Integration of AI in ATM systems

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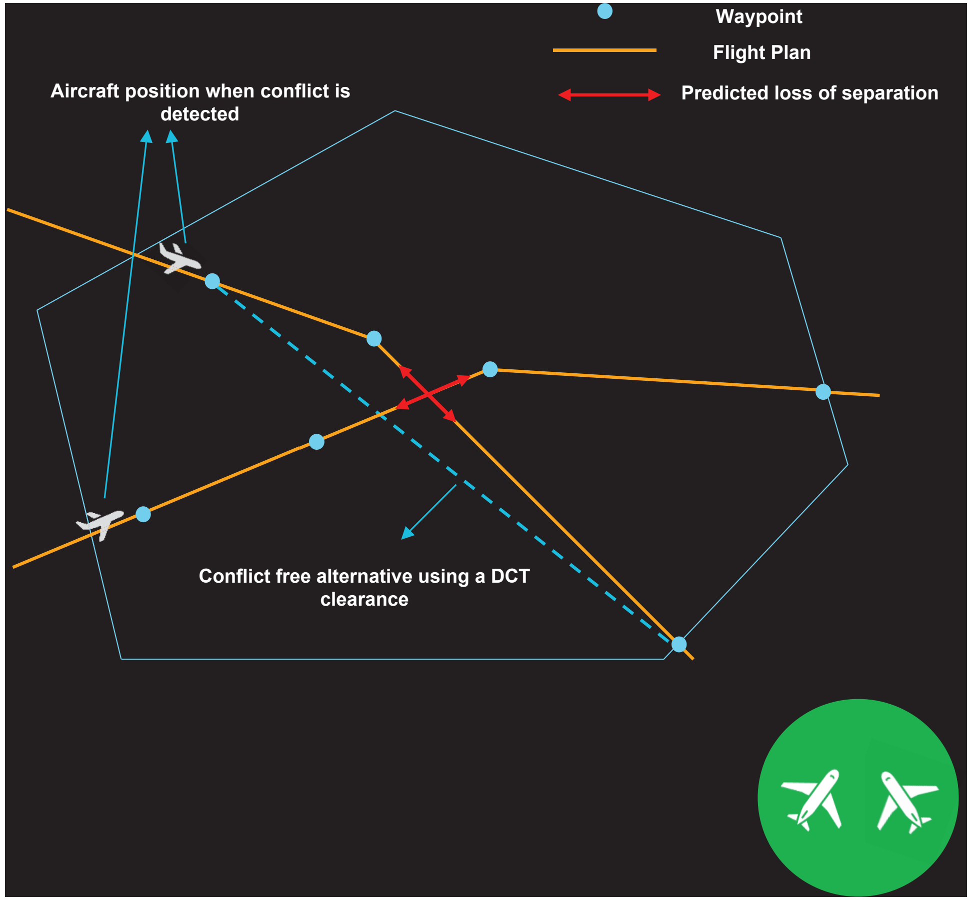
Conflict detection and resolution using AI in air traffic control systems

