EUROPEAN MECHANICS SOCIETY

Colloquium n. 609 – Granular Patterns in Oscillatory Flows

Dates and location

8 September — 10 September 2021, Genoa, Italy

Chairperson

Marco Mazzuoli

Co-chairperson

Markus Uhlmann

Conference fees

- Early bird registration, PhD Student: **290.00 €**
- Early bird registration, Regular : **340.00 €**
- Online attendance: **100.00 €**
- Late registration, PhD Student: **340.00 €**
- Late registration, Regular: **390.00 €**

What other funding was obtained?

The Colloquium 609 was supported with an onerous contribution by the University of Genoa.

What were the participants offered?

In person event:
- Welcome Cocktail/Dinner at Castello Bruzzo (https://castellobruzzo.it/) on the 7th Sep
- nr. 3 Coffee breaks (8th-10th Sep)
- nr. 2 Standing Light Lunches (8th-9th Sep)
- nr. 2 Tea breaks (8th-9th Sep)
- Gala Dinner at restaurant "Il Marin" (https://ilmarin.it/) on the 8th Sep
- Conference material (printed book of abstracts, customised notebook, pen and shopper)

Online event:
- Online services provided by "the triumph" agency (colloquia@thetriumph.com)

All contributions were recorded. The videos are available through the Colloquium website.

Applicants (members)

1. Wim-Paul Breugem
2. Maurizio Brocchini
3. Gianmarco D'Alessandro
4. Matias Duran Matute
5. Erick Franklin
6. Aman Kidanemariam
7. Michele Larcher
8. Cristian Marchioli
9. Ben Nadler
10. Thomas Pähtz
11. Thorsten Poeschel
12. Thorsten Pöschel
13. Germain Rousseaux Rousseaux
14. Dominique Salin
15. Julian Simeonov
16. Biniyam Sishah
17. Alfredo Soldati
18. Bernhard Vowinckel
19. Nathalie Vriend
20. Francesco Zonta

Applicants (non members)

1. Daniel Ahmed
2. Willian Assis
3. Paolo Blondeaux
4. Joseph Calantoni
5. Martijn De Munck
6. Alejandro, Adrian Garcia
7. Gaoyang Li
8. Peter Nielsen
9. Jan Pralits
10. Anna Prati
11. Ali Salimi Tarazouj
12. Markus Scherer
13. Salmi Soraya
14. B. Mutlu Sumer
15. Martin Trulsson
16. Timo Van Overveld
17. Song-Chuan Zhao

Scientific report

1. Motivation
Natural phenomena associated with flows that we perceive as steady or at the equilibrium state at the temporal and spatial scales of our observation, are often actually the result of flow fluctuations occurring at much smaller or much larger scales. Such fluctuations can be erratic, like the velocity of small turbulent eddies, or exhibit a certain regularity, like the oscillatory flow induced by wind waves. The former are responsible for the random pick-up of sediment grains from the seabed, while the latter originate the sedimentary pattern that we all can observe close to the coasts. Besides the formation of bedforms under surface waves, some other glaring examples of phenomena that are strongly related to oscillatory flows are the acoustic streaming, the granular segregation, the assembly of motile bacteria due to their collective motion. Indeed, oscillatory flows can be considered as prototypes of accelerating flows, and insights obtained in such a basic field are fundamental. Oscillatory fluctuations can be secondary flows generated as an effect of the interaction of steady flows with wavy solid boundaries (and vice versa) or primary flows generated by harmonic oscillations of boundaries (which can coincide with solid particles). In either case, solid-fluid interactions are clearly fundamental as the dynamics of the boundaries is coupled with that of the flow. The nature of these interactions can be purely mechanical (e.g. sediment grains) or involve for instance electrostatic forces (such as those acting on cohesive particles) or be driven by the biological collective behaviour. Granular patterns, which stem from solid-fluid interactions, reflect the microscopic properties of granular matter. The interest for granular and oscillatory flows is growing in different scientific communities, which is witnessed by the increasing number of articles and projects devoted to the subject, both for scientific purposes and because their knowledge finds applications in the environmental and industrial fields. The present colloquium provided an opportunity to discuss themes related to the mechanics of granular flows and suspensions and to the development of patterns of particles subjected to the action of oscillatory flows, highlighting the advancements and emphasising the improvements that the recent numerical and experimental techniques, such as DNS, LES, PTV and tomographic PIV, have led to our understanding of the interaction between particles and vortex structures. The objective of the colloquium was promoting the dissemination of recent developments and identifying innovative approaches of investigation of granular patterns through the cross-fertilization among different scientific communities.

