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☘TREVOL: aircraft Trajectory analysis for Reduced EnVirOnmentaL impact

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CONTENTS

- Project overview
- Project status
- Theoretical background
- Preliminary results
- Conclusions and future work

PROJECT OVERVIEW – Motivation

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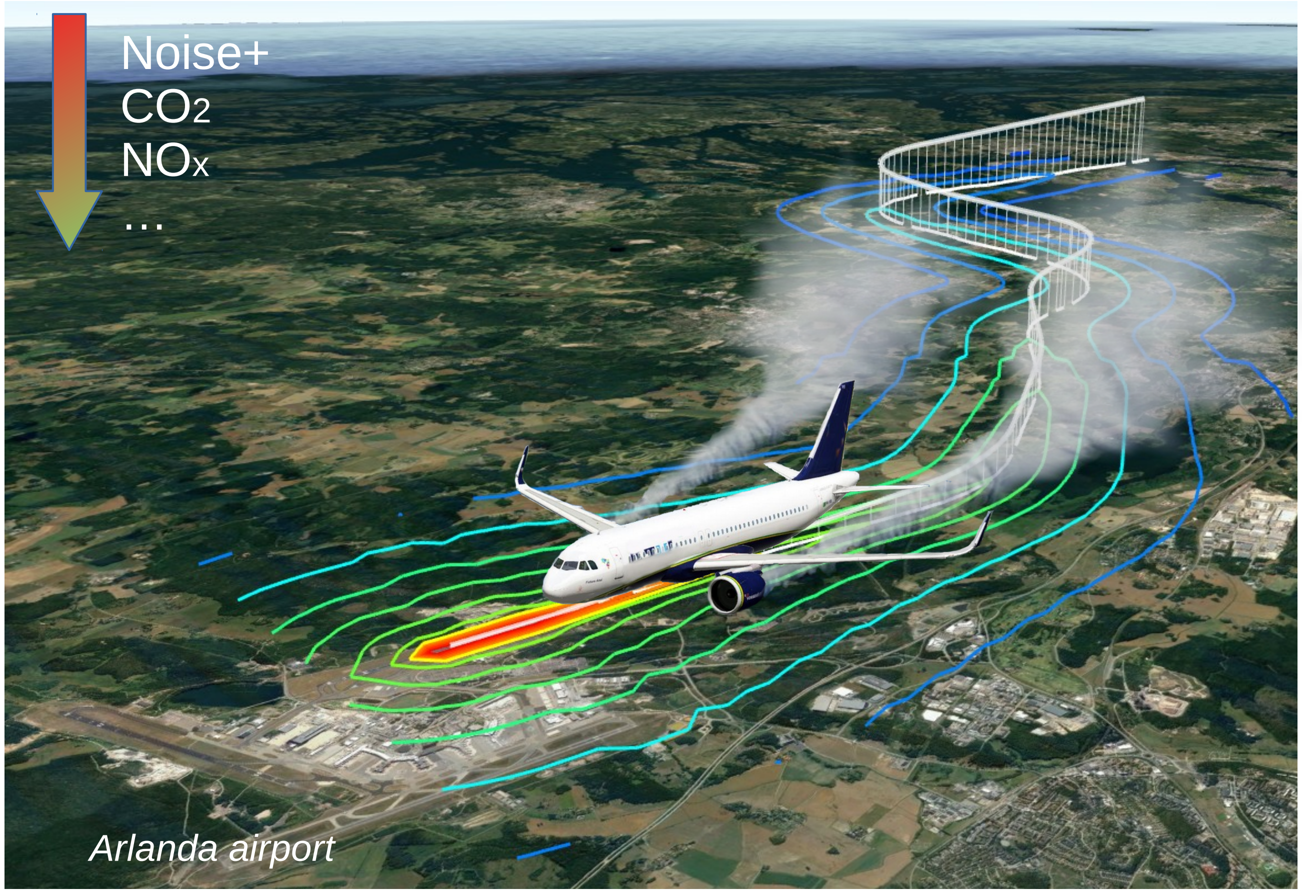
Reduction of the environmental impact in terms of noise and gas emissions through flight procedures analysis:

- *Safety approach angle*
- *Approach speed*
- *Flaps deployment time*
- *Landing gears extension time*
- *Circumnavigation of noise sensitive areas*

