International Gas Turbine Congress 2011 Osaka

1. Overview

The 10th International Gas Turbine Congress (IGTC '11) sponsored by the Gas Turbine Sciety of Japan (GTSJ) was held in Nakanoshima, Osaka, at the Osaka International Convention Center (Grand Cube Osaka, GCO) for six days from Sunday, November 13, to Friday, November 18, 2011. As was the previous conferences of this series, this event was presented in collaboration with International Gas Turbine Institute (IGTI) of the American Society of Mechanical Engineers (ASME), the Japan Society of Mechanical Engineers (JSME), the Japan Society for Aeronautical and Space Sciences (JSASS), and other 10 academic societies and organizations from around the world including United Kingdom, Germany, France, Korea, in addition to 25 domestic academic societies and organizations. This conference marked the first one to be hosted by GTSJ after its transition into a public interest incorporated association in 2011. Marking an increase of 36 percent from the previous 2007 conference's enrolment, registered attendees for this event totaled 481, with 368 from Japan and 113 from 19 countries overseas, to truly define the term “international congress.”

The opening lecture on the first day of the conference was a plenary talk commemorating the 10th congress offered since the initial 1971 event and celebrating 40 years of gas turbine development. A commemorative photo exhibition was also presented as a retrospective of the previous nine conferences. In addition, three gas turbine lectures were offered free of charge to high school students, university students, and the general public. All exhibits and lectures were successful.

Several events planned to enliven the conference included a welcome reception, a banquet, and plant tours. All were very successful and attracted many participants. The exhibition, held on the 10th floor of GCO, featured 79 booths from 39 organizations and offered information on such topics as actual gas turbines and models, turbo-superchargers, related instrumentation, numerical analysis software. In addition, an introduction to the research activities of 14 laboratories from 10 universities was presented. The total number of visitors to the four-day event exceeded 3950, which substantiated its popularity due to the events planned by the exhibitors who volunteered.

Photo 1.1 Congress venue at the Osaka International Convention Center

A total of 192 technical papers including keynote speeches and so forth were presented at this conference, 106 from Japan and 86 from other countries, which represented a 40% increase over the previous conference. The lectures were lively with numerous participants.

Seven lectures were given on the following topics during the keynote speech: (1) Shape Optimization of Casing Treatment for a Transonic Axial Compressor to Improve Operating Stability; (2) New Directions in Turbomachinery Aero-Acoustics; (3) Boosting and Turbocharger Needs for Highly Downsized Low Carbon Vehicles; (4) Recent Technologies for Concentrated Solar Power Systems and Steam Turbines; (5) Fluid Dynamic Efficiency Optimization of Steam Turbine Stages Considering Leakage Influences and Inter-stage

Reciprocal Interferences; (6) A Suggested Mechanism of Significant Stall Suppression by Air Separator Devices in Axial Flow Fans; and (7) Aerodynamic Losses in Turbines With and Without Film Cooling.

Two plenary talks were given on the following topics during the plenary talks: (1) Recollection on the Progress of IGTC over 40 years and (2) Europe's Framework Programme for Research in the Field of Aeronautics and Air Transport. Three plenary invited lectures were given on the following topics: (1) NASA's Future Propulsion Systems Research and Development; (2) Advanced Aeroengine Technologies to Reduce the Effect of Aviation on the Environment; and (3) How to Develop Sustainable Low-Carbon Society (LCS) for Japan and Asian Countries? -Model Simulation and Roadmap-. The special talks consisted of: (1) Learn to Think Like an Expert and (2) My Hope in Young Gas Turbine Professionals -Approach to Technical Opportunities-.

Two panel discussions and two forums were held on topics: (1) Trends in Aero Engine Technology Associated with Environmental Issues and CO_2 Reduction (Short- and Mid-Term Strategy); (2) CO_2 Reduction in Power Plants; (3) Trends in Aero Engine Technology Associated with Environmental Issues and CO_2 Reduction (Long Term Strategy); and (4) Asian Energy and Environmental Strategy.

During the technical session, 172 papers were presented in 66 sessions excluding three cancelations. The rooms for the technical sessions were concentrated on the 10th and 12th floors of the venue. Although the presentations ran concurrently in eight rooms, the audience members were able to move among the rooms smoothly. A spirited debate took place regarding the results of the latest research and development over a wide range of disciplines in various themes relative to gas turbines, which included practical development and axial fans in addition to such technologies in centrifugal and axial flow compressors; centrifugal and axial flow turbines; fuel and combustion; turbine cooling; noise, shaft, and blade vibration; coating materials; computational fluid dynamics (CFD); operations and maintenance; control and measurement; and new cycles. In addition, this conference included a new theme: 13 papers were presented on steam turbines, which prompted lively discussion.

Several events were offered during the conference, including a welcome reception attended by approximately 100 and a banquet in the Sanraku-no-Ma hall at the Rihga Royal Hotel attended by more than 190.

Plant tours with separate destinations were arranged. For Tour-1, 27 people visited Senboku LNG Power Plant of Osaka Gas and Sakaiko Power Station of Kansai Electric Power. Tour-2 brought 38 people to the Mitsubishi Heavy Industries Co., Ltd., Takasago Factory and Takasago Machinery Works of Mitsubishi Heavy Industries and Akashi and Seishin Works of Kawasaki Heavy Industries.

The success of IGTC '11 seemed to have overridden the country’s recent difficulties, including the Great East Japan Earthquake, the nuclear disaster at the Fukushima Daiichi Nuclear Power Plant, and the sudden appreciation of the Japanese yen, and is attributed to the efforts of collaborating and cooperating organizations both from Japan and overseas, participating companies, and the society members. The total number of participants came to 481 people and 192 papers were presented. This series of congresses has been held nearly once every four years since 1971 and has truly become an international conference in both name and actual meaning. Its success demonstrates its worldwide recognition as the preeminent international conference concerning gas turbine technologies in Japan. We hope to see the continued prosperity of this congress as a forum for international exchange in tandem with the ongoing development of gas turbines.

Photo 1.2　Participants of the Gas Turbine Open Seminar held on the first day of the conference

Photo 1.3　Banquet performance featuring *koto* music

by Ken-ichiro Takeishi (Osaka University)

2. Events Commemorating the 10th Congress

2.1 Lecture Marking the 10th Congress

IGTC ’11 represents a milestone in that it marks both the 10th international conference as well as the 40th anniversary since the first congress was held in 1971. Although no special announcement was made, three events differing from those implemented in the past were planned and conducted to recollecting the past memories and to position the congress in the future perspectives.

The first was the plenary talk offered by IGTC 2007 Executive Committee Chairman and professor emeritus Eisuke Outa (Waseda University) to present the memorial lecture recollecting the 40 years progress of IGTC. The second was the retrospective and memorial photo exhibition organized by IGTC 2003 Executive Committee Chairman and professor emeritus Osamu Kawaguchi (Keio University). The third was the implementation of an open seminar for the general public, offered by Professor Toshinori Watanabe (University of Tokyo) ; Mr. Hisao Futamura (Japan Aerospace Exploration Agency, JAXA); and Mr. Tsukasa Yoshinaka (formerly of Pratt and Whitney, Canada, PWC). The three lectures were planned during the IGTC ’11 executive committee meeting, and final preparations were conducted by the authors.

2.2 Plenary Talk 1

Because this conference was the 10th since the first International Gas Turbine Congress was held in Tokyo in 1971, a memorial talk titled ”Steps of IGTC; from 1st to 10th, with Background of Gas Turbine R&D in Japan“ was given by professor emeritus Eisuke Outa (Waseda University). This lecture detailed the history and technological developments of gas turbines in Japan during the past 40 years and traced the evolution of this series of international conferences. The following is a summary of the memorial lecture:

In the period immediately after World War II, when gas turbine development and production was prohibited, Japan lost much of its gas turbine-related technology and research facilities. However, the continuing efforts of those involved in research and development led to the first International Gas Turbine Congress, which was held in 1971. Subsequently, Gas Turbine Committee of Japan was established in 1972, and later in 1976 became the Gas Turbine Society of Japan. Since then, this series of international conferences has been held every four to six years.

The current practice of offering an exhibition in conjunction with technical sessions and lectures began with the first conference. With the advancements of gas turbine development in Japan, the congresses have attracted many participants from all over the world to present their technical papers as well as built up a cooperative relationship with many academic societies and industrial organizations overseas, and

the series of conferences has been recognized a truly international congress.

At each of the international conferences, special lectures and panel discussions were addressed by researchers and experts from various countries to address cutting-edge technologies and industrial challenges. Each conference also provided social events such as welcome reception, banquet and plant tours in addition to opportunities to exchange information in a wide range of technical fields.

The speaker addressed that behind the continuously holding the series of international conferences there have been numerous private sectors and research organizations participating into various national projects related to gas turbines, and that the outcomes have been supporting development and progress of advanced gas turbine technologies serving as the backbone of Japanese industries along with some historical context. Through these efforts, Japan's gas turbine technology continues to be employed in a number of disciplines such as power generation equipment including for emergency services, co-generation equipment, and aircraft engine. The nation's gas turbine technology proved itself reliable particularly in the aftermath of the Great East Japan Earthquake.

Summarizing the advancement and development of gas turbine-related technologies in connection with the previous 40 years of the conferences, the contents of the talk were of great interest to participants, particularly young engineers and researchers, and will likely serve as useful references in future research and development.

