

International Gas Turbine Congress 2003 Tokyo

November 2-7, 2003

Abstract

The 8th International Gas Turbine Congress, sponsored by the Gas Turbine Society of Japan, was held from November 2nd to 7th, 2003, at Tower Hall Funabori in Tokyo, Japan. The collaborating societies of this Congress included the International Gas Turbine Institute (IGTI), the Japan Society of Mechanical Engineers, the Japan Society for Aeronautical and Space Sciences, and several related societies in countries such as China, Korea, Great Britain, France, and Germany. The cooperation by ASME/IGTI, particularly the effort of Dr. Wisler, the former President of IGTI and the current Vice President of the ASME, helped increasing the number of applications and submissions of abstracts and papers from overseas countries.

In order to organize the 2003 International Gas Turbine Congress, an Organizing Committee was established, and this committee was placed within the Gas Turbine Society of Japan. This is different from the previous congresses. In the past, a one-time organizing committee was temporarily established for the administration and organization of each congress and was an independent committee outside of the Gas Turbine Society of Japan. However, since open and aboveboard accounting was sought for this particular congress, the Organizing Committee was set up within the Society as a temporary organization. Under the Organizing Committee, an Executive Committee was created as the actual working committee. Similar to the previous congresses, the Executive Committee consisted of 5 units: the General Affairs Committee, the Program Committee, the Exhibition Committee, the Event Committee, and the Financial Affairs Committee. Considering the current economic situation, we made a greater effort than ever to reduce cost as much as possible in the administration of the congress, including the selection of the site and a minimum trust in the innovators.

Four hundred seventeen people from Japan and 117 participants from 17 foreign countries attended the congress. The total number of 534 participants was more than our initial goal of 450 people.

One hundred sixty papers were selected for presentation during the congress, 87 of which were from Japan and 73 from foreign countries. Compared to the previous congress held in Kobe, the total number of presentation papers was increased by 15, and the total number of papers from overseas countries was increased by 20. The overseas presentation papers made up 46% of the total papers selected. This composition was adequate for the international congress.

The speeches and presentations were held under the following four categories:

- Keynote Speech 7 Presentations
- Forum..... 3 Sessions
- Panel Discussion..... 1 Session
- Technical Session 160 Presentations

Presentations by Keynote Speakers were the important features of IGTC. Similar to the previous congress, seven Keynote Speeches were given during the 2003 IGTC, and all were appreciated. The topics were as follows:

- (1) Micro- or Small-Gas Turbines
- (2) High Temperature Materials for Gas Turbines: The Present and Future
- (3) Fuel Cells and Gas Turbine for Future Energy System
- (4) Future View of Energy Supply and Role of Gas Turbine in Japan
- (5) Combustion Technology for Current and Future Gas Turbines

- (6) Recent Findings of Analytical Studies in Unsteady Aerodynamics, Aeroacoustics and Aeroelasticity of Turbomachines
- (7) Aeroengine Technology in 21st Century

The Forum, which did not require original papers, was held for the first time during the 2003 IGTC. It enabled participants to freely exchange their opinions and information. Three topics were discussed in the Forum. They were "Industry-University Cooperation in Gas Turbine Research," "Current Status and Strategy of Electricity and Energy Supply," and "Wave Rotor".

Two co-chairs and five guest panelists led a Panel Discussion entitled "Gas Turbines in the Future". The following topics were discussed in the Panel Discussion from the perspectives of different fields: the position of the gas turbines in the recent technology system, the technology of large gas turbines for the generation of electric power, aero-engines, the marine transportation system and gas turbine technology, small gas turbine technology, fuel technology for gas turbines, and gas turbines for aerospace engineering.

In the Technical Sessions, academic presentations and active question-answer sessions in various research and study areas were given. The presentation and discussion topics in these sessions were superalloy, unsteady flow and noise, aeroengines, cascade design, heat transfer, turbine flow simulation, combustion control, the blade structure, thermal barrier coating, internal flows, heat transfer and flow transition, the micro gas turbine, the ultra-micro gas turbine, the turbulence model, combustor design, advanced materials, diagnosis / control / measurement, the marine gas turbine and turbo-charger, the industrial gas turbine and power plant, and numerical analysis.

The presentation papers were collected and made into CD-ROMs. This is the first time that we have published IGTC proceedings on CD. However, the one-page abstracts were collected and published in print, and this printing material was provided to every participant as a reference at the congress.

The congress exhibitions were held in the exhibition hall on the first floor and in the lobby on the second floor. In the exhibition hall, 36 companies and organizations exhibited their products in 33 exhibition areas; these products included gas turbines, turbo-superchargers, related machines, and devices for numerical analyses. On the second floor, university research groups (11 research institutions from 8 universities) and the Gas Turbine Society of Japan introduced their research activities and results in panel sessions. There were about 3700 attendances in the exhibition in four days, and the exhibition was a great success.

Besides the above activities, congress participants attend several others. One hundred thirty-five people attended the Welcome Reception and 170 people attended the Banquet held at the Tokyo Sea Life Park restaurant in Kasai Rinkai Park. In addition, 74 participants attended the Tea Ceremony Lesson in two days, and among them, 31 were foreigners.

During the congress, we arranged two tours, Plant Tour A and Plant Tour B, which had different destinations. Twenty-nine people joined Plant Tour A, and visited the Japan Aerospace Exploration Agency (the National Aerospace Laboratory of Japan) and Tanashi Factory of Ishikawajima-Harima Heavy Industries Co., Ltd. Twenty people attended Plant Tour B, and visited the All-Nippon Airways Power Plant Maintenance Center and the Shinagawa Thermal-Power Station of Tokyo Electric Power Co., Ltd. All of these activities were successful and received warm appreciation.

Technical Program

1. Summary of Technical Sessions

1.1 Technical Paper Statistics

The number of selected papers is summarized in Data 1. The total number was 160, which was 15 more than in the previous congress. It is noteworthy that the number of contribution papers from overseas countries greatly increased. There were a total of 73 papers selected from overseas contributors, which was 20 more than in the last congress, and was 46% of the total number of papers.

1.2 Keynote Speech

In order to help the participants to gain better knowledge of the recent academic and technical trends in the research and development of gas turbines, 7 keynote speeches were arranged during the congress (Data 2), and three keynote speakers were invited from overseas countries.

1.3 Forum

During this congress, we attempted for the first time to arrange a free discussion section, calling it the "Forum". This discussion section did not require any original papers. The purpose of having this session was to enable the participants to exchange opinions and information on related topics. Under this goal, three topics were arranged for the Forum, as shown in Data 3.

1.4 Panel Discussion

Shown in Data 4 is a Panel Discussion with the theme of "Gas Turbine in the Future". Two chairpersons were elected to plan and bring out active discussions in the Panel Discussion, and five guest panelists were invited. Each of panelists gave a speech on a topic of the future of industrial large and small gas turbines, aero-engines, the marine gas turbine, and their prospects concerning the perspective of fuel.

1.5 Organized Session

Among the selected papers, those closely related to the marine gas turbine and the ultra-micro gas turbine were specially put together. We organized four sessions especially for these two topics.

