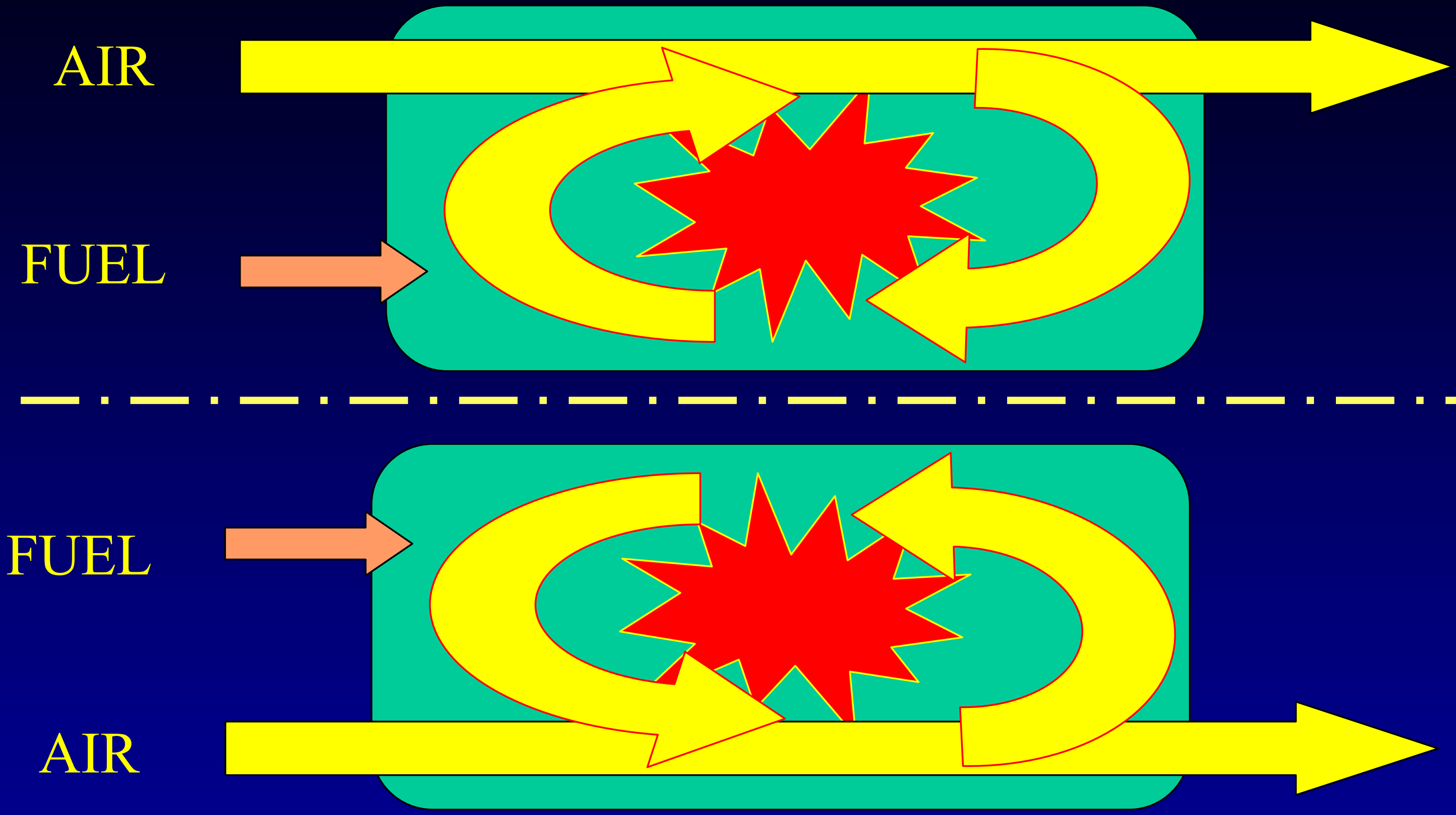
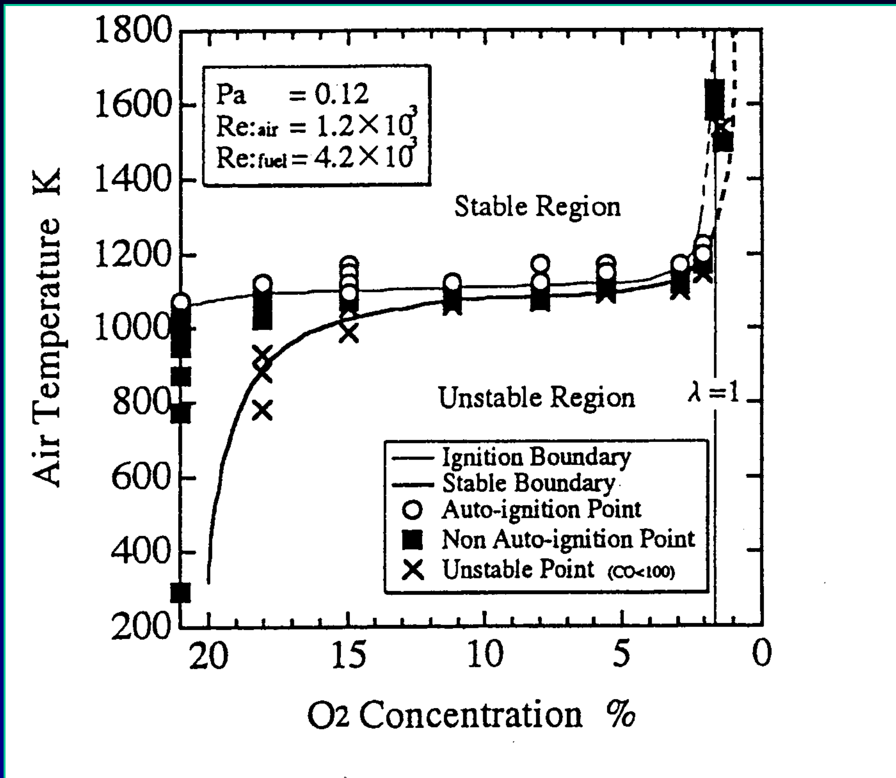
FLOXCOM
36 Month (Final) Meeting
Bari, Italy
November 21 2003

Technion - ISRAEL

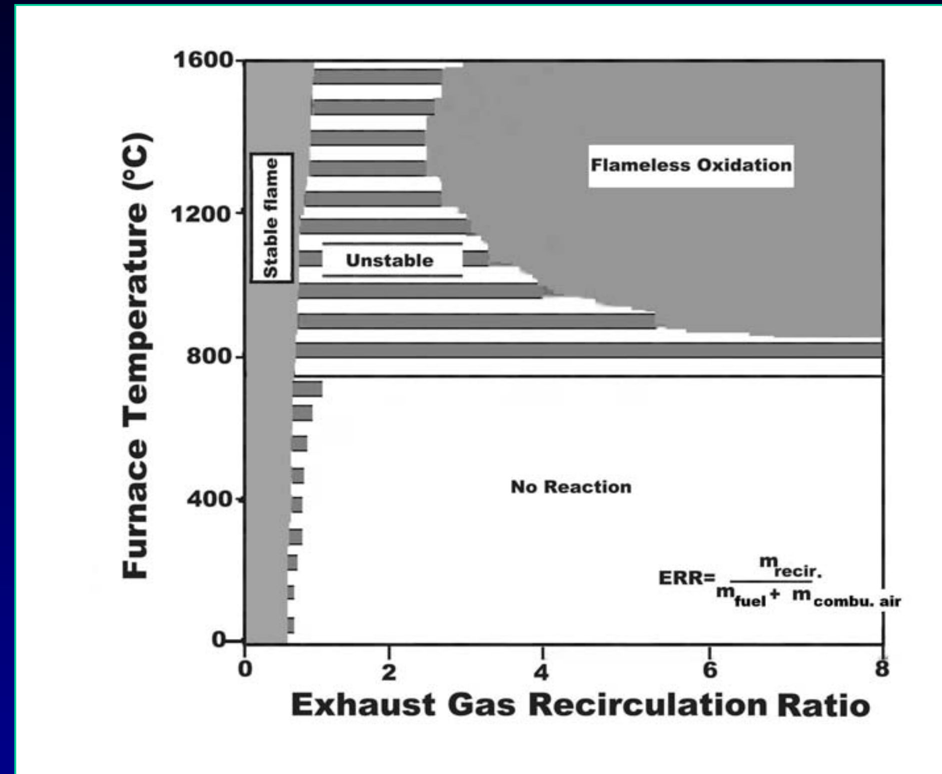
http://jet-engine-lab.technion.ac.il

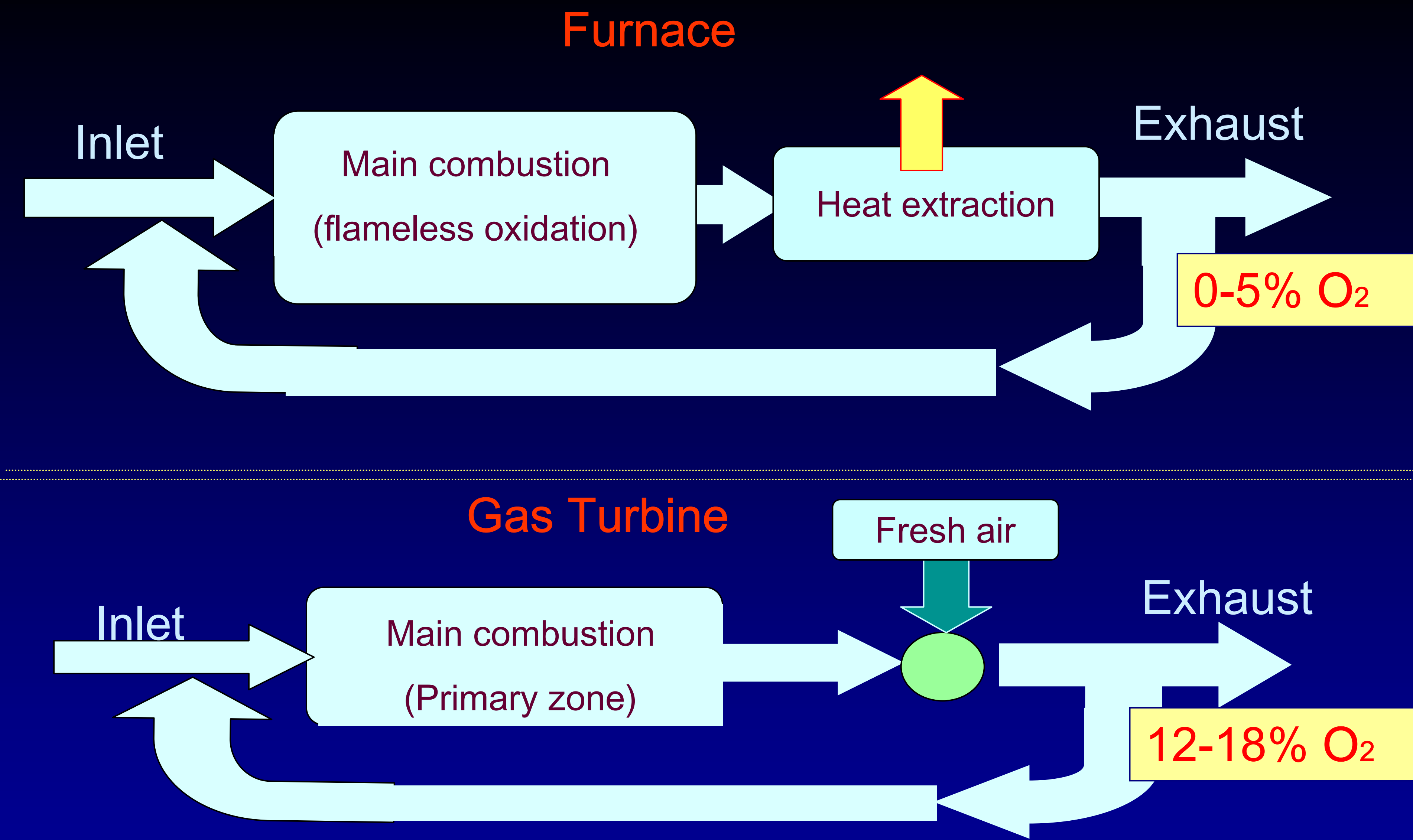

AIR
FUEL
FUEL
AIR

Experimental stability limits
After Katsuki and Hasegawa, 1998

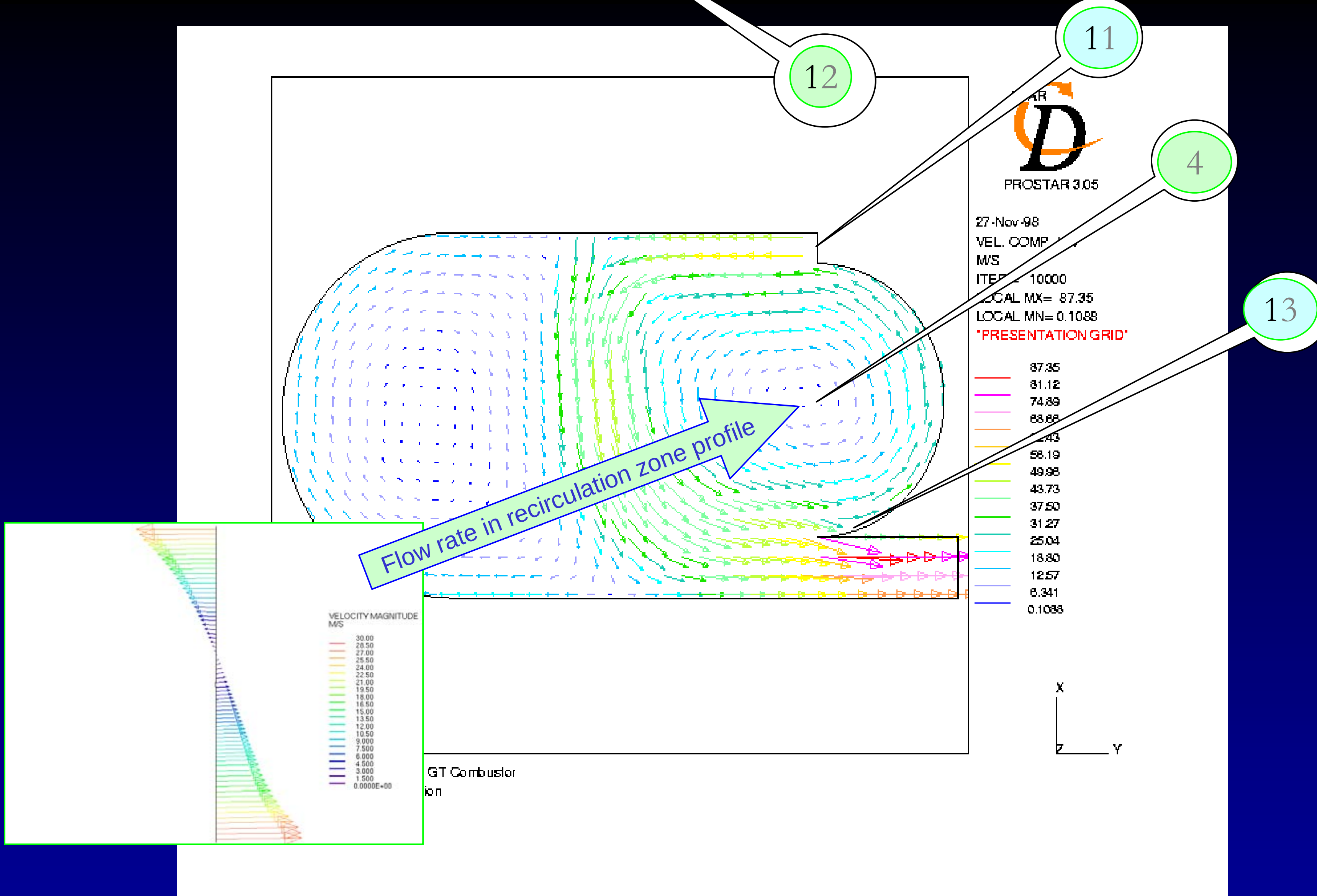


Stability limits -Schematic
After Wunning and Wunning, 1997

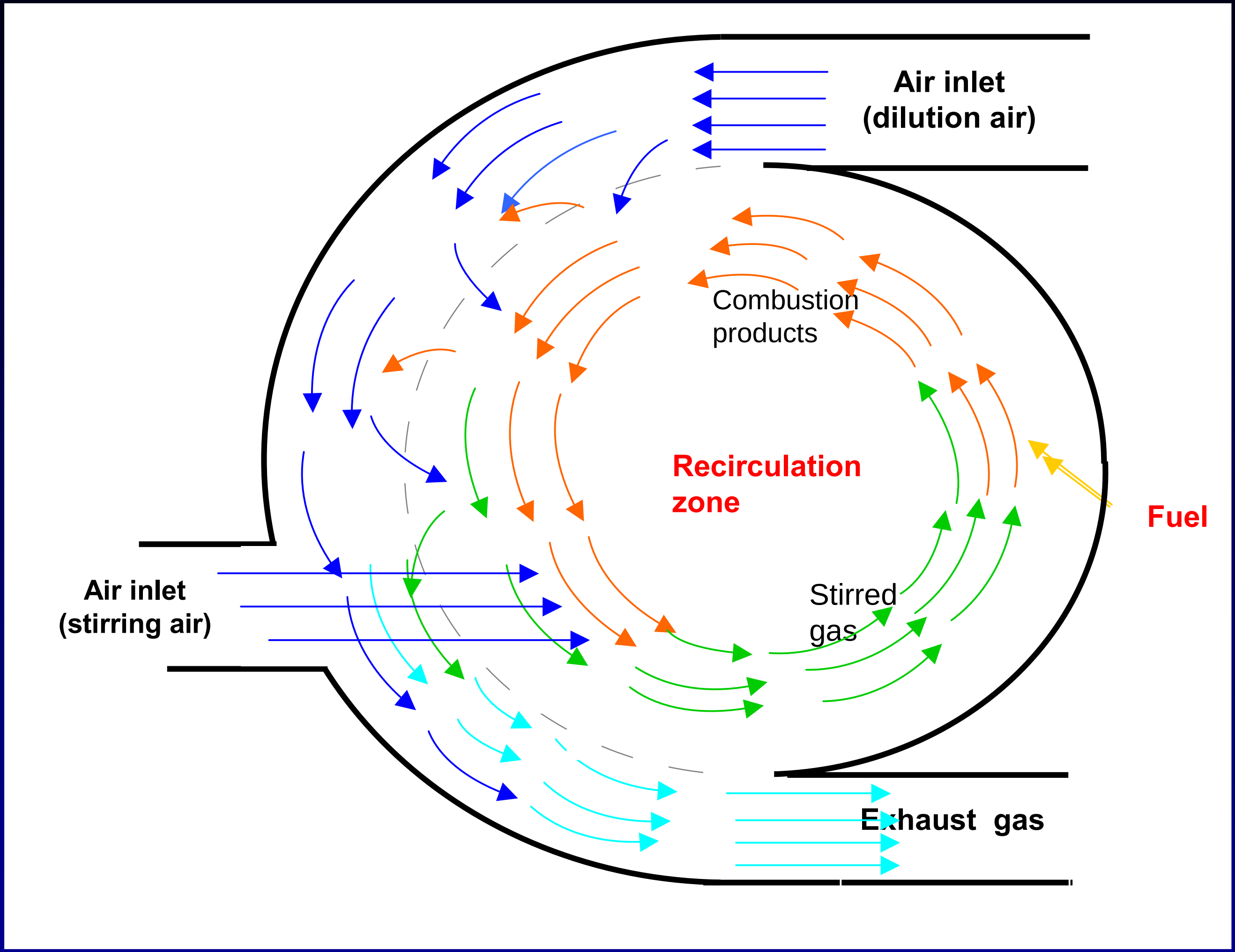




DIFFERENCE BETWEEN FLAMELESS OXIDATION IN FURNACES AND GAS TURBINE

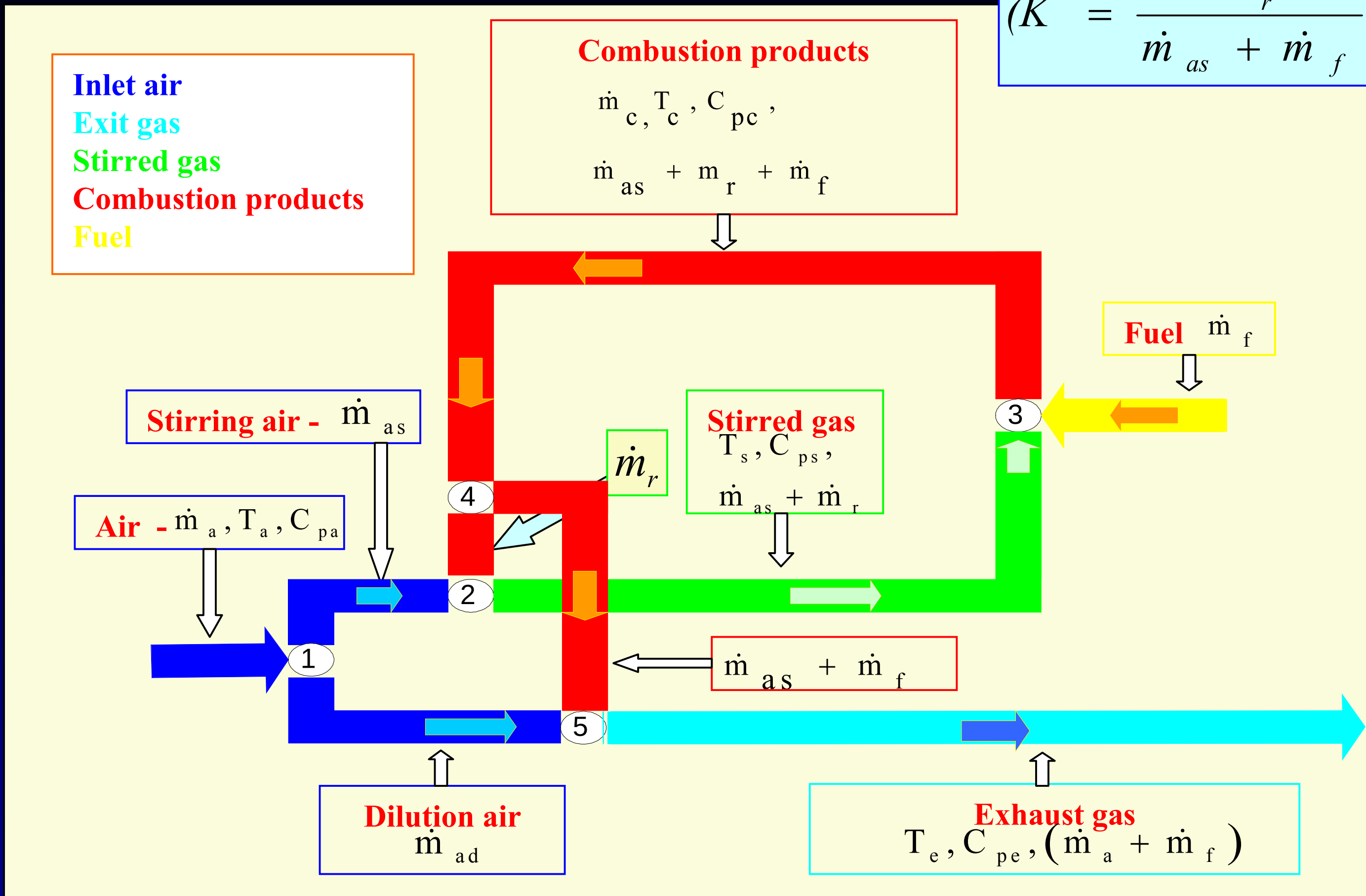


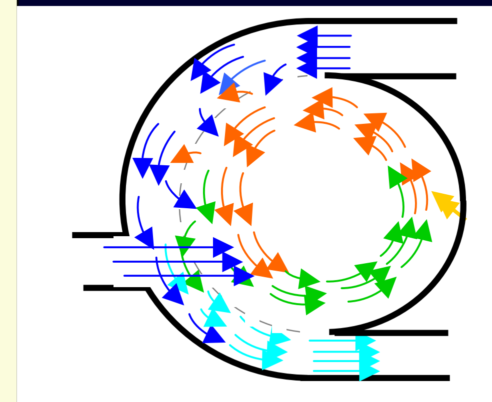
INTERNAL AERODYNAMICS, CFD



SCHEMATIC DRAWING OF THE COMBUSTOR LOCUS, SCHEME A

$$\left(K = \frac{\dot{m}_r}{\dot{m}_{as} + \dot{m}_f}\right)$$





SCHEME A (AIR IS MIXED WITH THE COMBUSTION PRODUCTS, TE AND TS ARE INDEPENDENT EACH FROM OTHER)

