2017 - 2018 Grand Challenge Award – Final Report

Awardee: **Fabrizio Bisetti, Assistant Professor**
Aerospace Engineering and Engineering Mechanics

Research Award Title: Deformation of Reactive Surfaces in Shear Generated Turbulence

Research summary

Interfaces are ubiquitous in natural and technological flows. When two fluids interact, the transfer of mass, momentum, and heat takes place across a thin interface. The area of the surface determines the rate of the exchanges between the two fluids. In turbulent flows, the rates of growth and destruction of interfaces are challenging to predict due to the presence of a wide range of scales, resulting in stretching, folding and destruction of the interfacial surface. In engineering applications (e.g. the burning rate of a flame, or the chemical conversion rate in a reactor), where flows often operate at high levels of turbulence, these mechanisms are dominant. There is an urgent need to formulate reduced models that capture the effect of turbulence on the evolution of surfaces. Motivated by the transformative impact that these models would have in technical and geophysical applications, we set out to elucidate the poorly understood mechanisms governing the interaction of surfaces with turbulent flows.

The Grand Challenge Award was used to support preliminary research work in preparation of a research proposal that was later submitted to and funded by the National Science Foundation (see Awards & recognitions received Section below).

The overarching goal of the project is to understand the evolution of surfaces in turbulence and to identify the dependence of its growth rate on the Reynolds number. To this end, a novel von Karma n turbulent swirling flow device featuring a shear-driven closed flow between counter-rotating impellers is considered. A schematic of the device is provided in Fig. 1 and the flow is shown in Fig. 2. The device generates intense turbulence by introducing a large mean shear and replicates practically relevant conditions in a controlled fashion. Reactive surfaces, i.e. thin fronts which propagate and can be thought of local long-time asymptotic solutions to the Fisher-KPP equation, are employed to study the interaction of surfaces and turbulence.

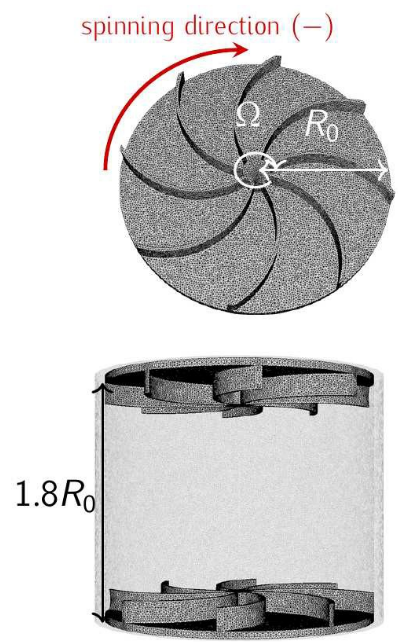

Figure 1 - Schematic of the von Karman device.

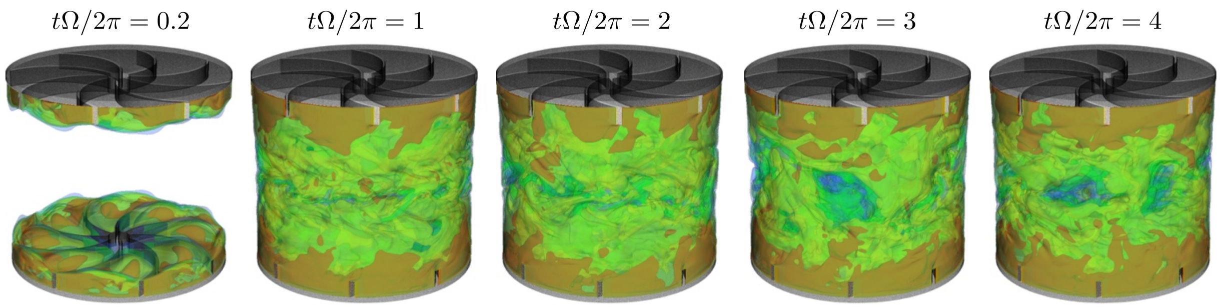

Figure 2 - Iso-surfaces of velocity in the von Karman device

We addressed and answered the following specific research questions:

- By what factor y does the growth rate of a surface area increase if the largest scales of flow increase by a factor of x?

- What parameters control the evolution of surfaces in turbulent flows?

The main conclusions emerging from our recent work during the past 3 years (including the first year, funded in part by the Grand Challenge Award) can be summarized in two points.

