Contract Number: N000141812590

Title: Center for Turbulence Summer Program-2018

Major Goals:

To investigate fundamental aspects of multi-physics turbulent flows, development and validation of advanced numerical methods for prediction of turbulent flows, and exploration of machine learning techniques for turbulence modeling.

Accomplishments Under Goals:

The seventeenth biennial Summer Program of the Center for Turbulence Research was held from June 24 to July 20, 2018. CTR hosted seventy-four participants from eight countries, including twenty-six U.S. institutions. Thirty-eight CTR staff members, including graduate students, postdoctoral fellows and faculty, worked alongside the participants and contributed to thirty-six projects spearheaded during the Summer Program. The participants were selected on the basis of quality of their research proposals and their synergy with current scientific interests of CTR. The role of CTR continues to be that of providing a forum for the fundamental study of multi-physics turbulent flows for engineering analysis. The 2018 Summer Program encompassed thirty-six reports, which are divided into five groups: Multi-phase Flows, Numerical Methods, Multi-physics and Data-driven Studies, Wall Turbulence, and Combustion. Preceding each group of papers is a technical overview that summarizes the main technical accomplishments. As in previous years, four weekly tutorials were given during the CTR Summer Program. The topics discussed in the tutorials this year were: “Hypersonic Aerodynamics and Propulsion" by Javier Urzay, “Machine Learning and Data Science in Turbulence" by Gianluca Iaccarino, “Sensitivity Analyses and Chaotic Dynamics in Turbulence" by Qiqi Wang, and “Moving Contact Lines" by Kamran Mosheni. The participants of the 2018 Summer Program presented their accomplishments on July 20. This final event was attended by several colleagues from industry, academia, and government.

Training Opportunities:

CTR hosted seventy-four participants from eight countries, including twenty-six U.S. institutions. Thirty-eight CTR staff members, including graduate students, postdoctoral fellows and faculty, worked alongside the participants and contributed to thirty-six projects spearheaded during the Summer Program

Results Dissemination

This proceedings volume contains thirty-six reports, which are divided into five groups: Multi-phase Flows, Numerical Methods, Multi-physics and Data-driven Studies, Wall Turbulence, and Combustion. Preceding each group of papers is a technical overview that summarizes the main technical accomplishments. The volume is available on the ctr website, and 190 copies of the volume were distributed to the participants and Stanford industrial affiliates, and government program managers.

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Honors and Awards

Nothing to Report

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Nothing to Report

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Participants

First Name: Parviz **Last Name:** Moin

Project Role: PD/PI

National Academy Member: Y **Months Worked:** 1

Countries of Collaboration

First Name: Javier **Last Name:** Urzay Lobo

Project Role: Other Professional

National Academy Member: N **Months Worked:** 1

Countries of Collaboration

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14. ABSTRACT
The seventeenth biennial Summer Program of the Center for Turbulence Research was held from June 24 to July 20, 2018. CTR hosted seventy-four participants from eight countries, including twenty-six U.S. institutions. Thirty-eight CTR staff members, including graduate students, postdoctoral fellows and faculty, worked alongside the participants and contributed to thirty-six projects spearheaded during the Summer Program. The participants were selected on the basis of quality of their research proposals and their synergy with current scientific interests of CTR. The role of CTR continues to be that of providing a forum for the fundamental study of multi-physics turbulent flows for engineering analysis.

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CTR Summer Program 2018

1. Introduction

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This proceedings volume contains thirty-six reports, which are divided into five groups: Multi-phase Flows, Numerical Methods, Multi-physics and Data-driven Studies, Wall Turbulence, and Combustion. Preceding each group of papers is a technical overview that summarizes the main technical accomplishments.

Research activities in the group of multi-phase flows focused on analysis and modeling of dispersed particle-laden turbulence and two-phase turbulent flows, with particular emphasis on multi-physics aspects. In the area of particle-laden turbulence, the problems addressed by this group included the dispersion of particles in electrified and rotating flows, the interaction of particles with shock waves, and the deposition of sand grains on turbine blades. In the area of two-phase flows, the activities encompassed the analysis and subgrid-scale (SGS) modeling of interactions of interfaces with turbulence, and the mesoscale description of turbulent flows in porous media.

