvement associated with a given LTAG-TG aircraft technology scenario were also estimated.

Operations Improvements Estimations

The LTAG-TG used a bottom-up approach for estimating costs and investments associated with operational measures underlying each LTAG-TG Integrated Scenario. This analysis focused on operational measures that would be implemented primarily for fuel burn and CO_2 emissions reductions reasons.

The LTAG-TG also considered large ATM modernization programs that will also require investments but those are generally motivated by capacity increase, congestion reductions, safety, airspace integration, etc. and less driven by CO_2 emissions reductions. These ATM modernization programs were considered by CAEP but are not included in the integrated scenario specific results.

Fuels Costs and Investments Estimations

The capital investments associated with scaling the production of LTAG-Sustainable Aviation Fuels (SAF), Lower Carbon Aviation Fuel (LCAF) and developing cryogenic hydrogen under IS3 were assessed. The LTAG-TG also estimated the infrastructure costs of developing hydrogen distribution networks from production facility to airport (aircraft) under LTAG-TG Integrated Scenario 3. Finally, costs to airlines in the form of incremental fuels costs i.e., minimum selling price of fuels vs. conventional jet fuel resulting from using LTAG-SAF, LTAG-LCAF or hydrogen vs. conventional jet fuel were estimated through 2050. A separate article on placing costs associated with LTAG Integrated Scenarios in context also provides details on unit fuel costs in context of historical jet fuel costs.

Approach for Geographical Breakdown of Cost Estimations

The LTAG-TG study resulted in a comprehensive, global analysis with regional level results when input data was available. It does not provide detailed regional analyses for all metrics and State level results due to the absence of disaggregate input data. Such forecast data would require substantial State and aviation stakeholder specific information that either does not exist or is highly confidential such as an aircraft manufacturer's strategic plan to develop future product lines or a SAF producer's planned production volume of SAF in the 2040s, 2050s, etc.

The LTAG-TG has also provided the data and information that underlies the LTAG-TG scenarios such that States can conduct their own assessments of their future potential for investing and benefiting from measures towards achieving an LTAG if they have data and wish to do so.

Cost and investments associated with LTAG scenarios

Figure 2 provides the summary of cumulative costs and investments associated with each LTAG scenario from 2020 to 2050 across each group of stakeholders. It is important to note that costs and investments associated with a scenario are not meant to be added towards a total cumulative cost. Some investments from upstream stakeholders are passed on downstream in the form of incremental price of products. For example, investments from fuel suppliers will be passed on to operators as part of minimum selling price. As such the costs and investments are displayed across a chain of stakeholders.

Investments from States (i.e., governments): To support aircraft technology developments, States may need to invest in research and development. Under an IS1 scenario, investments could be ≈$50 billion (range $15–180B) through 2050. To support advanced aircraft configurations in an IS2 scenario and/or energy systems i.e., hydrogen powered aircraft under IS3, investments could increase to ≈$160 billion (range $75–870B).

Investments from aircraft manufacturers: To deliver aircraft technology improvements captured in IS1, aircraft manufacturers would need to invest in the order of $180 billion (range $150-$380B) between 2020 and 2050. Developing aircraft with unconventional configurations (IS2) and hydrogen powered aircraft (IS3) would require a substantial increase in investments on the order of $350 billion (range $260-$1000B) between 2020 and 2050.

Investments from fuel suppliers: To start to scale the production capacity for fuels under IS1, fuels suppliers would need to invest ≈$1,300 billion through 2050 broken down into $480 billion for SAF biomass-based fuels by 2050 (to cover 19% of international aviation energy use in 2050), $710 billion for SAF from gaseous waste (8%) and $50 billion towards LTAG-LCAF (7%). Scaling the production of Fuels under IS2, would require investments of $2,300 billion through 2050. Finally, under IS3 investments of ≈$3,200 billion broken down into $950 billion for SAF biomass-based fuels by 2050 (to cover 42% of international aviation energy use in 2050), $1,700 billion for SAF from gaseous waste (46%), $460 billion from SAF from atmospheric CO_2 (10%), $60 billion towards LTAG-LCAF (0%) and $55 billion towards hydrogen (2%) would be required.

These capital expenditures are for green field fuel production plants and were not reduced by investments that would be made to the conventional fuel sector that would be needed in a baseline (IS0) scenario. In addition, investments captured in the CAEP analyses would lead to local economic development e.g., refineries that are using renewable or waste feedstocks to produce SAF would spur economic development and opportunities for their communities.

Costs and investments for airports: Towards the implementation of operations measures, airports may need to spend or invest from $ 2 to 6 billion across LTAG scenarios. In addition, under an IS3 scenario where hydrogen aircraft may enter service after 2035, airports may need to invest into infrastructure of ≈ $100–150 billion by 2050.