Photo 2.1 Plenary talk marking the 10th congress

2.3 Memorial Photo Exhibition

Held to commemorate the 10th IGTC, the photo exhibition offered general descriptions and scenes of the lecture, exhibition halls, banquets, and tours from each of the previous nine conferences from 1971 to 2007. The materials and statistics for each congress were summarized in one poster, and each poster was displayed together with proceedings, abstracts, circulars, and other items memorable (Photo 2.2). The posters were exhibited in a room on the 10th floor, where the exhibitions by college students were held.

The same posters also were displayed on the wall next to the registration desk in front of the main hall on the 12th floor during the whole congress period. Because the main hall was a gathering place for many conference participants, the exhibition became a focal point for nostalgia and reflection. In conjunction with the previously mentioned memorial lecture, this display offered an opportunity to recall the accumulation of technology and human interaction of the previous 10 conferences. Since participants seemed to express enthusiasm for the next conference, the 11th, we believe this photo exhibition was a significant milestone. In the future, we would like to continue to feature these and future photographs to preserve a record of the conference's academic activities.

Photo 2.2 Exhibits and display panels

2.4 Gas Turbine Open Seminar for the General Public

On November 14 (Monday) in the special conference hall, a public seminar was held to introduce gas turbine technology to high school, college, and university students, in addition to members of the general public. In 2011, gas turbine technology

garnered the nation-wide attention, and we aimed to enhance the substance of these lectures so that members of the general public, particularly young people, would have an opportunity to understand the effectiveness and consider the benefits of this advancement. Hence, we invited three experts to present lectures beginning with an overall summary of the gas turbine and how it relates to power generation, in addition to the historical and future significance in Japanese aviation engine production as well as the history and ongoing technological development in the world. Although the lectures for the general public were held during the international conference, 149 students were included among the participants.

The moderator, Mr. Nozaki, opened the seminar by introducing the three lecturers, after which time the lectures were held in a relay format.

The first lecturer was Professor Toshinori Watanabe from the University of Tokyo. In his lecture titled “The Mechanisms of Gas Turbines—The Source of Electrical and Jet Power,” he described the makeup and varieties of gas turbines used for electrical power generation and aviation. In addition, he addressed current challenges, citing examples of gas turbine usage during the Great East Japan Earthquake. Professor Watanabe went on to elucidate concretely about the future direction of gas turbines. His summary was compact, encompassing a wide range of topics dense with information for both students and professionals, and his brief explanation was followed by lectures from the two speakers.

The next speaker was Mr. Hisao Futamura of JAXA, whose lecture titled “Go Japan! With Your Craftsmanship Soar in the Sky" focused on the history of jet engine development in Japan. He spoke on the manner in which acquired technological development knowledge helped to realize the development of the V2500 with international cooperation, and he revealed that Japan’s technology is at a world-class level in the field of individual component manufacturing technology. Mr. Futamura also addressed the importance of aviation industry for Japan’s economy and emphasized the importance of harnessing the traditional fundamental technologies for the country’s future.

“The Evolution and Future of the Jet Engine—The Heart of an Airplane” was the last of the three lectures for the general public and was given by Mr. Tsukasa Yoshinaka formerly of PWC. He began by describing the historical background of the rapidity of turbo fan engine commercialization, then cited some of the current challenges regarding jet engines and discussed the future of geared fans and open rotors. Of particular interest to many members of the general public in the audience, Mr. Yoshinaka completed his lecture by drawing comparisons between the fuel efficiency of aircraft and automobiles, citing the new A380 as an example.

Following the lecture session, members of the audience posed questions concerning technological developments in the United States after World War II and the future rise in temperature of the combustor. Both lecturers gave concise answers, satisfying both professionals and members of the general public.

Photo 2.3 Lecturers for the gas turbine open seminar

by Terutaka Fujioka (CRIEPI), Kei-ichi Okai (JAXA), Takeharu Hasegawa (CRIEPI), and Osamu Nozaki (JAXA)

3. Special Lectures, Panels & Forums

3.1 Plenary Talks

Two separate plenary talks were organized. The details for the first plenary talk, which commemorated this 10th international conference, can be found in Chapter 2. The following is a summary of plenary talk 2.

Plenary Talk 2: Europe's Framework Program for Research in the Field of Aeronautics and Air Transport

Dr. Denos of the European Commission began his title plenary

talk immediately following the forum on the long-term strategy of environmental technology relative to aircraft engines. In his talk, Dr. Denos introduced aviation-related research currently being conducted under the Seventh Framework Programme and summarized the joint research program recently established between Japan and Europe. In addition, he described future collaborative prospects.

This program, which encompasses the framework of European research and development across all science and technology-related fields, was started in 2007 and is scheduled to run until 2013. It has been allocated approximately 140 million euros per year in funding for aviation-related projects divided into four groups: the environment, including global warming strategies and emissions; economic efficiency; energy, including fuel efficiency and alternative fuels; and societal aspects, including low-cost fares, safety, and punctuality. Its research topics include the aerodynamic characteristics of aircraft, new concepts, composite materials, propulsion technology, alternate fuels, and design systems, in addition to geared turbofan sophistication, inverted fans, inverted open-rotor fans, and regenerative intermediate cooling systems. Further, publicly offered research proposals were introduced in 2012. The coordinated call with Japan's (L1) applied research program was to be funded with 400 million euros from Europe and Japan.

3.2 Plenary Invited Lectures

Three plenary invited lectures were planned for this conference.

Plenary Invited Lecture 1: NASA's Future Propulsion Systems Research and Development.

Mr. Ramon Lugo of NASA's Glenn Research Center (GRC) was scheduled to give a lecture on trends in NASA research and development of propulsion systems. However, due to an emergency, he was unable to make the trip to Japan. The lecture was given instead by Dr. Chunill Hah, also of NASA's GRC.

The topics of by Dr. Hah lecture included air-breathing propulsion, in-space propulsion and cryogenic fluids management, physical science and biomedical technologies in space, communications technology and development, and materials and structure for extreme conversion. In addition, the lecture touched on economic efficiency in the field of aviation and environmental compatibility with a focus on safety. Dr. Hah went on to cite targets of approximately 70% in fuel savings; a 75% reduction of NOx; a 90% reduction in noise using drag/lift mechanisms; lightweight constructions; laminar flow wings; fuel-compatible, low NOx burners; open rotors; ultra-high bypass ratio turbofans; aerodynamic sound shield structures; and distributed implementation.

Plenary Invited Lecture 2: Advanced Aeroengine Technologies to Reduce the Effect of Aviation on the Environment

This discussion was planned with the intention of introducing the latest technology of aircraft engines and was designed to address environmental concerns. The scheduled lecturer was Professor Parker of Rolls-Royce Inc.; however, he was unable to attend. Taking his place was Dr. Simon Weeks, also of Rolls-Royce Inc.

The lecture topic included an overview of environmental compatibility constraints imposed on aircraft engines and introduced some of the fundamental eco-technologies on which Rolls-Royce is currently working. After touching on trends in CO_2 and SFC reduction, Dr. Weeks presented examples of those developmental technologies, including open rotors, lean-burn technology, biofuel use, integrated electronic control systems, and advanced cycle technologies. This lecture renewed the belief of participants that multifarious approaches are available for environmental responsiveness. In addition, Dr. Weeks also made it clear that the spirit of Rolls-Royce has not changed since Charles Rolls and Henry Royce first met in 1904 and that the company will continue to meet challenge in developing innovative aircraft engines.

Plenary Invited Lecture 3: How to Develop a Sustainable Low-Carbon Society (LCS) for Japan and Asian Countries—Model Simulation and Roadmap

The theme of plenary invited lecture 3 addressed urgent global environmental issues. In this lecture, Dr. Fujino of the National Institute for Environmental Studies discussed a plan for Asian nations, particularly Japan, to develop future low-carbon societies and to incorporate simulation research results to ensure progress toward that goal.

Dr. Fujino stated that if the policy objectives to mitigate global environmental issues can be summed up in the 3E philosophy—energy, environment, and economy—the concept of security could be added to create a 3E+S philosophy. On this basis, he said, we should the pursue a 3S philosophy—smart, secured, and sustainable—with the addition of resilience, or 3S+R. Dr. Fujino said it is precisely now, in the wake of the Great East Japan Earthquake, that we are experiencing vulnerability in our energy supply, marked by our reliance on only stockpiled crude oil reserves, and that we should recognize the necessity of constructing distributed energy systems to maintain, at a bare minimum, the independence and stability of each region.

Scenarios for a low-carbon society have promoted "emphasizing harmony with the natural environment" and "reliance on advanced technology." However, the challenges we should undertake in the future have shifted to the importance of a social system design that incorporates the benefits of technological advances and the creation of mechanisms to implement regional societies with highly resilient regenerative power.

3.3 Special Talks

Two special talks were scheduled.

Special Talk 1: Learn to Think Like an Expert

Dr. Wisler, formerly of GE Aviation, newly appointed at IGTC '11 as an honorary member of the Gas Turbine Society of Japan, gave a presentation concerning engineering education.

This lecture analyzed in detail the differences between technology experts and novices from the perspective of knowledge structure and discussed simple points and methodologies required to become an expert. Dr. Wisler said it is possible to solve a problem by clearly distinguishing facts, concepts, and generalizations in a variety of information. Experts organize technical information into a conceptual framework and capture the individual design issues and problems into a pattern, then comprehensively consider the elements of that structured information. In contrast to this approach, novices try to solve each individual problem and issue in a piecemeal fashion. Engineers should acquire the ability to think like an expert. As such, they build a structured body of knowledge, and when faced with new phenomena or problems, they employ critical thinking and the ability to make decisive judgments incorporating a body of knowledge. He pointed out there is a fundamental limit to the conventional methods of thinking taught in universities, particularly in the memorization of formulas and theories. It is necessary to develop educational programs that involve practical, hands-on knowledge and lessons that students can experience for themselves.

