The Spirit of Leonardo
Complexity, Interdisciplinarity and Engineering sciences

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The Spirit of Leonardo:
Complexity, Interdisciplinarity and Engineering sciences

Outline

- CNRS
- ICARE : Institut de Combustion, Aérothermique, Réactivité et Environnement – UPR 3021 CNRS, Orléans, France
- Complexity and Interdisciplinarity in Engineering sciences: examples from Combustion research and the Energy question
- How to strengthen disciplinary interactions : examples from my attempts

ICARE

More than half a century history

1958 : Création de l'Aérothermique à Meudon
1969 : Création du CRCCHT à Orléans
1991 : CRCCHT devient LCSR
1991 : Démarrage du projet de relocalisation de l'Aérothermique à Orléans
1995 : Recréation de l'Aérothermique à Orléans
1998 : Création de la FR EPEE
2001 : Installation de l'Aérothermique et du LCSR dans les nouveaux locaux
2003 : Nouveaux mandats pour l'Aérothermique et le LCSR
2007 : Création d'ICARE
2009 : Mi-parcours ICARE
2010 : Evaluation A+ par l'AERES
2012: Nouveau mandat 2012 – 2015
2012: Labellisation du LABEX CAPRYSSES

ICARE in Orléans

ICARE se trouve à Orléans, 125 km de Paris

ICARE – CNRS
Institut de **C**ombustion, **A**érothermique
Réactivité et **E**nvironnement
1c, avenue de la Recherche Scientifique
45071 Orléans – Cedex 2 – France

Personnel total : 91 (+ 25 stagiaires divers**)**
27 chercheurs (11) et ens-cher UO (16)
17 personnel technique et administratif
22 doctorants
25 post-doctorants, ATER, contractuels

The Spirit of Leonardo

Complexity, Interdisciplinarity and Engineering sciences

ICARE in Orléans

- Institut de
- Combustion
- Aérothermique
- Réactivité et
- Environnement

ICARE in Orléans and
The Myth of Daedalus and Icarus

- **Daedalus** was a famous architect, inventor, and master craftsman. He created many objects that figure prominently in various myths.

- When he came to Crete, he worked at the court of King Minos and Queen Pasiphae, in the palace of Knossos

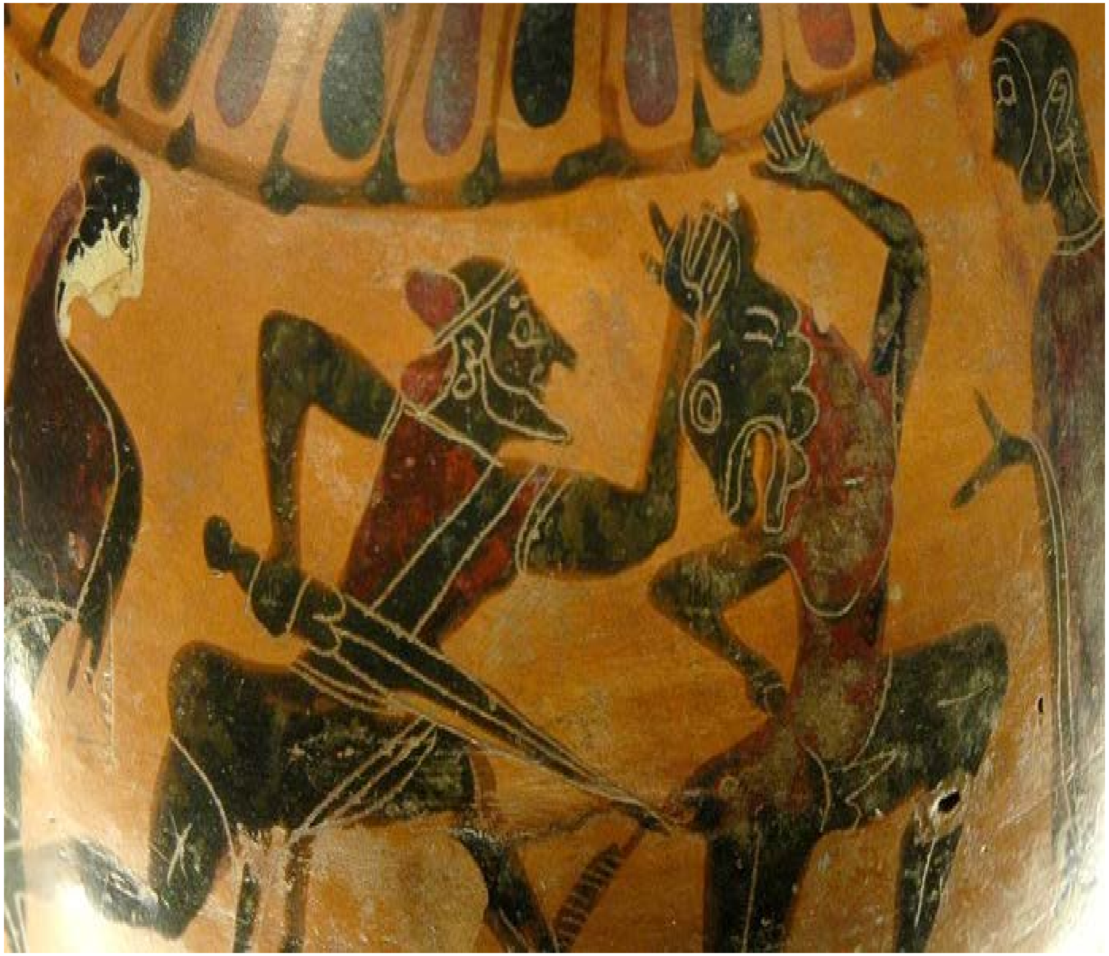
- When the Minotaur was born, Daedalus built the Labyrinth to contain the monstrous half-man, half-bull.

- King Minos obliged the Athenians to pay each year a tribute of youths and maidens to the monstrous Minotaur kept in the Cretan labyrinth.

- But Theseus of Athens came to Crete and killed the Minotaur. King Minos suspected Daedalus of helping him and emprisoned Daedalus and his son **Icarus** in the Labyrinth.

*Clay tablet bearing the motive of the Labyrinthe, Mycenian (*XIV*e s. b. J.-C.), Museum of Athens*

Theseus and the Minautor, amphora detail, 575-530 av. J.-C., musée du Louvre



Daedalus made wings for his son and himself to escape from the Labyrinth and Crete. Daedalus flew to safety but **Icarus** was so impressed with the power and strength of his wings that, despite the warnings of his father, he flew ever higher in the sky, out into space, and even to the Sun. The wings, being made of feathers and wax, melted in the Sun's heat, and Icarus died by falling into the Icarian Sea near Icaria, the island southwest of Samos

The Lament for Icarus, by Herbert Draper (1863-1920)
Tate Gallery, London

ICARE in Orléans

- **I**nstitut for
- **C**ombustion
- **A**erothermal sciences
- **R**eactivity
- **E**nvironment

- ICARE also reads as ***I care***

Main research domains

Two main research domains

Energy & Environnement

Space & Propulsion

Three main research thematics

Chemical kinetics and dynamics of combustion and reactive systems

Atmospheric chemistry

Supersonic, hypersonic, rarefied, ionized flows

Mission

Développer les domaines de la combustion et la détonation,
la propulsion aérospatiale et automobile, la réactivité atmosphérique,
les nouvelles ressources et matériaux pour l'énergétique

Research domains of ICARE
Energy & Environment
Propulsion & Space

- Combustion
  - Chemical kinetics
    - Plasmas physics
      - Fluid mechanics, turbulence
        - Two phase flows
          - Supersonic, hypersonic flows
            - Ionized, rarefied flows

Application domains

- Aerospace propulsion
- Electric propulsion
- Liquid and solid propulsion
- Atmospheric reentry
- Atmospheric chemistry
- Energy production
- Alternative fuels, biofuels, hydrogen
- Pollutant emissions reductions
- Industrial risk prevention

Main R&D cooperations

International cooperations: EU, Russia, USA, Canada, China, Japon, Ukraine, Türkiye, India…

Nouveaux développements (2012-

- LABEX CAPRYSSES (ICARE + PRISME, 2012-2019)
- ERC Senior Grant 2G-Csafe (P Dagaut, 2012-2016)
- HELIOS Chambre atmosphérique à irradiation naturelle
- Chaire Fondation EADS Propulsion et Environnement
- (2013-2016)
- FP 7 OPTIMASH (2012-2015)
- MITHYGENE ANR-RSNR Risque hydrogène CNRS-ICARE, IRSN, CEA, EDF, AREVA; AIR LIQUIDE (2013-2016)

L'Université d'Orléans

Ancrée dans le territoire, ouverte à l'international
Rooted in the region, open to the international world

LABEX CAPRYSSES
Cinétique chimique et Aérothermodynamique pour des Propulsions et des Systèmes Energétiques Propres et Sûrs
ANR-11-LABX-06

Le projet de recherche – Actions à mener I

I] Coupled phenomena between chemical kinetics & fluid dynamics for internal combustion engines, gas turbines and gasification