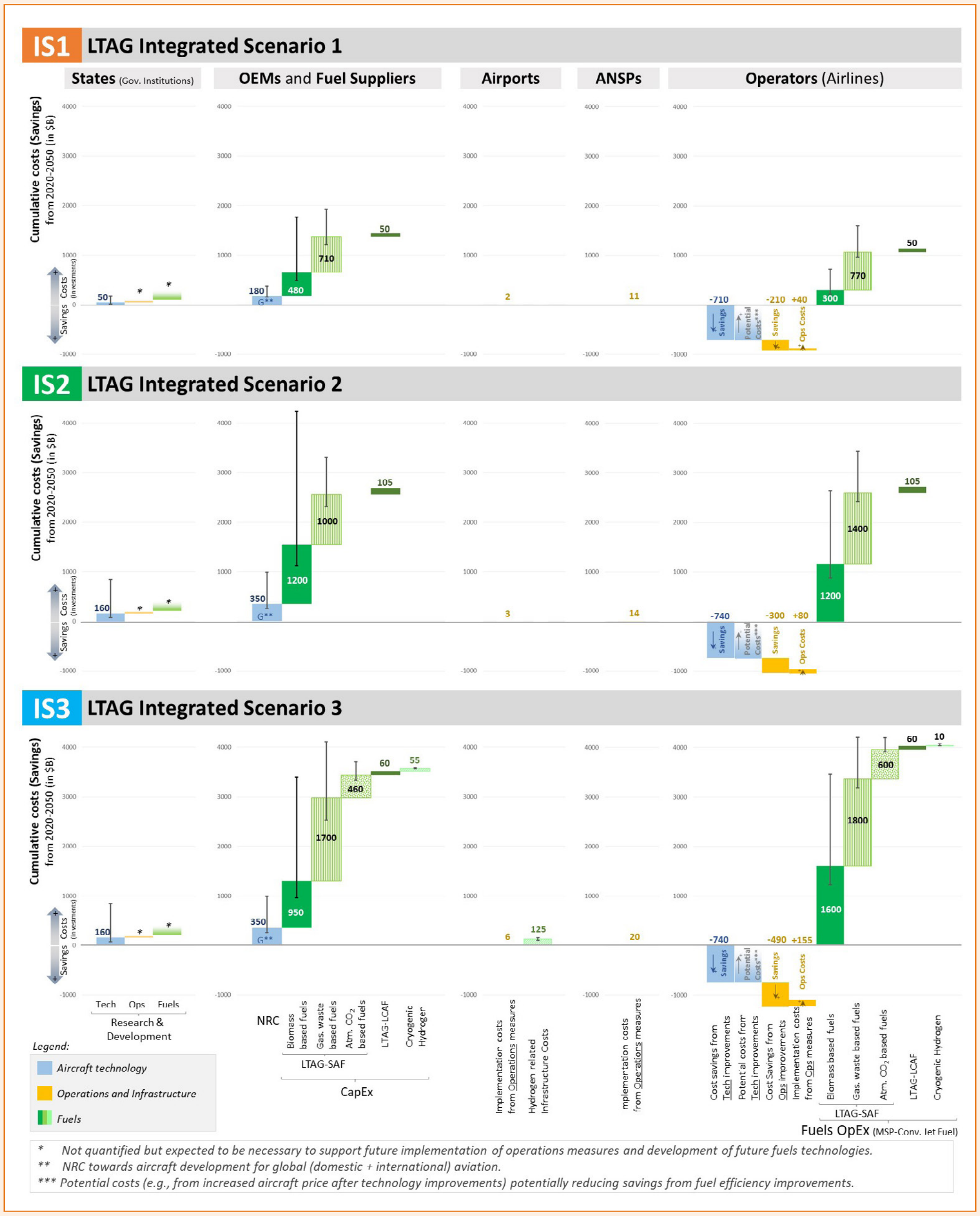


FIGURE 2: Integrated cost and investments associated with LTAG Integrated Scenarios

Costs and investments for Air Navigation System Providers (ANSPs): LTAG specific operations measures would require investments and costs by ANSPs from $ 11 to 20 billion by 2050.

Costs and investments for Operators (airlines): The entry into the fleet of aircraft with technology improvements would reduce fuel burn and operating fuel costs to airlines of ≈ $710 to 740 billion through 2050. Investments to cover any incremental aircraft prices (after technology improvements) may be required which would reduce the net savings from aircraft technology improvements to airlines.

Note 1. - The CAEP acknowledged that fuel savings from aircraft technology improvements may be reduced by an increase in aircraft acquisition costs driven by Price After Technology Improvement i.e., aircraft technology improvements are not expected to "come for free" to airlines. Airline acquisition of new aircraft is a multi-attribute decision making process, including aircraft capabilities, operating costs (including fuel efficiency), commonality with other aircraft types in the fleet, etc. The transactions are also not publicly available, and it is challenging to isolate the contribution of aircraft technology improvement to aircraft total price.

The implementation of operational measures could reduce operators' fuel costs by ≈ $210 to 490 billion through 2050 but would require additional costs and investments ranging from $40 to 155 billion. Fuel related costs in the form of incremental costs of fuels minimum selling price vs. conventional jet fuel in a baseline scenario would have the largest impact on operators. In an IS1 scenario, acquisition of fuels by airlines could result in incremental costs compared to conventional jet fuel of $1100 billion broken down into $300B, $77B, and $ 50B for biomass-based SAF, waste-based SAF and LCAF respectively. Incremental fuels costs would increase under an IS2 to ≈ $2700 billion. Finally, under an IS3 scenario where 100% of conventional jet fuel is replaced starting in 2040, the costs to airlines would reach $4000 billion through 2050 (broken down into $1600B, $1800B, $600B, $60B, and $10B for SAF biomass based, SAF waste-based fuels, SAF from atmospheric CO_2, LCAF and hydrogen respectively). A separate article on placing costs associated with LTAG Integrated Scenarios in context also provides details on costs in context of fuel and operating costs, as well as incremental costs per flight and per passenger.

Sensitivity to traffic forecasts: The LTAG-TG also assessed the sensitivity of the costs and investments associated with LTAG IS to traffic forecasts. To first order the investments associated with aircraft technology developments (including the research and development support from States) are independent of traffic forecasts. Regarding fuels related investments and costs, SAF biomass-based fuels and SAF from gaseous are constrained by capacity in the IS1 scenario and do not change across traffic levels. For IS2 and IS3, traffic levels do influence the demand for fuels. As a results, investments (CapEx) from fuel suppliers and incremental costs to operators (airlines) scale with the forecast traffic levels.

Conclusion

The costs and investments associated with the LTAG integrated scenarios are largely driven by fuels (e.g. SAF) acknowledging that incremental costs of fuels (i.e., minimum selling price of SAF compared to conventional jet fuels) further motivate fuel (energy) efficiency improvements from aircraft technology and operations. This will also require some investments from governments and industry.

Long-Term Aspirational Goal Scenario Development

By David Moroz (UK) and Yuxiu Chen (China)[1]

Introduction

As is made clear elsewhere in this supplement, the ICAO LTAG feasibility study is based closely on the methods and models used for the CAEP Trends assessment, with important differences.

Most importantly, the LTAG analysis is not aimed at forecasting future emissions trends in aviation but is explicitly a scenario-based analysis. This means that it aims to show not what is *likely to happen*, but what *could happen* if certain conditions are met. This approach reflects the need for 'aspiration' in this analysis.

External conditions (primarily level of policy effort) were assumed to allow an assessment of the full range of feasibility, while "readiness and attainability" of in-sector measures (aircraft technology, operational improvements and alternative fuel use) were carefully considered by the LTAG experts in line with the Terms of Reference. This ensured that the study focussed on technical feasibility without prejudging political decisions yet to be made.

The Scenario Development Sub-Group was formed after the 2020 CAEP Steering Group to lead the development of integrated scenarios, coordinate the final analysis and lead communication and outreach. It had around 110 members and held 23 virtual meetings. The Cost Estimation ad hoc (CEahg) group was also established to review and develop an approach and methodologies for estimating cost and investments associated with the LTAG-TG Integrated Scenarios.

Importance of scenario development work

ICAO's LTAG analysis sits in the context of a multitude of similar exercises carried out in recent years by states, industry and others. These include the ATAG Waypoint 2050 report, the Destination 2050 report from European industry and many others.[2]

Drawing on this prior work, but consciously aiming to take the most inclusive possible approach, it was important that the scenarios considered responded directly to the request of the ICAO Council to consider the full "range of readiness and attainability" of "in-sector measures".

Unlike some other reports, CAEP was not asked to consider out-of-sector measures such as market-based measures. Indeed, consideration of policies required to implement the technical measures analysed by CAEP would be a matter for policymakers in ICAO, states and regional organisations, such as direct governmental and private investment, finance, technology assistance and capacity building to support implementation in developing states. The selection of these in-sector measures and out-of-sector measures is for states to consider.

The LTAG report therefore provides the technical evidence basis for consideration and possible future decision-making by the ICAO Council and Assembly, without pre-judging what those fora may decide.

1 The co-Leads David Moroz (Department for Transport, UK) and Yuxiu Chen (Civil Aviation University of China) would like to acknowledge the invaluable contribution of the 111 members of the Long-Term Aspirational Goal Task Group's Scenario Subgroup.

2 https://aviationbenefits.org/media/167187/w2050_full.pdf, https://www.destination2050.eu/

LTAG integrated scenarios

CAEP was requested to "create integrated in-sector scenarios of technology, fuels and operations that represent a range of readiness and attainability".

Rather than exhaustively define "readiness and attainability" in a quantitative way, an overarching narrative was developed for three scenarios to cover the range of feasibility.[3] Technology, operations and fuels sub-scenarios were then developed and integrated to ensure internal consistency.

These three integrated scenarios range from the most easily attainable scenario, relying on measures with a high level of readiness, but the lowest climate ambition (IS1) to the least attainable scenario, relying on measures with a low level of readiness, but the highest climate ambition (IS3).

A baseline or 'frozen technology' scenario is also used for reference which assumes no technological, operational or fuels improvements after 2018 (IS0). Figure 1 summarises the integrated scenarios.

