The Advanced Technologies for Next-Generation Products of Mitsubishi Heavy Industries

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1. Introduction

Mitsubishi Heavy Industries, Ltd. (MHI) develops new products in new fields including solar cells, intelligent robots, and semiconductor manufacturing equipment. This paper describes the features of leading-edge technologies in new fields such as nanotechnology, quantum mechanics, electronics, and IT, which play a major role in the development stage of these new products. A description is also given of the relation between the advanced technologies and the new products. MHI has basic core technologies that have been accumulated through the development of MHI's core products including aircrafts, engines and turbines, and ships, specifically in the fields of structure, vibration, tribology, fluid dynamics, combustion, and heat transmission. The paper also gives a brief overview of these core technologies focusing on the background of efforts to enhance their level and their utilization in product development.

2. Advanced technologies in new fields

2.1 Nanotechnology

Nanotechnology is the technology of creating new functions through the control of materials and structures at atomic and molecular levels. In Japan, the Council for Science and Technology Policy of the Cabinet Office adopted the subject of "Nanotechnology-Materials" in fiscal 2001 as one of the four science and technology fields to be the focus of national emphasis. Thus, nanotechnology is confidently expected to become a key technology in the 21st century.

Fig. 1 shows the impact of nanotechnology on society. From around the 1950s, microprocessing technology, precision analysis technology, computation science, and other new technologies have shown significant progress based on dramatic advances in physics, chemistry, biology, and other scientific fields. As a result, various types of nanotechnology (nanoscience) have appeared in the fields of materials, manufacturing technologies, semiconductors, electronics, bio-technologies, and other fields. Technologi-

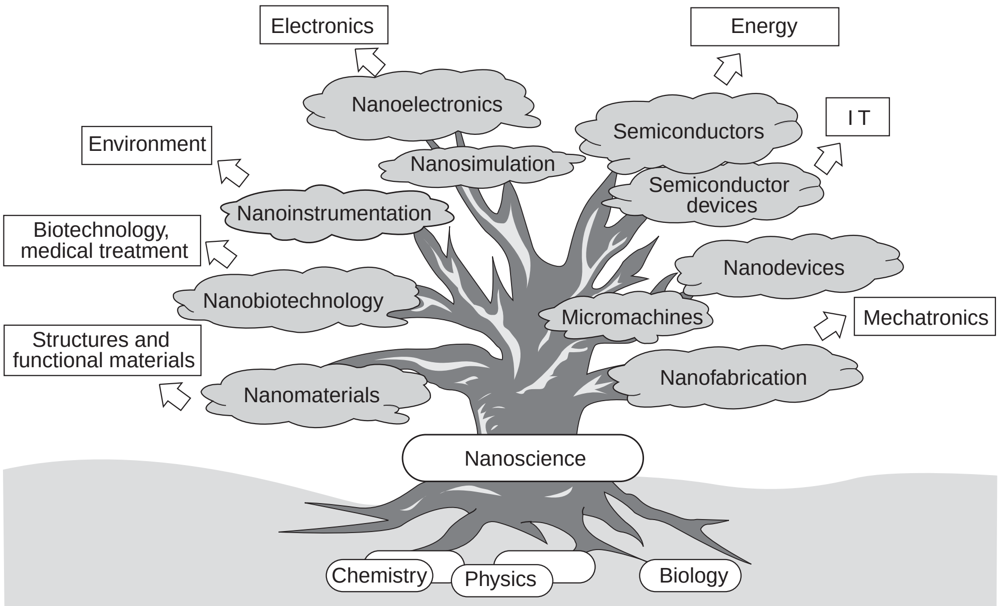

Fig. 1 Impact of nanotechnology on society
Nanotechnology has been applied in many fields including materials, manufacturing technologies, semiconductors, and biotechnology, based on physics, chemistry, biology, and other fields. Thus, the technology revolution utilizing nanotechnology has begun in a wide range of fields such as IT, electronics, medical treatment, environment, and energy.