Conflict Detection & Resolution today

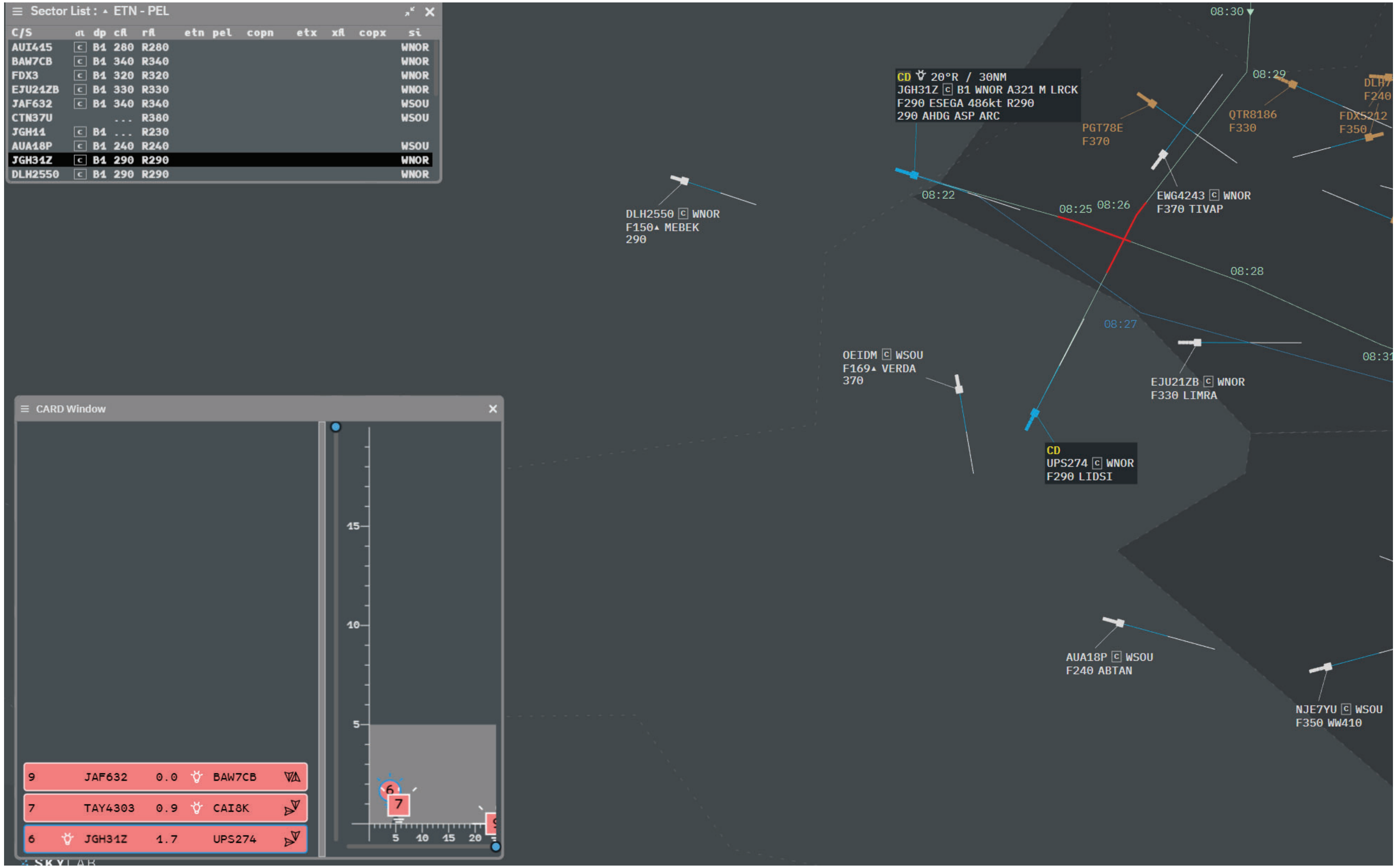
> **Ensure minimum separation of aircraft**
  - 5 Nautical Miles (NM) horizontal
  - 1000 feet vertical
  - May vary depending on operational requirements

> **Workflow**
  - Resolver searches for clearance(s) that solve the conflict
  - Solution is displayed to the operator
  - Operator validates and applies the solution

> **Validated in several MVP & SESAR exercises**



What it looks like



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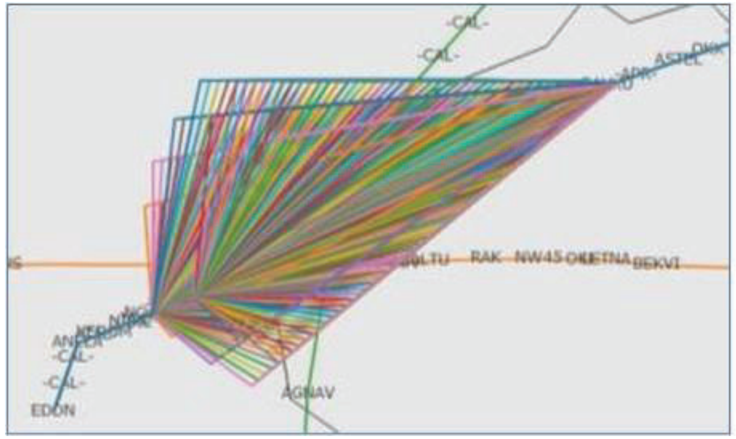
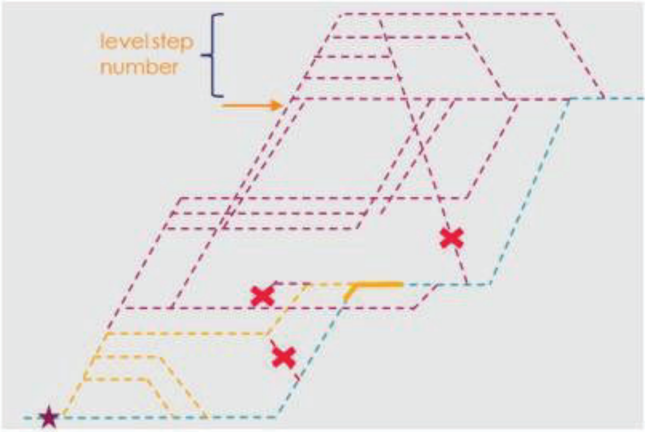
Resolution Advisory function today

