The Organized Research Combination System with Special Coordination Funds for Promoting Science and technologies
Smart Control of Turbulence:
A Millennium Challenge for Innovative Thermal and Fluid Systems

Fiscal year 2000 to 2002

Independent Administrative Institution **National Aerospace Laboratory**
Independent Administrative Institution **National Institute of Advanced Industrial Science and Technology**
Independent Administrative Institution **National Maritime Research Institute**

Midterm Evaluation Report

August 2002,

Research Evaluation Committee for

"Smart Control of Turbulence:

A Millennium Challenge for Innovative Thermal and Fluid Systems"

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1. Research Evaluation Committee Members List

Name	Affiliation
Kotaro INOUE*	Corporate Chief Engineer, Research and Development Group, Power and Industrial System Group Hitachi Ltd.
Isao IMAI	Professor Emeritus The University of Tokyo
Tadao TAKENO	Professor, Department of Mechanical Engineering, Meijo University
Hideo NAGASU	Former President of the Japan Society for Aeronautical and Space Science
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Christopher E. Brennen	Professor, Dept. of Mechanical Engineering, Vice-President of California Institute of Technology
Frank W. Schmidt	Professor Emeritus, The Pennsylvania State University
Michel Trinite	Directeur de Recherche CNRS, CORIA, Universite de Rouen
James H. Whitelaw	Professor, Head of the Thermo-fluids Section Imperial College of Science and Technology

*Chair

2. Budgetary Plan

(1) Research funds of each working group

Executive Manager: Hideo OHASHI, (President of Kogakuin University, NMRI)

(Unit: thousand yen)

Name of sub project	Working group Leader	Budget for FY2000	Budget for FY2001	Budget for FY2002
1. WG for Active Control of Turbulent Flow	Hiro YOSHIDA	176,865	179,081	174,402
2. WG for Turbulent Combustion Control	Satoru OGAWA	124,708	118,122	122,739
Total amount		301,573	297,203	297,141

(2) Yearly budgets for each national institute

(Unit: thousand yen)

Fiscal year / Institutes	Budget for FY2000	Budget for FY2001	Budget for FY2002	Total
1. NAL National Aerospace Laboratory	96,279	94,312	93,798	284,389
2. AIST National Institute of Advanced Industrial Science and Technology	83,309	70,312	93,298	246,919
3. NMRI National Maritime Research Institute	121,985	132,579	110,045	364,609
Total	301,573	297,203	297,141	895,917

3. Project Overview: Objectives and Results

Title: “Smart Control of Turbulence: A Millennium Challenge for Thermal and Fluids Systems”
Executive Manager: Prof. Hideo OHASHI
(President of Kogakuin University, National Maritime Research Institute)

3.1 Outline of Research Objectives

Many researchers in physics and engineering have been investigating turbulent phenomena because of its complexity and profundity as nonlinear phenomena, and its industrial usefulness. Nevertheless, Dr. Heisenberg predicted in the early 20th century that elementary particles and turbulent phenomena would be the last two unsolved problems in physics in late 20th century. As a matter of fact, turbulence has been the most difficult and unsolved problem in hydrodynamics.

However, several remarkable technologies have been developed in these days such as the high resolution and non-intrusive optical fluid flow measurement technologies with laser, the numerical simulation technologies for elucidating turbulent phenomena with computer, the micro-sensor and actuators technologies by using MEMS (Micro-Electro-Mechanical Systems: Micro machine) and the control theories, which may contribute to elucidating control turbulent phenomena. In this project we are aiming to further develop these technologies and elucidate turbulent phenomena, which are highly complicated and universal as well as dealing with development of turbulent flow control systems to reduce negative effects and to enhance its positive effects of turbulent flow.

Since turbulence phenomena are so universal and complicated that turbulent flow control technologies will bring about many spreading effects on engineering and science field; even though it would be a challenging task. For that purpose, it is essential to develop the highly advanced and extensive technologies including advanced hardware technologies such as the sensor/actuator development, and various software technologies that will support these technologies as well as to fully understand the basic mechanism of the phenomena, but also It is next to impossible to investigate and develop such technologies of various fields by a single private company or a research institute. Thus, we organized a research combination system that consists of many researchers from various organizations to implement this research project.

We chose two major turbulent forms that can be observed in the industrial field as control objectives; namely wall turbulence and free turbulence. Wall turbulence is an active eddy motion generated in a boundary layer. A boundary layer exists near the wall of an object and the layer containing high gradients in velocity. Wall turbulence can be observed along the wall surface of an object when objects such as an airplane, an automobile, a vessels move in fluid, or when fluid flows in a tube. While wall turbulence has negative effects such as drag friction or noise generation, it also has positive effects such as enhancing heat transfer between the wall and the fluid, or inhibiting separation. On the other hand, free turbulence can be observed where no wall surface exists. Free jet turbulence, which is a jet injected in fluid, generates a complicated eddy motion with the still fluid flow around the jet. Since it has strong mixture/diffusion effects, free jet turbulence can be utilized for manufacturing fluids, mixing of fuels and air engine, and fuel combustion, which is of high importance for industrial use.

The project consists of two sub project groups; namely, the Working Group for Active Control of Turbulent Flow and the Working Group for Turbulent Combustion Control. The working group for active control of turbulent flow aims to control wall turbulence and to construct a system that actively controls turbulent flows and also helps reduce frictional drag, enhance heat transfer between wall and fluids, and inhibit separation that can be, for example, generated on the wings of airplanes. We are aiming to develop control methods including MEMS technologies (installing a micro sensor or a micro actuator arrays on a wall surface) and basic technologies for controlling the properties of a fluid by adding micro bubbles or small amount of addictives to water (in three years).

Furthermore, we are aiming to construct a system that actively controls turbulent flows and helps reduce drag friction, inhibit separation and control heat transfer and chemical reactions. The working group for turbulent combustion control is aiming to control the combustion process in a turbulent jet. This group deals with the lean premixed combustion intensively, which is potentially environmental friendly combustion technology. Sensor-actuator technology that can function in high temperature will be developed (in three years). Furthermore, the group is aiming to build a lean pre-mixed combustion control system to enlarge the range of its application by controlling unstable condition such as blowout, combustion noise or oscillation, and to reduce pollutant emission gases (in five years).

These studies will contribute to elucidating turbulent phenomena and to develop turbulent control technologies, which will not only become an innovative fluid dynamic technology that have a great impact on various engineering field including manufacturing, transportation and energy industry, but also is expected to lead the development of science in various fields including the advanced nonlinear phenomenon control. In this way, we hope this project will contribute to creation of innovative and fundamental knowledge using engineering approach.

3.2 Outline of the study results

In this project, we are investigating the two main turbulent forms as control objects; namely, wall turbulence and jet turbulence to develop turbulent control techniques. In order to control turbulence, we should develop breakthrough techniques both in hardware and software and integrate all of these techniques. In other words, we need to (1) elucidate properties of turbulence to be controlled as a control objective (2) develop sensor technologies that enable to detect turbulent flows, (3) develop actuator technologies that enable to operate turbulent flows (4) develop a effective control system, and lastly (5) develop an integrated system using all of the experimental study results. In this chapter, we are going to explain the study results from the "active control of turbulence" and the "turbulent combustion control" according to these five items mentioned above.

(1) Elucidation of properties of turbulence to be controlled

To develop a turbulent control system, first of all, we are supposed to elucidate the properties of turbulence, and for that purpose, we are supposed to investigate the structure of turbulence by making examinations of the characteristics of control objectives such as the relation between input and output, in other words, what action will cause a certain change.

Since this project started, we have improved DNS (Direct Numerical Simulation) first, and used DNS to wall turbulence and turbulent combustion. DNS is a highly advanced simulation technique that solves Navier-Stokes Equations (a dominant equation for hydrodynamics) numerically without employing any approximation except for discretization, and it enables to reproduce actual turbulent phenomena on the computer screen. In this project, we applied DNS to the complicated phenomena including turbulent combustion fields, turbulent fields containing additives, which were considered to be challenging. DNS revealed several findings, which we might not obtain from experimental studies. As for wall turbulence, we have clarified the quasi-order vortex structure called "streak structure," which dominates the fluid movement in near wall turbulent field. We also have applied DNS to water flows and elucidated the non-Newtonian fluid mechanism of water by adding a small amount of surfactant, which has significant frictional drag reduction effects. We have injected micro bubbles to wall turbulence and applied DNS to the micro bubble flows, which has not shown frictional drag reduction, however. We are now investigating the reason. As for turbulent combustion, we have implemented DNS in detail and found out the flame-stabilizing phenomenon, which is essential for stabilizing lean premixed combustion. Moreover, we performed simulation in detail on turbulent combustion noise and have fostered a better understanding about mechanism of noise generation. We are going to apply these results form DNS to improve the combustor models for simulation and to make a modeling system to design a control system.

Optical measurement technology using laser enables the non-intrusive high-resolution measurements of fluid flows, which is one of crucial techniques for the research. In micro bubble flows, we added laser fluorescent tracers (surfactants) into water and measured the interference of turbulence with bubbles precisely by using PIV/LIF (Particle Image Velocimetry / Laser Induced Fluorescence) method. We have elucidated the mechanism of bubble that inhibits the generation of Reynolds stress, which is attributable to increase the drag friction by turbulence. As for turbulent combustion, we have measured the characteristics of lean premixed combustion with simple configurations and obtained in-depth information and time-series data. We have also obtained measurement data comparable to DNS, which enables us to elucidate the in-depth mechanism of flame stabilizing.

(2) Development of sensor technologies

In order to control turbulence, first, we need to develop sensor technologies to investigate the structures and movements of turbulence, which is highly complicated and transformable. While studying wall turbulence, we have developed several wall-sensors with high resolution spatially and temporal response by using micro machine technologies in order to monitor streak structures and movement near wall surface. Moreover, based on the design manual obtained by analysis or simulation, we have improved the performance in response and have arranged as an array to build a drag friction reducing system. As for turbulent combustion, the optical means are suitable for the turbulent combustion withstanding high temperatures and have high time and spatial resolution. Thus, "Diode Laser Absorption Spectroscopy" (DLAS) has been developed. By using DLAS, oscillation at the top of flame in the lean premixed combustion fields and its gas temperature can be measured with high time resolution, which would be applied to the flame stabilization control system. These technologies were applied to the turbulent premixed combustion burner. The obtained temperature sampled at the 20 kHz cannot be obtained with ordinary thermocouple. These highly advanced sensors are giving us a wealth of data. High-speed data processing software also have been developed.

In the future, we are going to examine a robust and optimum array in order to develop a system that can be installed to feedback the control system.

