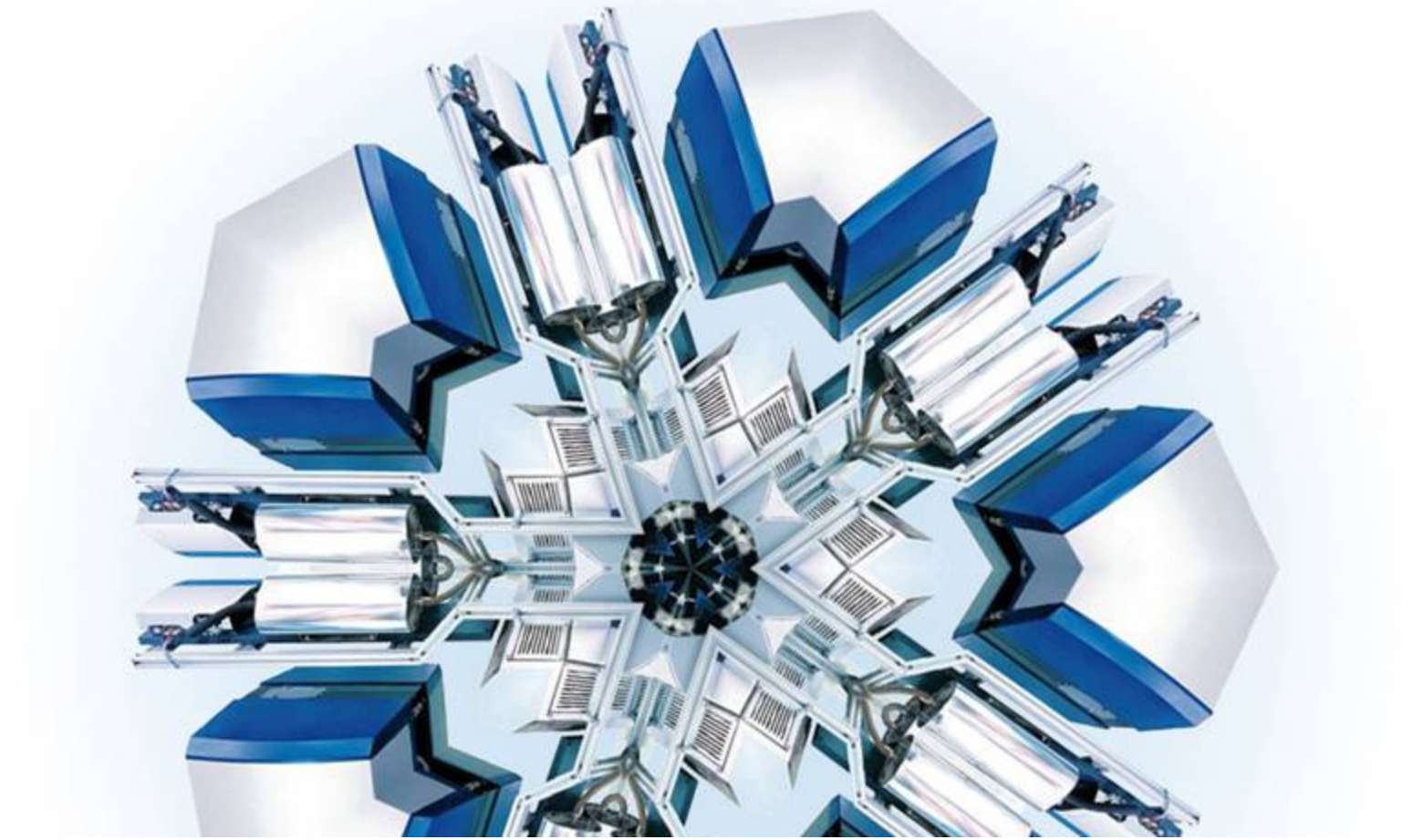
INDICATING AND COMBUSTION DEVELOPMENT TOOLS

September 2009

Alfred Kristoferitsch
Business Development Manager
AVL List, Graz/Austria



INDICATING AND COMBUSTION DEVELOPMENT TOOLS

CONTENT:

- The Indicating Measuring Chain
- Basics of Indicating and Parameters
- Indicating for Emission Reduction
- Contribution of Optical Measurement Tools
- AVL Combustion Measurement - Product overview
- Application Examples

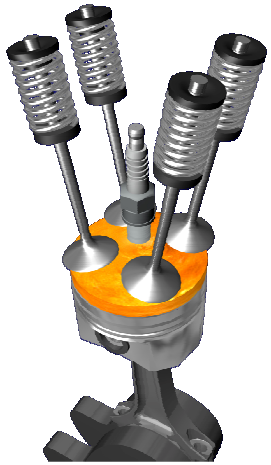
INDICATING AND COMBUSTION ANALYSIS
How we notice combustion ?

Amplifier

• Charge Amplifier

High Speed Data Acquisition

• Indicating System



Crank Angle Signal

• Crank Angle Encoder

Data Acquisition SW

• Control of HW

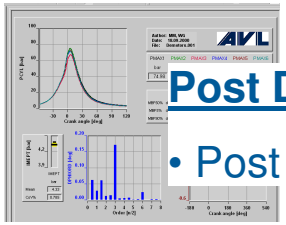
• Calculation / Analysis

Cylinder Pressure

• High Pressure Sensor (piezo electric)

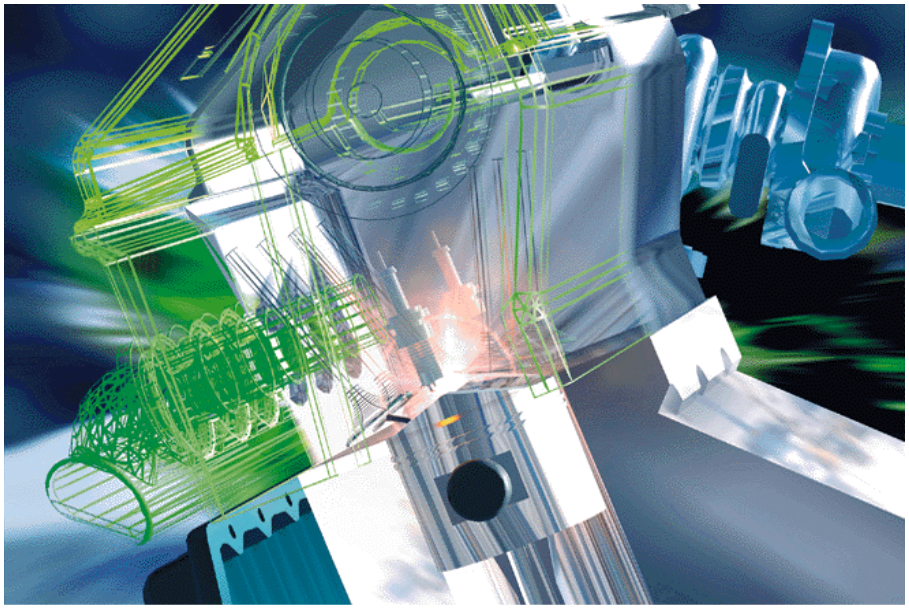
Post Data Processing

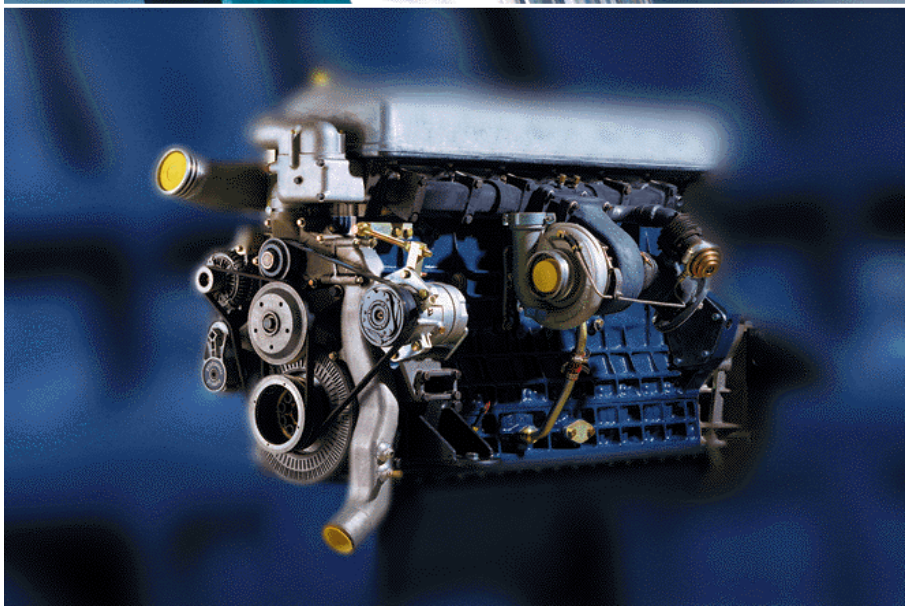
• Post Data Processing Tool



Meaningful Measurement Results require
… accurate Measurement tools

INDICATING AND COMBUSTION ANALYSIS
How we notice combustion ?

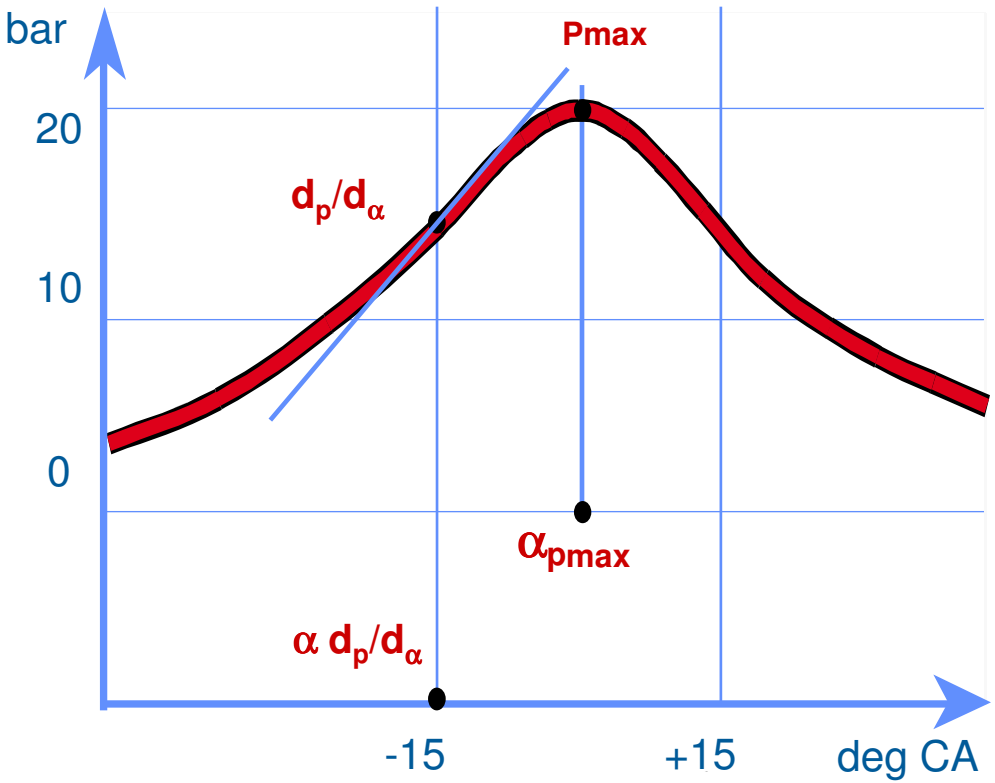




Typical measurements

- Cylinder pressure
- Degree Crank Angle – crank angle encoder / calculator
- Low Pressure measurement in intake and exhaust manifold
- Line Pressure Sensors (max. 3000 bar)
- TDC Sensor - Top dead center sensor
- Turbo Speed Sensor
- Needle Lift Sensor / Valve Lift Sensor
- Ignition / Injection Timing
- . . .