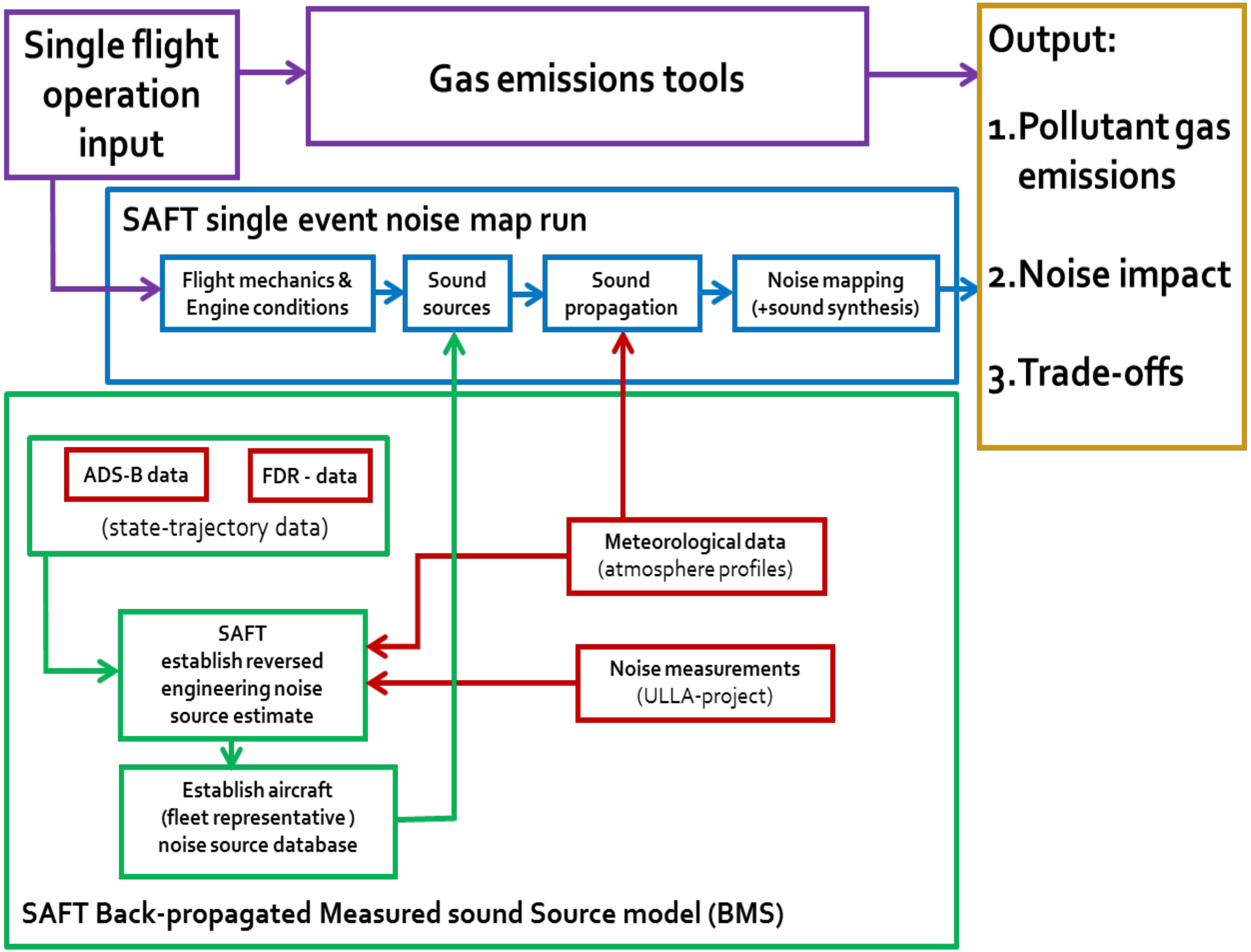
…

Define the most suitable trade-off strategy for a combined reduction in noise **and** gas emissions.