2. Colloquium contents
The Colloquium was carried out in hybrid modality in accordance with the constraints imposed by the COVID-19 pandemic. Nonetheless, 30 presentations were given: 13 talks took place in presence and 17 contributions were given online. Moreover,

three key lectures were given by the invited speakers Jason Butler (University of Florida, USA), Enrico Foti (University of Catania, Italy) and Daniel Ahmed (ETH, Switzerland), who introduced three of the significant themes of the Colloquium, namely the mechanical behaviour of granular suspensions subject to oscillatory flow, the effect of sea-waves on the marine sediment and exploitation of oscillatory flow properties for biomedical and industrial applications, respectively. In the spirit of the Colloquium, the participants showed multidisciplinary contributions of high quality. The scientific issues and the main achievements presented during the Colloquium are reported in the following.

2.1 Pattern formation in wall-bounded conditions
Basic mechanisms of particle attraction and repulsion associated with the secondary flows arising in a wall-bounded oscillatory flow were presented. It was found that such mechanisms are responsible for the formation of particle patterns which might be responsible for the origin of bedforms on a granular bed subject to flow oscillations in the viscous regime. In the oscillatory channel flow configuration, flow oscillations were found to generate a cross-flow which promoted the formation of particle concentration patterns. Moreover, the phenomena at the origin of bedforms induced by the flow generated by a vertically oscillating flexible plate was the object of fruitful discussions. The particle dynamics in turbulent steady wall-bounded flow were also described and useful indications for the modelling of complex suspensions were provided. The effect of the Reynolds number on the segregation of non-axisymmetric fibres was discussed on the basis of experimental observations. The effect of thermally-stratified turbulent channel flow on the dynamics of semi-buoyant particles was also described. Finally, the preliminary results of a numerical investigation of the dynamics of turbulent slurry pipe flow were shown.

2.2 Suspension mechanics
In the absence of the bottom confinement, the effects of flow oscillations on viscous dense suspensions was the object of three contributions. The granular stresses developing in a bed of cohesionless spherical particles subject to flow oscillations were shown and compared with those that can be predicted using two-phase rheological models. Oscillatory flows could be used to unblock shear-jammed configurations. In particular, it was shown that ellipsoidal particles changed their orientation during the oscillation period thereby reducing the overall viscosity of the mixture with respect to the case where spherical particles were employed. On the other hand, the orientation of grains can induce shear thickening and eventually cause the jamming depending on the grain geometrical properties. The hydrodynamics of coarse-grained granular material was improved with the objective of fluidised-bed modelling. In microgravity conditions, the aggregation rate of cohesive particles was experimentally observed which has been shown to be proportional to the square root of time, more rapid than expected if only Brownian motions were present. Therefore, the effects of high frequency oscillations, associated with the space navigation, on the aggregation mechanism could be the missing ingredient to explain the measurements.

