User-centric Cost-based Flight Efficiency and Equity indicators

.

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Belgrade, 30 of November 2017

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Abstract and Outline

The current implementation of efficiency measurement (as defined in the SES Performance Scheme) affects the ANSPs view on efficiency since the ANSPs have to report on specific KPIs to evaluate their performance and management of the air traffic. This implementation takes into consideration only the horizontal portion of the flight, measuring the excess horizontal en-route distance compared to the orthodromic. This approach lacks of important information from airspace users' objectives since it leaves out the vertical component of the flight or wind conditions.

In order to introduce the airspace users' objectives into the global net efficiency measurement, it is key to develop advanced metrics that consider fuel consumption, schedule adherence or cost of the flight. These new efficiency metrics require the design of user-preferred trajectories as the main reference for performing comparisons. Additionally, airspace users are claiming for equity metrics showing how these inefficiencies are distributed between them in certain areas such as Flight Information Regions or city-pairs.

This paper presents the methodology followed for the design of advanced user-centric cost-based efficiency and equity indicators as well as a flight efficiency and equity assessment of the European traffic flow in two particular days in February 2017 taking into consideration the airspace users' perspective.

This research was conducted under the AURORA project (Grant 699340) supported by SESAR Joint Undertaking under European Union's Horizon 2020 research and innovation programme. AURORA aims to propose new metrics to assess the operational efficiency of the ATM system and to measure how fairly the inefficiencies in the system are distributed among the different airline

Keywords Airlines; ANSP; Flight Efficiency; KPI; Air Traffic Management; SESAR; ADS-B.

- Motivation and current status
- Methodology
- Results
- Conclusions

WHY ASSESING OPERATIONAL EFFICIENCY?

- Airlines have their perspective of what is an ***efficient flight*** (punctuality, less fuel,…) -> **LESS COST**

- Regulators /ANSPs may have a different perspective on what is an efficient flight (Filed flight plan?Tactical decisions/updated flight plan?Direct flights?Free flight?....

- **ANSPs are measured to make airlines flight efficiently** according to their view on efficiency
  - **Not Vertical Profile nor Fuel Consumption considered;**
  - **Not Weather taken into account;**

ANSP EFFICIENCY IN EUROPE

- ICAO defines 11 KPAs to motorize the evolution of air traffic services [1]: SAFETY, ENVIRONMENT, COST-EFFECTIVENESS, CAPACITY, ….
- The European Commission formally designated Eurocontrol as the Performance Review Body (PRB) for ECAS ANSPs [2]
- Eurocontrol launched the Performance Review by creating the independent Performance Review Commission (PRC), supported by the Performance Review Unit (PRU)

  "to ensure the effective management of the European Air Traffic Management system through a strong, transparent and independent performance review"

- PRU provides metrics and methodology to calculate those metrics and review and harmonize the different local ANSPs reports into the annual Performance Review Report [3]

[1] International Civil Aviation Organization, "ICAO Manual on Global Performance of the Air Navigation System," Doc 9883, ICAO, 2009.
[2]. Regulation (EC) No 549/2004 laying down the framework for the creation of the single European sky (the framework Regulation)
[3]Eurocontrol."Performance Review Report 2015. An Assessment of Air Traffic Management in Europe during the Calendar Year 2015", 2016
Regulation (EU) No 691/2010 laying down a performance scheme for air navigation services and network functions.

PRU definition of Efficiency (under Environment KPA)

Evolution over time (EUROCONTROL level)

Results by entity (Jan-Mar 2017)

Entity	Flight plan	Actual trajectory
EUROCONTROL Area (PRR)	4.64%	2.71%
BLUE MED FAB	4.75%	2.69%
Bosnia and Herzegovina	1.82%	0.96%
Bulgaria	3.72%	1.50%
Croatia	2.15%	1.38%
Cyprus	7.85%	3.38%
Czech Republic	3.65%	2.17%
Estonia	1.45%	1.20%
FAB CE	3.00%	1.72%

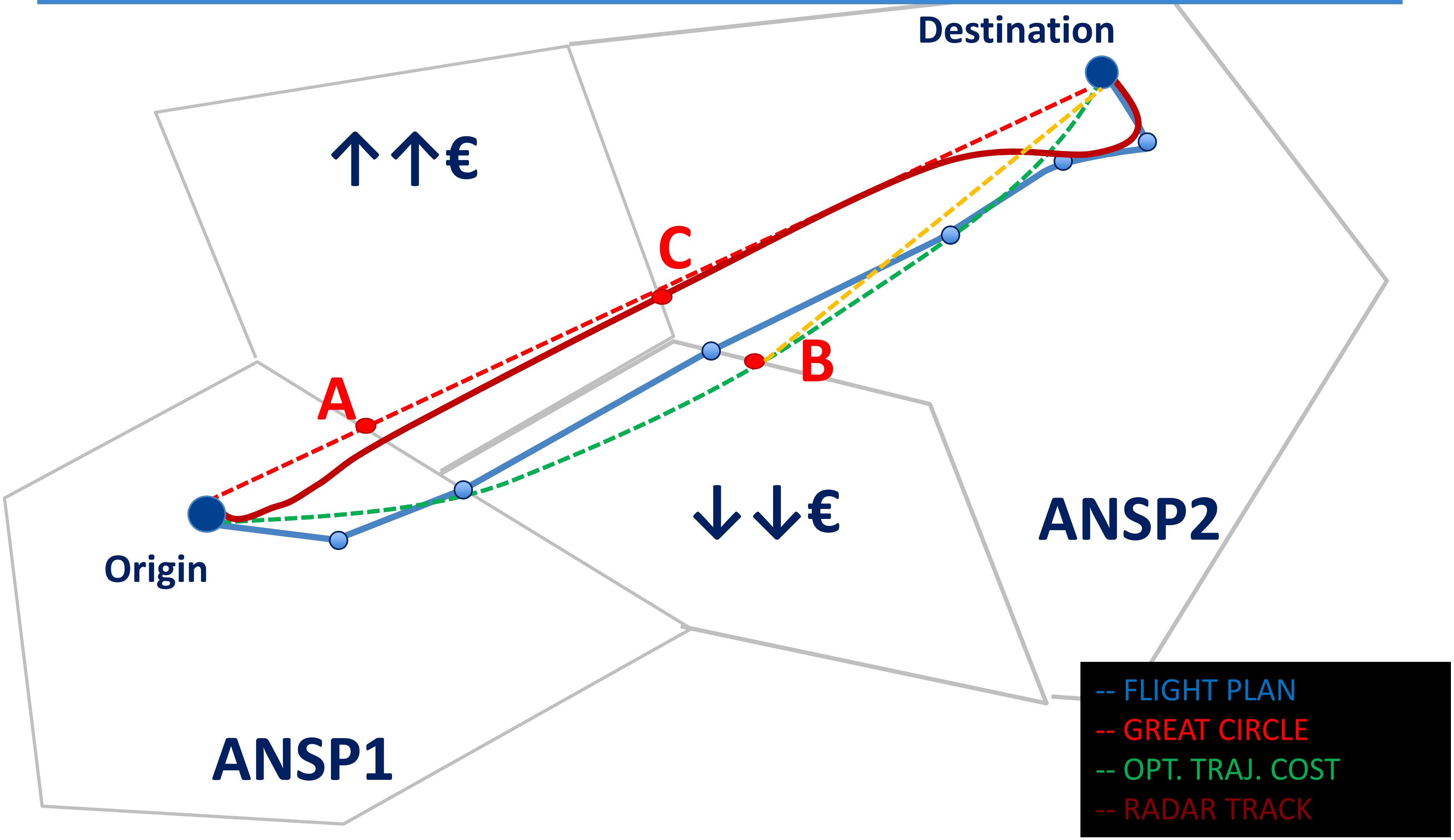
Performance Indicator – Horizontal Flight Efficiency, EUROCONTROL, 2014

http://ansperformance.eu/references/methodology/horizontal_flight_efficiency_pi.html

the comparison between the length of a trajectory and the shortest distance between its endpoints

INDICATOR	DEFINITION
KEP	Horizontal flight efficiency of last filed flight plan taking as reference minimum flown distance(achieve distance for local)
KEA	Horizontal flight efficiency of actual trajectory taking as reference the minimum flown distance (achieve distance for local)

To accomplish with their target ANSP´s try to adapt as much as possible the flown trajectory to the geodesic, but…
What happen if the Geodesic route is more inefficient in terms of fuel, cost…?



THE AURORA PROJECT

OBJECTIVES

- Define new efficiency indicators that better accommodate airline's view on efficiency based on fuel and cost (*).
- Data, methodology and tools that need to be deployed for an advanced operational efficiency assessment.
- Explore big data techniques for real time efficiency measurement
- Propose an open framework for global and local efficiency assessment

(*) Delays are considered by the PRU under a different KPA: Capacity

Example of AURORA new Indicators

INDICATOR	MEASURE	DEFINITION
KEA	Distance	Quantifies the horizontal deviations of the Actual Flown Trajectory (AFT) in comparison with the Optimal Distance Trajectory (ODT)
FEA-DW	Fuel	Quantifies the extra-fuel consumption of the Actual Flown Trajectory (AFT) in comparison with the Optimal Distance Trajectory (ODT).
FEA-FW	Fuel	Quantifies the extra-fuel consumption of the Actual Flown Trajectory (AFT) in comparison with the Optimal Fuel Trajectory (OFT).
CEA-CW1	Cost	Quantifies the extra-costs of the Actual Flown Trajectory (AFT) in comparison with the Optimal Cost Trajectory (OCT1).
CEA-CW2	Cost	Quantifies the extra-costs of the Actual Flown Trajectory (A[illegible]n with the Optimal Cost Trajectory (OCT2).
....		

INDICATOR	MEASURE	DEFINITION
EQ-3	Equity	Net difference in AU's fuel consumption in compa[illegible]n standard deviation of average percentage of actual [illegible] for each airline)
EQ-4	Equity	Quantifies the standard deviation of the mean ratio between the actual costs and the planned costs of all flights belonging to each airline
...		

LESS IS BETTER!!

Indicators Scheme

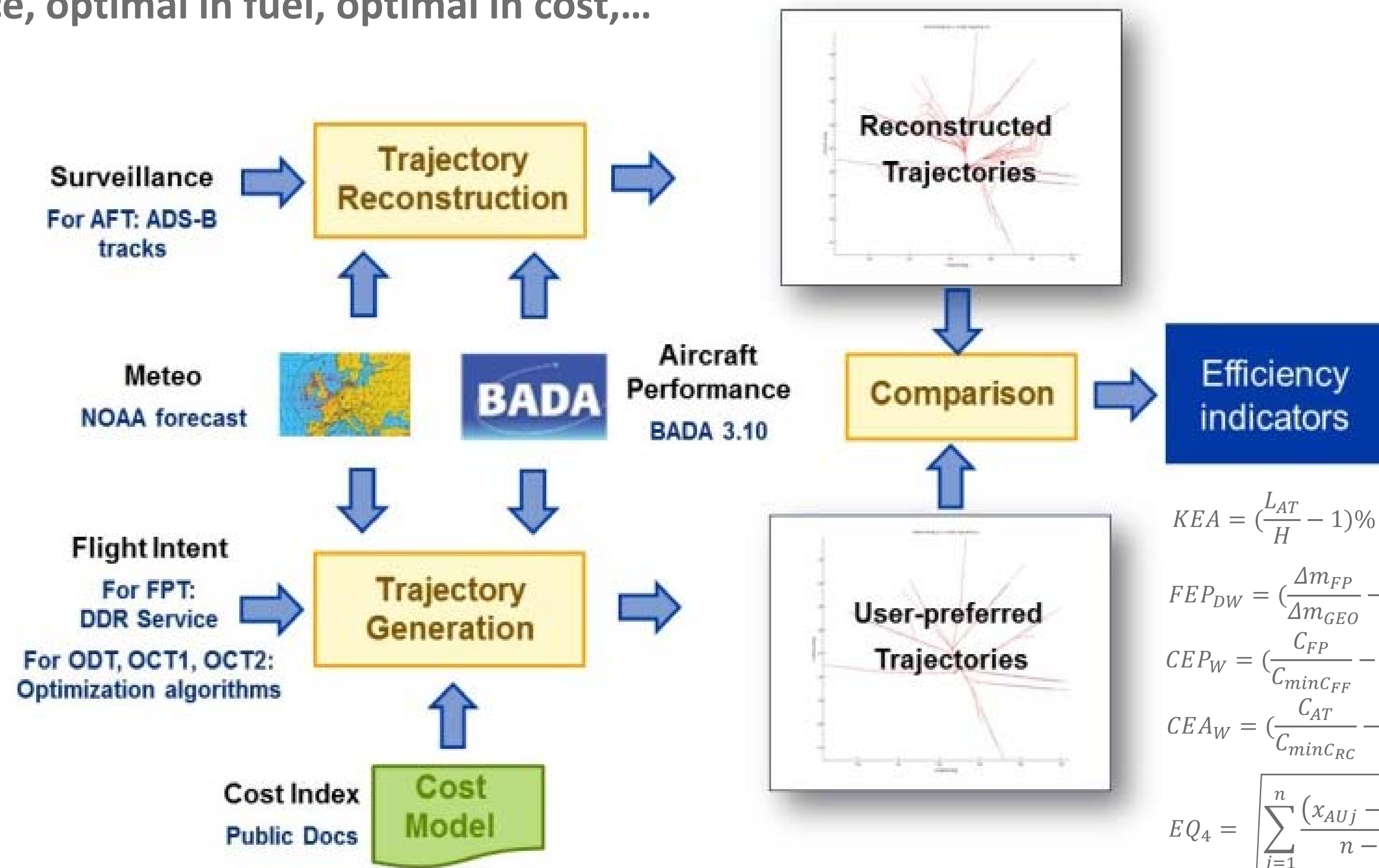
Increasing complexity in calculations

Indicators subset	Geodesic trajectory	Fuel-efficient trajectory	Cost-efficient trajectory (Time & Fuel)	Cost-efficient Trajectory (Time & Fuel & Taxes)
Distance-based	KEP KEA			
Fuel-based		Actual Planned		
Time & Fuel Cost-based			Actual Planned	
Total Cost-based				Actual Planned

Increasing representativeness

Methodology

Compare real flights (surveillance) with artificial what-if flights: flight plan, optimal in distance, optimal in fuel, optimal in cost,…



$$KEA = \left(\frac{L_{AT}}{H} - 1\right)\%$$

$$FEP_{DW} = \left(\frac{\Delta m_{FP}}{\Delta m_{GEO}} - 1\right)\%$$

$$CEP_{W} = \left(\frac{C_{FP}}{C_{minC_{FF}}} - 1\right)\%$$

$$CEA_{W} = \left(\frac{C_{AT}}{C_{minC_{RC}}} - 1\right)\%$$

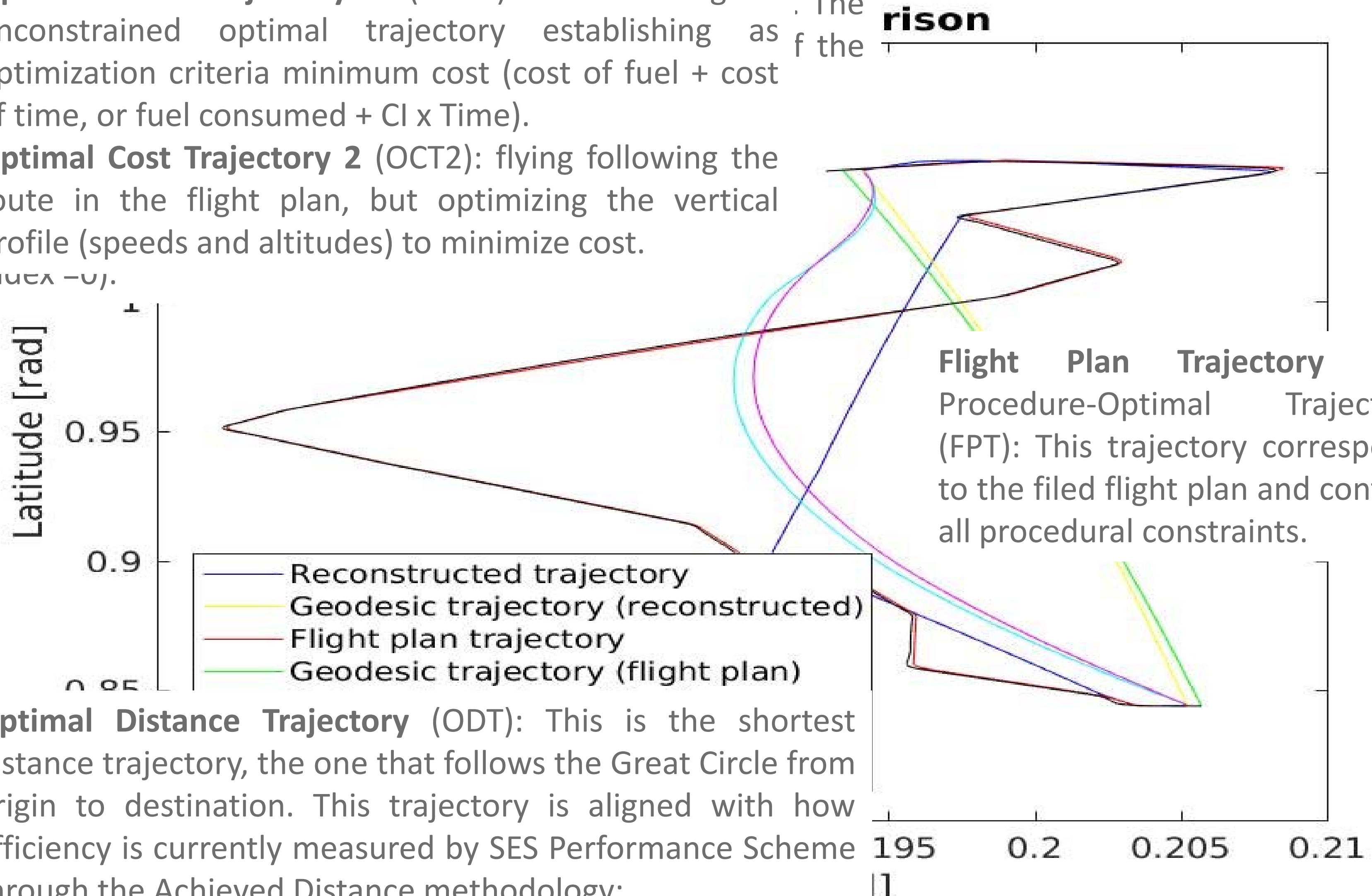
$$EQ_4 = \sqrt{\sum_{j=1}^{n} \frac{(x_{AUj} - \overline{x_C})^2}{n-1}}$$

Reference Trajectories obtained from FR24 ADS-B Tracks, NM Flight Plans and trajectory optimization algorithms

Methodology: Reference Trajectories

Optimal Cost Trajectory 1 (OCT1): Free routing or unconstrained optimal trajectory establishing as optimization criteria minimum cost (cost of fuel + cost of time, or fuel consumed + CI x Time).

