Ambient Gas Temperature

Group Leader: Maarten Meijer (Eindhoven University of Technology – TU\e)
Contributors: Louis-Marie Malbec and Gilles Bruneaux (IFPEN), Lyle Pickett (Sandia National Laboratory), Raul Payri (CMT), Tim Bazyn (Caterpillar)

Summary of the Ambient Gas Temperature Measurements Working Group Session
Aim of the session is to provide guidelines for ECN spray A ambient gas temperature characterization.
Guidelines are provided for hardware implementation and post processing methods. 2 different set-ups can be distinguished; pre-burn combustion vessels and constant flow rigs. Both type of set-ups are capable to reach spray A conditions. The fundamental difference in the operation of both set-ups lead to different measurement approaches to characterize the ambient temperature field.
For the constant flow test rigs time averaged measurements are executed both at Caterpillar and CMT. Based on the followed measurement approach, conventional hardware; thermocouples, signal conditioners and DAQ, can be selected. Different thermocouple diameters (at the same position) are used at both institutes in order to define the required radiation correction. Corrections are based on extrapolation to 0 [mm] diameter. The ambient temperature is measured at different locations inside the flow rigs. Ambient gas temperature fluctuations of +/- 10 [K] are reported based on 10 [s] and 20 [s] averaged measurement data for Caterpillar and CMT test rigs respectively. Wall temperatures are 800 [K] found at both facilities. No information on measurement deviations and error bounds is provided at this moment.
Temperature characterization for the pre-burn combustion vessels is executed at Sandia National Laboratory, IFPEN and TU\e. The wide temperature range which is crossed as a result of the used pre-combustion method in combination with the small time scales lead to an unconventional (thermocouple) measurement approach. Main goal of the executed measurements is to define the relation between the vessel core temperature and the bulk temperature. The bulk temperature is measured by using a piëzo-electric pressure sensor. All 3 institutes used fine wire thermocouples to define the core temperature. The used thermocouples are capable to follow the fast temperature change inside the combustion vessel. Sandia and TU\e implemented an adjustable probe with 5 different 50 [µm] thermocouples. The Platinum material from the type R thermocouples can result in an undesired catalytic respond when installed in the sequentially filled type pre-burn combustion vessels (used at IFPEN and TU\e). Therefore IFPEN used a 25 [µm] thick, single K-type thermocouple. At TU\e a Nitrogen/Oxygen mixture was used (no filling of pure oxygen), to avoid this undesired effect. High speed DAQ hardware is selected in combination with high measurement accuracy as well (number of bits). Signal conditioners can be used but direct logging of the [mV] signal from the thermocouples is also possible, applying cold junction and linearization afterwards. A similar approach is followed by all 3 institutes to correct the measured thermocouple signal for radiation and the convective respond. At the spray A injection temperature (900 [K]), the influence of these corrections is small. Measurement deviations at spray A are around 10 [K]. Measurement uncertainties are believed to be +- 7.5 [K], but are still under investigation. The found relation for the core and bulk temperature is 1.03 for IFP and 1.08 for Sandia and TU\e. Measurements with the type-R thermocouple probe show high temperatures at the top of the combustion vessel, caused by buoyancy effects.

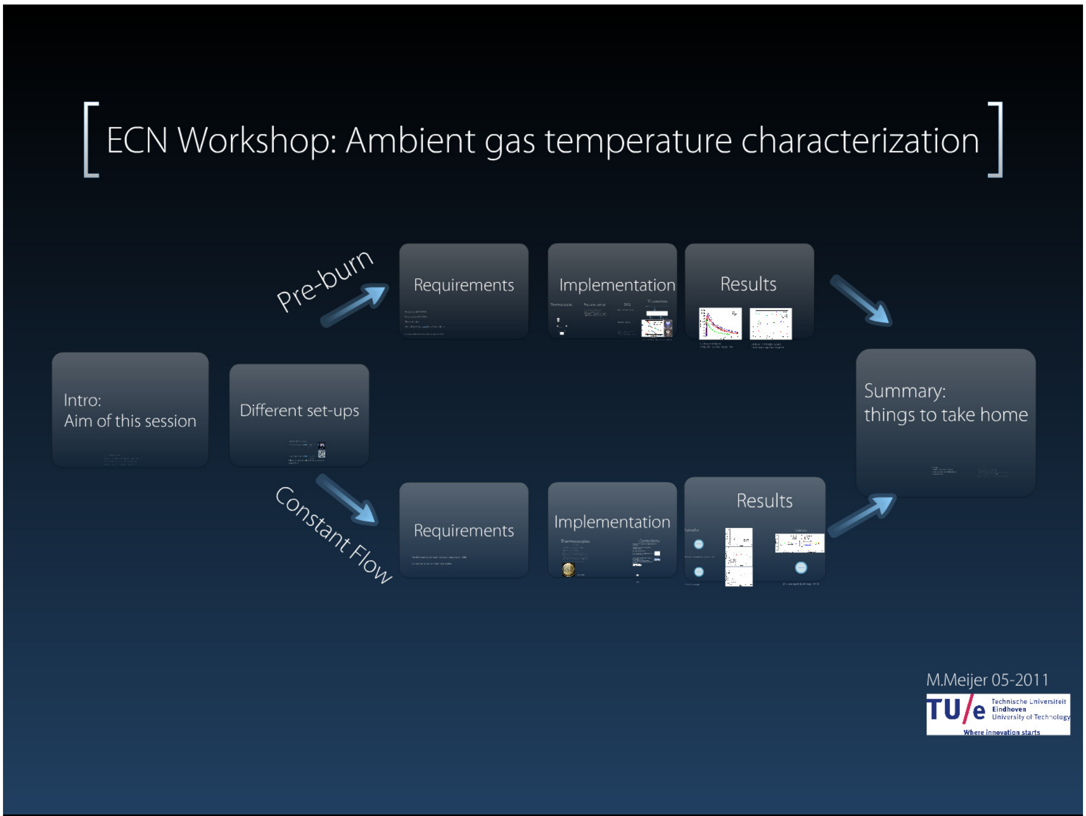
References:
Comparison of diesel spray combustion in different high-temperature, high-pressure facilities.
L.M. Pickett, C.L. Genzale, G. Bruneaux, L-M Malbec, L. Hermant, C. Christiansen, J. Schramm.
SAE 2010-01-2106

Engine Combustion Network: implementation and analysis of combustion vessel spray A conditions
M.Meijer, R.J. Christians, J.G.H. v. Griensven, L.M.T. Somers, L.P.H. de Goey
Illass-Americas 23rd conference paper number 151

Discussion Issues & Future Investigation
Constant flow: Until now, only time averaged ambient gas temperature measurements are executed. It seems that temperature fluctuations are small but the fluctuations over time are not investigated. This can be relevant for the temperature error estimation. Fine wire thermocouples are required for this.

Pre-burn combustion vessels: Further characterization of the temperature field right before fuel injection is required because small temperature fluctuations have a profound impact on ignition delay, spray penetration and the flame lift off length. Especially the temperature field close the fuel injector should be investigated and analyzed more in detail. More investigations on the used TC corrections (for radiation, convective respond and conduction) are ongoing which are critical in order to define the reached measurement uncertainty.

Workshop presentation:
See next pages. One additional slide is added from Gilles Bruneaux, giving a summary of the discussion and future investigation points.