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cal revolutions in the fields of IT and biology utilizing nanotechnology have already been proceeding apace. Furthermore, rapid technological innovation is expected to proceed utilizing nanotechnology in wide range of other fields such as electronics, environment, energy, and medical treatment, as well.

The current state of application of nanotechnology in MHI's materials technology and catalyst technology is outlined below.

(1) Material technology

Materials are one of the fundamental technologies of nanotechnologies. MHI has been investigated the application of nanometals, carbon nanotubes, nanoparticles, and other nanomaterials to industrial products. Among these new materials, nanometals (metallic materials provided with new characteristics by using nanotechnologies) have drawn attention as heat resisting and corrosion resisting materials applicable to boilers and turbines for power generation plant owing to their excellent strength and anti-corrosion characteristics. Specifically, MHI has been developing a new precipitation hardening stainless steel that has improved strength and toughness for rotor blades of steam turbines. Structure controlling technologies are utilized in the material to disperse and precipitate fine intermetallic compounds in several nm size. In addition, MHI has joined "the Nanometal Project" of New Energy and Industrial Technology Development Organization (NEDO) to promote basic researches on ultrahigh purity Cr-Fe alloys that contain nonmetallic impurity elements such as C, N, O, P, and S at levels as low as 100 ng/g or less. (This impurity level corresponds to Fe> 99.9995 mass% in case of pure iron. On the other hand, the purity of conventional pure iron is from 99 to 99.9 mass%.) The alloy is expected to become an epoch-making heat resisting and corrosion resisting material that can be applied in severely corrosive environments in waste incinerator boilers, coal gasification plant, chemical plants, etc.

(2) Catalyst technology

Advanced technology in the field of catalysis has been developed, including the control of micropores in catalyst supports and the nano-sizing of catalytic active metals. It is said that shrinking the particles down to nanosize improves the activity, as well as increase the surface area of the catalyst[1]. Hence, MHI has been studying how to improve catalyst activity by applying various methods such as the sol-gel, the coprecipitation, and colloids method.

In the field of flue gas treatment, in which catalysts are actively applied, the requirement for performance of catalysyts has become higher for both grid and off-grid power plants, incineration plants and vehicles in keeping with recent changes in environmental regulations. In response to these increasing requirements, MHI has developed and practically applied a high-grade catalyst preparation technology. **Fig. 2** shows an example of a catalyst used for reduction of NOx in flue gas. The catalyst activities has been improved by controlling the arrangement of the atoms composing the catalyst.

The development of polymer electrolyte fuel cells (PEFCs) has been accelerating around the world focusing on high efficiency and low-emission products for stationary power sources and for automobiles. MHI has developed a 1 kW system for a stationary type PEFC using natural gas that is the most compact system in the world. In addition, MHI has also developed an electrode catalyst for the system. That is, catalytic activity is doubled compared with conventional catalysts by controlling the size of the platinum particles on the carbon support to several nanometers and by arranging the particles in an optimum pattern. With the growing trend in PEFC applications and the increase in the amount of such units being shipped in the future, an emphasis has been placed on reseach for replacement of platinum, which is the definite mineral resource. Accordingly, the enhancement of technological development is expected in the fields that rely on the use of platinum as a catalyst to find suitable ways of reducing platinum consumption based on the catalytic function of platinum, the design and development of alternate catalysts, and the production of catalysts that utilize self-organization technology.