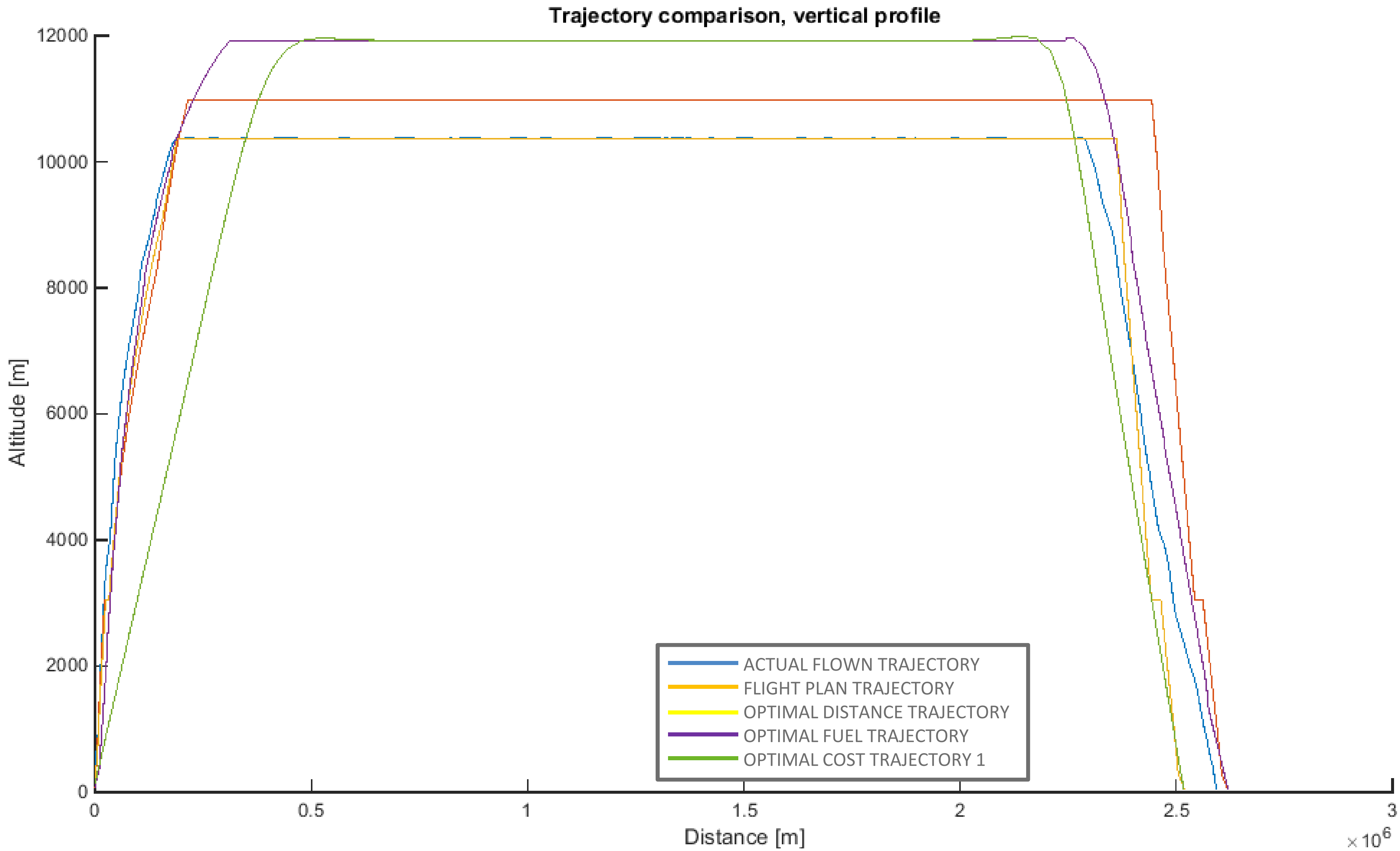
Optimal Cost Trajectory 2 (OCT2): flying following the route in the flight plan, but optimizing the vertical profile (speeds and altitudes) to minimize cost.



Flight Plan Trajectory (also Procedure-Optimal Trajectory) (FPT): This trajectory corresponds to the filed flight plan and contains all procedural constraints.

Optimal Distance Trajectory (ODT): This is the shortest distance trajectory, the one that follows the Great Circle from origin to destination. This trajectory is aligned with how efficiency is currently measured by SES Performance Scheme through the Achieved Distance methodology;

Methodology: Vertical Profiles

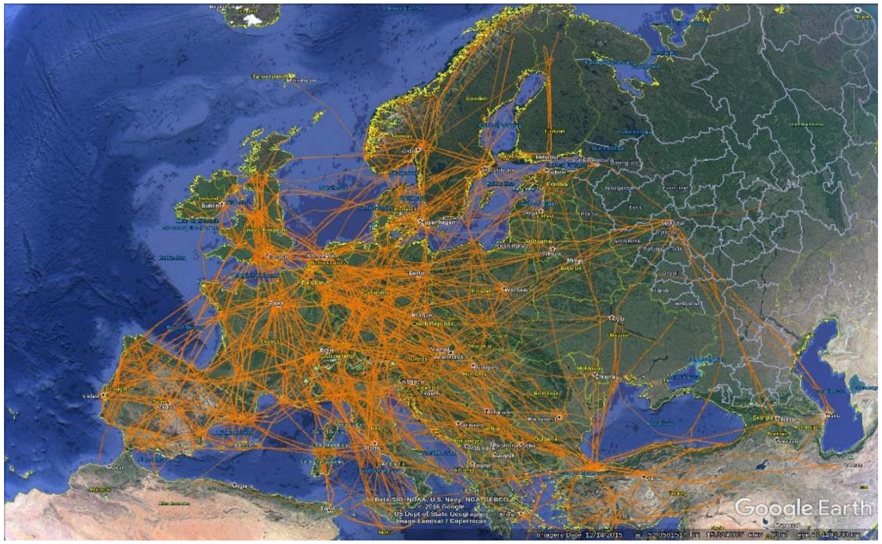


Scenarios

The study presented corresponds to the analysis of all real ADS-B equipped flights that took-off and landed inside the European Civil Aviation Conference (ECAC) area occurring on February 20th and 24th 2017 (~ 15.000 flights per day)

TYPE	FORMAT	SOURCE
Surveillance	ADS-B message	FR24
Flight Plan	FTFM point profile from ALLFT+ file BADA 3.10 APF files	EUROCONTROL
Aircraft Performance	BADA 3.10	EUROCONTROL
Weather	GFS data as grib2 files	NOAA
CI	One value per aircraft type	Aircraft manufacturers' documentation

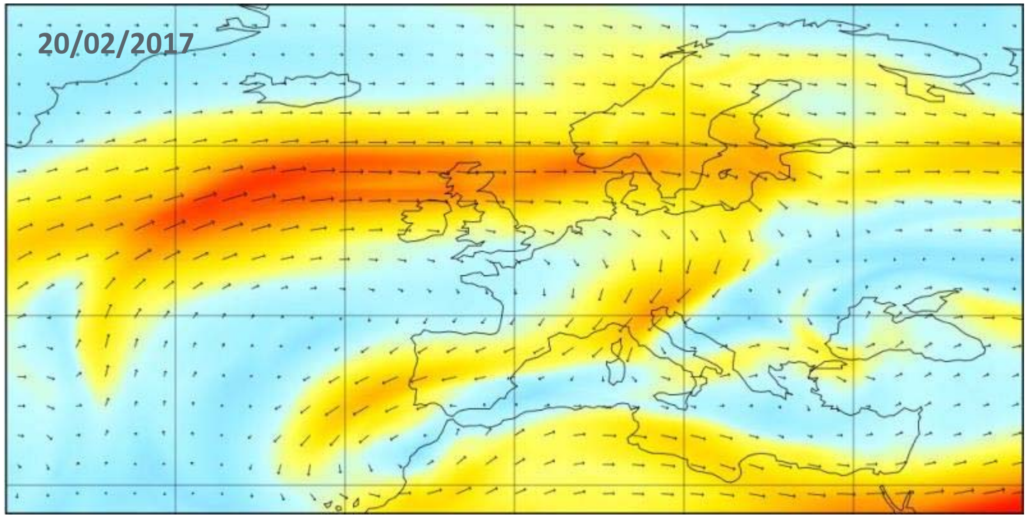
Summary of input data

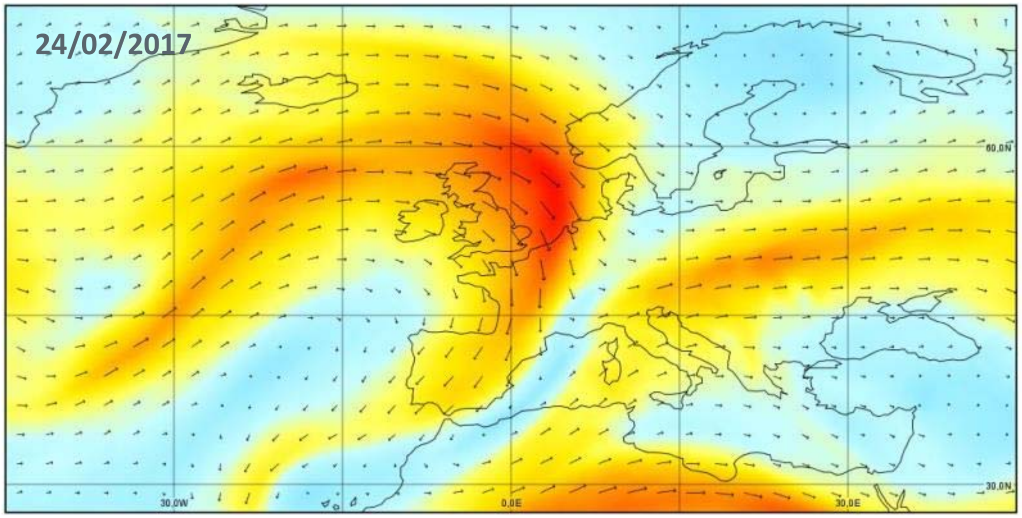


Sample of 2000 flights analysed for 02/20/2017

- Is It feasible?
- Will the picture of the European traffic change depending on the metric chosen?
- Can we observe some degree of correlation between simpler and complex KPIs?
- Could we use KPIs values to identify certain lost of efficiency events?

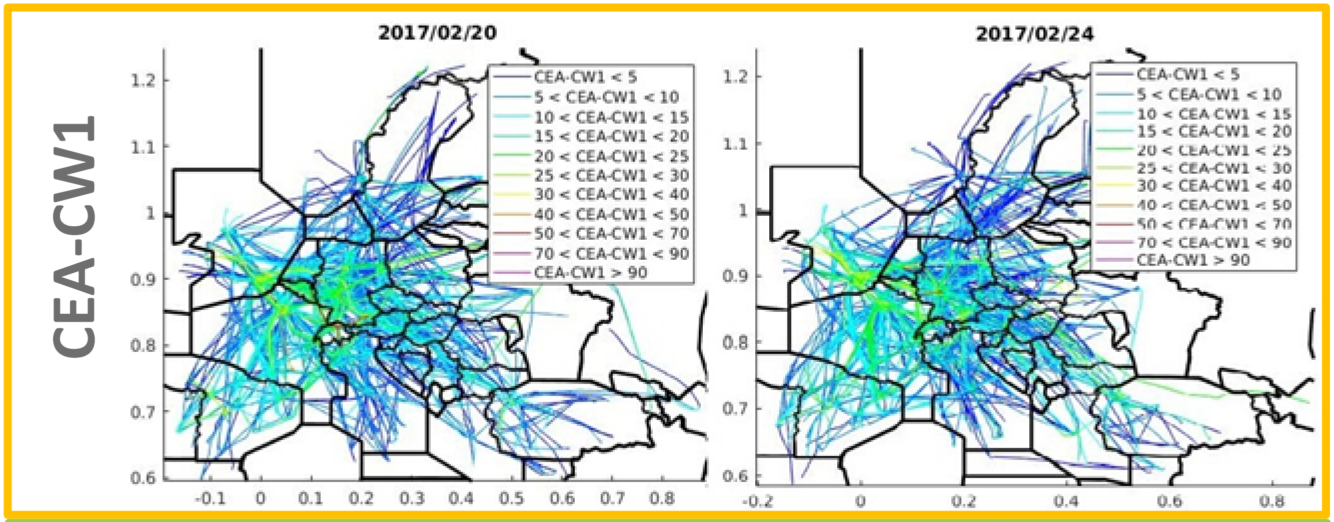
Scenarios: Weather

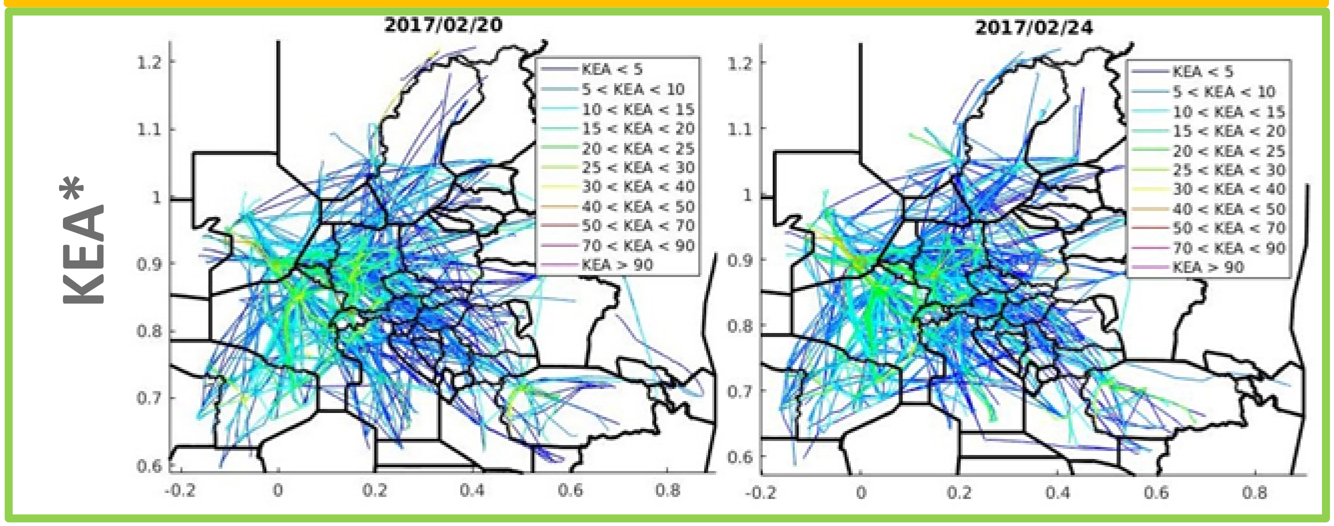




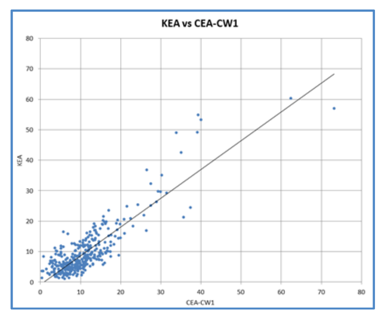
Results – Cost Efficiency (1/4)

CEA-CW1: Flown cost vs. Optimal cost O-D.





	KEA* MEAN VALUE	CEA-CW1 MEAN VALUE
20/02/2017	9.7%	9.3%
24/02/2017	10.2%	10.0%

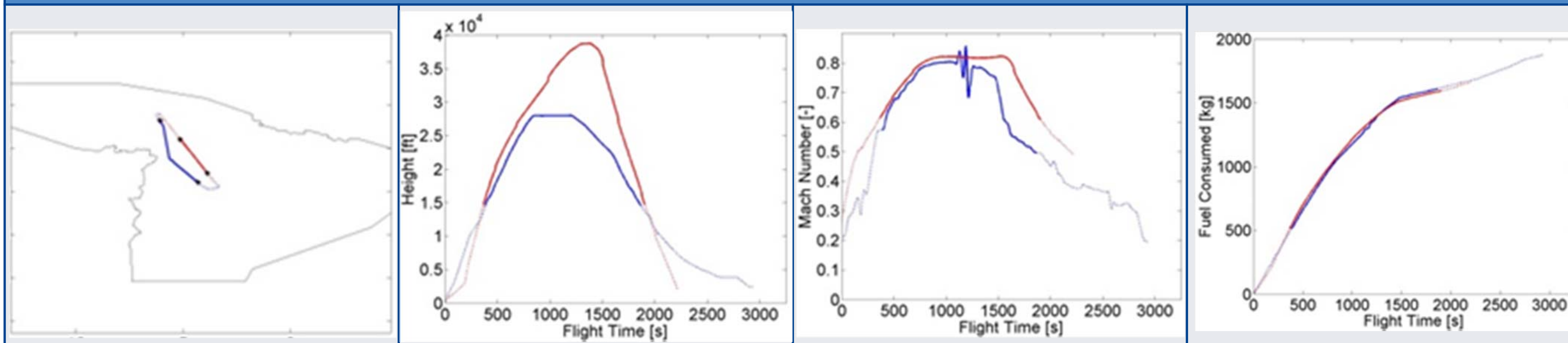


$$R^2 = 0.76$$

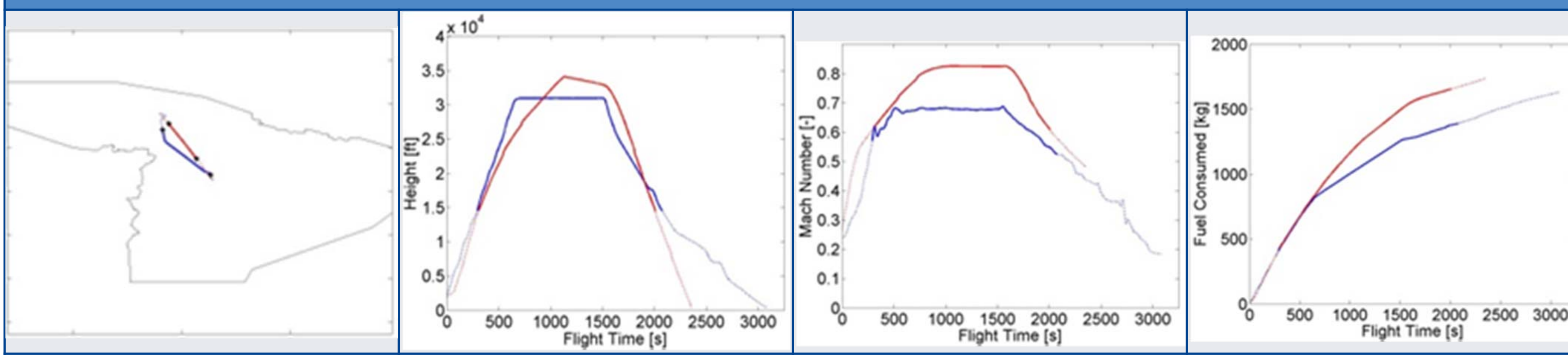
Results – Cost Efficiency (2/4)

AFT in blue
OCT1 in red

IBE481 from OVD to MAD - CEA_CW1: 30.2%



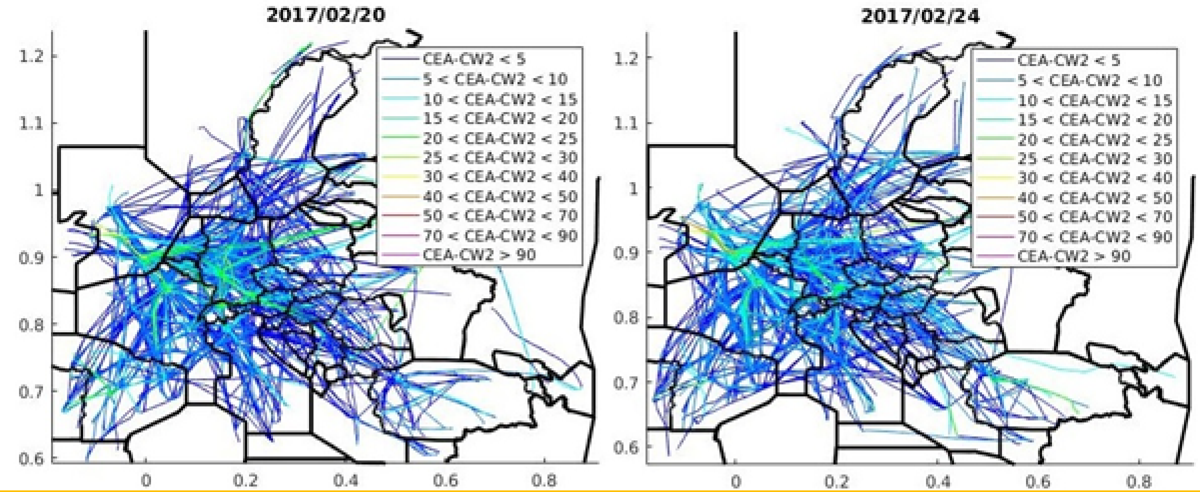
IBE04VM from MAD to OVD - CEA_CW1: 13.7%



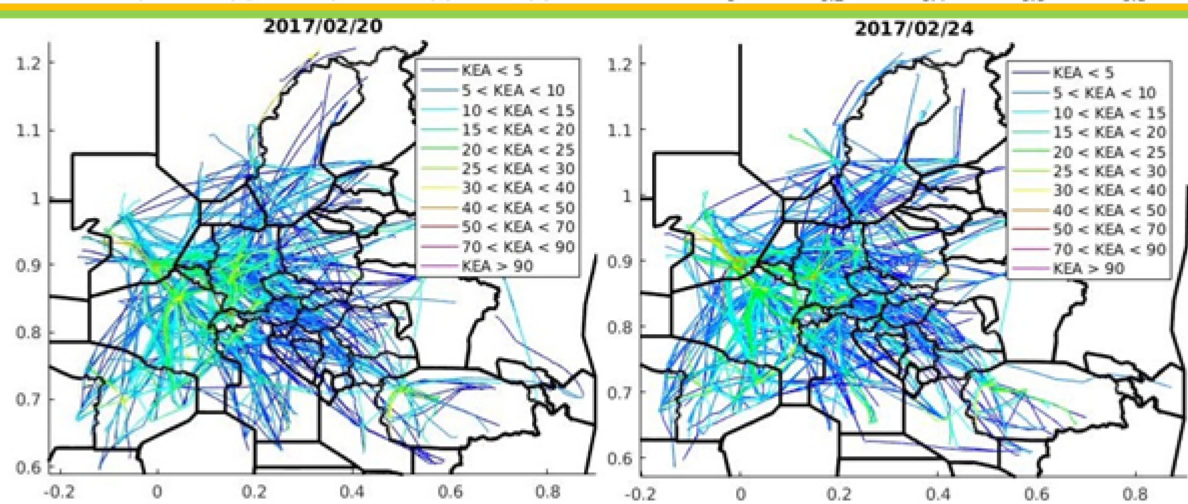
Results – Cost Efficiency (3/4)

CEA-CW2: Flown cost vs. Optimal cost O-D.

