Turbulent Reacting Flows (ME1540) 2014-2015

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COURSE OUTLINE , COURSE MATERIAL AND ASSESSMENT MATRIX
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1. Course schedule

Lectures:

Date	Topic
9.2	General introduction
16.2	Basic equations of reacting flow
23.2	Introduction to turbulent combustion (turbulence, DNS, RANS, LES)
2.3	Chemical reaction rates / Non-premixed combustion: fast chemistry models
9.3	Laminar flamelet model for turbulent combustion.
16.3	Turbulent premixed flames (regime diagram, closure models)
23.3	*To be determined*

Assignments:
Every week an assignment will be made available, related to the topic of the day. The solutions to the assignments have to be handed in after one week (on paper, or by email to d.j.e.m.roekaerts@tudelft.nl).

The grade obtained on the assignments contributes a bonus of a most 1 point to the grade obtained on the oral exam.

2. Course outline, illustrated with typical questions addressed in each lecture

Lecture 1 : General introduction

- What are relevant physical time scales in turbulent flow. How do they relate to chemical time scales ?

Lecture 2 : Basic equations of reacting flow

- In steady state combustion studies enthalpy h is often chosen as energy variable. What is the relation between enthalpy and temperature ? Explain the physical meaning of the different terms in the equation for enthalpy (equation will be given). Explain the physical meaning of the different terms in the equation for temperature (equation will be given).

Lectures 3 : Introduction to turbulent combustion (turbulence, DNS, RANS, LES)

- Give a short description of the three main approaches to the computation of turbulent flames and specify their advantages and drawbacks.
- Explain the main closure problems that arise when averaging the transport equations for an exothermic reacting flow.
- Density weighted averaging, also called Favre averaging, is an alternative way of averaging leading to a specific form of the averaged transport equations. What is Favre averaging ? What is this specific form ? Can it be expected to be a good approach for premixed flames / for non-premixed flames ?
- Explain how both the wide range of scales in turbulence and the difference in scale of turbulent eddies and flame fronts provide limitations to the feasibility of Direct Numerical Simulation
- Explain what is meant by Large Eddy Simulation of turbulent flow. Also discuss the need for subgrid models of combustion processes in the context of LES.

Lecture 4 :

Part I : Chemical reaction rates

- What is the Zel'dovich mechanism for thermal NOx formation ? Discuss the importance of temperature fluctuations in thermal NOx formation ?

Part II : Non-premixed combustion. Mixture fraction. Fast chemistry models.

- What is the typical structure of a laminar diffusion flame?
- Why is there no such thing as a laminar flame speed of a diffusion flame?
- Define mixture fraction. Which conditions have to be satisfied in order that mixture fraction becomes a useful variable? Explain the idea that the using mixture fraction, a non-premixed flame problem can be split in a mixing problem and a chemical problem.
- What are the essential differences between a laminar diffusion flame described for the case of infinitely fast irreversible chemistry, infinitely fast reversible chemistry, finite rate irreversible chemistry, finite rate reversible chemistry? How does the influence of the flow manifests itself in the solution?
- In which circumstances can enthalpy be considered to be equivalent to mixture fraction?
- The structure of a laminar diffusion flame can be described nicely if the chemistry is assumed to be fast. Explain the structure.
- explain how the influence of turbulent fluctuations of mixture fraction can be taken into account by making use of an assumed shape of its probability density function.
- Explain why one is interested in calculating the variance of mixture fraction. How does the scalar dissipation rate influence the variance of mixture fraction?

Lecture 5 : Laminar flamelet model for turbulent combustion.

- Explain the steady laminar flamelet model of turbulent non-premixed combustion.

Lecture 6 : Turbulent premixed flames (regime diagram, closure models)

- Discuss the structure of a flat laminar premixed flame
- Discuss the classical regime diagrams of turbulent premixed combustion (Borghi and Peters diagrams)
- Explain the thickened flame model for Large Eddy Simulation of turbulent premixed flames
- What is laminar flame speed? What is turbulent flame speed? How are they related?

Lecture 7 : *To be decided*

3. Course material

Slides of the lectures are made available

Book: Poinsot and Veynante, Theoretical and numerical combustion
http://elearning.cerfacs.fr/combustion/onlinePoinsotBook/buythirdedition/index.php

For each chapter the sections used in the preparation of slides are as follows:
Chapter 1: Conservation equations for reacting flows (Sections 1.1-1.4)
Chapter 2: Laminar premixed flames (Sections 2.1-2.2)
Chapter 3: Laminar diffusion flames (Sections 3.1-3.6)
Chapter 4: Introduction to turbulent combustion (Sections 4.1-4.5, 4.7)
Chapter 5: Turbulent premixed flames
(Sections 5.2 (5.2.1, 5.2.2 and 5.2.3 up to page213), section 5.4 (5.4.1, 5.4.3, 5.4.4, 5.4.5))
Chapter 6: Turbulent non premixed flames (Section 6.4)
Remark : the sections of the book of Poinsot and Veynante are course material only up to the level of detail presented in the slides, but it is allowed to study and answer using other material form the book.

Book : Warnatz, Maas, Dibble
Combustion . Physical and chemical fundamentals, modeling and simulation, experiments, pollutant formation.
http://www.springer.com/engineering/mechanical+engineering/book/978-3-540-25992-3
The book of Warnatz, Maas and Dibble in many cases offers a simpler treatment than the book of Poinsot and Veynante. will be used as a source of exercises for the assignments.

4. Additional reading:

Introduction to turbulent combustion modeling :
Introduction to turbulent combustion (by D. Roekaerts)
Chapter 8 from the lecture notes of the J.M. Burgers Centre course on Combustion

Flamelet modeling of non-premixed turbulent flames (by L.M.T. Somers)
Chapter 9 from the lecture notes of the J.M. Burgers Centre course on Combustion
(essential for understanding the slides of lecture 5)

Recent developments in turbulent combustion modeling:
S.B. Pope, Small scales, many species and the manifold challenges of turbulent combustion, Proc. Combust. Inst. (2012), http://dx.doi.org/10.1016/j.proci.2012.09.009, only the first 16 pages

Large eddy simulation and its application
L.Y.M. Gicquel, G. Staffelbach, T. Poinsot, Large Eddy Simulations of gaseous flames in gas turbine combustion chambers, Progress in Energy and Combustion Science, 38 (2012) 782-817

5. Assessment Matrix Turbulent Reacting Flows ME1540

Sub-goal	Contribution to bonus obtained based on solutions of assignments	Contribution to mark of final oral exam
Having knowledge of physical mechanisms determining flame structure in premixed and non-premixed reacting flows	10 %	30 %
Being able to derive and discuss model equations to describe turbulent reacting flows (TRF) as covered in the course	10%	30 %
Being able to select an appropriate set of model equations for a specific TRF problem and to describe the solution procedures	30 %	20 %
Being able to solve problems on topics covered in the course at the level of end-of-chapter exercises in the textbook "Combustion" by Warnatz et al.	40 %	10 %
Being able to identify some relevant aspects and make estimates of turbulent reacting flow in practical situations (e.g. to optimize industrial furnaces)	10 %	10 %
	100 % of bonus point	100 %