Top marks

Exclusive interview with the University of Alabama's Dr Phillip Ligrani: Behind the scenes of his award-winning research into innovative pumping devices

In early 2024 Dr Phillip Ligrani, Eminent Scholar in Propulsion and Professor of Mechanical and Aerospace Engineering in the College of Engineering at The University of Alabama in Huntsville (UAH) was awarded the prestigious American Society of Mechanical Engineers' (ASME) Henry R Worthington Medal for his work in developing innovative micro-, millimeter- and macro-scale pumping devices.

The Henry R Worthington Medal, which was established by Worthington Pump back in 1980, is bestowed for eminent achievement in the field of pumping machinery, systems, and concepts. Dr Ligrani's innovations are beneficial to a variety of different applications, according to UAH, such as transporting biological samples and supplying coolant to components subject to thermal loading.

The Henry R Worthington Medal provides additional recognition of a very successful career for Dr Ligrani, who has held top engineering roles at several leading universities around the world over the past 30 years, including at Saint Louis University and the University of Utah in the US, and the University of Oxford in the UK. He also held a Distinguished Advisory Professorship at Inje University in South Korea, and a Visiting Professorship at Shanghai Jiao Tong University in China. He is also a Fellow of ASME, an Associate Fellow of the American Institute for Aeronautics and Astronautics (AIAA) and is an elected member of the European Union Academy of Sciences (EUAS). He has received numerous academic awards and recognitions from the University of Alabama in Huntsville, as well as from the AIAA, and the ASME.

Pump work

Dr Ligrani's first work on pumping systems began around 2003 and involved the development of rotary shaft pumps (RSPs), which was motivated by the need for a simple and effective shrouded pump configuration. "The resulting RSP versions were unique with effective pump performance and characterized by design simplicity and ease of manufacture. Such advantages were illustrated by the impeller of the first RSP pump prototype, which was made by boring a 1.168mm hole in one end of a 2.38mm diameter shaft and cutting slots in the side of the shaft at the bottom of the bored hole, such that the metal between the slots defined the impeller blades. With this arrangement, the impeller blades and slots were 0.38mm tall," explains Dr Ligrani.

"Pump development involved the testing of several impeller designs over a range of operating conditions. Pump performance characteristics, including pressure rise, hydraulic efficiency, flow rate, and slip factor [referring to pump slip effects wherein the flow trajectory does not follow the contour of a pump impeller], were determined for several different pump configurations, with maximum flow rate and pressure rise of 64.9ml/min and 2.1kPa, respectively, when the working fluid was water," he adds.

Follow-on research and development efforts addressed the optimization of RSP performance, which was accomplished by comparing the performance of four different centrifugal rotary pump configurations: a hooked blades pump, a backward-curved blades ID=12.7mm pump, a contoured base pump, and a backward-curved blades ID=19.1mm pump, where ID was inner diameter. Each of these devices utilized the same general unique and simple impeller design where the blades were directly integrated into a shaft with an outer diameter of 25.4mm. Presented for each pump were performance data including volumetric flow rate, pump head, and hydraulic efficiency. When pumping water, the most optimal arrangement was the hooked impeller blades configuration, which produced a maximum flow rate of 3.22L/min and a pump head as high as 0.97m.

The work of Dr Ligrani, as recognized by the Henry R Worthington Medal, involved the development of innovative and unique pumping concepts and devices, such as the RSPs, with micro-, millimeter-, and macro-scale flow passage arrangements in consideration of the displacement of fluids subject to diverse physical phenomena. In addition to the development of different types of RSPs, his innovative contributions to the pumping sciences include different types of viscous disk pumps (VDP), an osmotic dispense pump for operation at different temperatures and pressures, and a viscous disk air flow displacement device (VDAFDD).

"A variety of different fluids are employed within these devices, including water, 5W-30 motor oil, sucrose solutions, polyacrylamide polymer solutions, and gases such as helium and air," he explains. "Of particular significance are the diversity of physical phenomena which are evaluated and investigated, such as elastic instabilities and elastic turbulence, convective heat transfer, rarefaction slip effects in liquids, rarefaction slip effects in gases, Newtonian flow behavior, and non-Newtonian flow behavior." Note the slip within this context is due to near-wall rarefaction phenomena.