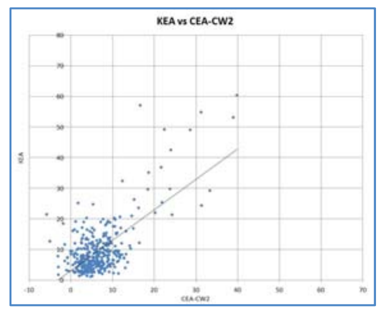
CEA-CW2



KEA*



	KEA* MEAN VALUE	CEA-CW2 MEAN VALUE
20/02/2017	9.7%	4.6%
24/02/2017	10.2%	6.2%

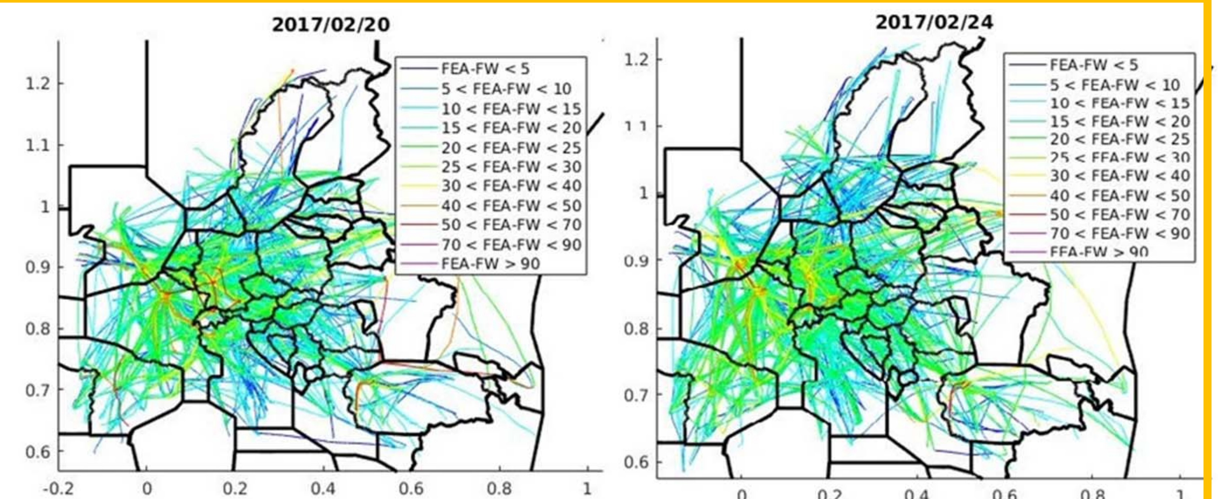


$R^2 = 0.45$

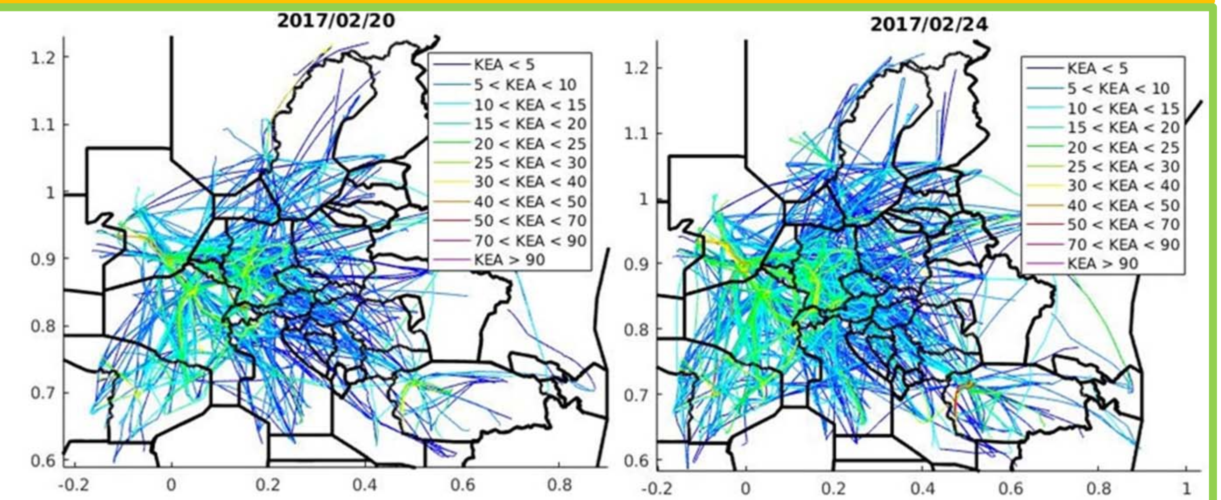
Results – Fuel Efficiency (4/4)

FEA-FW: Flown fuel consumption vs. Optimal fuel O-D.

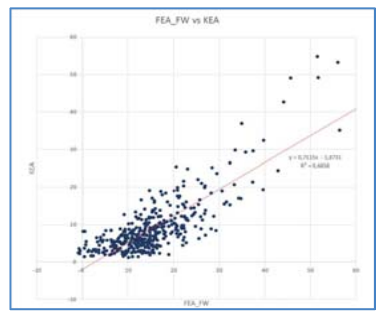
FEA-FW



KEA*

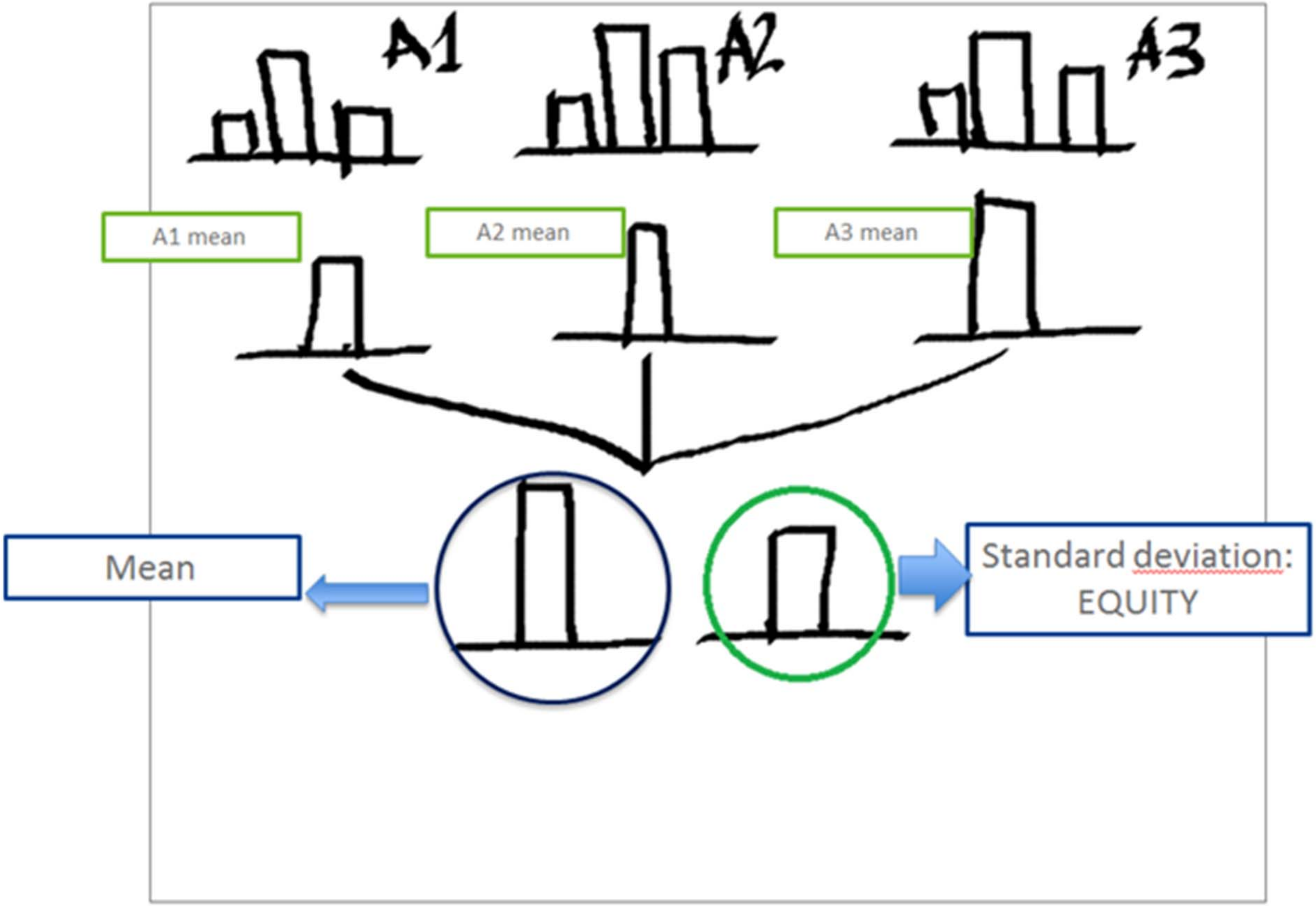


	KEA* MEAN VALUE	FEA-FW MEAN VALUE
20/02/2017	9.7%	14.9%
24/02/2017	10.2%	15.3%



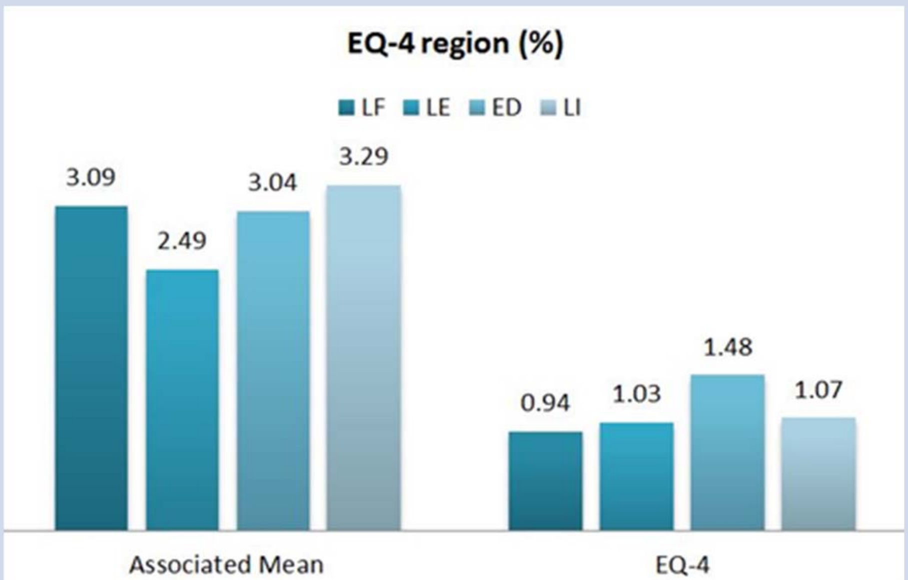
$R^2 = 0.68$

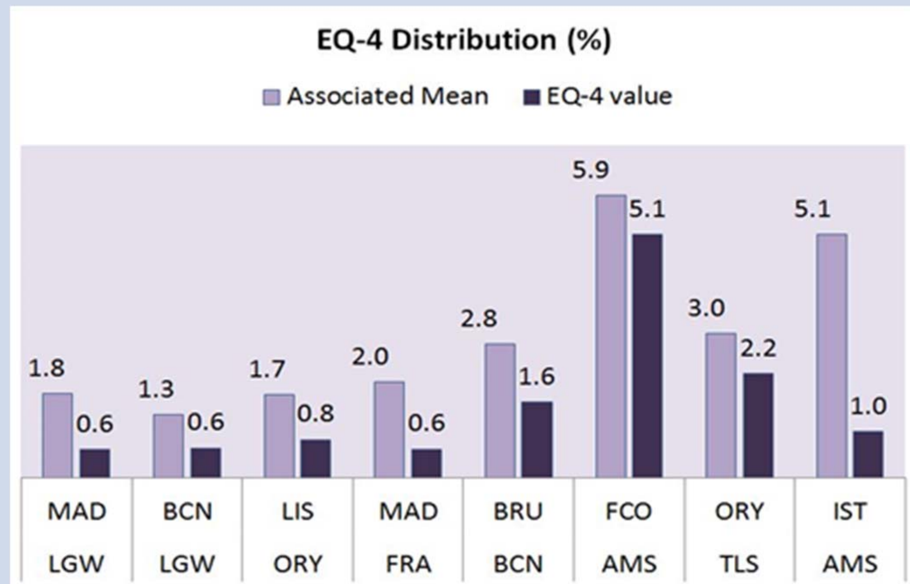
Equity Indicators Calculation



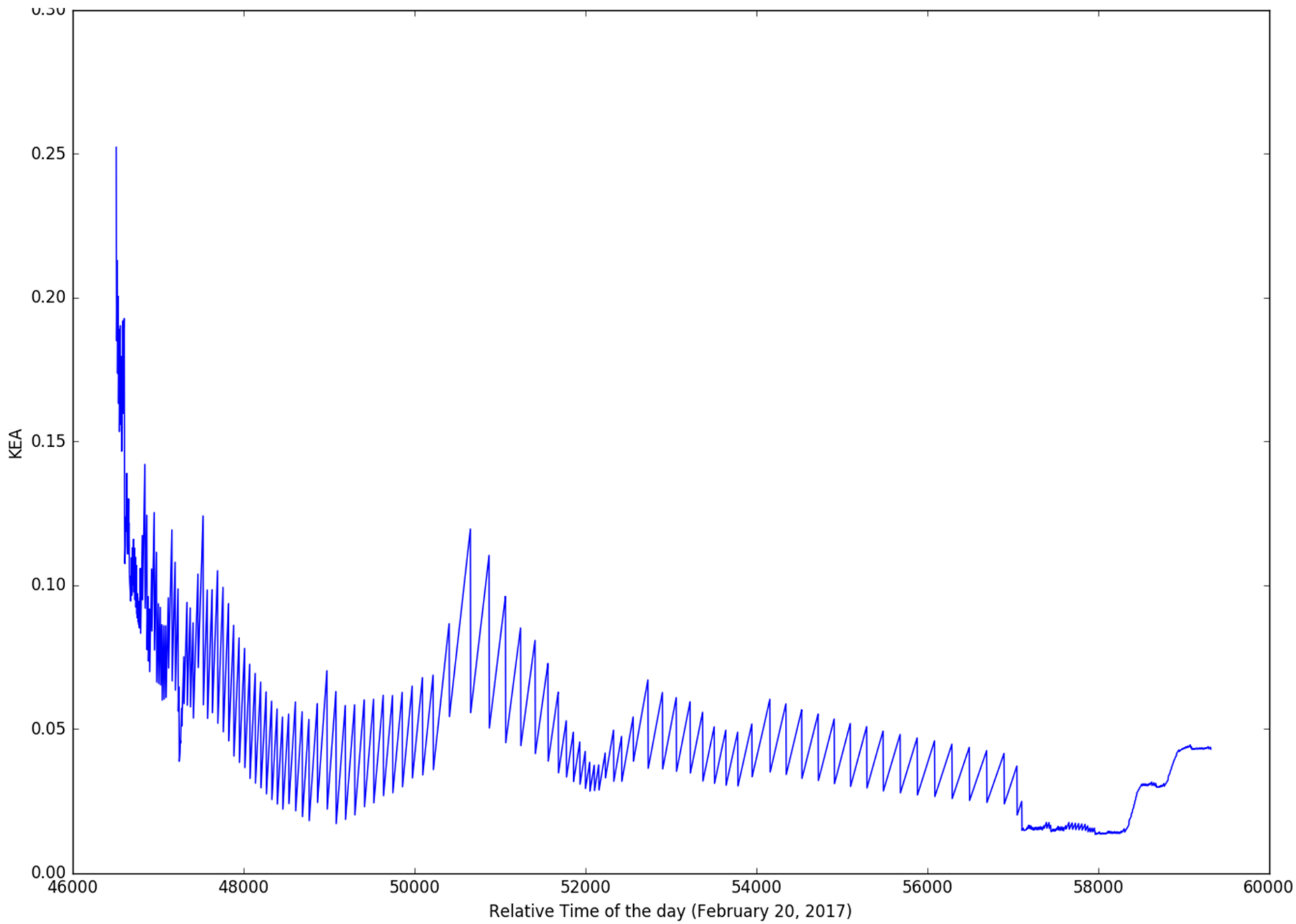
Results – Equity

BY REGION	BY CITY-PAIR





On-Line Calcution of Indicators



Conclusions and Final Remarks

- Lack of operational efficiency diminishes aircraft capabilities.
- ANSPs are currently evaluated in a way that is not clearly beneficial for the airlines.
- New indicators might close the gap on the different visions of efficiency.
- New indicators requires new trajectory computation capabilities, data management and access.
- Due to the methodology proposed, ADS-B data could serve as a reliable source on the performance monitoring at the ECAC level, providing a new paradigm in where ANSP's performance is only evaluated locally, i.e., at the level of an ANSP area of responsibility, but globally, i.e., how the actions of the ANSP impacts the overall ANSPs involved.
- ADS-B seems a global and reliable source for this process: fully exploited in online efficiency assessment

www.aurora-er.eu

ADS-B BASED AIR TRAFFIC PERFORMANCE ASSESSMENT: DEVELOP NEW METRICS FOR MEASURING ANSPS AND AIRLINES FLIGHT EFFICIENCY.

Thank you very much for your attention!

This project has received funding from the SESAR Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No [number]

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QUESTIONS ?