ECN Workshop: Ambient gas temperature characterization
Pre-burn
Requirements
Implementation
Results
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Aim of this session
Different set-ups
Summary:
things to take home
Constant Flow
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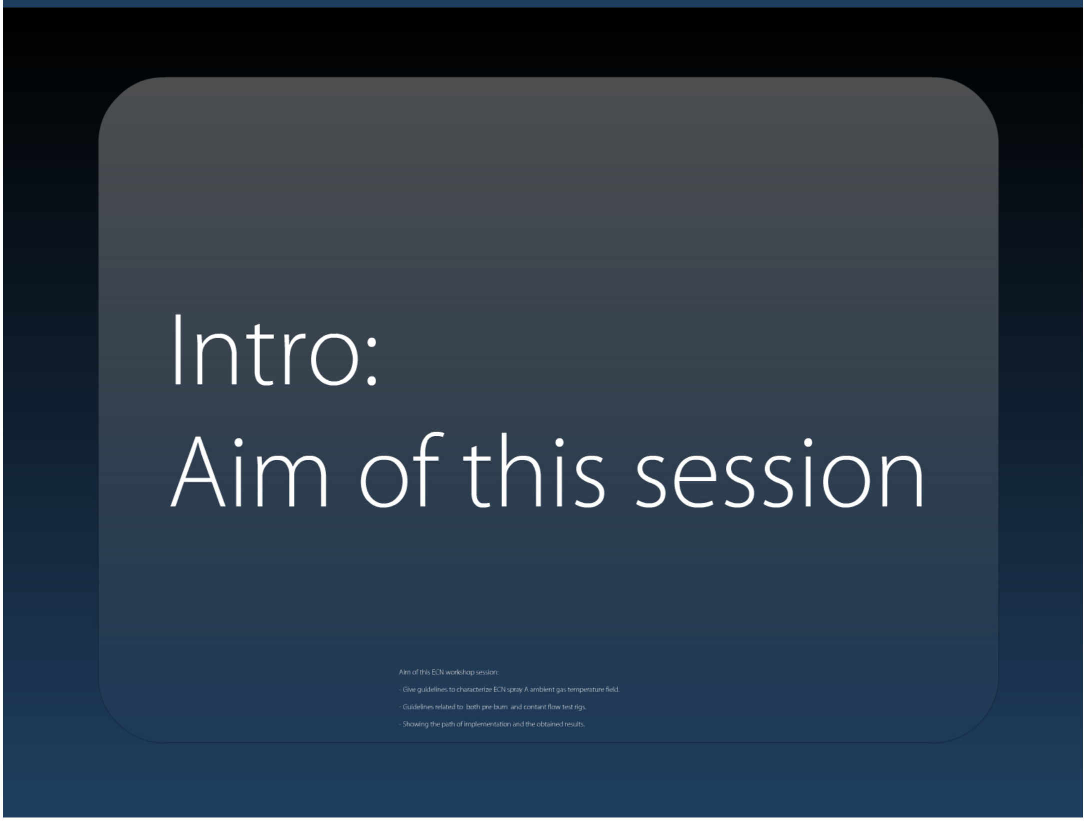
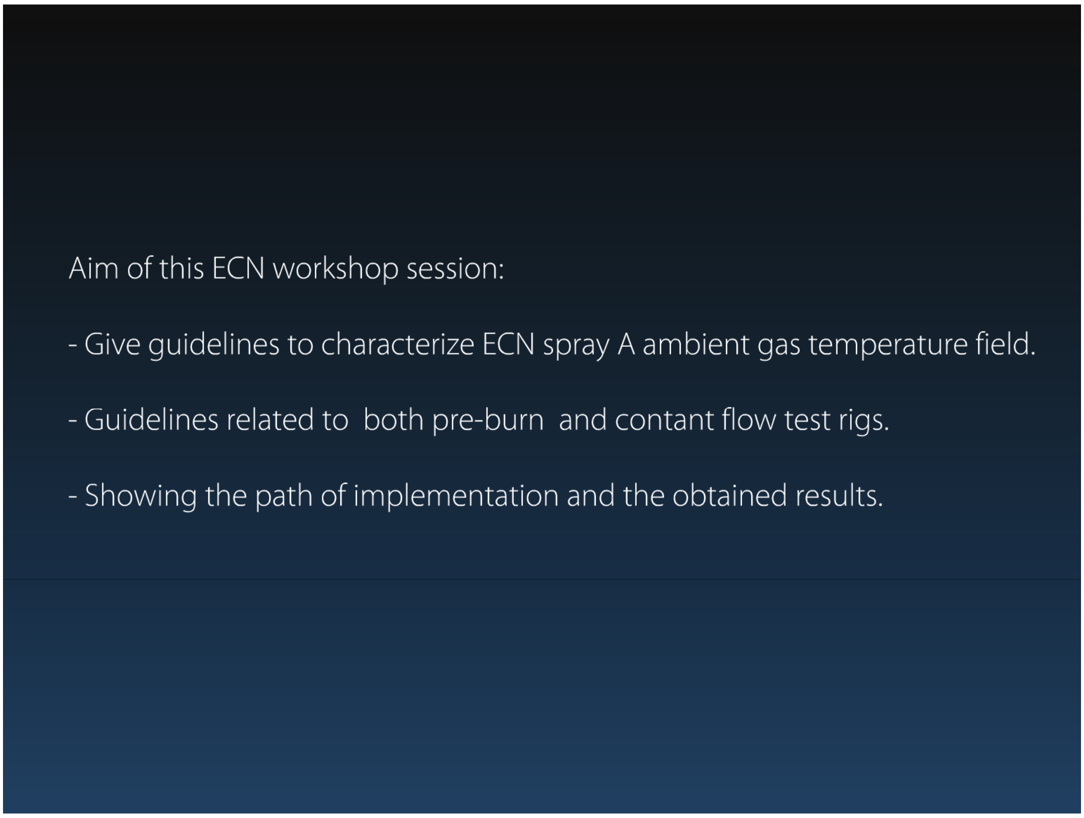
TU/e Technische Universiteit Eindhoven University of Technology
Where innovation starts


Intro:
Aim of this session
Aim of this ECN workshop session:
- Give guidelines to characterize ECN spray A ambient gas temperature field.
- Guidelines related to both pre-burn and contant flow test rigs.
- Showing the path of implementation and the obtained results.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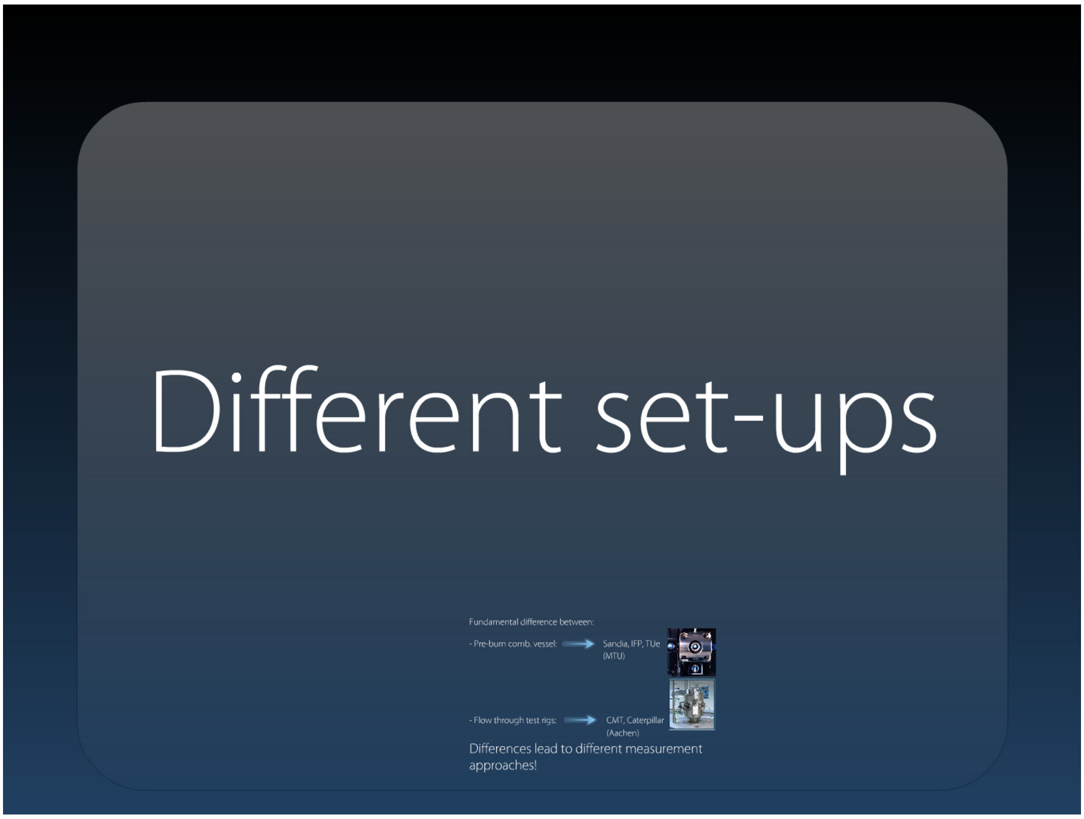
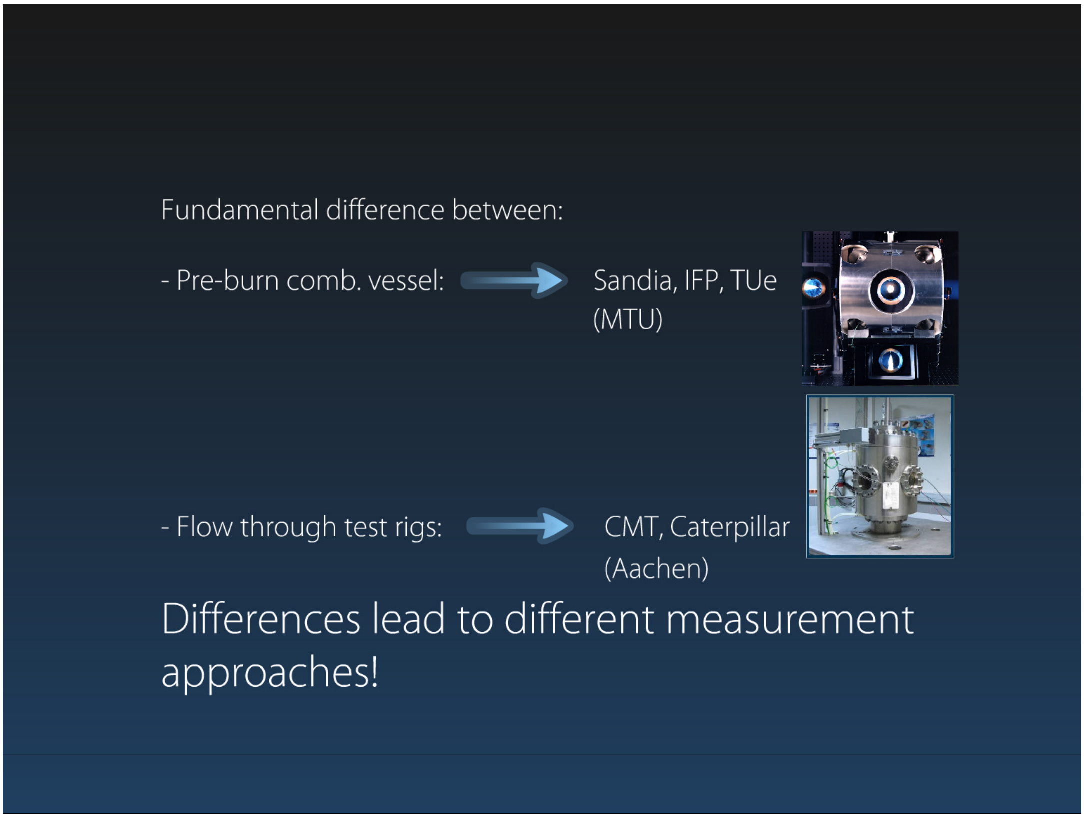

