BADA

ICAO/EUROCONTROL
Workshop BADA

Date: 03/08/2023

Index

Indra systems

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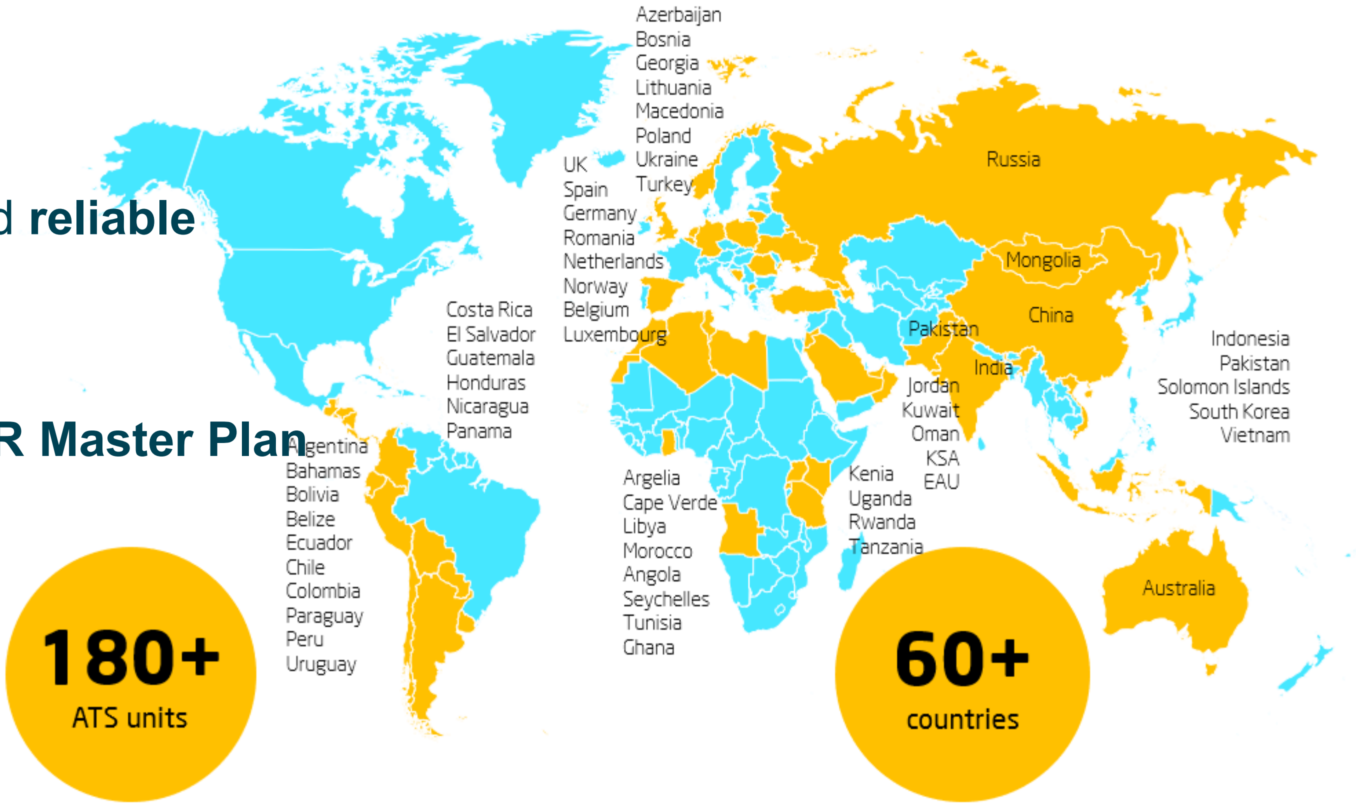
Introduction

- Leading automation for ATM
- Latest Indra solution: **advanced**, **safe** and **reliable**
- Most advanced ATC functionalities
- Continuous evolution following the **SESAR Master Plan**
- Flexible and modular architecture
- Optimised graphics and HMI
- Contingency and redundancy



iTEC SkyNex

Maastrich Upper Airspace Centre (*MUAC*) ATM system (***2008***). Air Navigation Service Provider (*ANSP*): Eurocontrol.

Prestwick Centre Upper Airspace (PCUA) ATM system (***2016***). ANSP: National Air Traffic Services Holdings (*NATS*). Country: United Kingdom.

Karlsruhe Upper Airspace Centre (*KUAC*) ATM system (***2017***). ANSP: Deutsche Flugsicherung GmbH (*DFS*). Country: Germany.

