ETH zürich

Symposium on Thermoacoustics in Combustion 2023

Industry meets Academia

11-14 September 2023 - ETH Zürich - Zürich, Switzerland

Program Booklet

https://SoTiC2023.ethz.ch

Impressum

ETH Zürich
Department of Mechanical and Process Engineering
Laboratory of Combustion and Acoustics for Power & Propulsion Systems

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Switzerland

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SoTiC 2023 – Zürich

Symposium on Thermoacoustics in Combustion: Industry meets Academia

Edited by
Matteo Impagnatiello | Florian Radack

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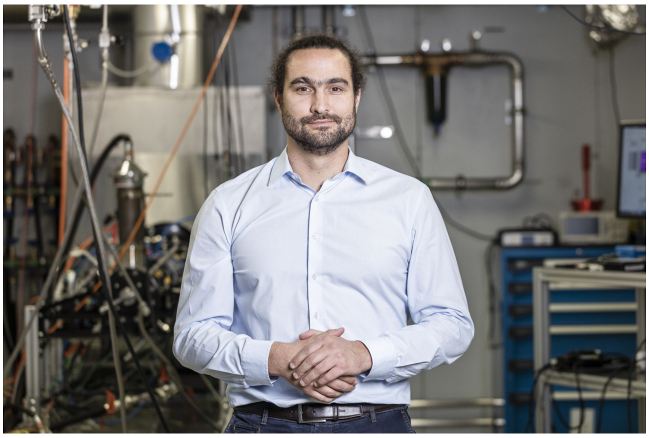
Welcome Note



Nicolas Noiray
ETH Zürich, Switzerland
Professor of Thermodynamics at the Department of Mechanical and Process Engineering
Head of the Laboratory of Combustion and Acoustics for Power and Propulsion Systems (CAPS)

It is a great pleasure for me to host this third edition of the Symposium on Thermoacoustics in Combustion (SoTiC) at ETH Zürich. This research field is more topical than ever, with the development of sustainable technologies for power generation and aeronautics, as well as with the development of new space launchers. A notable example of these new challenges is the control of thermoacoustic instabilities in the upcoming combustion chambers that will soon enable the on-demand combustion of pure H_2 produced without CO_2 emissions.

The first SoTiC, which was initiated in 2016 by Thomas Sattelmayer and Bruno Schuermans at the Technical University of Munich, was a great success on several levels: there were a large number of participants in relation to the size of our community; the quality of the presented papers was high; the invited speakers had given an excellent overview of the scientific challenges and successes at that time; a stimulating atmosphere also resulted from the participation of many researchers from industry in the scientific program; and finally, the two communities of researchers working respectively for rocket propulsion and gas turbine technologies were brought together thanks to this new symposium. The second edition, organized by Thomas Sattelmayer and Mirko Bothien, was for me, and I think for many of you, one of the best online conference experiences during the Covid period. The format they had defined was very judicious and enabled this event of high scientific quality to be very productive, lively, and interactive, despite the virtual nature of the exchanges imposed by the pandemic.

The bar was therefore set very high when Thomas, Mirko and Bruno approached me to host the third edition at ETH Zürich. I would like to thank them warmly for their trust. As I write these few lines two weeks before the start of the conference, I can already say that all the ingredients are in place to make SoTiC 2023 another success. Sixty papers will be presented at the symposium, with authors coming from all over the world. I sincerely thank all these authors. I also particularly thank the invited speakers for having accepted to participate to the SoTiC 2023: Sébastien Candel (CentraleSupelec, France), James Dawson (Norwegian University of Science and Technology, Norway), André Fischer (Rolls Royce Deutschland, Germany), Fei Han (GE Research, United States of America), Justin Hardi (German Aerospace Center, Germany), Matthew Juniper (University of Cambridge, United Kingdom), Kyu Tae Kim (Korea Advanced Institute of Science and Technology, South Korea) and Deanna Lacoste (King Abdullah University of Science and Technology, Saudi Arabia). I am also very grateful to the symposium sponsors for their significant financial contribution. Finally, I thank Anna Michailidis for having greatly coordinated the organization of the symposium, as well as Matteo Impagnatiello, Richard Martin and Florian Radack, doctoral students at CAPS, for the high efforts they invested in it.

I look forward to welcoming you to ETH Zürich very soon.

Nicolas Noiray

Scientific Committee

Prof. Dr. Nicolas Noiray

ETH Zürich, Switzerland

Head of the Laboratory of Combustion and Acoustics for Power & Propulsion Systems (CAPS)

Nicolas Noiray is Associate Professor at ETH Zürich, where he established the laboratory of Combustion and Acoustics for Power and Propulsion Systems in 2014. He obtained his Ph.D. from Ecole Centrale Paris in 2007, and then worked in the Gas Turbine Research Division of Alstom until his appointment at ETH. His research activities in the fields of combustion, acoustics and fluid mechanics address fundamental and applied problems, which are relevant for the development of workable and sustainable technologies in the energy and transport sectors. He received several academic and industrial awards, including the Silver Medal and the Hiroshi Tsuji Early Career Researcher Award of the Combustion Institute and the Alstom Innovation Award. In 2019, he was awarded a Consolidator Grant by the European Research Council. A key theme of the experimental, theoretical and numerical research performed by his group is the study of flow instabilities at various time and length scales.

Dr. Bruno Schuermans

ETH Zürich, Switzerland

Senior Scientic Collaborator at the Laboratory of Combustion and Acoustics for Power & Propulsion Systems (CAPS)

Dr. Bruno Schuermans received his master's in mechanical engineering from Delft University and a PhD degree from Swiss Federal Institute of Technology in Lausanne (EPFL). He did research and development in the field of gas turbine combustion at ABB, Alstom and General Electric where he was a Consulting Engineer until 2020. Dr. Schuermans then joined the Swiss Federal Institute of Technology in Zurich (ETHZ) as a Senior Scientific Associate. In parallel he has founded a consultancy company in the field of thermoacoustics: Schuermans Science&Engineering. Throughout his career he has been active in thermoacoustics and combustion control; always with a focus to use the latest scientific developments to solve real world engineering challenges.

Prof. Dr. Mirko Bothien

ZHAW, Switzerland

Head of Renewable Energies, IEFE, ZHAW
Associate Professor, Dept. of Energy & Process Engineering, Norwegian University of Science & Technology

Mirko Bothien is currently Head of Renewable Energy at the Institute of Energy Systems and Fluid Engineering, Zurich Applied University of Sciences (ZHAW) and Associate Professor at the Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU). His research is on the use of alternative fuels for decarbonizing the energy system with a focus on combustion dynamics. Before pursuing his research objectives in academia, he worked over 15 years in research and development with Ansaldo Energia, Alstom Power and Siemens Energy as expert for thermoacoustics and in different managerial roles. From 2016 to 2020, he was Head of Combustor Technology at Ansaldo Energia Switzerland developing key technologies for using hydrogen in gas turbines. From 2017 to 2020, he was Member of Board of the Norwegian CCS Research consortium – an international research cooperation on CO_2 capture, transport and storage. In 2018, he was awarded with the Rudolf Diesel Industry Fellowship of the Institute for Advanced Study, TU Munich for conducting research in thermoacoustics. Dr.-Ing. Bothien co-authored 95 technical publications and 50 invention disclosures in the field of gas turbine combustion dynamics and alternative fuels.

Prof. Dr. Thomas Sattelmayer

Technische Universität München, Germany

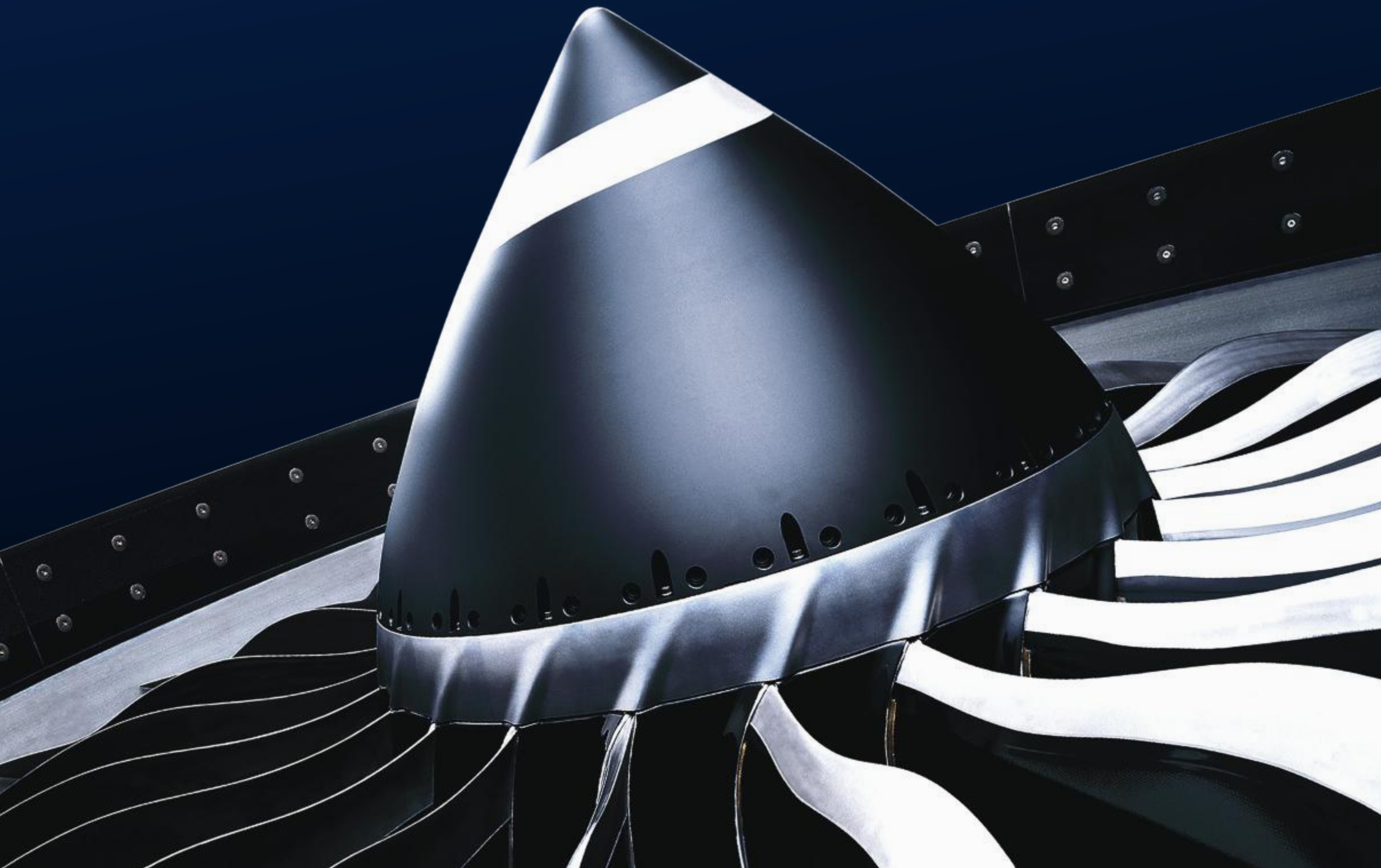
Former Chair of Thermodynamics (1997-2021)

After 11 years in industry at BBC/ABB Thomas Sattelmayer joined the Technical University of Munich as Thermodynamics Professor. He was Chair of the Thermodynamics Institute from 1997 until his retirement in 2021. His research interests are related to Thermofluiddynamics with special focus on Power Systems, Reliability & Safety, Mobility and Water. His research in combustion includes thermoacoustics instabilities, turbulent flame noise, flame propagation, self ignition and engine knock, turbulent mixing, pollutant formation, supersonic combustion, transition from deflagration to detonation and alternative fuels. Research projects in two-phase flow and heat transfer include energy systems, atomization, multiphase flows, subcooled boiling and catalytic exhaust gas treatment. He received the IGTI John P. Davis Award in 1990, the Asea Brown Boveri Technology Achievement Award in 1993, the ASME Gas Turbine Award in 2002 and 2011, the Innovation Award of the Global Power and Propulsion Society (GPPS) in 2017 and the IGTI Industrial Gas Turbine Technology Award in 2020. He published a total of more than 600 papers, including about 200 journal publications and some book chapters. So far, more than 120 students have completed their doctorates at the Thermodynamics Institute under his supervision.

GE Aerospace

The future is our starting point

Every day, we're working to help move the world forward. Today, and for generations to come. The future of flight starts now.



Invited Speakers

Prof. Dr. Sébastien Candel

CentraleSupelec, University of Paris-Saclay

University Professor Emeritus

Sébastien Candel is University Professor Emeritus at CentraleSupelec, University of Paris-Saclay. Engineer from the Ecole Centrale Paris, PhD from the California Institute of Technology (Caltech), he holds a doctorate in science from the university of Paris 6. His combustion research on flame structures, dynamics and control, turbulent flame modeling and simulation, transcritical combustion of cryogenic propellants, and his fundamental contributions to aeroacoustics have applications in the energy sector and in the field of aeronautical and space propulsion. Among many distinctions, Sébastien Candel received the Marcel Dassault grand prize from the Académie des sciences, the Pendray aerospace literature award from the AIAA, the Zeldovich gold medal of the Combustion Institute. Fellow of the AIAA and of the Combustion Institute, he is a member and former president of the French Academy of Sciences, a founding member of the Academy of Technologies, and a foreign member of the US National Academy of Engineering.

Presentation   Abstract   Full-Text

Prof. Dr. James R. Dawson

Norwegian University of Science and Technology

Professor & Deputy Head of Department for Research Department of Energy and Process Engineering

James Dawson is Professor of Fluid Mechanics and Deputy Head of Department (for research) of Energy and Process Engineering at the Norwegian University of Science and Technology (NTNU). Prior to joining NTNU in 2013, EPSRC Advanced Research Fellow at the Department of Engineering at the University Cambridge and Fellow of New Hall (now Murray Edwards College). He received his PhD from Cardiff University, UK. Professor Dawson's research interests are in the general areas of gas turbine combustion and fluid mechanics. His current research is focused on combustion of zero carbon fuels, namely hydrogen and ammonia, and was recently appointed to the editorial board of Combustion and Flame. He has received a number of awards which include a 5-year Advanced Research Fellow from the EPSRC (UK engineering and physical sciences research council), Garden Award for by the British section of the Combustion Institute (2013), a best paper award from ASME (2021), and a distinguished paper award at the 39th International Combustion Symposium (2022). He also led an EU funded Innovative Training Network (ITN) on annular combustion, ANNULIGhT.

Presentation

Dr. André Fischer

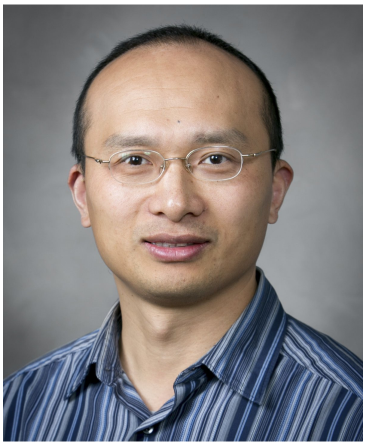
Rolls Royce Deutschland Ltd

Aerothermal Engineer for Combustion Noise and Thermoacoustics

André Fischer is an aerospace engineer with more than 15 years of work experience in industrial and academic environments. He did his PhD at TU-Berlin on laser optical measurement for acoustics in turbomachinery in strong cooperation with the German Aerospace Centre (DLR), Institute of Propulsion Technology, Department of Engine Acoustics. Since 2015 André Fischer is working at Rolls-Royce Deutschland in the combustor development group responsible for thermoacoustics and combustion noise. In his role, he gathered many experience in experimental work from engine testing to combustor-rig testing at various TRL levels and thermoacoustic modeling from low order to high fidelity 3D simulations.

Presentation

Dr. Fei Han



GE Research

Engineering Manager, Combustion Dynamics & Diagnostics Lab

Dr. Fei Han is a senior principal engineer in the area of gas turbine combustion at GE Research. Since joining GE in 1999, Dr. Han has conducted extensive research & development in the area of combustion dynamics, ranging from development of combustion dynamics modeling tools, development and implementation of various dynamics mitigation technologies, and techniques for combustion dynamics experiments for gas turbines, aero engines, and augmentors. He also served as the manager of a combustion team at GE Research from 2011 to 2017, leading a team of engineers and technicians in developing new technologies and maturing technology levels for combustion dynamics and diagnostics. Fei is the author of more than 30 peer-reviewed publications and over 75 GE internal publications, and currently holds 24 US patents. Fei holds a BS and Master degree in Acoustics from Nanjing University, China, and a Ph.D. degree in Mechanical Engineering from Purdue University, USA.

Presentation

Dr. Justin Hardi

German Aerospace Center (DLR)

Head of Rocket Propulsion Technology Department

Justin Hardi graduated with a double degree in Aerospace Engineering and Physics from the University of Adelaide in Australia, then moved to Germany to work on the topic of combustion instabilities in cryogenic rocket engines at the German Aerospace Center (DLR), Institute of Space Propulsion, Lampoldshausen. After receiving his PhD in 2012, he went to Purdue University in the US to work as a research associate in the Zucrow Propulsion Labs. Following this placement, he returned to DLR to lead the Combustion Dynamics research team at the Institute of Space Propulsion, conducting experimental and numerical research on ignition, transient flow phenomena, and combustion instabilities. In this role, he led international research collaborations as well as technology development projects for the European Space Agency. In 2020, Dr. Hardi became Head of the Rocket Propulsion Technology Department, responsible for R&T activities on cryogenic engine components.