(3) Development of actuator technologies

In the next stage, actuator technologies that enable turbulent flow direction control are required. Actuators must fulfill the following conditions: High-efficiency that makes it possible to change turbulent flows with minimum energy input, and selective functionality that makes it possible to make desirable changes exclusively.

As for wall turbulence, we have investigated and developed the following three kinds of actuators using micro machine technology; namely, a micro-electromagnetic actuator, a piezo-ceramic actuator with multi-layer structure, and a micro jet vortex generator (MJVG). As a result, we found out that the micro-electromagnetic actuator and the piezo-ceramic actuator with multi-layer structure would be utilized for control, but there might be some problems with the high input energy. We have also found out that the micro jet vortex generator was an effective tool for separation control. As for micro bubble technologies, we have examined and developed the following three bubble diameter control methods to maximize frictional drag reducing effects; namely, Water-jet, "Variable Cross Sectional Cannel," and "Air-water pre-mixing". As a result, we have found out that injecting micro bubbles ("pre-mix method,") has a significant effect of reducing frictional drag.

In combustion control sub project group, we have developed a flame stabilization device with variable swirl and secondary flame control device in order to stabilize unstable lean premixed combustion. Furthermore, to expand stable combustion range, we considered the possibilities of using an active noise control technique that controls combustion noise and oscillation, which contribute to unstable combustion. We have developed a combustion control speaker working as an acoustic excitation actuator. We have carried out an experiment for reducing combustion oscillation using a swirl type combustor, and we have achieved oscillation reduction at a certain frequency. We have examined to generate sound by changing secondary flame and to use it as a sound generator. We have considered using a valve with high speed responding as a practical device and carefully studied the fundamental properties of secondary flame. For example, we have investigated acoustic properties when fuel flows pulsate, frequency responses of acoustic pressure while burning or non-burning, and the difference of fuel impacts on frequency responses, by using a control valve with piezo elements.

In the future, we are going to improve the robustness of this actuator to install it to the control system, and also, we will examine the optimal arrangement of the actuators and develop more advanced actuators.

(4) Control methods

In order to develop a new control system, first of all, we are supposed to study the characteristics of control objects, and the relationship between input and output, in other words, what actions cause what results should be clarified.

As for wall turbulence, we have simulated the activities of turbulence and a micro sensor array, or a micro actuator array by using DNS. We have clarified from this simulation that turbulent control and drag reduction can be achieved by using control methods such as generic algorithm or neural net to reduce frictional drag.

As for combustion control, we have examined control algorithm for combustion noise and oscillation control by using acoustic excitation actuators, and also, we have developed a practical system and evaluated it. We have made simple controller as a prototype model and tested its performance while considering practical applications. To design a control law for model combustor, it is necessary to perform numerical simulation for complex configuration, and a turbulent combustion model for simulation is required. We have examined the validity of the established model and concluded that we should construct a new model. The information from in-depth experimental data and the comparison with DNS results will be useful for constructing this model.

In the future, while considering the performance characteristics of the sensor and actuator mentioned above, we are going to design and make a prototype controller that is available for practical use.

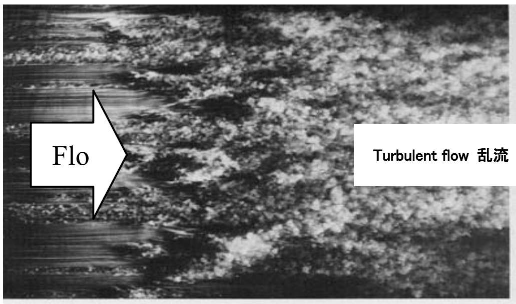
(5) Experimental system

In the study on active control of turbulence, our final goal is to construct a feedback control system to reduce wall turbulent frictional drag and separation. In conjunction with the development of device element mentioned above, we have developed a prototype control system.

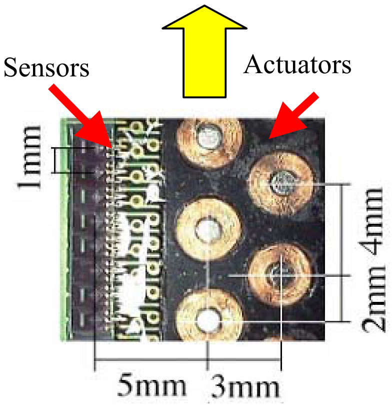
As for turbulent combustion studies, we have decided to focus on developing a premixed lean combustor for methane-fuelled gas turbine; our final goal is to construct a system that enables stable turbulent combustion in super lean mixture. We have already developed an experimental model combustor, which is improved in its flame stability, and it wound be applied to the future control system. The flame stabilization device is installed to the model combustor so that lean combustion is possible.

In the future, the properties of control device element will be improved, and we are going to integrate these devices in the optimal way to construct an experimental system.

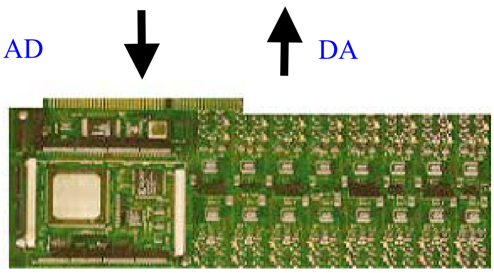
Turbulent flow generated on a wing



These devises are installed on the wall to control turbulent flows



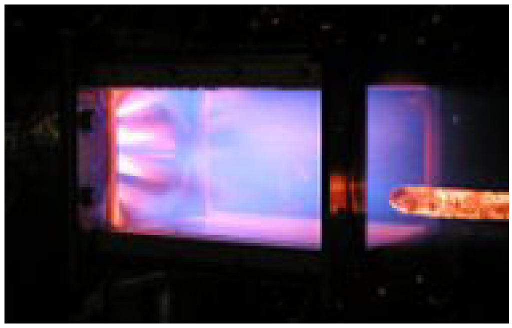
Prototype Sensor Actuator Array



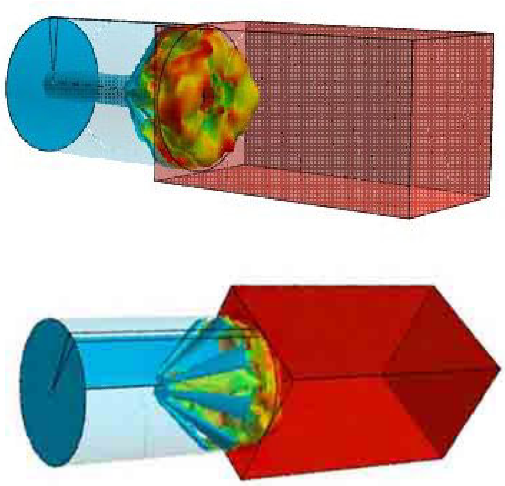
Prototype Controller (DSP)

Prototype system for wall turbulence control with arrayed sensors and actuators

Combustion Experiment with Model Combustor



Combustion experiments with model combustor
(On the right is a probe for gas-analysis)



Numerical Simulation of the model combustor (Thermal Field)
The cone-shape area is a part of the flame-stabilizing devise.

4. Project Overview: Information Release of Study Results

"Smart Control of Turbulence: A Millennium Challenge for Thermal and Fluids Systems"

Executive Manager: Prof. Hideo OHASHI

(President of Kogakuin University, National Maritime Research Institute)

4.1 Information Release of Study Results: Papers and Presentations

	Original article	Refereed Proceedings	Other published papers	Oral presentations	Total
Japan	18(4)	4(0)	7(1)	158(8)	187(13)
Overseas	28(16)	70(4)	3(0)	24(0)	125(20)
Total	46(20)	74(4)	10(1)	182(8)	312(33)

Note: ( ) number of prepublication papers

4.2 Patent Applications

6 (Japan 5, USA 1)

4.3 Awards

3（Japan 3, Other 0）

4.4 Papers published in major jounals

Journal	Impact Factor	Sub project 1	Sub project 2	Total
Journal of Fluid Mechanics	1.912	1	0	1.912
Experiments in Fluids	0.821	2	0	1.642
Int. J. Heat and Fluid Flow	0.968	5	0	4.840
Int. J. Heat and Mass Transfer	0.613	1	0	0.613
J. Computational Physics	1.716	3	1	6.864
Numerical Heat Transfer	1.033	2	0	2.066
Trans. ASME J. Heat Transfer	1.059	1	0	1.059
J. Enhanced Heat Transfer	0.906	1	0	0.906
Computer methods in applied mechanics and engineering	0.913	1	0	0.913
Physics of Fluids	1.799	1	0	1.799
AIAA J.	0.773	0	2	1.546
J. Physics D	1.179	0	1	1.179
Measurement Science Tech.	0.859	0	1	0.859
Combustion and Flame	1.56	0	1	1.56
Subtotal Papers published in major journals		20.898	6.86	27.758
Total Published papers		21.818	9.285	31.103

4.5 International Symposia

(1) Symposium on smart control of turbulence

We hold annual symposium for this project aiming at

(1) To release information about our achievements to the public

(2) To invite leading experts on turbulent control.

These invited speakers deliver lectures and join our discussion, and their comments and suggestions are great help to the development of our project.

(3) To report each study progress annually to the evaluation committee members.

Thus, the purpose of the annual symposium is not only to release results of the study but also the feedback from researchers outside the project. At this point of view, we held the "Symposium on Smart Control of Turbulence" three times including the feasibility study for FY 1999. All the speeches, lectures, and proceedings were delivered in English. The proceedings are available from the Symposium website for researchers who could not attend the symposium.

