LOW NOx COMBUSTOR FOR HIGH EFFICIENCY GAS TURBINES

CINAR Ltd

Dr. N. H. Kandamby

FLOXCOM *Final Meeting*

November 21, 2003

Presentation Outline

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1. Objective
2. Work Description
   - Optimisation of Combustor
   - Results and Observations
3. Conclusions and recommendations

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1. Current objective

Perform simulations of FLOXCOM combustor for improved mixing and combustion characteristics, FLOX stability, pattern factor and wall temperature distribution by varying input conditions.

2. Work description

Optimisation of the FLOXCOM combustor mixing and combustion performance, exhaust pattern factor, wall temperature distribution and combustion stability under FLOX conditions

FLOXCOM combustor geometry & specifications

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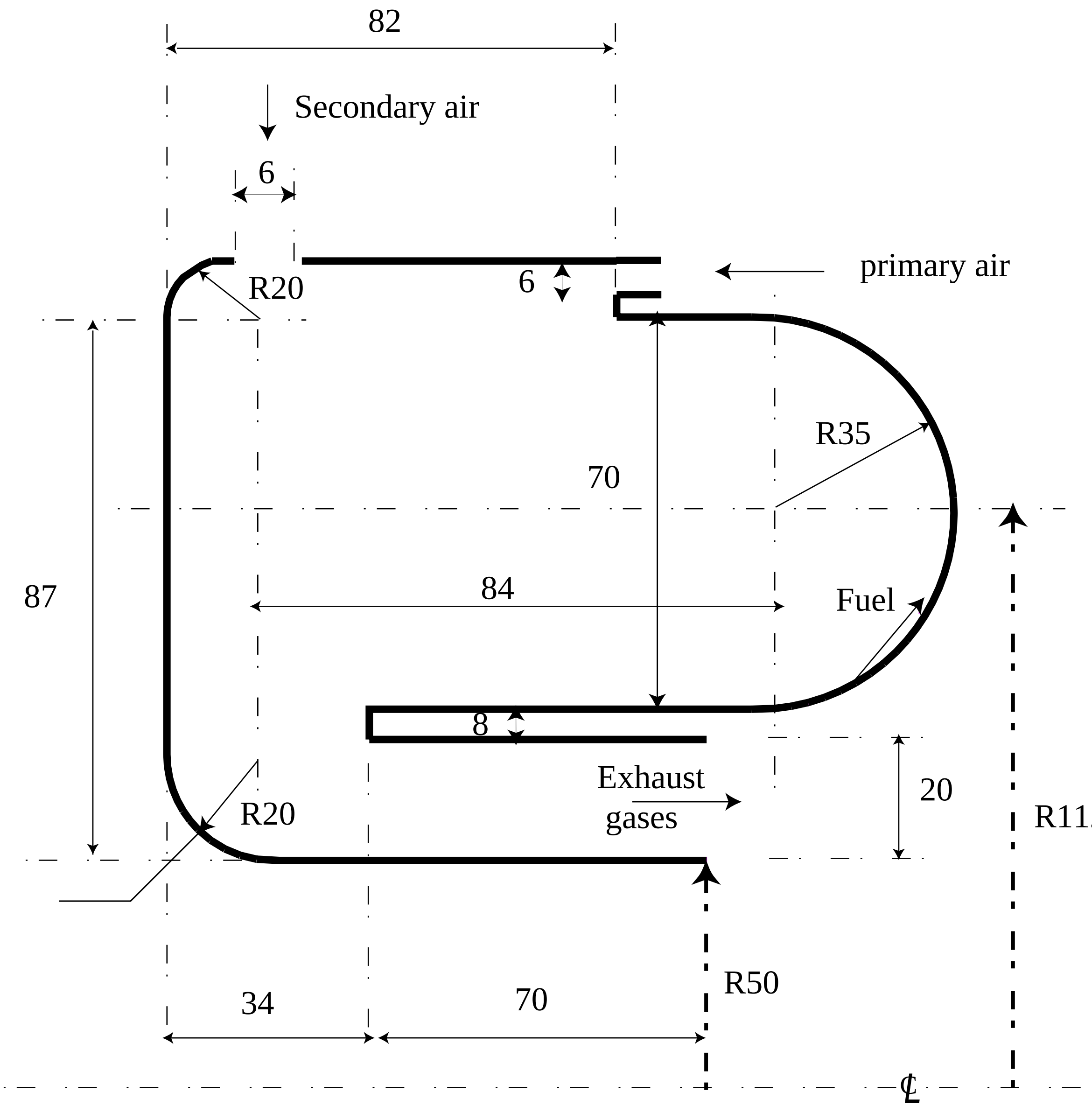

Fuel type : *Methane*

Fuel flow rate : *0.04Kg/s*

Fuel inlet temperature : *293K*

Air inlet temperature : *480K*

Combustor Pressure : *4.5 bars*

Total airflow rate : *2.0 Kg/s*

(Dimensions in mm)

Mathematical models

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Model formulation	:	Cartesian frame based contravariant vector/ tensor formulation of governing equations
Turbulence model	:	k-ε eddy viscosity model
Combustion model	:	SCRC combustion model with presumed shape pdf (β distribution)
Radiation model	:	Non-equilibrium diffusion radiation model. Absorption modelled by Truelove (1976) correlations.
Solution Algorithm	:	Extended SIMPLE algorithm with fourth order pressure smoothing for non-staggered variables. SIP based matrix inverter for unstructured meshes.

Discretised mesh of FLOXCOM combustor and inlets

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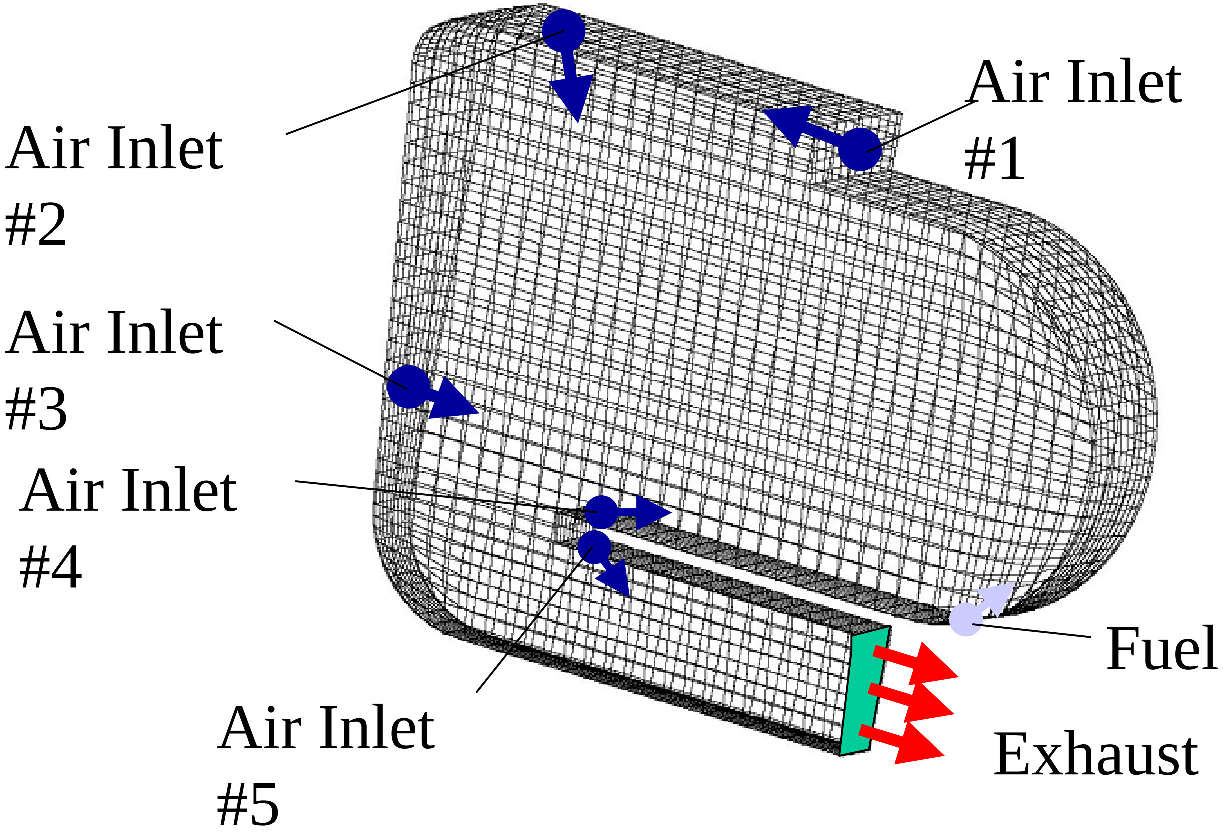

Discretisation method : Transfinite interpolation
mesh size 35x35x11 for 7.5º sector

- Air inlet ports: 48 holes for each inlet

Summary of Runs

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Simulation Code	Fuel #6 [kg/s]	Air Mass Flow Rate [kg/s] #1	#2	#3	#4	#5	Air Total [kg/s]	Remark
Run1	0.02	1	1				2	Original design
Case1	0.02	0.3478	0.8261	0.8261			2	Primary air (stoich amount) inlet positioned tow ards recirculation zone
Case2	0.02	0.8985	0.5507	0.5507			1.9999	Introudction of intermediate air
Case3	0.02	0.8985	0.5507	0.5507			1.9999	Stoich air and intermediate aiir combined & angle of jet optimised
NewRun1	0.02	0.8985	0.2755	0.826			2	Air redistributed
NewRun2	0.04	1.1304	0.2174	0.6522			2	Air redistributed
NewRun3	0.04	1.1304	0.2174	0.6522			2	Dilution air relocated to central axis of combustor
lcrun2	0.04	1.1304	0.2174	0.6522			2	48 holes and staggered arrangement of opposed jets
lcrun3	0.04	1.1304	0.2174	0.6522			2	dilution hole size reduced
								combusting run for cold flow experiment
COM4	0.0022	-	0.11	-	-	-	0.11	Combustion pressure - 1 bar, Air Temperature – 300 K
COM1	0.04	-	2	-	-	-	2	simulation of combusting run w ith condtions similar to cold flow expt
COM5	0.04	2	-	-	-	-	2	inlet number 1 employed
COM6	0.04	-	1.4	0.6	-	-	2	inlets number 2 and 3 employed
COM9	0.04	-	1.4	-	0.4	0.2	2	inlet number 4 introduced for cooling w all temperatures
COM10	0.02	1	-	0.5	0.5	-	2	inlet number 4 introduced for cooling w all temp
COM11	0.04	1	-	0.5	0.5	-	2	inlet number 4 introduced for cooling w all temp
COM12	0.02	0.8	0.8	-	0.3	0.1	2	Air #4 angle change to 70◦ to normal Air #1 angle at 10◦ dow n w ith normal Air #2 angle change to -30◦ to normal

COM4

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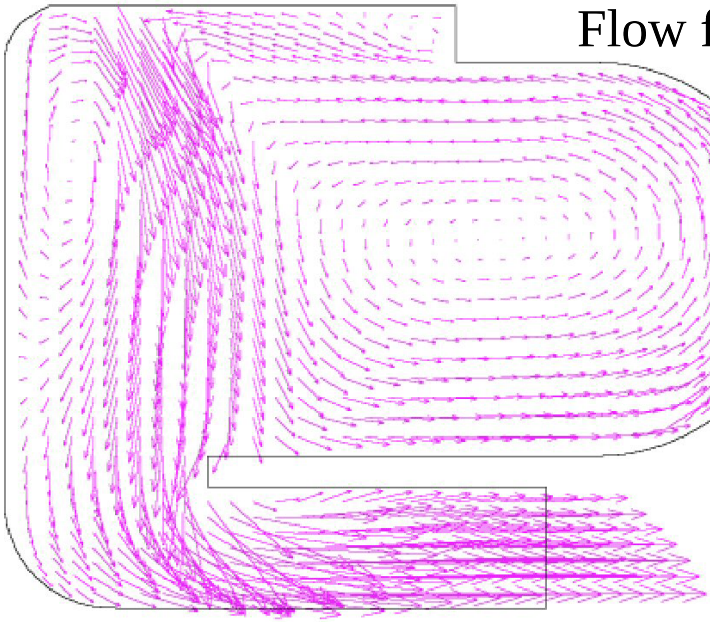
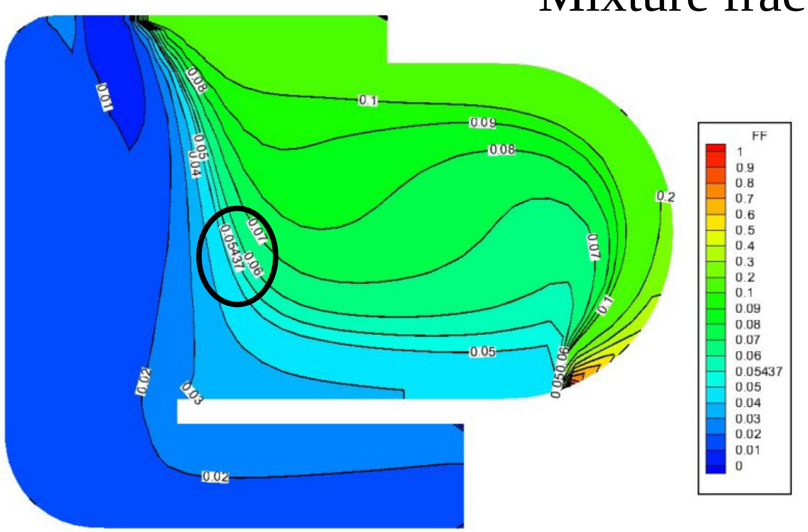
Flow field

