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Aircraft Fuel Flow Modelling with Ageing Effects

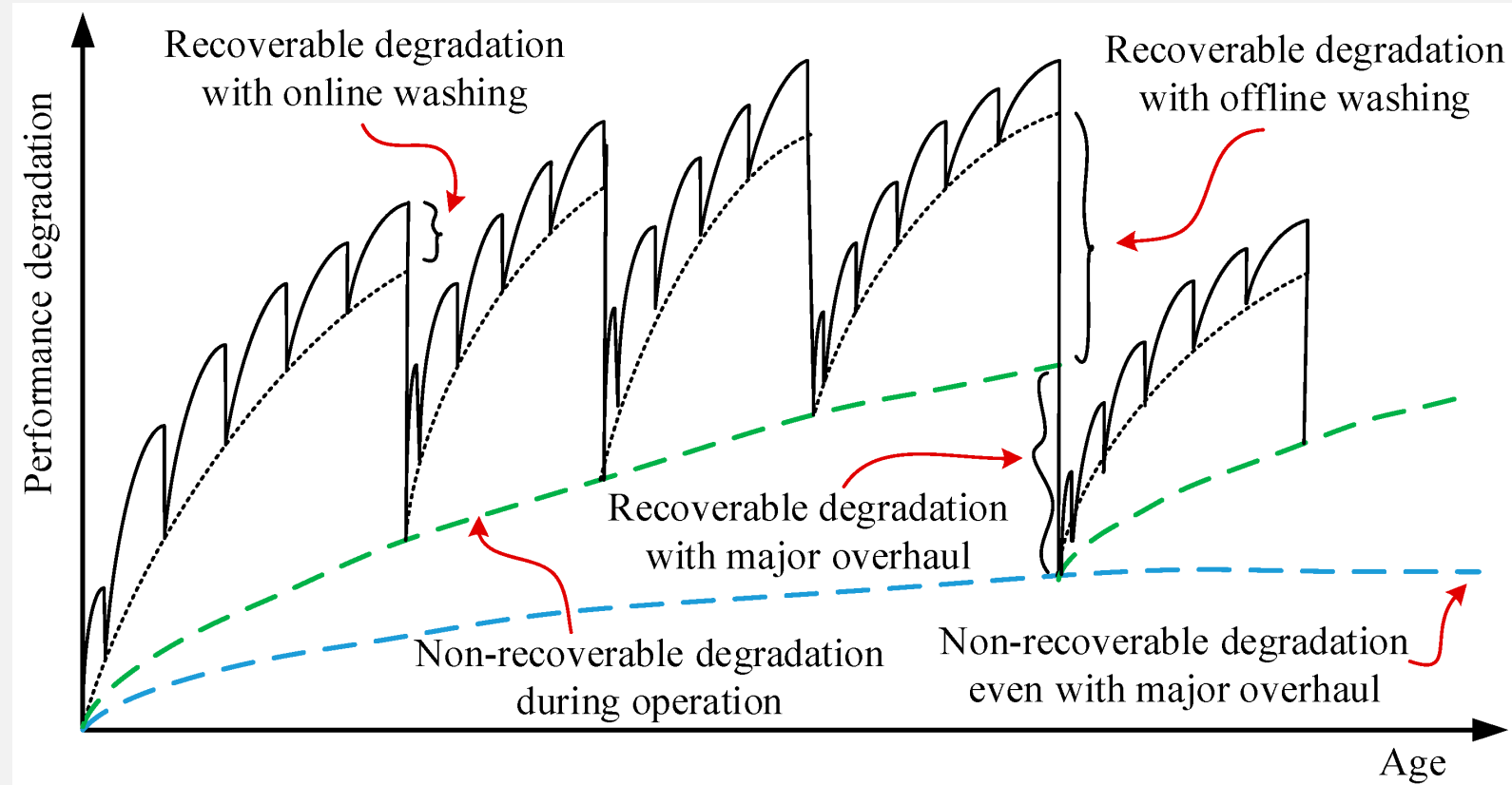
SESAR Innovation Days 2025

03-12-2025

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Aircraft & Engine & life cycle



Data availability

Maintenance plannings ?



QAR data ?