Photo 3.1 Plenary invited lecture 1

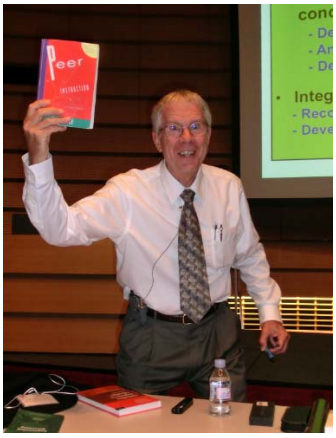

Photo 3.2 Dr. Wisler giving his dynamic lecture

Special Talk 2: My Hope in Young Gas Turbine Professionals: Approach to Technical Opportunities

Mr. Tsukasa Yoshinaka, formerly of Pratt & Whitney, Canada, gave a presentation for students and young engineers.

Mr. Yoshinaka began his lecture by first showing how to quantify expected increases in cycle and output efficiency by improving the efficiency of the compressor and turbine, thus increasing pressure ratio and turbine inlet temperature. He stated that this task is not simple, but it may be possible. To address these issues in the short term, one can learn from past successes and failures. In the long term, however, outside-the-box thinking is necessary. He then presented an example of thermal energy conversion with boundary layer control and semiconductors using ultrasonic waves. In addition, Mr. Yoshinaka explained that there are both grounds and context for established design criteria, and it is necessary to improve and optimize on the basis of a good understanding of those underlying principles. In addition, he mentioned the following example: Accurate loss estimates in light loads use current computational fluid dynamics (CFD), whereas heavy loads make such estimation difficult. That is, it is not sufficient to overly depend on CFD; a physical understanding of the basic internal flow of turbomachinery is also important.

He also explained with an actual example of the Great East Japan Earthquake that a great number of people's lives and livelihoods deeply connected to gas turbine technology, as is global climate change. Mr. Yoshinaka ended his lecture with the following plea to young technologists: "I want you to take up the challenge of solving these problems; they are both difficult and worthwhile."

3.4 Panel Discussions

Two panel discussions were also scheduled.

Panel Discussion 1: Trends in Aeroengine Technology Associated With Environmental Issues and CO_2 Reduction: Short- and Mid-Term Strategies

Six panelists were invited to partake in the first panel discussion, the theme of which was a general overview of short- and mid-term strategies of aeroengines and their role in environmental issues.

To begin, Mr. Yamaguchi from the Ministry of Land, Infrastructure, and Transport spoke from the perspective of formulating environmental regulations. He requested a 2% annual improvement in fuel efficiency for international aviation and explained that the preparations for CO_2 regulation are continuing to advance. Next, Dr. Epstein from Pratt & Whitney spoke regarding the development of the geared turbofan engine (GTF) and its merits over previous engines, including low fuel consumption and noise reduction. Dr. Weeks of Rolls-Royce discussed two separate paths by discussing the trade-off between the two contradictory problems of CO_2 and noise. In the open rotor design, which is inferior in noise reduction, the reduction in fuel consumption drastically reduce CO_2 emissions; however, the turbofan engine design, which produces much less noise, is inferior in reducing CO_2 emissions. From the IHI, Dr. Kodama spoke of the importance of reducing CO_2 emissions by reducing fuel consumption and outlined the status of technology development toward an optimization of turbine and fan parts constructed of lightweight composites such as carbon fiber reinforced composites and ceramic matrix composites. Mr. Saito from JAL reported on social activities regarding the environment by discussing the results of JAL's biofuel flight test results and the current status of biofuels. Mr. Noguchi of ANA discussed the progress of the ANA group's ecology plan, which took place from 2008 to 2011 and set targets to reduce CO_2 emissions. Following the discussions, Mr. Kanai from the Ministry of Economy, Trade, and Industry gave a short endorsement speech announcing the continued government support for advanced technology development to reduce environmental impacts.

Panel Discussion 2: CO_2 Reduction in Power Plants

On the final day of the convention, a panel discussion was held with the theme of low carbon from the power generation sector by three experts active in their own respective fields.

To begin, discussion moderator Professor Nakata of Tohoku University provided the audience with an introduction

to the topics to be discussed, which included a comparison of energy and carbon flows between the United States and Japan, scenario analysis methodology, the significance of technical proficiency, and expectations for future innovation. Professor Abhari of ETH subsequently presented a long-term retrospective on the history of man's environment and suggested future actions. Kepco's Mr. Toyama discussed the expectations of the efficiency of thermal power generation from an electric utility industry perspective. He presented concrete examples of technology improvements and industry goals such as improving the thermal efficiency of gas-combined thermal power generation, upgrading pulverized coal thermal power generation, and implementing clean coal technologies such as IGCC.

Mr. Suzuki from Toshiba introduced the latest trends in carbon dioxide capture and storage technology. He discussed the features and future outlooks of three types of carbon capture technologies currently under development: high-pressure pre-combustion capture, constant pressure combustion capture, and oxygen combustion capture. The discussion prompted listeners to recognize and consider the economic and social aspects associated with the introduction of low carbon technologies after opinions were raised concerning the management of advanced engineer training, financial aspects, the importance of governmental policy, and ensured environmental ethics and social acceptance for CO_2 capture.

Photo 3.3 Panel discussion 2

3.5 Forums

Two forums were held during this conference.

Forum 1: Trends in Aeroengine Technology Associated with Environmental Issues and CO_2 Reduction

A forum on the long-term strategy for aviation engine technology was held to introduce long-term plans of the United States, Europe, and Japan.

The American presentation was given by NASA's Kenneth L. Suder. It was addressed as follows. The organization's aviation sector has already set targets for noise, NOx, and fuel consumption and has begun a number of studies to realize those goals. With respect to airframe and wings, although both the advanced and integrated formats are under considerations, the fate of both will be decided by engine improvements. The organization's long-term plan is to examine the introduction of electric-powered aircraft as well as high-temperature heat-resistant materials.

Dr. Denos from the European Commission represented Europe. It was stated that the EU's efforts are to realize an 80% reduction of NOx, a 50% reduction in noise, and a 50% reduction in CO_2, and that the commission is endeavoring to introduce a new thrust mechanism more technologically advanced than the GTF, in addition to technologies, such as the control/prevention of stalls, three-dimensional wing design, etc., which are likely to be realized in the short to medium term.

Dr. Nishizawa from Japan's JAXA presented for Japan. He stated that realization of the high bypass ratio that would contribute to an improvement in engine performance would necessitate considering, at the research level, ideas such as a new form of an elliptically shaped engine.

An audience member raised a question on the possibility of using hydrogen as a fuel. In response, the NASA representative said although this concept would be challenging, hydrogen is the only viable long-term solution. However, he added that the current usage of hydrocarbon fuels, particularly natural gas, would remain for the foreseeable future. In addition, the EU representative commented that 30 years would be necessary for the integration of hydrogen-related technologies and that the installation of hydrogen supply systems to airports, for example, would be a lengthy process. On the contrary, the JAXA representative offered encouraging remarks. He said the agency's rocket department has a proven history of handling hydrogen and that the long-term outlook of hydrogen as fuel is possible.

Photo 3.4 Forum 1

Forum 2: Asian Energy and Environmental Strategy

In recent years, the energy situation in Asian regions has become unclear due to China's rapid economic development. Energy issues have become significant topics worldwide due to soaring energy prices, the securing of resources, and environmental conservation. Under these difficult circumstances, the three countries of Japan, China, and South Korea gathered for this information exchange forum to discuss such issues and future outlooks.

To begin, Mr. Wen of China introduced recent topics on the country's energy status. Because coal is a major source of energy in China, IGCC research and development in this sector is robust. In addition, CCS research and development is also vigorous due to the need for environmental support. Similarly, Mr. Lin of China speculated on the impact of man-made heat release on regional warming, citing the rapidly rising trends of CO_2 increases as well as rising temperatures in cities of China that began in the late 1970s and early 1980s.

South Korea's Professor Kim from Inha University discussed his country's energy status and outlined strategies for the future. South Korea depends almost entirely on imported energy sources. Security is a top priority, and the country and has established future strategies from a variety of sources. Starting in 2006 and scheduled to conclude in 2014, a national IGCC project is under way that uses a 300 MW model plant to seek a 42% rise in gas turbine efficiency.

Japan's representative, Mr. Kurosawa from the Institute of Applied Energy, was the last speaker in this forum. He stated that 30% of the electrical generation capacity of Tohoku Electric Power and Tokyo Electric Power Company (Tepco) was lost due to the Great East Japan Earthquake and subsequent tsunami; however, Japan was able to handle the summer season with no serious issues. In addition, he mentioned the country's intent to decommission a number of older nuclear power generating stations in the future. Mr. Kurosawa also stated that Cool Earth

21 is currently being maintained with the goal of a 50% reduction in CO_2 emissions by 2050. To achieve this goal, clean coal and safe large-scale nuclear power technologies are under consideration. In addition, Japan is currently promoting plans for the introduction of new sources of energy such as offshore wind, solar cells, and biomass.