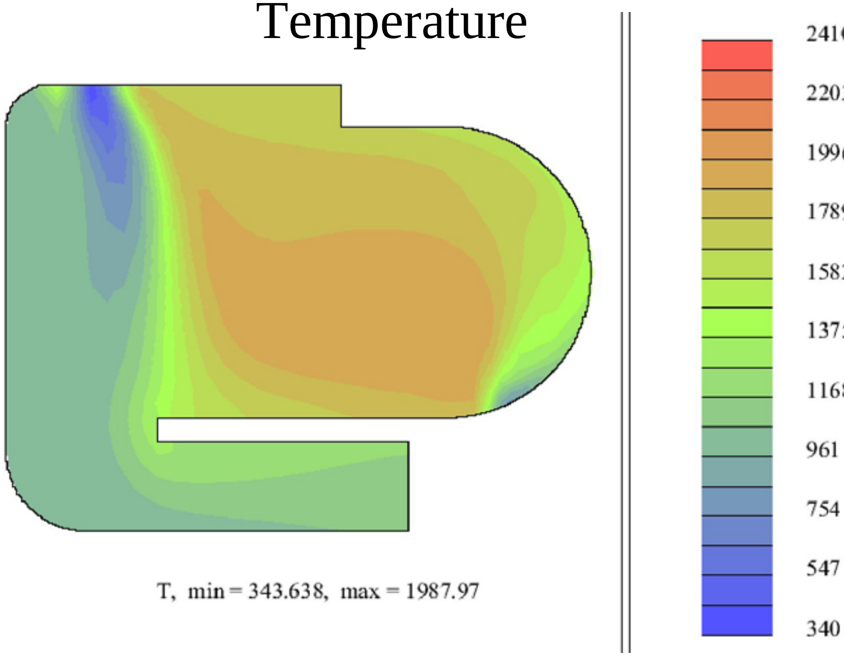


|V|, min = 0, max = 64.1084

Mixture fraction



Temperature



T, min = 343.638, max = 1987.97

COM1

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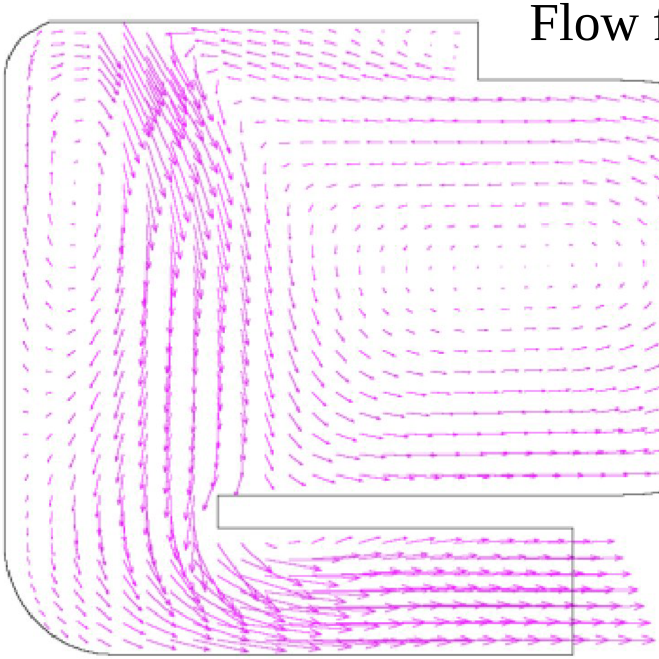
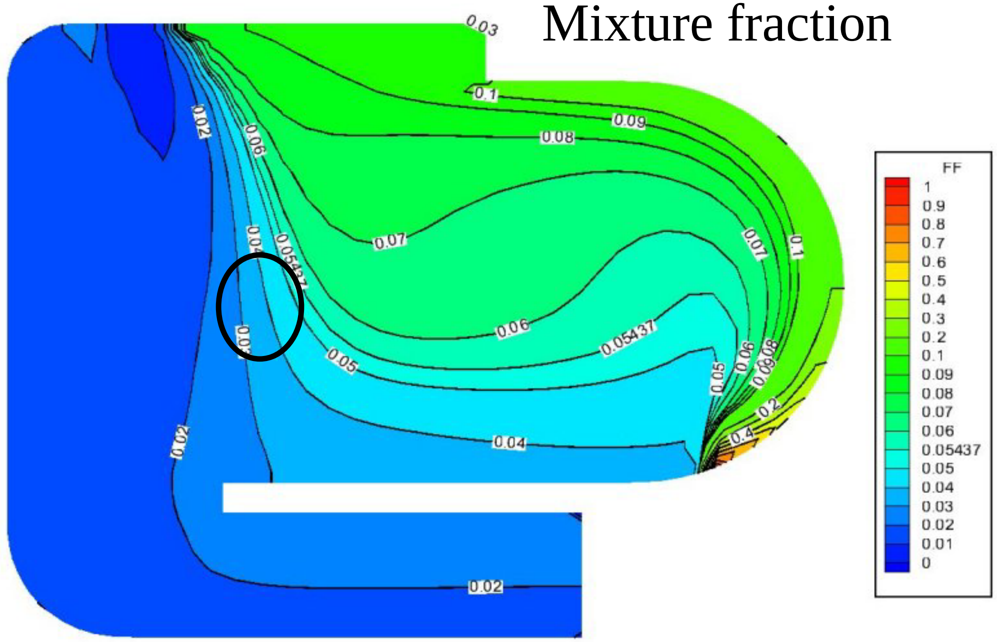
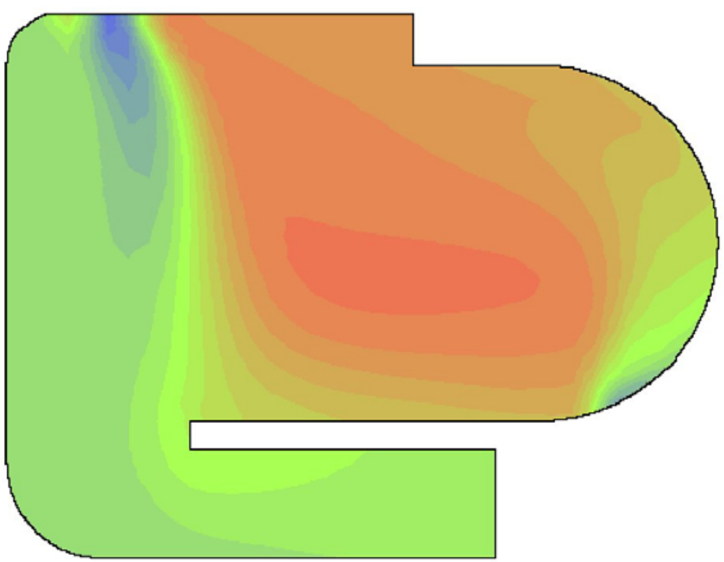
Flow field



Mixture fraction

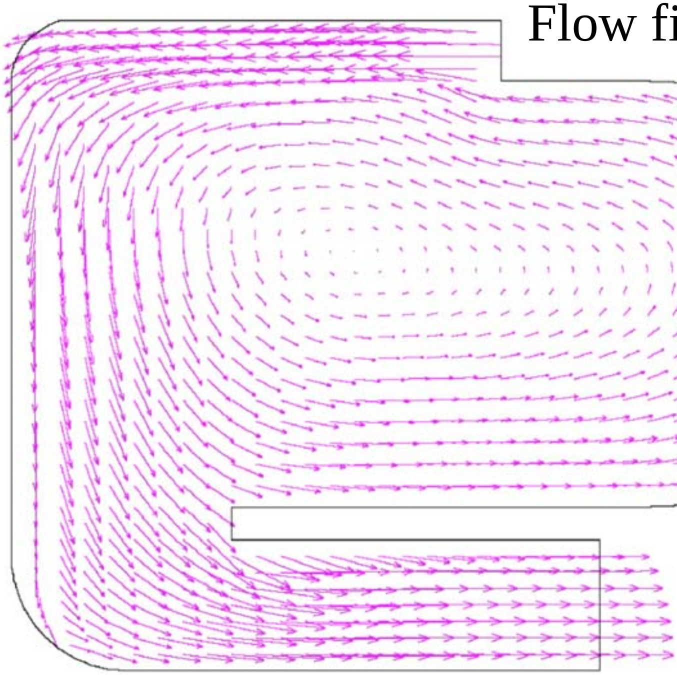


Temperature



T, min = 526.186, max = 2216.54

Flow field



COM5

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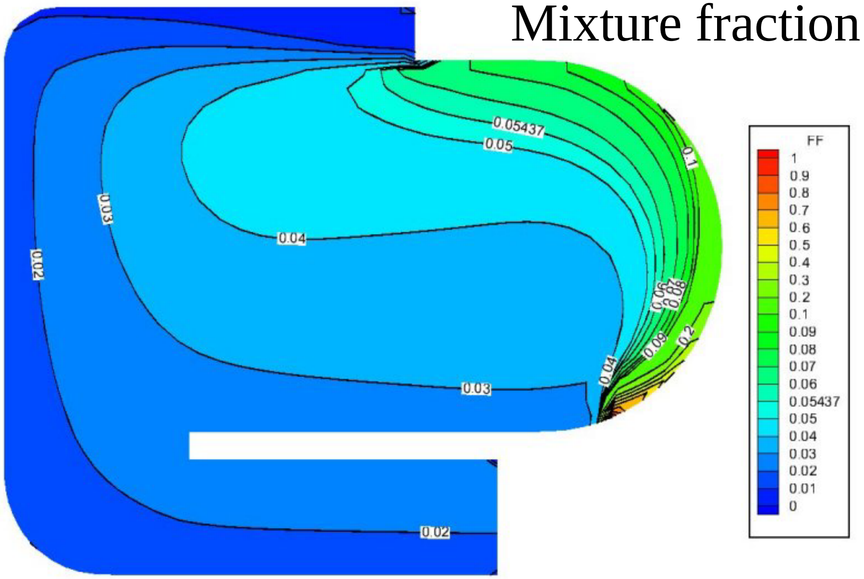
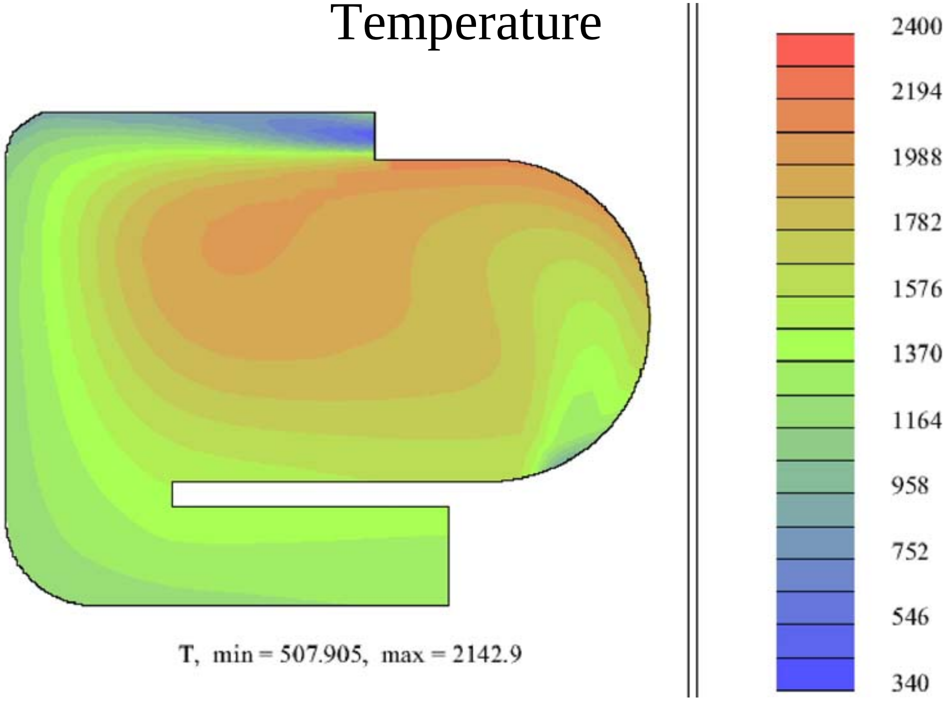
Mixture fraction