2.3 Sediment transport and origin of bedforms
A remarkable number of contributions was devoted to the sediment transport mechanics. The sediment transport associated with a turbulent oscillatory flow over a bed of cohesionless sediment was described in detail using particle-resolved direct numerical simulations (DNS). For the values of the parameters characterising wind-waves, the effects of the flow unsteadiness on the sediment flow rate were found quite small. Similar DNSs were also used, for turbulent open-channel flows, to compute the distribution of the bottom shear stress along flow-transversal bedforms and to explain the origin of sediment ridges. How reliable actually are wall-resolved and wall-modelled large eddy simulations in predicting the sediment transport? Such a question was also discussed in the Colloquium with the objective of extending the small computational domains characterising the computationally challenging DNS to spatial

scales that are relevant for engineering applications. In the context of the sediment transport mechanics, remarkable advances were made in the knowledge of the fundamental processes related to the formation and evolution of bedforms. The dynamics of the vortices stemming from the flow separation at the crest of small-scale sea bedforms were described using the RANS approach and their effect on the bedform evolution were emphasised. It was impressive to see that PIV measurements could also be made directly from the field. At a larger scale, the vortical structures induced close to the bottom and at the sea surface by breaking waves were analysed experimentally, using the PTV technique to identify the cores of the vortices, and numerically by means of 2D RANS simulations. Strong vertical pressure gradients associated with the interaction of turbulent vortices developing close to the bottom with a granular bed were found to cause the displacement and the transport of sediment particles. The action of fluid jets, like those generated by the rotor of helicopters, impinging into the sediment and the interaction between the surface vortices associated with breakers and the nearbed turbulent structures were described exploiting both experimental and numerical results.

2.4 Bedform dynamics and modelling
Bedforms adapt to transient flow configurations exhibiting exotic dynamics. Three contributions were devoted to interpret the behaviour of merging, repulsing and splitting dunes with the purpose of developing relatively simple models that predict the bedform evolution. Indeed, significant efforts were devoted to the modelling of bedforms. Beyond DNS, which can be considered as the numerical counterpart of physical experiments, Eulerian two-phase models were employed to investigate the evolution of ripples in an oscillatory flow. The results resembled the dynamics of actual ripples generated by wind-waves. On the basis of the results obtained with the ROMS model to simulate the flow over tidal sand-waves the relative enhancement of turbulence on the lee side of bedforms with respect to previous analytical predictions could be explained. Finally, the stability analysis of an oscillatory boundary layer at the bottom of finite amplitude surface waves was performed, and the mechanism of transition to turbulence was described.

3. Comments about the new “hybrid modality” experience
The Colloquium #609 was the second EUROMECH Colloquium that was organised in hybrid modality after the Colloquium #614. In fact, the COVID-19 pandemic did not allow several participants to join in presence because of travel restrictions. The Colloquium was successful, and many participants have thankfully left excellent comments. Our comments are left in the following to support the organisation of future Colloquia in hybrid modality.
Available recordings: all the presentations were recorded, and the videos are available on the website https://609.euromech.org/video/ using the following credentials:

username: 609
password: oscillatory

The recordings help remote participants from countries within different time zones to comfortably access every contribution.
Online participation to the sessions: attention was paid to make the remote participants in the conditions to easily interact with those in presence and vice versa during the QA sessions after each talk. The scientific discussions took place fluently.
Online discussions during the breaks: during the breaks (coffee/tea breaks, lunch time) the online participants exploited the “virtual coffee room” where the scientific discussion could actively continue. However, it should be mentioned that there was less exchange between on-site/remote participants during those virtual coffee breaks. For this purpose, communication terminals would need to be installed around the spaces used in the coffee breaks.
There were no online counterparts of social events. This fact still represents the main difference between virtual and in-presence Colloquia.

4. Conclusions
The colloquium 609 succeeded in gathering leading experts on the motion of grains in oscillatory flows who delivered excellent presentations. The participants (on-site and remote) engaged in fruitful scientific discussions which will hopefully have a noticeable impact on the future development of the field.

Number of participants from each country

Country	Participants
Italy	8
Netherlands	4
Germany	4
United States	3
Brazil	2
Canada	2
Australia	2
China	2
France	2
Switzerland	1
Argentina	1
New Zealand	1
Algeria	1
Turkey	1
Sweden	1
United Kingdom	1
Austria	1
Total	**37**