Photo 3.5 Forum 2

by Toshinori Watanabe (The University of Tokyo), Yoshinobu Tsujimoto (Osaka University), Makoto Yamamoto (Tokyo University of Science), Toshihiko Nakada (Tohoku University), Kuniyuki Imanari (IHI) and Atsushi Makino (JAXA)

4. Technical Sessions

4.1 Aerodynamics

Of the 37 papers presented in the field of aerodynamics, 9, held in 3 sessions, concerned axial flow compressors; 4 papers in 2 sessions related to centrifugal compressors; 15 papers in 5 sessions related to turbines; 6 papers in 2 sessions related to CFD; and 3 papers in 1 session concerned aerodynamic design.

The axial flow compressor field attracted a large audience, and papers presented on design optimization and design method proposals induced a lively debate. These papers included No. 064, 11th Stage Compressor Optimization and OGV Design Methods Using CFD; No. 055, Proposal for Optimal Wing Design Methodology Oriented to Reduce Losses in the Transonic Stage; No. 136, Development of High Load Compressors Aimed at Reducing the Number of Stages; and No. 046, Mixed Span Direction Predictions in Transonic Compressors. In addition, presentations on improving the understanding and performance of unsteady flow structures between blades included the following papers: No. 030, Experiments and CFD Concerning Unsteady Flow Fields of High Flow Windmill Operations; No. 056, Impact of Wing Tip Vortex Collapse Occurring in the Vicinity of Stall Point on Wide Wing Tip Gap; No. 106, Influence and Profile Drag Reduction of Flow Field Due to Libretto on the Blade Surface; No. 220, Experiments and CFD on the Secondary Flow Loss Caused by Interference with the Mainstream Flow and Leakage from the Seal Portion of the Stationary Blade; and No. 108, Verification Using CFD and Development of an Absolute Temperature/Absolute Pressure Probe for Entropy Measurements. The four papers presented in the centrifugal compressor field included No. 035, Surges in Two-Stage Compressors, Their Detection and Characteristics; No. 040, The Difference in Distance between the Diffuser and the Impeller and Its Impact on Performance and Noise; No.165, Design Optimization of the Low Solidity Diffuser Using GA; and No. 174, Proposal for Design Optimization Methodologies for Vortex Chambers Using CFD. Unfortunately, the centrifugal compressor sessions had relatively weak attendance, and the subsequent question-and-answer sessions were anemic likely because this session was offered in smaller rooms on the final Thursday of the conference.

In the fields related to turbines, most of the presentations concerned axial flow turbines. Only two radial

turbine-themed papers were presented: No. 162, Optimization of Small Radial Turbine Inlet Flow; and No. 007, Proposals for Basic Design and Development. In these presentations, the radial turbine was considered only as an application example. The axial flow turbine presentations mainly concerned unsteady flow structures between blades and included the following papers: No. 020, Analysis of Combustion Gas in the Passage between Blades; No. 194, Interface Problems with Measurement Probes; No. 113, Secondary Flow Losses and Detailed Internal Flow Measurements for Its Optimization; No. 117, Experimental Study on the Impact of Unsteady Flow Structures of Stationary Blades Brought on by Wing Tip Vortex Leakage; and No. 248, CFD Analysis of Moving/Stationary Blade Interference on the Supersonic Turbine Blade Row. The following papers were also presented: No. 063, The Relationship between Performance and Secondary Flow Loss Resulting from Changes in Blade Loading; No. 076, Reduction of Secondary Flow and Performance Improvements Due to Wall Contouring and Non-Axisymmetric End Walls; No. 175, Circumferential CFD Analysis of Non-Uniform Inlet Flow Influence; No. 215, Thermal and Aerodynamic Wing Design Methodology in the Development of the 1700 °C Class Gas Turbine; and No. 152, Interference with the Film Cooling Airflow and Secondary Flow Between Blades. In addition, three specialty papers were presented, including No. 125, Development of CFD Methodologies Using Mixed Gas Models and Examples of Their Applications to Axial Flow Turbines; and Nos. 254 and 255, The Influence of Unsteady Mainstreams of Laminar Boundary Layer Transition Mechanisms.

The following papers were presented concerning CFD: No. 114, Analysis of Labyrinth Seal Leakage Flow; No. 205, Analysis of Mixed-Flow Compressor Windmill Operation When Turbo Engine Precooling Is Used; No. 239, Analysis of the Variable Turbine Nozzle Section of Vehicle Turbochargers; and No. 241, Analysis of Ice Accretion under Moving/Stationary Blade Interference in Aircraft Engines. In addition, Professor W.N. Dawes of Cambridge University presented No. 072, Examples Introducing the Proposal for a Faster Method of Lattice Formation and Calculation Schemes, which evoked a lively discussion with many questions asked from the large audience in attendance.

Three presentations were made regarding aerodynamic design: No. 135, Proposal for the Basic Design of a Wide-Chord Blade Row; No. 201, Experiments and CFD of a Tesla Compressor Diffuser Design; and No. 127, Effects of Forward and Rearward Wing Sweep on Transonic Fan Performance.

In this conference, a change was made for presentations in the field of aerodynamic design in that stability enhancement and turbocharger technology were combined. Hence, fewer papers were presented than those offered in previous conferences.

by Yutaka Ohta (Waseda University), Takanori Shibata (Hitachi) and Eisaku Ito (Mitsubishi Heavy Industries)

4.2 Heat Transfer

In the field of heat transfer, 34 papers and 1 keynote lecture were presented in 13 sessions, which was a significant increase over the number of sessions in previous conferences. Of these, 12 papers in 5 sessions concerned Heat Transfer on Film Cooling I-V; 5 papers in 2 sessions concerned Heat Transfer with Impinging Jet I, II; 5 papers in 2 sessions were presented on Numerical Simulation of Heat Transfer I, II; 6 papers in 2 sessions concerned Internal Cooling I, II; 3 papers in 1 session concerned Conjugate Heat Transfer; and 2 papers in 1 session were presented on Heat Transfer Measurement.

The number of principal authors presenting from each country were Japan, 15; China, 6; Thailand, 2; Europe, 5; United States, 5; and South Korea, 1. (The number of presenters from South Korea was affected by earthquake complications.) The large number of international presenters and the versatile and high-level variety of research activities combined to create a successful international conference.

The following is a brief list of noteworthy items included in the presentations: In the heat transfer on film

cooling session, Professor Ligrani presented his keynote lecture titled “A Case Study on the Aerodynamic Loss Due to Film Cooling.” In addition, the following papers were presented: No. 138, The Effect of Bubbles and the Resulting Changes in the Incidence of Film Cooling Characteristics on Positive Pressure Wing Surface Using Cascade Test Equipment and PSP Technology; No. 148, Cooling Efficiency Determined by Experiments Using Temperature Sensitive Paint (TSP) Film on Four Different Film Hole Configurations Including a Transpiration Type; No. 057, LDV Measurements Used to Examine Detailed Structure and Flow Measurements of the Cooling Efficiency of Film Cooling Panels With Multi-Rows of Holes, and a detailed report on the Relationship between the Cooling Efficiency and Vortex Structure of Film Airflow; No. 227, The Influence of Film Cooling from the End Wall Given by Horseshoe Vortices Formed at the Wing Leading Edge Using PIV/LIF Methodology; No. 122, LES Analysis Considering Upstream Fluctuation Components Using Random Flow Generation Methodology on Thermal-Fluid Characteristics of Cooling Air from the Cooling Holes Situated on the Upstream Side of the End Wall Turbine Blade Row; and No. 234, LES Analysis of Unsteady Flow of Cooling Air from the Cooling Holes Using Open FOAM; No. 085, a presentation regarding Double Jet Film Cooling and a promising configuration of RANS Analysis of Thermal Fluid Properties of NEKOMIMI Geometry in the Cooling Hole Exit; No. 058, A Detailed Investigation of Temperature Sensitive Liquid Crystal Methodology and Unsteady RANS Analysis of the Effect Given to Mainstream Turbulence and Cooling Air in the Mixing Process, and the Efficiency of Film Cooling on the Blade Surface in a Turbulent Mainstream; and No. 195, An Evaluation of Transient Response Methodology Using an IR Camera to Study the Film Cooling Distribution and Heat Transfer Efficiency of a Cooling Side (Cutback) Dimpled Model on the Cooling Air Outlet in the Trailing Wing Edge.

In the impinging jet cooling sessions, two papers were presented: No. 257, Investigations into the Heat Transfer Characteristics in a Gyrating Jet Flow; and No. 003, Cooling Performance in High-Temperature Wind Tunnels Using a Test Model Subjected to Three Types of Surface Roughening on Opposing Jet Flow Surfaces, As Well As the Effect of the Jet Flow Passage Configuration, Determining the Most Effective to Be a Roughened Concave Surface.

The internal cooling sessions consisted of Nos. 216 and 226, A Detailed Investigation of a Projection on the Flow Path; No. 007, Its Optimization; Nos. 103 and 149, Research on Flow Paths Outfitted with Comparatively New Types of Heat Transfer Enhancement Mechanisms, Such As Dimples; and No. 203, Investigations of the Effective Pin Fin Tilt Angle.

The numerical simulation of heat transfer and conjugate heat transfer section consisted of the following presentations: Predictions Made by Conjugate Analysis of the Following; No. 086, Temperature Distribution of Leading Wing Edge with Film Cooling; No. 164, Temperature Distribution of the Cooling Blade Used in the Stream Cooling System; No. 204, Blade Surface Temperature Distribution in Boundary Layer Transition; No. 198, RANS Analysis Predictions Using Experimental Heat Transfer Coefficient Distribution Data of a Blade Surface with Film Cooling, Which Showed, As a Turbulence Model, the SST Model with the Transition Model Has Comparatively Better Results; and Nos. 016 and 060, Introduced Examples of Conducting DES and LES Analyses of Complex Flow Fields.