1.6 Lectures for Adolescents and the Public

In the exhibition halls, a lecture for general visitors was arranged to begin at 2 PM on Monday, November 3. Dr. Osamu Nozaki from the Japan Aerospace Exploration Agency was invited as the lecturer for this activity. We gave a simple explanation concerning the basic concepts, including the theory of the gas turbine jet engine used in airplanes, so that adolescents could easily understand. The lecture was held for the purpose of spreading knowledge about the gas turbine, enlightening the public, appealing to adolescents, and contributing to the Funabori community. We asked the staff of Tower Hall Funabori to distribute the guide to the elementary and junior high schools in the ward through the Board of Education of the Edogawa Ward.

1.7 Summary of Program

The program with the plans illustrated above is given in Data 5. Referring to the comments given by the members of the International Advisory Committee, we allocated 30 minutes for each presentation and a relatively longer lunch break. As a result, we had to arrange six parallel sessions instead of only four in the previous IGTC. Because of the time limitation, the

last session concluded behind schedule on some days during the congress, and some participants commented that this made the congress schedule a little bit tight.

2. Summary of speech

2.1 Keynote speeches

Keynote Speech 1: Micro- or Small- Gas Turbines, Terry Simon (University of Minnesota, USA)

Recently, there have been growing interests in micro-gas turbines, and micro-jet engines are beginning to be recognized in micro-manned or unmanned machines. Micro-gas turbines with regenerated heat exchangers in which hot-water supplies and power can be used concomitantly, and those combined with fuel cells, are achieving great successes as distributed power sources or engines, as well as heat sources for reactions or in space.

When developing micro-gas turbines for power generation, we must use utmost caution for the regenerated heat exchangers. There has been no other time since the development of the gas turbines for automobiles that this much focus has been placed on the research and development of the regenerator. The micro-gas turbine often utilizes a radial-flow turbo machine. In addition, the application of ceramic parts or ceramic coatings is drawing more attention in micro-turbo machines and their parts. Recent radial-flow turbomachines require a better understanding of radial-flow hydrodynamics, such as the effect of the streamline curvature in the boundary layer flow. Finally, smaller dimensions require closer attention to the effect of a smaller Reynolds number pertinent to boundary layer transition or flow separation, particularly in the case of an axial-flow turbine used in aircraft propulsion. In his speech, Professor Terry Simon also mentioned the recent developments relevant to the topic.

In terms of system integration technologies for micro-gas turbines, the one that combines a micro-gas turbine and a fuel cell is most famous. Research and development have been actively pursued on the endurance of new materials and parts in the use of ceramics. For the combustor, the compact low NO_x combustion technology and diversified fuel technology are being studied. For the regenerated heat exchanger, the focus has been on the improvement of manufacturing technologies in producing highly durable and reliable products at lower costs.

For researches and developments on turbomachines, there have been growing interests in radial-flow turbines and new CFD analysis technologies. For radial-flow turbines or high-load turbine blades, more attention has been paid to the investigation of the flow curvature effect on flow and heat transfer. In terms of the effect of a low Reynolds number, the micro-gas turbine has a low Reynolds number and high loads. In such cases, flow separation might greatly affect the performance of the design. Improvements on projection technology for turbulent transitions, such as separation and reattachment flow, will be necessary for turbine design. Various effects of turbine flow, including the wake in the upstream turbine blade, have an impact on the transition.

During the speech, recent achievements in research on transitions in the turbines were introduced in detail. The issue surrounding flow transition on a turbine blade is the main theme at University of Minnesota, where Professor Simon holds his research lab; therefore, we invited him to speak more about their achievements at the University of Minnesota.

Keynote Speech 2: High Temperature Materials for Gas Turbines: The Present and Future, Hiroshi Harada (National Institute of Material Science)

An overview of world trends in the technologies of heat resistant materials used for high temperature parts of aeronautical and industrial gas turbines, as well as the efforts

made within Japan centering on government projects and future projections, were discussed in this speech.

First of all, as for the development of superalloys, the creep strength has been improved in response to higher temperature combustion gases for gas turbines and jet engines. The Ni-based superalloys for turbine blades have progressed from cast alloys to normal casts through directional solidification (DS) to single crystal (SC) alloys, along with the progress of processing technologies. These single crystal alloys have also advanced through developments from the first generation, represented by Rene' N4, PWA1480, CMSX-2, to the 2nd generation, represented by Rene' N5, CMSX4, PW1484 containing about 3% Re, to the 3rd generation, represented by Rene' N6, CMSX10 containing about 5% - 6% Re, and then to the 4th generation. These were further targeted for greater strength by stabilizing the structures.

In response to such a global trend, researches and developments have been made in Japan centering on government projects such as TMD-5, MGA1400DS for DS alloys, TMS26 for the 1st generation SC, TMS82+ for the 2nd generation, and TMS75 for the 3rd generation. TMS82+ and TMS75 have also succeeded in the generating operation by the insertion of a 1300°C class gas turbine. In addition, the 4th generation SC was developed under the Japanese government project, "High Temperature Materials 21 Project," in which structural stabilization was achieved by adding Ru to Re. The heat resistant temperature was achieved at 1,102 °C by rafting a γ phase and miniaturizing the γ/γ' interface misfit dislocation network. These developed alloys have been studied to be applied to aero-engines under the ESPER program by the Ministry of Economy, Trade, and Industry of Japan. The project starting in 2004 for power generation was introduced, which would develop 1,700 °C class gas turbines using these alloys and would perfect the combined heat efficiencies at 60% (HHV) to reduce the emission of CO₂.

As for the Ni-based superalloys for the turbine disks, developments of the next generation of alloys have been anticipated. These superalloys can be used for long hours at 700 °C to meet conditions in which the temperatures of the high voltage turbines increase, and their commitments to both materials for casting and powder processing were introduced. In particular, a new casting process was introduced as having the FS for the 70,000 tons class large casting facilities.

In addition, as future materials beyond the Ni-based superalloys, the oxide-dispersion-strengthened alloys, intermetallic compounds, refractory metals, ceramics, and composite materials were also mentioned in the speech. Past efforts and achievements surrounding the government projects, as well as future possibilities, were discussed as well.

Keynote Speech 3: Development of High Efficiency Fuel Cell Power Plant Combined with Gas Turbine, Takao Watanabe (Central Research Institute of Electric Power Industry)

Fuel cells possess properties that are not part of the conventional type of power generating plant, such as high efficiencies, lower environmental loads, and flexibility with the output scale, and are expected to be utilized for a wide range of applications from consumer use to large-scale power generating plants. What has currently been developed or used are mainly the following four types: Proton-exchange membrane fuel cells (PEFC), Phosphoric acid fuel cells (PAFC), Molten salt carbonic acid fuel cells (MCFC), and Solid oxide fuel cells (SOFC). MCFC and SOFC are categorized as high temperature fuel cells (HTFC) and have been studied and reviewed for the development of a combined system with gas turbines.

The combined system between HTFC and gas turbines (GT) consists of a topping cycle in which GT are connected to the exhaust side of HTFC while pressurizing HTFC and a

bottoming cycle in which the exhaust of atmospheric HTFC is utilized as an air-heater for the GT. The pressurized type is compact and highly efficient; however, it has some shortcomings, such as the measures required for pressure fluctuations during emergencies and a cost increase in pressure containers.