I.1 Combustion in oxygen enriched air

* Chemical kinetics of oxygen enriched air combustion of natural gas
* Laminar and turbulent premixed & non premixed flames in oxygen enriched air
* Ozone and atomic oxygen assisted ICE combustion
* Magnetic forces enhanced oxygen enrichment

I.2 Hydrogen assisted combustion

* Combustion & emission chemical kinetics of CH_4 – H_2 and syngas mixtures
* Laminar & turbulent combustion of CH_4 – H_2, syngas and biogas mixtures
* H_2 generation with low temperature oxidation of metal particles in

Le projet de recherche – Actions à mener II

II Coupled phenomena between chemical kinetics & fluid dynamics for aerospace propulsion

II.1 Moderate and high speed flow control

* Boundary layer transition and separation; control and development of actuators
* Supersonic flow control by secondary flows
* Subsonic and supersonic flow control by plasmas

II.2 Chemical space propulsion

* Shock induced supersonic combustion
* Supersonic combustion of the pyrolysis products of hydrocarbons or biofuels
* Continuous detonation engine studies

Le projet de recherche – Actions à mener III

III Coupled phenomena between chemical kinetics & fluid dynamics relevant for chemical explosion mitigation and industrial site safety

* Flame acceleration & transition to detonation of gaseous & heterogeneous mixtures
* Blast effects induced by detonation

The Spirit of Leonardo

Complexity, Interdisciplinarity and Engineering sciences

Engineering Sciences

* Most of the present advanced technologies and socio-technical systems have been designed, developed and optimized by engineering sciences such as thermodynamics, heat transfer, fluid mechanics, mechanics of solids, combustion etc., together with more basic disciplines such as materials sciences, chemical-physics, plasma physics etc.

* In recent decades two developments also helped strengthening engineering sciences: they are computational sciences and advanced diagnostics mostly optical and laser based.

* The optimization of socio-technical systems such as network industries also necessitates the mobilization of social sciences and humanities.

Combustion

Combustion is a mode of chemical conversion of energy

Fuel and oxidant molecules react in the presence of an energy source (heat) to generate heat, CO2 and H2O in the case of the complete combustion of a carbon containing fuel reacting with air (or oxygen)

Combustion generates also other emissions than CO2 and H2O, such as SOx, NOx, soot particles etc

Fuel can be in the gaseous phase (natural gas, methane, H2), liquid phase (kerosene, fuel oil) or solid phase (coal, biomass, metals such as Al, Mg…)

Main oxydants are air, or pure oxygen, or oxygen enriched air, but H2O, CO2, may also be considered as oxydants

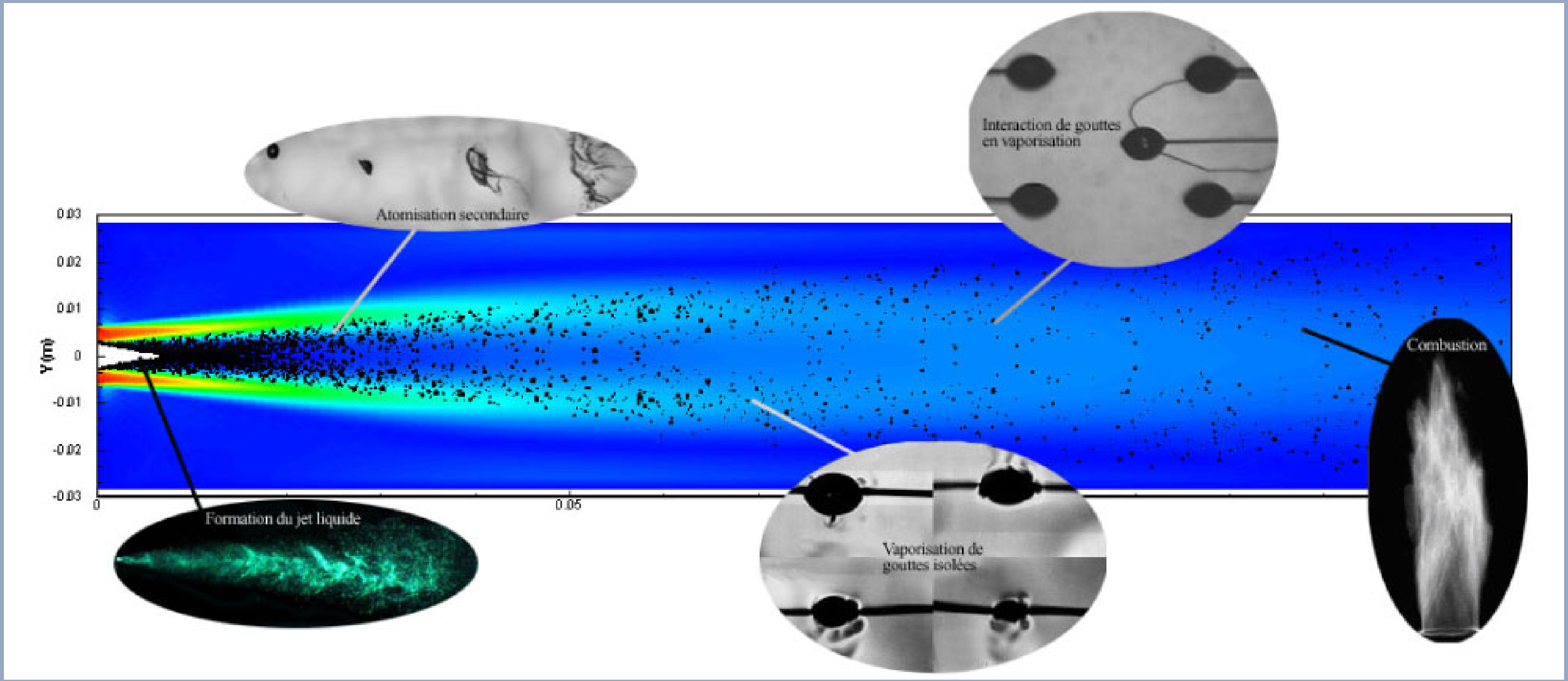
Combustion is a multidisciplinary research area

Combustion is a truly multidisciplinary research area where several phenomena/disciplines interact:

Thermodynamics, chemical kinetics, heat transfer, fluid mechanics, turbulence, multi-phase flows, material sciences, mainly

For example, to characterize and model the behavior of a liquid fuel flame in air necessitate studying the fuel properties (thermodynamics, chemical kinetics), the atomization properties (spray formation and vaporization), mixing properties and finally combustion (heat release rate or burning rate) and emission properties (CO, CO2, NOx, Sox, particulates matter…)

Liquid fuel atomization and combustion



Regimes of Combustion

Regimes of Combustion/Flames

Premixed or Non-premixed (or diffusion)

Laminar or Turbulent

Rich or Poor (compared to the ideal stoichiometric conditions)

Homogenous or Multi-phase

Subsonic or Supersonic

Subcritical or Supercritical

Engineering Sciences

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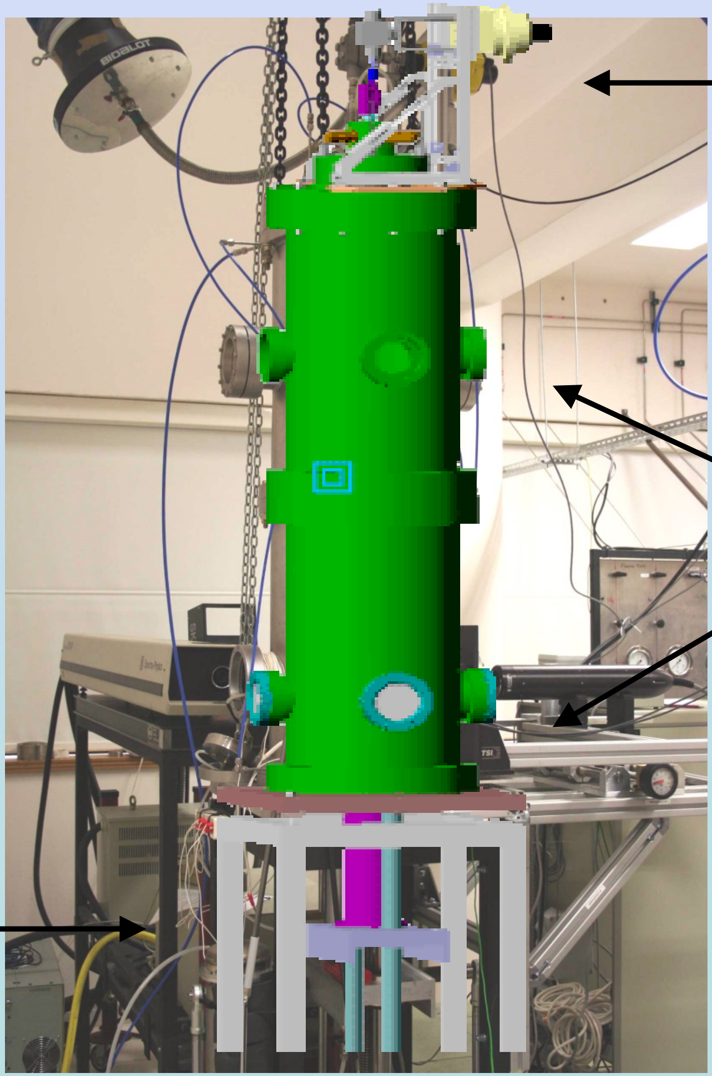
Experimental Approaches to Combustion Studies