Different set-ups
Fundamental difference between:
- Pre-burn comb. vessel:
Sandia, IFP, TUe (MTU)
- Flow through test rigs:
CMT, Caterpillar (Aachen)
Differences lead to different measurement approaches!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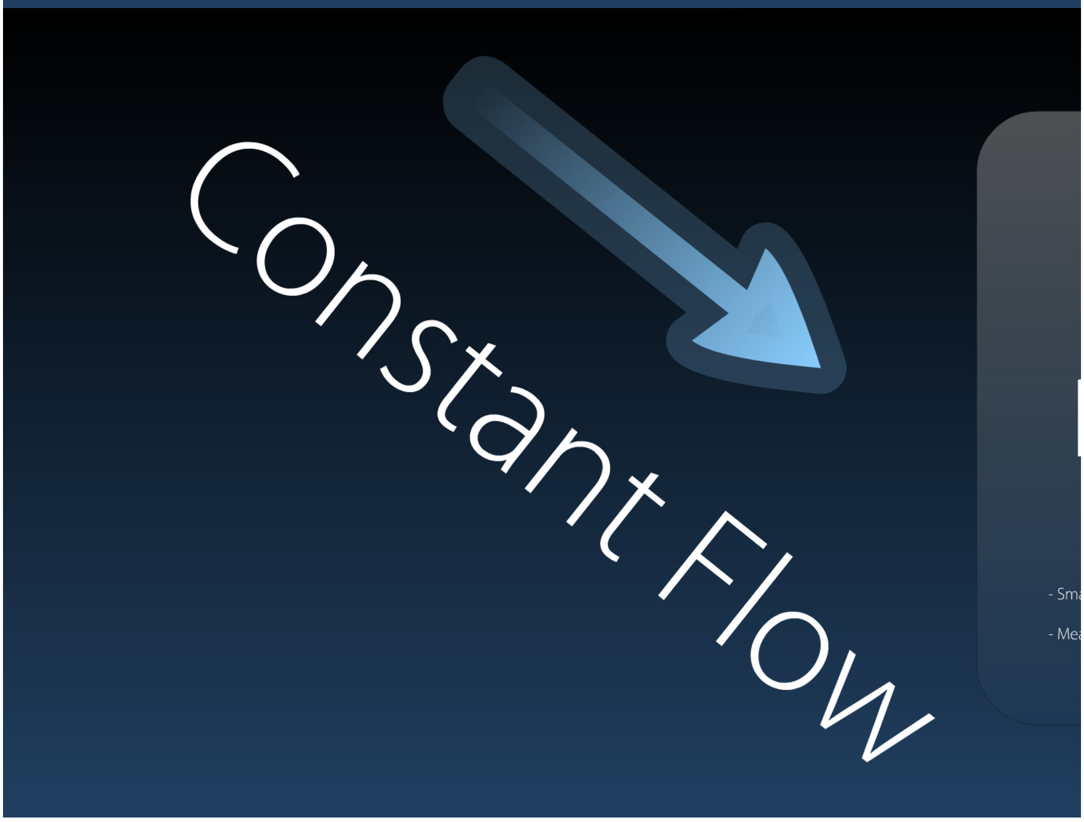
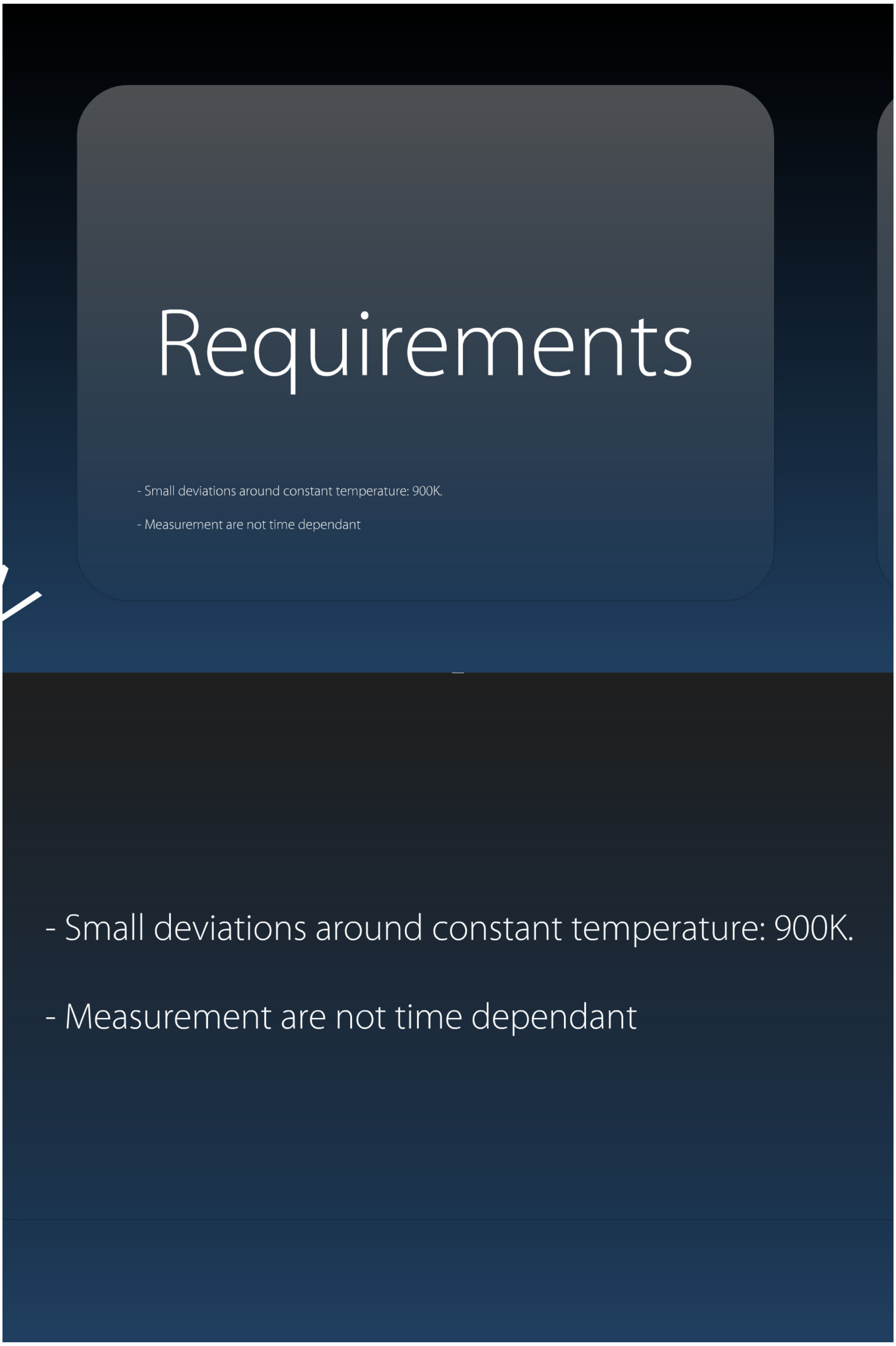
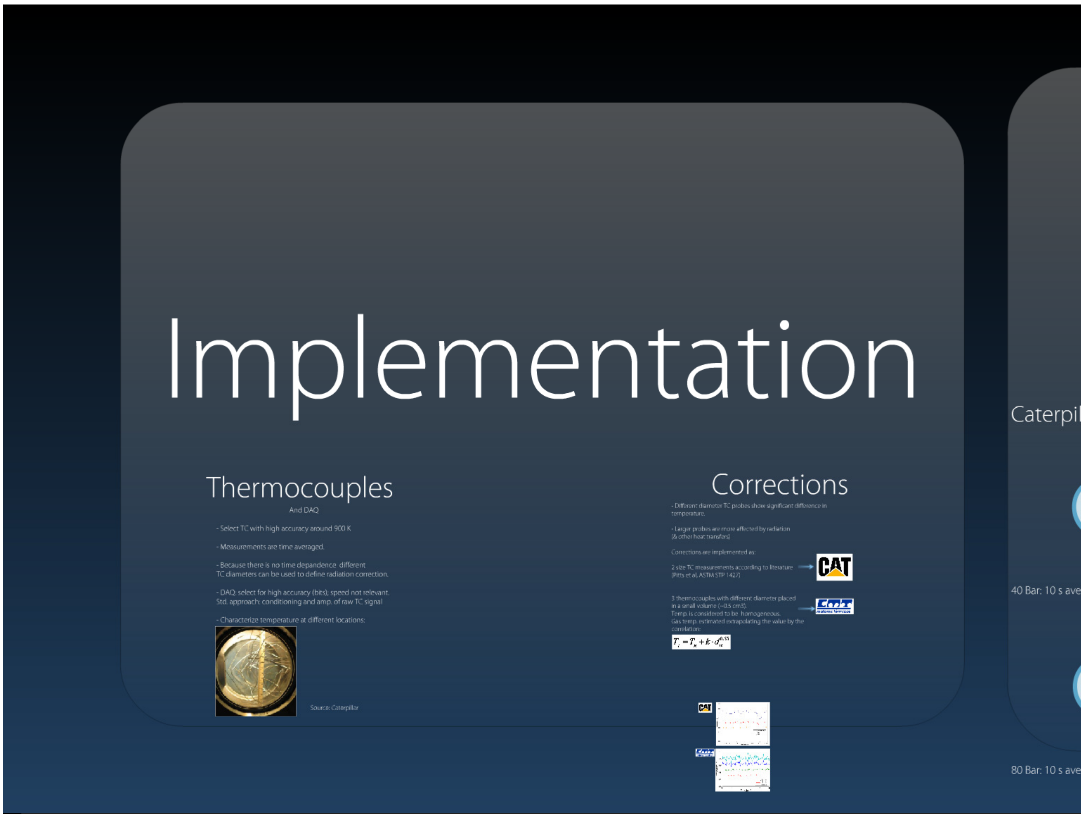
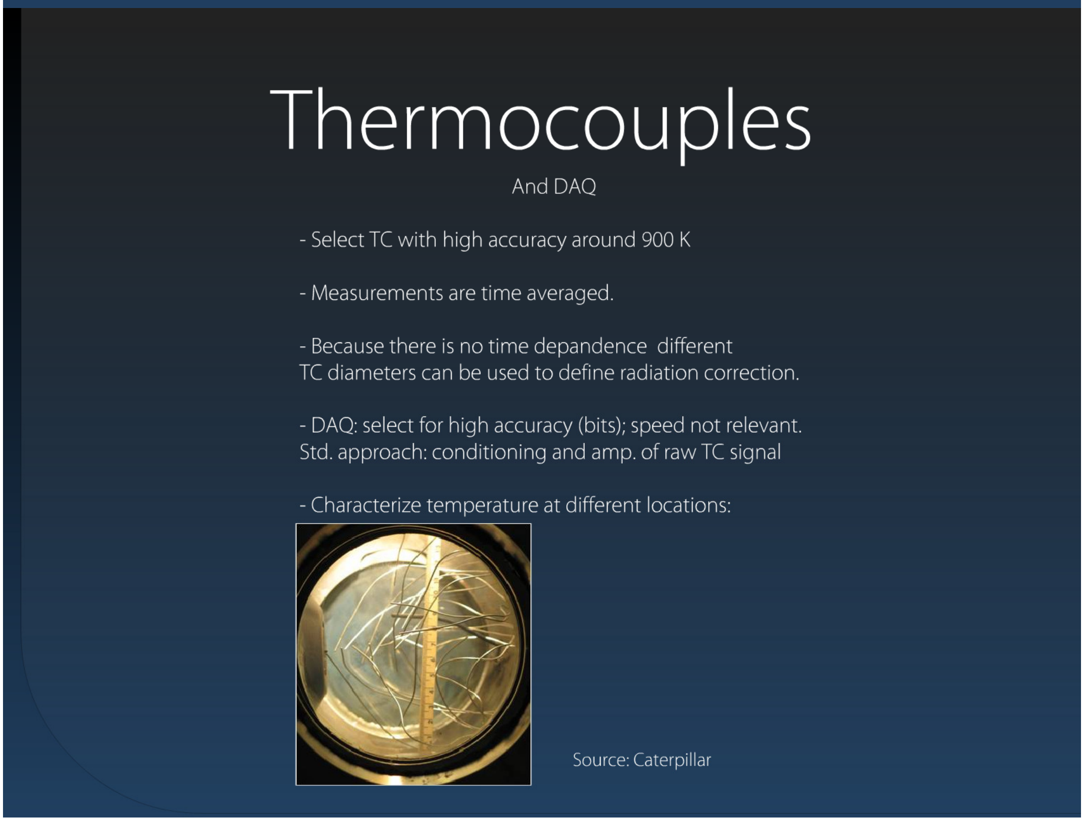

