Introduction to ICAO Environmental Trends

ICAO Committee on Aviation Environmental Protection (CAEP)

2022

Definitions

- **ASK:** Available Seat Kilometers
- **ATK:** Available Tonne Kilometers
- **RPK:** Revenue Passenger Kilometers
- **RTK:** Revenue Tonne Kilometers
- **LTF:** ICAO Long-term Traffic Forecast (passenger/freighter markets)
- **IBAC:** International Business Aviation Council (provides inputs for business jet forecast)
- **ICAO Route Group:** ICAO defined country and airport pair combinations
  - 51 ICAO route groups in the LTF
  - Covers international and domestic traffic (e.g., North America Domestic represents all domestic flights in U.S. and Canada)
- **ICAO/CAEP Region:** ICAO defined regions and airport pair combinations – 6 regions in the LTF
- **Distance Bands:** Aligns airport pairs within an ICAO route group by flight distance
  - Eighteen distance bands in 500nm (nautical mile) increments (0 – 8500+)
- **Seat Class:** Defines fleet evolution market type and capacity (e.g., Narrow Body 101-125 seats, Wide Body 211-300 seats)
  - Example of aircraft by market: Turbo prop: ATR72, Regional Jet: E175-E2, Narrow Body: B737-MAX8, A320-NEO, Wide Body: A330-9NEO, B787-8

Orientation

– A gray arrow indicates a step in or an input to a process.

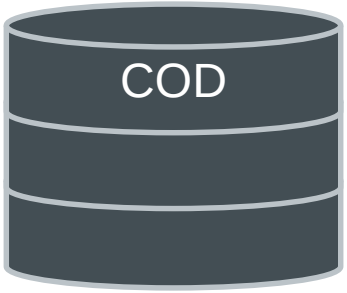
– A red arrow indicates an assumption or a specific methodology.

– A stacked cylinder represents a database.

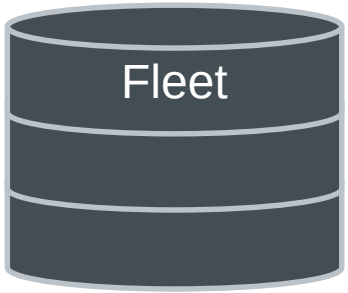
Overview

1. Databases
2. Trends Modelling and Assumptions
   - 2a. Fleet & Operations Forecasting and Assumptions
   - 2b. Environmental Modelling and Assumptions
3. Trends Results

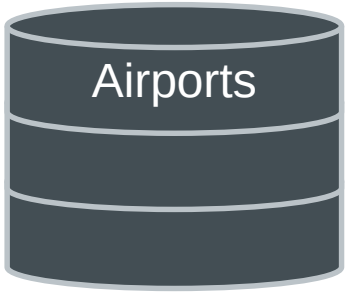
1. Databases



Common Operations Database

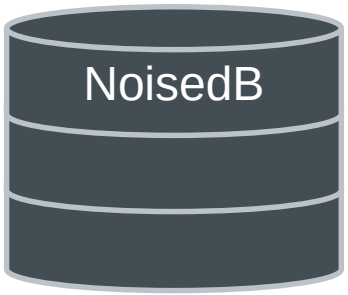


Fleet Database

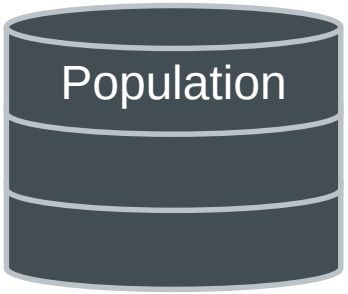


Airports Database

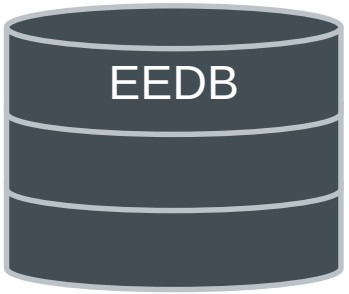
Growth and Replacement Database



Noise Certification Database



Population Database (Noise Modelling Only)



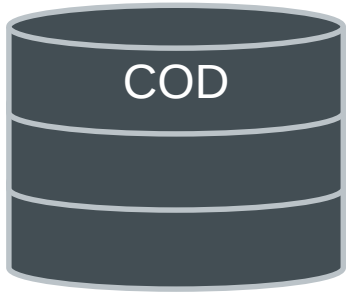
Engine Emissions Data Bank

Common Operations Database (COD)

The COD is built using:

- US Radar
- European Radar
- Brazilian Radar
- Flight Aware
  Adds operations to Australia, New Zealand, and a few other countries. Enhances Rest of the World (ROW) with tail number information (provided by ICAO Route Group).
- Official Airline Guide (OAG)
  Covers the ROW.

The COD contains a list of flights worldwide (but not their trajectories) for a given recent year.



Common Operations Database

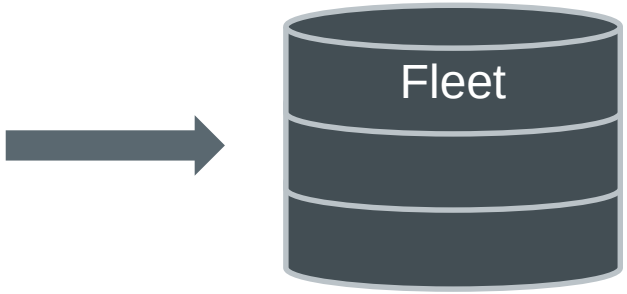
- Flight Aware and OAG are commercial databases and used with appropriate licenses.

Fleet Database

The major components of the Fleet Database are:

- Aircraft Noise and Performance Database (ANP) (280+)
- Aircraft Fleet Registry (83,000+)
- Base of Aircraft Data (BADA) (200+)
- Engine Emissions Data Bank (EEDB) (600+)
- PIANO Aircraft Performance and Emissions Database (500+)

The Fleet Database contains a list of aircraft in production or in service with their noise and emissions characteristics.



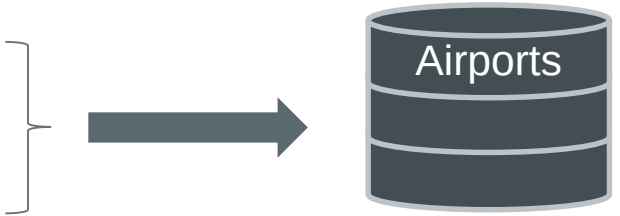
Fleet Database

- BADA and PIANO are proprietary databases and used in the respective tools with appropriate licenses.
- Among other uses, the Fleet Database supports the analysis used to develop the retirement curves overviewed in Slide 21.

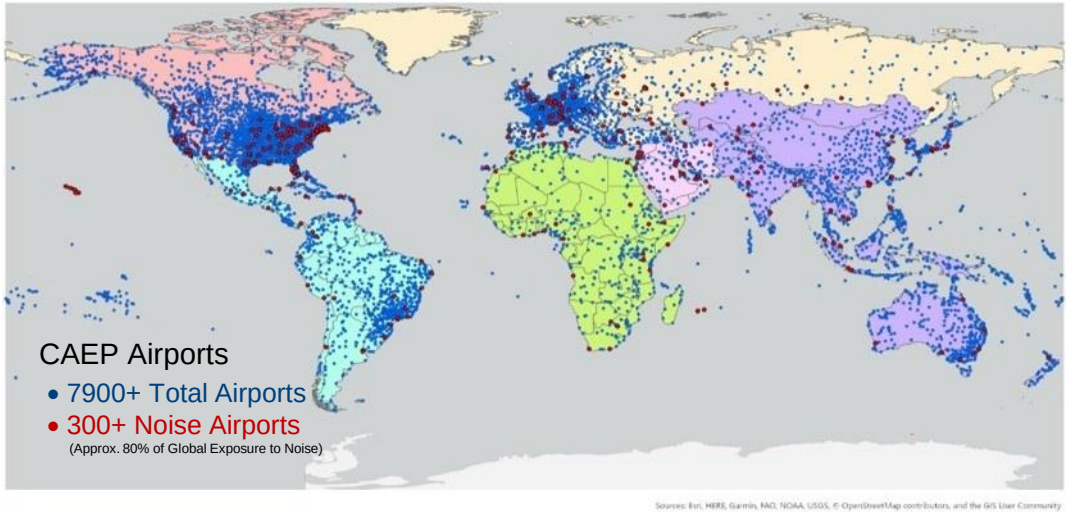
Airports Database

The major components of the Airports Database are:

- Airport Flight Tracks and Runway Utilization for Noise Modelling
- Airport details including Name, Codes, Coordinates, Country, ICAO/CAEP Region (7900+)



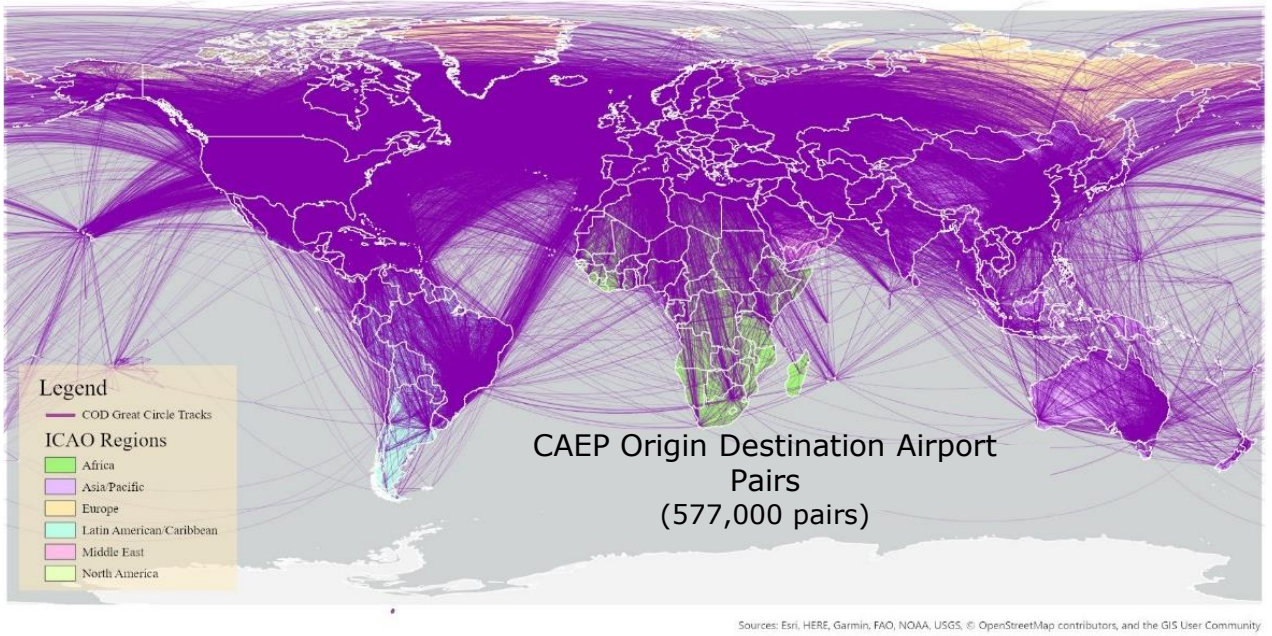
Airports Database



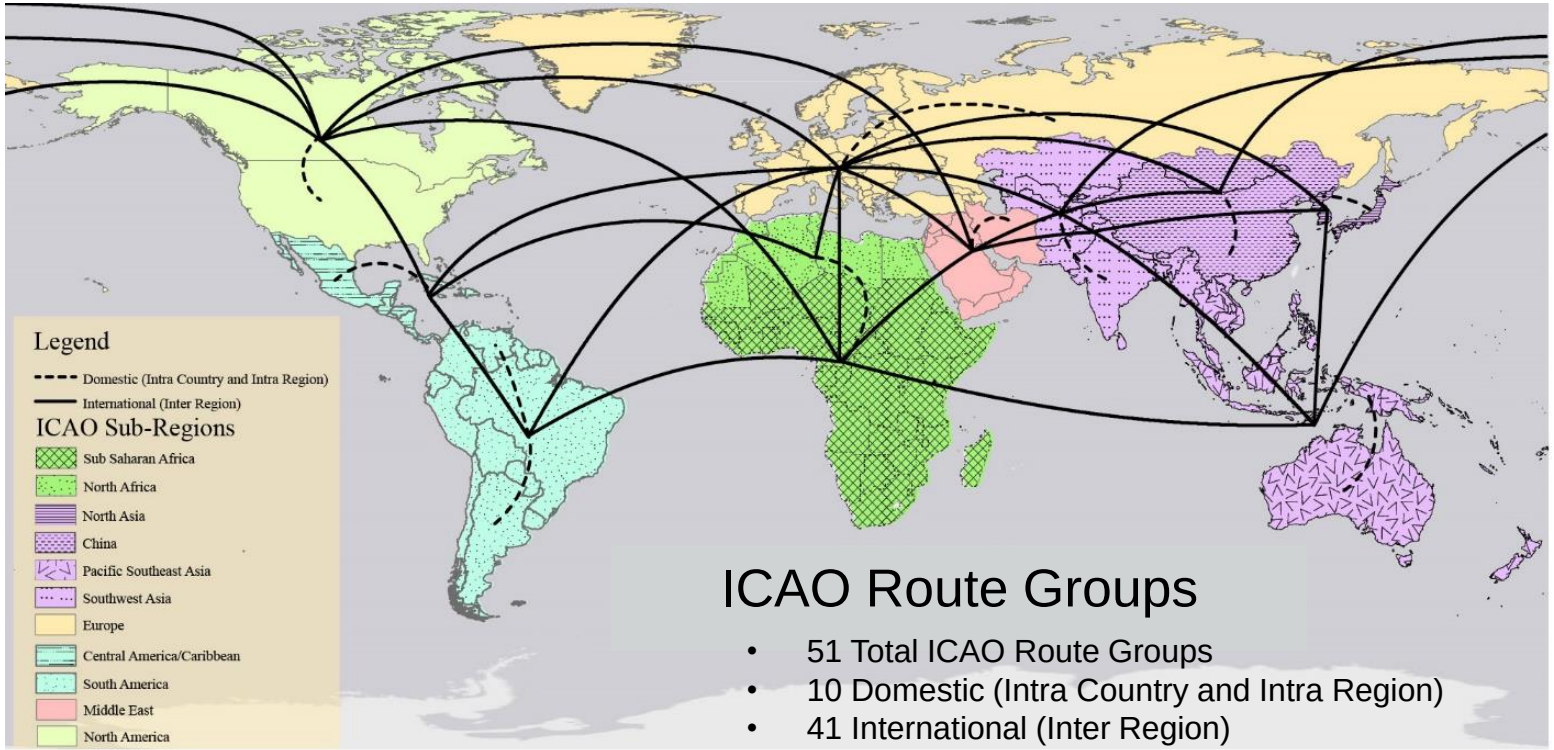
Airports Database: OD Pairs

Airport pairs are assigned:

- **ICAO/CAEP Region** based on departure airport country.
- **ICAO Route Group** (or Long-term Forecast (LTF) Route Group) based on departure and arrival airport LTF regions.



Airports Database: ICAO Route Groups



Growth and Replacement (G&R) Database

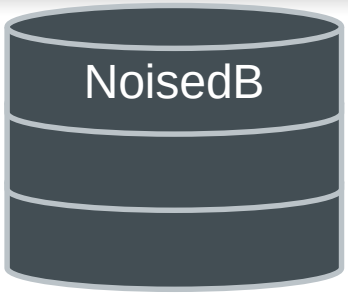
Information from a proprietary database

Growth and Replacement Database

G&R Database defines aircraft available to enter fleet for growth and replacement.

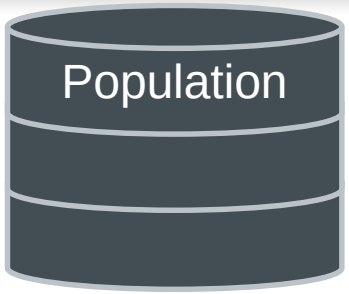
- In production aircraft in base analysis year or aircraft entering service in near future based on industry announcements.
- Passenger, freighter and business jet markets.