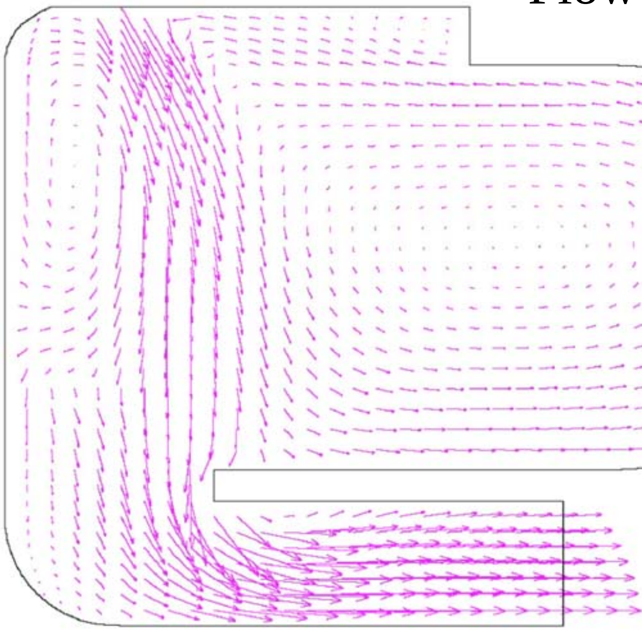


Temperature



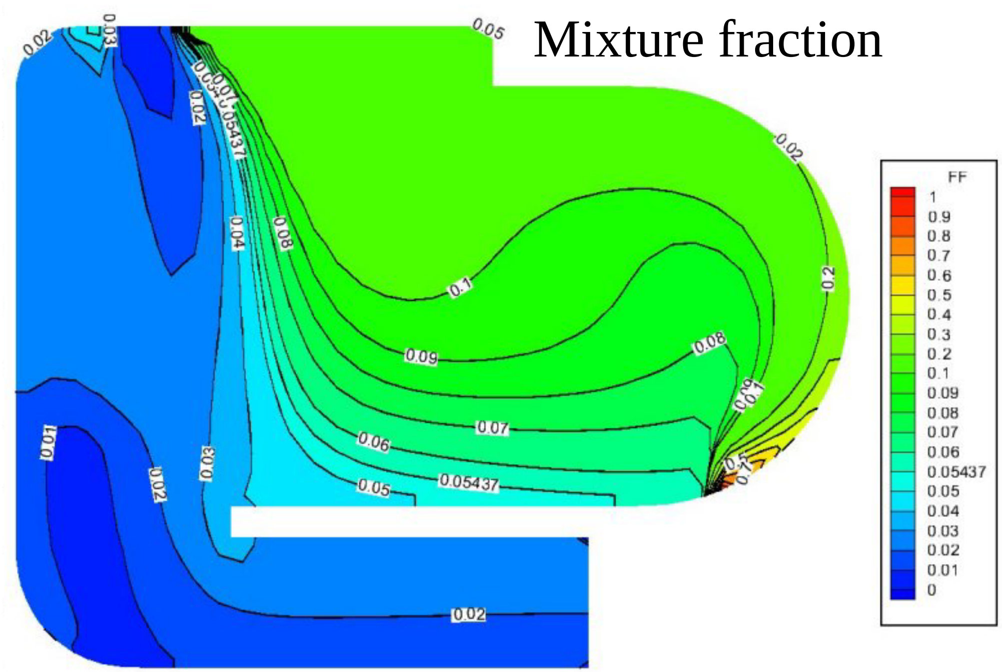
T, min = 507.905, max = 2142.9

Flow field

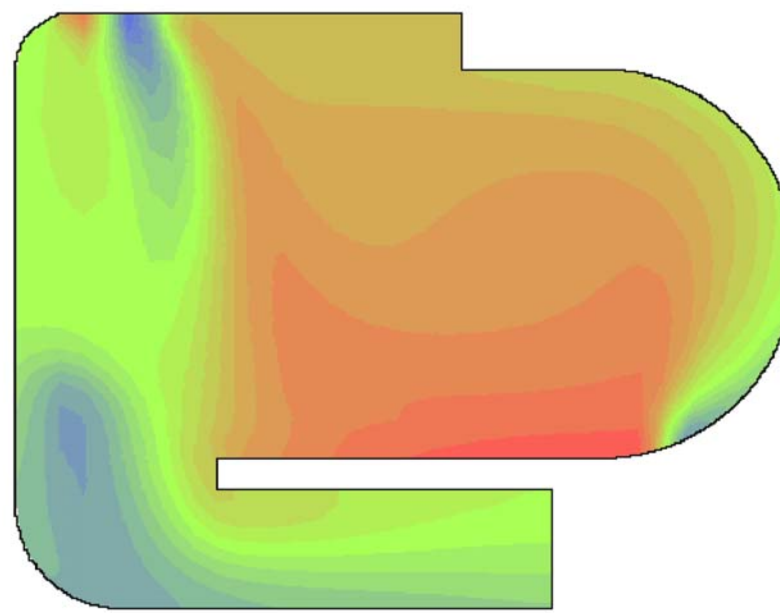


COM6 CINAR Ltd

Mixture fraction



Temperature



T, min = 534.971, max = 2404.95

COM9

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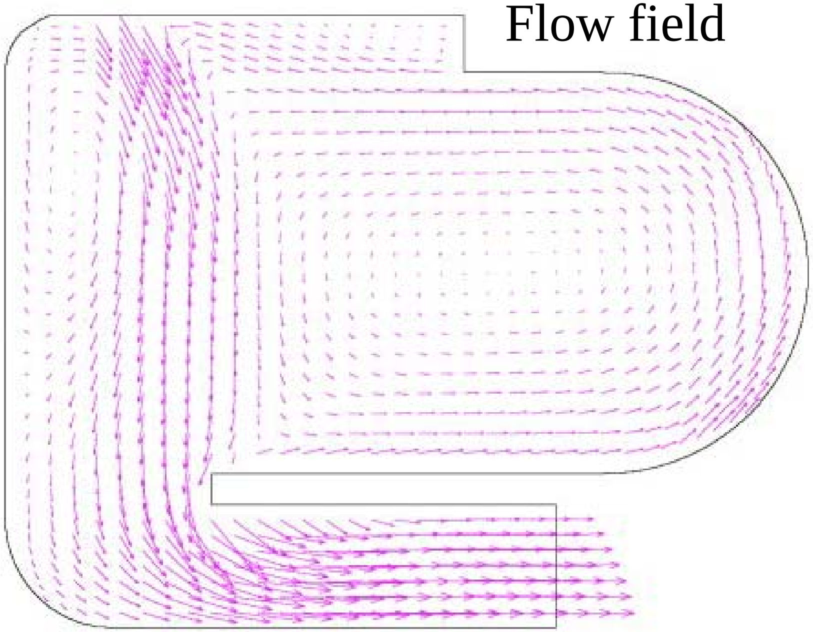
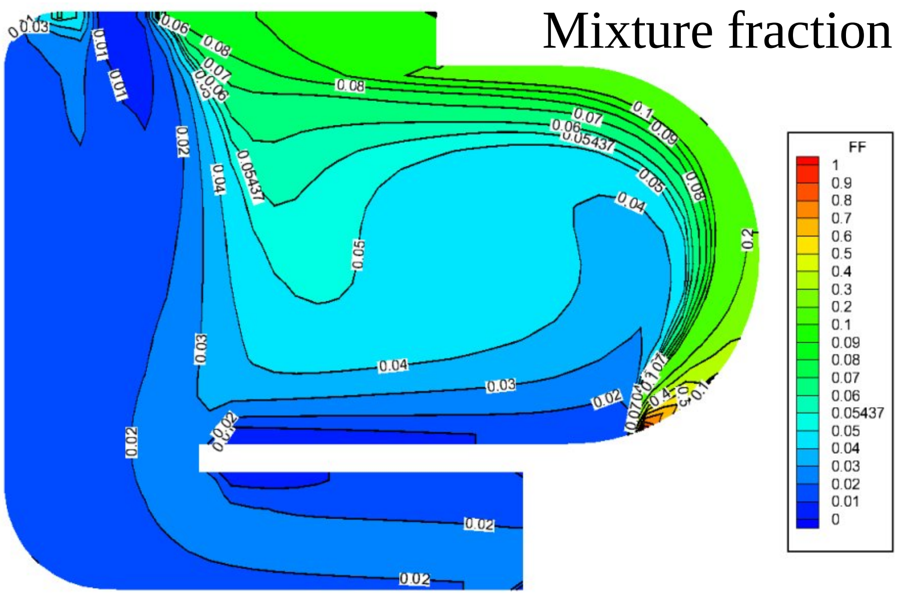
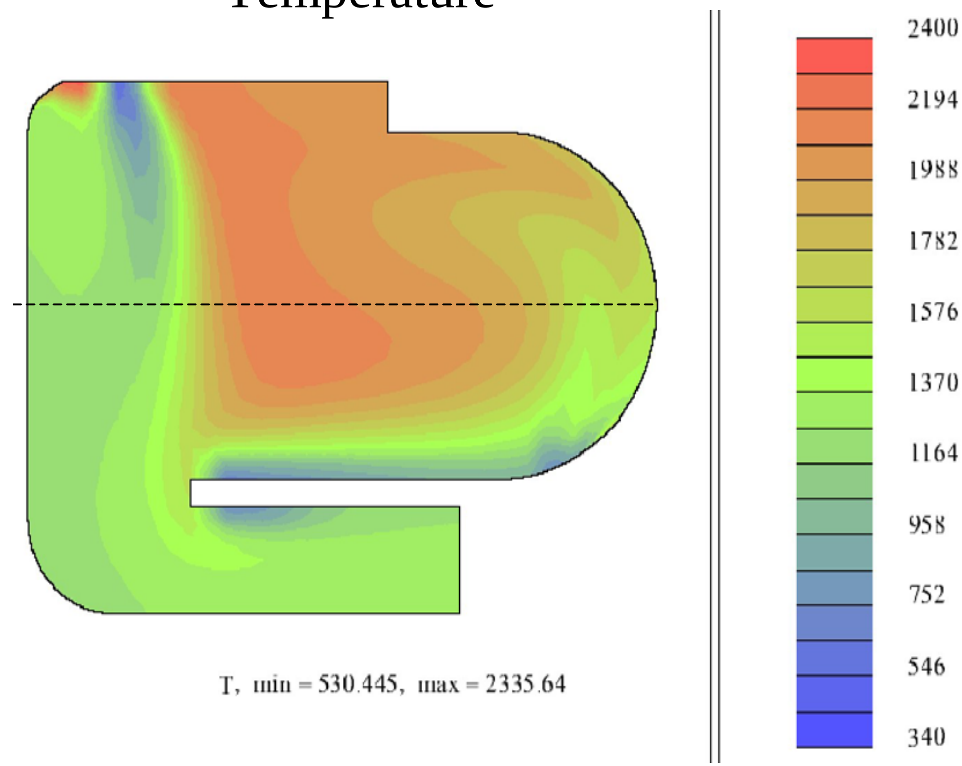
Flow field



Mixture fraction



Temperature



COM10

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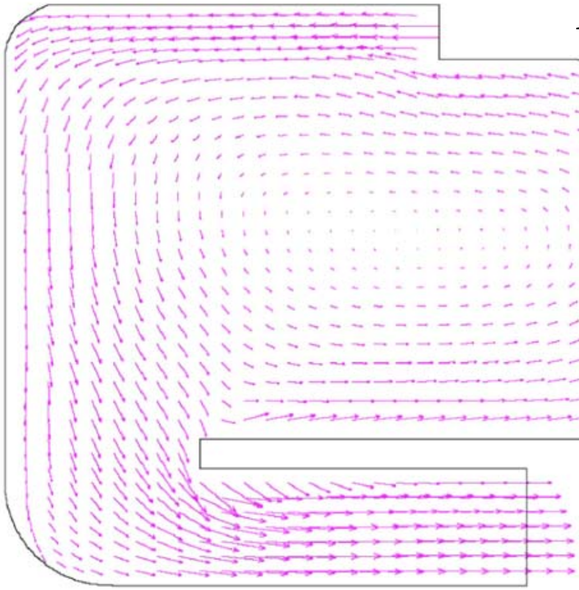
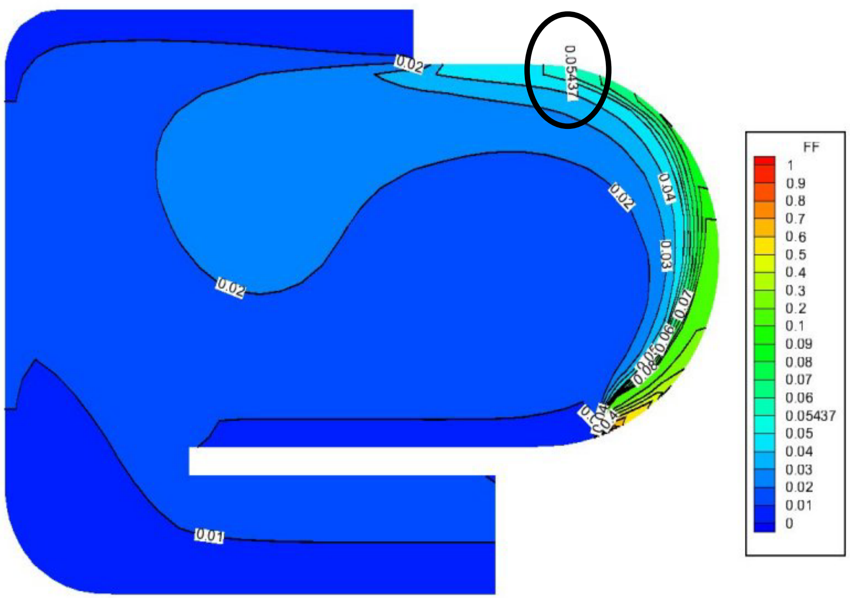
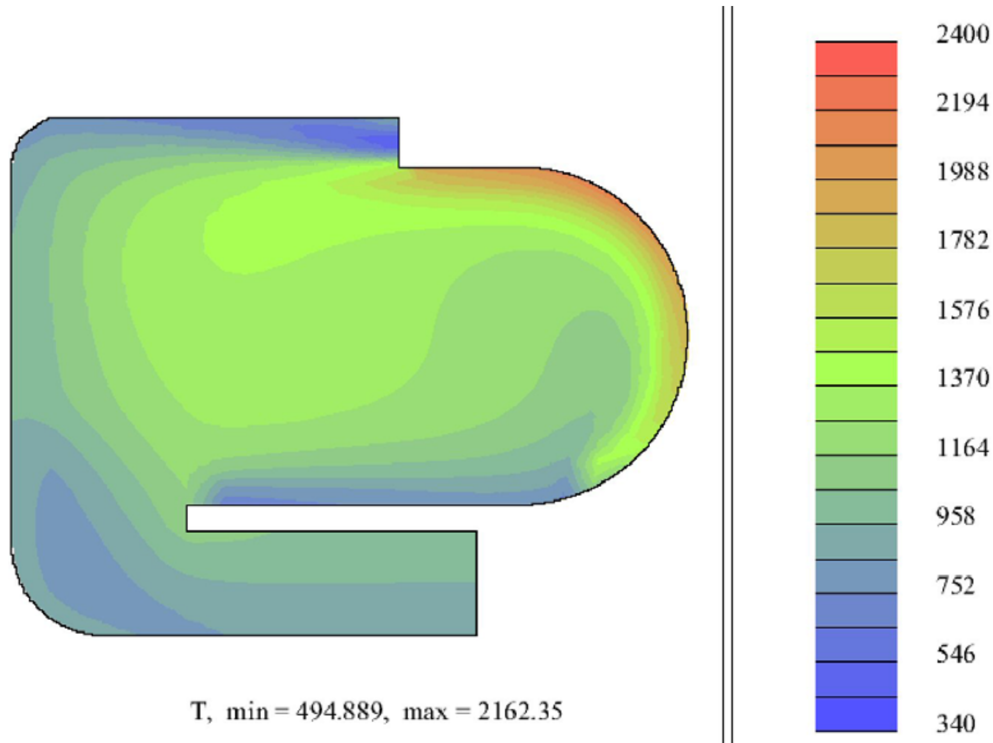