Experimental approaches use today mainly optical and laser diagnostics (rapid imagery, laser Doppler velocimetry, PIV, Rayleigh scattering, Raman scattering, laser induced fluorescence, but also several analytical techniques (gas analysis by several methods). The optical diagnostics are called non-intrusive compared for example to thermocouples or sampling probes

ICARE High Pressure Combustion Chamber

- $H = 1.2$ m
- $D_{int} = 0.3$ m
- Water cooling system
- Windows heating system
- Laser light absorbing paint



Pressure regulation

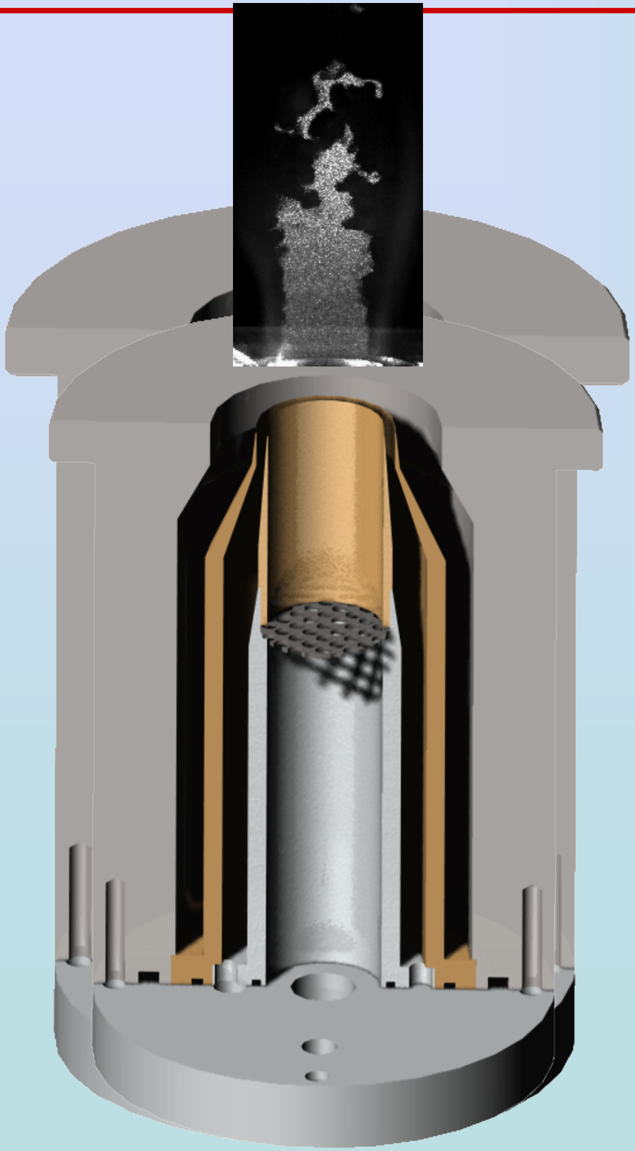
Windows

Axial displacement

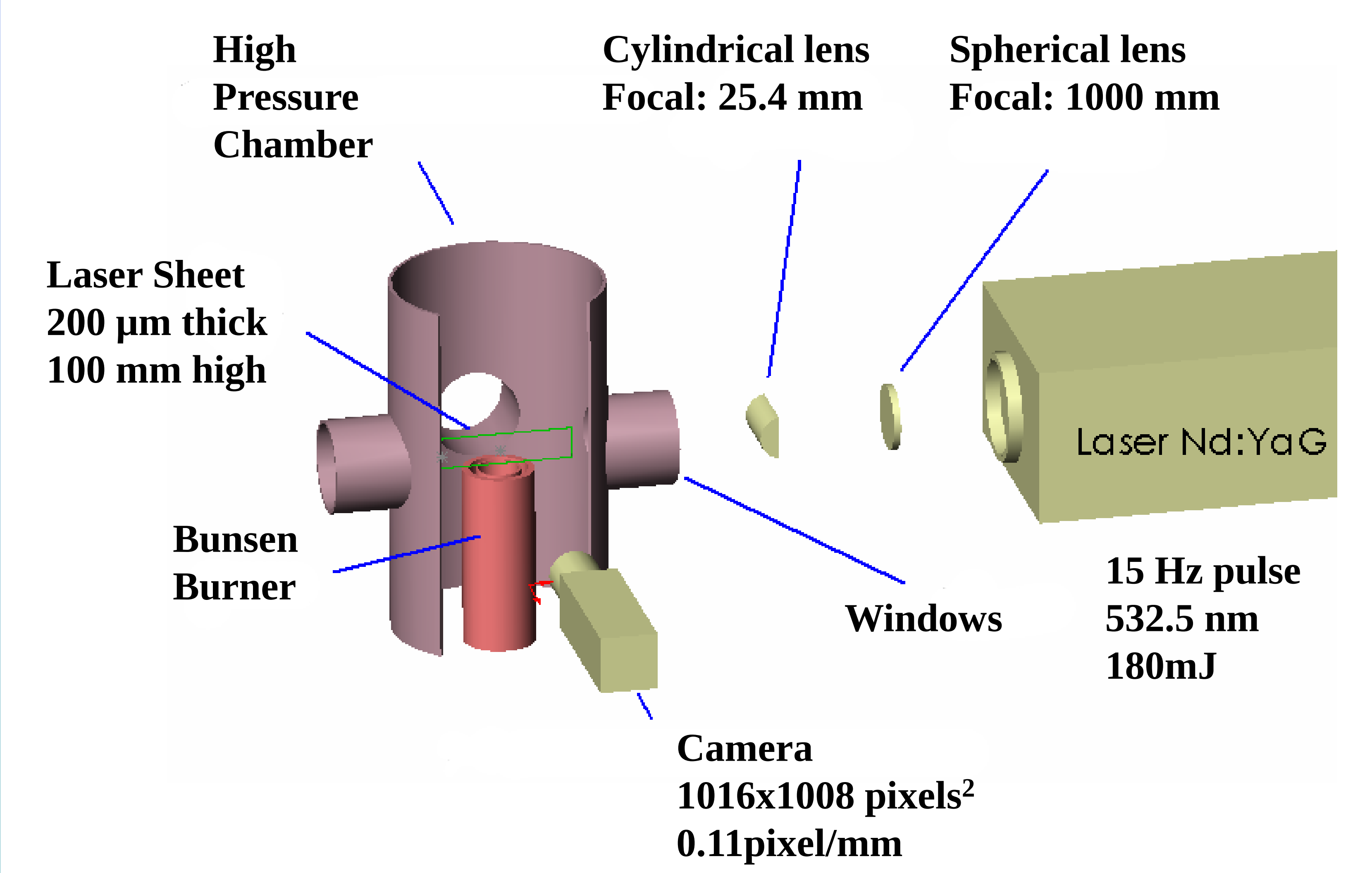
Turbulent Burner

<u>Experimental conditions</u>

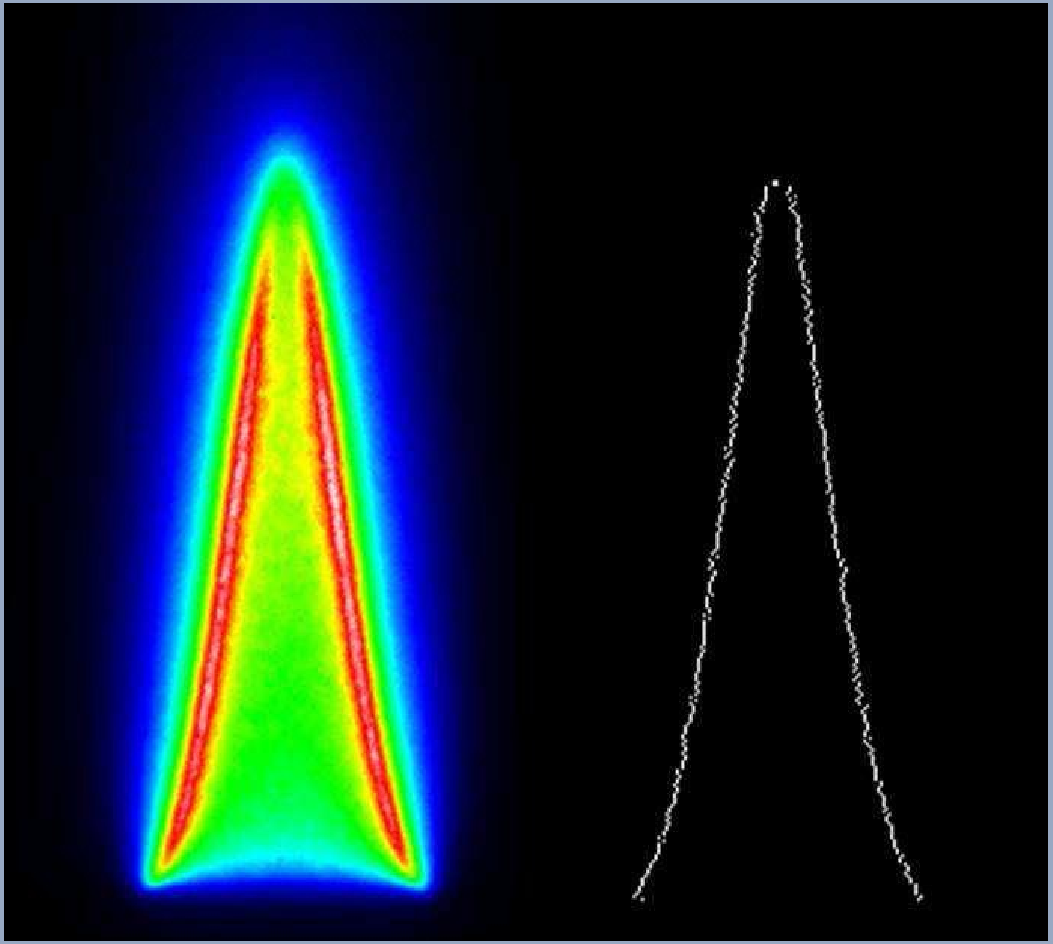
- $U \approx 2.1$ m/s
- $\phi = 0.6$ à 0.7
- P = 0.1 à 0.9 MPa
- Pilot flame flow < 7% Main flow
- T = 300 K
- u' et L_U cste