> Resolution advisory types

- ❖ Lateral Resolution Advisory
- ❖ Vertical Resolution Advisory
- ❖ Speed Restriction Advisory





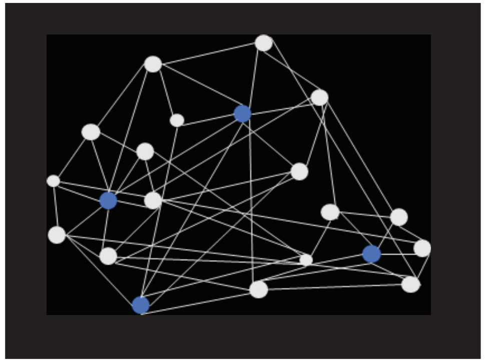
> Limitations

- ❖ Computational power limits the number of options that can be analysed
- ❖ May take several seconds depending on traffic complexity
- ❖ Chaining multiple solutions creates a larger combinatorial problem

Modern Artificial Intelligence and resolution in the future

> Why explore modern AI technology?

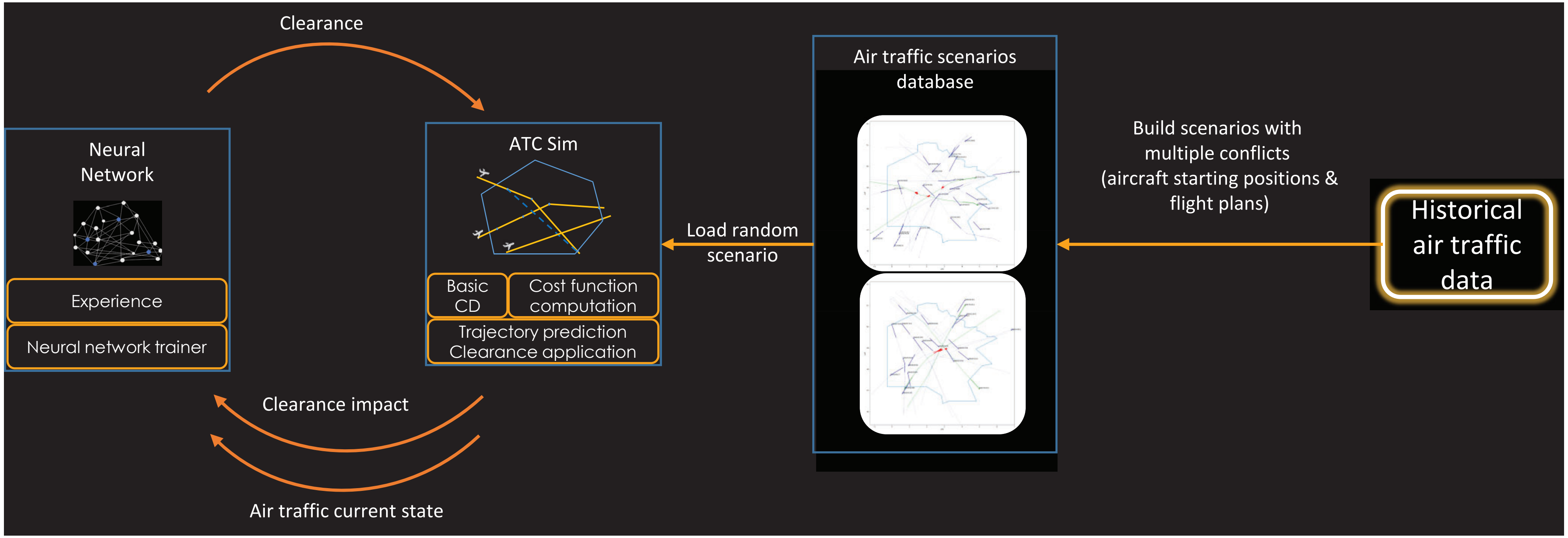
- Faster than classical algorithms
- Opens the door for new possibilities in the future
  - **Global optimization** of traffic
  - More **complex and optimal** solutions
  - Optimize various criteria: e.g. take into account **CO2 emissions, contrail reduction**
  - Can be applied to **simulation, drones, planning** and more