Presentation

Prof. Dr. Matthew Juniper

University of Cambridge

Professor of Thermofluid Dynamics

Matthew Juniper is Professor of Thermofluid Mechanics at the University of Cambridge. He completed his PhD in Cryogenic Combustion from Ecole Central Paris in 2001 and was appointed Lecturer in Combustion at the Engineering Department in 2003. His research interests are in flow instability, adjoint-based sensitivity analysis, shape optimization, and physics-based Bayesian inference, particularly when accelerated with adjoint codes. He is an Associate Editor of the Journal of Fluid Mechanics and has held visiting fellowships/professorships at Ecole Central Lyon, the Institute for Advanced Studies at TU Munich, KTH/Nordita Stokholm, IIT Madras, and the Center for Turbulence Research Summer Program at Stanford University.

Presentation

Prof. Dr. Kyu Tae Kim

Korea Advanced Institute of Science and Technology (KAIST)

Associate Professor of Aerospace Engineering

Kyutae Kim is an Associate Professor of Aerospace Engineering at KAIST, and EIRC Director for Carbon Neutral Gas Turbine Combustion Technology. He received his PhD in Mechanical Engineering from Penn State in 2009. After completion of his PhD, he accepted a Marie Curie Fellowship at the University of Cambridge, and then he worked at General Electric, where he contributed to the development of GE's advanced gas turbine engines, including GE9X and 9HA.01. In 2016, he joined KAIST. His current research efforts focus on (i) combustion instabilities in aircraft and heavy-duty gas turbine combustors, including low- and high-frequency instabilities associated with bulk, longitudinal, and transverse modes; (ii) hydrogen/ammonia-based carbon-free and low-carbon gas turbine combustion, including radial and axial fuel staging concepts; (iii) physics-based and data-driven modeling, including reduced-order modeling, numerical simulations, machine-learning and complex network frameworks.

Presentation

Prof. Dr. Deanna Lacoste

King Abdullah University of Science and Technology (KAUST)

Associate Professor of Mechanical Engineering

Deanna Lacoste is an associate professor of mechanical engineering at the King Abdullah University of Science and Engineering (KAUST), in Saudi Arabia. She graduated with a Ph.D. in combustion science from the University of Poitiers, France, in 2002. After eleven years with the French CNRS, at CentraleSupelec, in 2014 she joined KAUST. Since 2021, she has been an associate professor at the Clean Combustion Research Center, KAUST. She is an editorial board member of the Applications in Energy and Combustion Science journal, and an associate editor for the Proceedings of the Combustion Institute. Her research mainly focusses on plasma-assisted combustion, non-equilibrium plasma discharges at atmospheric pressure, control of flame dynamics, and detonation.

Presentation

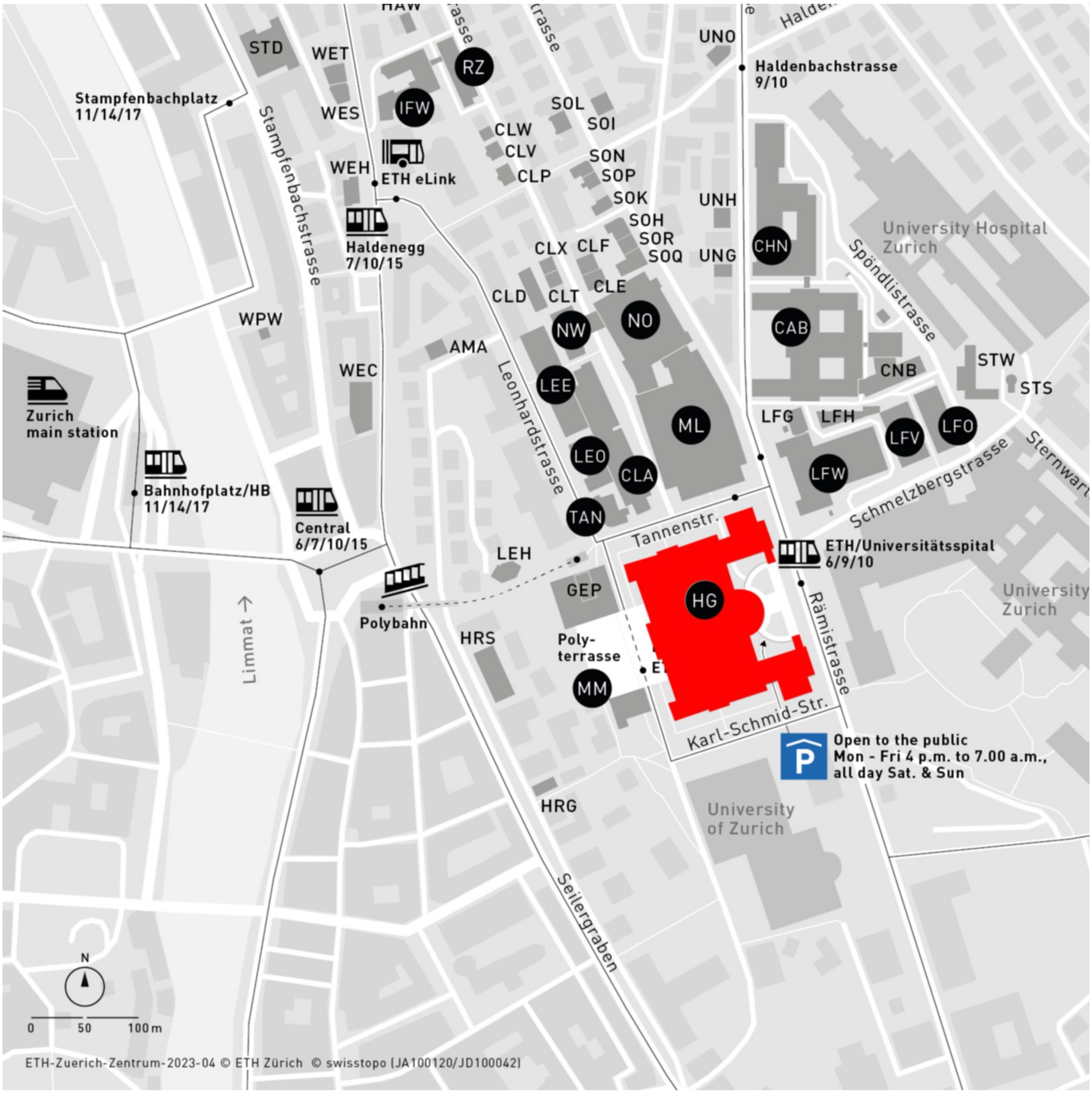
Welcome to Zurich

Zurich has a unique position in Switzerland. It is the country's largest city and home to an internationally reputed financial centre as well as being the focus of an economic region which acts as the motor of Switzerland, and along with Geneva is the most important gateway to the country.

The wide variety of cultural activities and educational institutions define Zurich's character as a diverse, open city with a passion for life. Zurich is the capital of the canton of the same name and the centre of a number of regions which together have some 1.9 million inhabitants. It is famous for its lakeside location and green, densely wooded chain of hills which run through the city from north to south.

Zurich's place on the world stage does not come down to its size but to its strong international networks. The high standards of living, working and accommodation are regularly confirmed in surveys of the local residents, and Zurich consistently finds itself at the top of international rankings of cities in terms of quality of life.

Campus Map and Symposium Location



The conference will take place at the main building, *Hauptgebäude* (HG), of ETH Zürich, located at Rämistrasse 101, 8092 Zürich.

Transportation

Travelling from from Zurich Central Station

From the “Bahnhofstrasse/HB” stop
Tram no. 6 (towards the Zoo) as far as the “ETH/Universitätsspital” stop.
Journey time: approx. 6 minutes

From the “Bahnhofplatz/HB” stop
Tram no. 10 (towards the Airport or Oerlikon station) as far as the “ETH/Universitätsspital” stop or Tram Nr. 3 (towards Klusplatz) as far as the “Central” stop (1 stop), from “Central” by Polybahn (departs every three minutes) to the Polyterrasse.
Journey time: approx. 8 minutes

You will require a ticket that is valid for zone 110 (city of Zurich).

Travelling from From Zurich Airport

By tram (From the “Zurich Airport” tram stop)
Tram no. 10 (towards Bahnhofplatz/HB) as far as the “ETH/Universitätsspital” stop. The tram runs every 7 to 15 minutes between 6 o’clock in the morning and 11 o’clock at night.
Journey time: 30 minutes

By rail
If you wish to travel from the airport to the city centre (Central Station), you are recommended to use the S-Bahn or mainline services. The trains depart from the “Zurich Airport” station
Journey time: approx. 10 minutes

You will require a ticket valid for 3 zones. If you are spending the whole day in Zurich, it is worth buying a day pass (valid for 24 hours). A 24h ticket costs only twice as much as a regular one-way ticket.

Car Parking

Wheelchair users arriving by car will find a marked parking space in the passage underground "Leonhardstrasse", under the Polyterrasse, on the left-hand side of the bus stop, as well as marked parking spaces on the ground floor (parking deck D) of the multi-storey car park, accessible via Karl-Schmid-Strasse. The barrier-free access to the main building is signposted.

By handing in your parking ticket at Campus Info (report to reception on the ground floor), you will be given a free exit ticket.

Connecting to the Internet

Guests visiting ETH can connect to the internet using WIFI for 24 hours through one of the following SSIDs: `public` (2.4GHz) and `public-5` (5GHz). Depending on your device and software, a login window will pop up. If not you may need to open a browser and navigate to any page outside of ETH, e.g. www.google.com. On the landing page, choose **Login for ETH guests**. You then have the option to register for access via SMS or E-Mail. You will then receive an SMS with an access code or an E-Mail with a link to validate the network access.

Alternatively, guests from other universities around the world may also have the option to access the `eduroam` network at ETH using their home university account.

More information can be found here.

Paper Download

The complete collection of papers submitted to the conference can be downloaded from here.

Individual papers can be downloaded from the links provided in Detailed Session Schedule or in Abstracts.

Best Paper Award

On the last day of the conference all SoTiC 2023 registrants will have the opportunity of recommending two best papers on the basis of outstanding writing quality, a high degree of originality, and an unusual contribution to science and engineering. Both awards are endowed with 500€ each. The **Best Fundamental Paper Award** recognizes the publication with the greatest contribution to fundamental understanding in the field of thermoacoustics, and the **Best Technical Paper Award** recognises the publication with the greatest technical relevance of all papers submitted to SoTiC 2023.

Only one vote per participant for each category is permitted. Participants are not allowed to vote for their own paper or for a paper submitted by their research group.

Follow the Link to the Form to cast your votes!
Please provide the email address associated with your conference registration for a valid vote submission.

Logistics

Registration (Main Building – Entrance Hall)

Registration will be open on Monday 11 September 2023 from 8.00 to 13.00. Please collect your nametag, which you will need to access the conference venue. Please wear your nametag at all times in order to get access to the coffee and lunch breaks and all social events you have registered for.

Coffee and Lunch Break (Main Building Foyer E-Nord)

All coffee and lunch breaks will be located in front of the two presentation rooms. See map at the next page.

Welcome Apéro (Main Building – Main Hall)

The welcome Apéro will take place on the 11th September 2023 after the last session in the main hall (behind the registration desk) and next to the presentation room.

Factory Tours

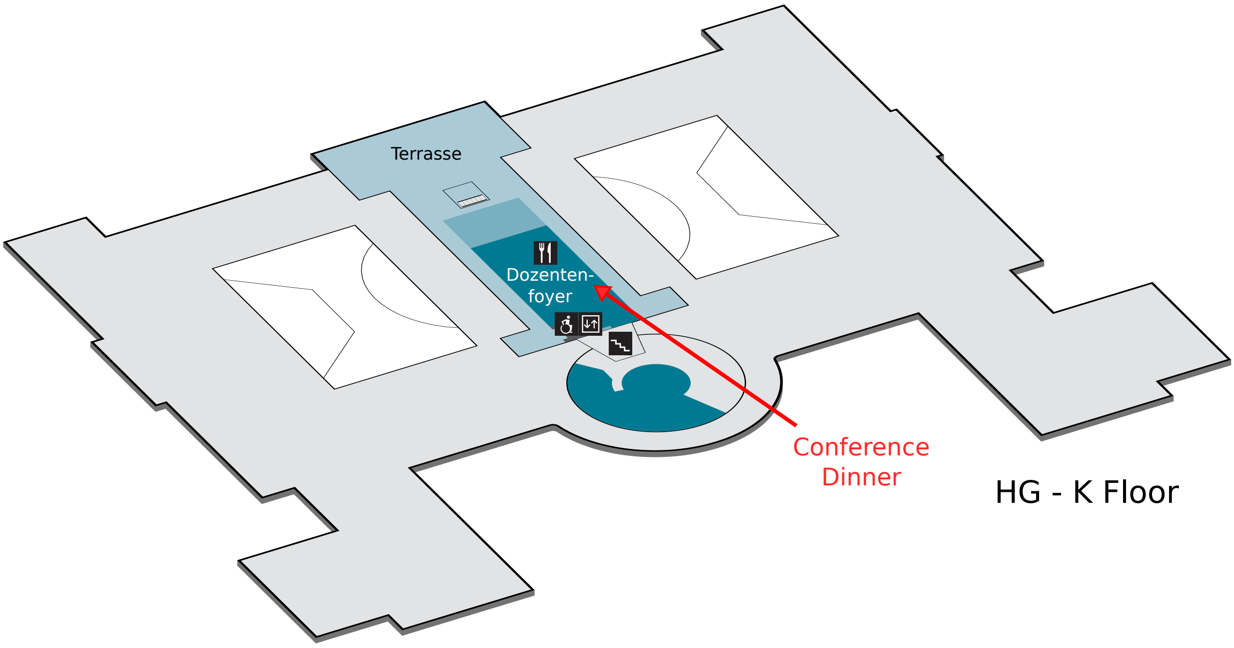
Buses have been organized for the transfer to the Factory Tours at Ansaldo and Kistler. Only registered participants will be allowed to enter the bus. Please leave the last presentation on Tuesday 12th September 2023 at 15.30 and proceed swiftly to the bus station. A SoTiC staff member will guide you.

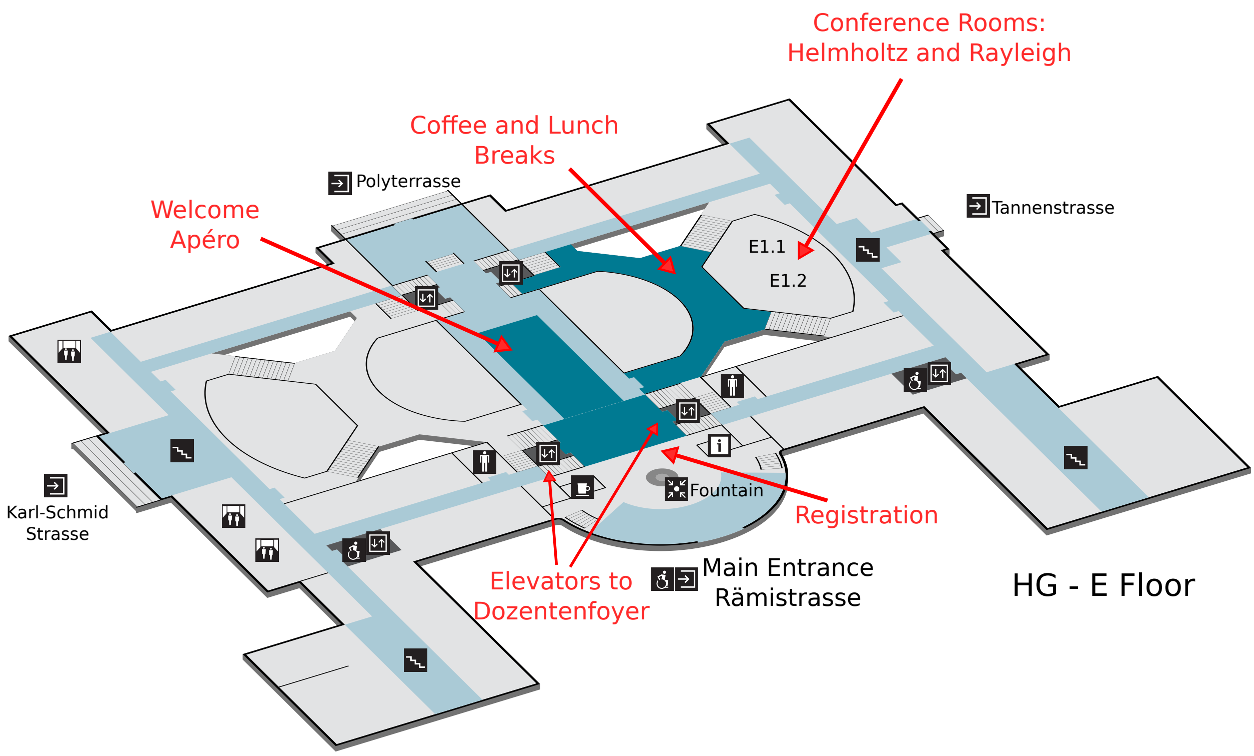
For the CAPS Lab Tour only registered participants will be allowed to enter the lab facility. Meeting point is at the coffee break area after the last session.

Conference Dinner (Main Building Dozentenfoyer K-Floor)

The dinner will take place at the Dozentenfoyer, please find the location on the map. Please keep your nametag visible at the entrance and during the evening. A wardrobe next to the venue will be available for us only.