Data4Safety
Partnership for Data Driven Aviation Safety Analysis

Supported by EASA



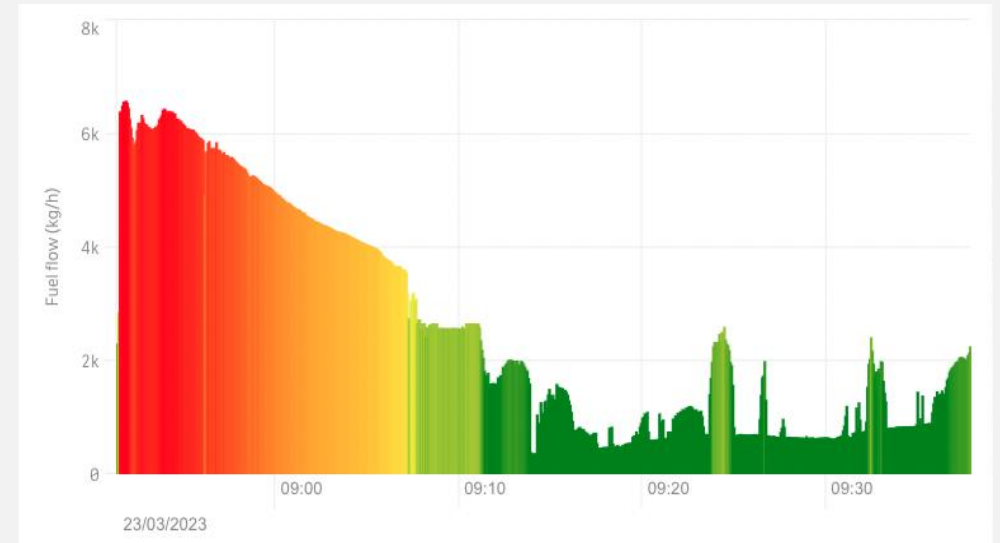
**Flight Data
Connect**



Current models do not include ageing

Environmental Impact Assessment :

- Physical based approaches like BADA (ideal brand-new aircraft)
- ML based approaches like Acropole (trained on QAR latent fleet age ?)



$$F_{corr} = \frac{F_{new}}{100 - \delta(\bar{t})}$$

$\delta(t) = -1.28\log(t + 1)$ for medium-haul aircraft

$\delta(t) = -1.34\log(t + 1)$ for long-haul aircraft

K. Seymour, M. Held, G. Georges, and K. Boulouchos, "Fuel estimation in air transportation: Modeling global fuel consumption for commercial aviation," *Transportation Research Part D: Transport and Environment*, vol. 88, p. 102528, 2020.

Research problems

- To what extent can aircraft-age information and QAR data reduce ageing-related bias in fuel-burn models?
- What are the resulting impacts on fuel-consumption estimation and future trend projections?