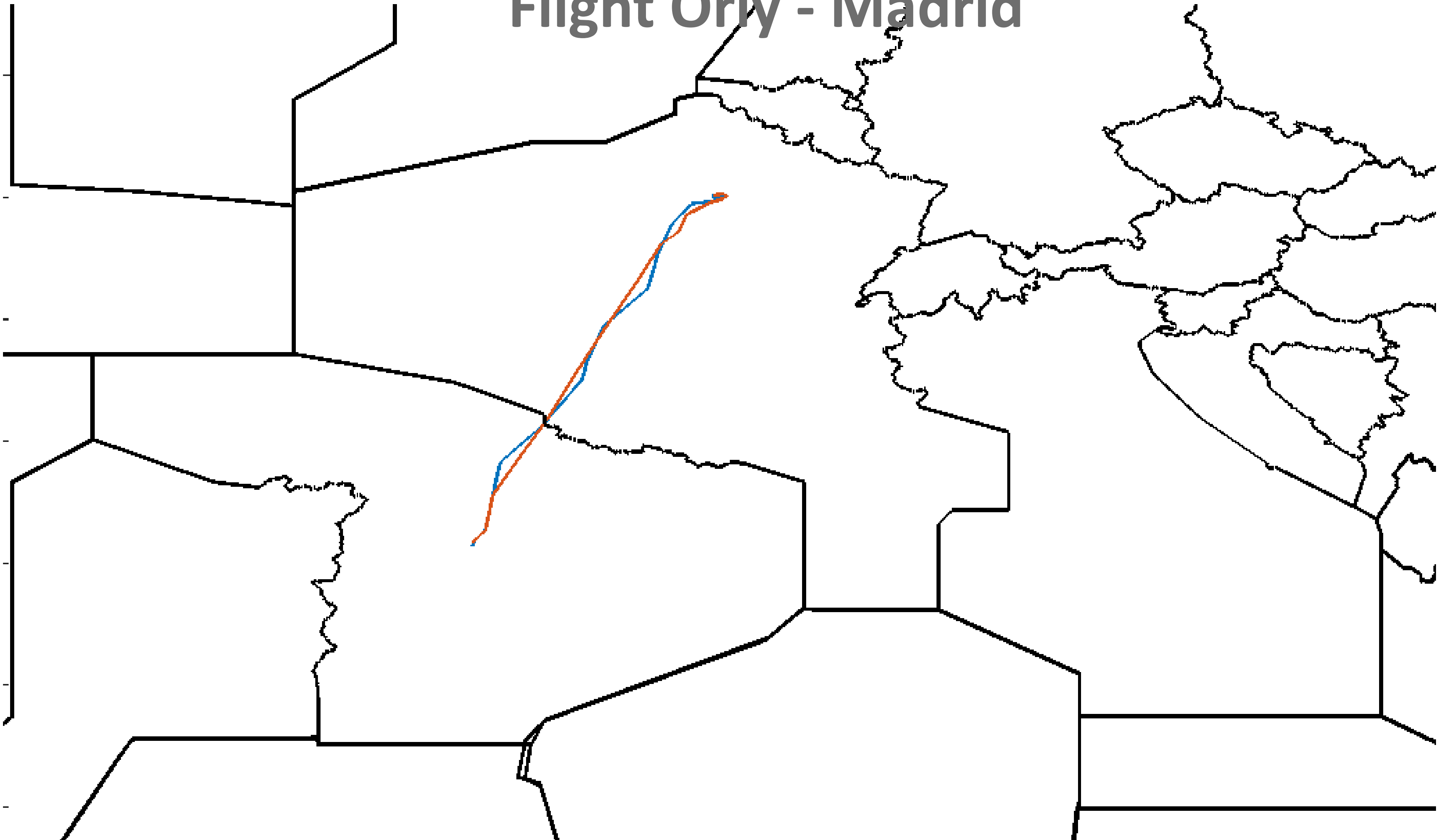
MOTIVATION

Airline Perspective	ANSP Perspective (European View)
▪ Punctuality, Fuel efficiency, Cost efficiency ▪ Airlines would like to fly their network optimal, or to adjust their Network to the new routes, not always allowed in the airspace structure	▪ PRU define the metrics based on ICAO KPA. ▪ Local Efficiency vs Global efficiency ▪ Currently, Horizontal Flight Efficiency

CAN WE PROVIDE AIRLINES and ANSPs with a set of METRICS to assess their performance with a common view?

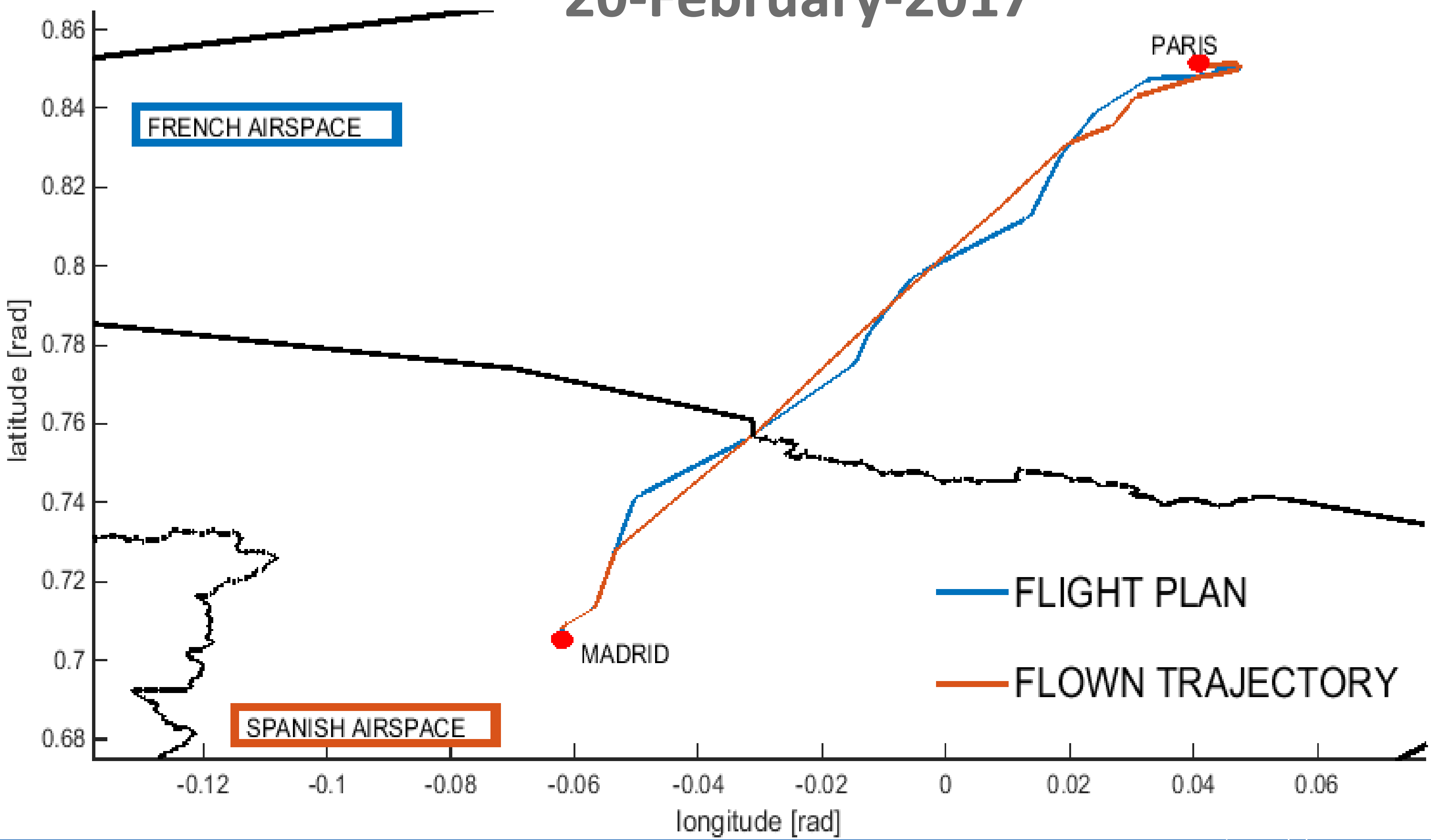
WHY ASSESING OPERATIONAL EFFICIENCY?

Flight Orly - Madrid



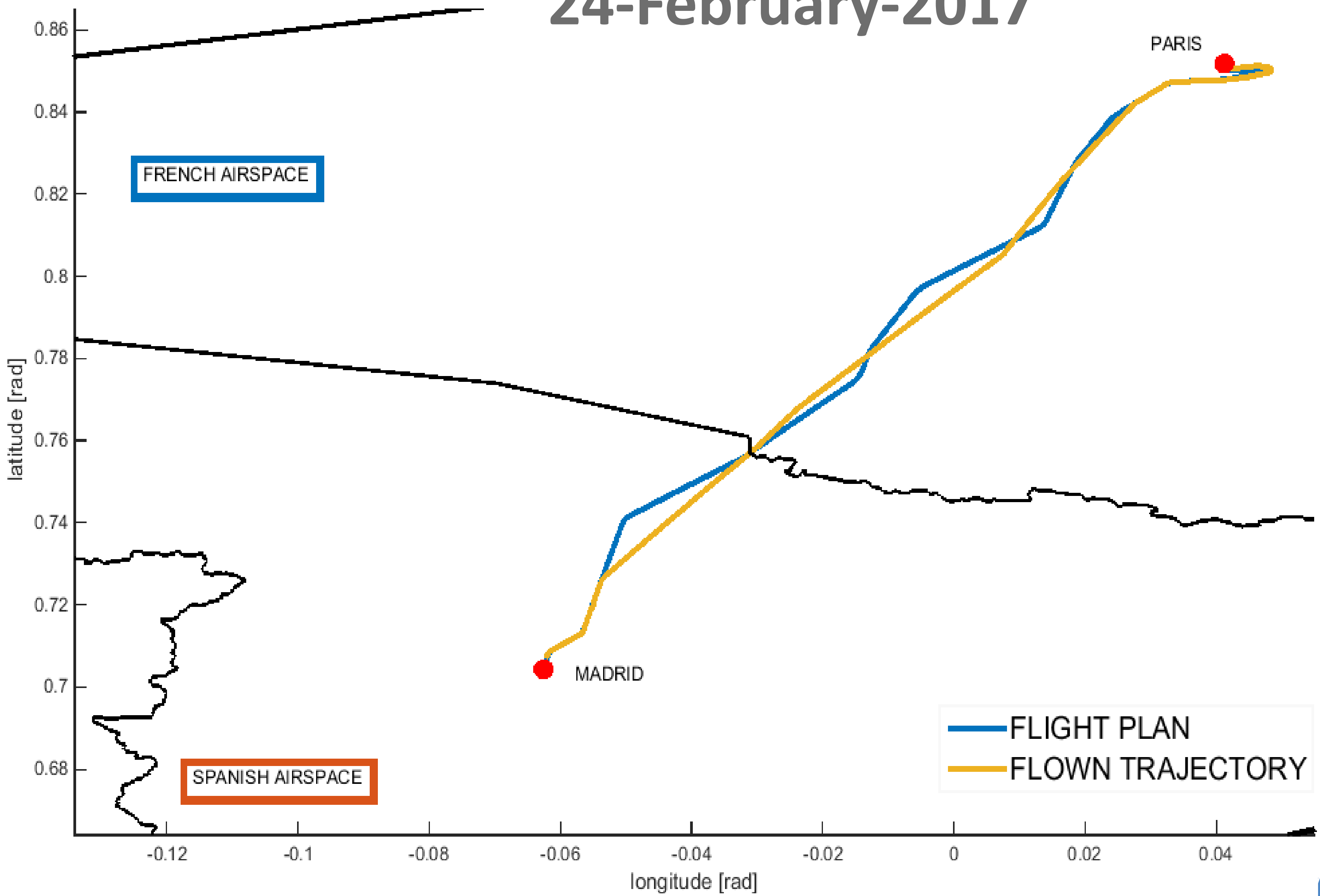
WHY?

Flight Orly – Madrid 20-February-2017



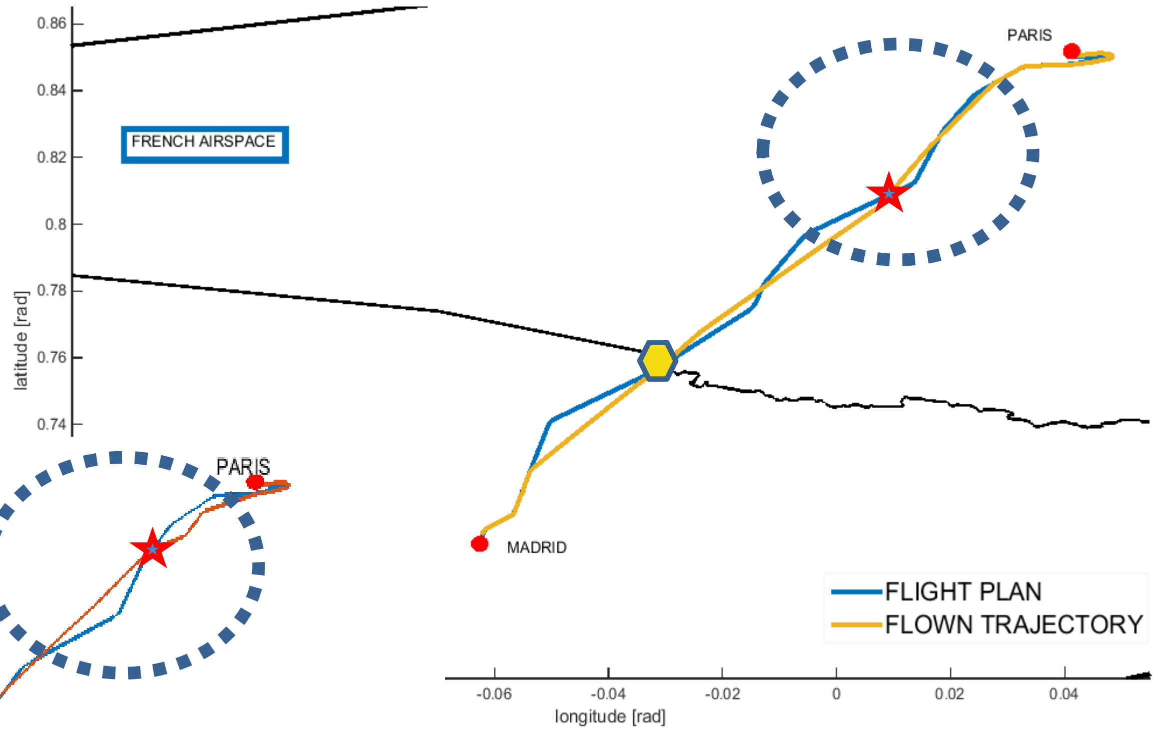
WHY?

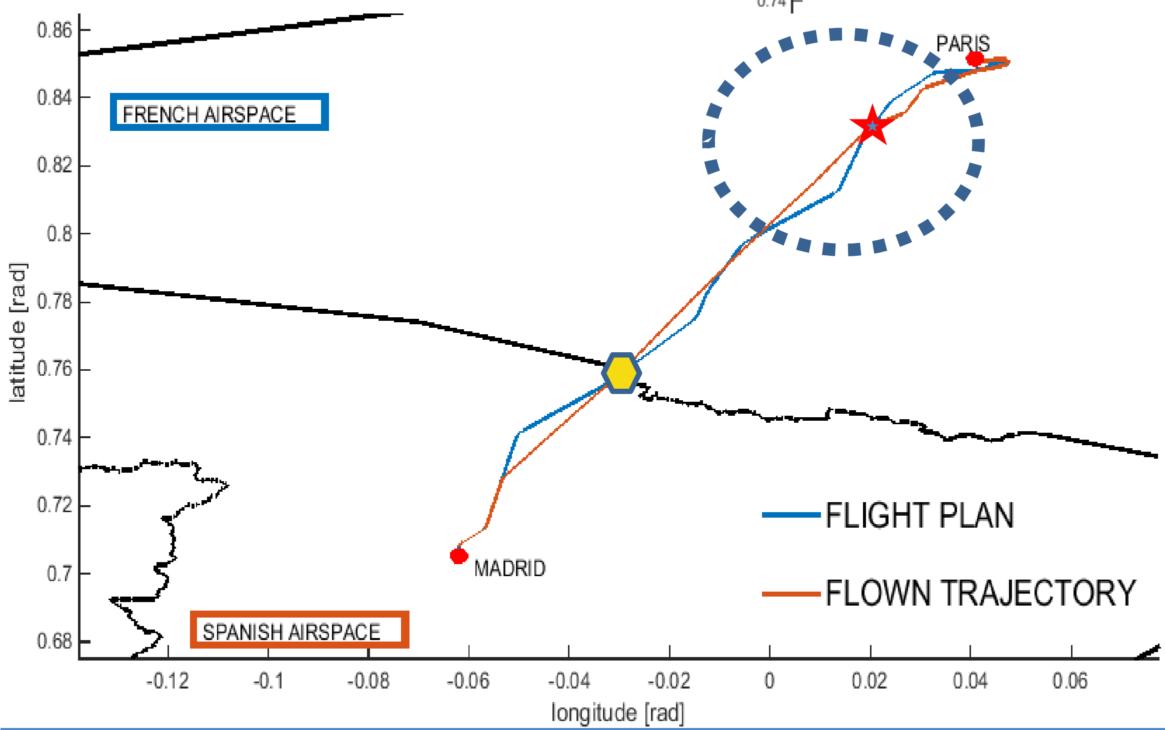
Flight Orly – Madrid
24-February-2017



WHY?

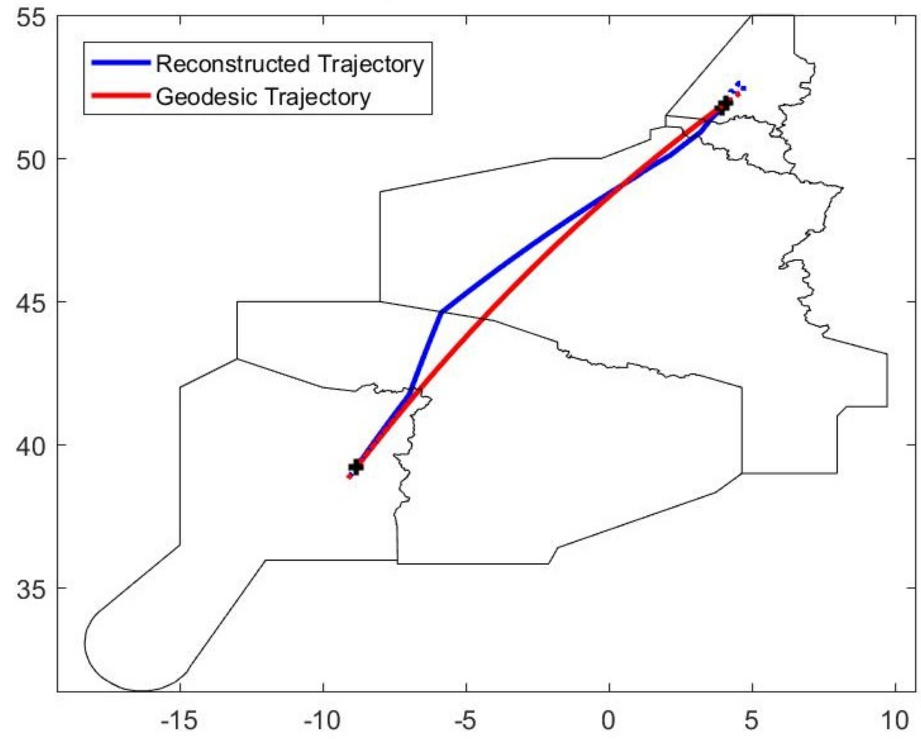
Very frequent "direct to" Spanish airspace