STANDARD EVALUATION OF THE CYLINDER PRESSURE

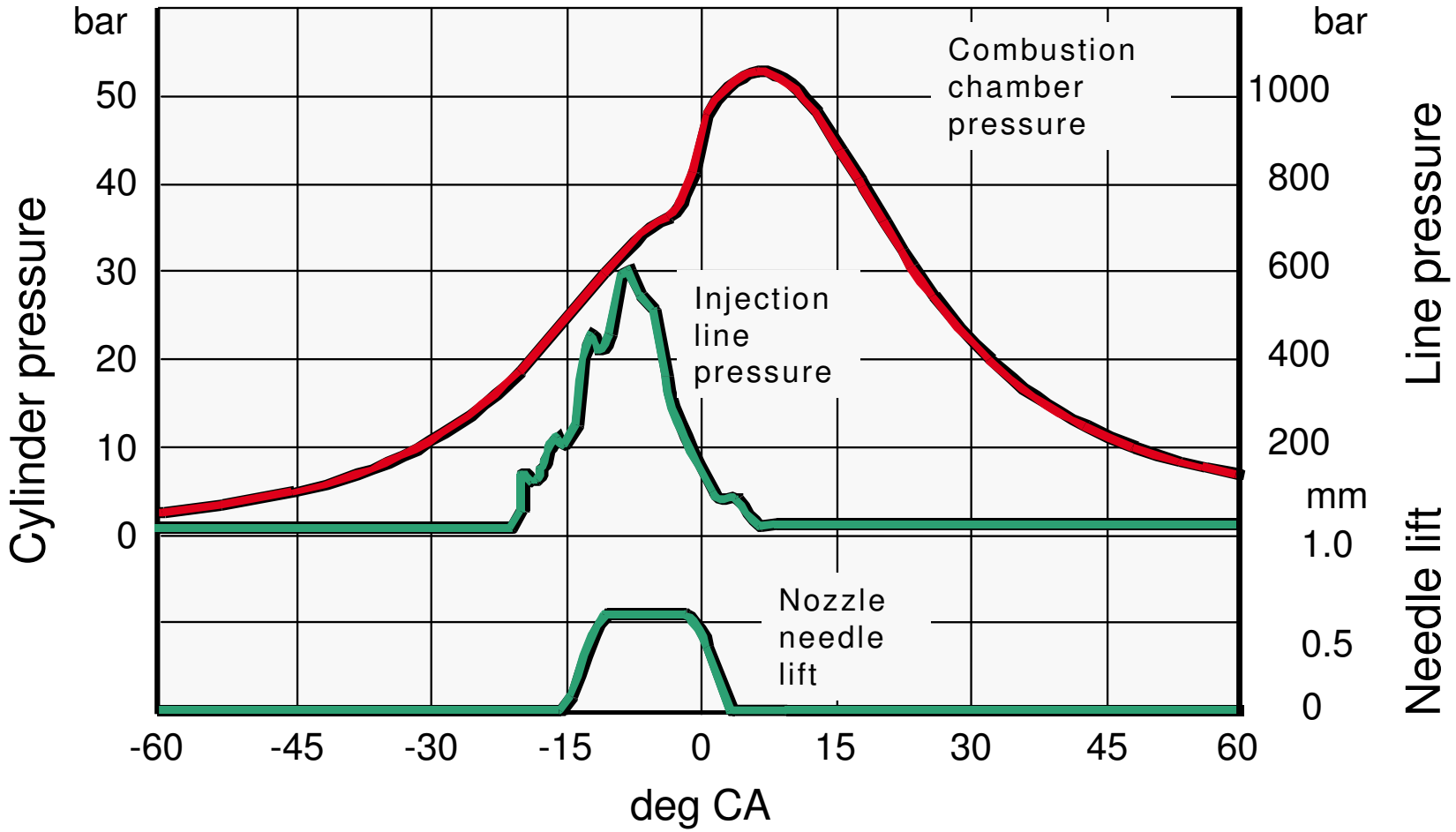


Indicating parameters

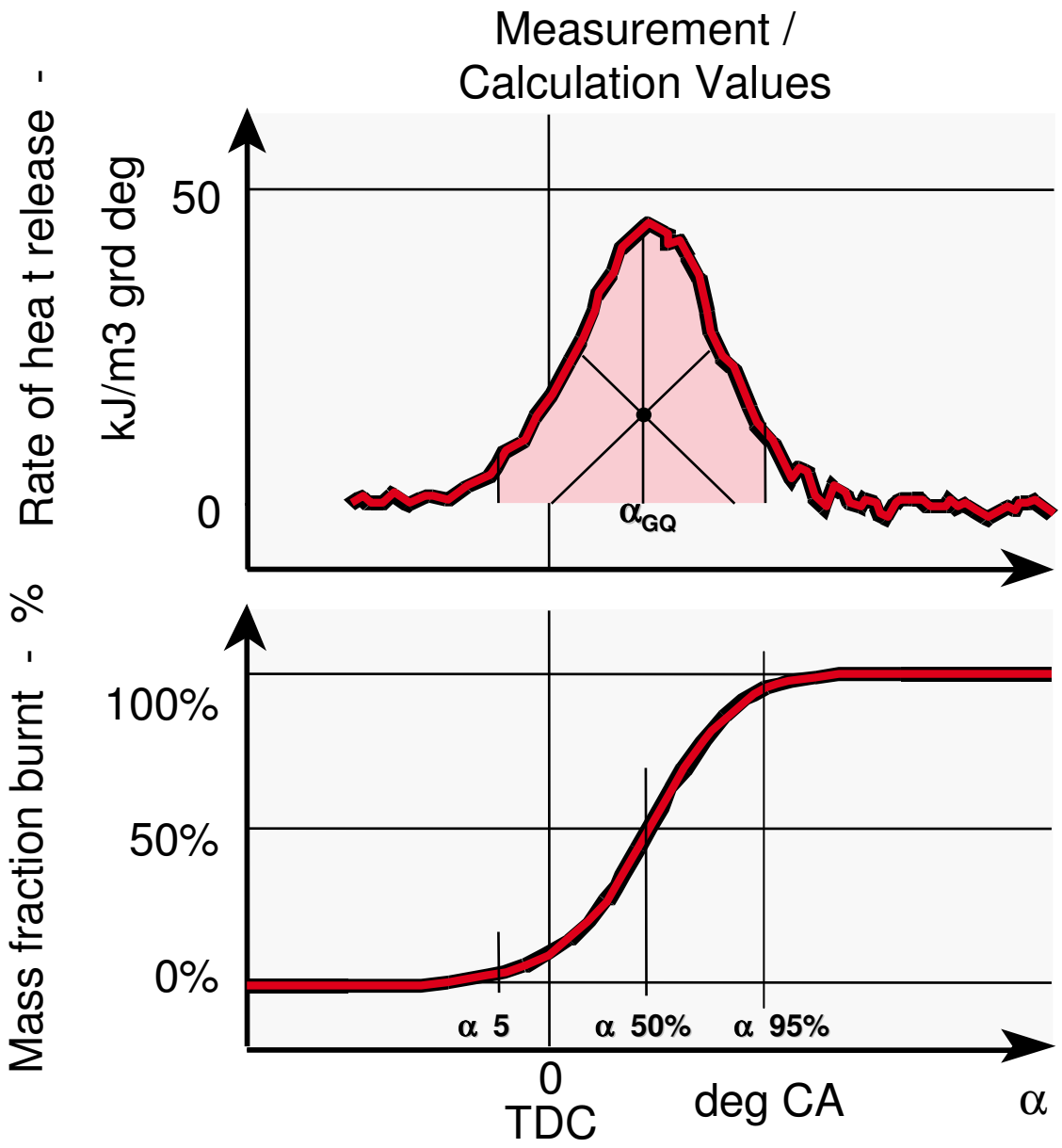
- IMEP – Indicated Mean Effective Pressure
- Maximum Pressure; pmax
- Angle of Maximum Pressure
- Maximum Pressure Rise
- 50% Heat Release Angle
- Start and End of Combustion
- Cyclic Variation of Above Values (statistics)
- Cylinder Distribution of Above Values (statistics)