Year	Theme	Overview	Number of Days	Number of Participants Total	
					from overseas
1999	The 1st Symposium on Smart Control of Turbulence as a preceding study (FY 1999) "Turbulence Control by Fluid-dynamic Devices with New Functions"	At the beginning of the project, we invited leading experts on the active control of turbulence and turbulent combustion control from overseas to deliver lectures. The project members also gave overview talks on the recent developments and future perspectives. Number of Introductory Lectures Invited Speaker: 5 Project Member: 4	2 days	136	10
2000	The 2nd Symposium on Smart Control of Turbulence	Progress reports for FY 2000 and some of the main research results were presented. We invited leading experts on active control of turbulence and on turbulent combustion control to deliver lectures Number of Lectures Invited Speaker: 4 Project Member: 18	3 days	158	25

2001	The 3rd Symposium on Smart Control of Turbulence	Progress reports for FY 2001 and some of the main research results were presented. We invited leading experts on active control of turbulence and turbulent combustion control to deliver lectures. Number of Lectures Invited Speaker: 4 Project Member: 15	3 days	141	21

(2) Launching the website, “Center for Smart Control of Turbulence Home Page”

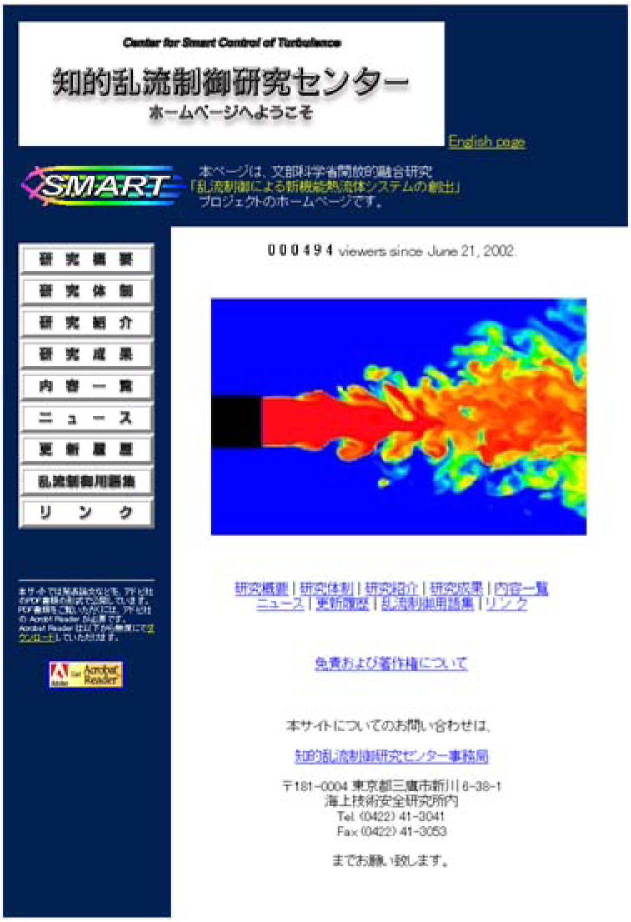
Internet is considered the most effective tool to release information internationally. We registered the original domain name “turbulence-control.gr.jp” to call more attention of visitors and launched our own site on World Wide Web, http://www.turbulence-control.gr.jp/.

The site consists of both English and Japanese pages.

The contents of this site include the project overview, information of the international symposium, all of which are informative. All papers of the proceedings are available on Symposium page (download in PDF format). Other materials for the study at the research progress meetings (General Research Committee) are also available (in Japanese).

As the result of these international information activities, our studies on turbulent control study have attracted the attention of researchers. One of the examples is that DARPA (Defense Advanced Research Projects Agency) has started research project for drag friction reduction by using polymer micro bubbles in 2000.

http://www.darpa.mil/ato/programs/drag_reduct.htm



5. Overall project: Organization of the Project "Organized Research Combination System"

Title: "Smart Control of Turbulence: A Millennium Challenge for Thermal and Fluids Systems"

Executive Manager: Prof. Hideo OHASHI

(President of Kogakuin University, National Maritime Research Institute)

5.1 Leadership of the Executive Manager

(1) Center for Smart Control of Turbulence

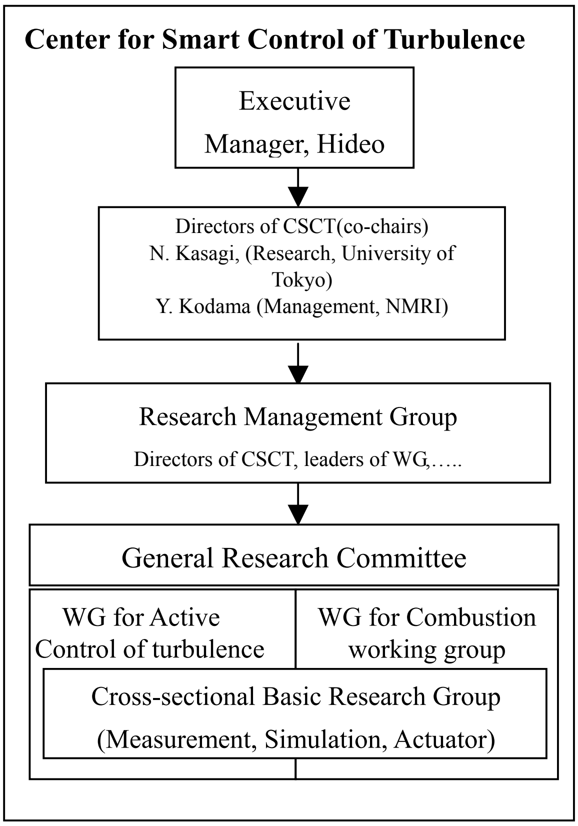
In this project, we have two sub projects; namely, "active control of turbulence" and "turbulent combustion control," which are closely related each other but are relevant to different physical phenomena. This project consists of the researchers in hydrodynamics from three independent administrative institutions of mechanical engineering; namely, the National Aerospace Laboratory, the National Institutes of Advanced Industrial Science and Technology and the National Maritime Research Institute, and also researchers from major universities in Japan, whereas all the other Organized Research Combination System consists of researchers from two national research institutes. "Center for Smart Control of Turbulence" is established at the National Maritime Research Institute (project organizer), which facilitates the executive manager's leadership. All the project researchers from these three institutes, the universities, and private companies were appointed to the members of the center. In this way, we made up such a systematic management organization.

(2) Organizational Structure of Center for Smart Control of Turbulence

Two directors (co-chairs) were appointed under the executive manager's direction; namely, the academic director (Dr. Kasagi, professor of University of Tokyo), and Dr. Kodama, the administrative director. Each director is responsible for supervising research and administration respectively.

Then, we organized the "Research Management Group," which consists of the leaders of the Working Groups (WG), the principal members of the three national institutes, the representative members from universities, and the private sectors, regardless of their affiliation, in order to discuss and decide the direction of overall study and effective budget allocation for implementation. The Research Management Group holds meetings to formulate yearly study plans and to draw up an annual research progress report. The agenda of the meeting should be reported to the executive manager after the each meeting and receive the executive manager's approval.

Furthermore, the "General Research Committee," which consists of all members participating in this research project holds meetings three times a year to hear each member's opinion to reflect in the implementation of experiments. The topics of the General Research Committee are as follows: (1) the conformation of the study plans (the first meeting of the year) , (2) the



Organization of the research group and

research progress report (the second meeting of the year), (3) the conformation of the annual achievement report (the last meeting of the year). The General Research Committee is useful to facilitate mutual understanding.

Each sub project group has organized Working Group (WG) and has carried out studies under each WG leader's leadership. Each working group has a monthly meeting and its progress report is reported to Management Group and Executive Manager. We also organize cross sectional basic research meetings on study topics of common interest (measurement, numerical simulation, actuators) in order to promote cooperation among the working groups.

5.2 Cooperation among the sub project groups

Basically, each sub project group implements its studies individually, but the study results are jointly discussed at the management group meetings, and the group give the feedback to the sub project groups. Moreover, the information exchange among the sub project groups are encouraged at the General Research Committee, in which all of the project members participate.

To promote more cooperation among the sub project groups, we organize cross-sectional basic research meetings; measurement research group and numerical simulation research group started their activities and had group meetings. There were enthusiastic discussions related to the topics of common interest at the meetings. These meetings help us improve simulation techniques and reexamine measurement techniques. Such activities between these two groups are going to be continued. A new cross-sectional basic research group on actuators also has been started.

5.3 Attempt s at the Organized Research Combination System

As we mentioned earlier, we established the “Center for Smart Control of Turbulence” within the National Maritime Research Institute. All participants of this project from the three national research institutes, universities and private sectors belong to the Center for Smart Control of Turbulence. This is the center for the research project, and, regardless of their affiliation or field of research, all the member work together under the joint research project.

Formally, the budget is allocated to the three research institutes; however, the Management Group controls all the funds of the Center for Smart Control of Turbulence practically under the Executive Manager’s supervision.

Center for Smart Control of Turbulence has hosted “International Symposium on Smart Control of Turbulence” three times including the preceding study (FY 1999) of “Turbulence Control by Fluid-dynamic Devices with New Functions.” These symposia were held at University of Tokyo, and many researchers from all over Japan and abroad participated in the meetings as well as the members of this project mainly from the three national institutes. These symposia helped to release information about our project activities and achievements.

The center is also in charge of managing website of the project both in Japanese and in English, to inform our projects achievements and the international symposium schedule. Some of the research papers are accessible to researchers outside the project from Japan to all over the world.

Moreover, we exchange and share information via e-mail (by a mailing list) with researches of different organizations, and also visit laboratories mutually to carry out the experiments and numerical calculation. When necessary, some researchers temporarily belong to different organizations at the same time, as all members of this project belong to Center for Smart Control of Turbulence where members of this project write research papers and reports study results collaboratively.

In addition to the cooperation in human resources, the joint agreements were reached among the research institutes and the universities to lease the equipments mutually, and we have already started this organization to avoid intellectual property right problems.

Moreover, we have strengthened cooperation with industries, and exchanged information by encouraging members from private companies to join the sub project group meetings, and sending questionnaires to several private companies. Such cooperation with industries helps us find out their needs and also clarify and concentrate research objectives. In this way, we combined members from industries, universities, and national research institutes to organize the research combination system.

It is also the duty of Center for Smart Control of Turbulence to call the Evaluation Committee. The list below shows the major activities of the evaluation committee.

Activities of the Evaluation Committee

Name	Time	Participants	Topics
The 1st Evaluation Committee	June	Domestic members	Notify the Committee the research plans for current year and action plans responding to the previous evaluation (The 1st General Research Committee is also held at the same day)
The 2nd Evaluation Committee	October	Domestic members	Notify the Committee the research progress report (The 2nd General Research Committee is also held at the same day)
The 3rd Evaluation Committee	January	Domestic members	Notify the Committee the research progress report (The 3rd General Research Committee is also held at the same day)
The 4th Evaluation Committee	Early March	All members	1st day: Notify the Committee the management and activity report 2nd and 3rd day: The Committee members attend International Symposium and are notified of the study results 4th day: Question and Answers session Discuss and evaluate the research progress
Submission of the Evaluation report	Mid/Late March	All members	Each evaluation committee member submits the evaluation sheet to the chair via e-mail. The chair collects each comment and draws up the evaluation report, and then, submits it to the Research Promotion Committee.

The evaluation committee members have the first annual evaluation committees at the beginning of the fiscal year to give approval to the action plans that has been made by the research members to respond to the previous evaluation comments. At the following 2nd and 3rd committees, each group reports research progress and results. The 4th committees are held at the end of the fiscal year, and all of the nine evaluation committee members including four from abroad participated in the meeting. The purposes of the meetings are to: (1) attend the international symposia to know the final reports of the study progress and results, (2) evaluate these study results of the current year. All evaluation sheets are submitted via e-mail and the annual evaluation reports are created. The evaluation reports and research progress reports are submitted to the Research Promotion Committee to receive approval. The achievements of the action plans responding to the previous comments are one of the evaluation items. The following list shows some of the comments from the evaluation committee (related to the project management) and the action plans.