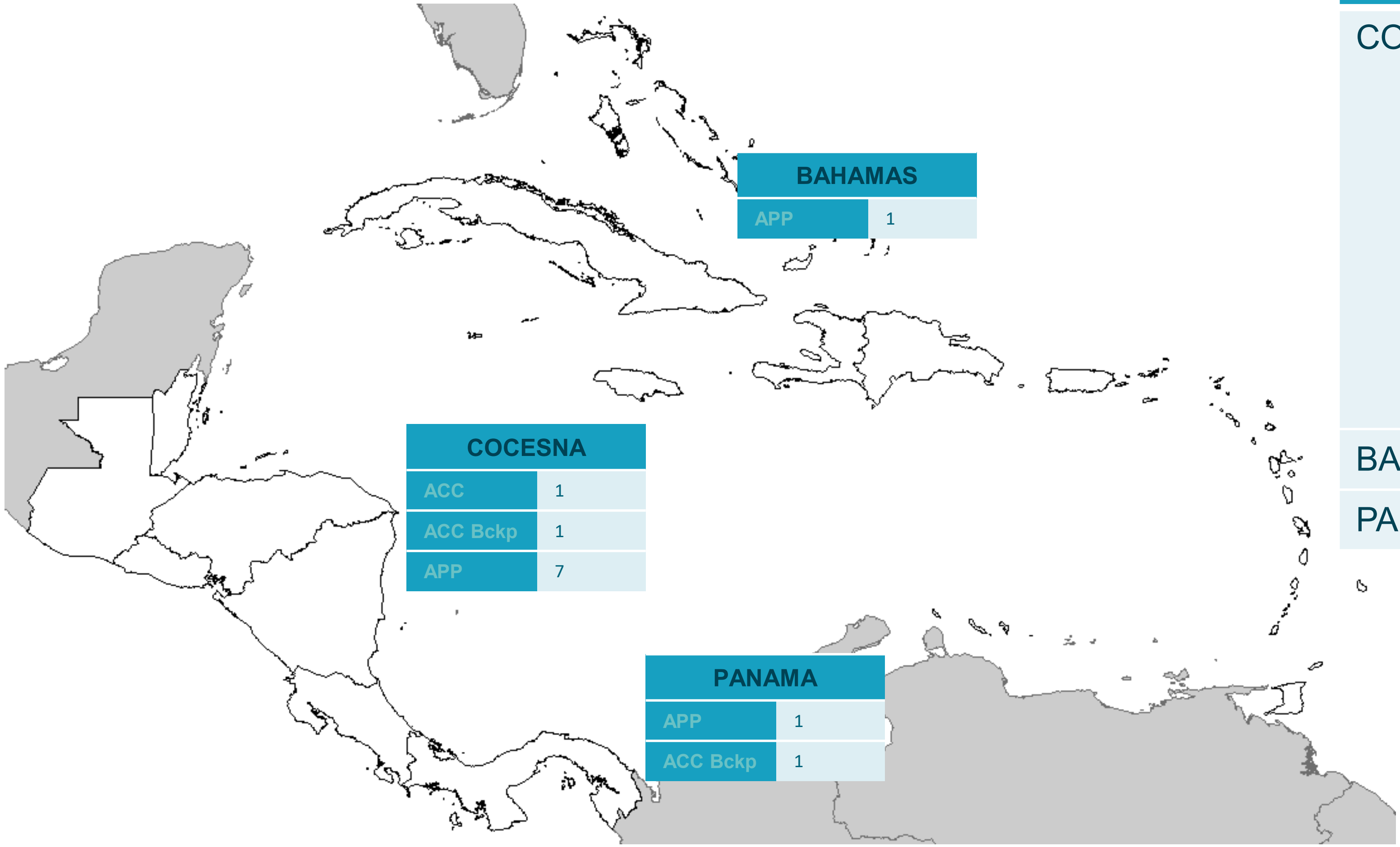
Romania ATM system (***2019***). ANSP: Romanian Air Traffic Services Administration (*ROMATSA*). Country: Romania.

Vilna ATM system (***2021***). ANSP: Oro Navigacija (*ON*). Country: Lithuania.

Munich ATM system (***2023***). ANSP: Deutsche Flugsicherung GmbH (*DFS*). Country: Germany.