Pressure measurement for thermodynamic analysis: power, heat, energy balance

STANDARD EVALUATION OF THE CYLINDER PRESSURE



THERMODYNAMIC RESULT VALUES



Result Values

Center of gravity of combustion α_{GQ}

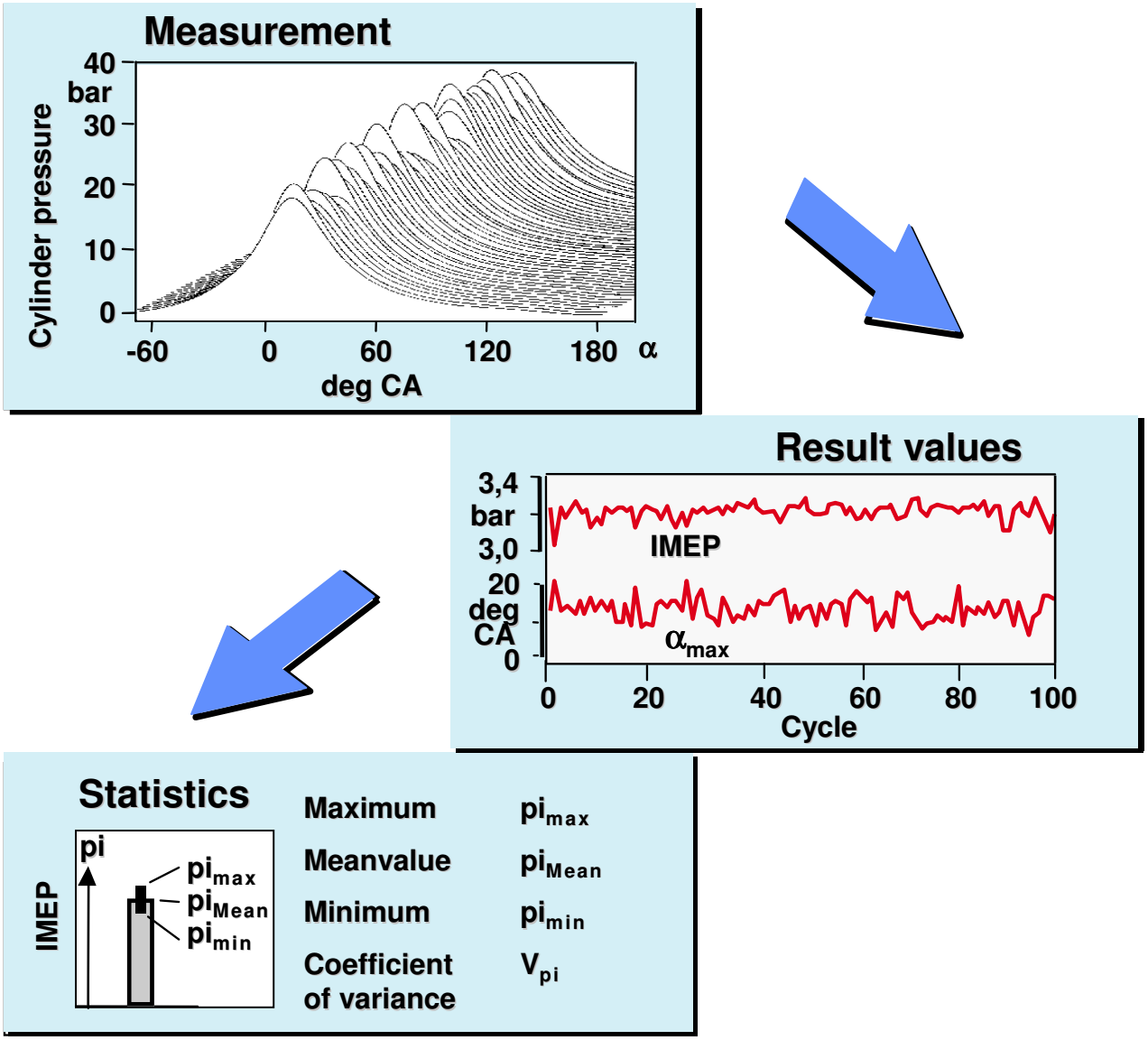
Angle of Integral Heat

α 5% StStart of combustion

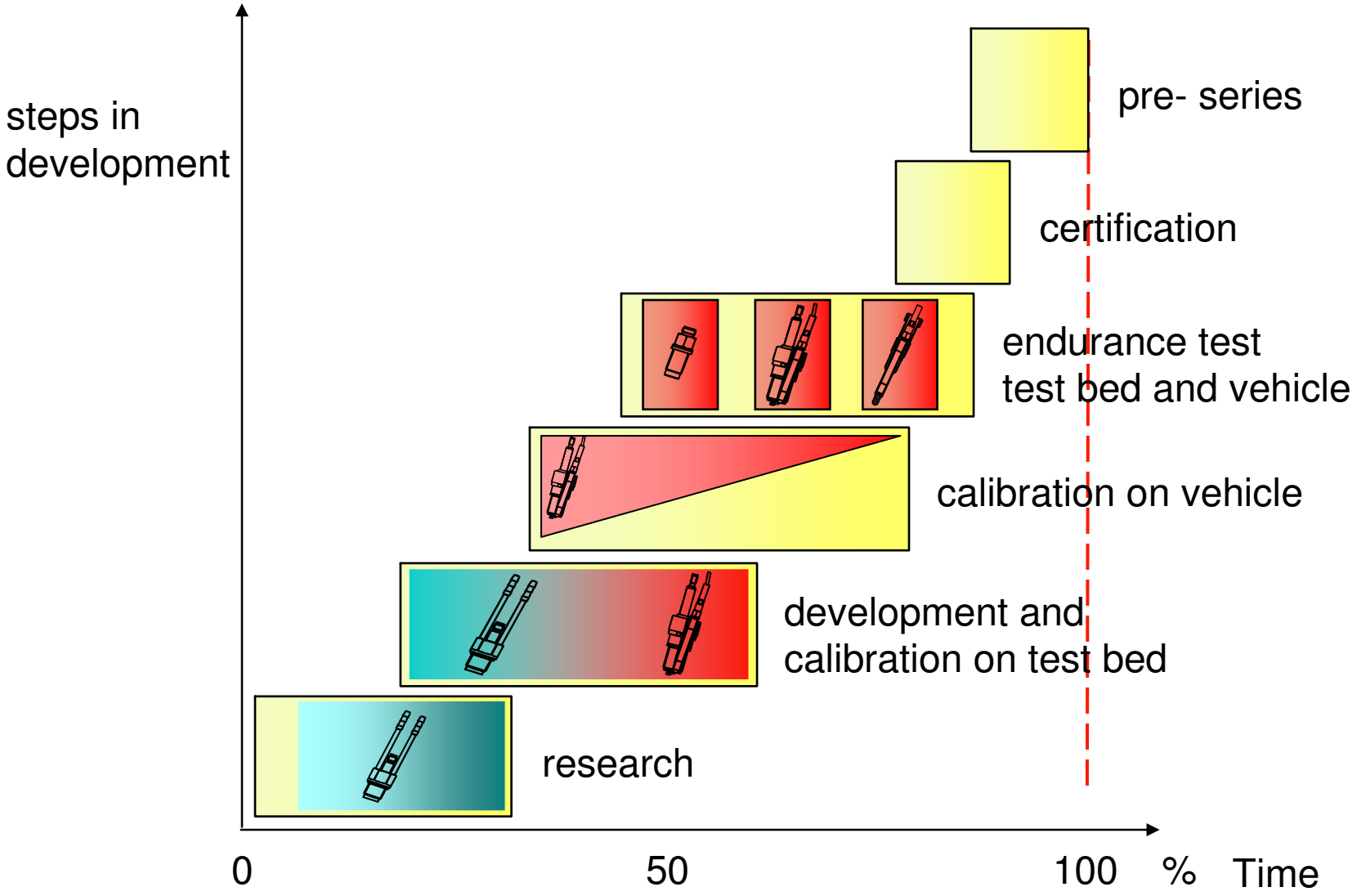
α 50% Main burning activity

α 95% End of combustion

STATISTICAL EVALUATION OF CYLINDER PRESSURE SIGNALS



ENGINE DEVELOPMENT CYCLE

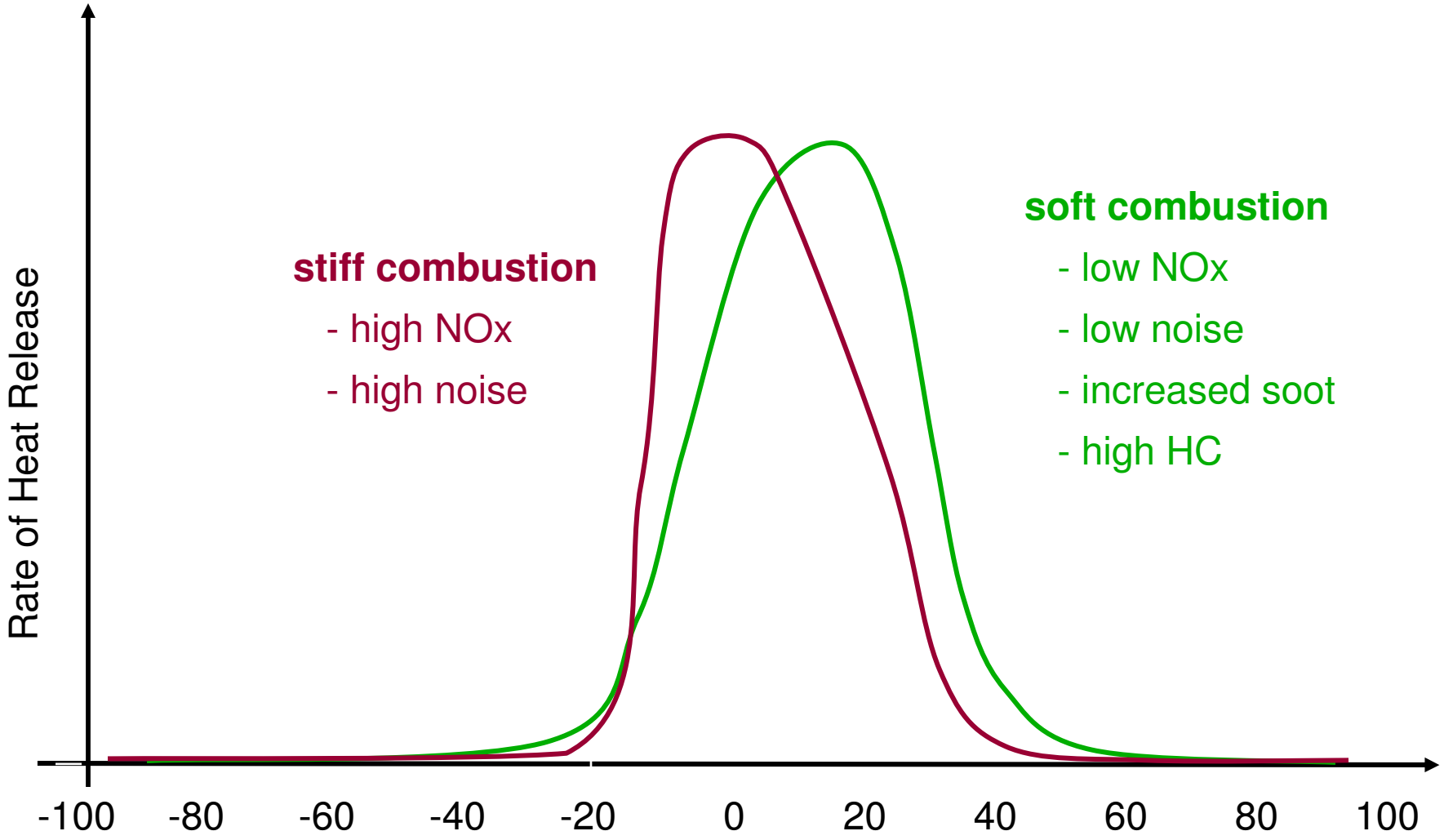


LINK BETWEEN COMBUSTION AND EMISSION

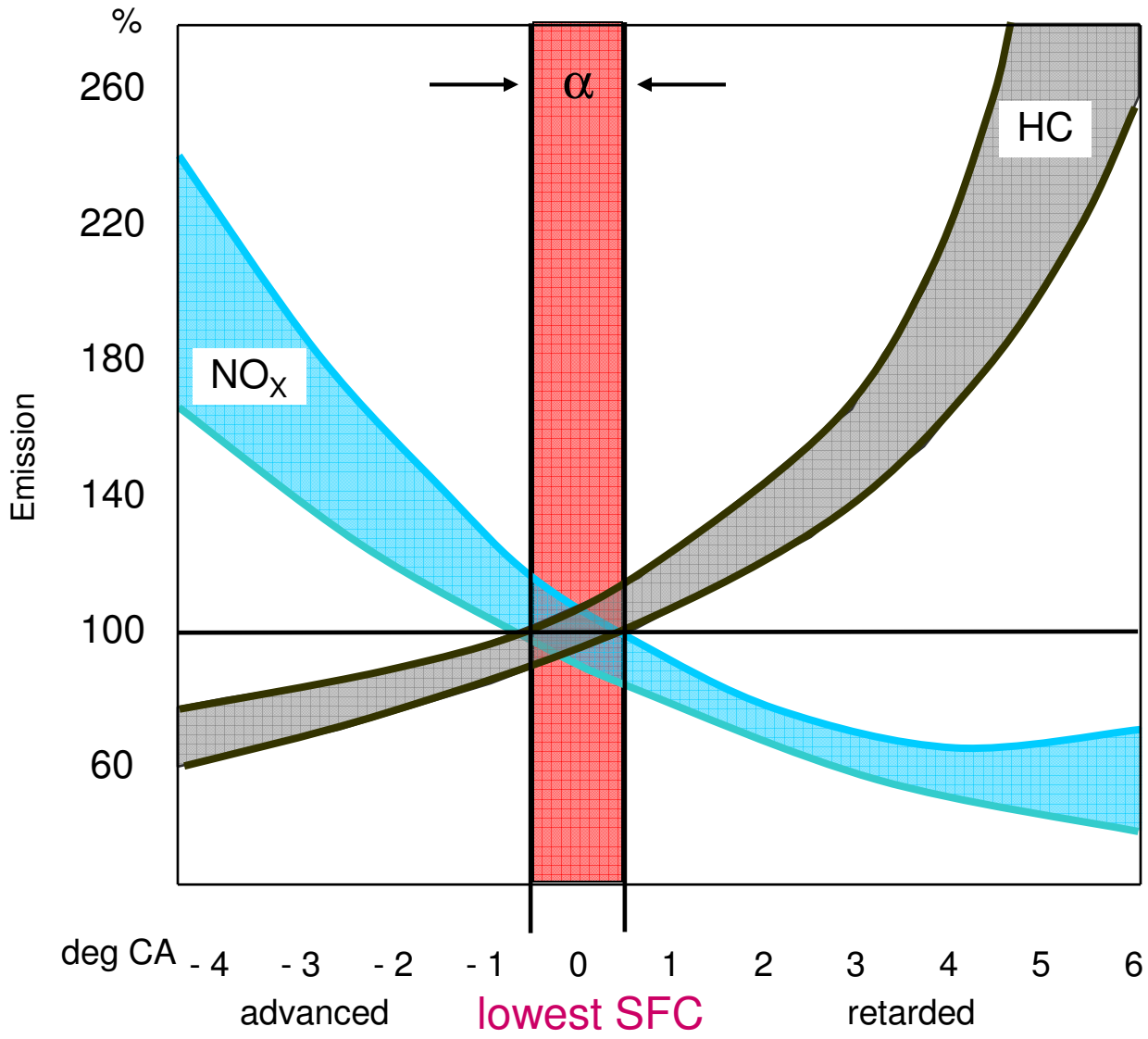
• misfiring	➢	HC
• knock	➢	NOx
• steep temp / pressure rise	➢	NOx
• too early combustion	➢	NOx
• too late combustion	➢	HC, PM, soot
• partial combustion (wall film, condensation/cold components, over fueling, fat mixture, improper spray / geometry, …)	➢	HC, PM, soot

NOx	➢	temp reduction - EGR
PM, soot	➢	premixed flame
HC	➢	no unburnt fuel, stable combustion

INFLUENCE OF COMBUSTION ON EMISSIONS



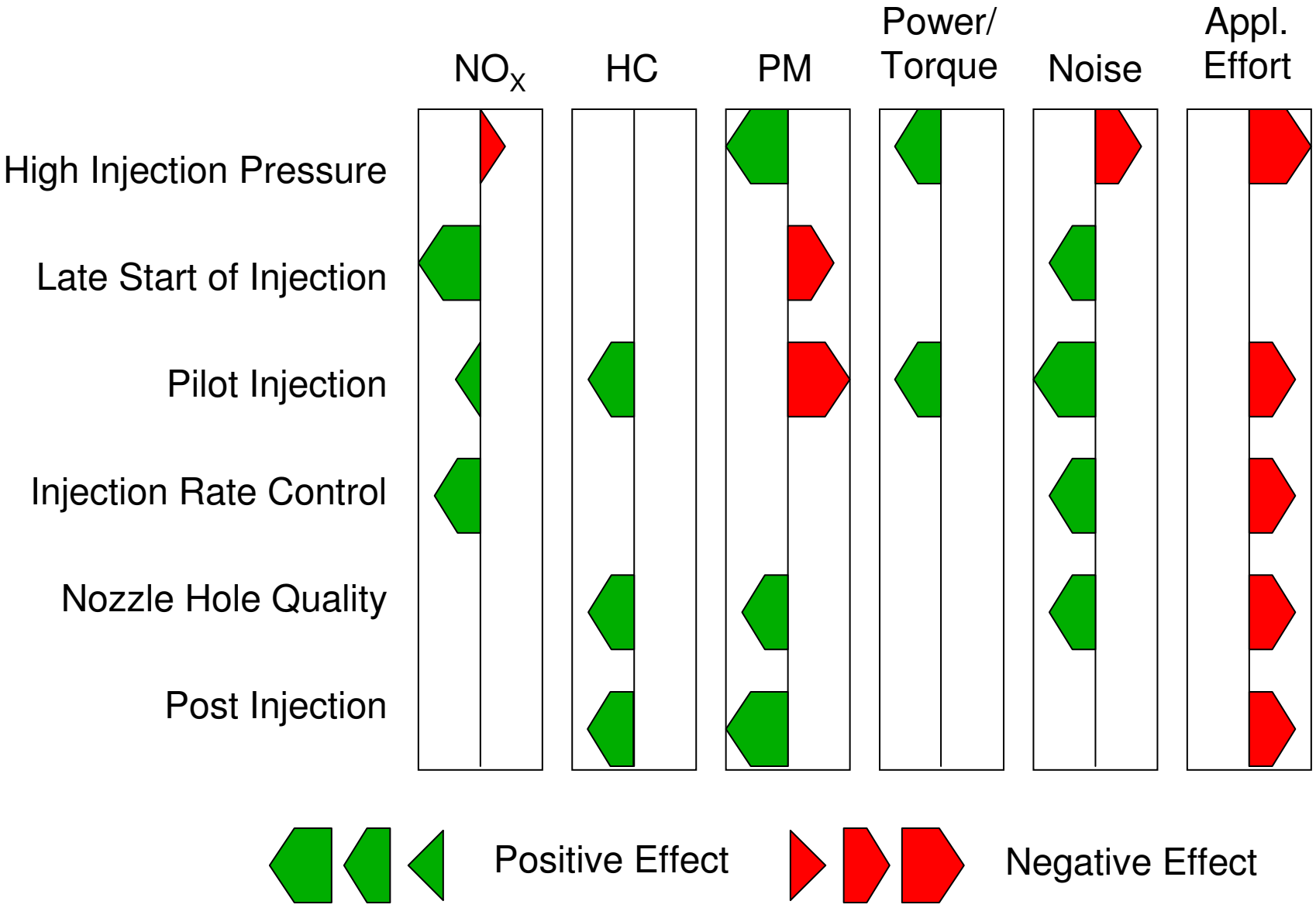
COMBUSTION TIMING AND EMISSIONS



SOI =

start of injection

INFLUENCE OF INJECTION PARAMETERS



INDICATING AND COMBUSTION ANALYSIS
How we notice combustion ?

Limitation of Information derived from Combustion Pressure

- Flame quality – can not be evaluated
- emissions are directly linked to flame quality

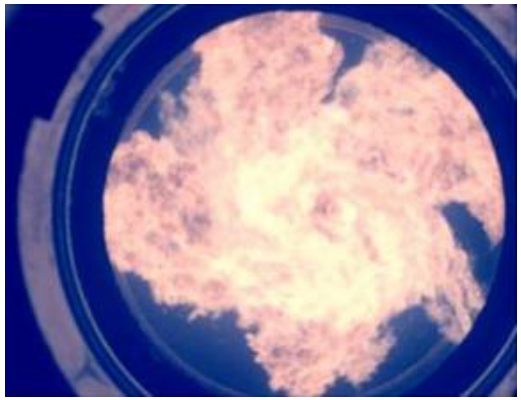
Flame quality can be studied in detail with optical methods giving a deeper understanding of the actual combustion

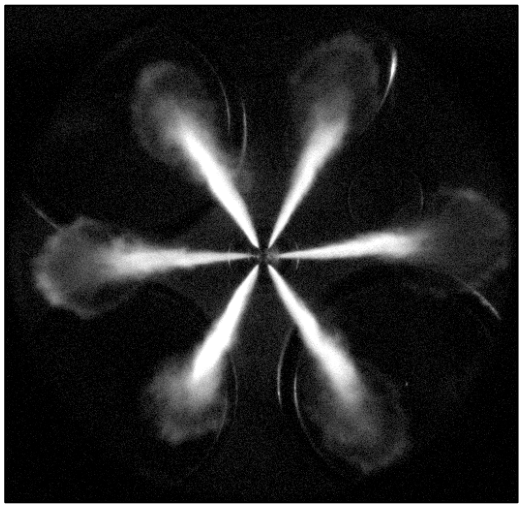
Optical methods are grown up – they are no longer a scientific tool for R&D only

- tailored test bed solutions for typical problems are available

INDICATING AND COMBUSTION DEVELOPMENT TOOLS - VISIOSCOPE

VISIOSCOPE

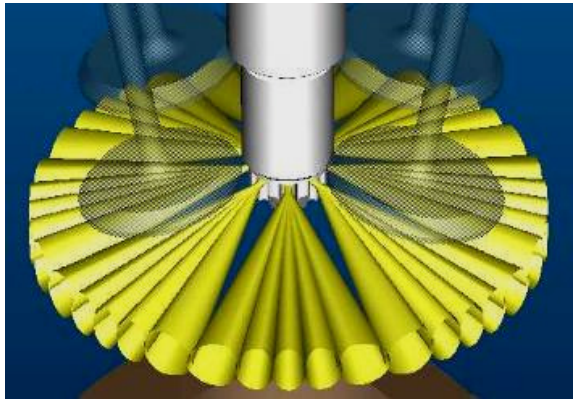


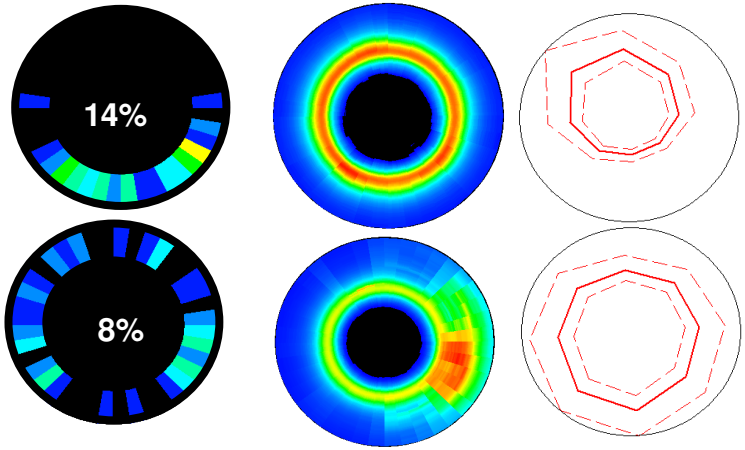


- live pictures with full geometry information or temperature information
- only one picture per cycle

INDICATING AND COMBUSTION DEVELOPMENT TOOLS - VISIOLUTION

VISIOLUTION





advantage:

- good information over entire cylinder cross section with highest CA resolution

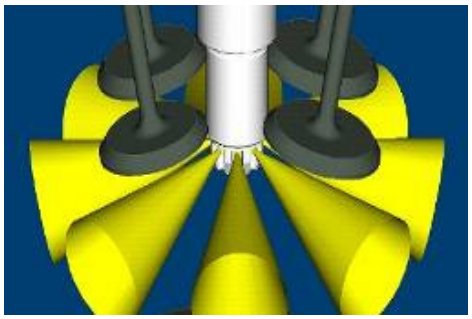
disadvantage:

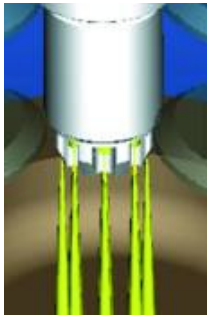
- lower spatial resolution

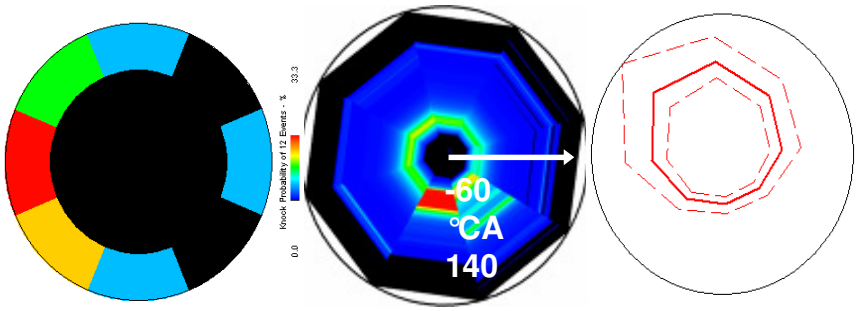
➢ up to 40 channels

INDICATING AND COMBUSTION DEVELOPMENT TOOLS - VISIOSET

VISIOSET







advantage:

- rough information over entire cylinder cross section and good information on flame around spark plug with highest CA resolution

disadvantage:

- lowest spatial resolution

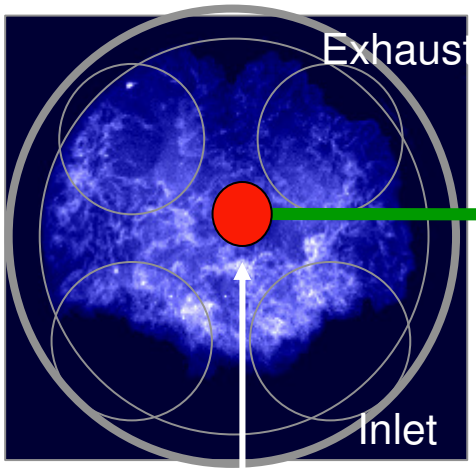
➢ up to 8 channels

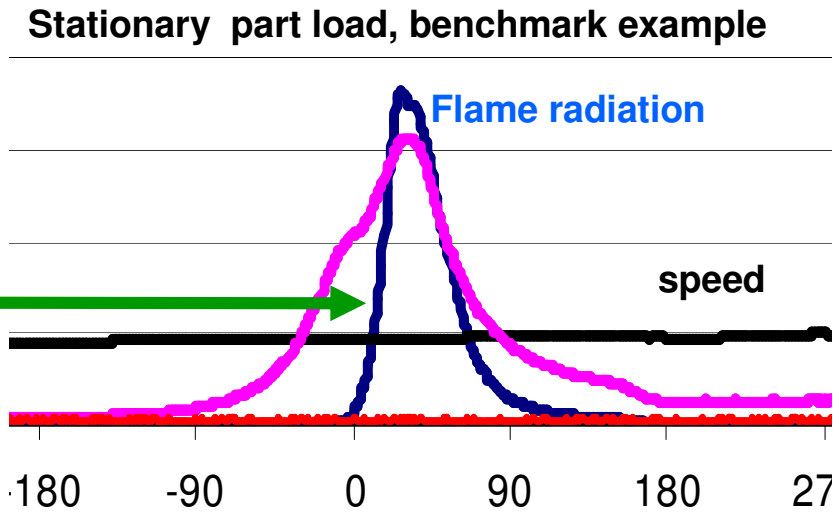
OPTICAL MEASUREMENTS – FLAME OKAY

Stoichiometric, premixed flame in warm engine:

all fuel evaporated and mixed with air

Flame radiation is synchronous with combustion pressure



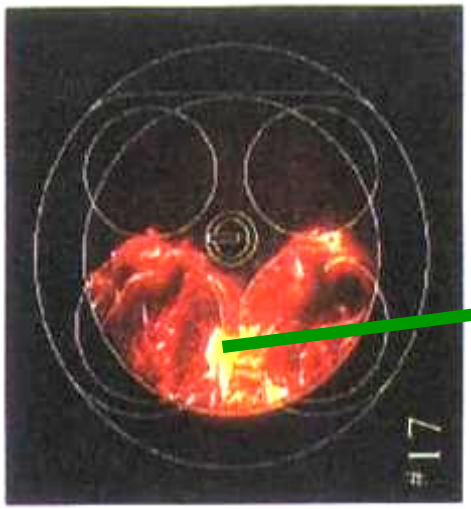


VisoFlame

Spark Plug Probe

OPTICAL MEASUREMENTS – SOOTING FLAME

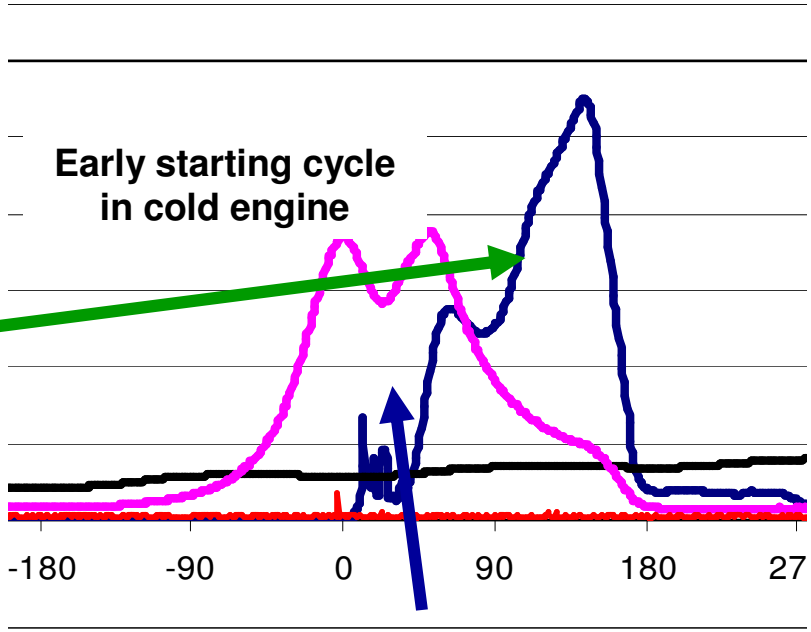
Premixed flame starts at spark plug and ignites wet surfaces fuel



Premixed flame not seen in photograph because of low intensity flame radiation. Very bright diffusion flame

Photograph by Witze, Green,Sandia

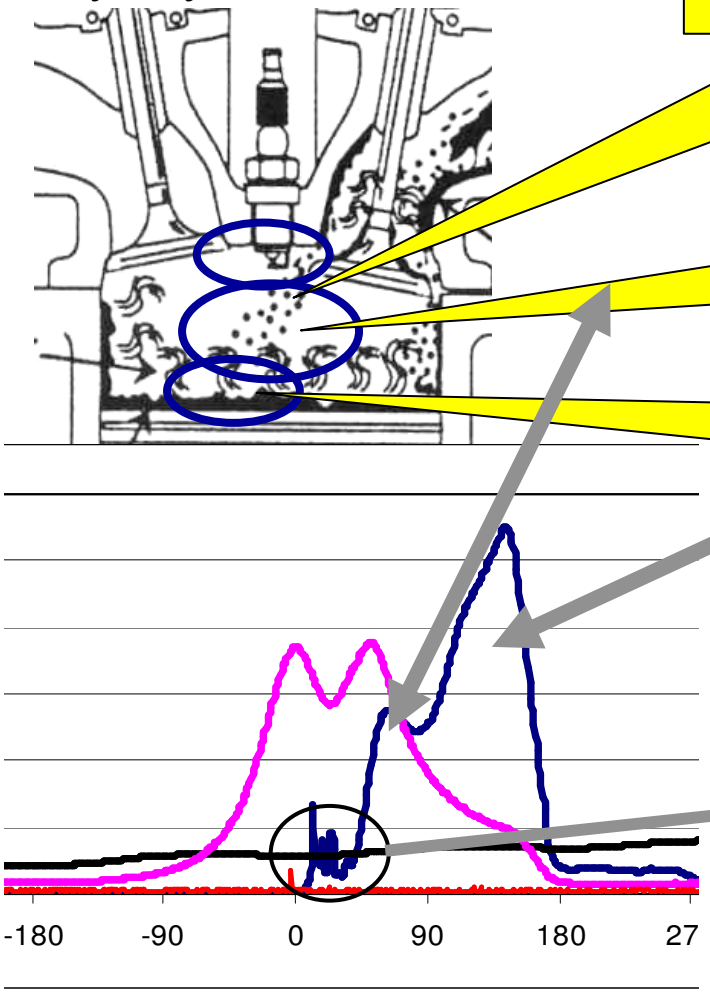
Premixed flame radiation, then ongoing surface diffusion flame radiation



Premixed flame burning volume charge yields combustion pressure

INDICATING AND COMBUSTION DEVELOPMENT TOOL - COLDSTART

Mixture conditions at cold start.
Schematic by Toyota, SAE 950074



Ignition: little fuel vapor near spark plug causes small flame

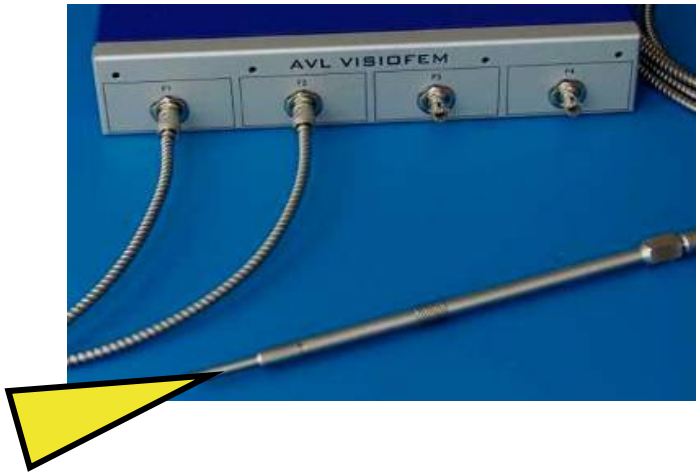
Premixed combustion: pressure rise as volume charge burns

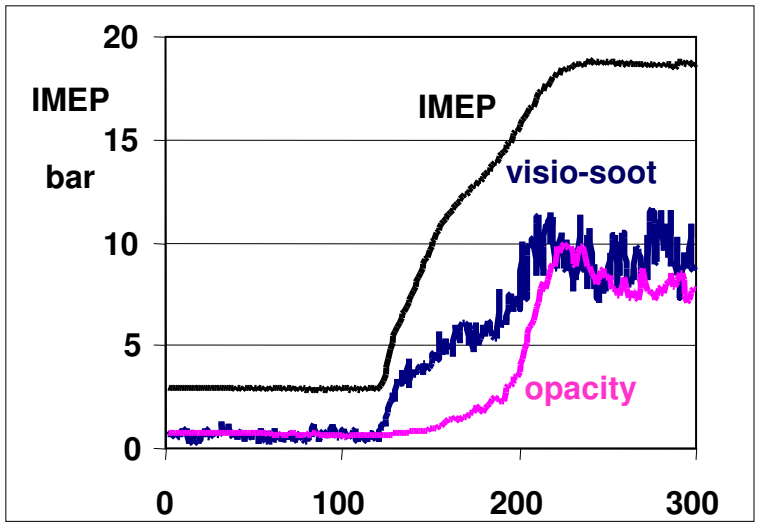
Liquid film combustion: very bright flame, but low rate of heat release

Ignition phase disturbed by overfuelliing, fuel droplets hitting the flame kernel

INDICATING AND COMBUSTION DEVELOPMENT TOOLS - VISIOFEM

VISIOFEM





advantage:

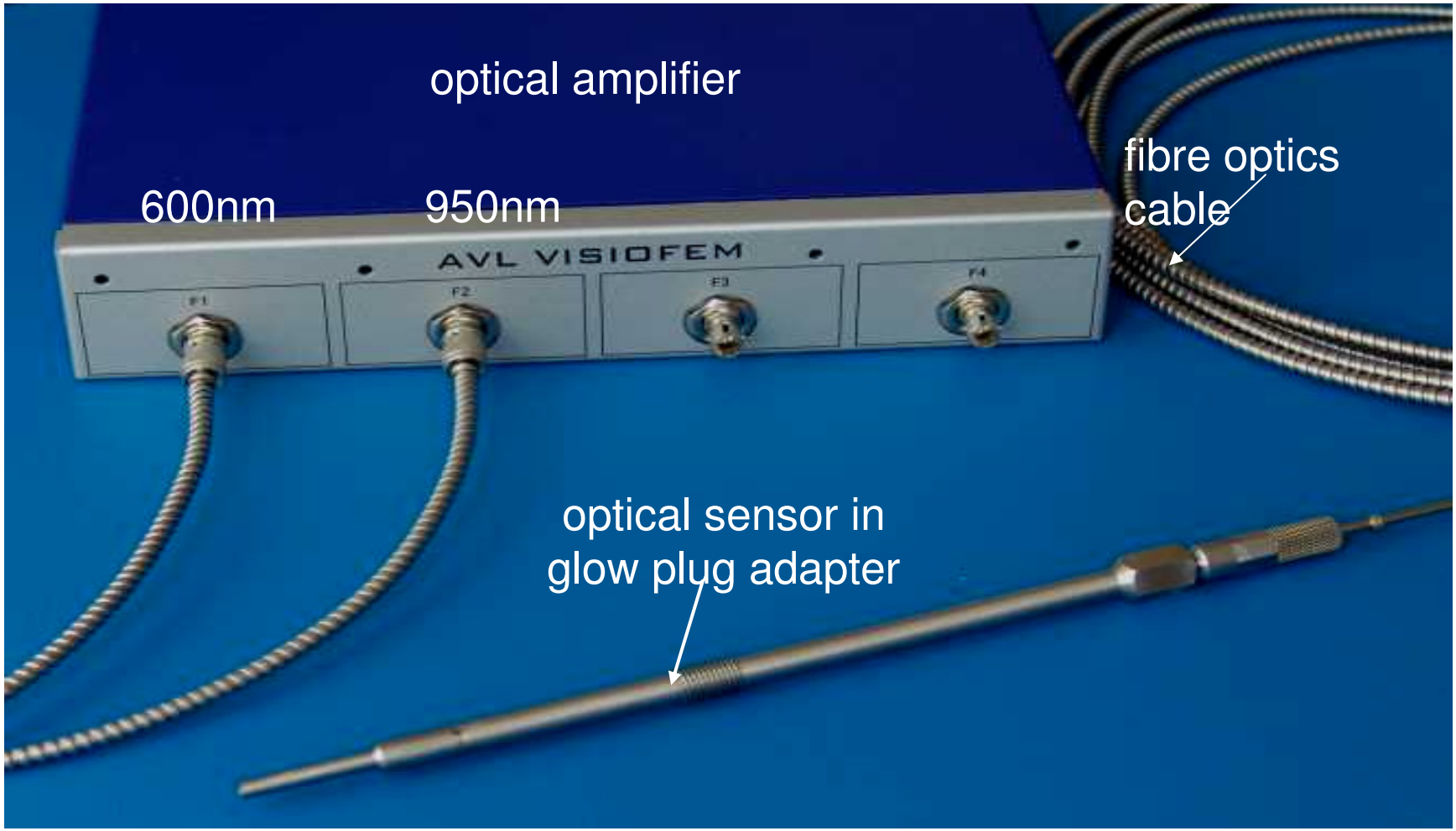
- cheapest optical system
- excellent for transient soot measurements

disadvantage:

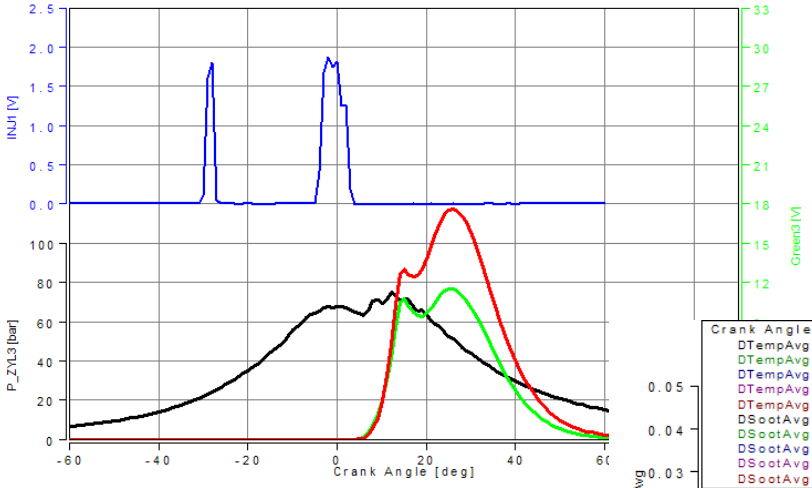
- only one conical segment can be viewed

➢ 2 channels

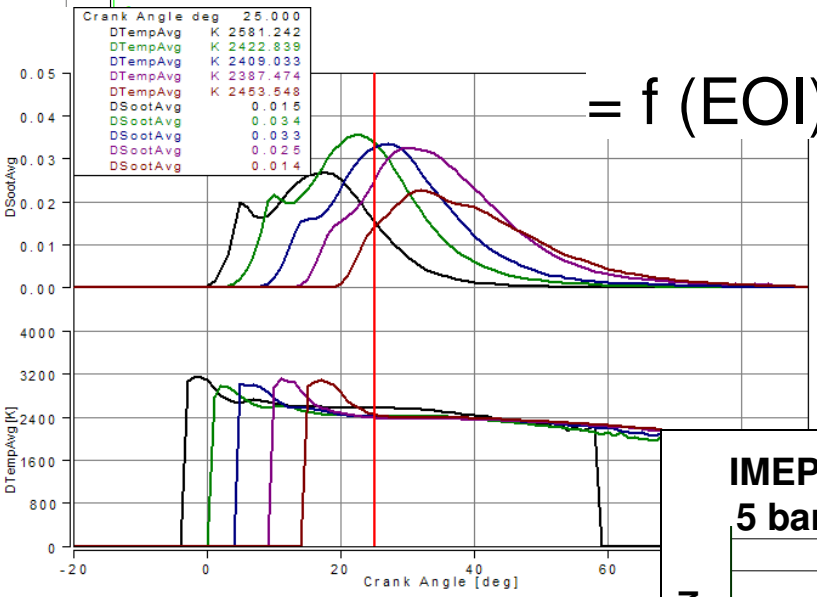
VISIOFEM


optical amplifier
600nm
950nm
AVL VISIOFEM
fibre optics
cable
optical sensor in
glow plug adapter

HOW TO READ THE DATA?



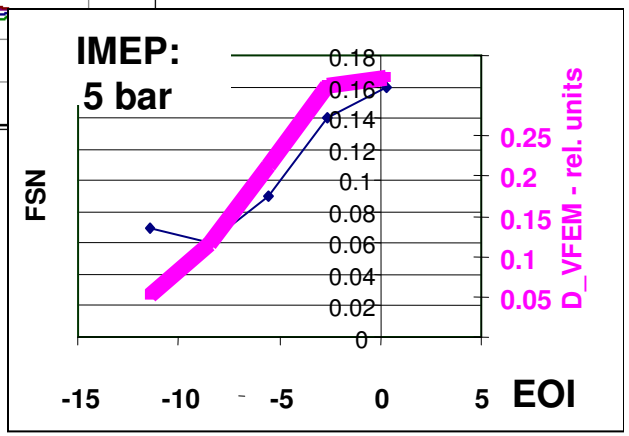
... we get traces of
- injection
- cylinder pressure
- flame intensity



= f (EOI)

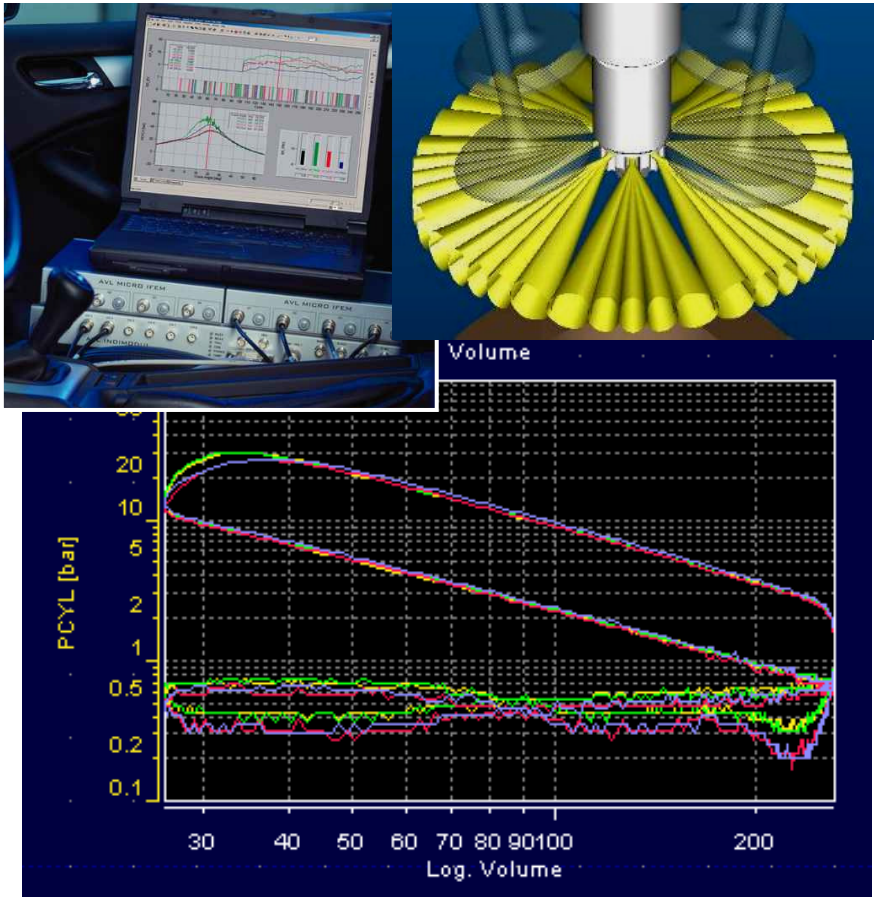
flame intensity
➥ amount of soot
two-colour flame evaluation
➥ temperature / NOx

figure of merit



trend verification with
Filter Smoke Number (FSN)

CONCLUSION – COMBUSTION MEASUREMENT



combustion analysis with pressure transducers is a very powerful tool for engine improvement

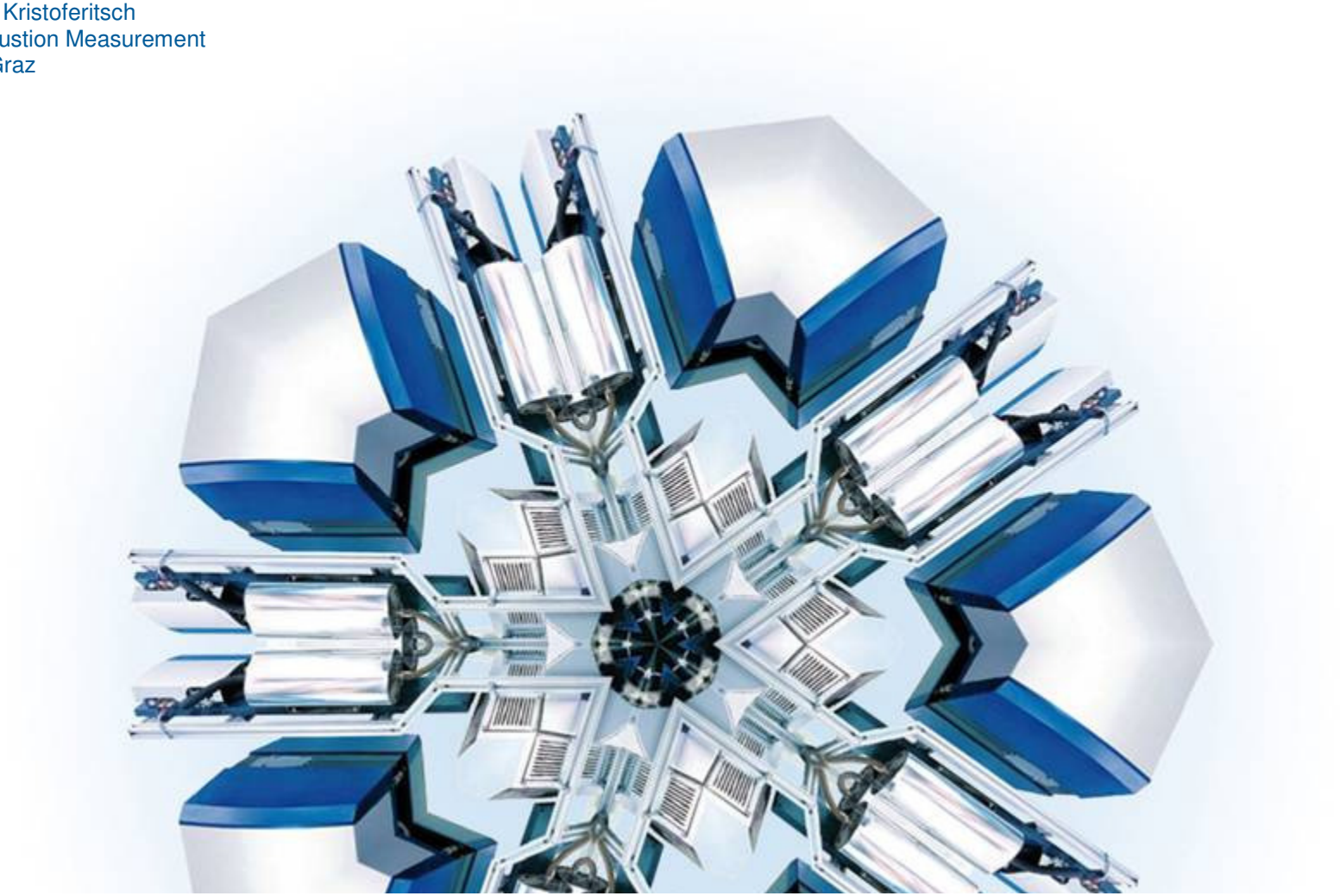
with some simple algorithm the trend in emissions, noise or fuel consumption can be easily assessed

before going to detailed emission analysis the extend of improvement can be already assessed
also by means of optical measurement tools

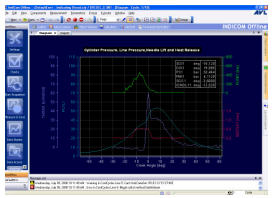
AVL COMBUSTION MEASUREMENT

Product Overview

Alfred Kristoferitsch
Combustion Measurement
AVL Graz

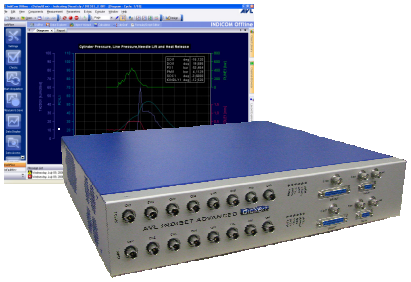


Product Overview



Post Data Processing

- AVL CONCERTO



Indicating Systems

- System Overview
- IndiCom

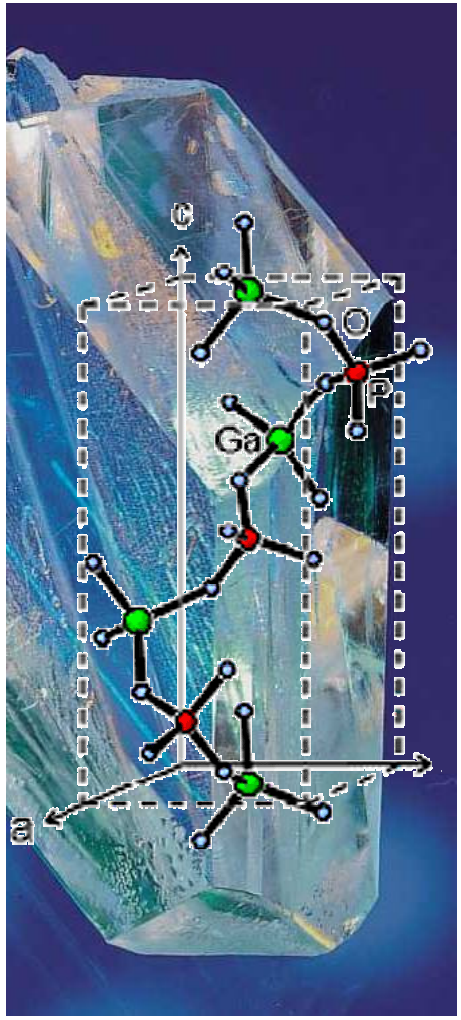
Amplifier

- Charge Amplifier
- Amplifier with more functions

Sensors

- Pressure Sensors
- Crank Angle Encoder

SENSORS
Combustion Pressure – **AVL $GaPO_4$**

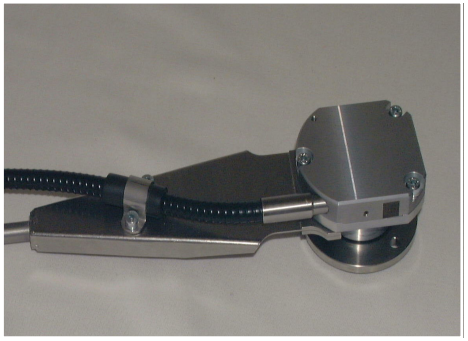


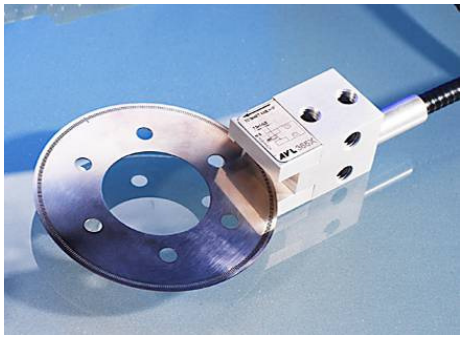
- **High thermal stability:**
  - temperature consistent up to 970°C
  - no twin growth (compared to quartz)
- **High piezoelectric sensitivity:**
  - high sensitivity in small sensors as well (GU21C 35pC/bar)
  - excellent distance between signal and noise
- **No thermal sensitivity change**
  - assumption for correct measuring results under all load point (typical sensitivity change for AVL GU12P between 20°C - 400°C : +0,5% / -0,2%)