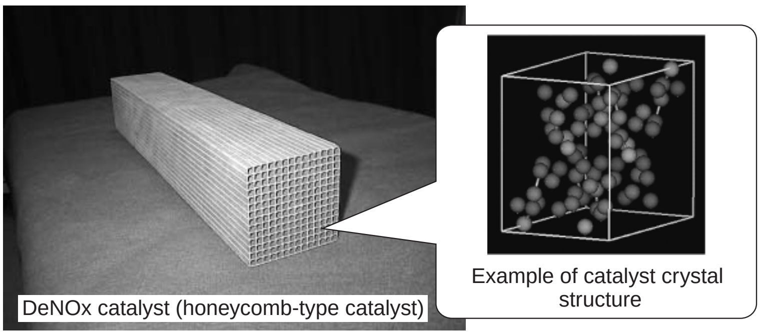


Fig. 2 A $V_4Cr_2O_{13}$ composite oxide in a honeycomb-type catalyst for DeNOx: Arrangement of crystal structure
Photograph shows the arrangement of Cr layer–O layer–V layer–O layer (C-axis) in the composite oxide structure of the honeycomb catalyst (70 mm square, 400 mm in length, and 5 mm in pitch) for low temperature DeNOx system.

2.2 The field of quantum mechanics

Many advanced technologies have been adopted in products produced by MHI in order to attain higher grade and higher added value in the products. The main performance characteristics of many products were obtained through the use of phenomena based on Newtonian mechanics. In the fields of energy and the environment, which have been gaining greater prominence at MHI, however, a growing number of new products have appeared that rely on quantum mechanics based phenomena for their main performance characteristics.

(1) Energy

A typical example of new technological development in the energy field is solar cells. In this field, diversification of energy sources is desired. In response, MHI has developed thin film amorphous silicon type solar cells utilizing solar rays, which are representative of natural energy. Solar cells utilizing the characteristics of silicon semiconductors require special technology to convert solar rays spanning the entire visible spectrum from ultraviolet to infrared light to electricity at low cost and high efficiency. At present, technological development has been proceeding from amorphous silicon type solar cells to tandem type solar cells (combination of amorphous silicon with fine crystals) that have increased efficiency. Technological development fully utilizes the most advanced technologies in the quantum field, particularly in the control of grain growth in thin film silicon semiconductors, the control of band gap width, and large area film-forming technology. Development work is proceeding under the collaboration of industry, academia, and government with the aim of attaining greater increases in efficiency and reductions in cost.

(2) Environment

In the field of the environment, there is an increasing demand for the removal of trace substances such as those represented by dioxins that are highly toxic. Existing chemical analysis technologies cannot adequately respond to this demand, and a need arose to develop a new "ultrahigh sensitivity and high speed analytical technology for toxic substances" that can detect them quickly on site. Responding to the need, MHI has developed a high-resolution analytical technology that can quickly analyze trace amounts of toxic substances. The newly developed analytical technology uses vacuum ultraviolet light to efficiently ionize very small amounts of toxic substances, in order to enrich these substances on site and to separate them from other substances present. This analytical technology is realized by a time-of-flight mass spectrometer (TOFMS) that uses an ion-trap. At present, MHI expects to apply the analytical technology to the monitoring of toxic generation sources in waste incinerators or other facilities. In the future, however, MHI intends to develop the technology for application to continuous monitoring of the global environment through the compact design of devices, in order to contribute to the safety and comfort of residents.

(3) Semiconductors

Semiconductor manufacturing equipment, which are also a new field of products produced by MHI, are products whose core operation relies on quantum mechanics based phenomena. When forming thin films on the surface of a semiconductor such as silicon, the semiconductor manufacturing equipment must be capable of securing the band gap of the semiconductor material in order to prevent any leakage in current due to tunnel currents, for example. The equipment must also be capable of decreasing dielectric constants in the film and of preventing the diffusion of metallic elements. To do this, MHI adopted the most advanced film-forming technology available. In addition, MHI has developed an exclusive film-forming technology called the "chloride reduction film-forming method." The technology is expected to contribute to the acceleration of developments in a wide range of fields, including ultra LSIs, in terms of the refinement of device structures and realizing significant improvements in performance.

