UNIVERSITY OF CAMBRIDGE

UK CTRF UK CONSORTIUM ON TURBULENT REACTING FLOWS

SIEMENS

archer

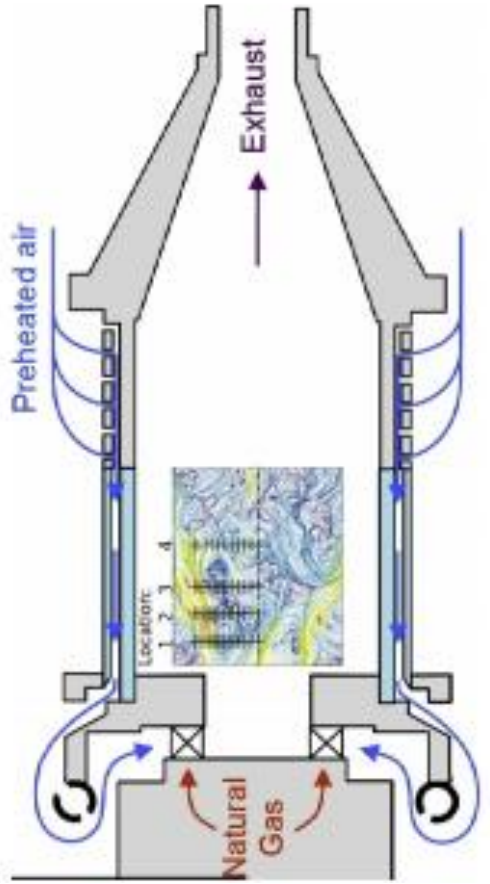
LES of an industrial gas turbine combustor

I. Langella and N. Swaminathan

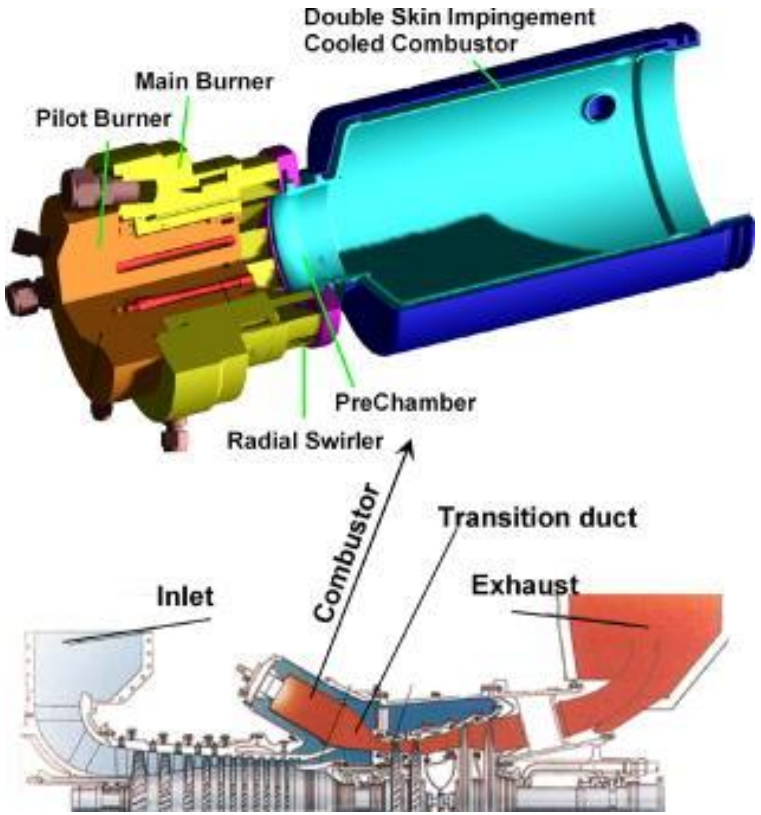
UKCTRF Annual Meeting – University of Southampton, UK, 08 September 2017

Test case

Siemens SGT-100



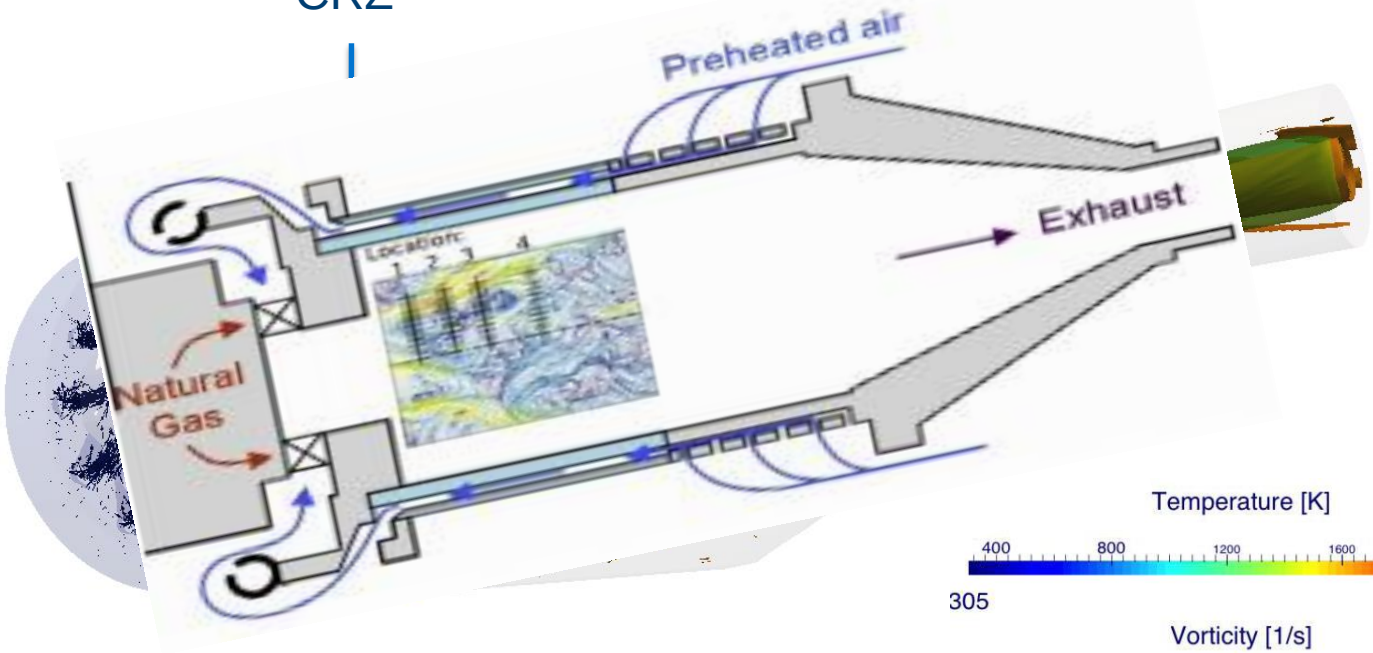
[Sadavisuni et et al. 2012, Stopper et al. 2013, Bulat et al. 2014, Bulat et al. 2015, etc.]