These are overlaid on ICAO's COVID-impacted air traffic forecasts to give nine series of results, as presented elsewhere in this supplement.

Using a cost minus baseline approach, CEahg assessed the costs and investments associated with integrated scenarios, including costs or savings from technology, operations and fuels measures across stakeholders. This assessment is described in more detail elsewhere in this supplement.

Comparison to Trends

As mentioned above, it is important to understand the similarities and differences between the LTAG analysis and the ICAO Environmental Trends assessment.

While both use the same models, base year and underlying traffic forecasts, they are intended for different purposes.

This means that, for the LTAG analysis, not only was the time horizon extended to 2070 to capture the impact of new technology entering the fleet up to 2050, but more innovative, radical and aggressive emission reduction measures are considered, within the limits of technical feasibility.

It is also important to note that the LTAG study only considers international aviation, meaning that some measures that may have an impact on domestic aviation (e.g. electrification) do not feature prominently.

MDG/FESG Baseline (for context)	**LTAG-TG Scenarios**		
Integrated Scenario 0 (IS0)	**Integrated Scenario 1 (IS1)**	**Integrated Scenario 2 (IS2)**	**Integrated Scenario 3 (IS3)**
• 'Frozen' scenario	• 'Low / nominal' scenario	• 'Increased / further ambition' scenario	• 'Aggressive / speculative' scenario
• Projection of current technologies available in the base year (through fleet renewal)	• Current (c. 2021) expectation of future available technologies, operational efficiencies and fuel availability	• Faster rollout of future technologies, increased operational efficiencies and higher fuel availability	• Maximum possible effort in terms of future technology rollout, operational efficiencies, fuel availability
• No additional improvements from technology, operations and no emissions reductions from fuels (SAF)	• Expected policy enablers for technology, ops and fuels	• Increased policy enablers for technology, ops and fuels	• Maximum policy enablers for technology, ops and fuels.
• No systemic change – e.g. infrastructure changes to accommodate growth only	• Low systemic change – e.g. no substantial infrastructure changes	• Increased systemic change – e.g. limited infrastructure changes	• High, internationally aligned systemic change - e.g. significant and broad change to airport and energy infrastructure

Decreasing readiness and attainability. Increasing aspiration.

FIGURE 1: LTAG integrated scenarios

3 The interpretations of 'readiness and attainability' adopted for technology, operations and fuels measures are described in the LTAG final report https://www.icao.int/environmental-protection/LTAG/Pages/LTAGreport.aspx

Climate science context

CAEP was requested to place the results of the LTAG feasibility study “within the context of the latest consensus scientific knowledge”, namely the allowable global emissions remaining within the temperature goals set out in the Paris Agreement.

The results of the LTAG analysis were therefore compared to the Shared Socioeconomic Pathways from the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment report, as summarised by CAEP.[4] This comparison “provides factual information to allow decision makers to do their work and does not seek to advise on a share of global carbon budgets that international aviation should consume”.[5]

This comparison shows that, over the 2020–2070 period, international aviation could represent approximately 4.1–11.3% of the global carbon budget for limiting global warming to 1.5°C (with 67% probability), depending on the integrated scenario. For limiting global warming to 2°C (with 67% probability) aviation’s share could be approximately 1.4–3.9%. For comparison, historical CO_2 emissions from global aviation (including domestic) represent approximately 1.5% of all global CO_2 emissions.

Sensitivity analysis

In developing the integrated scenarios, LTAG recognised that there could be multiple combinations of technology, operations and fuels measures to form alternative integrated scenarios. In particular, sensitivity analysis was conducted to examine the impact of lower technology and operations improvements, coupled with high reductions from fuels.

This shows that there are multiple paths that may result in similar levels of emissions but that in all cases the contribution from fuels is critical to decouple the growth in international air traffic from its emissions. It also shows that there is robustness in the LTAG scenarios and analysis.

Implementation considerations

“Roadmaps for realisation” or implementation of the scenarios were also considered, mindful of the use of these words in the report of the 40th ICAO Assembly. Some technical considerations were identified without pre-judging future decisions.

Anticipating a process for reporting progress towards any goal and the need not to duplicate existing process or place undue burden on non-state actors, it is identified that the ICAO State Action Plan process could be used by states to report progress towards any goal. Building on the expertise gained through the development of CORSIA, future work could be conducted in the process of implementation on possible metrics and reporting mechanisms.

Similarly, a triennial review process could be considered similar to the CORSIA Periodic Review, anticipating a need to review any goal adopted in light of information such as progress towards the goal, technological developments, progress in other sectors, costs and other impacts as well as the latest scientific knowledge on climate change mitigation and adaptation.

There is also a potential need for capacity building and assistance in order to realise any goal. This could include workshops on possible measures and associated costs, or assistance with monitoring and measuring emissions could form part of an overarching training programme similar to the successful ACT-CORSIA programme, as well as other assistance and support that could be considered in future.

4 https://www.ipcc.ch/assessment-report/ar6/, https://www.icao.int/environmental-protection/LTAG/Documents/ICAO_LTAG_Report_AppendixS1.pdf
5 https://www.icao.int/environmental-protection/LTAG/Documents/ICAO_LTAG_Report_AppendixR3.pdf

Global Aviation Dialogues (GLADs)

By ICAO Secretariat

Introduction

During its 40th Session, the ICAO Assembly requested to continue exploring the feasibility of a long-term global aspirational goal for international aviation CO_2 emissions reductions (LTAG). In 2021 and 2022, as part of the consultative process on an LTAG, ICAO organized the Global Aviation Dialogues (GLADs) as a series of regional online events. The presentations from the LTAG GLADs are available on the ICAO public website[1].

LTAG GLADs 2021

The 2021 LTAG GLADs held from 9 to 14 May 2021 aimed to provide information on ICAO LTAG process, and to allow for the exchange of views between States to facilitate the ICAO's further work on an LTAG.

A total of 295 participants from 94 States and 68 accredited international organizations attended the five events. Each day of the LTAG-GLADs started with an information-sharing plenary, followed by a thematic dialogue in small groups. Among different topics, the participants shared their views on top priority aviation CO_2 emissions reduction measures, at the global level, in the short, medium and long-term (Figure 1); and discussed the main challenges and barriers to the realization of the priority measures, based on an initial list provided to foster the deliberations (Figure 2). Some of the challenges were identified by the groups as being region-specific.

It should be noted that the short, medium and long-terms were not defined and each group was free to discuss and assume the three time scales. The general view for advanced aircraft technologies was that depending on the specific technologies considered, they could be available in the three time scales, while the overwhelming majority view for revolutionary aircraft technologies was that they would be available during the medium to long-term.

With regard to the operational improvements, the participants indicated them mostly as near-term reduction measures, while acknowledging their potential for the medium- and long-term scales. Regarding fuels, Sustainable Aviation Fuel (SAF) and Lower Carbon Aviation Fuel (LCAF) were identified mostly as the medium-term CO_2 emissions reduction measures, while power-to-liquids, non-drop in fuels and electrification were considered as medium to long-term.