Automation Systems

Central America (CAR)



COUNTRY	SITE	TYPE
COCESNA		
Honduras	Tegucigalpa	ACC
El Salvador	Ilopango	ACC
El Salvador	Comalapa	APP
Nicaragua	Managua	APP
Guatemala	Guatemala	APP
Guatemala	Mundo maya	APP
Honduras	San Pedro Sula	APP
Belice	Belice	APP
Costa Rica	San José	APP
BAHAMAS	Nassau	APP
PANAMA	Panamá	APP

Automation Systems

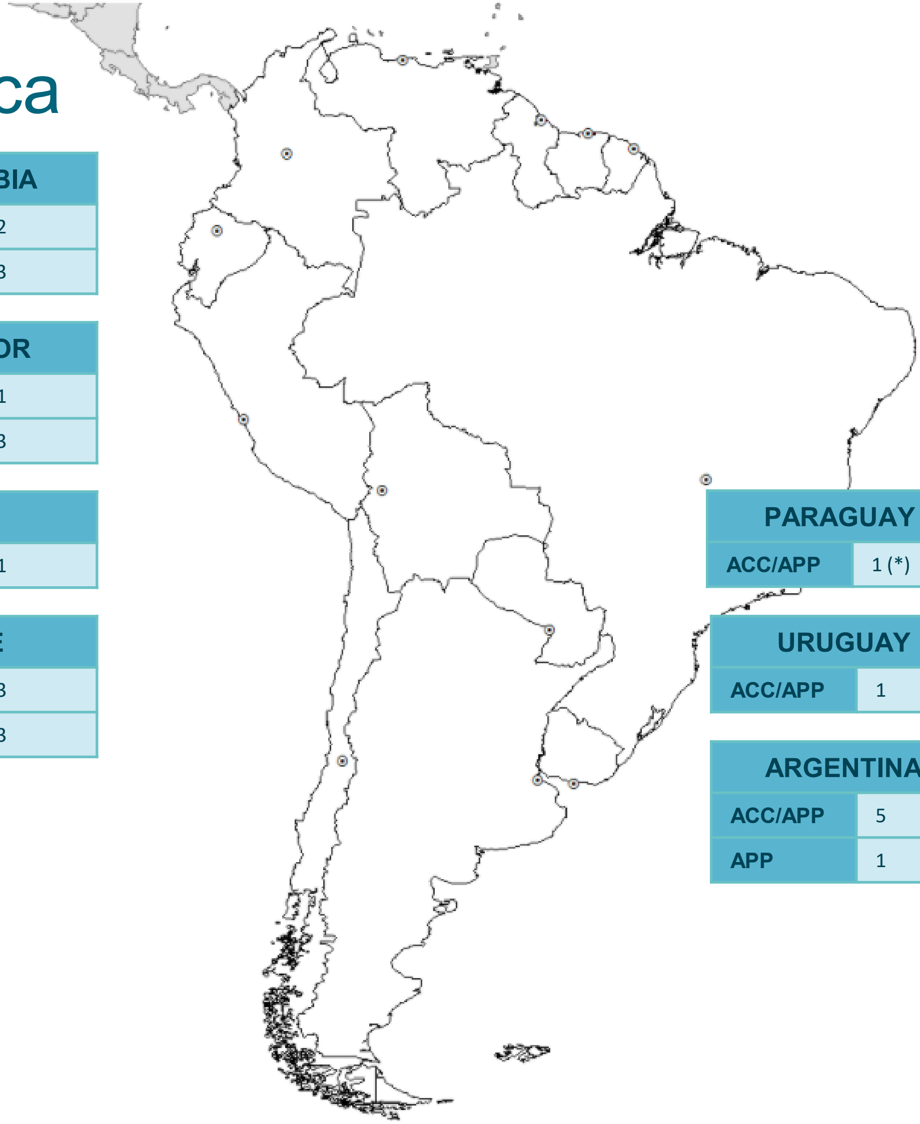
South America

COLOMBIA	
ACC/APP	2
APP	3

ECUADOR	
ACC/APP	1
APP	3

PERU	
ACC/APP	1

CHILE	
ACC/APP	3
APP	3



PARAGUAY	
ACC/APP	1 (*)