Comments from the Evaluation Committee (project management) and Action Plans

Fiscal year	Comments from the evaluation committee members	Action plans
2000	More cooperation between industries is needed.	In order to strengthen the connection, we are going to encourage industry members to participate in the project. We are gong to research industrial needs by using questionnaire.
	Study objectives should be concentrated	Each group will make more efforts to clarify study objectives and concentrate on its target.

	Cooperation among the sub project group should be fostered	Cross-sectional basic research group meetings will be started.
2001	Each working group should generate a very brief set of conclusion and action items at the end of each working group meeting.	Each working group will follow the advice and practice this process.
	Cooperation between the national research institutes needs to be improved.	A joint meeting between the national institutes will be arranged in order to accelerate utilization of other institutes' equipments and devices, and also to promote collaborative research presentation.

In this way, the evaluation committee members give us specific and clear suggestions. We made action plans to respond thesae comments, which helps us clarify study objectives and make progress.

5.4 Support of the Research Promotion Committee

The Research Promotion Committee consists of nine members; namely, the director generals and the directors of the department of general affairs and the heads of the research panning office of the three research institutes. The heads of the three institutes also organize the Research Promotion Committee Secretary Meeting and have occasional meetings.

The Research Promotion Committee was held at the end of each fiscal year and gave approval to the annual research progress reports and evaluation reports. It is difficult to call all the members to have the meetings as often as required, then the members of the Research Promotion Committee Secretary Meeting, the heads of the three national institutes have frequent meetings to discuss matters related to the office procedure.

The Executive manager told that the project organization should be coordinated, regardless of each organization's difference. In complying with it, the Research Promotion Committee is dealing with leveling out such differences, including personal affairs and budged allocation for the smooth implementation of the project. In addition, we have signed a joint research agreement between each university and research institute, which helped to simplify office procedures. The three institutes also started to employ post-doctorial fellows under the same labor conditions.

The Research Promotion Committee also supported to establish the Center for Smart Control of Turbulence, which is the center of this project, as well as other important jobs as issuing letters of appointment to the Center for Smart Control of Turbulence to all the members of this project.

6. Project Overview: Evaluation of Results

6.1 Progress of the Plan

(1) Achievement of goals

In the first half of the project before the midterm evaluation, in both the sub projects, the research goals are placed starting with the identification of the characteristics of turbulence to be controlled, then proceed to the development of advanced measurement techniques to support the identification, and finally end up with the development of software including highly accurate numerical simulation techniques.

In the sub project "Active turbulence control", in addition to those stated above, there is still another research goal, for the midterm evaluation, of developing a prototype system for turbulence control. The streaky structure has been identified as the characteristics of wall turbulence, and the sensor arrays were developed using MEMS technology, thus progressing steadily. On the other hand, although several actuators were developed using also the MEMS technology, they need further progress including faster response. But the overall progress is highly evaluated because the intermediate goals have been met by developing a prototype turbulence control system consisting of MEMS sensor-actuator arrays and a controller, and by investigating control algorithms. The research on the control of wall turbulence by changing physical properties of the liquid using additives should also be highly evaluated in so far as elucidating skin friction reduction mechanisms using DNS and optical measurement techniques. Although the bubble size control in the microbubble study is unique, further study should be conducted.

In the sub project "Turbulence combustion control", as the prototype development is not included as an intermediate research goal, the progress is less than the other. This partly reflects the fact that this sub project was started in FY2000, in contrast to the other sub project " Active turbulence control" starting in FY1999 together with the beginning of the preceding project. The internal evaluation for FY2000 reported that the sub project project was not well organized and its research goals were not well focused. Consequently, in FY2001, considerable progress both in the organization and the research goals was made, such as selecting methane as fuel. And, at this stage of the midterm evaluation, the progress started to produce results such as the development of a model combustor for methane premixed lean-burn gas turbines, and the stabilization of flames using a pilot flame. The premixed lean-burn combution technique has wide application, and it is important to establish fundamental techniques that this sub project aims at, in order to put it to practical use. Therefore it is highly recommended that the researchers engaged in the sub project should work harder to meet the final research goal.

Considering what have been stated above for the two sub projects, the overall degree of achievement of the intermediate research goals is evaluated as 85%.

(2) Overall Progress of the Research

Although there was some delay in the development of the model combustor in the sub project "Turbulence combustion control", the overall progress of research is satisfactory.

6.2 Objectives and Goals

(1) Appropriateness of intially set objectives and goals

The initial research goals of establishing basic techniques and then constructing control systems were of sufficient high level and importance, and therefore appropriate.

(2) Need for changing final goals

At the present stage, most of the basic techniques to be utilized for achieving the final goal of the development of turbulence control systems have been developed, and it is expected to be developed furthermore by combining those techniques and further refining them. Therefore it is not necessary to change the final research goals

6.3 Research results

(1) Scientific value of the research results

The final goal of the project, of controlling highly nonlinear phenomena such as turbulent flows, a new development of science through engineering aprroaches, is yet to be achieved, but there are several noticeable products of element techniques.

In the sub project "Active turbulence control", the development of a prototype turbulence control system consisting of MEMS sensor-actuator arrays and a controller is expected to give a new direction to the development of MEMS technologies.

DNS, a technique to numerically simulate fluid motions, will keep increasing its importance, in pace with the development of computer technology. The DNS techniques for complicated flows such as turbulence, turbulence control, bubbly turbulent flows, and turbulent combustion, being developed in the present project, have scientific value. Those techniques should be further improved.

Some new developments in optical measurement techniques for turbulent flows deserve attention.

(2) Spreading effect of the research results

The final goal of the project "turbulence control", cannot be evaluated at the present stage, and therefore the achievements on element techniques are evaluated here.

The spreading effect of the research results of the present study, which belongs to engineering, should be evaluated from the viewpoint of practical application, or the contribution to industry. The skin friction sensor developed using MEMS technology utilizes the most advanced techniques, and therefore has high practical value of its own. The PIV/LIF optical measurement technique for bubbly flows, being developed in the present study, is expected to gain popularity as a technique for measuring multiphase flows. The generation methods for microbubbles will contribute, not only to the performance improvement as a skin friction reduction device for ships, but also to engineering fields related to environmental purification and enhancement of chemical reactions. The measurement techniques for combustion using semi-conductor lasers can be utilized for monitoring manufacturing processes at high temperature. Generally speaking, the measurement techniques and the simulation techniques developed in the present study are of fundamental character, and therefore have a wide application area. They can be applied, not only to fluid machinery design, but also to wider fields such as material processing, medicine, and micro-labs, and therefore further efforts should be made.

(3) Information release of the research results

In the both sub projects, a large number of papers have been presented in academic meetings. Further publicity is made through the international symposium held each year, and through the web site, both in Japanese and English. Finally, the fact that this project has helped to activate the research in this field internationally should be evaluated.

6.4 Research Organization

(1) Leadership of the executive manager

It is highly valued that the executive manager set up the Center for Smart Control of Turbulence to organize three national research institutes and universities participating in the project, and to establish a systematic body for the leadership. Also, he contributed to the smooth implementation of the program by addressing the importance of leveling out procedures in the three national research institutes in the beginning of the project.

(2) Cooperation between the sub projects

The cooperation between the two sub projects, having significantly different flows to control, is not easy, so that continuous efforts are needed. Therefore, it is effective to exchange information and opinions through symposia among all the research committees, and management groups, and cross-sectional basic research meetings for numerical simulation, measurement, and actuators. Further efforts should be made to produce the results of cooperation, for example, to utilize the control algorithms developed for active wall turbulence control in turbulent combustion.

(3) Attempts at Organized Research Combination System

It is highly valued that Center for Smart Control of Turbulence has been set up and a systematic body for the leadership has been established. In the second half of the project, it becomes more important to guide the direction of the research in the two groups, in order to reach the final goal. This should be carried out by utilizing the center organization.

It agrees with the policy of the present research system to unify the research budget, which is distributed separately to the three national research institutes, at the center.

The actions taken to meet the requirements by the Research Evaluation Committee, in the form of action plans to be carried out in the next fiscal year, have been satisfactory. The addition of research members from industry, in order to enhance cooperation with industry, is a good example.

(4) Support by the Research Promotion Committee

The address given by the executive manager in the beginning of the project that was on the importance of leveling out procedures among the three national research institutes for the smooth implementation of the program has been handled by the committee, and significant improvement in that respect was realized. Thus, enough support has been provided by the committee. More freedom is expected due to the reorganization of the three research institutes transformed from national organizations to independent administrative institutions. It is hoped that this will be utilized in improving the management of the present research project.

7. Sub project 1 "Active Control of Turbulence": Outline of Study Objectives and Results

Title: "Smart Control of Turbulence: A Millennium Challenge for Thermal and Fluids Systems"

Suttee title: "Working Group for Active Control of Turbulent Flow"

(Hiro YODHIDA: National Institutes of Advanced Industrial Science and Technology)

7.1 Outline of the research objectives

Wall turbulence is accompanied with active eddy motion, which is generated in the thin layer along the wall containing high gradients in velocity (boundary layers), and it can be observed when an object, such as an airplane, an automobile or a vessels moves in fluid flows, or in duct flows. Wall turbulence has some negative effects such as increasing drag friction 100 times as much as that of non-turbulent flow (laminar flow), or as making a noise. However, wall turbulence has some positive effects such as enhancement of heat-transfer and reducing separation, which is important especially for transport machinery. In this sub project group, the object to be controlled is wall turbulence, and we are aiming at reducing negative effects such as drag friction and enhancing positive effects such as heat-transfer between wall and fluids or reducing separation generated on the wings of an airplane.

The turbulent control methods are classified roughly into two categories. The first one is a "passive way," which means to install prearranged devices into flows. The other one is "active way" to act directly on longitudinal eddies of turbulent flows depending on the flow conditions. The active turbulent control methods are significantly superior to the passive turbulent control methods and have great impacts on turbulent control technologies, because the former enables micro-control depending on conditions. However, in order to enable the active control of fine scale eddies in turbulence, it is necessary to develop sensors and actuators that have almost the same size as fine scale eddies (mm-μm) as well as to develop control algorithms that enables to organize devices to monitor complex flow changes and to control them in an appropriate way. Some researchers started to develop in the 1980s mostly in the US; however, they are still conducting the basic research.