Events Map


Terrasse
Dozenten-
foyer
Conference
Dinner
HG - K Floor


Conference Rooms:
Helmholtz and Rayleigh
Coffee and Lunch
Breaks
Polyterrasse
Welcome
Apéro
Tannenstrasse
E1.1
E1.2
Fountain
Registration
Karl-Schmid
Strasse
Elevators to
Dozentenfoyer
Main Entrance
Rämistrasse
HG - E Floor

Schedule at a Glance

	Monday 11/09	Tuesday 12/09	Wednesday 13/09	Thursday 14/09
08:00-08:30	Registration and Coffee			
08:30-09:00				
09:00-09:30	Welcome Speech	IS: Dawson	IS: Fischer	IS: Han
09:30-10:00	IS: Candel			
10:00-10:30		Coffee Break	Coffee Break	Coffee Break
10:30-11:00	Coffee Break	30 / 52	14 / 21	8 / 49
11:00-11:30	28 / 45	31 / 53	15 / 22	9 / 50
11:30-12:00	29 / 46	32 / 54	16 / 23	10 / 51
12:00-12:30	Lunch	Lunch	Lunch	Lunch
12:30-13:00				
13:00-13:30	IS: Hardi	IS: Juniper	IS: Lacoste	IS: Kim
13:30-14:00				
14:00-14:30	35 / 1	Coffee Break	17 / 24	11 / 57
14:30-15:00	36 / 2	33 / 55	18 / 25	12 / 58
15:00-15:30	37 / 3	34 / 56	19 / 26	13 / 59
15:30-16:00	38 / 4	Factory/Lab Tours at: Ansaldo, Kistler, CAPS Lab	20 / 27	Closing Note and Best Paper Award Ceremony
16:00-16:30	Coffee Break		Coffee Break	
16:30-17:00	39 / 5		42 / 47	
17:00-17:30	40 / 6		43 / 48	
17:30-18:00	41 / 7		44	
18:00-18:30	Welcome Apéro			
18:30-19:00			Banquet Dinner	
19:00-19:30				
19:30-20:00				
20:00-20:30				
20:30-21:00				
21:00-21:30				

- Invited Speaker
- Nonlinear and Stochastic Phenomena
- Annular, Can-Annular & Transverse Modes
- Passive and Active Control of Instabilities
- Dynamics of Spray and Autoignition Flames
- Physical Mechanisms, Flame Response
- Generation, Propagation and Damping of Perturbations
- Stability Analysis and Uncertainty Quantification
- Machine Learning, Artificial Intelligence and Data-Driven Methods
- Tools & Methods Development

Monday 11/09/2023 – 9:30-10:30

Invited Speaker Room Helmholtz

Prof. Dr. Sébastien Candel

Key factors in combustion instability analysis of annular systems

The considerable effort made in recent years to analyze combustion instabilities in annular systems will be reviewed to examine the state of knowledge and identify issues that need further consideration. A theoretical framework relying on an acoustic energy balance is also proposed to analyze some of the key factors, estimate the growth rate of instabilities coupled by azimuthal modes and guide efforts aimed at predicting domains of instability and at reducing oscillations. This will be illustrated with an analysis of the acoustic power flow in injection units and with investigations of azimuthal instabilities in a laboratory scale annular combustor.

Bio Abstract Full-Text

Monday 11/09/2023 – 11:00-12:00

Passive and Active Control of Instabilities	Room Helmholtz
STC 28	11:00-11:30
Discussion on the limitations of the κ and μ criteria as figures of merit to evaluate the thermoacoustic quality of burners with flames	
F. Ganji, Kornilov, van Oijen, Lopez Arteaga	
Page 53	Abstract · Full-Text
STC 29	11:30-12:00
A reduced-order model for the control of thermoacoustic instabilities in a dump combustor	
Bourny, Sarotte, Genot, Theilliol	
Page 48	Abstract · Full-Text

Stability Analysis and Uncertainty Quantification	Room Rayleigh
STC 45	11:00-11:30
Prediction of autoignition-stabilized flame dynamics in a backward-facing step reheat combustor configuration	
Gopalakrishnan, Heggset, Gruber, Bothien, Moeck	
Page 56	Abstract · Full-Text
STC 46	11:30-12:00
An efficient computational model to estimate the flame transfer function of non-premixed jet diffusion flames	
Giraudi, Morgans, Picciani	
Page 55	Abstract · Full-Text

Monday 11/09/2023 – 13:00-14:00

Invited Speaker	Room Helmholtz

Dr. Justin Hardi

Windows into the inferno: experiments for cryogenic rocket combustion instability

The Combustion Dynamics Team of the Department of Rocket Propulsion Technology at DLR Lampoldshausen has been studying combustion instabilities using high power rocket combustion experiments for more than two decades. The stability characteristics of sub-scale rocket thrust chambers with liquid oxygen and either hydrogen or methane propellants are explored, and the interaction of combustion chamber processes with acoustics are visualised under conditions highly representative of those in launcher engines. The experiments provide insights into the mechanisms which drive combustion instabilities and serve as test cases for numerical modelling.

Bio

Monday 11/09/2023 – 14:00-16:00

Physical Mechanisms, Flame Response		Room Helmholtz
STC 35		14:00-14:30
Contribution of Shear Layer Dynamics to Thermoacoustic Instabilities for a Reacting Jet in Cross-flow		
Bonnaire, Panek, Polifke		
Page 48	Abstract	Full-Text
STC 36		14:30-15:00
Towards the Prediction of Flame Transfer Functions: Evaluation of a Hybrid LES-CAA with Compressible LES		
Reinhardt, Alanyalıoğlu, Fischer, Lahiri, Nicolai, Hasse		
Page 62	Abstract	Full-Text
STC 37		15:00-15:30
Dynamics of vortex-flame interaction in a novel swirl combustor		
Ren, Wang, Xia, Qi		
Page 62	Abstract	Full-Text
STC 38		15:30-16:00
Comparison of acoustic, optical, and heat release rate based flame transfer functions for a lean-burn injector under engine-like conditions		
Alanyalioglu, Reinhardt, Fischer, Lahiri, Nicolai, Hasse		
Page 44	Abstract	Full-Text

Annular, Can-Annular & Transverse Modes		Room Rayleigh
STC 1		14:00-14:30
Experiments on the effect of cross-talk geometry on the whistling phenomenon in a two-can system		
Blondé, Schuermans, Noiray		
Page 46	Abstract	Full-Text
STC 2		14:30-15:00
Connecting can-annular acoustic modes to their annular limits		
Pedergnana, Orchini, Moeck, Noiray		
Page 61	Abstract	Full-Text
STC 3		15:00-15:30
Network- and CFD/CAA-Modelling of the High Frequency Flame Response in Multi-Jet Combustors		
Rosenkranz, Neu, Sattelmayer		
Page 64	Abstract	Full-Text
STC 4		15:30-16:00
Linearized Navier-Stokes modelling of acoustic modes in a LOX/Methane rocket thrust chamber		
Trotta, Armbruster, Schneider, Hardi, Börner, Suslov, Traudt, Zandbergen		
Page 67	Abstract	Full-Text

Monday 11/09/2023 – 16:30-20:00

Physical Mechanisms, Flame Response	Room Helmholtz
STC 39	16:30-17:00
Influence of wall-to-wall radiative heat transfer on premixed flame dynamics	
Désor, Eder, Silva, Polifke	
Page 51	Abstract · Full-Text
STC 40	17:00-17:30
Experimental investigation of self-sustained thermoacoustic instabilities in pure hydrogen swirling flames	
Vaysse, Durox, Vicquelin, Candel, Renaud	
Page 68	Abstract · Full-Text
STC 41	17:30-18:00
On the significance of modeling turbulent transport when linearizing the governing equations of a turbulent Bunsen flame	
Kaiser, von Saldern, Goldack, Polifke, Varillon, Zhang, Zirwes, Bockhorn, Oberleithner	
Page 57	Abstract · Full-Text

Annular, Can-Annular & Transverse Modes	Room Rayleigh
STC 5	16:30-17:00
A model of acoustic reflection coefficient in the transition ducts of can-annular combustors based on mode matching method	
Wang, Yang, Zhu	
Page 70	Abstract · Full-Text
STC 6	17:00-17:30
Predicting nonlinear thermoacoustic modes in annular combustors by combining a 2D low-order network model and experimentally-measured Flame Describing Functions	
Wang, Laera, Yang	
Page 69	Abstract · Full-Text
STC 7	17:30-18:00
Intermittency transition to azimuthal instability in a turbulent annular combustor	
Singh, Bhavi, R., Bhaskaran, Mishra, Chaudhuri, Sujith	
Page 65	Abstract · Full-Text

Main Hall	18:00-20:00
Welcome Apéro	

Tuesday 12/09/2023 – 9:00-10:00

Invited Speaker	Room Helmholtz

Prof. Dr. James R. Dawson

The thermoacoustic response and flame dynamics of hydrogen-methane blends

I will present a summary of what we have learned from several years of research at NTNU into the main effects that increasing hydrogen mass fraction has on the thermoacoustic response and flame dynamics of premixed hydrogen/methane blends. An effective and simple method to modify the Flame Transfer Function (FTF) through controlled hydrodynamic interference between the shedding of vortices from bodies upstream of the flame and the vortex roll-up at the flame base caused by acoustic forcing will be discussed. Finally, I will discuss some aspects of how increasing the hydrogen mass fraction has on the non-linear response of the flame.

Bio

Tuesday 12/09/2023 – 10:30-12:00

Passive and Active Control of Instabilities		Room Helmholtz
STC 30		10:30-11:00
Thermoacoustic Stabilization in a Sequential Combustor at Elevated Pressure using Nanosecond Repetitively Pulsed Discharges		
Dharmaputra, Reckinger, Shcherbanev, Schuermans, Noiray		
Page 51	Abstract	Full-Text
STC 31		11:00-11:30
Shape Sensitivities for Thermoacoustic Stability of Annular Combustors		
Ekici, Juniper		
Page 52	Abstract	Full-Text
STC 32		11:30-12:00
A modified Helmholtz resonator combined with membrane		
Yang, Yu, Zhu		
Page 72	Abstract	Full-Text

Tools & Methods Development		Room Rayleigh
STC 52		10:30-11:00
Thermoacoustic stability analysis and robust design of burner-deck-anchored flames in combustion systems using flame transfer function synthesis		
F. Ganji, Kornilov, van Oijen, Lopez Arteaga		
Page 53	Abstract	Full-Text
STC 53		11:00-11:30
A comprehensive linearised flow model for swirling jets		
Varillon, Kaiser, Brokof, Oberleithner, Polifke		
Page 68	Abstract	Full-Text
STC 54		11:30-12:00
Comprehensive tracking of acoustic and intrinsic modes for thermoacoustic systems with a general flame model		
Orchini, Cronqvist, von Saldern, Humbert, Moeck		
Page 60	Abstract	Full-Text

Tuesday 12/09/2023 – 13:00-14:00

Invited Speaker	Room Helmholtz

Prof. Dr. Matthew Juniper

Adjoint-accelerated Bayesian Inference and Bayesian Experimental Design

Bayesian Inference provides a probabilistic framework to penalize physical models that (i) do not fit data or (ii) fit data but require excessively delicate tuning. Although Bayesian Inference is usually prohibitively expensive, it becomes cheap if all probability distributions are Gaussian. This is because posterior probability distributions can be found with an efficient combination of gradient-based optimization, Laplace's method, and adjoint methods. I will outline Bayesian inference, Laplace's method, and Bayesian experimental design, and show how they are accelerated with adjoint methods. I will demonstrate this with model selection in thermoacoustics, assimilation of 3D Flow-MRI data, and Bayesian identification of nonlinear dynamics.

Bio

Tuesday 12/09/2023 – 14:30-19:00

Passive and Active Control of Instabilities		Room Helmholtz
STC 33		14:30-15:00
Modal coupling and mode degeneracy in annular combustor with multiple Helmholtz resonators		
Yin, Dong		
Page 72	Abstract	Full-Text
STC 34		15:00-15:30
Effect of nanosecond repetitively pulsed discharges on the transfer function of premixed methane-air swirl flames at elevated pressure		
Aravind, Yu, Lacoste		
Page 45	Abstract	Full-Text

Tools & Methods Development		Room Rayleigh
STC 55		14:30-15:00
Reconstruction of Downstream Acoustics from Two Separate SISO Measurements of Flame		
F. Ganji, Kornilov, van Oijen, Lopez Arteaga		
Page 54	Abstract	Full-Text
STC 56		15:00-15:30
Investigating the influence of hydrogen-rich fuel mixtures on the assessment of the flame transfer function		
zur Nedden, Paschereit, Orchini		
Page 73	Abstract	Full-Text

	15:30-19:00
Factory Tours: Ansaldo, Kistler, CAPS	

Wednesday 13/09/2023 – 9:00-10:00

Invited Speaker	Room Helmholtz

Dr. André Fischer

Thermoacoustics in aero engines – a Rolls-Royce perspective

The talk aims to provide an overview of thermoacoustics in aero engines. It will cover the basic principles of thermoacoustics and emphasise the role it plays from engine design to engine operation. Thermoacoustics has gained significant importance in the aerospace industry due to its impact on engine performance and safety. The talk will discuss the challenges associated with implementing solutions in this field, including the need for accurate experimental measurements and the development of reliable numerical methods. By overcoming these challenges, researchers and engineers can effectively mitigate adverse effects and improve the overall performance of future modern aero engines.

Bio

Wednesday 13/09/2023 – 10:30-12:00

Machine Learning, Artificial Intelligence and Data Driven Methods		Room Helmholtz
STC 14		10:30-11:00
Experimental validation of data-driven nonlinear dynamical flame model		
Wildemans, Kornilov, Lopez Arteaga		
Page 71	Abstract	Full-Text
STC 15		11:00-11:30
Machine Learning for predicting the flame describing function of CH4/H2 laminar flames		
Shen, Morgans		
Page 65	Abstract	Full-Text
STC 16		11:30-12:00
Data-driven modelling of thermoacoustic instability in a ducted conical flame		
Yoko, Juniper		
Page 73	Abstract	Full-Text

Nonlinear and Stochastic Phenomena		Room Rayleigh
STC 21		10:30-11:00
A flame describing function mapping of the operating domain of an annular combustor and instability prediction		
Latour, Durox, Renaud, Candel		
Page 58	Abstract	Full-Text
STC 22		11:00-11:30
The relationship between the OH^* signal and the heat release rate for spray flames: consequences on the Flame Describing Function		
Moriniere, Schuller		
Page 59	Abstract	Full-Text
STC 23		11:30-12:00
Nonlinear Global Flame Response Behaviors for Triggering of Combustion Instabilities		
Acharya		
Page 43	Abstract	Full-Text

Wednesday 13/09/2023 – 13:00-14:00

Invited Speaker	Room Helmholtz

Prof. Dr. Deanna Lacoste

Combustion stabilization by non-thermal plasma

Energy conversion systems based on combustion are facing multiple challenges such as the arrival of new fuels, increasingly drastic pollutant regulations, and the pressure of extremely ambitious nationally determined contributions of the Paris Agreement. In this fast-evolving environment, perfect flame control is becoming both more important and more difficult. Combustion processes are sensitive to the chemical composition of the medium, the thermodynamic conditions, and the flow. By changing any of these, it is possible to modify the combustion rate and to control the flame. Non-thermal plasma produced by electric discharges have chemical, thermal and transport effects that can be used to stabilize combustion. In this talk, I will present recent progress in control of flame dynamics by non-thermal plasma produced by nanosecond repetitively pulsed discharges, with a special focus on high-pressure combustion and ammonia combustion.