The group on numerical methods emphasized advancing the state of the art of low-dissipation numerics in Large Eddy Simulations (LES) and their compatibility with SGS models, including applications to complex geometries. The latter were illustrated by predictive wall-modeled LES of realistic aeronautical configurations carried out during the Summer Program with turnaround times of industrial relevance. Other activities included performance assessments of hybrid meshes in LES of low Mach-number flows, and developments of Discontinuous Galerkin methods in turbulent flows, including applications to wall modeling and energy transfer.

Data-driven analyses and data-assimilation techniques for turbulent flows were the main areas of research in the group on multi-physics and data-driven studies. The activities involved analyses of rare events in turbulent flows, adjoint-based control, shadowing-based methods for adjoint sensitivities, along with challenging multi-physics applications that included autonomous navigation of swimmers in turbulence, passive scalar mixing through shock waves, supercritical fluids, and supersonic jet noise.

The wall turbulence group focused on fundamental analyses of flow structures near walls, including non-equilibrium and rough-wall boundary layers. The understanding and control of near-wall turbulence, as well as its prediction from wall quantities, occupied most of the attention in the group, with relevant applications to complex surfaces and rapidly-swept boundary layers being also demonstrated during the Summer Program.

Activities related to research on combustion focused on physics, modeling, uncertainty quantification and data analysis. The problems addressed by this group involved SGS modeling of heat-release effects on small-scale turbulence, fundamental studies of reacting discontinuities, simulations of vaporizing fuel droplets in turbulent flows, as well as applications of data-assimilation and deep-learning techniques to important combustion processes such as thermoacoustic instabilities and turbulent premixed-flame propagation.

As in previous years, four weekly tutorials were given during the Summer Program. The topics discussed in the tutorials this year were: “Hypersonic Aerodynamics and Propulsion" by Javier Urzay (Stanford), “Machine Learning and Data Science in Turbulence" by Gianluca Iaccarino (Stanford), “Sensitivity Analyses and Chaotic Dynamics in Turbulence" by Qiqi Wang (MIT), and “Moving Contact Lines" by Kamran Mosheni (University of Florida).

The participants of the 2018 Summer Program presented their accomplishments on July 20. This final event was attended by several colleagues from industry, academia, and government.

The 2018 Summer Program was sponsored by the US Air Force Office of Scientific Research (AFOSR), National Science Foundation (NSF), National Aeronautics and Space Administration (NASA), Department of Energy (DoE), and the Office of Naval Research (ONR). The joint commitment of five different federal agencies to support the Program underscores the importance of understanding and modeling multi-physics turbulent flows for engineering analysis. The wide discretionary mandate they afforded to CTR for selection of the technical projects featured in these volumes has been much appreciated.

We are grateful to Vi Nguyen and Pamela Nelson Foster for their assistance and efficient organization of the 2018 CTR Summer Program, to Steve Jones for his guidance to the external participants who utilized the CTR Certainty cluster for their simulations, and to Curtis Hamman for his help on compiling the manuscripts featured in this volume.

This volume is available online at the CTR website
http://ctr.stanford.edu/

2. Research Activities on Multiphase Flows

The specific topics addressed by the Multi-phase Flow group were subdivided into two themes: i) dispersed particle-laden turbulent flows, and ii) two-phase turbulent flows. In this Summer Program, this group addressed problems that involved multi-phase flows subjected to electric effects, flow rotation, high-speed compressibility effects, phase change, and porosity. This is an expression of the particular emphasis made at the time of review of project proposals that the selected projects should encompass multi-physics aspects of relevance for emerging engineering applications.

In the area of dispersed particle-laden turbulent flows, the group focused on fundamental analyses of dispersion and deposition of inertial particles in complex flows. Di Renzo et al. investigated the utilization of electric fields for controlling the near-wall accumulation of particles in turbulent channel flows. Bragg and Dhariwal studied the dynamics of particles as a result of centrifugal forces in rotating turbulence. Vartdal and Osnes analyzed the turbulent fluctuations and forces created by shock waves moving through clouds of particles. Jain et al. addressed the problem of ingestion of sand grains in aircraft engines and their deposition on hot turbine blades downstream of the combustor.

