Advanced modeling of aircraft fleet renewal

Illustration on the Narrow body segment

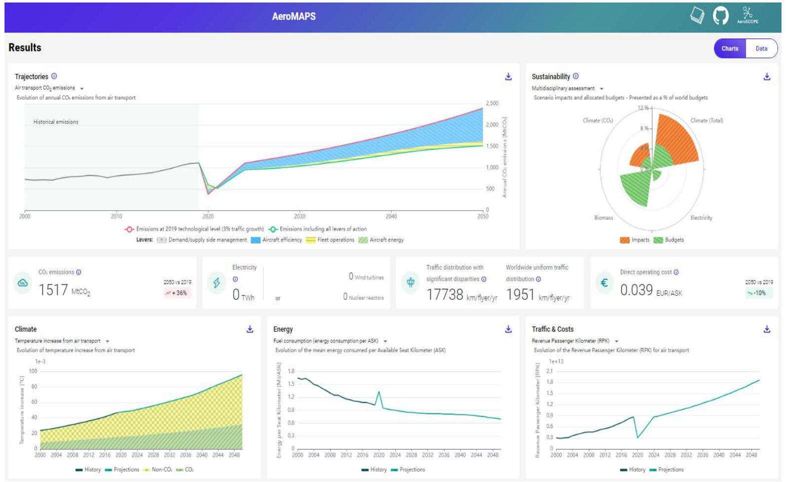
09/07/2024

The AeroMAPS project

Complexity and uncertainty of the aviation system

Multi disciplinary evaluation tool

Scientific transparency



Thesis objective : moving toward an **IAM**

Logics understanding, Multi-fidelity

Calibration (trend & prospectif)

AeroMAPS development axis + past experience

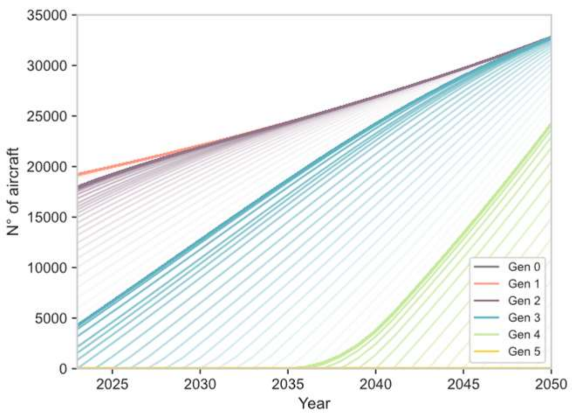
➢ First work on **fleet renewal**

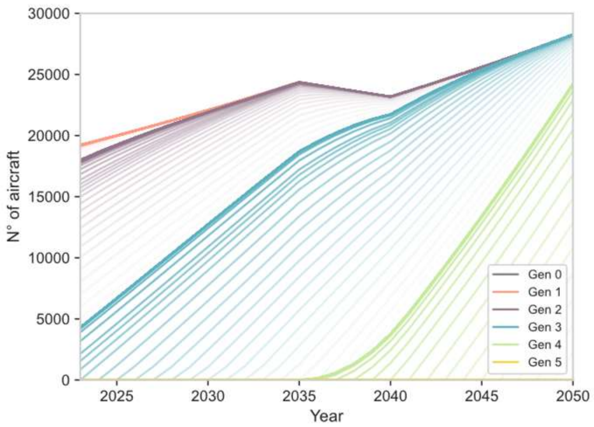
Why studying fleet renewal ?

- an **environmental, economic** and **strategic** challenge

- **Logics** (economical) and **constraints** (industrial)

- **Uncertainties** (traffic, demand, technology, fuel price…)



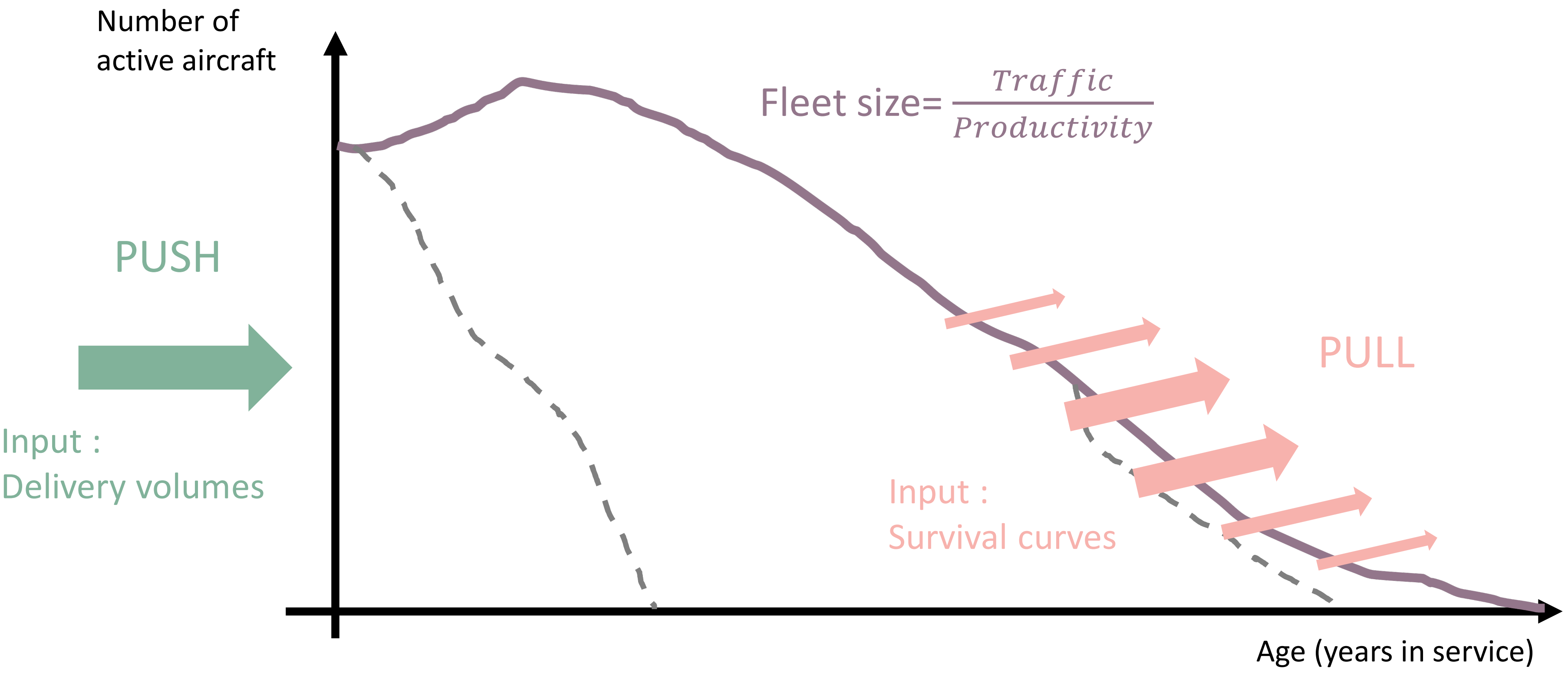


Examples of fleet renewal scenarios

State of the art

Approach on **retirements heterogeneity** (Dray & Al.) or on **deliveries volume** (Kulhen & Al.).

References : AIM2015 Dray & Al., Kuhlen & Al. (DLR), ICAS article



State of the art

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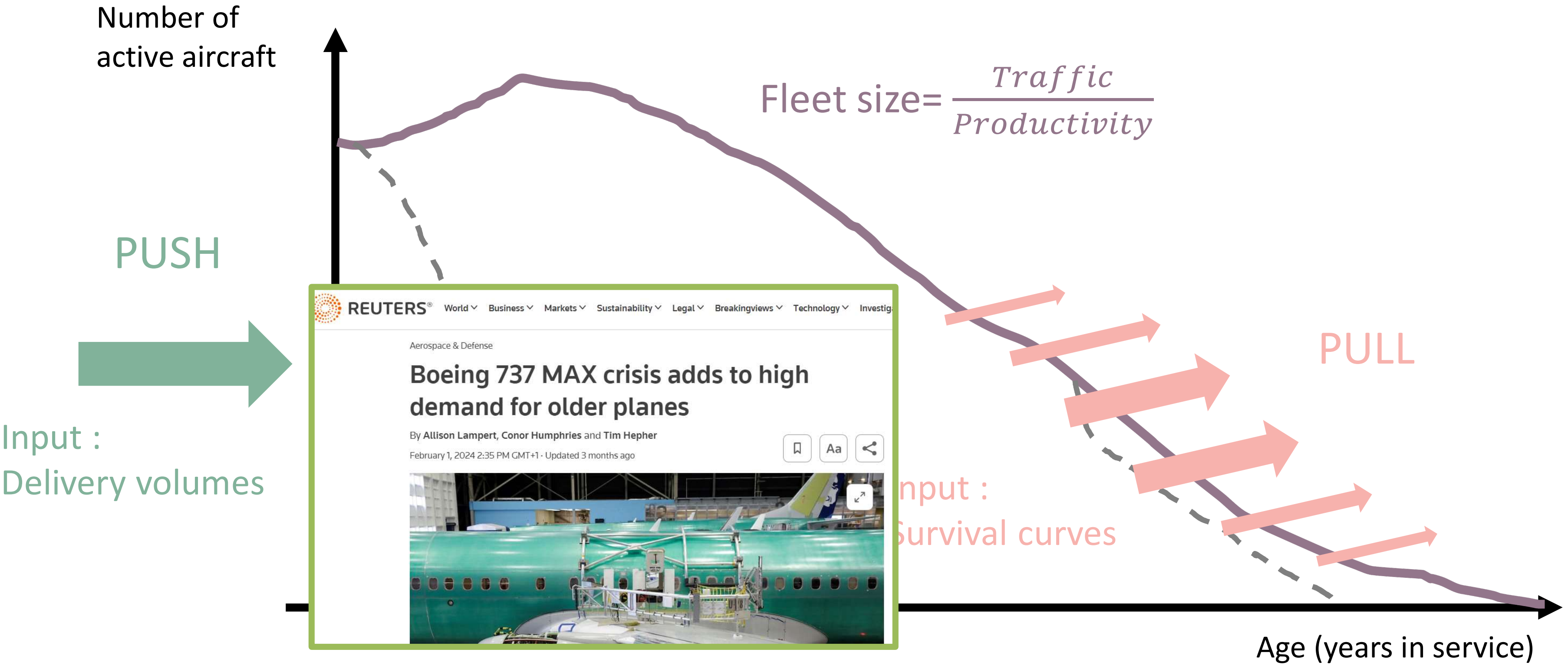


REUTERS World Business Markets Sustainability Legal Breakingviews Technology Investig

Aerospace & Defense

Boeing 737 MAX crisis adds to high demand for older planes

By Allison Lampert, Conor Humphries and Tim Hepher

February 1, 2024 2:35 PM GMT+1 · Updated 3 months ago

Scientific approach

AeroMAPS **realism, flexibility** and **calibration** criterias

- ➢ **« push »** model + **statistical retirement heterogeneity** module

Aircraft segmentation simplification

Research questions:

1. How does fleet fuel consumption relate to the volume and timing of fleet renewal?
2. To what extent are aircraft retirements heterogeneous?
3. What is the emissions reduction potential of prioritising the retirement of older aircraft?