Bio 🔗

Wednesday 13/09/2023 – 14:00-16:00

Machine Learning, Artificial Intelligence and Data Driven Methods — Room Helmholtz

STC 17	14:00-14:30
Flame transfer function shaping for robust thermoacoustic systems: Application to a kinematic flame model	
Reumschüssel, Kroll, von Saldern, Paschereit, Oberleithner, Orchini	
Page 63	Abstract · Full-Text

STC 18	14:30-15:00
Linear and nonlinear flame response prediction of turbulent flames using neural network models	
Tathawadekar, Ösün, Eder, Silva, Thuerey	
Page 67	Abstract · Full-Text

STC 19	15:00-15:30
Evaluation of thermo-acoustic quality indicator in the case of factorizable dispersion relation.	
Kornilov, de Goey	
Page 57	Abstract · Full-Text

STC 20	15:30-16:00
Bayesian data assimilation of acoustically forced laminar premixed conical flames	
Giannotta, Yoko, Cherubini, De Palma, Juniper	
Page 55	Abstract · Full-Text

Nonlinear and Stochastic Phenomena — Room Rayleigh

STC 24	14:00-14:30
Noise in a Rijke tube with mean flow and a non-uniform temperature field	
Wei, Arabi, Pralits, Bottaro, Heckl	
Page 70	Abstract · Full-Text

STC 25	14:30-15:00
Characterization of combustion dynamics in a Trapped Vortex Combustor for various cavity sizings	
Singh, Nair	
Page 66	Abstract · Full-Text

STC 26	15:00-15:30
Effect of colored noise on precursors of thermoacoustic instability in model gas turbine combustors	
Vishnoi, Gupta, Saurabh, Kabiraj	
Page 69	Abstract · Full-Text

STC 27	15:30-16:00
Flame describing functions of a real scale injection system for various operating pressures	
Bodoc, Garraud, Orain, Anthony, Gajan	
Page 46	Abstract · Full-Text

Wednesday 13/09/2023 – 16:30-21:30

Physical Mechanisms, Flame Response	Room Helmholtz
STC 42	16:30-17:00
Numerical investigations of the effect of non-equilibrium plasma discharges on the dynamics of a sequential combustor	
Impagnatiello, Malé, Noiray	
Page 56 · Abstract · Full-Text	
STC 43	17:00-17:30
Effect of stratification on the combustion behavior and dynamic response of a bluff body-stabilized ammonia–hydrogen flame with radial staging	
Sampath, Moeck	
Page 64 · Abstract · Full-Text	
STC 44	17:30-18:00
Investigation on a frequency drop of combustion instability in a lean premixed single swirl burner	
Xu, Zheng, Xia, Qi	
Page 71 · Abstract · Full-Text	

Stability Analysis and Uncertainty Quantification	Room Rayleigh
STC 47	16:30-17:00
Systematic modulation of the FTF and its effect on thermoacoustic stability	
Æsøy, Moeck, Dawson	
Page 43 · Abstract · Full-Text	
STC 48	17:00-17:30
Acoustic analysis and stability map in an aerial combustor for take-off and cruise conditions	
Nosrati, Elkaei, Pourfarzaneh, Barjesteh, Zadsirjan	
Page 60 · Abstract · Full-Text	

Dozentenfoyer K-Floor	18:30-21:30
Banquet Dinner	

SICHERE, ANSPRUCHSVOLLE UND KOMPLEXE AUTOMATIONSLÖSUNGEN

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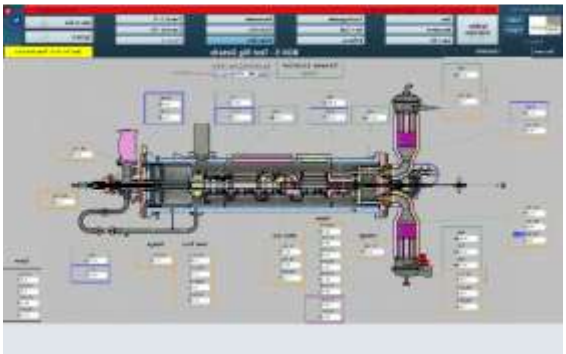

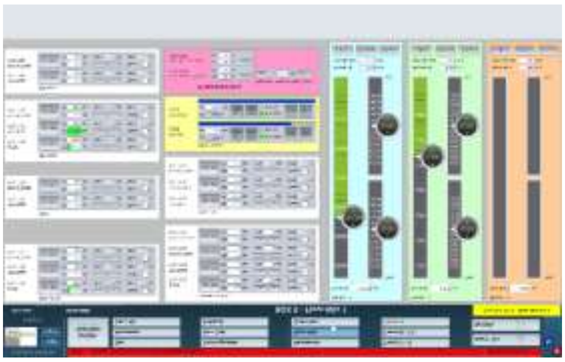

We would like to thank ETH Zurich for the good cooperation and wish them every success for SoTiC 2023.

Thursday 14/09/2023 – 9:00-10:00

Invited Speaker	Room Helmholtz

Dr. Fei Han

Combustion Dynamics Research at GE Research

GE Research is at a unique position where researchers work on both gas turbine can-annular combustors and on aircraft engine annular combustors. This talk overviews both the experimental and modeling capabilities at GE Research that have been developed in handling combustion dynamics in both types of combustors. Several examples of fundamental research on combustion dynamics will be highlighted. These include the effect of flame – flame interactions on flame transfer functions, the fundamental thermoacoustic behaviors and mitigation of combustion dynamics in can-annular combustors, and thermoacoustics of an annular combustor. Challenges and future research needs will also be provided.

Bio

Thursday 14/09/2023 – 10:30-12:00

Dynamics of Spray and Autoignition Flames		Room Helmholtz
STC 8		10:30-11:00
Identification of the dynamics of a turbulent spray flame at high pressure		
Eder, Fischer, Lahiri, Merk, Staufer, Eggels, Silva, Polifke		
Page 52	Abstract	Full-Text
STC 9		11:00-11:30
Effect of the fuel composition and the equivalence ratio on the dynamics of swirl-stabilized spray flames to a transverse acoustic mode		
Alhaffar, Patat, Blaisot, Domingues, Baillot		
Page 44	Abstract	Full-Text
STC 10		11:30-12:00
The effect of second stage H2 addition on the stability of an axially staged can combustor		
Ånestad, Sampath, Moeck, Worth		
Page 45	Abstract	Full-Text

Stability Analysis and Uncertainty Quantification		Room Rayleigh
STC 49		10:30-11:00
Early Detection of Combustion Instabilities in Liquid Rocket Engines: Assessment of Statistical, Recurrence, and Fractal Analyses for Sub- and Supercritical Pressure Conditions		
Martin, Börner, Armbruster, Hardi, Oschwald		
Page 59	Abstract	Full-Text
STC 50		11:00-11:30
Robustness and Reliability of state-space, frame-based modeling for Thermoacoustics		
Cances, Giraud, Bauerheim, Gicquel, Nicoud		
Page 49	Abstract	Full-Text
STC 51		11:30-12:00
Validation of a combined optic-acoustic probe on hydrogen flames using an atmospheric lean premix pilot burner		
Paulitsch, Giuliani, Hofer		
Page 61	Abstract	Full-Text

Thursday 14/09/2023 – 13:00-14:00

Invited Speaker	Room Helmholtz

Prof. Dr. Kyu Tae Kim

Thermoacoustic interactions in an axially-staged lean-premixed combustor

The transition from non-premixed to lean-premixed combustion systems has proven central to achieving higher combined cycle efficiency, without increasing NOx emissions. According to thermodynamic analyses, the development of more efficient gas turbine engines with higher than 65% net efficiency necessitates turbine inlet temperatures of 2000 K, at which point conventional architectures are unable to meet stringent NOx emission requirements. This chemical kinetics-related fundamental limitation can be circumvented by means of axial fuel staging strategies. The main purpose of the present investigation is to understand how an axial fuel-staged system behaves in a complex thermoacoustic environment, in comparison with single injection non-staged conditions.

Bio

Thursday 14/09/2023 – 14:00-15:30

Generation, Propagation and Damping of Perturbations		Room Helmholtz
STC 11		14:00-14:30
Numerical study of the linear and non-linear damping in an acoustically forced cold-flow test rig with coupled cavities		
Marchal, Schmitt, Fougnie, Ducruix		
Page 58	Abstract	Full-Text
STC 12		14:30-15:00
Doak's Momentum Potential Theory extended to multi-component and reactive flows - Theoretical formulation and LES data application		
D'Aniello, Seo, Koob, Reinhardt, Hasse, Knobloch		
Page 50	Abstract	Full-Text
STC 13		15:00-15:30
Entropy wave transport in an industry-like model geometry using a linearized global framework		
Suman, Xia, Sharkey, Verma, Oberleithner, Kaiser		
Page 66	Abstract	Full-Text

Tools & Methods Development		Room Rayleigh
STC 57		14:00-14:30
Towards a Momentum Potential Theory for Reacting Flows		
Brokof, Varillon, Inoue, Polifke		
Page 49	Abstract	Full-Text
STC 58		14:30-15:00
Assessing the thermoacoustic quality of the known subsystems using stability quality factors: figure of merit		
F. Ganji, Kornilov, van Oijen, Lopez Arteaga		
Page 54	Abstract	Full-Text
STC 59		15:00-15:30
Developments of the time-domain impedance boundary condition for combustion problems		
Roncen, Cardesa, Marchal		
Page 63	Abstract	Full-Text

Room Helmholtz	15:30-16:30
Closing Note and Best Paper Award Ceremony	

Acharya, Vishal

Nonlinear Global Flame Response Behaviors for Triggering of Combustion Instabilities (STC 23)

Combustion instabilities result in large combustor acoustic amplitudes due to a feedback loop between exciting acoustic/hydrodynamic disturbances and flame response. This paper addresses the global heat release properties required for a seemingly stable combustor to exhibit bi-stable behavior; i.e., be destabilized by a large enough disturbance amplitude, commonly referred to as ”triggering” in the combustion instability literature. This question has enormous practical significance; e.g., it has motivated a whole set of flight certification protocols for rocket engines, usually done by detonating explosive charges inside the combustion chamber. It is shown that a fifth order flame response model is required to capture these behaviors. Moreover, the third and fifth order non-linearity must satisfy very specific relationships in phase but not amplitude. While the analysis is quite general, we also present an example problem for an anchored, premixed flame to find the combination of control parameters where triggering is possible. The ultimate goal for the presented results is that it can be used to screen data-sets (such as from single nozzle flame characterization experiments) and identify parametric spaces where triggering tendencies are the highest.

Detailed Schedule Full-Text

Æsøy, Eirik

Moeck, Jonas P.

Dawson, James R.

Systematic modulation of the FTF and its effect on thermoacoustic stability (STC 47)

We investigate the thermoacoustic response of a simple combustor where the flame response is varied systematically through modulations in the gain and phase of the flame transfer function. We demonstrate and quantify two methods to modify the flame transfer function in a systematic way: 1) The center of heat release rate is changed for a fixed volume flow rate and thermal power by varying the methane/hydrogen fraction of the fuel. 2) For a fixed fuel blend, the flame response is significantly modified by placing a set of cylinders upstream of the flame base. We show that these two methods enable us to independently modify important scales in the FTF and that by combining them, the FTF can be manipulated in a straightforward and systematic way. A Distributed Time Lag model is used to generalize and describe the FTF modifications in terms of the two convective time delays. The DTL model is implemented into a network model of the system, and results from a linear stability analysis are compared with measurements of self-excited instabilities. Changes to the growth rate are shown to be consistent with the experimentally observed limit cycle amplitudes when the time delay related to the modulations is varied. Modification to the gain extends the initial eigenvalue trajectory, whereas a change in the phase leads to a rotation. The overall effect on the growth rate depends on the initial location of the eigenvalue in the complex plane. The effect of an exceptional point on the eigenvalue trajectories is apparent.

Detailed Schedule Full-Text

A B C D E F G I K L M N O P R S T V W X Y Z

A B C D E F G I K L M N O P R S T V W X Y Z

Alanyalioglu, Cetin Ozan

Reinhardt, Hanna

Fischer, André

Lahiri, Claus

Nicolai, Hendrik

Hasse, Christian

Comparison of acoustic, optical, and heat release rate based flame transfer functions for a lean-burn injector under engine-like conditions (STC 38)

The determination of the flame transfer function plays a crucial role during the development phase of lean-burn injectors to predict the overall combustion system stability. The Rolls-Royce SCARLET (SCaled Acoustics Rig for Low Emissions Technology) allows measurement of the flame response of real aero-engine injectors under realistic single-sector operating conditions using both optical (OH^* chemiluminescence) and purely acoustic measurements. While the purely acoustic measurement of the flame transfer function is advantageous in terms of practicality, the post-processing is not trivial due to the complicated design of the rig, and following the standard practice in the literature leads to excessive deviations from the actual flame transfer function. In this work, we focus on acoustic network modeling and compressible large-eddy simulation (LES) of the SCARLET rig and analyze the differences between acoustical, optical, and HRR-based flame transfer functions. We show that HRR-based FTF from LES agrees well with the optical FTF from the experiment. The baseline acoustic post-processing method, when applied to both LES and experiments, yields different results. Using LES data and an acoustic network approach, we suggest that comparable results can be obtained if additional acoustic features of the rig are taken into account. We further discuss the underlying assumptions of each method, and applicability of the analytical flame transfer matrix derived from linearized Rankine-Hugoniot relations.

Detailed Schedule

Full-Text

Alhaffar, Abdallah

Patat, Clément

Blaisot, Jean-Bernard

Domingues, Eric

Baillot, Françoise

Effect of the fuel composition and the equivalence ratio on the dynamics of swirl-stabilized spray flames to a transverse acoustic mode (STC 9)

Lean combustion technologies are prone to combustion instabilities in aircraft engines, which are fed with multi-component liquid fuels, among which Sustainable Aviation Fuels (SAF) produced from biomass are promising as drop-in alternative biofuels. A key issue is the effect of the fuel composition, in particular due to the preferential evaporation of the different chemical species, on flame dynamics. This work investigates the dynamics of a linear array of three swirl-stabilized spray/air flames fed with different fuel mixtures constituted of n-heptane and dodecane, placed at a pressure antinode of a controlled standing transverse acoustic field. Flame response is first analyzed within the framework of the Flame Describing Function (FDF) and the Rayleigh criterion. The results indicate that the potential of the system to drive instabilities increases with the proportion of n-heptane. An acoustic-induced longitudinal wave propagating along the flame front, captured with high-speed OH^* imaging, shows a large dependency on the fuel mixture. Results obtained are consistent with the global flame analysis performed within the FDF framework. The equivalence ratio appears as an essential quantity when analyzing flame dynamics for various mixtures. The two-component fuel spray is analyzed utilizing PDPA (Phase Doppler Particle Analyzer) system. The results reveal that the modification of the evaporation process, when the fuel mixture is changed, would be the main factor explaining the modification of the flame response.

Detailed Schedule

Full-Text

Ånestad, Aksel

Sampath, Ramgopal

Moeck, Jonas

Worth, Nicholas A.

The effect of second stage H2 addition on the stability of an axially staged can combustor (STC 10)

An investigation of flame structure and stability was conducted in a two-stage combustor operated with CH4 and H2 fuel blends. To characterise the thermoacoustic stability of the first CH4 flame, a bifurcation experiment was conducted in which the equivalence ratio was varied, with constant bulk velocity. This led to the selection of 0.75 and 0.8 as a stable and unstable test case, respectively. A secondary flame zone was then created by injecting premixed air and CH4-H2 mixtures through opposing radial jets downstream of the main flame, with a constant equivalence ratio 0.8. OH* imaging was used to examine a range of secondary flame structures, across a broad range of bulk velocities H2 power fractions. Further bifurcation experiments were conducted by varying the jet velocity, while the main flame condition remained unchanged, showing that the system stability could be altered to either encourage or prevent instabilities. Pressure and PMT data were used to analyse the oscillation cycle for Phi=0.8. Mode suppression was shown for a range of bulk velocity and H2 content where the jet and main flames oscillate in antiphase. Phase averaged dynamics were then analysed at select velocities revealing a transition from dynamics dominated by jet flapping/puffing to flame collisions and merging as the jet-to-crossflow momentum flux ratio increased, causing the jet flames to interact strongly. The addition of H2 decreased the delay of the jet HRR oscillations by shortening it. As a result, mode suppression occured at lower velocity, with a less pronounced effect on the limit-cycle amplitude.

Detailed Schedule 🔗 Full-Text ↗

Aravind, Balakrishnan

Yu, Liang

Lacoste, Deanna

Effect of nanosecond repetitively pulsed discharges on the transfer function of premixed methane-air swirl flames at elevated pressure (STC 34)

An experimental investigation on the effect of nanosecond repetitively pulsed (NRP) discharges on the dynamic response of lean premixed methane-air swirl flames at elevated pressure up to 2.5 bar was carried out in the present study. The NRP discharges were generated in the annular gap between the bluff body and a metallic ring embedded at the outlet of the injection tube. The applied voltages were 7.0 kV at 1.2 bar and 9.2 kV at 2.5 bar, with a pulse repetition frequency of 30 kHz. The plasma power was 0.32 % of the thermal power of the flame at both pressures. Flame transfer functions (FTF) were determined with and without plasma, for frequencies ranging from 48 to 380 Hz. NRP discharges had a strong influence on the flame transfer function. A significant reduction in the FTF gain was achieved in the low frequency regions (48-112 Hz) with a maximum of approximately 45 % at 80 Hz. Possible mechanisms responsible for the decrease in gain based on the phase-locked imaging of flame are discussed.

Detailed Schedule 🔗 Full-Text ↗

A
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Blondé, Audrey

Schuermans, Bruno

Noiray, Nicolas

Experiments on the effect of cross-talk geometry on the whistling phenomenon in a two-can system (STC 1)

This paper deals with an experimental investigation of the acoustic interaction between two neighbouring combustor cans in a mock-up configuration. The experimental set up is a strong abstraction of an actual combustor configuration but it was designed to reproduce the essential features to study the acoustic and hydrodynamic can-to-can coupling as observed in can-annular gas turbines. It consists of two separate straight channels with an anechoic termination on the upstream and choked conditions on the downstream sides by means of vanes that represent the first turbine stage. Right before the vanes, the two channels are connected via a small gap, the so called cross-talk area, to allow for acoustic communication between the two cans. While conducting non-reactive experiments with pressurized air, an intense whistling is observed. The whistling frequency and amplitude depend on the cross-talk area and geometry. The frequency of oscillations scales well with a Strouhal number based on the cross-talk distance, which suggests a hydrodynamic nature of the modes. The investigation of the probability densities of the pulsation time traces shows a bifurcation from linearly stable stochastically driven oscillations to linearly unstable stochastically perturbed limit cycle amplitudes. This work highlights the possible presence of shear layer flapping at the cross-talk in can-annular combustors. The range of frequencies and amplitudes of this phenomenon overlaps with typical frequency and amplitudes of thermoacoustic modes observed in gas turbine combustors. Hence these pulsations can be coinciding with thermoacoustic modes or mistakenly be interpreted for thermoacoustic modes in practical combustors.

Detailed Schedule Full-Text

Bodoc, Virginel

Garraud, Julien

Orain, Mikael

Anthony, Desclaux

Gajan, Pierre

Flame describing functions of a real scale injection system for various operating pressures (STC 27)

The flame response of a real scale aeronautical injector burner is explored experimentally through the use of describing functions that depend on the forcing level and/or the forcing frequency. In these experiments the flame is forced by a siren connected to the combustor on the fresh gas feeding line. The experimental setup is equipped with two microphones placed on waveguides connected to the combustor air feeding tube and a photomultiplier equipped with an OH* filter used to measure the heat release rate fluctuations. The describing functions between the photomultiplier signal and velocity reference signal are analyzed for 1, 3 and 5 bars operating pressures and for two tested fuels: Jet A1 and Alcohol To Jet.

