Data on APU emission indices from remote sensing at airports

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Background
Problems and solutions
Measurement techniques
Measurement results
Improvement of measurement technique
Plume shape observation
Comparison with other measurement methods
Future

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Motivation

- **Airport air quality is not well known because emission inventories are estimated only**

- **On airports, aircraft engines are one of the major sources for air pollutants**

- **APU are running during all services**

- **Emission indices of APU are not listed by ICAO**

- **Initiatives within the EU-Network of Excellence ECATS (Environmentally Compatible Air Transport System)**

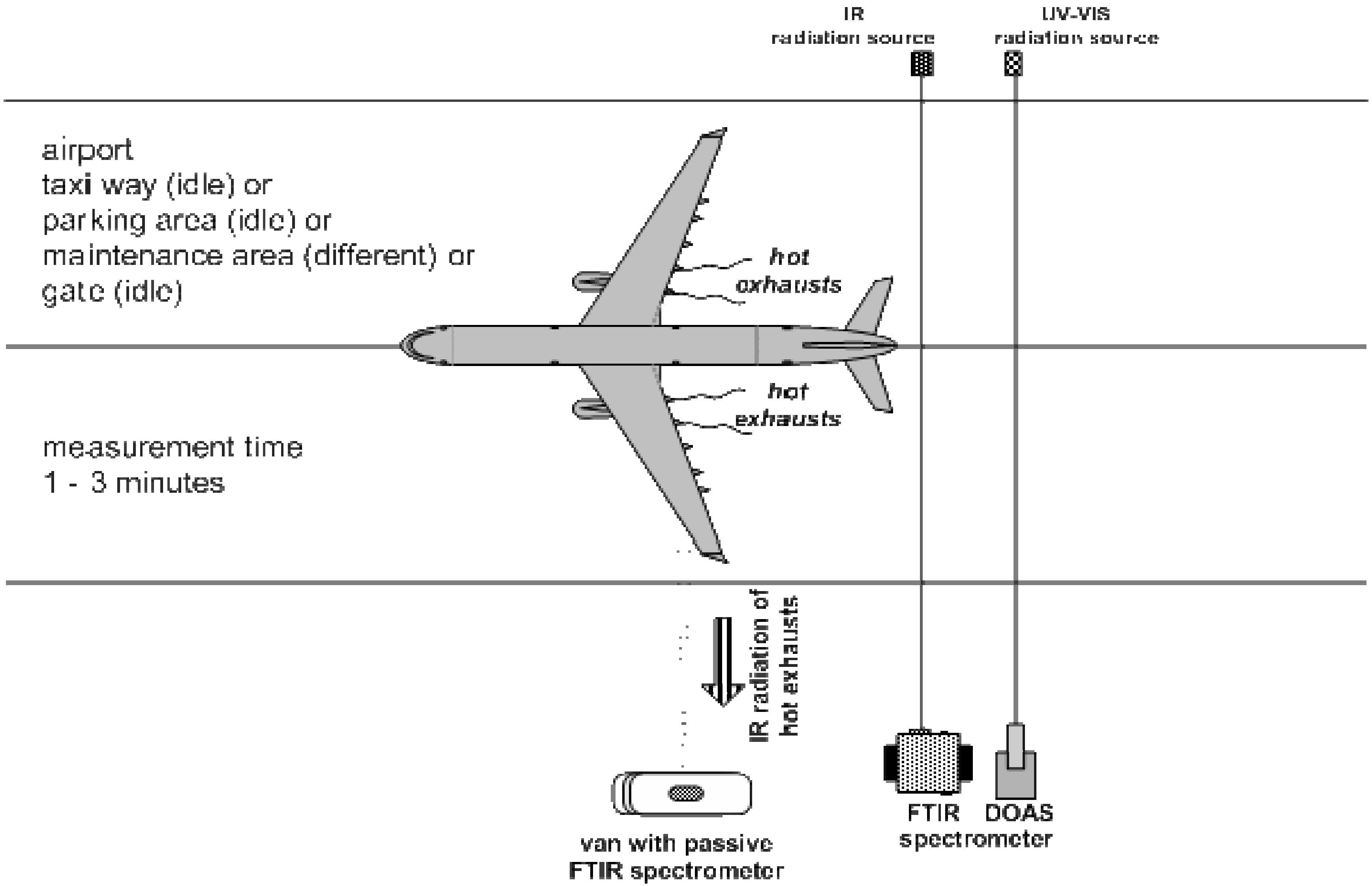
Methods

- **Passive remote sensing using FTIR-spectroscopy (K300, SIGIS) for determination of exhaust composition at nozzle exit**