Summary

I. *Deliveries volume and temporality : a « push » model*

II. *Retirements heterogeneity : statistical module*

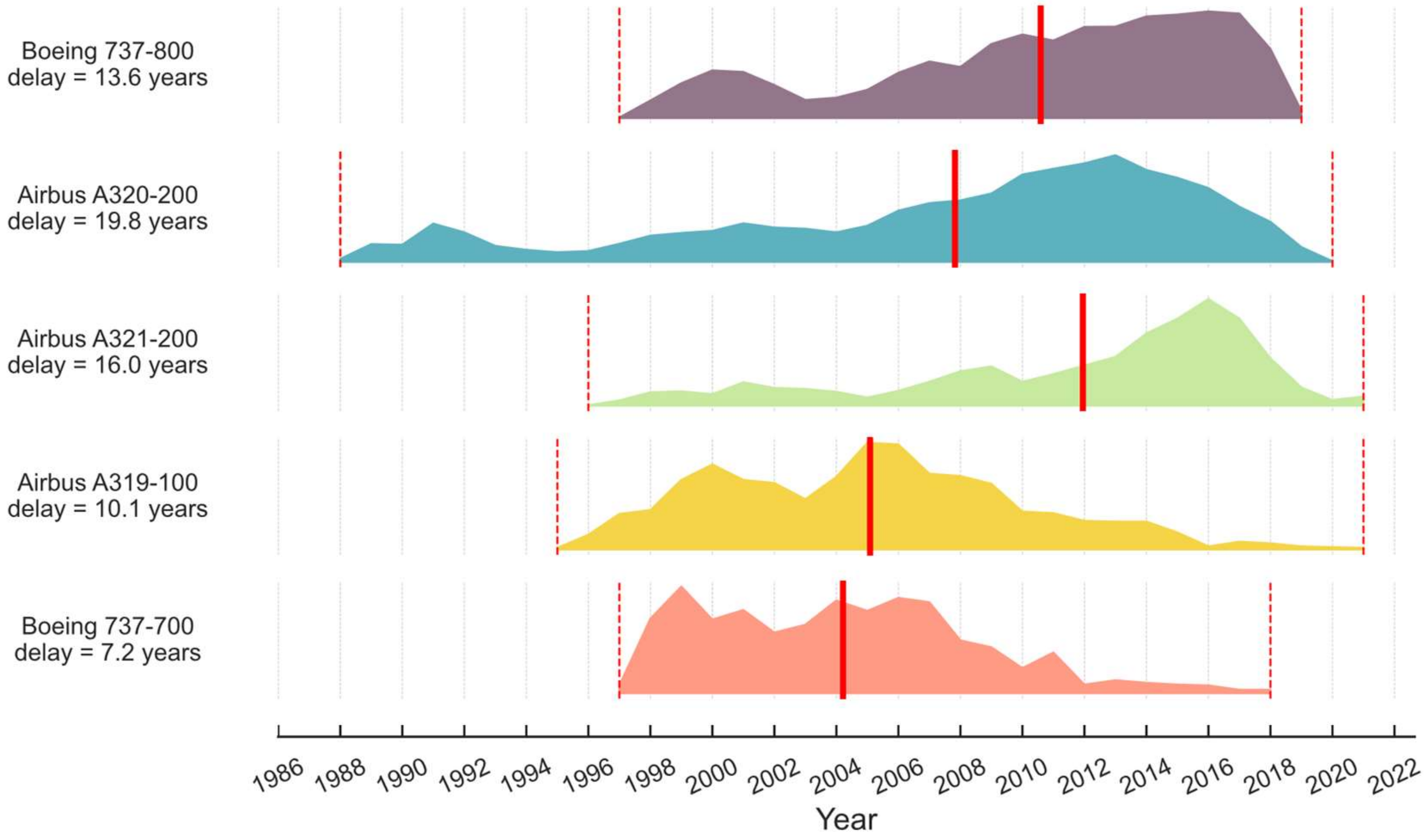
III. *Integrated fleet modeling*

IV. *Limits and next steps*

I. Fuel burn and delivery temporality

Analysis and quantification using a push model

Late deliveries



Relative production profile of top 5 produced NB, mean delay of production (continuous red lines), Planespotters data.

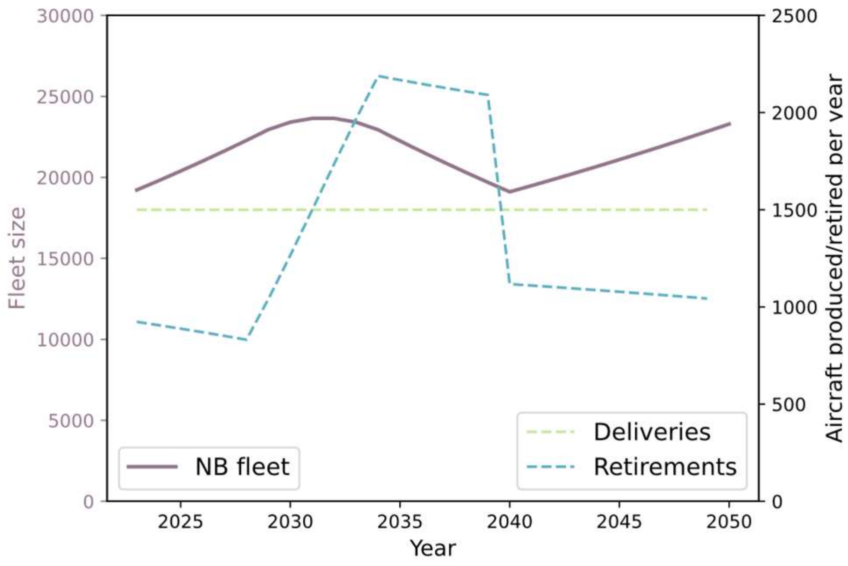
Push modelling on an aircraft segment

Inputs :

- **Traffic** (ASK/year) , productivity (*)
- **Deliveries** (**)

Outputs :

$$Ret_t = (F_{t-1} - F_t) + Del_t$$



Illustrative scenario of the relation between fleet size, deliveries and retirements

**Adjustments are made to take account of variable aircraft productivity.*

*** Delivery assumptions can be built up by smoothing long-term withdrawal assumptions (25-year service life).*

Scenario context

<u>Other hypotheses</u>(*value chosen*):

Introduction date, aircraft performance (*35/50, -15%*)

Initial fleet composition(*100% Gen 3*)

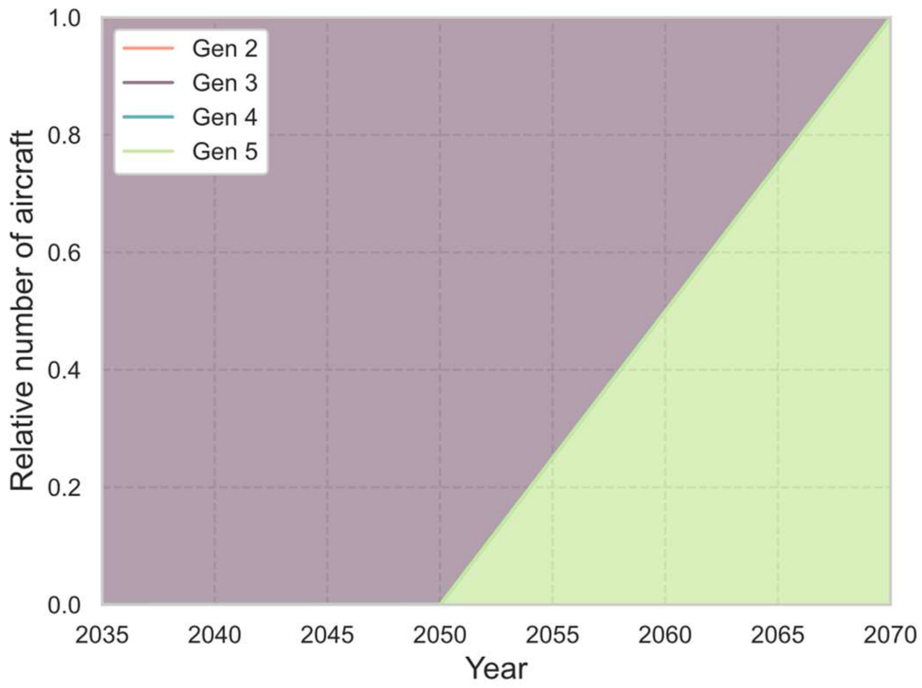
Deliveries and traffic post-scenario (*5%/an, 0%)*

Deliveries composition (*prioririsation*)

Retirements composition (*prioririsation*)