URUGUAY	
ACC/APP	1

ARGENTINA	
ACC/APP	5
APP	1

COUNTRY	SITE	TYPE
COLOMBIA	Bogota Barranquilla Rio Negro Cali Villavicencio	ACC/APP ACC/APP APP APP APP
ECUADOR	Guayaquil Quito Manta Shell	ACC/APP APP APP APP
PERÚ	Lima (1)	ACC/APP
ARGENTINA	Ezeiza Aeroparque Cordoba Mendoza Resistencia Comodoro	ACC/APP APP ACC/APP ACC/APP ACC/APP ACC/APP
CHILE	Iquique Antofagasta Concepción Temuco Puerto Montt Punta Arenas	ACC/APP APP APP APP ACC/APP ACC/APP
URUGUAY	Carrasco	ACC/APP
PARAGUAY	Asunción	ACC/APP

Introduction

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Introduction

Importance of Accurate Aircraft Trajectory Prediction for ATM Systems

- Aircraft Performance Model (APM) is the core of trajectory prediction, being BADA demonstrated being suitable APM for prediction as well as for simulation.
- The iTEC system, initiated by the VAFORIT project for DFS in 1999, relies on BADA for calculating trajectories in four dimensions (4D).
- Benefits of accurate trajectory prediction include improved punctuality, efficiency, reduced emissions, and lower operating costs.
- Trajectories are calculated based on flight plans, meteorological data, aircraft performance, and ATC procedures.

Introduction

Inputs of a Trajectory Prediction

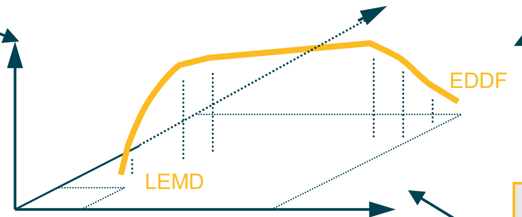
ATC Flight Plan
- Route, Aircraft Type
- RFL, Speed, EOBT,…

Track-Data
- GS, ROCD, AFL...

Enviromental Data
- SIDs, STARs, ATS Routes
- Letter of Agreements (LoAs)
- Strategic Constraints (Level and Speed Constraints)
- Sectorization
- Airports and RWY`s

Monitoring and Planning Tools
- Conformance Monitoring
- Conflict Detection
- What if Probing

Weather Data
- Wind, Temperature, QNH



OLDI Supported Co-ordination
- OLDI
- Estimates and Crossing Conditions

Aircraft Performance Data (BADA)
- 339 Aircraft Types
- Covers 95% of European Traffic
- Calculation based on „Total-Energy Model“

Tactical Clearences
- CFL, Heading, Holding, Direct Routing
- Speed Constraints, ROCD Contraints
- Sector Crossing Conditions

Airspace Availability
- CDRs, TRAs (Restricted Areas)
- ATC Constraints

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Introduction

Factors Affecting Planned Trajectory Calculation Accuracy

- Uncertainty in planned manoeuvres: Tactical instructions and clearances may affect planned manoeuvres, leading to inaccuracies in trajectory predictions.
- Assumptions based on models: Trajectory prediction relies on models (e.g., weather, aircraft performance) rather than individual flight data.
- Unavailability of operator preferences and criteria: Operator-specific data and optimization criteria are often unavailable unless exchanged via radio communication.
- Major improvements with aircraft operator and FMS data: Utilizing data from aircraft operators and Flight Management Systems (FMS) can enhance trajectory accuracy.
- Data sources for the Trajectory Prediction (TP) function: SFPL updates, LOAs, aircraft performance data models, airspace availability, meteorological data, and track data.

BADA

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BADA

What is BADA?

"Theoretical model specifications and related specific datasets to accurately stimulate the behaviour of any aircraft"

In practice, BADA consists of:

BADA User Manual

It includes a set of mathematical formulas for:

- Physics of the atmosphere
- Physics of the flight

The formulas for the flight depend on lots of adaptation parameters.

It also includes some guidance and recommendations on the most common piloting manoeuvres

BADA Files

OPF Files: They provide:

- A/C-specific adaptation parameters for the formulas
- A/C-specific flight envelope and physical description

APF Files: They only provide A/C-specific speed schedule.

GPF File: It includes parameters for common piloting manoeuvres (i.e. non-aircraft-specific)

BADA

Example of what BADA implies: climb phase

Let's assume we want to build a climbing trajectory, from the actual conditions up to the RFL (mandatory target)

What BADA provides? And what not?

BADA provides you which is the maximum Thrust force the engines are able to produce
BADA also provides a formula to compute the fuel consumption based on the Thrust.
BADA recommends to mode climbing trajectories with maximum Thrust.
BADA does NOT force using Maximum Thrust. You can use lower ones!