- **Concentration measurement across the plume with FTIR & DOAS**

- **Determination of emission indices**

Measurement – Set up



Average emission index *EI* of a molecule *X* in g/kg kerosene:

$$EI(X) = EI(CO_2) \times \frac{M(X)}{M(CO_2)} \times \frac{Q(X)}{Q(CO_2)}$$

***M*: molecular weight**

***Q*: concentrations (mixing ratios, column densities etc.), difference to background**

Theoretical emission index of CO_2: calculated from stoichiometric combustion of kerosene to be 3,159 g/kg

EI (NO_x) = EI (NO* and NO_2) is related to the mass of NO_2:
EI (NO*) = EI (NO) x 46/30

Measurement Locations

Airport Zurich Klothen (ZRH)

Vienna

Airport Paris Charles de Gaulle (CDG)

Measured Pollutants by FTIR and DOAS

Name		Comment
CO	Carbon monoxide	very good, passive and active
CO_2	Carbon dioxide	very good, passive and active
H_2O	Water	high background, passive/active
HCOH	Formaldehyde	good
C_2H_4	Ethene	very good
C_2H_2	Ethine	good, interferences to CO_2 & H_2O
CH_4	Methane	difficult, passive and active
C_3H_6	Propene	good, low concentrations
C_4H_6	Butadiene	good, low concentrations
N_2O	Nitrous oxide	difficult, passive and active
NO	Nitrogen oxide	very good, passive and active
NO_2	Nitrogen dioxide	very good

Measured emission indices

CO2

NO2

Measured compounds:

- FTIR passive: CO, NO, CO_2 – simultaneous
- FTIR active: CO, CO_2 – simultaneous
- DOAS: NO, NO_2 – one after another

Averaging temporal interval: ~ 1 - 3 minutes

CO

NO

Measurements at airports were performed up to now during:

- **run up tests of aircraft engines (Berlin, Oberpfaffenhofen, London-Heathrow in 1999 and 2000, Frankfurt/Main in 2000, Vienna-Schwechat in 2001)**

- **during aircraft services at the airport gate or other positions (Frankfurt in 2000, London-Heathrow in 2001 and 2004, Zuerich in 2004, Paris CDG in 2004 and 2005, Budapest in 2004 and 2005)**

Data from the aircraft about APU:

- **engine data (diameter of nozzle exit, type, age etc.)**
- **fuel flow**

These data were collected by the co-operating airlines

- **Austrian Airlines Group (AUA)**
- **British Airways (BA)**
- **Deutsche Lufthansa (DLH)**
- **SWISS**

Aircraft	Number of aircraft	APU type	EI CO [g/kg]	EI NO [g/kg]	EI NO_x [g/kg]
A320-200	1	APS3200	2.9 ± 0.30 (2.5 -3.1)	0.3 (bdl - 0.8)	0.4 (bdl - 1.3)
B737-406	1	APS2000	2.7 ± 0.29 (2.5 - 3.1)	1.7 ± 0.34 (1.4 - 2.2)	2.5 ± 0.53 (2.3 - 3.3)
B737-800	1	GTCP85-98DHF	13.9 ± 1.07 (12.4 - 15.1)	0.8 ± 0.07 (0.7 - 0.8)	1.2 ± 0.11 (1.0 - 1.3)
B747-236	1	GTCP660-4	2.2 ± 0.32 (1.9 - 2.4)	0.1 (bdl - 0.3)	0.2 (bdl - 0.4)
B747-400	3	PW901A	11.6 ± 3.98 (5.5 - 18.0)	1.1 ± 0.37 (0.6 - 1.8)	1.7 ± 0.56 (0.8 - 2.7)
B747-436	8	PW901A	12.4 ± 5.26 (0.5 - 31.3)	0.6± 0.75 (bdl - 2.7)	1.0 ± 1.14 (bdl - 4.2)
B757-236	3	GTCP331-200/250	1.1 ± 0.41 (0.2 - 1.7)	2.6 ± 0.79 (0.4 - 3.6)	3.9 ± 1.21 (0.6 - 5.5)
B777-236	3	GTCP331-500	1.3 ± 0.63 (0.5 - 2.2)	3.0 ± 0.87 (bdl - 4.5)	4.6 ± 1.33 (bdl - 6.9)

Mean values of emission indices of APU

bdl: below detection limit i.e. a signature in the measured spectra cannot be inverted

Extrema as minimum and maximum value of all measured data are given in brackets

Conclusions

The presented method is a tool to determine emissions of a single aircraft

For better conclusions, more measurements are necessary for a statistical treatment of the data

Improvement of measurement technique

Passive FTIR emission spectrometry has also the capability to determine the composition of hot exhausts but also the plume behaviour non-intrusively

This is necessary because the measurements of composition are performed in different parts of the exhaust plume: at the nozzle exit, behind the aircraft

Are there inhomogeneous distributions along the plume i.e. temporal variations in the measurement volumes?