Flow field



Mixture fraction



Temperature

COM11

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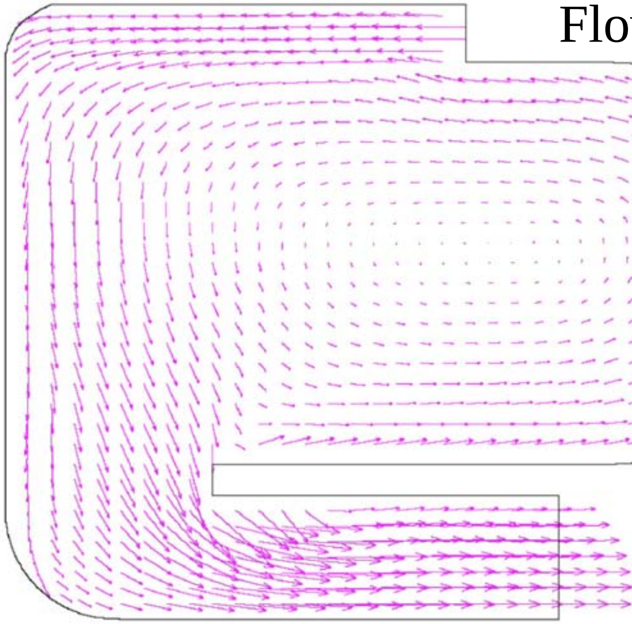
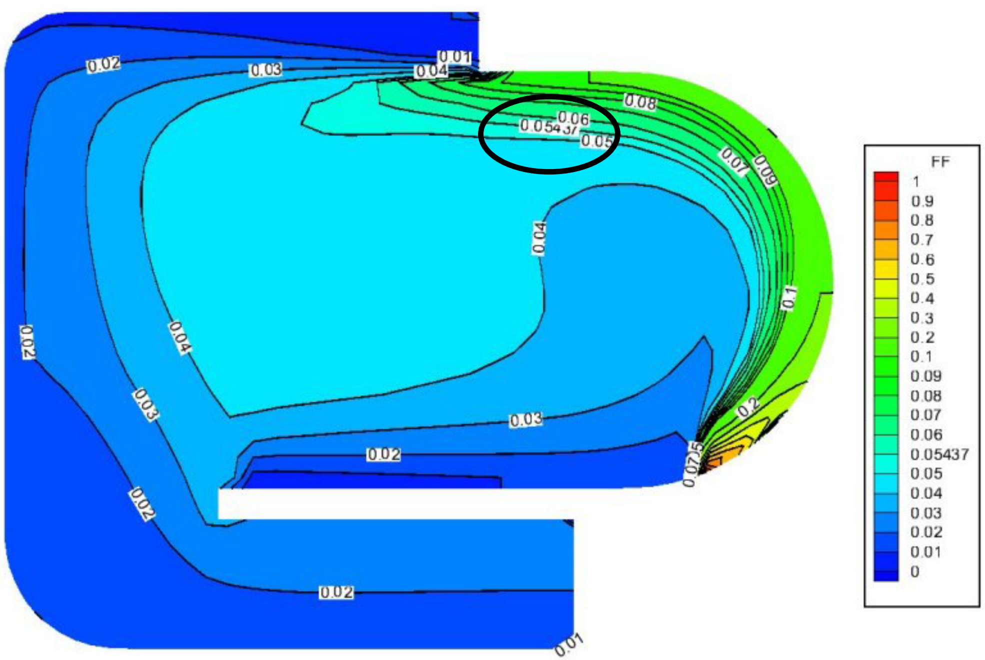
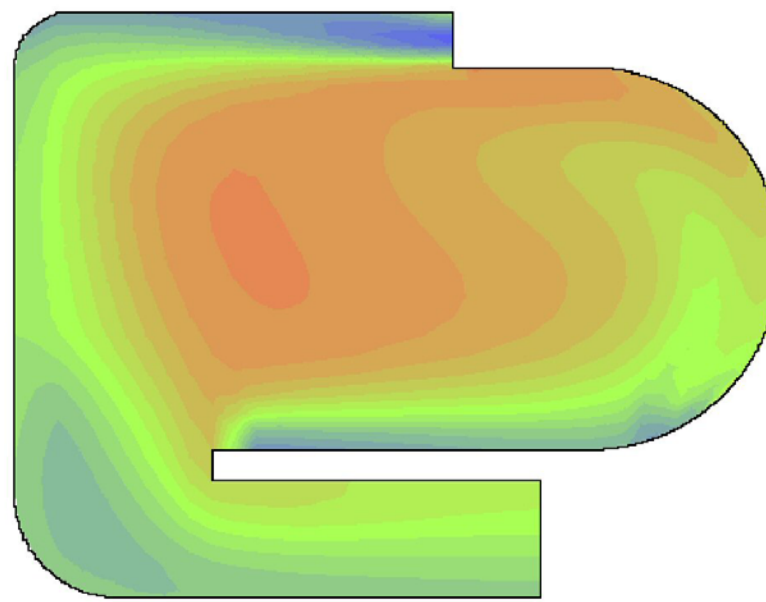
Flow field



Mixture fraction

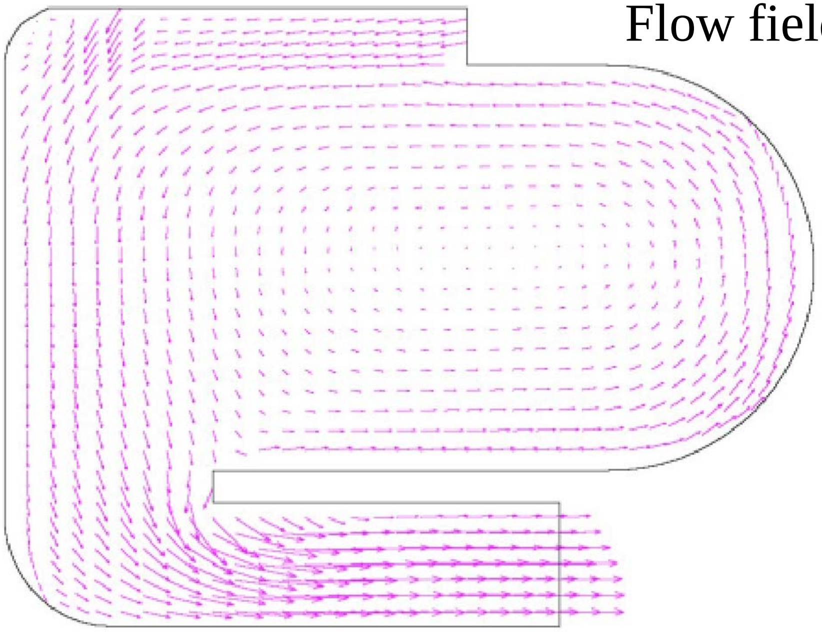


Temperature



T, min = 510.228, max = 2102.37

Flow field



COM12

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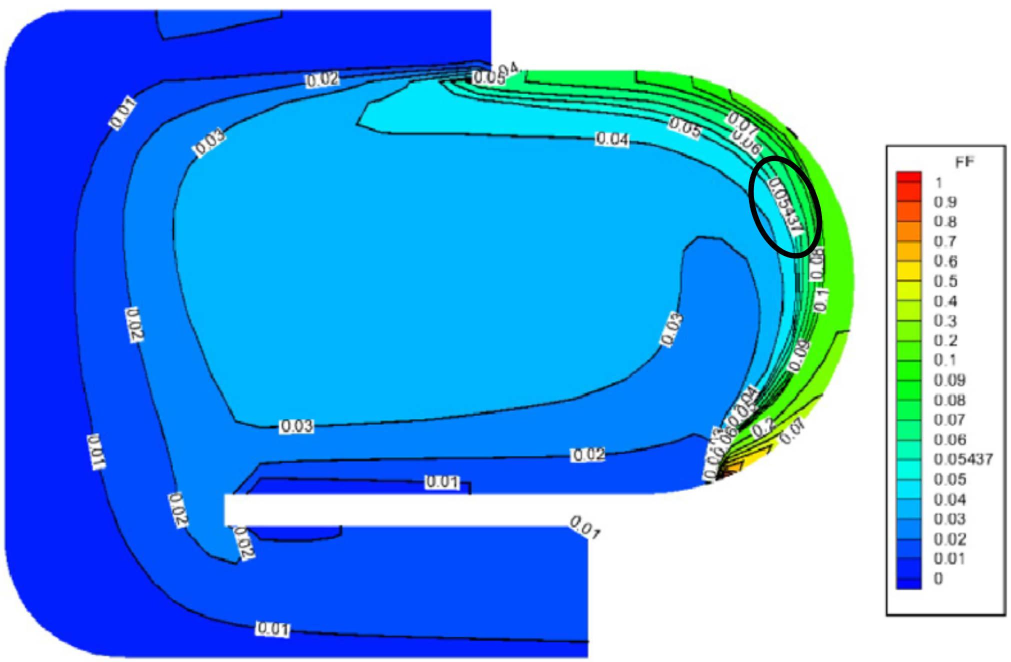
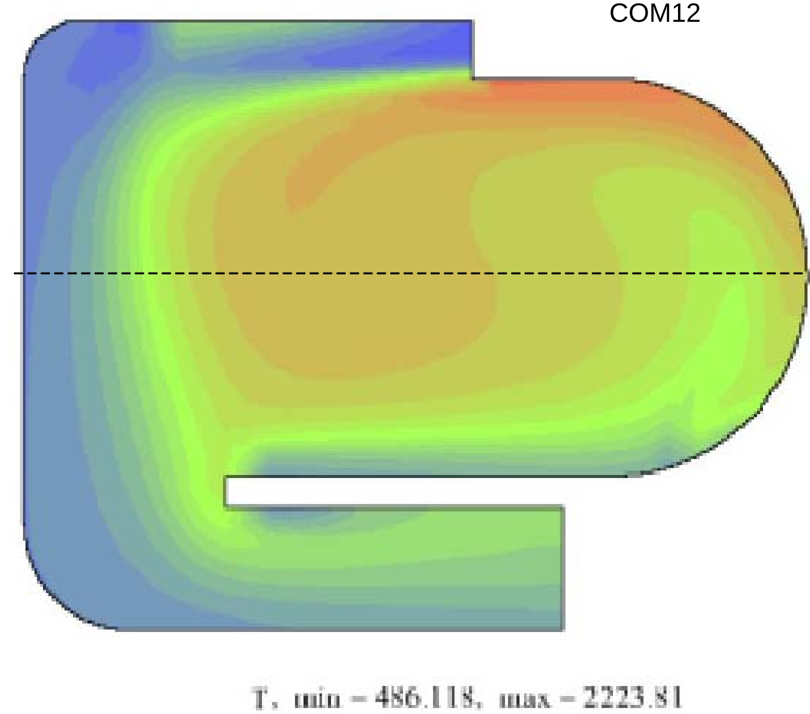
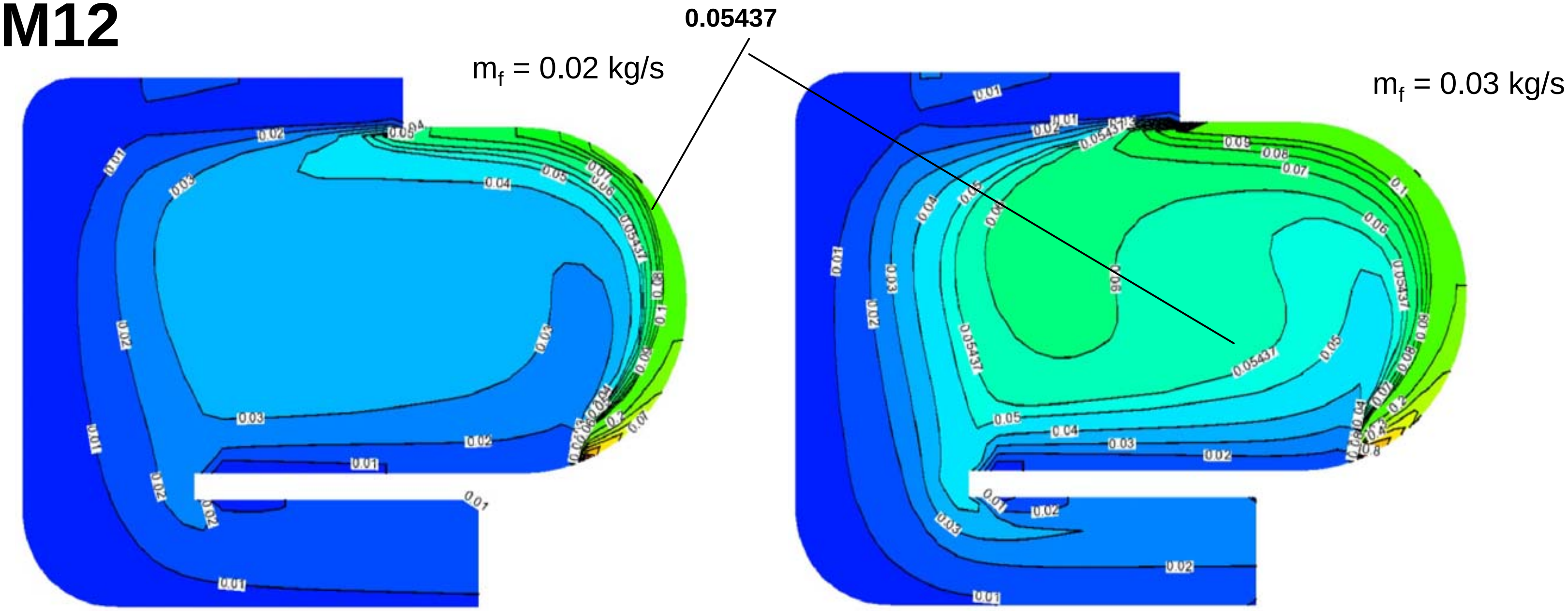
Mixture fraction