> Limitations

- requires a specific training framework and complicated algorithms
- Safety concerns
  - cannot provide solution guarantees
  - Lack of explainability

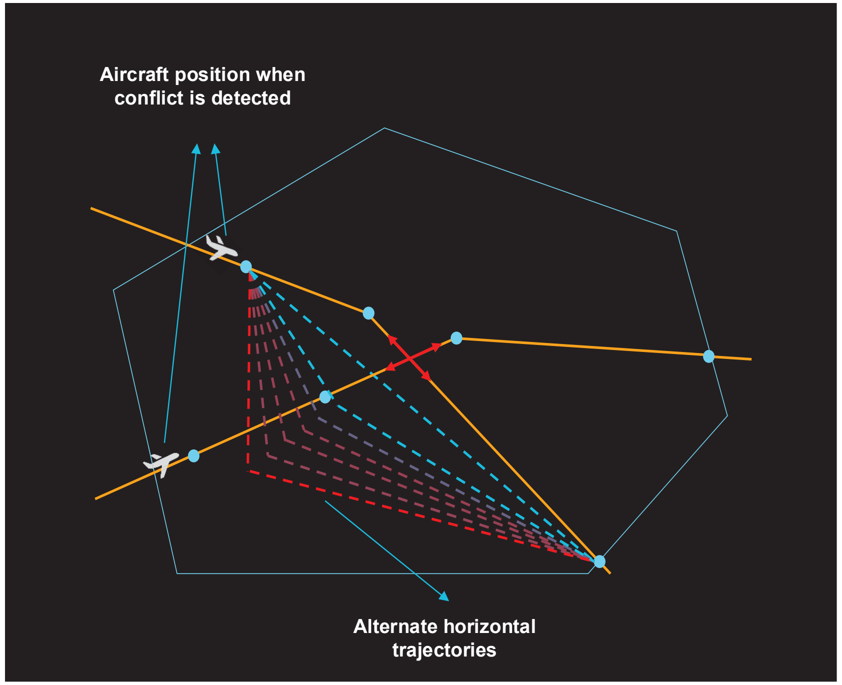
AI model training pipeline



Hybrid approach

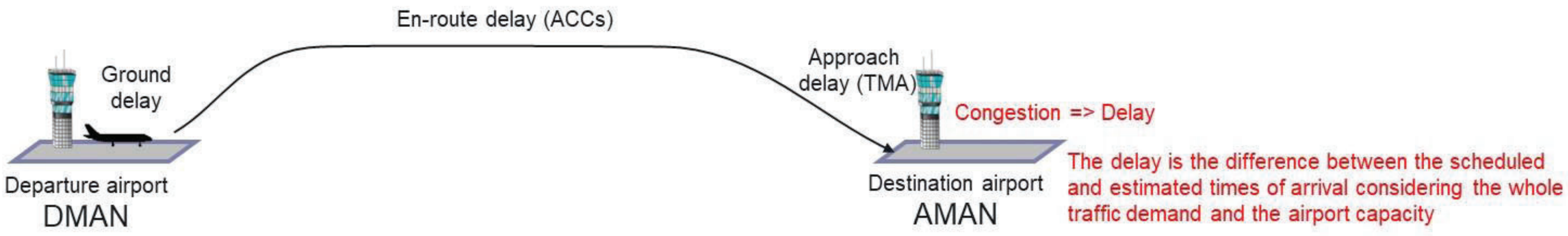
> The best of both worlds

- Apply tree-search only on a sub-set of solutions proposed by the neural network
- Solutions are always checked against the rules and validated by the classical component
- ➡ **Faster** and **more efficient**



TopSKy Sequencer

TopSky Sequencer – Operational purpose



> The operational goal is to allocate flight delays across the different collaborative control centers based on the following objectives:

- Ensuring the optimal flow of traffic from & to the airport,
- Distributing the tower, en-route and approach controllers workload,
- Ensuring that the various control centers (Area Control Centers (ACC) and Terminal Manoeuvring Area (TMA)) operate at optimum capacity,
- Favouring ground delay followed by linear delay absorption along the flight's route,
- Avoiding holding stack patterns.