Instrumentation improved also to detect exhausts composition of aircraft on the ground nearly automatically

Spectrometer OPAG coupled with an IR camera giving an infrared image of the scenery so that a rapid selection of the hottest exhaust area is possible

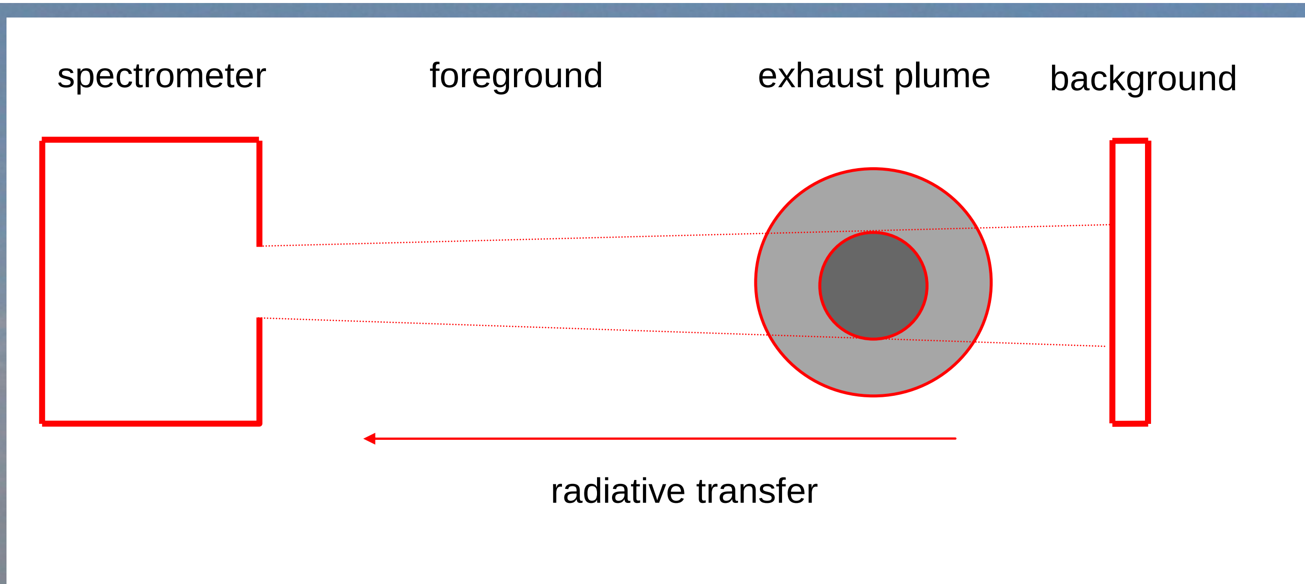
Imaging of the whole scenery behind the turbine exit or a part of the infrared camera image with the scanning mirror:

- **low-resolution spectra are measured and analysed in a spectral range which is sensitive for plume temperature**

- **software for real-time visualisation of the plume shape in this spectral range**