GLOBAL EVALUATION OF THE FLOXCOM COMBUSTOR

Known parameters and assumptions:

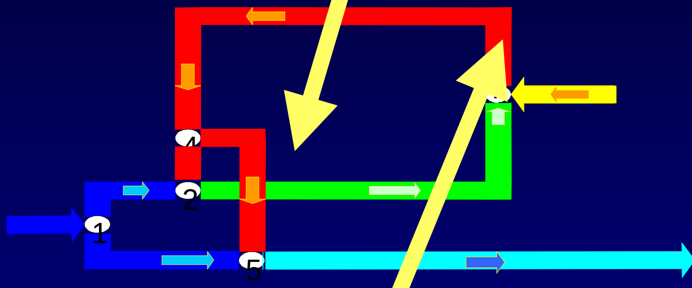
- Inlet air temperature T_a
- Inlet mass flow rate m_a ,
- Adiabatic flame temperature and exit temperatures T_c and T_e
- Recirculation rate k
- 100% combustion and mixing efficiency

calculated Values:

•mass flow rates:	stirring air, m_{as},
	dilution air, m_{ad}
	stirred gas, $m_{as}+m_r$
•Temperature:	stirred gas, T_s
•oxygen percentage:	in every stage of the cycle

The Stirring Gas Temperature, Ts, is calculated from heat balance between air and combustion gases (junction 2):

$$C_{pa}\cdot T_a\ \dot{m}_{as}+C_{pc}\cdot T_c\cdot \dot{m}_r=C_{ps}\cdot T_s\cdot(\dot{m}_r+\dot{m}_{as})$$

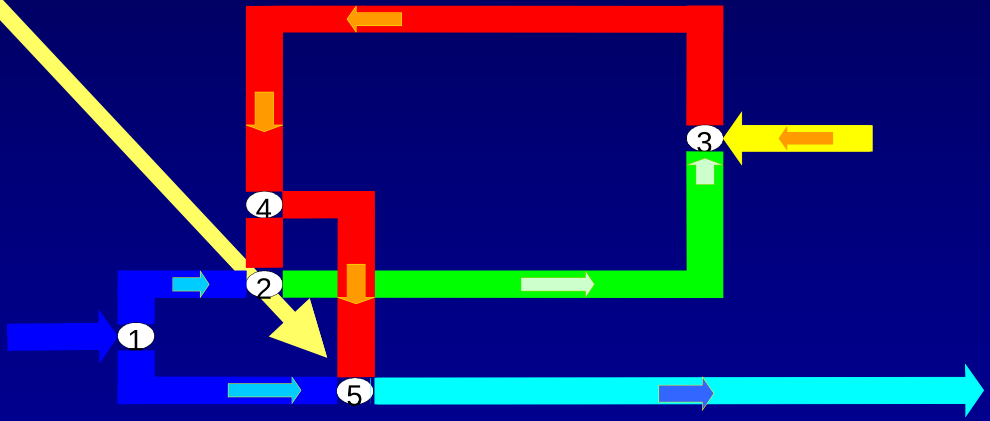


And by using the energy balance in the combustion zone

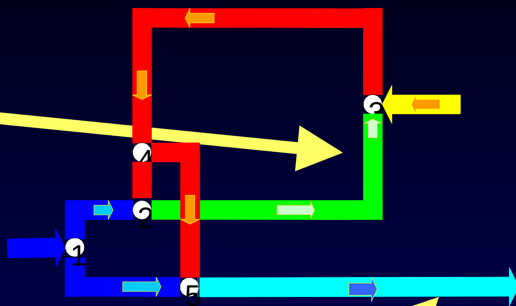
$$C_{ps}\cdot T_s\ \ \dot{m}_s+\dot{m}_f Q_r=C_{pc}\cdot T_c\cdot(\dot{m}_s+\dot{m}_f)$$

RATIO BETWEEN FLOW RATES OF THE DILUTION AIR m_{ad}, AND STIRRING AIR, m_{as} (JUNCTION5):

$$C_{pa}\cdot T_a \cdot m_{ad} + C_{pc}\cdot T_c\cdot(m_{as}+ m_f)= C_{pe}\cdot T_e\cdot(m_{ad}+m_{as}+m_f)$$



The oxygen percentage in the stirring gas (upstream the fuel injection point):



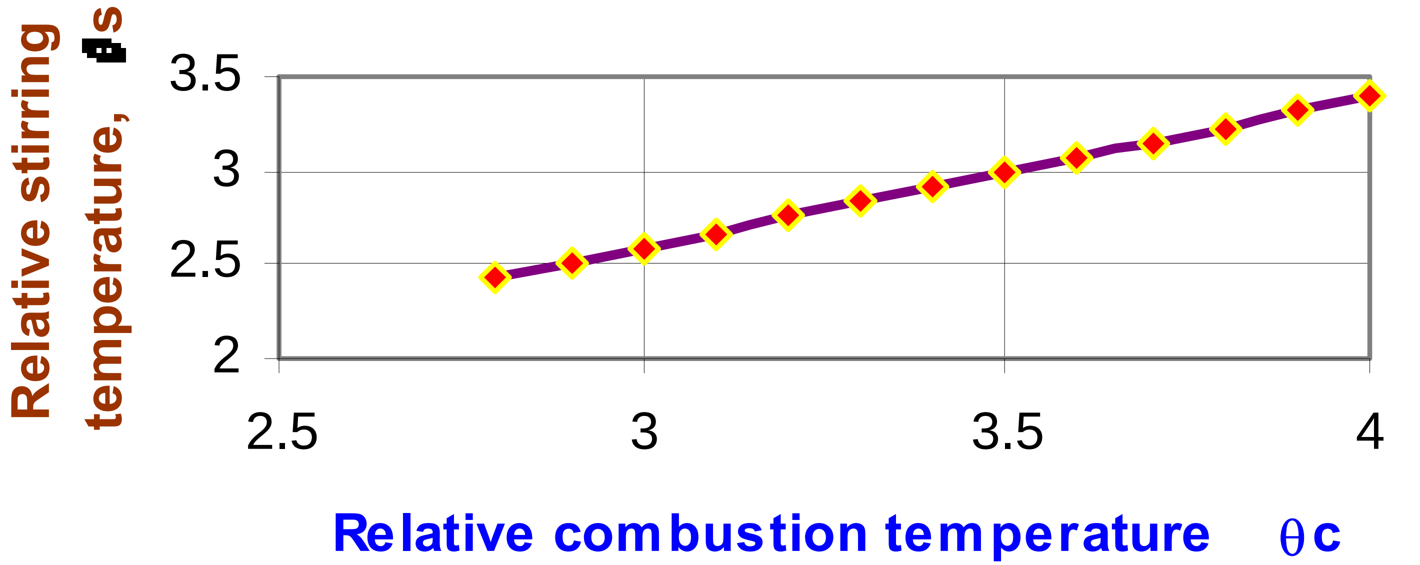
$$O_c \cdot \dot{m}_r + 23\dot{m}_{as} = O_s \cdot (\dot{m}_r + \dot{m}_{as})$$

The percentage oxygen O_e at the exit may be found from the global equivalence ratio Φ_e

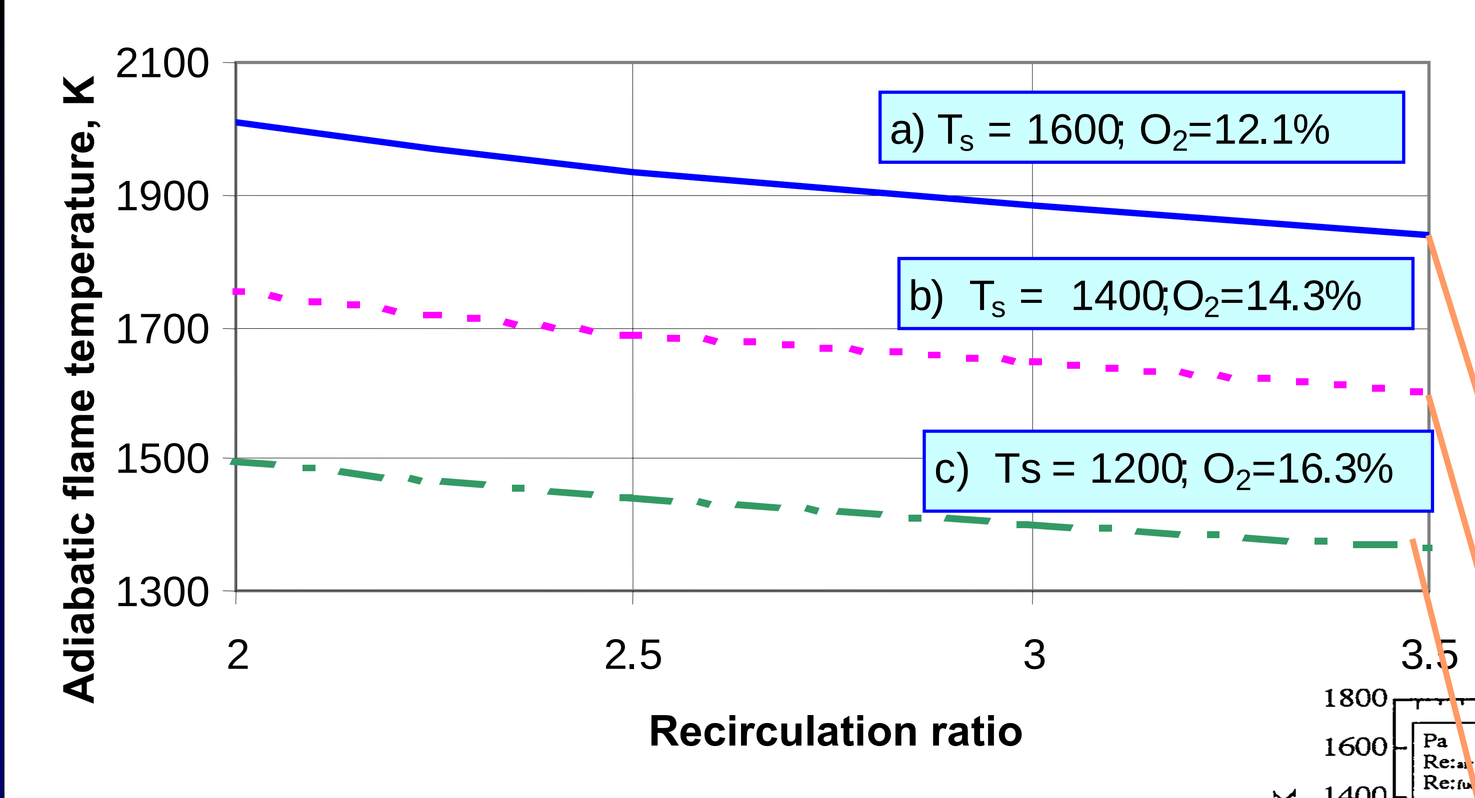
$$O_e = 23 \cdot (1 - \Phi_e)/(1 + \dot{m}_f / \dot{m}_a)$$

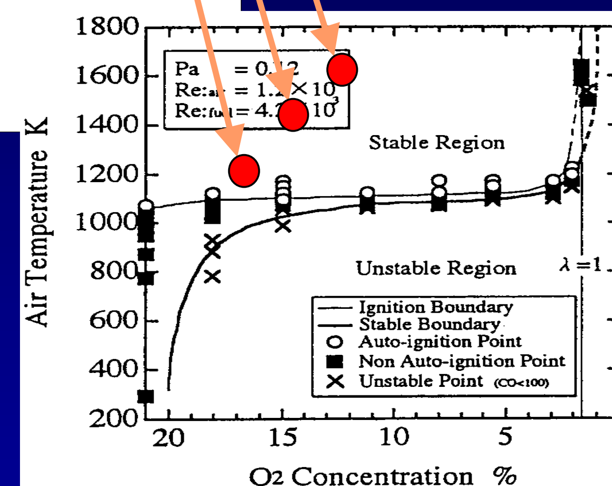
It can also be found from oxygen mass balance

$$O_e \cdot (\dot{m}_{as} + \dot{m}_{ad} + \dot{m}_f) = 23 \cdot \dot{m}_{ad} + Oc \cdot (\dot{m}_{as} + \dot{m}_f).$$



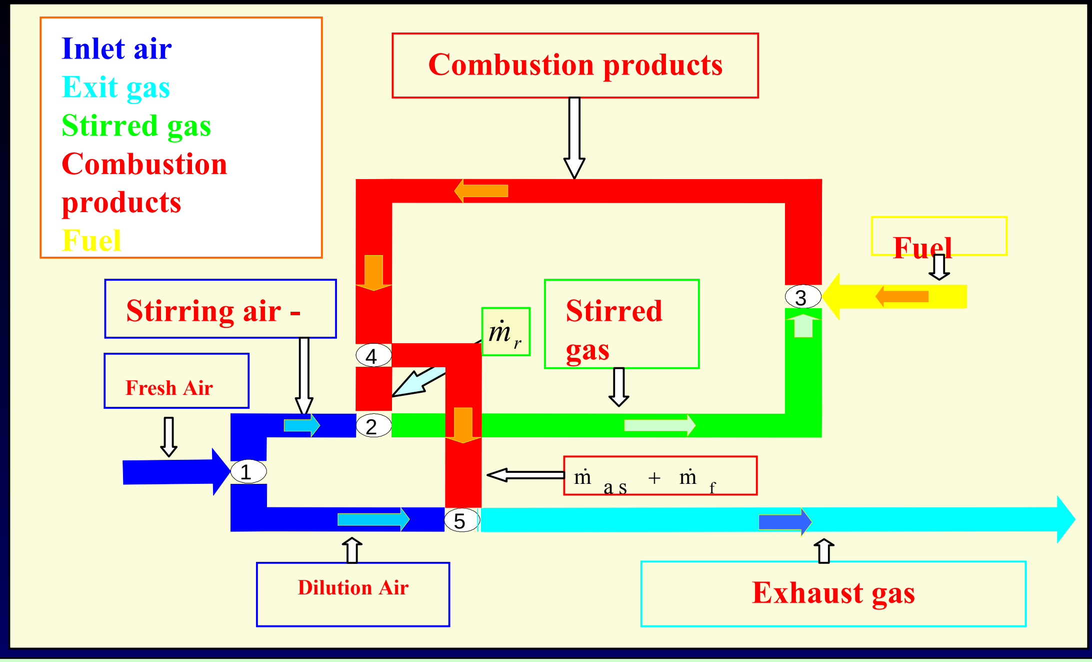
Dependence of the relative stirring temperature on the combustion temperature, scheme A, recirculation rate ***K=3*.**

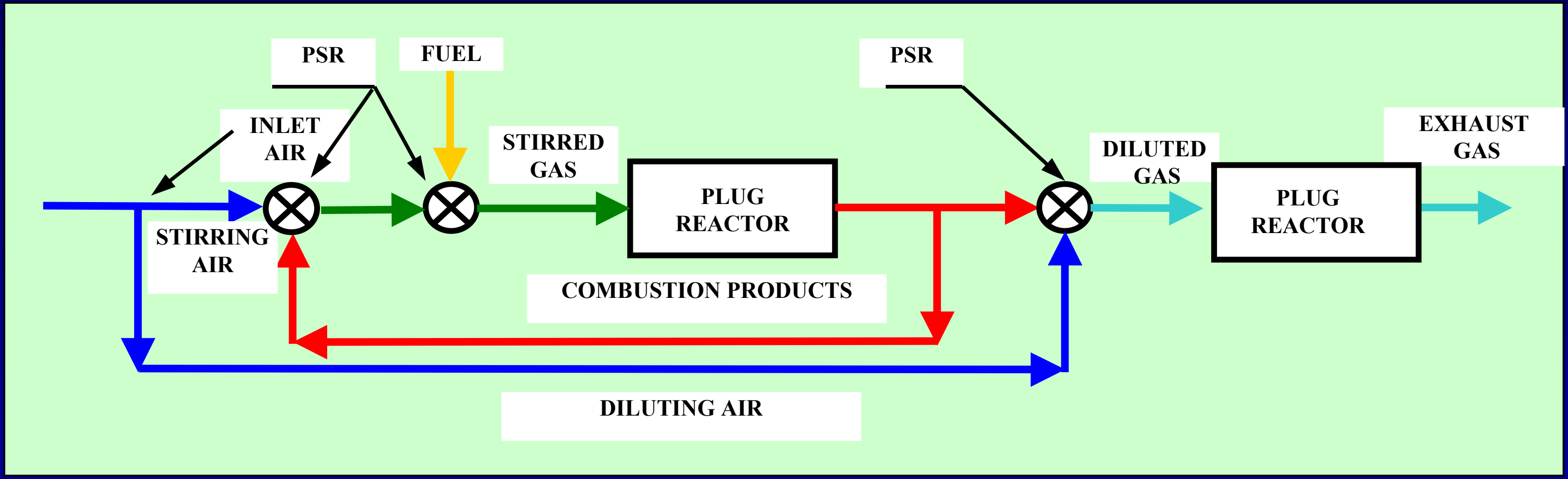




Ta = 500K

Dependence of the Adiabatic Flame Temperature (T_c) on Recirculation Ratio K and Stirring Temperature (T_c)