Detailed Schedule Full-Text

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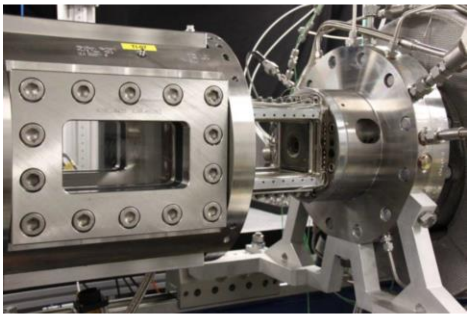

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- Manufacturing and procurement
- Assembly and commissioning

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CH-5704 Egliswil

Bonnaire, Philip

Panek, Lukasz

Polifke, Wolfgang

Contribution of Shear Layer Dynamics to Thermoacoustic Instabilities for a Reacting Jet in Cross-flow (STC 35)

This paper examines the conditions under which a combustion system with a reacting jet in cross-flow operating at fully premixed, lean conditions exhibits thermoacoustic oscillations in the high-frequency range. The objective is to explore the hypothesis that the flow structures of the jet can serve as a possible amplifier for the thermoacoustic feedback cycle. The jet in cross-flow shows a multitude of vortex structures that can potentially interact with the acoustic frequency. For this purpose, it is first investigated how precisely the relevant flow regions, such as shear and boundary layers, must be resolved in the numerical simulation. It is then examined if there are preferred frequencies in the hydrodynamic field and with which parameters they scale. For reacting test cases with a jet-to-cross-flow density ratio of 3.29 in an environment without thermoacoustic feedback, a Fourier analysis of the jet shear layer shows a broadband spectrum. With increasing momentum flux ratio, the broadband distribution shifts to higher frequencies. When translating the operating points to a generic axial stage combustor geometry, the shear layer structures interact with the thermoacoustic feedback loop close to their natural frequency range. If the momentum flux ratio is increased, the natural frequency of the jets increases, while the amplitudes of pressure fluctuations decrease.

Detailed Schedule Full-Text

Bourny, Quentin

Sarotte, Camille

Genot, Aurelien

Theilliol, Didier

A reduced-order model for the control of thermoacoustic instabilities in a dump combustor (STC 29)

Combustion instabilities may develop, due to the formation of vortices at a geometrical change, as a step, which causes flame wrinkling. This may be preponderant for ramjets. In the literature, low-order models for pressure and velocity oscillations have been proposed, in which the oscillations are induced by the coupling between the flame wrinkling and the acoustics. These models have a nonlinear dynamics (kicked oscillator, limit cycle) with a complex frequency spectrum. In order to control the development of thermoacoustic instabilities using these models, they should be written as a state-space representation. However, writing these models under a state-space representation is difficult due to their formulation as kicked oscillators. For this reason, the objective of this paper is to reduce the model to its most simplified form: considering a one-way interaction between the combustor acoustic and the convection of vortices, adopting a deterministic model rather than a stochastic one as proposed by some previous authors. The main contribution of this paper is to propose a reduced-order model, derived from pre-existing models, which is suitable for control. This model is compared to the Nair and Sujith model in this paper and we find satisfactory results: similar spectrum, close amplitude prediction for various operating conditions. This degree of similarity between the models is sufficient in order to develop a model-based control methodology.

Detailed Schedule Full-Text

Brokof, Philipp

Varillon, Grégoire

Inoue, Yasuhiko

Polifke, Wolfgang

Towards a Momentum Potential Theory for Reacting Flows (STC 57)

Mutual coupling of (thermofluiddynamic) modes of perturbations can affect the thermo-acoustic stability of combustors and contribute to combustion noise. For example, vortical or entropic perturbations can be transferred to acoustic perturbations if accelerated by the mean flow. The decomposition of perturbation fields into the respective modes and a linear description of their interactions in terms of fluctuating primitive variables is challenging. In contrast, Doak's Momentum Potential Theory (MPT) promises an unambiguous decomposition in terms of momentum fluctuations, which is not limited to the linear regime. In the present study, the MPT is extended to study mode conversions relevant to combustion noise. Whereas classical MPT takes into account hydrodynamic, acoustic and entropic modes in unconfined flows, the investigation of noise generation in combustion chambers requires the extension of the MPT to capture modes linked to the fluctuation of species mass fractions ("species mode") arising from the change in chemical composition due to the reaction. Furthermore, a rigorous treatment of boundary conditions due to the confinement of the flow inside the combustor is required. The herein presented extension to reacting flows consists of two steps, (i) the formulation of a potential for momentum fluctuations related to species modes and (ii) identification of the enthalpy fluctuation related to species modes. The usefulness of the extended theory is explored by its application to post-processing of computational fluid dynamic simulation data of the propagation of entropy and species perturbations through one-dimensional ducts, nozzles and premixed flames.

Detailed Schedule 🔗 Full-Text ↗

Cances, Mathieu

Giraud, Luc

Bauerheim, Michael

Gicquel, Laurent

Nicoud, Franck

Robustness and Reliability of state-space, frame-based modeling for Thermoacoustics (STC 50)

This study is built upon the state-space formalism and the frame modal expansion introduced for thermo-acoustics in Laurent et al., Comb. and Flame, 206, (2019) and extended to complex geometries by Laurent, Badhe and Nicoud, J. of Comp. Physics, 428 (2021). The low-order modeling based on this frame modal expansion is prone to several numerical issues, particularly with the emergence of non-physical components in the output. A methodology based on the singular value decomposition is proposed to identify the sources of the spurious modes, and remove them. By preventing any interaction between the physical and non-physical components in the outcome, the proposed methodology drastically improves the robustness and reliability of the frame-based low-order modeling for thermoacoustics.

Detailed Schedule 🔗 Full-Text ↗

A B C D E F G I K L M N O P R S T V W X Y Z

A B C D E F G I K L M N O P R S T V W X Y Z

Candel , Sébastien

Latour, Véranika

Durox, Daniel

Renaud, Antoine

Key factors in combustion instability analysis of annular systems (IS)

A considerable effort has been made in recent years to analyze combustion instabilities in annular systems, a geometry that is commonly used in aeroengines and gas turbines. Much insight has been gained from experiments and from analytical developments accompanied by numerical simulations. This effort will be reviewed to examine the state of knowledge and identify the issues that need further consideration. A theoretical framework relying on an acoustic energy balance is also derived that can be used to analyze some of the key factors and estimate the growth rate of instabilities coupled by azimuthal modes. The focus of this analysis will be placed on the role of injection unit dynamics, acoustic energy dissipation and impedance of this unit, acoustic modes of the annular configuration, energy balance in the combustion system, flame response, and its representation in terms of flame describing functions. An understanding of the interplay between these different items may be used to guide efforts aimed at predicting domains of instability and at reducing or suppressing self-sustained oscillations. Application of the theoretical framework is illustrated by an analysis of the acoustic power flow in injection units and by investigations of azimuthal instabilities in a laboratory scale annular combustor.

Detailed Schedule

Full-Text

D'Aniello, Raffaele

Seo, Bonggyun

Koob, Philipp

Reinhardt, Hanna

Hasse, Christian

Knobloch, Karsten

Doak's Momentum Potential Theory extended to multi-component and reactive flows - Theoretical formulation and LES data application (STC 12)

This paper presents an application of Doak's "Momentum Potential Theory of Energy Flux carried by Momentum Fluctuations", extended for analyzing multi-chemical-component and reactive flows. New components, related to the dynamics of the mixtures, are superimposed to the canonical Doak's decomposition in turbulent, acoustic, and thermal momentum fluctuations. The extended model is used here to characterize the thermoacoustic behavior of a bluff-body stabilized premixed flame, represented by Large Eddy Simulation data of the Volvo Test Rig. The main characteristics of the combustion noise are highlighted by combining the results obtained through the model with the Spectral Proper Orthogonal Decomposition.

Detailed Schedule

Full-Text

Dharmaputra, Bayu

Reckinger, Pit

Shcherbanev, Sergey

Schuermans, Bruno

Noiray, Nicolas

Thermoacoustic Stabilization in a Sequential Combustor at Elevated Pressure using Nanosecond Repetitively Pulsed Discharges (STC 30)

This study demonstrates the stabilization of a sequential combustor operated at elevated pressure with Nanosecond Repetitively Pulsed Discharges (NRPD). A constant-pressure sequential combustor offers many advantages compared to a conventional combustor, including higher fuel flexibility and a wider operational range. However, thermoacoustic instability remains a barrier to widening the operational range of the combustor. In the past decades, active and passive control strategies for gas turbine combustors have been studied. Passive control strategies have been more widely used in commercial systems due to their simplicity in terms of implementation. Active control strategies have seen less practical application, mainly due to the lack of robust actuators with sufficient control authority. In this study, we demonstrate the applicability of nanosecond repetitively pulsed discharges (NRPD) as actuators to stabilize a lab-scale sequential combustor operated at pressures ranging from one to three bars. We employ continuous forcing of NRPD to stabilize the sequential combustor in both stationary and transient cases. In the transient case, the combustor pressure is progressively increased from one to two bars while continuously applying the NRPD to stabilize the system. Additionally, we demonstrate that NRPD can access operating conditions with low NO emissions, which are only stable with NRPD.

Detailed Schedule 🔗 Full-Text ↗

Désor, Marcel

Eder, Alexander J.

Silva, Camilo F.

Polifke, Wolfgang

Influence of wall-to-wall radiative heat transfer on premixed flame dynamics (STC 39)

The inclusion of conjugate heat transfer (CHT) in simulations of flame dynamics and thermoacoustic stability is a recent development promising higher accuracy than established methods for setting thermal boundary conditions at the combustor walls. However, radiative heat transfer represents a significant challenge for CHT simulations. A comprehensive treatment of thermal radiation requires modeling of both gaseous and solid wall emission and absorption. Wall-to-wall radiative heat transfer in particular may reduce temperature gradients in solids or transport heat upstream of the flame, where it leads to elevated upstream wall temperatures and affects flame anchoring, quenching, and flow velocities. This paper investigates these effects in large eddy simulation of a swirl-stabilized, fully premixed, hydrogen-enriched methane flame. A parameter study on radiative properties of the solid walls is performed while keeping all other variables constant. The findings demonstrate that while neglecting radiation can lead to accurate mean flame predictions, wall-to-wall radiation strongly influences flame dynamics. Elevated wall temperatures in outer recirculation zones are responsible for more flame activity in those regions, promoting a higher flame response gain. Additionally, increased upstream preheating of the fuel/air mixture decreases convective time delays, impacting phase predictions. This mixture preheating is a combined effect of direct radiation onto the upstream wall materials and the stronger flame activity in the outer recirculation zone. Fortunately, large uncertainties in the radiative properties of the solid materials are permissible as the estimated flame dynamics is rather insensitive to the specific values of radiative properties.

Detailed Schedule 🔗 Full-Text ↗

Eder, Alexander J.
Fischer, André
Lahiri, Claus
Merk, Moritz
Staufer, Max
Eggels, Ruud
Silva, Camilo F.
Polifke, Wolfgang

Identification of the dynamics of a turbulent spray flame at high pressure (STC 8)

The flame dynamics of a kerosene spray flame is investigated under realistic operating conditions (T inlet $\simeq$ 850 K, p inlet $\simeq$ 30 bar). The present work evaluates the flame transfer function of a turbulent spray flame by applying system identification (SI) to time series data extracted from incompressible large eddy simulation (LES) using the Rolls-Royce in-house code PRECISE-UNS. The identified acoustic flame response is compared to experimental data from the Scaled Acoustic Rig for Low Emission Technology (SCARLET) using the multi-microphone method. The present work investigates the potential of the LES/SI methodology as a predictive tool in the early design phase of an aircraft engine. In addition, the validity of the established calculation of the flame transfer matrix (FTM) and the Rankine-Hugoniot jump conditions to extract the flame transfer function from the FTM is analyzed with a low-order acoustic network model of SCARLET.

Detailed Schedule Full-Text

Ekici, Ekrem
Juniper, Matthew P.

Shape Sensitivities for Thermoacoustic Stability of Annular Combustors (STC 31)

Modern gas turbine combustors are susceptible to oscillations caused by the interaction between sound waves and the flame. If the acoustic pressure is sufficiently in phase with the heat release rate, the oscillations can grow significantly, which may cause extra heat transfer, excessive noise, or even failure of the engine. We use the thermoacoustic Helmholtz equation to model this instability problem as an eigenvalue problem. The eigenfrequency and the growth rate of the system are obtained using a finite element based Helmholtz solver by defining the geometry and system parameters as well as by imposing the acoustic boundary conditions and fluctuating body forces. After calculating the eigenvalue and eigenvector of the problem, we use adjoint methods to calculate the sensitivity of the eigenvalue to changes in the shapes of the surfaces of the combustor geometry. We demonstrate the application of this procedure to an example annular combustor with dilution holes for two different eigenmodes. The computed shape sensitivity fields can guide design changes that will improve the stability of the combustor.

Detailed Schedule Full-Text

A B C D E F G I K L M N O P R S T V W X Y Z

F. Ganji, Hamed

Kornilov, Viktor

van Oijen, Jeroen

Lopez Arteaga, Ines

Discussion on the limitations of the κ and μ criteria as figures of merit to evaluate the thermoacoustic quality of burners with flames (STC 28)

Thermoacoustic instability poses a significant challenge in combustion appliances due to the complex interaction between unsteady combustion, heat transfer, and acoustic modes within the system. Accurately predicting system stability requires modeling all components, including the burner. Traditionally, the burner is represented as an acoustically active two-port block with passive upstream and downstream acoustic terminations. The dispersion relation of the thermoacoustic system is commonly used to anticipate eigen-frequencies and assess system stability. However, in practical scenarios, crucial information about the specific upstream and downstream terminations for burner integration may be unavailable during the development phase. This raises an important question: How can the thermoacoustic performance of burners, along with their associated flames, be evaluated without specified upstream or downstream acoustics? This paper addresses this question by relooking at the concept of a figure of merit for burners with flames. One proposed approach is to consider the μ and κ factors from microwave theory as potential figures of merit for burners. However, this study demonstrates that limitations and invalid assumptions associated with the application of these factors in the context of thermoacoustics make them unsuitable as figures of merit for burners. While they can accurately predict the histogram of unstable frequencies, their use as figures of merit for burners is not recommended. By highlighting the drawbacks and limitations of the μ and κ factors, this research emphasizes the need for alternative methodologies to evaluate the thermoacoustic quality of burners and their associated flames when upstream or downstream acoustics are unspecified.

Detailed Schedule ⚭ Full-Text ↗

F. Ganji, Hamed

Kornilov, Viktor

van Oijen, Jeroen

Lopez Arteaga, Ines

Thermoacoustic stability analysis and robust design of burner-deck-anchored flames in combustion systems using flame transfer function synthesis (STC 52)

Thermoacoustic instabilities in combustion systems are influenced by the thermoacoustic properties, such as the transfer function (TF) of the burner with flame. One promising approach to address these instabilities is by targeting the burner's thermoacoustic properties. One idea for modifying or designing the TF of a flame is based on the heuristic notion that the acoustic response of one flame can be compensated by the correspondingly tuned response of another flame. For premixed conical flames anchored on the burner deck, the TF depends on the diameter of the perforation and its flame spacing (pitch). This suggests the concept of combining different sizes and shapes of perforations in one burner deck. In this study, we investigate the acoustic response of burners made of sintered ceramic fibers with multiple patterns of perforation using the TF composition principle. This approach allows us to represent the cumulative flame TF as a weighted sum of the elemental TF of the flame groups, based on the additive nature of the individual heat release rate of the flames. We first show how this approach can be used to synthesize a burner that operates thermo-acoustically stable in the given system. Then, we mark the critical frequency range for the synthesized burners in the frequency domain using the so-called direct conservative stability (DCS) criterion. Following this, a stability map representing the complete picture of safe values of gain and phase of the flame TF is introduced that can serve as a designing target. Finally, we use stability margin and uncertainty analysis based on Monte-Carlo simulation to check [...]

Detailed Schedule ⚭ Full-Text ↗

F. Ganji, Hamed

Kornilov, Viktor

van Oijen, Jeroen

Lopez Arteaga, Ines

Reconstruction of Downstream Acoustics from Two Separate SISO Measurements of Flame (STC 55)

This study presents a prospective method for evaluating the thermoacoustic properties of components downstream of a flame, utilizing two separate Single-Input-Single-Output (SISO) acoustic measurements. Traditional direct assessment of the downstream reflection coefficient often encounters practical challenges due to the necessity of measurements or modeling in the high-temperature downstream region of the system. Additionally, characterizing downstream acoustics typically requires incorporating the heat inflow from the flame, making it difficult to independently characterize components such as heat exchangers apart from the combustion segment. By leveraging the widely employed form of the dispersion relation in the theory of radio-frequency circuits, which has recently found application in thermoacoustic problems, an opportunity arises to reconstruct downstream acoustics from two SISO acoustic tests. The first measurement, known as the flame transfer function (TF) technique, is extensively employed in the field of thermoacoustics. The second measurement involves a standard impedance tube test based on a one-port acoustic reflection test, conducted with a flame present from the upstream/cold side. The proposed method is demonstrated on a ducted premixed burner-stabilized Bunsen-type flame. The resulting downstream reflection coefficients showed a strong sensitivity to the noise/uncertainty in the measured flame TF and input reflection coefficient, and therefore require special treatment of data. Applying the current approach to a theoretical ducted-flame model also confirmed the presence of strong sensitivity observed in the laboratory test case. However, the straightforward reconstruction in the cold condition (in the absence of flame) exhibited a good correspondence with the analytical model. Hence, it can be inferred that the active part of the combustion system causes this sensitivity.