In the area of two-phase turbulent flows, the group investigated the interactions of turbulence with liquid/gas interfaces and with porous media. Herrmann et al. formulated novel subgrid-scale models for predicting the corrugation of interfaces by turbulence. Lai and Fraga searched for fundamental explanations to the spectral-energy decay of turbulence observed in rising columns of bubbles. Brandt et al. studied the deformation of droplets and bubbles in homogeneous shear turbulence. To close the list of activities, Apte et al. derived a mesoscopic model to describe turbulent flows through porous media.

3. Research Activities on Numerical Methods

Large-eddy simulation (LES) of turbulent flows has become an attractive tool for prediction of complex engineering flows. Tackling such applications has become possible due to advances in numerical methods, computer hardware, and subgrid-scale (SGS) models. These advances have also rendered LES affordable, and therefore viable for industrial applications. The main reason for the higher accuracy of LES compared with Reynolds-averaged Navier-Stokes (RANS) is the resolution of a portion of the turbulence spectrum, as opposed to phenomenological modeling of the entire turbulence stresses in RANS. It is therefore important to minimize the distortion of the resolved turbulence structures by numerical artifacts. For example, a common practice in traditional computational fluid dynamics, which has been adopted in some LES, is the introduction of numerical dissipation to counter nonlinear numerical instabilities, to capture shock waves, and to achieve robustness of the computations. However, numerical dissipation artificially dampens the turbulent eddies that one presumably intended to resolve in the first place by choosing LES over RANS. Other important requirements for LES are higher grid quality, suitable for the resolution of turbulent eddies, and compatibility of the SGS model with the numerical method. These issues were the focus of the five projects by the Numerical Methods group.

In one of the most complex applications of LES to date, Lehmkuhl et al.simulated flow over realistic aircraft configurations at high angles of attack. Finite-element and finite-volume codes were used. The only common feature of the methods was the use of minimal numerical dissipation. Both calculations used the same equilibrium wall model and SGS model. The agreement of the global forces and pressure distributions with the experiments at various angles of attack, including at maximum lift and post stall, was remarkably good. Another remarkable outcome was that the calculations were completed in 1 to 3 days on 2000 CPUs, demonstrating that LES has now “arrived" and is ready for exploitation in a myriad industrial applications.

In applications with highly complex configurations, the use of hybrid unstructured mesh topologies is often necessary. Domino et al.assessed the suitability of heterogeneous hybrid meshes for turbulence simulations in a benchmark low-Reynolds-number channel flow. The mesh was intentionally chosen not to be symmetric across the channel, and the symmetry of the flow statistics was used as a measure of the quality of the results. The mean velocity profile was predicted with reasonable accuracy. However, as expected, given the strong link between the SGS model and the grid, turbulent intensities were asymmetric across the channel, with the symmetry increasing with mesh refinement.

Discontinuous Galerkin (DG) methods have received some attention for numerical simulation of turbulent flows owing to their parallel scalability and potential for higher-order numerical accuracy. The variational multiscale approach (VMS) originally proposed for the finite-element method is naturally extended to DG. Naddei et al.analyzed the spectral properties of energy transfer in the DG-VMS approach and defined the large-scale field in LES based on truncation of polynomial expansions in DG. In an application to the Taylor-Green vortex, these authors showed that, with sufficient resolution, the energy transfer spectrum achieved the desired shape, consisting of concentration of energy transfer to subgrid scales from the smallest resolved scales. Murman and Frontin showed that SGS modeling approaches should take into account the numerical dissipation (or stabilization schemes) used in DG methods. They showed that an entropy-conservative scheme, together with an appropriate SGS model, results in better predictions of isotropic turbulence and channel flow than entropy-stabilized schemes with or without SGS models.

Finally, Lv et al. developed a novel wall model for DG-based LES of turbulent boundary layers. The model is based on augmenting the DG expansion in the cell adjacent to the wall by an additional basis function that incorporates the logarithmic law of the wall. The results from LES of high-Reynolds-number turbulent channel flow and the NASA transonic bump are very encouraging. Similar to Murman and Frontin, Lv et al. noted the necessity of including explicit SGS model in DG, as well as the inadequacy of numerical stabilization in DG as an SGS model.

