Overview of the Study for Organized Research Combination System: "Smart Control of Turbulence: A Millennium Challenge for Innovative Thermal and Fluids Systems"

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1. Framework of the Project

Yoshiaki Kodama, SRI

1.1 Outline of Organized Research Combination System

The research funding system, which is formally called the Organized Research Combination System (ORCS) with Special Coordination Funds for Promoting Science and Technology, is a program of the Ministry of Education, Culture, Sports, Science and Technology (MEXT) for stimulating national research institutes. This program is a successor of the COE (Center of Excellence Promotion) project, and was started in the fiscal year of 1998. Researchers from various national institutes join to produce results that may lead to breakthroughs. Several projects have been studied every year on biology, materials, and information science. One of the current study themes, "Smart Control of turbulence: A Millennium Challenges for Innovative Thermal and Fluid Systems," is the first mechanical engineering topic in the COE and ORCS programs. It was proposed by the following three national institutes:

Mechanical Engineering Laboratory, National Institute of Advanced Industrial Science and Technology, Ministry of Economy, Trade and Industry,
National Aerospace Laboratory, Ministry of Education, Culture, Sports, Science and Technology, and
Ship Research Institute, Ministry of Land, Infrastructure and Transport,

and was started in the fiscal year of 2000.

This topic will be studied for the five fiscal years from 2000 to 2004, inclusive, with an annual research fund of 3 billion yens. The laboratories in charge will continue this study project after the fiscal year of 2001, when administrative restructuring will change the organizations of these institutes. However, adoption of new themes in the Organized Research Combination System itself will terminate in the fiscal year of 2001.

1.2 Organization of the Project

(1) Research Promotion Committee
1) consists of the director-generals, the directors of the department of general affairs, and the heads of the research planning offices of the three institutes,
2) assigns the executive manager of the project,
3) supports the executive manager for smooth execution of the project, and
4) establishes a board consisting of the heads of the research planning office.

(2) Executive Manager
1) is Professor Hideo OHASHI (President of Kogakuin University), appointed by the members of the Research

Promotion Committee,

2) is on equal footing with the three national institutes through the Center for Smart Control of Turbulence,

3) collects information from universities and private institutes to help the project, and

4) presents annual project reports to the Research Promotion Committee.

(3) Research Evaluation Committee

1) is established by the institutes involved,

2) consists of Chair Hideo NAGASU, five members from Japan and four members from other countries,

3) evaluates the studies conducted and presents evaluation reports to the Research Promotion Committee each fiscal year,

4) will present a midterm evaluation report in the third year (FY 2002) and a final evaluation report in the fifth year (FY 2004) to MEXT, and

5) monitors the progress of researches and makes comments if necessary.

(4) Center for Smart Control of Turbulence (CSCT)

1) has been established within the Ship Research Institute,

2) consists of researchers of the three national institutes, as well as universities and private sectors, and

3) formulates study plans, performs studies, and publishes results at the behest of the Executive Manager.

CSCT consists of:

Directors (co-chairs)

in charge of coordination and promotion for all research studies.

Research Management Group (MG)

consists of principal members of the three national institutes, universities, and private sectors, and deliberates on important topics regarding studies and the management of the center.

General Research Committee

consists of all members participating in this research project with the Executive Manager as chair, is held twice a year, and discusses and approves research plans and results.

Working Group (WG) for Active Control of Turbulent Flow

conducts studies on active control of turbulent flow and consists of the MEMS working subgroup, which mainly utilizes MEMS technologies, and the physical properties working subgroup, which mainly utilizes modified physical properties of fluids.

Working Group (WG) for turbulent combustion control

conducts studies on the control of turbulent combustion.

Center office

prepares and submits documents (research plans, reports, etc.), executes international symposia, prepares web pages and performs other publicity work, invites researchers, serves as liaison to Evaluation Committee members, and performs other office work.

(5) Scientific Advisory Board

consists of guest lecturers of symposia and guest researchers who give scientific advice on the studies.

2. Overview of the Project

Nobuhide Kasagi, The University of Tokyo

2.1 Objectives of the Project

Mechanical engineering is the foundation of industries in Japan, which is an advanced industrial country, and innovative studies in this field should be promoted for the 21st century. This project aims to achieve smart control of turbulent flow, which is a major fundamental issue to be solved in the fields of fluid, thermal, and combustion engineering, which are the core subjects of mechanical engineering, by using advanced technologies such as micro-machines. Smart control of turbulent flow will lead to breakthroughs in mechanical engineering and may help solve global energy and environmental problems.

