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Report on the PhD thesis of RNDr. Patrick Švančara

To whom it may concern.

The topic of P. Švančara's PhD is the study of flows of superfluid Helium, notably superfluid turbulence. Velocimetry in superfluid Helium is extremely challenging due to the difficult access to the fluid in the cryostat, the extremely low temperature and the fact that the range of length scales characterizing turbulence reaches almost atomic scales because of the existence of the quantized vortices in the superfluid phase. A major evolution occurred in the last 15 years with the use of particles tracking velocimetry using high speed cameras. In this way it was possible to improve by several orders of magnitude the spatial resolution of velocity measurements and even to visualize the dynamics of individual quantum vortices. The Prague Superfluidity Group played a leading role in this respect. When reading P. Švančara's thesis, I am truly impressed by the quality of the experiments that are reported there. He reached a very high-quality control of the experimental conditions as well as of the seeding of the particles in the flow which is a highly delicate and crucial step. In particular, he used different gases (hydrogen, deuterium) to fabricate flakes with more recently the use of deuterium hydride flakes which have the great advantage of being neutrally buoyant so that the measurement is not impacted by sedimentation of the particles.

Another nice quality of this work is the collaboration with French colleagues from Institut Néel in Grenoble to exchange expertise on cryogenic PTV experiments and to use second sound tweezers developed in Grenoble. These tools have the great advantage of enabling high spatial resolution measurement of the vortex line density. This collaboration already allowed a joint publication and I have no doubt that others should follow.

Superfluid flows can be induced by inertial mixers and such flows are characterized by the fact that the velocity of the normal and superfluid phases are very close to each other's. At large scale, these flows resemble a lot, classical flows. By contrast, thermal counter flows are fully specific of superfluid fluids as normal and superfluid phase follow extremely distinct paths, the large-scale velocities being flowing in opposite directions. Channel flow experiments reported in chapter 3 of the thesis address in particular the issue of the motion of particles in such a flow. As the particles are coupled to both phases the resulting motion is highly complex. Indeed, the normal fluid drags the particle due to viscosity. However, the superfluid phase interacts as well with the particle through their trapping around quantum vortices so that the particles motion reflects also the dynamics of quantum vortices, notably the extremely violent events of vortex reconnection. By comparing both ways of generating superfluid turbulence, P. Švančara observed very different behaviors. For inertial forcing, using advanced statistical data processing, he showed that the motion of the particles has similar characteristics than that observed in classical turbulence, notably the time irreversibility due to the energy cascade in scale, although the dissipation mechanisms are quite different. The statistical properties of particle velocity in the counter flow are totally different due to the fact that the particles have a dual personality sometimes following one phase then the other. This is reflected also in the study of the velocity probability density that shows different properties as a function of the strength of the counterflow displaying in particular a bimodal distribution with velocities close to the normal velocity but also to half the normal velocity. This observation is really puzzling to me and I wonder if

a physical mechanism has been proposed to explain this observation. P. Švančara also studied the region of the flow close to the heater which is very original. He observed in particular a stronger vortex line density close to the heater wall. A question is that of the physical mechanism that would be responsible for this observation in a region which is quite complex with the conversion of superfluid to normal fluid. Another question is if this observation using particles could be confirmed with second sound probes? The various experiments reported in the chapter 3 are quite innovative and very high quality. They stimulate many questions for future work on particle dynamics in superfluid flows as well as on the understanding of these flows.

The chapters 4 and 5 deal with jets. These are among the canonical configurations typically studied in turbulence, due in part to their interest in industrial processes as well as to their relative geometrical simplicity. Again, superfluid turbulence shows a specificity as compared to normal jets, that is that the injection can be made using counterflows. Chapter 4 is concerned by continuous jets, while chapter 5 deals with pulsed jets that create vortex rings. The experiments reported in chapter 4 result from the collaboration with Institut Néel in Grenoble and they were done in Grenoble. Second sound tweezers are being used to investigate the vortex line density maps in the jet as function of the downstream and radial positions, at different temperatures. These measurements illustrate the performance of the tweezers in terms of spatial resolution. Self-similar maps are reported as expected from previous measurements. Although these data are somewhat preliminary, their interest is that they provide so called “turbulent” data, i.e. data on the turbulent part of the velocity, specifically the superfluid part. The discussion of the scaling quantities of the self-similar maps show similarities both to normal jets but also to thermal counterflows. Thus, this preliminary study raises questions on the physical mechanisms of the vortex line generation. There is no doubt that it will trigger further studies.

Chapter 5 reports investigations of vortex rings. A first investigation was made using particle tracking and an evaluation of the vorticity using the Lagrangian pseudo vorticity. I find this experiment very elegant and creative. It was published in J. Fluid Mech. The measurement shows a self-similar development of the vortex ring similar to classical rings. The exception of the estimation of the vortex ring radius deserves further study to understand it. The second half of the chapter reports a proof of concept of the simultaneous use of particle tracking and second sound studies which seems to me as a promising perspective for turbulent studies. I wonder how the second sound quantitatively behave for strongly polarized vortex tangles as in vortex rings?

After reading P. Švančara’s thesis, I must say that I am quite impressed by the variety of experiments that are reported in it. This impression is further reinforced by the fact that cryogenic experiments are notoriously challenging. Turbulence is already a difficult topic and adding a superfluid component in it, certainly does not make it simpler. The studies reported here include several experimental setups and use both particle tracking velocimetry and second sound measurements. I also appreciated the clarity and rigor developed in the data analysis and the care to understand the limitations of the measurements and thus of the bounds to their interpretation. This thesis appears to me as a very high-level work in terms of quality of experimentation. It lies among the best theses I had to read as a reviewer of PhD theses. For sure, some preliminary studies introduced in the thesis will be followed by many developments. They will contribute to expanding the tools available to the studies of cryogenic flows and to the understanding of turbulence in cryogenic fluids, which is the object of an increasing number of investigations.

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