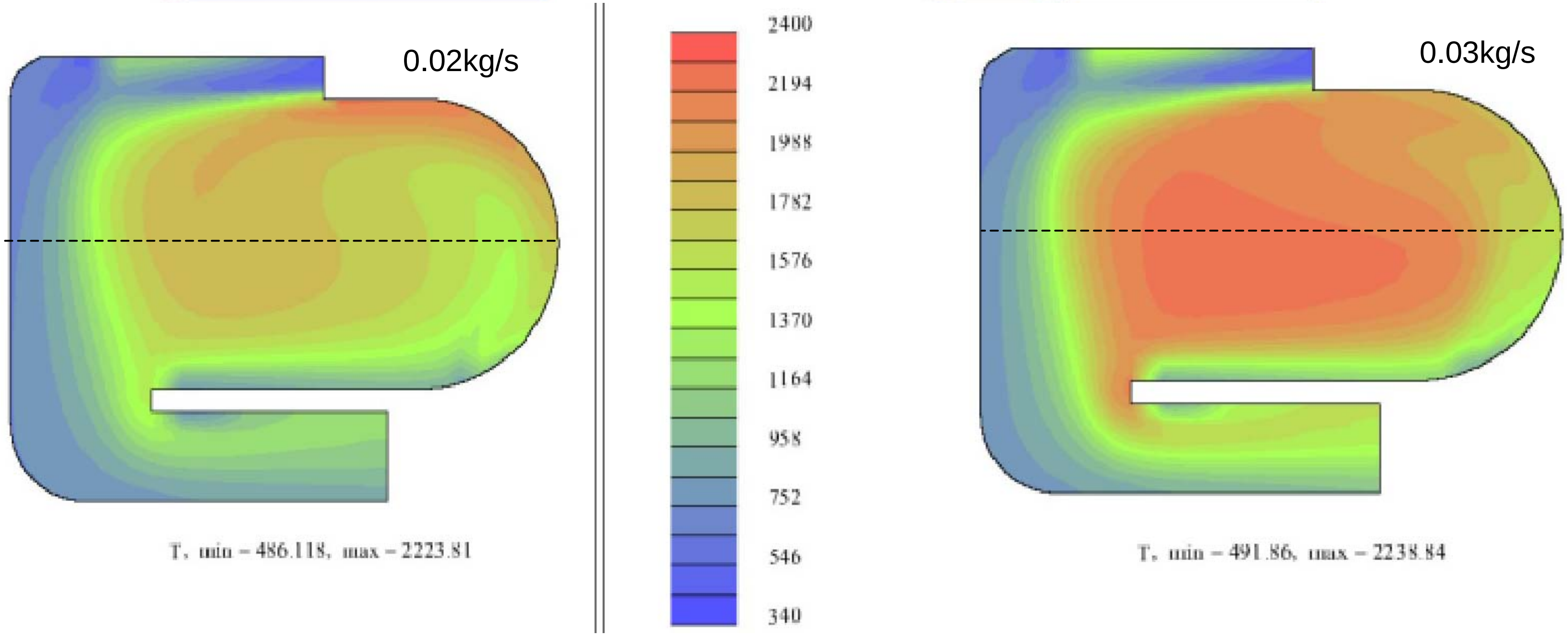
Temperature



COM12



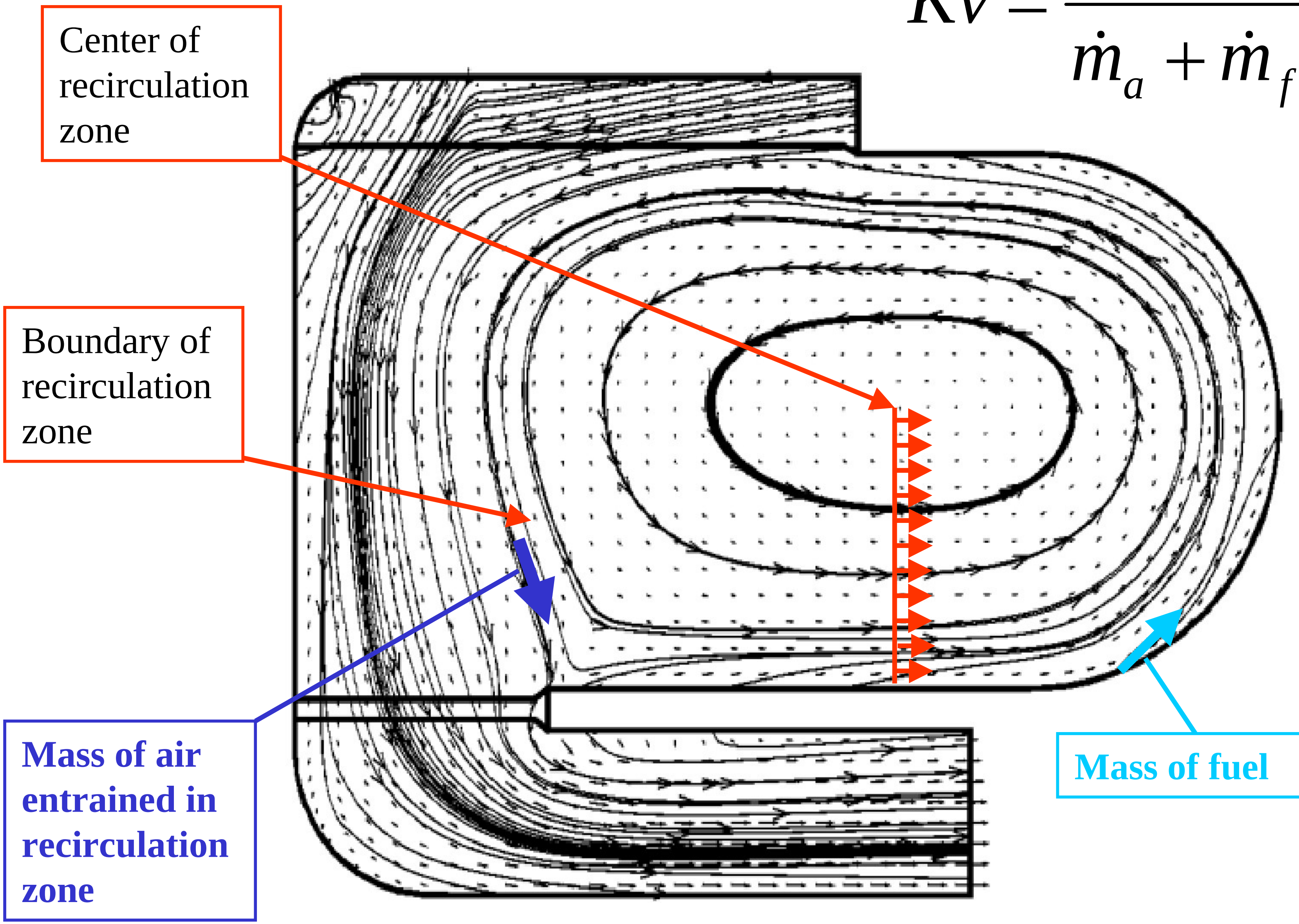
m_f = 0.02 kg/s
0.05437
m_f = 0.03 kg/s



0.02kg/s
2400
2194
1988
1782
1576
1370
1164
958
752
546
340
0.03kg/s
T, min = 486.118, max = 2223.81
T, min = 491.86, max = 2238.84

Estimation of recirculation ratio

$$Kv = \frac{\dot{m}_{rec}}{\dot{m}_a + \dot{m}_f}$$



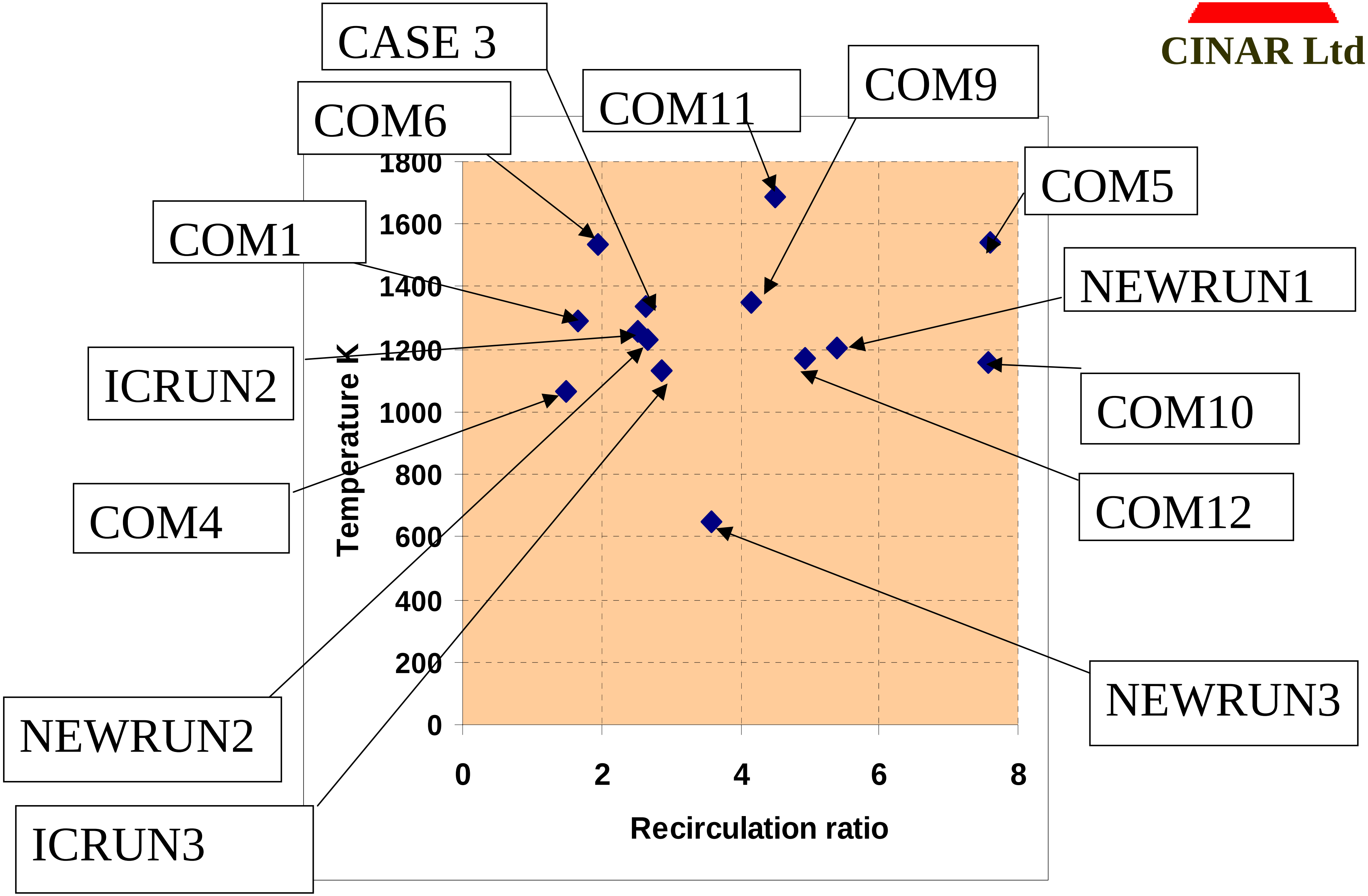
Summary of Results: recirculation ratio, Kv and Tair