Detailed Schedule 🔗 Full-Text ↗

F. Ganji, Hamed

Kornilov, Viktor

van Oijen, Jeroen

Lopez Arteaga, Ines

Assessing the thermoacoustic quality of the known subsystems using stability quality factors: figure of merit (STC 58)

Thermoacoustic instability represents a significant concern in combustion appliances, as it arises from intricate interactions between unsteady combustion, heat transfer, and acoustic modes within the system. Accurate modeling of all components is vital to predict system acoustics reliably. Conventionally, the burner is characterized as an acoustically active two-port block, coupled with passive upstream and downstream acoustic terminations. However, evaluating the thermoacoustic quality becomes challenging when only one side of the termination is specified, leading to the exploration of a figure of merit for subsystems. This paper investigates the application of the direct conservative stability (DCS) criterion in the frequency domain to assess the limitations associated with employing Monte Carlo (MC) simulations for determining the probability of instability. Our findings highlight the potential for misinterpretation and misrepresentation when employing this MC approach to evaluate and compare the thermoacoustic quality of different burners. To address this issue, we propose alternative performance metrics termed the stability quality factors (SQF). Through our analysis, we establish the stability quality factors as a more reliable figure of merit to replace the probability of instability for subsystems in thermoacoustic problems.

Detailed Schedule 🔗 Full-Text ↗

A B C D E F G I K L M N O P R S T V W X Y Z

A B C D E F G I K L M N O P R S T V W X Y Z

Giannotta, Alessandro

Yoko, Matthew

Cherubini, Stefania

De Palma, Pietro

Juniper, Matthew

Bayesian data assimilation of acoustically forced laminar premixed conical flames (STC 20)

We perform experiments on an acoustically-forced laminar premixed conical flame and assimilate experimental flame position data into a physics-based premixed flame model. The experimental rig is a ducted conical flame supplied by a mixture of methane and ethylene. A high-speed camera captures the dynamics of the perturbed flame, as well as snapshots of the stable flame. We model the flame with a front-tracking solver with an imposed velocity field. We use adjoint-accelerated Bayesian inference to identify the most probable model parameters, given the data. Through this, we create a quantitatively-accurate model with quantified uncertainty bounds. The trained model provides access to quantities that weren't directly measured, such as the fluctuating heat release rate, which cannot be extracted reliably from the flame emission alone.

Detailed Schedule 🔗 Full-Text ↗

Giraudi, Pietro

Morgans, Aimee S.

Picciani, Mark A.

An efficient computational model to estimate the flame transfer function of non-premixed jet diffusion flames (STC 46)

This work presents a new model for how diffusion flames respond to flow perturbations based on the advection- diffusion equation of the mixture fraction that considers variable density and diffusivity effects. The model was validated and tested for CH4 – air and H2 – air flames across a range of powers and frequencies. The model outperformed the main existing model in predicting flame shape, particularly in the case of H2 – air where density and diffusivity variations are more significant. The findings indicate a strong correlation between the flame length and the Peclet number, highlighting the balance between convective and diffusive forces in dictating flame behavior. Flame transfer functions (FTFs) exhibited a low-pass filter behavior, with distinct deviations noted especially for H2 – air reactions, emphasizing the unique combustion characteristics of hydrogen. These findings demonstrate the potential of the new model for improving predictions of thermoacoustic instabilities in the next-generation hydrogen combustors.

Detailed Schedule 🔗 Full-Text ↗

Gopalakrishnan, Harish

Heggset, Tarjei

Gruber, Andrea

Bothien, Mirko

Moeck, Jonas

Prediction of autoignition-stabilized flame dynamics in a backward-facing step reheat combustor configuration (STC 45)

Hydrogen combustion in a sequential combustor with a propagation-stabilized flame in the first stage and an autoignition-stabilized flame in the second reheat stage offers fuel flexible and efficient power generation with minimal greenhouse gas emissions. However, unsteady thermoacoustic phenomena driven by the interactions between the flame dynamics and the combustor acoustics can result in large amplitude heat release rate and pressure oscillations. A key component required to understand and predict thermoacoustic oscillations in reheat combustors is the knowledge of the response of autoignition front to unsteady acoustic and convective disturbances. In this paper, we extend a simplified particle based framework, originally proposed for a one-dimensional combustor configuration, to a two-dimensional backward-facing step geometry. The present particle based framework treats the flow as a collection of independent Lagrangian fluid elements which evolve in time. The temperature evolution of each fluid particle is computed by integrating the momentum, energy and species mass balance equations for that particle in time. The unsteady heat release rate and instantaneous flame position are then computed by stitching together the particle evolution data. The predictions of the flame response framework are thereafter compared with fully compressible Large eddy simulations (LES) of a reheat flame forced by acoustic and entropy disturbances. The flame response predictions obtained from the present approach match well with the LES data, suggesting that the present particle based framework can be used to compute flame transfer functions of reheat flames and consequently give insight into the thermoacoustic stability characteristics of reheat combustors.

Detailed Schedule

Full-Text

Impagnatiello, Matteo

Malé, Quentin

Noiray, Nicolas

Numerical investigations of the effect of non-equilibrium plasma discharges on the dynamics of a sequential combustor (STC 42)

The effects of Nanosecond Repetitively Pulsed Discharges (NRPDs) on the dynamics of the second stage of a sequential combustor are investigated numerically at atmospheric pressure using Large Eddy Simulation. The response of the sequential stage to an harmonic forcing at a frequency of 327 Hz is analyzed with and without the activation of NRPDs upstream of the main flame brush. 327 Hz corresponds to the frequency of a thermoacoustic instability that develops in the experimental rig, which is successfully stabilized via the application of plasma discharges. The discharges significantly affect the anchoring mechanism of the second stage flame. When NRPDs are off, the flame is aerodynamically anchored at the inlet of the combustor chamber and no auto-ignition events are observed upstream of the main flame brush. Conversely, when NRPDs are on, trains of ignition kernels are generated upstream of the main flame brush and interact with the latter in the combustion chamber. The integrated heat release signal loses its coherence with the acoustic forcing when plasma is active. The igniting kernels generated by plasma introduce heat release fluctuations that are out-of-phase compared to those produced by the main flame brush, thereby reducing the capability of the combustion to act as a source of acoustic energy. This work shed light on the mechanism enabling thermoacoustic instability suppression when discharges are applied: the change of the mean flame morphology induced by the discharges drastically decreases the fluctuating component of the heat release that participates to the instability.

Detailed Schedule

Full-Text

A B C D E F G I K L M N O P R S T V W X Y Z

Kaiser, Thomas Ludwig

von Saldern, Jakob

Goldack, Miriam

Polifke, Wolfgang

Varillon, Gregoire

Zhang, Feichi

Zirwes, Thorsten

Bockhorn, Henning

Oberleithner, Kilian

On the significance of modeling turbulent transport when linearizing the governing equations of a turbulent Bunsen flame (STC 41)

Linearizing the governing equations of reacting turbulent flows would allow to significantly enhance the understanding of thermoacoustic instabilities and provide new efficient ways to control them. Driven by this goal, we linearize the governing equations of a turbulent reacting Bunsen flame around its temporal mean, which is obtained by Large Eddy Simulations (LESs). LESs furthermore provide the flame response to harmonic acoustic actuation as reference solution to the linearized framework. The fluctuations of reaction rate in the linearized framework are modeled by a linearized Reynolds-averaged Navier Stokes (RANS)-Eddy Break Up (EBU) flame model. This linearized flame model is tested in an a priori analysis, against the LES, showing very good agreement. However, the results of an a posteriori analysis are less favourable: When this linearized flame model is applied in combination with the entire set of linearized governing equations, an acoustic actuation in the linearized framework yields coherent fluctuations in reaction rate, which qualitatively agree well with the LES. Quantitatively, however, the results disagree, resulting in deviating Flame Transfer Functions (FTFs) of LES and the linearized approach. This study finds that one possible reason for the deviations is an inadequate modelling of turbulent transport. Finally, this study demonstrates using an a priori analysis, that for a correct description of the turbulent fluxes in the linearized framework, the effect of counter gradient diffusion needs to be accounted for.

Detailed Schedule　　Full-Text

Kornilov, Viktor

de Goey, Philip

Evaluation of thermo-acoustic quality indicator in the case of factorizable dispersion relation. (STC 19)

A class of burners with gaseous, premixed, aerodynamically or burner deck stabilized flames has the thermo-acoustic property of an “acoustic velocity sensitive source of acoustic velocity”. For these flames, the transfer matrix has particular symmetries that enable the factorization of the dispersion relation used to find the eigen frequencies of the system. This allows the acoustic properties of the flame/burner termination to be gathered separately from the factor associated solely with the thermo-acoustic characteristics of the flame/burner. Accordingly, the factors can be studied separately. Particularly, Monte-Carlo method of sampling of the acoustic factor, considered as a mapping of two randomly taken passive reflection coefficients (of upstream and downstream), makes it possible to reveal the universal probability density field of the acoustic subsystem factor in its complex plane. Consequently, the identified features of the acoustic factor mapping provide an opportunity to test, evaluate and rank various burners in respect to their thermo-acoustic properties. The corresponding idea of how to evaluate the probability of burner instability is proposed and demonstrated on an illustrative example. The ultimate goal of this developed methodology is to provide a procedure for calculating the burner-with-flame thermo-acoustic figure of merit and therefore to rank different flames in respect to their thermo-acoustic quality. One of intriguing outcome of this study is that the thermo-acoustic eigen frequencies of many systems tend to be localized where the flame transfer function has a phase around -π, -3π,... etc., and this universal property is not directly linked to the burner intrinsic instability mode.

Detailed Schedule　　Full-Text

Latour, Véranika

Durox, Daniel

Renaud, Antoine

Candel, Sébastien

A flame describing function mapping of the operating domain of an annular combustor and instability prediction (STC 21)

Models to predict combustion instabilities are of considerable importance at a stage where new architectures and alternative fuels are being proposed to tackle the environmental challenges the aviation industry is facing. Recent investigations highlight the need for improved reduced-order models that can be used to analyze the stability of combustion systems. These models usually rely on flame transfer or describing functions (FTFs or FDFs) representing the flames' response to incoming disturbances. Recent measurements indicate that FDFs exhibit gain and phase variations with fuels, fuel blends, injector characteristics but also with operating conditions. FDFs are generally documented for a few operating points, but a systematic database covering the domain of operation of a combustion system is generally not available. The logical step taken in the present investigation is to collect the FDFs for a large number ($k=$30) of operating points of the laboratory-scale annular combustor MICCA-Spray. This is achieved using a single-injector system, SICCA-Spray, that allows external flame modulation. The collected FDF data correspond to injectors of two types, characterized by different flame dynamics in MICCA-Spray. This FDF database, in combination with a stability analysis framework derived from acoustic energy balance equations, serves to determine growth rates and define a theoretical instability domain. A comparison with the stability maps obtained in the annular combustor indicates that the general layout of these maps can be retrieved for the two injector types, validating the relevance of a data-driven model-based approach in the investigation of thermo-acoustic instabilities.

Detailed Schedule Full-Text

Marchal, David

Schmitt, Thomas

Fougnie, Alexandre

Ducruix, Sébastien

Numerical study of the linear and non-linear damping in an acoustically forced cold-flow test rig with coupled cavities (STC 11)

Thermoacoustic instabilities within liquid rocket engines (LRE) result from a coupling between the dynamics of the injection, the combustion process and the acoustics of the propulsive system. Several combustion models exist accounting for the unsteady heat release rate under acoustic solicitation [Méry (2010)]. On the contrary, few studies offer a precise analysis of the mechanisms underlying the acoustic damping processes. The NPCC setup, a three-injector cold-flow test rig mimicking the geometry of a LRE [Gonzalez-Flesca (2016)], was designed in this purpose. Using a perforated wheel, the device can be efficiently forced at its eigenfrequencies. The competition between forcing and damping lead to a limit-cycle for three chamber eigenmodes: 1T, 1T1L (which is coupled with the 1T mode of the dome) and 1T2L. The 1T mode triggers strong non-linear harmonic response. Previous studies have shown that Large Eddy Simulation (LES) was able to retrieve the limit-cycle of all three eigenmodes [Marchal (2021)]. Lowering the forcing amplitude enables to remain in the linear acoustic regime. Disturbance energy budgets [Brear (2012)] are then used in the LES code to characterize the damping phenomena during chamber-only and coupled dome-chamber forcing. Using the budget's fluxes, we retrieve the correct global damping of the system and extract the local damping contributions (jets, chamber, injectors, dome). Then, a non-linear term representing the energy transfer to the harmonics observed in the experiment is derived from non-linear acoustics theory. Finally, this model is tested on the NPCC rig and retrieves the limit-cycle amplitude of the 1T mode.

Detailed Schedule Full-Text

A B C D E F G I K L M N O P R S T V W X Y Z

Martin, Jan

Börner, Michael

Armbruster, Wolfgang

Hardi, Justin

Oschwald, Michael

Early Detection of Combustion Instabilities in Liquid Rocket Engines: Assessment of Statistical, Recurrence, and Fractal Analyses for Sub- and Supercritical Pressure Conditions (STC 49)

Safe shutdown of a liquid rocket engine in ground testing prior to the onset of damaging combustion instabilities through reliable detection of instability precursors would translate to time and cost savings in engine development programs. Methods derived from statistical, recurrence, and fractal analysis have been successfully applied in literature to detect precursors in unsteady pressure signals from canonical combustion experiments, gas-turbine combustion experiments, and sub-scale rocket combustion experiments operated at low pressures. In the present work, several such methods were applied to data from two cryogenic oxygen-natural gas rocket experiments operated at higher pressures than previously reported; both sub- and supercritical with respect to oxygen. The goal was to identify methods which can discern limit-cycle instabilities from intermittently unstable operation and are sufficiently responsive to be applied as emergency shut-down criteria in engine tests. Among the methods applied were the standard deviation, variance of the auto-correlation, the second spectral moment, the ratio between determinism and recurrence rate, the Hurstexponent, and the multifractal range. The second spectral moment, the Hurst-exponent, and a measure derived from the multifractal spectrum all have short detection delays for instability onset and intermittency could be discerned from instability with an appropriate choice of threshold value. They also have moderate computation cost which makes them of interest for potential real-time implementation. The Hurst-exponent has the additional advantage of a common threshold value for all test cases addressed, demonstrating its potential for broader application independent of combustion device or operating conditions.

Detailed Schedule 🔗 Full-Text ↗

Moriniere, Titouan

Schuller, Thierry

The relationship between the OH* signal and the heat release rate for spray flames: consequences on the Flame Describing Function (STC 22)

The relationship between fluctuations of the OH* chemiluminescence signal emitted by a flame and fluctuations of the heat release rate is studied in a laboratory swirl spray combustor. In fully premixed systems, relative heat release rate fluctuations can directly be deduced from relative OH* intensity fluctuations. In spray flames, equivalence ratio disturbances need also to be considered as they affect the OH* chemiluminescence. Experiments at steady state conditions are conducted at different thermal powers and equivalence ratios to deduce an empirical scaling law linking OH* intensity as a function of heat release rate and equivalence ratio. This relation is used to infer how the OH* relative fluctuations and relative heat release rate disturbances are interrelated in the limit of quasi-static disturbances. Three limit cases are considered assuming a fully premixed regime, a fuel stiff and a disturbed fuel injection system resulting from the acoustic modulation of the transport of fuel droplets in the air stream. The Flame Describing Function (FDF) between heat release rate and velocity disturbances at the burner outlet is deduced in these three regimes for different perturbation levels. The FDF with the fully premixed model has roughly a constant gain over the frequency domain studied, while the gain of the FDFs deduced with a stiff or a disturbed fuel injection system exhibit several humps. The low-frequency limit of the FDF deduced with the fully premixed model does not match that predicted by theory., while the FDFs deduced with the stiff and disturbed fuel injection models match it.

Detailed Schedule 🔗 Full-Text ↗

Nosrati, Somayeh

Elkaei, Abbas

Pourfarzaneh, Hossein

Barjesteh, Mohammad Mehdi

Zadsirjan, Saeed Reza

Acoustic analysis and stability map in an aerial combustor for take-off and cruise conditions (STC 48)

To study acoustic condition of an aerial combustor, in a certain range of operating conditions, a theoretical model was used. This method leads to predictions for the frequencies of oscillations and the susceptibility to instabilities in which linear disturbances grow exponentially in time. For the flame model the fuel is assumed to be injected in the steady rate. A convection time is assumed to characterize the required time for the acoustic velocity fluctuations to travel from the point of injection to the location of flame front in the combustion chamber. By applying proper boundary conditions between the components of combustor model, along with the combustor inlet and outlet boundary conditions, a system of equations can be obtained. The required data were obtained using test conditions and numerical solutions verification. This system of equations has a related eigenvalue equation which has complex roots. The sign of imaginary part of these roots determines whether disturbances grow or decay, and the real part of these roots gives the frequency of the modes. Acoustic mode shapes of the combustor are also studied by using software. According to the tools, it is possible to examine the change of fuel and the change of flight conditions (take off or cruise for example) in the flight envelope and the stability conditions of the combustion chamber.

Detailed Schedule Full-Text

Orchini, Alessandro

Cronqvist, Frida

von Saldern, Jakob G. R.

Humbert, Sylvain C.