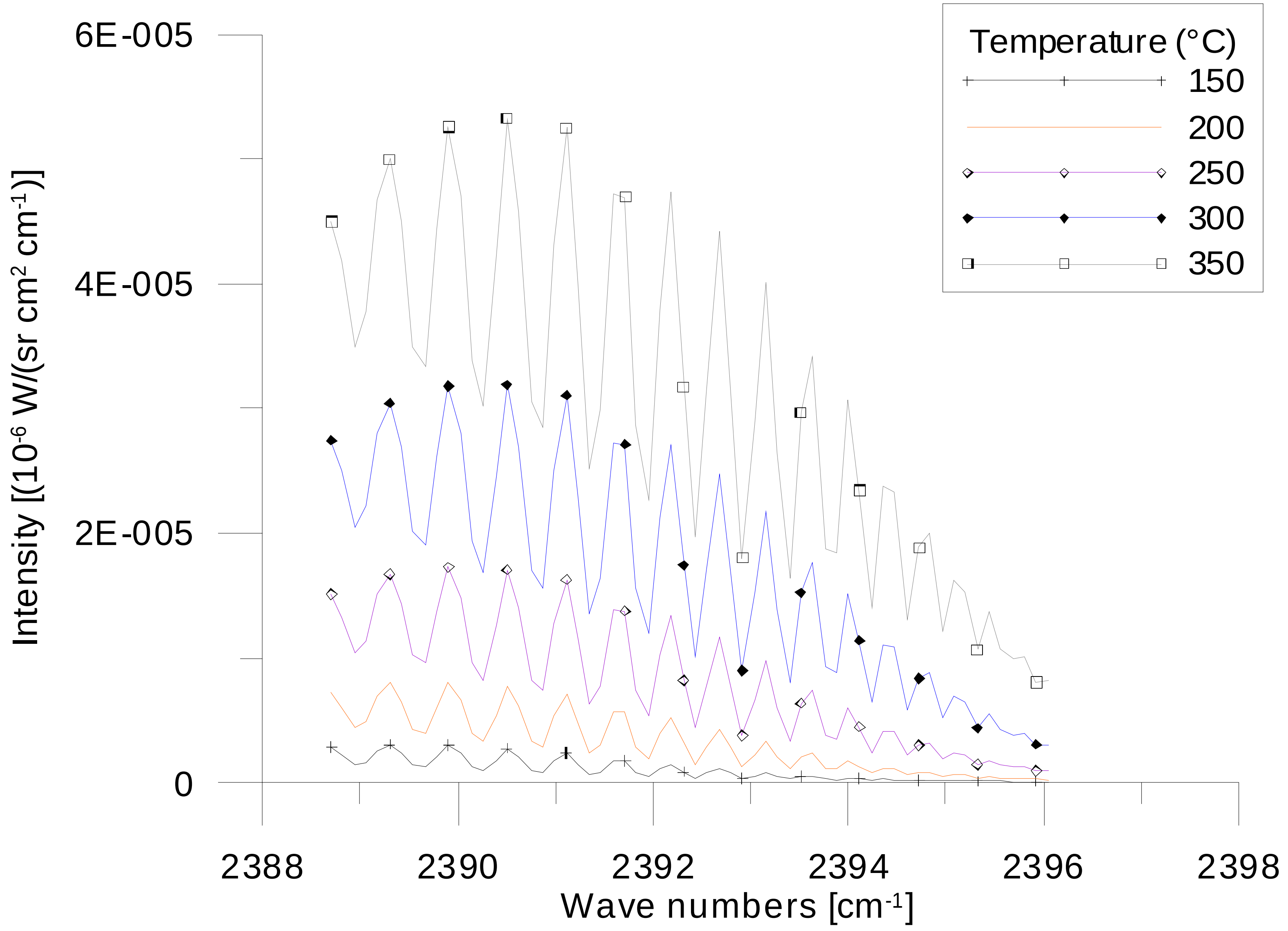
Scanning Infrared Gas Imaging System (SIGIS)