Other Databases



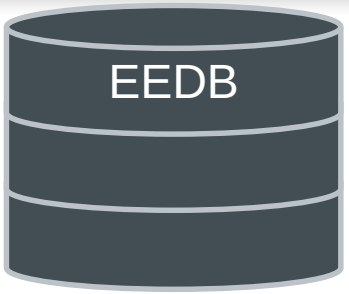
Noise Certification Database

- NoisedB is a publicly available database.
- NoisedB contains noise levels of certified aircraft.
- Uses ICAO standards and recommended practices or Code of Federal Regulation, Title 14, part 36.
- Current Version: 2.29



Population Database (Noise Modelling Only)

- U.S. Census (2010)
- U.K. Census (2011) (Extrapolated to 2015)
- Mainland Europe EEA Census (varies by country)
- Brazilian Census (2010)
- GPW Version 4 (2010)



Engine Emissions Data Bank

- ICAO Aircraft Engine Emissions Databank contains information on exhaust emissions of production aircraft engines.
- Measured according to the procedures in ICAO Annex 16, Volume II, and where noted, certified by the Countries of Design of the engines according to their national regulations.
- Current Version: 26A

EEA: European Economic Area; GPW: Gridded Population of the World

2. Trends Modelling and Assumptions

Step 1: Forecast demand and fleet by market.
(Passenger, Freighter, and Business Jet)

Step 2: Model the noise, fuel burn, and emissions based on forecasted fleet.

Step 3: Present results of the trends analysis.

2a. Fleet & Operations Forecasting

Fleet & Operations Forecasting Process

- **ICAO-LTF:** Passenger and Freighter markets.
- **IBAC:** Business Jet market.

2a. Fleet & Operations Forecasting

FESG Fleet Forecast Output
Fleet forecasts by market type (passenger, freighter and business jet) and defined by ICAO route group, distance band and seat class.

COD Database
Base-Year network, operations by airport pair, ICAO route group, distance and seat class, and aircraft type.

Growth and Replacement Database
Provides details of aircraft (e.g., type (narrow body, turboprop, etc.), capacity, available to enter fleet in future years).

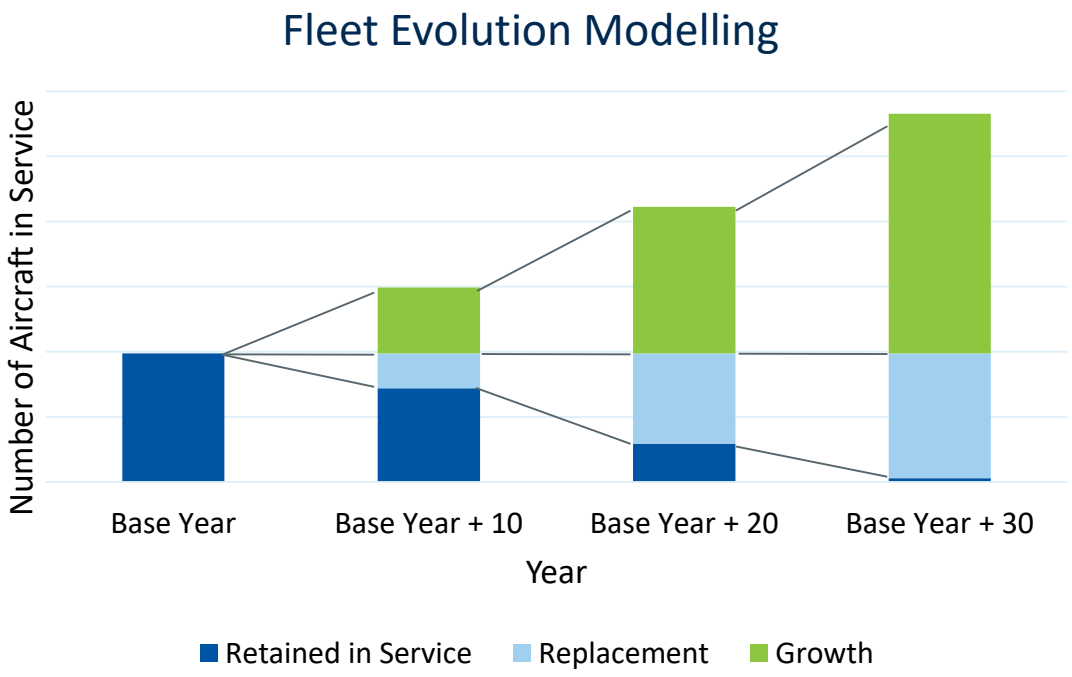
Aircraft Retirement Curves
By market (e.g., commercial narrow body, freighter wide body, etc.).

→ **Fleet Evolution Modelling**

Fleet Evolution Models generate future fleet mix — base year and future operations by airframe/engine combination, airport pair and aircraft year of entry into fleet

More detail on fleet evolution is provided in the Appendix.

2a. Fleet & Operations Forecasting



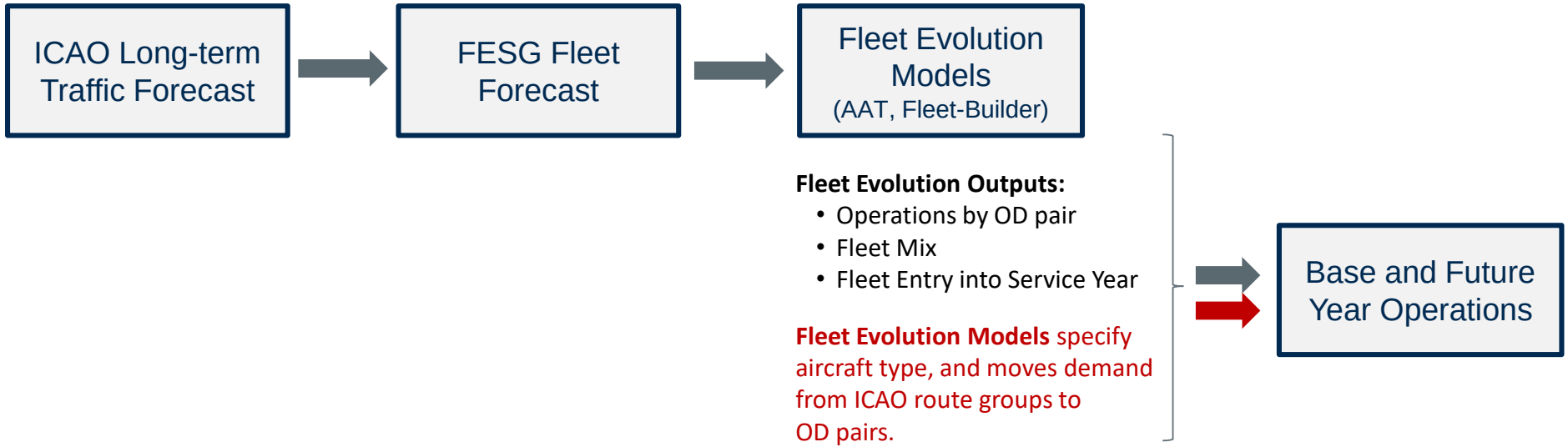
***Growth*: Aircraft needed to meet demand forecasts**