Laser diagnostics

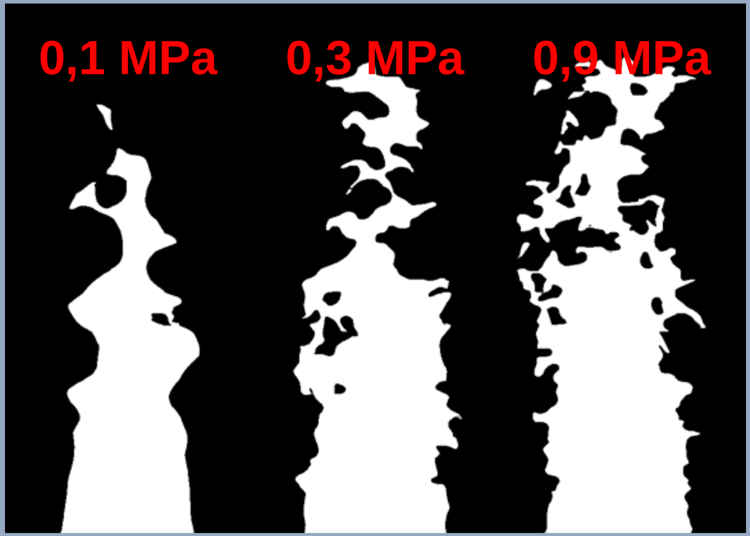


Laminar Bunsen type flame

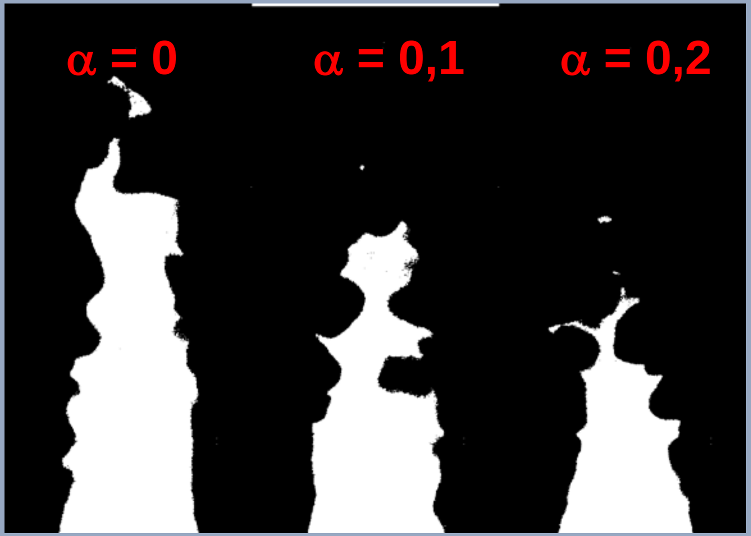


Global shape of turbulent Bunsen flames

Pressure effect

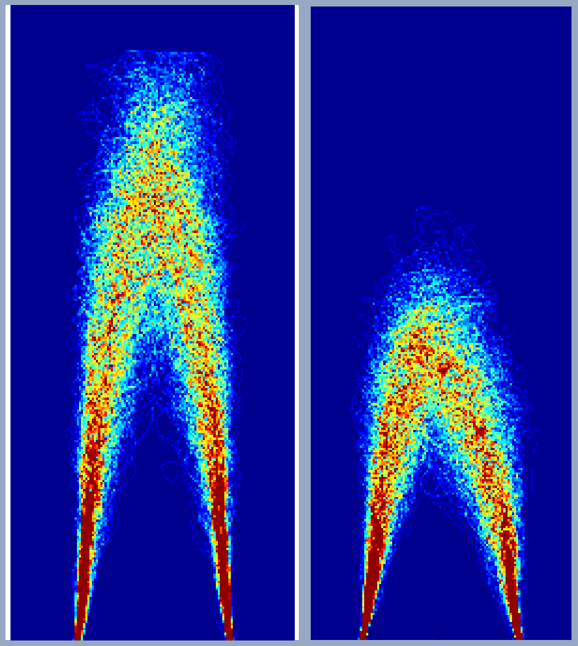


H_2 effect

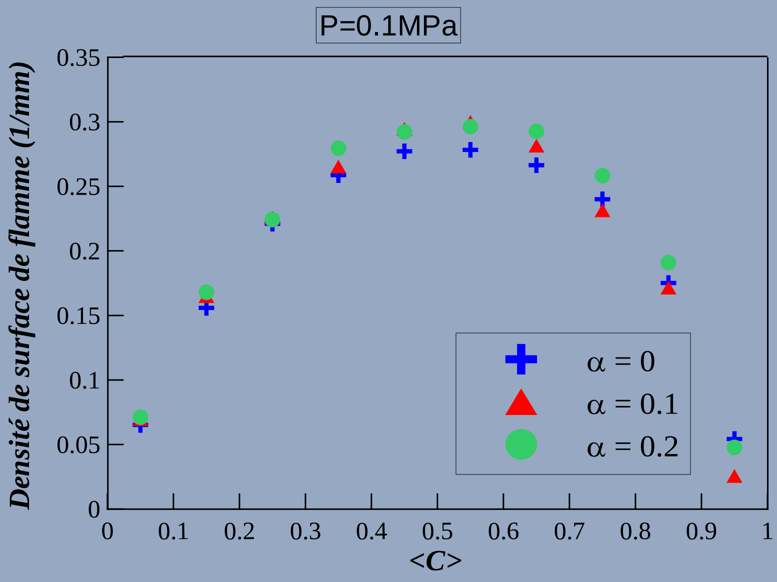


Flame surface density

H_2 effect

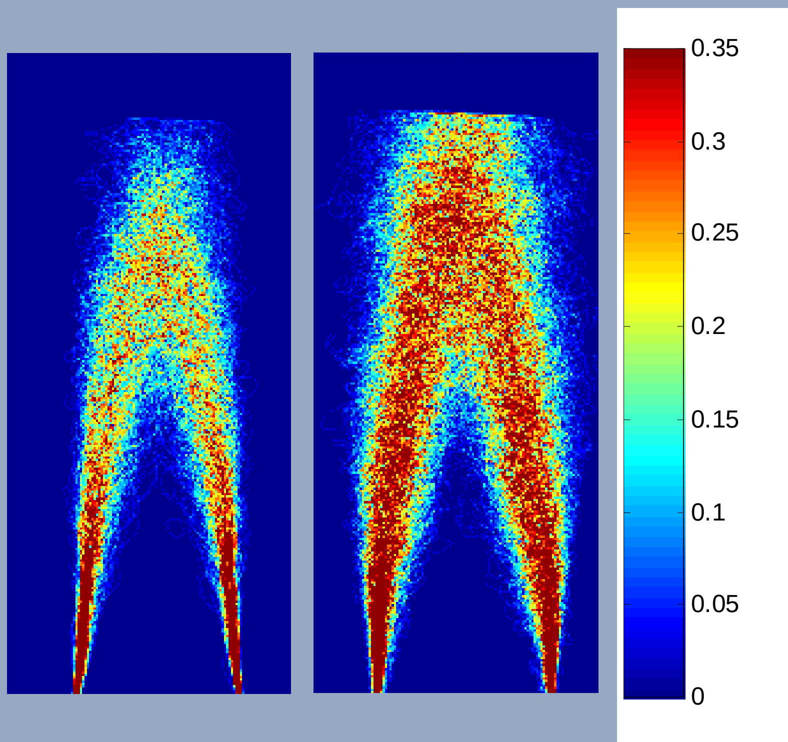


α = 0 α = 0.2

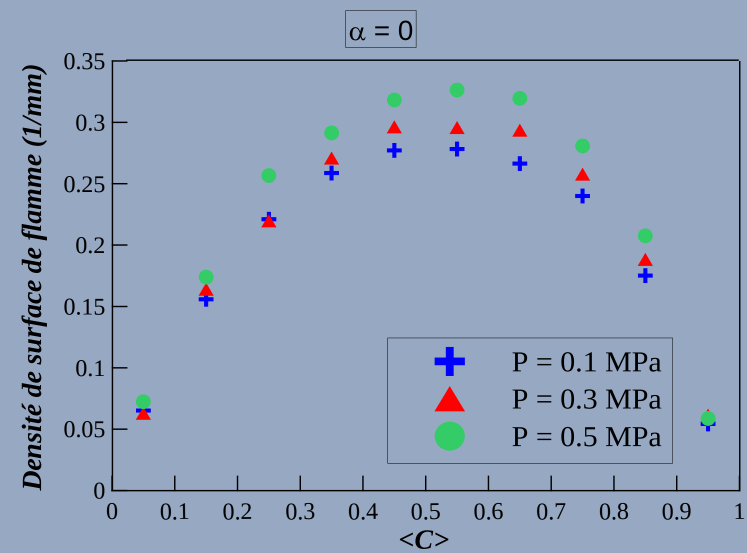


Flame surface density

Pressure effect (α = 0)

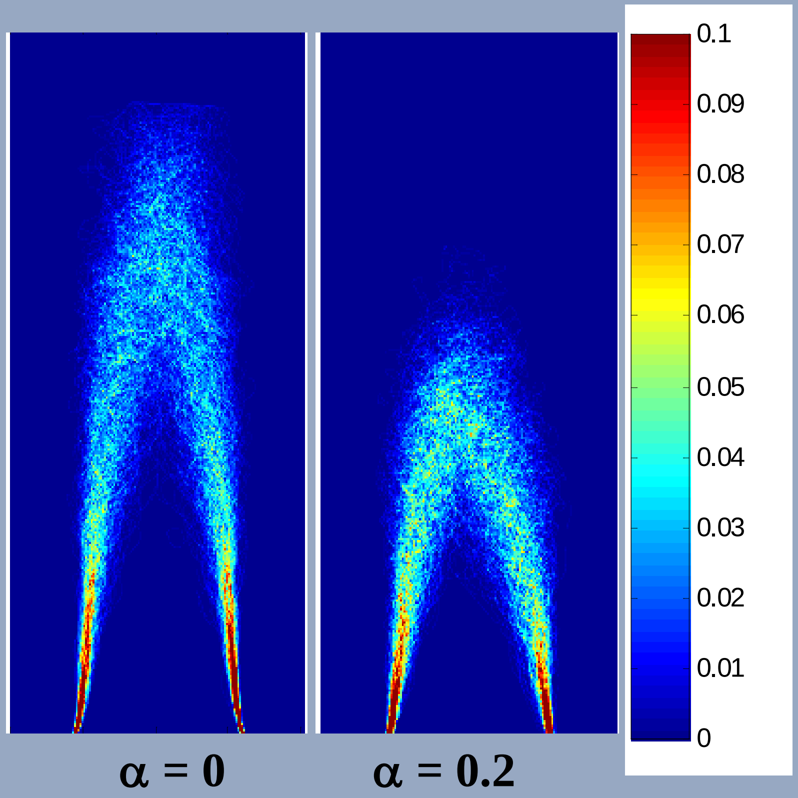