Constant Flow


Requirements
- Small deviations around constant temperature: 900K.
- Measurement are not time dependant
- Small deviations around constant temperature: 900K.
- Measurement are not time dependant


Implementation
Thermocouples
Corrections


Thermocouples
And DAQ
- Select TC with high accuracy around 900 K
- Measurements are time averaged.
- Because there is no time dependance different
TC diameters can be used to define radiation correction.
- DAQ: select for high accuracy (bits); speed not relevant.
Std. approach: conditioning and amp. of raw TC signal
- Characterize temperature at different locations:
Source: Caterpillar

Corrections

- Different diameter TC probes show significant difference in temperature.

- Larger probes are more affected by radiation (& other heat transfers)

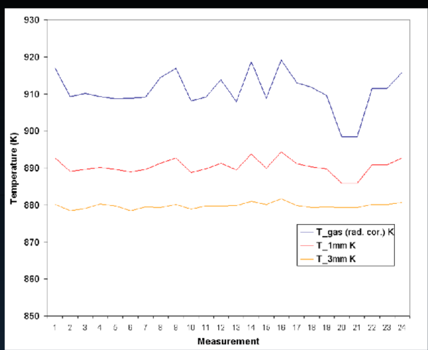
Corrections are implemented as:

2 size TC measurements according to literature (Pitts et al, ASTM STP 1427) → CAT

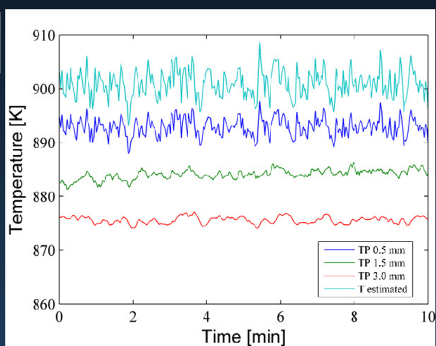
3 thermocouples with different diameter placed in a small volume (~0.5 cm3).
Temp. is considered to be homogeneous.
Gas temp. estimated extrapolating the value by the correlation: → CMT motores térmicos