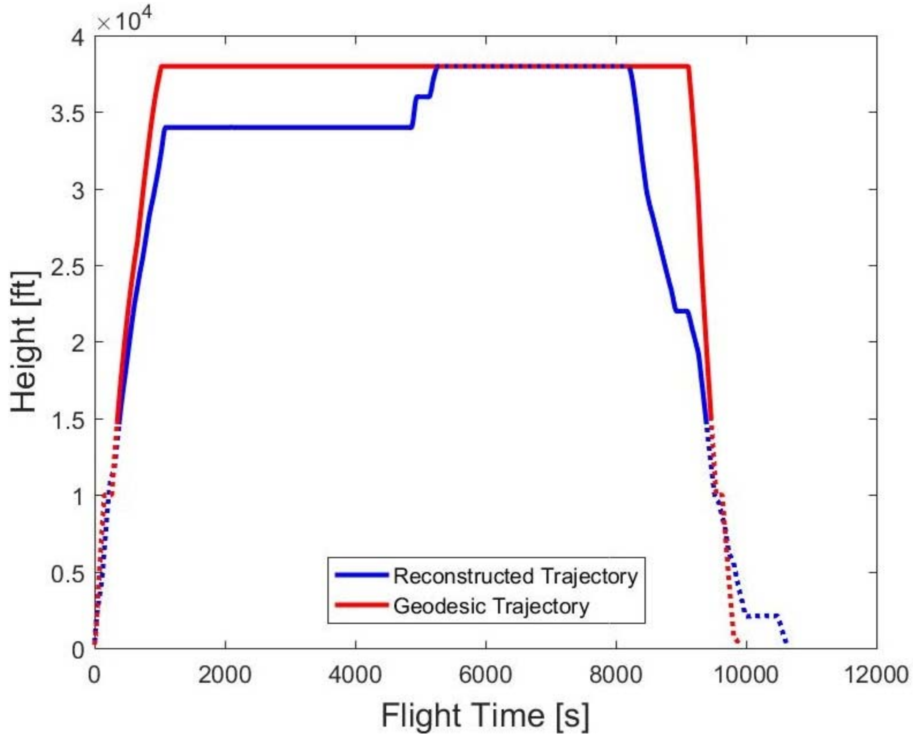




Airline carries extra fuel for planning a longer route

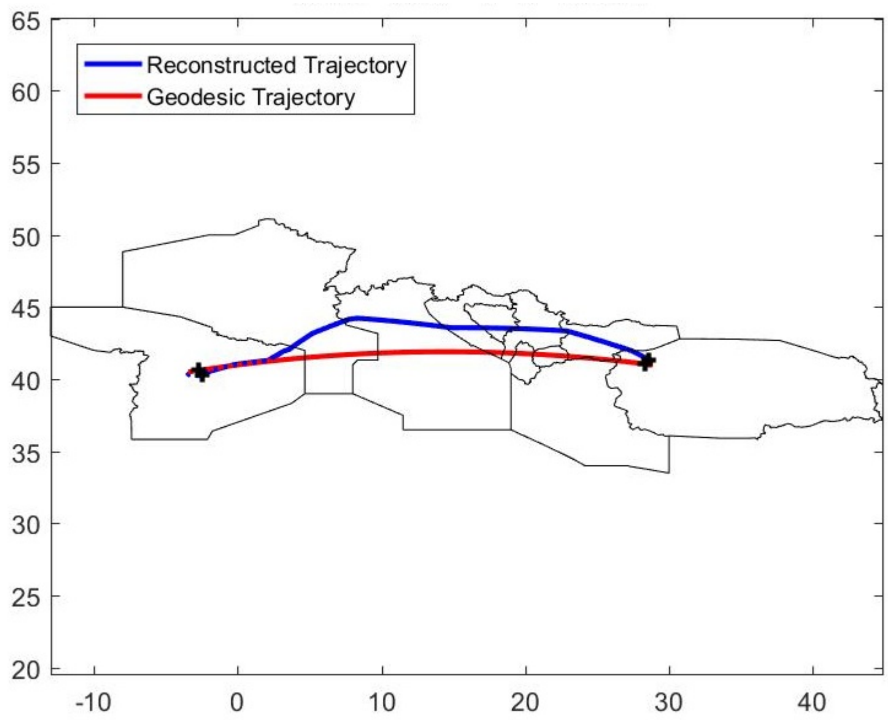
KEA & FEA-DW - Example I

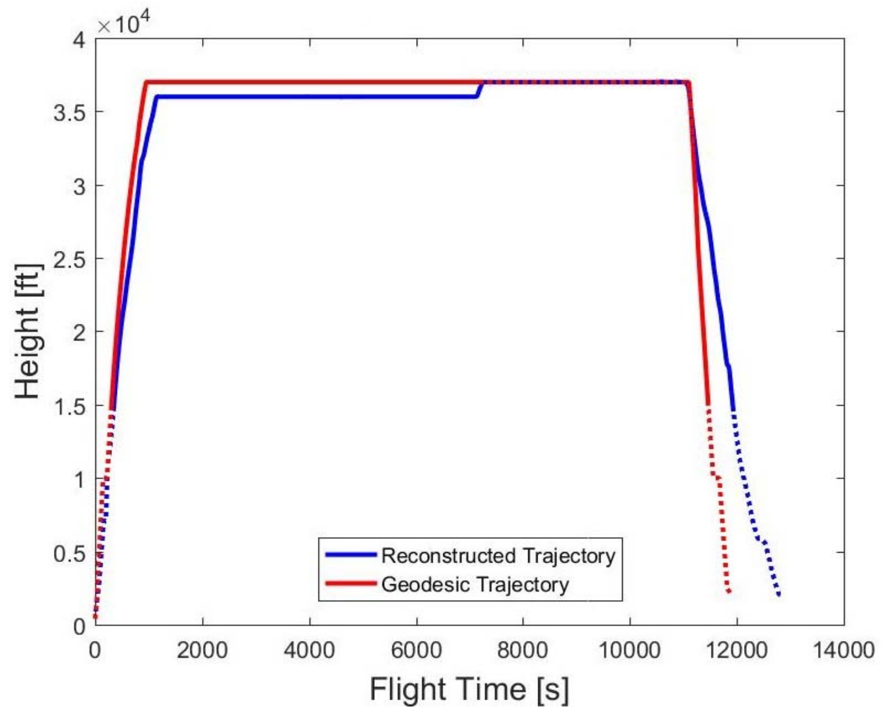




KEA	FEA-DW
4.91	7.78

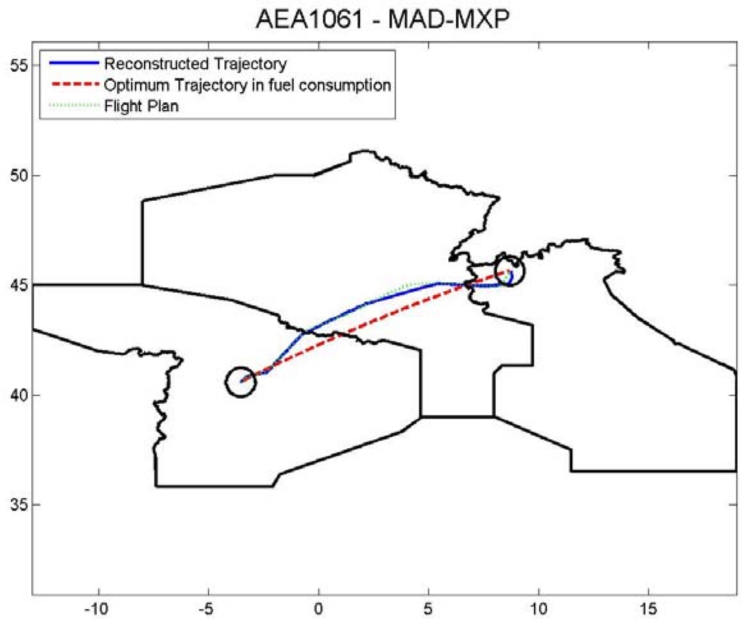
KEA & FEA-DW - Example II

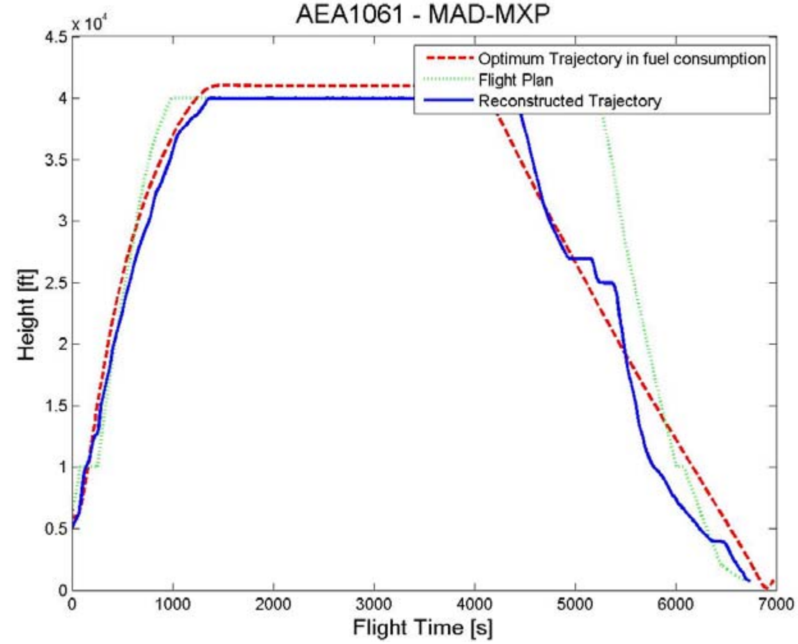




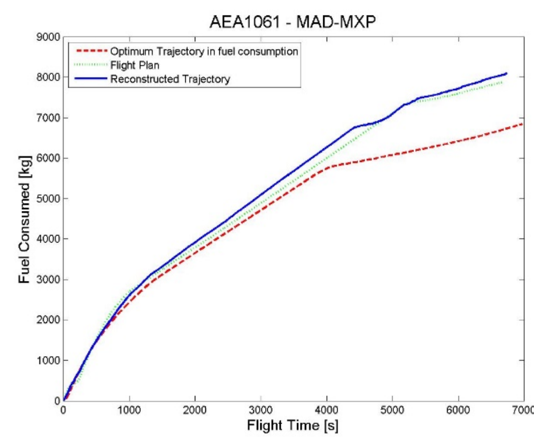
KEA	FEA-DW
5.32	0.53

KEA & FEA-FW - Example I

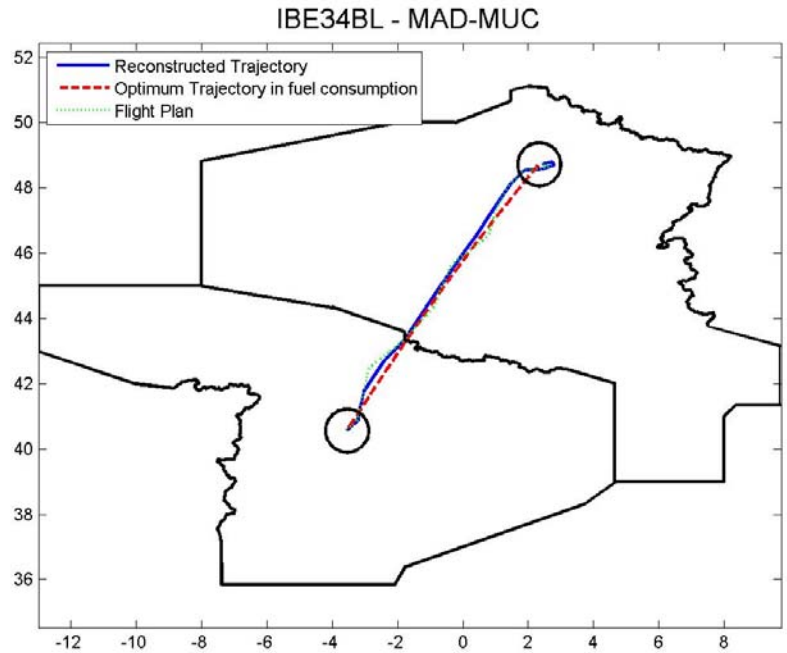


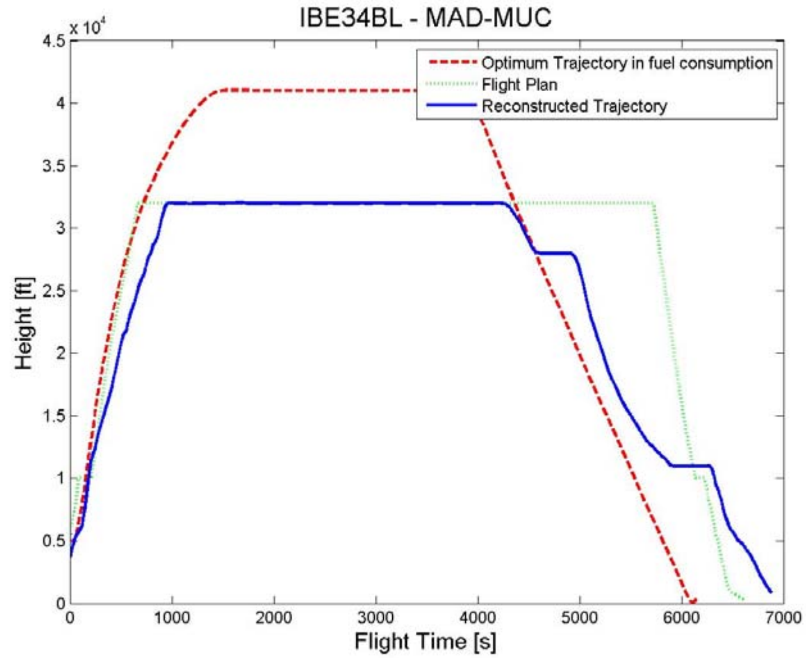


KEA	FEA-FW
7.77	18.47

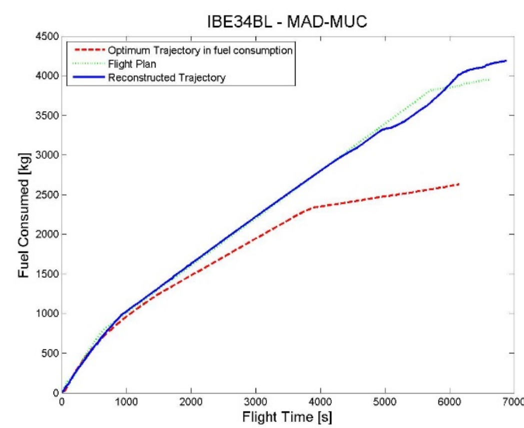


KEA & FEA-FW - Example II





KEA	FEA-FW
7.68	59.35

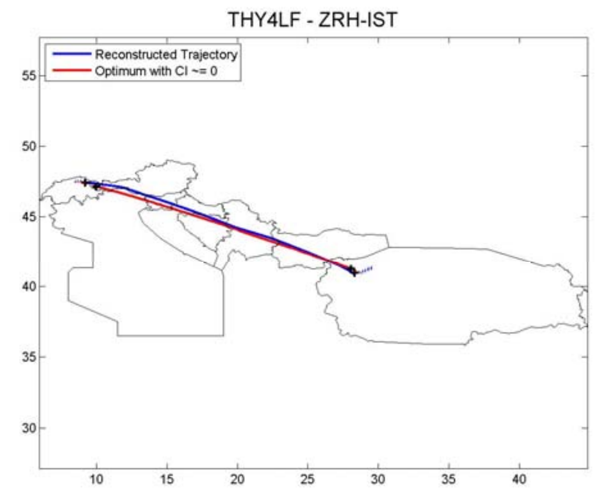


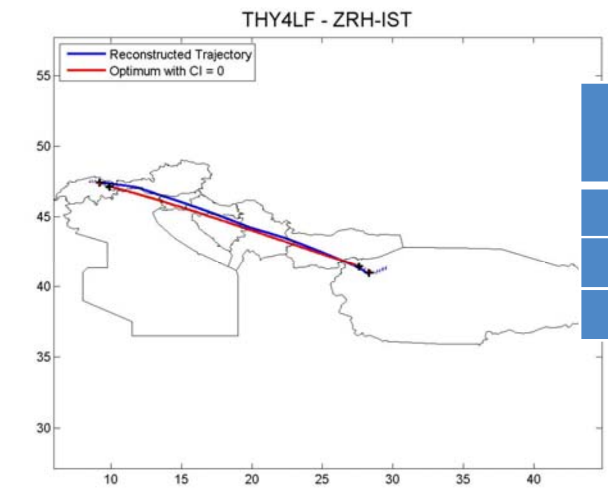
KEA & CEA-CW1 - Example 1

Cost Based (Free route and CI>0)
Reference trajectory

Fuel Based (Free route and CI=0)
Reference trajectory

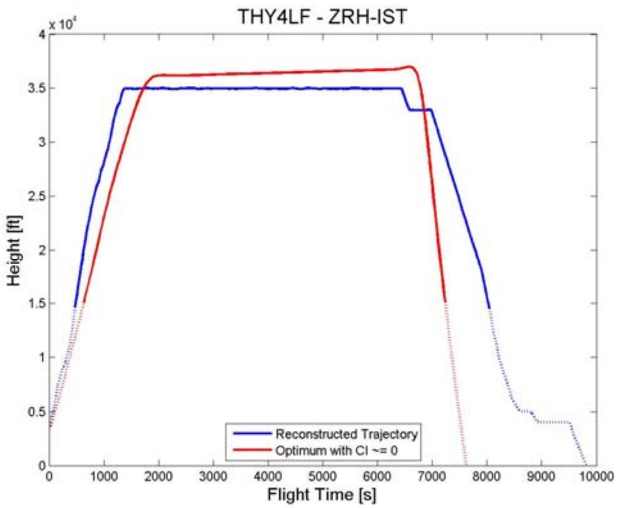
Horizontal

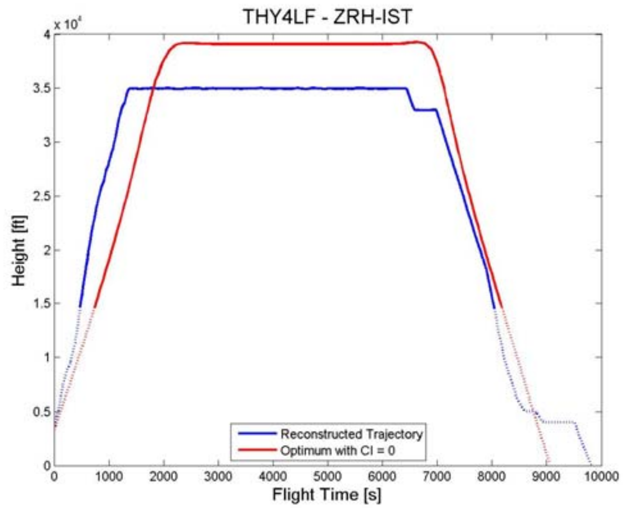




THY4LF	Zurich-Istanbul
KEA	10.05 %
FEA-FW	20.53 %
CEA-CW1	**17.37 %**

Vertical



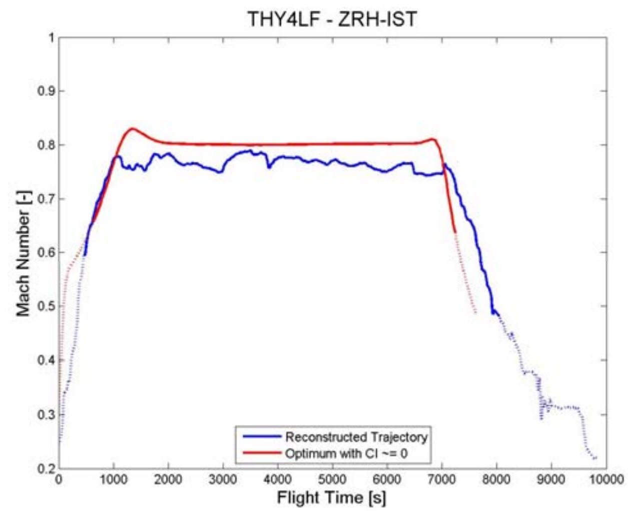


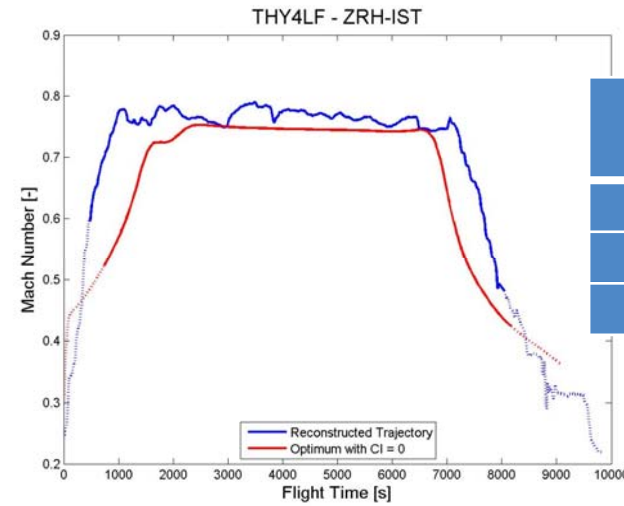
KEA & CEA-CW1 - Example 1

Cost Based (Free route and CI>0)
Reference trajectory

Fuel Based (Free route and CI=0)
Reference trajectory

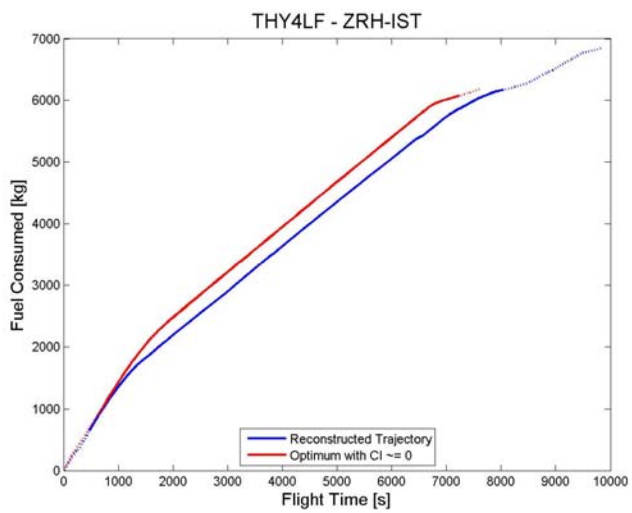
Speed

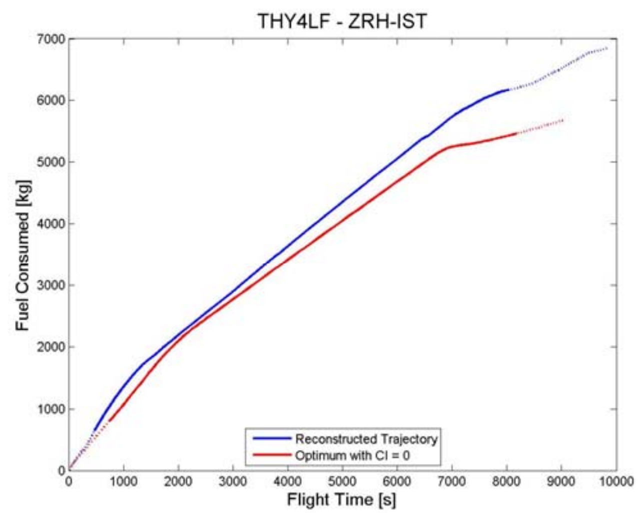




THY4LF	Zurich-Istanbul
KEA	10.05 %
FEA-FW	20.53 %
CEA-CW1	**17.37 %**

Fuel



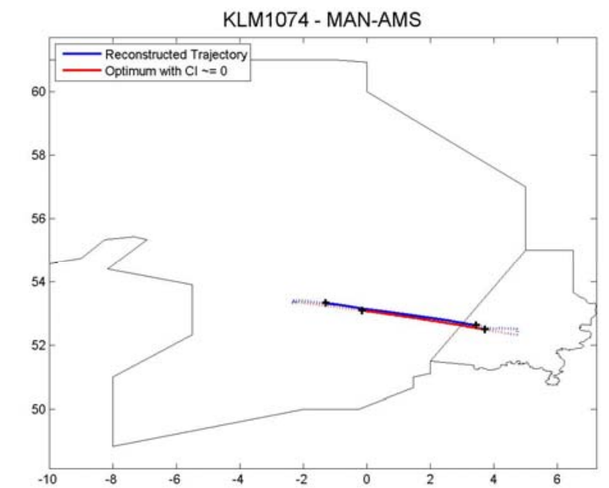