TopSky Sequencer is a decision making tool aimed at minimizing aircraft delays and excessive fuel consumption by providing the controllers with advisories to properly expedite the traffic

TopSky Sequencer interface

Predicted ETAs & Flexibility Windows

> ACCEP model predicts:

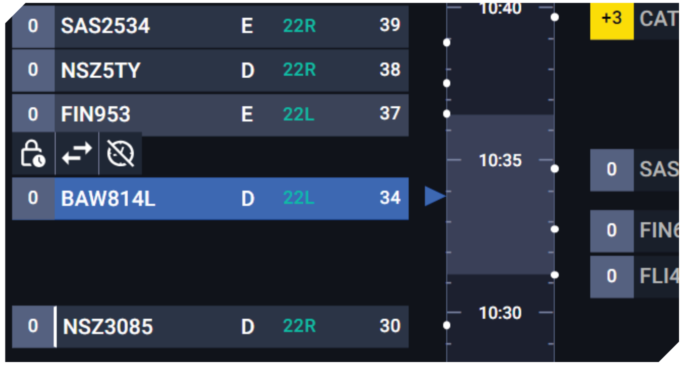
- ACC entry point
- **Time-to-fly from** current position to ACC boundary

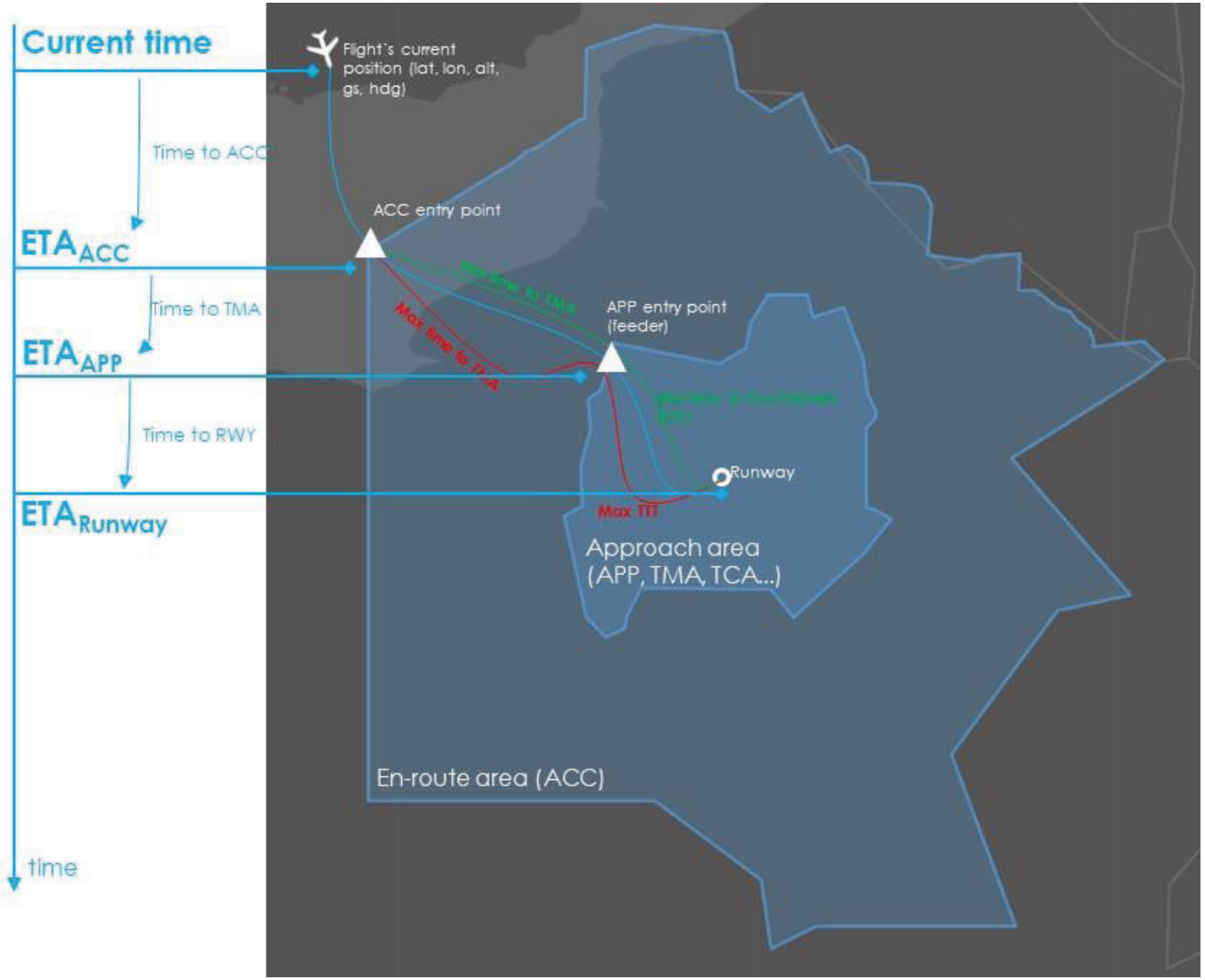
> TMAEP model predicts:

- APP entry point
- Flex Window in ACC given by [min_{TTTMA},max_{TTTMA}]

> FLEXWIN model predicts:

- **Time-to-fly** from APP boundary to runway
- Flex Window in APP given by [min_{TTT},max_{TTT}]





MLOps – Models instanciation & lifecycle

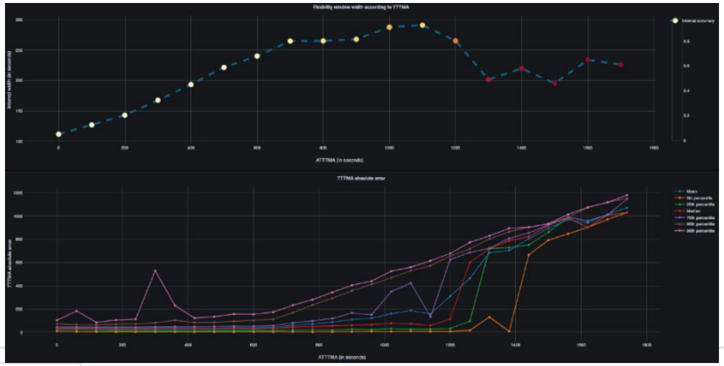
> **All models used to provide the service on a new airport are available within 2 days through an automated pipeline:**

- production pipeline fully automated with AirFlow

- offline evaluation performed on validation datasets produced in parallel with the training dataset
- models lifecycle is managed with ML Flow

> **Models validation through automated tests covering functional, performance & robustness requirments**

> **Continuous monitoring of models against live data allows to detect and prevent performance decay**