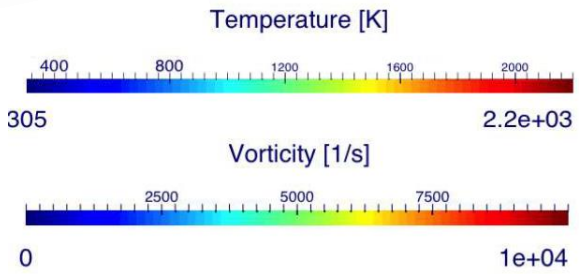


Test case

Siemens SGT-100

CRZ

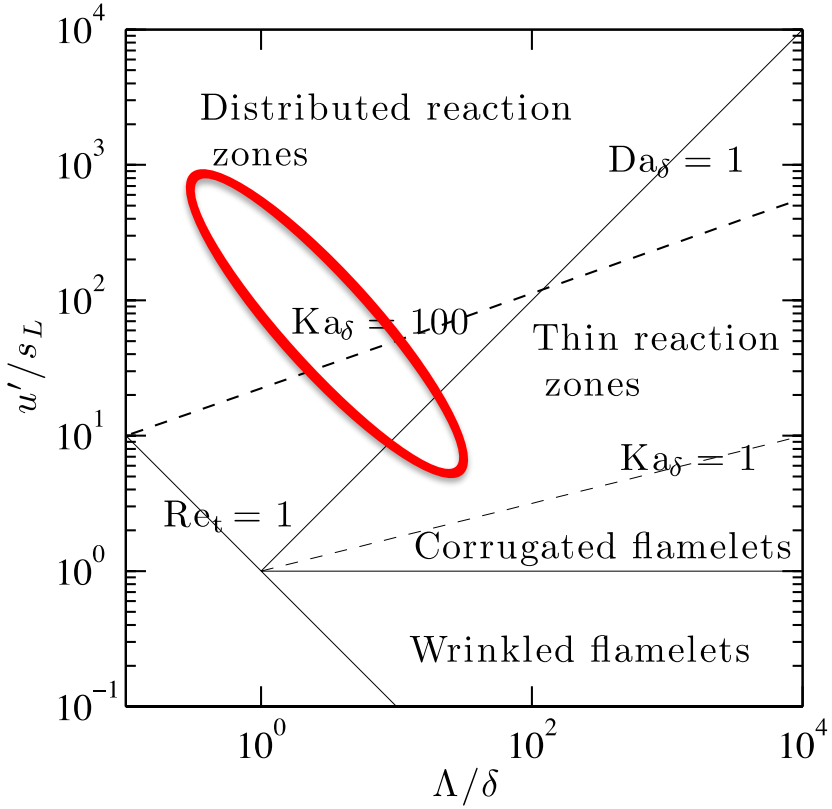




(Winner ARCHER photography competition 2015)

Introduction

FLAMELETS: turbulence does not alter flame inner structure and can be separated from thermochemistry



Are flamelets valid outside flamelets regime?

Still valid in the TRZ regime in premixed combustion

[Meneveau and Poinsot 1991, Dunn et al 2007, 2009, Langella et al. 2015]

Unstrained flamelets model still yields accurate results in DRZ regime

[Langella et al. 2016 (CTM)]

Unstrained flamelets model

$$\frac{\partial \overline{\rho}\widetilde{c}}{\partial t} + \frac{\partial \overline{\rho}\widetilde{u}_i\widetilde{c}}{\partial x_i} = \frac{\partial}{\partial x_i}\left(\overline{\rho D \frac{\partial c}{\partial x_i}}\right) - \frac{\partial}{\partial x_i}(\overline{\rho}\widetilde{u_i c} - \overline{\rho}\widetilde{u}_i\widetilde{c}) + \overline{\dot{\omega}^*}$$

$$\overline{\dot{\omega}^*} = \overline{\dot{\omega}}_c + \overline{\rho\,\chi_{\xi\xi}\frac{c}{\psi^{eq}}\frac{d^2\psi^{eq}}{d\xi^2}} + 2\,\overline{\rho\,\chi_{\xi c}\frac{1}{\psi^{eq}}\frac{d\psi^{eq}}{d\xi}} = \overline{\dot{\omega}}_{\mathrm{fp}} + \overline{\dot{\omega}}_{\mathrm{np}} + \overline{\dot{\omega}}_{\mathrm{ct}}$$