Turbulent flow is characterized by small eddying motion in a fluid, and has negative effects, such as increasing the amount of friction that an aircraft or ship receives from air or water, and also positive effects, such as enhancement of mixing, heat transfer, and combustion. Control of such turbulent flows will reduce their negative

influences while promoting the positive effects, and is regarded as a technology awaited in all areas of energy production and consumption. It will reduce resistance, improve combustion, promote and control heat transfer, and optimize chemical reactions.

To enable advanced turbulent flow control, attempts are being made mainly in Europe and North America to understand the phenomena of turbulent flow and to develop an appropriate control system. Although various systems have been proposed, no effective control method and practically realistic device have been developed. This is mainly attributable to the lack of a strong collaborative framework that brings together the knowledge and technologies from various fields. To develop a control system, we must elucidate the complicated phenomena of turbulent flow, develop technologies to design turbulent flow control devices, and create optimum control technologies, all of which still have many problems to be solved.

In Japan, studies on turbulent flow have been conducted mainly at universities for decades. Although the studies are at a world-class level, there has not been systematic research collaboration for large-scale studies on control of turbulent flow. Japan is a world leader in the technologies for monitoring turbulent flow, such as optical sensing, micro-machine technologies for sensors/actuators, numerical simulation for elucidating and predicting the phenomena of turbulent flow, and other technologies that are indispensable for controlling turbulent flow.

In this project, experts on fluid, thermal, and combustion engineering from three national research laboratories in Japan that study mechanical engineering will collaborate to develop turbulent-flow control systems that reduce the negative influence of turbulent flow and enhance its positive effects. The project consists of two subprojects. The first is the active control of turbulent flow and aims to 1) develop micromachine technologies for sensors/actuators and basic technologies for controlling the properties of a fluid by applying small amounts of additives (in three years) and 2) construct a system that actively controls turbulent flow and helps reduce resistance and control heat transfer and chemical reactions (in five years). The other subproject is a research and development study on the control of turbulent combustion. It aims to 1) develop sensing technologies by understanding the phenomena of turbulent combustion (in three years) and 2) control and accelerate the diffusion and mixing of fuel and air in a turbulent jet, stabilize premixed lean burn combustion to enlarge the range of its application, improve engine cycle efficiency, and reduce pollutant gases (in five years). The project working groups as a whole will create an innovative thermal and fluid system through the work on these two subprojects.

2.2 Scientific and Technical Contents of the Project

(1) Study on active control of turbulent flow

A micro sensor that precisely detects microstructures of turbulent flow (e.g., longitudinal eddies and streaks), a micro actuator for controlling these microstructures, and a control algorithm will be developed to actively control wall turbulent flow. Methods for controlling the properties of fluid and wall surface will also be developed to improve the efficiency of active control. The knowledge thus obtained and the technologies developed will be integrated into a system for smart control of turbulent flow, which will reduce frictional drag and control mixing, diffusion, heat transfer, and phase change. To use the system in practice, peripheral and engineering technologies will also be developed such as diagnostic methods for complex turbulent flows.

The three-year goal is the development of technologies for active control of turbulent flow, such as micro sensors and actuators. The five-year goals are the construction of a model system for active control of turbulent flow and verification of its effectiveness by monitoring the reduction in frictional drag and other characteristics.

(2) Study on control of turbulent combustion

A technology for controlling turbulent jets will be developed to control the mixing of fuel gas and air before combustion. A diagnostic sensor that operates under hot and high-pressure combustion environments will then be developed using optical sensing technologies. Using these technologies and control theories, a system for controlling turbulent combustion will be developed to enlarge the application range of premixed lean burn combustion.

The three-year goals are to 1) elucidate turbulent flow, such as the relationship between combustion and the structures of turbulent flow, using highly precise numerical simulation and 2) develop sensors that are appropriate for the sites of combustion. The five-year goals are to 1) construct a model system for controlling turbulent combustion, 2) stabilize premixed lean burn combustion by controlling the rate of combustion, and 3) control the composition of burnt gases (reduce the emission of pollution products).

2.3 Constitution of Working Groups

Two working groups will be formed, each of which is in charge of its respective subproject.