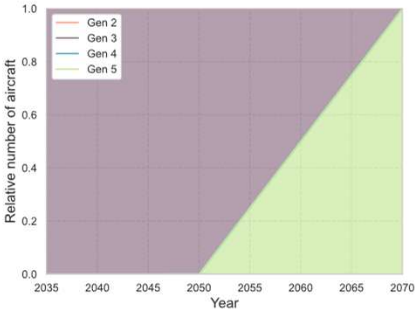
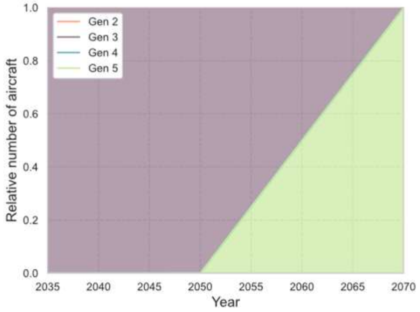
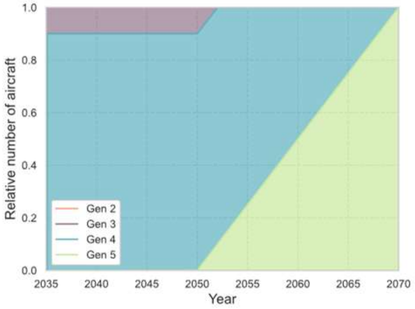
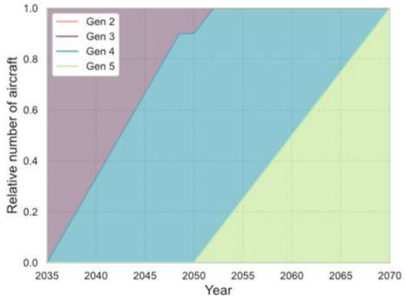
Aircraft productivity (*constant*)

Aircraft performance (*fixe temps et espace*)

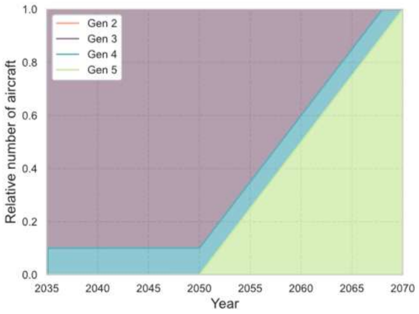
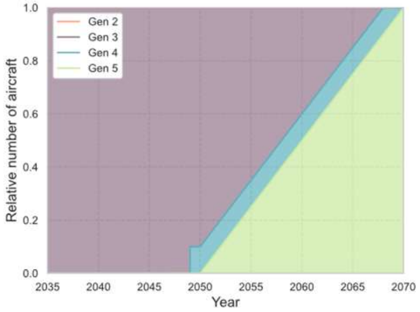
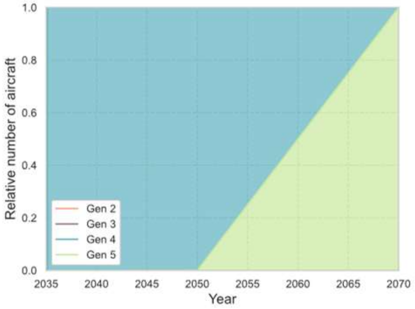
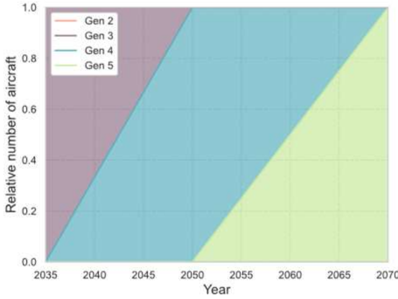


Evolution of the fleet composition in a no-renewal scenario

The renewal impact depends on the context

Rate /production timing	0 year	15 years
0 %		
90 %		

The renewal impact depends on the context

<table>
<tr><th>Rate /production timing</th><th colspan="2">0 year</th><th colspan="2">15 years</th></tr>
<tr><td>0 →10%</td><td>
</td><td>35 years impact</td><td>
</td><td>20 years impact</td></tr>
<tr><td>90 → 100%</td><td>
</td><td>15 years impact</td><td>
</td><td>Little impact</td></tr>
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Production delay and **renewal rate** are key variables for the efficiency of fleet renewal.

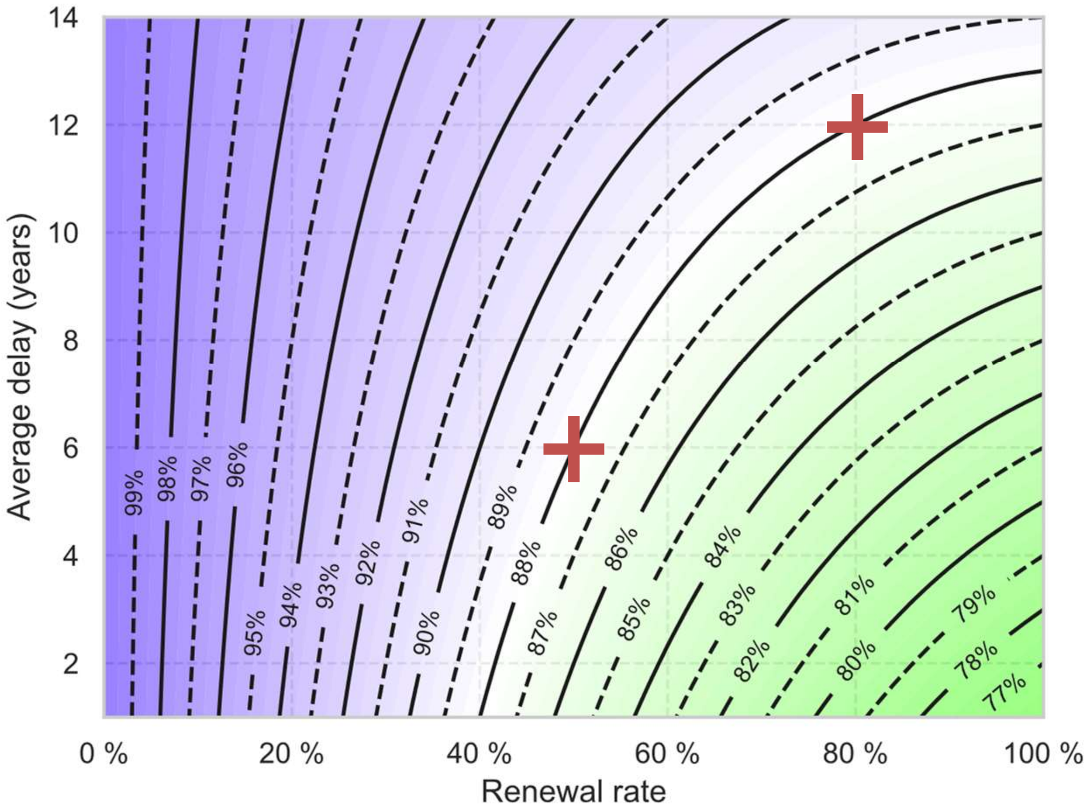
Environmental indicator and results

Ramp-up des SAF.
Availability constraint ?
High costs

- ➢ Cumulated fuel consumption.

Fleet produced on 15 years
Impacts on 30 years

- ➢ Normalisation on relative gains



Coupled impact of the variables on the cumulated fuel consumption indicator

Metric :

$$M_2 = 1 - \frac{F_{2035-2070,\text{No renewal}} - F_{2035-2070,\text{Scenario}}}{F_{2035-2050,\text{No renewal}}}$$

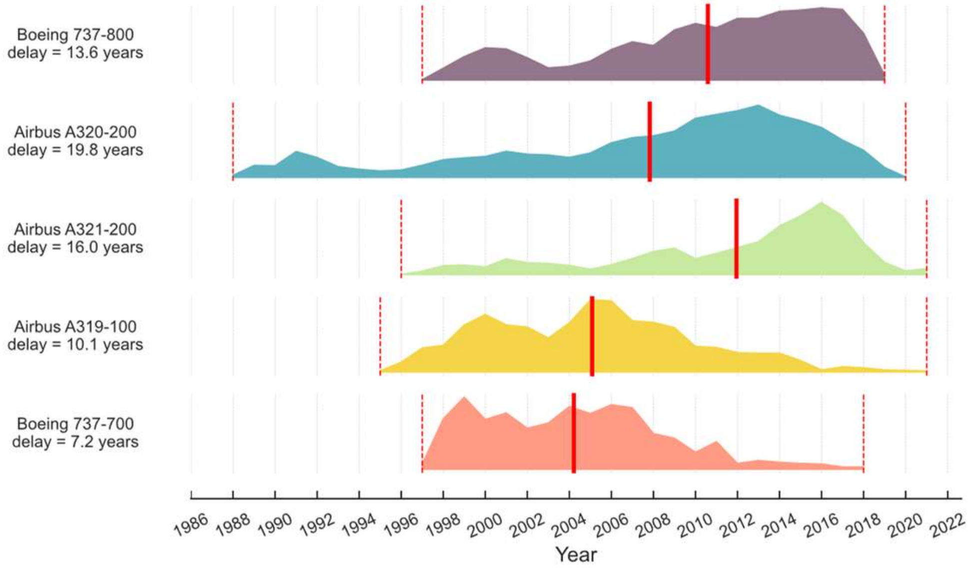
Summary of the *push* case study

Production delay and **renewal rate** are key environmental parameters

Delay determinants? *(ramp-up, commercial success, traffic growth context…)*

Limits of this work:

- productivity
- energy decarbonisation
- aircraft manufacturing emissions
- incremental improvements
- **heterogeneity of retirements & deliveries**

