INTERNATIONAL CIVIL AVIATION ORGANIZATION

REPORT ON THE FEASIBILITY OF A LONG-TERM ASPIRATIONAL GOAL (LTAG) FOR INTERNATIONAL CIVIL AVIATION CO_2 EMISSION REDUCTIONS

Appendix M4 Operations Sub Group Report

ICAO COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION
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APPENDIX M4

LTAG-TG OPERATIONS SUB GROUP REPORT

1. BACKGROUND

1.1 The role of the Operations (OPS) sub-group within LTAG-TG was 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 analyze in-sector scenarios of operations that represent a range of readiness and attainability. The LTAG OPS sub-group led by two experts nominated by the EU and the United Arab Emirates held 25 conference calls since May 2020 with an average attendance of 30-40 experts per call. The overall structure of the OPS sub-group is given in Figure 1.

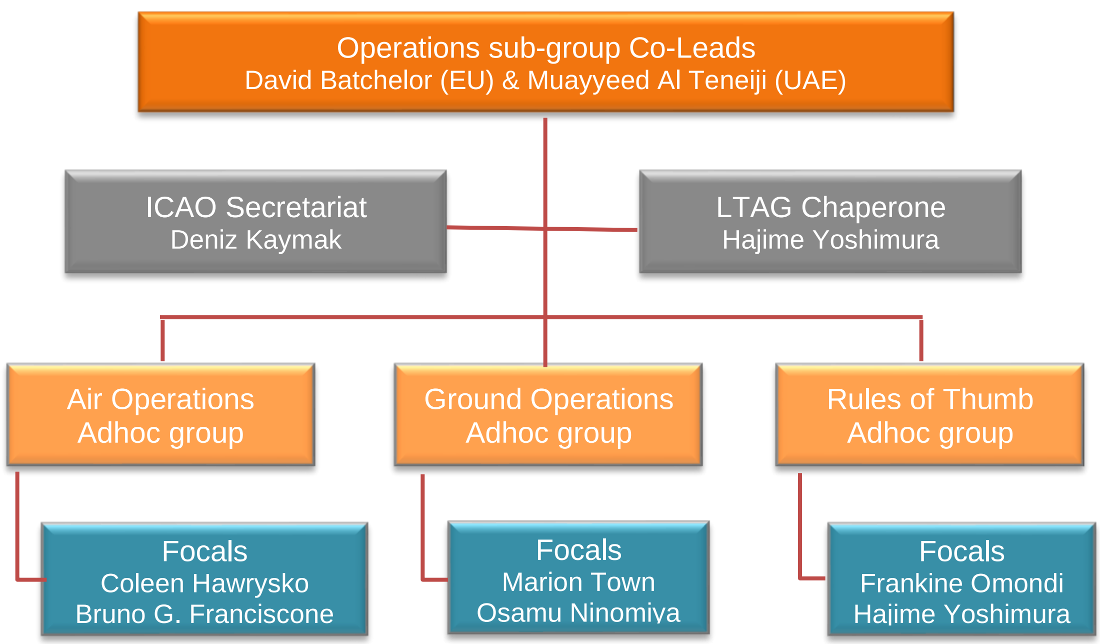

Figure 1 Operations Sub-group Structure

1.2 This appendix provides information on the work of the OPS sub-group, including a summary of its overall approach, and the methodology developed to assess the potential CO_2 emissions reductions associated with operational measures.

2. METHODOLOGY

2.1 The initial focus of the sub-group was on the data gathering task (task LTAG.02 in the LTAG-TG work programme). This involved data gathering from internal sources (ICAO and CAEP) and external groups (new stakeholders and through workshops and stocktaking) to both identify and evaluate existing, foreseen, and innovative in-sector measures relating to operations that could potentially contribute to reducing CO_2 emissions from international civil aviation.

2.2 It was agreed at the outset to divide the work of the sub-group into two components – air operations and ground operations. Two ad hoc groups (Oahgs) were therefore established – one for air and one for ground - and sub-group members were invited to volunteer to participate in each. Two focal points for each Oahg were nominated. In terms of methodology, the sub-group established an overall approach based on three phases: data collection, data analysis, and outputs to be delivered to the Scenarios Development sub-group. 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.

2.3 **Phase 1 – Data collection:** This phase involved a full 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 (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.