BADA provides you Drag force in clean configuration, depending on mass, speed and MET
BADA also provides the minimum and maximum mass for each A/C type
BADA recommends a clean configuration above certain speed.
BADA does NOT force setting a particular mass, neither to fly on clean configuration

BADA provides formulas to compute Rate of Climb for a given Thrust and Drag, assuming a constant operating climb IAS or Mach
BADA also provides formulas for those cases where the speed is not constant
BADA recommends to compute trajectories where the speed is the scheduled one
BADA does NOT force using that scheduled speed, neither even flying at constant speed!

BADA
In summary

BADA provides physical A/C description and operating envelope.
BADA provides formulas modelling physical consequences for any manoeuvre

BADA recommends certain manoeuvres, being common ones

BADA does NOT force setting any particular manoeuvre

SESAR PJ18 TP Research

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SESAR PJ18 TP Research
Program View

Within SESAR program Framework, several Projects and its associated research Solutions have been carried out to further improve the ATM systems.

Within PJ18, on SESAR2020 Waves 1&2, a big focus has been put on the use of the new ADS-C information downloaded from the aircraft (Extended Projected Profile and Speed Schedule reports) in order to better capture on the ground Planned Trajectories the Airspace Users intent, and so allow a common view of the Flight trajectory between stakeholders. There are also other additional improvements on the TP not directly linked with ADSC usage, aswell as additional CPDLC improvements.

This work will be continued on SESAR3 within ATC-TBO project, currently on its initial steps.

SESAR PJ18 TP Research

High level view on the improvements

Which of the TP inputs were improved?

ACTUAL CONDITIONS ✓

4D Position
Speeds
Yaw/pitch/roll…
…and mass!

MANDATORY TARGETS ✗

Expanded Route
Restrictions
Current Clearances

WEATHER FORECAST ✓

Wind
Temperature
Pressure
Density

AU PREFERENCES ✓

Speed Schedule
Turning manoeuvres
Thrust Setting Policy
Flaps Setting Policy
CDA manoeuvres

PERFORMANCE MODEL ✓

Engine Power
Fuel consumption
Aerodynamic Drag
Lift

SESAR: TP improvements

High level view on the improvements

TP input	PJ18 Wave 1	PJ18 Wave 2
Actual conditions	Using the EPP mass	Initial Speed from surveillance
AU preferences	Using ADS-C speeds (Scheduled & Predicted Speed) plus surveillance stable speed	Catch-up manoeuvres below/above
Weather forecast	---	Nowcasting wind info and using it. Improvements on GRIB resolution.
Performance Model	---	Coefficient to adjust performance comparing EPP & BADA

SESAR: Actual Conditions

Mass & Speed

IMPROVING MASS

Current mass received through ADS-C EPP report.

Simple tests to ensure Mass is within reasonable limits (higher/lower than minimum/maximum).

Not immediately used. Stored for future usage, considering mass consumption algorithm.

(EPP RECEPTION DOES NOT TRIGGER TRAJECTORY RECOMPUTATION)

IMPROVING SPEED

Taking actual TAS as initial speed (from Mode-S)

Before, TP used default BADA speed, and not actual speed.

BADA is a total energy model. A correct initial speed is critical to estimate an appropriate initial kinetic energy.

Not using it means short-term prediction errors on BADA model.

SESAR: AUs Preferences

Preferred Speeds

The TP speeds are improved in the following way:

- ADS-C Speed Schedule (Computed based on FMS Cost Index) replaces BADA Speed Schedule from APF files for the concerned flight.
- ADS-C EPP Predicted Speeds on Cruise Points are set as targets for Ground Points with same name.
- Mode-S IAS/MACH speeds are analysed for stability (Next slide).
    - This is kind of an improvement from the legacy ETO Monitoring, which could only propagate on levelled, straight segments. Additional improvements are being defined on how the extrapolation to be done for reaching the final functionality.

SESAR: AUs Preferences

Preferred Speeds

The CMON / FPM monitors the stability of both IAS and MACH speeds from received Mode-S tracks. When either IAS and/or MACH are stable, they are compared with the speed of the trajectory.
If it is different, the stable speed is sent to the TP.

When TP receives the event:

- In case both IAS & MACH were stable, it selects the appropriate one (reasonable choice).
- It recomputes the trajectory assuming that the stable speed will be maintained until:
  - The end of the current Phase (Climb/Cruise/Descent)
  - The cross-over altitude (if any)
  - The next speed restriction (if any)

This is the same "Deselection Point" logic that the FMS makes when a Selected Speed is set on the FCU (and so, it is reflected on the EPP trajectory).