Moreover, presentations were offered on Annular Cascade Test Results on HP Cooled Turbine Blade Materials Produced in CMC, in addition to The Durability of Trip and Adequacy of Cooling Performance.

4.3 Combustion

4.3.1 Outline

General combustion-related lectures included the following: CB (1) (fuel), three presentations; CB (2) (combustion emissions I), three presentations; CB (3) (combustion emissions II), two presentations; CB (4) (combustion phenomenon I), two presentations; CB (5) (combustion phenomenon II), three presentations; CB (6) (combustor development I), three

presentations; CB (7) (combustor development II), three presentations; CB (8) (atomization of fuel and ignition), three presentations; CB (9) (numerical analysis of combustion I), three presentations; CB (10) (numerical analysis of combustion II), three presentations. Of these 28 presentations, 21 were domestic, and seven were foreign. Although we were concerned that complications from the Great East Japan Earthquake would result in fewer lectures, the number in this series was only one fewer than the 29 lectures offered at the last conference in 2007. It would appear that interest remains high in environmental issues associated with combustion and fuel diversification.

4.3.2 Fuel

In session CB (1) (fuel), three presentations were made relative to biofuel. No. 013, together with a comparison of fuel properties of liquid fuel synthesized from natural gas or biomass with that of jet fuel, reported its impact on transport efficiency and range when used in large-, medium-, and small-sized aircraft. No. 092 reported the burning characteristics of bio-gas generated by microbial fermentation as fuel for a small gas turbine. No. 171 reported the burning characteristics of a gas turbine when methyl ester synthesized from cooking waste oil was used as gas turbine fuel. Commonly questioned was the price of biofuel compared with that of traditional fuels; however, it was believed that this issue was politically motivated.

4.3.3 Combustion Emissions

In session CB (2) (combustion emissions I), three presentations were made relative to combustion emissions. No. 38, using a thoroughly stirred reactor combustion model and a combustion model that consolidates completely and partially stirred reactors, reported estimates of NOx and CO emissions of a 250 MW single-single shaft industrial gas turbine combustor when using different compositions of natural or synthetic gas as a fuel.

No. 142 reported experimental results of the formation mechanism of prompt NOx during lean premixed combustion that used heat loss of the burner to keep the combustion temperature of the planar flame forming on sintered metal at or below 1800 K to suppress the generation of thermal NOx. For verification, numerical analysis was reported on the results of one-dimensional flame propagation undergoing detailed elementary reactions. In No. 232, with respect to ECO engines, experimental results on a low-NOx combustor using a new jet swirler to achieve rapid mixing of fuel and air were reported.

In session CB (3) (combustion emissions II), two presentations related to emission were given. No. 101 reported the combustion characteristics of methylated ester biodiesel oil synthesized from waste cooking oil for aircraft and industrial gas turbines, and No. 84 reported on Large-Eddy Simulation (LES) using the two-scalar flamelet approach targeting industrial gas turbines that use lean premixed combustion of the 18 MW class.

4.3.4 Combustion Phenomena

In session CB (4) (combustion phenomena I), two presentations related to combustion phenomena were given. No. 059 reported the combustion characteristics of fuel spray droplets for the rich-fuel combustion area of a double-swirling, prefilming-type fuel injection nozzle with a 1/2 scale RQL combustor using the results of simultaneous measurements of fuel droplet velocity and particle size measured by a phase Doppler anemometer (PDA). In No. 129, the alternate appearances of fuel spray and combustion areas was reported for the instantaneous structure of a spray flame using a laboratory-scale spray combustion burner that considered detailed, two-dimensional plane measurement results of the fuel spray and fuel area during both noncombustion and combustion.

In session CB (5) (combustion phenomena II), three presentations related to combustion phenomena were given. No. 209 reported the phenomenon of flashback during lean premixed combustion using a detailed velocity field of the flame propagation surface obtained through high-speed time-series PIV measurement. No. 235 reported the suppression of combustion oscillation of a micro gas turbine combustor under high pressure. No. 224 reported PIV measurement of the

velocity field of a gas turbine combustor model during non-combustion.

4.3.5 Combustor Development

In session CB (6) (combustor development I), three combustor development-related presentations were given. No. 068 reported that a significant reduction of NOx emissions was possible for small aircraft engines. For the CAEP/4 NOx Standard, tests were conducted on five fuel-injection nozzles designed on the basis of the lean staged combustion concept. No. 179 reported on a 1500 °C-class industrial gas turbine that uses steam to cool the turbine blade. #182 reported on a dry low emission (DLE) gas turbine combustor with very low concentrations of NOx and CO emissions.

In session CB (6) (combustor development II), three presentations on combustor development were given. No. 217 reported research results using PIV and LES for combustors of industrial gas turbines with 1700 °C-class inlet temperature using exhaust gas recirculation (EGR), which is currently being promoted as a national project. No. 236 reported experimental results for a low NOx combustor for aircraft gas turbines that uses OH radicals chemiluminescence, Mie scattering from fuel spray using a laser sheet, and PIV. In No. 184, experimental results were reported on lean premixed, prevaporized (LPP) combustors for ECO engines.

4.3.6 Atomization and Ignition

In session CB (8) (atomization and ignition), three presentations concerning atomization and ignition were given. No. 081 reported on visualization experiments and numerical analysis through interface-tracking methods concerning the liquid jet of a coaxial-type fuel injection nozzle. No. 145 reported the results of experiments concerning laser ignition of lean premixed gas by laser-induced breakdown using a picosecond-order ultra-short pulse laser. No. 223 reported on the ignition of fuel spray using a nanosecond-order short pulse laser.

4.3.7 Numerical Analysis of Combustion

In session CB (9) (numerical analysis of combustion I), three presentations concerning numerical analysis of combustion were given. No. 27 reported numerical analysis of aircraft engines using the Reynolds-averaged Navier–Stokes (RANS) formulation. No. 066 reported on LES for the rich-fuel combustion area of a double-swirling, prefilming-type fuel injection nozzle with a 1/2 scale RQL combustor, which was previously presented in No. 059. In No. 071, a visualization experiment of the atomization process though air flow of the liquid film and detailed numerical analysis by using the interface tracking method were reported.

In session CB (10) (numerical analysis of combustion II), three presentations related to combustion simulation were given. No. 256 reported the usefulness of detailed elementary reaction analysis using equivalent reactor networks (ERN). No. 187 reported experimental results for a two-stage combustor consisting of main and pilot that used PIV measurement, Mie scattering measurement, and computational fluid dynamics (CFD) analysis. No. 043 reported LES results for spray combustion formed in a high-pressure field using the flamelet model that applied the so-called new philosophy of determining the position of a lifted flame by solving the G-equation.

4.3.8 Miscellaneous Impressions

In this combustion-related general presentation, the application of complex optical measurement techniques for spray combustion fields, detailed numerical analysis by the interface tracking method concerning LES of combustion and atomization process of liquid fuel fulfilled both quantity and quality; however, It was determined that a more active question-and-answer discussion session was necessary.

by Fumiteru Akamatsu (Osaka University)

4.4 Noise, Vibration, and Structure.

Ten papers and one keynote lecture were presented on structural

vibration. The keynote lecture was given by Professor Zoltan Spakovszky, head of MIT's gas turbine laboratory. Titled "New Directions in Turbomachinery Aero-Acoustics," the lecture provided a simple explanation of Dr. Spakovszky's current research and was composed of the following three sections: 1) a method for evaluating the shielding effect of noise generated by new types of aircraft; 2) a method for evaluating fan rotor noise in an inlet at supersonic speeds; and 3) a noise design method for new low-noise, double inversion-type propeller fans. It was concluded that the problem of aerodynamic noise associated with new propulsion systems and new types of aircraft requires alternative solutions to maintain aerodynamic performance. Lecture No. 047 was a presentation from Japanese companies related to noise evaluation in co-generation systems (CGS). No. 207, from Japanese research institutions, concerned a device to reduce jet noise that was recently evaluated by the Japan Aerospace Exploration Agency (JAXA). No. 065, from a Japanese university, was based on a theoretical study for improving the characteristics of blade vibration due to mistuning. The influence of this parameter on vibration reduction effectiveness was evaluated through the Monte Carlo method. No. 079, from a Japanese university, detailed theoretical and experimental research related to the reduction of aerodynamic noise generated by supersonic-speed jet engines. No. 186, from an American university, was based on theoretical research concerning blade vibration due to mistuning and the characteristics of applying an original technique known as the modified modal domain approach（MMDA). No. 218, from a Japanese research university, analyzed a numerical calculation of three-dimensional, irregular aerodynamic forces acting on wing vibration. No. 034, from Japanese companies, announced the proposal of a flutter analysis tool based on the harmonic balance technique and included verification of its effectiveness. No. 093, from Korean companies, was based on a study that clarified countermeasures against the phenomenon whereby a centrifugal compressor impellor blade comes into contact with the casing. No. 246 was an announcement from Japanese companies concerned with a new method of stacking fan blades. Finally, a Japanese university introduced a design tool related to foil-bearing performance, thermal deformation, and stability.