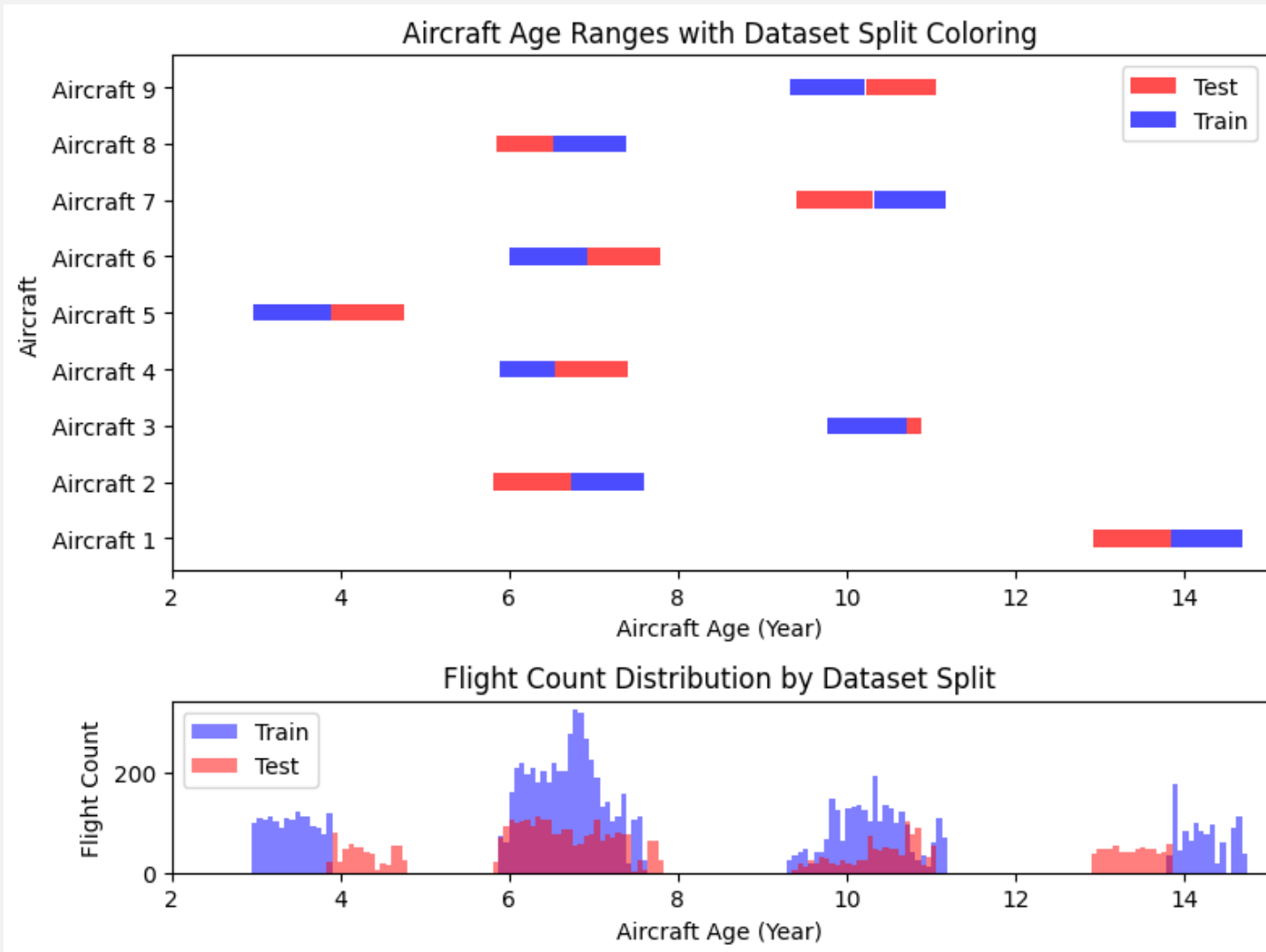
Outlines

1. Model & Data
2. Result & future projection
3. Limitation & Conclusions

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Quick Access Recorder (A320) data with ages



- 1 Airline
- 9 aircraft
- 2 Year period

Baselines and proposed architectures

Baselines

BADA

ACROPOLE
(neural net)

G. Jarry, D. Delahaye, and C. Hurter, "Towards aircraft generic quick access recorder fuel flow regression models for ads-b data," in International Conference on Research in Air Transportation, 2024. 10.13140/RG.2.2.23229.27360