The stable speed will be also recorded and used in future trajectory recomputations, as long as the aircraft is still in the same Phase (Climb/Cruise/Descent)

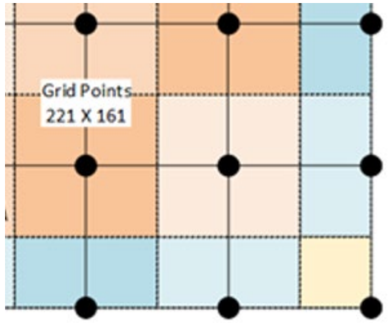
SESAR: Weather Forecast

Improved MET grid resolution

DFS wanted to improve the resolution for the MET data received from its MET provider DWD, compared to the operational iCAS system.

- Horizontal resolution: up to 161 cells in latitude, 221 in longitude.
    - This gives a resolution for DFS AOI of 0.0625º, around 3.6NM.
- Vertical resolution: up to 20 levels, scalable to support more in the future.
- Time resolution: 1 hour time steps inside the same forecast.
- Periodicity: we can receive 1 new forecast every hour.

Additionally, the logic for the centre of the steps was changed, both in 2D and in time.



SESAR: Weather Forecast

Nowcast model

Objectives:

- To deduce, from each Mode-S Track, wind + temp information at the track position
- To nowcast weather data based on all the individual wind + temp data from Mode-S.
- To apply this nowcast weather model in Planned Trajectory computations

These was tested with an initial prototype in which an "empty" GRIB was filled with the Mode-S data.

For the continuation on SESAR3, a prototype will be developed where the ModeS information is properly merged with a previously received GRIB.

For the theoretical analysis and algorithm implementation, a colaboration with the UPM is expected (Universidad Politécnica de Madrid).

SESAR: Performance Model

Performance Coefficients

The BADA physical model (Thrust & Drag) cannot be perfect as it lacks some information.

Inaccuracies are derived from:

- Same polygonal regression formulas for all A/C types.
    - Nice enough for all A/C types, but not optimized for any of them
- Not aware of the specific engine for a given flight.
- Not aware of AU de-rating policy on the Thrust for this specific flight.
- Not aware of maintenance activities on the aircraft.

BADA

adjusts

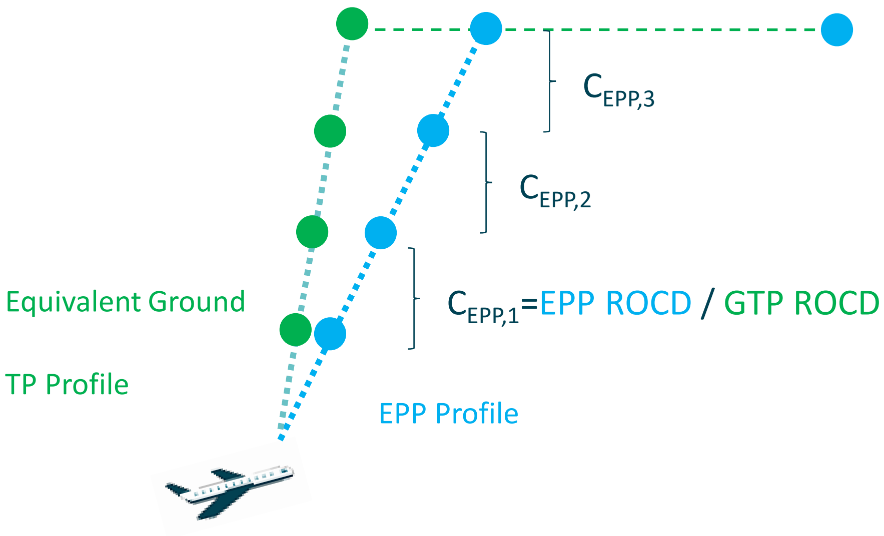
ADS-C

SESAR: Performance Model

Performance Coefficients

The FMS implements a detailed performance model, with additional information and fine tuned for the specific A/C type, version and engine, and is also aware of maintenance activities and flight-specific de-rating and idle policy.

So, our FDP compare the EPP profile with an equivalent BADA profile, computing and array of "calibration coefficients". This allows to adjust the performance model, by adjusting the ROCDs of any subsequent TP computation..



$$ROCD = C_{EPP} * \frac{T - \Delta T}{T} * \frac{(Thr_{max\_climb} - D) * V_{TAS}}{m g_o} * ESF$$

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At the core