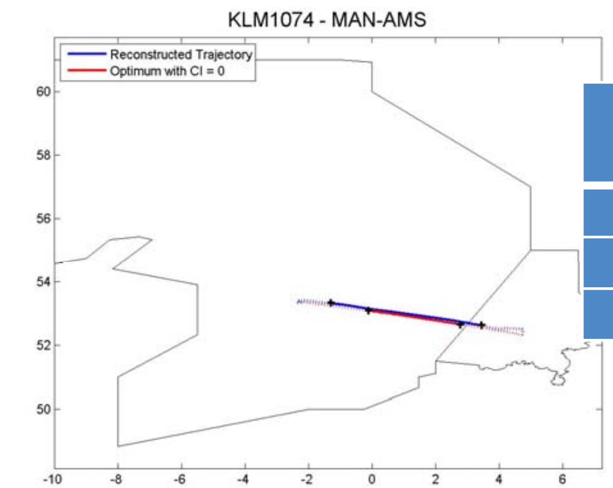
KEA & CEA-CW1 - Example 2

Cost Based (Free route and CI>0)
Reference trajectory

Fuel Based (Free route and CI=0)
Reference trajectory

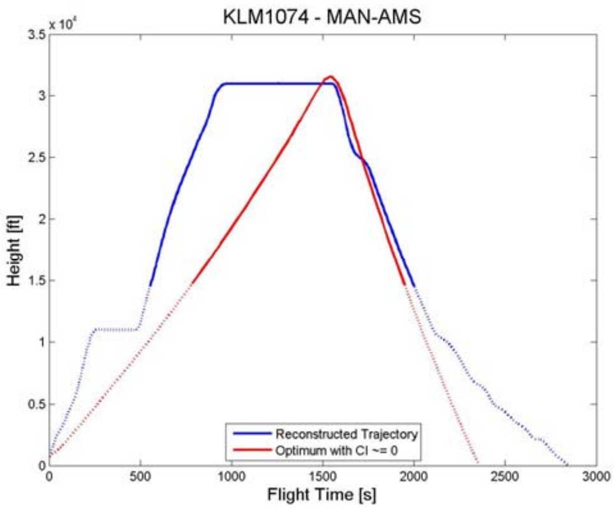
Horizontal

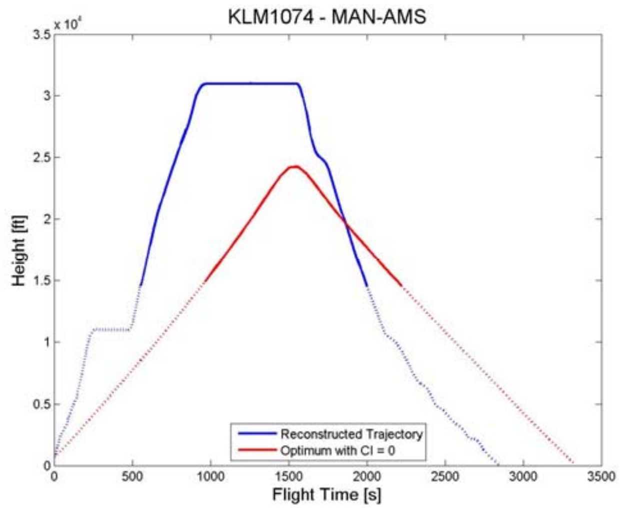




KLM1074	Manchester-Amsterdam
KEA	9.22 %
FEA-FW	15.67 %
CEA-CW1	**3.76 %**

Vertical



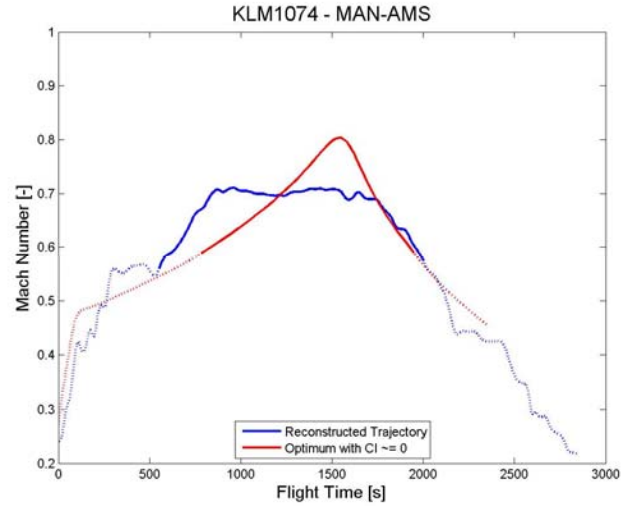


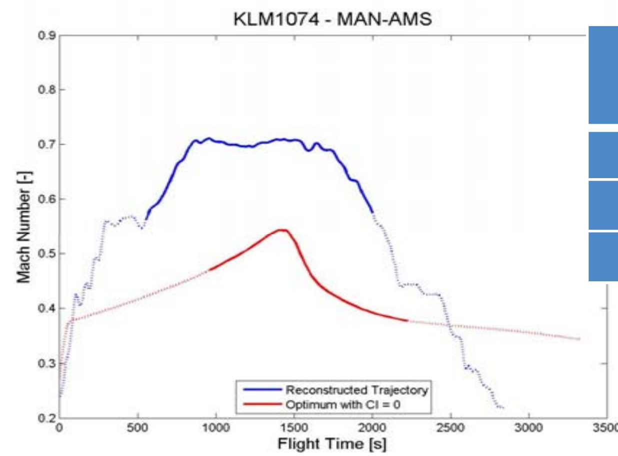
KEA & CEA-CW1 - Example 2

Cost Based (Free route and CI>0)
Reference trajectory

Fuel Based (Free route and CI=0)
Reference trajectory

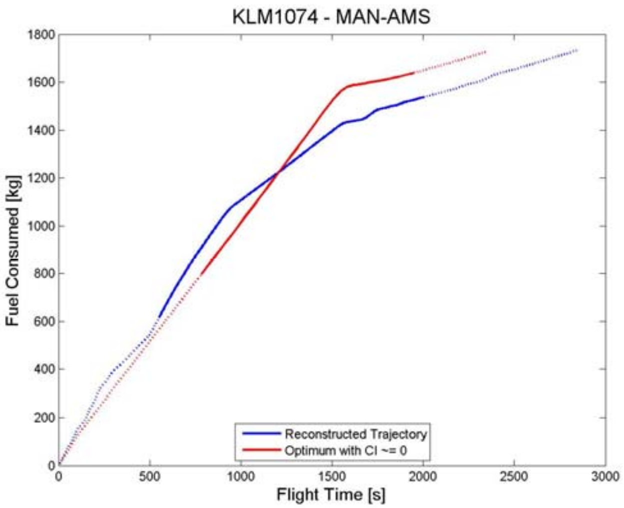
Speed

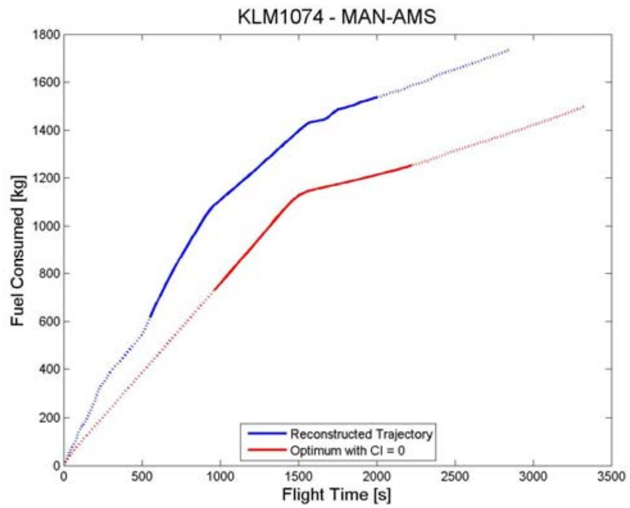




KLM1074	Manchester-Amsterdam
KEA	9.22 %
FEA-FW	15.67 %
CEA-CW1	**3.76 %**

Fuel

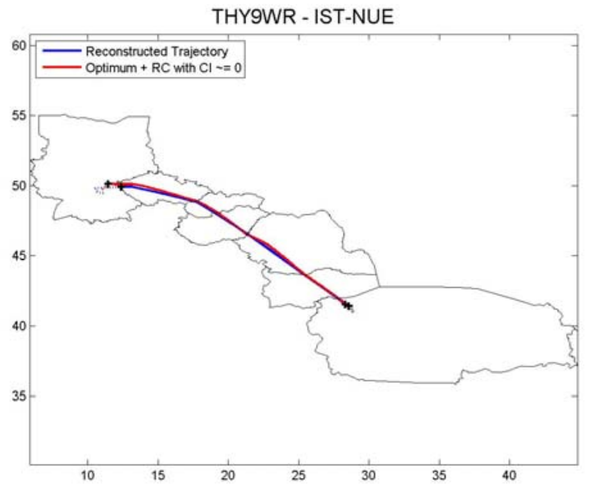


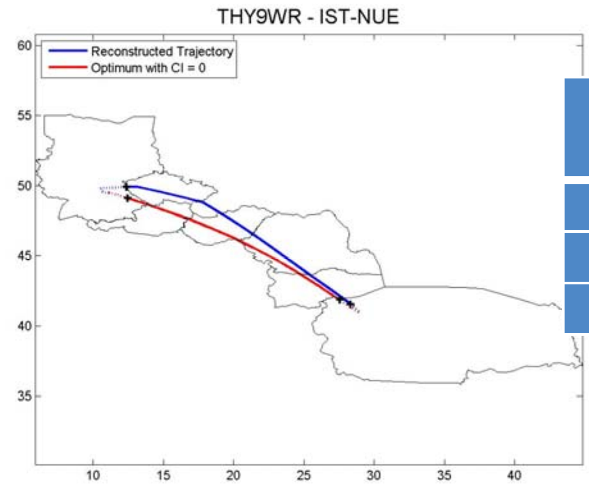


KEA & CEA-CW2 - Example 1

Cost Based (Flight Plan and CI>0) Reference trajectory	Fuel Based (Free route and CI=0) Reference trajectory

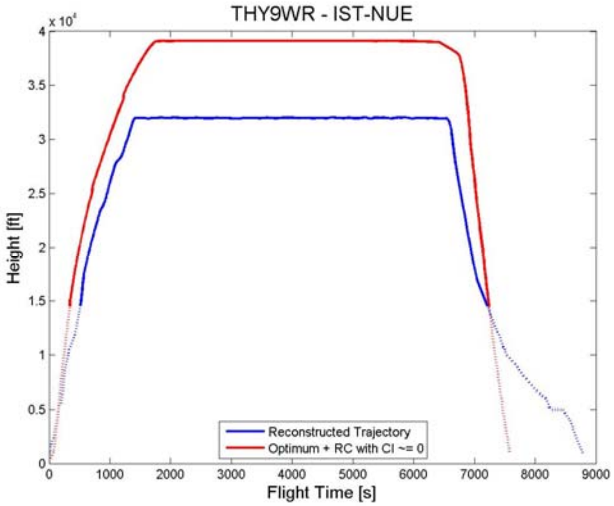
Horizontal

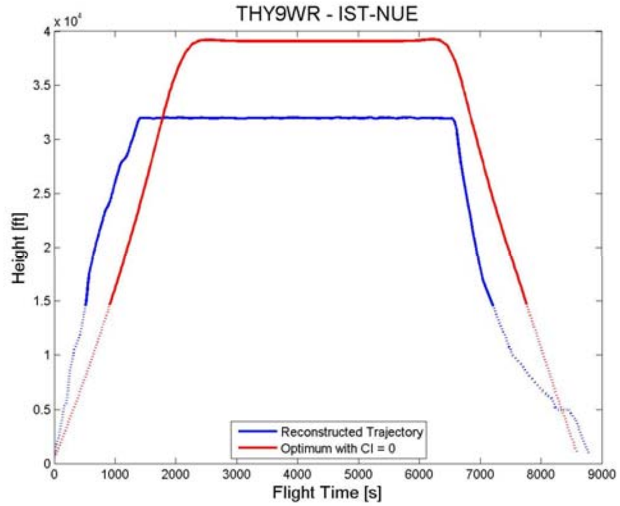




THY9WR	Istanbul-Nuremberg
KEA	9.60 %
FEA-FW	20.77 %
CEA-CW2	**11.49 %**

Vertical





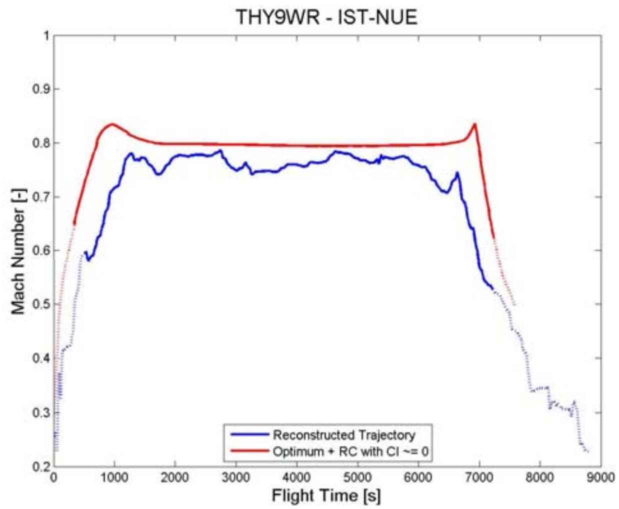
KEA & CEA-CW2 - Example 1

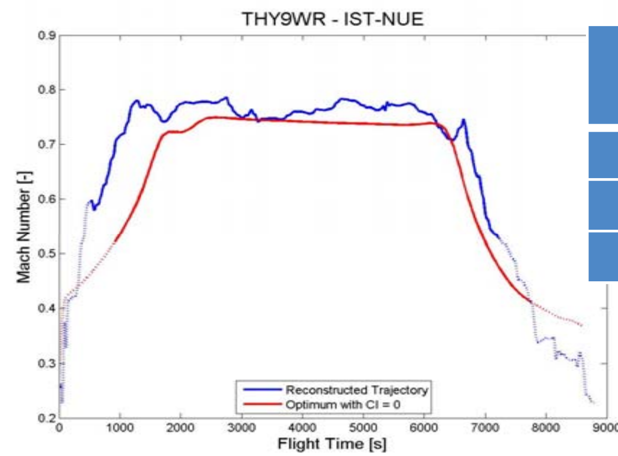
Cost Based (Flight Plan and CI>0)
Reference trajectory

Fuel Based (Free route and CI=0)
Reference trajectory

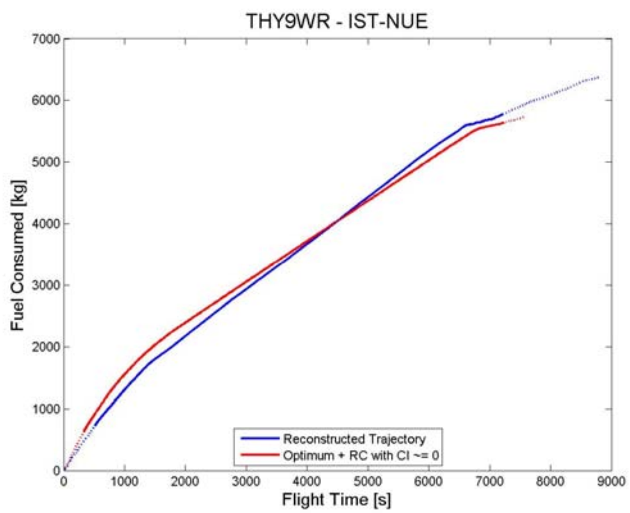
THY9WR	Istanbul-Nuremberg
KEA	9.60 %
FEA-FW	20.77 %
CEA-CW2	**11.49 %**