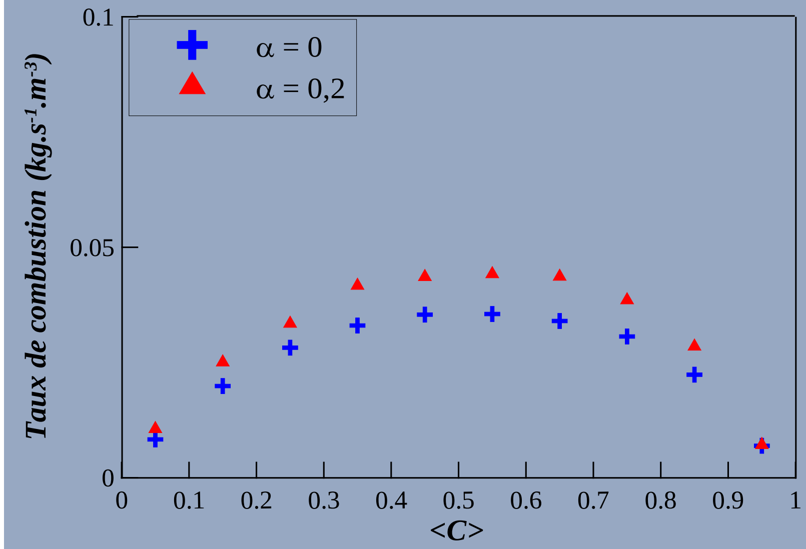
P = 0.1 MPa **P = 0.5 MPa**



Combustion rate

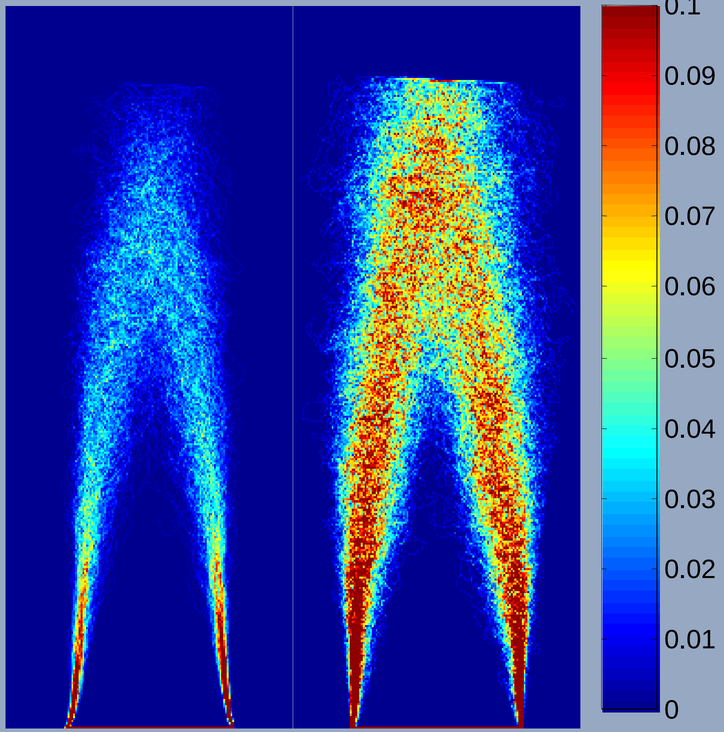
H_2 effect

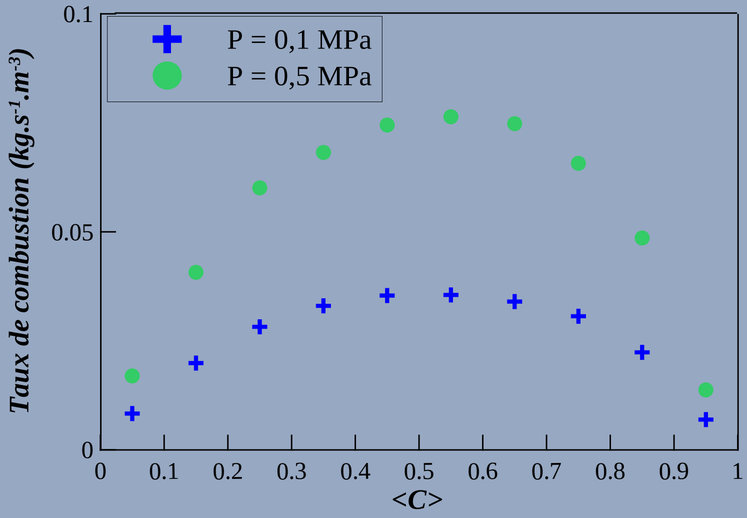




Combustion rate

Pressure effect (α = 0)





P = 0.1 MPa P = 0.5 MPa

Numerical Approaches to Combustion Studies

Numerical methods use either commercial CFD codes or homemade codes (RANS, LES, DNS) for the simulation of the chemical kinetics of heat release and emissions, flame dynamics (stability), burning rates, heat transfer (radiation…)