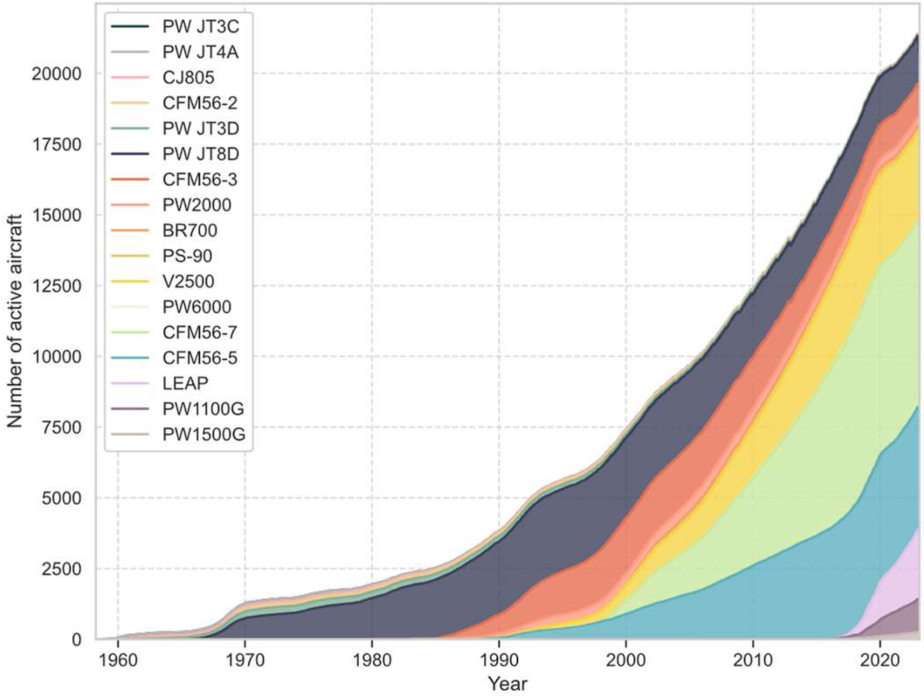


Relative production profile of top 5 produced NB, mean delay of production (continuous red lines), Planespotters data.

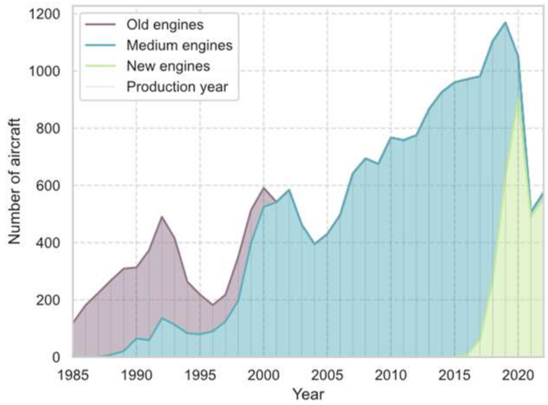
II. Retirements heterogeneity

A statistical module to measure and project the future heterogeneity of retirements

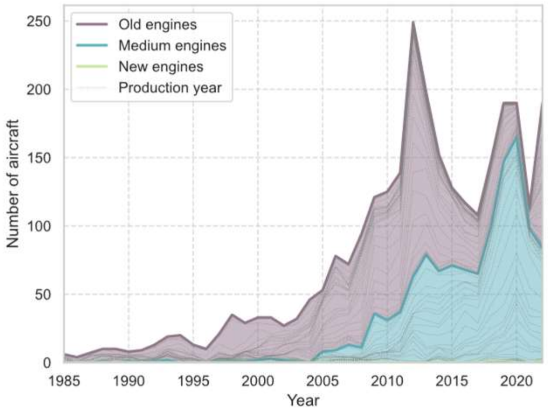
From fleet data to production and retirement data



Evolution of the narrow body fleet categorised per engine type, Planespotters data



Aircraft produced per year, per generation

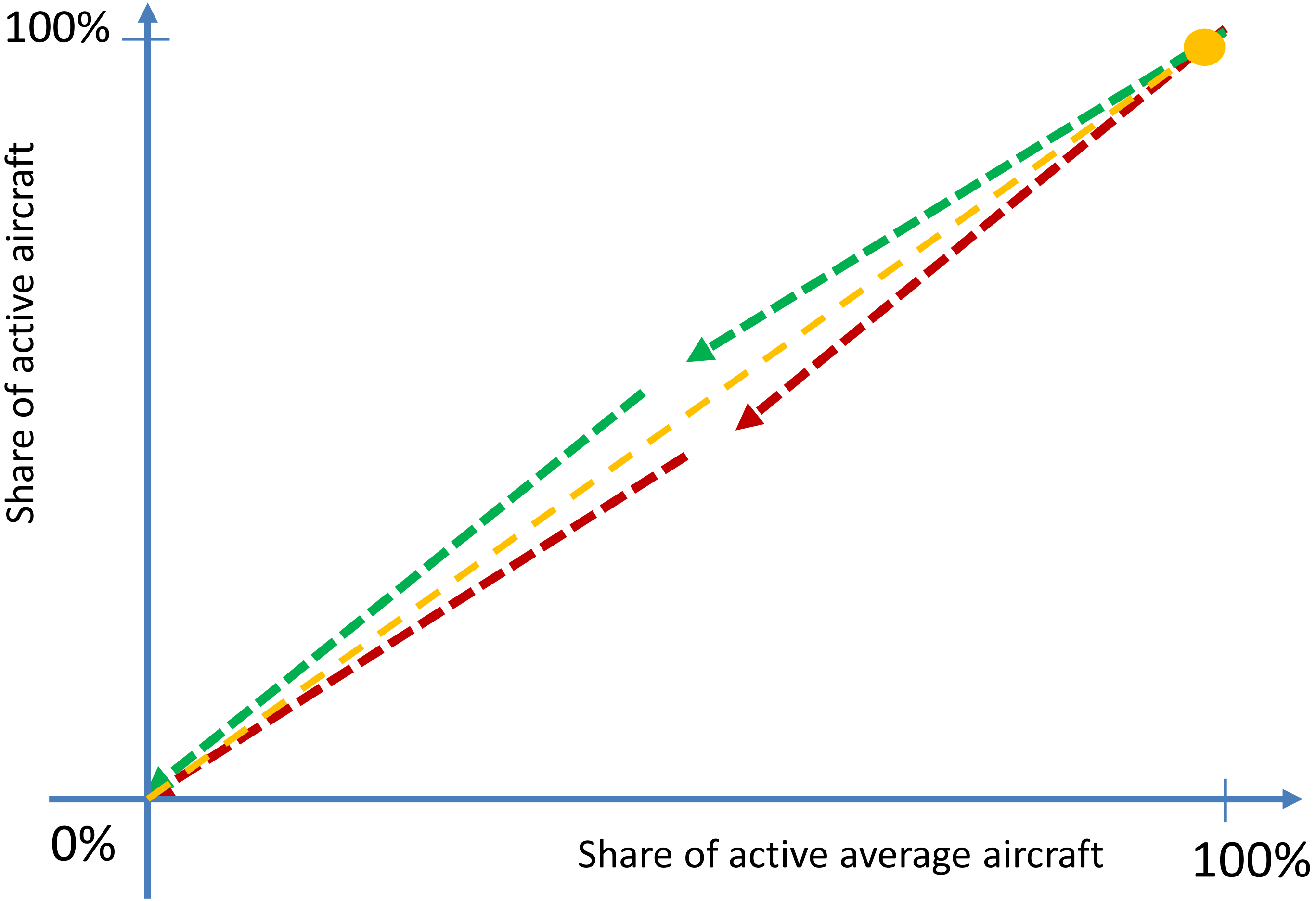


Aircraft produced per year, per generation and millesime

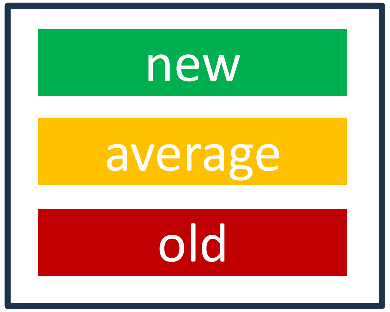
Hard to model…

Visualisation of retirement heterogeneity (8269 retirements)

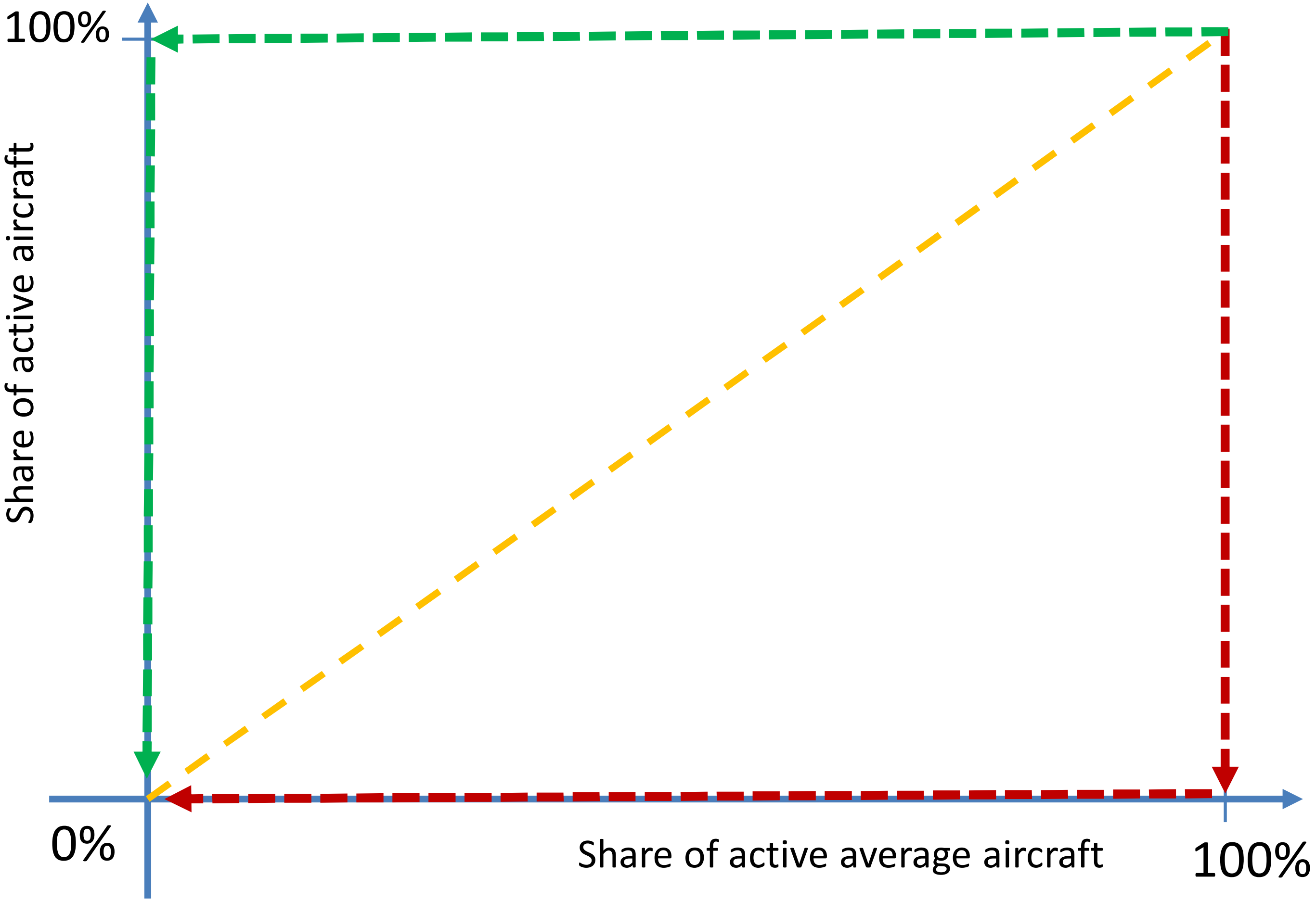
Heterogeneity graphs (1)