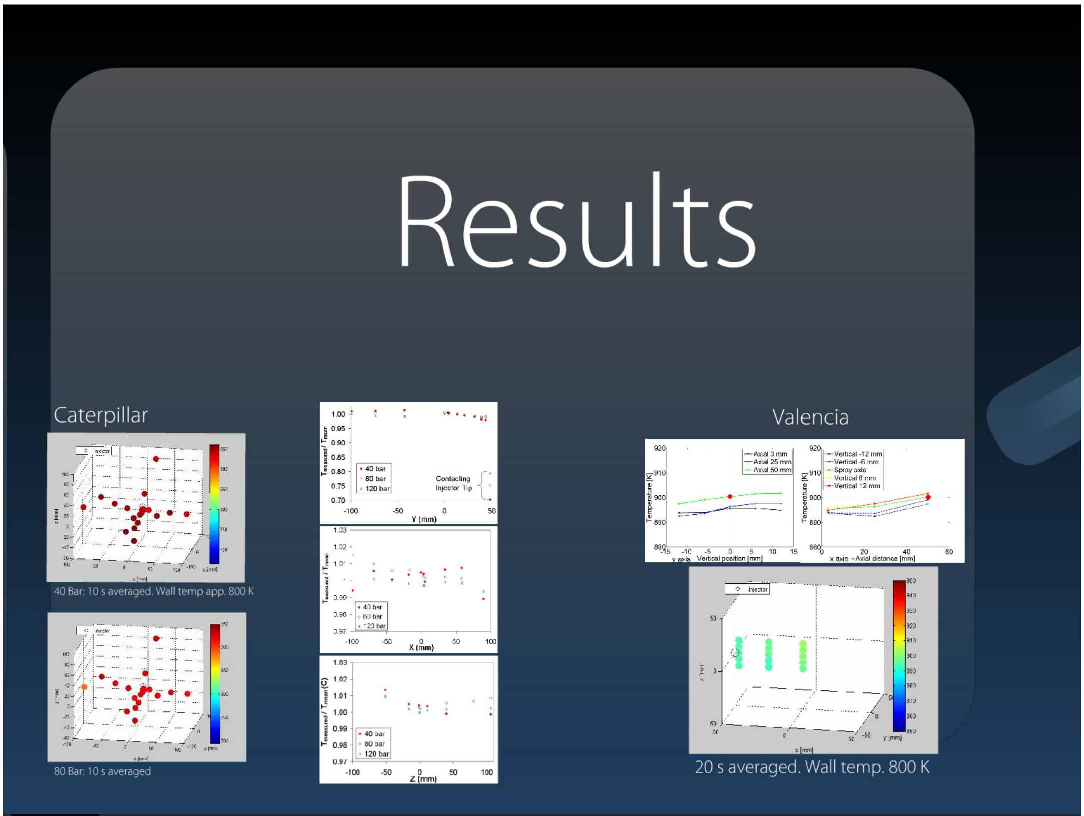
$$T_j = T_g + k \cdot d_{tc}^{0.55}$$

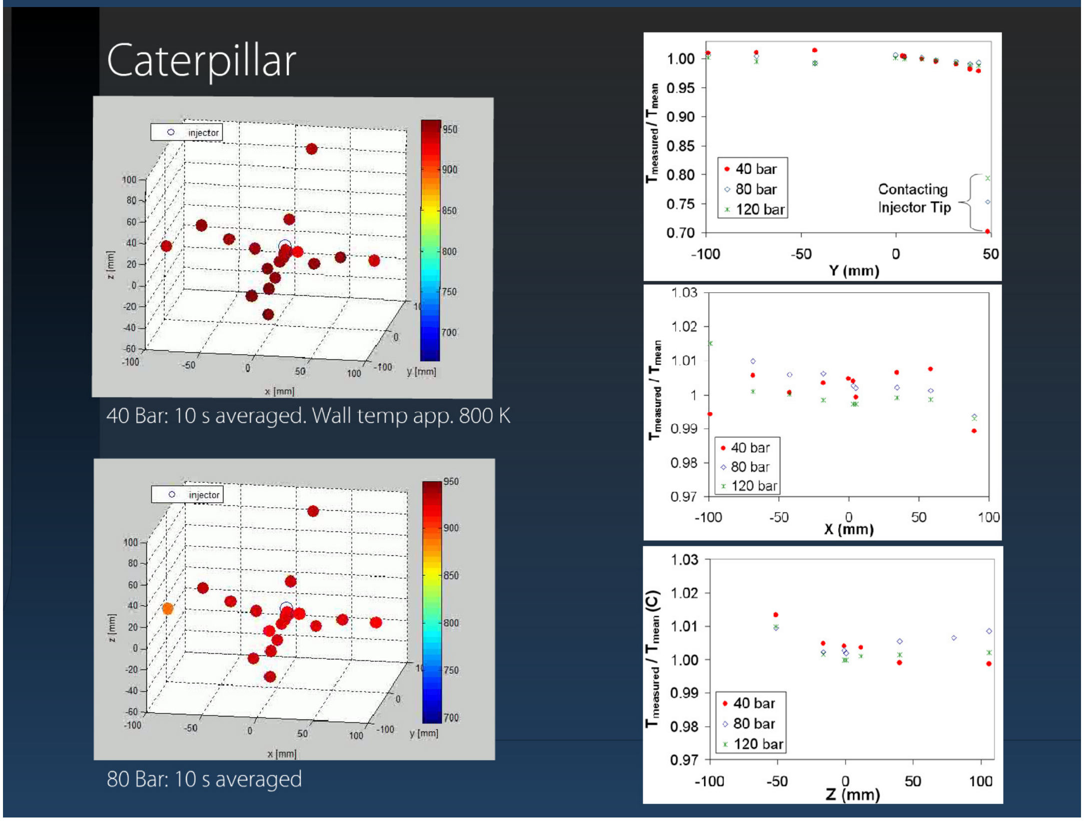
CAT

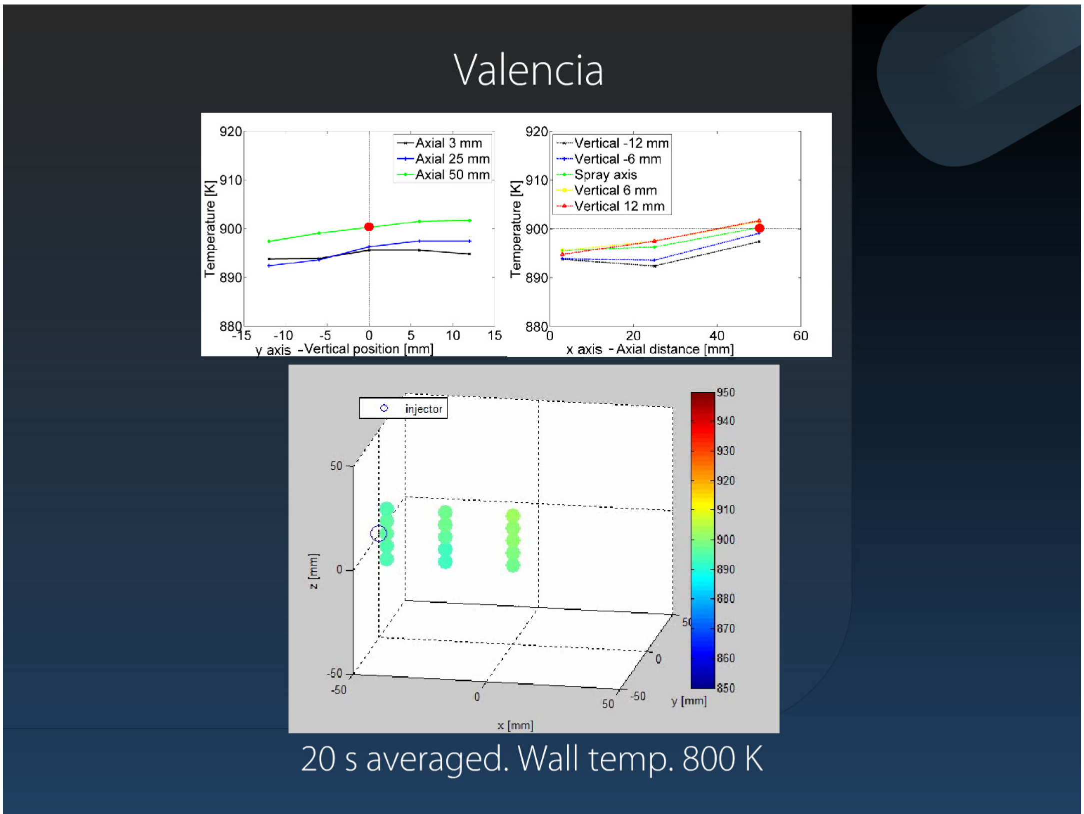


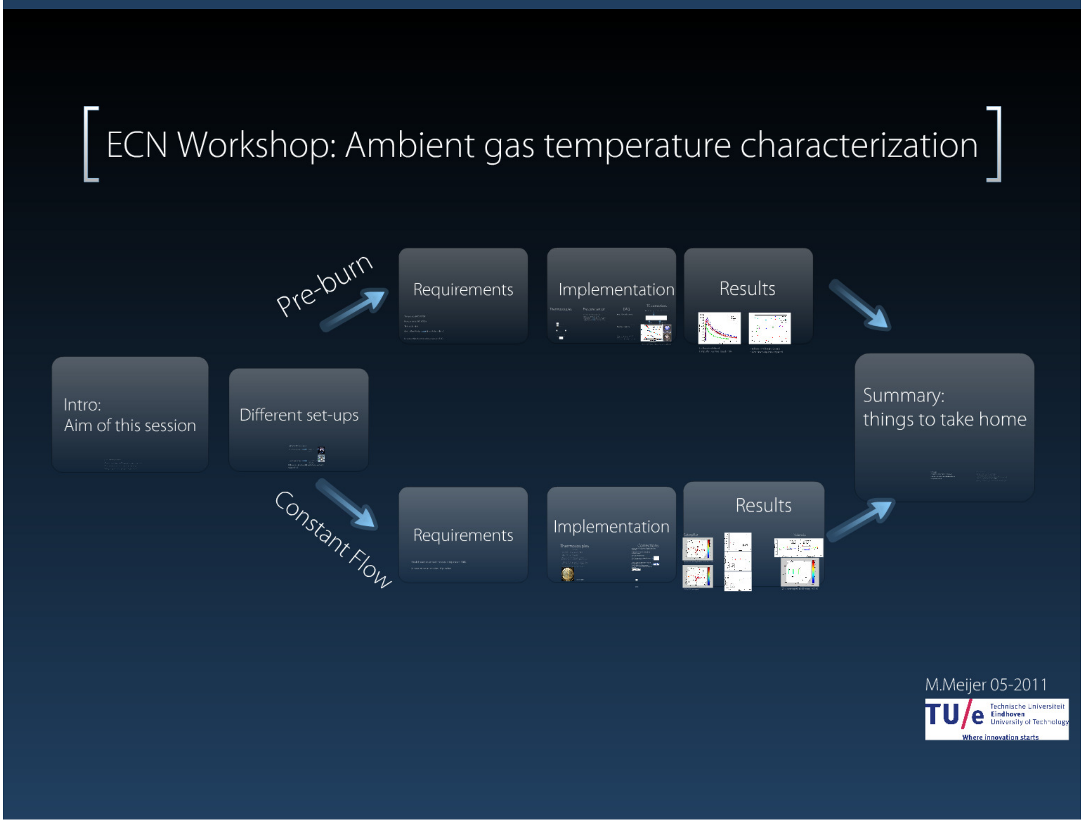
CMT motores térmicos




Results
Caterpillar
40 Bar: 10 s averaged. Wall temp app. 800 K
80 Bar: 10 s averaged
Valencia
20 s averaged. Wall temp. 800 K


Caterpillar
injector
z [mm]
x [mm]
y [mm]
40 Bar: 10 s averaged. Wall temp app. 800 K
80 Bar: 10 s averaged
40 bar
80 bar
120 bar
Contacting
Injector Tip
Y (mm)
X (mm)
Z (mm)


Valencia
Axial 3 mm
Axial 25 mm
Axial 50 mm
Temperature [K]
y axis - Vertical position [mm]
Vertical -12 mm
Vertical -6 mm
Spray axis
Vertical 6 mm
Vertical 12 mm
x axis - Axial distance [mm]
injector
z [mm]
x [mm]
y [mm]
20 s averaged. Wall temp. 800 K


ECN Workshop: Ambient gas temperature characterization
Intro:
Aim of this session
Different set-ups
Pre-burn
Requirements
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things to take home
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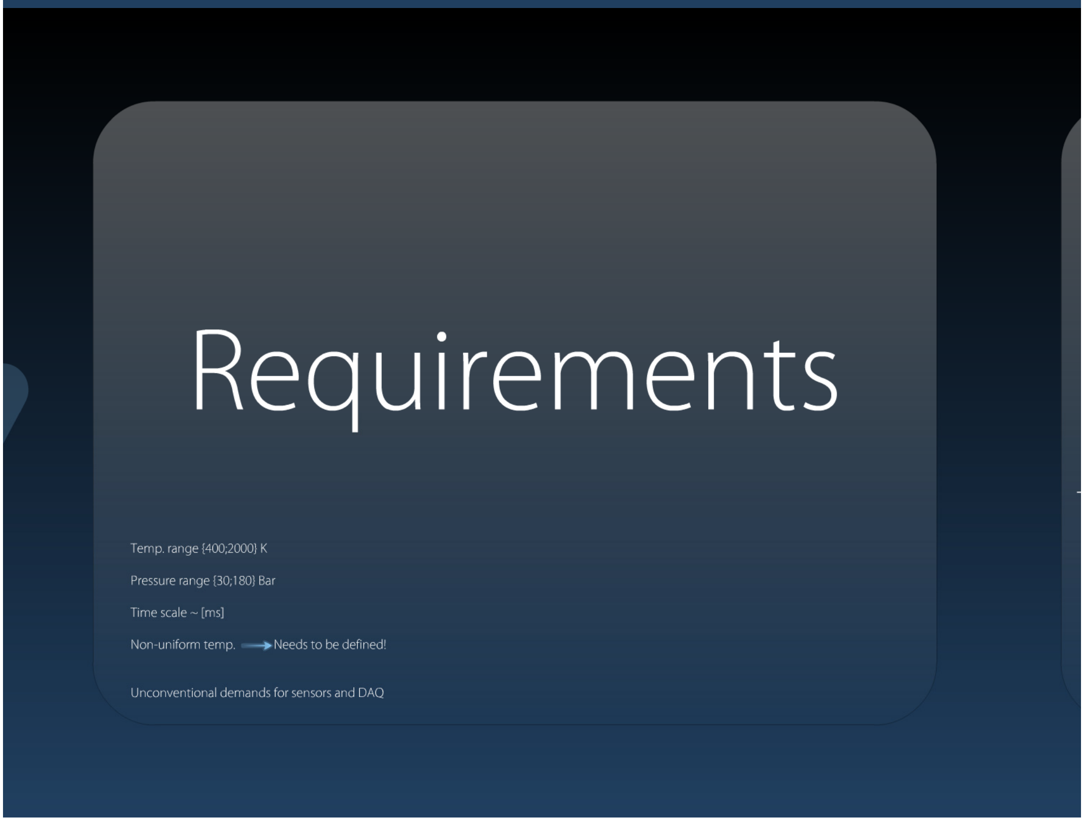
Pre-burn