Exact transport equation of Σ

Cant et al. (1990)

$$\frac{\partial \Sigma}{\partial t}+\overbrace{\nabla.(\tilde{\mathbf{U}}\Sigma)}^{\text{Terme 4}}=\overbrace{-\nabla.(\langle \mathbf{u}''\rangle_S \Sigma)}^{\text{Terme 5}}\overbrace{-\nabla.(\langle w\mathbf{n}\rangle_S \Sigma)}^{\text{Terme 3}}+\overbrace{\underbrace{(\nabla.\tilde{\mathbf{U}}-\langle \mathbf{nn}\rangle_S : \nabla.\tilde{\mathbf{U}})}_{A_T}\Sigma}^{\text{Terme 1}}+\overbrace{\underbrace{\langle \nabla.\mathbf{u}''-nn:\nabla\mathbf{u}''\rangle_S}_{a_T}\Sigma}^{\text{Terme 6}}+\overbrace{\langle w\nabla.\mathbf{n}\rangle_S \Sigma}^{\text{Terme 2}}$$

Terme 4: Terme de convection par l'écoulement moyen

Terme 5: Terme de diffusion turbulente

Terme 3: Terme de propagation

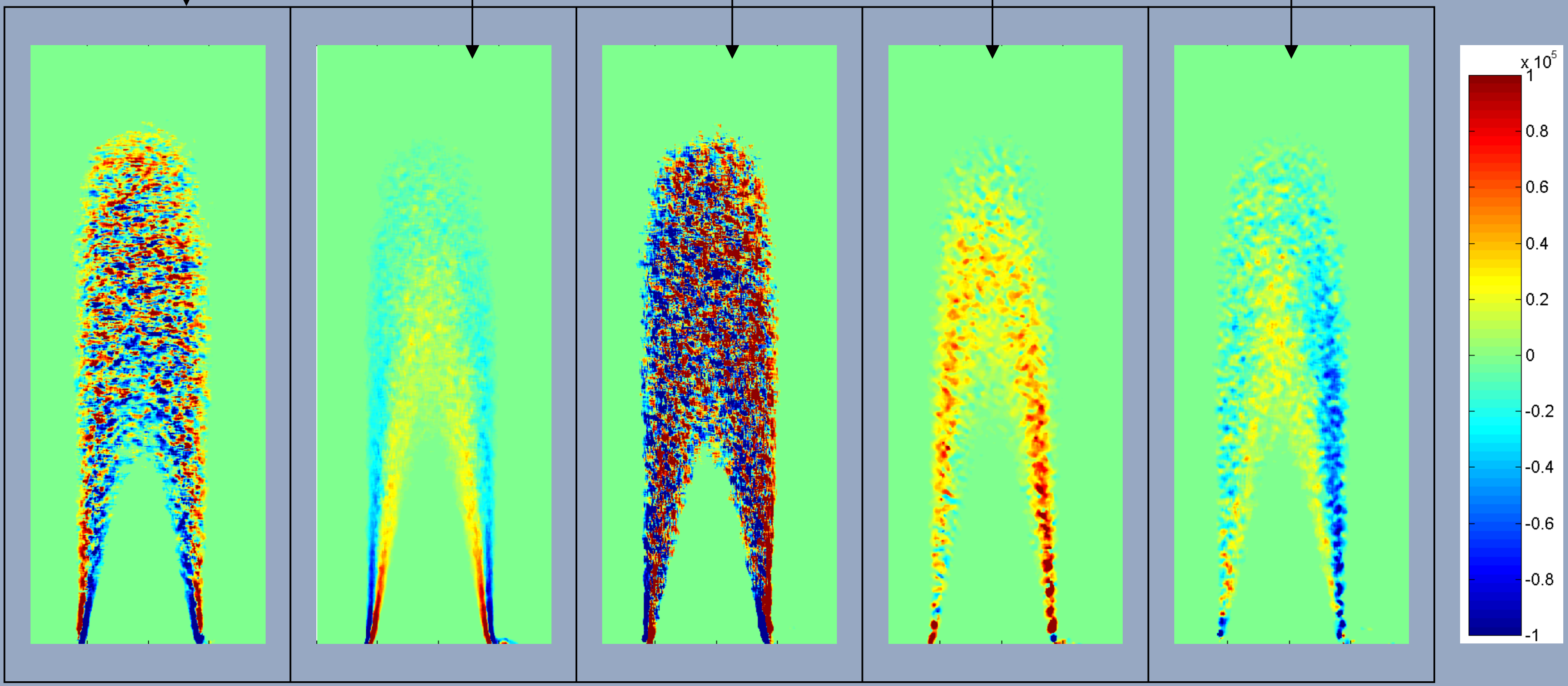
Terme 1 (A_T): Taux d'étirement dû à l'écoulement moyen

Terme 6 (a_T): Taux d'étirement dû à l'écoulement turbulent

Terme 2: Terme de courbure

Results

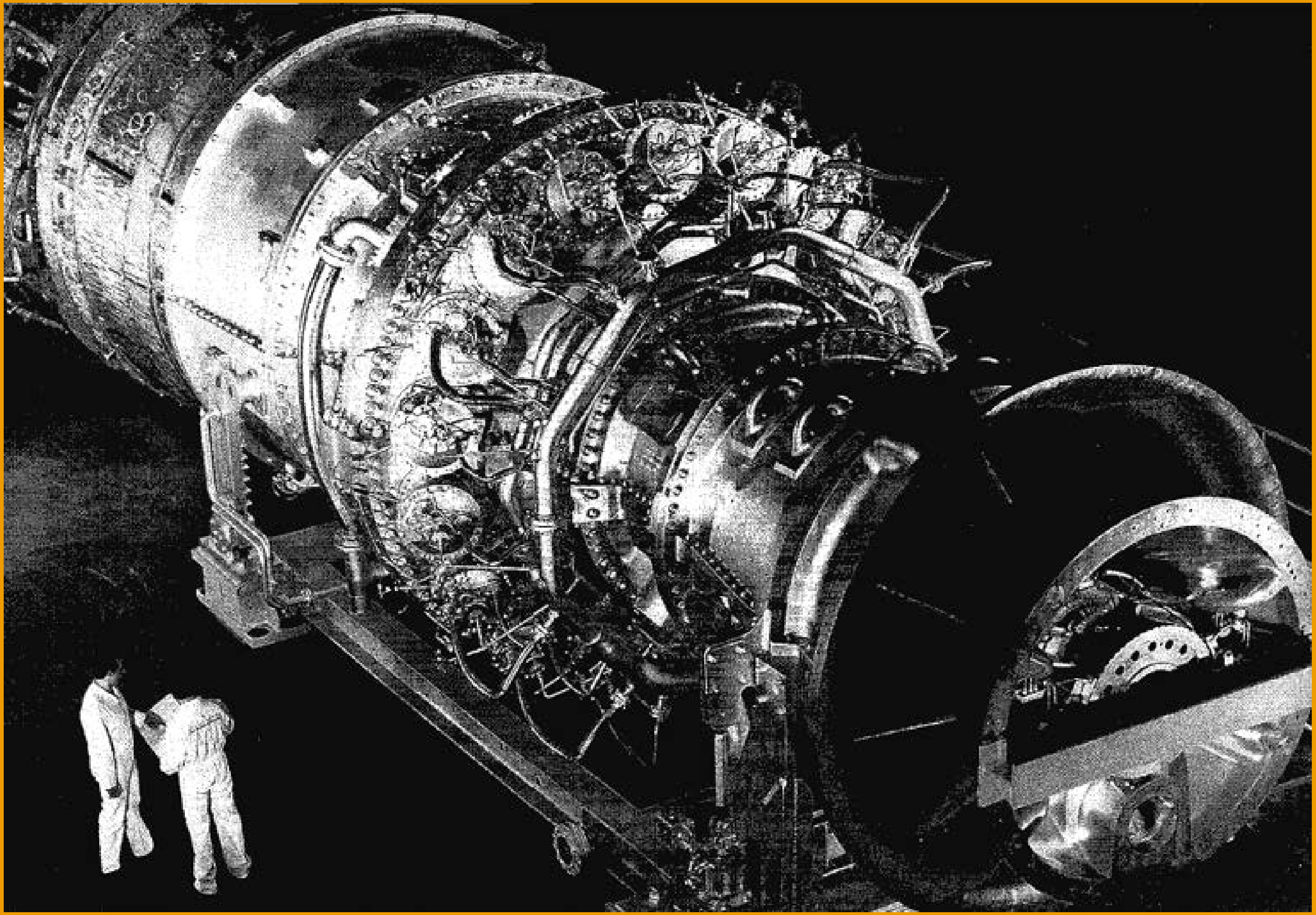
$$\frac{\partial \Sigma}{\partial t} = -\nabla.(\tilde{\mathbf{U}}\Sigma) + \left(-\nabla.(\langle w\mathbf{n}\rangle_S \Sigma) + \langle w\nabla.\mathbf{n}\rangle_S \Sigma\right) - \nabla.(\langle \mathbf{u}''\rangle_S \Sigma) + \underbrace{(\nabla.\tilde{\mathbf{U}} - \langle \mathbf{nn}\rangle_S : \nabla.\tilde{\mathbf{U}})}_{A_T}\Sigma + \underbrace{\langle \nabla.\mathbf{u}'' - nn : \nabla\mathbf{u}''\rangle_S}_{a_T}\Sigma$$