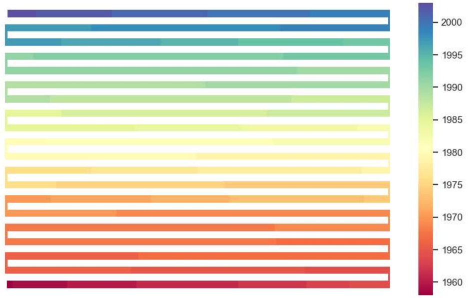


Random



Heterogeneity graphs (2)





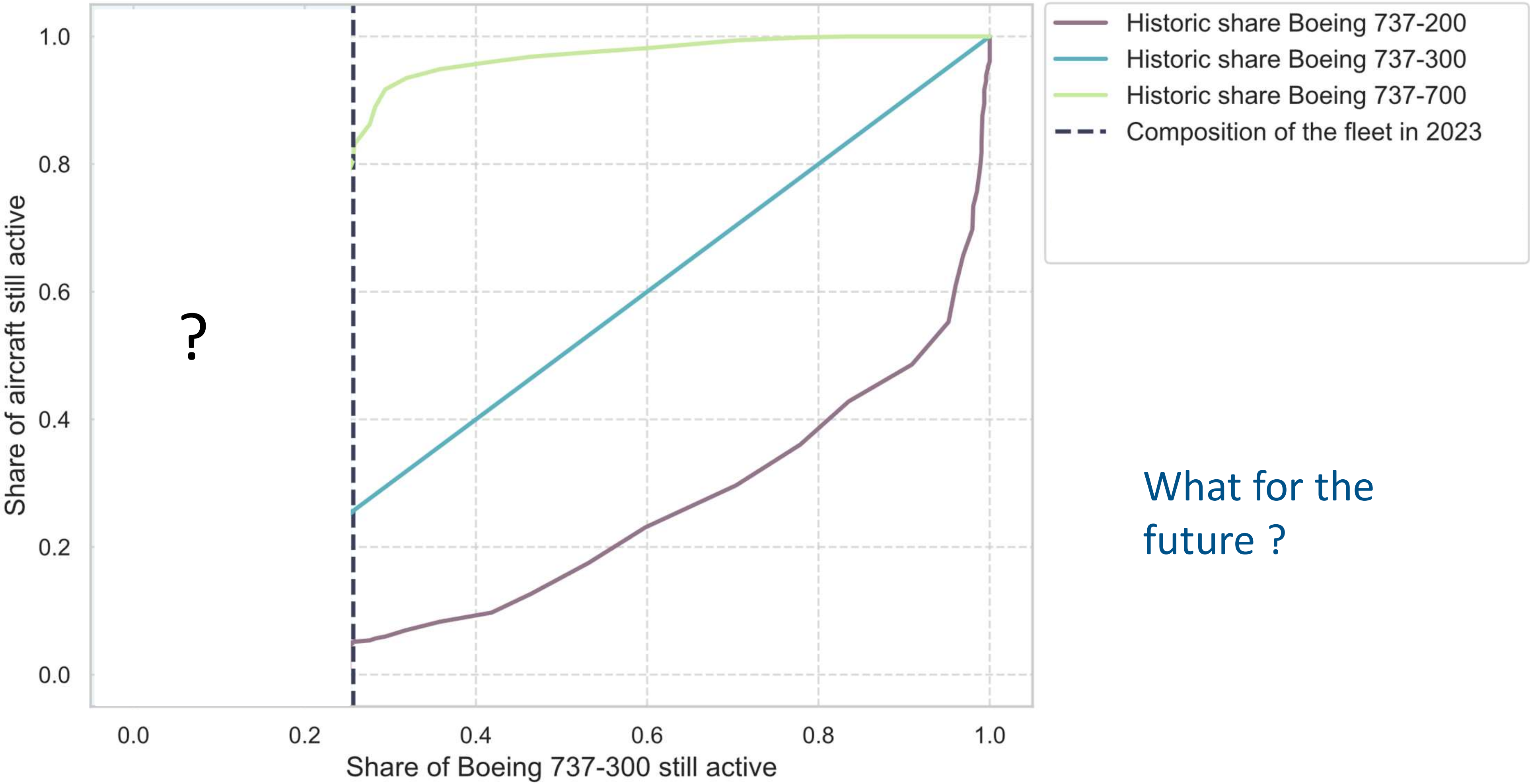
Prioritised

- new
- average
- old

Illustration with the 737 family

	Entry in service	Engines	Max PAXs	Max payload range (nm)
 Boeing 737-200 « Original »	1967	PW JT8D	136	1900-2400
 Boeing 737-300 « Classic »	1984	CFM56-3B	149	2850
 Boeing 737-700 « Next Generation »	1997	CFM56-7B	149	3300-5500

What degree of prioritisation ?



What for the future ?

Statistical approach on relative propension

Probabilist model

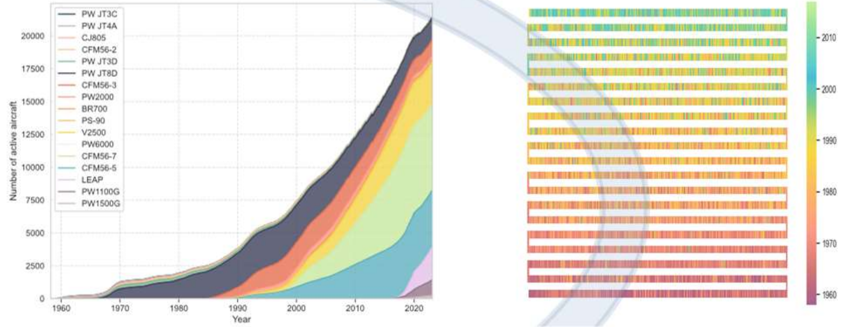
$$rp_{i,j} = e^{-\alpha_{i,j}}$$

i : aircraft type, j : prod year

$$\Rightarrow \quad P_{i,j,t} = \frac{F_{i,j,t} \times rp_{i,j}}{\sum_{m,n} F_{m,n,t} \times rp_{m,n}}$$

Past data likelyhood

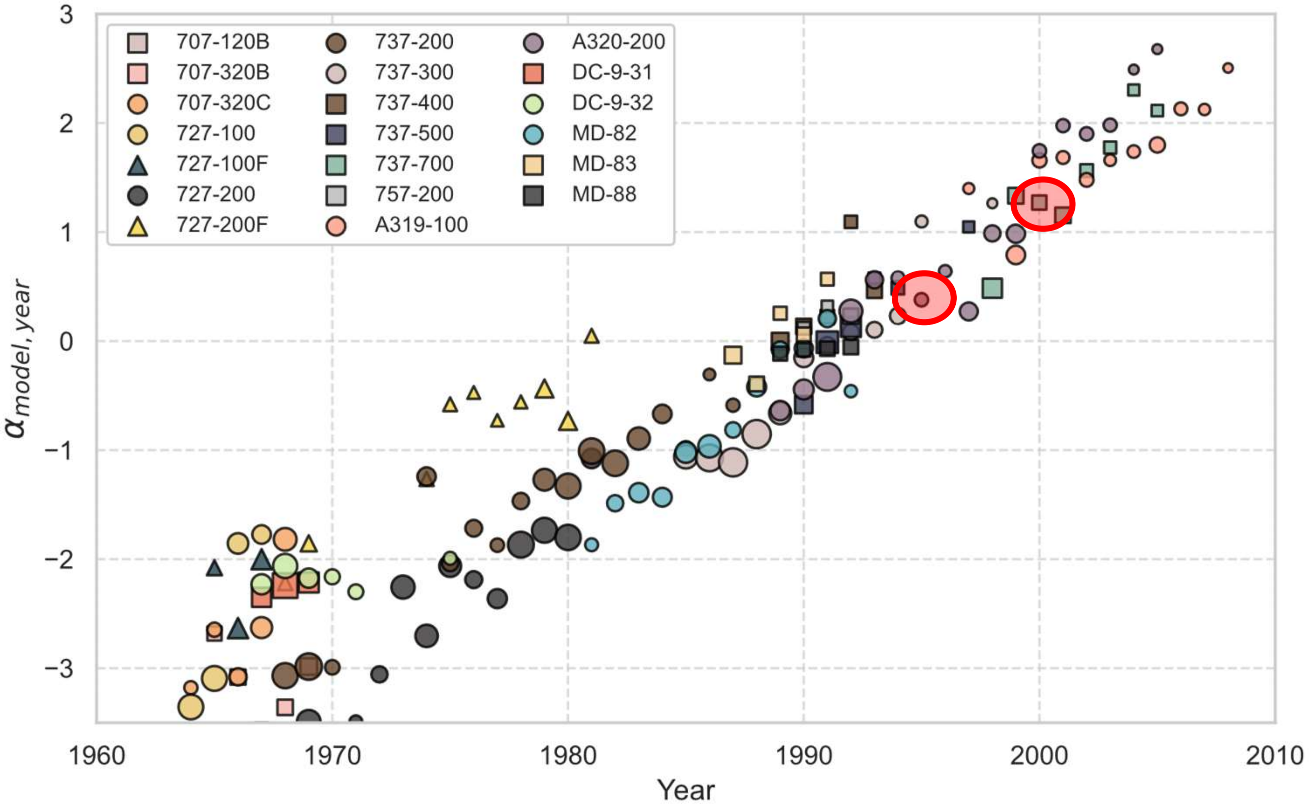
$$V_{X_t=(i,j)}\left(\left(\alpha_{i,j}\right)_{i,j}\right) = \frac{e^{-\alpha_{i,j}} \times F_{i,j,t}}{\sum_{m,n} e^{-\alpha_{m,n}} \times F_{m,n,t}}$$



Fleet and retirements historic

To be maximised for 8 269 observations !