The progress of fuel cells has been outstanding. For example, in the case of the MCFC 10 kW stacks 10 years ago, an initial cell voltage of 800 mV decreased to 600 mV in only 1,500 hours, while at present, an initial cell voltage of 900 mV only decreases to about 860 mV in 10,000 hours. This indicates a higher efficiency and extended longevity.

Development of the performance simulation models based on fuel cell stack performances has also progressed and become practically useable for the positioning of the HTFC combined cycle system and for selecting optimum operational conditions. Cycle efficiencies (HHV) of the combined cycle system in the case of natural gas reformation are about 65% for SOFC 40MW, of which GT contributes 15% points; 53% for SOFC 300 kW, of which GT contributes 10%; 64% for MCFC 20MW, of which GT contributes 9%; and 51% for 300 kW, of which GT contributes 5%. This indicates higher contributions of gas turbines in the SOFC compared to the MCFC.

Along with the progress in the development of micro-gas turbines (MGT) during these recent years, developments of a few 100 kW class systems have been pursued, in which HTFC and MGT are combined. In the case of IHI (Ishikawajima-Harima Heavy Industries, Co., Ltd.) for example, a 300 kW system (efficiency 47% LHV) is in operation where the MCFC of 0.4 MPa is being utilized, and a demonstration of an atmospheric SOFC 220 kW has been completed at SWPC (Siemens Westinghouse Power Co.). Those of a 0.3 MPa pressurized 300 kW has been in development. As for the future prospects of large systems, actual proof and cost reductions are the important challenges in these compact systems.

Keynote Speech 4: Future View of Energy Supply and Role of Gas Turbines in Japan (View of Electric Power Company), Hiroyuki Ino (Tokyo Electric Power Company)

Gas turbine power generation in our country has been developed with circumstantial backgrounds, such as import-dependent fuel resources, power loads that can fluctuate greatly between seasons, and day or night and strict environmental regulations. Out of all of them, combined cycle power generation with gas turbines and steam turbines is the most desired power generating system.

Gas turbines were introduced into our country in the 1970's, and the first gas turbine power generation was a simple cycle gas turbine system taking advantage of short-term construction. Since then, highly efficient gas turbine combined cycle systems have been introduced, along with the outstanding developments of gas turbine technologies. Today, it has become to practical to use an advanced combined cycle system with a 1,300 °C TIT class gas turbine.

Based on projections for primary energy supplies and final energy consumption by end consumers in our country, energy conservation and industrial rebuilding have been progressing while the use of atomic power and natural gas has been expanding. The balance of atomic power and natural gas in the use of energy resources will probably be more leveled in 2010. Industrial fields have been used to occupy the majority of final energy consumption. However, there has been an evident increase in energy consumption by consumers and transportation divisions due to the decline in petroleum prices and changes in lifestyles. In our country, it is likely that there will not be major changes in the overall energy demand and supply; nonetheless, the trend towards an increase in power demands will also stay.

In addition to the increase in electric power demands, it

has been projected that the liberation of electric power retail will advance, resulting in 60% of the entire electric volume being the subject of liberalization by the spring of 2005. Therefore, more strategic and flexible investments on power generation facilities will be required for electric power companies.

Based on the energy circumstances mentioned above, the electric power companies should address the following topics.

- Cost reduction
- High reliability
- Adaptability of fuels
- Dealing with load fluctuations
- Environmental protection

In order to deal with these subjects we are expecting the development of gas turbine technologies in the following four areas.

First of all, we must strive to increase the scale (high efficiency and large power generation facilities) through increases in temperatures at the turbine inlet and pressure ratios. This is currently under development and needs to be continued further. Tokyo Electric Power Company has developed and applied 1,500 °C class gas turbine combined cycle systems called More Advanced Combined Cycle systems.

Next is the development of small-medium gas turbines, although this appears inconsistent with the former statement. They are installed corresponding to uncertain power demands that are expected for short periods of time. The micro-gas turbines belong to this category.

Thirdly, reliability should be improved within the existing gas turbines. In particular, the extension of longevity for high temperature parts of gas turbines is our major goal.

Lastly, we should expand the scope of fuels with efficiency without contaminating the environment. This equates to the development of coal gas combined power generation technologies, which enable the use of coals and crude oil.

Gas turbine related technologies have advanced rapidly, making gas turbine power generation a major force for thermal power generation, and we will continue to expand that role into the future. Considering the energy situations in our country and the world, gas turbine power generation must expand its role as it makes further advancements. From the standpoint of the power companies, we hope that the gas turbine technologies will continue to make progress and contribute to economical development and protection of the environment.

Keynote Speech 5: The Challenges of Lean Premixed Combustion, Ann Dowling (Cambridge University, UK)

In addition to industrial gas turbines, clean combustors for the next generation jet engines often employ a lean premixed combustion in order to reduce emissions, particularly nitrogen oxide NO_x . In such cases, however, pressure oscillations during combustion can become an issue. In this keynote speech, Professor Ann Dowling outlined the unstable combustion of such gas turbine combustors using a model with mathematical formulas for heat generation caused by combustion and its acoustic interaction. Then, the physical phenomena of vibrations during combustion through simple lab experiments and the study results of CFD modeling, as well as a control method using both still and moving images, were introduced so that listeners could understand them easily.

The phenomenon in which noise occurs when combustion becomes unstable had been scientifically analyzed and clarified as an issue a long time ago. There is also a similar phenomenon of oscillation during combustion caused by a lean, premixed combustion. In recent years, as the development of low emission combustors for gas turbines became more popular, this issue has drawn more attention. When an unstable heat

generation takes place within the combustor, it triggers acoustic energy fluctuations, hence inducing small pressure fluctuations. When the pressure fluctuations resonate with the acoustics of the combustor system, it can grow into a vibration with powerful energy that can not only destroy the combustor, but also the engine.

For the combustors employing a lean, premixed combustion, experimental research has been implemented along with an analysis using CFD and an acoustic network model regarding predictions for resonance frequencies, energy amplification, and control of combustion oscillations. When a complex configuration such as the actual combustor is used as the subject, an analysis using CFD has several problems in terms of the capacity of the computer; therefore, analyses using network models are more practical. There are two methods for the control of combustion oscillation: passive or active controls. One of the former is a Helmholtz resonator, which is installed onto a combustor system to instantly absorb the generated energy that is the result to an unstable combustion. This is extremely effective when the vibration frequency is already known, but is not as effective for combustion oscillation below 200 Hz when considering the volume attached. An active control is more effective for combustion oscillations at lower frequencies. This is configured by a feedback control that monitors oscillations within the combustor and controls the vibrations by using some kind of actuator. One way to supply the actuator is to modulate the fuel fluid to a frequency in which the fuel vibrations are controlled, for which many experiments are currently being conducted.

Keynote speech 6: Recent findings of Analytical Studies in Unsteady Aerodynamics, Aeroacoustics, and Aeroelasticity of Turbomachines, Masanobu Namba (Sojo University)

Professor Masanobu Namba of Sojo University (also emeritus professor of Kyushu University) made a comprehensive lecture on the theoretical analysis by singularity method regarding the unsteady aerodynamics of turbomachines, aeroelasticity, and aeroacoustics.