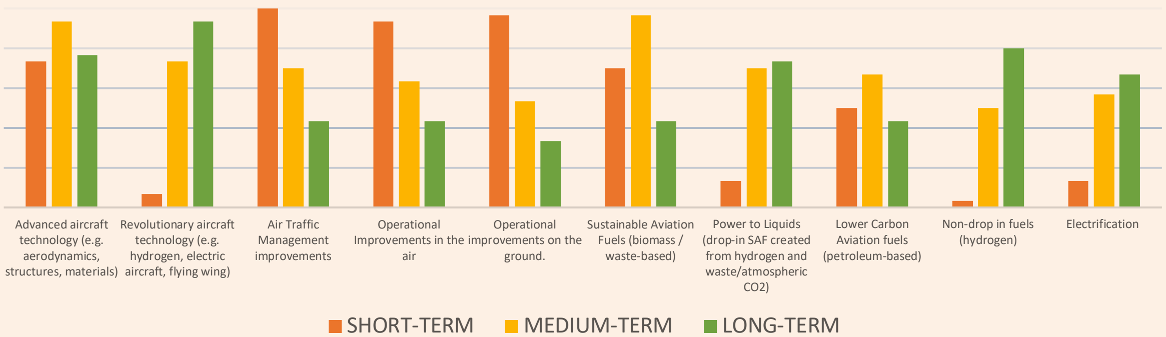


FIGURE 1: Global Average – Expectations for the CO_2 emissions reduction measures.

1 ICAO LTAG GLADs 2021:
https://www.icao.int/Meetings/2021-ICAO-LTAG-GLADS/Pages/Agenda-and-Presentations.aspx
ICAO LTAG GLADs 2022:
https://www.icao.int/Meetings/2022-ICAO-LTAG-GLADS/Pages/Agenda-and-Presentations.aspx

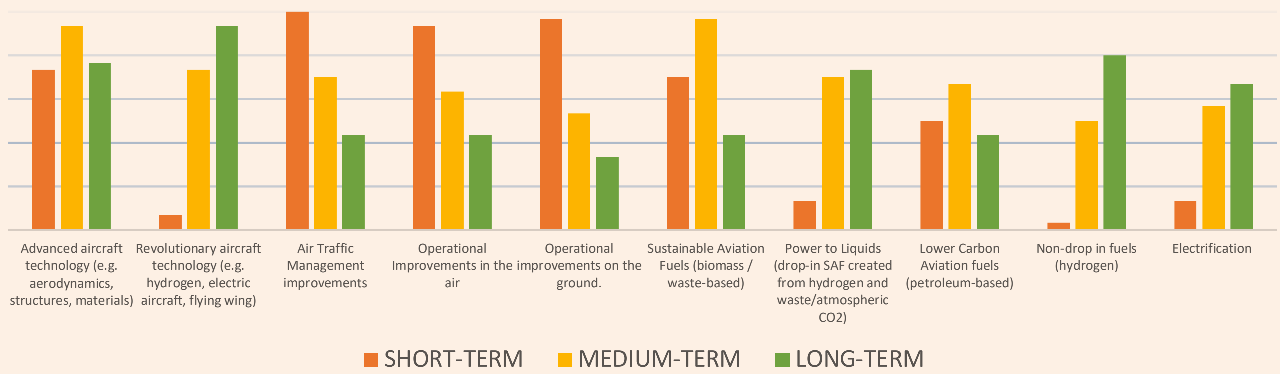


FIGURE 2: Agreement rate with the identified challenges and barriers to the realization of aviation CO_2 emissions reduction measures – global average and regional levels.

The most frequent comment raised during the 2021 LTAG GLADs was the need for receiving more information on LTAG, including cost analysis results. In this regard, an additional series of GLADs in 2022 was requested with more information on LTAG, in particular the results of Committee on Aviation Environmental Protection (CAEP) analysis on LTAG scenarios with cost impacts.

LTAG GLADs 2022

In this triennial, ICAO worked very hard and CAEP has completed a detailed technical analysis on LTAG, which was made available, together with all the presentation materials and discussion topics[2]. Therefore, 2022 ICAO LTAG GLADs were held from 28 March to 8 April 2022. A total of 421 participants from 108 States and 11 organizations attended the five events. Each day of the GLADs started with an information-sharing plenary, followed by a thematic dialogue.

The objectives of the 2022 GLADs were to ensure that participants understand the latest ICAO technical work on an LTAG and to allow for the exchange of views amongst States on the feasibility of an LTAG and its building blocks (recognition of scientific understanding, technical feasibility of LTAG scenarios, level of LTAG ambition, means of implementation, support to States with action plans and roadmaps, monitoring of progress to achieve LTAG), thus facilitating the well-informed deliberations at the subsequent High-level Meeting and the 41st Session of the ICAO Assembly.

During the first day of the GLADs, participants considered and discussed the ICAO's technical work by the CAEP on the feasibility of an LTAG, including the LTAG feasibility study report overview, LTAG scenarios and costs, LTAG inputs and modelling assumptions from technology, operations and fuels. A firm basis for supporting well-informed future decision making on an LTAG was formed with the participants' discussions on the completeness and relevance of the aviation in-sector CO_2 reduction measures considered under the LTAG report, as well as on the level of aspirations under the LTAG integrated scenario options, and the associated costs and needed investments. Participants' questions related to the LTAG report and corresponding answers were compiled and made available on the GLADs website[3].

During the second day, the participants were informed on the upcoming ICAO LTAG process toward the Assembly, and further exchanged their views on the elements of the LTAG analysis, such as: scientific understanding and context, expected potential contribution of technology, operations and fuels, and the level of LTAG ambition. The participants also discussed the barriers, solutions and needed support for the implementation of the CO_2 reduction measures. Finally, the participants exchanged views on the possible means of implementation, expected support to States with action plans and roadmaps, and

2 ICAO LTAG Report: https://www.icao.int/environmental-protection/Pages/LTAG.aspx
3 ICAO LTAG GLADs 2022 FAQ: https://www.icao.int/environmental-protection/Pages/LTAG-FAQ.aspx

ways of monitoring progress to achieve an LTAG. The views expressed by the participants were also compiled and made available on the GLADs website[4].

Next Steps

The 2022 series of LTAG GLADs enhanced overall understanding of the ICAO LTAG Report and paved the way for the later ICAO milestones in 2022, such as the LTAG High-Level Meeting (HLM)[5] in July and the 41st Session of the Assembly in September, by facilitating well-informed decisions on long-term sustainability goal options for international aviation.

The HLM-LTAG was held on 19 to 22 July 2022 as a hybrid event and served as the forum to discuss the CO_2 emissions reduction scenarios and options for an LTAG, along with the means of implementation and the monitoring of progress (more details on HLM-LTAG and its conclusions are provided in article "High-level meeting on the feasibility of a long-term aspirational goal for international aviation CO_2 emissions reductions" of this special supplement). The HLM was preceded by the 2022 ICAO Stocktaking, held on 18 July 2022, and enabled sharing of the latest relevant information, including the innovations on technology, operations and fuels.

The culmination of the ICAO LTAG Process will happen on the 41st Session of the ICAO Assembly in September-October 2022 and will be a turning point for the sustainable future of the international aviation.

4 ICAO LTAG GLADs 2022 Views Compilation: https://www.icao.int/Meetings/2022-ICAO-LTAG-GLADS/Documents/LTAG_GLADS_2022_Compilation_Views.pdf
5 ICAO LTAG-HLM: https://www.icao.int/Meetings/HLM-LTAG/Pages/default.aspx

Placing Costs Associated with LTAG Integrated Scenarios in Context

By Philippe A. Bonnefoy and Roger Schaufele (USA)

Introduction

The costs associated with each Long-Term Aspirational Goal (LTAG) Integrated Scenario were assessed as part of the LTAG-Task Group (LTAG-TG) analyses. Given the long-time horizon, from 2020 to 2050, and the scope of the sector considered (i.e., international aviation) some cost numbers run in the $ billions or $ trillions and may appear to be large.