Best estimates from the model



Best estimates of relative propension for aircraft type and aircraft production year for which $N_{prod} > 10$ et $N_{ret} > 5$, top 20 NB

Absolute **comparison scale**

A320-200 (1995) vs 737-700 (2000) :

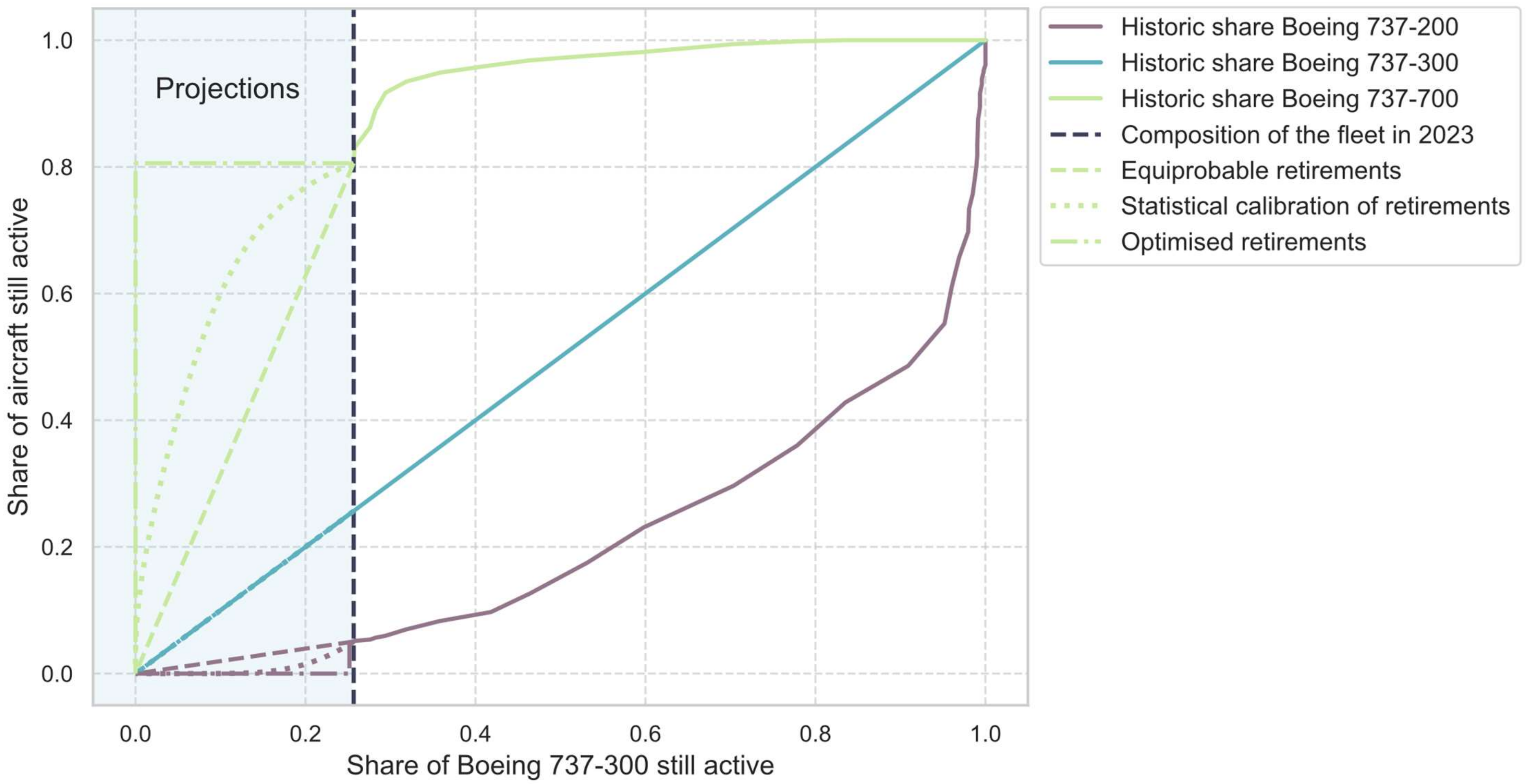
$$e^{0,89} - 1 = +\mathbf{144}\%$$

Trend

Being produced one year sooner :

$$e^{0,104} - 1 = +\mathbf{11,3}\%$$

Using the results to build relevant projections



Summary of the statistical modelling

Independance regarding the retirements timing

Absolute scale, and measurements for each aircraft type

On average, $\delta_{1\ year} \rightarrow +11{,}3\%$ retirement probability

- **Application to fleet modelling (trend calibration or exploratory)**

Current limitations :

- Retirement definition vs variation of productivity, and storage
- Constant relative propension hypothesis
- Model **validity** checks and **measurement uncertainties** (ongoing)
- Segmentation

III. Integrated fleet modeling

Push model combined with the heterogeneity module

Scenarios definition

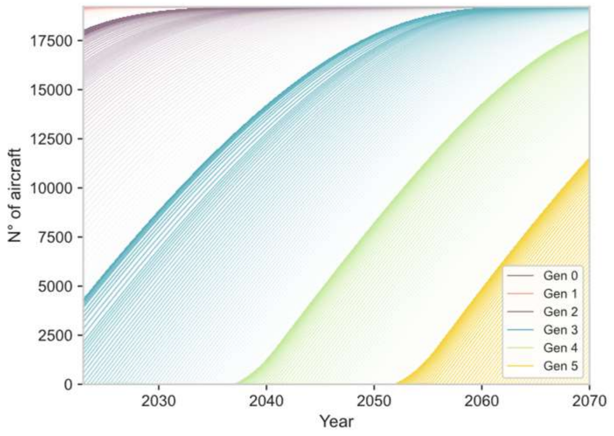
Traffic and fleet growth : 0%

15% **performance improvements** per generation (2035 & 2050)

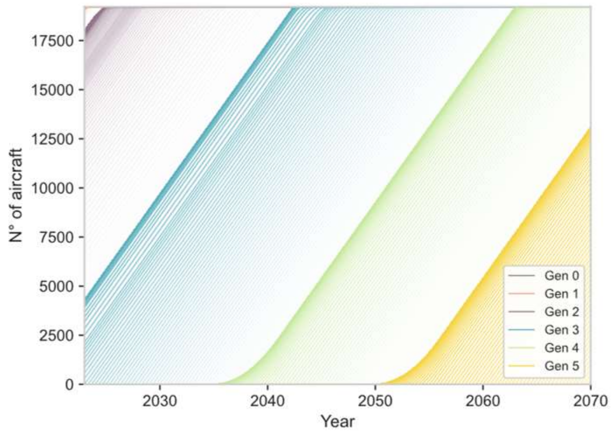
Constant operational efficiency

N°	Name	β	T	Annual fleet renewed
1	Trend (Reference)	0.107	6	4%
2	Optimised retirements	5	6	4%
3	Optimised retirements and deliveries	5	0	4%
4	Instantaneous optimised renewal	5	0	100%