***Replacement*: Aircraft needed to replace retiring aircraft**

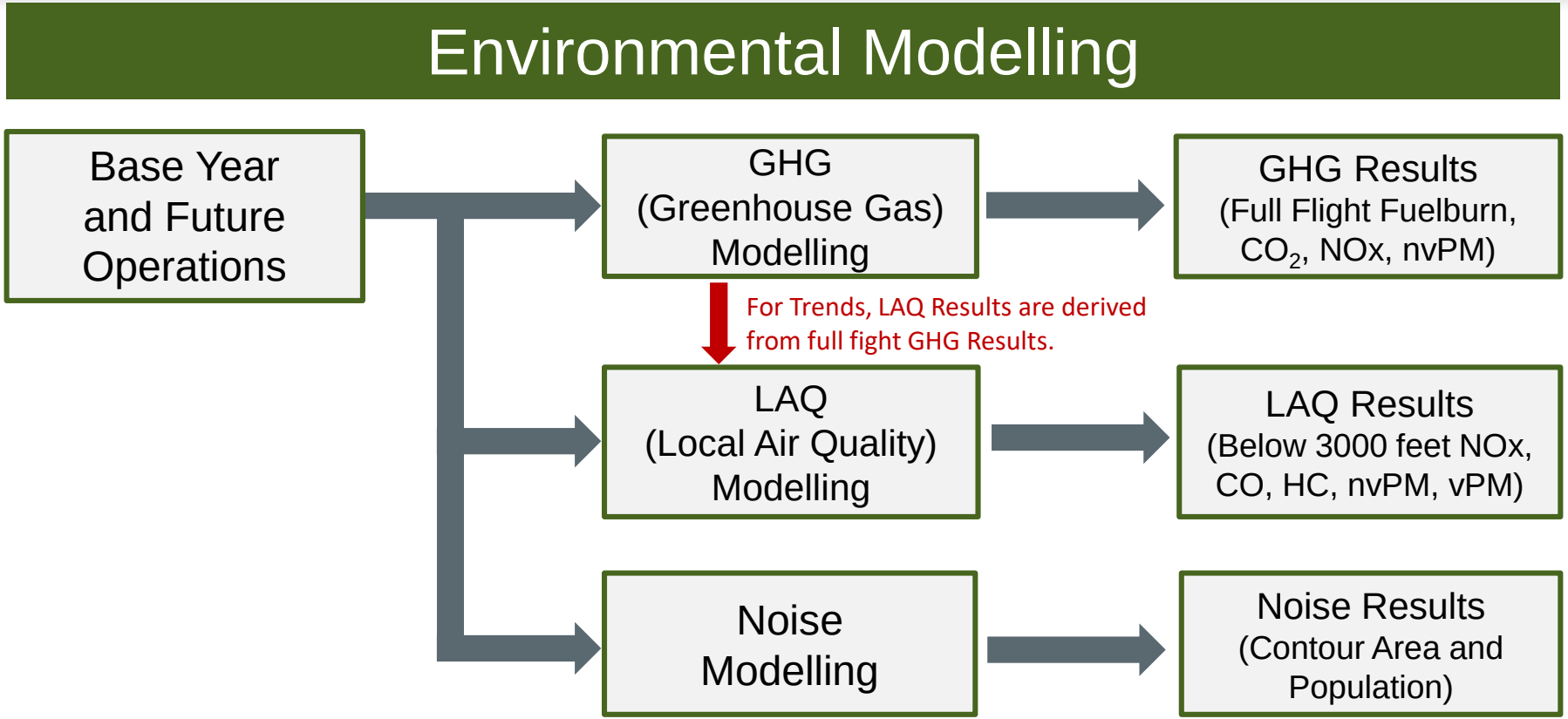
Both Growth and Replacement operations are introduced annually. FESG *retirement curves* define the rate at which in-service aircraft are retired from the active fleet.

More detail on year-on-year fleet rollover, retirement curves, and application technology improvements is provided in the Appendix.

2a. Fleet & Operations Forecasting



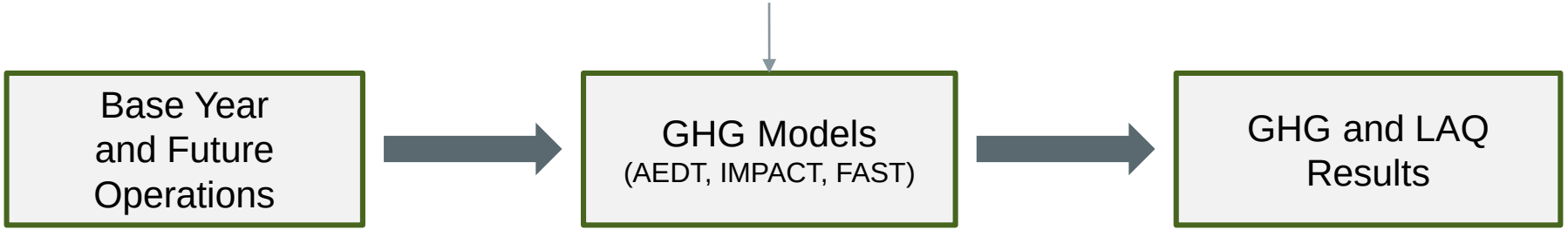
2b. Environmental Modelling



2b. GHG (Full Flight) and LAQ Modelling

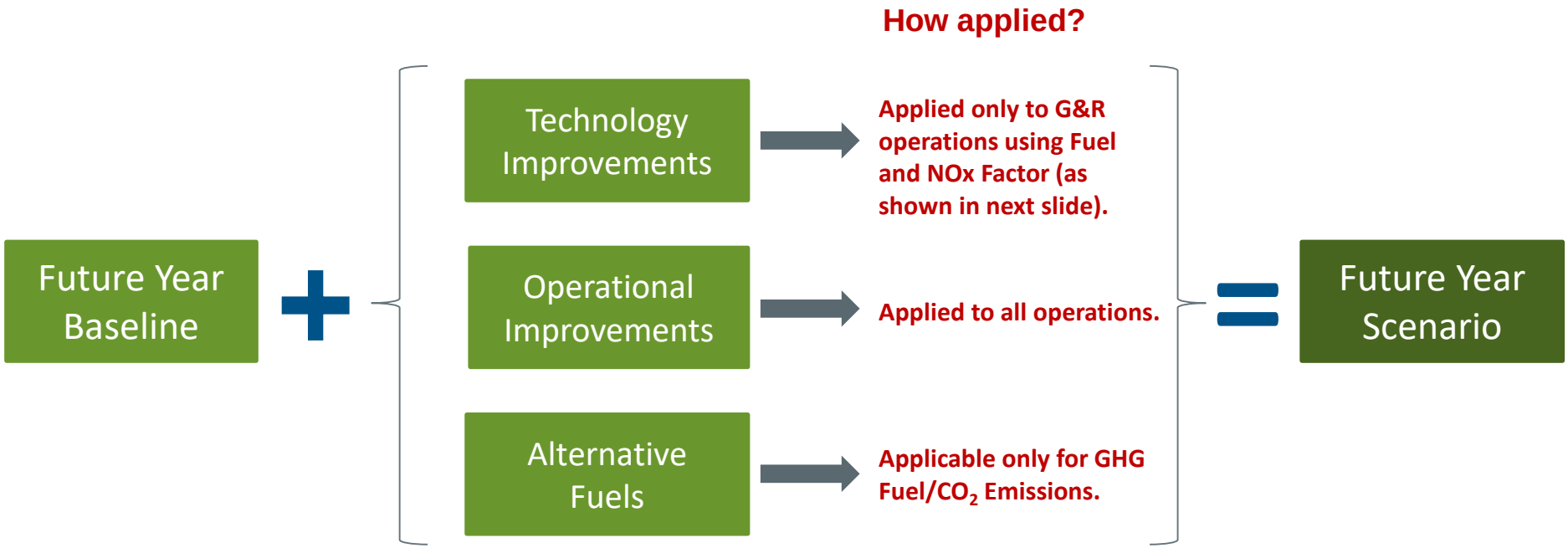
Inputs:

- Operations input is grouped into distinct aircraft types and representative distances and used as a proxy to cover the entire set of base year and future operations.
- Standard Day Sea Level Airport, 8 knots headwind at take off and zero enroute wind conditions.
- Great Circle Ground Tracks including adjustments* for fuelburn and emissions.
- Full Takeoff Power and All Engines used for taxiing.