As for the theoretical research of recent years in the said fields, many studies consist of computational fluid dynamics (CFD) and computational aeroacoustics (CAA), while purely theoretical analysis is considered classic. For a theoretical analysis, the restrictions are very tight on the flows that can be handled, and the simplicity of the boundary shapes and flow linearity are anticipated. However, it has some great advantages, which include that computational load is extremely light when compared to the numerical analysis method and that an analysis on a wide range of parameters can be conducted in a short time period while being able to make clear insights on the physical phenomena.

First of all, in this keynote speech, the basic ideas of the singularity analysis methods of unsteady cascade flows were organized by general formulation and were uniformly interpreted. Three application examples, which had recently been analyzed by Professor Masanobu Namba *et al.*, were then introduced using these techniques.

First, the issue of cascaded blade vibration was analyzed in the field of rotor-stator interaction in a counter-rotation rotor. The results showed that the impact of adjacent cascades is extremely great, as indicated by the case of multistage blade flutter. Next, the analysis on discrete frequency noises due to rotor-stator interaction was introduced. However, it was indicated that in order to make an accurate projection of the acoustic field, both flow interaction and aeroacoustic interaction between rotor and stator must be considered.

Finally, an active control analysis on interfering noises between the gust and rotor blades was introduced. For the control, an attempt was made to attenuate noises by providing an

active acoustic disturbance in order to erase acoustic waves generated in the rotor blades from the actuator surfaces in the downstream field. However, the results of the analysis indicated that it was extremely difficult to suppress noises in general even if an acoustic disturbance of a duct-cut-on mode is superimposed. Instead, there was a possibility of attenuating the noises effectively by using acoustic disturbances only in the cut-off mode.

This lecture indicated that the theoretical analysis techniques were an effective means of finding key factors and provides basic knowledge for new unsteady aerodynamic challenges. It also provides a useful benchmark to verify CFD and CAA techniques. It is expected that a purely theoretical analysis will continue to go forward on the intellectual frontline through such roles in the future.

Keynote Speech 7: GEAE Propulsion Vision for the 21st Century, Mike Benzakein (General Electric Aircraft Engines, USA)

Dr. Benzakein introduced to us the image of aero-engines while looking towards the 21st century and the efforts being made at General Electric.

With an outlook for 21st century airplanes, we are expecting an advent of med-large jets with further enhanced safety and environmental compliance than the current regional jet engines. A subsonic jet plane group that reaches further to long-distance military transporters, environmentally compliant supersonic transporters starting with ultrasonic business jet engines, propeller planes, and various types of unmanned airplanes are also being expected. Furthermore, there are needs for safe and low-cost spacecrafts. What has been commonly expected is a response to clients' satisfactions regarding performance, noise, emissions, reliability, and convenience and to realize ownership at lower costs. General Electric's efforts towards these goals were introduced as follows:

General Electric has prepared two engine platforms for consumer engines.

The first is the CFM56/CF34-10 series (compressor of a mid-level pressure ratio driven by single-stage turbines, perfecting enhanced reliability and low maintenance costs) for regional and narrow body planes. The CFM56 series is a bestseller engine widely adopted for the A320 and B737 series. The development of the CF34-10 series is also progressing smoothly, and technical developments of each engine element for the Tech 56 project are also under way. For example, high loads and high efficiency compressors (setting the pressure ratio of CFM56 at 15/16 instead of 11/9, the number of blades is reduced from 1518 to 963 to lower the maintenance cost), TAPS (Twin Annular Premixing Swirler), low NO_x combustors, high efficiency turbines, etc., are planned to be sequentially reflected on the products.

Another architecture is the GE90 series (compressor of a high pressure ratio driven by a two-stage turbine) for wide body and medium-long distance planes. The development of the GE90-115B has advanced smoothly and the technical certificate was obtained from the United States Federal Aviation Administration. As the B7E7 engine is scheduled to fly in 2008, the GENX engine is being developed with a targeted noise reduction of 26 dB as compared to Stage 3 and NO_x reductions of 60% as compared to the ICAO CAEP4 with a GE90 basis core. For the GENY engine, which is targeted for operation around 2012 ~ 2015, goals are set for a noise reduction of 33 dB as compared to Stage 3, NO_x reductions of 85% as compared to CAEP4, a reduction in defects during flight by 50%, and takeoff delays and cancellation decreases by 50%. Besides these goals, many new technologies are also being challenged. They include noise reduction technologies, such as variable chevron nozzles by shape memory alloys and active acoustic liners, CMC combustors, CMC turbine blades, new alloy shaft disks, super

intelligent technologies (non-compliance detection, optimized operation, necessary maintenance timing prediction), etc.

For military engines, the F136 for JSF fighter planes and the F414 for F18E/F are in development, although further improvements will be necessary on the thrust-weight ratio (from 9 to 20 for the F414) and studies of adaptive cycle engines applicable to each model. These projects are being proposed for government programs such as NASA's UEET or RTA, and IHPTET or VAATE for DOD.

PDE (Pulse Detonation Engines) and fuel cells were mentioned as future technologies. PDE has already been studied at the General Electric research labs in cooperation with universities, and the manufacturing of a full-scale demonstration plane is being planned in 2006. Breakthrough improvements on fuel cells are indispensable, as well as switching fuel to hydrogen, which will require more time.

Finally, it was introduced that these foundations and leading technical studies have been globally outsourced. The technology centers for General Electric's research labs are placed in Bengal, India; Shanghai, China; and Munich, Germany under the global research world headquarters in NY, and studies have been conducted by taking advantage of characteristics at each location. Universities both in and out of the United States use their specialties to play a part in the General Electric research program through cooperative relationships with each other.

2.2 Forums and Organized Sessions

Forum 1: "Industry-University Cooperation in Gas Turbine Research"

Co-Chairs: David Wisler and Toshinori Watanabe

Panelists:

David Wisler (General Electric Aircraft Engines, USA), Xiaofeng Sun (Beijing University of Aeronautics and Astronautics, China), Chisachi Kato (University of Tokyo, Japan)

In this forum, Dr. David Wisler of General Electric in the United States, Professor Xiaofeng Sun of Beijing University of Aeronautics and Astronautics in China, and Professor Chisachi Kato of the University of Tokyo provided information regarding the current status and future outlook of industry-university joint research.

Dr. Wisler is the manager of a section called University Programs and Aero Technology Laboratories. In his speech, he explained the difference in value between the manufacturers and universities in a manner that was easy to understand. Based on acknowledgement, he emphasized the importance of joint research between industries and universities towards technical developments. He also appealed the necessity to change ideas in order to overcome differences and conduct joint research. In addition, he introduced the current status of General Electric's joint research with the universities. They have globally established joint research agreements with nine universities: six United States universities, two European universities, and one Asian university. The only Asian university is Tsinghua University in China. Their approach was revealed as building joint international research strategies and effectively utilizing a wide range of knowledge for products.

Professor Sun of Beijing University of Aeronautics and Astronautics introduced the current status of the industry-university joint systems in the aero-engine field. With aero-related industry organizations AVIC-1 and AVIC-2 as the central figure, it clearly indicated that the industries, universities, and research labs are cooperatively structured. The universities in China have actively established these international cooperative systems. They have particularly deepened their cooperation with universities in Europe and the United States, including mutual exchanges between the faculties. Since the

basis for a strong partnership lies in human relationships, it appears that they send students to many different places and are building the foundation for human exchanges.