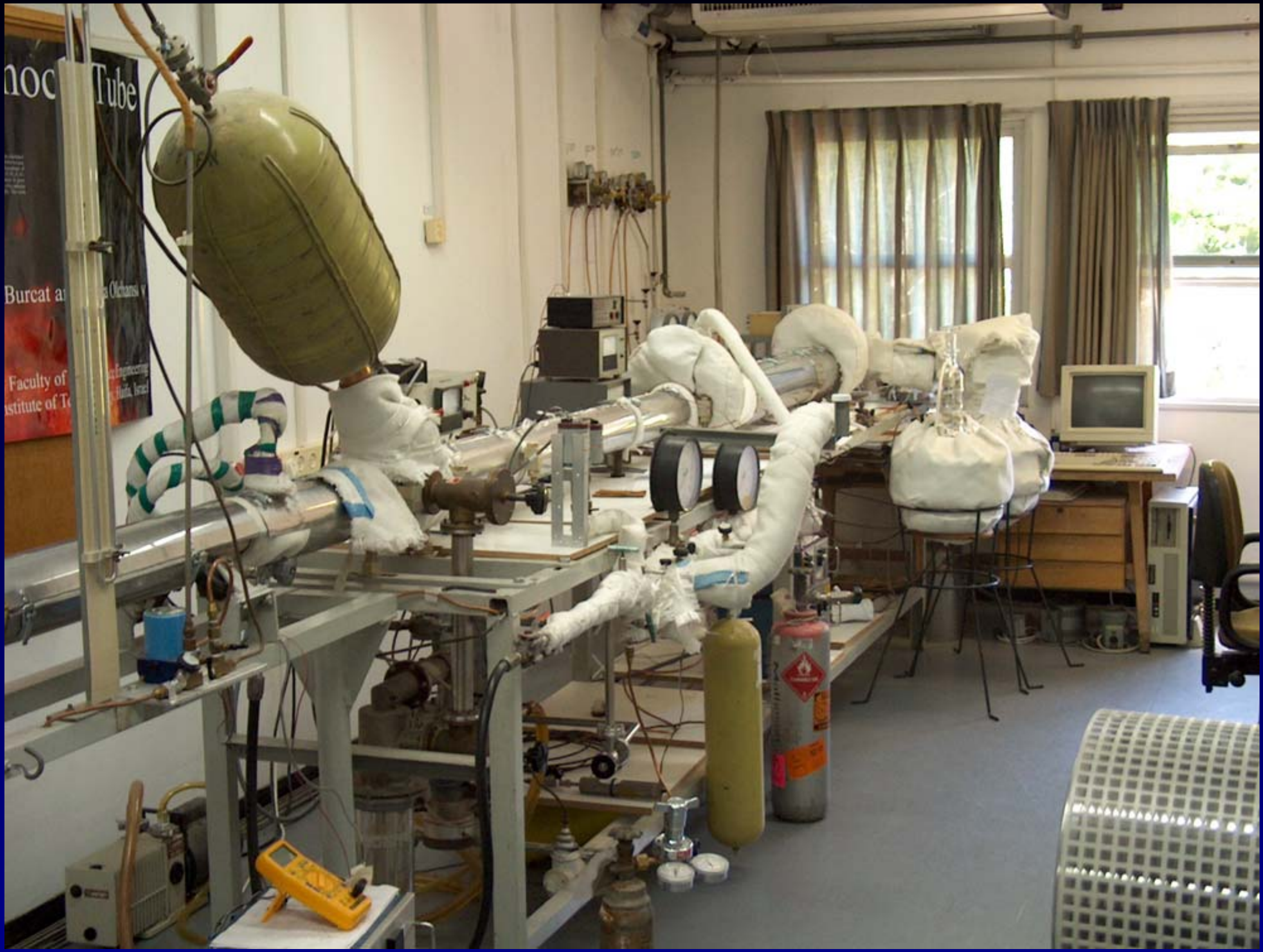




PROCESS SIMULATION USING CHEMKIN

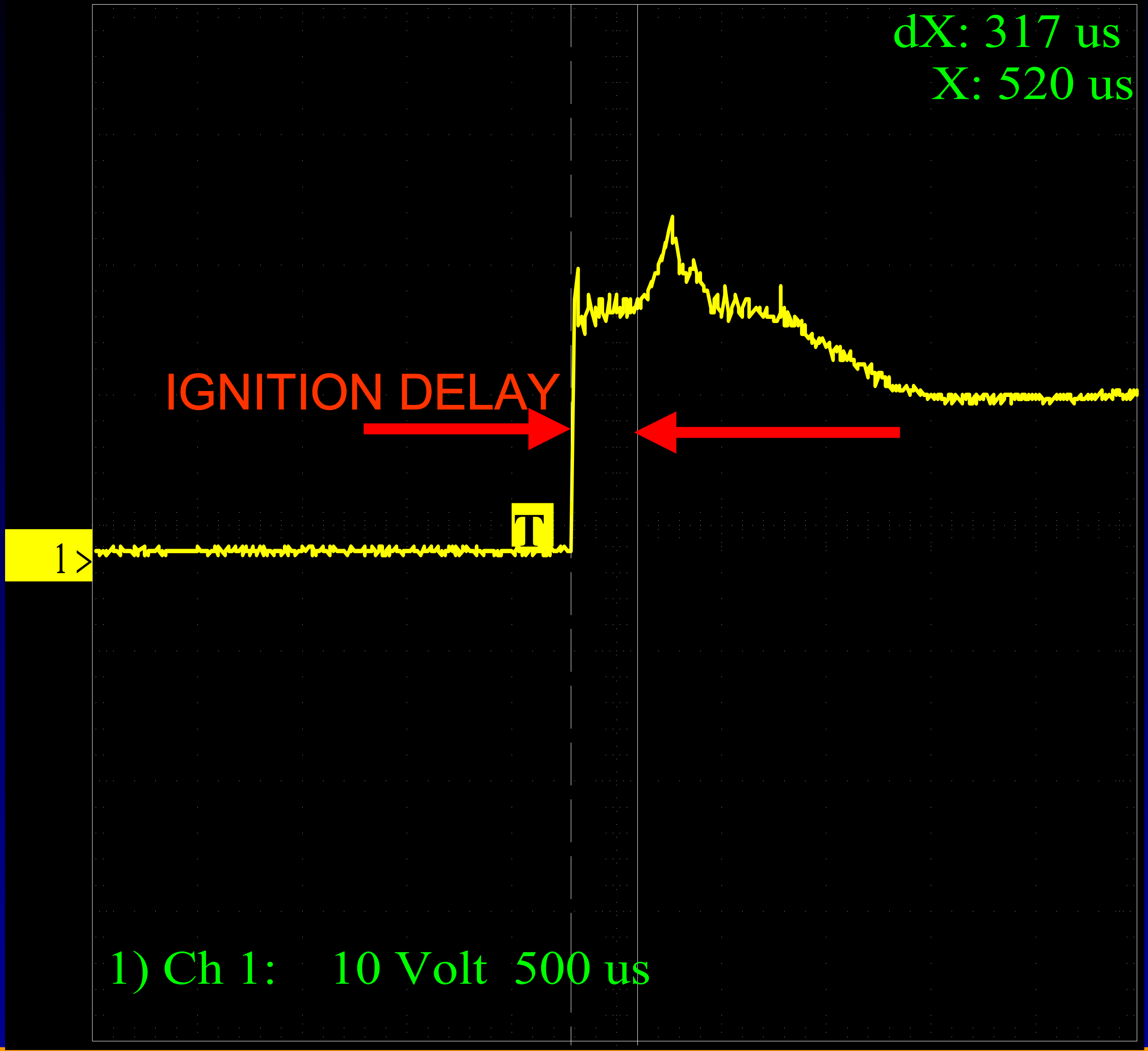
BASIC FLAMELESS OXIDATION STUDY –

– SHOCK TUBE TESTS



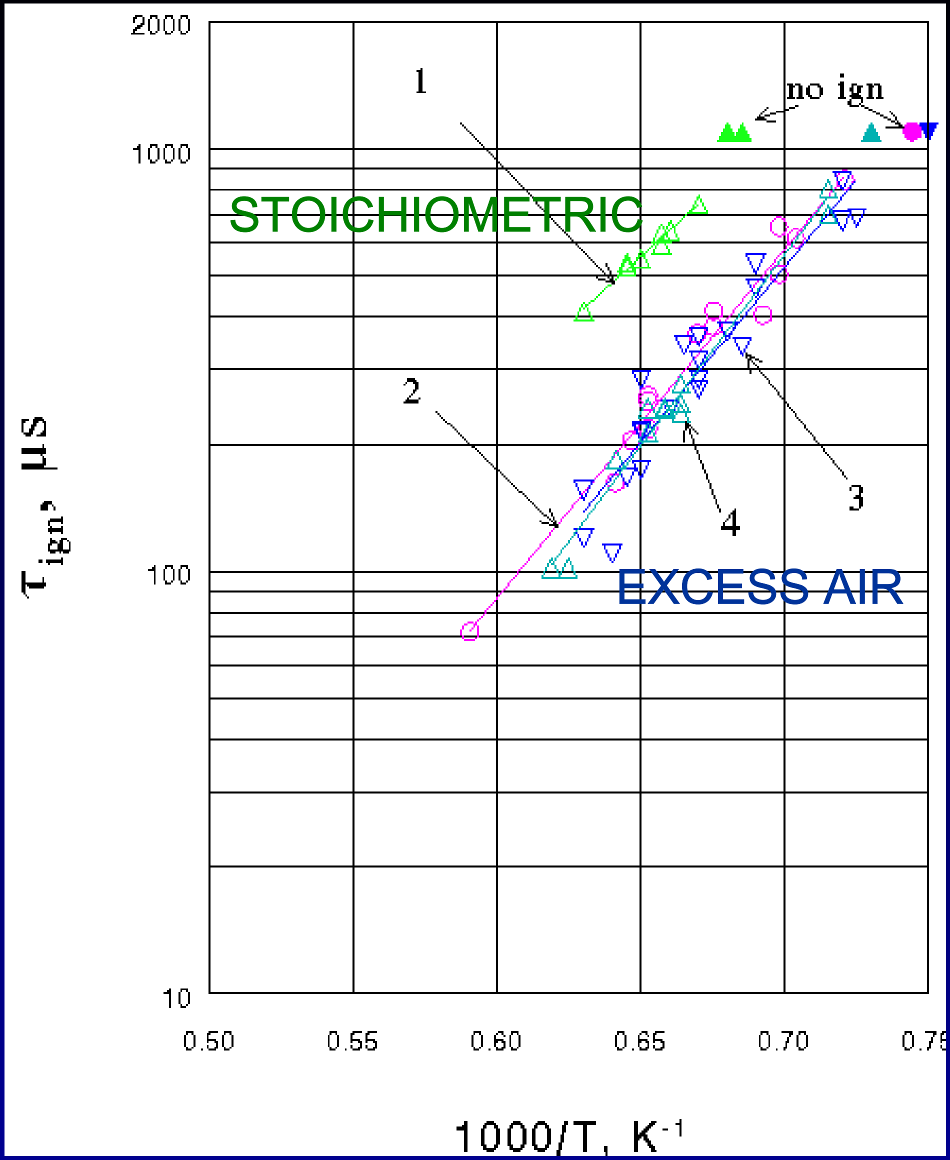
DIFFERENT MIXTURES OF REACTIVE GASSES AND INNERTS ARE SUBJECTED TO A RAPID SHOCK WAVE THAT HEATS UP THE MIXTURE.

THE SHOCK TUBE



AT A CERTAIN TIME AFTER THE SHOCK WAVE (HEAT WAVE),

A REACTION OCCURES, THIS IS THE "IGNITION DELAY" OR THE "REACTION DELAY".

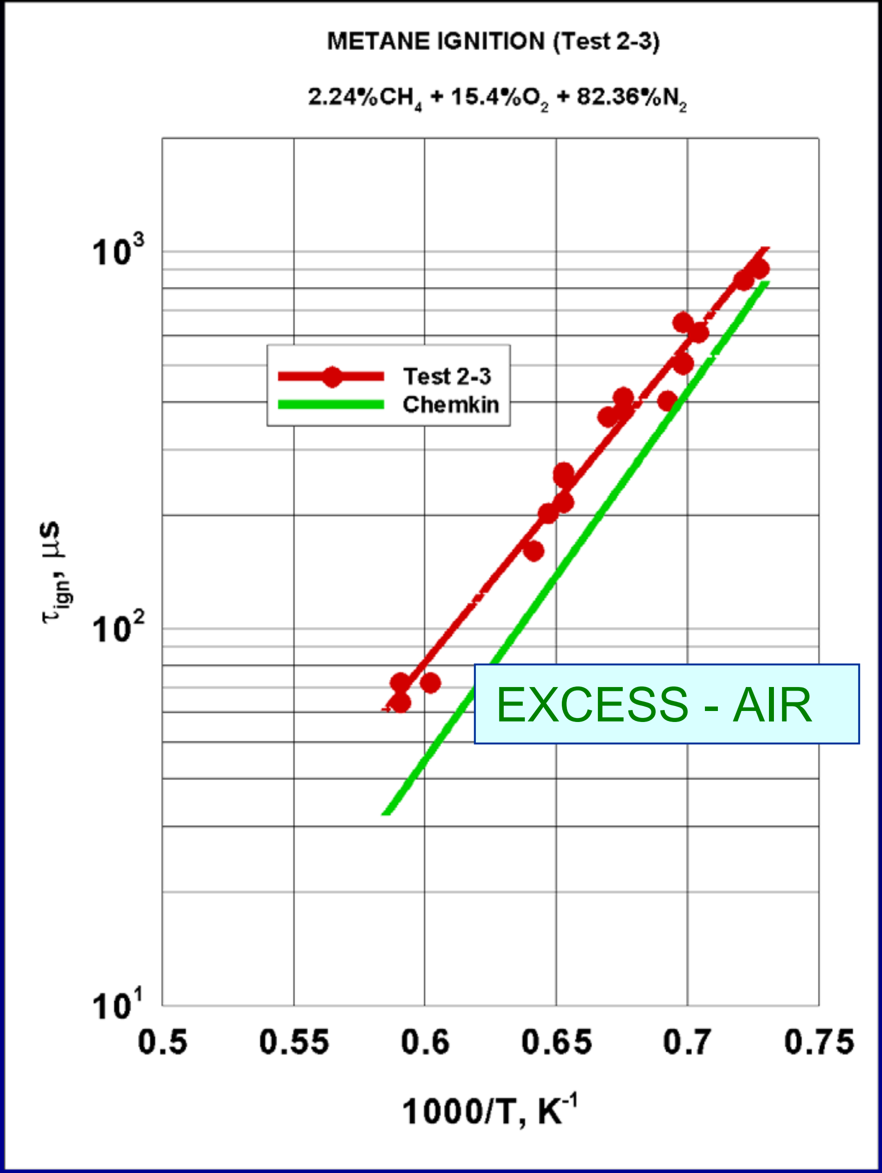


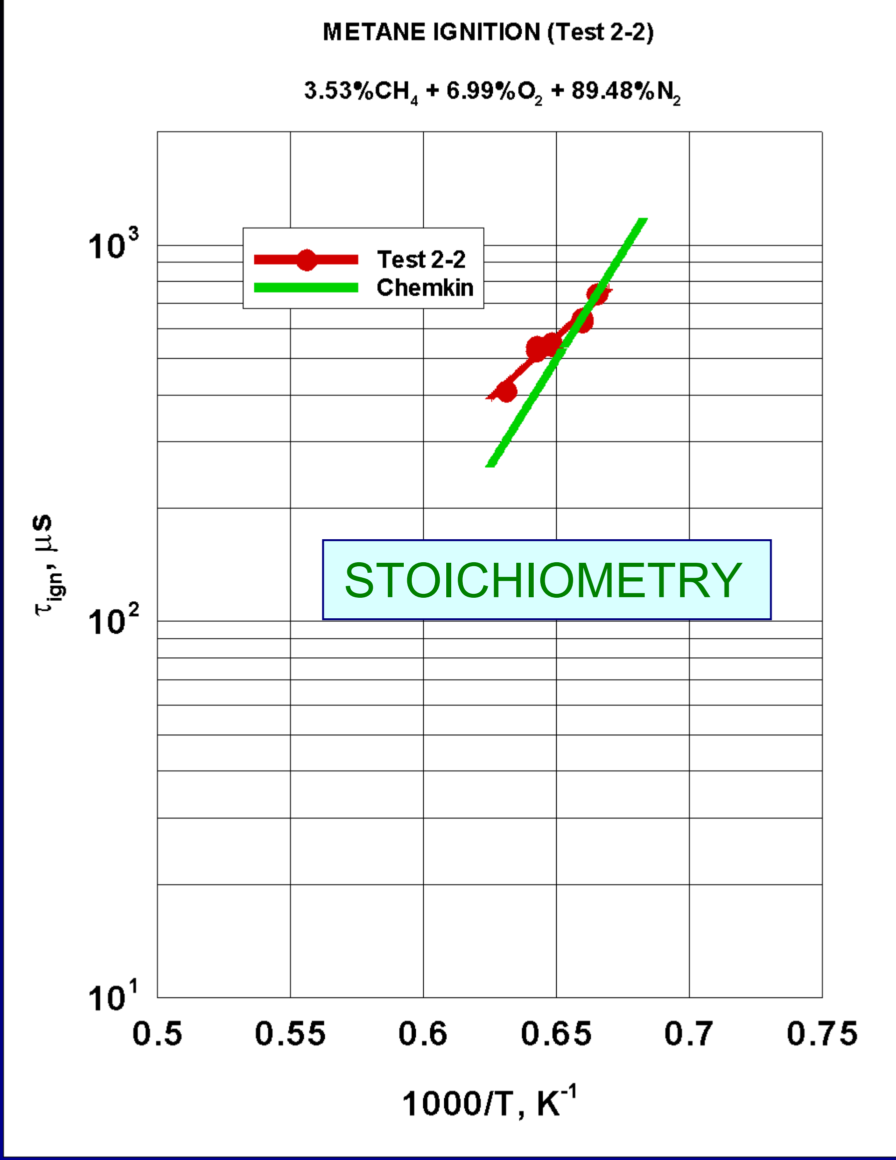
#	CH4	O2	CO2	H2O	N2
1	3.53	6.99	-	-	89.48
2	2.24	15.4	-	-	82.4
3	2.24	15.47	5.15	4.02	73.2
4	2.25	15.13	5.20	-	77.2

- Excess of free oxygen at high temperature increases reaction rate!
- Dilution with H_2O and CO_2 at high temperature have no significant effect on reaction rate

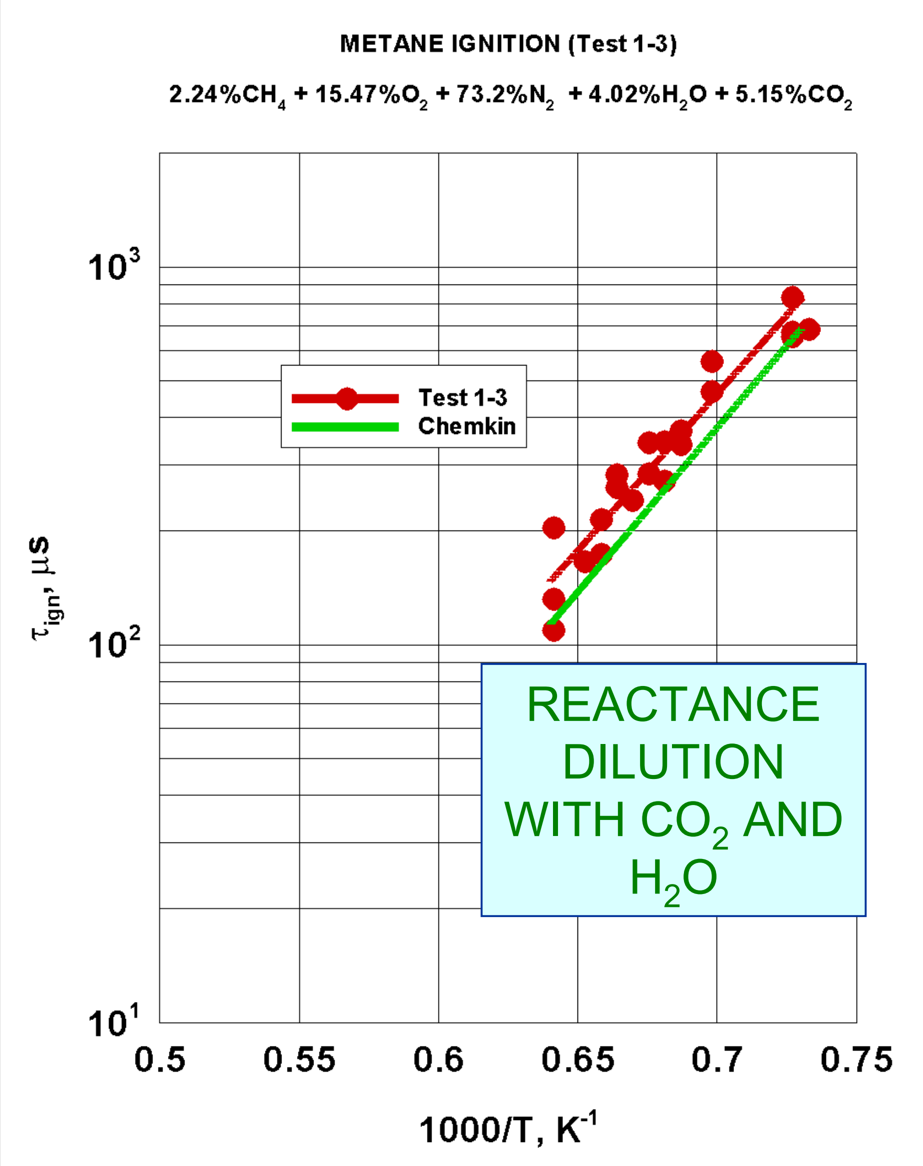
Methane Ignition:

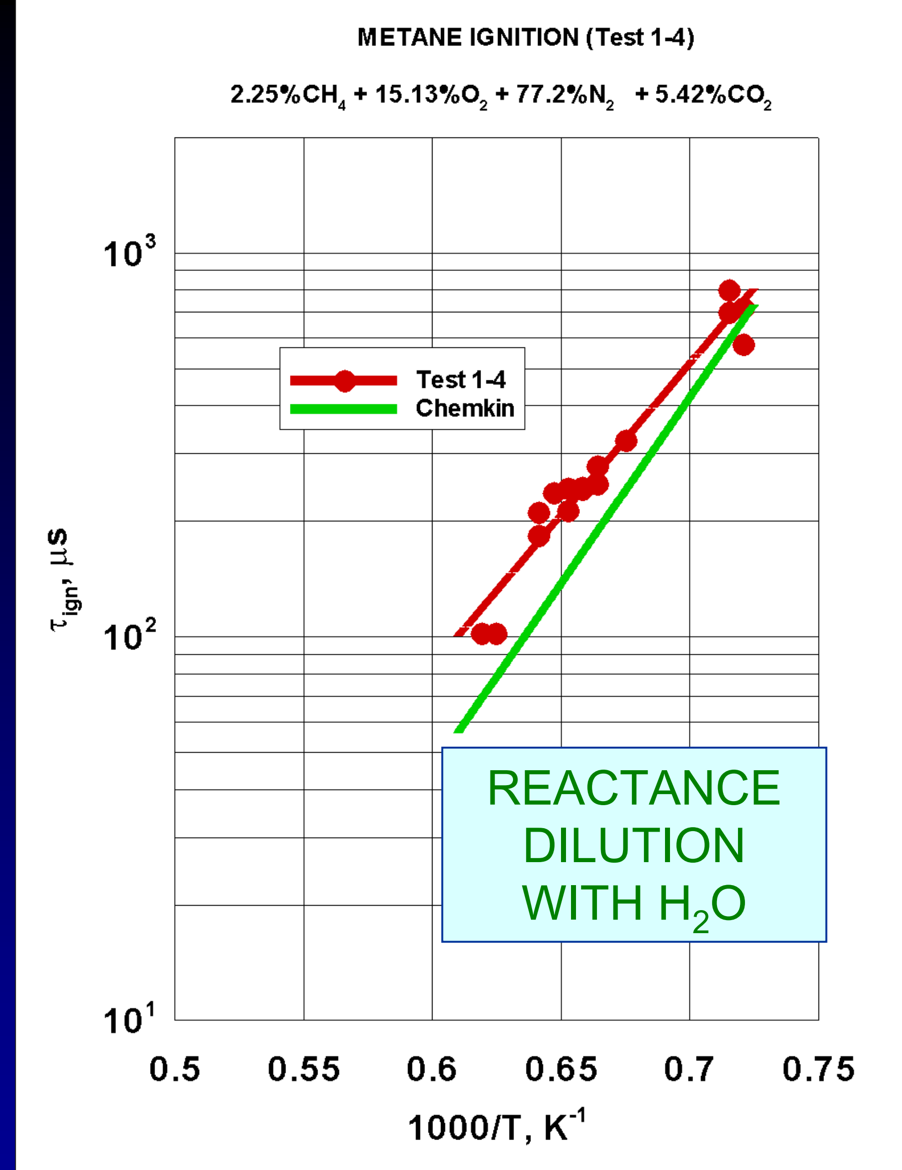
REACTANCE: $CH_4+O_2+N_2+CO_2+H_20$

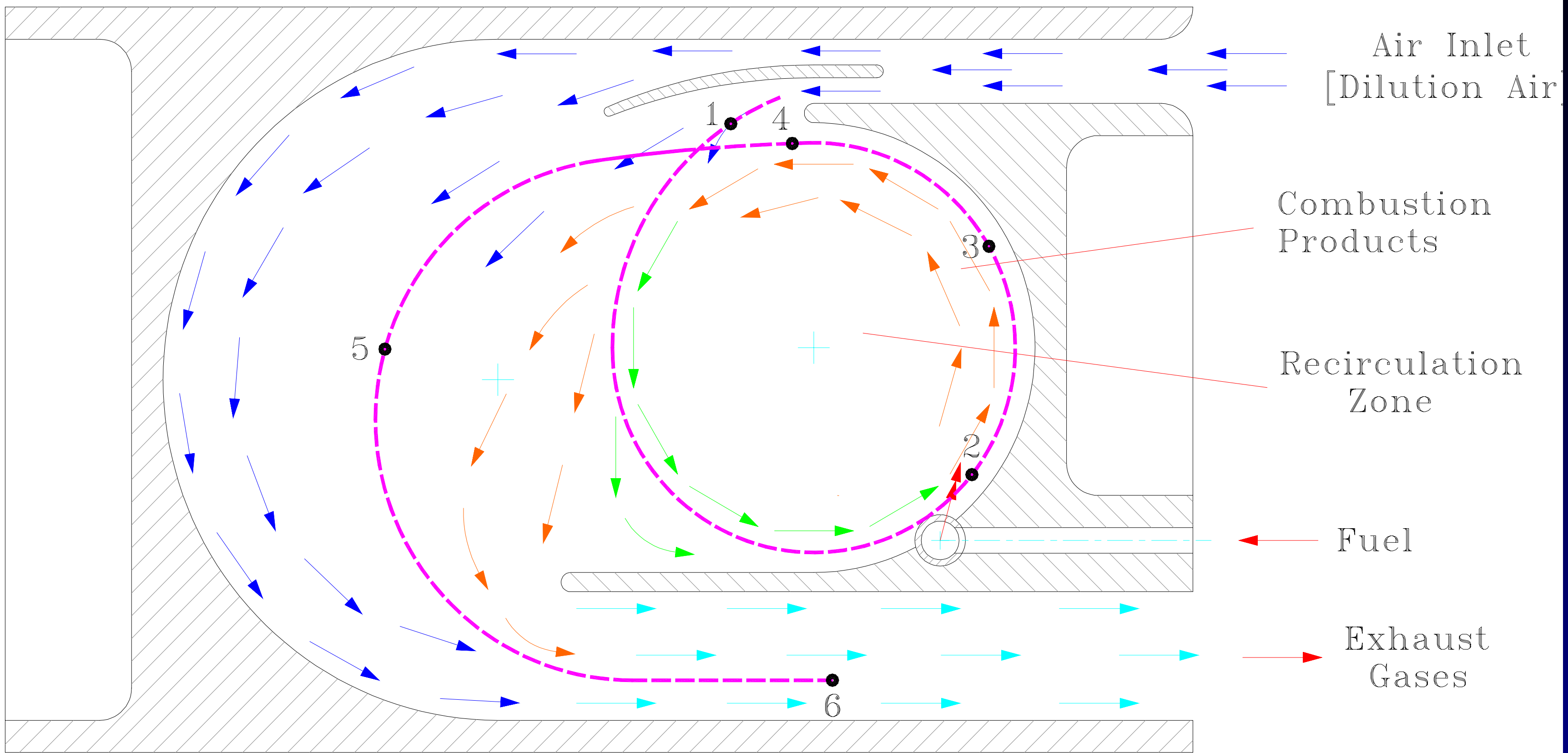




CHEMKIN simulation - comparison with experiments


METANE IGNITION (Test 1-3)
2.24%CH4 + 15.47%O2 + 73.2%N2 + 4.02%H2O + 5.15%CO2
Test 1-3
Chemkin
τign, μs
10^3
10^2
10^1
0.5
0.55
0.6
0.65
0.7
0.75
1000/T, K^-1
REACTANCE DILUTION WITH CO2 AND H2O


METANE IGNITION (Test 1-4)
2.25%CH4 + 15.13%O2 + 77.2%N2 + 5.42%CO2
Test 1-4
Chemkin
τign, μs
10^3
10^2
10^1
0.5
0.55
0.6
0.65
0.7
0.75
1000/T, K^-1
REACTANCE DILUTION WITH H2O



$$L = \sum_i \int_{\tau_i} V_i \cdot d\tau_i$$

SCHEMATIC DRAWING OF THE FLOXCOM COMBUSTOR.