5. Research Activities on Multiphysics and Data Driven Studies

Since 1987, the Summer Program of the Center for Turbulence Research has gathered a large community of turbulence researchers at Stanford University. The program originated as a means to exploit databases of large-scale simulations generated at NASA Ames Research Center. Over the last three decades, the analysis of data resulting from simulations, or collected from experiments, has been a critical component of turbulence research, either to generate and test ideas for modeling purposes or to clarify the physical processes in play. In pursuit of these goals, numerous data analysis techniques have been explored and, in many cases, have found broad applicability in other fields. Today, data science is attracting increasing attention in a variety of disciplines; the reports in this section represent research at the intersection of data science and turbulence.

The first group of four contributions revolved around the development and demonstration of novel algorithms for data analysis. Schmidet al.explored two novel strategies to identify and extract modes that contribute to intermittent and extreme behaviors in turbulent flows. Advanced data clustering techniques enabled the identification of extreme transitions in near--wall turbulence, whilea conditioned POD highlighted acoustic bursts in supersonic heated jets. Bodony investigated the derivation of adjoint operators starting from experimental images on liquid jets for the purpose of controlling mixing. The pproach includes elements of image analysis, feature extraction, and, ultimately, forecasting. Arza focused on modern inference techniques to assess the feasibility of autonomous navigation in complex fluid flows; he used reinforcement learning techniques to study source localization problems, that is, to identify the source of a contaminant using a local sensor that can navigate in a two-dimensional or three-dimensional field. Bermejo-Moreno et al. developed a sophisticated data analysis and feature-extraction technique and applied it to the study of the shock-turbulence interaction problem. The proposed approach enables the dynamical tracking of physical structures and constructs a graph of events relating different structures, such as break up or merge, that can be employed both forward and backward in time to assess causality relations.

The second group of four contributions investigated the application and improvement of existing data analysis techniques in challenging multi-physics applications. Tamm built a database of high-fidelity simulations of turbulent jets exhausting from military-style nozzles; his aim was to investigate the effect of inflow temperature non-uniformity on overall jet noise. In addition to detailed comparisons to available experimental data, he used spectral POD to identify changes in the most energetic modes. Blonigan et al. investigated the shadowing-based technique to compute adjoints in chaotic turbulent flows; they focused on lowering computational cost by selectively reducing the accuracy of the approach and tracking a limited number of unstable modes. Wanget al.investigated the use of geometrical modification to nozzle shapes to reduce overall jet noise; they built high-fidelity databases and used Lyapunov exponent analysis to investigate the most unstable modes. These modes provide insights into how changes in the geometry, such as serrations or chevons, lead to reduced noise generation by increasing mixing. Last, but not least, Goriet al. studied geometrical optimization of turbine blades to improve the performance of organic Rankine cycle compressors. The challenge in this case was to infer the properties of the working fluid (octamethyltrisiloxane) from available experimental measurements of nozzle flows; they used Bayesian inference and incorporated the resulting fluid parameters together with their joint probability distribution in a probabilistic optimization strategy. The results illustrate how carefully designed blades can minimize the impact of fluid properties, uncertainties on the overall turbine operation.

5. Research Activities on Wall Turbulence

Turbulence analysis and modeling are two of the foundational research topics of the Center for Turbulence Research (CTR), and they remain at the core of the activities developed at the center. Even after more than a century, turbulence research is deemed in its infancy by the most critical researchers in the field. And they might be right, although we do possess a crude practical understanding of turbulence, we lack a comprehensive theory capable of providing the accurate predictions demanded by the industry at an affordable computational cost. The elusive nature of turbulence also makes the subject challenging to interpret and model in a field described by Liepmann as the graveyard of theories. Despite these acute dificulties, technological considerations call for advances in the field, since wall turbulence accounts for 25% of the energy consumed by the industry in moving uids along pipes, or vehicles through air or water, in addition to the 5% of the CO2 dumped by mankind into the atmosphere.