Tested architectures

BADA
+ Seymour

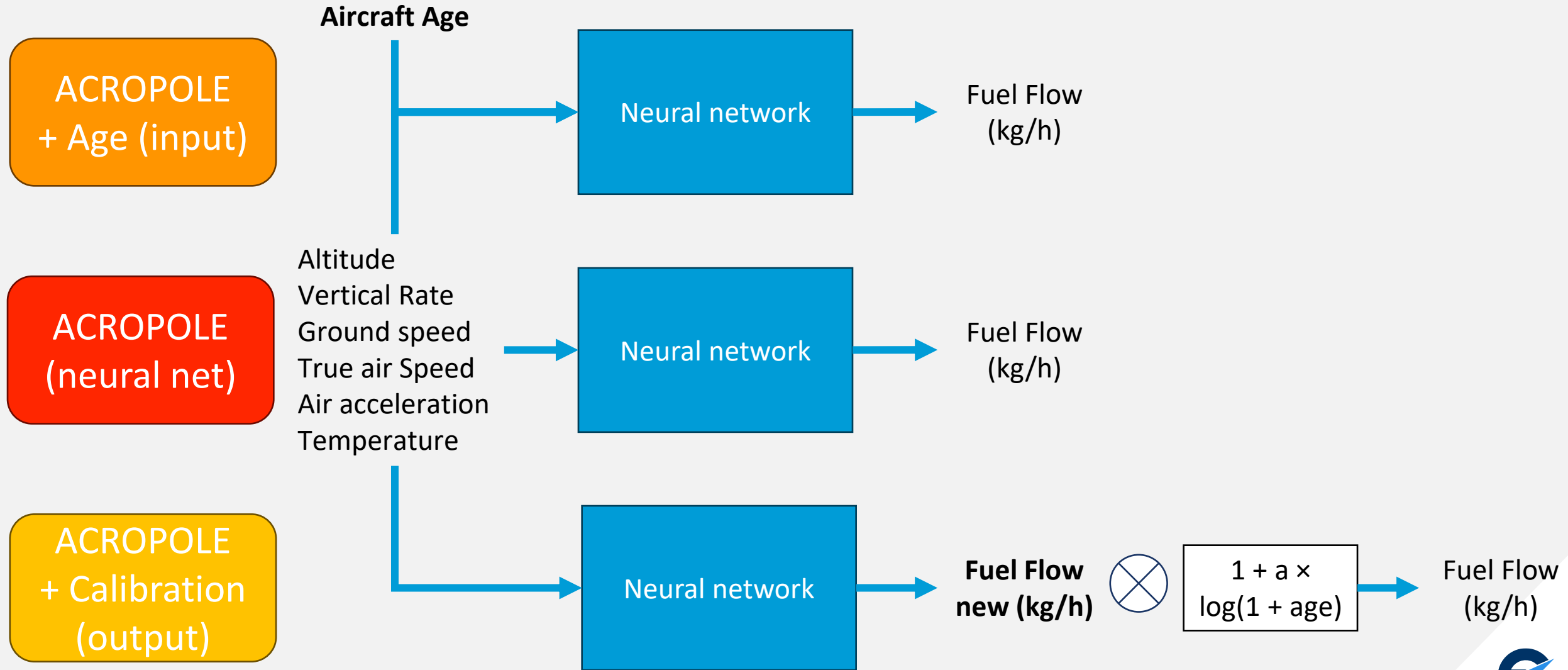
ACROPOLE
+ Age (input)

BADA
+ Calibration

$$1 + a \times \log(1 + \text{age})$$

ACROPOLE
+ Calibration
(output)

Acropole Model architectures



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Calibrated coefficients & analysis