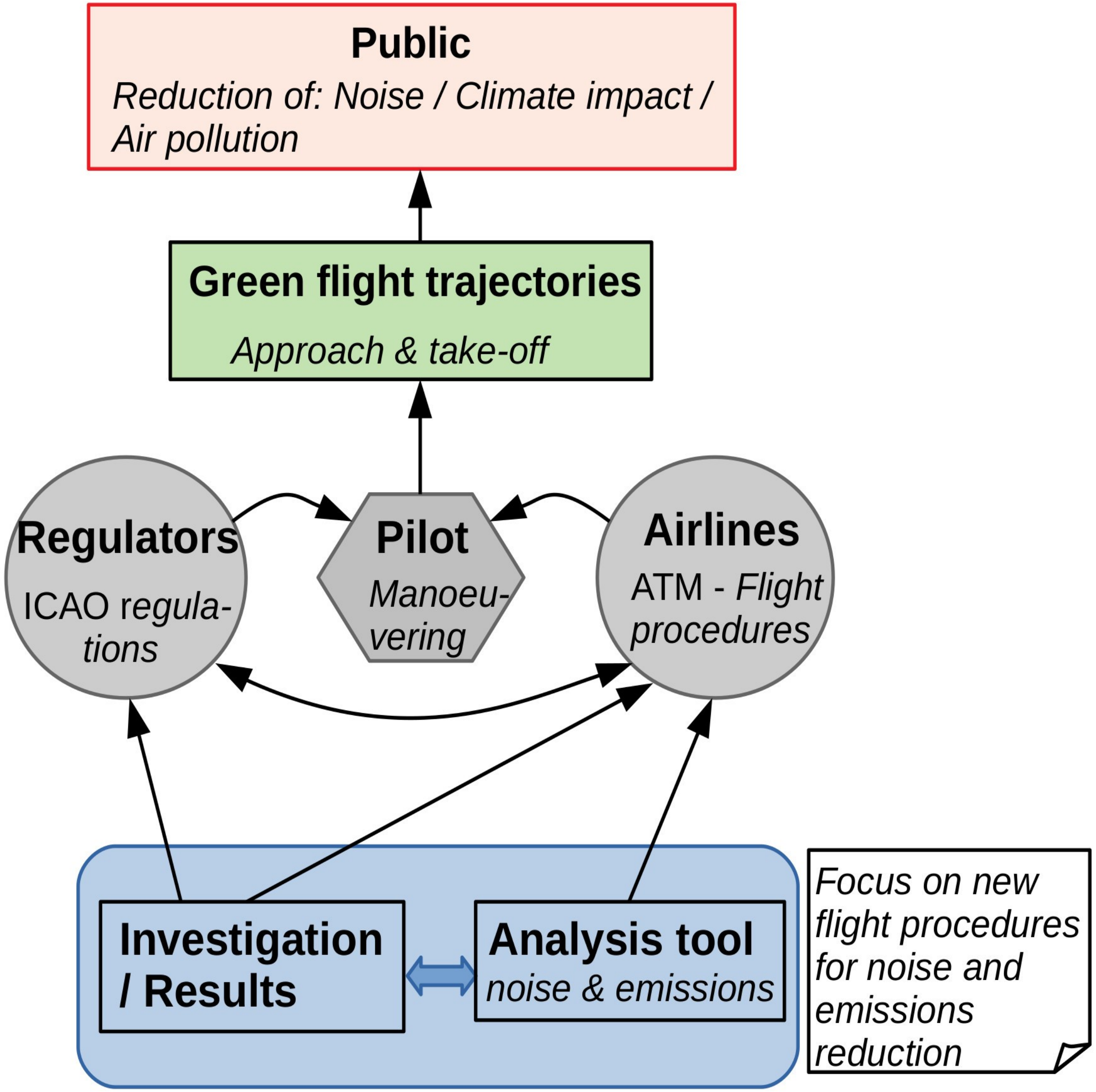


PROJECT OVERVIEW – Final tool

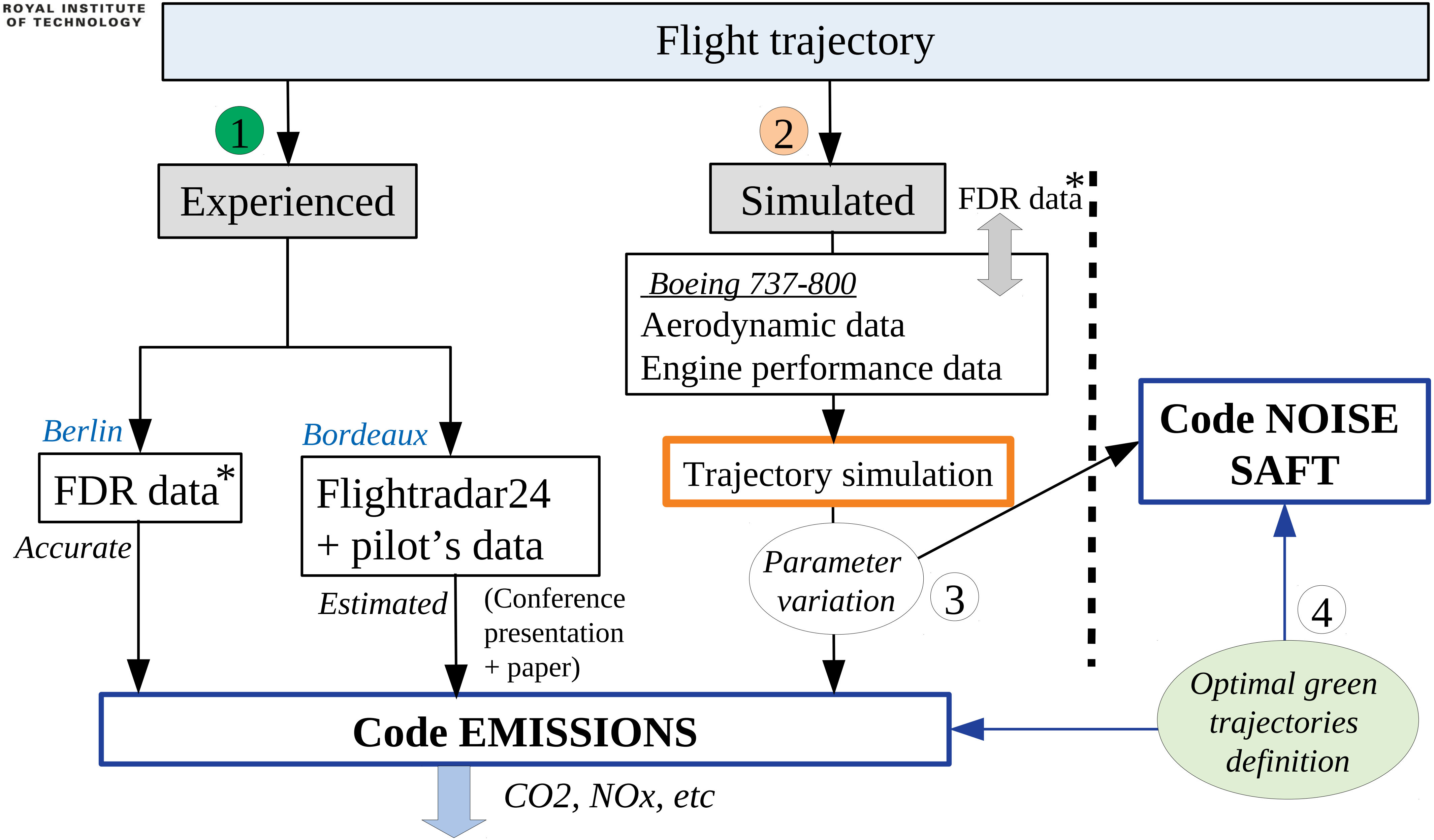
- A combined tool for noise and gas emissions simulation.



PROJECT OVERVIEW – Impact



PROJECT STATUS



THEORETICAL BACKGROUND, 1

Flight trajectory simulation

- No unsteady aerodynamic model
- Point mass approximation

⇒ Time integration of the equations of motion (non linear ODE)

$$m\dot{V} = T\cos(\alpha+\epsilon) - D - mg\sin\gamma$$

$$mV\dot{\gamma} = T\sin(\alpha+\epsilon) + L - mg\cos\gamma$$

$$\dot{h} = V\sin\gamma$$

$$\dot{m}_f = -b,$$

$$\dot{x}_E = V\cos\gamma$$

THEORETICAL BACKGROUND, 2

Flight trajectory simulation

$$m\dot{V} = T\cos(\alpha+\epsilon) - D - mg\sin\gamma$$

$$mV\dot{\gamma} = T\sin(\alpha+\epsilon) + L - mg\cos\gamma \quad \Rightarrow \quad 0 = T\sin(\alpha+\epsilon) + L - mg\cos\gamma$$

$$\dot{h} = V\sin\gamma$$

$$\dot{m}_f = -b,$$

$$\dot{x}_E = V\cos\gamma \quad \Rightarrow \quad x_E(t_F) = \int_{t=0}^{t_F} V(t)\cos\gamma(t)dt$$

- Assumptions: $\dot{\gamma}$ small
- Control variables: γ and δ_T

THEORETICAL BACKGROUND, 3

- **Flight trajectory simulation**:

  - Final system for time integration:

$$\dot{V} = (Tcos(\alpha + \epsilon) - D)/m - gsin\gamma$$

$$\dot{h} = Vsin\gamma$$

$$\dot{m} = -b$$

$$\dot{y} = f(y, c), \qquad \underbrace{y = \begin{pmatrix} V \\ h \\ m \end{pmatrix}}_{\text{State variables}}, \qquad \underbrace{c = \begin{pmatrix} \gamma \\ \delta_T \end{pmatrix}}_{\text{Control variables}}$$

  - Aerodynamic and engine performance model integrated.