Professor Kato from the University of Tokyo introduced a case example, the CFD industry-university joint project implemented at the Institute of Industrial Science, University of Tokyo. The CFD codes built at the institute were disclosed in a way that could be easily used and the system offered for industrial use was indicated in an easy to understand manner.

Although the industry-university joint system in Japan is still in organization, the importance has been emphasized in various scenes and joint research has been gradually developed. Such cooperative efforts are being anticipated on the academic platform in the gas turbine field as well.

Forum 2: "Current Status and Future Strategy of Electricity and Energy Supply"

Chairperson: Keizo Tsukagoshi (Mitsubishi Heavy Industries, Ltd.)

Panelists: Morihiro Kurushima (New Energy and Industrial Technology Development Organization, Japan), Yuhong Li (Tsinghua University, China), Hyung Hee Cho (Yonsei University, Korea), Prutichai Chonglertvanichkul (Electricity Generating Authority of Thailand, Thailand), Alberto Dalla Rosa (Electric Power Development Co., Ltd., Japan)

In this forum, each panelist introduced the current state, future plans, and measures on energy supply in Japan, China, South Korea, Thailand, and the European Union countries and regions.

Prof. Kurushima of NEDO in Japan lectured on the measures for utilizing high efficiency energy and introduced a model project that targets it.

Professor Li of Tsinghua University in China explained the current status and projection for energy supply based on the effective use of coal in China and the role of gas turbines related to that.

From South Korea, Professor Cho of Yonsei University spoke about the outlook of energy supply and demand and related academic studies.

From Thailand, Mr. Prutichai of the Energy Agency participated and introduced their electric power situation. He expressed their desire to propagate gas turbine power generating systems in the future.

Mr. Alberto Dalla Rosa from Italy, who currently works at the Electric Power Development Co., Ltd., introduced a detailed present status of European power supply and explained the outlook for European Union energy with a strong focus on environmental compatibilities in the future.

Unfortunately, there were not as many listeners as we expected, which might have been because of the fact that the forum was held in the late afternoon. However, we received very positive responses from the participants that they had obtained information that was not normally available.

Organized Sessions "Ultra Micro Gas Turbines"

Ten lectures were given in 3 sessions (OS - 1, 2, 3) related to the ultra micro-gas turbines that are only a few centimeters in size.

These organized sessions centered on achievements reported by the Investigative Research Committee of the Gas Turbine Society of Japan. Lectures were given on the elements of research, such as a concept studies (OS-103) on ultra micro-gas turbines, system analysis such as an overall analysis (OS-109) and structural analysis (OS-106), concept study (OS-102) on heat exchangers, CFD / experiment analysis (OS-104, 107) on flows within the turbines, test results (OS-108) on combustors

with a 10-mm diameter and 1-mm height and optimization (OS-101, 105) eyeing on ultra-micro compressors. There was also an example reported from outside the Research Committee that introduced that an ultra-micro-centrifugal compressor with a 10-mm diameter using SiN was actually manufactured and went through a rotation test. This example report drew much attention from the audience.

The interests for ultra micro-gas turbines were great, and questions were raised actively from the audience, particularly on the actualization in the system analysis lecture.

Organized Session "Gas Turbines for Ships and Superchargers"

In this session, lectures were given on the developments of small turbochargers, 2,500 kW gas turbines for ships, loading WR21 gas turbines on destroyers, and the status of development and market for the MT30.

The turbocharger developed is a small model with a turbine diameter of 44.5 mm and a rotation speed of 180,000 rpm. The engine for the PWC (Personal Water Craft) currently uses a 2-stroke engine, which is in transition to switch to a 4-stroke engine in compliance with enforced environmental regulations, such as regulations of the Environmental Protection Agency. A new turbocharger was developed with the specification for ships to increase the output of 4-stroke engines. The diagonal flow turbines and ceramic bearings are adopted to enhance corrosion resistance against salt water and to improve its response (OS-201).

The SMTG (Super Marine Gas Turbine) is a regenerative gas turbine with a rated output of 2,500 kW. Its target performance is being able to use A crude oil, a 38% heat efficiency, and NOx emission rate of 1g / kWh. It successfully completed a land test in March of 2003. In the future, after passing an endurance test, it is scheduled to be loaded onto a next generation domestic vessel, the super eco-ship, in 2005 as a part of the project started by the Ministry of Land, Infrastructure and Transportation of Japan (OS-202).

The WR21 is an ICR (Inter-Cooling and Regenerative cycle) type gas turbine with a rated output of 21 MW, which was loaded onto a T45 destroyer of the British Navy for the first time. The T45 adopted an IEP (Integrated Electric Propulsion) electric propulsive system. The power generation system consists of WR21 direct-coupled power generators (2 units) and two 2 MW diesel power generators and supplies 2 propulsive motors and non-propulsive power. The WR21 has a fine part-load performance, showing not only the reduction in life cycle cost, but also an improvement in operation. The vessel is operated by the CODOG method using two 20 MW gas turbines, which might be changed to the more cost effective WR21 (OS-203).

The MT30 is a gas turbine for ships with a standard output of 36 MW. The output is at maximum as a single machine output. According to detailed market analysis, needs for large output engines are increasing for both military ships and commercial use, and development was decided in 1999. The durability test to obtain DNV model certification is currently being conducted (it is scheduled for completion by the end of 2003). 80% of the parts are shared with aircraft engine TRENT800; therefore, the design changes corresponding to vessels are limited to the major rotation parts. There are cruisers and aircraft carriers for the 70 MW ~ 80 MW class vessels. Other uses are for electric and machine propulsions in large passenger ships, LNG tankers, and high speed ferries of over 35 kt (OS-204).

Forum "Wave Rotor"

As an attempt to facilitate the exchange of information among researchers specializing in the field of wave rotor, we arranged a forum called "Wave Rotor" for published treatises

and oral reports in this area. As a result in the two sessions (F - 1, Forum 3) six reports were presented (three papers and three oral reports.)

We usually spend a great deal of time in presenting lectures on wave rotor to the audience, whom are unfamiliar with the principle. However, because almost all of the participants in the audience are specialists in this field, every speaker had presented his topic without the usual preamble. Although none of the lectures had presented any new outstanding topics, know-hows that are not normally discussed at the usual lectures and in treatises were vigorously debated.

These sessions were highly relevant to the specialists on wave rotor; as a result, a similar session will be arranged in the ASME International Mechanical Engineering Congress, which will be held in November 2004.

2.3 Technical Paper Sessions

Diagnosis, Control and Measurement

In the two sessions (F - 4 and F - 5) on diagnosis, control, and measurement, nine presentations were given. As has been the case in other international conferences held in recent years, studies of the diagnoses (six cases) was vigorous, while in contrast those on control (two cases) and measurement (one case) were moderate. The following methods of diagnoses were reported: The diagnoses by neural network (TS-1, TS-2, TS-3); the method of raising the reliability of the gas-path analysis with statistical means (TS-4); and diagnosis (TS-5) that employs the model of deterioration of capacity. Also there was a report (TS-6) that compares the predictability and measurability of the APU.