Partially premixed approximation

Product of Beta functions

$$\overline{\dot{\omega}}_{\mathrm{fp}} = \int_0^1 \int_0^1 \dot{\omega}(\zeta,\eta) P(\zeta,\eta)\, \mathrm{d}\zeta\, \mathrm{d}\eta$$

$$\overline{\rho}\frac{D\widetilde{c''^2}}{Dt} = \frac{\partial}{\partial x_j}\left[\left(\frac{\widetilde{\mu}}{Sc_l} + \frac{\mu_t}{\sigma_{c^2}}\right)\frac{\partial \widetilde{c''^2}}{\partial x_j}\right] - 2\overline{\rho}\widetilde{\varepsilon}_c + 2(\overline{\dot{\omega}c} - \overline{\dot{\omega}}\widetilde{c}) - \frac{\partial}{\partial x_j}\left(\frac{\mu_t}{\sigma_c}\frac{\partial \widetilde{c}^2}{\partial x_j}\right) + 2\frac{\widetilde{\mu}}{\sigma_c}\frac{\partial \widetilde{c}}{\partial x_j}\frac{\partial \widetilde{c}}{\partial x_j}$$

Unstrained flamelets model

$$\overline{\rho}\frac{D\widetilde{c''^2}}{Dt} = \frac{\partial}{\partial x_j}\left[\left(\frac{\widetilde{\mu}}{Sc_l}+\frac{\mu_t}{\sigma_{c^2}}\right)\frac{\partial\widetilde{c''^2}}{\partial x_j}\right] - 2\overline{\rho}\widetilde{\varepsilon}_c + 2(\overline{\dot{\omega}c} - \overline{\dot{\omega}}\widetilde{c}) - \frac{\partial}{\partial x_j}\left(\frac{\mu_t}{\sigma_c}\frac{\partial\widetilde{c}^2}{\partial x_j}\right) + 2\frac{\widetilde{\mu}}{\sigma_c}\frac{\partial\widetilde{c}}{\partial x_j}\frac{\partial\widetilde{c}}{\partial x_j}$$

Linear relaxation

$$\widetilde{\varepsilon}_c = a\frac{\nu_{\text{sgs}}}{\Delta^2}\widetilde{c''^2} \sim \tau_t$$

FlaRe

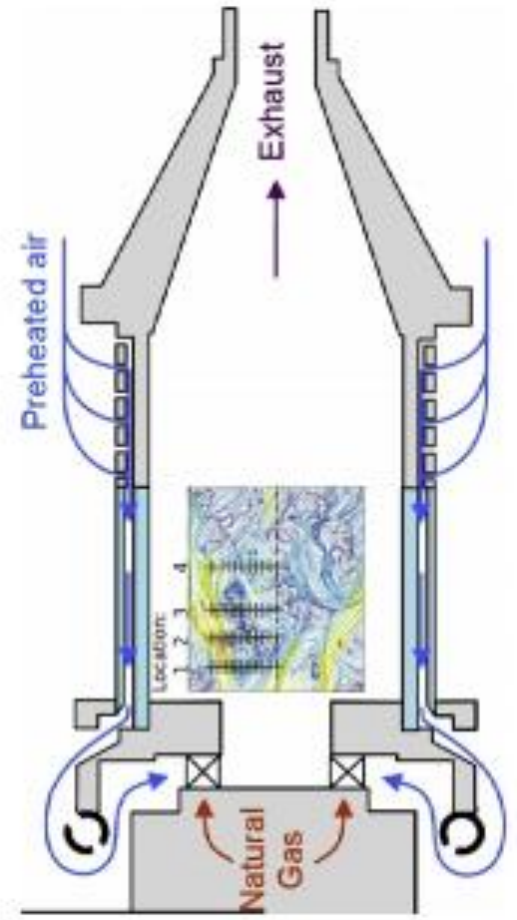
$$\widetilde{\varepsilon}_c = \left(1 - e^{-\theta_5\Delta^+}\right)\left[2K_c\frac{s_L}{\delta_{th}} + (C_3 - \tau C_4 \mathrm{Da}_\Delta)\frac{2u'_\Delta}{3\Delta}\right]\frac{\widetilde{c''^2}}{\beta_c}$$

$$\sim \tau_t + \tau_c + \tau_{ct}$$

[Dunstan *et al.* 2013,
Langella & Swaminathan 2015,
Langella *et al.* 2015, 2016]

Results

Siemens SGT-100 combustor



Boundary conditions:

$\widetilde{h}$ → $T_f = 305\,K \quad T_{\text{air}} = 600\,K$

$\widetilde{c}$ → Based on (CO_2+CO), zero at inlet

$\widetilde{c''^2}$ → Zero at inlet

$\widetilde{\xi}$ → $\xi_f = 1 \quad \xi_{\text{air}} = 0$

Zero gradient for scalars on walls and outlet

Updated values for mass flow rates

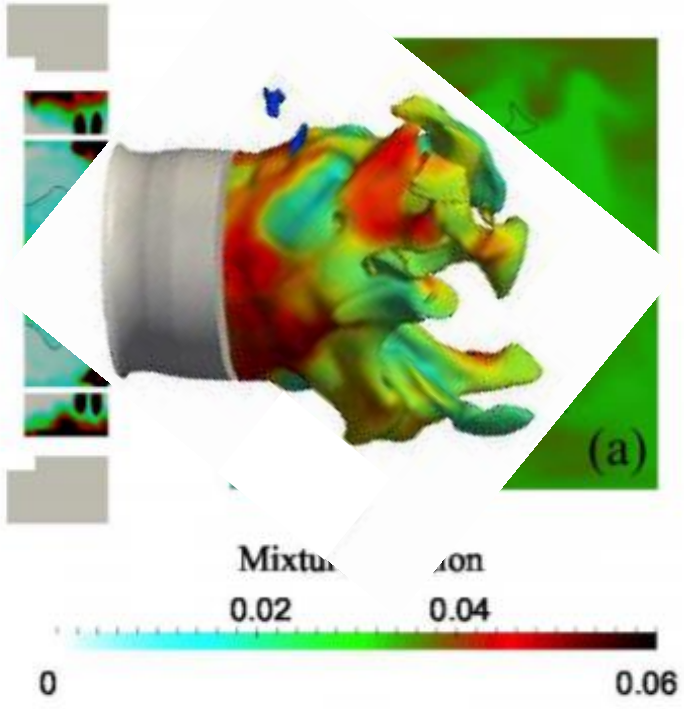
SGS modelling: → k_{sgs} equation, dynamic β_c

Schemes → Second order with limiters

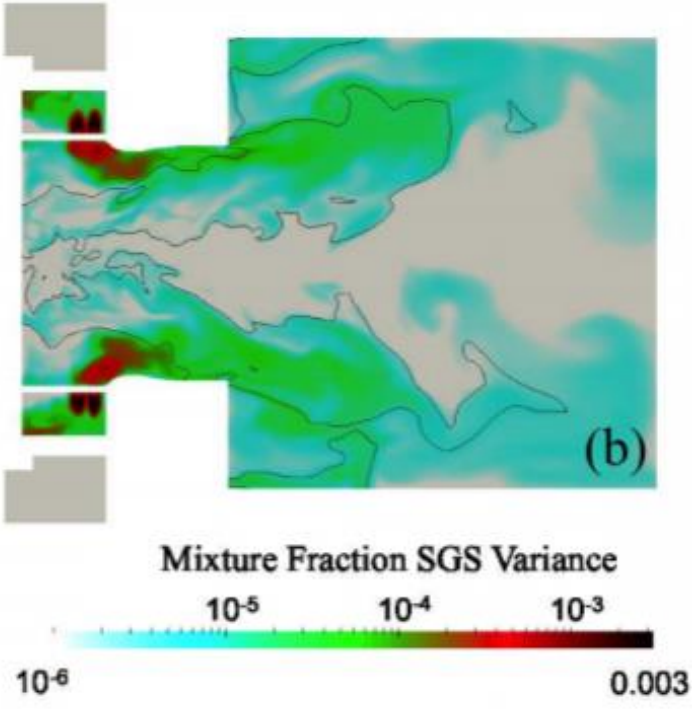
LES time	On wall clock	N. proc.	Max CFL	Δt
0.2 s	3 days	768	0.3	5×10^{-7} s

≈ 830 kAU per simulation

Results
Siemens SGT-100 combustor



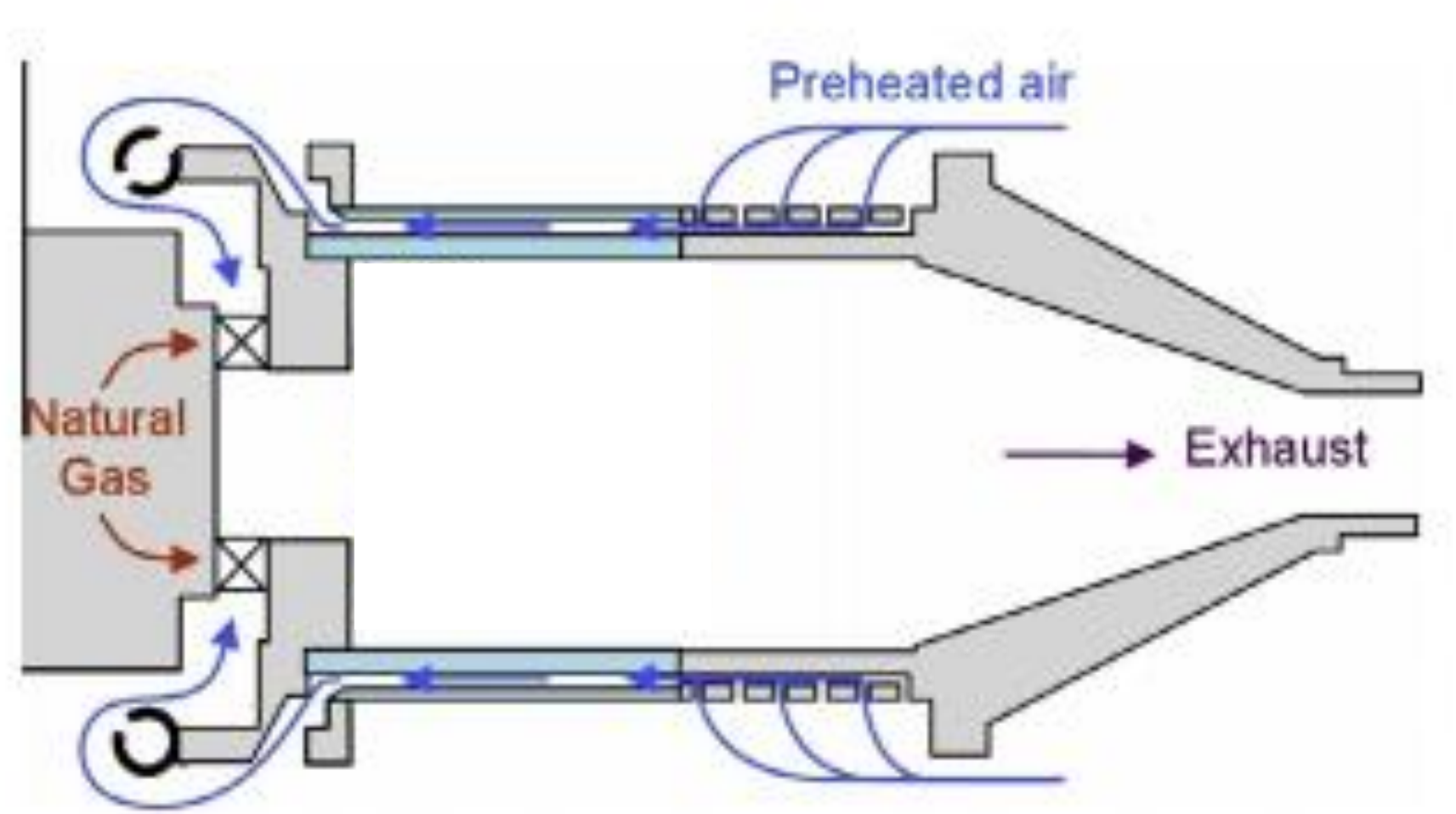
Mixture fraction varies a lot in the region of the flame…