GEOMETRICAL CONSIDERATIONS

The (schematic) streamline length, L, is:

$$L = \sum_i \int_{\tau_i} V_i \cdot d\tau_i$$

Where:

τ_1 – stirring time, (1-2), mixture OF air-combustion products

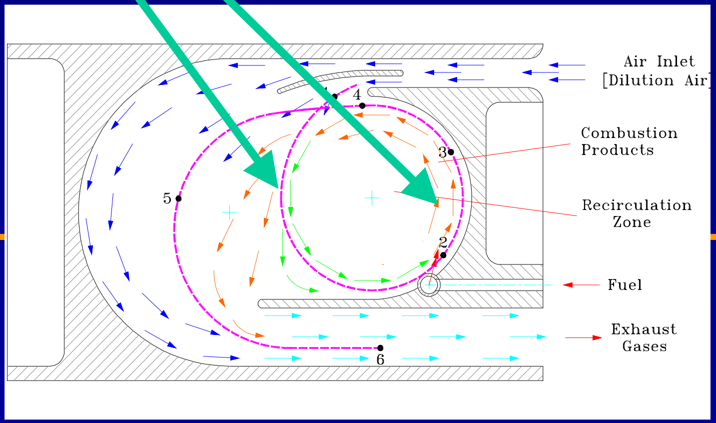
τ_2 – combustion delay, (2-3), time for the rapid temperature rise,

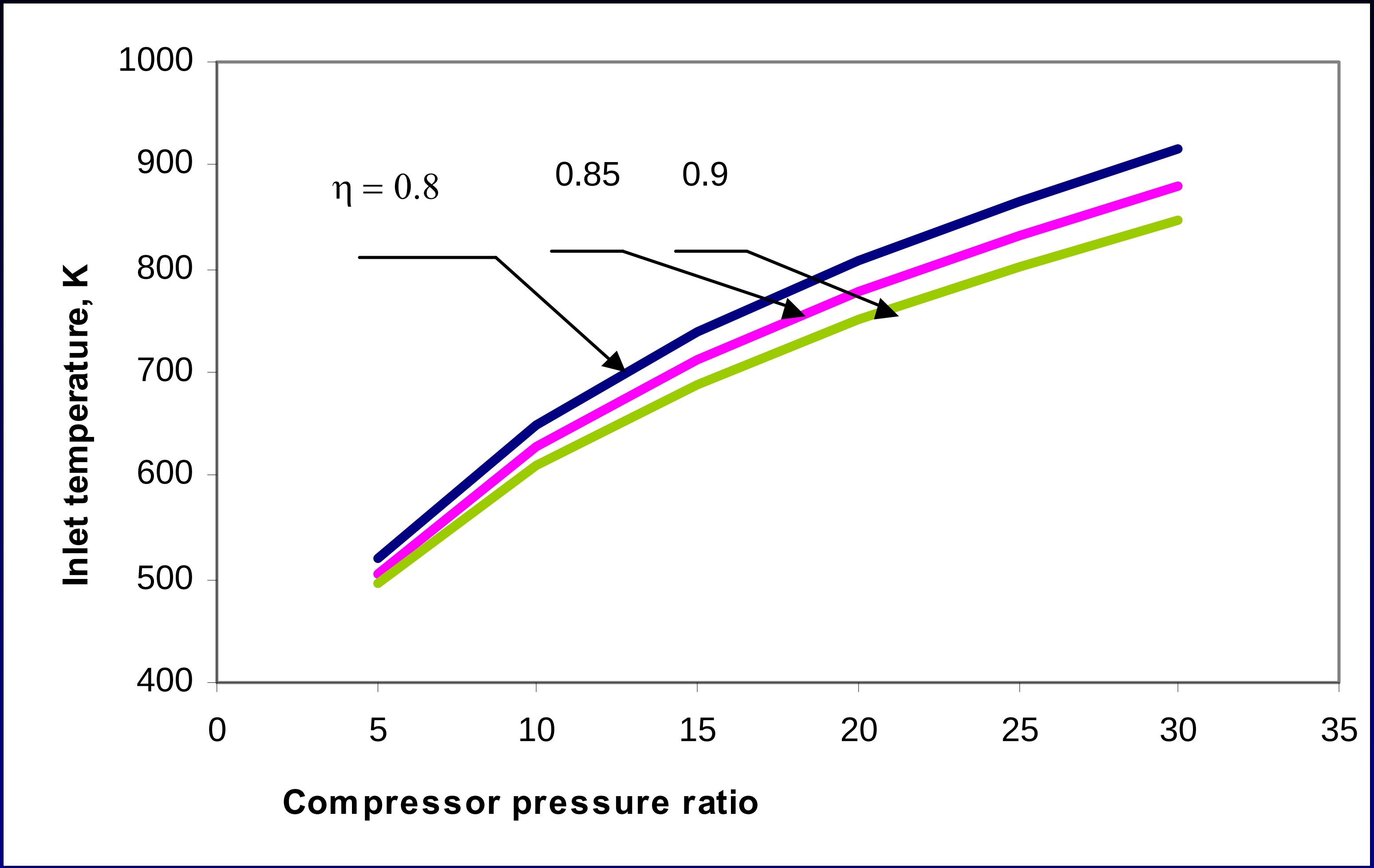
τ_3 – combustion time, (3-4), combustion products achieve 99.9% of adiabatic flame temperature.

τ_4 –combustion completion, (4-5), CO achieves an asymptotic value.

τ_5 - dilution, (5-6), combustion products mixed with fresh air for a required TIT.

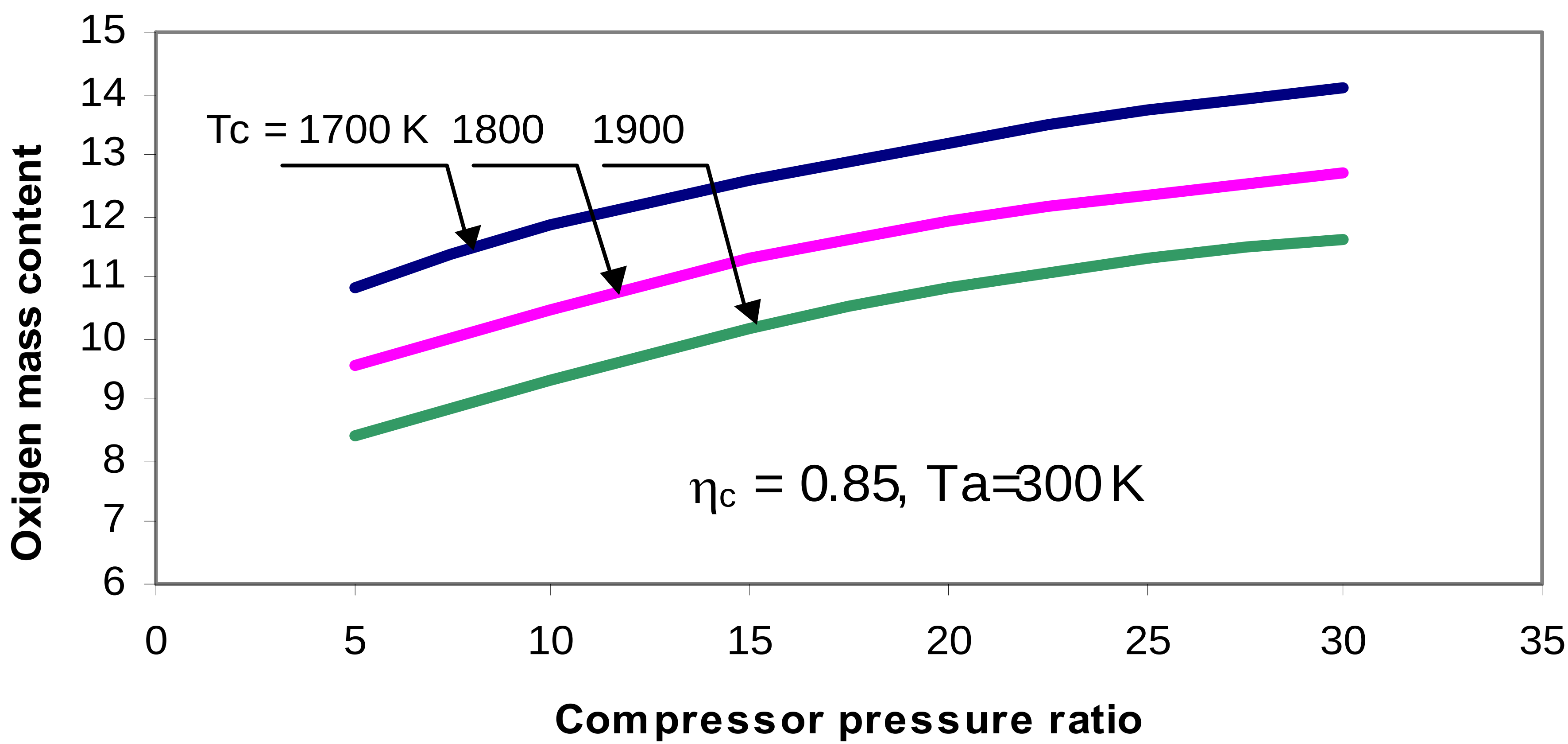
V_i - gas velocity at the each section of combustor.





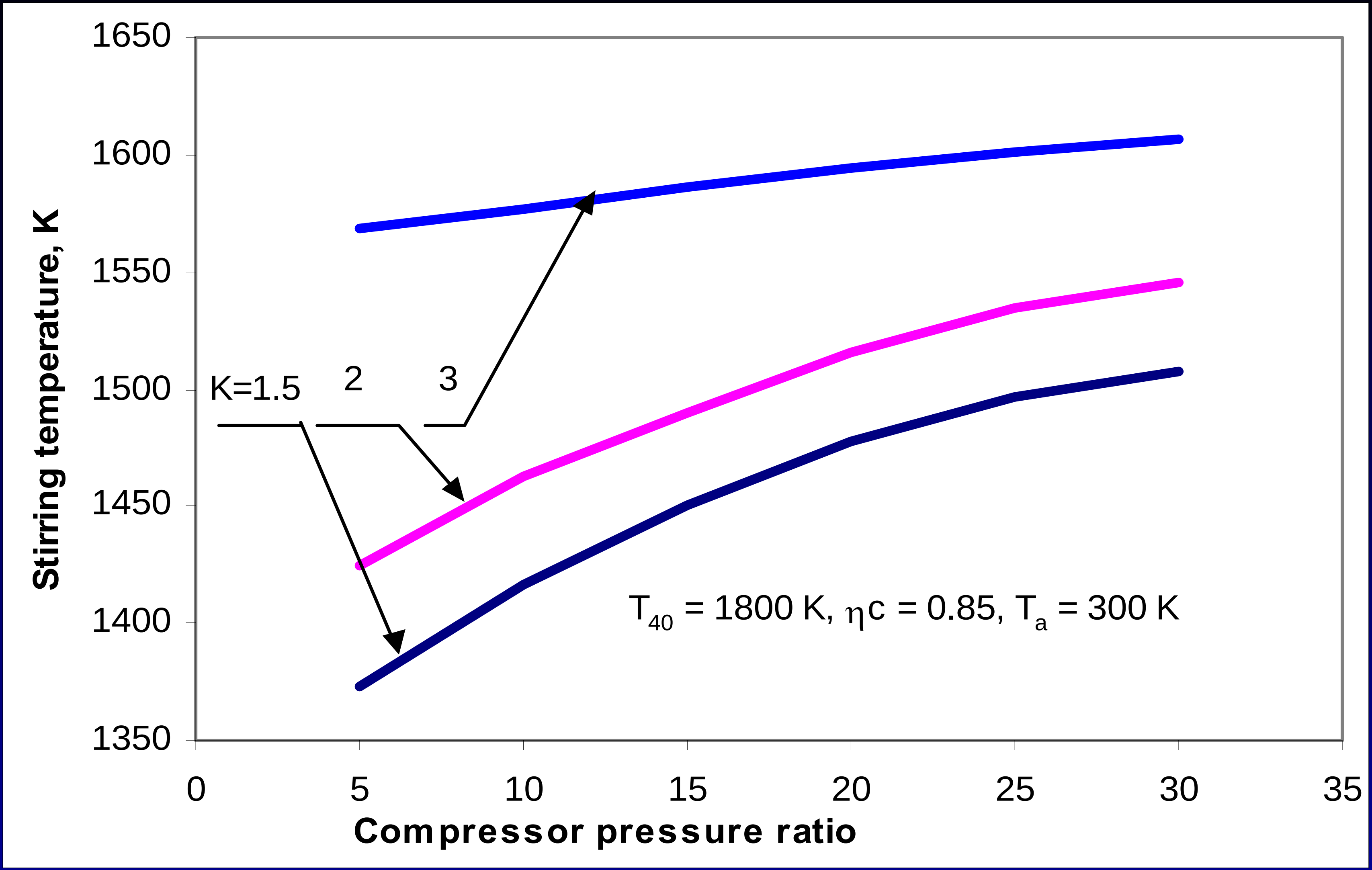
Ta=300K

VARIATION OF TEMPERATURE BEFORE COMBUSTOR (T_{03}) ON COMPRESSOR PRESSURE RATIO.

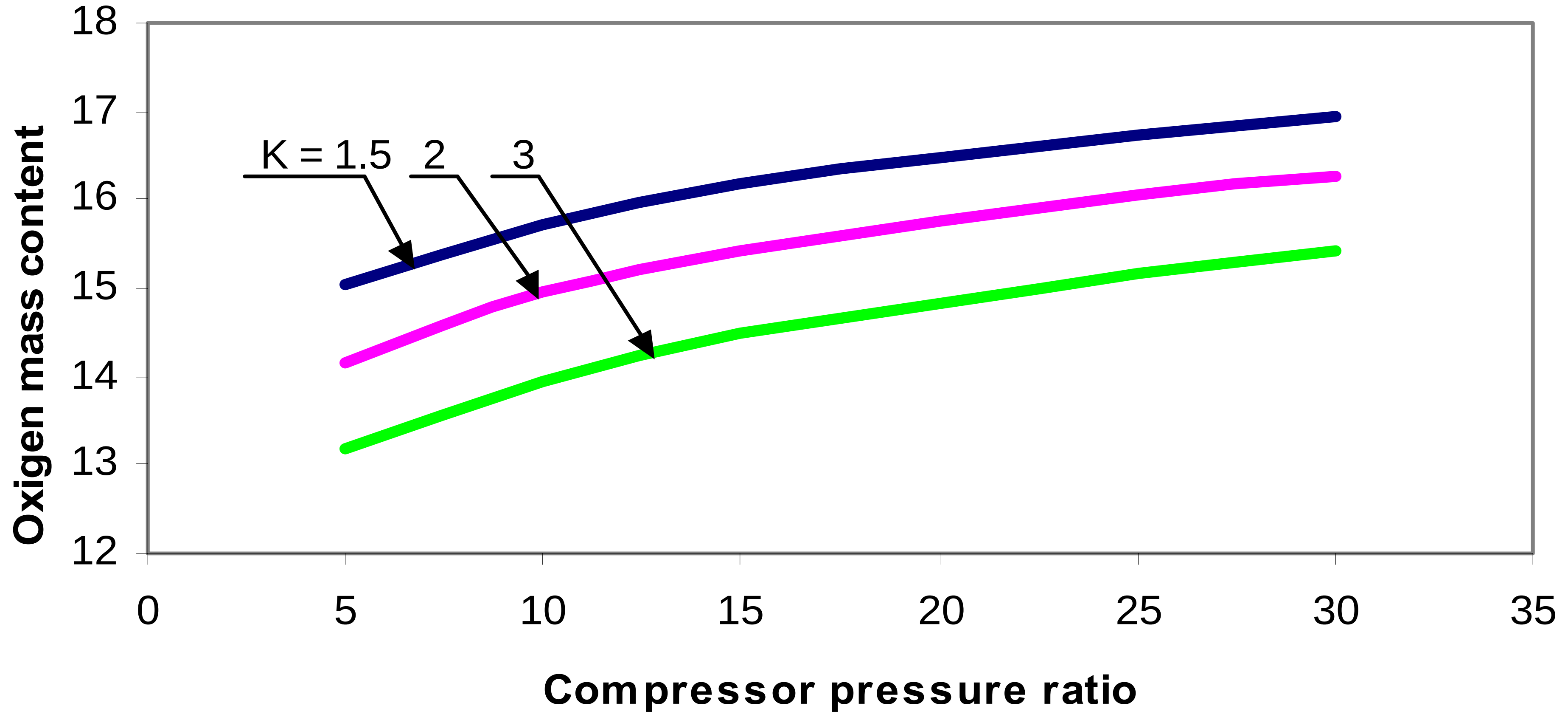


Ta=300K, for all K

VARIATION OF OXYGEN MASS CONTENT (%) (AFTER COMBUSTION) WITH COMPRESSOR PRESSURE RATIO



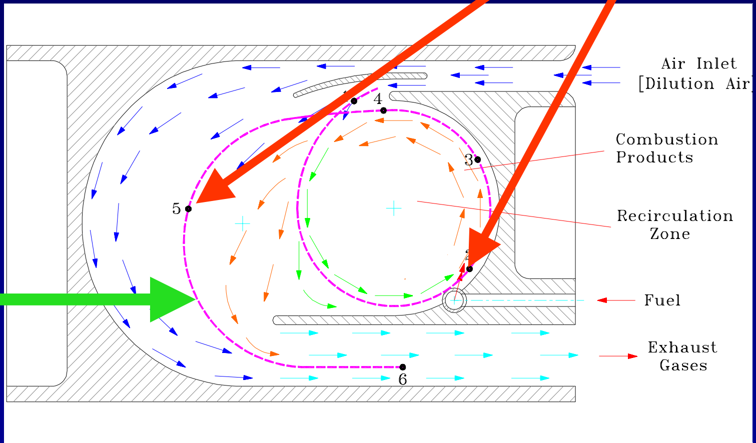
VARIATION OF STIRRING AIR TEMPERATURE WITH COMPRESSOR PRESSURE RATIO AND RECIRCULATION RATE.

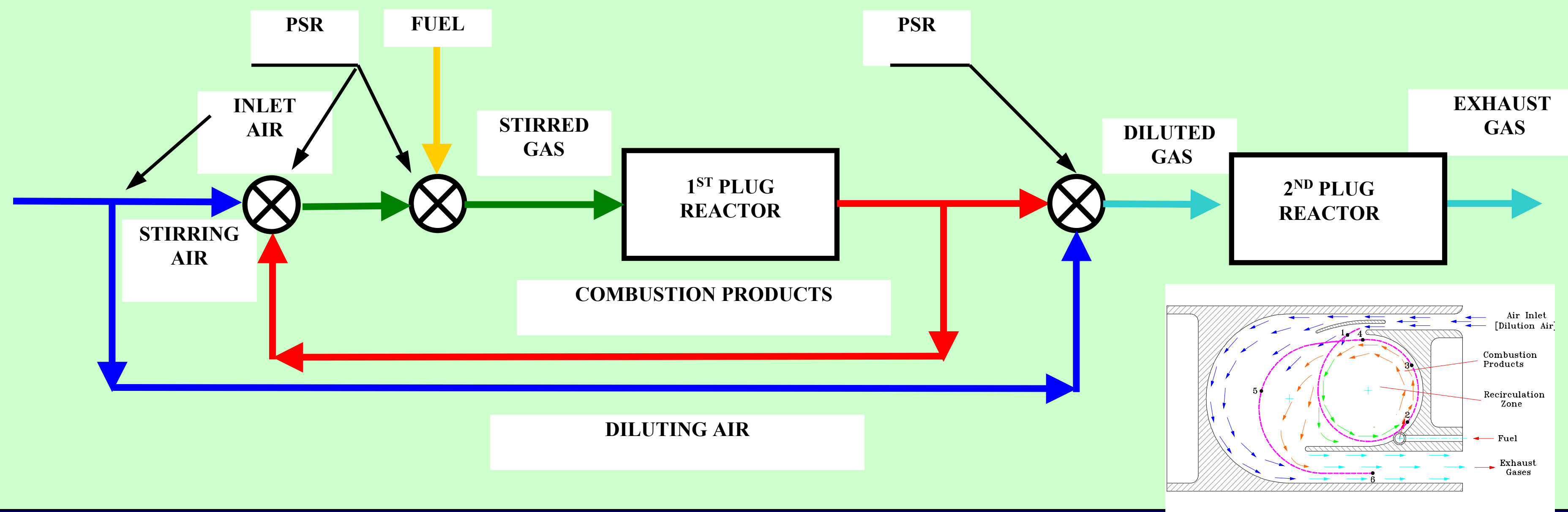


Ta=300K, T04=1800K, Efficiency=0.85

VAIATION OF STIRRING OXYGEN MASS CONTENT (%) WITH COMPRESSOR PRESSURE RATIO AND RECIRCULATION RATE.

1. THE SUBJECT OF THE PRESENT STUDY IS THE CHEMICAL PROCESSES THAT OCCUR BETWEEN POINTS 2-5
2. REACTIONS CONTINUE DURING DILUTION AS WELL, HOWEVER THEY ARE OF SECONDARY IMPORTANCE FOR UNDERSTANDING THE FLOX REGIME.

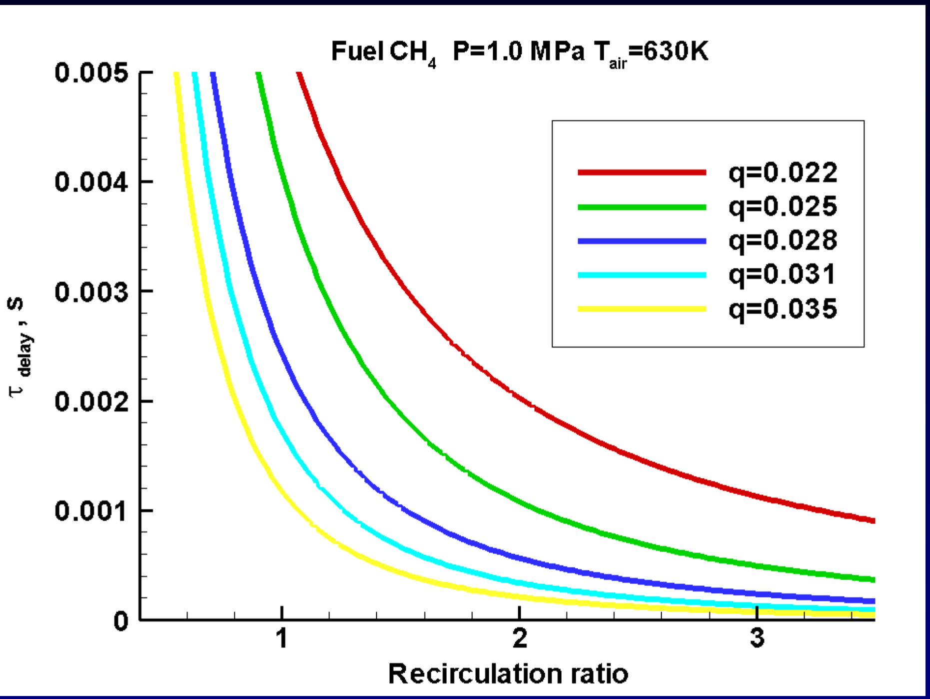




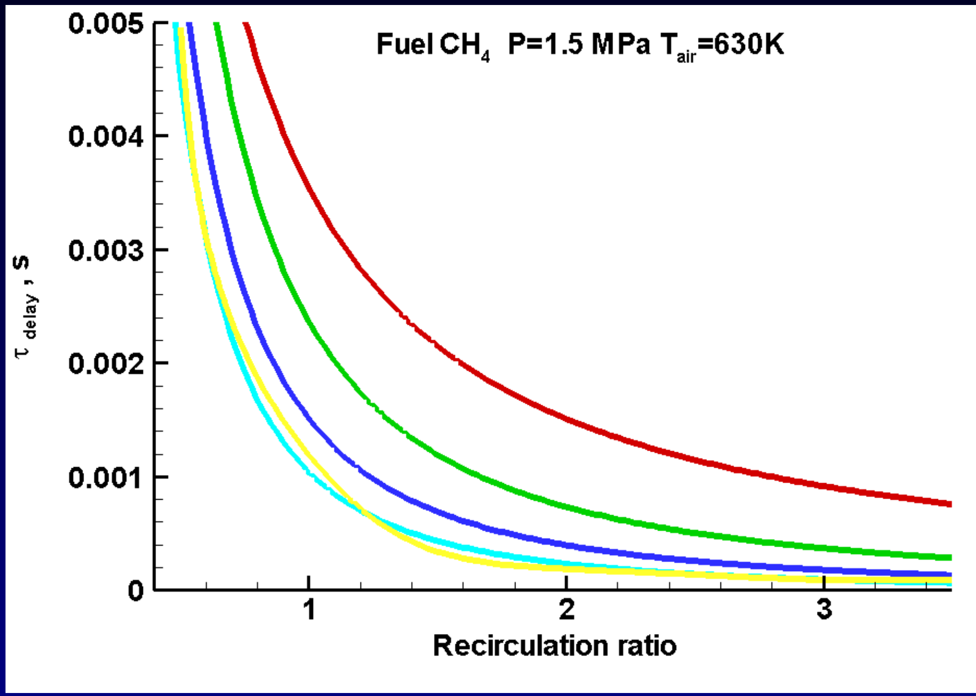
1. AIR IS MIXED WITH COMBUSTION PRODUCTS (AT DIFFERENT RECIRCULATION RATIO),
2. FUEL IS ADDED TO THE MIXTURE
3. PLUG REACTOR FOR CHEMICAL PROCESS SIMULATION
4. PSR FOR DILUTION (INSTANTANEOUS MIXING)
5. CALCULATION OF CHEMICAL REACTIONS WAS PERFORMED USING **GRI-MECH VERSION 3.0** PACKAGE WITH 350 REACTIONS
6. RESIDENCE TIME IN THE 1st PLUG REACTOR WAS SET TO EQUAL TO 5 AND 10 MS.