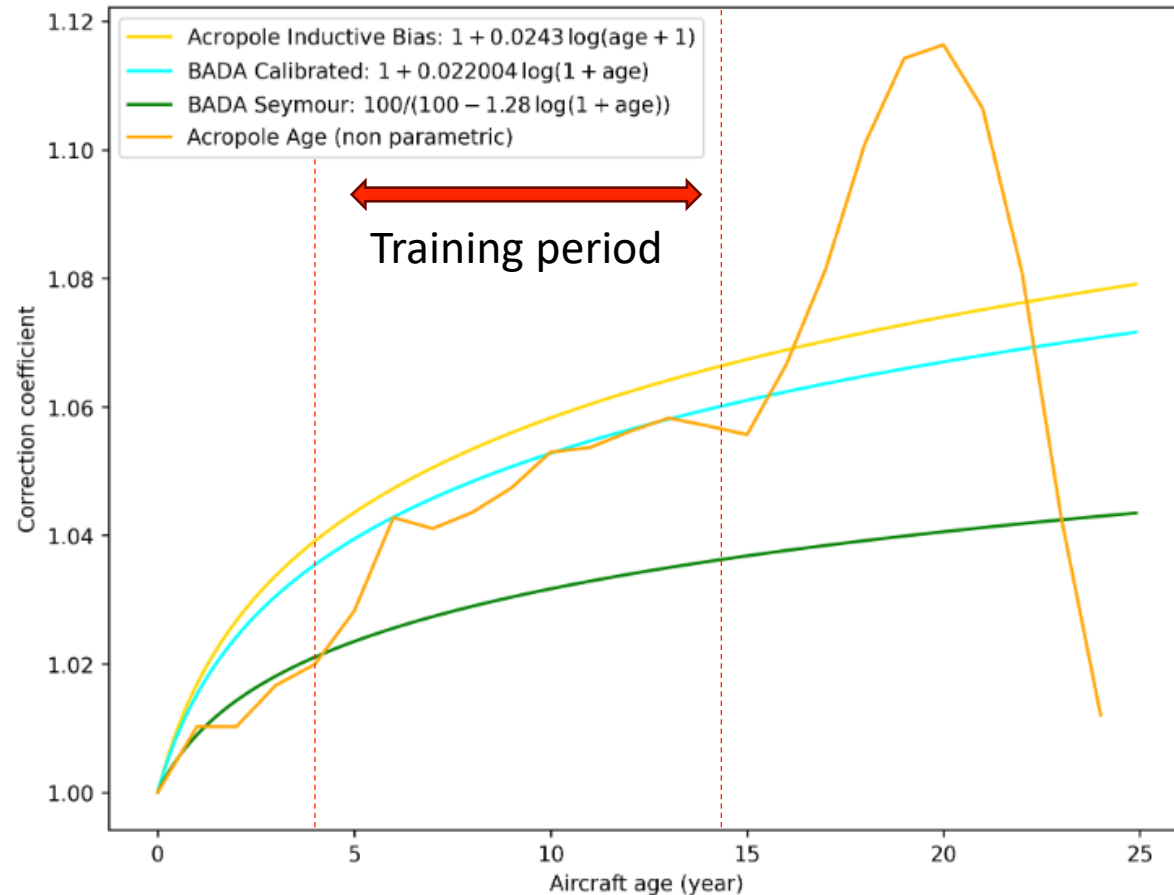
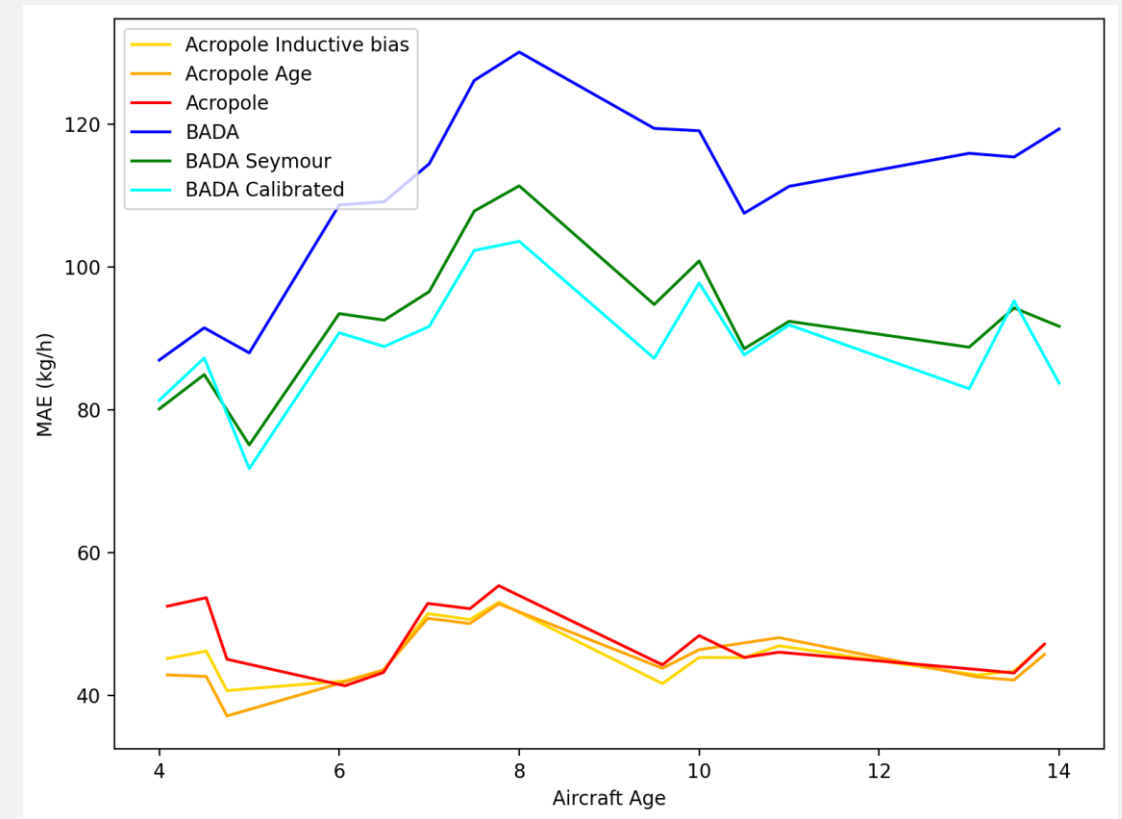
