EUROPEAN MECHANICS SOCIETY

Colloquium Final Report

N. 625 – Advances in LES of Turbulent Multiphase Flows

Dates and location: **22/06/2022 - 24/06/2022, Udine, Italy**

Chairperson **Cristian Marchioli (University of Udine, ITA)**

Co-Chairperson **Joern Sesterhenn (University of Bayreuth, GER)**

Conference fees

- In Person - PhD Student Attendee/Speaker Fee **395.0 €**
- In Person - Regular Attendee/Speaker Fee **475.0 €**
- Online - PhD Student Speaker Fee **345.0 €**
- Online - Regular Speaker Fee **425.0 €**
- Online - Attendee (Non Speaker) Fee **100.0 €**

What other funding was obtained? **Funding (1,000 EUR) from the University of Udine to cover the conference material offered to the in-person participants.**

What were the participants offered? **The services offered to in-person speakers/attendees included: Printed version of the Book of Abstract; printed version of the Scientific Program; stationery and other conference material; 5 Coffee & Tea Breaks, 3 lunches, a Welcome Cocktail and the Gala Dinner; 3-day access to a fully-equipped room, exclusively reserved for the Colloquium.**

The services offered to the online speakers included: Electronic version of the Book of Abstract; electronic version of the Scientific Program; Access to live streaming of the talks; Post-conference access to recorded talks.

The services offered to the online attendees included: Electronic version of the Book of Abstract; electronic version of the Scientific Program; Access to live streaming of the talks.

Number of members of Euromech (reduced registration fee) **17**

Number of non-members of Euromech (full registration fee) **21**

Applicants (members)

- Marco Atzori
- Marco Atzori
- Antonio Buffo
- Jesse Capecelatro
- Sergio Chibbaro
- Catherine LE RIBAULT

- Cristian Marchioli
- Francesco Picano
- Alessio Roccon
- Mohamed Aly Sayed
- Mohamed Aly Sayed
- Mohamed Aly Sayed
- Wolfgang Schröder
- Marco Vanni
- Sencer Yücesan
- Sencer Yücesan
- Rémi Zamansky

Applicants (non members)

- Gustavo Abade
- Gustavo Abade
- Antonella Abba'
- Laurent André
- Thibaut APPEL
- Luca Banetta
- HADRIEN CALMET
- Gabriele Camerlengo
- Salvatore Cito
- Max Hausmann
- Wei-Xi Huang
- Guodong Jin
- Perry Johnson
- Richard Meller
- Fernando Kevin Miranda Santa Cruz
- Jakub Nowak
- Jacek Pozorski
- David Richter
- Cheikhna Talebmoustaph
- Test Test
- Ivana Vinkovic

Scientific Report

Multiphase flows are ubiquitous in nature as well as technological applications, and are often turbulent. The resulting wide range of flow length- and time-scales makes direct numerical simulation of the micro-scale governing equations intractable for many of these applications. Hence, Large-Eddy Simulation (LES) has emerged as a powerful simulation tool for multiphase flows, especially shear-dominated and/or flows controlled by large-scale mixing. LES is a turbulent scale-resolving strategy that can be used to treat complex, multiphase flow topologies, but its success is intimately related to the ability to connect the super-grid (resolved) and subgrid (unresolved) physics of the flow.
The aim of the Colloquium was to discuss the latest advancements in LES-based simulations of multiphase flows, sharing modeling methods, difficulties and (rigorous or more phenomenological) analyses that can be of interest for both academia and industry. Because of their importance for practical applications, the Colloquium was focused on turbulent two-phase flows. To narrow down the spectrum of targeted applications, inert flows will be considered. One important issue, that is currently receiving a great deal of attention, is the development of predictive LES closures to be incorporated in the Lagrangian evolution equations for the dispersed phase: This task is challenging from a physical point of view -

proper Sub-Grid Scale (SGS) physics that reproduce the effect of the filtered flow scales must be included in order to capture the macroscopic particle dispersion characteristics - but also computationally - due to issues such as load balancing, particle tracking, data exchange, and control of statistical errors. A number of studies have been conducted for the case of dispersed gas-solid flows, e.g. through the development of stochastic SGS models for the dispersed phase. However, such models still lack the desired level of universality and the quality of their predictions depends critically on the accuracy of the mesoscopic closures describing the microscopic physics of the flow. Sharing recent modeling efforts will be certainly useful to improve current predictive capabilities.
A very active area of research is represented by droplet-/bubble-laden flows characterized by the presence of moving immiscible interfaces. The interaction of turbulence with a two-phase interface encompasses complex multiscale flow phenomena that lead to significant deformation rates of the dispersed phase (possibly leading to an increase of the inter-phase surface area due to breakup and coalescence) and to modulation of turbulence. Current use for LES for this kind of flows is still limited, mainly because of the challenge represented by the modeling of the smallest hydrodynamic scales, which are originated by the turbulence-interface interaction at the interfacial regions and can be a few times smaller than the Kolmogorov scale. An additional modeling challenge is represented by the SGS contributions to curvature, which must be taken into account to reproduce surface tension effects. It is thus crucial to discuss and compare the different approaches available and their modeling implications, in order to break new ground in a field of obvious broad engineering interest.
Overall, the use of LES for the numerical prediction of multiphase turbulent flows offers plenty of opportunities to improve our understanding of the link between modeling and physical processes involved. The challenge is to exploit at best the knowledge developed so far and the new computational capabilities in order to generate realistic transient simulations of turbulent dispersed and/or interfacial flows at reasonable computational costs and accuracy, and then use these results to improve models and make them interesting for practical applications (not just for academic purposes). For this reason, papers with a clear twist towards industrial or environmental applications have been solicited.