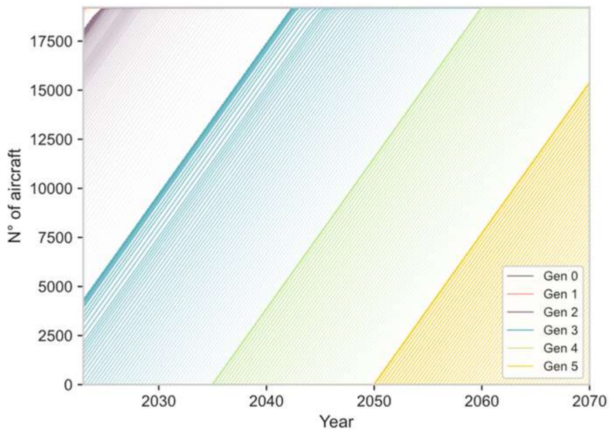
Results of the simulations



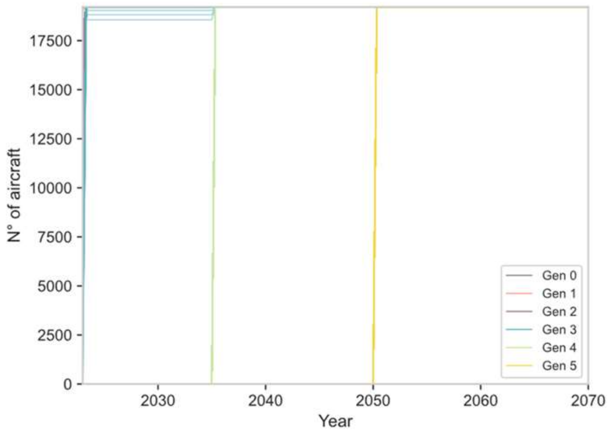
Trend



Retirements prioritisation

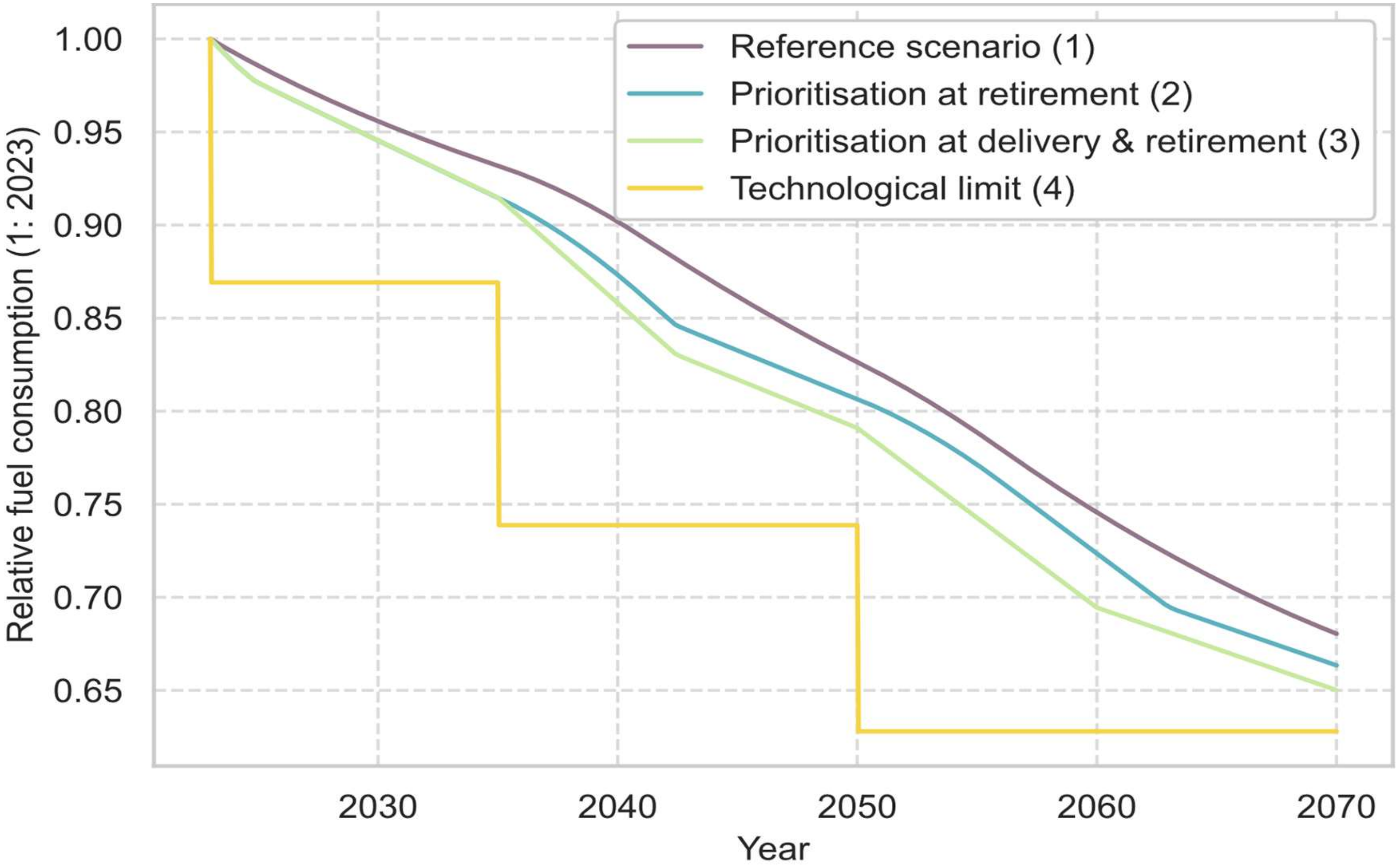


Retirements & deliveries prioritisation



Full and instant fleet renewal

Fuel consumption dynamics

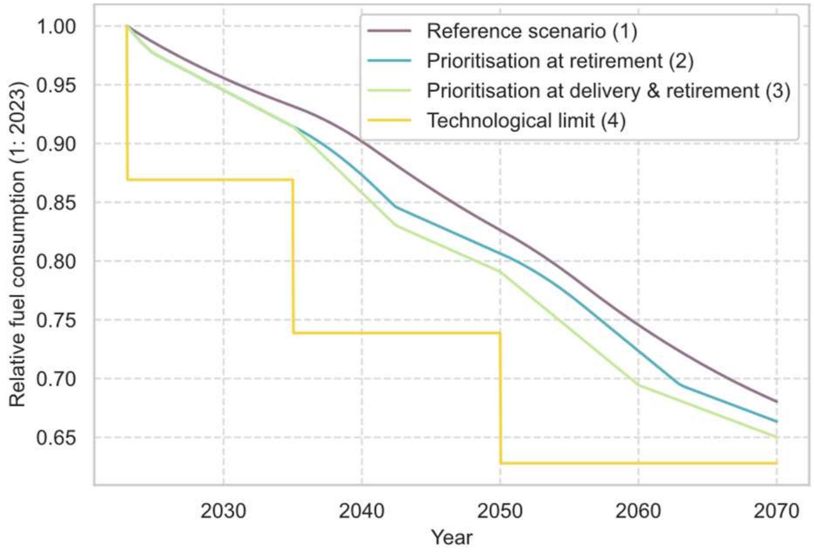


Relative evolution of the fuel consumption of the NB fleet for each scenario

Estimation of the potential of fleet renewal levers

Technological potential : **-14% Fuel Burn**
- ➢ Production prioritisation (1,6%)
- ➢ Retirements prioritisation (2,3%)
- ➢ Volume/temporality of production

Limitations :
- Coupled levers
- **Productivity heterogeneity**
- **Arbitrary segmentation**



Relative evolution of the fuel consumption of the NB fleet for each scenario

IV. Limits and perspectives

Aircraft/route allocation and aircraft productivity

Main blindspots of the current work

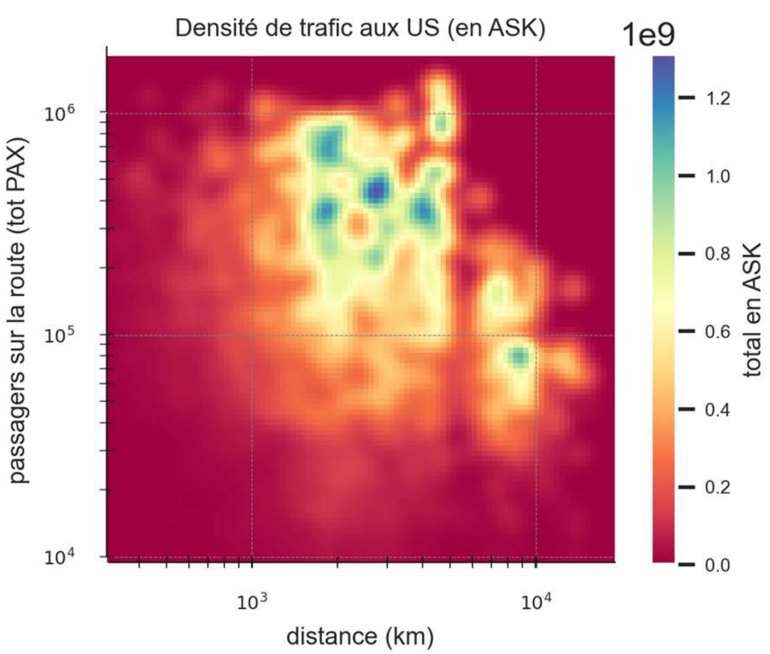
Aircraft/route allocation

- Combined with AeroSCOPE, creating growth assumptions
- **Substitution patterns between aircraft** (importance of **relative efficiency**)
- Impacts fuel burn **et the aircraft conception**
- Impacts productivity

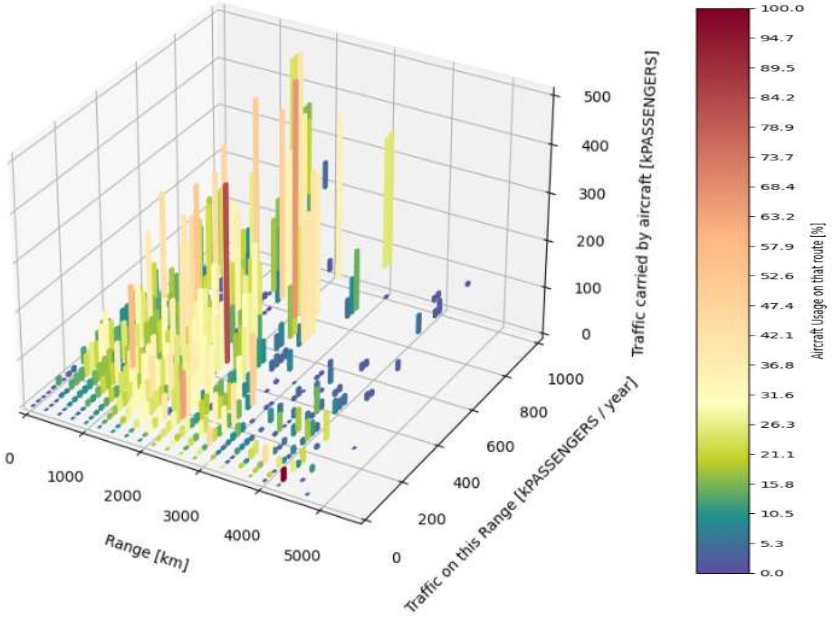
Heterogeneous productivity

- **Lowers** the relevance of a massive renewal
- **Reinforces** the relevance of a rapid renewal
- Diminishes flight hours for old aircraft