Experimentation with DEEL-LIP python library from Confiance.AI

> DEEL-LIP

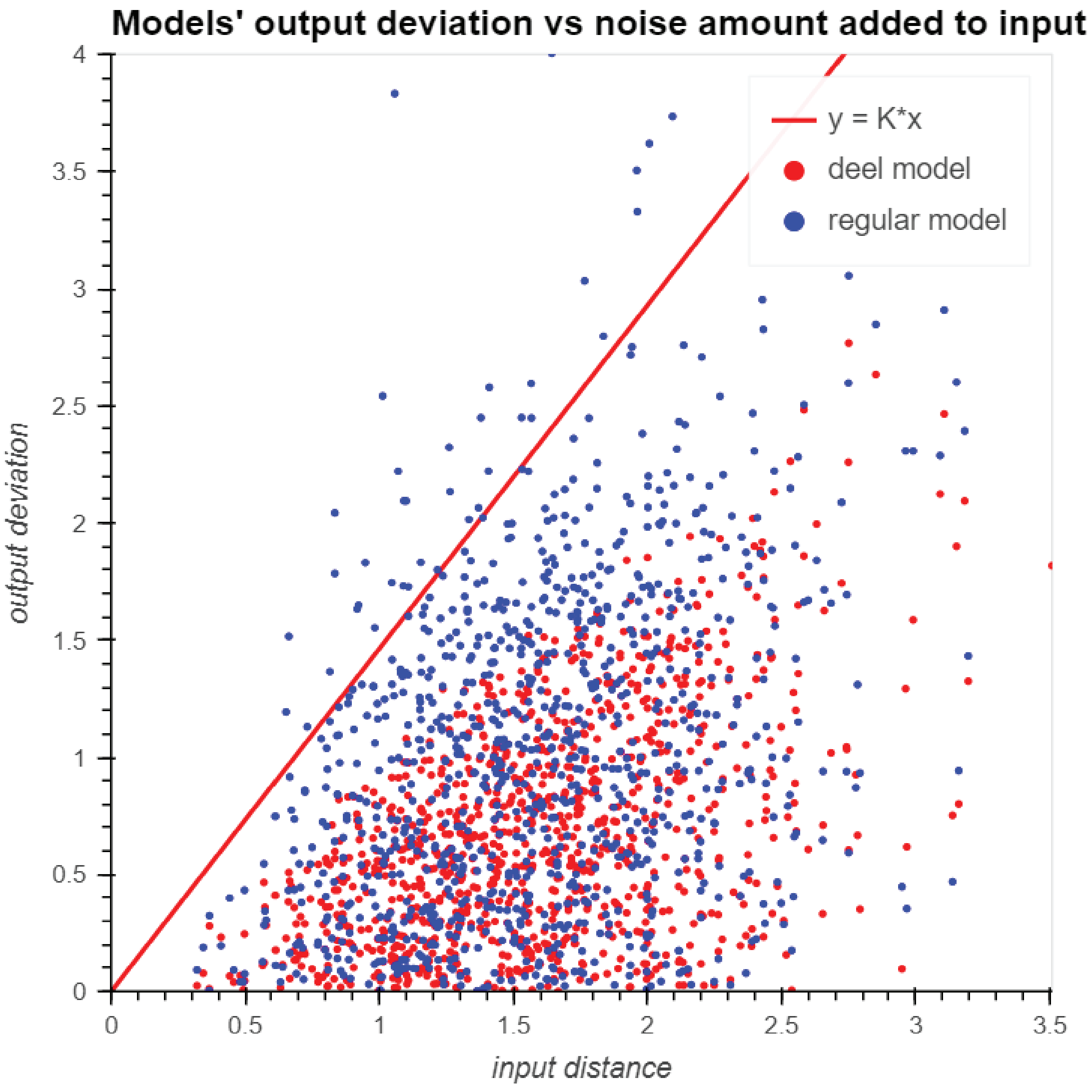
- Train a neural network with spectral normalization. This way, you can ensure your neural network is a C-lipschitzian function.

> C constant need to be carefully chosen

- Compute the theoritical value of C from your dataset.
- Or train several neural networks with different C values and chose the best trade-off.

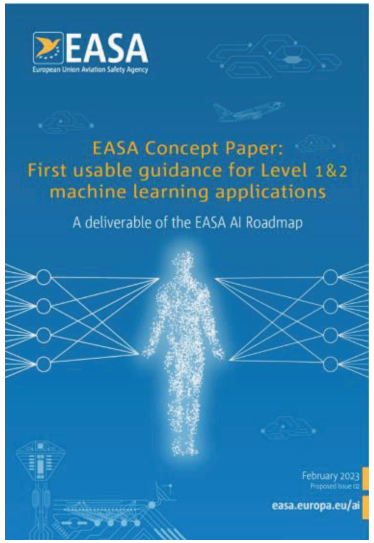
> Results

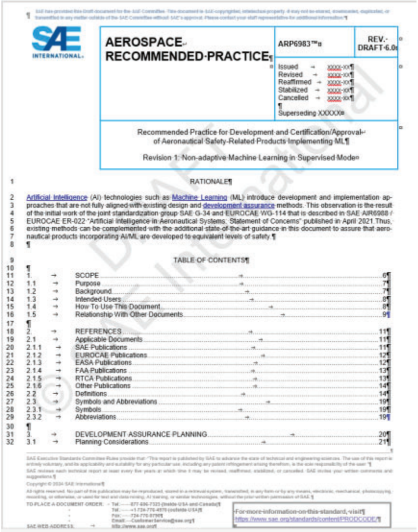
- The new trained neural network has **better stability** with **comparable performances**