During the 2018 CTR Summer Program, the projects dedicated to wall turbulence have contributed to the development of new, groundbreaking ideas in the field. The focus of the group revolves around the common theme of turbulent ows in the presence of bounding surfaces, and 20 scientists from 12 institutions worked for a month at Stanford University. The participants, supported by 13 hosts, tackled problems of fundamental and technological significance, ranging from basic understanding of turbulence to novel control and modeling strategies. The activities during the Summer Program are naturally divided into two subgroups: analysis of wall turbulence, and non-equilibrium and rough-wall turbulence. The former is concerned with novel approaches for ow reconstruction from limited measurements and flow control. Efficient active control requires the knowledge of the ow at wall dis tances of the order of the size of the ow structures to be controlled. Jimenez et al. argue that, to be of practical use, reconstruction techniques must comply with the cur rent technological limits for time and length measurements at the wall. They show, using time-resolved channel direct numerical simulation (DNS) data, that wall-attached structures can be accurately reconstructed from their shear and pressure footprint at the wall, including ow motions whose sizes are comparable to the boundary layer thickness. The complementary control investigation is done by Farrell et al. using the framework provided by statistical state dynamics. In contrast to traditional transition control theory for systems with non-modal growth, the authors propose more eficient control strategies by targeting the first Lyapunov vectors of the perturbed velocity field. They demonstrate that inhibiting this component terminates the dynamic turbulent cycle and favors laminarization of the flow.

The insights accumulated during the last decades on eddy structure are exploited by Yang et al. to model the interaction between uid and electric fields. The problem is especially significant for electrodialysis processes (e.g., purification of brackish water), which are poorly understood in a discipline where numerical simulations have become available only in recent years. The authors apply well-established turbulence methodologies, such as the multifractal formalism and Townsend's attached eddy model for physical understanding and reduced-order modeling. An even more fundamental question stems from the mathematics of turbulence itself and the equations that describe the uid motion adequately. Are the Navier-Stokes equations well posed in the presence of walls? Are they singular under certain conditions? The project by Kerr et al. employs vorticity moments to perform regularity diagnostics of the Navier-Stokes equations in turbulent boundary layers. The outcome of the research is not merely to satisfy the interest of mathematicians but is also relevant for the development of turbulence models at high Reynolds numbers, where dissipation becomes finite as viscosity vanishes.

The second subgroup is devoted to non-equilibrium and rough-wall boundary layers. Non-equilibrium ows with mean-ow three-dimensionality are particularly stimulating given their ubiquity (swept wings, stern regions of ships, etc.) and counter-intuitive behavior, such as drag and Reynolds stress depletion in the presence of enhanced strain. These observations have captivated many researchers in the field and pose new challenges for large-eddy simulation (LES) and Reynolds-averaged Navier-Stokes (RANS) modelers. The project by He et al. aims to unveil the mechanisms of turbulence reduction in transversely strained boundary layers. In their unique approach, the authors reinterpret temporally developing three dimensional turbulent boundary layers in the context of cross-ow and bypass transition theory. High-Reynolds-number, non-equilibrium wall turbulence also necessitates practical, single-point closures with non-local information. Yuan et al. address this matter through the structure-tensor concept to assess the effects of roughness and textures using a rich DNS/LES data set to inform structure-based closures. Equally important is the necessity of a unified theory for wall turbulence over complex surfaces and realistic roughness to hasten the development of wall modeling methodologies. To this end, Garcia-Mayoral et al. systematically analyze how various wall textures produce varying complexity of near-wall turbulence and scrutinize the validity of virtual origins theory as a framework for drag prediction in difierent technologies (riblets, superhydrophobic surfaces, porous coatings, canopies, etc.). The investigation of non-equilibrium ows in real-world applications is addressed by Lee et al., who assess the impact of transverse shear on turbomachinery by means of LES.

6. Research Activities on Combustion

he combustion group at the 2018 CTR Summer Program consisted of seven research teams, covering a wide range of topics pertaining to fundamental combustion analysis, model development, multiphase flows, and data analysis. To foster close discussions, two overarching research topics were identified: (i) combustion physics and modeling and (ii) uncertainty quantification and data analysis. To guide to reader through the research briefs, an overview of all research topics and accomplishments is given.

The project by MacArt and Mueller was concerned with examining subgrid models for the prediction of turbulent scalar fluxes in premixed flames for conditions spanning low- and high-Karlovitz-number. Three different models were considered through a-priori and a-posteriori analyses, showing that low-Karlovitz-number conditions pose significant challenges for current models in accurately predicting dilation-induced turbulent production at small scales.

Aboulhasanzadeh and Mohseni revised the limits of the Euler equations and derived a set of observable equations to regularize conservation laws. The formalism was extended to two-phase and reacting flows and applications to challenging shock/bubble-interaction problems, and one-dimensional unsteady detonation systems showed good success. Since this approach introduces a regularization at the level of a partial differential equation, it holds promise for other applications.