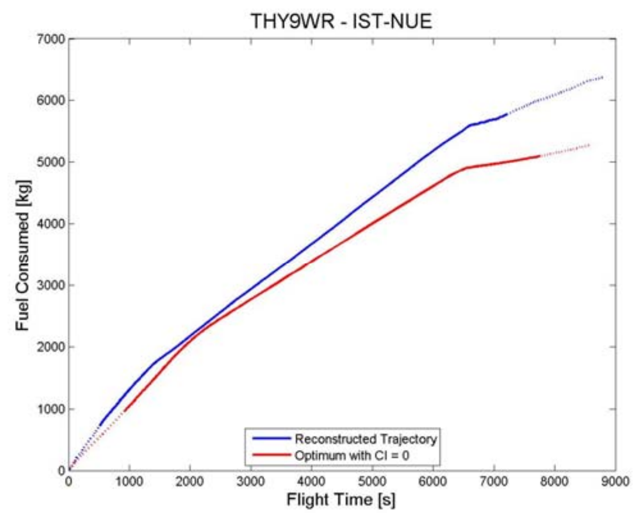
Speed





Fuel



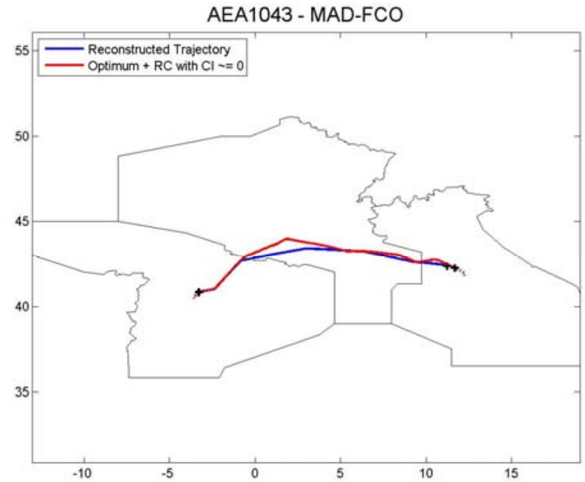


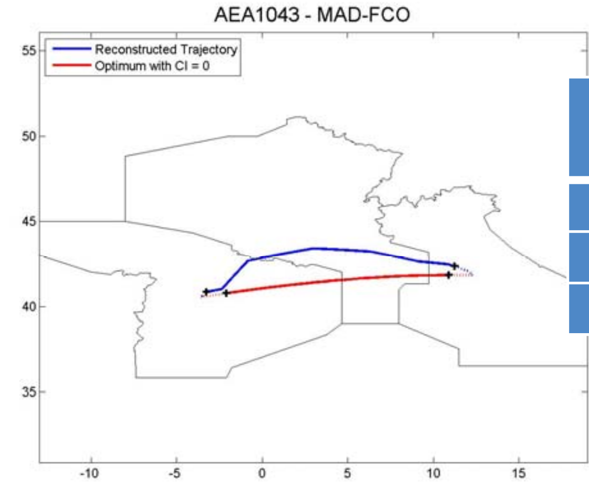
KEA & CEA-CW2 - Example 2

Cost Based (Flight Plan and CI>0) Reference trajectory

Fuel Based (Free route and CI=0) Reference trajectory

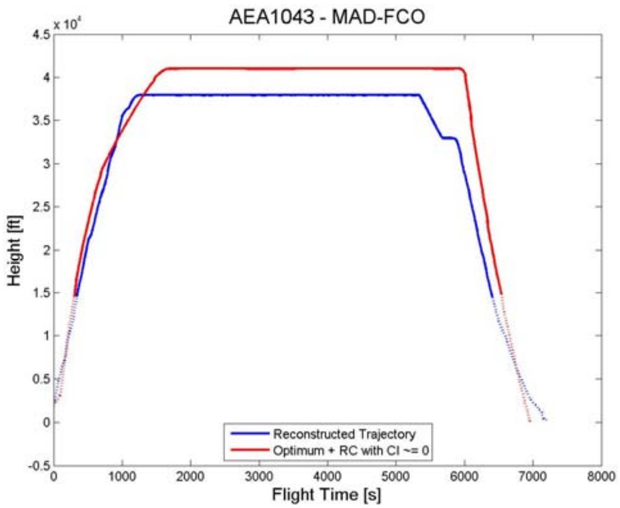
Horizontal

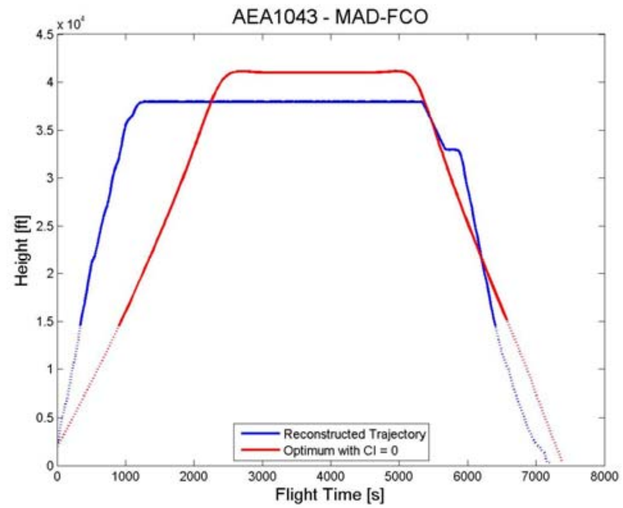




AEA1043	Madrid-Rome
KEA	11.49 %
FEA-FW	16.70 %
CEA-CW2	**-0.17 %**

Vertical



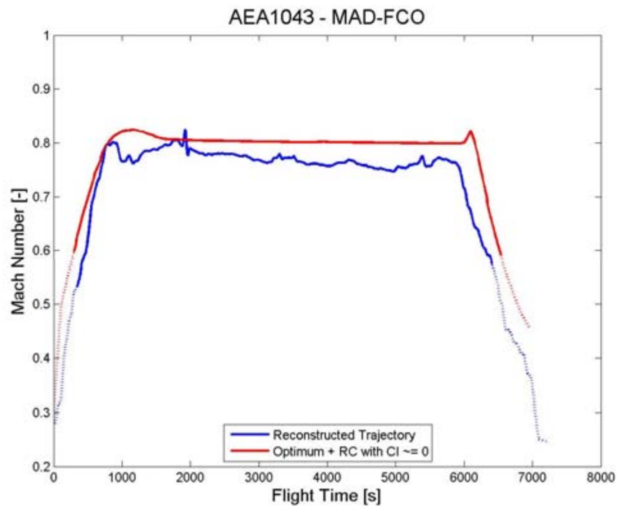


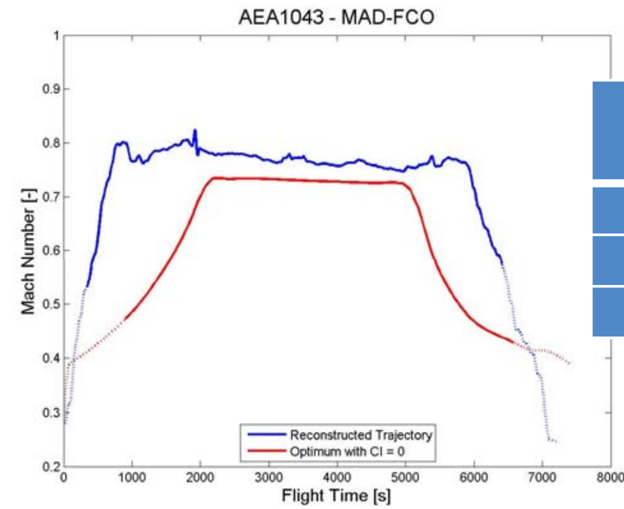
KEA & CEA-CW2 - Example 2

Cost Based (Flight Plan and CI>0)
Reference trajectory

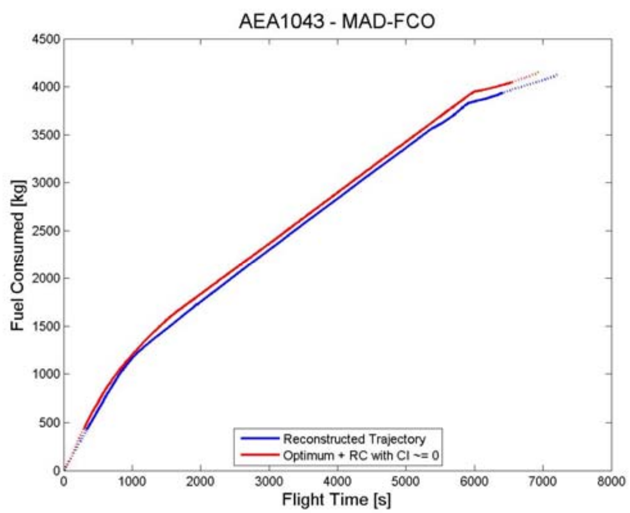
Fuel Based (Free route and CI=0)
Reference trajectory

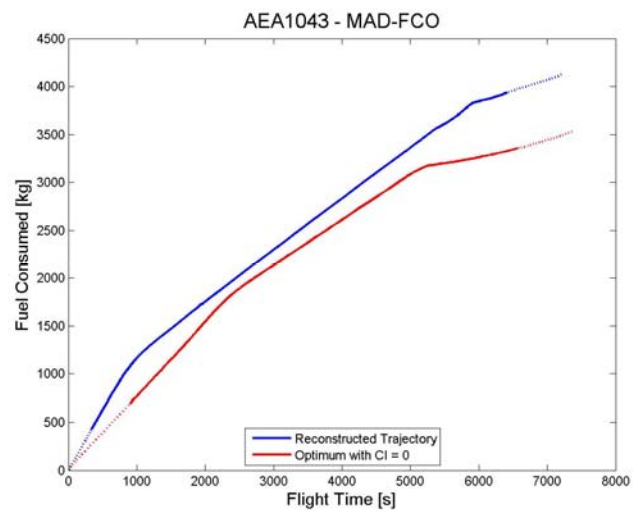
Speed





Fuel





AEA1043	Madrid-Rome
KEA	11.49 %
FEA-FW	16.70 %
CEA-CW2	-0.17 %

KEA

Horizontal flight efficiency of actual trajectory taking as reference the minimum flown distance (achieve distance for local)

Covered Gaps (according to RP2):

- Its main purpose is for statistics to drive stakeholder behaviour to improve route design.
- It can be computed very precisely, checked and understood by everyone.

FEA-DW

Comparison between calculated fuel consumption of actual flown route and minimum distance route, considering weather

Covered Gaps:

- Weather.
- Fuel Consumption.

Hypothesis for the minimum horizontal distance trajectory:

- It starts and ends at the same point than the actual trajectory.
- Cruise Flight Level for minimum distance route is the highest flown Flight Level.
- Cruise Speed is the average of the actual cruise speed.
- Geodesic route from point to point (not aware of TMA configurations).

FEA-FW

Comparison between calculated fuel consumption of actual flown route and minimum fuel consumption route, considering weather

Covered Gaps:

- Weather.
- Fuel Optimization.

Hypothesis for the minimum fuel consumption trajectory:

- It starts and ends at the same point than the actual trajectory.
- Minimum fuel consumption trajectory from point to point (not aware of TMA configurations).
- Free flight.

CEA-CW1

Comparison between calculated cost of actual flown route and free route trajectory optimizing costs, considering weather

Covered Gaps:

- Weather.
- Cost (fuel, time and route charges)

Reconstruction criteria for the **free route** trajectory **minimizing costs**:

- It starts and ends at the same point than the actual trajectory.
- Set Cost Index (C.I.) for aircraft type.
- Set fuel price according to IATA.

CEA-CW2

Comparison between calculated cost of actual flown route and flight plan horizontal trajectory optimizing costs, considering weather

Covered Gaps:

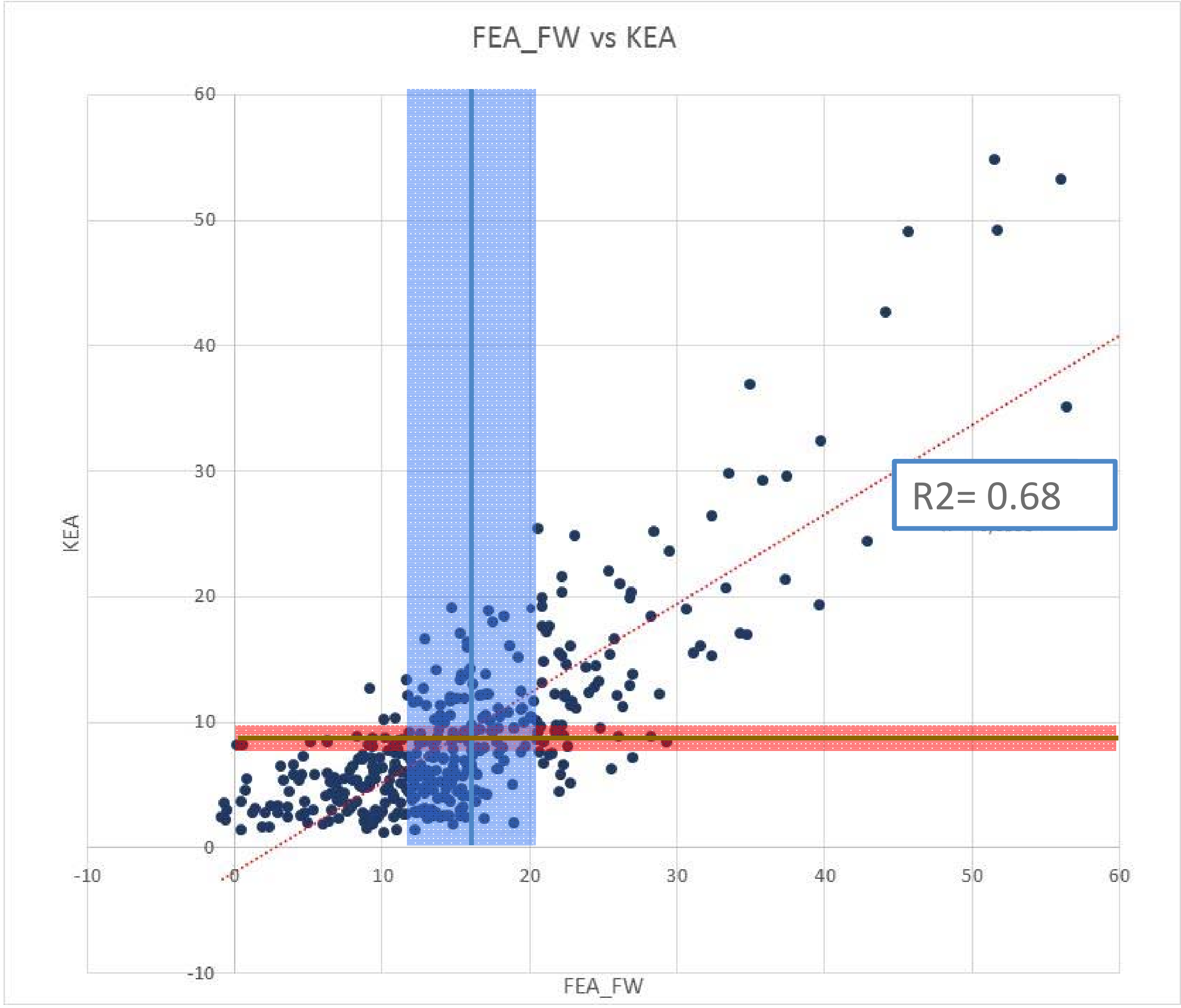
- Weather.
- Cost (fuel, time and route charges)

Reconstruction criteria for the route following **flight plan horizontal profile** and **minimizing costs**:

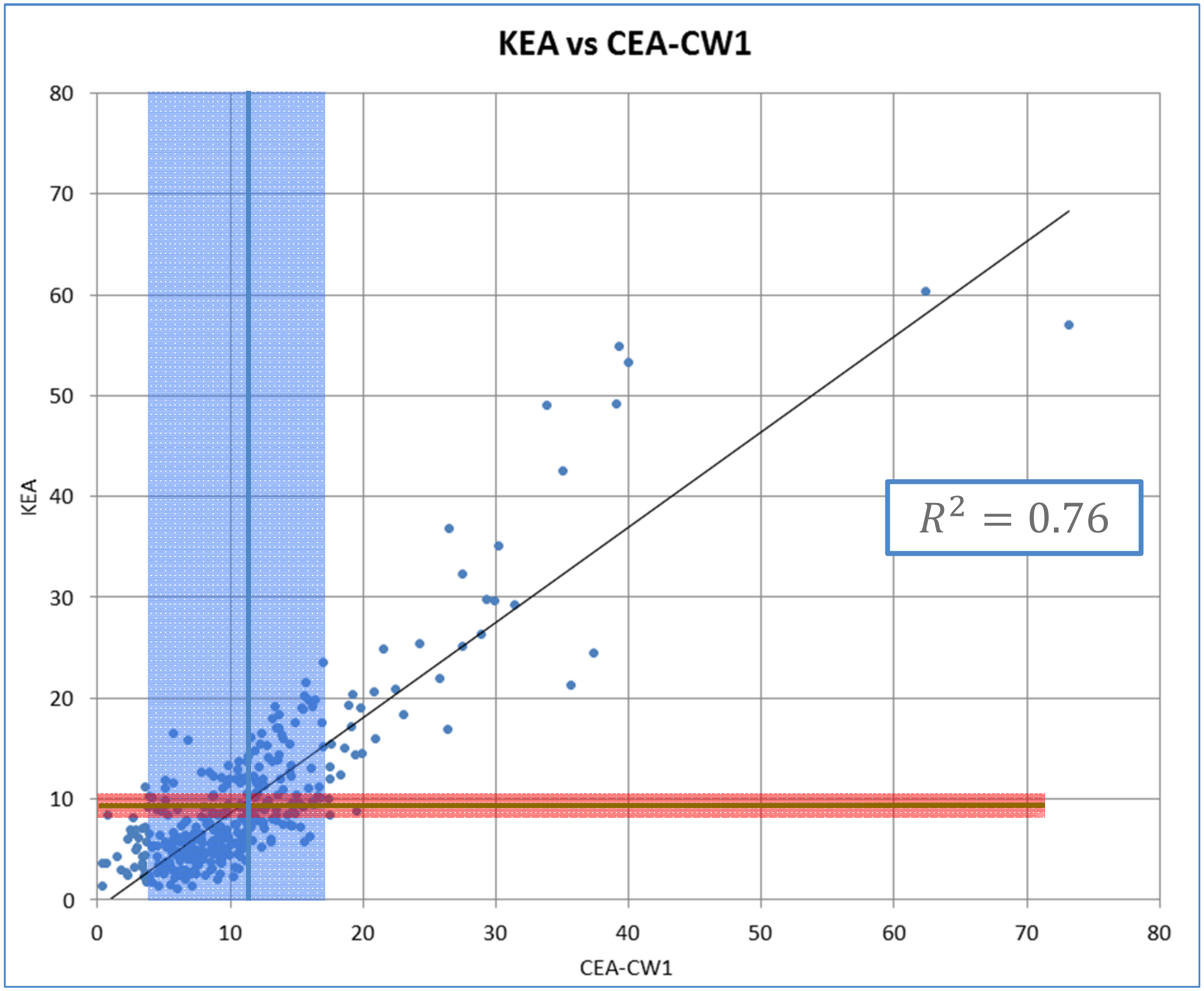
- It starts and ends at the same point than the actual trajectory.
- The horizontal profile is the last filed flight plan, assuming this path as the minimum route charges path.
- Set Cost Index (C.I.) for aircraft type.
- Set fuel price according to IATA.