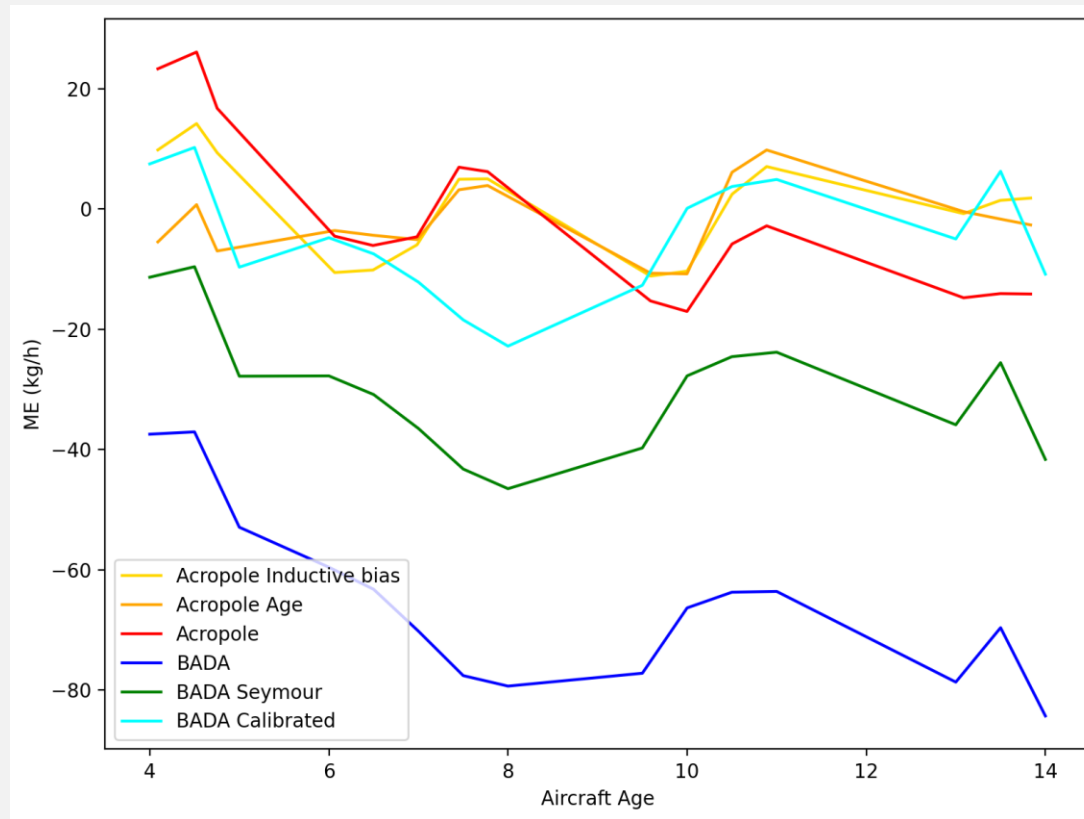