…but its variance is very small

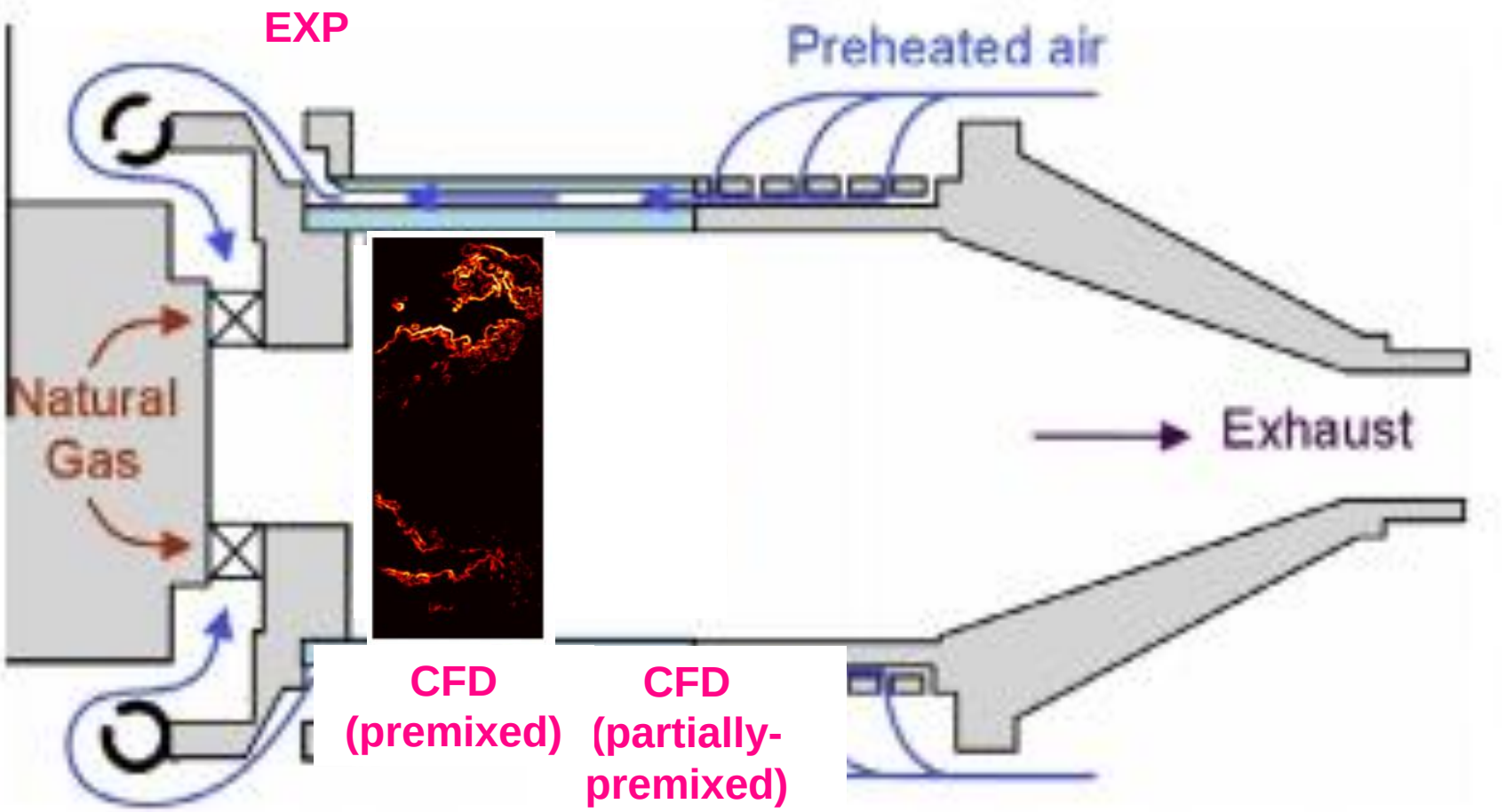
Results

Siemens SGT-100 combustor



Results

Siemens SGT-100 combustor