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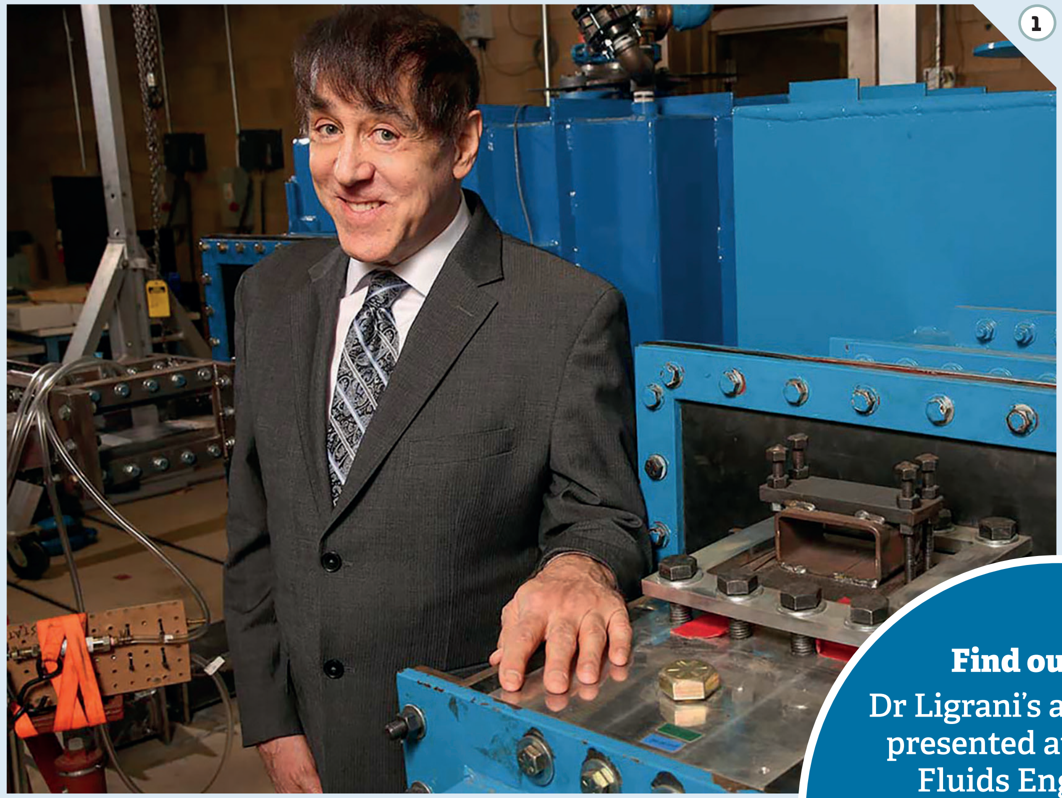

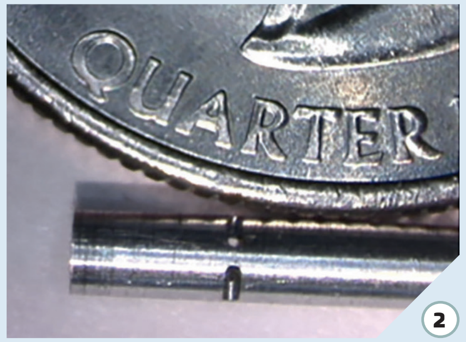

1. Dr Ligrani in one of his laboratories at the University of Alabama in Huntsville

2. Photograph of rotary shaft pump (RSP) with an outer diameter of 2.38mm next to a US quarter coin

Experiments in Alabama

Currently VDP devices are employed for experimental investigations at the University of Alabama, which consider rarefaction slip phenomena. "Here, rarefaction slip occurs when flow passage dimensions are on the order of the size of the mean free path of the flow gas molecules," explains Dr Ligrani. "The flows of interest involve a combination of shear-induced Couette flow and pressure-driven Poiseuille flow, which are present as a disk is rotated along the top of a C-shaped fluid passage. Measured are the static pressure rise, volumetric flow rate, and rotational speed of the disk. Surfaces with different roughness textures are used along the bottom of the C-shaped fluid passage to induce different amounts of rarefaction slip. Present efforts are focused on surface textures with mean roughness heights that are of the order of the magnitude of molecular mean free path. The parameter which characterizes such rarefaction effects is the Knudsen number, which, for the present investigation, ranges from 0.001 to 0.05 for the considered fluid mediums: atmospheric air and helium.

"The goal is development of improved analytic models which more accurately account for the effects of rarefaction slip. Such models are important for micro-scale fluid flow environments, as well as for supersonic and hypersonic vehicles travel in the upper atmosphere, where the atmospheric gas is naturally rarefied," he adds.

The micro-scale VDP arrangements were also developed to create well controlled and deterministic flow environments to investigate and illustrate elastic turbulence and elastic instabilities. "Here, elastic instability is characterized by the development of local secondary flows, and increased local mixing, which are due to local stretching, convolutions, and twisting of long-chain flexible polymers, which are distributed throughout the viscoelastic fluid," says Dr Ligrani.

"Recent advances in electronics cooling, bioengineering, and bio-medical engineering, which involve fluid flows within micro-scale and millimeter-scale passages, require control and enhancement of mass, momentum, and thermal transport levels. However, numerous challenges are inherent to implementing enhancements of these quantities within such small-scale environments, where length-scales are very small, flows are generally laminar, local fluid shear rates are augmented, and local Reynolds numbers are on the order of one. One solution, which is gaining increasing attention, is through the implementation and use of elastic instabilities and elastic turbulence," he adds.

Future developments

According to Dr Ligrani, he is now working on the development and design of pumping devices which operate to provide coolant for the thermal management of high-power laser diode arrays (LDA) within solid-state high energy laser assemblies (SSHEL). "The key for thermal management of electronic cooling components, as well as for high-power LDAs within SSHEL devices is maintaining components at acceptable temperature levels. Such thermal management is essential for LDA and SSHEL devices to operate properly because the overall energy conversion efficiency of lasers is relatively low, and operating lasers generally create significant amounts of heat," he explains.

"Also important are laser materials, whether they are semiconductor chips or solid-state crystals, because they are very sensitive to temperature. Raising the associated operating temperatures generally results in diminished operating efficiencies and shorter operating lifetimes of these components. Therefore, it is paramount to equip high-power lasers and electronic components with effective and efficient thermal management systems that can quickly remove generated heat, wherein coolant is provided by efficient small-scale pumping devices," Dr Ligrani concludes.

Find out more

Dr Ligrani's award will be presented at the ASME Fluids Engineering Division summer meeting on July 15-17 in Anaheim, California, where Ligrani will give a plenary lecture detailing his findings.

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