Duwig et al. analyzed a direct numerical simulation (DNS) database of interface-resolved evaporating droplets by considering of four-way coupling between droplets and its turbulent environment. Direct comparisons of large-eddy simulation (LES) results with a Lagrangian particle tracking (LPT) method showed significant deficiencies of point-particle methods in captured droplet dynamics. These deficiencies could be attributed to finite-size effects and bulk-flow interaction, demonstrating the need for further research in improving commonly employed LPT methods.

Yu et al. employed data assimilation to improve the predictive capability of low-order models in capturing the transient flame dynamics in premixed flames. To this end, an ensemble Kalman filter was employed for state and parameter estimations in the context of a computational twin experiment and by assimilating data from a DNS into a low-order level-set model. Interestingly, it was shown that the assimilation improves the qualitative prediction of the flame dynamics to the limit of saturating the model fidelity due to the lack of underlying physics that is not contained in the low-order model.

Silva et al. utilized generalized chaos expansion for quantifying uncertainties in thermoacoustic models. This formulation enables the consideration of state variables, boundary conditions, and model parameters as stochastic variables, providing a probabilistic description of uncertainties in thermoacoustic systems. The method was applied to problems of different complexity, demonstrating its merit as an affordable technique for evaluating global sensitivity analysis.

Lapeyre et al. explored the prospect of using deep learning as a means for the construction of models for flame-surface density in turbulent premixed flames. To this end, a convolutional neural network was trained from DNS data. Evaluations of this network-model in \emph{a-priori} and \emph{a-posteriori} tests showed promising results, and limitations in its generalization and application to other configurations were identified.

Research by Edoh and Gallagher addressed the analysis of coupling effects between numerical discretization and filtering on numerical errors in LES. To this end, different spatial discretization schemes were examined in the context of explicitly filtered LES by employing a so-called tandem DNS, and strategies for mitigating the propagation and amplification of numerical errors were developed. It was concluded that high-order spatial discretization and an increasing filter-to-grid ratio for explicitly filtered LES provide opportunities for the effective mitigation of numerical errors.

7. List of Publications Compiled in the Proceedings of the 2018 Summer Program - https://ctr.stanford.edu/proceedings-2018-summer-program

I. Multi-phase Flows

Electrically induced suppression of turbophoresis in particle-laden turbulent channel flows.
M. Di Renzo, P. L. Johnson, M. Bassenne, L. Villafane and J. Urzay
Confinement, enhancement, extremes and inversions in the mixing and transport of particles by rotating turbulent flows.
A. D. Bragg and R. Dhariwal
Using particle-resolved LES to improve Eulerian-Lagrangian modeling of shock-wave/particle-cloud interactions.
M. Vartdal and A. N. Osnes
Turbulent multiphase flow and deposition of ingested sand on high-temperature turbine blades.
N. Jain, L. Bravo, S. T. Bose, D. Kim, M. Murugan, A. Ghoshal and A. Flatau
A dual-scale subgrid closure for LES of phase interfaces in turbulent flows.
M. Herrmann, D. Kedelty and T. Ziegenhein
Energy cascade in a homogeneous swarm of bubbles rising in a vertical channel.
C. C. K. Lai, B. Fraga, W. R. H. Chan and M. S. Dodd
Emulsions in homogeneous shear turbulence.
M. E. Rosti, Z. Ge, S. S. Jain, M. S. Dodd and L. Brandt
Volume-averaged continuum approach for turbulent flows in porous media: An a-priori DNS analysis.
S. V. Apte, X. He and B. D. Wood

II. Numerical Methods

Large-eddy simulation of practical aeronautical flows at stall conditions.
O. Lehmkuhl, G. I. Park, S. T. Bose and P. Moin
The suitability of hybrid meshes for low-Mach large-eddy simulation.
S. P. Domino, L. Jofre and G. Iaccarino
Large-scale space definition for the DG-VMS method based on energy transfer analyses.
F. Naddei, M. de la Llave Plata, E. Lamballais, V. Couaillier, M. Massot and M. Ihme
Analysis of numerical dissipation in entropy-stable schemes for turbulent flows.
S. M. Murman and C. Frontin
Physics-based near-wall turbulence modeling in an enriched discontinuous Galerkin framework.
Y. Lv, X. I. A. Yang, G. I. Park and M. Ihme