This meeting, concerning structural vibration, consisted of four sessions. Because of its diverse subject matter, which included structure, vibration, noise, and bearings, session participation was limited. However, the smooth management by the session chair, allowed questions to be drawn successfully from the participants, resulting in a successful question-and-answer session.

by Shigehiko Kaneko (The University of Tokyo)

4.5 Performance

In the field of performance, a variety of gas turbines including aero engines, aeroderivative gas turbines, micro-turbines, and combined-cycle gas turbines were chosen as topics, and nine presentations throughout three sessions were given.

Presentation No. 010 concerned secondary air design techniques in aero engines. With respect to unmanned aerial vehicle (UAV) turbo-prop engines, numerical analysis focusing on engine intake flow, exhaust flow, and pressure loss was calculated to conduct high-altitude performance analysis in a test vessel (No. 087), and artificial intelligence methods for fault diagnosis were considered (No. 107).

No. 259 presented installation examples of various flexible systems for aero-derivative gas turbines that can be used as backup power sources to renewable energy installations. For centrifugal compressors of micro-gas turbines, a new technique using a one-dimensional model was proposed, in addition to the examination of a performance benchmark in the same study. In addition, No. 0170 proposed a method of estimating the simple thrust loads of radial turbines equipped with permanent magnet generators,

For power generation in large gas turbines, safeguards against turbine blade overheating and its effect in the case of gas fuel produced through gasification were studied in F-class gas turbines (No. 020). No. 231 presented performance estimates for oxygen combustion in the case of existing

semi-closed combined-cycle gas turbines, and No. 190 presented a state diagnosis of combined-cycle gas turbines through remote monitoring center data.

by Norihiko Norihiko (AIST)

4.6 Steam Turbines

At the newly established IGTC'11 steam turbine session, 15 papers including two keynote lectures were presented in six sessions(GS 2, OS 4). Four presentations were made in organized general sessions under the topic of Efficiency Enhancement of Steam Turbines. Paper No. 002, based on new performance enhancement technologies that focus on unsteady phenomena, presented the results of a model turbine test to control the mixture phenomenon of the mainstream and the cavity flow that undergoes periodic variations from upstream stationary and downstream moving blades. By varying the axial and radial distances of the cavity-like shape of the peripheral edge between stator and moving blades, a stage performance enhancement of a maximum of 1.7% can be achieved. This presentation received significant attention for its substantial effects on performance enhancement.

. The keynote lecture, "Fluid Dynamic Efficiency Optimization of Steam Turbine Stages Considering Leakage Influences and Inter-Stage Reciprocal Interferences," made by Professor Yuan, Tsinghua University, and concerned typical two-stage high pressure turbines. The lecture presented an optimal design method to attempt performance enhancement using CFD including steam leakage of the inner diameter side of the stationary blade and the blade-tip seal fins to automatically change the shape of the three-dimensional design of first-stage moving blades in the optimal design system. Because such changes affect the down-stream stage, the two-stage efficiency was employed as the objective function. Many engineers and researches who study the related issues attended this session, which allowed for detailed, extended questions and discussions. No. 155 presented an optimal design method for low-pressure turbine cascades that includes a quasi-three-dimensional streamline curvature method to result in a 3.1% performance improvement for a 300 MW low-pressure turbine machine. No. 173 presented the development of a new high-performance labyrinth seal that reduces stream leakage through a vortex generated by a step set inside the seal; through experimentation and analysis, an approximately 30% reduction in leakage volume flow was reported. No. 146 presented an analytical investigation on the effects on turbine performance of the machining accuracy of turbine blade surfaces.

In the organized session titled "Long Blade Technology of Steam Turbine," paper Nos.168, 211, and 249 were presented on the recent development of final-stage long blades in the 1.2–1.3 m class (3600 rpm) by three domestic steam turbine companies: Hitachi, Mitsubishi Heavy Industries, and Toshiba. In general, a supersonic airfoil design is necessary for the inlet of moving blades in this long blade class and centrifugal stresses approach the limits of conventional material strength, each company employed confident design to ensure reliability and performance repeating analysis and model turbine experiments including actual blade tests. This topic has attracted the attention of a large global audience.

Relating to the wet steam flows through steam turbine blades, No. 104 presented development of a non-equilibrium wet steam flow RANS two-dimensional unsteady condensation analytical method using the quadrature method of moments (QMOM), which properly considers the size distribution of condensed water droplets. Regarding the prediction of unsteady flow forces of steam turbine blades, No. 053 considered the influence of the axial distance between stator blades and rotating blades on the unsteady fluid forces on the rotating blades separating the unsteady flow force applied to the moving blades due to the potential interference effect of the stationary and moving blades and the unsteady flow force applied to the moving blades due to the interference effect of the stator blade wakes and moving blades. This paper presented a study of two-dimensional analysis of the unsteady compressible RANS and analysis of two-dimensional unsteady non-viscous flow with an approximately zero-thickness trailing edge using

cusps attached to the trailing edges of the stator blades at the same time to separate the potential and wake unsteady interactions.

A large global audience gathered for the presentation of the keynote lecture titled “Recent Technologies for Concentrated Solar Power Systems and Steam Turbines” by Mr. Okita from Toshiba Corporation. This seemed to show that the technology trends in this field garnered significant attention. Regarding solar thermal energy power generation systems, or concentrated solar power systems (CSP), in which steam turbines generating electricity are driven by steam generated by the exchange of heat gathered with a reflector that heats a molten salt medium or oil, constructions have been performed in regions such as North Africa, the Middle East, Southern Europe, and North America, where solar thermal energy steam turbines of a 50 MW or more per-unit capacity are currently running. The future prospects of CSP and characteristics required for solar steam turbines were introduced in detail, and we believe that along with geothermal turbines, the use of renewable energy for steam turbines has the potential for future important research and development topics.

Four papers were presented in the ultra-supercritical pressure steam turbine session, three of which centered on the development of materials and design development of the 700 °C-class Advanced Ultra-Super Critical steam condition (A-USC) through a Japanese national project. The remaining paper was a report concerning developments in Europe of applications of welding and casting materials such those for turbine casings. Paper No. 169 from Japan presented the development of Ni-based alloy for steam turbine rotors with similar linear expansion coefficient to 12Cr steel and the mock-up of dissimilar metal welding with the developed Ni-based alloy and the conventional 12Cr steel, while the conventional Ni-based alloys have a limitation for large scale rotor forgings. No. 210 introduced an example of a turbine structural design that, by cooling with the relatively low-temperature steam of high-pressure turbine exhaust in the high-temperature section of a medium-pressure rotor, can use steam hotter than 700 °C, even when employing 12 Cr steel in a medium-pressure rotor. No. 176 introduced the development of a new material in which the temperature change is regulated for the phase-precipitation hardening that dominates the creep strength of the Ni-based alloy, which satisfies the reciprocal relationship of forge ability and high temperature–high-strength and can be expected for application to the 800 °C Class. These papers presented advanced, original technologies in the development of A-USC specific to Japan. No. 188 presented from Europe where the development of Advanced USC technologies had been launched first introduced the reason why the Alloy 625 was recommended for casting material and their manufacturing examples. In addition, the presentation on production verifications of l welding mockups from several casting material left the impression that 700 °C-class steam turbine casings and high temperature valve boxes are becoming to be ready for their practical applications.

by Tadashi Tanuma (Teikyo University) and Eiji Saito (Hitachi)

4.7 Materials

The materials sessions offered the newly-established topic of steam turbine materials.

Although submissions related to the development and evaluation of advanced ultra-supercritical steam turbine project material development and evaluation were invited, these related submissions were summarized as project reports from the topic of steam turbines, also newly established.

Therefore, as usual, the program consisted of gas turbine components classified into topics of “Maintenance/Lifetime Evaluation,” “Advanced Materials/Repair Technology,” and “Coating Technology.” However, a numerous submissions for the “Maintenance/Lifetime Evaluation” required entire “Damage/Lifetime Valuation” and “Crack Progression” sessions to be divided into five sessions, with the first part of presentations related to “Maintenance/Lifetime” made on the first day and lectures concerning the development of materials

presented on the second day. These 13 presentations were attended by approximately 30 participants on the first day and approximately 50 on the second day, resulting in standing-room only and demonstrating the high level of interest in materials technology.

The "Maintenance/Lifetime Evaluation" presentation was composed of three papers, Nos. 199, 185, and 075, a series of reports on research results on the analysis of actual machine phenomena related to gas turbine disk damage, clarification of phenomena based on reproducible laboratory experiments, and the effectiveness of shot peening constructed as a measure, respectively. No. 069 presented evaluation and analysis results for solving the problem of fretting fatigue in the fixings of the moving blade section of a gas turbine. Nos. 042 and 031 introduced examples of gas turbine first-stage moving blade damage and reported on material degradation and related damage analysis results, respectively. No. 061 reported fundamental evaluation results of the dependency of Ni-based alloy fatigue crack propagation behavior on crystal orientation, targeting the static/moving blade damage that has become problematic in actual machines.

Concerning "Advanced Materials/Repair Technology," No. 181 reported the development and evaluation of the recent trend of constraining the volume of Re added to an alloy, relative to an Ni-based single-crystal alloy, which has become indispensable in changing gas turbines to high temperatures. No. 008 presented the development concept and performance evaluation results of a burner-rig test machine developed as a corrosion-resistance evaluation technique in alloy production. No. 074 reported the development of repair materials attached to a stationary blade diffusion row and evaluated the results of actual applications.