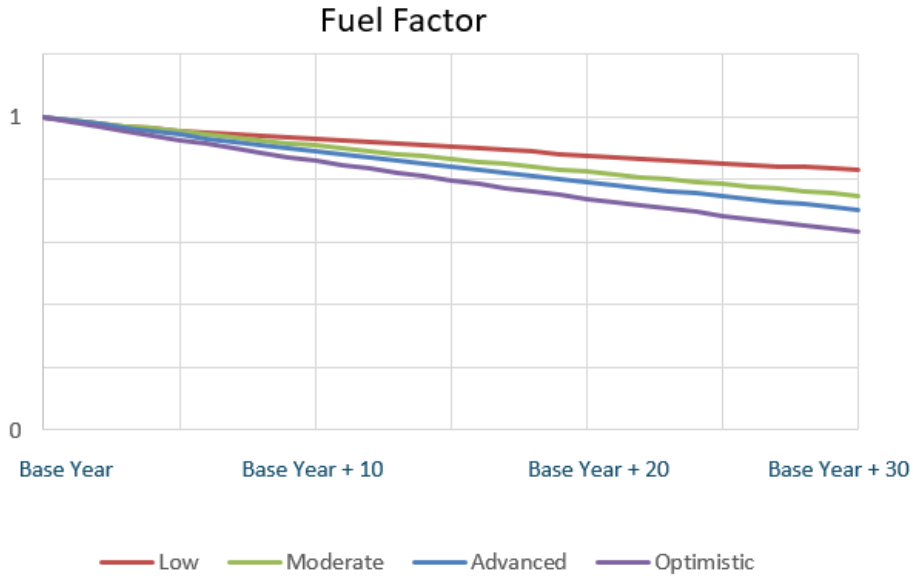


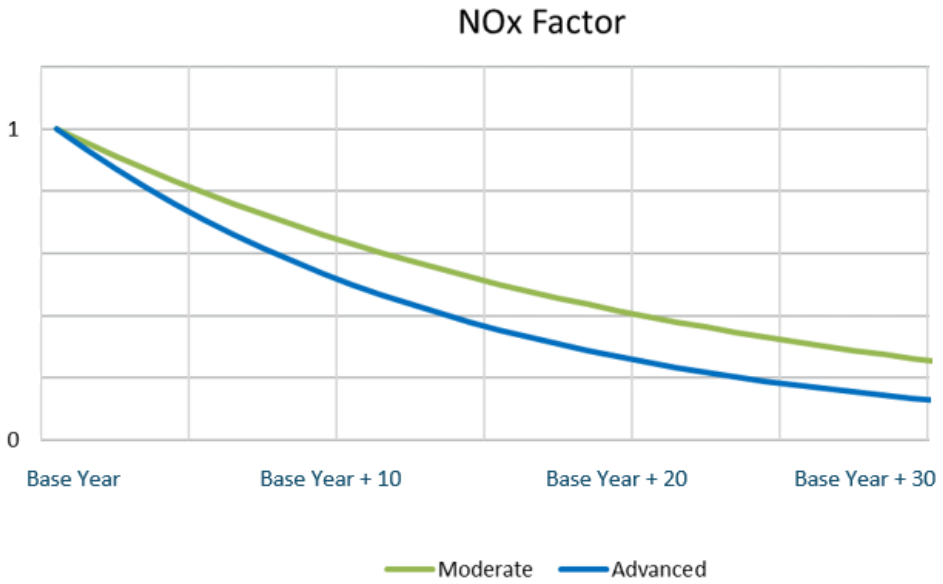
*Up to CAEP/11 cycle historical radar trajectories derived adjustments were used.
Starting CAEP/12 cycle, ICAO/CAEP working group 2 provided values are used.

2b. GHG and LAQ Future Years Processing



2b. GHG and LAQ Technology Improvements





Fuel Factor is a multiplicative coefficient applied to fuelburn and the following emissions: CO_2, HC, CO, nvPM, and vPM.

NOx Factor is a multiplicative coefficient applied only to NOx.

2b. GHG and LAQ Operational Improvements

Route Group	2025 Goal	2035 Goal	2045 Goal
AFRICA	0.951	0.917	0.883
AMERICAS - CHINA / MONGOLIA	0.966	0.948	0.931
AMERICAS - INDIA / SOUTHWEST ASIA	0.966	0.948	0.931
AMERICAS - OTHER ASIA / PACIFIC	0.966	0.948	0.931
CHINA / MONGOLIA	0.936	0.899	0.863
EUROPE	0.937	0.902	0.868
EUROPE - AFRICA	0.962	0.936	0.911
EUROPE - CHINA / MONGOLIA	0.964	0.944	0.925
EUROPE - INDIA / SOUTHWEST ASIA	0.964	0.944	0.925
EUROPE - MIDDLE EAST	0.969	0.943	0.918
EUROPE - OTHER ASIA / PACIFIC	0.964	0.944	0.925
INDIA / SOUTHWEST ASIA	0.936	0.899	0.863
INTRA AFRICA	0.961	0.933	0.905
INTRA ASIA / PACIFIC	0.955	0.930	0.907
INTRA EUROPE	0.950	0.921	0.892
INTRA LATIN AMERICA	0.951	0.919	0.888
INTRA MIDDLE EAST	0.943	0.909	0.877
INTRA NORTH AMERICA	0.930	0.893	0.858
JAPAN	0.936	0.899	0.863
LATIN AMERICA	0.946	0.911	0.877
MID ATLANTIC	0.964	0.945	0.927
MIDDLE EAST	0.935	0.897	0.860
MIDDLE EAST - CHINA / MONGOLIA	0.961	0.940	0.920
MIDDLE EAST - INDIA / SOUTHWEST ASIA	0.961	0.940	0.920
MIDDLE EAST - OTHER ASIA / PACIFIC	0.961	0.940	0.920
NORTH AMERICA	0.931	0.898	0.866
NORTH AMERICA - CENTRAL AMERICA / CARIBBEAN	0.950	0.921	0.893
NORTH AMERICA - SOUTH AMERICA	0.962	0.938	0.914
NORTH ATLANTIC	0.964	0.945	0.927
OTHER ASIA / PACIFIC	0.936	0.899	0.863
OTHER INTERNATIONAL ROUTES	0.956	0.927	0.899
SOUTH ATLANTIC	0.966	0.948	0.931

Route Group	2025 Goal	2035 Goal	2045 Goal
AMERICAS - CHINA / MONGOLIA	0.966	0.948	0.931
AMERICAS - INDIA / SOUTHWEST ASIA	0.966	0.948	0.931
AMERICAS - OTHER ASIA / PACIFIC	0.966	0.948	0.931
CHINA / MONGOLIA	0.936	0.899	0.863
EUROPE	0.937	0.902	0.868

Operational improvement is a multiplicative coefficient applied to fuelburn and all emissions.

The values shown are examples for illustrative purposes only.

2b. GHG Alternative Fuels

- The **potential for sustainable aviation fuel (SAF) production was evaluated using a scenario-based approach** based on, inter alia, the IPCC socioeconomic pathways, location-specific agricultural yields for a wide set of feedstock's, SAF fuel conversion efficiency assumptions, and different ambition levels by policy-makers.

- The **scenario results ranged** from zero production to as high as full jet fuel replacement by 2050.

- The illustrative case from this analysis would lead to **emissions reduction of approximately 19%**, but would require high availability of bioenergy feedstock's, whose production, and use for aviation biofuels would need to be significantly incentivized by price or other policy mechanisms.

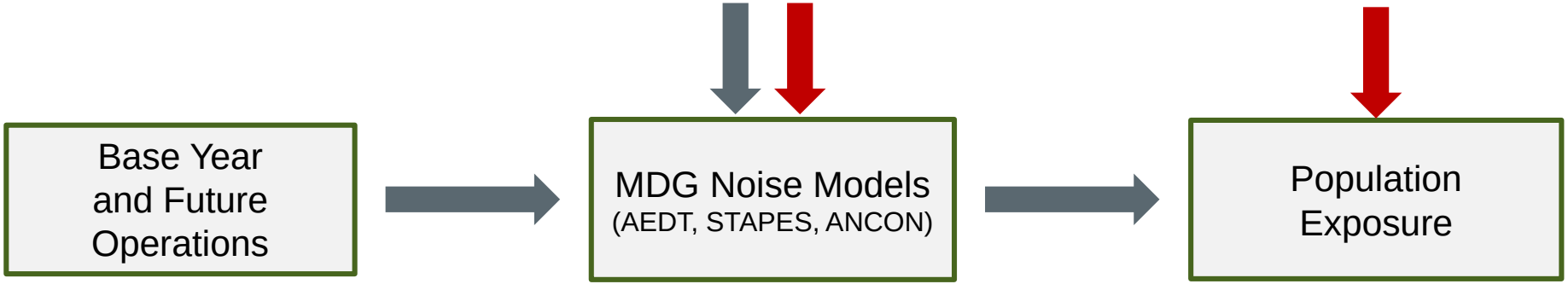
2b. Noise Modelling

Inputs:

- Standard Day Sea Level Airport, 8 knots headwind at take off
- Full Takeoff Power
- SAE AIR 1845 Atmosphere