These numbers raise questions such as: *"what do these costs represent in context of the costs of operating the international aviation sector during the next 30 years?"*, and *"what could it mean for an airline or passenger?"*.

The need to place the costs of LTAG Integrated Scenarios in context also became apparent during the ICAO Global Aviation Dialogues (GLADs), a consultative process on LTAG held by ICAO, through a series of five regional events that took place on 27 March to 8 April 2022.

Following the request from States on more detailed information on the costs within the ICAO LTAG Report, the ICAO Secretariat requested support from CAEP to complement the existing assessment to the extent possible with such information. The CAEP Chair and the LTAG-TG leadership provided support to address these questions to help with interpretation of LTAG-TG results and deliberations towards the 41st Session of the ICAO Assembly. This information does not replace or substitute any information agreed at the CAEP/12 meeting but rather complements the results of the assessment by putting it in a more detailed context, using the same assumptions and methodology from the ICAO CAEP LTAG assessment.

Approach

To place the potential costs associated with LTAG integrated scenarios in context, data from the LTAG-TG analyses on cost and investments were leveraged. Contextual data was also collected using a range of sources including: (1) CAEP Forecasting and Economic Study Group (FESG) traffic forecasts e.g., ATK, ASK, number of flights, (2) ICAO Air Transport Statistics for passenger data, (3) IATA Industry Statistics Fact Sheet (2010–2022) for breakdown of operating costs i.e., fuel and non-fuel costs and profit margins. The incremental costs associated with an LTAG (compared to a baseline scenario) are largely driven by fuels related costs. This analysis therefore focuses on these costs.

Unit fuel costs in context of historical jet fuel costs

Historically, the international aviation industry has experienced substantial volatility in unit jet fuel prices (measured in $/litre). While the transition to Sustainable Aviation Fuels (SAF), Low Carbon Aviation Fuels (LCAF) and possibly Hydrogen may increase the unit costs of fuels, the increase in unit costs is expected to be gradual and by 2050 within historical volatility ranges of unit fuel prices.

Figure 1 shows the evolution over time of unit fuel prices. Over the last ten years, the average cost of fuels varied from 0.4 to 1.0 $/L (a factor of 2.5×).

When the LTAG-TG analyses conducted by CAEP were completed and documented in November 2021 the baseline scenario assumed a unit cost of conventional jet fuel of 0.60 $/L. As shown on Figure 1, since the LTAG-TG report

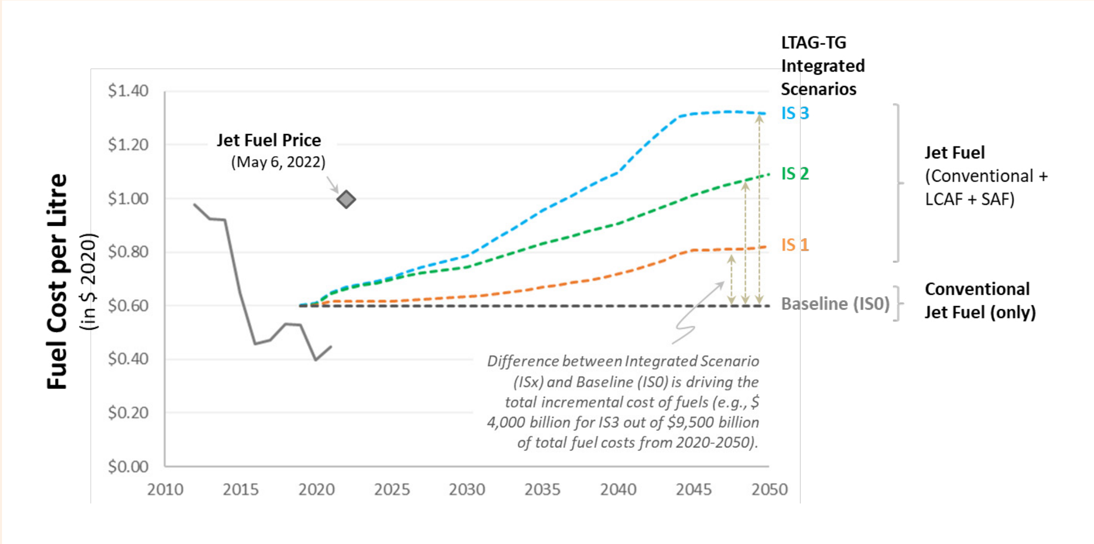


FIGURE 1: Unit fuel costs in context of historical jet fuel costs

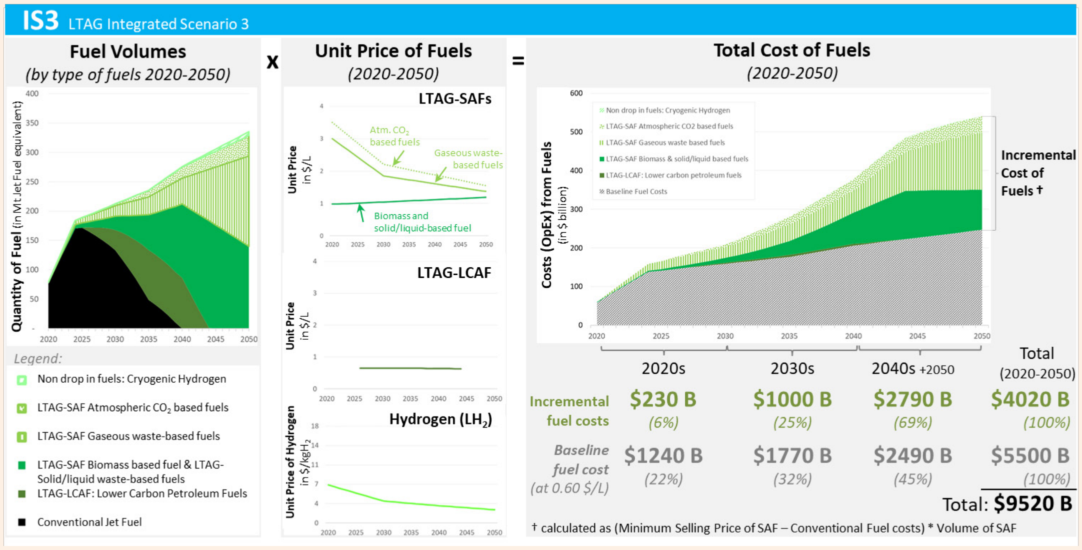


FIGURE 2: Total cost of fuels driven by fuel volumes and unit prices

was published, jet fuel price has increased to about 1 $/L in May 2022. It should be noted that this price in May is punctual and unlike the baseline 0.6 $/L does not represent an average annual price. Future conventional jet fuels are also uncertain.

As the shares of SAF and LCAF start to increase in the 2020s (under an LTAG Integrated Scenario 1), the average fuel cost per litre would increase slightly to 0.63 $/L by 2030 and 0.82 $/L by 2050 (1.4x baseline fuel cost). Under an LTAG Integrated Scenario 2, the average fuel cost per litre would reach 1.09 $/L by 2050 (1.8x). Under an LTAG Integrated Scenario 3, where 100% of conventional jet fuel is replaced by SAF starting in 2044, the average fuel cost per litre would reach 1.32 $/L by 2050 (2.2×).

