# LTAG Assessment from a Technology Perspective

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## 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.

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[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

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[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.