Simulation Code	Fuel #6 [kg/s]	Air Total [kg/s]	Mair [kg/s]	Mrec [kg/s]	Mcirc [kg/s]	Kv	Tair ºK
Run1	0.02	2	-	-	-	-	241.69
Case3	0.02	1.9999	2.1	5.53	7.64	2.64	1335.1
NewRun1	0.02	2	3	16.41	19.43	5.4	1204.5
NewRun2	0.04	2	2.28	6.22	8.49	2.68	1233.3
NewRun3	0.04	2	1.94	7.14	9.09	3.59	646.85
Icrun2	0.04	2	0.62	1.75	2.39	2.53	1258
Icrun3	0.04	2	0.61	1.88	2.49	2.88	1130.9
COM4	0.0022	0.11	0.033	0.0468	0.0841	1.5	1064.7
COM1	0.04	2	0.76	1.31	2.06	1.65	1288.7
COM5	0.04	2	0.393	3.29	3.684	7.6	1542.9
COM6	0.04	2	0.468	1	1.468	1.96	1538.3
COM9	0.04	2	0.322	1.51	1.83	4.17	1351.2
COM10	0.02	2	0.349	2.79	3.14	7.56	1158.6
COM11	0.04	2	0.391	1.94	2.33	4.51	1687
COM12	0.02	2	0.3	1.57	1.87	4.92	1173.5

Summary of Results: Exhaust pattern factor and properties

Simulation Code	Fuel #6 [kg/s]	Air Total [kg/s]	Pattern Factor %	Tmax ºK	Tmean ºK	Exit Fuel Conc. $X10^{-5}$	Exit O_2 Conc.
Run1	0.02	2	204.87	2036	990.6	2.85	0.18
Case3	0.02	1.9999	173.71	1706.5	928.08	0	0.187
NewRun1	0.02	2	56.15	1207.3	945.8	0	0.187
NewRun2	0.04	2	107.19	2190	1305.5	18.88	0.148
NewRun3	0.04	2	120.7	2296	1303	18.21	0.149
lcrun2	0.04	2	18.48	1470.8	1316.3	0	0.145
lcrun3	0.04	2	9.21	1395.8	1318.6	0	0.145
COM4	0.0022	0.11	8.21	1174.7	1122	0	0.148
COM1	0.04	2	4.42	1353.8	1316.9	0	0.145
COM5	0.04	2	7.28	1396.8	1334.6	0	0.143
COM6	0.04	2	19.6	1471.8	1309.2	0	0.145
COM9	0.04	2	2.49	1333	1312.2	0	0.146
COM10	0.02	2	18.38	1024.3	939.84	0	0.187
COM11	0.04	2	26.02	1522	1306.8	0	0.146
COM12	0.02	2	20.91	1179.2	1058.3	0	0.173

Summary of Results



Cold flow simulation: only inlet 1 employed

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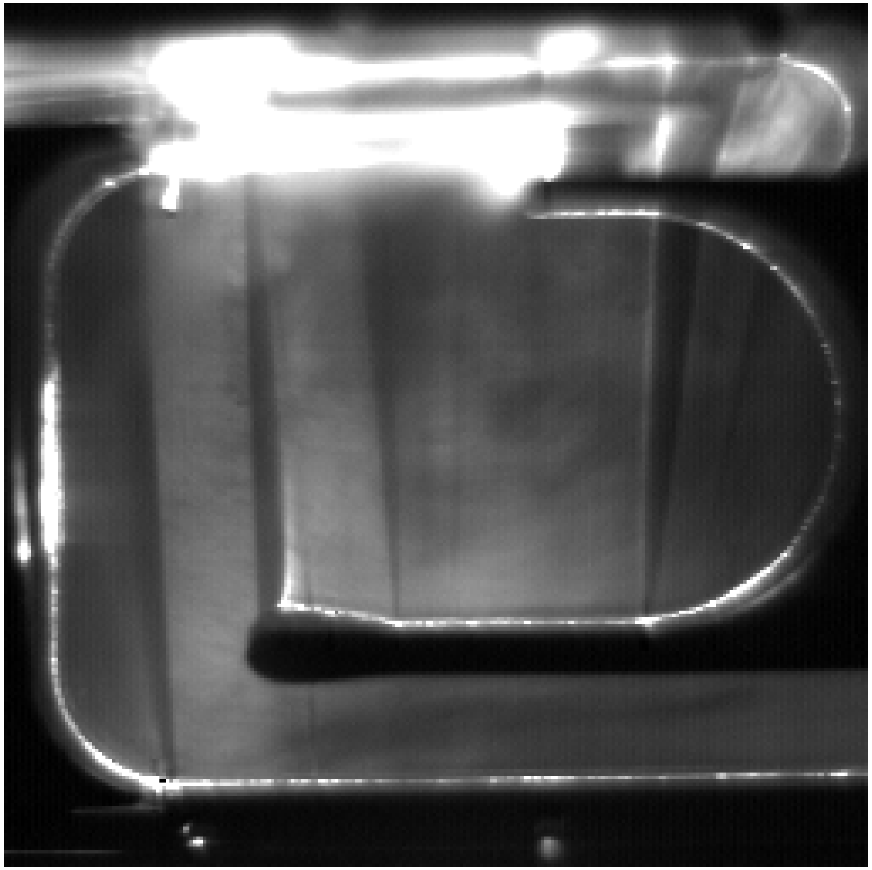

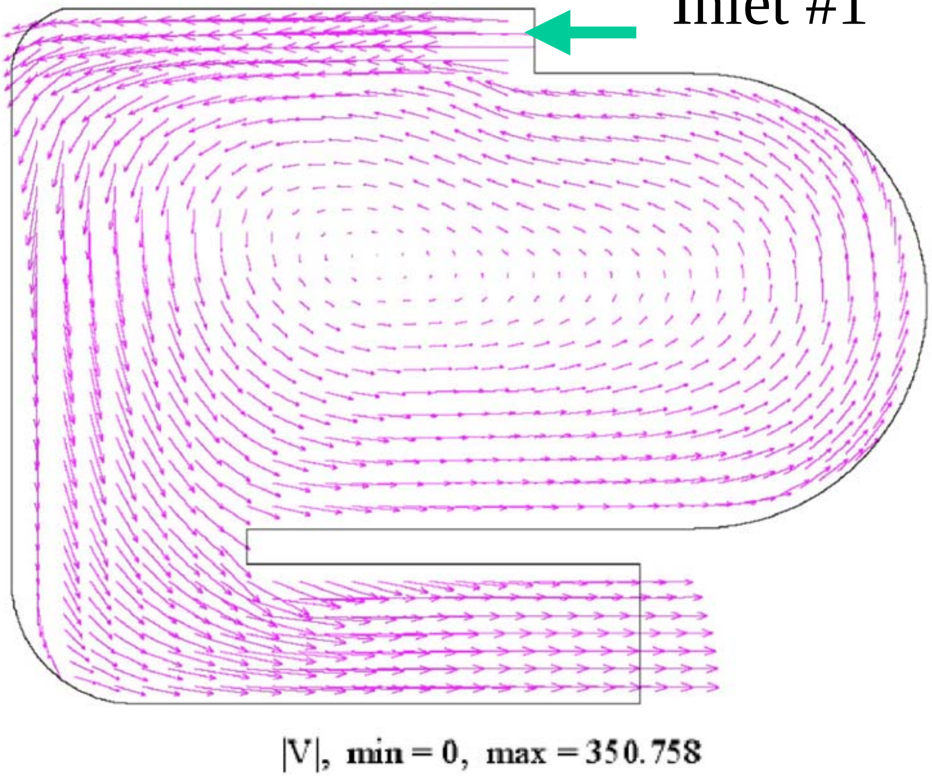

Cold flow simulation: only inlet 2 employed

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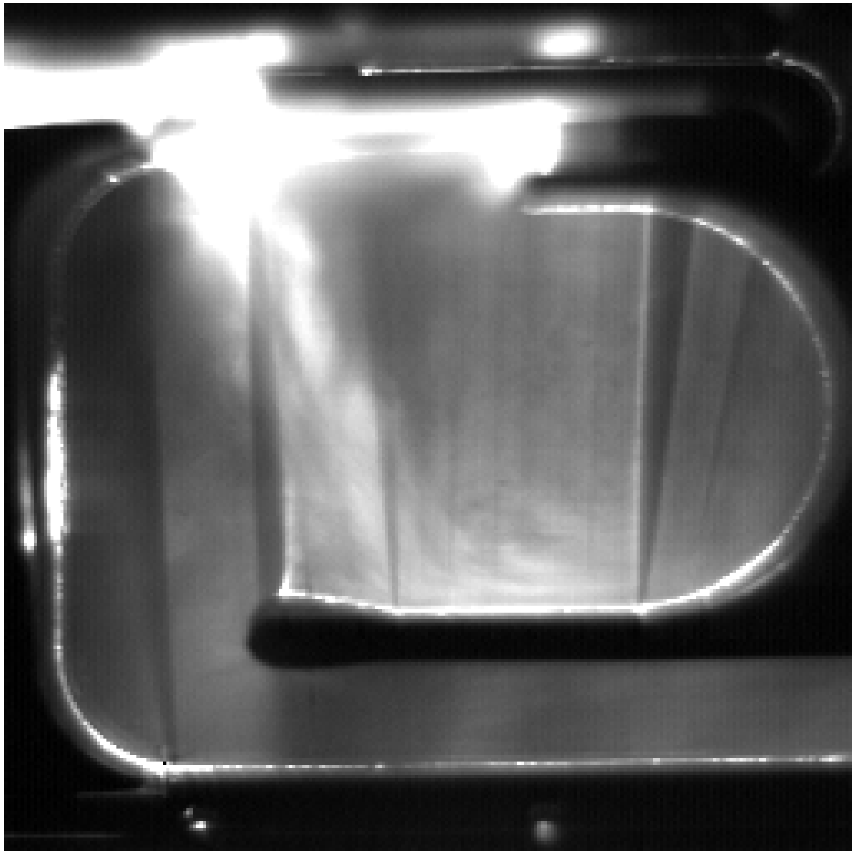