2.4 A specific task was undertaken to define whether certain measures should be deemed to be in or out of scope of the LTAG analysis. There was extensive discussion in the OPS sub-group over whether operational measures aimed at increasing, stabilizing or reducing airport capacity (e.g. building new runways, taxiways, airports, or reducing the infrastructure available, etc.) should be considered as within the scope. A number of elements were considered. It was acknowledged that increasing airport capacity has the potential to reduce aviation CO_2 emissions per aircraft, while growth in air traffic without corresponding growth in airport capacity could result in increased congestion at airports and terminal areas, likely resulting in an increase in CO_2 emissions per aircraft. However, given that (a) the ability to increase airport capacity is subject to widely varying local circumstances, and (b) the impact on CO_2 emissions reductions will also depend heavily on local conditions, it would be extremely difficult to estimate potential CO_2 reductions from increasing airport capacity at aggregated level in any meaningful way. The OPS sub-group therefore concluded not to include increasing airport infrastructure, such as building new airports or runways and taxiways at existing airports, as a measure to be assessed. However, the OPS sub-group analysis will nevertheless take into account individual operational measures which can increase airport capacity and thereby reduce CO_2 emissions.

2.5 **Operations Categorization:** 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 to provide inputs to MDG/FESG for the purposes of the CAEP Environmental Trends Analysis. This data had included operational improvements (OI) for the years 2028, 2038 and 2050 for Horizontal Flight Efficiency (HFE), and CAEP WG2 was also now considering Vertical Flight Efficiency. This previous analysis, which served as the baseline for the OPS sub-group's analysis, 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. The operational measures included the following:

- 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

2.6 It should be noted that further operational measures were identified which could provide fuel / emissions savings. However, these were not included in the analysis if:

- There was a potential for double counting the available benefits with another operational measure;
- The full extent of potential benefits could not be estimated;
- There was unclear information on the current / planned implementation status; or,
- The implementation date was expected to be after 2025.

2.7 As a result of its data collection exercise, the OPS sub-group identified a number of operational measures additional to those assessed by CAEP WG2. These are listed in Attachment A below.

2.8 **Phase 2 – Data Analysis:** For this phase it was decided to apply the same methodology as that used previously by CAEP Working Group 2 in its assessments of individual operational measures. This involved the development of so-called "Rules of Thumb" for each individual operational measure. A dedicated "Rule of Thumb" ad hoc group was established to conduct the detailed analysis of each of the measures. The objective of the "Rule of Thumb" for each measure is to identify its potential contribution to CO_2 emissions reductions. Each "Rule of Thumb" addresses the following aspects:

- Develop an assumption for consideration of fuel saving by the measure
- How much fuel saving per hour or per operation by the measure
- When (e.g. peak hour, night time) is the measure applied?
- Where (e.g. specific airport, region, global) is the measure applied?
- Which timeframe (2030, 2040, 2050, 2060, 2070) is this measure ready for?

2.9 The results of the "Rule of Thumb" work and the list of the individual operational measures assessed by the OPS sub-group that are additional to those previously assessed by CAEP WG2 are summarised in Attachment A below. In addition to identifying the potential contributions to CO_2 emissions reductions, the "Rule of Thumb" ad hoc group also made estimates of the likely costs associated with implementation of these measures. The summary information is included in Attachment A, and the detailed analysis was provided as input to the Cost Estimation Ad Hoc Group.

2.10 The OPS sub-group updated the baseline in the WG2 analysis to take into account the following sources of inefficiency, the final three of which were new and additional to previous work performed by WG2:

- ***Horizontal flight inefficiency*** - the comparison between the length of a trajectory and the shortest distance between its endpoints;
- ***Vertical flight inefficiency*** - the flight cannot reach its optimum cruising level during the flight or 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. If this is the case, the impact on overall flight efficiency could potentially be positive, with different flight profiles allowing greater capacity, or negative, if greater heterogeneity in the fleet produces greater complexity.

2.11 **Phase 3 – Outputs for Scenario sub-group:** The starting point for the development of the operations scenarios was to update the baseline previously established by WG2 in order to take into account the following sources of inefficiency, the final three of which were new and additional to previous work performed by WG2:

- ***Horizontal flight inefficiency*** **-** the comparison between the length of a trajectory and the shortest distance between its endpoints;
- ***Vertical flight inefficiency*** **-** the flight cannot reach its optimum cruising level during the flight or 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. If this is the case, the impact on overall flight efficiency could potentially be positive, with different flight profiles allowing greater capacity, or negative, if greater heterogeneity in the fleet produces greater complexity.