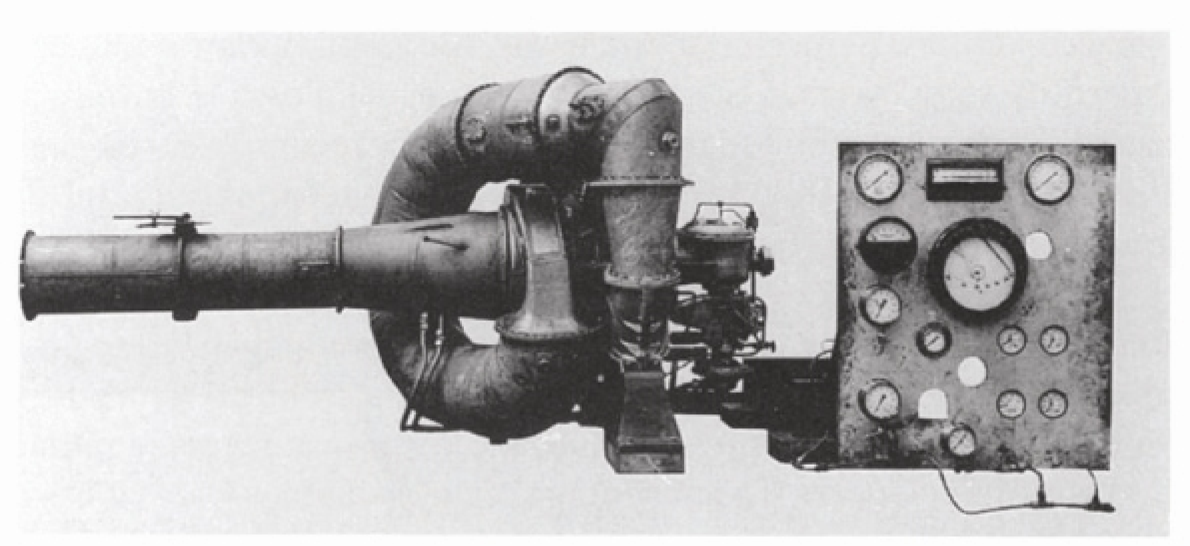


Combustion is a complex research area

- The main difficulties in combustion studies are related to the complexities of reacting turbulent flows where all thermodynamic parameters are non linearly correlated, fluctuate in space and time and where several space and time scales are observed
- So combustion is a complex topic
- It is complex in lab scale flames; you can imagine how complex it is for an industrial scale flame

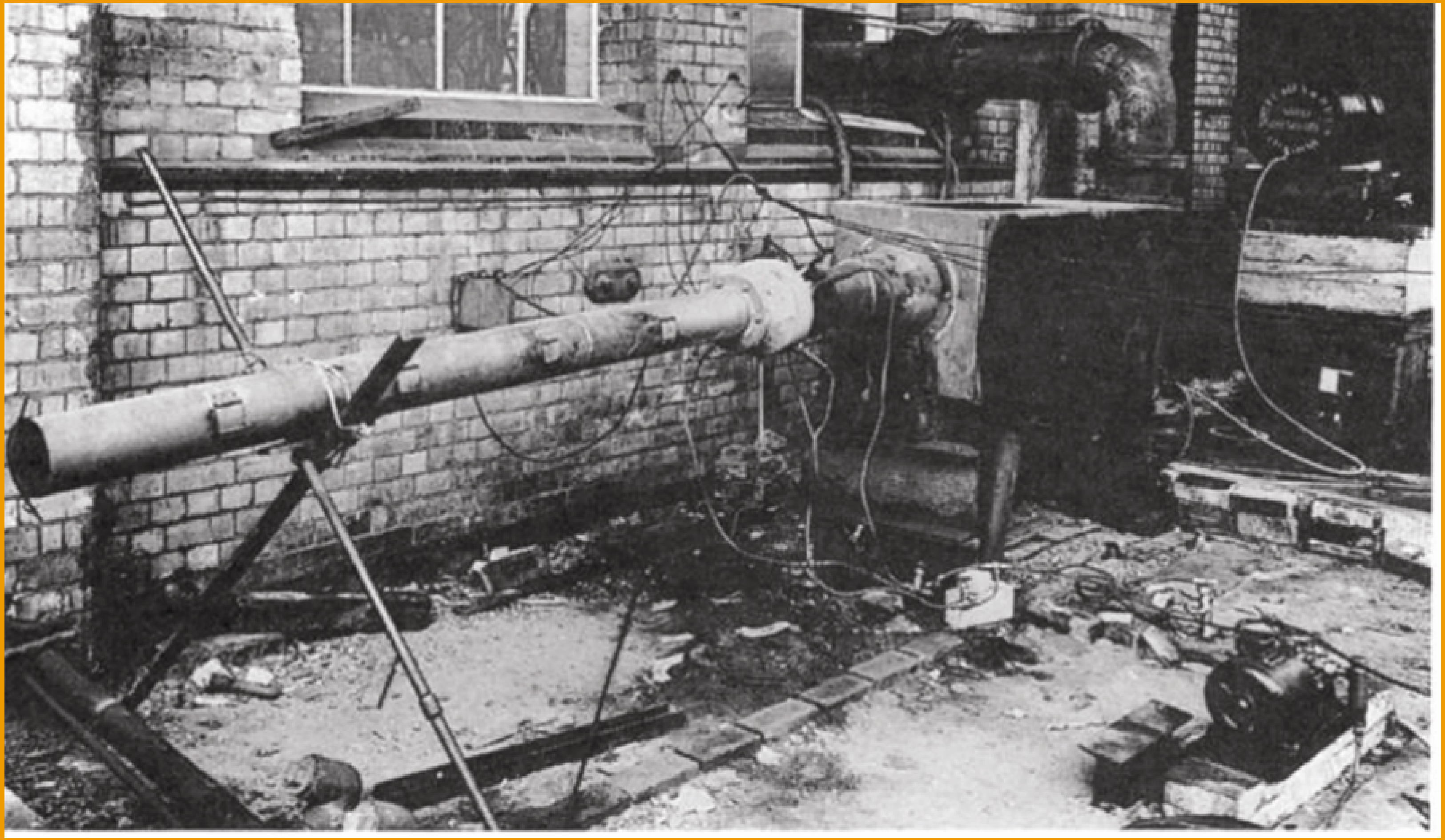
Some History
Industrial Gas Turbine Technology from a Socio-Historical Perspective





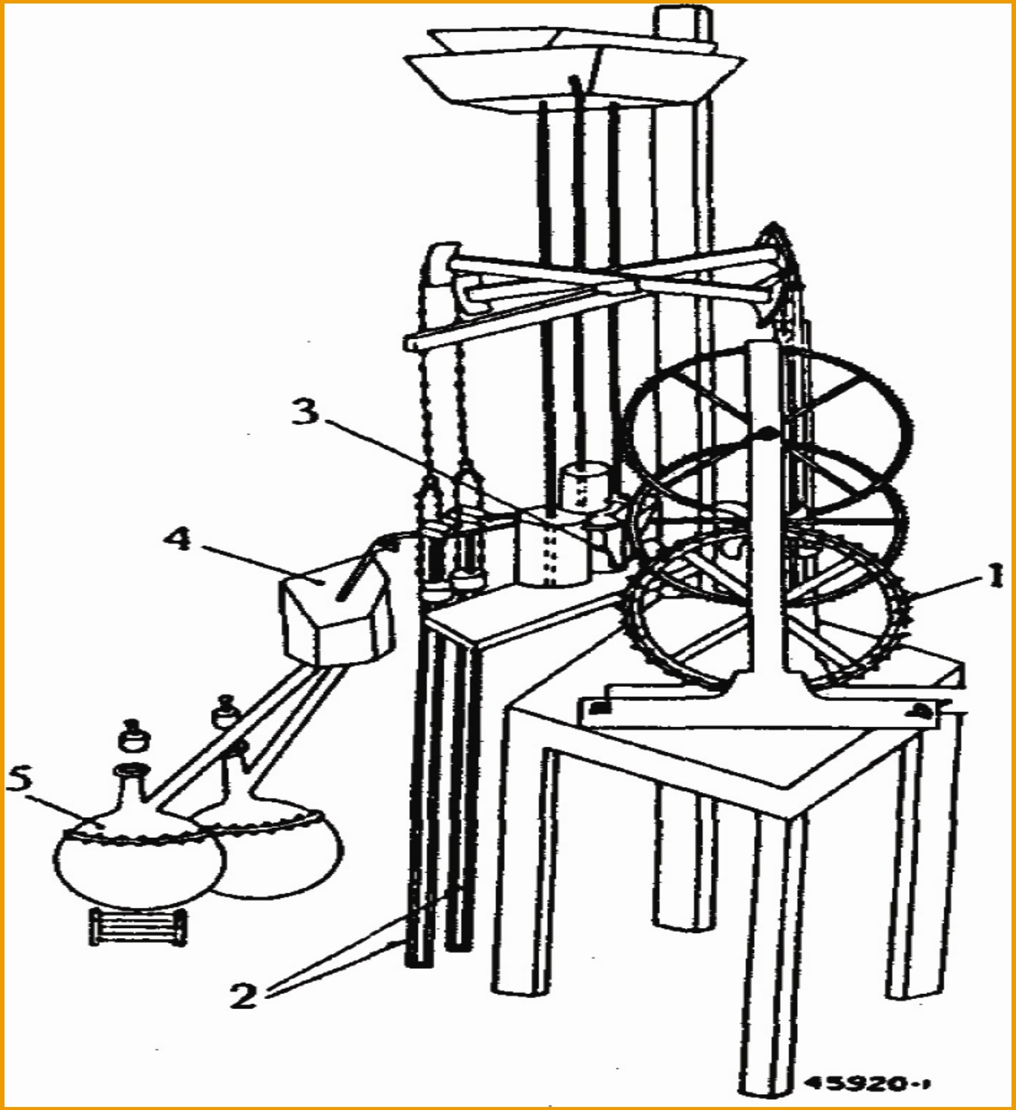
Assembly of the first model of Whittle's experimental engine which run for the first time on 12 April 1937.