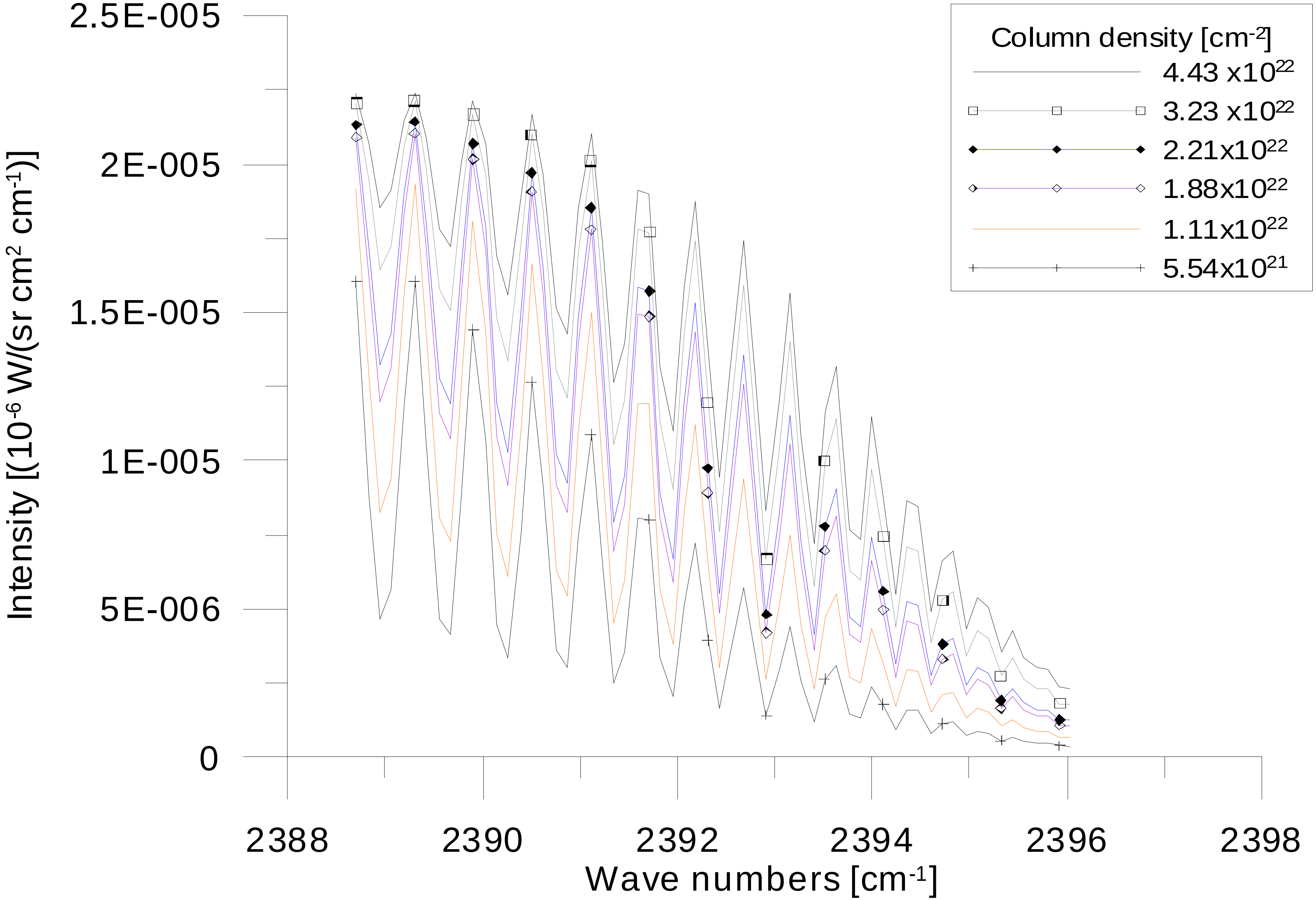
Measurement principle

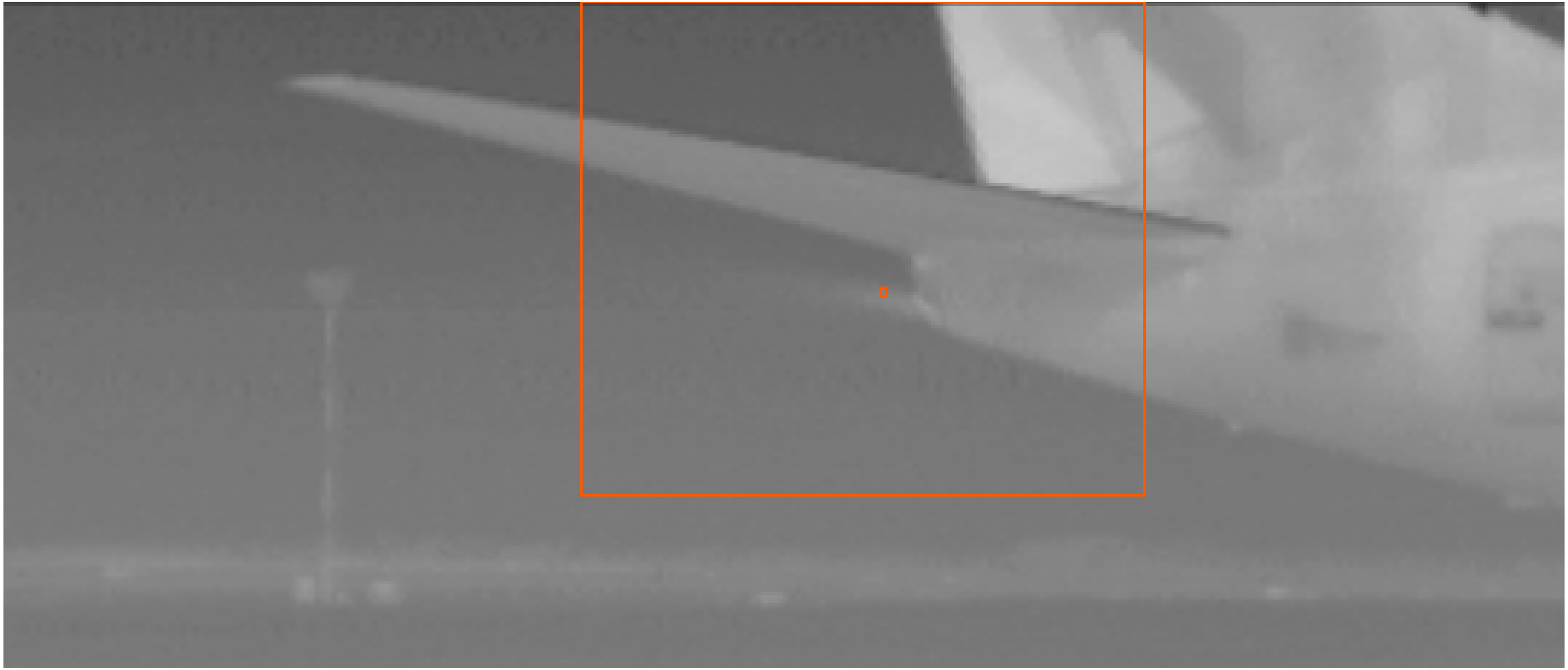


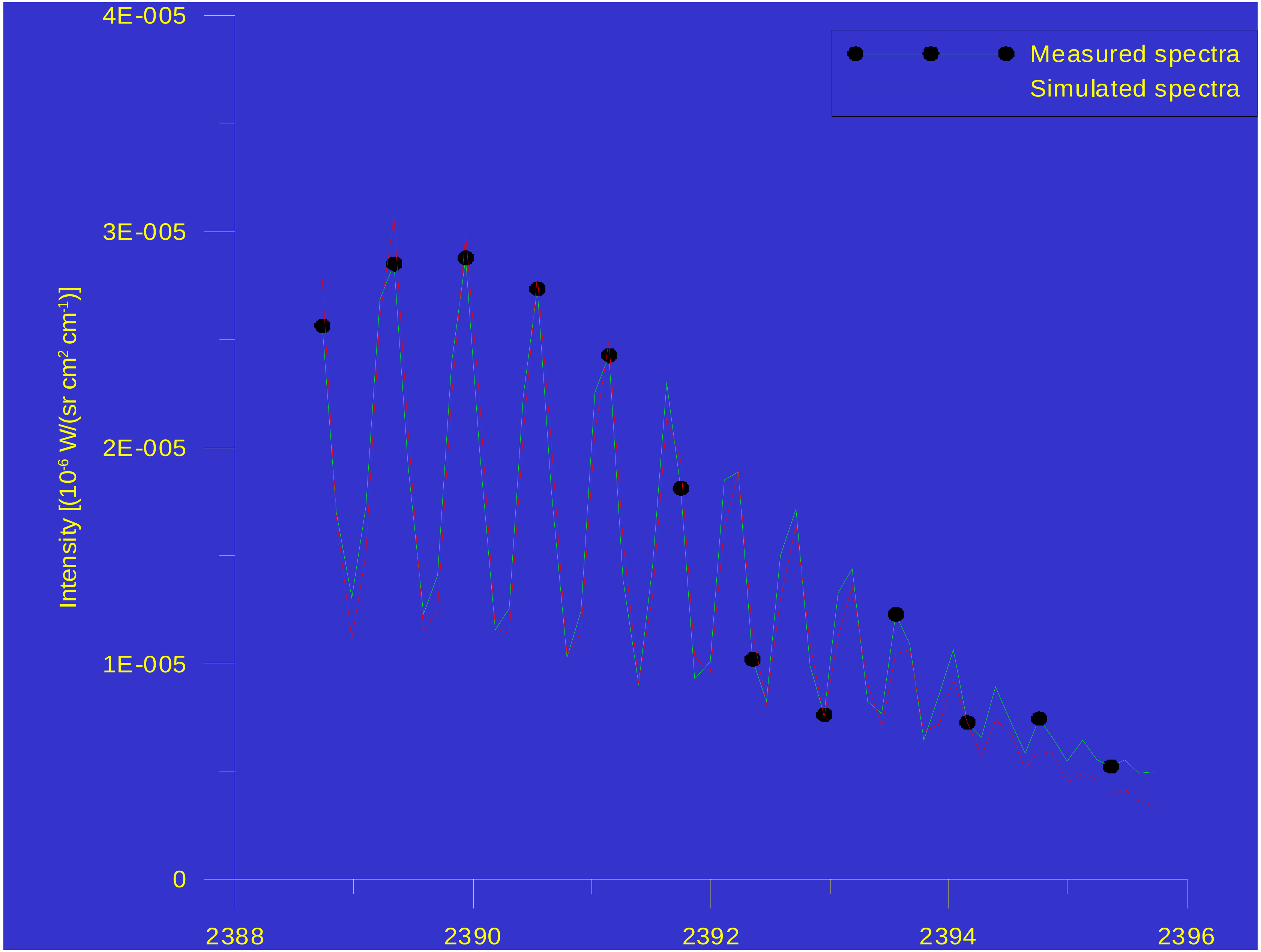
$$I = I_b \tau_p \tau_f + I_p \tau_f + I_f$$

$$\tau_{\Delta\nu}(L) = \left\{ \int_{\Delta\nu} \prod_{i=1}^{N} \exp[-k_i(\nu) n_i L] d\nu \right\} \exp[-k_a(\Delta\nu) n_a L]$$


Temperature (°C)
150
200
250
300
350
6E-005
4E-005
2E-005
0
Intensity [(10-6 W/(sr cm2 cm-1)]
2388
2390
2392
2394
2396
2398
Wave numbers [cm-1]


2.5E-005
2E-005
1.5E-005
1E-005
5E-006
0
Intensity [(10-6 W/(sr cm2 cm-1)]
2388
2390
2392
2394
2396
2398
Wave numbers [cm-1]
Column density [cm-2]
4.43 x1022
3.23 x1022
2.21x1022
1.88x1022
1.11x1022
5.54x1021