THEORETICAL BACKGROUND, 4

- **Emissions modeling:** Boeing Fuel Flow method

Proportional to the fuel burn

$$EICO_2 = 3155 \text{ g/(kg fuel)}$$

$$EIH_2O = 1237 \text{ g/(kg fuel)}$$

$$EISOx = 0.8 \text{ g/(kg fuel)}$$

Atmosphere dependent

$$EICO_{alt} = EICO_{sl}(f_{sl})\frac{\theta^{3.3}}{\delta^{1.02}}$$

$$EIHC_{alt} = EIHC_{sl}(f_{sl})\frac{\theta^{3.3}}{\delta^{1.02}}$$

$$EINOx_{alt} = EINOx_{sl}(f_{sl})\sqrt{\frac{\delta^{1.02}}{\theta^{3.3}}}e^{H}$$

Atmosphere

$\theta = T/T0$

$\delta = P/P0$

H: Humidity correction factor

ICAO emissions databank

BADA database

PRELIMINARY RESULTS – real data based

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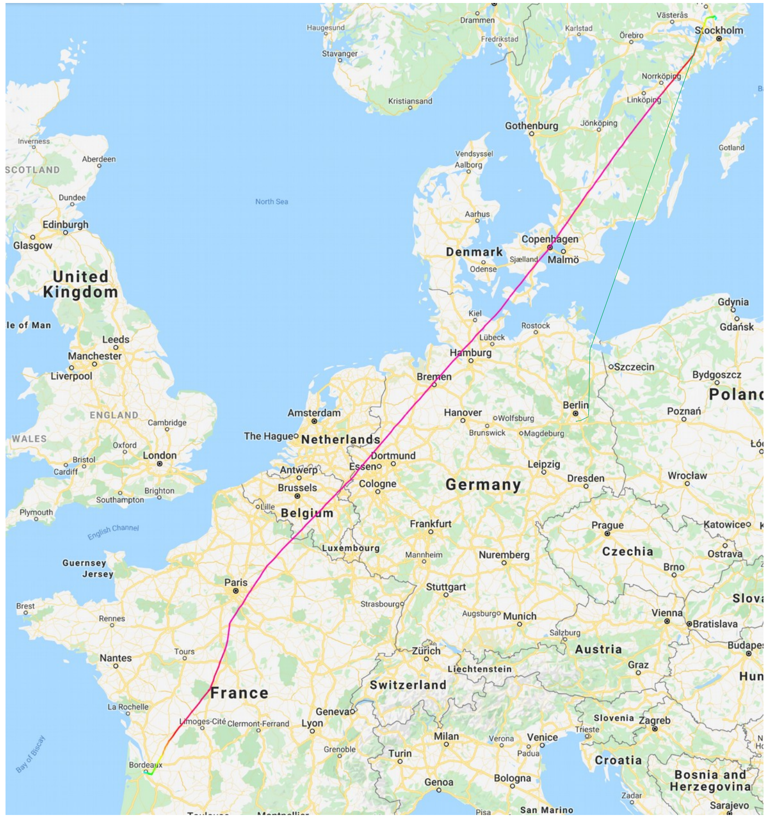
- **Stockholm-Berlin/Bordeaux with Boeing 737-800**

	Berlin (ARN-SXF)	Bordeaux (ARN-BOD)
Distance	813 km	2063 km
Time in the air	1 hour 20 mins	3 hours
Total fuel burn	3900 kg + taxi fuel 200 kg	7182 kg
Gross weight	69 500 kg	64 270 kg
Initial fuel load	10 200 kg	10 870 kg
Crew	6	6
Passengers	180	125
Temperature	ISA+3	ISA+6
Wind at cruise altitude	220 deg/60 knots	208 deg/46 knots