Figure 3: Correction coefficient function of aircraft age for the different modelling approaches

- Dedicated A320-214 coefficients slightly higher than from Seymour generic formula
- Inductive bias with calibrated coefficients smoother and more robust outside training period

Per plot fuel flow error metrics



- Bada : Bias Removal and general gain of 20/30% MAE with calibration
- Acropole learned a latent fleet age that is corrected with calibration)
lower gain in MAE

Total aggregated consumption

TABLE II: Computed consumption over test set in Tonnes of fuel

	Ground Thruth	BADA	BADA Seymour	BADA Calibrated	Acropole	Acropole Inductive Bias	Acropole Age
Consumption (tonnes)	23176.4	22061.9	22673.5	23115.2	23124.8	23142.2	23141.2
Difference (tonnes)		-1114.5	-502.9	-61.2	-51.6	-34.3	-35.2
Difference Ratio		-4.81%	-2.17%	-0.26%	-0.22%	-0.15%	-0.15%

- Bada : At consumption level BADA tends to underestimate fuel consumption, bias corrected with calibration
- Acropole already learned the fleet average age, calibration has lower impact

What about future projection of consumption ?

- Same fleet, same flights,
- 15 years projection
- Average of fitted coefficients

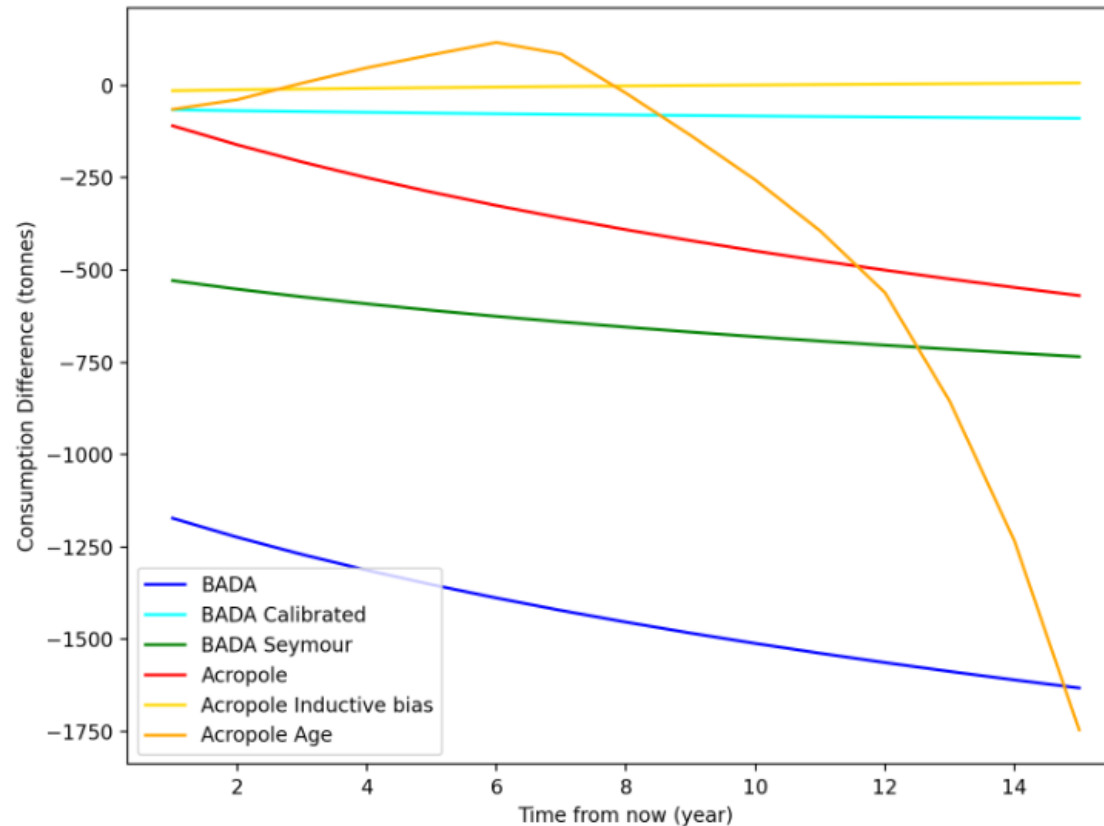


Figure 4: Projected fuel consumption differences (tonnes) over a 1–15 year horizon under the assumption of a constant fleet.

- Acropole, BADA, and Acropole Age diverge
- Inductive bias models are much more robust

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Limitations and Future Work

-  Limited fleet diversity

-  Restricted age range



Extend fleet and age coverage

-  No maintenance history

-  Deterioration not disentangled from other factors



Include maintenance data and modelling (ANSP / Airlines)

Conclusions

- Age-dependent corrections **reduce bias**, especially calibrated ones.
- Neural network models **implicitly learn partial ageing trends but** remain dataset-dependent.
- **Inductive-bias architectures** (multiplicative age factor) offer the best robustness-to-interpretability trade-off.
- Accounting for ageing is **essential** for accurate fuel estimation and long-term environmental assessments.



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Thank you!

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