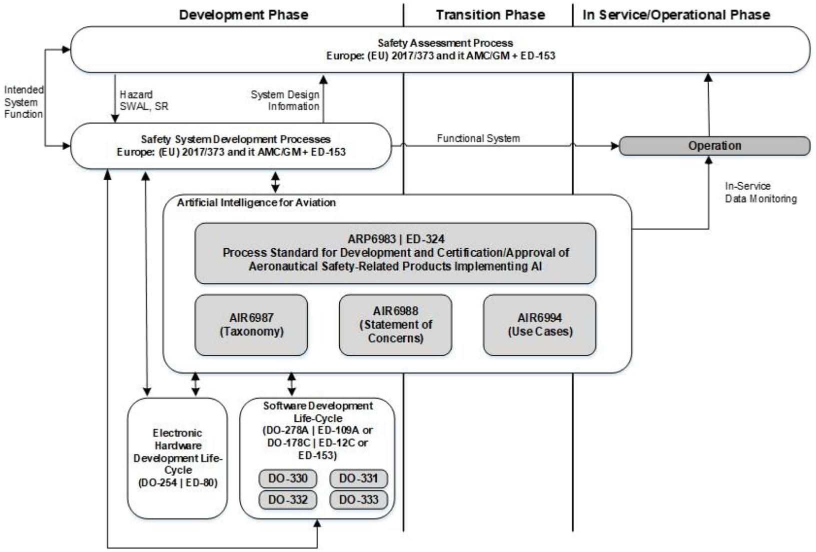


Approval/Certification and qualification of our products

- Thales is recognized by the aviation community (EASA, Airbus, DGAC, etc..) as one of the most active contributor in EUROCAE WG-114 and SAE SG-34
- The future standard ED-324/ARP-6983 is submitted to WG-114|SG-34 ballot and will be submitted to EUROCAE Open Consultation and published in 2025
- The EASA concept paper and ARP-6983|ED-324 have a very good level of alignment
- We are working to prepare our product to be compliant to the next standard ARP-6983|ED-324







Compliance to EASA and ARP6983 | ED-324 objectives

> Define the Operational Domain Design (ODD)

- Example:
  - What to do in case of a storm ?
  - What is the impact on the model output ?

> Specify the MLC requirements (~70 reqs)

- Refine the solution requirements into ML constituent requirements (functional and non-functional requirements, including safety, software assurance and cybersecurity)
- Data quality attribute of the test dataset
  - Edge cases
  - Feasible/infeasible corner cases
  - Outliers (out of ODD)
- High level properties the model must satisfy (stability, robustness, …)
  - Definition of a solution architecture with an independent monitor able to detect concept drift
  - Monitoring models performances (concept drift)

> Example of MLC requirement:

- TTT error must be less than 90 seconds for a horizon of 15 minutes.
- Neural network must predict a TTT for aircrafts with a ground speed between MIN_GS and MAX_GS

Compliance to EASA and ARP6983 | ED-324 objectives

> Validate ML requirements

- Ensure that the model requirements are correct, complete, consistent and traceable with upper requirements (solution requirements)
- Analyze the justification of the derived requirements

> Verification of ML constituent implementation against MLC requirements

- All MLC requirements will be covered by MLC tests
  - Implementing tests to evaluate the model performance
  - Verify that the test datasets contains enough edge/corner cases and outliers
  - Verify model stability
  - Verify data processing (outliers filtering, …)
  - Verify the integration of data processes with the ML model
- Verify the monitoring capabilities
  - Verification of the concept drift detection
  - Verify the integration of the monitoring with the ML constituent

> Main concepts of ML qualification has been learnt by data scientists team

Standardisation and Reinforcement learning

- EASA concept paper and ARP-6983|ED-324 only limited to ML algorithms. Qualification/Validation of RL algorithms is not yet covered and THALES will explore new methodologies and tools for their approval with safety constraints.

- THALES has initiated collaboration with TU Delft about Qualification of RL Algorithm for CDR. This project tries to cover this gap by producing a detailed overview on:
  - Definition of the limitations of the current guidelines for RL, with emphasis in RL applications for aviation
  - Guidelines on how to ensure certifications rule adherence for RL, with special emphasis on the training aspect of RL applications
  - Overview of current tools/algorithms which can increase explainability and predictability of RL applications
  - Indication of necessary future steps/initial roadmap for the creation of a viable certification framework for RL

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