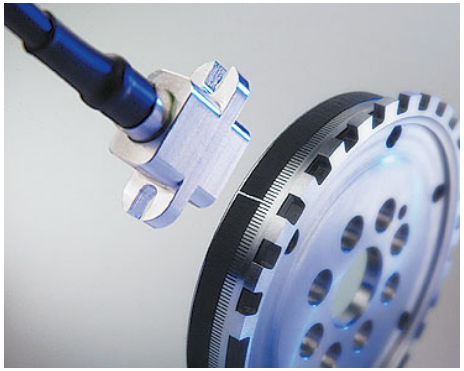
SENSORS
Combustion Pressure AVL - $GaPO_4$

- Direct mounted
  - preferred solution for highest accuracy
  - ideal mounting position possible
- Spark Plug
  - no additional bore in cylinder head required
  - wide range customer spark plugs available
  - sensor is as close as possible to the combustion chamber – high accuracy / no pipe oscillation
- Glow plug
  - no additional bore in cylinder head required
  - sensor is as close as possible to the combustion chamber – high accuracy / no pipe oscillation

SENSORS
Crank angle based measurement – optical sensor







- **AVL Chrank Angle Encoder 365C**
  - standard combustion engines
  - optical measurement principle
  - for mounting a free shaft end or belt pulley is required
- **AVL Chrank Angle Encoder 365X**
  - open disc
  - used for mounting situations without free shaft end, e.g. on drive side
- **AVL Chrank Angle Encoder 365R**
  - designed for racing application

SENSORS
Further sensors available:

- Low Pressure Sensor
  - Pressure measurement in Intake and exhaust manifold
- Line Pressure Sensors
  - up to 3000 bar line pressure
- TDC Sensor
  - Top dead center sensor
- Turbo Speed Sensor
  - Laser sensor
- Needle Lift Sensor
- Valve Lift Sensor

AVL Amplifier Product Portfolio

MicroIFEM

MicroIFEM - 4 Channel amplifier

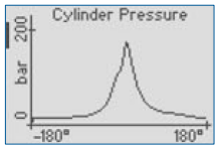
- ⇨ 4 Ch. Piezo
- ⇨ 4 Ch. Multi Purpose (MP)
- ⇨ 2 Ch. Piezo / 2 Ch. MP

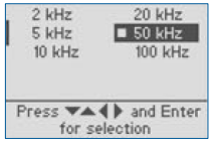
FlexIFEM

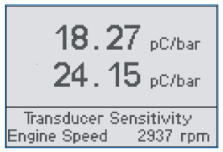
FlexIFEM – 1/2 Channel amplifier

- ⇨ 1/2 Ch. Piezo
- ⇨ *MP available 2010*

FLEXIFEM – MORE VALUE







LCD Display

- Visualizes operation menu
- User-friendly setting of parameters
- Displays results or pressure curve

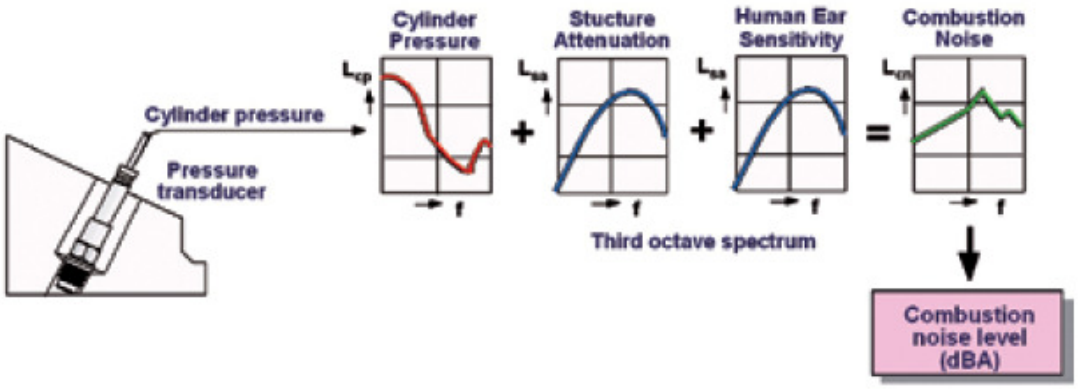
Calculation

- Provides cycle by cycle calculations
- Peak cylinder pressure p_{max}
- Engine speed
- Output of warning and alarm levels

FlexIFEM Advanced

- Combustion Noise function
- Knocking (not yet available)

FLEXIFEM Advanced – Combustion Noise Meter



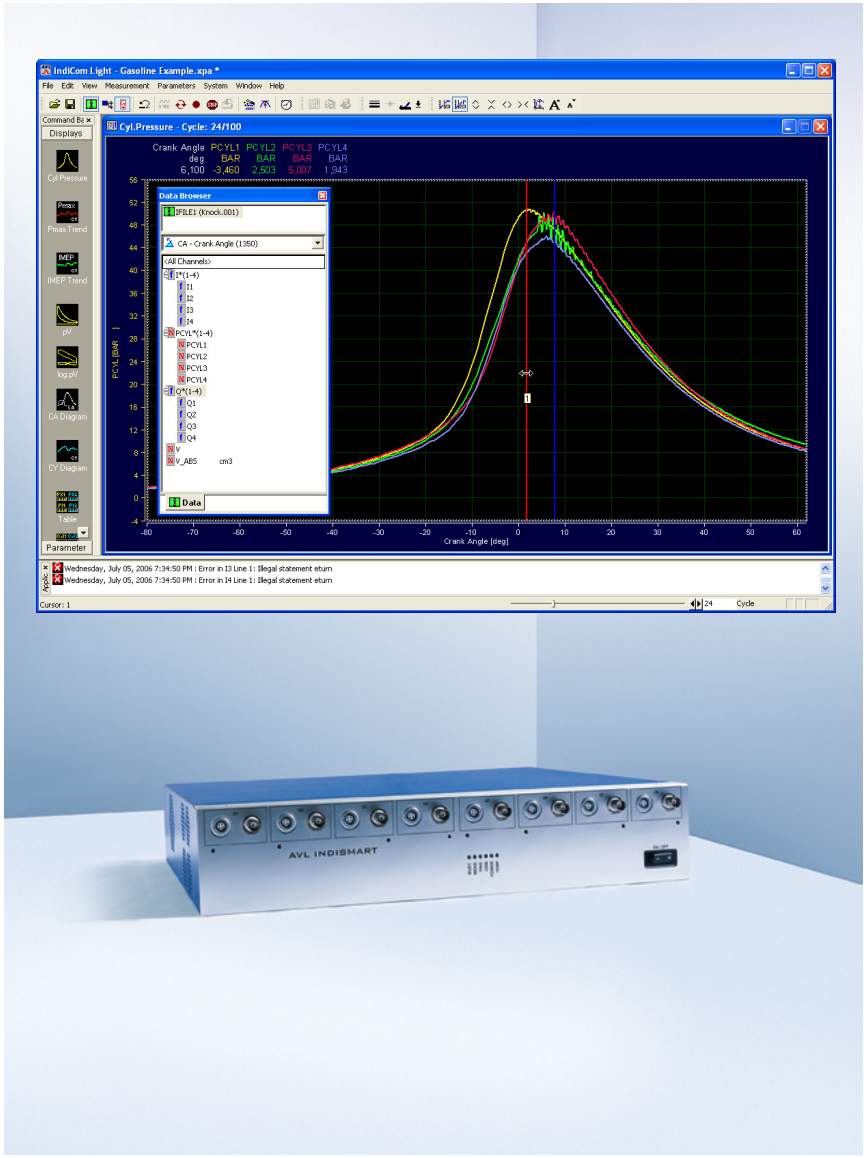
- Stand alone charge amplifier with integrated combustion noise function
- Comparability to
  - Analog AVL 4050 Combustion noise meter
  - AVL combustion noise function in IndiCom
- Download your own transfer (MFFR) curve
- Updates via software
- Further algorithms planned : e.g. AVL CKI

AVL INDICATING SYSTEMS
LIGHT LINE

NEW

- Cost-Effective Solution for Standard Indicating applications
- Light System with full upgradeability to Advanced Indicating System
- Ideal for combustion investigation on 4-6 cylinder engines
- Easy-to-use IndiCom Light Interface
- 0.1 deg. CA measurement resolution up to 11000 rpm with max. 1530 measuring points per cycle
- IEEE1394 Firewire interface

INDICOM LIGHT SOFTWARE



Graphical User Interface:

- very easy to use
- workflow oriented architecture
- built-in plausibility control
- fast and seamless PUMA integration
- wide range of standard calculations
- extension packages for Diesel and Gasoline engines
- AVL Sensor Data Management SDM

LIGHT LINE SPECIALS – UNIVERSITY PACKAGE

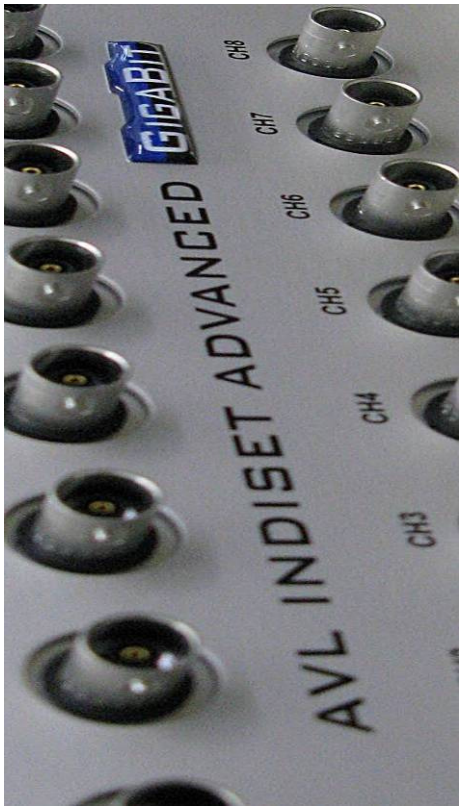
Development package

- IndiModul Start (8 channels)
- IndiCom Advanced
  - Coldstart
  - Knock Analysis
  - Noise Analysis
- 1x Micro IFEM (Piezo or Multipurpose)
- 365C Crank Angle Encoder
- 2x uncooled Piezo-Tansducers with mounting tools
- Concerto with 5 NW licenses
- Care Support (2 years without SW subscription)

AVL INDICATING SYSTEMS
Advanced Line

IndiModul

IndiSet



IndiMaster

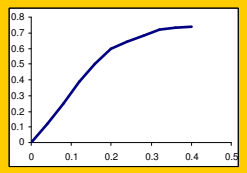
DATA POSTPROCESSING WITH AVL CONCERTO

- Detailed analysis of the indicating data (IFile) in the office
- Investigation of the correlation between combustion values and testbed results
- Sophisticated diagrams and graphical objects for clear result presentation
- Advanced calculation library, easy to use with CalcGraf and Formula Editor
- Automated data processing with scripting

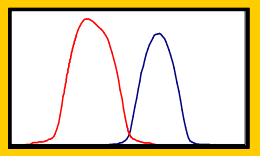
GCA

Geometry of cylinder and ports (customer)

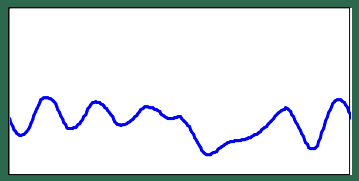
coeffs of discharge (customer)



Valve lift (customer)

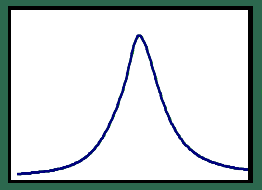


P_{intake}, T_{intake}

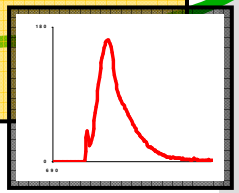


Adjustment using pressure

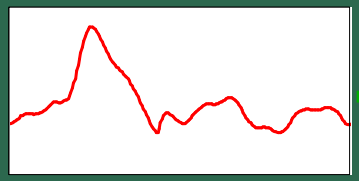
$p_{cylinder}$



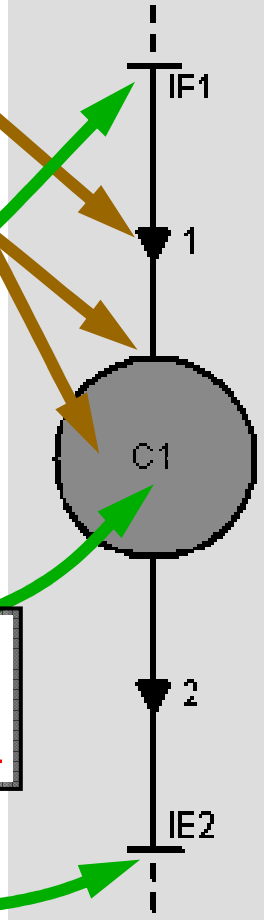
Filter, Adjustment and Combustion Analysis