SIMULATION SCHEMATICS

P=1.0 MPa



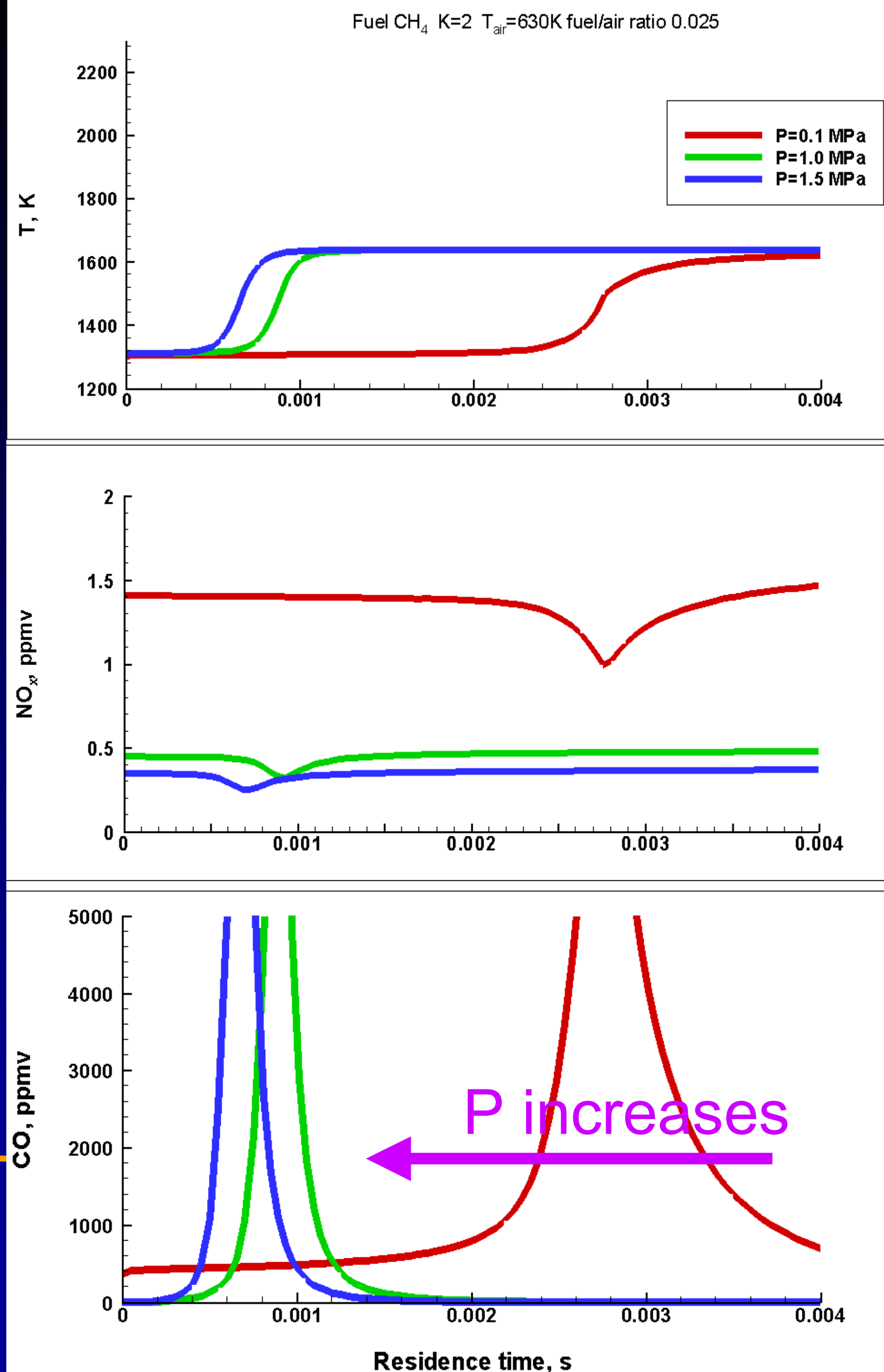
P=1.5 MPa



τ_{delay} reduces with K, pressure and heat addition !

VARIATION OF DELAY TIME WITH K (R.R.) AND HEAT ADDITION

EFFECT Of τ and P ON REACTION



K=2

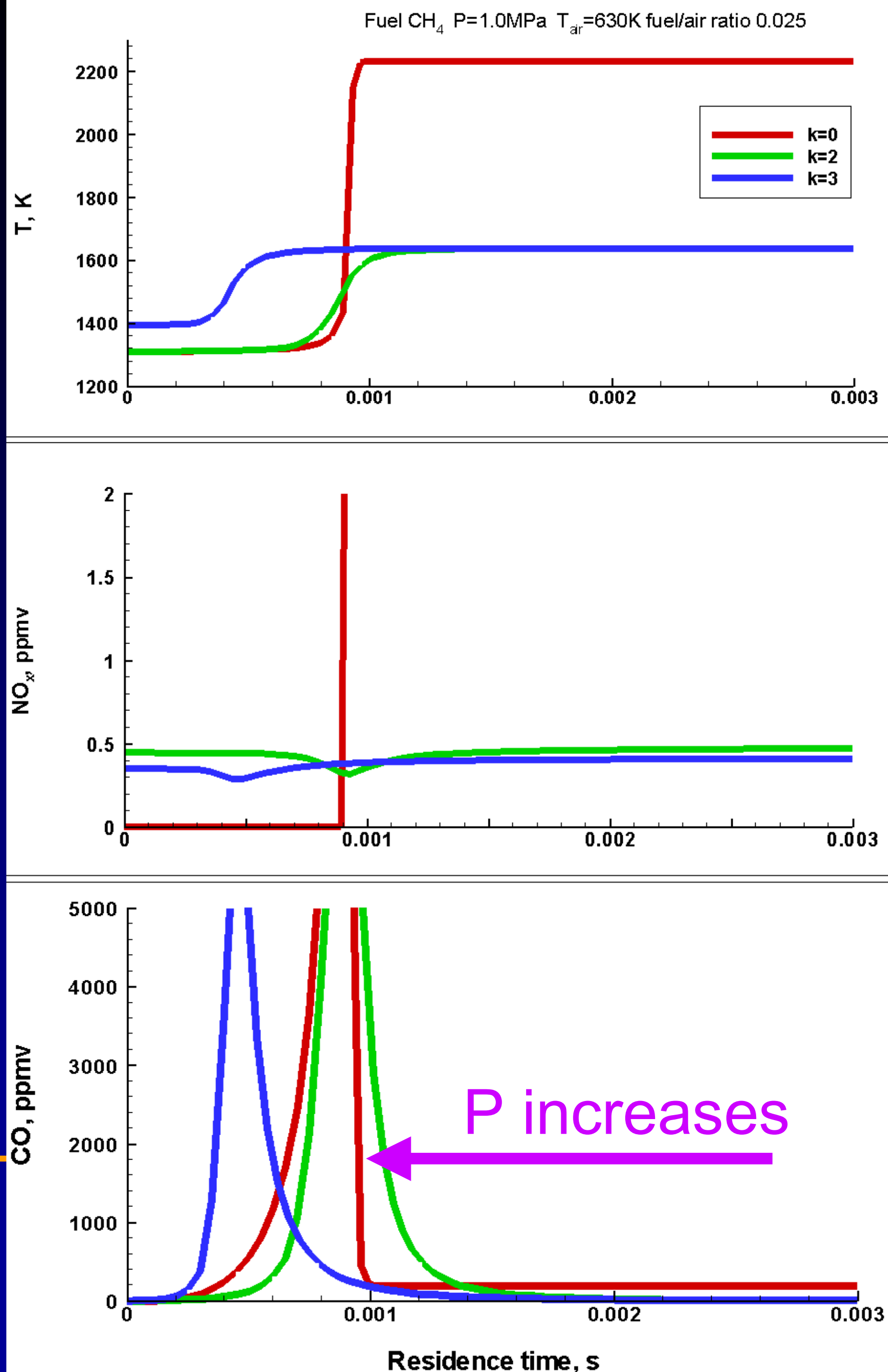
for k=0, Ts=1350 K

for K=2,3, Ta=630 K

NOx and CO reduces with pressure

for k=0, Ts=1350 K

for K=2,3, Ta=630 K



EFFECT OF

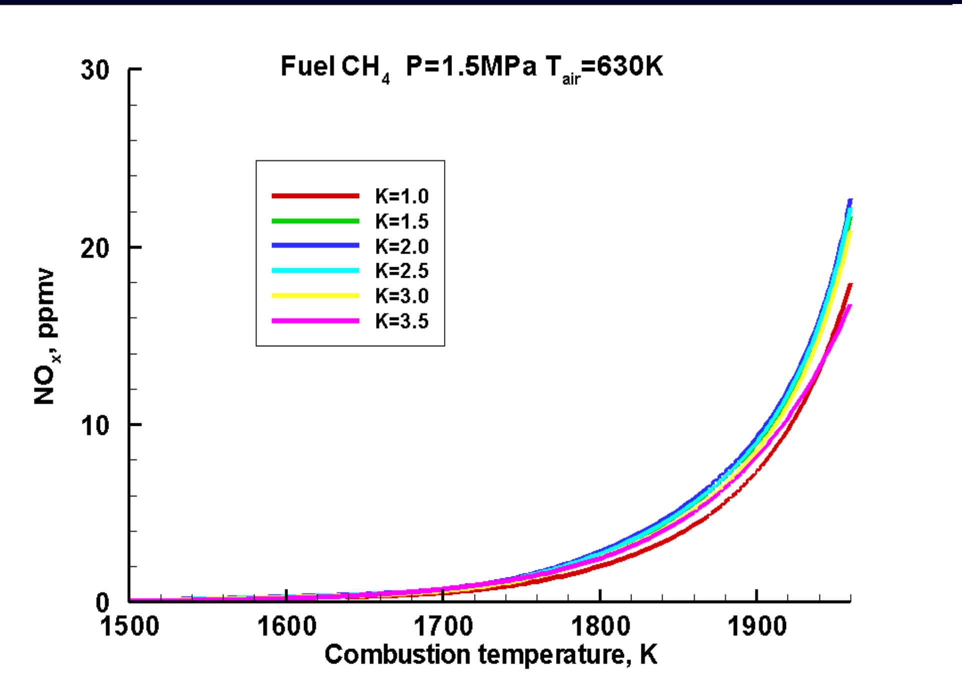
K & τ_{res}.

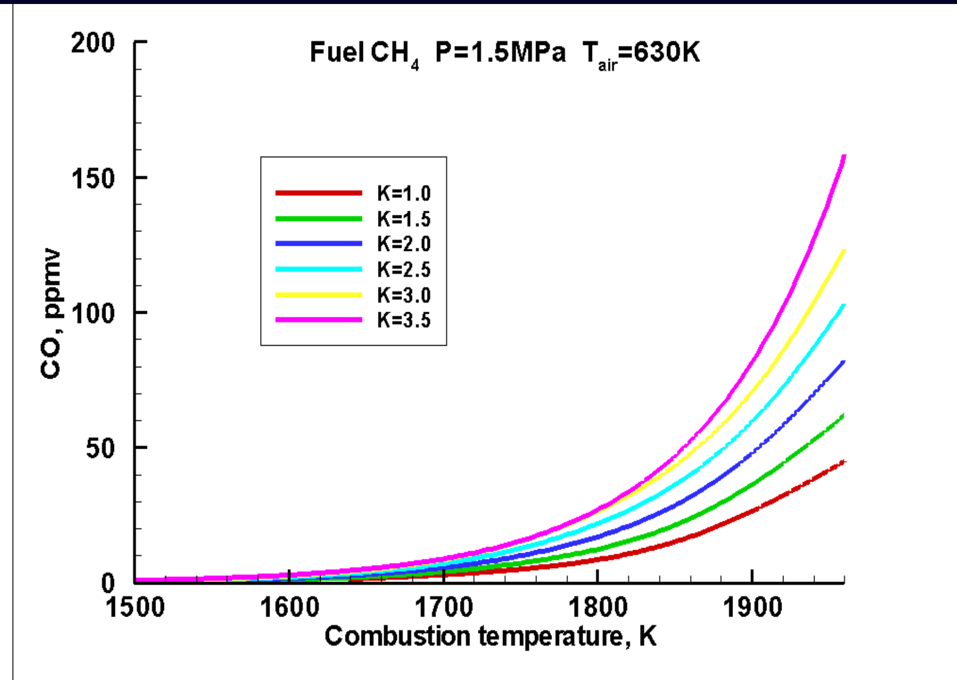
ON REACTION

P=1.0 MPa

NOx (ppmv)

CO (ppmv)





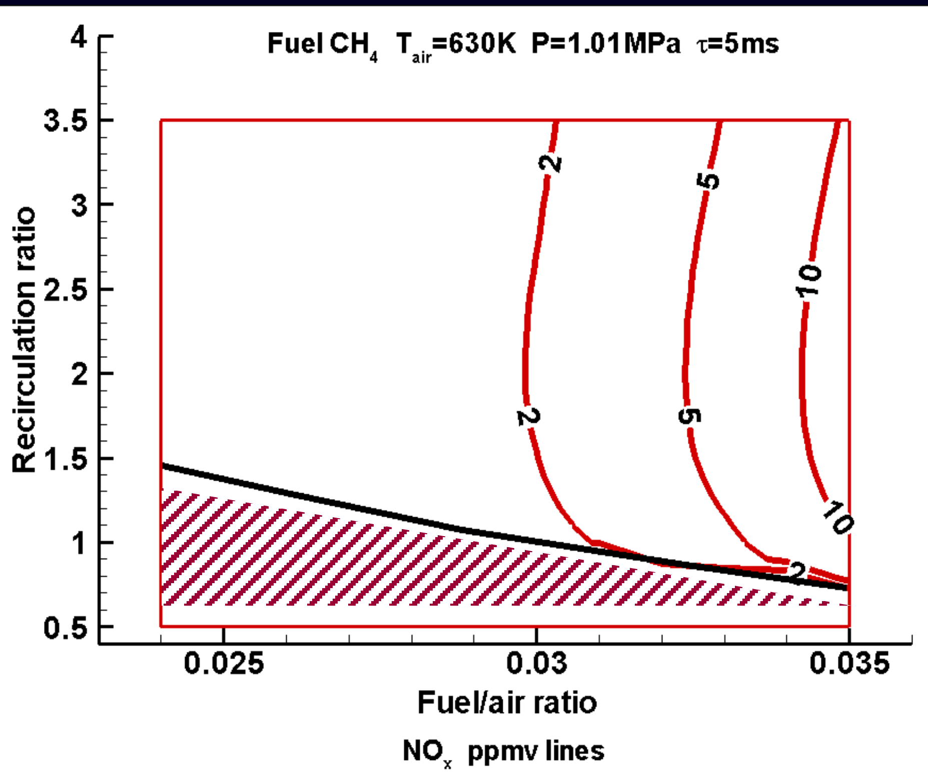
NOx does not depend on K, CO does.

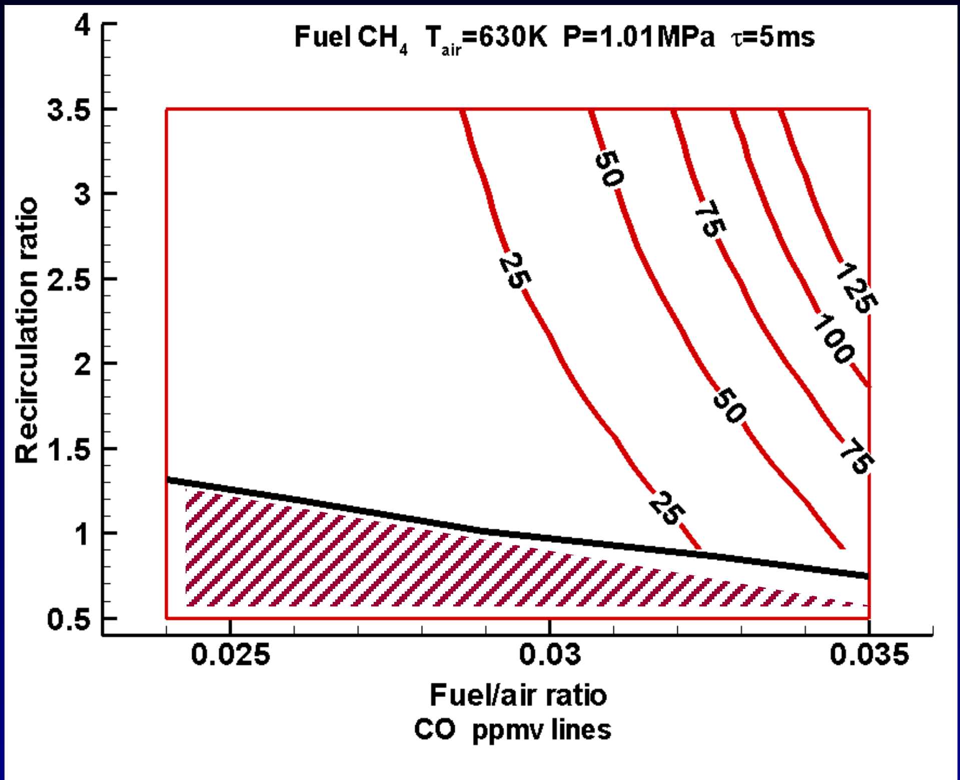
EMISSION DEPENDENCE ON COMBUSTION TEMPERATURE AND K

