Journal of Fluids Engineering

Technical Forum

Questions in Fluid Mechanics: Opportunities and Challenges of Flow Experiments in Helium

by K. R. Sreenivasan[1] and Russell J. Donnelly[2]

One of the frontier areas in low temperature research is in the micro-Kelvin range. The other frontier, with which this note is concerned, lies in harnessing helium in place of air and water for flow research, model testing, and turbulence experiments at high Reynolds numbers. Above the so-called λ-transition (which occurs at about 2.2 K), helium is a classical Navier-Stokes fluid, and offers two advantages. First, its low kinematic viscosity (on the order of 2×10^{-4} cm^{2}s^{-1} compared to 10^{-2} for water and 0.15 for air), makes it possible to create, for a fixed Reynolds number, a flow with an apparatus which is fifty times smaller than that using water and seven hundred and fifty times smaller than that using air; this reduced size diminishes both capital equipment and operating costs by orders of magnitude. Second, by varying the pressure of gaseous helium, many decades of Rayleigh numbers can be achieved in a convection cell of a fixed size; this flexibility is ideal for research purposes.

This much has been known for a long time. Why, then, has no concerted effort been made to take advantage of these features? The answer is partly the natural resistance to adopting something novel, partly the hassle of refrigeration and the cost of installation when a helium facility exceeds a modest scale, and partly the extra demands placed on instrumentation by the small-scale of the apparatus. For instance, at a Reynolds number of ten million, easily achieved on a 10 cm model, the viscous sublayer is on the order of 10 μm, not accessible to meaningful measurements with the instrumentation available today. While forces and moments can indeed be measured accurately in helium flows—in fact the splendid technology of superconductors becomes available in liquid helium—demands on aerodynamic smoothness of testing models and the like will become more stringent. These issues—both favorable and unfavorable—have been discussed in the book *High Reynolds Number Flows Using Liquid and Gaseous Helium*, edited by R. J. Donnelly, Springer-Verlag, 1991.

Some new developments may well have placed helium facilities above the threshold of uncertainty. As is well known, the Department of Energy (DOE) was engaged in a project on Superconducting Super Collider in Waxahachie, Texas. Among the achievements made there was the construction of a unique and massive refrigeration facility, originally intended for cooling various SSC components such as magnets. This facility, constructed at the cost of about $32 million, consists of three independent helium refrigeration systems, each with a 4 kW capacity at the temperature of 4.5 K, and is now available for other uses. This availability has created a unique opportunity for constructing and operating *much bigger* helium facilities at much less cost than was possible until now.

Quite early in the days of the SSC project, we had recognized the advantage of constructing an off-line facility at the SSC Laboratory for the study of heat transfer and turbulence in helium gas. This proposal, received with enthusiasm at the time, lay dormant when the status of the SSC was hanging in balance. Following its eventual termination by the Congress, DOE solicited expressions of interest for using the facilities already in place. Along with Professor Robert Behringer of Duke University and Dr. Michael McAshan, formerly the Head of the Cryogenics Department of SSCL, we re-expressed an interest and, with some support from DOE, are now engaged in a study of the precise scientific objectives, design and instrumentation, and prospects as well as problems associated with the facility.

A few details might be worth mentioning even at this preliminary stage. The proposal is to build a large helium cell (on the order of 10 m in height and about half the height in diameter) which could be used for several experiments forming a coherent program of research. The most obvious candidate is a convection experiment using helium gas; by scaling up the pioneering experiments of A. Libchaber and colleagues (see, for example, the 1991 Ph.D. thesis of X. Z. Wu of the Department of Physics at the University of Chicago), it is estimated that Rayleigh numbers in the vicinity of 10^{18} can be produced without significant non-Boussinesq effects. These Rayleigh numbers come close to those attained in solar convection, and allow both the testing of the scaling laws expected at high Rayleigh numbers and the elucidation of the mechanisms of turbulence convection. The refrigeration needs are estimated to be on the order of 1.5 kW, well within the capacity of a single refrigeration unit at SSCL. One can also use the facility to study grid turbulence at high Reynolds numbers (typical mesh Reynolds number of the order of 20 million) by sweeping the grid (with and without heating) across the cell and allowing the resulting turbulence to decay. In a 1988 Ph.D. thesis of the Department of Mechanics and Materials Science at Johns Hopkins University, M. D. Walker has demonstrated the advantages of this configuration for studying grid turbulence. It is thought that these studies will provide the much-needed high-Reynolds-number measurements of classical features of shear-free turbulence both as a testing ground for

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competing theories and as a point of departure for shear flow turbulence with attendant complexities and constraints. Other possibilities such as oscillating and pulsed grid experiments, towed spheres, and so forth, are being considered. We are also proposing to undertake a study for establishing, within the convection cell, a helium tunnel for very high-Reynolds-number model testing purposes.

