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

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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.

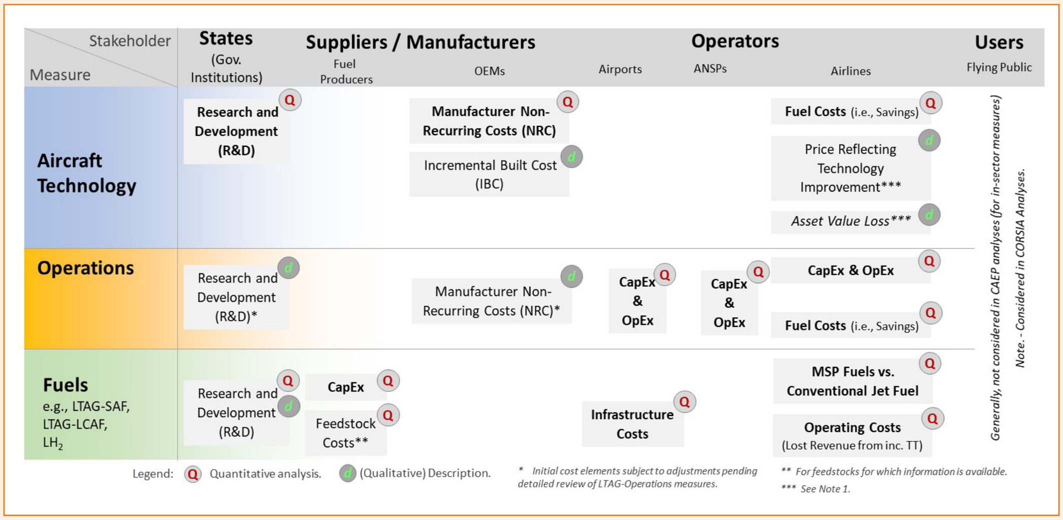

FIGURE 1: Costs and investments elements considered by the LTAG-TG

- **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.

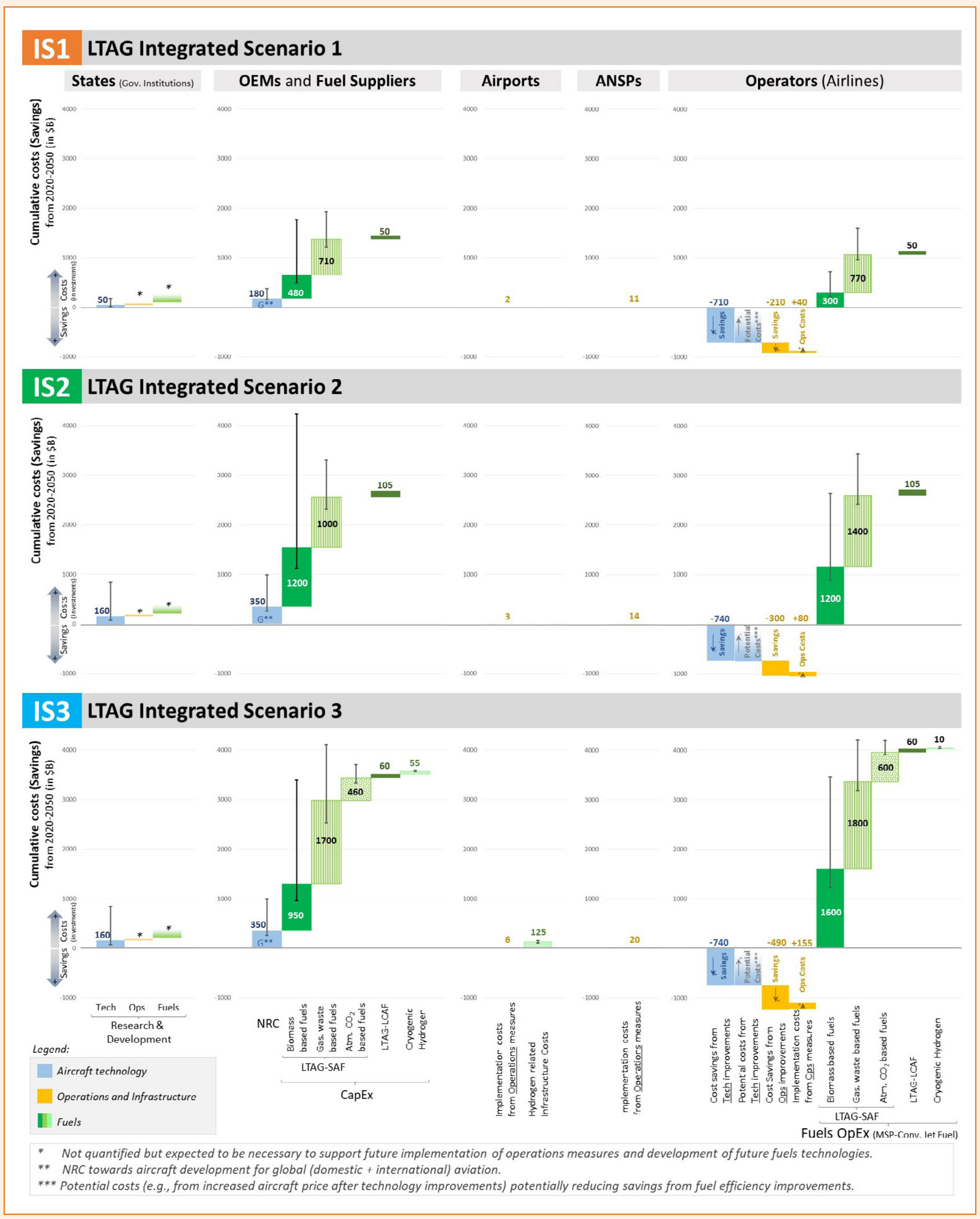

FIGURE 2: Integrated cost and investments associated with LTAG Integrated Scenarios

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.