NOx (ppmv) lines

τ =5ms

CO (ppmv) lines



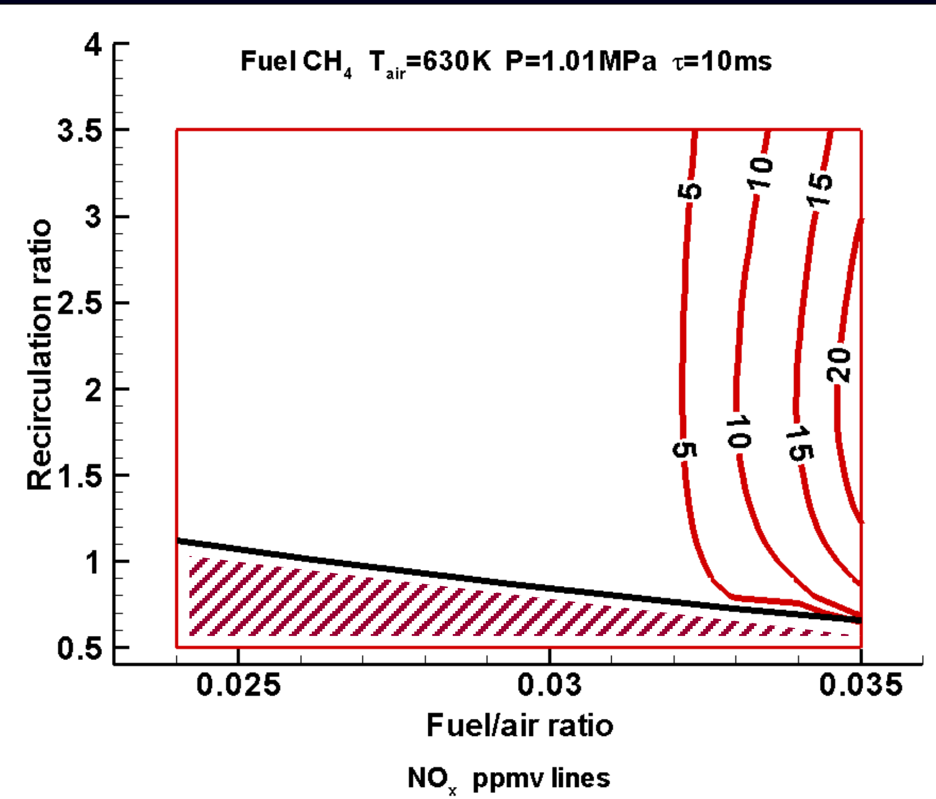


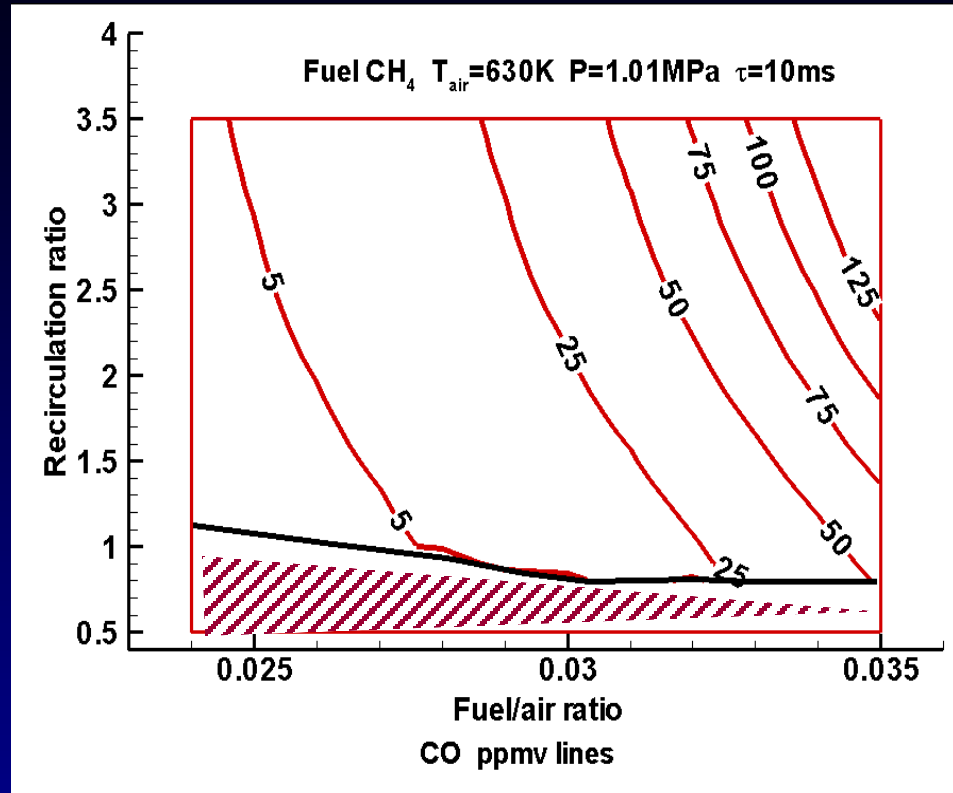
COMBUSTION STABILITY LIMITS FOR τ =5ms

NOx (ppmv) lines

τ =10ms

CO (ppmv) lines





stable region increases with τ

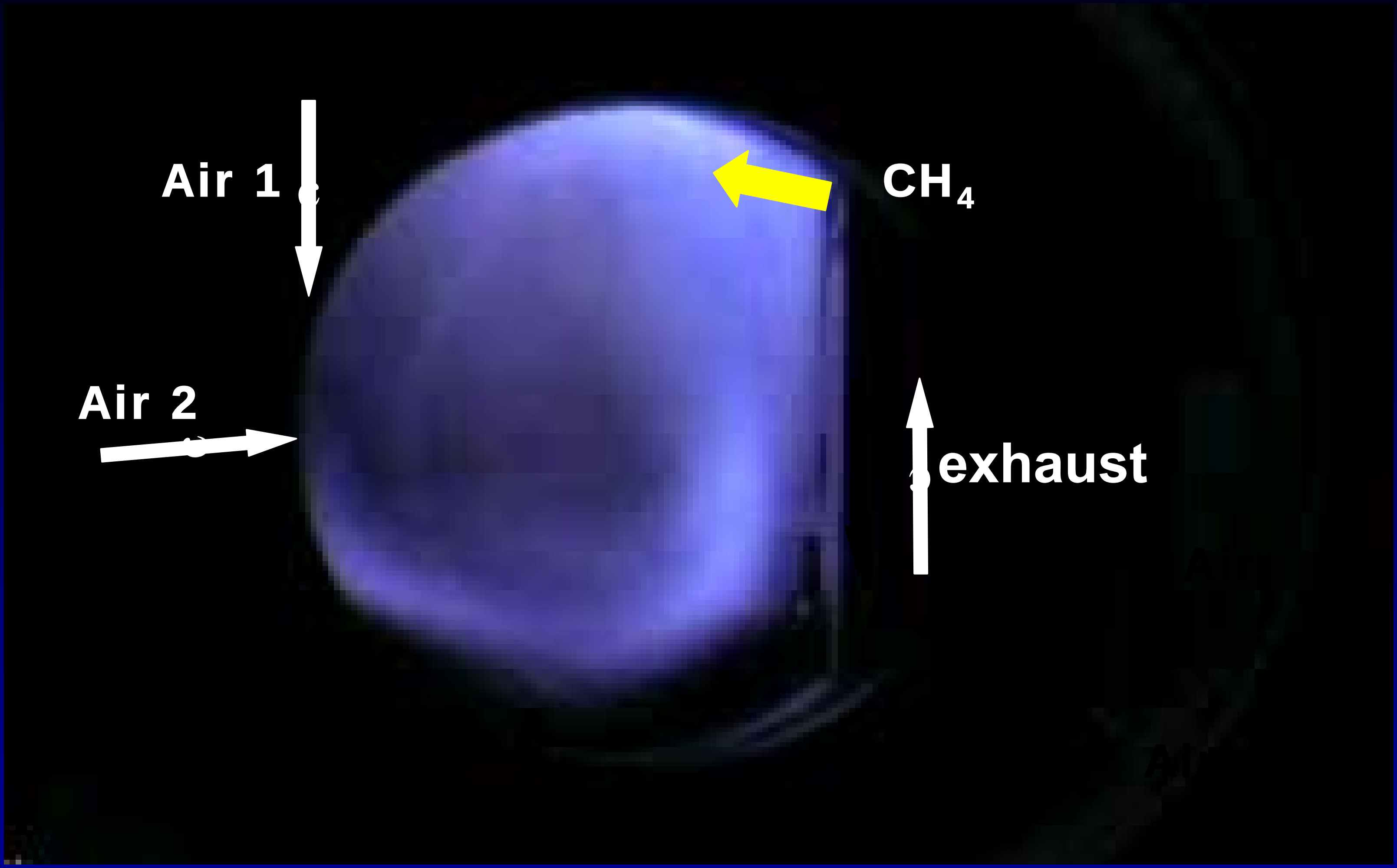
COMBUSTION STABILITY LIMITS FOR τ =10ms

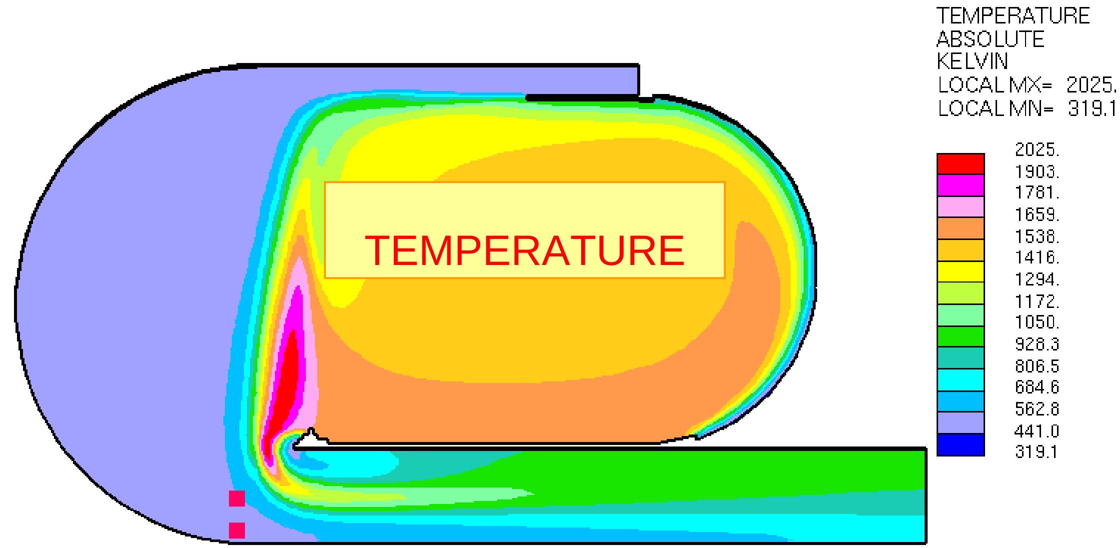
Conclusion:

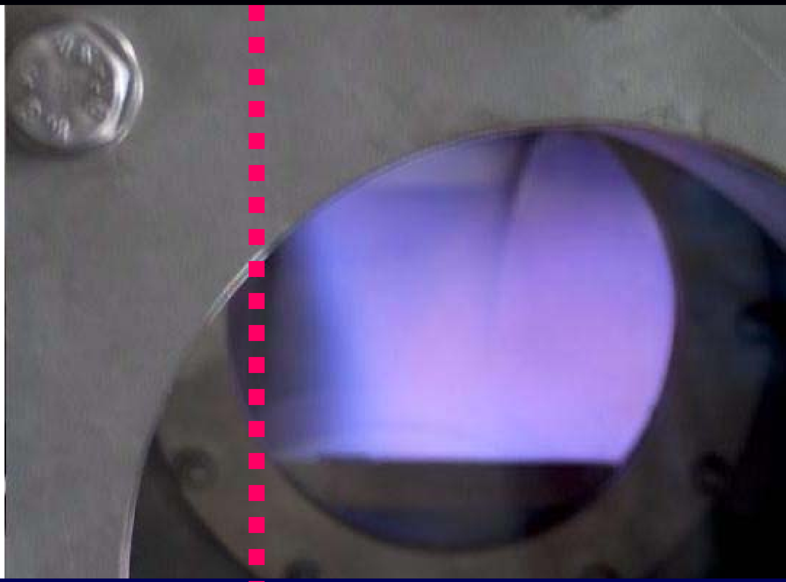
As NOx is almost independent of K we can restate the Objectives:

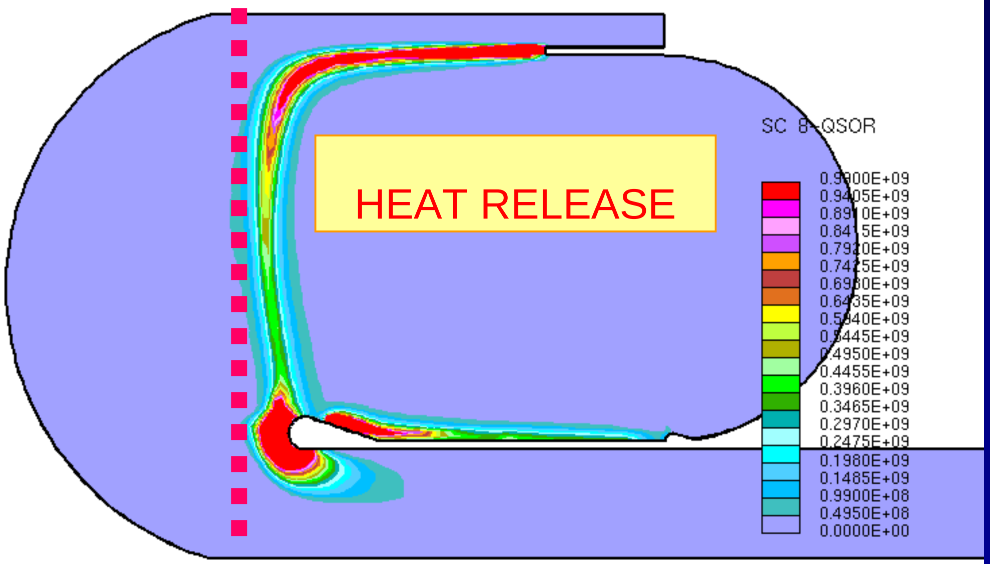
Optimisation (minimisation) of recirculation ratio with respect to maximum heat release rate, $Qr/(\tau_3 + \tau_4)$, (total combustion time)

Flame Visualisation

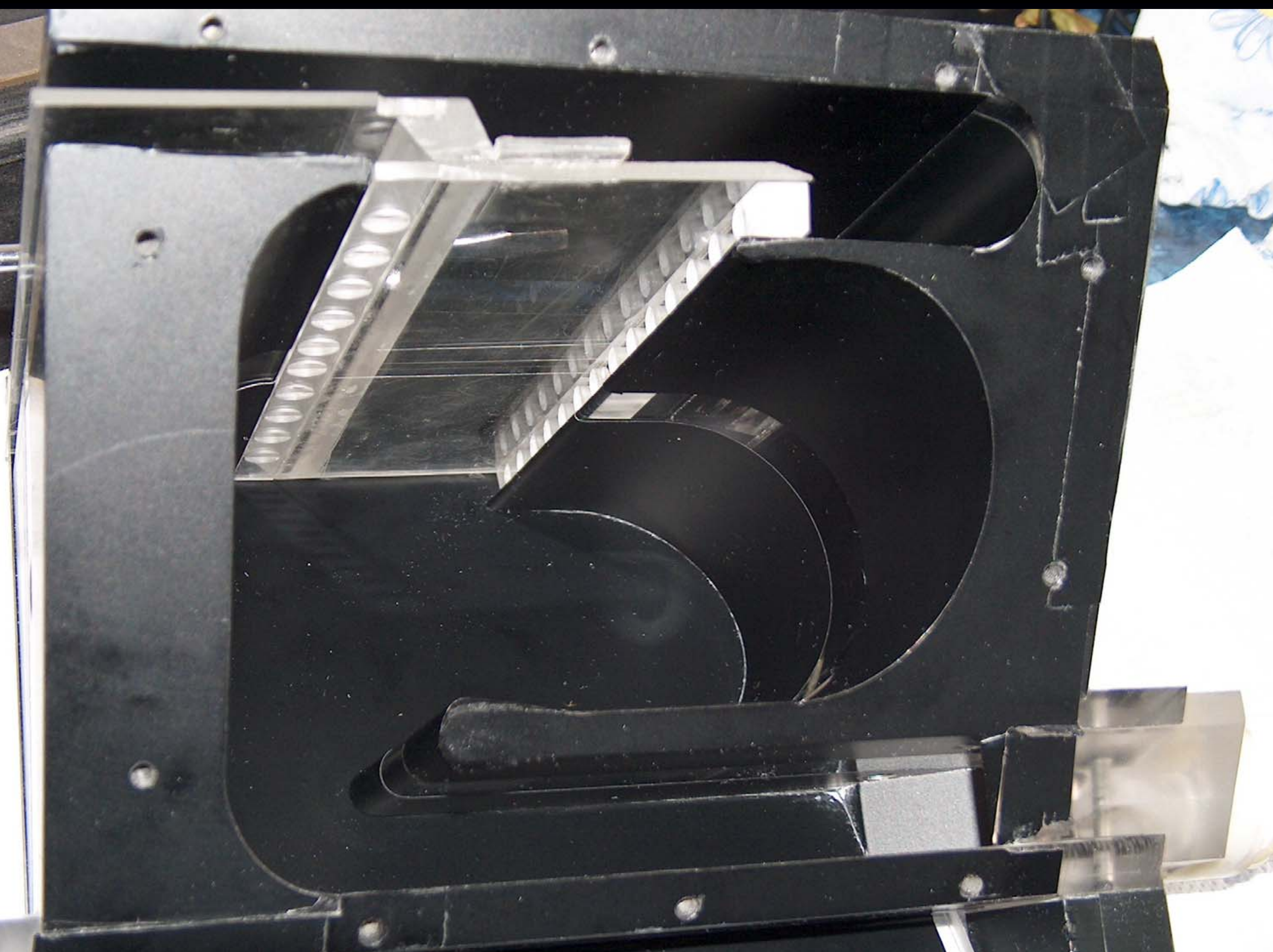


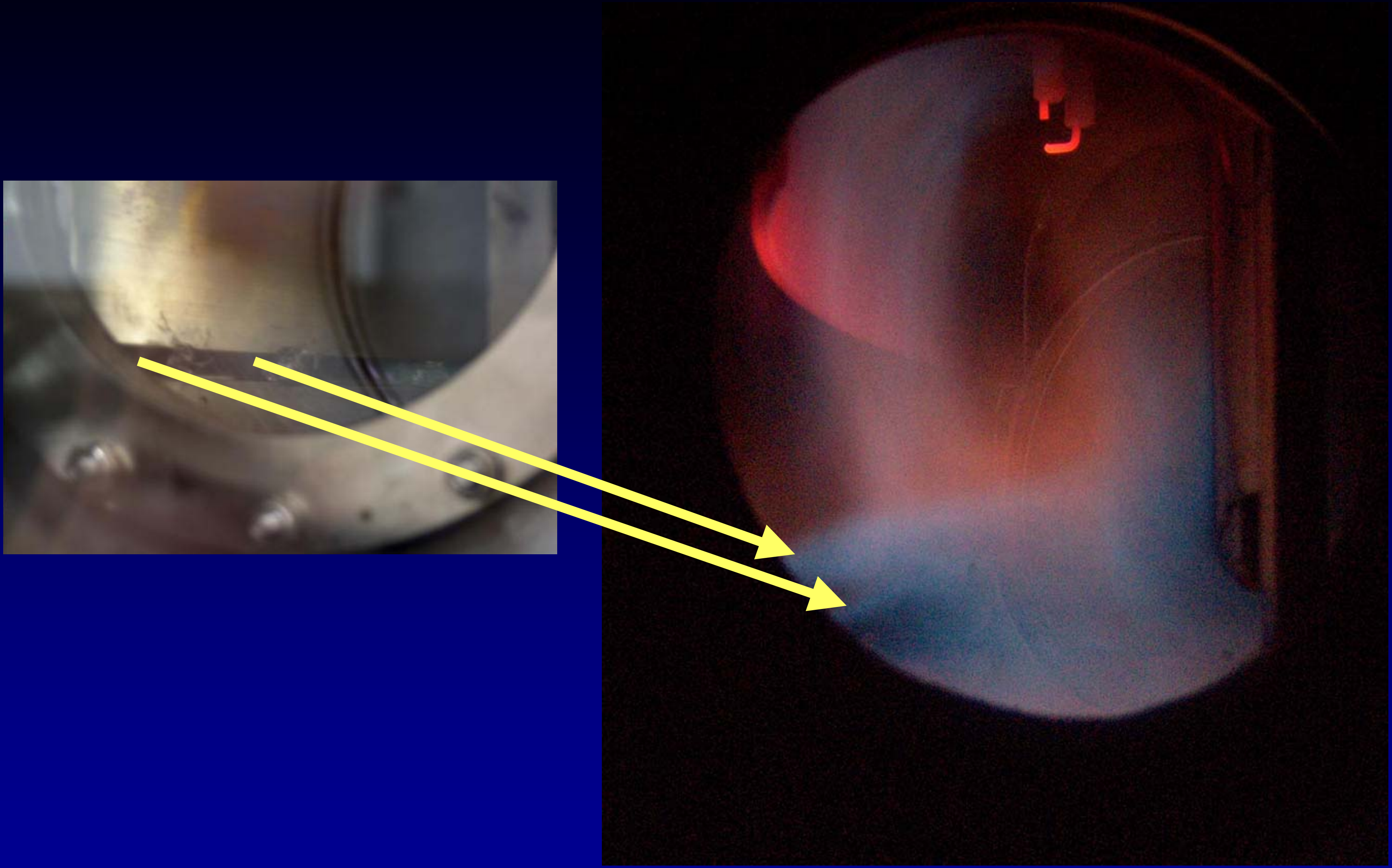


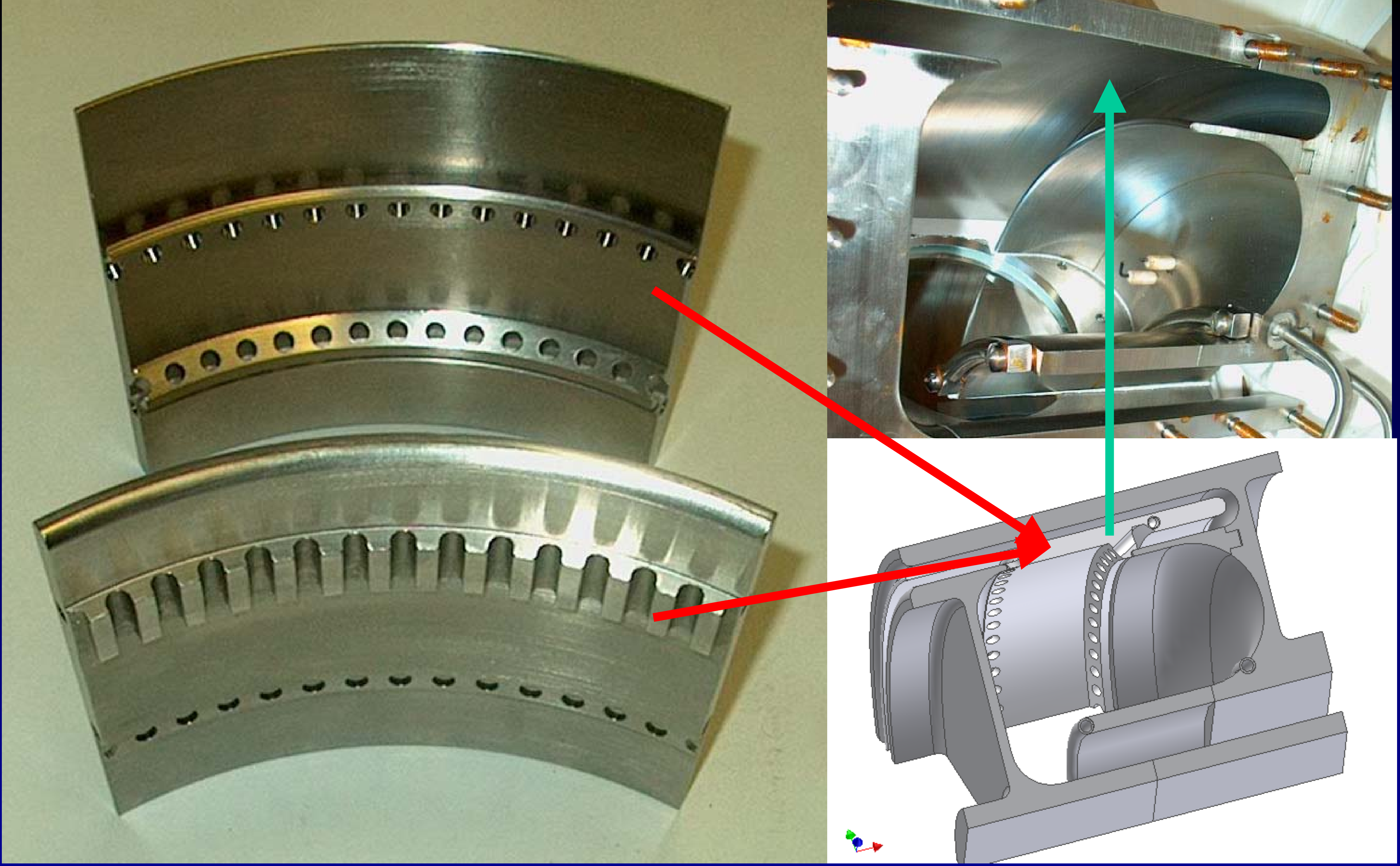




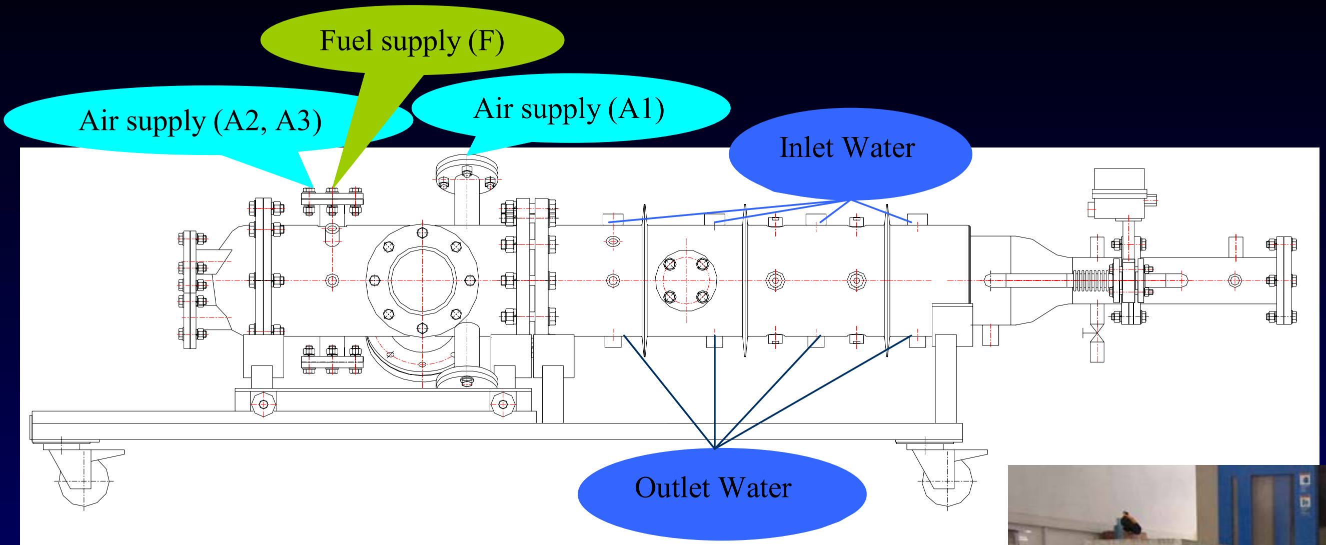
DESIGN PHASE 1 - POOR MIXING OF STIRRED GAS, NARROW REACTION REGION