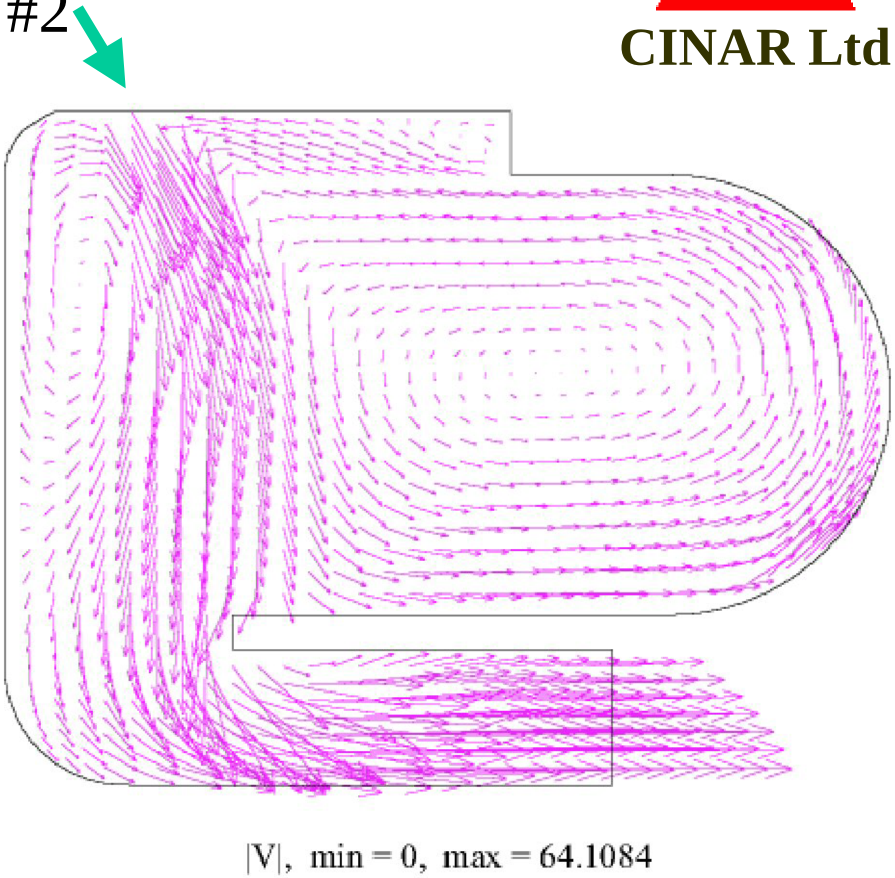

Cold flow simulation: both inlets 1 and 2 employed

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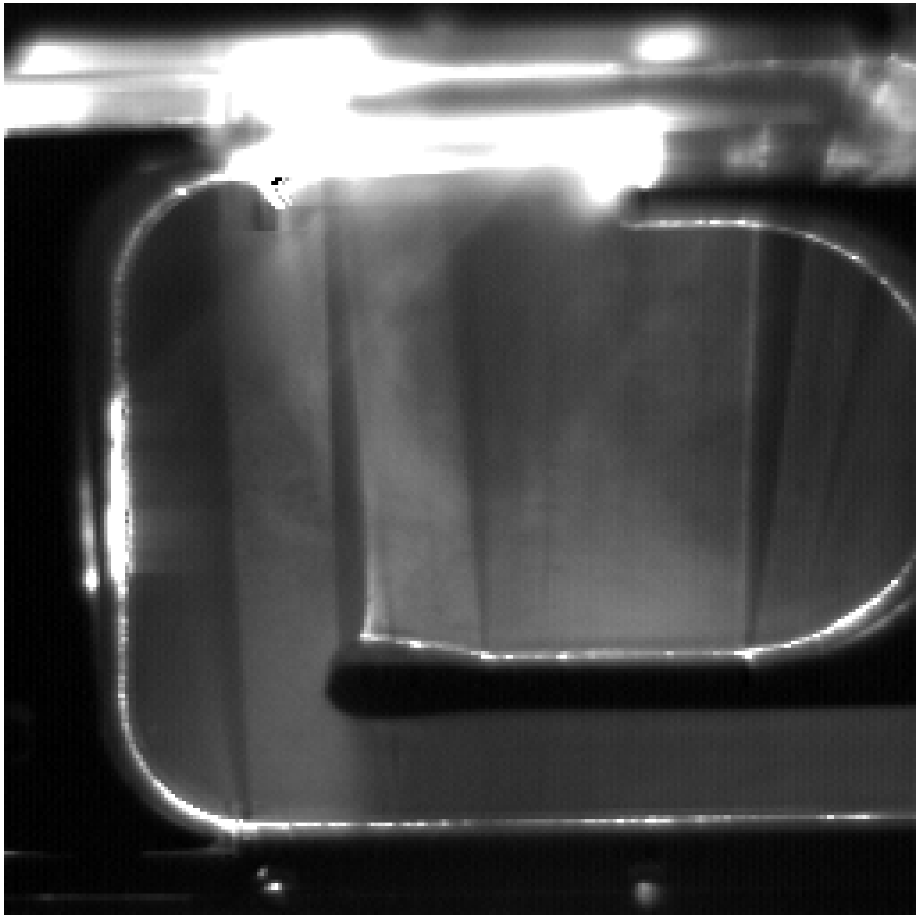

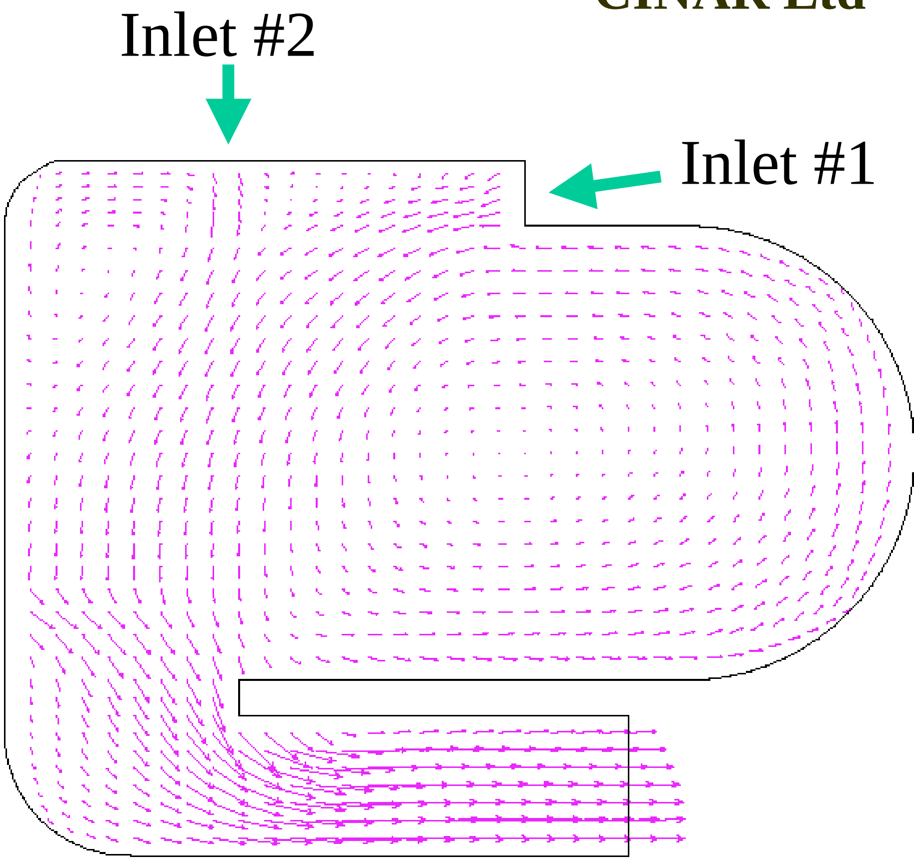

Mixing and Temperature Distribution (COM12)

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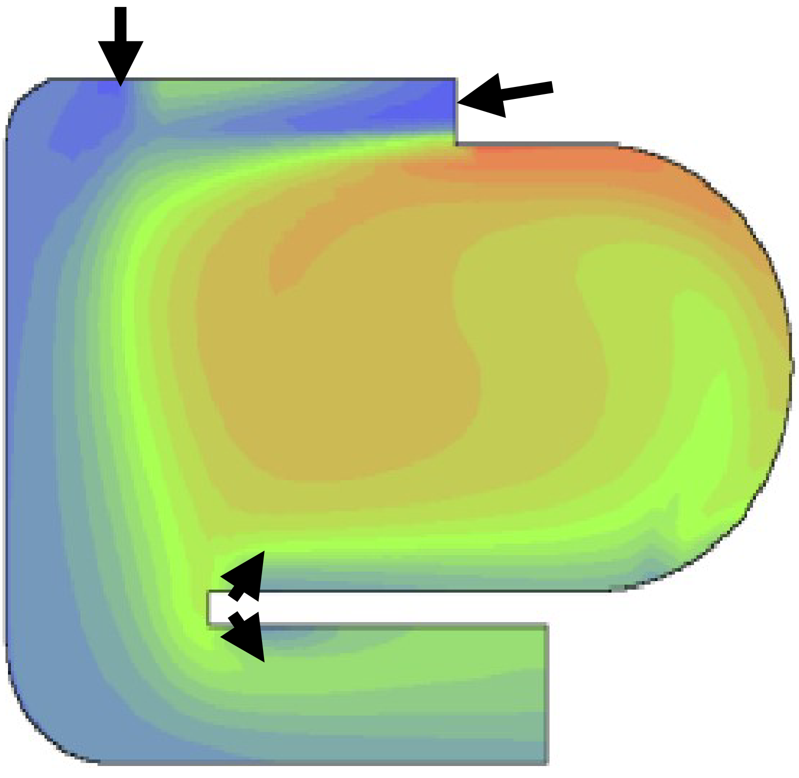
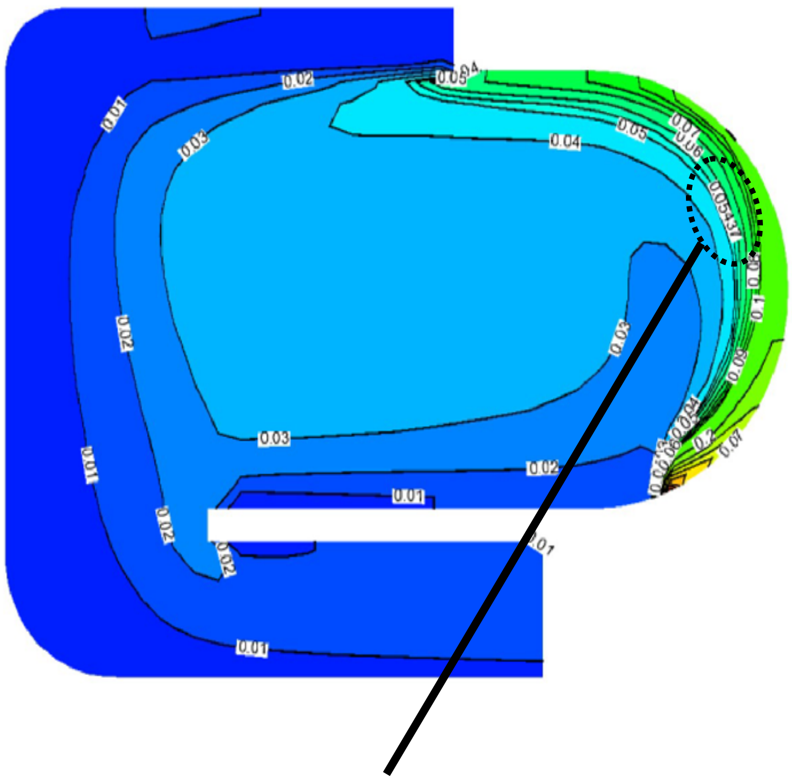
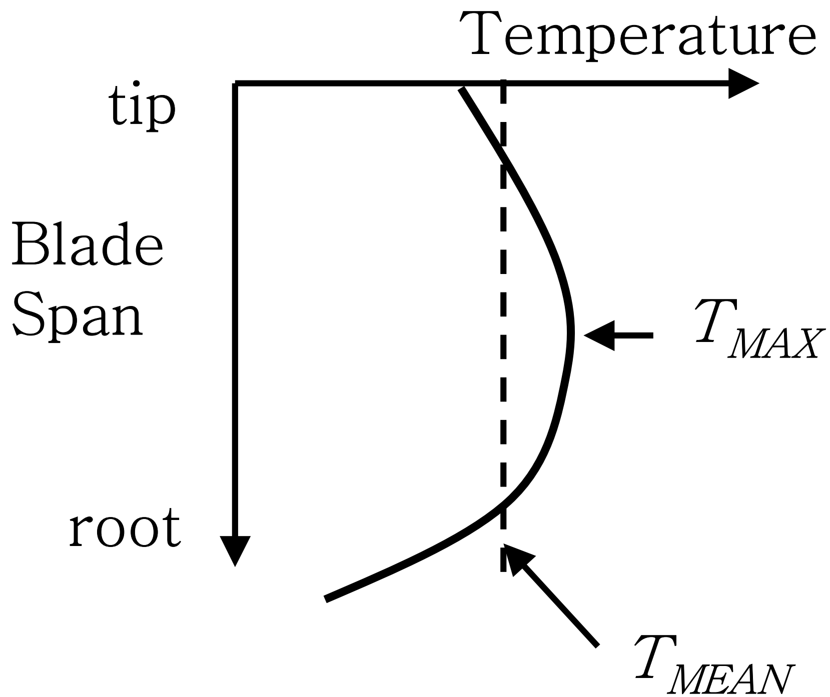


T, min = 486.118, max = 2223.81

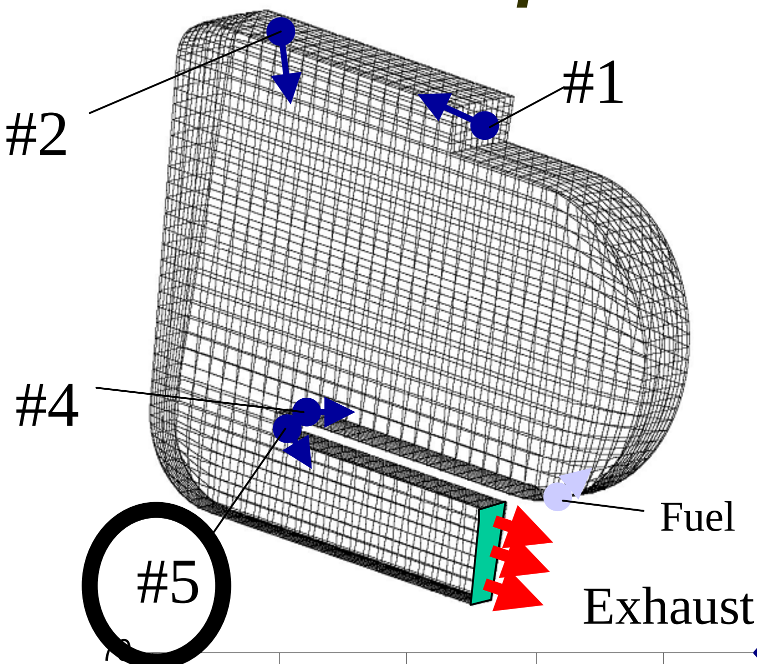


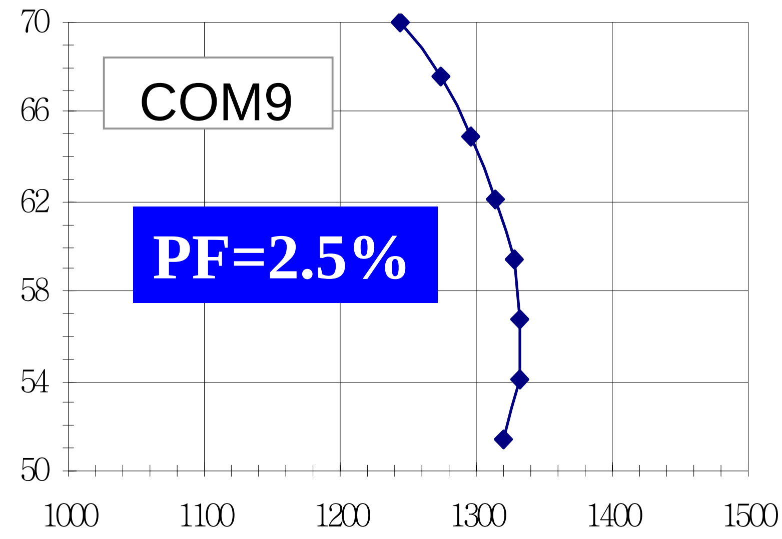
Exhaust Temperature Profile – Pattern Factor