2.12 The OPS sub-group then prepared a high-level description of the operations scenarios to feed into the integrated scenarios developed by the Scenarios Development sub-group. Three scenarios were proposed **-** conservative, medium, and aggressive – aligned with the IS1, IS2 and IS3 scenarios proposed by SDSG. These scenarios were constructed according to different rates at which the five above categories of measures were assumed to be implemented. he three scenarios are summarised here and in Figure 2 below:

Operations Scenario 1 (O1)

O1 represents the low or conservative end of the range of potential GHG reductions from operations. In this scenario, there is a low rate of ASBU element deployment to optimise HFE, VFE and GFE.

Operations Scenario 2 (O2)

O2 represents the middle of the range of potential GHG 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 GHG 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.

	MDG/FESG Baseline	LTAG-TG Scenarios		
	Integrated Scenario 0 (IS0)	**Integrated Scenario 1 (IS1)**	**Integrated Scenario 2 (IS2)**	**Integrated Scenario 3 (IS3)**
		Decreasing readiness and attainability. Increasing aspiration.		
General Description	Projection of current technologies available in base year (through fleet renewal). No additional improvements from tech, ops and fuels. No systemic change – e.g. infrastructure changes to accommodate growth only.	**Low / nominal** Current (c. 2021) expectation of future available tech, ops efficiencies, fuel availability, costs. Includes expected policy enablers for technology, ops and fuels. **Low systemic change** – no substantial infrastructure changes.	**Increased / further** Approx. mid-point. Faster rollout of future tech, increased ops efficiencies and higher fuel availability. Assumes increased policy enablers, therefore decreased costs for technology, ops and fuels. **Increased systemic change** – limited infrastructure changes.	**Aggressive / speculative** Maximum possible effort: tech rollout, ops efficiencies, fuel availability, costs. Assumes max policy enablers for tech, ops and fuels. **High, internationally aligned systemic change** e.g. significant and broad change to airport and energy infrastructure.
Operations (O)	No emissions reductions from operations after 2025 (implementation of ASBU blocks 0 and 1)	**Low CO2 reduction from Operations** 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 optimise HFE, VFE and GFE	**Mid CO2 reduction from Operations** 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 optimise HFE, VFE and GFE, Low rate of operational measure deployment to optimise IFE and AFE	**High CO2 reduction from Operations** 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 optimise HFE, VFE and GFE, Medium rate of operational measure deployment to optimise IFE and AFE

Figure 2 Summary of operations scenarios

ATTACHMENT A TO APPENDIX M4

OPERATIONAL IMPROVEMENTS ANALYZED BY CAEP LTAG-TG OPS SUB-GROUP

Measure	Description	Fuel Saving	Readiness	Cost
Dynamic Sectorization	The sectorization tool enables the dynamic management of a large number of possible sector configurations. Based on the volume of pre-defined ATC sector configurations, the automated system continuously evaluates traffic demand and complexity in the future and proposes optimum sectorization solutions.	High: 0.0782 %/ flight Low: 0.0582 %/ flight	0% of all flights per region in 2020 25% of all flights per region in 2030 35% of all flights per region in 2040 45% of all flights per region in 2050 55% of all flights per region in 2060 65% of all flights per region in 2070	[ATC] ATC capabilities infrastructure and ATC controllers training costs: $3.4B (Low), $10.7B (Mid) and $20.1B (High).
Reduced Extra Fuel Onboard	Reduce the amount of extra fuel carried by reducing the flight fuel planning uncertainty; carrying extra fuel results in more fuel being burnt.	High: 0.239 %/ flight Low: 0.217 %/ flight	5% of all flights per region in 2020 25% of all flights per region in 2030 50% of all flights per region in 2040 75% of all flights per region in 2050 100% of all flights per region in 2060 100% of all flights per region in 2070	This CO_2 reduction benefit of this measure is covered by RoT63 Airline Fuel Management System. So it is concluded that the cost estimation for this measure is not needed.
Best Practices in Operations-Minimizing Weight	Weight reduction can take different forms as using lighter unit load devices, lighter seat, etc.	High: 0.85%/flight Low: 0.65%/flight *Fuel saving by this measure is covered by Airline Fuel Management System	50% of all flights per region in 2020 75% of all flights per region in 2030 85% of all flights per region in 2040 95% of all flights per region in 2050 100% of all flights per region in 2060 100% of all flights per region in 2070	[Supplier] Suppliers' investment costs: $0.1B (Low), $0.7B (Mid) and $1.2B (High). [Airline] Retrofit of cabins (lighter seats ...): $15.4B (Low), $39.5B (Mid) and $74B (High).
In-Trail Procedure (ITP)	ITP is primarily intended to help facilitate access to optimum flight levels for aircraft operating in airspace where no ATS surveillance service is available. The ITP aircraft must acquire and process position broadcast (ADS-B) data from up to two non-manoeuvring aircraft.	High: 0.87 %/ flight Low: 0.65 %/ flight	33% of all flights per region in 2020 65% of all flights per region in 2030 85% of all flights per region in 2040 100% of all flights per region in 2050 100% of all flights per region in 2060 100% of all flights per region in 2070	[ATM] $3M per system (e.g. system update of oceanic ATM system): $8M (Low), $42M (Mid) and $76M(High) [Airline] $0.15M per aircraft (e.g. equipage/activate for ADS-B IN): $0.4B (Low), $1.9B (Mid) and $3.4B (High)