In the "Coating" session, No. 118 evaluated damage to thermal barrier coatings, which is an interface strength assessment technique that applies the indentation method, heat cycle testing, and actual damage to machine materials, in addition to the development of coating materials. No. 180 examined low thermal conductivity thermal barriers and actual machine case studies. Finally, No. 253, concerning a thermal barrier coating material attracting recent attention, reported the research results of research on La2Zr2¬¬O7, SrZrO3, and LaLiAl11O18.5 ,which are systems of pyrochlore, perovskite, and aluminates respectively; new segment structures; and new processes of suspension plasma thermal spraying and extreme low-temperature plasma thermal spraying.

By Yomei Yoshioka (Toshiba)

4.8 Turbochargers

Nine presentations, including the keynote lecture, were done in the turbocharger session, offered for the first time in IGTC'11. Five papers came from overseas. The session began with the keynote lecture by Dr. Ricard Martines–Botas of Imperial College, U.K, titled "Boosting and Turbocharger Needs for Highly Downsized Low Carbon Vehicles." This lecture concerned the potential improvement in fuel consumption of passenger-car engines through the introduction of high-boost systems, in addition to the effect of turbine characteristics under flow pulsation on turbochargers and engine matching. An attempt to to improve fuel consumption by significantly reducing loss through heat and friction through downsizing engines by high boost pressure generated by turbochargers and to improve the response of the turbocharger at the low engine speeds by an electric compressor are done. In addition to above attempts, the "Hyboost project" incorporates a system for energy recovery through a power turbine into a gasoline engine. "Hyboost project" demonstrates the possibility of improving further fuel consumption of internal combustion engines. General issues and guidelines for the design of turbines with efficient energy recovery of the engine exhaust gases were also presented.

The following includes a summary of the eight general presentations.

No. 026, a paper related to turbocharger development for an IMO-2 four-stroke marine engine, focused on the aerodynamic design of a turbine and a compressor. The

compressor employed a recirculating-flow-type casing treatment with counter swirl vanes at the aim of expanding the operating range. The turbine achieved a high efficiency by optimizing the angle and the thickness of the impellor blade.

Three papers related to compressors were presented. Two dealt with unstable phenomena and one dealt with performance. No. 121, related to unstable phenomena, investigated the difference between the surge characteristics caused by a certain volume of plenum chamber downstream of the compressor and the same piping volume, defined by the volume from the compressor outlet to the discharge valve, as the volume of the plenum chamber. No. 080 presented a result of unsteady CFD analysis to show the different performance/surge characteristics of two compressors. For a compressor impeller with better surge characteristics without the existence of a stall cell, the entire circumferential shroud section in the inducer was covered with the stable separation. The compressor impeller with worse surge characteristics showed that a localized separation propagated in the direction of the circumference as a rotating stall. In No. 088, the effect of two types of vane shape, straight vane and curved vane set inside a cavity of a recirculation-flow-type casing treatment, on the performance/surge characteristic and impeller flow field was investigated through CFD calculation. Particularly for the curved vane, it was shown that the suppression of the positive pre-swirl of the recirculating flow at the impeller inlet results in a decrease in surge flow rate and an increase in pressure ratio. Relative to compressor performance, No. 233 examined the effect of clearance on compressor performance to obtain fundamental data used in a centrifugal compressor for an MGT. Numerical calculation was implemented for four types of clearance and a case of non-clearance.

Next, four papers were related to radial turbines, two of which presented as variable nozzles as the subject. Radial turbines used in turbochargers are operated at a variety of rotational speeds depending on engine operating conditions. Hence it is difficult to completely avoid impeller blade resonance caused by nozzle wake, and understanding vibrational stress is an indispensable technique in ensuring turbocharger reliability. No.109 presented a model for predicting the increase of vibrational stress through mistuning, and No. 112 examined by CFD analysis the relationship among structure, flow field, and aerodynamic performance of variable nozzles. A cylindrical spacer was placed in the upstream of the nozzle to preserve nozzle clearance. There were button-shaped cylindrical shaft seals, which connected the nozzle rotation axis to the nozzle vane at both ends of the nozzle vane. The impacts of each of these elements and nozzle clearance on aerodynamic performance were described in detail.

The theme of the remaining two papers related to the keynote lecture. No. 052 presented the development process of low-pressure-ratio power turbines for turbo-compound engines. Turbine impellers targeted at 1 KW power generation turbine with an expansion ratio of 1.1 have a unique shape of (turbine impellor exit area)/(turbine impellor inlet area) = 0.35. It was reported that the radial turbine demonstrated significantly higher efficiency than conventional turbines with expansion ratio of between 1.05 and 1.3. No. 158 described the prediction of turbine performance under pulsating inlet flow. Unsteady turbine performance was estimated through a mean-line model and one dimensional CFD. Although prediction accuracy for flow volume fluctuation was slightly lower, other obtained parameters were in good agreement. In addition, practical level predictions of average turbine performance were reported for one fluctuation per cycle.

by Hideaki Tamaki (IHI)
and Seiichi Ibaraki (Mitsubishi Heavy Industries)

4.9 Development and Operation

A total of eight papers were presented in three sessions in the field of Development and Operation: DO (1), DO (2), and DO (3). In session DO (1), which concerned the retrofitting of thermal plants, No. 005 reported changes and aging of combined cycle steam power units. In this paper, a scheme was presented to reduce costs and shorten the construction period by

taking full advantage of existing facilities and to improve environmental performance and thermal efficiency by updating equipment.

In DO (2), three papers were presented relative to MW-class gas turbine development. No. 51 announced the development of Kawasaki Heavy Industries Ltd. M1A-17, which, through the application of CFD, demonstrated a 2.5 point improvement in thermal efficiency and a 200 kW improvement in output while clearing 15 ppm of NOx over the M1A-13 with the same dimensions. From the MAN Company, element examination and unsteady CFD results on the 6 MW gas turbine currently in development were presented in No. . No. 94, from Doosan Heavy Industry and Construction, presented a summary of performance test results and activation schedule optimization for the DGT-5 5 MW class gas turbine generator, which was developed jointly with The Ukraine.

Three papers were presented in DO (3). In a presentation on the flow of lubricating oil in the accessory gearbox, No. 214 introduced results of visualization experiments and CFD simulation of the flow guide effect, which were in good agreement. No. 189 presented the Mitsubishi Heavy Industries 1600 °C-class gas turbine. Improvements in thermal barrier coating (TBC) and cooling technologies to achieve the 1600 degree Centigrade TIT prevented damage to the high-temperature parts, which was validated through hundreds of hours of operating tests. In a presentation on 1700 °C-class gas turbines (No. 197), simulation results on the DLE combustor for exhaust gas recirculation system were introduced as a technology for achieving both high temperature–high efficiency and low NOx, along with a variety of research results on blade cooling technology, coating technology, and aerodynamic design. Numerous participants attended both sessions. In particular, DO (2) and DO (3) were standing-room only.

by Eiichi Koda (CRIEPI)

and Kazuhiko Tanimura (Kawasaki Heavy Industries)

4.10 Systems and Control

In the session on systems and control, the number of papers presented was twice that of the previous event; therefore, the six papers were divided into two sessions. Nos. 041, 200, 208, and 240 concerned research on reduction of fuel consumption and lowering of NOx emissions, suggesting that the increased interest in technology development meets the needs of society. In addition, research on the control infrastructure of active control stabilization and system identification, Nos. 159 and 251, respectively, is also relevant.

No. 041, which concerned aircraft engine fuel pumps, was based on a case study conducted on fuel consumption improvement that introduced an electric fuel system driven by an electric motor from a conventional accessory gear box (AGB). In this process, the heat balance can be improved by removing the air cooled oil cooler (ACOC). No. 200 introduced simulation results of controlling power load variations of the gas turbine and nuclear reactor cogeneration system aimed at developing countries. No. 208 concerned a gas turbine using catalytic combustion. This paper explained the concept of maintaining combustion performance against deterioration of the catalyst whereby the main fuel is switched between activation and rotational acceleration control by fuzzy logic, and the precombustion fuel can be adjusted according to the temperature difference between the front and the rear of the catalyst. In No. 240, for twin spool turbofan and single spool turbojet engine, minimization control of SFC in a test engine was implemented by estimating thrust and SFC using a constant-gain Kalman filter and by manipulating fuel and variable mechanisms.

No. 159 was a presentation on active stabilization control. By detecting compressor instability using the standard deviation of the shift in pressure rate change of the compressor wall, a method of adjusting the fuel start-up schedule using the exponentially-weighted moving average of the pressure rate change in the wall was confirmed in simulation. No. 251 concerned a twin spool turbofan engine, whereby system identification of engine response was introduced for fuel and

variable mechanisms, and comparative verification was performed for models and engine tests.

Session attendance was 20 to 30 per paper; numerous question-and-answer sessions and discussions were active; and time allocation was appropriately managed.

by Hiroyuki Furukawa (IHI)

4.11 Stability Enhancement

In the “Stability Enhancement” organized session, five papers and two keynote lectures were presented in two sessions. Of the five, four papers concerned expansion of the operating range of axial fans and axial flow compressors with the use of casing treatment and air separators. The first keynote lecture (KL-01) reported on optimization of the type of casing treatment of grooves along the circumference. In this presentation, for optimization of the groove depth based on surrogate modeling, it was reported that the stall margin was larger than the casing without treatment. In No. 014, the effects of the circumference groove using analysis of steady-state and unsteady-state RANS were examined. Unsteady flow largely influenced the performance type of casing treatment of the circumference groove, and capturing this effect through unsteady RANS or LES analysis proved important.