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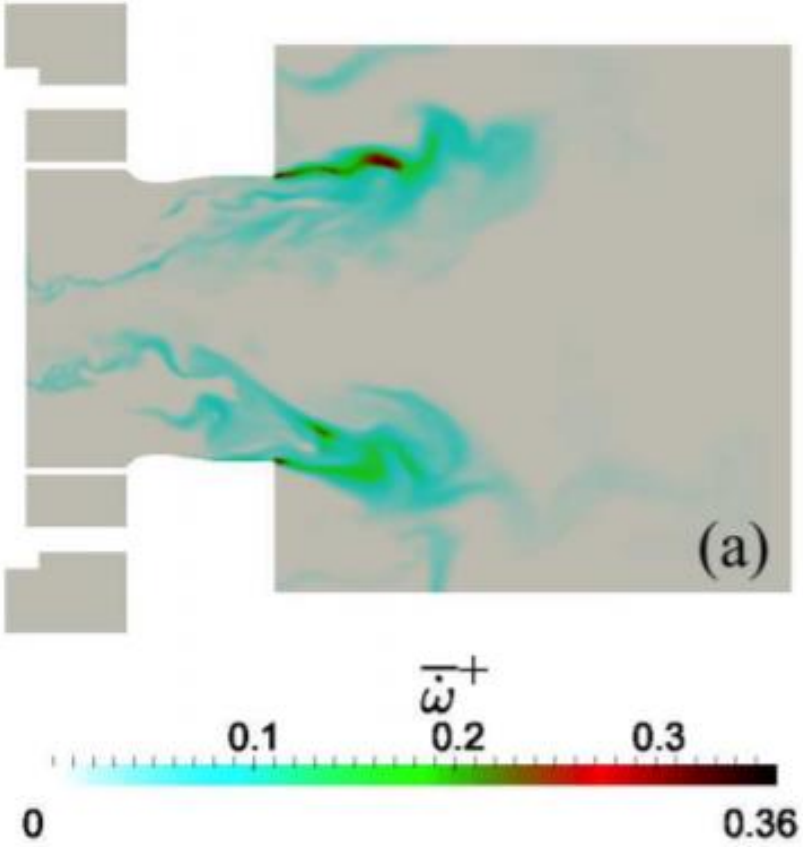
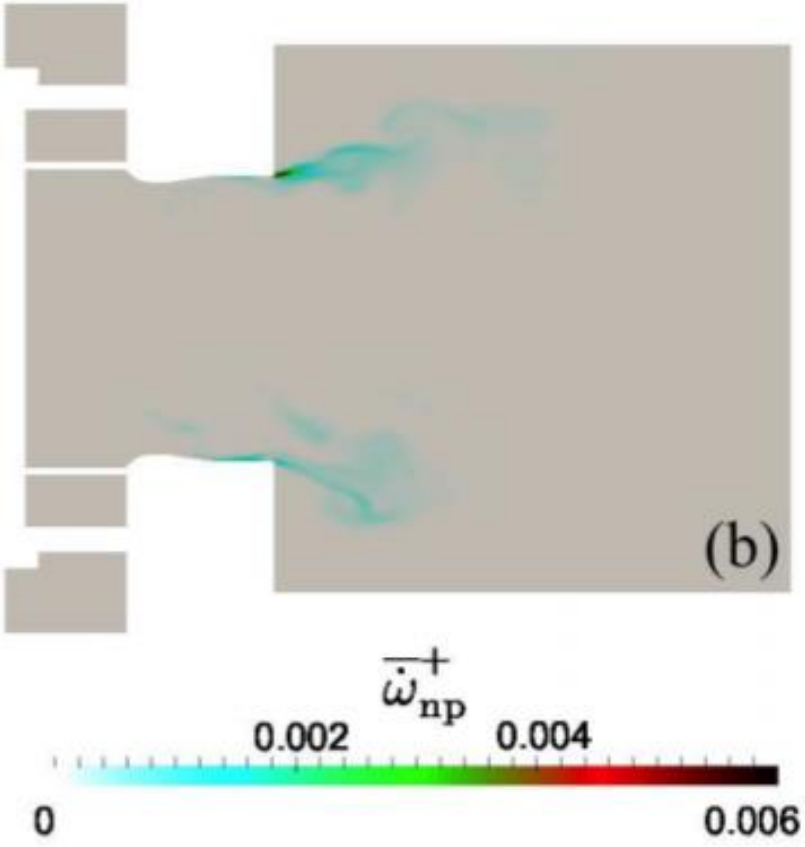
Siemens SGT-100 combustor