Formation Flight	Two or more aircraft flying in close proximity to reduce the drag of one of them, in the same way some birds use when migrating	High: 7.1%/ flight Low: 3.3 %/ flight	0% of all flights per region in 2020 3% of all EUR / NAM deps in 2030 3% of all EUR / NAM / APAC flights in 2040 15% of all flights per region in 2050 30% of all flights per region in 2060 30% of all flights per region in 2070	[ATM] ATC certification cost: $1.0B(low), $2.4B(mid) and $4.7B(high) [Airline] Crew additional cost per year: $21B(low), $27B(mid) and $34B(high)
Airline Fuel Management System	Software helps airlines cut fuel use and carbon emissions by transforming operational data into personalised performance feedback and targets, motivating and empowering employees to take charge of their own performance and therefore improving their individual fuel efficiency by up to 30 percent, thus reducing resource consumption.	High: 2 %/ flight Low: 1 %/ flight	0% of all flights per region in 2020 5% of all flights per region in 2030 10% of all flights per region in 2040 15% of all flights per region in 2050 20% of all flights per region in 2060 25% of all flights per region in 2070	[Airline] Cost for implementation of fuel management programs at additional airlines and cost for software annual fee : $2.5 B(Low), $4.5B(Mid) and $7.4B(High) (Note: 2020-2050)
Optimized Runway Delivery Support tool and Reduced Pair-Wise Weather Dependent Separation between Arrivals	The Optimized Runway Delivery (ORD) tools support controllers increasing the accuracy of the separation delivery task. The static pair-wise separation (S-PWS) is an evolution of the reduction in separation allowed by the seven wake categories. The S-PWS matrix provides time or distance-based separation minima in a 96x96 matrix, as well as a simplified 20-category matrix. Weather Dependent Separation WDS-A for Arrivals allows the reduction of minima between arrivals when crosswind conditions will take the wake turbulence away from the flight path of the following aircraft. The reduced WDS-A table provides reduced time-based separation minima for the 7 RECAT-EU categories.	High: 0.758 %/ flight Low: 0.511 %/ flight	0 % of all flights per region in 2020 25 % of all flights per region in 2030 50 % of all flights per region in 2040 100 % of all flights per region in 2050	[ATM] Project cost and ATC training costs: $896M(low), $1.4B(mid) and $2.2B(high)