III. Multi-physics and Data-driven Studies

Analysis and prediction of rare events in turbulent flows.
P. J. Schmid, O. T. Schmidt, A. Towne and M. J. P. Hack
Low-rank modeling of primary atomization.
D. J. Bodony, P. Sashittal and A. Towne
Scalar source tracking in turbulent environments using deep reinforcement learning.
V. Spandan, P. Bharadwaj, M. Bassenne and L. Jofre
Scalar mixing under shock/turbulence interaction: DNS, statistical and geometric analyses.
X. Gao, J. Buchmeier, I. Bermejo-Moreno, J. Larsson, L. Fu and S. K. Lele
Leveraging large-eddy simulations to investigate the influence of temperature non-uniformity on jet noise.
P. Tamm, G. A. Bres, A. Towne and S. K. Lele
Reducing the cost of shadowing-based adjoint sensitivity analysis for turbulent flows.
P. J. Blonigan, S. M. Murman and A. Towne
Toward computing sensitivities of average quantities in turbulent flows.
N. Chandramoorthy, Z. N. Wang, Q. Wang and P. Tucker
Robust optimization of turbine cascades for Organic Rankine Cycles operating with siloxane MDM.
N. Razaaly, G. Gori, O. Le Maitre, G. Iaccarino and P. M. Congedo

IV. Wall Turbulence

Reconstructing channel turbulence from wall observations.
M. P. Encinar, A. Lozano-Duran and J. Jim´enez
Parametric mechanism maintaining Couette flow turbulence is verified in DNS.
B. F. Farrell, P. J. Ioannou and M. A. Nikolaidis
Modeling electrical currents through an ion-selective membrane in the overlimiting regime.
X. I. A. Yang, K. M. Wang, H. H. A. Xu and A. Mani
Regularity diagnostics applied to a turbulent boundary layer.
H. J. Bae, J. D. Gibbon, R. M. Kerr and A. Lozano-Duran
Turbulent-turbulent transition of a transient three-dimensional channel flow.
S. He, A. Lozano-Duran, J. He and M. Cho
Single-point structure tensors in rough-wall turbulent channel flows.
J. Yuan, G. Brereton, G. Iaccarino, A. A. Mishra and M. Vartdal
Virtual origins in turbulent flows over complex surfaces.
G. Gomez-de-Segura, A. Sharma and R. Garcia-Mayoral

Impact of transverse shear on turbomachinery endwall flow.
J. Lee, G. Xia, G. Medic and O. Sharma

V. Combustion
Scaling and modeling of heat-release effects on subfilter turbulence in premixed combustion.
J. F. MacArt and M. E. Mueller
Observable regularization of two-phase flows and reacting flows.
B. Aboulhasanzadeh and K. Mohseni
Direct numerical simulation, analysis, and modeling of the evaporation of multiple fuel droplets in a hot turbulent flow.
C. Duwig, G. Lupo, A. Gruber, L. Brandt, P. B. Govindaraju, T. Jaravel and M. Ihme
Physics-informed data-driven prediction of premixed flame dynamics with data assimilation.
H. Yu, T. Jaravel, J. Labahn, M. Ihme, M. P. Juniper and L. Magri
Generalized chaos expansion of state space models for uncertainty quantification in thermoacoustics.
C. F. Silva, P. Pettersson, G. Iaccarino and M. Ihme
A-posteriori evaluation of a deep convolutional neural network approach to subgrid-scale flame surface estimation.
C. J. Lapeyre, A. Misdariis, N. Cazard and T. Poinsot
Characterizing discretization and filter effects on LES via DNS-assisted evaluations.
A. K. Edoh and T. P. Gallagher

8. Participants' Countries/Institutions

Country	Institution
France	CERFACS
	Ecole Polytechnique
	INRIA
	ONERA
	Universite Paris-Saclay
Germany	Technische Universitat Munchen
Greece	National and Kapodistrian University of Athens
Italy	Politecnico di Bari
Norway	Norwegian Defence Research Establishment
	SINTEF
	Norwegian Research Center NORCE
	Norwegian University of Science and Technology
	University of Oslo
Spain	Barcelona Supercomputing Center
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Sweden	Royal Institute of Technology
United Kingdom	Imperial College London
	University of Birmingham
	University of Cambridge
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