PRELIMINARY RESULTS – real data based

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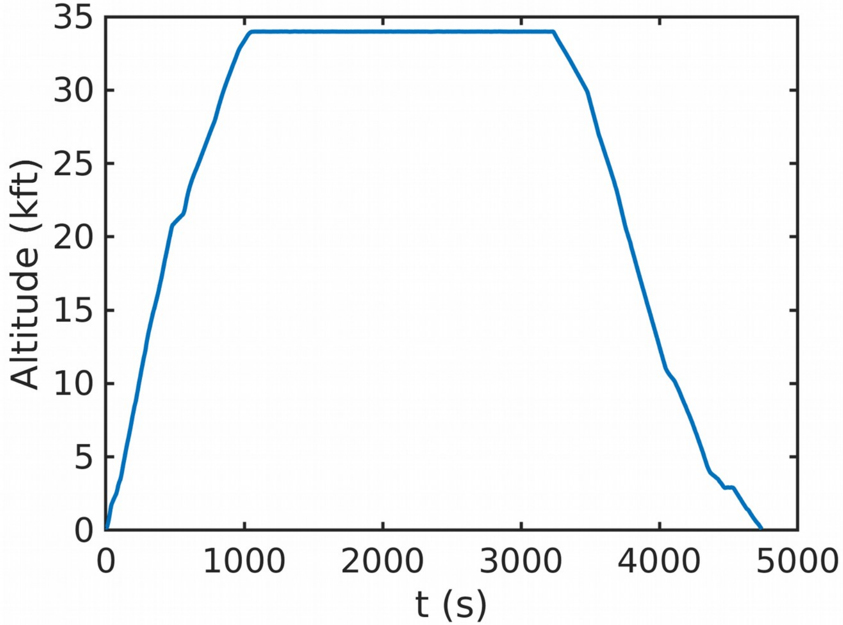
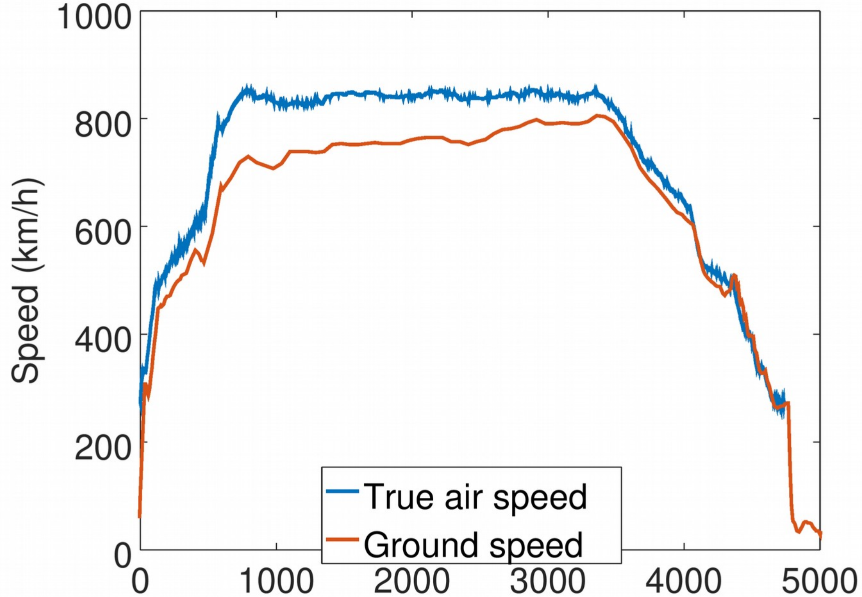
Flight path