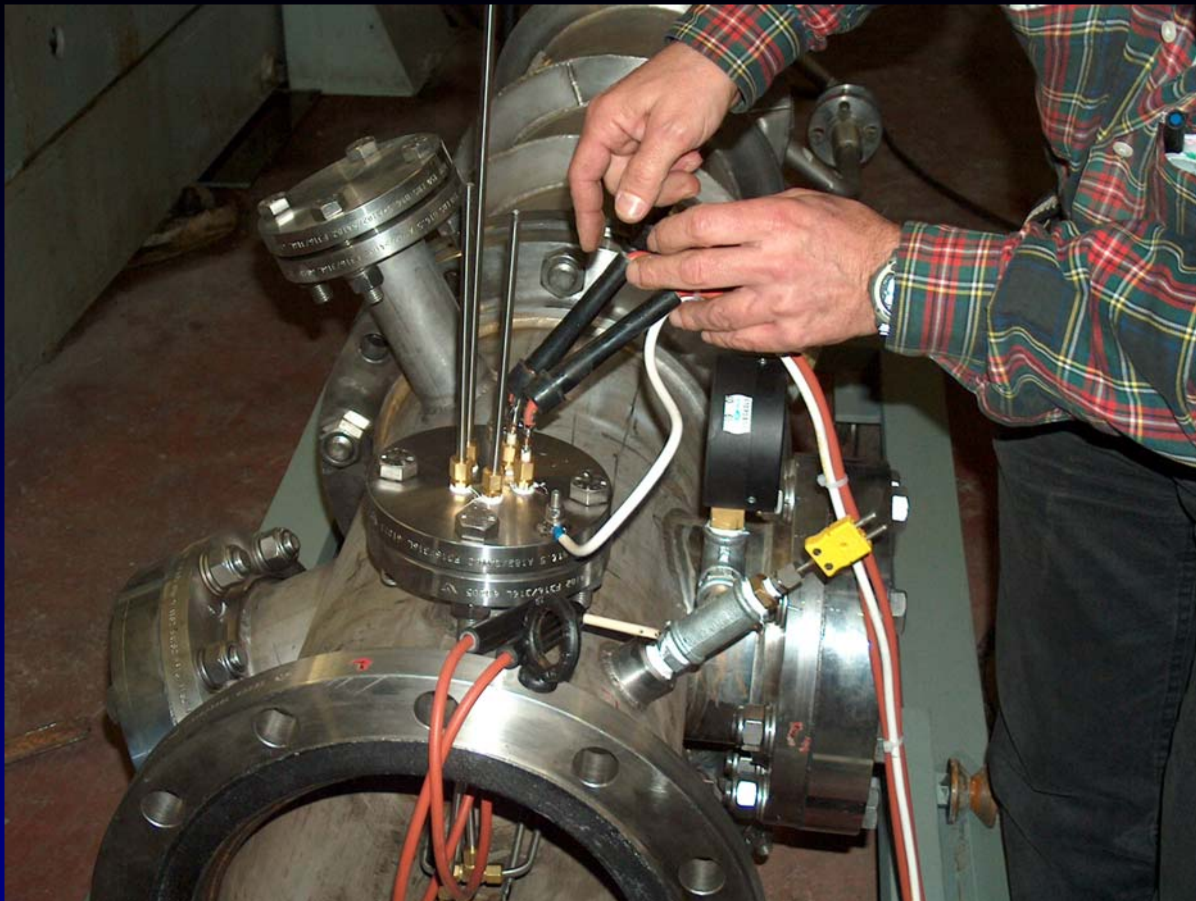




AIR INLETS OPTIONAL MODIFICATIONS



HIGH PRESSURE COMBUSTOR SECTOR TEST RIG



HIGH PRESSURE COMBUSTOR SECTOR TEST RIG

Laboratory tests before delivery to Ansaldo, Italy

Deliverable 1.3 was “Delivered”


BARI-ITALY
HIGH PRESSURE COMBUSTOR
SECTOR TEST RIG
התקנה באיטליה בחב'
Ansaldo Caldaie Ltd,

HIGH PRESSURE COMBUSTOR SECTOR TEST RIG

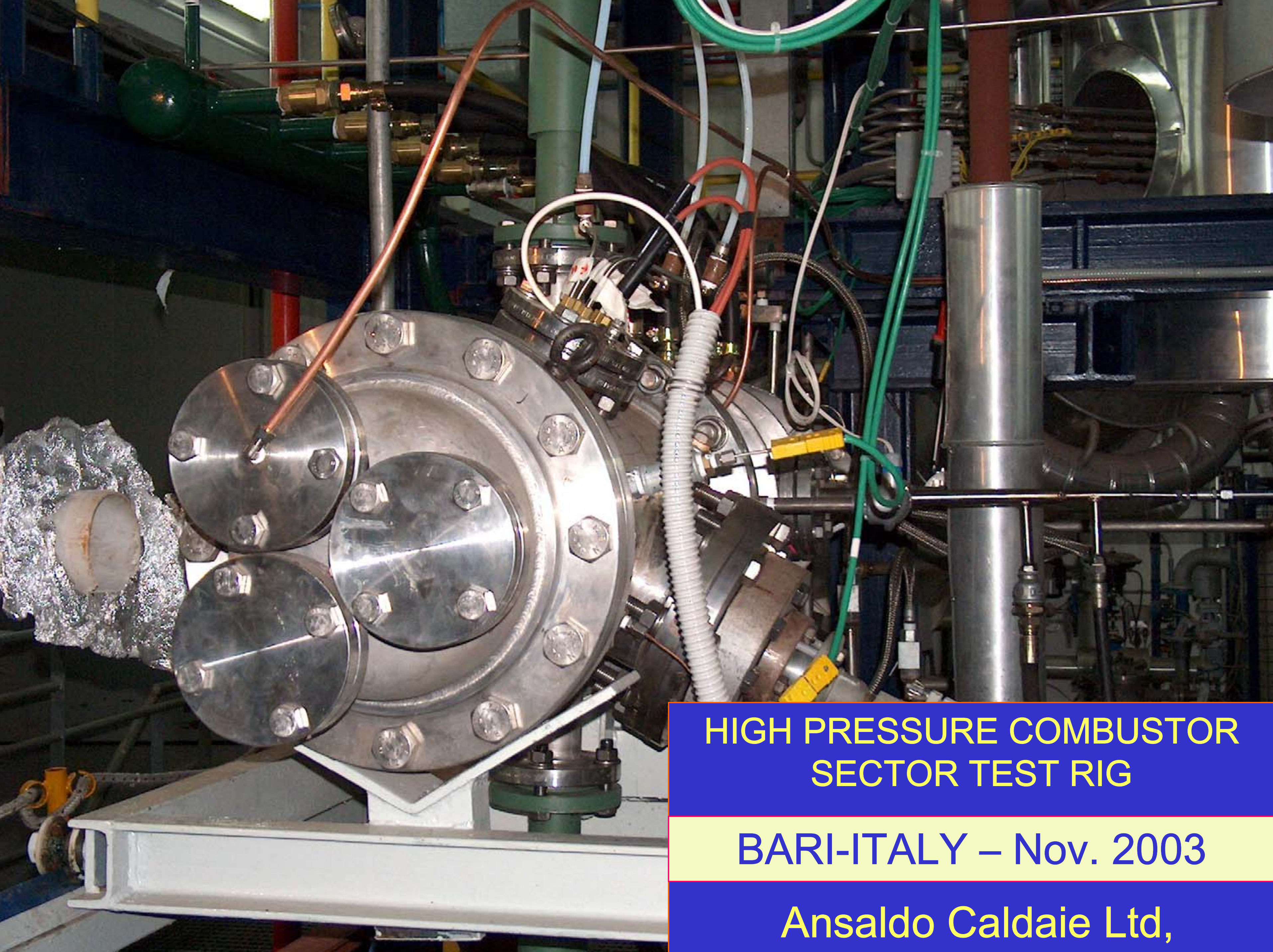
ב' BARI-ITALY ה

Ansaldo Caldaie Ltd,

HIGH PRESSURE COMBUSTOR
SECTOR TEST RIG

BARI-ITALY – June 2003

Ansaldo Caldaie Ltd,



HIGH PRESSURE COMBUSTOR SECTOR TEST RIG

BARI-ITALY – Nov. 2003

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HIGH PRESSURE COMBUSTOR SECTOR TEST RIG

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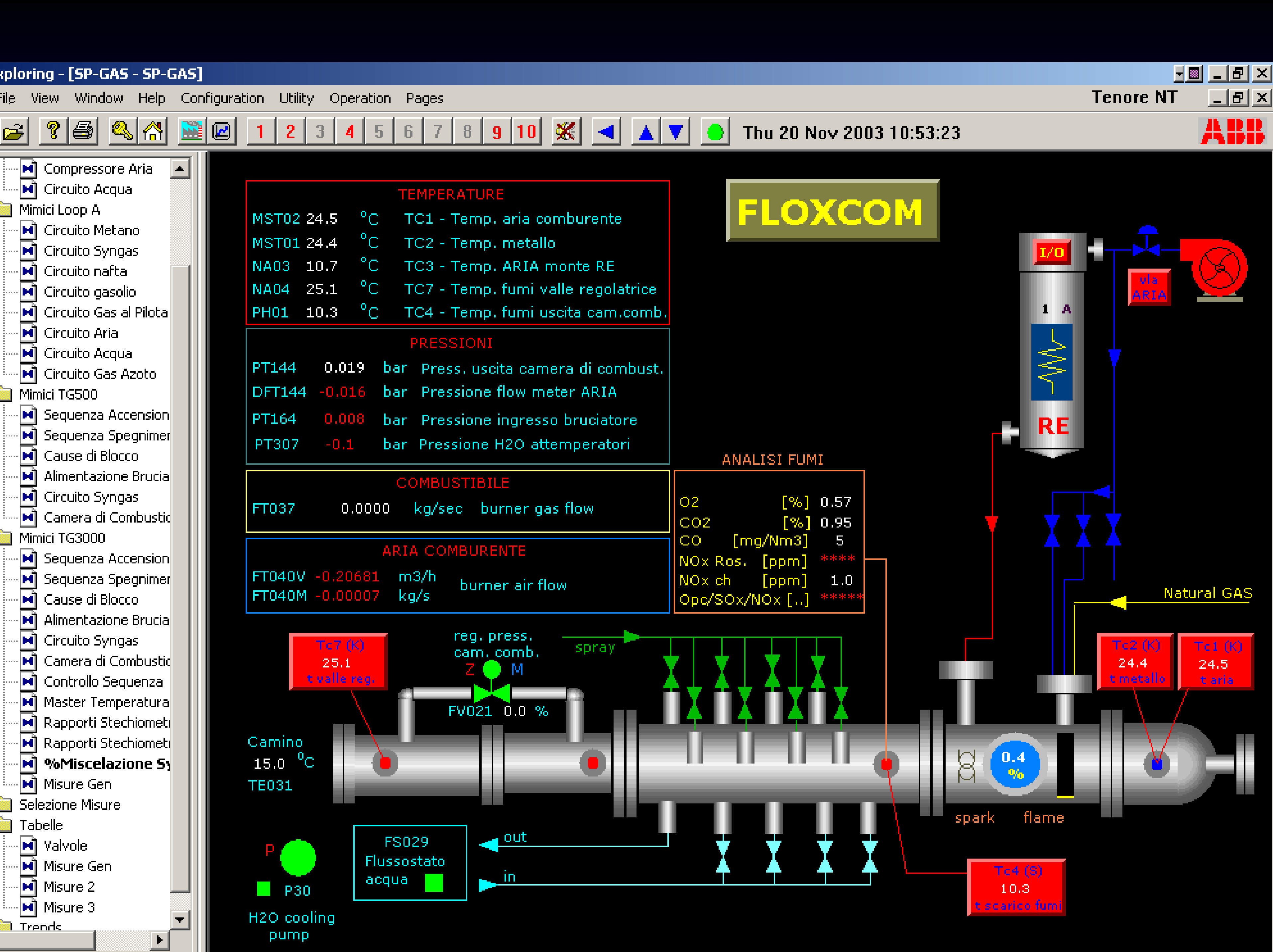
Ansaldo Caldaie Ltd,

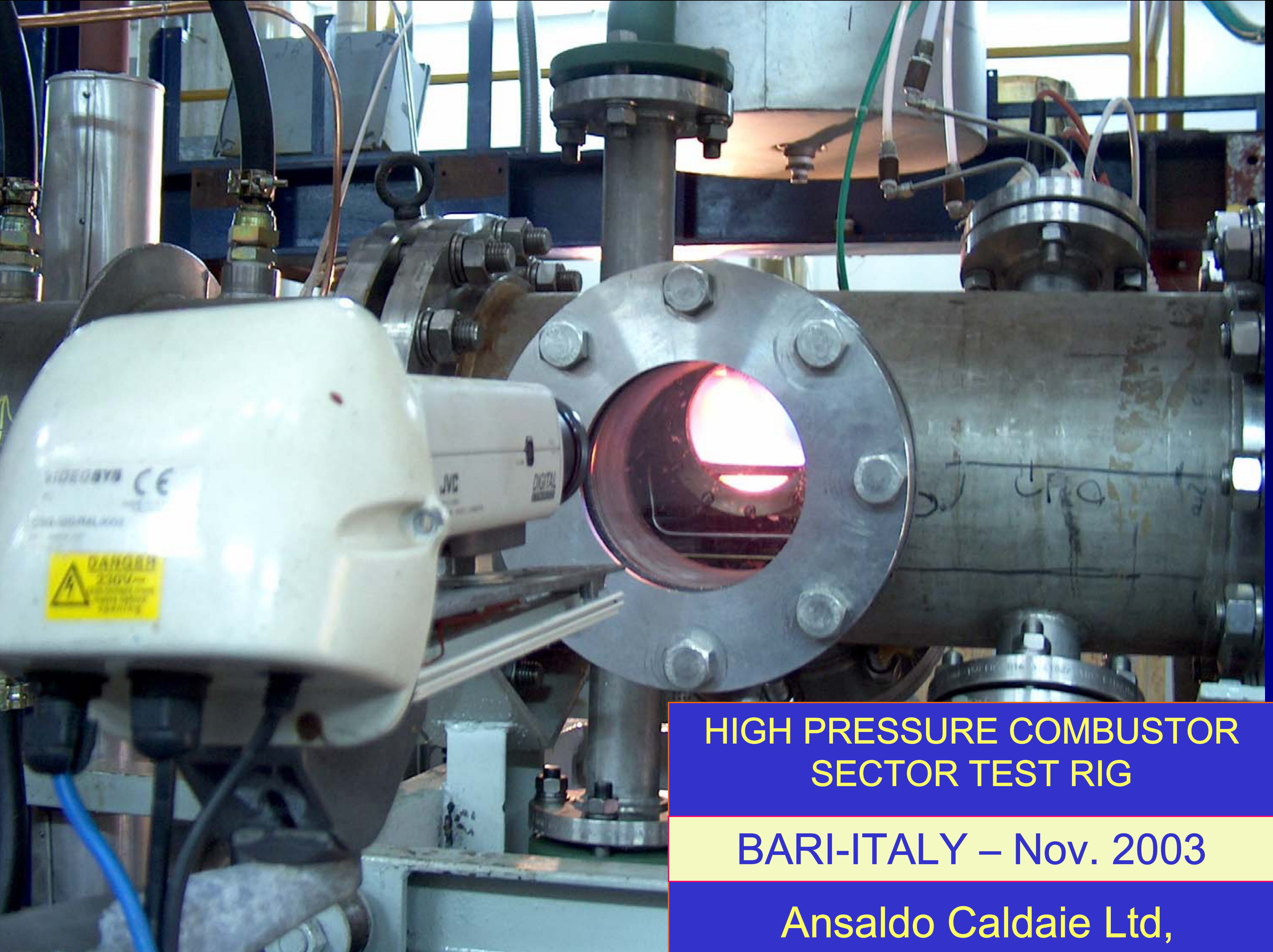
HIGH PRESSURE COMBUSTOR SECTOR TEST RIG

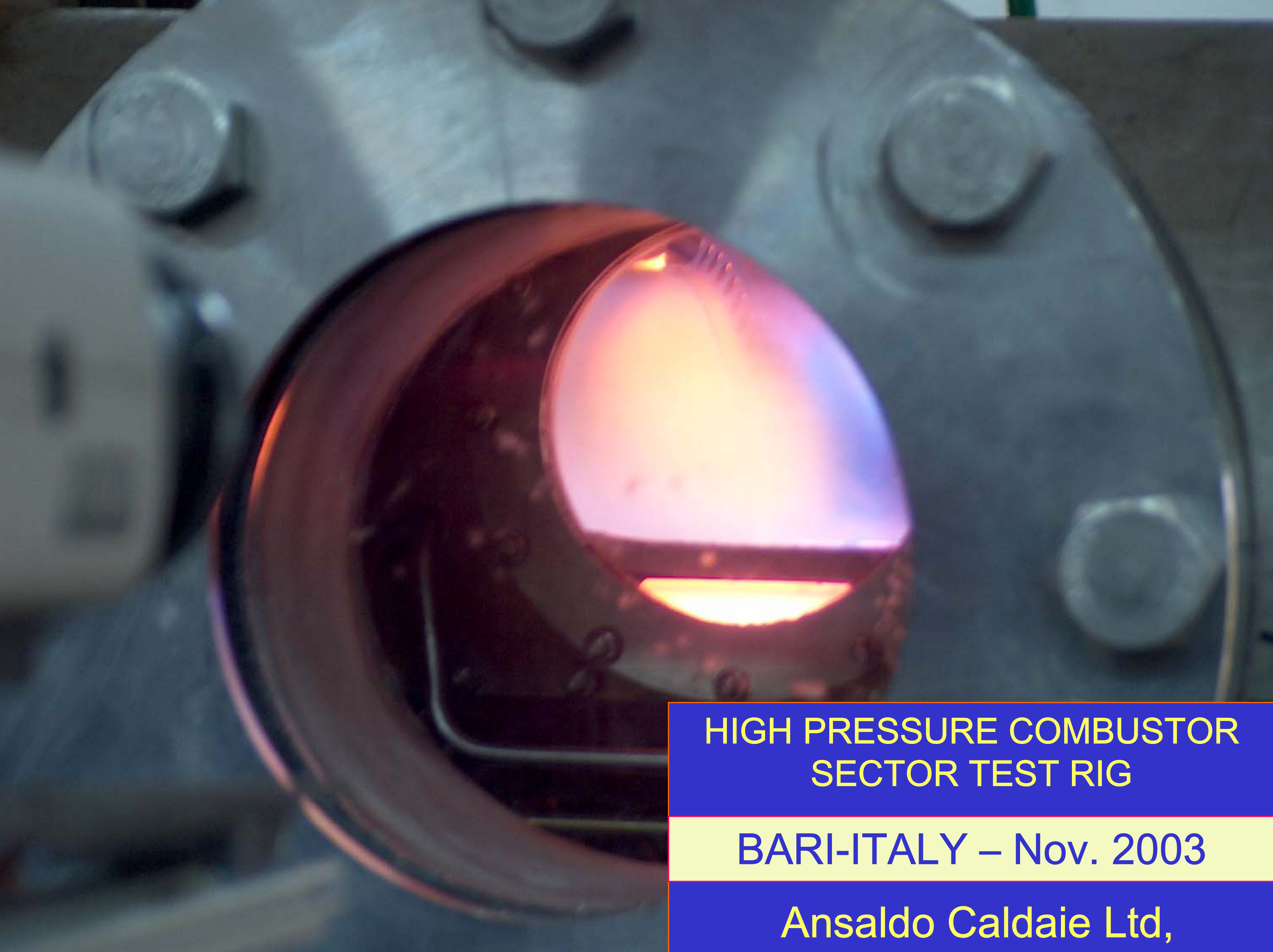
BARI-ITALY – Nov. 2003

Ansaldo Caldaie Ltd,


xploring - [SP-GAS - SP-GAS]
File View Window Help Configuration Utility Operation Pages
Tenore NT
Thu 20 Nov 2003 10:53:23
ABB
Compressore Aria
Circuito Acqua
Mimici Loop A
Circuito Metano
Circuito Syngas
Circuito nafta
Circuito gasolio
Circuito Gas al Pilota
Circuito Aria
Circuito Acqua
Circuito Gas Azoto
Mimici TG500
Sequenza Accension
Sequenza Spegnimer
Cause di Blocco
Alimentazione Brucia
Circuito Syngas
Camera di Combustic
Mimici TG3000
Sequenza Accension
Sequenza Spegnimer
Cause di Blocco
Alimentazione Brucia
Circuito Syngas
Camera di Combustic
Controllo Sequenza
Master Temperatura
Rapporti Stechiometi
Rapporti Stechiometi
%Miscelazione Sy
Misure Gen
Selezione Misure
Tabelle
Valvole
Misure Gen
Misure 2
Misure 3
Trends
TEMPERATURE
MST02 24.5 °C TC1 - Temp. aria comburente
MST01 24.4 °C TC2 - Temp. metallo
NA03 10.7 °C TC3 - Temp. ARIA monte RE
NA04 25.1 °C TC7 - Temp. fumi valle regolatrice
PH01 10.3 °C TC4 - Temp. fumi uscita cam.comb.
PRESSIONI
PT144 0.019 bar Press. uscita camera di combust.
DFT144 -0.016 bar Pressione flow meter ARIA
PT164 0.008 bar Pressione ingresso bruciatore
PT307 -0.1 bar Pressione H2O attemperatori
COMBUSTIBILE
FT037 0.0000 kg/sec burner gas flow
ARIA COMBURENTE
FT040V -0.20681 m3/h
FT040M -0.00007 kg/s
burner air flow
FLOXCOM
ANALISI FUMI
O2 [%] 0.57
CO2 [%] 0.95
CO [mg/Nm3] 5
NOx Ros. [ppm] ****
NOx ch [ppm] 1.0
Opc/SOx/NOx [..] *****
I/O
vla ARIA
1 A
RE
Natural GAS
Tc7 (K) 25.1 t valle reg.
reg. press. cam. comb.
spray
Z M
FV021 0.0 %
Tc2 (K) 24.4 t metallo
Tc1 (K) 24.5 t aria
Camino 15.0 °C TE031
0.4 %
spark
flame
P
P30
H2O cooling pump
FS029 Flussostato acqua
out
in
Tc4 (S) 10.3 t scarico fumi


01:25:27 05


JVC
DIGITAL
DANGER
HIGH PRESSURE COMBUSTOR
SECTOR TEST RIG
BARI-ITALY – Nov. 2003
Ansaldo Caldaie Ltd,