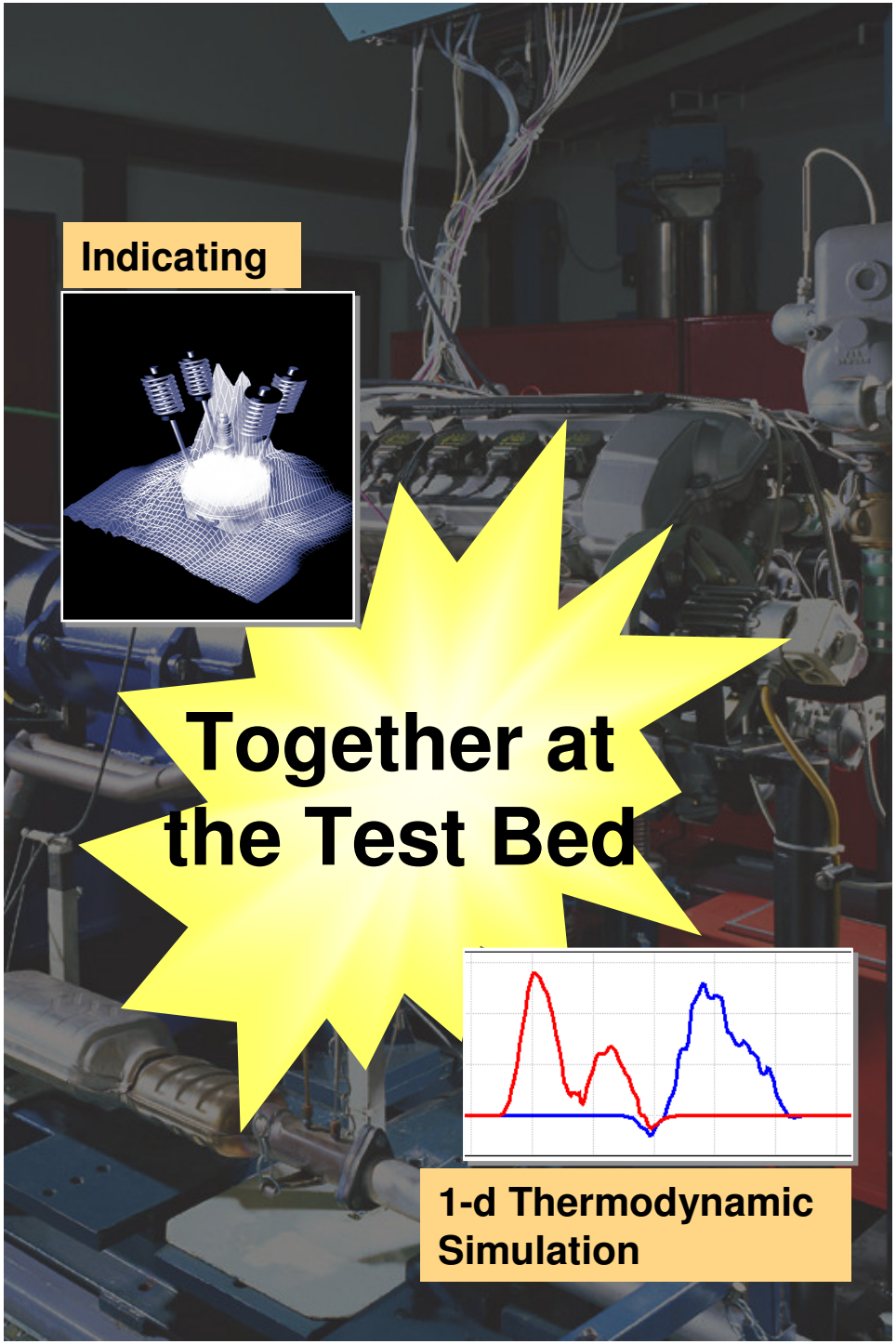


$p_{exhaust}$, $T_{exhaust}$



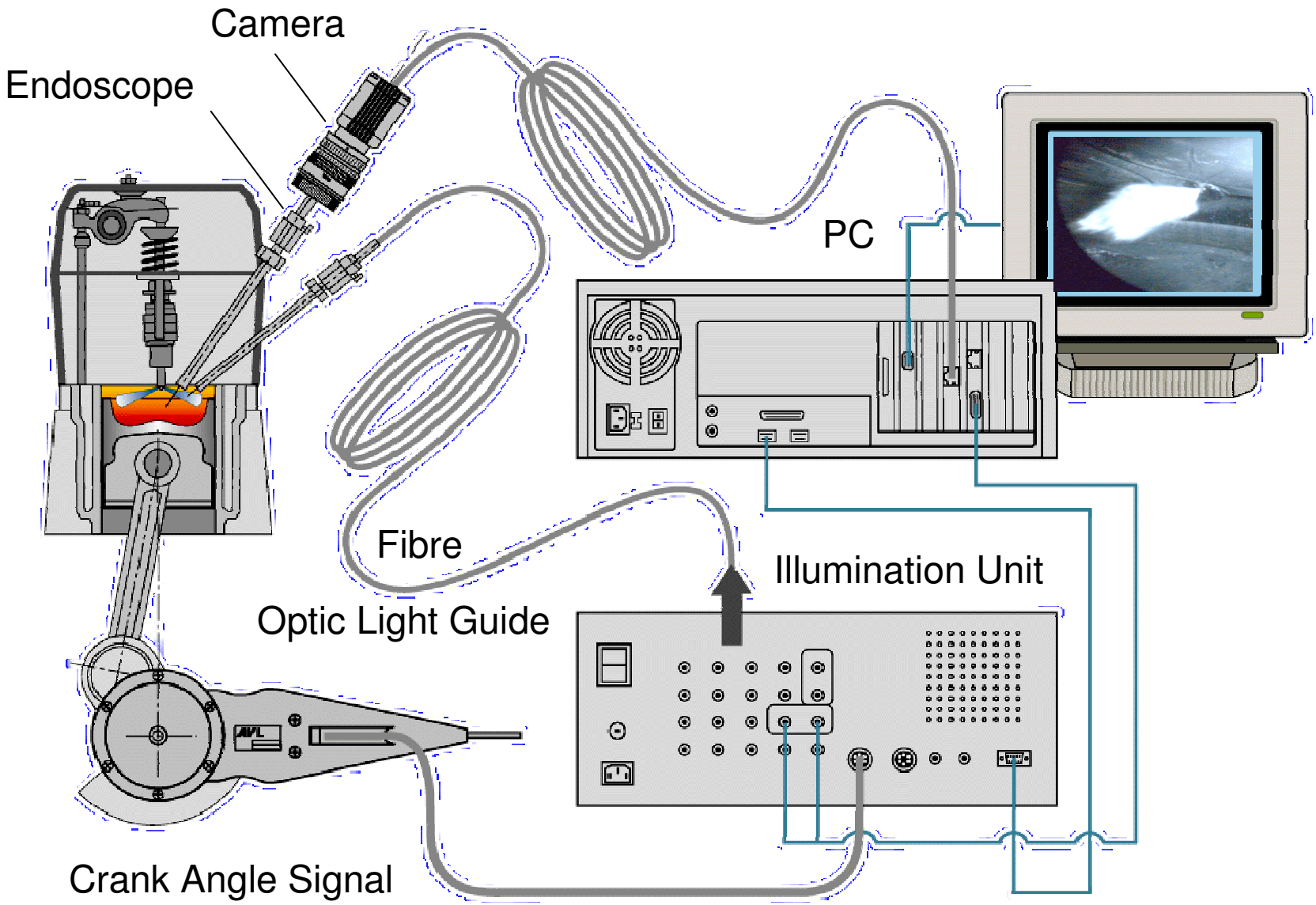
Adjustment using pressure



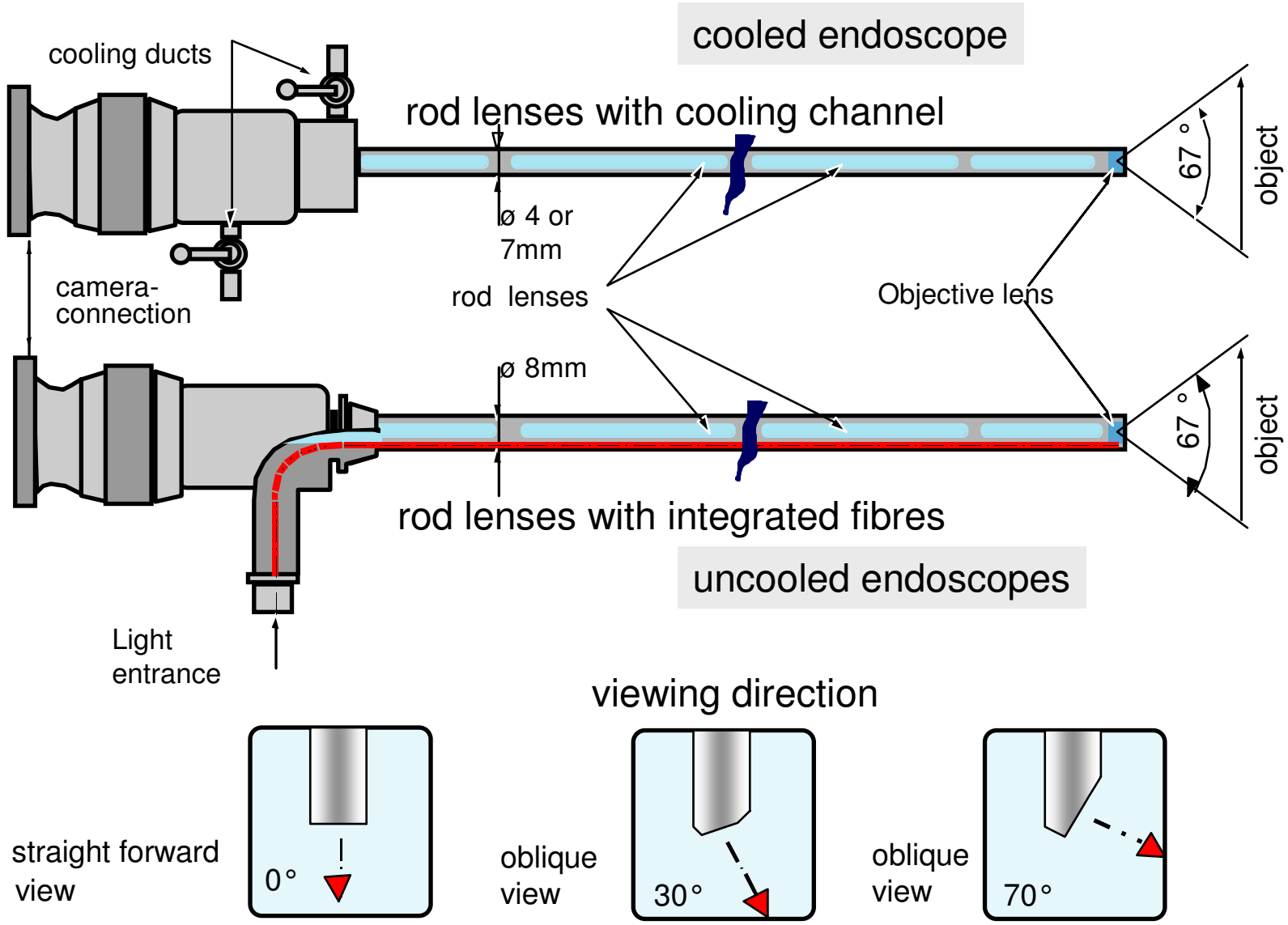


- **short loop between simulation and measurement**
- Application of Simulation Tools at the Test Rig
- Indication and Simulation Together