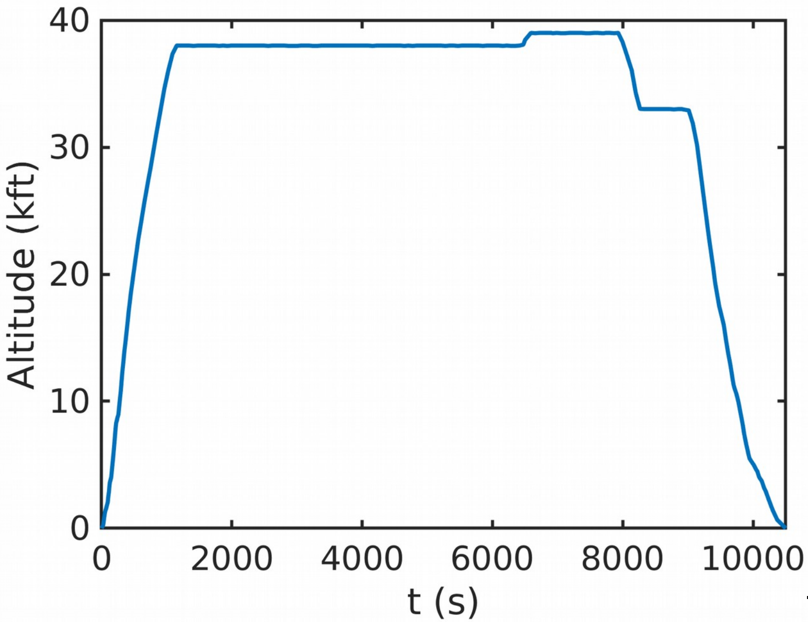
Ground speed

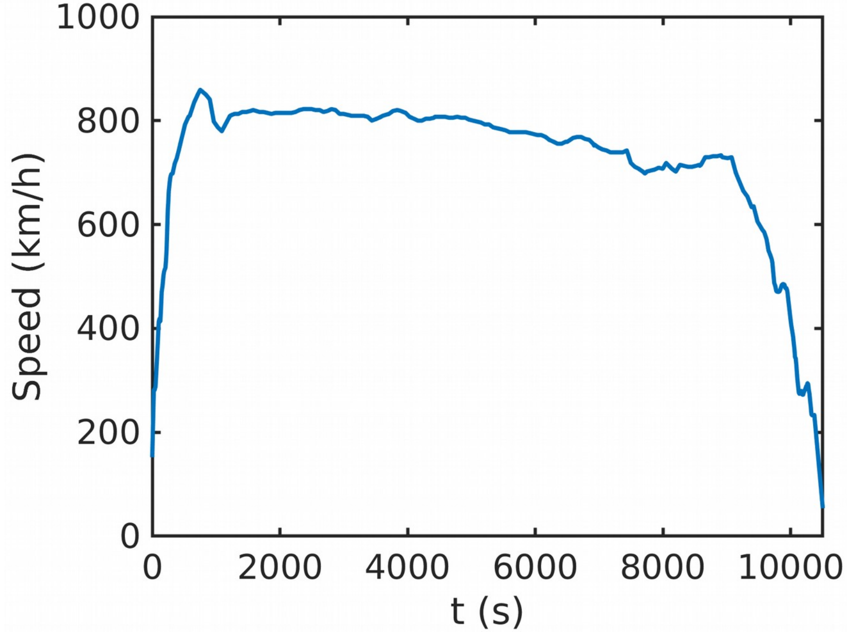
Berlin





Bordeaux





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PRELIMINARY RESULTS – real data based

- **Emissions computation**

Berlin

Dimensions			
Total fuel (ARN-SXF)	3730	kg	
Fuel/pax	21	kg	
Total energy required	39	GJ	(10900 kWh)
Energy content of fuel used	163	GJ	
Efficiency	24%		
Energy/pax	218	MJ	(60 kWh)
Total Emissions			
CO	19.0	kg	
HC	0.8	kg	
NOx	46.0	kg	
CO2	11800.0	kg	
H2O	4600.0	kg	
SOx	3.0	kg	
Emissions per pax			
CO	0.1	kg	
HC	0.005	kg	
NOx	0.25	kg	
CO2	65.0	kg	
H2O	26.0	kg	
SOx	0.02	kg	