Requirements
Temp. range {400;2000} K
Pressure range {30;180} Bar
Time scale ~ [ms]
Non-uniform temp. Needs to be defined!
Unconventional demands for sensors and DAQ

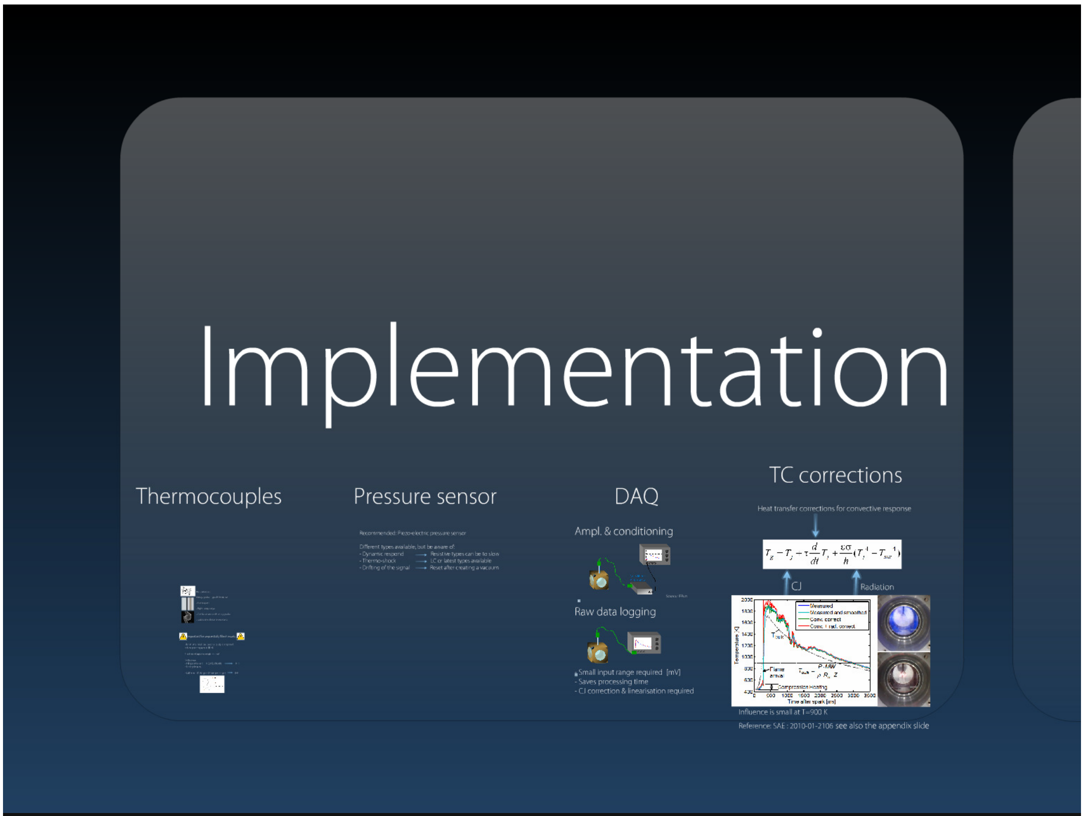
Temp. range {400;2000} K

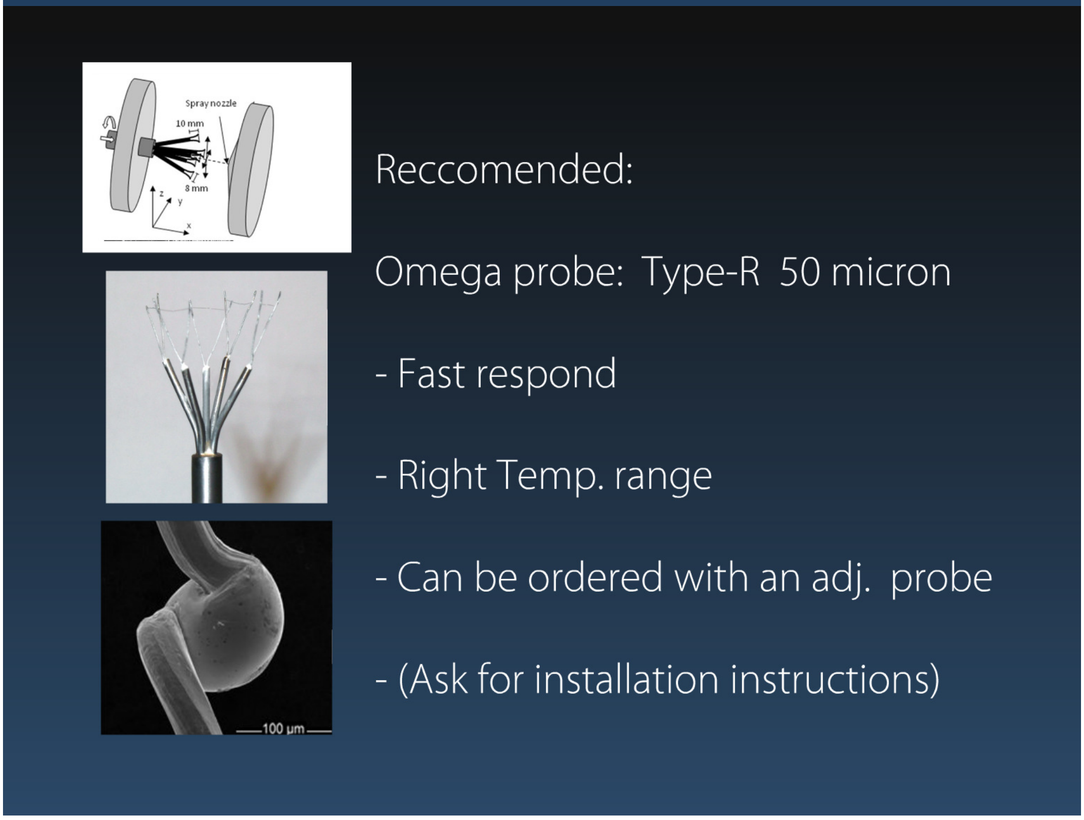
Pressure range {30;180} Bar

Time scale ~ [ms]

Non-uniform temp. → Needs to be defined!

Unconventional demands for sensors and DAQ


Implementation
Thermocouples
Pressure sensor
DAQ
TC corrections
Ampl. & conditioning
Raw data logging
CJ
Radiation


Spray nozzle
10 mm
8 mm
100 µm
Reccomended:
Omega probe: Type-R 50 micron
- Fast respond
- Right Temp. range
- Can be ordered with an adj. probe
- (Ask for installation instructions)

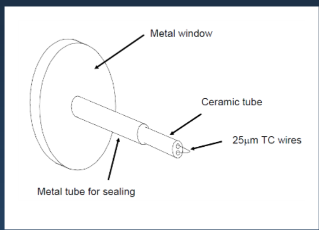
Important for sequentially filled vessels

The Pt. material can cause a catalytic respond when pure oxygen is filled.

Undesired ignition might occur!

Sollutions:
- Fill gas mixture: N2/O2 (60/40) → TUe
- No Hydrogen

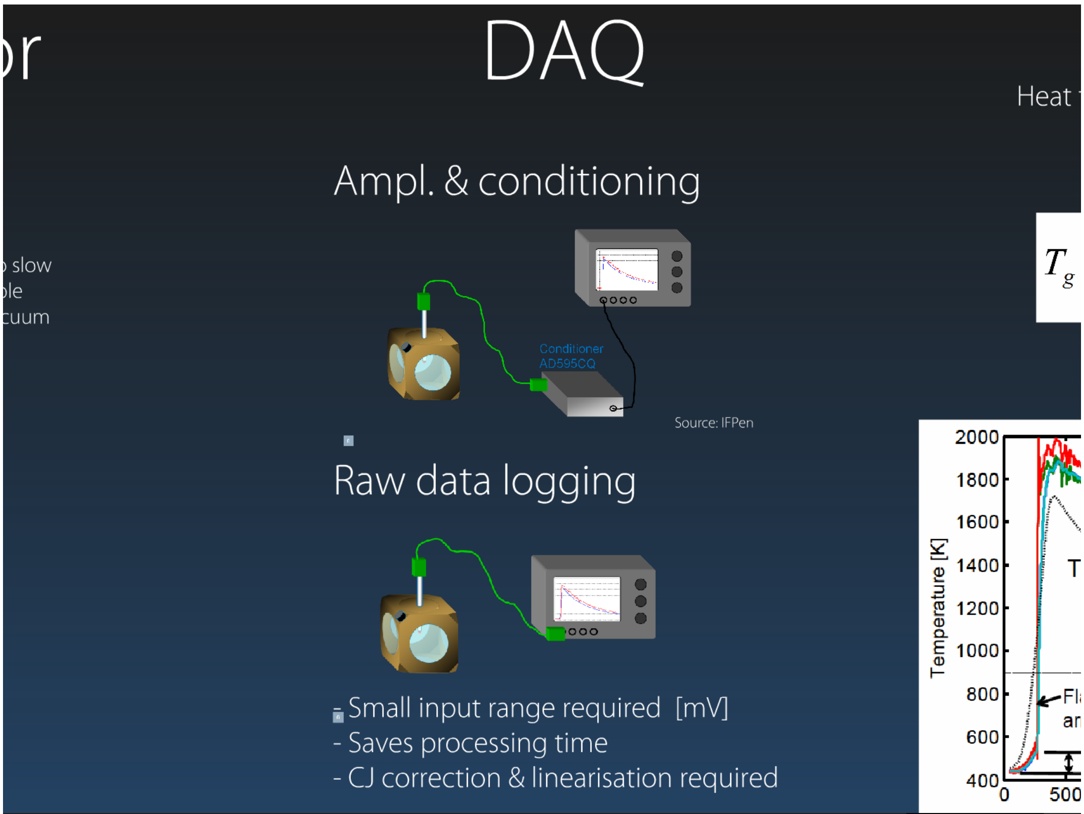
- Different TC; K-type 25 um prototype → IFP