Under (higher) baseline fuel cost, such as jet fuel price experienced in May 2022, the incremental costs from Fuels (e.g., SAF, hydrogen) would be substantially reduced, making these fuels more competitive to acquire and use.

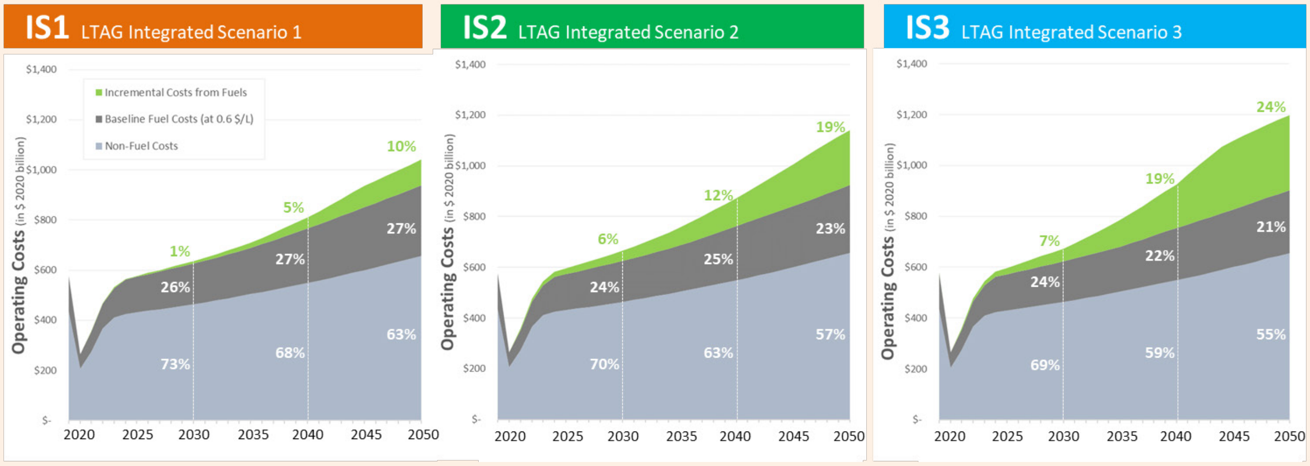


FIGURE 3: Incremental costs from LTAG scenarios in context of operating costs from international aviation

Costs in context of fuel and operating costs

Fuel costs are borne by airlines and aircraft operators and are part of their total operating costs. Figure 2 shows the total costs of fuels from 2020 to 2050 for the illustrative LTAG integrated scenario 3. The incremental costs of Fuels are driven by fuel volumes and unit prices. The incremental costs of Fuels are expected to slowly increase in the 2020s due to the gradual replacement of conventional jet fuels by LCAF, SAF and Hydrogen despite higher unit prices of these fuels. Approximately 6% of incremental fuel costs would be borne in the 2020s and 69% in the 2040s. The total incremental fuel costs of ≈$4000 billion from 2020 to 2050 also need to be placed into context of the baseline fuel costs (i.e., costs of fuel if conventional jet fuel at 0.6 $/L was used instead) that would represent ≈$5,500 billion from 2020 to 2050.

It should also be noted that aircraft technology and operational improvements, that improve from LTAG integrated scenarios 0 to 3, help to mitigate the incremental costs of Fuels. Under a baseline scenario (IS0) where technology and operational improvements are limited, the cumulative baseline fuel costs would be ≈$6,800 billion from 2020 to 2050.

Total fuel costs represent a portion of the total operating costs by airlines and should be put in context of ≈ $15,500 billion for non-fuel costs from 2020 to 2050. Figure 3 shows the evolution over time of incremental costs of Fuels, baseline fuels costs and non-fuel costs. By 2030, the incremental costs of Fuels associated with LTAG scenarios may represent from 1% to 7% of total operating costs by the international aviation industry (under IS1 and IS3 respectively). This may represent 5% to 19% by 2040 and possibly 10% to 24% in 2050.

Incremental costs per flight

From an airline perspective, the incremental cost from Fuels in 2030 may represent an additional $650 to $3300 (in $2020) per flight for an average flight of about 2700 km from Montreal (Canada) to Denver (U.S.). While these costs run in the hundreds or thousands of dollars this represent an increment on top of an average costs to operate such flight of $42,900-$41,600 (in $2020) under IS1 and IS3 respectively. Placing this cost in a per seat context, this represents about $3 to $15 per seat equivalent.

Furthermore, the incremental cost per flight would be driven by flight distances. The incremetal costs per flight for a short haul flight (e.g., ≈630 km such as Zurich to Amsterdam) would range from $130–660 per flight or $0.8 to $4.4 per seat. As expected, the incremental costs would be higher for long-haul flights.

By 2050, the incremental Fuel costs may add $3,500 to $10,000 (in $2020) on top of an average flight may cost about $31,000 to $30,000 (in $2020) to operate.

Flight Distance *Illustrative Origin & Destination*		**Incremental Cost* per Flight** *(Incremental Cost* per Seat**)* in 2030	in 2050
Short *Haul Flight* 630 km (≈10th percentile of int. aviation flights) Zurich → Amsterdam; *Switzerland* (LSZH), *Netherlands* (EHAM)	IS1	$ 130 ($0.8)	$ 780 ($4.4)
	IS2	$ 520 ($3.3)	$ 1600 ($9.2)
	IS3	$ 660 ($4.3)	$ 2200 ($13)
Average *Haul Flight* 2700 km (average for international aviation) Montreal → Denver; *Canada* (CYUL), *U.S.* (KDEN)	IS1	$ 650 ($3)	$ 3500 ($15)
	IS2	$ 2600 ($12)	$ 7200 ($31)
	IS3	$ 3300 ($15)	$ 10,000 ($43)
Long *Haul Flight* 5800 km (≈90th percentile of int. aviation flights) Singapore → Dubai; *Singapore* (WSSS), *UAE* (OMDB)	IS1	$ 1600 ($5)	$ 8000 ($25)
	IS2	$ 6600 ($20)	$ 17,000 ($53)
	IS3	$ 8300 ($26)	$ 23,000 ($73)

* Costs in $ 2020 (adjusted for inflation).
** Seat equivalent including available seats for passenger, equivalent seats for freighters and 13 seats (default) for business jets.

FIGURE 4: Incremental costs per flight and per seat equivalent

		Potential impact on ticket price* in 2030	in 2050
Average *Passenger Trip Length* 2900 km	IS1	$ 3	$ 13
	IS2	$ 11	$ 28
	IS3	$ 14	$ 38

* Proxy based on revenue per passenger, assuming an average 3% profit margin and 75% revenue from passenger (based on historical global averages from 2010-2019).

FIGURE 5: Potential impact on ticket price

Incremental costs per passenger

From a passenger perspective in 2030, the costs associated with IS1 could represent ≈ $3 to a ticket price and ≈ $14 in an IS3 scenario. While difficult to forecast, average ticket price may be on the order of $190–$200 (in $2020) in 2030. By 2050, the incremental costs associated with IS1 and IS3 may represent ≈ $13 to $38 per passenger in context of an average fare of ≈$140–$160 (in $2020).

This analysis also assumes that unit non-fuel costs will decline at historic rates observed due to further liberalization of the aviation sector and airline productivity improvements. It is important to understand that like average ticket prices, any forecast of unit non-fuel costs over the period 2020–2050 will have a large amount of uncertainty.