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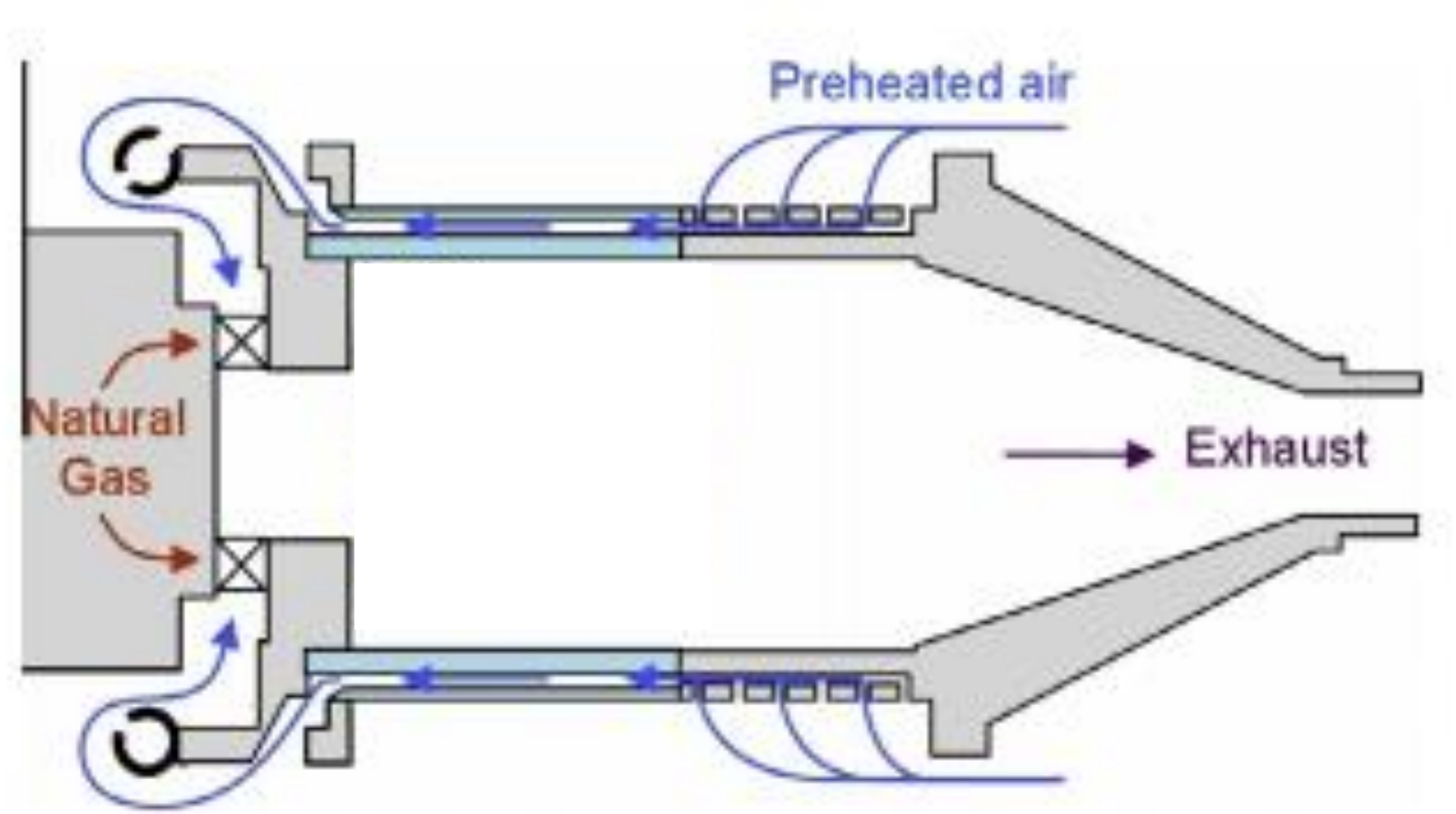