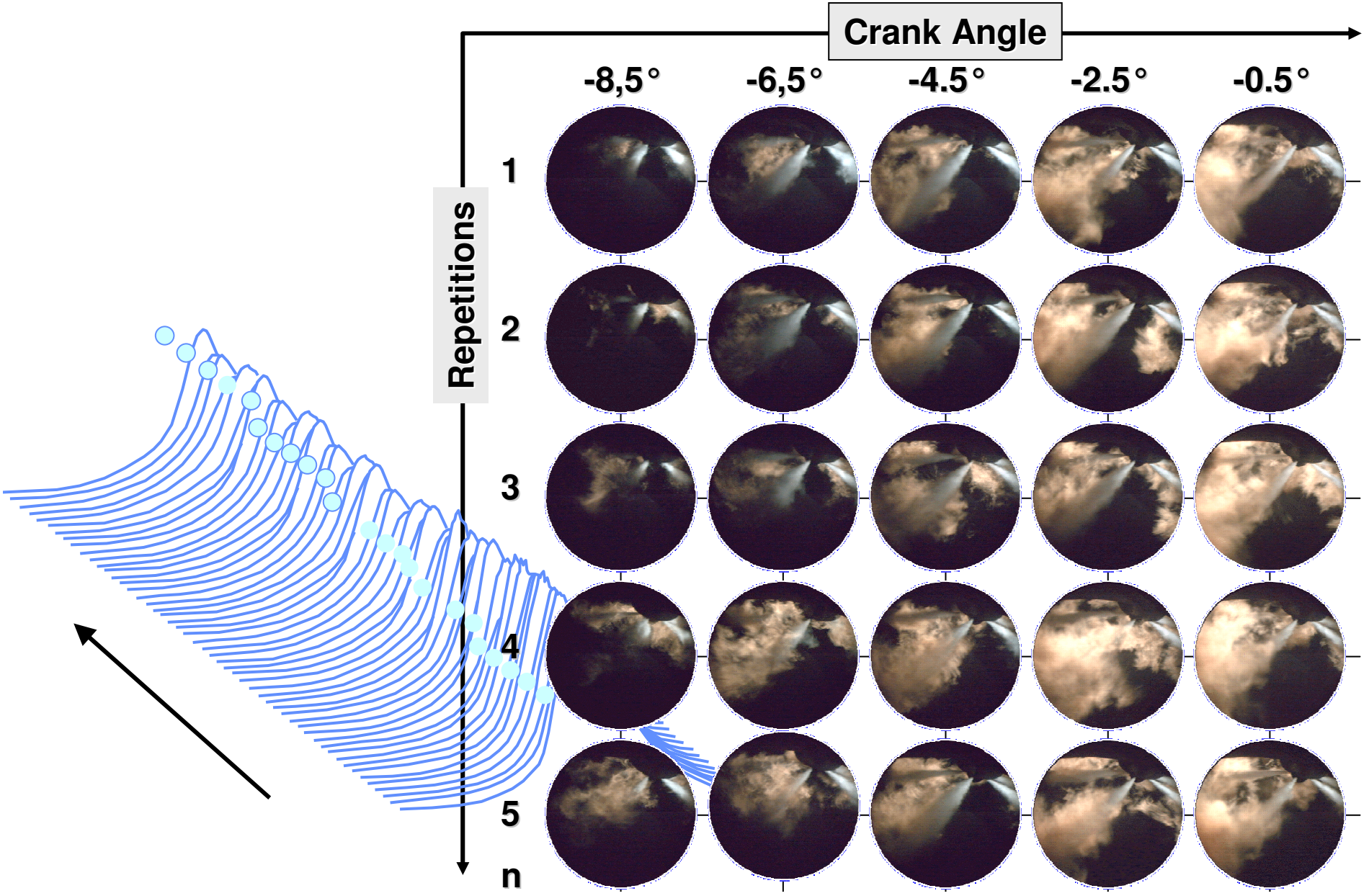
AVL VISIOSCOPE - SYSTEM OVERVIEW



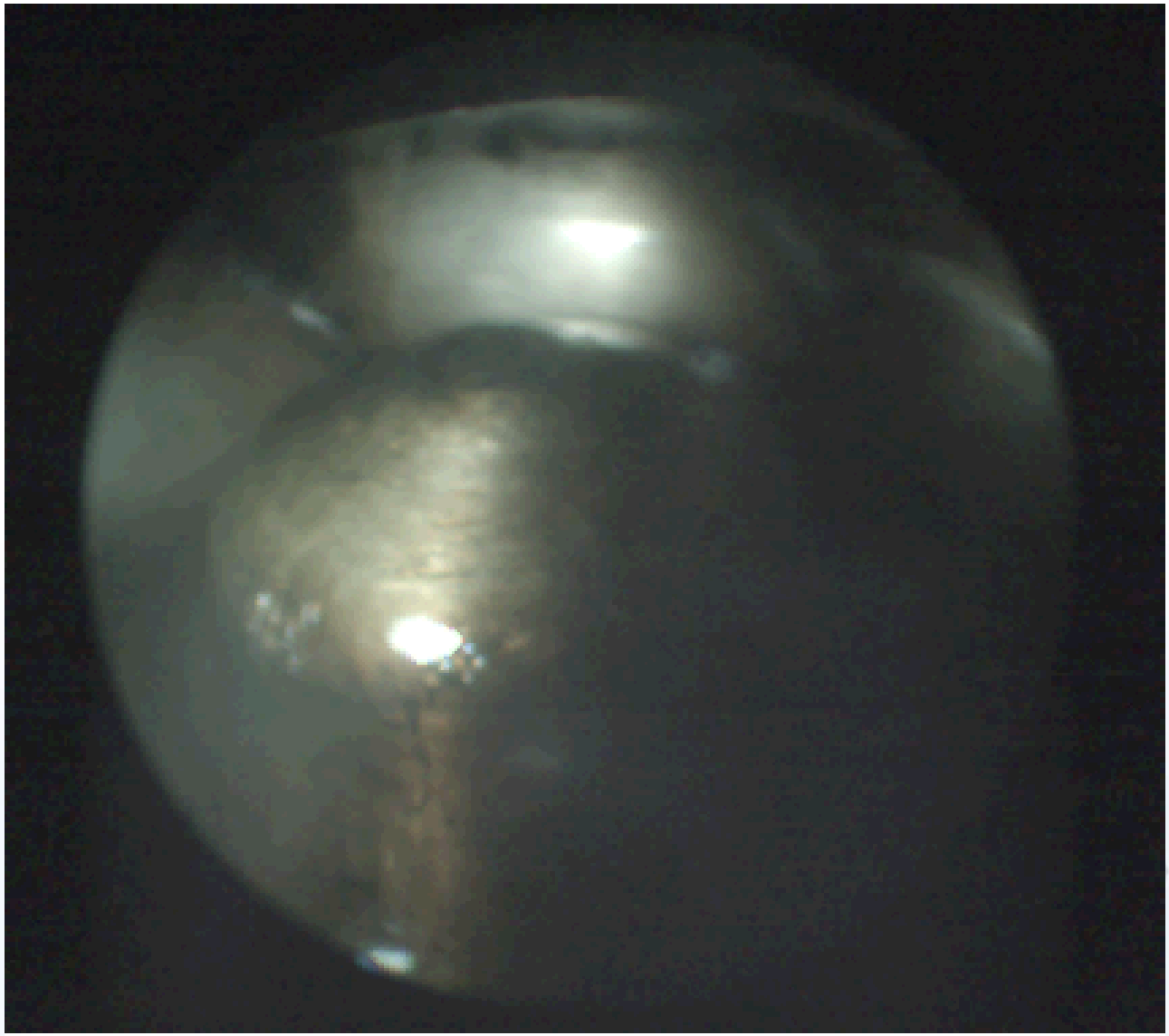
AVL VISIOSCOPE - OPTICAL ACCESS



AVL VISIOSCOPE - RECORDING TECHNIQUE

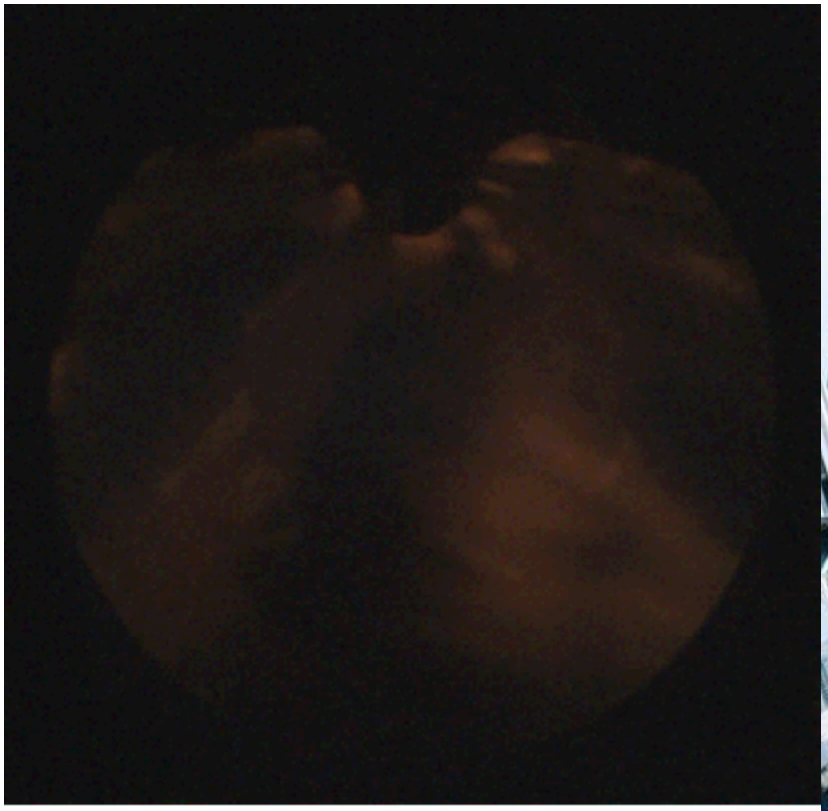


Example Visioscope Diesel Flame

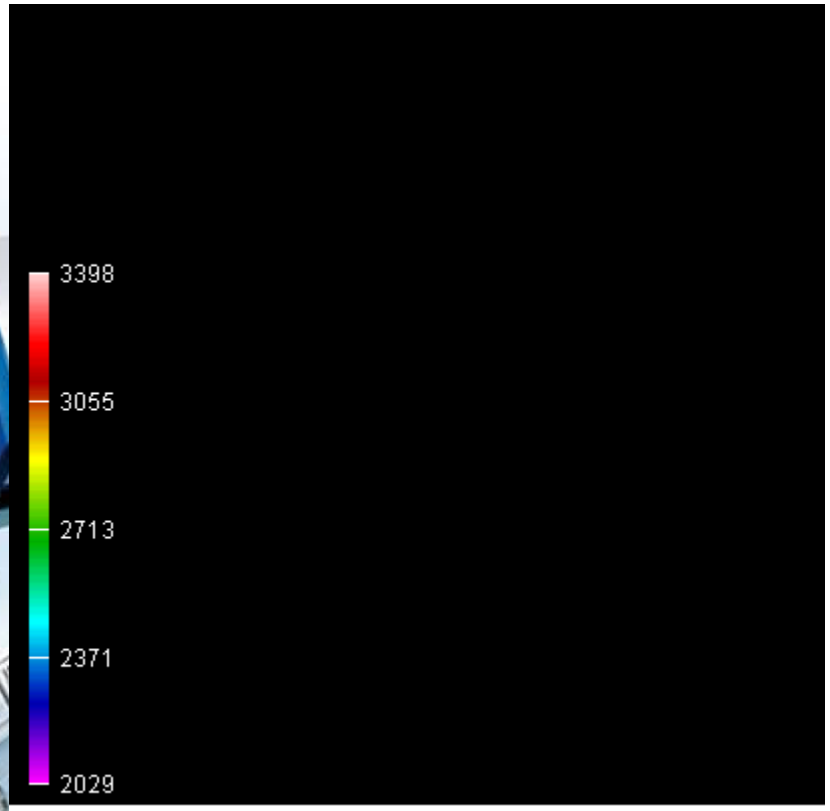


-5.0 deg CA
DI_Diesel_flame__

Example Visioscope Diesel Flame / Flame Temperature

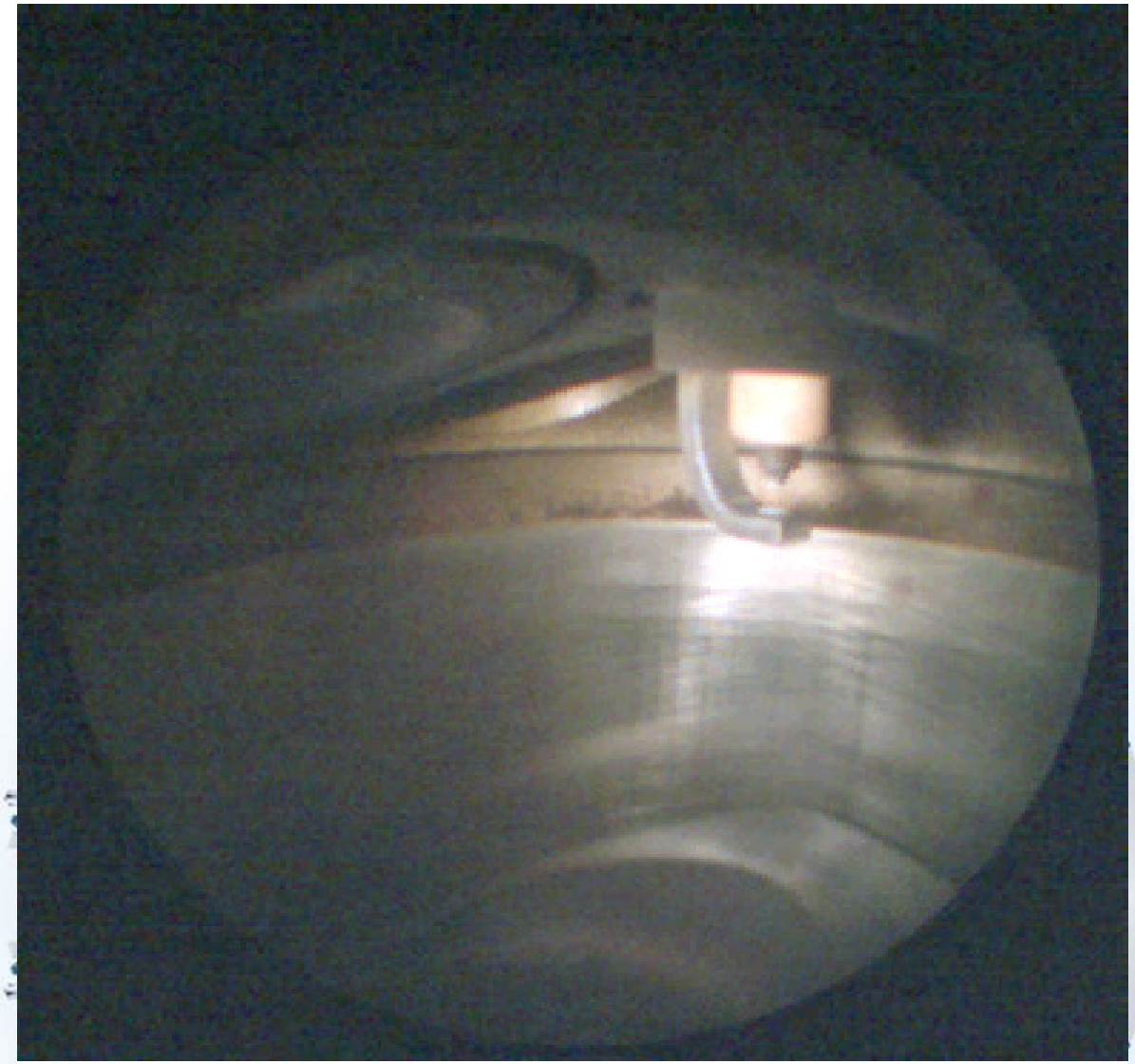


12.0 deg CA, Rep 0
A-Flame_images

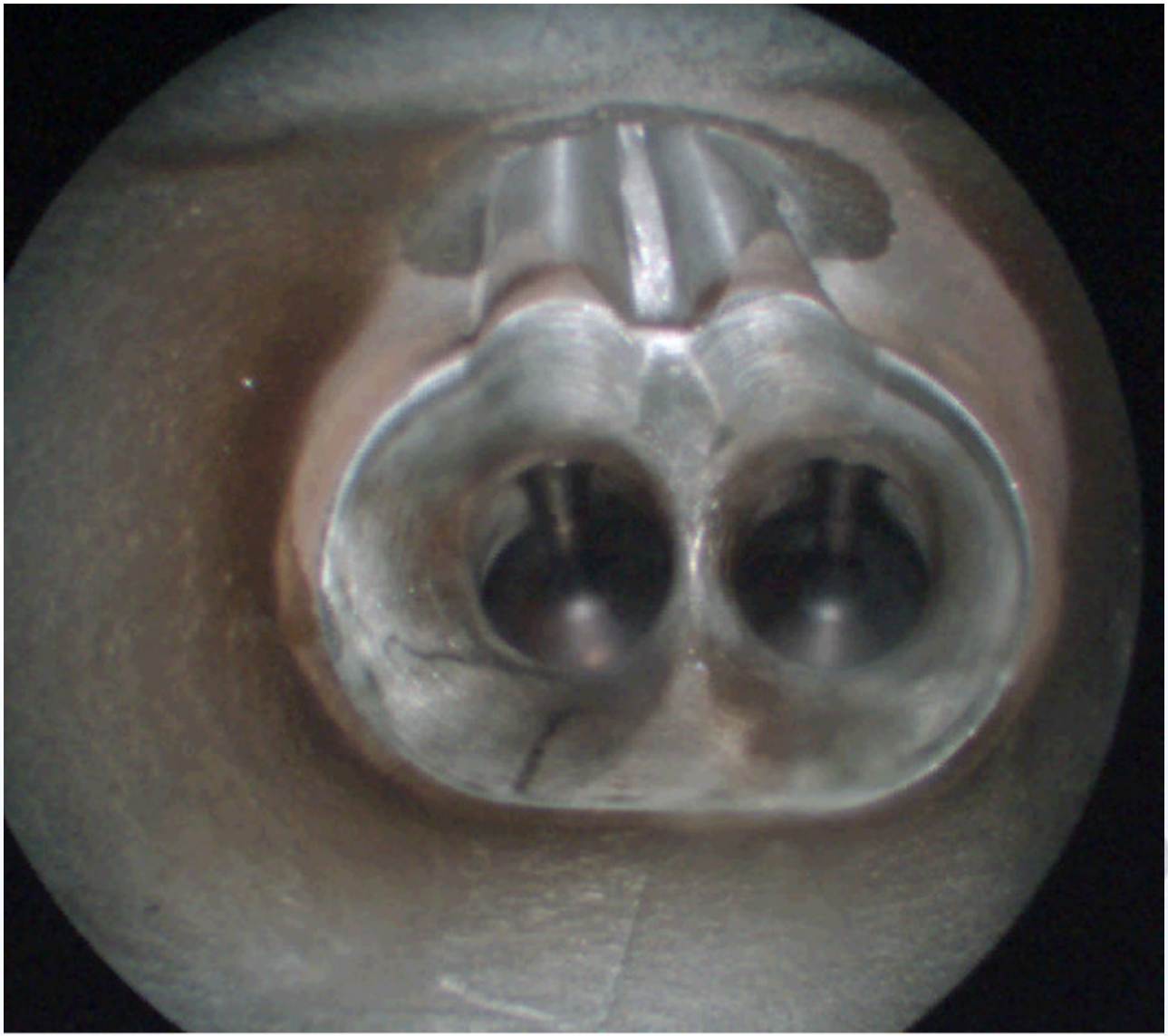


12.0 deg CA
B-Flame_temperature

Example Visioscope DI Gasoline



Example Visioscope Gasoline Wall Wetting



0.0 deg CA
Wall_wetting

THANK YOU FOR YOUR ATTENTION