(1) Working Group (WG) for Active Control of Turbulent Flow

This WG consists of the following working subgroups (WSG), which will be the focus of resources from the initial state of studies.

MEMS WSG

This WSG investigates methods for actively controlling wall turbulent flow by mainly using MEMS, which consists of micro sensors, actuators and controllers.

Physical Properties WSG

In parallel to MEMS WSG, this WSG uses the properties of a fluid and a wall surface, to control turbulent flow and will develop a turbulent flow control technology, including chemical reactions, that is widely applicable.

(2) WG for Turbulent Combustion Control

This WG will develop a stable lean burn combustion system that is below the present lower flammability limits by combining various approaches, such as turbulent combustion experiments, numerical analyses, laser diagnostics technologies, and application to practical systems.

2.4 Budgetary Plan for FY 2000

The research funds that have been distributed to the three laboratories as shown below are re-apportioned to three groups: MEMS WSG and Physical Properties WSG of the WG for active control of turbulent flow, and WG for turbulent combustion control.

(Unit: thousand yen)	NAL	MEL	SRI	Total
Research funds	96,279	83,309	121,785	301,373

2.5 Center for Smart Control of Turbulence (CSCT)

(1) Current Personnel

Directors: N. Kasagi (Research), Y. Kodama (Management)

Advisory Section: H. Ohashi

Advisory Council: H. Nagasu (Chair), C. Brennen, I. Imai, K. Inoue, F. W. Schmidt, T. Takeno, M. Trinite, J. H. Whitelaw, H. Yamasaki

Advisory Board: R. K. Cheng, K.-S. Choi, M. Gad-el-Hak, A. Glezer, H. Kato

Scientific Section

Coordinators: K. Hayashi, K. Hishida, Y. Matsumoto, T. Miyauchi

Associate Scientists/Officers: Y. Kawaguchi, S. Ogawa, K. Suzuki, H. Yoshida

Members: Younger and backbone researchers in national institutes and universities

Basic Research groups

- Sensors: K. Hishida
- Actuators and Control: N. Kasagi
- Numerical Simulation: T. Miyauchi
- Combustion: K. Hayashi

Secretariat: K. Harumi

Partners and Associates: S. Ohnishi, K. Tamura

Affiliates: NAL, MEL, SRI, Univ. of Tokyo, Tokyo Inst. of Tech., Aoyama Gakuin Univ., Keio Univ., Kobe Univ., NEC, Fuji RIC Co.

(2) Activities

1. Promotion of the collaborative research project on "Smart Control of Turbulence: A Millennium Challenge for Innovative Thermal and Fluids Systems," which is supported through the Organized Research Combination System by the Ministry of Education, Culture, Sports, Science and Technology.
2. Publicity of the activities of the above collaborative research project through technical reports, newsletters, and webpages.
3. Sponsoring and organizing "Symposia on Smart Control of Turbulence."
4. Exchange of information on innovative turbulence control mainly via the internet.
5. Promotion of overseas research cooperation by inviting and sending researchers.
6. Dissemination of new research results on turbulence control through various lectures and talks planned in

cooperation with relevant technical societies.

2.6 Organization of International Symposium on Smart Control of Turbulence

For the purposes of promoting turbulence control research, disseminating the results of the present project and offering the chance to exchange information and ideas with researchers, CSCT organizes and supports an series of international symposia. The Second Symposium on Smart Control of Turbulence will be held at the Sanjo Conference Hall, the University of Tokyo on March 4-6, 2001. Research Evaluation Committee will have a meeting right after the Symposium, on March 7, 2001.

3. Research Plan of R&D of Advanced Control Systems with Distributed MEMS Devices

Hiro Yoshida, MEL
MEMS working subgroup, WG for active control of turbulent flow

3.1 Purpose of Subproject and Technical Contents

The target of the project involves the enhancement of mass and heat transport, flow separation control, and reduction of the turbulent skin friction drag. Establishment of the optimal design methodology of the control system composed of the integrated micro sensor and actuator arrays is the major task in this project. Wall shear stress and pressure sensor arrays are considered as candidate devices sensing and detecting characteristic vortical structures in turbulent flows. Prototype actuator arrays exploiting wall deformation based on electromagnetic, electrostrictive and piezoelectric force will be developed. We will also develop and assess drag free micro vortex generators and micro-suction/blowing matrix. Advanced feedback control algorithm applicable to laboratory experiments and real applications will also be developed using optimal control theory and/or adaptive algorithm. The control system will be evaluated through extensive experiments in wind tunnels and model turbine-blades/airfoils.

