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Dear Members of the ICMF 2016 Awards Committee

ICMF 2016 International Multiphase Flow Senior Award Nomination

I take great pleasure in nominating Professor Said Elghobashi for the 2016 ICMF International Multiphase Flow Senior Award. Throughout the 30 years I have known him, Said's multiphase flow research has been an inspiration to me, not only for the impact it has had on my own work, for the insights it has given but also for the way his research has been carried out, for its clarity and painstaking precision, for the way it has been built upon and developed, and for the influence it has had on the way multiphase flow research is carried out. So I believe I am well qualified to testify to the immense contribution Said has made to our understanding of multiphase flow processes and to the contribution his work has made to scholarship and learning as a whole. Without doubt Professor Elghobashi both as a researcher and educator has been an inspiration to all of us, his students and colleagues alike who have had the privilege of working and interacting with him throughout his long career.

Prof Elghobashi is one of the most distinguished and highly regarded members of our community. Whilst his publications are less prolific than those of others in the field, they are by far the most cited. In describing his own research output, Said has recalled the motto of the great mathematician Carl Friedrich Gauss, 'Pauca sed matura' (few but ripe): quality not quantity you might say. Many of Said's papers are seminal, much cited and of an enduring nature for their insights and the understanding they have provided.

It is worth pointing out that Said's research and the contributions he has made to multiphase flow research are recognized not only within our community but in the wider International Engineering Community as a whole. He is a recipient of numerous titles and a member of a number of distinguished scientific bodies and institutions. Perhaps most important of all, he was recently made a member of the US National Academy of Engineering, one of the highest honours bestowed upon an engineer in the USA. The high esteem in which he is held is also reflected in the many invited keynote lectures and seminars he has given over the years, in my experience invariably given to packed audiences. In addition he has served on many scientific committees for conferences, serves on the Editorial Advisory Board and was a Special Issue Editor for the International Journal of Multiphase Flow.

In nominating Said for this prestigious award, let me here be more explicit about the nature of his research and elaborate on some of his major research achievements. In a career spanning over 30 years, Professor Elghobashi, has made profound and lasting contributions to our fundamental understanding of the way turbulence influences and controls the behaviour of dispersed two phase flow: to the way in particular the large and small scales of the turbulence transport and mixes the two phases; to the way turbulence itself is modulated by two way coupling between the phases and how this in turn controls drag reduction in a turbulent boundary layer.

However his early work pioneered the application of CFD in multiphase flows and his two-fluid turbulence averaged equations which model the transport and coupling between phases have provided the current foundations for the CFD treatment of practical particle-laden flows. In particular he was able to provide a suitable closure approximation for the net force due to the turbulence and to derive transport equations for turbulence kinetic energy and for the dissipation rate for particle-laden turbulent flows.

Whilst Prof Elghobashi is largely known and regarded for his pioneering development and application of DNS in multiphase flow, it is important to recall his experimental studies of dispersed particle flows and mention that he was the first to use two-component LDA to measure the instantaneous velocities of particles and fluid in a turbulent round air jet laden. The results showed that particles reduce the Reynolds stresses, and the radial spreading rate of the jet. It explains why aircraft contrails persist for several kilometers behind the aircraft.

With the advent of super-computing Prof. Elghobashi has performed a remarkable series of DNS studies on a range of turbulent dispersed flows in which he has identified the underlying mechanism that control particle segregation, turbulence modulation and drag reduction in turbulent boundary layers (particularly for suspensions of micro bubbles). In each case the DNS has been carried out with scrupulous care and precision and are superlative examples of the way DNS studies should be carried out. Not only have these studies added insight and understanding but have proved of inestimable value in the development of better models for two way coupling and transport and mixing in turbulent flows. In this regard Prof. Elghobashi is in a class of his own.

In this regard it is worth singling out three important studies. The first is concerned with the two-way interaction between homogeneous turbulence and dispersed solid particles which revealed the mechanisms by which small particles (with diameter smaller than the Kolmogorov length scale) in decaying isotropic turbulence modify the energy spectrum: how they can enhance the production of turbulent energy at the large scale and increase the energy dissipation at the small scales. His study showed that this can happen in such a way that the turbulence kinetic energy of the particle-laden flow remains equal to that of the flow without particles. It is worth noting that this study and other studies were carried out in decaying isotropic homogeneous stationary turbulence rather than in steady state because of Elghobashi's concern that the artificial forcing of the turbulence at the small scale can influence the kinetic energy spectrum at all wave numbers and lead to spurious results.

The second study was concerned with the physical mechanisms of drag reduction in a spatially-developing turbulent boundary layer laden with micro bubbles. Experiments showed that injecting micro-bubbles into a turbulent boundary layer over a flat plate reduce skin friction. However, it was incorrectly concluded that the major effect of micro-bubbles was to alter the effective viscosity and density, thereby effectively changing the Reynolds number rather than re-structuring the turbulence. Later and in contrast, Elghobashi showed micro-bubbles actually modify the structure of turbulence near the wall. In particular, the micro-bubbles create a mean velocity normal to and away from the wall, reducing the mean streamwise velocity, and in turn displacing the quasi-streamwise vortical structures away from the wall, whilst increasing the spanwise spacing of wall streaks and reducing streak strength. This leads to a substantial reduction in skin friction. This in my opinion is a quite remarkable study and a perfect example of how DNS can be exploited to understand and identify physical mechanisms relating to turbulence transport and mixing and two way coupling.

The third study is really two studies both devoted to the influence of particles with sizes greater than the Kolmogorov length scale on turbulence modulation and to whether this depends on particle Stokes number. In essence it is an examination of the validity of the point particle approximation. It is the first DNS study that fully resolves the motion around each of more than 6000 spherical particles freely moving in decaying isotropic turbulence. The results provide physical insight into the two-way interactions between the particles and turbulence and show that the conventional Stokes number based on to the Kolmogorov time scale should not be used as an indicator for the modulation of turbulence by particles whose diameter is larger than the Kolmogorov length scale. This finding has major implications on the understanding of numerical and experimental results of particle-laden turbulent flows.

This study was used to up date an earlier paper 'On Predicting Particle-Laden Turbulent Flows' (over 700 citations) which presented the first classification of the effects of small particles on turbulence as functions of volumetric fraction and response time of the dispersed particle phase. The map identified the various distinct physical domains in the parameter space. The term "*four-way coupling*" was coined in that paper to describe fluid-particle and particle-particle interactions that occur simultaneously in dense suspensions of particles in a turbulent flow.

So in summary and conclusion then, I am nominating Prof. Said Elghobashi for the ICMF Senior Award for his profound and enduring contributions to our understanding of the role of turbulence in multiphase flow processes, and in particular for his pioneering application of DNS in identifying the physical mechanisms that lead to turbulence energy production and decay, to the two way coupling between phases, to drag reduction and the influence of particle size on turbulence modulation (and the validity of the point particle approximation). His work is highly cited and has been a model of clarity and precision much in the spirit of Gauss (*pauca sed matura*) providing insight and understanding and has been and will continue to be an inspiration to others working in this most challenging field of multiphase flow research.

23/04/2019

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