On the subject of control technology, there were reports (TS-7) on start-up control and VSV control by means of the optimizing method; and a report on a system for control and monitoring the micro-gas turbine, designed by the author on his PC, together with the report on the operation of the machine (TS-156).

On the measurement technology, there was a report (TS-8) on the revision of the data on the pyrometer that took into account the radiant heat of the gas and flame.

Structure and Vibration

Nine treatises on structures and vibration were presented.

In two sessions (E - 3 and E - 5), treatises on stress and vibration, as well as on the bearing and the effect of vibration on it were reported.

There were four presentations on the blade and structure session (E-3). When birds had flown into the aircraft engine of an Indian airline, the FEM stress analysis of the rotor blade corresponded closely with the experimental result (TS009). On the vibrational stress of the rotor blade of an axial machine, the analysis and experiments revealed that the vibrational stress of the rotor was reduced with uneven pitch stator (TS-010). A theoretical and experimental study was conducted by changing the number of the stators of the upper and lower half of the axial flow compressor; as a result its vibration-reducing effect was found when the difference in the number of upper and lower blades was large. As for radial machines, the measurement results of the vibration stress and the rate of logarithmic attenuation were reported on a turbocharger under development (TS-011). An interface that can be used for the stress analysis of the FEM was proposed; it uses the result of the CFD analysis; its application to the virtual turbine model (1400°C -class) was introduced. (TS-012).

Five reports were presented in the session "Rotor Dynamics and Bearing" (E - 5). A report from Poland presented a unique analysis of the oil film in the high-speed bearing (TS-018). An interesting report from the United States stated that a maximum-size foil bearing and magnetic bearing had been

developed and used in application (TS-017). A report from Japan stated that a possibly smallest foil bearing (30mm) had been developed and tested (TS-019). On the vibration of the rotary-type bearing, the effect due to the vibration resulting from the misalignment of the balanced shaft system was reported. Although the study of the experimental results is not sufficiently adequate, further contribution in this field is anticipated (TS-015). The vibrational characteristic of the rotor with a non-circular section was analyzed with the FEM; and the procedure of the analysis of the vibration and the solid model — instead of the beam element, which was placed on the non-symmetric cross-section — of the vibrational analysis was described. (RTS-016)

The number of participants of this session was small; nonetheless, all of the participants engaged in vigorous discussion of the issue.

Aerodynamics

The numbers of participants in the aerodynamics sessions was the largest. Totally, there were thirty-nine papers delivered in twelve sessions.

On the utilization of the CFD for the design and analysis of the compressor, the following papers were delivered: The effect of backward-swept blade on the compressor performance (TS-029), the analysis of the tip section flow (TS-030), CFD application to the design of turbine blade (TS-028, TS-042), centrifugal compressor (TS-020, TS-043, TS-049), and the effect of surface roughness (TS-033) and humidity (TS-021) on the performance. Also, the unsteady flow analysis on the clocking effect (TS-058), rotor-stator interaction in turbine (TS-048), and simulation of active stall control (TS-027), as well as the relationship between the tip flow and radial flow distribution (TS-051) were introduced. The effect of the turbine rim seal (TS-025); the cavity flow of the compressor (TS-024); and an analysis that included the exhaust flow system (TS-031, TS-026), which included CFD application to problems other than cascade flow, were reported. The applications of the optimization of inverse design technique to compressor design (TS-034), and to the turbine, which took into account the outlet of the compressor (TS-034), were presented (TS-035 and TS-036). A higher order unsteady multi-grid CFD method was introduced (TS-022).

On the problem of surge and stall, passage shock was taken into account in proposing a model of compressor stability (TS-037). Besides this, the followings were reported: The active control of the centrifugal compressor (TS-58) and the development and verification of a surge prediction method (TS-040), the measurement of fan flow prior to or under rotating stall (TS-039, TS-044, and TS-045). Numerical analysis of the active flutter control, which assumed active vibration of trailing edge (TS-055), was also reported. For unsteady measurement, detailed measurements were reported on transition phenomena of the vaneless diffusers (TS-046), the unsteady loss of an axial turbine (TS-056), and the wake decay in the stator passage of an axial compressor (TS-057). On vibration problems, the forced response of the centrifugal turbine (TS-053), and the comparison of results between double-linearized theory and CFD on the vibration of circular cascade blades were presented (TS-054).

In the area of conceptual design, a proposal was made on the design tool for regenerative compressor (TS-050), and a simple through-flow design model was proposed for replacing the mean radius calculation (TS-052). The concept of a new turbine, named tunnel turbine, was introduced, which conceived for application to the micro-gas turbine (TS-041).

In addition, the followings were also reported: The measurement of the three-dimensional PIV of the impeller's internal shock-wave (TS-032); the measurement of the shock-boundary layer interaction in a rectangular duct (TS-023); the development of the multi-stage compressor test rig (TS-114);

a trial experiment to reduce the noise of the low-speed turbo-fan by varying the outlet angle of the impeller (TS-047).

Heat Transfer

The number of contributed papers in the area of heat transfer was the second highest behind that in aerodynamics - 26 papers presented in seven sessions. Some of them are: impact of the trailing edge injection on the heat transfer coefficient of the blade surface in a turbulence analysis of transonic turbine blades to which film cooling was conducted (TS-70), the result of a high speed cascade test regarding the effect of a trailing edge shock wave on the heat transfer coefficient or film cooling efficiency on the pressure side of the blade (TS-77) and the analysis of film cooling on 3-dimensional blade surfaces in the cases of leading edge, suction surface, and pressure surface. There was also a technique to optimize the shape of the film cooling hole with CFD by suppressing the mixing with the main stream (TS-71), and also LES analysis was tried for an anisotropic flow field where the film-cooled jet and mainstream met (TS-60). The LES was also applied to the analysis of mixing between the cooled air from the trailing edge slot and the mainstream (TS-62). As for the heat transfer prediction on the blade surfaces, an analysis using the SST turbulence model with a high accuracy for transition was presented (TS-59). In addition, there was another analysis of an unsteady heat transfer coefficient that was conducted on the rotor blade surface, which received an impact from the wake from the stator vane (TS-73). Experimental researches were conducted on boundary layer transition on the model of a blade leading edge placed in the downstream wake generated by moving bars (TS-68), and the transition from the separation bubble at a surface position near leading edge (TS-69).

For the problem solved by coupling the fluid and structure, a coupled analysis was performed among the film-cooled air by the showerhead in the leading edge area of a turbine blade, the showerhead structure and the mainstream (TS-83). (TS-84) was that the cooling efficiency is solved on the multi-layered full surface film cooling structure on which the TBC is built. In addition, the following was introduced: an analysis on the flow path and cooling efficiency where impingement cooling, pin-fin cooling, and full surface cooling are combined (TS-85), and an analysis on the metal temperature of cooled blades implemented as a part of the High Temperature Materials 21 Project (TS-66).