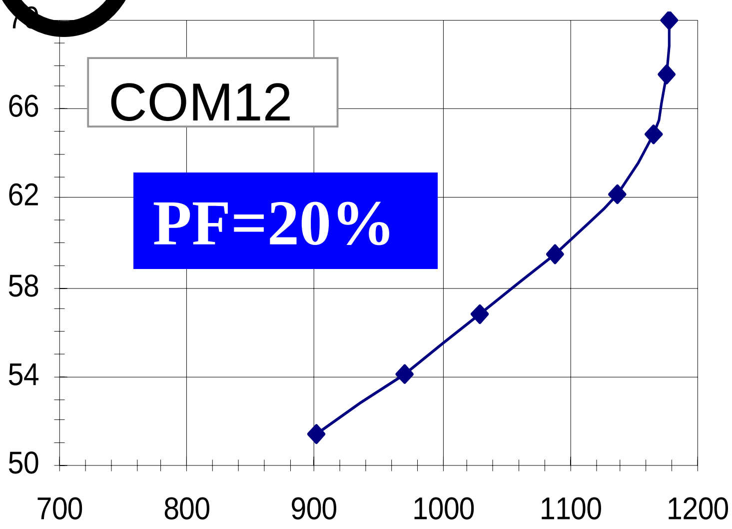


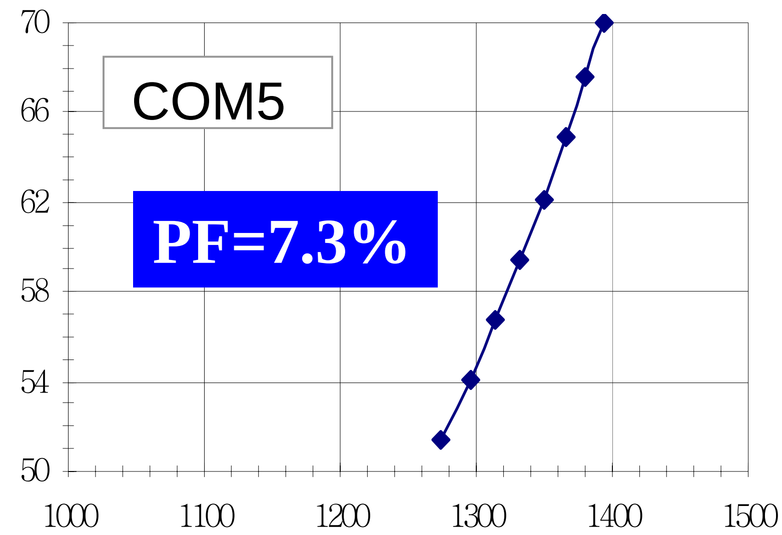
$$PF = \frac{T_{MAX} - T_{MEAN}}{T_{MEAN} - T_{AIR}}$$

Exhaust Temperature Profile – Pattern Factor









Assessment on Cooling System Design

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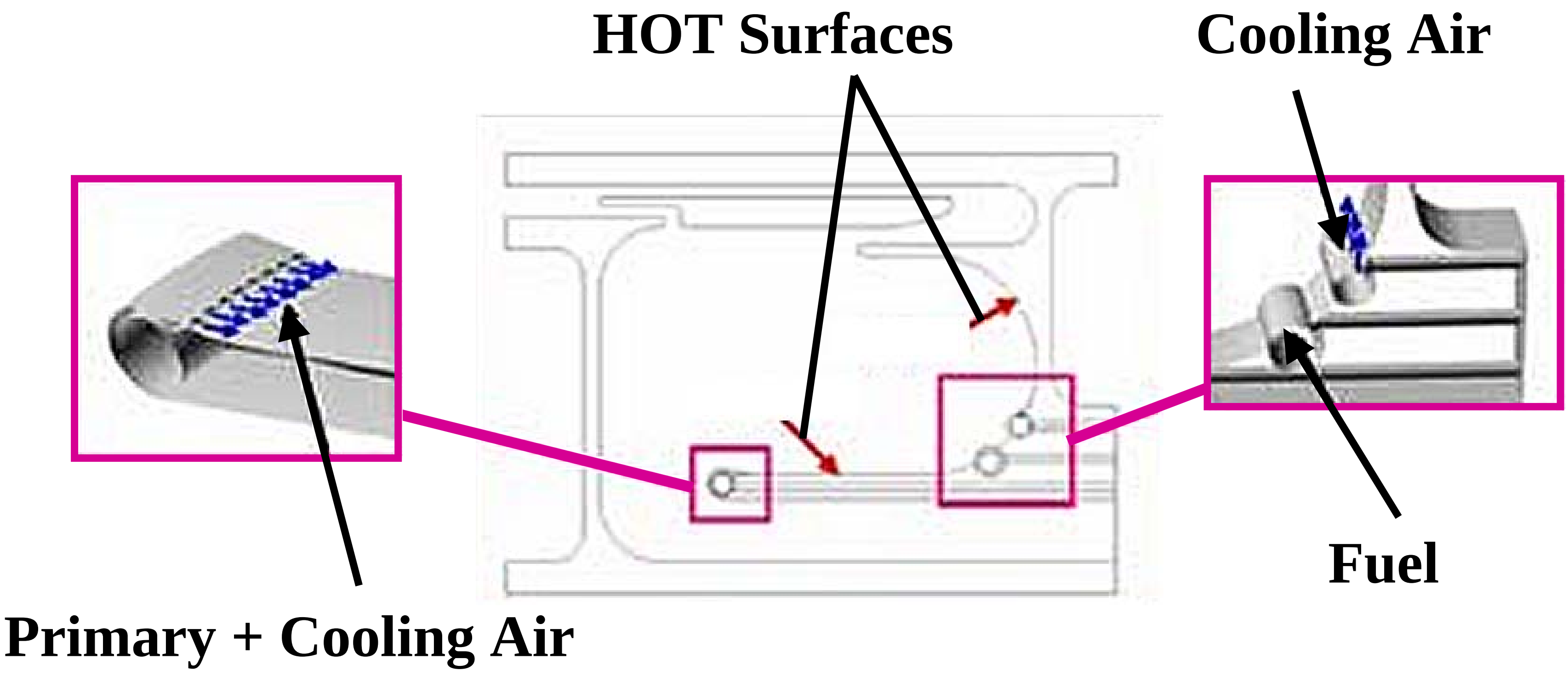

Combustor Wall Temperature Distribution

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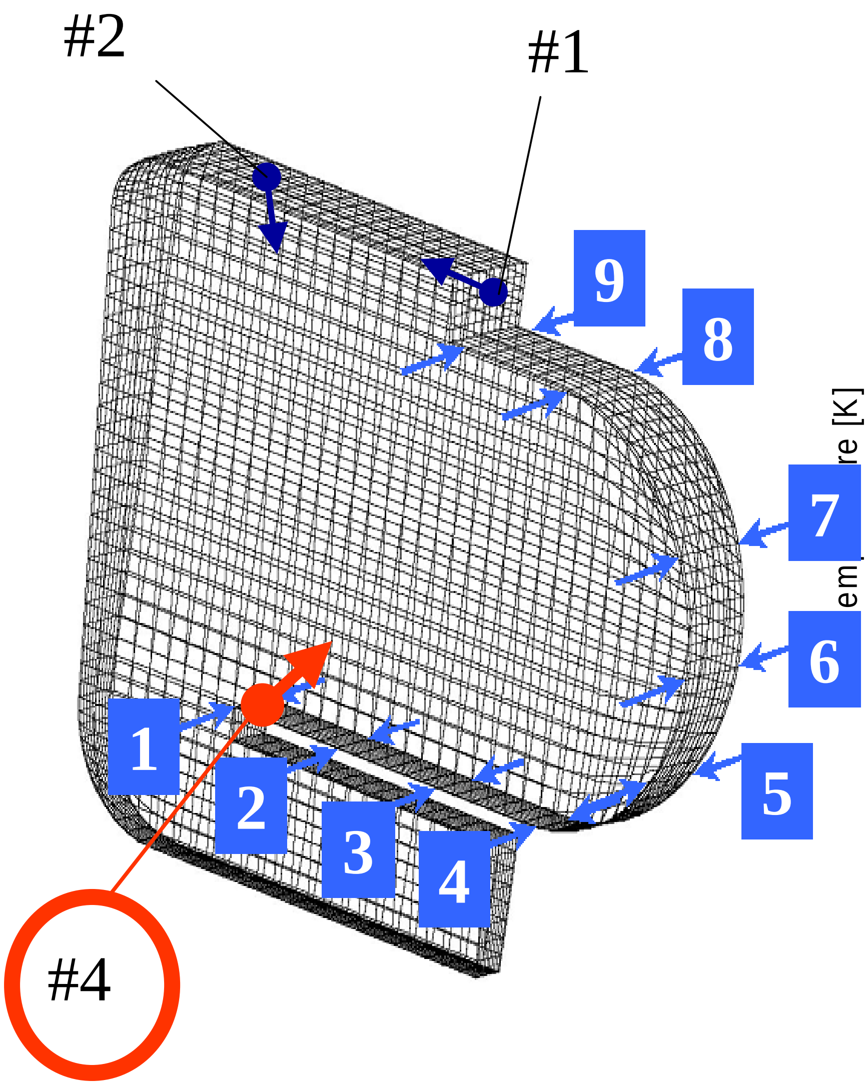

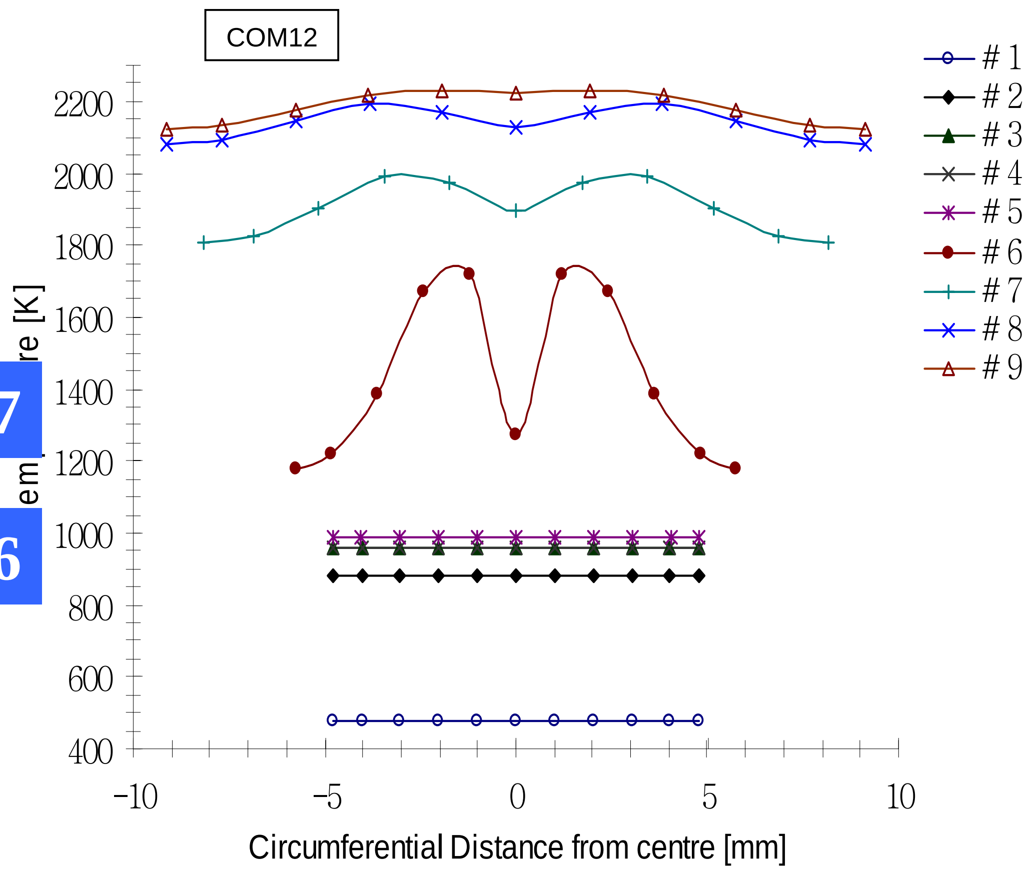

Conclusions & recommendations

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- Numerical simulations demonstrate the feasibility of the proposed FLOXCOM gas turbine design to operate under FLOX regime, with Kv >3.0 & $T_{combair}$ > 800K
- Improved exhaust pattern factor (<25%) achieved by introduction of a tertiary air stream (inlet #5).
- Good wall temperature distribution can be realised by introduction of an axial dilution air stage (inlet #4) upstream to the main combustion zone.
- Relative reduction of combustion zone temperature gradients can be obtained by introduction of a cooling air stage (inlet #4) upstream to the fuel injector.