On the other hand, development of supercomputers enables the high-precision direct numerical simulation of the turbulence. In addition, we have found out that fluid properties can be changed dramatically by injecting microbubbles or applying small amount of or surfactants into fluid, which leads to changing the characteristics of turbulence significantly. A new three-dimensional fluid measurement technique has been developed, and great strides have been made in the development of micro-machine technique so that the significant progress has been made in designing the micron-order control devices. In this way, we have made great progress in elucidating mechanisms turbulence and developing control devices, which allows forming the basis for development. Thus, the three institutes participating this project have carried out their studies actively to develop active control systems.

In this sub project group, we are aiming to control wall turbulence as a control object while reducing negative effects such as a frictional drag and flow separation as well as enhancing positive effects such as heat-transfer between wall and fluid. We are using MEMS technology (installing a micro-sensors array or a micro-actuators array on the surface of the walls) and their control algorithm (software) technology as control methods (under the three years project). We are also using the control technologies for fluid properties by injecting fine bubbles (microbubbles) into water together with applying small amount of surfactants into water to establish a prototype turbulent control system (under the three years project). Thus, we are aiming to the frictional drag reduction, separation reduction, and heat transfer control by using the active turbulent control technologies (under the five years project).

7.2 Outline of the Research Results

We are aiming to establish a feedback control system for wall turbulence and separation by using micro- devices and therefore have investigated and developed the main components of the control system including both hardware (such as sensors and actuators) and software (mainly control algorithm). As for turbulent control technologies by using physical properties, we have investigated the mechanism of drag frictional reduction and examined the elemental techniques for turbulence control.

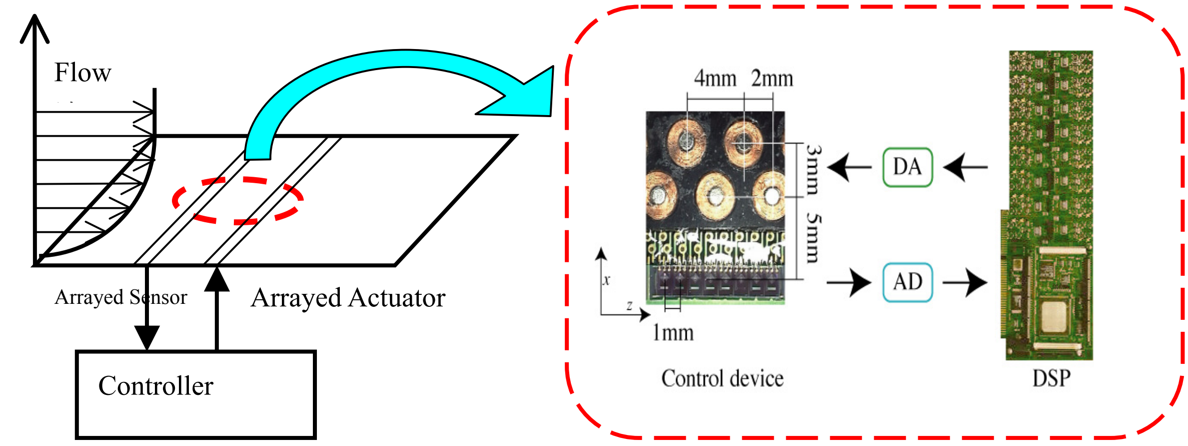
As for the study of active control of wall turbulence and separation, we have found out by using DNS that wall turbulence has a quasi-ordered vortex configuration called “streak structure”(See 3.2), which dominates the behavior of near-wall turbulent flow field. We investigated the parameters of sensor specifications that are required to detect streak structure and made developmental maps. In response to the results of these studies, we have developed several types of sensors using the heat-mechanical principles while analyzing theories. For example, we made a prototype hot-film shear stress sensors (2 mm×1.7 mm) to measure the local wall shear stress by using MEMS processing technologies. We performed its characteristic tests in air channels and examined its heat shielding performance and frequency response and have made some improvements on it. We have reached a conclusion that these sensors can be set in an array. In addition, we have examined the applicability of cantilever sensors that detect flow directions precisely, and optical fiver sensors that are used for evaluating frictional drag reduction effects.

As for control actuators, we have examined several applicable actuator principles based on the performance that are required to control. We have made a prototype system by using the micro-magnetic actuators (1 mm in diameter) and the hot-film shear stress sensor array mentioned above while developing devices in order to establish control systems as early as possible. We understand that further examination is needed to optimize the specification of actuators; nevertheless it can be said that this prototype system facilitated to clarify its problems to be solved. In addition, we have examined the principles of performance of the piezo ceramic actuator array that can be used in the high frequency domain and also examined the electrostriction actuators and the micro-jet vortex generator (MJVG) for active separation control. We applied for patents to these devices.

As for the control algorithms for activating these devices mentioned above, we used DNS to simulate the motion of turbulent flows and microsensor-, micro actuator-arrays and considered the possibilities of using algorithms including genetic algorism and neural network. We found out the array specification of the sensors and actuators, and the optimal control input, which will contribute to the development of the new system mentioned above. .

In the study on control of wall turbulence using microbubbles, we used PIV/LIF method (adding tracers that show fluorescence with laser) to measure the interaction between microbubles and turbulence precisely. We have elucidated the mechanism of how bubbles inhibit the generation of Reynolds stress, which is the main cause of increasing frictional drag in turbulent flows. We also developed three methods to control a bubble diameter; namely the water-jet, the variable cross sectional channel and the bubble pre-mixing, in order to determine the optimized bubble diameter to maximize the drag friction effects. Tiny bubbles, which are approximate 20 μm in diameter, could be generated with the bubble premixing method, and to be encouraged, we obtained double frictional drag reducing effects. In the future, we are going to identify the most effective bubble diameter to reduce frictional drag and will investigate the generation methods for practical use.

As for the study on turbulent control technology by adding surfactants, we have measured vertical structure of turbulent by the use of LDV (Laser-Doppler Velocimetry) and PIV, and elucidated the turbulent feature modification with drag reduction. We analyzed the non-Newtonian rheological properties of the surfactant additive fluid up to high Weissenberg number by using DNS with high resolution scheme, and achieved a drag reduction effect as high as 50% equal to the results obtained during the experiment. In the future, as we continue to carry out numerical simulations and experiments, we are going to develop a control method that fulfills both drag reduction and heat transfer control.



Prototype system for wall turbulence control with arrayed hot-film sensors and micro magnetic-actuators

8. Sub project 1 "Active Control of Turbulence": Information Release

Title: "Smart Control of Turbulence: A Millennium Challenge for Thermal and Fluids Systems"

Sub project title: "Working Group for Active Control of Turbulent Flow"

(Hiro YODHIDA: National Institutes of Advanced Industrial Science and Technology)

8.1 Information Release: Papers and Presentations

(1) Number of Papers and Presentations

	Original article	Refereed Proceedings	Other published papers	Oral presentation	Total
Japan	7(4)	0(0)	5(1)	52(8)	64(13)
Other countries	6(11)	38(4)	0(0)	7(0)	51(15)
Total	13(15)	38(4)	5(1)	59(8)	115(28)

Note: ( ) number of prepublication papers

(2) List of Original Articles

1) Papers published in Japan

〔Author(s), Title, Publication name, (Journal, Volume, Number, Page, Year of Publication etc.)〕

1. Kasagi, N., "Active Feedback Control of Turblence" JSME Series B, Vol.67, No.658, pp.1298-1304(2001).
2. Kawaguchi, Y., Daisaka, H., Yabe, A., Hishida, K. and Maeda, M. "Structure of Thermal Boundary Layer and Heat Transfer Characteristics in Drag Reducing Flow with Surfactant Additive" JSME Series B, Vol.67, No.658, pp.15-22(2001).
3. Fujiwara, A. and Hishida, K., "Bubble Motion in the Liner Shear Flow" JSME Series B, Vol.68, No.667, pp.696-703 (2001).
4. Kodama, Y., "Skin Friction Reduction of Ships by Microbubbles", JSFM *Nagare*, Vol.20, No.4 pp. 278-284 (2001).

(Total 11 Papers)

2) Papers published in other countries

〔Author(s), Title, Publication name, (Journal, Volume, Number, Page, Year of Publication etc.)〕

1. Segawa,T., Kawaguchi, Y., Kikushima, Y.,and Yoshida,H., "Active control of streak structures in wall turbulence using an actuator array producing inclined wavy disturbances", Journal of Turbulence, Vol.3 015 (2002).
2. Endo, T., and Kasagi, N., "Active Control of Wall Turbulence with Wall Deformation," JSME Int. J., Vol. 44, No.2, pp. 195-203 (2001).
3. Li P.W., Kawaguchi, Y., Daisaka, H., Yabe, A., Hishida, K. and Maeda, M., "Heat transfer enhancement to the drag-reducing flow of surfactant solution in two-dimensional channel with mesh-screen inserts at the inlet",

ASME Journal of Heat Transfer, 123, pp.779 – 789 (2001).
4. Iwamoto, K., Suzuki, Y., and Kasagi, N., “Reynolds number effect on wall turbulence: Toward effective feedback control”, Int. J. Heat & Fluid Flow, (to appear).

(Total 17 Papers)

(3) List of Other Published Papers

1) Papers published in Japan
［Author(s),Title, Publication name, (Journal, Volume, Number, Page, Year of Publication etc.)］

1. Kasagi, N., Suzuki, Y., and Fukagata, Y., “Turbulent Control,” *PARITY,* Vol. 15, Nov 2002. (to be published)
2. Suzuki, Y. and Kasagi, N., “Active Smart Control of Wall Turbulence,” *“Savemation Review: special edition Microflow sensor, ”* Yamatake Corporation, pp. 50-57 (2001).
3. Kasagi, N., “Toward Smart Control of Turbulence,” JSASS, Vol.48, 554, pp. 155-161 (2000).

(Total 6 papers)

2) Papers published in other countries
0 (None)

(4) Refereed Proceedings

1) Papers published in Japan
0 (None)

2) Papers published in other countries
［Title, Author(s), Publication name, (Journal, Volume, Number, Page, Year of Publication etc.)］

1. Iwamoto, K., Suzuki, Y., and Kasagi, N., "Effect of Nonlinear Interaction on Feedback Control of Wall Turbulence", Proc. 2nd Int. Symp. on Turbulence and Shear Flow Phenomena, June, 2001, Stockholm, Vol. 3, (2001), pp. 17-22.
2. Yoshino, T., Suzuki, Y., Kasagi, N., and Kamiunten, S., "Assessment of the Wall Shear Stress Measurement with Arrayed Micro Hot-film Sensors in a Turbulent Channel Flow", Proc. 2nd Int. Symp. on Turbulence and Shear Flow Phenomena, June, 2001, Stockholm, Vol. 2, (2001), pp. 153-158.
3. Segawa,T., Kawaguchi,Y., Kikushima,Y., and Yoshida,H.,” An active control of wall turbulence by actuator array producing spanwise perturbations”, Proceedings of 2nd International Symposium on Turbulence and Shear Flow Phenomena, Vol. 1, pp. 187-192 (2001).