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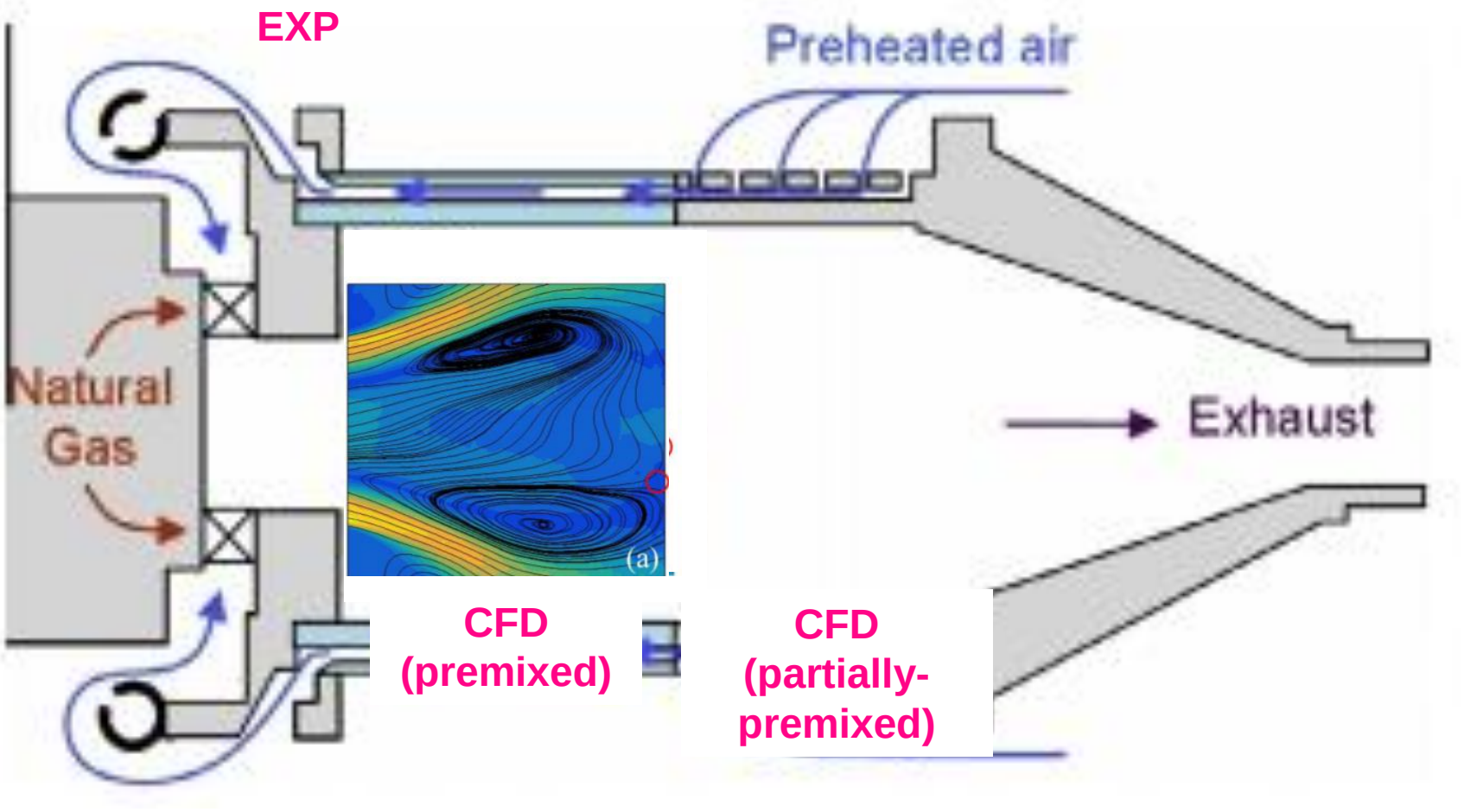
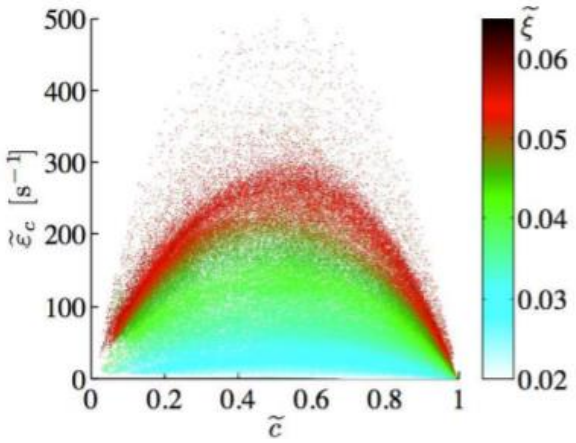
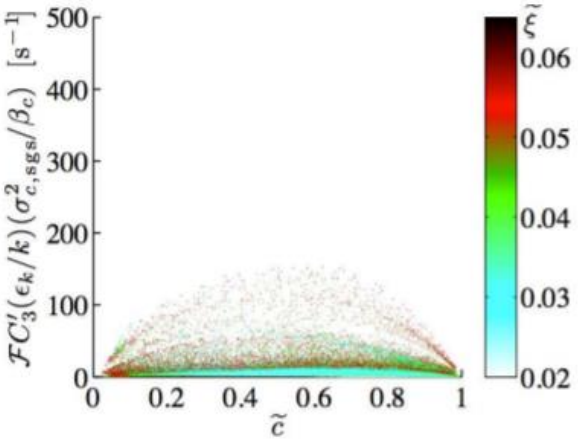


Results

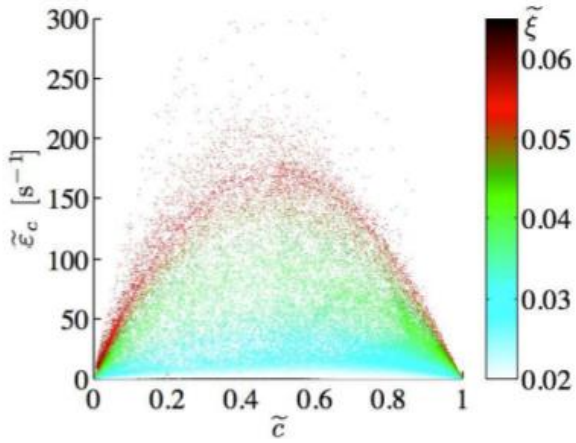
Siemens SGT-100 combustor

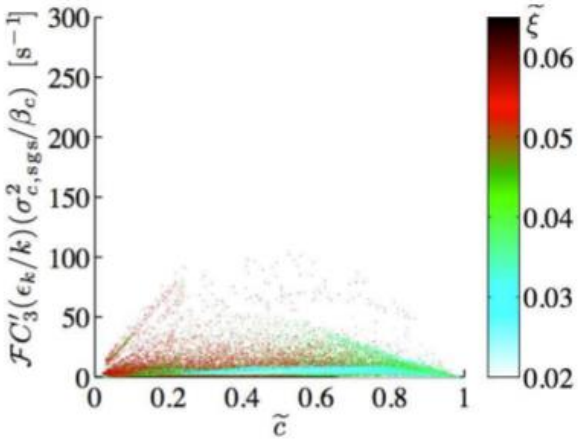
Premixed





Partially premixed





- The SDR (and the pgr variance) ultimately affect the reaction rate
- Linear relaxation model leads to significantly smaller SDR

Conclusions

- Unstrained flamelets show to work well for the Siemens SGT-100 under the operating condition investigated in this study
- Despite the mixture fraction variance and the non-premixed mode are SMALL, the reaction rate changes significantly from a “premixed” to a partially premixed model
- Small variation of mixture fraction seems to affect significantly the SDR and variance of the progress variable. This indirect effect leads to significant changes in the reaction rate magnitude.

THANKS FOR YOUR ATTENTION

Thanks in particular to:

UK CTRF UK CONSORTIUM ON TURBULENT REACTING FLOWS

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SIEMENS