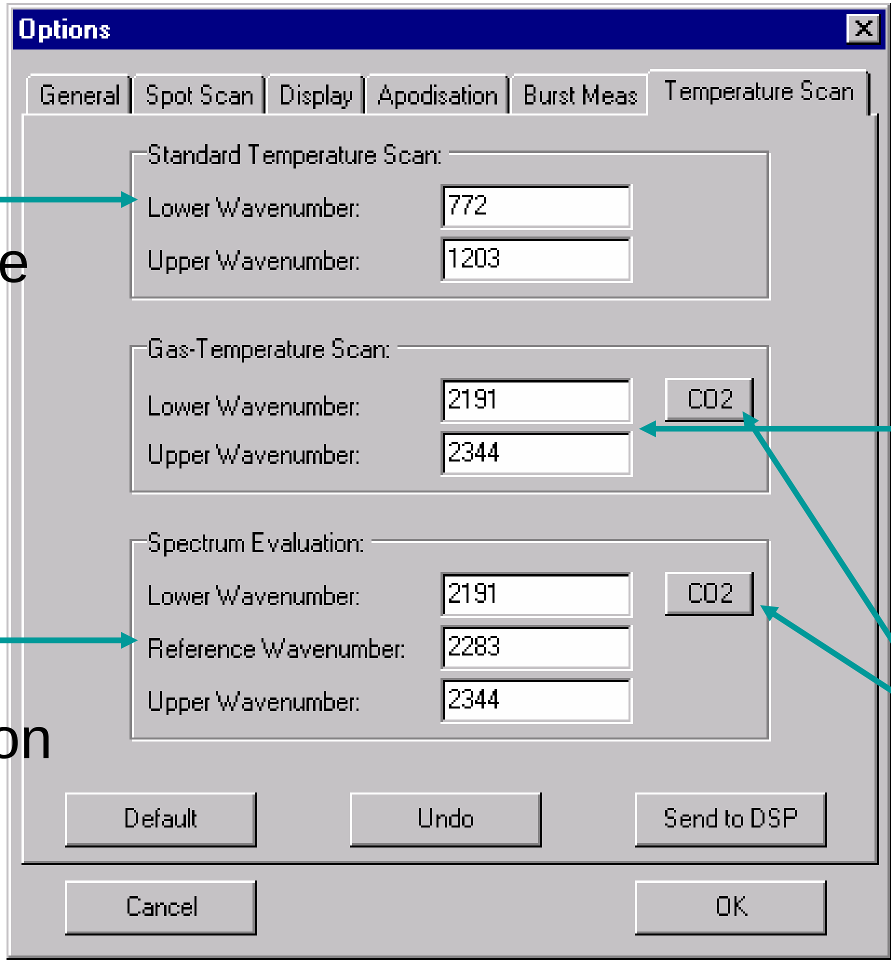



4E-005
3E-005
2E-005
1E-005
0
Intensity [(10-6 W/(sr cm2 cm-1)]
2388
2390
2392
2394
2396
Measured spectra
Simulated spectra

Compound	Calculated Emission Index
CO	22 (g/kg)
NO	0.20 (g/kg)

Spectral region for measurement of background temperature

Parameters for absorption and emission characterisation



Spectral region for measurement of gas temperature

Standard values for CO_2

Measurement results

Aircraft at airport, APU: gas temperature mode

approximated plume diameter 2.5 m, length 5.2 m

APU: gas radiation mode (absorption / emission)

approximated plume diameter 2.8 m, length 5.5 m

Comparison of different measurement methods

- **Operation of kerosene powered burner to apply FTIR emission spectrometry and intrusive methods**
  - **during the same time**
  - **at nearly the same exhaust gas volume**
- **Burner**
  - **nozzle exit diameter of 37 cm**
  - **power of about 150 kW**
  - **temperature of the exhaust inside the tube is about 270° C**
  - **fresh air pumped into the burner tube by a fan**
  - **calibration gases CO and NO (pure gases) in different amounts**
- **Sampling probe of the intrusive HORIBA PG-250 in the centre of the exhaust stream near the exhaust exit for measurements of CO_2, CO, NO, NO_2, UHC, SO_2 and O_2**