Moeck, Jonas

Comprehensive tracking of acoustic and intrinsic modes for thermoacoustic systems with a general flame model (STC 54)

In a thermoacoustic feedback loop, the flame gain parameter can be used to measure the coupling strength between the acoustic field and the flame response. In this study, it is shown for an arbitrary flame model that the thermoacoustic solutions in the zero-coupling limit split into two distinct sets: modes of (i) acoustic and (ii) intrinsic (ITA) origin. This result was previously shown in a rigorous manner only for n–τ flame models, which are special in the sense that they have poles only at infinity. Consequently, all thermoacoustic eigenvalues can generally be calculated from the acoustic and intrinsic poles using continuation methods. In this study, we provide an explicit eigenvalue tracking scheme based on the integration of the local sensitivity of the eigenvalues to the flame gain parameter. The initial conditions required for integration are considered in detail. While the acoustic poles can be determined directly via Helmholtz solvers, the intrinsic poles are less trivial since they depend on the flame model. An asymptotic expansion of a generic transfer function is derived that is representative of all common flame models. It provides the necessary estimates for the intrinsic poles as the flame gain approaches zero in terms of the Lambert W function. This approach represents an explicit scheme that guarantees to find all thermoacoustic eigenvalues. The methodology is demonstrated using a simple Rijke tube network model.

Detailed Schedule Full-Text

A B C D E F G I K L M N O P R S T V W X Y Z

A B C D E F G I K L M N O P R S T V W X Y Z

Paulitsch, Nina

Giuliani, Fabrice

Hofer, Andrea

Validation of a combined optic-acoustic probe on hydrogen flames using an atmospheric lean premix pilot burner (STC 51)

This paper reports on a dynamic optic-acoustic probe called Rayleigh Criterion Probe (RCP) and its validation on lean, premixed hydrogen flames obtained on an atmospheric test rig. Within the test campaign, the focus is put on monitoring the hydrogen flame including detection of ignition, of steady and transient states monitoring, of flame flashback as well as of combustion instabilities and of thermo-acoustic forcing. A pilot burner comprising a novel, additively manufactured multi-point injector resulting in a premixed, swirl-stabilised hydrogen flame was operated at various equivalence ratios and power levels in the low kW range. Two test rig configurations (with/without exhaust pipe extension) were applied. The tests including thermo-acoustic forcing were produced on the short combustor configuration. A high-pressure siren adjustable in frequency and amplitude was employed to modulate the inlet combustion air flow. The extension generates a strong, naturally induced combustion oscillation at around 160 Hz. The optic and acoustic response of the hydrogen flame was obtained by the RCP, which combines four fast-responding, optical sensors (broadband sensitive in the visible and infrared range) with an industrial dynamic pressure transducer. All gathered data of the RCPs in the test campaign are presented and discussed in detail in this paper. The combined arrangement of optical and acoustic sensors allows to better understand the flame noise and to avoid misinterpretation of dynamic pressure signals. The RCP was originally developed for use in gas turbines (high pressure, elevated temperature) for conventionally fuelled flames, but showed satisfactory and promising results applied on hydrogen flames.

Detailed Schedule   Full-Text

Pedergnana, Tiemo

Orchini, Alessandro

Moeck, Jonas

Noiray, Nicolas

Connecting can-annular acoustic modes to their annular limits (STC 2)

In the thermoacoustics literature, a distinction is typically made between annular and can-annular systems. However, most real-world systems do not correspond to either of these two extremes, but lie somewhere in between them. To better understand the sound field in this general case, we analyze the acoustic spectrum of an idealized can-annular combustion chamber. A variable geometry is considered where the length of the gap connecting the individual cans, whose size determines the coupling strength, may be adjusted. We present two models: the first uses a perturbative modeling approach based on the Rayleigh conductivity and Bloch wave theory to describe how clusters of azimuthal modes emerge from the longitudinal modes as the coupling strength is increased from zero. The second model uses a pressure field ansatz to directly obtain the dispersion relation from the Helmholtz equation. These analytical calculations are validated then against finite element simulations of the Helmholtz equation, demonstrating that, as predicted by the models, the azimuthal modes perturb into the eigenmodes of an annular chamber as the gap is fully opened. Below a certain frequency, all the modes in between the can-annular and annular limits can be classified by their axial and azimuthal mode orders. As a side result, we gain insights into the emergence of whispering gallery modes in round cavities with periodic gratings.

Detailed Schedule   Full-Text

Reinhardt, Hanna

Alanyalıoğlu, Çetin Ozan

Fischer, André

Lahiri, Claus

Nicolai, Hendrik

Hasse, Christian

Towards the Prediction of Flame Transfer Functions: Evaluation of a Hybrid LES-CAA with Compressible LES (STC 36)

The prediction of flame transfer functions, particularly in practically relevant systems, remains challenging and computationally demanding. Numerical approaches are typically a valuable addition to experimental acoustic characterizations of industrial configurations. Conventionally, fully compressible numerical simulations are used that naturally include acoustic fluctuations in their computations. Depending on the configuration, however, compressible simulations can be computationally expensive. Therefore, a convenient approach to use tailored numerics for the underlying physics is considered in this work. This paper applies a runtime-coupled method of Computational Fluid Dynamics (CFD) and Computational Aeroacoustics (CAA) to a single-sector aero-engine combustor. This hybrid CFD- CAA method captures fluid flow behavior and combustion dynamics in a low Mach CFD domain while allowing for acoustic perturbations in the CAA. Runtime exchange of hydrodynamic and acoustic quantities between the two solvers allows for a bidirectional coupling and, by extension, a complete description of the combustion system. In this work, the hybrid CFD-CAA is applied in a high-fidelity LES configuration. The flame transfer function (FTF) of the system is evaluated for both compressible and hybrid simulations. The results for both numerical approaches are validated with each other and compared to the experimentally obtained FTF. Finally, the computational effort for the numerical approaches is considered. This paper presents the first application of a high-fidelity CFD framework using LES with bidirectional coupling with the acoustic solver to an industry relevant configuration. The aim is to provide a roadmap toward investigating thermoacoustic instabilities in a real gas-turbine engine at reduced computational costs.

Detailed Schedule Full-Text

Ren, Yongzhi

Wang, Qiuxiao

Xia, Xi

Qi, Fei

Dynamics of vortex-flame interaction in a novel swirl combustor (STC 37)

This study conducts an experimental analysis of the flame-vortex interaction mechanism in V-shaped swirl flames of a novel swirl combustor, based on time-resolved simultaneous particle image velocimetry (PIV) and OH* chemiluminescence measurements combined with quantitative analysis of vortex using spectral proper orthogonal decomposition (SPOD). The V-shaped flame is studied in detail by focusing on two cases near the lean blowout limit (LBO) and near the stoichiometric point, respectively. Time-averaged results show a compact flame and higher flow speed for the richer case due to a larger flame speed and stronger thermal expansion effect. Transient dynamics of quasi-periodic flame-flow interaction in the outer shear layer (OSL) is found to be dominant in HRR oscillation for both cases. Based on SPOD analysis, the main coherent structures in both flow and flame are found to be OVR and its harmonics in OSL. Through phase-averaging of SPOD-based reconstructed vortical field, quantitative analysis of flame-vortex interaction through flame stretching is analyzed. A new type of OVR pattern is found in the richer case that a weak vortex would form through vortex splitting from a strong vortex. It could be separated into two parts, with the weak vortex being continuously strengthened by the thermal expansion effect and causing local extinction to reduce HRR until it merges with weak vortex.

Detailed Schedule Full-Text

Reumschüssel, Johann Moritz

Kroll, Paul-Florian

von Saldern, Jakob G. R.

Paschereit, Christian Oliver

Oberleithner, Kilian

Orchini, Alessandro

Flame transfer function shaping for robust thermoacoustic systems: Application to a kinematic flame model (STC 17)

Thermoacoustic oscillations are a major challenge in gas turbine combustor design. Data-driven methods can help to design combustors without requiring an understanding of the underlying physics. However, data-driven optimization is usually associated with a high number of tests and is therefore not practical for costly combustion processes. A methodology to assess thermoacoustic stability prior to full engine tests involves capturing the flame transfer function and combining it with a low-order acoustics model for chamber acoustics. In this paper we propose a data-driven optimization technique that modifies the flame transfer function. By combining it with a low-order acoustic model, the method allows to increase the thermoacoustic stability margin in an automated manner. The key feature of the methodology is that cost function evaluation and thus the stability assessment is performed only at targeted critical frequencies, which allows efficient data-driven optimization for costly processes. The methodology is demonstrated using a thermoacoustic model consisting of a Rijke tube acoustic model coupled with a G-equation solver to model flame dynamics. Two parameters of the flame model are used as degrees of freedom for the optimization routine. The method is shown to efficiently increase the stability margin of the system. It requires minimal experimental effort and is therefore found to be especially useful for experimental optimization of combustion systems.

Detailed Schedule 🔗 Full-Text ↗

Roncen, Rémi

Cardesa, José I.

Marchal, Thomas

Developments of the time-domain impedance boundary condition for combustion problems (STC 59)

Thermoacoustic instabilities can cause significant pressure oscillations and potentially lead to the failure of combustion systems. These instabilities result from the interaction between heat release fluctuations and acoustic waves. One potential solution to mitigate thermoacoustic instabilities is to use passive acoustic damping devices, referred to as liners. These liners absorb acoustic waves and aim to break the instability loop. To represent such materials in time domain solvers, a complex impedance convolution problem must be solved. In this work, we describe a recently implemented time-domain impedance boundary condition, with extended capabilities that make it a promising candidate for combustion solvers.

Detailed Schedule 🔗 Full-Text ↗

Rosenkranz, Jan-Andre

Neu, Jonas

Sattelmayer, Thomas

Network- and CFD/CAA-Modelling of the High Frequency Flame Response in Multi-Jet Combustors (STC 3)

Low order networks are widely used for linear stability analysis of combustors in the low frequency limit. High frequency stability analysis, however, is limited to cost-intensive numerical or experimental methods, since derivation of analytical solutions is either cumbersome or impossible. The paper at hand provides a quasi two-port network model for the effective acoustic pressure and axial velocity normalised with the transverse acoustic field for cylindrical combustors. This network modelling approach includes transfer matrices of acoustic area jumps, ducts for longitudinal, standing and spinning transverse and mixed mode wave propagation. The purely acoustic transfer matrices are validated with a generic non-reactive experiment. On the basis of phase-locked OH* images of an engine-similar multi-jet combustor with a forced T1 mode, a locally distributed flame response model is derived, which is reduced to a global flame transfer matrix. A correspondingly locally resolved convective flame response model is implemented in a numerical model in order to verify the provided theory by the comparison of the analytical and numerical flame transfer matrix for the high frequency regime.

Detailed Schedule 🔗 Full-Text ↗

Sampath, Ramgopal

Moeck, Jonas

Effect of stratification on the combustion behavior and dynamic response of a bluff body-stabilized ammonia–hydrogen flame with radial staging (STC 43)

Ammonia and hydrogen form prospective zero-carbon fuels for practical applications and it is vital to study combustion characteristics and flame dynamics with the possible control of the latter by tailoring the ammonia and hydrogen mixtures through stratification. In this regard, the stratified laminar ammonia-hydrogen flames stabilized on a bluff body are investigated to study their dynamic response to the input acoustic forcing. A radially staged burner is considered in this study consisting of two concentric tubes (inner and outer tube) and a central bluff body forming annulus passages between (i) inner-outer tube and (ii) inner tube-bluff body regions in which premixed hydrogen-air and ammonia-air mixtures are supplied respectively. The stratification is controlled by varying the upstream location of the inner tube, termed mixing length (L m). For the unforced flames with stratification, the flames are narrower and the spatial separation between OH* and NH 2 * regions increases towards a richer equivalence ratio of NH 3 /air mixtures, ϕ NH3-air . For the forced flames with a forcing amplitude of 4% of the mean velocity, the OH* fluctuations are higher for frequencies less than 100 Hz for any of the flame conditions. The forced flames accompany lobed spatial patterns in OH* and NH2* spatial distribution towards richer ϕ NH3-air . From the phase-averaged images, the mechanism of heat release modulation is found to be the flame base oscillation and the wrinkle propagation for the less stratified flame as compared to the oscillations in the dominant region of NH2* and OH* with insignificant flame base oscillations with stratification.

Detailed Schedule 🔗 Full-Text ↗

A B C D E F G I K L M N O P R S T V W X Y Z

Shen, Yazhou

Morgans, Aimee

Machine Learning for predicting the flame describing function of CH4/H2 laminar flames (STC 15)

As a promising strategy to mitigate carbon emissions, hydrogen enrichment of conventional fuels is gaining increasing interest, but leads to increased propensity to damaging thermoacoustic instability. This paper demonstrates the ability of machine learning algorithms to reliably predict a key flame behaviour relevant to thermoacoustic stability prediction - the flame's nonlinear response to upstream acoustic forcing. Using computational simulations of a laminar premixed flame, this is predicted as a function of equivalence ratio and hydrogen content, including extrapolating into new hydrogen content regimes. The effect of algorithm choice, data structure, data size, and extrapolation distance on the performance of different machine learning models is investigated. It is found that a type of neural network known as the multi-layer perceptron (MLP) model outperforms the Gaussian process and random forest models in both interpolation and extrapolation tasks. A novel preprocessing strategy, involving extracting the time delay of the flame response (which can be deduced from geometry and flow parameters) prior to applying machine learning, is found to remarkably improve the accuracy of machine learning models, especially in extrapolation tasks. When the extrapolation into new hydrogen content levels is strong enough, the MLP model no longer performs well. However, for small and intermediate extrapolation, the MLP model shows a commendable level of prediction, even with small data sets, fulfilling needs relevant to thermoacoustic stability prediction.

Detailed Schedule   Full-Text

Singh, Samarjeet

Bhavi, Ramesh S.

R., Midhun P.

Bhaskaran, Anaswara

Mishra, Pruthiraj

Chaudhuri, Swetaprovo

Sujith, R. I.

Intermittency transition to azimuthal instability in a turbulent annular combustor (STC 7)

We experimentally study the transition from combustion noise to azimuthal thermoacoustic instability in a laboratory-scale turbulent annular combustor. The combustor has sixteen swirl-stabilized burners with continuous and spatially distributed combustion along the annular region. We simultaneously measure the chemiluminescence emission of the flame using two high-speed cameras and the acoustic pressure fluctuations using eight pressure transducers. We report that the transition from combustion noise to azimuthal instability occurs through a mode-switching phenomenon where the combustor switches from longitudinal mode to azimuthal mode as the equivalence ratio is decreased. Throughout this progression, the combustor exhibits various dynamical behaviors, including intermittency, dual-mode instability, standing azimuthal instability, and beating azimuthal instability. These dynamical states are determined from eight pressure transducers by decomposing the acoustic pressure fluctuations into clockwise and counterclockwise waves, enabling a reconstruction of the amplitude of acoustic pressure fluctuations, nature angle, nodal line location, and spin ratio. The global heat release response was also assessed during different dynamical states to contrast their behavior at different non-dimensional time steps by taking the phase-averaged fluctuations of the heat release rate over the acoustic pressure cycle. A number of differences were observed in the flame behavior depending on the direction of pressure wave propagation, demonstrating characteristic counterclockwise (CCW) spinning, standing, and clockwise (CW) spinning heat release patterns. Our study provides insights into the mode-switching phenomenon present during the transition from longitudinal to azimuthal modes in the annular combustor.

Detailed Schedule   Full-Text

A B C D E F G I K L M N O P R S T V W X Y Z

Singh, Ashutosh Narayan

Nair, Vineeth

Characterization of combustion dynamics in a Trapped Vortex Combustor for various cavity sizings (STC 25)

Trapped vortex combustors are commonly used for flame stabilisation; however, acoustic instabilities can occur as the flow passes through cavities in the presence of combustion, leading to large-amplitude pressure fluctuations. Therefore, experiments were conducted in a laboratory scale trapped vortex combustor for various cavity sizes (L/D=0.75-2.65) by varying the cavity length (L). Unsteady pressure measurements reveal a bifurcation route of limit cycle $\rightarrow$ period-2 $\rightarrow$ quasiperiodicity $\rightarrow$ Strange non-chaotic attractors $\rightarrow$ chaos as L/D increases. We use nonlinear time-series analysis to describe these dynamic transitions in greater detail.

Detailed Schedule　　Full-Text

Suman, Ahsan Kabir

Xia, Yu

Sharkey, Patrick

Verma, Ishan

Oberleithner, Kilian

Kaiser, Thomas Ludwig

Entropy wave transport in an industry-like model geometry using a linearized global framework (STC 13)

This study investigates the transport and diffusion of entropy waves in a industrial complex geometry using large eddy simulation (LES) and linear mean field analysis (LMFA). The LES include a transport equation for a passive scalar, which models entropy. The fluctuations in the passive scalar (or entropy waves) are introduced at the temporally averaged flame location via a harmonically fluctuating source term. The advection and diffusion of the fluctuations in passive scalar are investigated by time stepping the LES. Subsequently, the linear analysis of the entropy wave convection is conducted. The transport equation of the passive scalar is linearized around the temporal mean state, which is obtained by the LES, and transferred into frequency domain, which leads to a transport equation of passive scalar fluctuations (entropy waves). The dissipation of entropy waves via turbulent mixing is modeled using a turbulent diffusivity, which in this study is determined by a k-epsilon model. The linearized transport equation of the passive scalar is solved for the same frequencies, which are investigated in the LES, using the finite element approach. The results obtained by the LMFA are in very good agreement with the LES, which demonstrates that it is well suited to address the transport of entropy waves in real world combustors.

Detailed Schedule　　Full-Text

Tathawadekar, Nilam

Ösün, Alper

Eder, Alexander J.