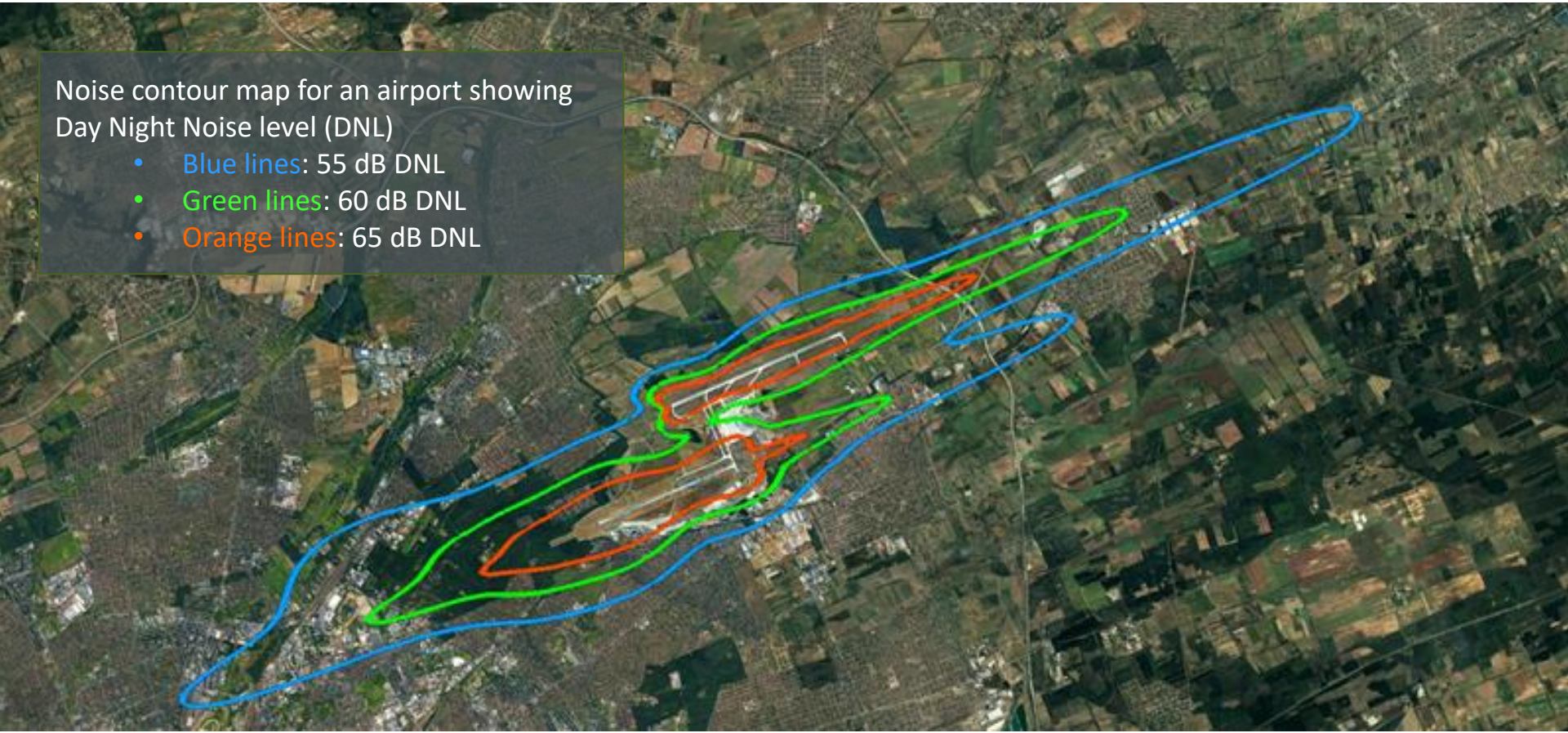
Annual average day (AAD) operations are computed from COD for each of the 320+ airports.

Population Exposure computed using noise contours in conjunction with GIS software.

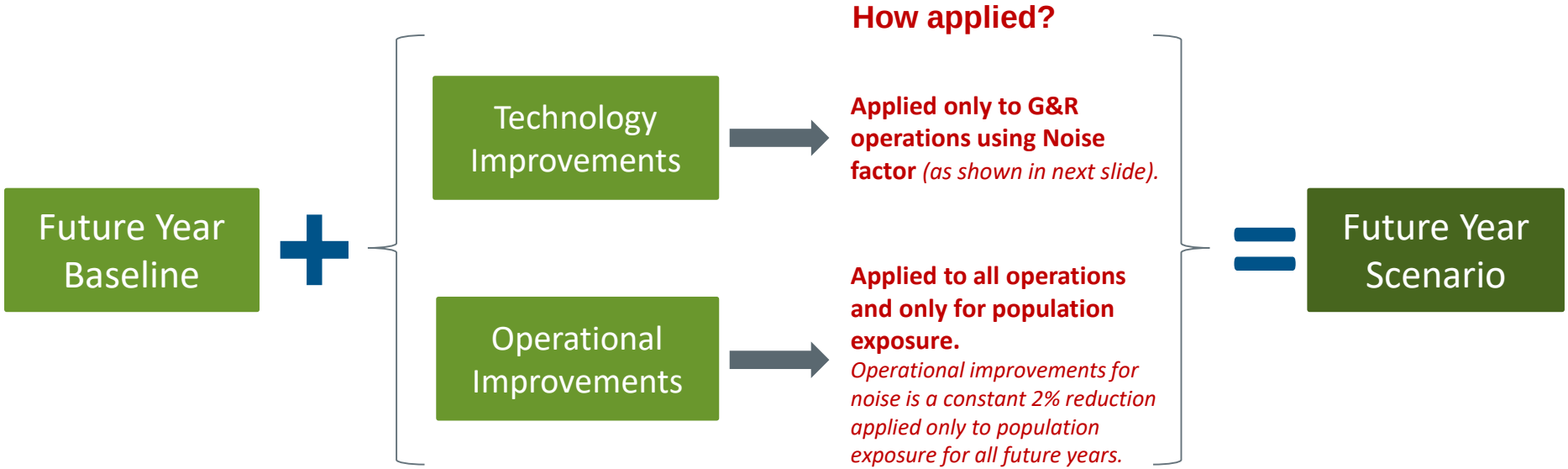


More detail on noise modelling is provided in Appendix.

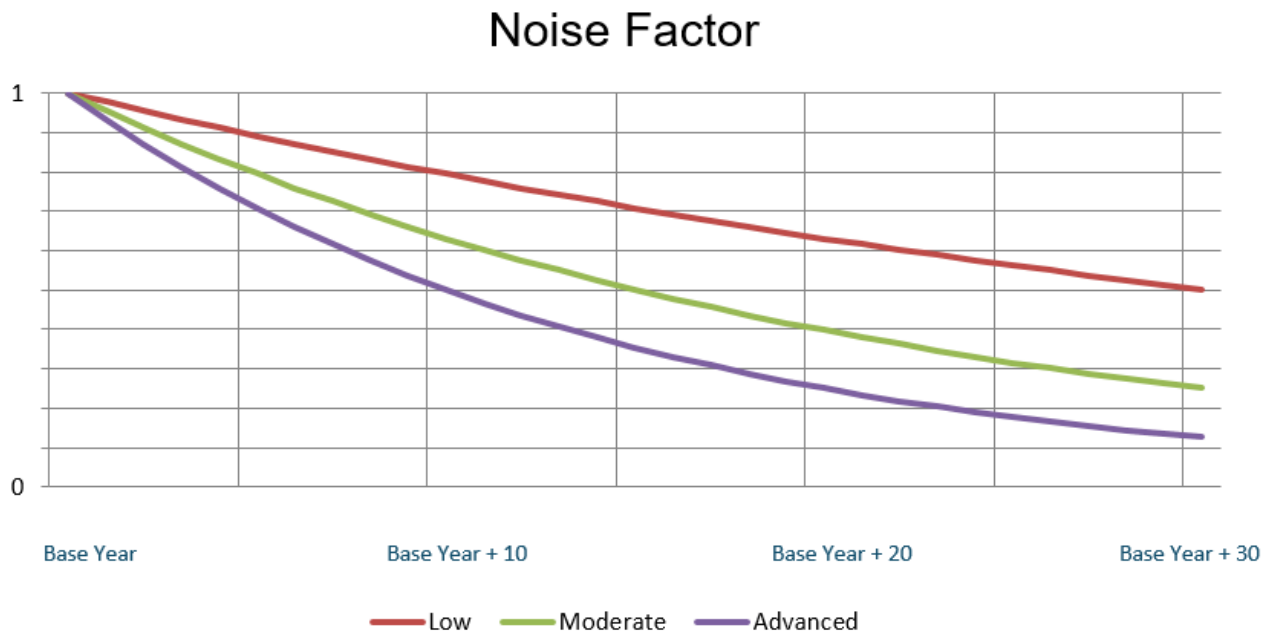
2b. Noise Modelling



2b. Noise Future Years Processing



2b. Noise Technology Improvements



Noise Factor is a multiplicative coefficient applied to noise operations before running noise models.