Support for Optimized Separation Delivery and Reduced Pair-Wise Weather Dependent Separation between Departures	Weather Dependent Separation WDS-A for Arrivals allows the reduction of minima between arrivals when crosswind conditions will take the wake turbulence away from the flight path of the following aircraft. The reduced WDS-A table provides reduced time-based separation minima for the 7 RECAT-EU categories. The Optimized Separation Delivery (OSD) tools support controllers increasing the accuracy of the separation delivery task.	High: 0.189 %/ flight Low: 0.038 %/ flight	0 % of all flights per region in 2020 25 % of all flights per region in 2030 50% of all flights per region in 2040 100% of all flights per region in 2050	[ATM] Project cost and ATC training costs: $896M(low), $1.4B(mid) and $2.2B(high)
Geometric Altimetry and RVSM Phase 2	This measure is based on the reduction of wake and radar separation minima to 500 ft. for most medium aircraft; it will allow the use of intermediate flight levels from the ground (265, 275, 285, 295, 305) all the way to the higher airspace. It will require the increased precision enabled by geometric altimetry, either by itself or in combination with barometric altimetry. RVSM Phase 2 will make it possible for more aircraft to fly at their optimum flight level, thereby enabling a reduction of CO_2 emissions. Note that it will also avoid the "loss of airspace" in the transition layer. Geometric altimetry will also eliminate the inefficiencies caused by aircraft climbing and descending when flying at a constant barometric altitude across isobars. There is an interim concept to allow RVSM 2 without a move to geometric altimetry. It is based on more precise altimeters and a real time background process to compare in real time Mode S or ADS-B barometric altitude downlink/broadcast against ADS-B geometric altitude broadcast in order to improve the confidence on the barometric altimeter readings.	High: 1.09%/flight Low: 0.75%/flight	0 % of all flights per region in 2020 0 % of all flights per region in 2030 20 % of all flights per region in 2040 30 % of all flights per region in 2050 40 % of all flights per region in 2060 100 % of all flights per region in 2070	[ATM] ATM training costs: $700M(low), $1.4B(mid) and $2.1B(high) [Airline] Pilots training costs: $3.9B(low), $7.8B(mid) and $11.7B(high)

Global Air Traffic Flow Management	In case of DCB imbalance, aircraft departing from an airport in the European Regulation Area are assigned a Calculated Take off Time (CTOT). CTOT must be complied with [-5min,+10min], managed by the TWR. Global ATFM is not the uptake of this process in other areas, but a global concept to provide a DCB service to aircraft that fly from one regulation area to another; unlike intra-area ATFM, global ATFM may include in-flight speed adjustment for long-hauls for DCB purposes.	High: 0.053%/ flight Low: 0.020%/ flight	0 % of all flights per region in 2020 25 % of all flights per region in 2030 50 % of all flights per region in 2040 100 % of all flights per region in 2050	[ATM] ATC capabilities infrastructure and ATC controllers training costs: costs (investments) ranging from $809M (Low), $1.5B (Mid) and $2.3B (High).
Satellite Based VHF for oceanic/remote areas	This measure enables Direct Controller Pilot Communications via SB VHF for both voice and CPDLC. It builds on the measure "Performance Based Longitudinal and Lateral Separation Minima" (which is taken as an assumption) and will enable further reductions of separation minima in oceanic and remote airspace, eliminating the operational difference that currently exists between continental and oceanic/remote ATC. Solution is under development by the SESAR Very Large Demonstration VOICE, maturity expected in 2022.	Fuel savings accounted for in combination with benefits from Satellite-based ADS-B as part of the WG-2 work, but with SB-VHF being included only from 2030 onwards (due to later availability).	0 % of all flights per region in 2020 100% of all flights per region in 2030 100 % of all flights per region in 2040 100 % of all flights per region in 2050	Cost information not yet available
Electrical Tug Detachable Aircraft Towing Equipment	Use operational semi-autonomous (controlled by aircraft pilot) tow-truck to convey aircraft to runway, while maintaining main engines off. APU on.	High: 0.80%/ flight Low: 0.47%/ flight	10% of all flights per region in 2030 30% of all flights per region in 2040 80% of all flights per region in 2050 100% of all flights per region in 2060	[Airline] Purchase of new fleet of electric tugs: $18.2B (Low), $25.1B (Mid) and $32.0B (High). [Airport] Electrical changes at airports (e.g. electrical grids and charging stations): $2.4B (Low ,Mid and High)
APU Shut Down	Enabled through PCA and GPU at gates	High: 2.3%/ flight Low: 2.1%/ flight	10% of all flights per region in 2020 30% of all flights per region in 2030	[Airport] PCA and 400Hz installation costs: $3.4B(Low),

			60% of all flights per region in 2040 100% of all flights per region in 2050	$4.3B(Mid) and $5.2B(High)
MAINTENANCE - difference between maintenance and modification to aircraft, technology related	Regular aircraft maintenance, including washing engines, replacement of blades, diagnostics and inspection to ensure optimal aerodynamic - repainting fuselage or polish (not regular maintenance)	High: 1.9 %/ flight Low: 0.2 %/ flight	30% of all flights per region in 2020 50% of all flights per region in 2030 70% of all flights per region in 2040 100% of all flights per region in 2050	[Airline] Engine wash cost: $1.3B(Low), $2.6B(Mid) and $5.1B(High). (Note: 2020-2050)

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