The W1 engine had its first run on 12 April 1941 and was first flight tested with The Glouster E28 aircraft on 15 May 1941



Whittle’s combustion chamber test rig

The prehistory of the gas turbine technology starts with the patent issued to **John Barber in England (1791)**, but no working model of it was ever built.



Engineering Sciences

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* In recent decades two developments also helped strengthening engineering sciences: they are computational sciences and advanced diagnostics mostly optical and laser based.

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The energy question: nuclear energy, renewable energy, shale gas & oil, CO2 issues and the need for social sciences and humanities in Engineering Sciences curriculum

* The energy question today (but also for all times) is a vital question for human societies: can we really say that a country or a region which has no energy independency is an independent country or region ?

* To deal with such questions we need to mobilise technical expertises but also expertises from social sciences and humanities: economics, geopolitics, sociology, psychology, law sciences etc. If not

- How to explain the Saskatchevan nuclear energy debate without such integrated expertises
- How to explain the boom of shale oil and gas in US and Canada without such integrated expertises
- How to explain the ban of shale gas in France without such integrated expertises
- How to explain the sortie from nuclear energy and the boom of renewables in Germany without integrated expertises
- How to explain that the only country where there are successful examples of CCS is Canada without such integrated experises…..

How to strengthen Disciplinary Interactions

* The necessary level of interactions between all these advanced knowledge bodies or disciplines, impossible today to be mastered by single individuals, imposes the development of various disciplinary interaction regimes (DIRs).

* There are several Disciplinary Interaction Regimes (DIRs), depending on the cognitive or conceptual distances between interacting knowledge bodies:

Weak DIR (turbulent combustion)
Mild DIR (biochemistry)
Strong DIR (dynamics of socio technical systems)

Orléans ICARE UPR n°3021 du CNRS

CNRS CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

My experience in DIR building (1)

Réflexions sur l'interdisciplinarité au CNRS et dans les Sciences Pour l'Ingénieur, en particulier

Séminaire IPGR, CNRS, Promotion Louis De Broglie

Iskender Gökalp , ***Directeur de recherche au CNRS, Août 1997***

discipline (lat. *disciplina*)

disciple (lat. *discipulus*, élève)

❍

“ Disciplines, like nations, are a necessary evil that enable human beings of bounded rationality to simplify their goals and reduce their choices to calculable limits. But parochialism is everywhere, and the world badly needs international and interdisciplinary travelers to carry new knowledge from one enclave to another.

Having spent much of my scientific life in such travel, I can offer one piece of advice to others who wish to try an itinerant existence : It is fatal to be regarded as a good economist by psychologists, and a good psychologist by political scientists.

Immediately upon landing on alien shores, you must begin to acquire the local culture, not to deny your origins but to gain the full respect of the natives (...) The task is not onerous ; after all, we acculturate new graduate students in a couple of years (...) Learning a new language every decade or so is a great immunizer against incipient boredom ”

Herbert A. Simon, Models of my life, The MIT Press, 1996, p. 367

My experience in DIR building (2)

- GÖKALP, I., On the dynamics of controversies in a borderland scientific domain: the case of turbulent combustion, Social Science Information, 26(3): 551-576, 1987.
- GÖKALP, I., The interrelating of scientific domains: the case of turbulence and combustion Studies in History and Philosophy of Science, 21(3), pp 413-429, 1990.
- GÖKALP, I., Sur les interrelations entre domaines scientifiques: le cas de la combustion et de la turbulence , Revue de Synthèse, IVè. Série, N° 3-4, Juillet-Décembre 1989, pp. 453-468.
- GÖKALP, I., Turbulent reactions: impact of new instrumentation on a borderland domain, Science, Technology and Human Values, 15(3), pp. 284-304, 1990.
- GÖKALP, I., BAGLA, L., and COZZENS, S.E. Impact of the introduction of laser based optical measurement techniques on turbulence studies in Instruments and Institutions: making history today (ed. by R. Bud and S.E. Cozzens), pp. 180-198, SPIE Publications, vol. IS 9, Bellingham, Washington, 1992

My experience in DIR building (3)

- GÖKALP, I., Intellectual cooperation between research and Design in engineering sciences. Or how to cross the border between the engine and the laboratory. In Big Culture. Intellectual cooperation in large scale cultural and technical systems. An historical comparison. Edited by Giuliana Gemelli, Editrice CLUB, Bologna, pp. 263-286, 1994

- GÖKALP, I. On complexity and interdisciplinarity: or how to bridge disciplinary cultures. In University as a Bridge from Technology to Society: IEEE International Symposium on Technology and Society, IEEE Piscataway, NJ, pp. 35-40 (2000)

- GÖKALP I. Invitation à la lecture de *La flamme d'une chandelle* de Gaston Bachelard. Combustion. Revue des Sciences et Techniques de Combustion Vol 1(1) pp. 81-84 (2000)

My experience in DIR building (4)

- **GÖKALP, I., On the analysis of large technical systems , Science, Technology and Human Values, 17(1), pp. 57-78, 1992**
- **GÖKALP, I. Global networks: space and time. In Global telecommunication networks: strategic considerations. Ed by G. Muskens and J. Gruppelaar. Kluwer Academic Publishers, pp. 185 – 210, 1988**

My experience in DIR building (5)

- GÖKALP, I. and BAGLA L, Acceptability of new energy technologies, Proceedings of the CNRS Energy Colloquium, Montpellier, 28-30 Mars 2011
- BAGLA L. and GÖKALP I. Deconstructing the CCS policy : the case of Saskatchewan Province in Canada. To be submitted to Science, Technology & Human Values (2013)
- GÖKALP I., BAGLA L., GALIEGUE X. A socio-technical analysis framework for energy transitions. To be submitted to Technological Forecasting and Social Change (2013)
- BAGLA L. and GÖKALP I. A critical review of the CCS social acceptability studies. To be submitted to Energy Policy (2013)

My experience in DIR building (5)

- **The basic ingredients of DIRs are analogies, commensurability attempts, association of ideas and references to universal concepts such as space and time, use of hybrid concepts, frontier situations, borderland concepts, isolation of factors, composition of factors, pertinent effects, ensemble effect, interaction space between subsystems, among others**

10 Hot Topics in the Chemical Conversion of Energy Research Area for a Sustainable Energy System

- Fuel flexibility (mainly H2 containing fuels) in gas turbines (business model: retrofit or new engines ?)
- Bio-liquid fuels in ICEs and Aircraft engines (sustainability of biofuels and bioenergy in general)
- New chemical propulsion fuels and modes for aerospace (dual use)
- Coal/biomass combustion and gasification (how to legitimate the new coal area)
- Hydrogen generation from renewables including organic waste, using thermochemical processes (hydrogen society)
- Hybrid systems (SOFC+GT; CSP+thermal power plants) (business models)
- Carbon capture facilitating combustion modes (CCS social acceptability, environmental law aspects, long term liability)
- New fuels (microalgae, nano particle doped fuels…) (innovation and business models)
- Chemical conversion related safety (namely H2 explosions…) (nuclear energy safety, H2 distribution networks…)
- Advanced diagnostics (in situ); advanced data analysis and numerical simulation methods and tools (advanced physics, mathematics, computational engineering)

Recommendations for Lassonde Engineering (1)

- *Rennaissance engineering* is probably the right concept where students should be immersed in an integrated curriculum composed of technical and social sciences and humanities. Project management, quality control, LCA, SWOT and TRL type approaches should also be included in the integrated curriculum

- The curriculum should be completed by student immersion in research ambiances where interdisciplinary research is conducted; these research ambiances should also contain interactions with real like systems such as pilot systems or demonstrators in connection with relevant industries or any real like situation where integrated knowledge is needed (safety scenarios, social acceptability situations, innovation based business situation…)

Recommendations for Lassonde Engineering (2)

- Such challenging developments require the presence of faculty members capable of playing the role of « **translators** » between disciplines, various spaces and individuals, insuring their frequent encounters and making them interact. Such translators are not many but should be discovered wherever they are in the world and should be recruited.

Leonardo da Vinci's Double Helix Staircase in Chambord Chateau