Silva, Camilo F.

Thuerey, Nils

Linear and nonlinear flame response prediction of turbulent flames using neural network models (STC 18)

Modeling the flame response of turbulent flames via data-driven approaches is challenging due, among others, to the presence of combustion noise. Neural network (NN) methods have shown good potential to infer laminar flames' linear and nonlinear flame response when externally forced with broadband signals. The present work extends those studies and analyses the ability of NN models to evaluate the linear and nonlinear flame response of turbulent flames. In the first part of this work, the NN is trained to evaluate and interpolate the linear flame response model when presented with data obtained at various thermal conditions. In the second part, the NN is trained to infer the nonlinear flame response model when presented with time series exhibiting sufficient large amplitudes. In both cases, the data is obtained from large eddy simulation (LES) of an academic combustor when acoustically forced by broadband signals.

Detailed Schedule Full-Text

Trotta, Luca

Armbruster, Wolfgang

Schneider, Dirk

Hardi, Justin

Börner, Michael

Suslov, Dmitry

Traudt, Tobias

Zandbergen, Barry

Linearized Navier-Stokes modelling of acoustic modes in a LOX/Methane rocket thrust chamber (STC 4)

In this study, the acoustic modes in a methane-fueled rocket engine combustion chamber are modelled with different approaches of increasing complexity. A sub-scale thrust chamber with 42 injectors tested with liquid oxygen and liquified natural gas at a pressure of 63 bar is used as a test case. The assumption of chemical equilibrium in the combustion chamber leads to large errors in the prediction of the acoustic eigenfrequencies, more than 50% for transverse modes, and is thus inadequate for this application. The current industrial state-of-the-art approach for the acoustic modelling of rocket combustion chambers is based on a combined CFD-CAA approach in which the acoustic field properties obtained from a RANS CFD simulation are radially averaged and the resulting 1D-profiles are used as input into an acoustic solver. This approach showed a significant increase in eigenfrequency accuracy for the current test case.The best accuracy was achieved with a Linearized Navier-Stokes (LNS) solver including 3D acoustic property distributions obtained from a steady-state CFD solution which was interpolated onto the domain in the acoustic solver and includes the details of the strong stratification in properties due to the long cryogenic flames extending from the 42 injectors. This approach is able to achieve sub-5% eigenfrequency errors with an acceptable increase computational times. This makes the LNS approach using a mapped 3D CFD field of interest for the future of the rocket propulsion industry since it could allow for more accurate combustion instability predictions.

Detailed Schedule Full-Text

A B C D E F G I K L M N O P R S T V W X Y Z

Varillon, Gregoire

Kaiser, Thomas Ludwig

Brokof, Philipp

Oberleithner, Kilian

Polifke, Wolfgang

A comprehensive linearised flow model for swirling jets (STC 53)

Inflow perturbations are imposed on an axisymmetric, enclosed, turbulent, non-parallel, and compressible swirling flow, for which the swirler is modelled and included in the numerical analysis. Swirl fluctuations are non-negligible on this configuration representative of a swirl burner and to match analytical mode shapes of inertial waves on an inviscid uniform flow. The stability map presents two eigenvalues driving a modal amplification. The acoustic modes sustained in the mixing duct and the combustion chamber, respectively, coupled with the Kelvin-Helmholtz mechanism at the mixing duct exit and the acoustic-vorticity mode conversion process in the swirler, act as a frequency selection criterion. Finally, one of the optimal forcings is similar to an unsteady heat source in the combustion chamber, and the resulting optimal amplification mechanism is likely to be triggered in reacting flow with unsteady heat release rate.

Detailed Schedule Full-Text

Vaysse, Nicolas

Durox, Daniel

Vicquelin, Ronan

Candel, Sébastien

Renaud, Antoine

Experimental investigation of self-sustained thermoacoustic instabilities in pure hydrogen swirling flames (STC 40)

The replacement of hydrocarbon fuels in energy production and aeronautical applications by hydrogen raises issues linked to its enhanced reactivity, broad flammability limits and augmented burning velocity. Hydrogen flames may also feature specific sensitivity to acoustic disturbances that may lead to combustion instabilities. This problem is examined in the present work in the case of a single flame formed by a swirling injection unit where hydrogen is injected in crossflow to enhance mixing to reduce hotspots. Self-sustained oscillations (SSOs) are observed using optical diagnostics and acoustic pressure measurements. It is shown that changes in flame shape during one oscillation cycle feature a periodic attachment and detachment of the flame from the injector, and aerodynamic disturbances enhancing flame wrinkling. The influence of thermal power and global equivalence ratio is investigated and it is shown that unstable oscillations arise when the system is operated in an intermediate thermal power regime where the flame alternates between lifted and attached configurations. Investigations of the effect of swirl number and recess of hydrogen injection with respect to the chamber backplane show that the unstable range is diminished when the recess takes large values and also when the swirl number is increased.

Detailed Schedule Full-Text

A B C D E F G I K L M N O P R S T V W X Y Z

Vishnoi, Neha

Gupta, Vikrant

Saurabh, Aditya

Kabiraj, Lipika

Effect of colored noise on precursors of thermoacoustic instability in model gas turbine combustors (STC 26)

In this work, we analyze the noise-induced response of a generalized Van der Pol oscillator system (prototypical thermoacoustic system) subjected to colored noise. Specifically, we investigate the effects of noise color (or noise correlation time) and noise intensity on coherence factor and Hurst exponent prior to Hopf bifurcation (subthreshold region). We model the correlated noise as an additive Ornstein Uhlenbeck (OU) process with varying correlation times, which mimics the combustion noise in practical systems. We find that the coherence factor is a more reliable precursor than the Hurst exponent. We find that the Hurst exponent increases with an increase in both noise color and intensity. Hurst exponent can only be employed as a precursor when both noise color and intensity are small, provided the minimum threshold value for its implementation is chosen carefully.

Detailed Schedule Full-Text

Wang, Kai

Laera, Davide

Yang, Dong

Predicting nonlinear thermoacoustic modes in annular combustors by combining a 2D low-order network model and experimentally-measured Flame Describing Functions (STC 6)

In annular combustors, thermoacoustic instabilities may involve waves propagating in both longitudinal and circumferential directions. Recent experiments have found pure longitudinal, spinning, standing and slanted modes. This refers to the experiments performed in the MICCA annular combustor from EM2C Laboratory. In this work, following previous studies (Stow and Dowling (2004) and Yang et al. (2019)), a novel 2D low-order network model which considers 16 discrete burners coupled with independent flame describing functions obtained from experiments is adopted to predict the thermoacoustic modes established in the annular combustor. Differently from previous studies (Laera et al. (2017b)) where the burners were assumed as a continuous annulus, resulting that only spinning or longitudinal modes could be considered, the discrete burner approach allows to predict all mode patterns. The present results show that the spinning limit cycle can be predicted by using the FDF obtained under the same experimental condition when pure spinning mode occurs. However, longitudinal, standing and slanted modes can be also found by using the same FDF. Similarly, longitudinal, spinning and slanted modes, except for the standing mode can also be found by using the FDF corresponding to the pure standing mode experimental case. The respective spinning and standing limit cycles are validated by comparing with numerical simulations and experiments. Further explanation is needed to explain why only one mode appears in each experiment.

Detailed Schedule Full-Text

A B C D E F G I K L M N O P R S T V W X Y Z

Wang, Yichen

Yang, Dong

Zhu, Min

A model of acoustic reflection coefficient in the transition ducts of can-annular combustors based on mode matching method (STC 5)

Heavy-duty land-based gas turbines with can-annular combustors usually exhibit a set of thermoacoustic modes with close frequencies. Because of the rotational symmetry, the Bloch boundary condition is often used to simplify the combustors. Although it is more reasonable to consider a full 2D acoustic field in the transition duct, it is more convenient to use an equivalent reflection coefficient which is actually a quasi-one dimensional model. The quasi-one dimensional model cannot naturally consider the high-order modal components in the 2D acoustic field. Therefore, the reflection coefficient is useful only when the frequency is low enough and the gap length is short enough. In this paper, we present a 2D theoretical model using the mode matching method to take the high order modal components into consideration. The results show that the high-order acoustic modes have an effect on the phase of reflected waves in the low frequency range. When the frequency is larger than the cut-off frequency, the reflection coefficient should be extended to a reflection coefficient matrix (RCM) in order to accurately describe the acoustic characteristics. The reflection matrix depends on the nondimensional cross-sectional area ratio ,Helmholtz number based on the length of the transition duct and Bloch number. The eigenvalue problem of a four-flames can-annular combustor is studied, and the oscillation frequency and growth rate could be predicted accurately by using the RCM. This is validated by comparing with numerical solutions for capturing both low-and high-frequency modes.

Detailed Schedule 🔗 Full-Text ↗

Wei, Jiasen

Arabi, Sadaf

Pralits, Jan. O.

Bottaro, Alessandro

Heckl, Maria

Noise in a Rijke tube with mean flow and a non-uniform temperature field (STC 24)

In industrial combustion systems, noise from various sources is a prevalent challenge that can significantly impact system dynamics. External noise introduces complexities, potentially leading to untimely transitions and alterations in stability behaviors. This research introduces a comprehensive and adaptable framework designed to model and forecast thermoacoustic instabilities within a Rijke tube, utilizing a Green's function approach. The framework encompasses factors such as an amplitude-dependent nonlinear heat source, a steady mean flow, and stochastic additive noise. Stability evaluations are conducted across distinct mean flow velocities, employing heat source positioning as a key control parameter. Variations in frequency and growth rate are identified concerning diverse Mach numbers. Additionally, the study indicates the bistable regions become wider when the mean flow is included, because of the hysteresis effects. The investigation delves into two noise categories—white noise and pink noise—integrated into the system as additive sources. The findings shed light on triggering phenomena that emerge as noise levels increase. Particularly, the study shows the profound influence of pink noise on system stability, surpassing the effects induced by white noise. This research contributes to a deeper comprehension of the intricate interplay between noise, system parameters, and stability in combustion systems, providing insights crucial for enhancing system design and operation.

Detailed Schedule 🔗 Full-Text ↗

A B C D E F G I K L M N O P R S T V W X Y Z

Wildemans, Roeland
Kornilov, Viktor
Lopez Arteaga, Ines

Experimental validation of data-driven nonlinear dynamical flame model (STC 14)

In this paper, a new nonlinear dynamical flame model for laminar premixed flames is experimentally validated. The nonlinear governing equations of the flame dynamics are identified with the data-driven method of sparse identification of nonlinear dynamics only based on time-series of self-excited oscillations produced by a pure intrinsic thermo-acoustic mode. This flame model has the structure of two coupled oscillators and is able to accurately describe the self-excited oscillations of pure ITA modes. In this paper it is shown that this model also provides a good description of the flame dynamics in a wide range of acoustic embeddings. Thereto, the model response is compared with the response of an experimental setup. This setup can simulate a wide variety of acoustic embeddings, since the reflection coefficients of the up- and downstream mufflers and the length of the upstream duct can easily be varied. In general, the model response is in good agreement with the experimental data for a wide variety of acoustic embeddings. The model is capable of producing both the limit cycle and beating oscillations. Furthermore, the importance of modal coupling is elucidated by the model since it predicts the single frequency limit cycles accurately in case of two linearly unstable modes.

Detailed Schedule Full-Text

Xu, Liangliang
Zheng, Jianyi
Xia, Xi
Qi, Fei

Investigation on a frequency drop of combustion instability in a lean premixed single swirl burner (STC 44)

Combustion instability presents a significant challenge within lean premixed gas turbine combustors. The shifting frequency of thermoacoustic oscillations is often associated with the flame configuration within a swirl burner. However, the intricate mechanisms governing frequency shifts during self-excited thermoacoustic instabilities in swirl combustors remain incompletely understood. In this study, we delve into the phenomenon of frequency reduction in combustion oscillations under constant operating conditions within a lean premixed swirl-bluff body stabilized combustor. To comprehensively investigate these dynamics, we construct a low-order network model aimed at predicting and analyzing the instability patterns of thermalacoustic modes. Our experimental findings illuminate a distinct correlation between changes in flame shape and the observed frequency reduction. Notably, our modeling results reveal that large-amplitude oscillations induce a transition in the flame structure, thereby impacting the flame's response in terms of both gain and time delay. Optical diagnostic measurements offer further insights, demonstrating that as the frequency decreases, the flame undergoes a detachment from its original position and subsequently reattaches to the rim of the bluff body. These observations lead us to a preliminary conclusion: the reduction in frequency is primarily induced by alterations in the flame's configuration, driven by an increase in velocity perturbations.

Detailed Schedule Full-Text

A B C D E F G I K L M N O P R S T V W X Y Z

Yang, Qianwen
Yu, Zhijian
Zhu, Min

A modified Helmholtz resonator combined with membrane (STC 32)

This paper investigates the acoustic performance of two kinds of Helmholtz resonator combined with circular membrane. The clamped membranes are fixed at the cavity bottom and middle of cavity respectively. A theoretical model with the application of low-order network is established, in which the acoustic impedance of membrane is figured out according to the motion governing equation and clamped boundary conditions. The following study mainly focuses on the effect of membrane in different vibration modes on HR and attempts to observe the actual performance of modified resonators though experiments. The theoretical results reveal that the application of membrane introduce more resonance peaks to HR, relevant to the material properties and the order of vibration mode. Additionally, the resonance frequencies of resonators will increase along with the rising pre-stretch tension imposed on membrane. The phenomena described by theoretical model are fulfilled in experiments and a good agreement between them is achieved. The behavior of clamped membrane is also well illustrated. Based on the predicted results and experimental investigation, it can be concluded that the application of membrane can not only extend the working frequency range of HR, but also make it possible to take effect in the lower frequency range without increasing the volume. This may contribute to improving the acoustic properties of HR in compact mechanical structures and complex operating conditions.

Detailed Schedule Full-Text

Yin, Liming
Dong, Yang

Modal coupling and mode degeneracy in annular combustor with multiple Helmholtz resonators (STC 33)

Modern aero-engines and power generation gas turbines often use annular combustors, where many burners are installed in the circumferential direction. These gas turbines usually operate under lean-premixed conditions, which make the flame susceptible to acoustic disturbance; this may cause thermoacoustic oscillations. When the flame model is determined, our previous work has shown that a 2-D low-order network model can capture different thermoacoustic oscillation modes in annular combustors, including longitudinal, circumferentially spinning/standing, and slanted modes. This kind of low-order network modelling tool has been recognised as a computationally efficient way of analysing thermoacoustic oscillations in annular combustors. Helmholtz resonators (HRs) have been widely used for damping thermoacoustic oscillations. In annular combustors, the presence of HRs can cause modifications to the natural frequencies and mode shapes of the system, leading to the coupling between different modal components. In this paper, HRs are incorporated into the aforementioned low-order network model. Assuming that all resonators are the same and uniformly distributed over the circumference, the effect of the number of HRs on the nature of the thermoacoustic modes are studied in detail.

Detailed Schedule Full-Text

A B C D E F G I K L M N O P R S T V W X Y Z

A B C D E F G I K L M N O P R S T V W X Y Z

Yoko, Matthew

Juniper, Matthew P.

Data-driven modelling of thermoacoustic instability in a ducted conical flame (STC 16)

We learn the most probable parameters of a thermoacoustic network model from experimental data using Bayesian data assimilation. We first perform a series of automated experiments on a ducted flame rig. We then propose several candidate models, and assimilate the data into each model to find the most probable parameters for that model. We rank the candidate models based on their evidence to select the most probable models. We begin by constructing a quantitatively accurate model of the acoustics of the cold rig. We then propose several candidate models for the fluctuating heat release rate and rank them according to their evidence, given the data. We find that the most probable model is influenced by the velocity perturbations from both the burner tube and the duct, even though studies in the literature typically neglect either one of these. We infer the flame transfer functions for 24 flames using only pressure measurements. We find that our inferred flame transfer functions are generally consistent with those from several studies in the literature.

Detailed Schedule Full-Text

zur Nedden, Philipp

Paschereit, Christian Oliver

Orchini, Alessandro

Investigating the influence of hydrogen-rich fuel mixtures on the assessment of the flame transfer function (STC 56)

To achieve the decarbonization of electrical power generation, gas turbines need to be upgraded to combust high- hydrogen content fuels reliably. One of the main challenges in this upgrade is the burner design. A promising burner concept for a high-hydrogen fuel mixture is a jet burner, which is highly flashback resistant thanks to its high bulk velocity. Due to its non-acoustically compact extension and the presence of hydrogen in the fuel mixture, new challenges arise in assessing the (thermo)acoustic response of this burner design. A burner transfer matrix (BTM) and the flame transfer function (FTF) or transfer matrix (FTM) are typically measured with the multi-microphone method (MMM) to assess the performance of new burner types in relation to thermoacoustic stability. With the switch towards hydrogen, the fuel/air mixture is significantly altered in its properties regarding the speed of sound and density, which are of fundamental importance to acoustic propagation and the accuracy of the MMM. The influence of the modified gas composition on the reconstruction of BTMs and FTFs is investigated in this work by using an analytical model and experimental results. To do so, we adapt the preheating temperature during the measurement of the BTM with a non-reactive mixture to match the speed of sound of the hydrogen-air mixture required in reactive conditions. Additionally, we present an analytical model for the jet burner transfer matrix, which is validated against the experimental data showing good agreement. The influence of the variation in reactant composition of the BTM on the FTM assessment is noticeable. For the assessment of the FTF, the influence of the differing BTMs due to varying reactants is small on the phase values and noticeable in the gain values.

Detailed Schedule Full-Text