(Total 42 papers)

8.2 Patent Applications

1) Japan (4)

“Vibration type torque control system” Segawa, T., Kikushima, Y. and Yoshida, H., Japanese patent pending No.

2000－181182, Jun.16, 2000

“Longitudinal Vortex Generator,” Abe, H., Japanese patent pending No. 2001-058702, March 2, 2001.

“A skin friction reduction device for ships,” Higaki, S., Kawakita, C., Ishikawa, A., Takano, S., Takahashi, T., Japanese patent pending No. 2001-358659, Nov. 26, 2001.

“A drag-reduced ship, ” Kodama, Y., Japanese patent pending No. 2001-379550, Dec. 13, 2001.

2) Other countries (USA) (1)
“Heat Exchanger Using Drag Reducing Fluid”, Kawaguchi, Y., Yabe, A., U.S. Patent 6, 112, 806, Sep.5, 2000.

8.3 Awards

1) Japan (2)

JSME Young Engineers Awards 2000

“Development of an intelligent nozzle equipped with an array of miniature actuators for jet control”
Hiroaki SUZUKI,

Heat Transfer Society Award for Scientific Contribution 2002

“Active Control of the Jet Structure with Electromagnetic Flap Actuators”
Nobuhide KASAGI, Yuji SUZUKI,

2) Other countries (0)

(None)

9. Sub project 1 "Active Control of Turbulence": Outline of the Project Organization

Title: "Smart Control of Turbulence: A Millennium Challenge for Thermal and Fluids Systems"

Sub project title: "Working Group for Active Control of Turbulent Flow"

(Hiroo YODHIDA: National Institutes of Advanced Industrial Science and Technology)

9.1 Leadership of the sub project group leader

This project consists of researchers from various research laboratories; three national research institutes, which formerly belonged to different ministries and agencies (former Ship Research Institute of the Ministry of Land, Infrastructure and Transport, National Aerospace Laboratory of the Agency of Science and Technology, and former Mechanical Engineering Laboratory of the Ministry of Economy, Trade and Industry.) and also from various universities and industry. Each Institute or university has its own culture, which might hamper coordination among these agencies. First, the director generals of the three research institutes started to have regular meeting five years ago prior to this project. Next, some of the researchers started to visit other laboratories and to have regular meetings, which facilitated communication across these researchers. After the project was adopted formally, we continued to have regular meeting to check the research progress.The study objectives were reviewed in response to the comments or suggestions from participating companies and the questionnaire data from other private companies. These objectives were assigned to each member to maximize their potential, and then the objectives were clarified and concentrated. We desided to give priority to the studies of control devices such as sensors and actuators, to which budget were allocated intensively. There existed many problems to be solved, especially with regard to actuators. We cooperatively have made specification maps and created better conditions for joint-research. We also took a new look at research progress and, if necessary, recruited promising members. We have employed seven postdoctral fellows including from overseas so far, which will contribute to foster young researchers.

The sub project group leader, under the Executive Manager's and the Directors' leadership, support the group members while seeing how the research is progressing.

9.2 Attempts at Organized Research Combination System

In addition to the regular meeting that are held three times a year, we have another research meeting as needed to share common understanding about research directions. We check each study group's study progress at these meetings.

The study results obtained in this project are released to the public on the web, at the international symposia, or in special sessions of academic conferences. Several researchers are participating from private companies in this project, and we have great opportunities to hear the opinions of industries. We concluded mutual agreements among the institutes to promote sharing measuring devices, using other institutes equipments for experiments mutually. Researchers from institutes have implemented studies and written papers under joint authorship with researchers from different institutes or have made presentations at academic conferences in cooperation.

As for budget allocation, prior to budget requests, we make adjustments with each member to decide the allocations of the project fund. In addition, the three research institutes set up meetings to discuss urgent matters as needed; for example, to send some researchers to the international symposia to gather the latest information.

10. Sub project 1 “Active Control of Turbulence”: Evaluation and comments

Title: “Smart Control of Turbulence: A Millennium Challenge for Thermal and Fluids Systems”

Sub project title: “Working Group for Active Control of Turbulent Flow”

(Hiro YODHIDA: National Institutes of Advanced Industrial Science and Technology)

10.1 Progress of the Plan

(1) Achevement of Objectives

The study goals of the first half of the project, by the time of the mid-term evaluaiton, are as follows. First, we are aiming to understand the characteristics of turbulent flows to be controlled, and then, to establish fundamental technologies (sensors, actuators, control techniques) and to develop advanced measurement techniques to support the fundamental technologies and software technologies such as high-accuracy simulation technologies, and finally to develop a prototype system for turbulent control.

As for understanding of the characteristics of wall turbulence, streak structures have been identified as control objects, and a prototype sensor array by using MEMS technologies have been made. In general, the study is in steady progress. On the other hand, as for actutors, this group have made a prototype actuator by using MEMS technology, which is left to be improved regarding its response and so forth, however. It is their credit that they have developed a prototype turbulent control system by combining a sensor-array, an actuator-array and a controller, and also we have made the in-depth examination of control system including control algorithms, as originally planned. In the study of wall turbulent control by changing fluid physical prosperities with additives, it is our credit that they have shown progress in elucidating the mechanisms of frictional drag reduction by using DNS or optical measurement techniques. On the other hand, DNS results have not revealed the frictional drag reducing effects of microbubbles satisfactorily; we hope further progress will be made in the future. Although comprehensive results have not been obtained so far, the attempt to control diameter of microbubbles can be said unique, and we should raise the precision of experiments continuously.

The improvements of measurement and simulation technologies are significant, and these improved technologies will be utilized for elucidating the phenomena and specifying the designs of sensors and actuators.

The overall degree of achievement so far is evaluated as 90%.

(2) Overall progress of the research

In the conventional way, in this field of study the goals are set to develop devices (hardware). On the other hand, in this project, we have developed each device aiming to apply to a turbulent control system. In fact, some specific ideas about sensors or actuators for practical use have been obtained.

The wall shear sensor by using MEMS technologies, which is arranged in an array, has been developed as well as high performance devices. It seems that the study is progressing well.

Many results have been achieved with regard to control techniques such as the evaluation for control algorithms using MEMS and increasing the frictional drag reduction effects with additives. The study also seems progressing well; however, a further examination of control algorithms seems to be required.

In addition, a simple prototype control system is being developed, and the development goals for practical use have been clarified.

As for actuators, several devices have been presented; however, further progress is expected.

In general, the study also seems progressing well.

10.2 Objectives and Goals

(1) Appropriateness of initially set objectives and goals

Initially set ovjectives and goals are approproate.

(2) Need for changing final goals

At this stage, each study is in progress to develop a new system. There are no need for changing final goals.

10.3 Research Results

(1) Scientific values of the study results

Elucidating the mechanism of turbulent phenomenon is vital to control of complicated phenomenon of turbulence. In this study, we have focused on the studies of basic research tools such as measurement technologies and simulation technologies, which are considered to contribute to turbulent research in general.

For example, these studies are contributing to the establishment of technologies including the non-intrusive three-dimensional high-precision observation methods with laser, the direct numerical simulation methods and the micro-device design technologies, and eventually to promoting better understanding of the phenomena.

(2) Spreading effects of the research results

Significant progress has been made in developing elements for control devices such as sensors or actuators. For examples, the wall shear stress sensor developed in this project is of world-class performance. It is not only a sensor for turbulent, but also would help create innovation in fluid measurements. In addition, we expect the micro bubble generation method will be applied to manufacturing fields such as cleaning or accelerating chemical reaction. These elements themselves are close to be available as a result of this project. In other words, these study results have potential for application in various fields such as a medical or micro-lab area. We hope these results will be applied to in various fields beyond this project's targets.

In addition, this research project stimulated research and development in the U.S, which actually existed prior to our project but was not active enough, and mortivated them to restart their conference activities in the U.S. even more actively than before. In Japan, several special sessions have been organized which may enhance opportunities for cooperation among industries, research institutes, and universities. Researchers from industry gives us several suggestions regarding to practical devices for application.

Various spreading effects are expected in the future.

(3) Information release of research results

The study results of this project have been released through publication of papers and presentation at academic conferences. In addition, several research results are presented at the international symposia, and theses results are also released on the website. We share information with several interested companies, and, as the need arises, we ask these companies to participate in this project. In conclusion, we think information is well released.

10.4 Organization of the project

(1) Leadership of the sub project group leader

Regular meetings have been held with various researchers from independent administrative institutions, universities and private companies, in order to share information about research targets and objectives. In addition, the leader of this working group has discussed the research progress with each member as needed in order to comprehend the progress in detail. He also shows strong leadership in the budget implementation; he accommodates each member’s request and contributes to the smooth implementation. In this way, the leader of this working group shows sufficient leadership.

(2) Attempts at Organized Research Combination system

Generally speaking, there might be some difference in terms of research direction among the participating researchers respectively from independent administrative institutes, universities and private companies. The leader of the sub project has allocated various study topics that is essential for turbulent control technologies including the fundamental understanding of the phenomena, device manufacturing technologies or control theories to each group. The laboratories at universities are assigned to the research in a fundamental area, and independent administrative institutes are assigned to the investigation in the more applied area. In this way, we utilize the research resources in an effective way. We have interacted with some interested companies, which make the research more fruitful. In addition, it is to the leader’s credit that he has promoted to exchanging information between the researchers and sharing equipments for joint research.

11. Sub project 2 “Turbulent Combustion Control”: Objectives and Results

Title: “Smart Control of Turbulence: A Millennium Challenge for Thermal and Fluids Systems”

Sub project title: “Working Group for Turbulent Combustion Control”

(Satoru OGAWA: National Aerospace Laboratory)

11.1 Outline of Research objectives

First, we have clarified our objectives of the combustion control; we are aiming for expanding stability range of lean premixed combustion. We expect lean premixed combustion will be developed as an environmental friendly combustion control technology; even though its application is limited due to its instability. Furthermore, we decided to focus our study on a methane fueled lean premixed combustor, which is the most important topic for practical use, and expanding the stable combustion field by controlling the combustor.

Although the control target has been focused on, to succeed in controlling turbulent combustion, the knowledge of various study fields including combustion, fluid flows or control are necessary. In addition, there had been no other prior studies of turbulent combustion control in Japan. Thus, we started form fundamental research as needed, aiming to develop technologies for practical use or applied technologies.