3. Trends Results

Results:

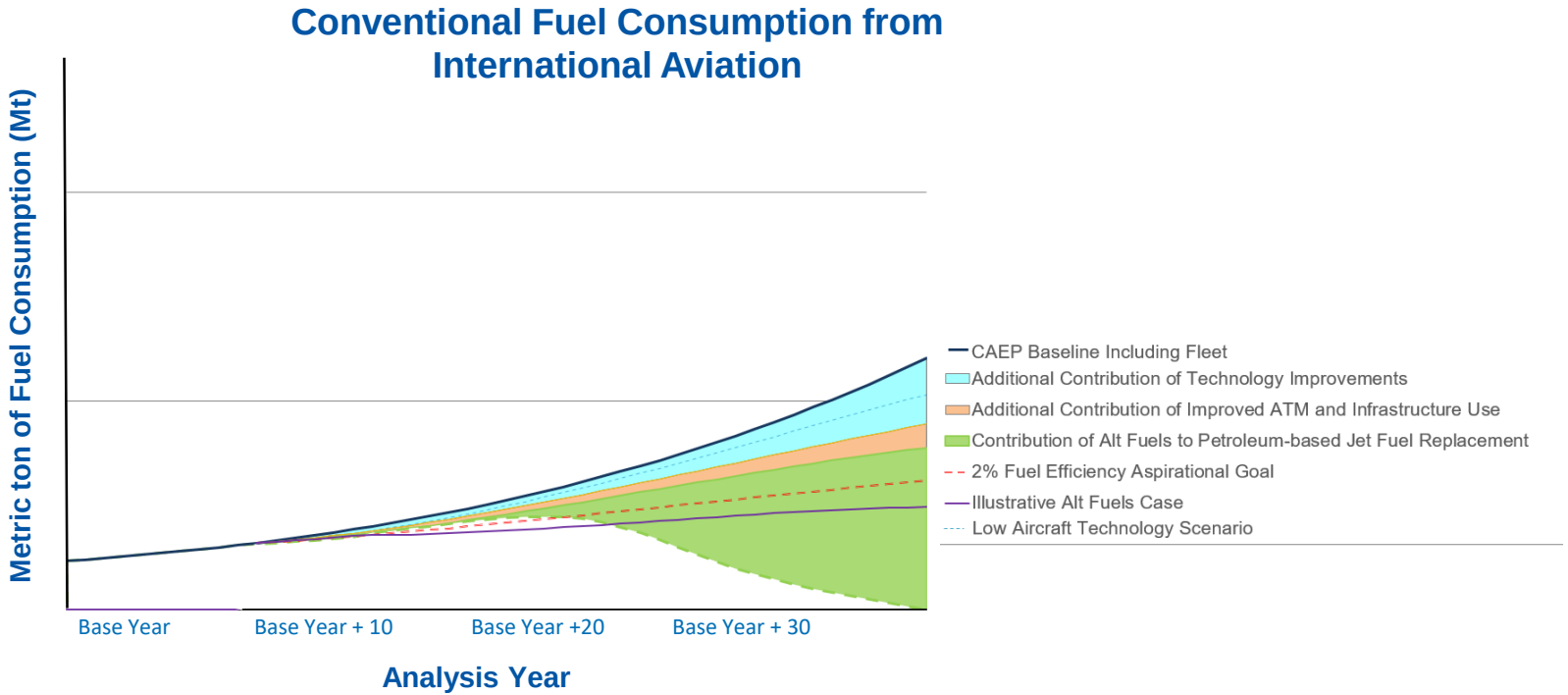
- GHG and LAQ Results
- Full Flight Fuelburn and CO_2
- Full Flight NOx
- Full Flight nvPM

- LAQ (Below 3000 feet) NOx
- LAQ (Below 3000 feet) nvPM + vPM
- LAQ (Below 3000 feet) CO and HC
  (computed but not reported)

Tables and Graphics reported by ICAO/CAEP region, International Only and International plus Domestic (Global):

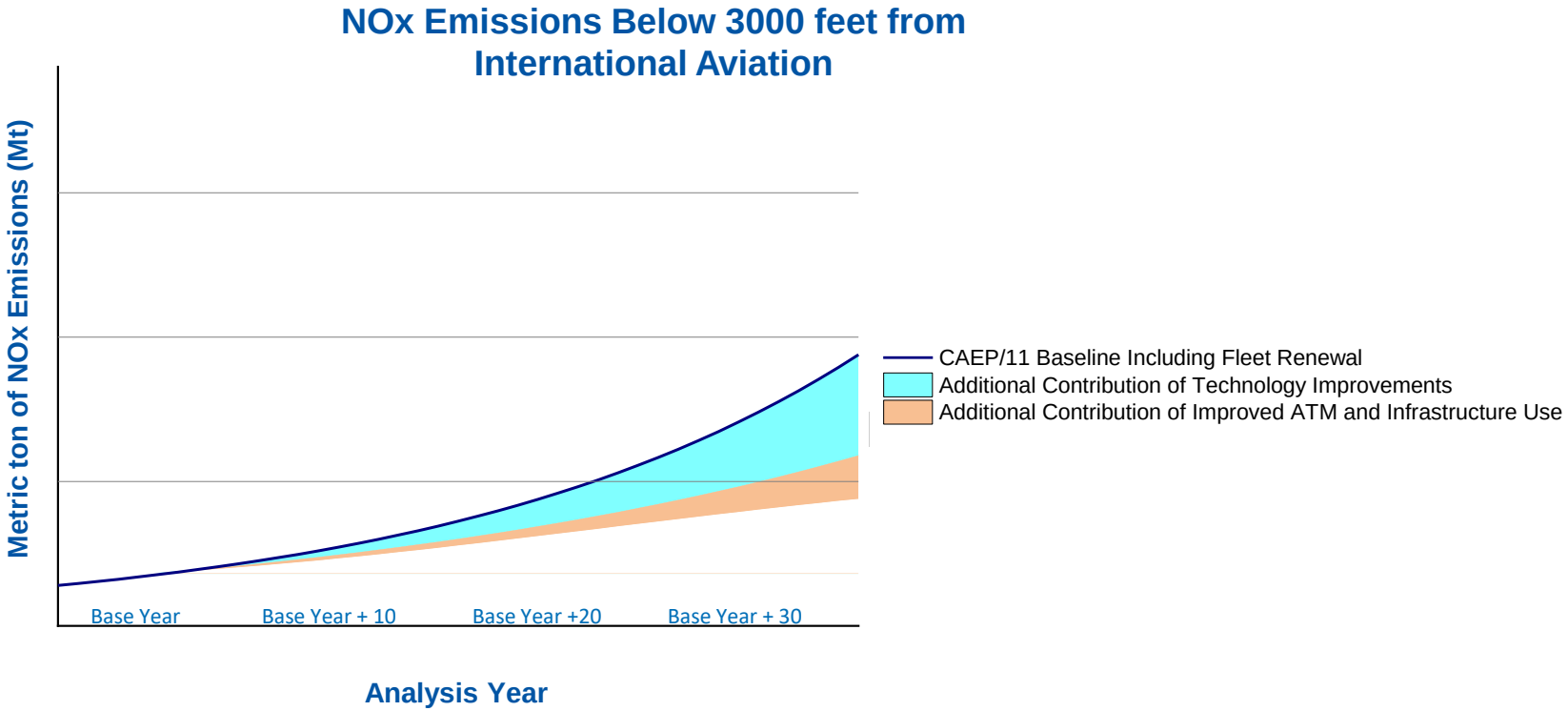
- Noise Results
- Day Night Average Sound Level (DNL) Contour Area
- DNL Population Exposure