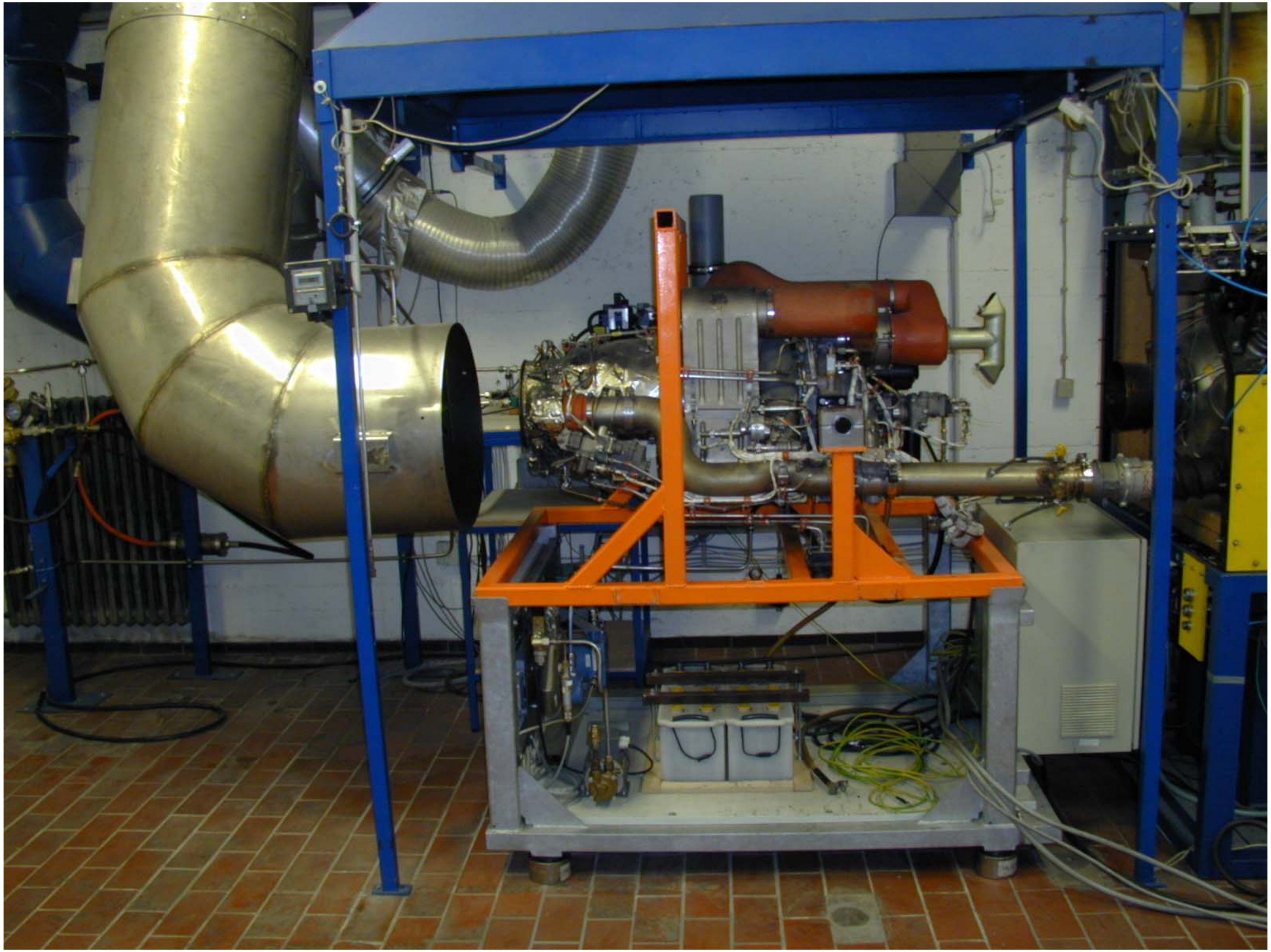
Results of comparison

- **Differences in the measured CO_2 data in the order of a factor of 2: influences of wind upon the plume temperature, plume shape and variation of concentration of CO_2 in the foreground**
- **Intrusive data in correspondence with the added CO plus the exhaust CO concentration**
- **Differences in CO between FTIR emission spectrometry and intrusive measurements in the order of 10 %**
- **FTIR emission spectrometry about 10 % lower for NO than the intrusive measurement results**
- **Intrusive measurement results about 20 up to 50 % lower than the added NO: formation of NO_2 from NO in the exhaust**

Second comparison of different measurement methods

- **Auxiliary Power Unit GTCP36-300 (Airbus A320) in the laboratory**
- **80 - 140 kg kerosene per hour**
- **Power 220 - 160 kW**
- **Pure CO added in different amounts**
- **DOAS and FTIR absorption spectrometry installed on the roof of the laboratory building across the exit of the chimney for turbine exhaust**
- **Passive FTIR and in situ measurement techniques installed in the laboratory between nozzle exit and chimney entrance:**

  problems with different sounding volumes



Results of comparison

- **Measurements of NO concentration at the exit of the chimney show clear dependence from APU power setting**

- **Comparison difficult sometime due to strong wind influence upon exhausts**

- **Deviations between NO and CO data of DOAS, FTIR and intrusive measurements less than ±20 %**

- **Problems with homogeneous mixing and chemical transformation of added gases (CO, NO) found in FTIR emission spectrometry and intrusive measurements behind the nozzle exit**

Future activities

- **EU-network of excellence ECATS (Environmentally Compatible Air Transport System):**
  Capability gap analyses
  Capability enhancement
  Research initiatives
  Education

- **Research projects: 7th Framework Program of the EC**

Acknowledgements

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Without this co-operation no reliable investigations would have been possible