The venture is not without some uncertainties. The velocity and temperature scales to be resolved in these experiments are estimated to be on the order of tens of microns, between one and two orders of magnitude smaller than those encountered *typically* in moderately high Reynolds number facilities. Thus, an issue that needs to be addressed is one of suitable instrumentation. Modern developments in micro-electro-mechanical systems seem to allow the measurement of fluctuating temperature, wall stress and wall pressure with Kolmogorov scale resolution; also possible are variants of shadowgraph and schlieren techniques. In liquid helium, the use of quartz microspheres and frozen hydrogen-deuterium mixtures has already been demonstrated for flow visualization, as well as for laser-Doppler velocity measurements. With good tracer particles comes the feasibility of using particle image velocimetry. In the presence of substantial mean flow, micron-sized hot-wires using superconducting and resistive thin films can be (and have been) used for turbulence velocity measurements. In spite of the progress already made in these various directions, it is clear that some nontrivial work will be needed before their potential and limitations can be established satisfactorily.

The turbulence community has been in constant search for ways to reach high Reynolds numbers. Helium offers a way to progress rapidly in this desired direction. When coupled with the tools of low temperature physics and the unique opportunity offered by the cryogenic facilities at the site of SSCL, time seems ripe for moving ahead. Opportunities and challenges often go together, and this particular opportunity comes with the challenge—quite realizable, it would seem—of extending instrumentation to increasingly finer scales of resolution.

In keeping with the spirit of this Column, it is useful, in addition to inviting comments on it, to end with two questions: (*a*) What other uses can the unique facility now sitting in Texas be used for fluid-dynamic research purposes? (*b*) What new developments in instrumentation can be brought to bear usefully on the helium experiments presently contemplated?

Comments on the Policy Statement on Numerical Accuracy

by Joel H. Ferziger[1]

Although I did not participate in the writing of the Policy Statement on Numerical Accuracy (Freitas, 1993), I have urged such a policy for many years and have read it, the comments on it by Shyy and Sindir (1994) and the various responses to those comments (Vanka, 1994; Freitas, 1994, Roache, 1994) with great interest. I would like to make the following suggestions and comments.

There seems to be no question that reporting of numerical accuracy is central to assessment of the quality of work in computational fluid dynamics (CFD) and that any paper published in this (or any other) journal must contain an assessment not only of the numerically introduced errors, but those arising from other sources (modeling, for example) as well. I would leave the matter at that.

It should not be our business to specify what methods may or may not be used. The range of methods in use is so broad that trying to police this issue will become very difficult. While I personally regard first order upwind methods as passe, it is not my job to prevent others from committing what I regard as foolishness. If someone wishes to spend more than necessary to find a solution, that is his/her business. However, I want to be assured of its accuracy, and of course, I want to retain the right, as a reviewer, to comment on the effectiveness of the methods used.

The required accuracy is a function of the field in which the work is done. What is acceptable to one field may be completely unusable to another. The *Journal of Fluids Engineering* covers a wide enough range of subjects that no uniform criterion can or should be given. A requirement that accuracy estimates be given and their genesis be carefully explained should be the only absolute. On the other hand, a referee should be permitted (indeed, encouraged) to recommend rejection of a paper on the ground that the solutions it contains are not accurate enough.

The judgment as to what constitutes quality and ultimate responsibility for seeing that the intent of the policy is carried out must remain, as it always has, a matter of the judgment of editors and reviewers. It is this author's hope that they will remain firm and consistent in the face of complaints that may issue from authors. This behavior will go a long way to further improving the quality of this journal.

I would like to close with a few remarks on the perspective by Douglas and Ramshaw (1994). They write "these concepts (essentially the issues addressed by the policy statement) are largely irrelevant to large-scale practical engineering applications of CFD"; this is a statement that (with variations) is often made. I believe it is more correct to say some engineering problems are too difficult to treat routinely with sufficient accuracy using CFD at the present time. While it is possible to correctly predict trends from computations that are somewhat inaccurate, when the errors are too large, it may not be possible to predict even the trend correctly. Thus, there are engineering problems for which one may need to forego CFD altogether until methods and/or computers are up to the task or use other approaches in conjunction with CFD. Development of methods for these problems is needed but should not be used prematurely. One should take advantage of whatever CFD can provide, but to adopt the attitude that because computers exist, we must solve the problems using CFD, may be flirting with danger.

These authors also address the issue of robustness, one that will be with us for a long time to come. A code that could be easily installed and run on any computer and would always produce reliable answers is the ideal, but no such method exists at present. Although the authors recommend methods that are

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