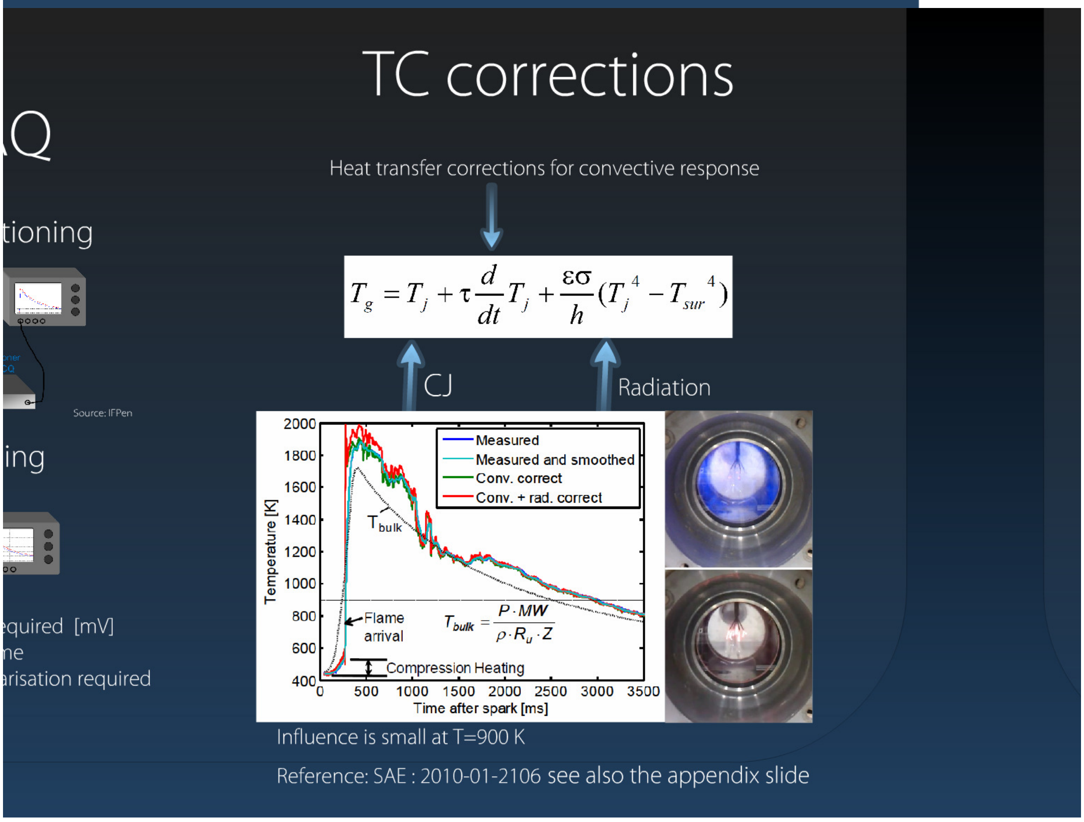


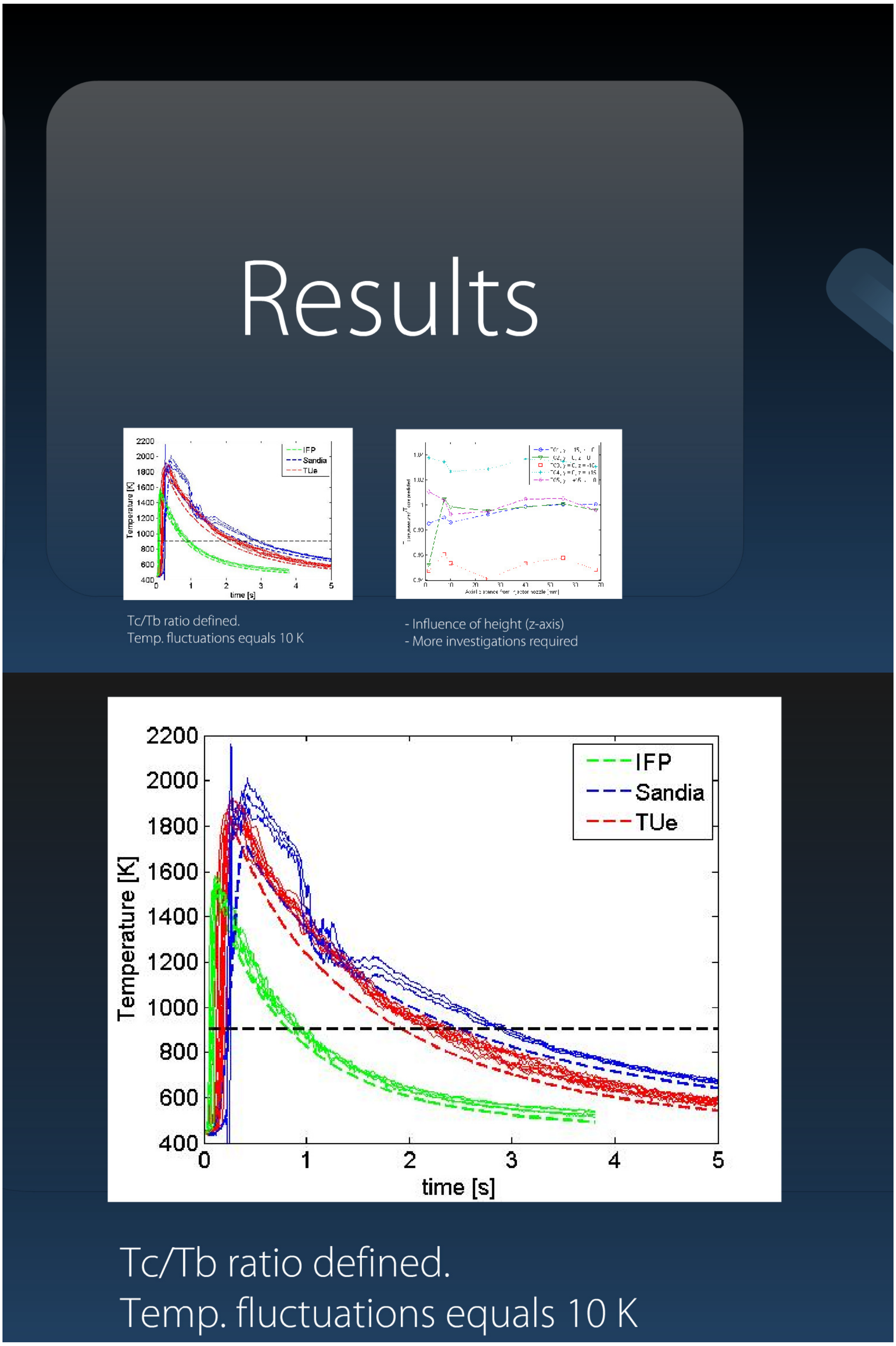
Pressure sensor

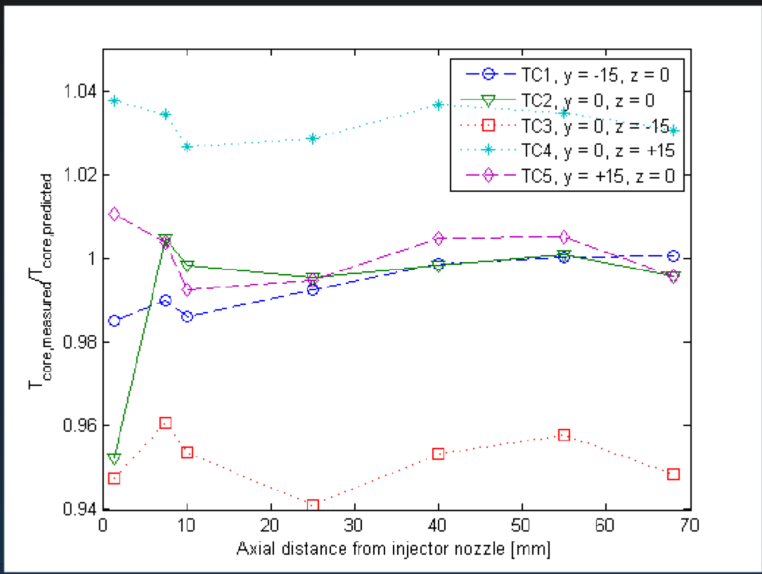
Recommended: Piezo-electric pressure sensor