The effect of a single circumference groove installed on the leading edge of rotor blade was reported in No. 082. CFD was used to study these effects on two types of rotor blades, and the effect of the circumferential groove type casing treatment was determined to be dependent on the inception mechanism of the stall of a single rotor blade as well as the flow induced by the groove.

The second keynote lecture (KL-06) reported on the mechanism of the effect of the operating range expansion due to an air separator equipped with radial vanes. It was demonstrated that an air separator subject to stall suppression and operating range expansion exhibits several features. Apart from these, No. 070 reported the first model of a three-dimensional wing shape that considered stall. No. 099 concerned expansion of operating range by injection and clarified the inception mechanism of a stall. A method of expanding the operating range on the basis of this concept is expected to be actively studied in the future.

by Takahiro Nishioka (Hitachi Plant Technologies)

5. Exhibition

5.1 Introduction

From November 14 (Monday) to November 17 (Thursday), the International Gas Turbine Congress 2011 (IGTC '11) exhibition was held on the 10th floor of the Osaka International Convention Center (GCO) in the exhibition hall and exhibition room on the same floor, an area of approximately 1,000 square meters. Thirty-nine domestic and international companies and organizations participated. In addition, 9 exhibiting companies conducted presentations on their products and technologies for students and the general public during the exhibition period. Fourteen laboratories from 10 universities displayed their activities at the panel exhibits held in the exhibition room. As a special event, pupils from neighboring elementary schools were invited to attend lectures and handicraft classes. A large number of participants from the general public were also in attendance.

A photo exhibition for the 10th anniversary of IGTC is reported in chapter 2.

5.2 Company Exhibitions

The opening ceremony was conducted in front of the exhibition hall at 11:30 a.m. November 14 (Monday), beginning with opening remarks from the chairman of the IGTC '11 exhibit committee. Approximately 100 attendees participated in the opening ceremony, which was conducted by the president of the Gas Turbine Society of Japan, the vice chairman of the IGTC ’11 organizing committee, and the chairman of the IGTC ’11 executive committee. Because the event was held during a break between presentations, attendance was strong, and the ceremony was considered successful.

Exhibitors included companies from a variety of technology fields related to gas turbines and jet engines such as

gas and steam turbines; gas turbine superchargers; materials, parts, and related equipment; machine tools; test equipment; measurement and data processing equipment; computers and related software; and publications. In addition, special panels were held, and presentations included actual products and mock-ups, as well as video features.

Booth demonstrations afforded each company the opportunity to demonstrate its respective products and software. During the exhibition period, a special stage was set up in the company's exhibition section of the main exhibition hall. Nine companies introduced their products and latest technologies, and each offered lectures for university students that were scheduled to coincide with the open seminar for other students and general audiences, which were highly successful.

In addition, for the first time in congress history, approximately 100 pupils from neighborhood elementary schools were invited to a lecture titled "How Does an Airplane Fly?" and were given handicraft lessons in a lecture titled "Build a Wind Car" to provide an understanding of gas turbines. Including university students and elementary school pupils, approximately 660 people attended the company exhibitor's events.

5.3 Student Exhibitions

The student exhibitions began November 14 (Monday) and ended November 17 (Thursday). Each university presented the contents of its latest research on panel displays, while some universities distributed introductory fliers. The ability to observe a summary of trends in gas turbine engine research at universities helped to make the event a great success.

Table 5.1 List of Company Exhibitors

1	Tyco Thermal Controls Japan Co., Ltd.
2	Brüel & Kjær Japan
3	Japan Aerospace Exploration Agency
4	General Electric International Inc.
5	SHINWA CORPORATION
6	SHINKAWA Electric Co., Ltd.
7	DAIICHI SYSTEM ENGINEERING Co., Ltd.
8	OHTE GIKEN Inc.
9	B&B-AGEMA
10	Concurrent Nippon Corporation
11	UEMURA GIKEN Co., Ltd.
12	Softinway, Inc.
13	Spraying Systems Co., Japan
14	Maruyama Excell Co., Ltd.
15	VINAS Co., Ltd.
16	Atsuita Press Industry Co., Ltd.
17	Ohmura Seisakusho Co., Ltd
18	National Institute of Advanced Industrial Science and Technology
19	IHI Castings Co., Ltd.
20	NIPPON MUKI Co., Ltd.
21	WOODWARD GOVERNOR (JAPAN), Ltd.
22	Fuji Techno Industries Corporation
23	Maruwa Electronic Inc.
24	Mitsubishi Heavy Industries, Ltd.
25	Kawasaki Heavy Industries, Ltd.
26	MITSUBISHI HEAVY INDUSTRIES PRECISION CASTING Co., Ltd
27	Japanese Aero Engines Corporation
28	Honda
29	EAGLE INDUSTRY Co., Ltd.
30	TOSHIBA Corporation
31	AIKOKU ALPHA CORPORATION AP DIVISION
32	JAPAN AIR TECCo., Ltd.
33	WOOD GROUP
34	Rotadata, Ltd. (International Servo Data Corp.)
35	EVERLOY SHOJI Co., Ltd.
36	SANKYO INTERNATIONAL Corp.
37	Reaction Design Japan, KK
38	IHI Corporation
39	Hitachi Ltd. Power System Co.

Table 5.2 Number of exhibition visitors

Date	Opening hours	Number of visitors
November 14 (Mon)	11:30–17:00 (5.5h)	1,013
November 15 (Tue)	10:00–17:00 (7 h)	874
November 16 (Wed)	10:00–17:00 (7 h)	1,155
November 17 (Thu)	10:00–14:00 (4 h)	910
Cumulative total number of visitors	(Total: 23.5 h)	3,952

Table 5.3 List of Student Exhibitors

Name of laboratories of university exhibitors
Kawada Laboratory, Osaka Institute of Technology
Watanabe Laboratory, University of Tokyo
Takeishi and Komiyama Laboratory, Osaka University
Ota Laboratory, Waseda University
Yamamoto Laboratory, Tokyo University of Science
Yuasa Laboratory, Tokyo Metropolitan University
Hayashi Laboratory/Tsujita Laboratory, Hosei University
Yamasaki Laboratory, Kyushu University
Tsujimoto Laboratory, Osaka University
Honami Laboratory, Tokyo University of Science
Funazaki Laboratory, Iwate University
Furukawa Laboratory, Kyushu University
Yamamoto/Sasao Laboratory, Tohoku University
Yoshida/Iwai/Saito Laboratory, Kyoto University

Photo 5.1 Opening ceremony

Photo 5.2 Company exhibition space (exhibition hall)

Photo 5.3 Student exhibition (exhibition room)

Photo 5.4 Exhibitor's event

by Junichiro Masada (Mitsubishi Heavy Industries)

6. Plant Tours

On November 18, the final day of the congress, two different plant tours were provided. Tour 1 visited the Senboku Gas Plant of Osaka Gas Co., Ltd., and Sakaiko Power Plant of Kansai Electric Power Co. Inc. Twenty-nine people attended the tour, including two members of the event committee and 27 participants from three countries; 23 were from Japan. In the morning, the group visited the Senboku Gas Plant of Osaka Gas. A video introduction to Osaka Gas and the Senboku Gas Plant in the Gas Science Museum, and the tour continued by bus and on foot. In the turbine building, visitors were offered a close view of the exterior of a steam turbine, generator, and 7EA+e gas turbine. In the question-and-answer session, questions were raised on earthquake and tsunami measures for power plants in

coastal areas in light of the March 11 earthquake.

After lunch, the group visited Sakai City Hall observation lobby for sightseeing. Although cloudy skies persisted, the visitors were able to enjoy views of the tomb of Emperor Nintoku and Osaka Bay.

The tour then arrived at the Sakaiko Power Plant of Kansai Electric Power Co., Inc., and received a video introduction to Kansai Electric Power Co., Inc., as well as Sakaiko Power Plant in the company's seminar room. After inspecting the central control room, the tour continued with observations of the power generation equipment, mainly from inside the bus. The interior of the power plant contained abundant greenery, which demonstrated the company's position on environmental issues.

Tour 2 visited Takasago Machinery Works, Mitsubishi Heavy Industries, Ltd., and the Akashi and Seishin plants of Kawasaki Heavy Industries Co., Ltd. Thirty-eight participants from five countries, including 19 from Japan and two committee members, attended the tour.

The bus departed from the Osaka International Convention Center on time. In the morning, the group visited Takasago Machinery Works, Mitsubishi Heavy Industries, Ltd. A video introduction to the company's gas turbine business was shown, after which the group observed the manufacturing process from element to assembly and the plant's combined cycle (T-point). The tour lasted less than two hours and was rich in content. After lunch, the group visited the Seishin Plant of Kawasaki Heavy Industries Co., Ltd., to observe the assembly of medium-pressure compressors for large aircraft engines. The tour then continued to the Akashi plant, where the group visited the industrial gas turbine overhaul shop and domestic private power generation energy center. Both companies divided the visitors into two groups to allow for plenty of questions and answers. The tour ran later than the scheduled return time and was forced to forgo a scheduled stop in Maiko Park on the way back. However, they were fortunate enough to get a close view of the Akashi Kaikyo Bridge from the bus windows, lit up in rainbow-colors.

Photo 6.1 Tour 1 at Senboku Gas Plant, Osaka Gas Co., Ltd

Photo 6.2 Tour 2 at Takasago Machinery Works, Mitsubishi Heavy Industries, Ltd

by Yasuhiro Kinoshita (Kawasaki Heavy Industries)