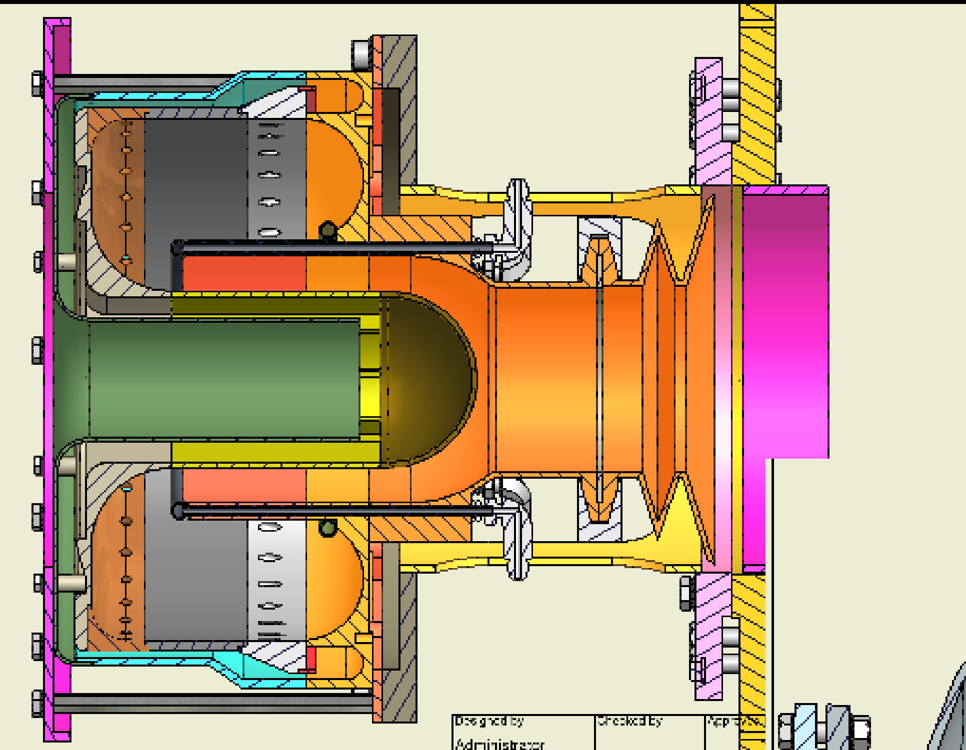


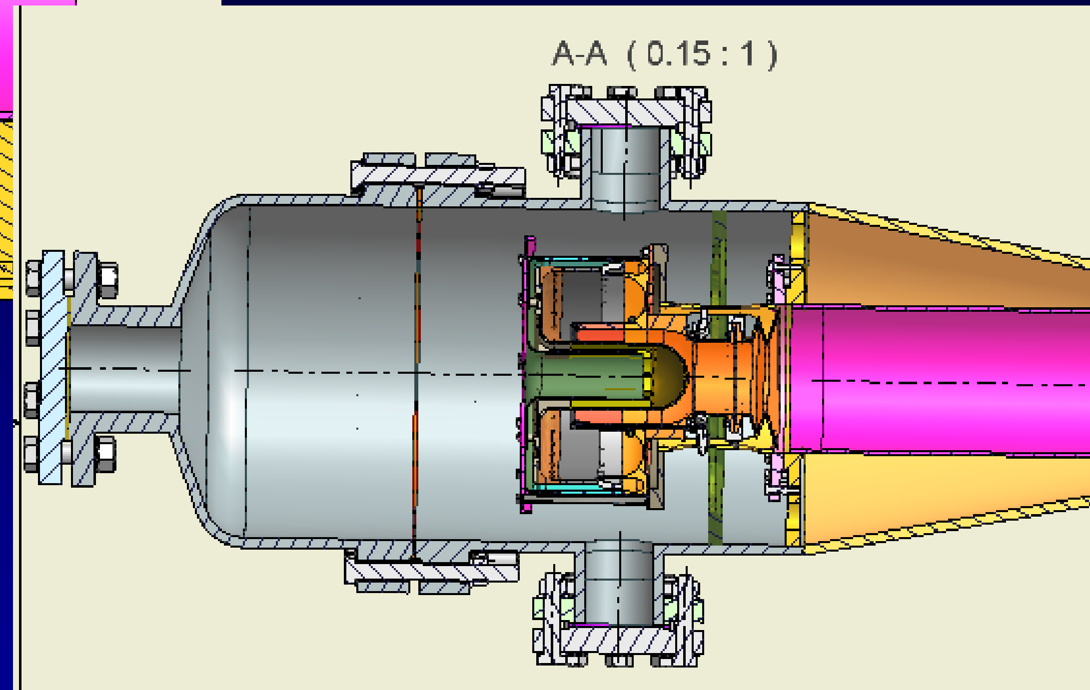
HIGH PRESSURE COMBUSTOR
SECTOR TEST RIG

BARI-ITALY – Nov. 2003

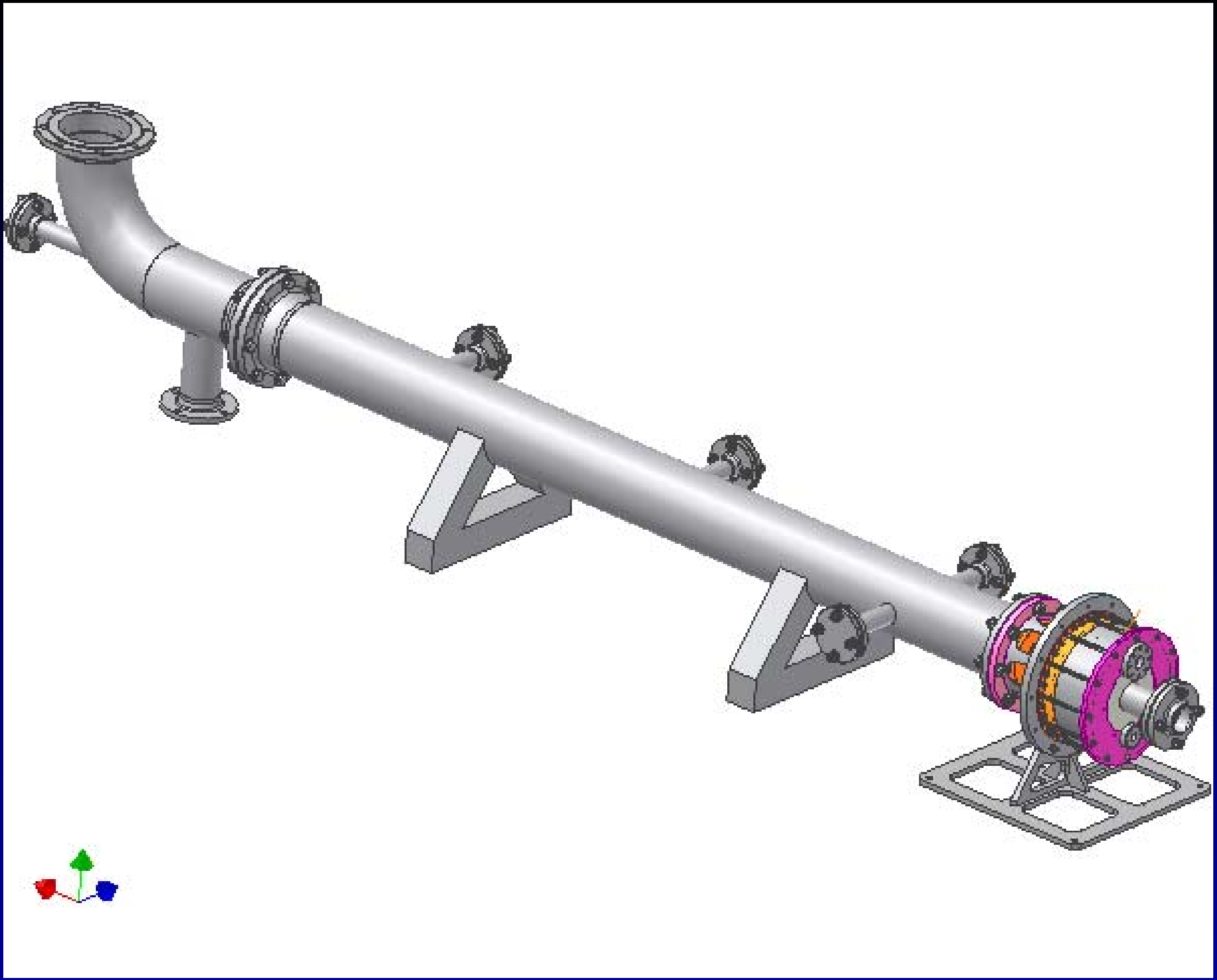
Ansaldo Caldaie Ltd,

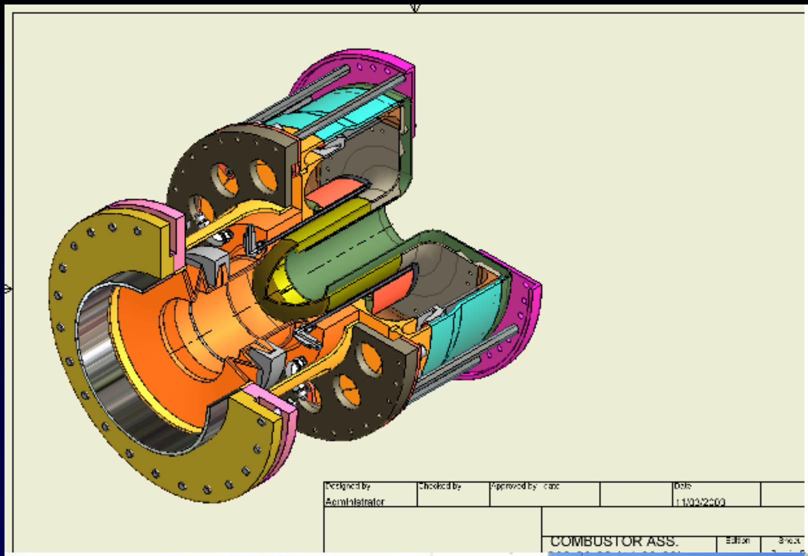

HIGH PRESSURE COMBUSTOR
AFTER 2 HOURS ELEVATED
PRESSURE
BARI-ITALY – Nov. 2003
Ansaldo Caldaie Ltd,

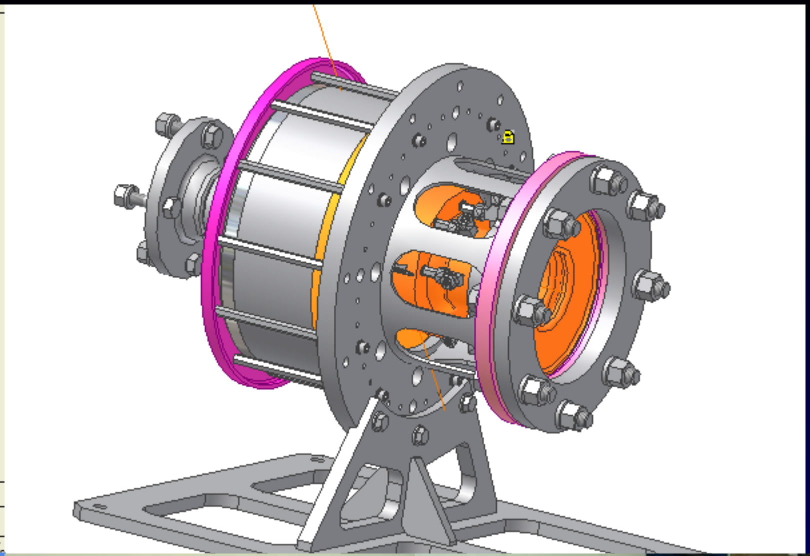


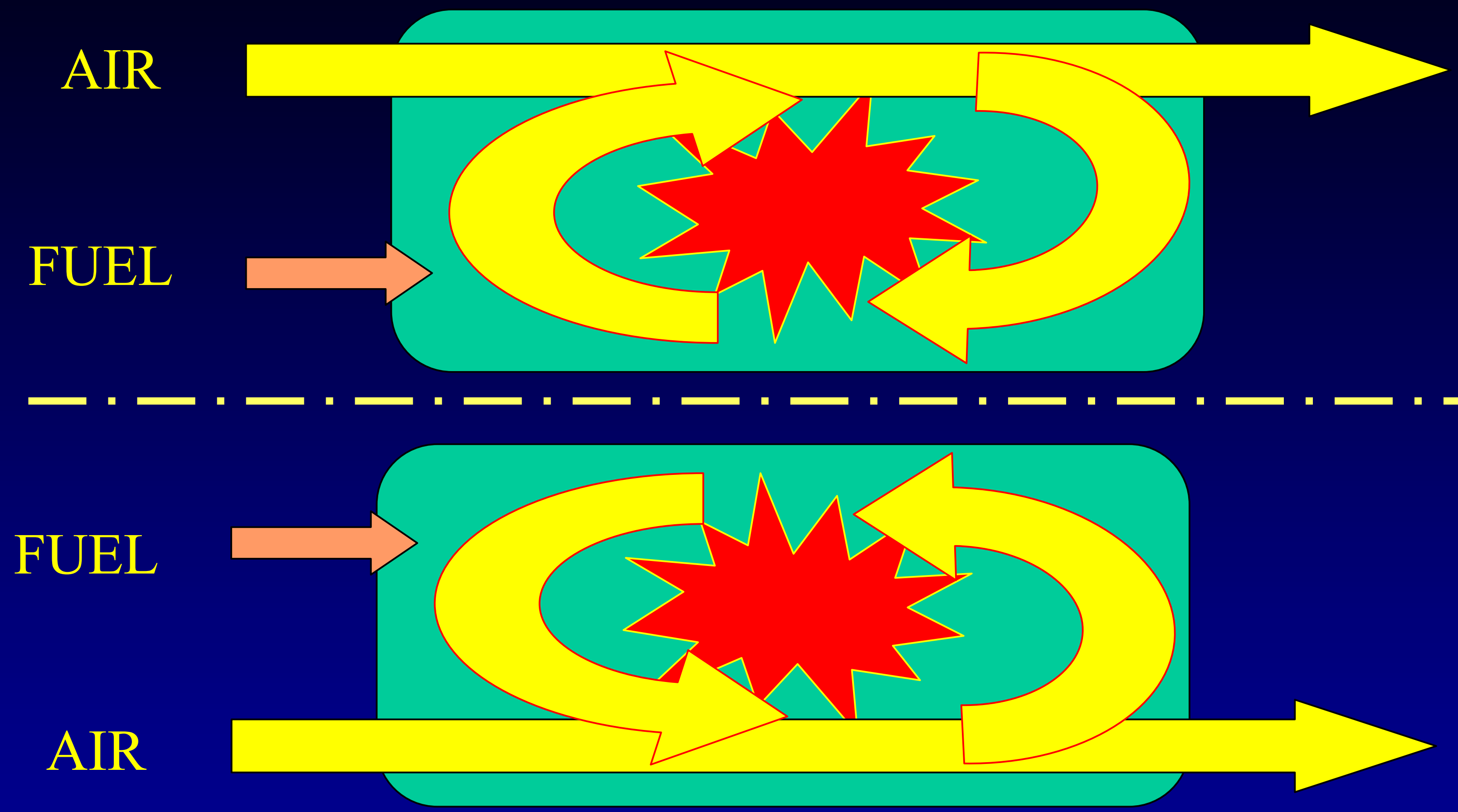


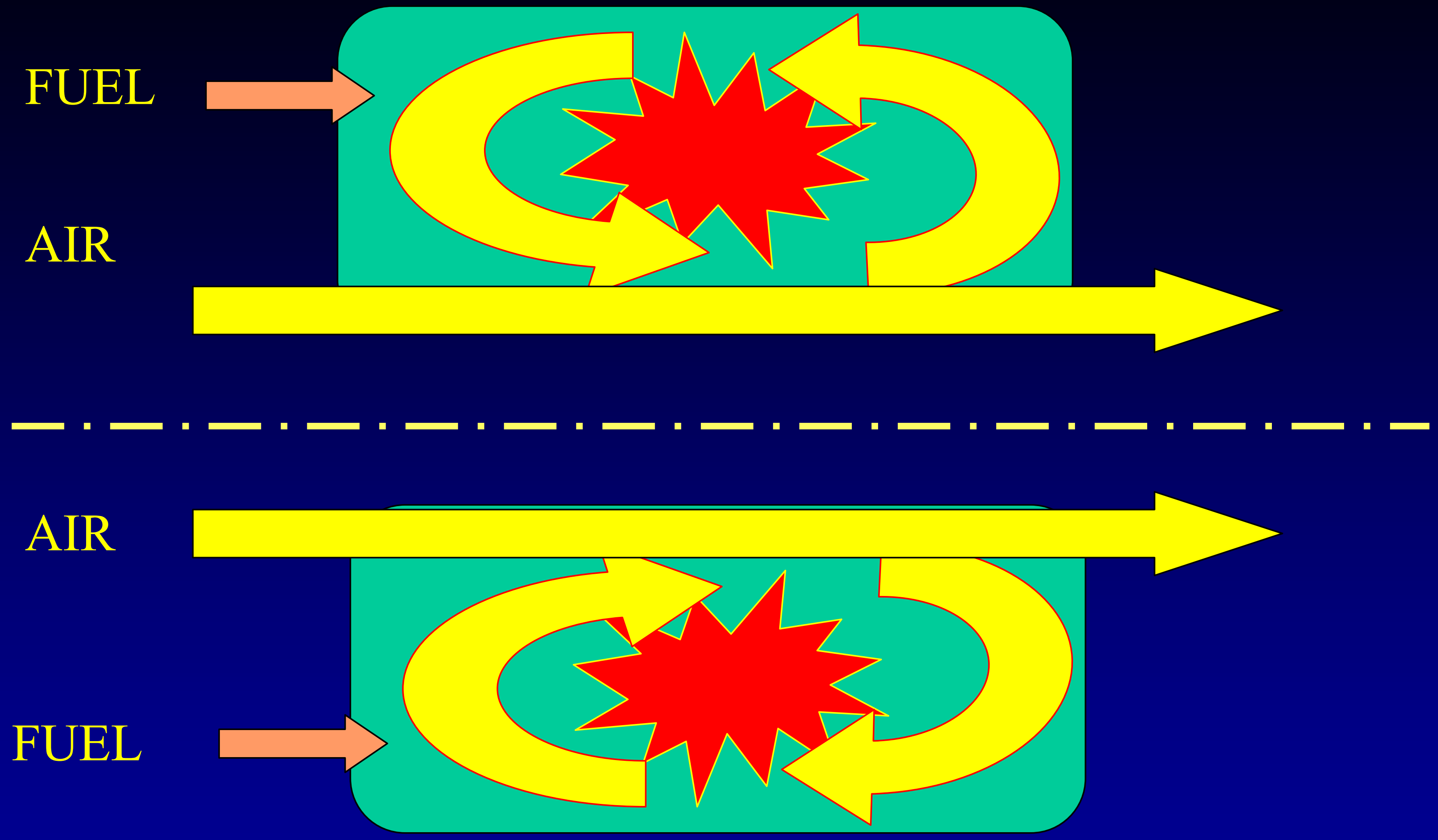
PILOT COMBUSTOR

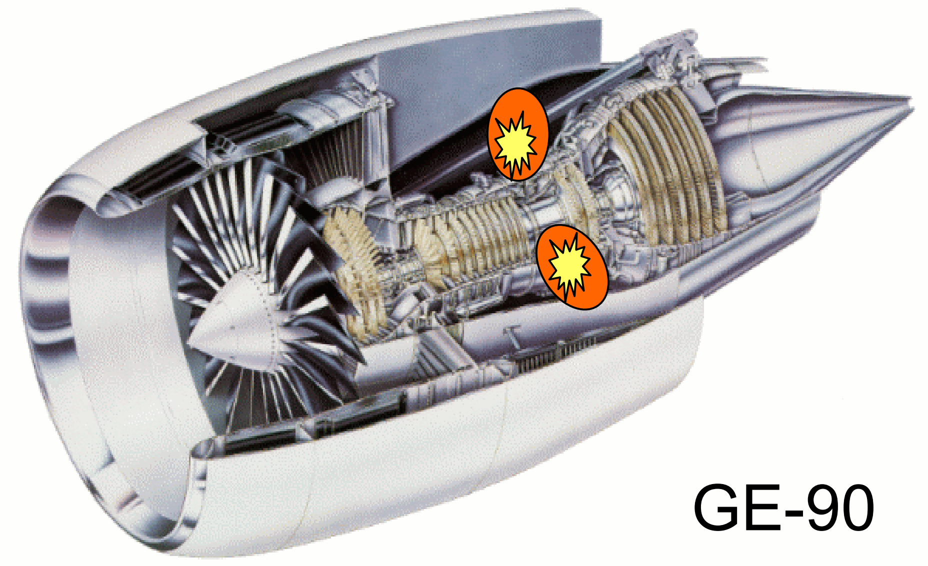


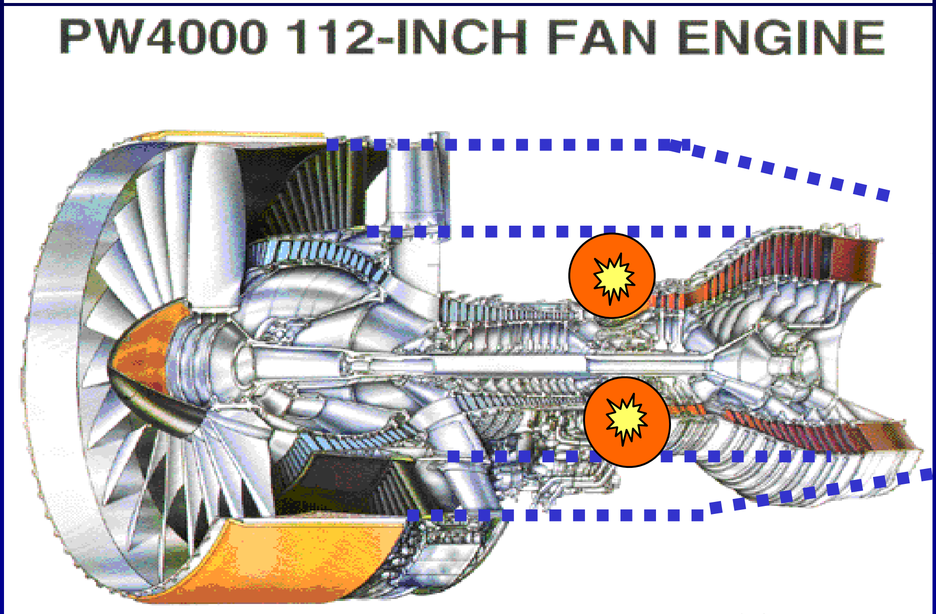

Designed by
Administrator
Checked by
Approved by
Date
COMBUSTOR ASS.



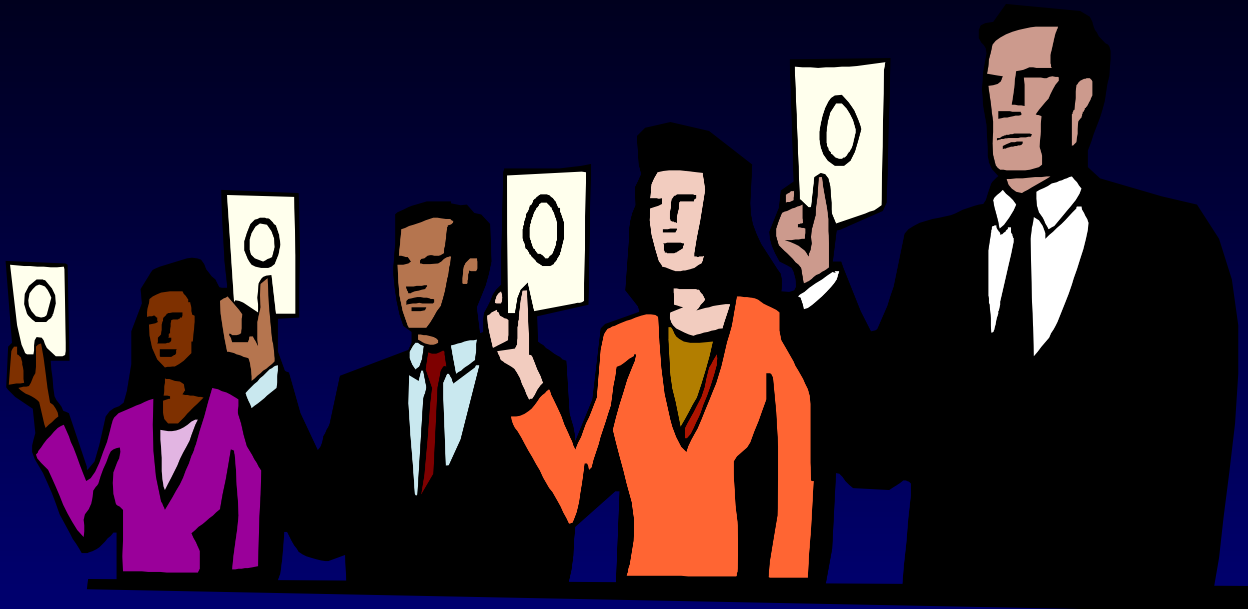

AIR
FUEL
FUEL
AIR


FUEL
AIR
AIR
FUEL





$$\frac{U_{9'}^{2}}{2} = \eta_{n'} C_{pc} T_{07'} \left[1 - \left(\frac{P_{9'}}{P_{07'}} \right)^{\frac{\gamma_c - 1}{\gamma_c}} \right]$$



(THANK YOU)