The purpose of the study objectives is elucidating the turbulent combustion phenomena. To succeed in controlling, we should solve problems including elucidating flame instability, structure, mechanisms of flame holding or extinguishing. Elucidating these phenomena will contribute various fields including establishing a control theory as a system. In this way, we have set our goals to solve these problems and examined combustion phenomena in detail by using high precision numerical analysis and optical measurement.

As for applied research on this topic, we are going to examine current combustors and find out their problems. We are going to design a new model combustor for practical use and construct an integrated model while combining with the results of fundamental studies including actuators, sensors, and controller. Our study objectives are to develop combustion control devices and control system, and to carry out experimental study in a model combustor. We are aiming to investigate and develop basic technologies that are required for advanced combustor.

In this way, our final goal of this project is, while combining various basic technologies on new turbulent combustion control, to develop a new combustor for next generation that enables expanded stability range of lean premixed combustion.

11.2 Outline of the Research Results

In FY 2000, we carried out the following works: 1) exchanged information about research progress both in Japan and other countries, 2) carried out fundamental research on control system, 3) examined measurement technologies for combustion control, 4) fundamental studies on flame structure by using numerical simulation of combustion system, or on noise generation mechanism to elucidate these phenomena and so on. Based on the fundamental research and investigation, in FY2001, we have carried out several experiments to develop a model combustor and implement experiments with it, to develop control element technologies (sensors, actuators) and to examine the phenomena by using numerical simulation. In this way we have started to construct a model system for lean premixed combustion control based on results of these experiments and studies. The following is the outline of the study results, which are categorized into three groups: “Basic research on combustion,” “Study of control system,” “Applied research of combustion.”

< Basic research on combustion >

In order to control unstable phenomena such as blowout, oscillating combustion and noise, we have done fundamental research on mechanisms of flame structure in detail and combustion noise generation.

As for the research on flame structure in detail, DNS calculations were carried out with numerical wind-channel (NWT) at NAL to investigate flame structure in detail and elucidate flame-stabilizing mechanism. For the most part, we have engaged in measuring in a lifted-jet flame and examined flame structure and stabilizing mechanism. A complicated three-dimensional structure that consists of diffusion zone, rich premixed zone, and lean premixed zone is formed in the bases of lifted–jet flame. The DNS calculation reveals that rich premixed flame is formed the center of the jet under strong turbulence, and island-shaped diffusion flame is formed just outside the rich premixed flame.

We also implemented DNS calculation with regard to noise generation from combustion field. We have clarified the relationship between turbulent filed and noise generation, and evaluated the equation for predicting acoustic fields.

In addition, we have examined the turbulent combustion model for the calculation of practical cases based on the results of DNS. Turbulence has an effect on inner-structure of flame under strong turbulence, and there exists a discrepancy between distribution of fuel consumption rate and heat generation rate. In this way, we identified the existence of flame that cannot be explained by using flamelet model used in conventional combustion LES *(Large Eddy Simulation)* calculation. In the future, we are going to analyze DNS data and construct a new LES model that can be used in strong turbulence combustion field.

We have investigated advanced technologies in combustion measurement to apply them to turbulent combustion control. The quality of measurement technologies depends on its time and spatial resolution. We have applied diode laser absorption spectroscopy (DLAS) to measure flame stabilizing at lean premixed combustion field and unsteady motion of flame-tip using high time-resolution. We have succeeded in taking temperature samples at 20 kHz, which cannot be obtained with conventional thermocouples. We have also attempted to detect flame oscillation while measuring fluid flows at the turbulent flow field with PIV. Furthermore, we have developed a method to measure movement velocity and direction by spontaneous luminescence (chemiluminescence) spectral measurement, which suggests local flame structure of turbulent flames can be measured by using this method. By using this time resolved non-intrusive precise measurement technique, we have measured lean-premixed flame around a bluff-body. We measured unsteady movement of flame at flame-stabilizing region in chronological order and succeeded in specifying the frequency of the combustion oscillation at flame-stabilizing region by analyzing the time-series data. In the future, based on the DNS results, we are going to elucidate flame stabilizing and extinguishing phenomena and investigate the relationship between local flow fields or flame structure.

<Study of control system>

In order to construct a full-fledged control system, we have examined characteristics of actuators and made a prototype simple control system with built-in actuators. We have developed a simple method for reducing turbulent combustion noise and oscillation, whose effectiveness has been confirmed.

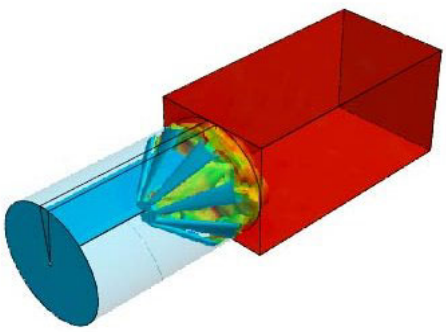
First we have designed a flame-stabilizing device with a cone-shaped flame holder, a variable swirler, and secondary flame. We have confirmed its flame-holding and gas emission performance and installed it in the model combustor.

In the next place, we have examined the application of active noise reducing technologies by using secondary sound source to reduce turbulent combustion noise and oscillation. We made a speaker for combustion control as an acoustic vibration type actuator and carried out experiments to reduce combustion oscillation with the swirl-type combustor. We have succeeded in reducing oscillation at the specific frequency. In addition, we have investigated control algorithms for active control, which will be applied to a model combustor. We have also considered using a secondary sound source generated with micro-jet piezo-nozzles. To generate acoustic sources under the circumstances of combustion fields, which reach high-temperatures and high pressures, it is a way to generate acoustics from heat generation variation by change of fuel flow rate. We have applied control valves with piezo-electric elements as actuators, which have functions for flow volume control at high flow rate. We have examined acoustic properties of flames with pulsating flow rate of fuel, spectral characteristics of sound pressure while burning and non-burning, and effects of the fuel gas on properties of frequency, which, in conclusion, can be used as secondary sound sources.

<Applied research of combustion>

We have designed and developed an experimental model combustor that has flame stabilization performance to demonstrate a control system aiming at super lean stable lean premixed combustion. We have started to evaluate its performance. As for development for model combustor with a device for flame holding, we have started to measure in details with LIF and PIV in order to elucidate flame stabilizing and extinguishing mechanisms, combustion oscillation phenomena, and generation mechanism of these phenomena.

We implement examination of this combustor with LES (Large Eddy Simulation) method. Calculations are carried out under the similar conditions that of model combustor experiment. Recirculation zone that is required for flame stabilizing is built up in pilot area and peripheral skirt area of a flame holder, and also small recirculation is formed at the arm of a flame holder. As velocity is increased, flame is formed at downstream, and then it moves away from flame holder. These results have good correlation with experiment results, and indicate that LES would be used as a tool for elucidating control law.



Numerical Simulation of the model combustor with LES (Thermo Field)

12. Sub project 2 "Turbulent Combustion Control": Information Release

Title: "Smart Control of Turbulence: A Millennium Challenge for Thermal and Fluids Systems"

Sub project title: "Working Group for Turbulent Combustion Control"

(Satoru OGAWA: National Aerospace Laboratory)

12.1 Information Release: Papers and Presentations

(1) Number of Papers and Presentations

	Original article	Refereed Proceedings	Other published papers	Oral presentation	Total
Japan	11(0)	4(0)	2(0)	96(0)	113(0)
Other countries	22(5)	32(0)	3(0)	27(0)	84(5)
Total	33(5)	36(0)	5(0)	123(0)	197(5)

Note: ( ) number of prepublication papers

(2) List of Original Articles

［Author(s), Title, Publication name, (Journal, Volume, Number, Page, Year of Publication etc.)］

1) Papers published in Japan

1. Tanahashi, M. et al., "The Structure of High Intensity Turbulent Premixed Frames," JSME Series B, Vol.67, No.654, pp.536-543, (2001).
2. Ikeda, Y. et al., "Local Chemiluminescence Measurement of Turbulent Premixed Frame," JSME Series B, Vol.67, No.658, pp. (2001).
3. Mizobuchi, Y., et al., "DNS Analysis of Hydrogen/ Air Lifted Flame," Proc. High Performance Computing and Sciences, pp.107-112, (2002).

(Total 11 Papers)

2) Papers published in other countries

［Author(s), Title, Publication name, (Journal, Volume, Number, Page, Year of Publication etc.)］

1. Tanahashi, M., Nada, Y., Ito, Y. and Miyauchi, T., "Local Flame Structure in the Well-Stirred Reactor Regime," Proc. Combust. Inst., Vol. 29, pp. (2002) in press.
2. Choi, G-M., Tanahashi, M., Li, Y. and Miyauchi, T., "Verification of Reduced Kinetic Mechanism by Hydrogen-air Non-Premixed Flame Formed in Shear Layer," Thermal Science and Engineering, Vol.10, No.4, pp. (2002) in press
3. Mizobuchi,Y., Tachibana, S., Shinjo, J., Ogawa, S., and Takeno, T., "A Numerical Analysis on Structure of Turbulent Hydrogen Jet Lifted Flame," Proc. Combust. Inst., Vol. 29, (2002) in press.
4. Shinjou, J., Mizobuchi,Y., Tachibana, S. and Ogawa, S., "Numerical simulation of flame behavior in a gas turbine combustor toward its control," Proc. Combust. Inst., Vol. 29, (2002), in press.
5. Hayashi, K., Yamazaki, Y., Sato, H., "Active Control of Combustion Oscillations for Premixed Combustion Systems," J. Physics D, (2002) in press
6. Li, Y., Tanahashi, M., and Miyauchi, T., "Sound Generation in Compressible Mixing Layers," JSME International Journal, Series B, Vol.44, No.4, pp.505-512, (2001).

7. Yoshida, S., “An Opposed Jet Burner for the Study of High-Intensity Combustion,” Measurement Science and Technology, Vol. 10, No. 12, pp. 1-3. (2000).

(Total 27 Papers)

(3) List of Other Published Papers

1. Miyauchi, T., Tanahashi, M., and Li, Y., “Sound Generation in Chemically Reacting Mixing Layers,” Smart Control of Turbulent Combustion, Springer, pp.28-38, (2001).
2. Mizuno, T., “Mechanical Dynamics / Measurement Control, Chapter 9: Control of Movement and Oscillation,” 1999 Mechanical Engineering Almanac, (1999).