Regarding the issue of heat transfer in the passages with a turbulence promoter, a comparison between experimental observation and numerical analysis of the detailed flow behavior in a triangle shaped passage in the trailing edge portion of turbine rotor blades (TS-78) was reported. The comparison between numerical analysis and the experiment on the heat transfer coefficient and pressure loss on the flow surface with the triangle passage aspect ratio as the parameter (TS-80) was also documented. In addition, there was also an observation on the flow by PIV in the rotating smooth U-bent and that with 90° - rib angle (TS-79), and the effect of a 2-passage rotation at a similar U-bent on heat transfer efficiency was measured in detail by the Naphthalene sublimation method (TS-81). Regarding the heat transfer promotion due to the secondary flow of the ribs placed as tilted towards the flow in a square passage, an analysis result using RANS was reported (TS-82). For impingement cooling, the following was reported: the effect of dimples made on the impingement surface (TS-74), heat transfer characteristics of the cooling structure where the ribs are attached in the direction of the mainstream and in the direction where a cross flow occurs (TS-75), and the result of a detailed study by the Naphthalene sublimation method on the effect of heat transfer promotion by attaching various rib shapes to the impingement surface (TS-76).

The following findings were also reported: pressure loss

in a rotating duct which leads cooling air from the compressor to the turbine rotor blade (TS-63), the effect of swirl flow due to disk rotation (TS-64). A flow analysis was conducted on a rotating U-bent related to the cooling passage flow of the turbine rotor blade (TS-65), and the result of comparison was presented between the numerical simulation with the 2-equation turbulence model and the DNS analysis concerning the flow field in rotating 2 parallel passages (TS-61).

Performance

Nine presentations were made in three sessions concerning performance.

During the session on the water spray and filter for air intake (Session E - 6 Performance Analysis of Gas Turbines: Intake Air Humidification & Filtration), two presentations on water spray towards air intake and one presentation regarding the filter were made. Hitachi, Ltd. indicated that when they had conducted a performance analysis in the case where the position of a cool air outlet is changed for the AHAT system proposed, it became the most efficient when the humidified air was used for cooling. This indicated a 1.3% efficiency improvement when compared to the combined cycle using the gas turbine (TS-090). On the other hand, the Alstom Company presented, after reviewing the impact of air intake water spray on the compressor, the development of the air intake water spray test result using the actual GT26 machine and a compressor performance model with water spray (TS-091). In addition, Freudenberg & Nonwovens Co. introduced their filter using non-woven fabric.

During the session on a new model system (Session F - 7 Performance Analysis of Gas Turbines and New Systems), Tabriz University introduced that the tendency of calculated efficiencies varies greatly between the turbine with non-cooling and the turbine with cooling. These are being considered for heat efficiency calculation for simple cycles and reheat and regenerative cycles (TS-088). The Chinese Academy of Sciences proposed a CO₂ recovering power generation system in which the power generation rate exceeds 50% using the equivalent ratio combustion of LNG and oxygen (TS-087). Warsaw University presented that when they had developed and analyzed a part load property model of the Graz cycle, the same cycle contained superior part load properties (TS-089).

During the performance model and calculation tool sessions (Session F - 8 Performance Analysis Modeling & Tools), Shenyang Institute of Aeronautical Engineering in China introduced the function table in which the already proposed thermodynamic functions were organized and made applicable to a wide range. The programs that were developed were based on it (TS-093). In addition, Cranfield University made a presentation on a simulation model in which a radial direction flow profile is being considered for a low bypass ratio turbo fan engine (TS-094). Seoul National University presented an analysis model to predict the fouling phenomenon of the axial compressor (TS-095).

Development / Operation

For development and operational experiences of gas turbines, a total of 16 papers were presented in a total of five sessions. For the large power generating gas turbines and the related complex power generating system using the turbines, six papers were presented in two sessions (C - 7 and C - 8). One paper is about an attempt (the Modernization & Upgrade Program) to improve performance and reliability by applying the latest technology to the established gas turbine of which performance is inferior to the latest model (TS-099). Other reports were the papers on the status regained by thermal power plants over the years (TS-101 and TS-102). As for the development of the latest gas turbines, developments of the M701G2 by MHI (TS-100) and the V94.3A by Siemens (TS-098) were introduced. A research paper was also presented,

discussing a gas turbine that used low calorie fuels, such as a byproduct gas and a high furnace gas (TS-1083).

For micro power generation, four papers were presented in the micro gas turbine session (D - 2). The cogeneration system using the 30 kW class micro gas turbines was evaluated from both the performance and operation control standpoint (motion properties) (TS-117). Another study presented the development of a 300 kW class micro gas turbine (TS-115). As an element development, a paper regarding the concept of a new turbine (Tunnel turbine) projecting an application to a hybrid system with micro gas turbines and fuel cells (TS-116) and the development of a micro jet engine test system for university education (TS-113) were introduced.

For aero-engines, six papers were presented in two sessions (C - 1, C - 2). To introduce the achievements of the past four years in engine development for helicopters (TS-107) and the environmentally compatible next generation ultrasonic propulsion system (ESPR project) (TS-104), as well as innovative aeronautical propulsion technologies in the 21st century, two papers were presented from NASA (TS-105, TS-106). As an element technology, two papers were also submitted regarding the tandem cascades (TS-108, TS-109).

Materials

In this division, a total of 14 progressive technical papers were presented on materials. They consist of the superalloy session related to Ni-based single crystal alloys (Superalloy-1 and Superalloy-2), a thermal barrier coating session, and the next generation materials session handling products besides steel materials, such as ceramics (Advanced Materials).

During the superalloy session, single crystal alloys developed in Japan from the 2nd to 4th generations were presented. For the 2nd generation alloys, the casting property of the YH61 materials in which a low tilted-angle particle strength is enhanced (TS-124) was reported. The study on TMS-82+ materials in which W and Re were added to improve the creep strength and promoted the form of the raft structure within the creep (TS-123) was also included. For the 3rd generation alloys, a report on the impact of thermal treatment on the properties of single crystal alloys that had been designed based on the d-electro-theory (TS-121) was made. The TMS-82+ was offered to the rotation test by the 15 MW class gas turbines and reported that oxidation and damages, such as fatigue cracks, will not occur. For the 4th generation alloys, Ru and Re were added to stabilize the structure, and improved the mechanical properties, such as fatigue. Materials TMS-138 (TS-118) and TMS-162 in which high-temperature strength had been improved with TMS-138 as the base (TS-119) were reported. In particular, TMS-162 has the world's top-level strength and is indicated to have achieved the target value (Creep resistant temperature was 1,100 °C at 137 MPa/1,000 hours). Furthermore, as the technology related to the Ni-based superalloys and as the longevity extension technology for gas turbine rotor blades that had been disposed due to the end of manageable longevity, the following was reported: "Regenerative treatment technology where hot isostatic press (HIP) and thermal treatment are combined" (TS-120), as well as "The development of a simulated turbine system where the alloy design program and gas turbine design program are combined and the turbine performance is simulated from the materials" (TS-122).

During the thermal barrier coating session (TBC), new plasma flame-coating TBC technology was reported. It was about flame-coating the La₂Zr₂O₇ or Nd₂Zr₂O₇ layer on the conventional Zirconia layer (ZrO₂-Y₂O₃) in order to improve heat cycle properties (TS0129). Furthermore, TBC technology (TS-130) studied by the government project, "Development of technology for 1700°C -class closed-cycle gas turbine corresponding to CO₂ collection" and TBC technology (TS-131),

which is based on Hafnia (HfO₂) developed by "Nanostructure coating project," were introduced, respectively. Hafnia TBC has, when compared to zirconia, a low heat transfer rate within 1000 °C to 1300 °C, and it became clear that the sintering start temperature improves it by as much as 100 °C.