FLIGHT(S) CALCULATED AVERAGE CO2 EMISSIONS IS 91.65 KG/PERSON
SOURCE: ICAO CARBON EMISSIONS CALCULATOR

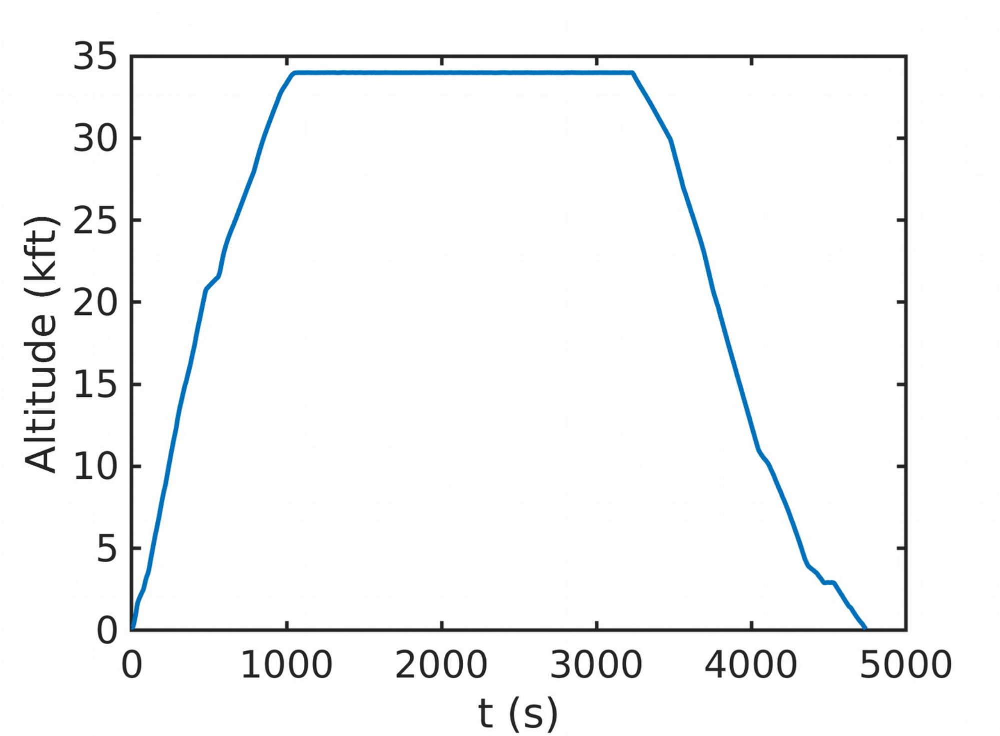
Bordeaux

Dimensions	
Total fuel (ARN-BOD)	7182 kg
Fuel/pax	57.5 kg
Total energy required	86 GJ / (23900 kWh)
Energy content of fuel used	330 GJ
Efficiency	26%
Energy/pax	497 MJ / (138 kWh)
Total Emissions (kg)	
CO	36.6
HC	1.4
NOx	80.7
CO2	22659.2
H2O	8884.1
SOx	5.7
Emissions (kg) per pax	
CO	0.29
HC	0,0114
NOx	0.64
CO2	181.3
H2O	71.1
SOx	0.05

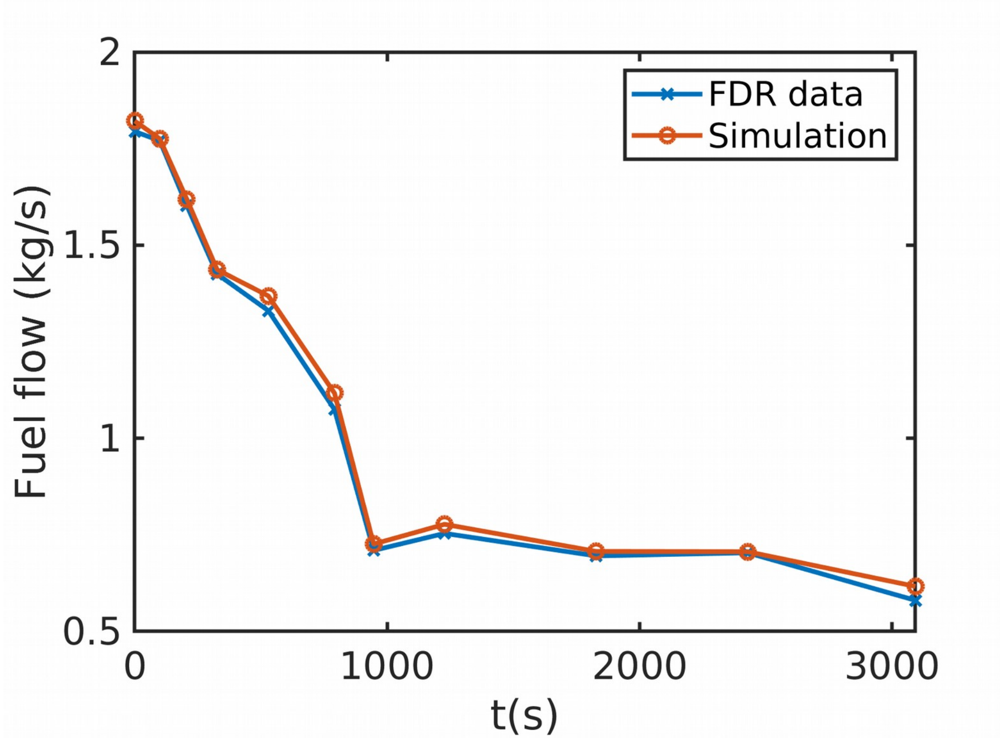
FLIGHT(S) CALCULATED AVERAGE CO2 EMISSIONS IS 165.41 KG/PERSON
SOURCE: ICAO CARBON EMISSIONS CALCULATOR

PRELIMINARY RESULTS – flight Simulation

- **Engine performance validation (no flaps)**



Flight path
Stockholm-Berlin (FDR data).



Fuel flow comparison between simulated data and real data (FDR).

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CONCLUSIONS AND FUTURE WORK, 1

- The emissions code computes different types of gas emissions for a given trajectory.

- Consistency in emissions between both travels and the simulated CO2 emissions are of the same order as the ones indicated by flight tickets.

- Trajectory simulation implemented.

- Aerodynamic and engine performance model integrated and validated (no flaps).

CONCLUSIONS AND FUTURE WORK, 2

- **NEXT STEPS**
  - Trajectory simulation for extended flaps and landing gears.
  - Parameter investigation for optimal trajectory with minimum gas emissions.
  - Combined investigation with SAFT for both gas emissions and noise reduction.
  - Comparisons with respect to IMPACT.

  - **New master's level course:**

    Aircraft performance and air traffic management (SD2830) 7.5 credits

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