# Overview of Turbulence Control Project

**Nobuhide Kasagi**
Leader, Research Management Group
Department of Mechanical Engineering
The University of Tokyo

and

**Yoshiaki Kodama**
Leader, Fluid Functionalization Group
Ship Research Institute

## 1. Background

Fluid flow phenomena such as winds, ocean currents, blood vessel flows and those in industrial equipment are closely related with human life and societies. Therefore, technologies to predict and control flows have been a major target of engineering research and development. Conventional methods for controlling flows, however, originate from intuitions and/or experiences rather than rational scientific strategies, depend on non-local and averaged information of flow physics, and exploit only macroscopic means such as on-off operating flow valves.

Turbulence, originating from fluid-dynamical instability at high Reynolds numbers, is a collection of vortices of both micro- and macro-scales. Turbulence appears in most flows of practical importance, and has significant effects on the flow characteristics. It has positive effects in enhancing diffusion/mixing and thus promoting combustion, whereas it causes negative effects, for example, in increasing skin friction. The skin frictional drag that airplanes and ships experience when moving in air or water increases by more than two orders of magnitude, when the flow around the moving body changes from non-turbulent (called *laminar*) to turbulent states.

In spite of its importance, the progress in understanding turbulence physics and developing effective turbulence control methods have been very slow so far, because turbulence is a highly nonlinear and complex phenomenon. In the beginning of the 20th century, Heisenberg made a remark which means that the problems in physics that will remain unsolved long are quantum mechanics and turbulence. Quantum mechanics, as we know well, have made significant progress since then, while turbulence still remains to be fully explored.

Recently, the research on turbulence has seen several new major developments. One is the development of large-scale numerical simulation of turbulence. Being helped by the rapid development of both computer hardware and software, direct numerical simulation has become a powerful tool to elucidate and analyze complex turbulence structures, even in reacting (combusting) flow. In Japan, the National Aerospace Laboratory (NAL) has developed the so-called NWT (Numerical Wind Tunnel), one of the world's fastest and largest supercomputer system dedicated to numerical simulations of complex fluid motion. NAL has also developed the software that runs on NWT and achieves its highest performance in simulation of turbulence.

Another new development is an emerging micromachining technology, which is based on the LSI processing technology. It can produce machines several orders of magnitude smaller than conventional ones, and thus can be utilized in manufacturing devices of micro scales that are quite suitable to control turbulence consisting of minute vortices. The Mechanical Engineering Laboratory (MEL), since the beginning of a large scale research project on micromachines in 1989, has focused their efforts on mechano-electronics and micromachinings, and has produced practical outputs such as a microscopic lathe.

The third is the development of a new methodology of exploiting additives, which controls flow behavior including turbulence by selectively extracting and enhancing a certain function of the fluid. The methodology is named here as functionalization of fluids. For example the Ship Research

Institute (SRI) has been studying microbubbles; a device for injecting small bubbles into the flow and reducing skin friction of a solid body advancing in water. The 400m long towing tank of SRI has been fully utilized in the microbubble study, aiming at its application to full-scale ships. MEL has been working on surfactants, which reduce skin friction and heat transfer drastically for regional heating/cooling systems.

The fourth development has been made in combustion studies. Turbulence plays important positive roles in combustion, and therefore the study on turbulence control is indispensable in fulfilling cleaner and more efficient combustion. Recently, new optical techniques for measuring combusting flows together with direct numerical simulation have make turbulence control studies for combustion feasible. NAL, MEL, and SRI have been engaged in turbulent combustion studies.

With this background, the three national laboratories

## 2. Open and Integrated Research Program Sponsored by Science and Technology Agency

The Open and Integrated Research Program, funded by the Science and Technology Agency (STA), aims at activating national research organizations. A joint team of two or three national research organizations is eligible to the program, and a recipient is allocated a research fund for five fiscal years. In March this year NAL, MEL, and SRI, the three national research organizations mentioned above, applied for the program in FY1999, with the research title of "Turbulence Control by Fluid-dynamic Devices with New Functions." Several supporting universities such as the University of Tokyo, Tokyo Institute of Technology, Keio University and Aoyama Gakuin University also joined. Their proposal was approval as a one-year preceding study for FY1999 with reduced budget. With the fruitful results of this preceding study, the team aims at getting full approval as a five-year project in the next fiscal year.

## 3. Purpose and organization of the project

In the present study, the three national research organizations, i.e.,

National Aerospace Laboratory (NAL), Science and Technology Agency,
Mechanical Engineering Laboratory (MEL) of Agency of Industrial Science and Technology, Ministry of International Trade and Industry,
Ship Research Institute (SRI), Ministry of Transport

are united to carry out the preceding study for smart turbulence control, with the help of researchers in collaborating universities and industry. As described in Appendix A1, the purpose of the present study is to demonstrate the possibility of smart turbulence control, which should lead to tremendous technological impacts such as drag reduction and enhancement in combustion and heat transfer, by developing highly intelligent fluid-dynamic devices with new functions.

The organization of the project team is shown in Appendix A2. The Research Promotion Committee, which consists of top managing members of the three national research organizations, appoints an Executive Manager, and is responsible for helping the manager in carrying out the project. The committee has appointed Professor H. Ohashi, President of Kogakuin University, as Executive Manager of the project. The committee has also appointed members of the Research Evaluation Committee, whose task is to peer-review the project and qualify its extension to a full-sized project. The Research Management Group, headed by Professor N. Kasagi, University of Tokyo, is responsible for the practical management of the project under the directions by the Executive Manager. The membership and activities of the group is summarized in Appendix A3.

The main body of the research is being carried out by three subgroups, whose research themes are active control of wall turbulence, turbulence control by functionalization of fluids, and turbulent combustion and its mechanism, respectively. The membership and activities of each subgroup is shown in Appendices A4, A5, and A6. Each subgroup has carried out the research extensively, and the results are reported in more details in the following chapters.

## 4. Summary

(1) The study on turbulence phenomena, one of the most difficult remaining problems in modern science and physics, is now accelerated by the new research tools such as numerical simulation and image processing measurement techniques, and the knowledge on turbulence mechanism and its possible control methodology is rapidly increasing.

(2) The study on the active control of wall turbulence has demonstrated that the MEMS technology can be exploited for manufacturing micro sensing and activating devices suitable for active control of wall turbulence.

(3) The study on the turbulence control by functionalization of fluids has shown that this technique is effective in controlling not only turbulence properties but also heat and mass transfer properties of the fluid flow system.

(4) The study on turbulent combustion and turbulence mechanism has shown that turbulence plays essential roles in combustion and therefore its control should be pursued. The study also showed promising techniques for controlling turbulent combustion.

(5) Based on the accumulated knowledge on turbulence and the techniques developed in the present study, the turbulence control has become feasible in several kinds of flows of engineering interest, including wall shear flows, jets, and combustion.

(6) The present preceding study should be extended to a full-size project, in which technological breakthroughs on turbulence control are expected to be accomplished in various kinds of turbulent flows, leading to further developments in wider areas of fluids and thermal engineering.