High-level meeting on the feasibility of a long-term aspirational goal for international aviation CO_2 emissions reductions

By ICAO Secretariat

Introduction

Ministers and officials from 119 Member States and International Organizations attended the High-level Meeting on the feasibility of a Long-Term Aspirational Goal for international aviation CO_2 emissions reductions (HLM-LTAG), which was convened from 19 to 22 July 2022, at ICAO Headquarters in Montréal, Canada, as a hybrid event with in-person and virtual participation.

The need for the HLM-LTAG stems from the ICAO Assembly Resolution A40-18, paragraph 9, which requested the Council to explore the feasibility of an LTAG, and for the progress of the work to be presented to the 41st Session of the ICAO Assembly. The HLM-LTAG was invited to discuss the CO_2 emissions reduction scenarios and options for a goal, along with the means of implementation and the monitoring of progress, before concluding with recommendations. The meeting documentation is available on the dedicated web-page[1].

The HLM-LTAG was preceded by the online 2022 ICAO Stocktaking, held on 18 July 2022, to enable the sharing of the latest information, including green innovations on technology, operations and fuels, and to set the scene for the subsequent High-Level Meeting. The figure below shows the ICAO LTAG process and timeline leading up to the HLM-LTAG.

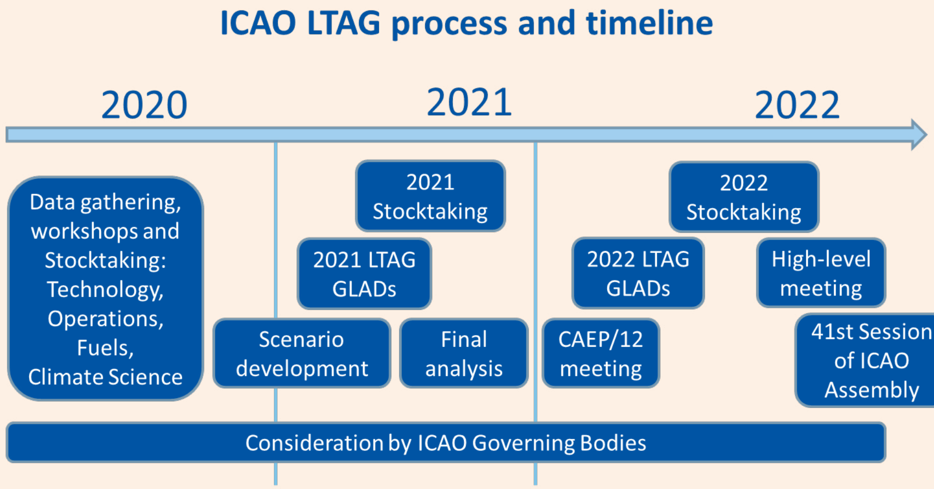
HLM-LTAG Opening

On Tuesday, 19 July 2022, the HLM-LTAG was opened with an address by the President of the ICAO Council and a video on LTAG[2]. The President welcomed the Delegations and encouraged them to demonstrate collective determination to build a sustainable future for international aviation, and to show strong political will on the part of States to work together through ICAO with each other and with the aviation industry to deliver outcomes for an ambitious LTAG. He underscored that LTAG must be delivered together with concrete and practical means of support for implementation support and for monitoring progress, as agreement of a "balanced package" for all, under the leadership of ICAO in a post-COVID world.

Afterwards, Dr. Bertrand Piccard, Initiator and Chairman of the Solar Impulse Foundation, provided his keynote address, underscoring the crucial role of innovations and aspirations in sustainable growth and development of the aviation sector.

Participants of the meeting unanimously elected The Honourable Bishop Juan Edghill, Minister of Public Works of Guyana, as Chairperson for the event, as well as first and second Vice-Chairpersons Ms. Aishath Nahula, Minister of Transport and Civil Aviation of Maldives, and Ms. Charity Musila, the Alternate Representative of Kenya to ICAO.

1 HLM-LTAG web-page: http://www.icao.int/Meetings/HLM-LTAG/Pages/default.aspx
2 ICAO LTAG video: https://youtu.be/8fCvQ_Htmqo



Following a comprehensive presentation from the ICAO Secretariat to set the scene for the LTAG, the floor was opened for pre-reserved oral statements from Member States' high-level representatives. The statements were delivered by high-level representatives from 27 Member States: Argentina, Brazil, Cabo Verde, Canada, Chile, China, Czechia, France, Greece, India, Indonesia, Japan, Malaysia, Maldives, Netherlands, New Zealand, Oman, Qatar, Republic of Korea, Russian Federation, Rwanda, Saudi Arabia, Singapore, Spain, United Arab Emirates, United Kingdom and the United States. Guatemala and Peru provided their views on an LTAG. The Airports Council International, Air Transport Action Group, and the European Union also delivered oral statements.

HLM-LTAG Discussions

A total of 8 Working Papers were presented by the ICAO Secretariat, and 22 by Member States and International Organizations at the HLM-LTAG. There were 12 Information Papers. The HLM-LTAG agenda (Table 1) provided the basis for the discussions.

All HLM-LTAG participants expressed the importance of taking action on the existential threat of climate change, and the need for a global long-term objective for international aviation, taking into account different circumstances and readiness levels of States, and the flexibility for each States to contribute to the collective efforts, while also recognizing the necessary means of implementation of an LTAG in the spirit of ICAO's No Country Left Behind initiative.

Many also expressed views on the critical importance of establishing practical means of implementation, including through ICAO State Action Plans (SAPs), facilitating the implementation of robust actions by States in reducing international aviation CO_2 emissions, as well as the establishment of ICAO's partnerships with States and other international organizations for assistance projects for aviation CO_2 reduction measures. They also expressed the view that capacity-building, financing and other assistance to States, in particular to developing countries, would be crucial in ensuring the implementation of any agreed LTAG, recognizing different circumstances of individual States and regions and that not one solution will fit all States and stakeholders.

Agenda Item 1:	CO_2 emissions reduction scenarios and options for a long-term global aspirational goal for international aviation
Agenda Item 2:	Means of implementation for a long-term global aspirational goal for international aviation
Agenda Item 3:	Means of monitoring progress and next steps
Agenda Item 4:	Conclusions and Recommendations of the Meeting

TABLE 1: HLM-LTAG Agenda.

Recognizing that the largest potential impact on aviation CO_2 emissions reduction will come from fuel-related measures, participants supported the recent June 2022 launch of the ICAO Assistance, Capacity-building and Training for Sustainable Aviation Fuels (ACT-SAF), and noted its possible extension to additional aspects (such as aircraft technologies, operational improvements), as a means to provide implementation support for the collective achievement of any agreed LTAG.

Establishing the means to monitor the progress for the achievement of any agreed LTAG, on a regular basis, and in a non-intrusive and transparent manner would be important, building upon existing means to do so, such as the ICAO Stocktaking process and tracker tools as part of monitoring the latest innovations and initiatives for reduction of aviation CO_2 emissions, as well as information from SAPs and the CO_2 reporting mechanism under CORSIA.

HLM-LTAG Conclusions

Following the exchange of views by the participants on possible HLM-LTAG outcomes, in light of the latest IPCC scientific understanding, the meeting agreed to recommend the Conclusions[3] of the HLM-LTAG to be further considered by the ICAO Council for presentation of its proposal to the 41st Session of the ICAO Assembly, as provided below.