Different types available, but be aware of:
- Dynamic respond → Resistive types can be to slow
- Thermo-shock → LC or latest types available
- Drifting of the signal → Reset after creating a vacuum


DAQ
Ampl. & conditioning
Conditioner AD595CQ
Source: IFPen
Raw data logging
- Small input range required [mV]
- Saves processing time
- CJ correction & linearisation required
Heat
Temperature [K]
2000
1800
1600
1400
1200
1000
800
600
400
0
500


TC corrections
Heat transfer corrections for convective response
$T_g = T_j + \tau \frac{d}{dt} T_j + \frac{\varepsilon\sigma}{h}(T_j^4 - T_{sur}^4)$
CJ
Radiation
Measured
Measured and smoothed
Conv. correct
Conv. + rad. correct
T_{bulk}
Flame arrival
$T_{bulk} = \frac{P \cdot MW}{\rho \cdot R_u \cdot Z}$
Compression Heating
Temperature [K]
Time after spark [ms]
Influence is small at T=900 K
Reference: SAE : 2010-01-2106 see also the appendix slide


Results
Tc/Tb ratio defined.
Temp. fluctuations equals 10 K
- Influence of height (z-axis)
- More investigations required
IFP
Sandia
TUe
Temperature [K]
time [s]
Tc/Tb ratio defined.
Temp. fluctuations equals 10 K



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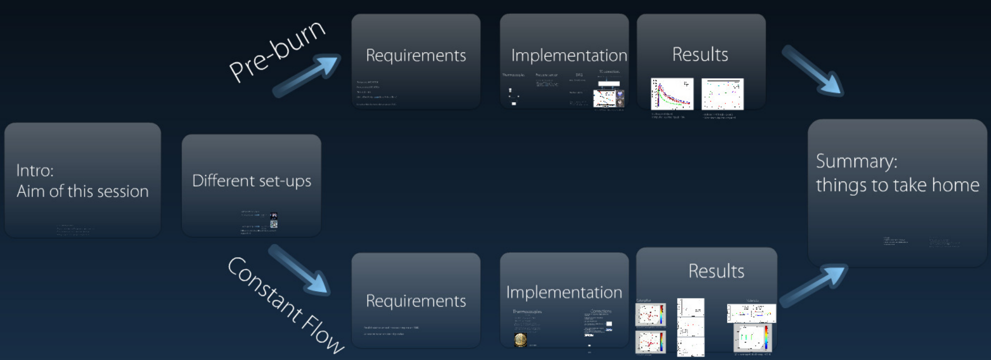
[ECN Workshop: Ambient gas temperature characterization]



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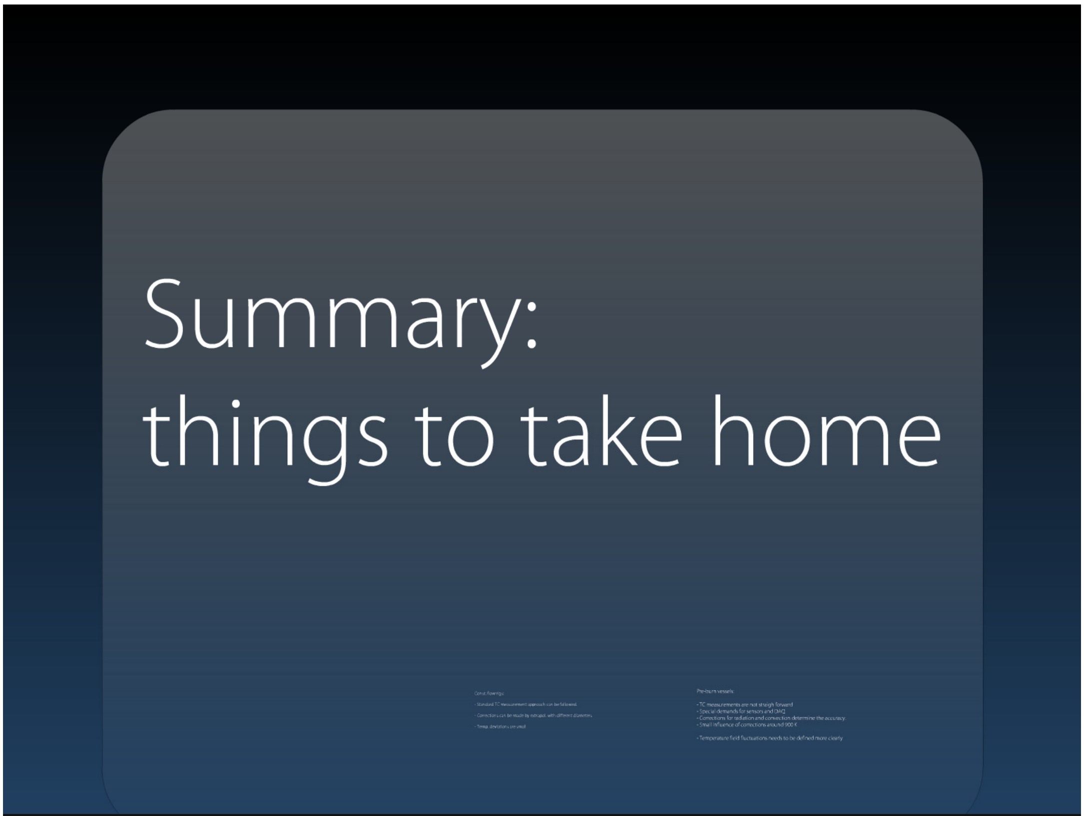
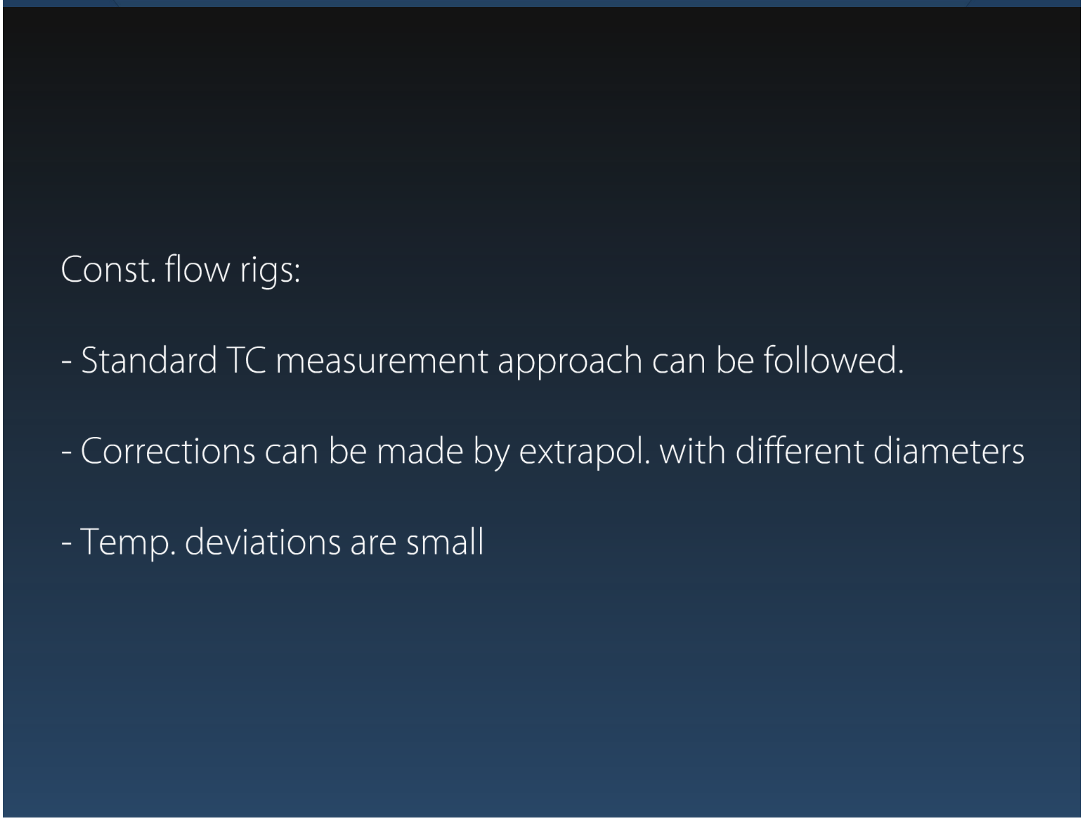

Summary:
things to take home


Const. flow rigs:
- Standard TC measurement approach can be followed.
- Corrections can be made by extrapol. with different diameters
- Temp. deviations are small

Pre-burn vessels:

- TC measurements are not straigh forward
- Special demands for sensors and DAQ
- Corrections for radiation and convection determine the accuracy.
- Small influence of corrections around 900 K

- Temperature field fluctuations needs to be defined more clearly

Appendix: TC corrections

Starting from:
Determination of the Time Constant of Fine-Wire Thermocouples for Compensated Temperature Measurements in Premixed Turbulent Flames. P.C. Miles

$$h(T_g - T_j) - \sigma\epsilon(T_j{}^4 - T_g{}^4) - \frac{\rho c d}{4}\frac{d}{dt}T_j = 0$$

Conduction neglected: small wires

$$T_g = T_j + \tau\frac{d}{dt}T_j + \frac{\varepsilon\sigma}{h}(T_j{}^4 - T_{sur}{}^4)$$

Convective respond at T=900 [K] small (derivative)

Vessel temperature

- Constant flow rigs
  - Standard TC measurements OK
  - Interesting to perform fast TC measurement to assess small scale temperature fluctuation
- Precombustion vessels
  - Recommended Omega probe and DAQ
  - Radiation corrections
- More detailed investigation of boundary layer temperature inhomogeneities is required (effect on liquid length, lift off length...)