(Total 5 Papers)

(4) Refereed Proceedings

［Author(s), Title, Publication name, (Journal, Volume, Number, Page, Year of Publication etc.)］

1. Tsukinari, S., Saito, T., Tanahashi, M., Miyauchi, T. and Choi, G-M., “Estimations of the Heat Release Rate in Methane-air Premixed flames by CH-PLIF,” The 6th ASME-JSME Thermal Eng. Joint Conf., (2002) submitted.
2. Ikeda Y., Kojima J., Hashimoto H. and Nakajima T., “Detailed Local Spectra Measurement in High-Pressure Premixed Laminar Flame,” 40th AIAA Aerospace Sciences Meeting and Exhibit, AIAA paper, 2002-0191, (2002).
3. Tanahashi, M., Ito, Y., Fujimura M. and Miyauchi, T., “Local Flame Structure in Hydrogen-Air Turbulent Premixed Flames,” IUTAM Symp. on Turbulent Mixing and Combustion, pp.102-103, (2001).
4. Tanahashi, M., Ito, Y., Yu, Y. and Miyauchi, T., “The Structure of Hydrogen-Air Premixed Flames in High-Intensity and Small-Scale Turbulence,” Proc. 3rd Asia-Pacific Conf. on Combustion, pp.75-78, (2001).
5. Kurosawa, Y, Yoshida, S., Yamamoto, T., and Suzuki, K., “Structure of Swirler Flame in Gas Turbine Combustor” The 15th International Symposium on Air Breathing Engine, (2001).
6. “Local Flame Structure in Hydrogen-Air Turbulent Premixed Flames,M. Tanahashi,” Ito, Y., Fujimura, M. and Miyauchi, T., IUTAM Symp. on Turbulent Mixing and Combustion, pp.102-103, (2001).
7. “Tracking Control Using Exogenous Signals Synchronized with Reference Signals,” Suzuki. H., and Mizuno T. Proc.5th International Conference on Motion and Vibration Control, pp.187-192, (2000).

(Total 36 Papers)

12.2 Patent Applications

1) Japan (1)

“Lean premixed combustor ” Yamamoto, T., Japanese patent pending No. 2002-207547, Jul. 16, 2002.

2) Other countries (0)

(None)

12.3 Awards

1) Japan (1)

“Local Flame Structure of a H_2-Air Turbulent Premixed Flame”

Mamoru TANAHASHI, Yuzuru NADA, Masahiro IMAMURA, Toshio MIYAUCHI

JSME Medal for Outstanding Paper 2000

2) Other countries None (0)

13. Sub project 2 "Turbulent Combustion Control": Outline of the project organization

Title: "Smart Control of Turbulence: A Millennium Challenge for Thermal and Fluids Systems"

Sub project title: "Working Group for Turbulent Combustion Control"

(Satoru OGAWA: National Aerospace Laboratory)

13.1 Leadership of the sub project group leader

When we started this sub project group, we had several difficulties to overcome. First, turbulent combustion phenomenon is so complicated that each researcher has a different understanding of "control" of this phenomenon. One of the reasons might be that there had been no preceding research of active control of turbulent combustion in Japan, partly because some of the researchers in combustion who had investigated instruments such as engines suspected the possibility of active control of turbulent combustion, in consideration of instrument robustness. And also, almost none of the researchers in Japan investigated this study topic. Consequently, the sub project leader started with presenting the significance and perspective of the study, and then, organized the sub project study group.

In the evaluation committee of FY 2000, some committee members pointed out that research organization did not function well and study objectives should be concentrated. To respond these comments, the leader held group meetings frequently to promote information exchange among the members and made efforts to reach a group consensus of the study objectives. The leader sought for participants from industry and clarified the problems of research implementation with actual devices, which helped us clarify turbulent combustion targets. Based on the agreed targets, each group and member was assigned to specific topics. Consequently, this sub project group has become more organized and functioning well as a group.

It had been difficult to implement joint research among three national research institutes and universities because every institute or university had its own background or culture. We have combustions control meetings including participants from private companies almost every month in order to promote a better understanding of direction of research by reporting research progress, clarifying the problems and presenting research papers. In addition, study group meetings are also held to discuss each study objective. In this way, objectives of this sub project group and research organization have been improved significantly.

13.2 Attempts at Organized Research Combination System

While focusing on the direction of study, we have attempted to organize a more cooperative research group regardless of each researcher's affiliation.

Independent administrative institutions had been implement application oriented research to develop new technology, while universities, in general, had been dealt with basic research. As for combustion, universities mainly had dealt with themes such as elucidating flame structures. On the other hand, private companies had attempted to develop a new technology that was connected directly with product development. In this way, each organization had a totally different direction. This project is aiming to organize and promote close cooperation among researchers of different organizations and to develop an advanced technology. We expected to create a cross-sectional, more open research organization.

When the project started, each group did not pay much attention to the difference of system or cultural background among the institutes, univestsities and industies, and basically, each group continued individual study themes and reported results on various topics. However, as communication among the members was fostered, each group started studies that were more complementary and mutually supportive to each other. Responding to the suggestions of evaluation committee members, we asked researchers from industry to join this project, which was helpful to clarify the study objectives to meet the needs of industry. It also helped every participating researcher fully understand the research direction.

Next, we arranged our research organization based on the common goal of “study of turbulent combustion control.” We have organized the following groups: basic research group, applied research group, study of control system group. The members of these groups were assigned based on not the researchers’ affrications but on their research experiences. Some of them belong to more than two groups. While a group implementing a certain study, it happens that the group obtains results that might meet other group’s needs. The research organization has consolidated cooperation between the independent administrative institutions, the institutions and the universities or private companies. Some of the examples of such results from cooperation are as follows; we have compared results of simulations at NAL with those of measurements at universities, NMRI and universities jointly utilized combustion measurement system at NMRI.

14. Sub project 2 "Turbulent Combustion Control": Evaluation and comments

Title: "Smart Control of Turbulence: A Millennium Challenge for Thermal and Fluids Systems"

Sub project title: "Working Group for Turbulent Combustion Control"

(Satoru OGAWA: National Aerospace Laboratory)

14.1 Progress of the Plan

(1) Achevement of Objectives

During the first half stage of this project, we have focused on establishing fundamental technologies of elements of control system including sensors actuators or control techniques and improving measurement and simulation technologies for elucidating phenomena to clarify control methods.

We have clarified the target of combustion control, and according to the agreed target, we have implemented studies to elucidate the phenomena. Study themes such as lifted flames, combustion noise simulation, and advanced optical measurement technique will be useful for future progress. In addition, some control methods for flame stabilization (especially control of combustion noise reduction and oscillation reduction) have already been designed and some of them have been proven their effectiveness for practical use. However, there is room for improvement regarding flame stabilizing. As for study on control algorithms, we have just started research; however, a further development of this study is expected. Several performance tests for actuators such as acoustic devices, high-speed nozzle, have been implemented. The objectives for improvement for practical use have been clarified. In addition, we have developed a highly advanced optical sensor, and we will evaluate its possibilities for practical application.

Measurement technology and DNS simulation technology have been developed and achieved highly advanced level, and these technologies will be useful to understand such phenomena. However, correlation between measurement results and simulation is not enough for explanation so that further investigation is expected.

In order to build a control system, each elemental technology needs to be improved. The overall degree of achievement of the intermediate research goals is evaluated as 80%.

(2) Overall Progress of the Research

As for basic research, including advanced measurement technology and simulation technology, world-class quality research results have been obtained.

In addition, we have investigated some unique devices for turbulent combustion control such as actuators for a combustion noise or oscillation control. These devices, however, need to be improved for practical use. The performance of the monitoring system with diode laser is satisfactory as a sensor, and the system has also a good time and spatial resolution. This device also requires further improvement for practical use.

As for control technology, we have developed unique techniques for turbulent combustion control such as combustion noise or oscillation control reduction techniques. The research is progressing well; however, the control algorithms need further investigation.

We are constructing a simple prototype control system at present, and the development goals for the system are clarified.

In this way, some notable results of element technology have been obtained so far. We have integrated these elements and have made a model combustor assuming that it would be applied to a lean-premixed methane gas turbine to demonstrate the system. There is, however, room for improvement in terms of its specific design, immediate actions should be taken.

In general, even though it is a challenging theme, the research is progressing well.

14.2 Objectives and Goals

(1) Appropriateness of initially set objectives and goals

Initially set ovjectives and goals are approproate.

(2) Need for changing final goals

Each study is in progress to develop a new system at this stage. There are no need for changing final goals.

14.3 Research Results

(1) Scientific values of the research results

The most important thing is that we should elucidate and understand the phenomena that enable to control the complex phenomena of turbulent combustion. We, therefore, have focused on developing several research tools including measurement technology and simulation technology, which will contribute to the overall study of turbulence.

For example, measurement system with high time and spatial resolution by using laser and DNS technology at combustion field have been established, which help us improve understanding of this phenomena.

(2) Spreading effects of the research results

One of the major spreading effects of the research that we have investigated is the world-class measurement and simulation technology. Simulation technology has been improved significantly, and several results have been obtained so far. These results are not only useful for turbulent combustion control but also for fundamental technology in the manufacturing industry such as combustor design. In addition, we have investigated some unique actuators for a combustion noise or oscillation control. Some devices need to be improved; for example a device using acoustics fields or using high-speed valve with secondary fuel jet. These devices, however, will be applied for actual devices when once it is put into practical combustor.

In conclusion, widespread effects of the research results are expected.

(3) Information release of the research results

Information about the study results is released through papers and presentations. The research results are also released at the annual international symposia, and they are available on the web. Moreover, some researchers from private companies join this research group. In this way, information release is sufficient.

14.4 Research Organization

(1) Leadership of the leader of sub project working group

At the first year, evaluation committee member expressed concerns about this group including that the research organization was not functioning well; the research objectives were not well defined. To respond these comments, we started to have regular meetings and discussions, which helped better communication among the members. As the situation improved, the leadership of sub project working group improved, the leader is showing appropriate leadership. In addition, the leader adjusts each member's demands to allocate budgetary funds in appropriate way, and implement the research smoothly. As the number of participants increases, on the other hand, the research targets tend to scatter and less-focused so that we should always be reminded of the agreed objectives. It might be partly because combustion control requires some element technologies in various fields. In the future, however, more cooperation among the members and more specific and concentrated study objectives to develop a concrete control system are needed. Moreover, during the latter half of the project, the leader should organize all results, which requires more strong leadership.

(2) Attempts at Organized Research Combination System

In general, there are some differences about the study direction among the members from independent administrative institutes, universities, and private companies. The leader of the subgroup, however, has organized the joint research group despite such differences, and the members have helped each other. The leader sought for the new member from private companies in order to clarify the study objectives, and as a result, the group is well unified. On the other hand, the members exchange information with the researchers form other organization, and joint research is carried out, some machines and devices are utilized jointly between the institutions. Above all, cooperation between institutions and universities are sufficient, and organized research combination system seems functioning well. On the other hand, no positive results such as papers or patents have been produced from the cooperation between the insitituions so far. At this this point of view, there is room for improvement.