1. ICAO and its Member States are encouraged to work together to strive to achieve a collective long-term global aspirational goal for international aviation (LTAG) of net-zero carbon emissions by 2050, in support of the Paris Agreement's temperature goal, recognizing that each State's special circumstances and respective capabilities (e.g., the level of development, maturity of aviation markets, sustainable growth of its international aviation, just transition, and national priorities of air transport development) will inform the ability of each State to contribute to the LTAG within its own national timeframe.

2. While recognizing that the LTAG is a collective global aspirational goal, and it does not attribute specific obligations or commitments in the form of emissions reduction goals to individual States, each State is urged to contribute to achieving the goal in a socially, economically and environmentally sustainable manner and in accordance with national circumstances.

3. Recalled the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement and acknowledged its principle of common but differentiated responsibilities and respective capabilities, in light of different national circumstances;

4. Also acknowledged the principles of non-discrimination and equal and fair opportunities to develop international aviation set forth in the Chicago Convention.

5. Affirmed that addressing GHG emissions from international aviation requires the active engagement and cooperation of States and the industry, and noted the collective commitment announced by the international air transport industry, to achieve net-zero carbon emissions by 2050.

6. ICAO and its Member States are invited to work together with relevant organizations to strive to achieve the maximum possible level of progress on the implementation of aviation in-sector CO_2 emissions reduction measures (e.g. technology, operations and fuels), recognizing that the largest potential impact on aviation CO_2 emissions reduction will come from fuel-related measures.

7. ICAO and its Member States are encouraged to keep abreast of innovative aircraft technologies, new types of operations conducive to emissions reductions, and Sustainable Aviation Fuels (SAF), Lower Carbon Aviation Fuels (LCAF) and other cleaner energy sources in line with the *No Country Left Behind* initiative, in order to enable timely certification, as well as timely update and development of relevant ICAO SARPs and guidance, as appropriate. ICAO and its Member States are urged to continue work on the elements of the basket of measures for the achievement of the LTAG, including:

   - ***Regarding Aircraft Technology:***
     ICAO and its Member States are encouraged to

3 https://www.icao.int/Meetings/HLM-LTAG/Documents/HLM-LTAG_SD_004_REV2_v2_clean.pdf

work with manufacturers and aircraft operators to encourage the introduction of increasingly fuel-efficient aircraft into the market and facilitate cost-effective fleet renewal as well as to incentivize and accelerate investments in the research and development of new aircraft with zero CO_2 emissions.

- ***Regarding Operations:***
  ICAO and its Member States are encouraged to work with manufacturers, Air Navigation Service Providers (ANSPs), aircraft operators and airports to implement enhanced air and ground operations, including by accelerating the deployment of the ICAO Aviation System Block Updates (ASBUs) and its implementation in accordance with the Global Air Navigation Plan (GANP).

- ***Regarding Fuels:***
  a) ICAO Member States are invited to incentivize, through policies and policy tools, the research, development and deployment of Sustainable Aviation Fuels (SAF), Lower Carbon Aviation Fuels (LCAF) and other cleaner energy sources for aviation;
  b) ICAO is invited to review the 2050 ICAO Vision for SAF, including LCAF and other cleaner energy sources for aviation, at the third ICAO Conference on Aviation and Alternative Fuels (CAAF/3) in 2023, in order to define a global framework in line with the *No Country Left Behind* initiative and taking into account national circumstances and capabilities; and
  c) ICAO and its Member States are invited to work with the relevant stakeholders to accelerate the research and certification of new fuel pathways and the certification of new aircraft and engines, to allow the use of 100% SAF, to scale up SAF supply, especially through encouraging and promoting SAF and/or LCAF purchase agreements, as well as to support timely delivery of any necessary changes to airport and energy supply infrastructure.

8. Means of implementation commensurate to the level of ambition, including financing, will promote the achievement of the LTAG. It requires substantial investments for States, according to their national circumstances, and that various possible modalities and/or funding mechanisms could be used by ICAO to facilitate financing and investment support for implementation of specific aviation CO_2 reduction measures. ICAO is invited to initiate specific measures or mechanisms so as to facilitate, in particular for developing countries and States having particular needs, better access to private investment capacities, as well as funding from financial institutions, such as development banks, for projects contributing to the decarbonisation of international aviation, as well as encourage new and additional funding to this purpose. ICAO is also invited to further consider the establishment of a climate finance initiative or funding mechanism under ICAO, while addressing the possible financial, institutional and legal challenges, and report to the 42nd Session of the ICAO Assembly.

9. This will be complementary to a robust assistance and cooperation programme dedicated to LTAG in order to share information on best practices and provide guidance, capacity building, and other technical assistance. Welcoming the establishment of the ICAO Assistance, Capacity-building and Training for SAF (ACT-SAF) programme, it should be extended to add support to the implementation of other emissions reduction measures in an ICAO ACT-LTAG programme (e.g., aircraft technologies, operational improvements, infrastructural changes, LCAF and other cleaner energy sources for aviation).

10. Additionally, ICAO is encouraged to promote the voluntary transfer of technology, in particular for developing countries and States having particular needs, to enable them to adapt to cutting-edge technology and to enhance their contribution to achieve the LTAG.

11. In line with the *No Country Left Behind* initiative, ICAO Member States are urged to make regular and substantial contributions to the ICAO Environment Fund, to address specific ICAO activities on the LTAG, including ACT-SAF programme, aiming at assisting developing States and States having particular needs. States are also encouraged to develop specific projects under the ICAO Technical Cooperation Programme.

12. All ICAO Member States are encouraged to submit and update voluntary action plans to ICAO to reduce CO_2 emissions from international aviation, with a view to achieving the LTAG. State Action Plans should outline respective actions and roadmaps, including long-term projections, and highlight respective national capacities and circumstances and any specific assistance needs for the implementation of CO_2 reduction measures. ICAO and its Member States are invited to provide assistance for preparation and implementation of such plans and the necessary capacity building, including through cooperation and assistance on identifying possible sources of financing for decarbonization of aviation, in cooperation with financial and other relevant organizations.

13. ICAO is invited to regularly monitor progress on the implementation of all elements of the basket of measures towards the achievement of the LTAG, including through: the ICAO environment stocktaking process; the review of the ICAO Vision for SAF; further assessment of the CO_2 reduction and cost impacts of a changing climate on international aviation and regions and countries, in particular developing countries, and the impact on the development of the sector, as well as the cost impacts of the efforts to achieve the LTAG; monitoring of information from State Action Plans for international aviation CO_2 emissions; and means of implementation. To this purpose, ICAO is invited to consider necessary methodologies for the monitoring of progress, and report to a future Session of the ICAO Assembly.

14. Starting from the conclusions of the HLM-LTAG above, further deliberations among Member States will continue towards the 41st Session of the ICAO Assembly.

Towards 41st Session of ICAO Assembly

In his closing remarks to the four-day round of discussions, ICAO Secretary General Juan Carlos Salazar emphasized that recovering from the effects of the pandemic and combatting climate change go hand-in-hand. He also underscored that, as a global sector, aviation has a golden opportunity to show leadership as we "build back better", aiming towards a sustainable decarbonized future.

The ICAO Council deliberated the outcomes of the HLM-LTAG, and agreed on the Working Paper[4] proposing revisions to the Assembly Resolution A40-18 on international aviation and climate change. These will be considered during the 41st Session of the ICAO Assembly (27 September – 7 October 2022).

4 https://www.icao.int/Meetings/a41/Documents/WP/wp_369_en.pdf