3.2 Key Words

Wall turbulence, micro sensor, micro actuator, feedback control, separation control, drag reduction, MEMS fabrication

3.3 Milestone

At mid-term estimation (2002)
To develop micro devices and control algorithm, and to establish concept of the control system for practical application to, i.e. blades or airfoils.
At post-term estimation (2004)
To establish optimum integration and assembling of the sensors and actuators on single chip, and to propose a prototype of the control system and to verify its effectiveness.

4. Research Plan of Control of Turbulence Functions in Heat and Mass Transfer

Yasuo Kawaguchi, MEL
Physical properties working subgroup, WG for active control of turbulent flow

4.1 Purpose of Subproject and Technical Contents

The primary goal of the subproject is reduction of negative influence of turbulence. We are going to make fundamental investigation on active or feedback control of turbulence by using of functionality of fluid property. The secondary goal is development of novel control method, which allows "turbulence-like" high performance thermal or mass transport in non-turbulent flow.

To achieve these goals, at the first stage, we establish the method to reduce turbulent frictional drag, which is

large problem in ship propulsion and district heating/cooling system, by adding bubbles or surfactants. In next stage, we enhance fluid functionality by introducing external force in the aim of getting higher performance of drag reduction and heat and mass transfer enhancement in non-turbulent flows.

4.2 Key Words

Micro-bubble, surfactant, sol-gel transition, nano-scale chaotic mass transfer, functional paint, drag reduction, application for ship, application for district heating/cooling system, optical measurement, computer simulation, parallel computation

4.3 Milestones

At mid-term estimation (2002)
Develop a drag reduction method using micro bubbles which is double effectiveness compared to conventional method. Prove the effectiveness through 12 m model ship test. Elucidate functionality of fluid properties by macro-molecular structure.
At post-term estimation (2004)
Develop and test an active control system using bubbles. Propose a enhance method for chemical reaction using non-Newtonian fluid.

5. Research Plan of Control of Turbulent Combustion: Mechanism and Control of Premixed Lean Oscillating Turbulent Combustion

Satoru Ogawa and K. Suzuki
Working group for turbulent combustion control

5.1 Purpose of Subproject and Technical Contents

The objective of this program is to create new technologies by integrating research groups in developing a super-lean combustion system that operates below the combustible limit. Research fields such as fundamental turbulent combustion experiment, numerical simulation, laser measurement, and flight application are integrated, a unified database is constructed by integrating data of each research field, modeling methods and know-how, and a new active control method will be developed. Development of a high efficiency and environmentally friendly gas turbine combustor will be achieved by clarifying the structures of turbulent combustion, predicting and preventing oscillatory combustion in a lean premixed flame, achieving stable combustion, developing measurement methods and investigating the pollutant emission mechanism in a turbulent premixed flame to reduce it. Furthermore, monitoring and actively-controlling methods of turbulent combustion will be developed by integrating these fundamental knowledge and technologies, and this will give us future directions toward development of a future highly efficient and less environmentally-costly gas turbine combustor.

5.2 Key Words

turbulent combustion, lean combustion, oscillating combustion, active control, numerical simulation, DNS, intelligent control

5.3 Milestones

At mid-term estimation (2002)
A high efficiency and environmentally friendly jet and swirl burner system will be developed by laser measurement and numerical simulation, and fine structures of turbulent combustion and oscillatory combustion mechanisms will be shown and characteristics of oscillatory combustion and pollutant emission will be predicted. Also, simple prediction methods based on an acoustic analogy and experimental control methods will be developed. The mechanism of NOx emission in turbulent combustion will be investigated by experiment and numerical simulation, and active combustor controlling factors will be found. Through these achievements, prediction and control of oscillatory combustion and pollutant emission that have been difficult so far will be realized.
At post-term estimation (2004)

In an integrated system of a burner and a combustor, real-time measurement of pollutant emission such as NOx and combustion state will be conducted in order to enhance its efficiency. Furthermore, based on such information, flame stabilizing techniques and monitoring systems, active control of the combustor will be achieved. Knowledge necessary for future gas turbine combustor development will be obtained and a prototype combustor will be developed.