Aircraft allocation on routes



Traffic per route type in the US, Tobias Bischoff, BTS data

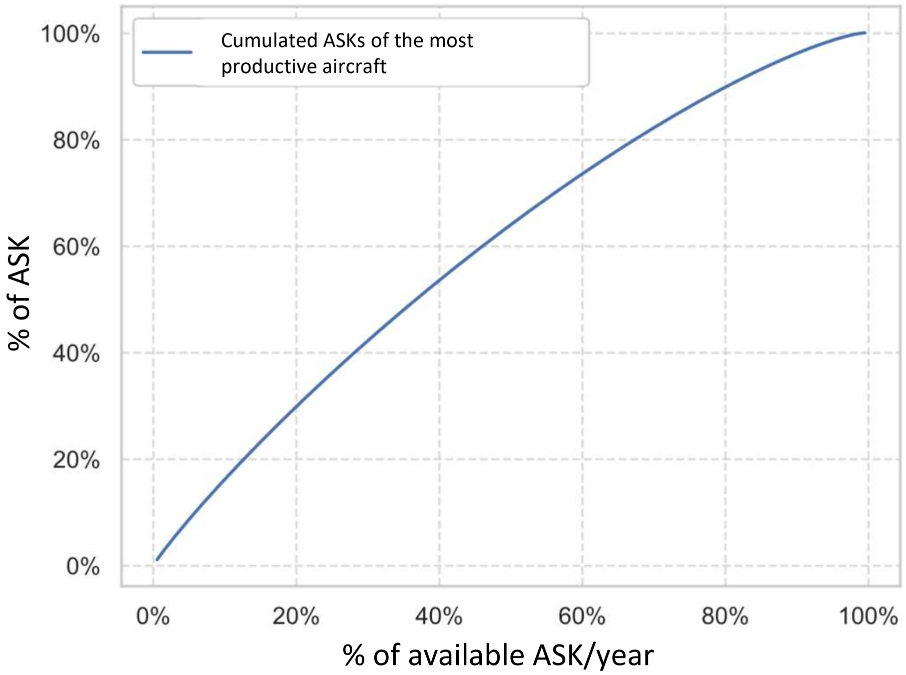


B737-800 allocation on route type in the US, Tobias Bischoff, BTS data

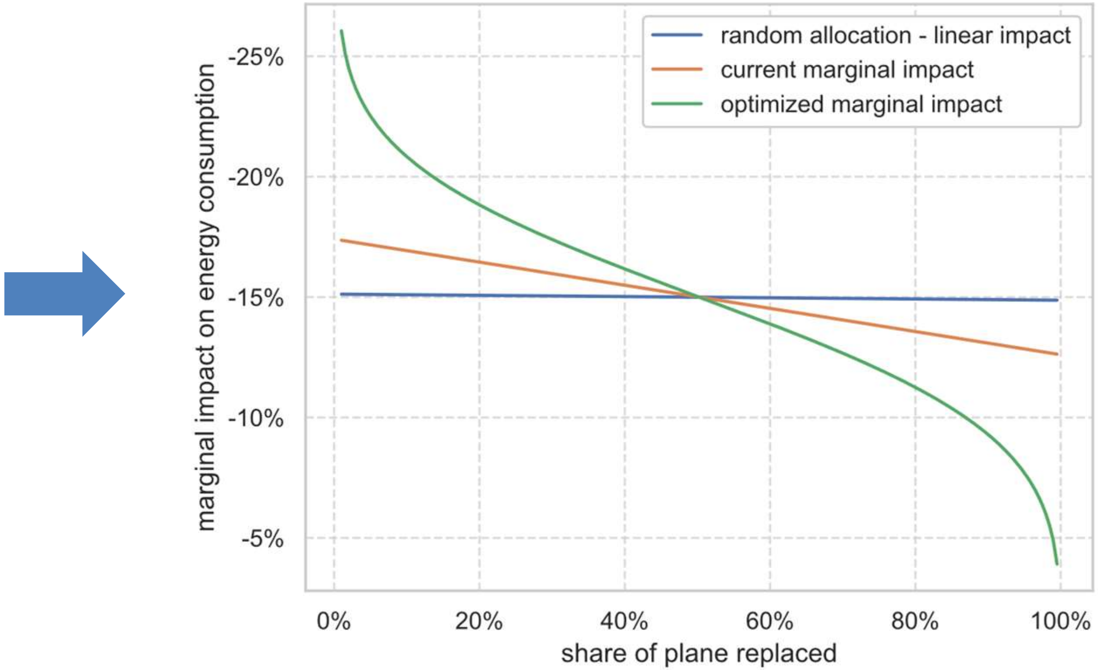
Understanding the **market segmentation** *(flow intensity, distance, freight, severity, fuel prices, labor prices...)*

- ➢ Potential for an aircraft with original specifications (hydrogen for instance)
- ➢ Complementarity and timing of aircraft programmes

Impact of the productivity– Pareto analysis



Pareto analysis showing of a minority of aircraft do a majority of the trafic, with environmental implications
Illustrative non-calibrated graph

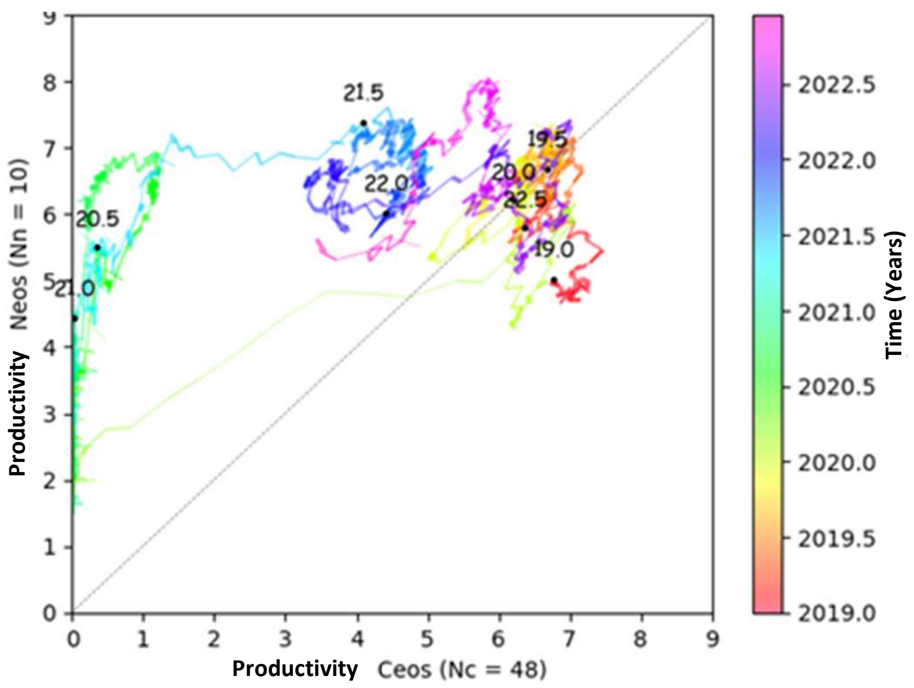


Marginal relative performance brought by new aircraft
Illustrative non-calibrated graph

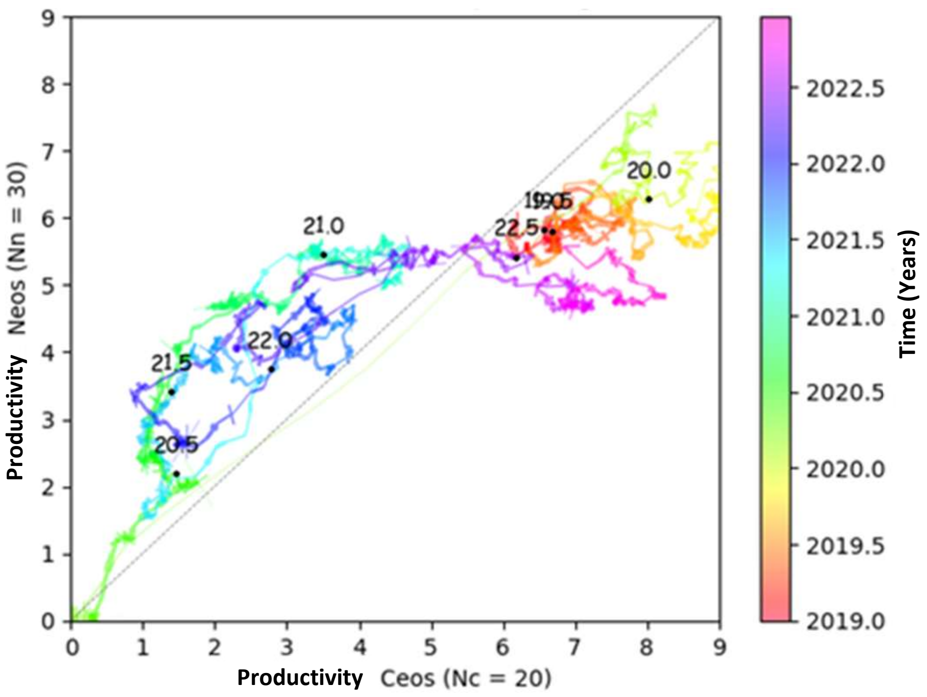
Multi-factoriality *(technical constraints, industrial constraints, regionality, inter/intra company inefficiencies)*

At the airline level

Lufthansa (Germany)



Indigo Airlines (India)



Productivity graphs for A320s NEOs & CEOs for Lufthansa and Indigo Airlines (h/aircraft), weekly smoothing, Opensky data

Conclusion

New **realist, flexible** and **calibrated** fleet model**.**

Quantification decarbonisation potential associated with :

- Volume & cyclicity of deliveries (between 0 and 14%, realistically a few %)
- Prioritisation of new technologies in production (1,5%)
- Prioritisation of old technologies at retirement (2,3%)

Next steps :

- Calibration with commercial data, integration in AeroMAPS
- Economic determinants of environmental inefficiencies *(regional dimesnsion, airlines role, leasing, maintenance cost…)*
- Aircraft allocation on routes (Tobias internship)
- Evolution of aircraft productivity through aging

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Thanks for your attention !

Any questions ?