1) When the temporal evolution of the surface was simulated via large-scale simulations of turbulent reactive fronts at increasing values of the Reynolds number and compared across cases, **the increase in surface area brought by turbulent wrinkling, normalized by a suitable mean area, does not vary with turbulence intensity (velocity fluctuation) when holding the Reynolds number constant.**

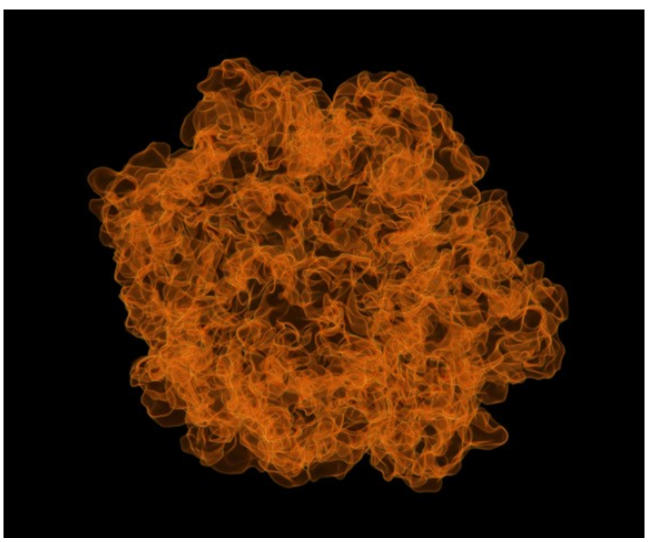

Figure 3 – Reactive surface expanding in isotropic turbulence.

2) We demonstrated clearly that the extent of "surface packing", measured as the ratio of the surface area to the volume of linear size proportional to the size of the vessel, increases rapidly with the Reynolds number. **This implies that scale separation, as measured by the Reynolds number, is the primary cause of the increase in the area of turbulent interfaces** and puts forth a new line of inquiry into the fundamental mechanisms behind this macroscopic behavior. An example of "packing" is provided in Fig. 3, which shows a reactive front propagating outward in isotropic turbulence (Kulkarni et al, JFM, 2020).

Presentations

1. T Kulkarni, R Buttay, M Kasbaoui, A Attili, and F Bisetti. "On the role of scale separation in the enhancement of burning rates in turbulent premixed flames." 11th U.S. National combustion meeting, Pasadena, California, March 24-27, 2019.
2. T Kulkarni, R Buttay, M Kasbaoui, A Attili, and F Bisetti. "The scaling of the surface area of turbulent premixed spherically expanding flames with Reynolds number." 17th International Conference on Numerical Combustion, Aachen, Germany, May 6-8. 2019.
3. T Kulkarni∗, R Buttay, M Kasbaoui, A Attili, and F Bisetti. "On the role of scale separation in the enhancement of burning rates in turbulent premixed flames". 11th U.S. National combustion meeting, Pasadena, California, March 24-27, 2019.
4. T Kulkarni∗, R Buttay, M Kasbaoui, A Attili, and F Bisetti. "The scaling of the surface area of turbulent premixed spherically expanding flames with Reynolds number". 17th International Conference on Numerical Combustion, Aachen, Germany, May 6-8, 2019.
5. M H Kasbaoui∗ and F Bisetti. "Numerical characterization of the von-Karman swirling flow with a moving Immersed Boundary method". 71st meeting of the American Physical Society, Division of Fluid Dynamics, Atlanta, Georgia, Nov 18-20, 2018.
6. T Kulkarni∗, M Kasbaoui, R Buttay, A Attili, and F Bisetti. "On burning rate enhancement in spherically expanding turbulent flames". 71st meeting of the American Physical Society, Division of Fluid Dynamics, Atlanta, Georgia, Nov. 18-20, 2018.

Journal Papers

1. T Kulkarni, F Bisetti, Proc. Combust. Inst. (2020), in press
2. T Kulkarni, F Bisetti, Proc. Combust. Inst. (2020), in press
3. T Kulkarni, A Attili, M. H Kasbaoui, R. Buttay, F Bisetti, J. Fluid Mech. (2020), in press
4. H Kasbaoui, T Kulkarni, F Bisetti (2020), Phys. Rev. Fluids, under review

Awards & recognitions received

1. NSF award #1805921, "Collaborative Research: Experimental and numerical study on the Reynolds number dependence of surfaces in von Karman turbulent swirling flows." $500,000 (09/2018-08/2021).