CORRELATION KEA & FEA-DW

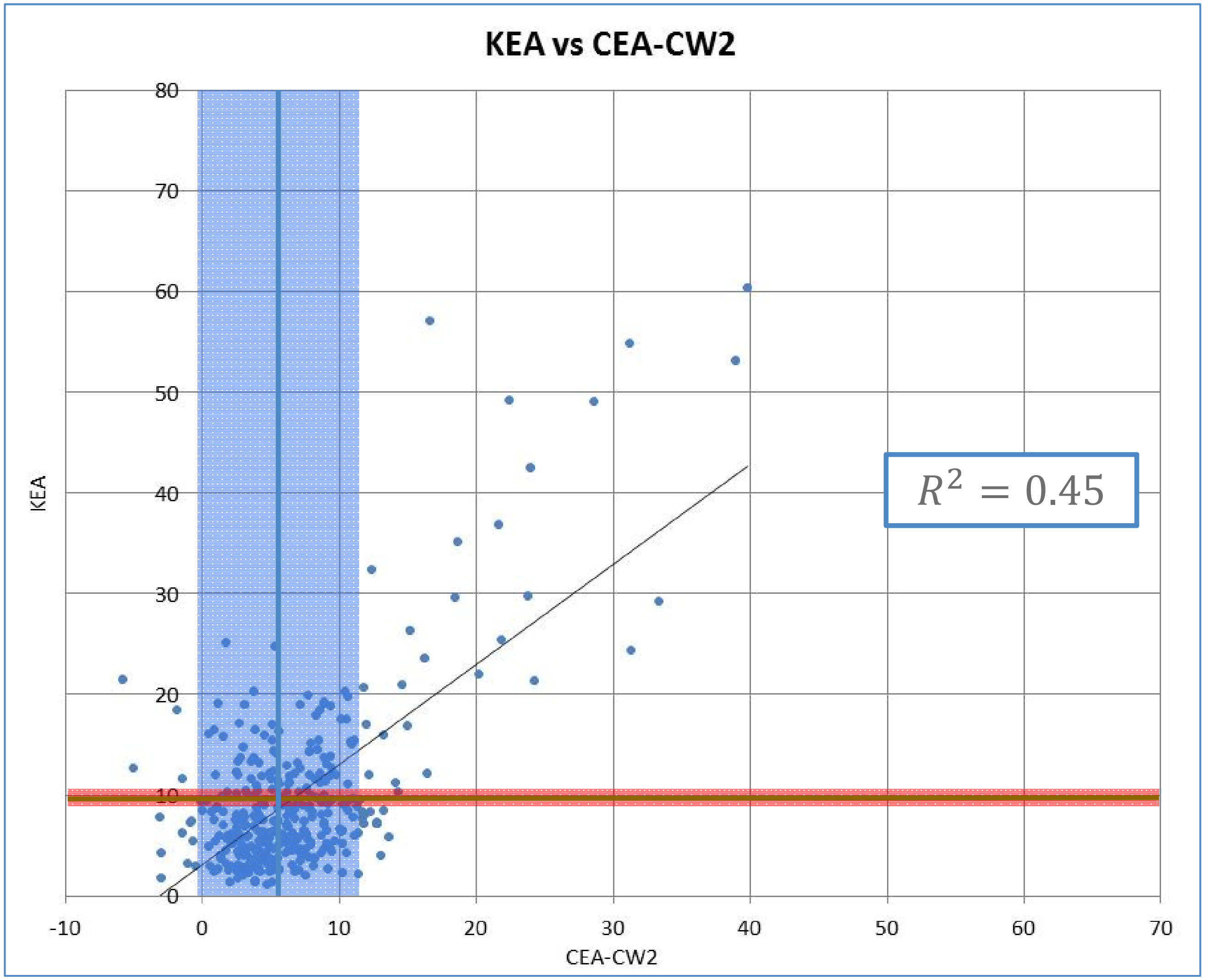
CORRELATION KEA & FEA-FW



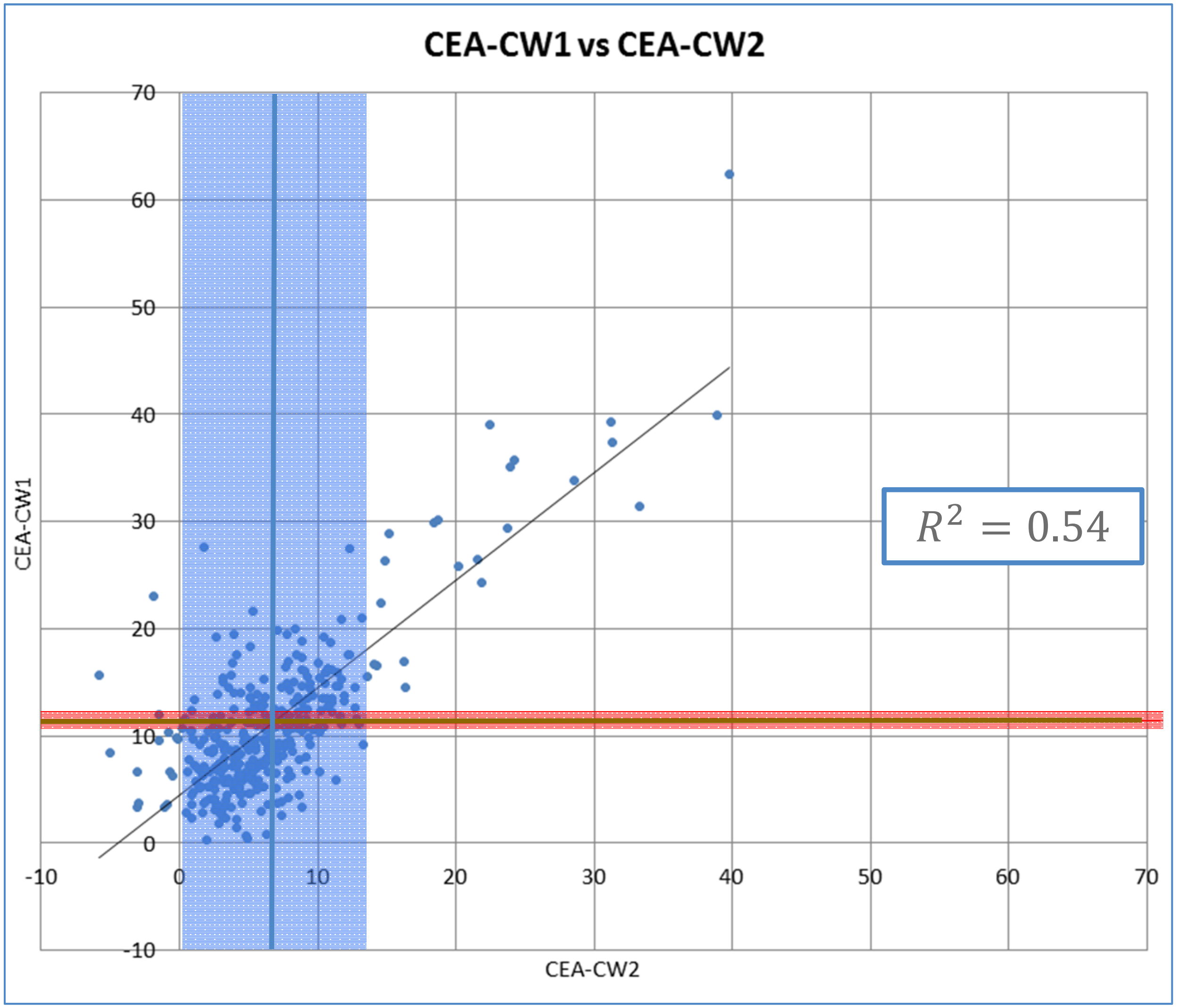
CORRELATION KEA & CEA-CW1



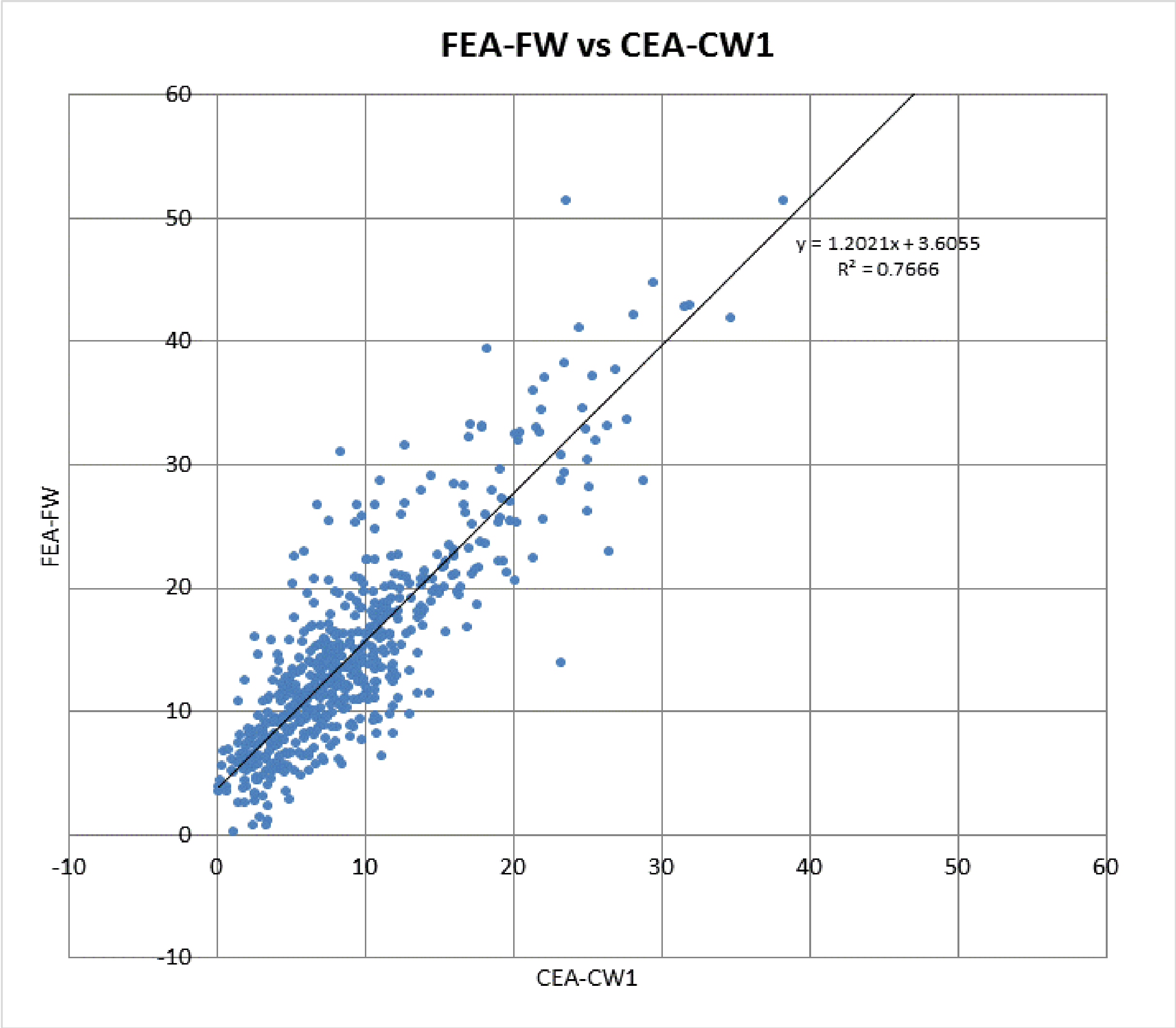
CORRELATION KEA & CEA-CW2



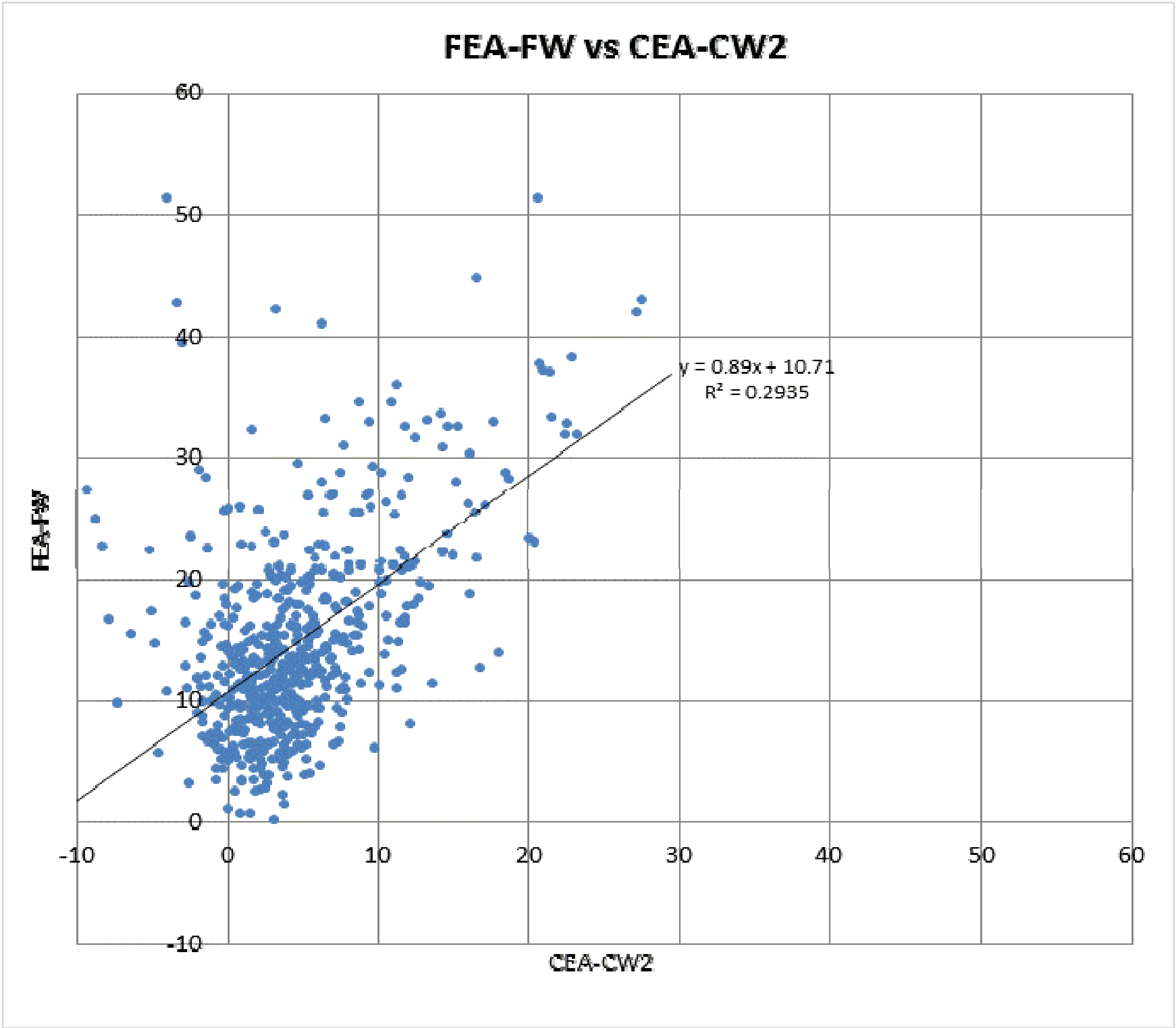
Correlation CEA-CW1 & CEA-CW2



CORRELATION FEA-FW & CEA-CW1



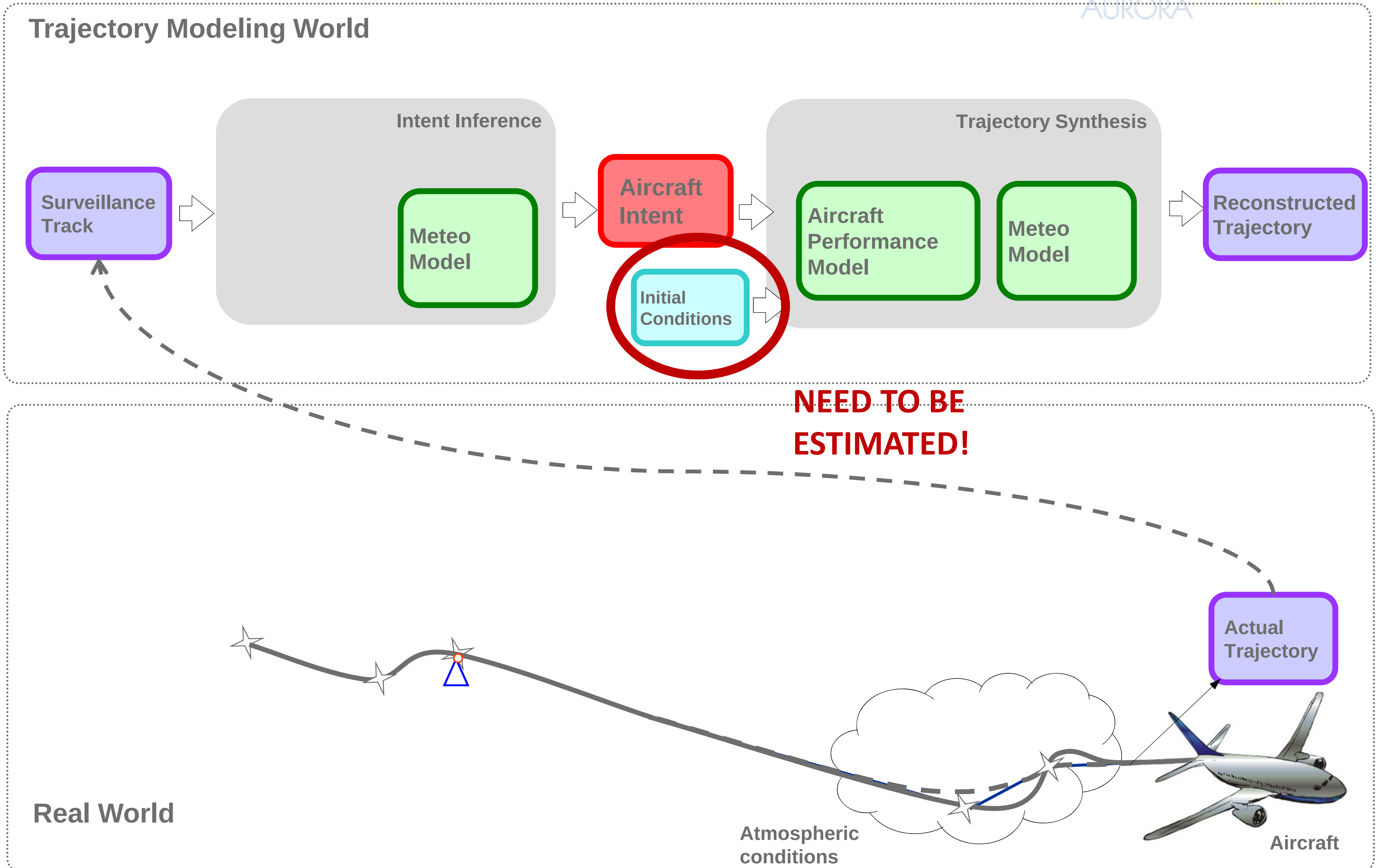
CORRELATION FEA-FW & CEA-CW2



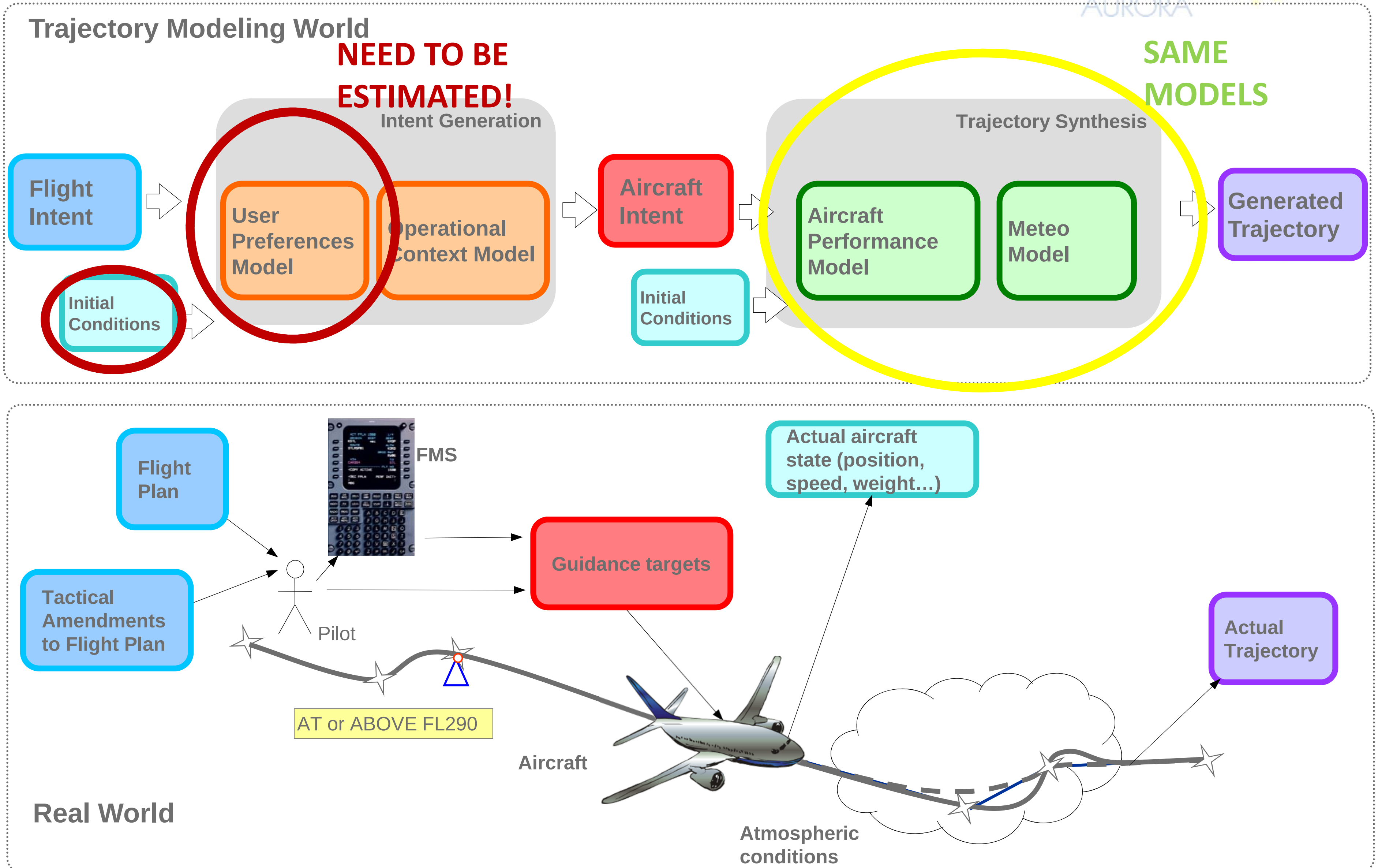
Take Away messages

- Tools at your disposal (used in this Project):
  - Aircraft Performance Model library (based on BADA 3 and 4) - APML
  - Trajectory prediction service - INCEPT
  - Trajectory reconstruction service - INTRAC
  - Extensive data base of Flight data – ADAPT
    - ADS-B track data - FR24 , Flight Aware, BR&TE ADS-B network
    - Weather data - NOAA
    - Flight plans – EUROCONTROL
    - Aeronautical information – SWIM services from EUROCONTROL Network Manager
  - Data visualization
  - Metrics calculation

Trajectory Modeling (Intent Inference)



Trajectory Modeling (Intent Generation)



PERCEPT: Characteristics

- Interfaces with NOAA (weather), FIXM and DDR (flight plans), ADS-B (surveillance), BADA (performance data)
- AIDL-based core (computation engine)
- Optimization capabilities (using optimal control)
- Very detailed trajectories: all the variables, from lat. lon. altitude time, to thrust, flaps setting, fuel flow or measured wind
- Leverage big data technologies:
  - Link to HDFS databases
  - Calls are distributed (cluster) and totally parallelised