About 50 participants (40 speakers, 10 non-speakers) attended the Colloquium, which was held in hybrid form (in-person+online). The Colloquium was subdivided into 5 main blocks, each introduced by a keynote lecture. A brief summary of the topics discussed during the event is given below:

DAY 1. The morning of day 1 was focused on LES of particle-laden flows. The discussion was opened by the keynote lecture of Prof. Simon Schneiderbauer ("Interphase forces in turbulent dispersed multiphase flows") on the impact of interphase forces on the modulation of turbulence in multiphase flows. The discussion then continued addressing other crucial aspects of LES of particle-laden flows, including the role of sub-grid fields on particle statistics and small-scale processes in the case of homogeneous isotropic turbulence, the applicability of LES-based computational approaches to the study of erosion, transport and deposition processes (with specific reference to sand dunes evolution) or to the study of more industrially-relevant configurations, such as bubble columns or flows with separation.
In the afternoon, the discussions addressed the modeling issues associated with the application of LES to multiphase flows. The discussion, opened by the keynote lecture of Prof. Aymeric Vie entitled "Towards statistically-consistent formalisms for two-way coupled turbulent particle-laden flows", addressed a number of important sub-topics such as stochastic force models, wall-modeling approaches and hybrid modeling approaches for studying particle dispersion and deposition, subgrid

scale enrichment.

DAY 2. The morning of day 2 was focused on the multiphase applications that can be tackled by LES. The discussion was opened by the keynote lecture of Prof. Olivier Desjardins ("Sub-grid scale break-up modeling
for high-fidelity LES of liquid atomization") on the applicability of LES to liquid atomization processes, with specific reference to breakup and spray formation. The discussion then continued addressing a variety of important practical applications, such as flow of fluidized solids and bubbles in risers, two-phase flows in autoclaves, slaked lime dissolution and cavitation phenomena in hydrofoils.
In the afternoon, the discussions addressed the modeling issues associated to interfacial two-phase flows or flows with phase change, in particular related to airborne droplets and aerosols. The discussion was opened by the keynote lecture of Prof. Marcus Hermann entitled "Modeling the subgrid dynamics of immiscible interfaces with a dual scale approach", in which a dual-scale modeling approach developed to describe turbulent phase interface dynamics in a large-eddy-simulation-type spatial filtering context was presented. Then, the discussion continued addressing particle resuspension processes generated by impinging jets and particle deposition processes generated by swirling flows. The day was concluded by a focus session on airborne droplets and aerosols dynamics in the context of virus transmission via respiratory events. On the occasion of this session, the 2022 International CFD challenge on violent
expiratory events was launched, which has now come to an end and its results are being evaluated for publication in Physics of Fluids. This may be regarded as an important scientific outcome of the Colloquium.

DAY 3. In day 3, the Colloquium was held only in the morning, focusing the discussion on the Euler-Euler/Euler-Lagrange approaches. The session was opened by the keynote lecture of Prof. Antonino Ferrante entitled "From DNS to MANN-LES of droplet-laden decaying isotropic turbulence", in which Prof. ferrante presented a novel Euler-Lagrange approach to study the physical mechanisms of droplet/turbulence interaction via a mixed artificial neural network (MANN) approach for LES. The session continued with talks that explored both general and specific aspects of LES-based Euler-Euler and Euler-Lagrange approaches to the simulation of multiphase flows, and in particular two-phase flows, such as those occurring in atmospheric clouds or sedimentary bed-forms (as far as environmental applications are concerned) or submerged jets and flows near heterogeneous surfaces (as far as industrial applications are concerned).

Overall, the scientific program of the Colloquium has allowed plenty of time for discussions both during the Q&A session after each presentation and during the 30-minute long coffee breaks, the nearly 2-hour long lunch breaks (lunches were held just outside of the conference room and were attended by all participants, being included in the registration fee) and also during the dinners. Thanks to the contribution of all participants, and to the limited number of online talks, discussions on the various aspects of LES of Turbulent Multiphase Flows were very lively and engaging. This has allowed not only a significant advancement in terms of general consensus on several of the crucial aspects tackled during the Colloquium, but also an increased awareness of the current limits and potentials of LES, paving the way for the future research paths that the multiphase flow community should undertake on the subject.

To conclude this report, a sincere thank to Euromech for making this meeting possible and for providing financial and organizational support is in order.

Number of participants from each country

Country	Participants
Cyprus	1
Germany	5
Austria	5
France	6
Spain	2
Switzerland	3
China	2
Italy	7
Poland	4
United States	3
Total	**38**

Please send this report in electronic form to the Secretary General of EUROMECH, within one month after your Colloquium.