3. Trends Results

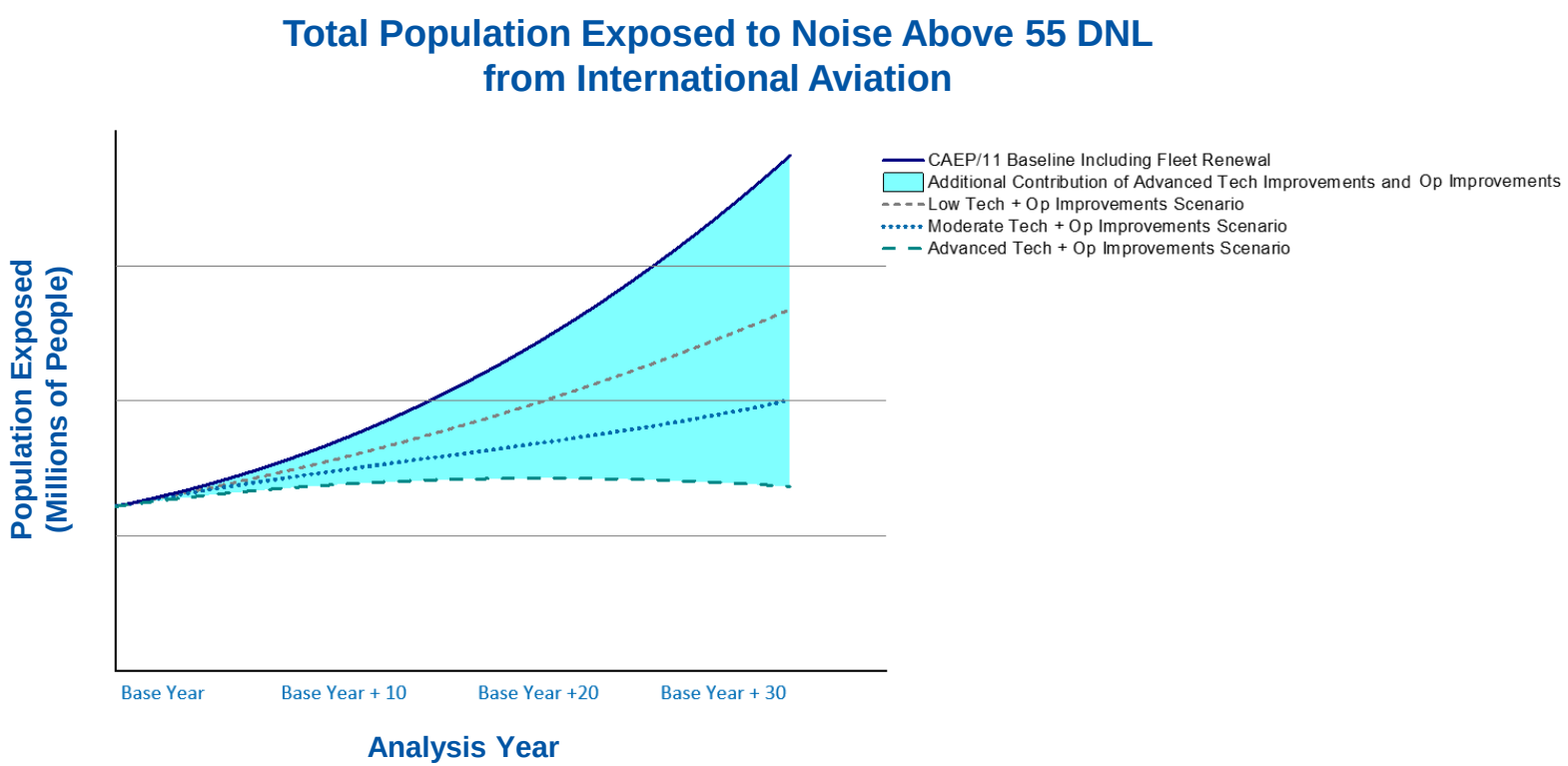


ICAO Fuel Efficiency is measured as Fuel per Revenue Tonne Kilometer and 2% per annum is the long-term aspirational goal.

3. Trends Results



3. Trends Results



Considerations for Improving Future Trends Assumptions

- **LAQ Dispersion modelling** for a limited number of airports as a feasibility study.
- **Fleet evolution modelling** using a hybrid (discrete aircraft technology improvements up to certain year and then switch per annum improvements).
- **Population forecasting.**
- **Airport constrained forecast** used for fleet evolution.

Appendix

- Links
- Fleet Evolution Models
- Environmental Modelling
  - GHG Models
  - Noise Models
  - LAQ Models
- Fleet Technology Rollover
- Retirement Curves

Links

- **Base of Aircraft Data (BADA):**
  https://simulations.eurocontrol.int/solutions/bada-aircraft-performance-model/
- **PIANO:**
  https://lissys.uk/index2.html
- **Engine Emissions Data Bank (EEDB):**
  https://www.easa.europa.eu/easa-and-you/environment/icao-aircraft-engine-emissions-databank#group-easa-downloads
- **Aircraft Noise and Performance (ANP):**
  https://www.aircraftnoisemodel.org/
- **Noise Certification Database (NoisedB):**
  http://noisedb.stac.aviation-civile.gouv.fr/bdd
- **Gridded Population of the World (GPW v4):**
  https://sedac.ciesin.columbia.edu/data/collection/gpw-v4

Fleet Evolution Models

	FOM	FLEET-Builder	AAT
Used for	CAEP 5 – 11	CAEP 12+	CAEP 10+
Developed by	U.S. FAA	U.S. FAA	EASA and EUROCONTROL, EC
Model Name	Fleet and Operations Module	FLEET-Builder	Aircraft Assignment Tool

FLEET-Builder was designed to replicate the FOM fleet evolution approach for Trends.

Environmental Modelling: GHG Models

	AEDT	IMPACT	FAST
Used for	CAEP 9+	CAEP 11+	CAEP 9+
Developed by	U.S. FAA	ECTL	U.K. MANCHESTER METROPOLITAN UNIVERSITY
Model Name	Aviation Environmental Design Tool	Integrated Aircraft Noise and Fuel Burn and Emissions Modelling Platform	Future Civil Aviation Scenario Software Tool

Environmental Modelling: Noise Models

	AEDT	STAPES	ANCON
Used for	CAEP 9+	CAEP 10+	CAEP 8+
Developed by	U.S. FAA	ECTL, EC and EASA	U.K. CAA
Model Name	Aviation Environmental Design Tool	SysTem for AirPort noise Exposure Studies	Aircraft Noise Contour Model

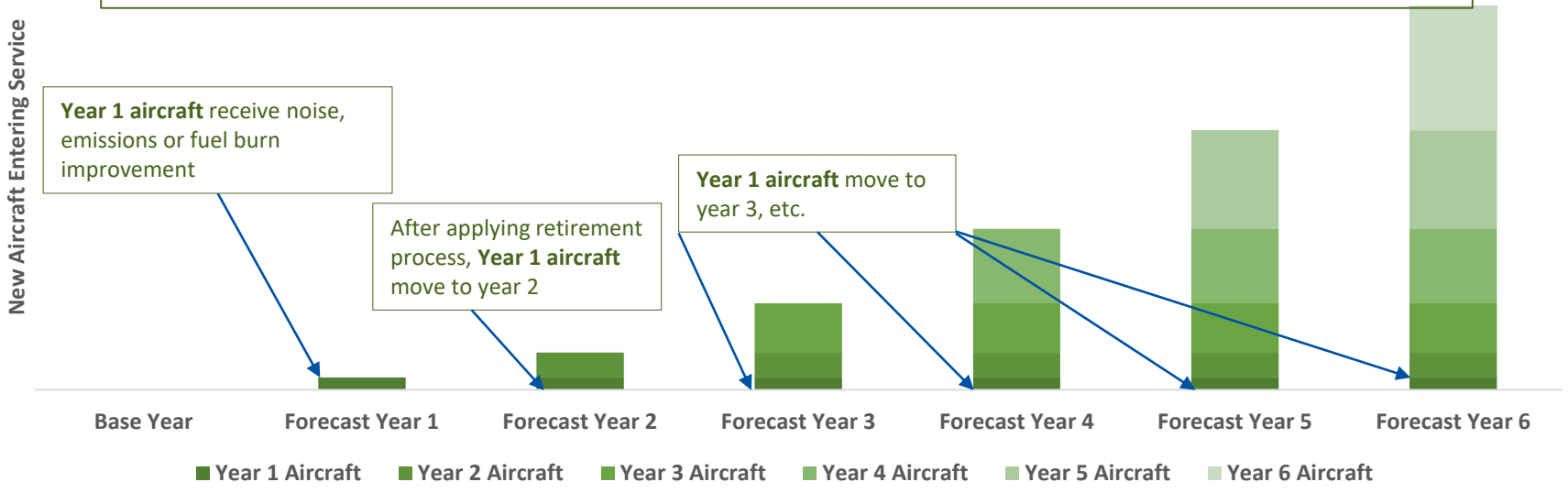
Environmental Modelling: LAQ Models

	AEDT	OPEN-ALAQS	LASPORT	PolEmiCa
Used for	CAEP 9+	CAEP 12+	CAEP 8+	CAEP 12+
Developed by	U.S. FAA	ECTL	JANICKE CONSULTING	Ukraine, NAU
Model Name	Aviation Environmental Design Tool	Open-ALAQS	LASAT for Airports	Pollution and Emission Calculation

Fleet Technology Rollover

New cohorts of aircraft performance improves year-on-year based on the technology scenarios defined by WG1 and WG3

Aircraft entering the fleet in year 1 receive an analysis specific noise, emissions or fuel burn improvement that stays in place as they move through the forecast -- same process for new aircraft in each subsequent year.



Retirement Curves

Retirement curves developed using historical data on aircraft retirements by age.

Curves developed for all markets: passenger, freighter and business jet.

Passenger Aircraft Retirement Curves