During the session for the next generation materials, as related to turbine disk materials, results were reported on rotation test (TS-126) for disk materials using SiC fiber dispersion reinforced type Ti-based complex materials. Also, results were reported for a dual property disk (TS-127) in which the inside is made of fine particles and the outside is structurally controlled as coarse particles by the heat treatment. As for the dual property disk, the impacts of heat treatment conditions on the structural control to N18 and U720Li, and the high temperature strength of the materials to creep, etc., were reported. Furthermore, a study on the applicability of metal growth composites consisting of eutectic complex materials to the actual products was introduced (TS-125). The eutectic complex materials are represented by Al₂O₃ and Y₃Al₅O₁₂ (YAG), and Al₂O₃ and GdAl₃ (GAP), in which the target for application is 1,700 °C class gas turbine materials. Also, the status of the development for the Nb-based alloys, which has been in development centering on Japan Ultra-high Temperature Materials Research Institute, was introduced (TS-128). Paying attention to the environmental proof issue will be important when applying the Nb-based alloys, about which active discussions were exchanged.

Combustion

Presentations related to combustion and combustors were: four papers in session D - 2 (combustion control), four papers in session D - 4 (combustor development), five papers in session D - 5 (low emission combustors), and four papers in session E - 7 (Combustor design), totaling 17 papers. There were many papers on NO_x reductions; however, there were only five cases on the clarification of combustion vibrations that occur at premix combustion and on control technology. It is evident that interests in combustion vibration control are rising. TS-146 in D - 2 states two Helmholtz resonators have proven combustion vibration control. TS-147 has proven the combustor pressure fluctuation control system by using the combined cycle power plant. TS-148 tested the acoustic properties of the laminar flow diffusion flame by which fuel flow is controlled. TS-132 is a research on LES for inter-combustor vibration combustion. TS-150 and TS-151 in D - 4 are reports on the development of the low NO_x combustors for the ESPR project for which this year is the last year. TS-149, TS-141, and TS-142 in D - 5 are researches on a new concept for diluted premixed combustion. TS-149 concerns the impact of the shape of fuel supply unit, TS-141 is a comparison between the conical flame holder and the swirl flow type flame holder in combustion properties, and TS-142 reports about the research on the diluted two-stage combustion system for realizing a low NO_x in a wide equivalence ratio. TS-139 is a research on a diluted limit expansion where a recirculation flow and a premixed pilot flame are used. TS-135 and TS-136 are researches on low NO_x by a strong circulation of diffusion combustion. TS-152 in D - 4 is an investigation on the pre-vaporized, premixed combustion for HCRF for the purpose of low emissions, and TS-144 in E - 7 is a study on a low NO_x by the oxygen injection IGCC using synthetic gas cleansing. TS-143 is a research on a cooling structure for a combustor liner using MGC materials, TS-145 is an improvement of combustors using CFD, and TS-134 is an analysis of a two-stage premixed combustor using LES.

2.4 Panel Discussion

Title: "Gas Turbines in the Future"

Co-chairs: Nobuhide Kasagi (University of Tokyo) and

*Kimio Sakata (Japan Aerospace Exploration Agency)
Panelists: Yoshiaki Tsukuda (Mitsubishi Heavy Industries,
Ltd., Japan), Mike Benzakein (GE Aircraft Engines, USA)
Shoichiro Inoue (Ministry of Land, Infrastructure and
Transport, Japan), Terry Simon (University of Minnesota,
USA), Mikio Sato (Central Research Institute of Electric
Power Industry, Japan)*

In order to help our panelists lead successful free discussions and exchanges of opinion, the committee specially selected several topics on the "Future and Outlook of the Gas Turbine" for these panelists when determining the schedule and agenda of the first created Panel Discussion. Since the chairpersons were important to guarantee that the discussion be more active, Professor Nobuhide Kasagi of the University of Tokyo and Mr. Kimio Sakata of the Japan Aerospace Exploration Agency were invited to chair the Panel Discussion. On the Panel Discussion, each panelist was asked to give a 15-minute speech at the beginning, and then 30-minute discussions on the schedule were arranged.

Co-chair Professor Nobuhide Kasagi made an outline opening speech. He described the positions of energy technology and the gas turbines in the current technological system. He also introduced the future development direction of the gas turbine and its functions in the future energy network. After his brief outline speech, the following speakers gave their speeches:

Mr. Yoshiaki Tsukuda from Mitsubishi Heavy Industries, Ltd. introduced the current development in the technology of large gas turbines for the generation of electric power and future development, including related environmental concerns. He also introduced and explained the outlook of the gas turbine in the future electricity supply system.

Dr. Mike Benzakein from General Electric Co. used insightful materials and information and described the current development and future outlook of energy used in aerospace technology.

Mr. Shoichiro Inoue from the Maritime Bureau, the Ministry of Land, Infrastructure and Transport, Japan, talked about the future of the Japanese ocean shipment and transportation system, including the future and outlook of SMGT gas turbine engine technology.

Professor Terry Simon of the University of Minnesota described the future of small gas turbine technology and its related technology. His speech gave us some future outlook into very wide application area and possibility of the technology.

Dr. Mikio Sato from the Central Research Institute of the Electric Power Industry, Japan, introduced and described the future diversification of gas turbine fuels. He also evaluated characteristics of several fuels in details.

Finally, co-chair Mr. Kimio Sakata made a concluding remark on the future and outlook of the contribution of the gas turbine to the development of aerospace technology.

The enthusiastic speeches given by the panelists contained much information and were extremely meaningful. Since the impressive speeches drew many excited responses and discussions, the meeting times often had to extend past the timetable. Finally, we had to limit the discussion time and ask each participant to briefly answer the co-chair's question.

The main questions prepared by our co-chair, Professor Nobuhide Kasagi, were the followings:

1. How can gas turbine technology play a major role in supporting and improving the quality of human life in the future? Please talk about what kind of scenario and/or concept you may dream?
2. How do you think about possible merger and fusion of gas turbine technology with other technologies and disciplines, such as bio-, nano-, and information technologies? Do you think we should make much more effort in such direction, if we want to make major breakthroughs in gas turbine technology and better

contributions to the society?

Conclusion and Acknowledgment

The contents and topics of the speeches on the IGTC have been expanded with the congresses. During this congress, many of the contributed papers were from overseas countries. We believe that this was an active and profound international congress. We sincerely hope that the gas turbine research and technology of Japan can contribute to the great international development in this area and help to stimulate and expand the exchanges among European, American, and Asian countries' institutes, industries, research fellows, and engineers.

We thank the many participants that made this congress a successful one with a decent, academic environment. Although, there were a few things that could have been improved, we can conclude that this congress was a great success.

We want to thank every participant and speaker, every reviewer, chair, and co-chair. We also want to thank everyone who helped us to make this event possible and successful. We are also grateful to all of the hard-working students who helped us, traveling to all of the meeting destinations. We can now announce that our wonderful congress is successfully closed.