As described in sections (1) through (3) below, the development of technology and improvements in performance in these products essentially rely on the development of technologies in the quantum mechanics field in order to achieve proper product performance. At the same time, however, the creation and development of fundamental technologies to support basic technologies should also be emphasized. Quantum mechanics is often compared with Newtonian mechanics. It can be said that Newtonian mechanics stands on a macroscopic and visible foundation, while quantum mechanics may be said to be the invisible "controlling principle of the microscopic world." Thus, in this way Newtonian mechanics and quantum mechanics can be said to differ from each other. However, the above-mentioned products reflect the principle in visible form, so engineering reliability can only be attained with the support of macroscopic world technologies. Hence, what is referred to as high-grade technology based on Newtonian mechanics is absolutely necessary in order to achieve any improvements in performance and reliability as well as any reductions in cost. Examples of these supporting technologies include vacuum technology, heat and structure technology, and chemical analysis technology. These supporting technologies in particular are ones in which MHI has accumulated extensive experience over a long period of many years. By fusing advanced technologies with supporting technologies, MHI is making every effort to provide products that meet the most demanding needs of its customers.

2.3 Electronics technology

Reflecting recent trends towards maturation and upgrading society and industry, the products of MHI are required to have levels of performance, precision, and function that will allow them to overcome the limits of existing technologies in every application. Electronics technology is one such technology where major breakthroughs have been made that surpass previous limits. In this regard, MHI has successfully developed electronic devices and applications that simulate five major functions of the human body. These include systems and sensors that gather and recognize information to control systemic response similar to the sensory organs; information and communication engineering resembling the nerve network; microelectronics and computing systems resembling the brain; power electronics resembling the muscles; and system controls which govern movement, knowledge, learning, and reasoning, thus administrating individual organs. Based on this scheme, MHI re-organizes existing technologies for further upgrading and enhancement. The following is a brief overview of the activities of MHI in these core technologies and a reflection of core technologies thus far developed in the products of MHI.

(1) Sensing technology

A number of issues have become increasingly important in various aspects of the development stage of sensing technology. These include such things as the need for greater speed and scope of non-destructive inspection technologies and techniques that were developed through inspections of power generation plants and facilities. Issues in instrumentation technology together with image processing include the need to improve robustness to cope effectively with disturbances and the need to quantify judgment criteria. Issues of concern in new fields such as microsensing and biometrics include the securing of greater product reliability.

It is expected that non-destructive inspection technology will show further improvements through the adoption of multidimensional arrays for ultrasonic flaw detection, thereby contributing to securing enhanced product reliability and widening the business of after-sale service of plants. Furthermore, efforts are underway to develop image instrumentation and image recognition technologies that are robust to variations in the environment, as well as to develop advanced spectroscopic technology for color measurement, which will be applied to autonomous machine systems having high-level judgment functions and to high-level inspections such as adhesion inspections using infrared light. In addition, the development of differentiation technology centering on optic fiber sensors is expected in laser-applied instrumentation technology.

(2) Information and communication engineering

Electronic toll collection (ETC) systems at expressways and electronic road pricing (ERP) systems in urban areas are systems of automatically collecting tolls from vehicles that enter a toll area using radio communication. Issues of particular concern to these types of systems include the development of low cost and highly reliable communication technology and the development of highly functional moving image recognition technology capable of detecting the approach of a vehicle and identifying the type of vehicle involved. Switching communication waves to high frequency waves will allow the communication to transfer signals at high speed and greater capacity. Such development will make it possible to realize the fine and detailed control of machines moving at high speed, and will lead to the application to precision sensors. In addition, the study of energy transfer technology using radio waves is in the development stage. Once these technologies are established, it will be possible to realize machines that can be operated completely wirelessly.

(3) Microelectronics

The development of exclusive processors that integrate intelligent processing and parallel processing with the most advanced LSIs has been an issue of great interest in improving performance in decision-making and image compression. Investigations are also moving ahead on the application of commercially produced components in the fields of aviation, space, and defense. To realize such applications, however, it is absolutely essential that there be satisfactory means of improving the reliability of such commercial components, including improvements in the ability to withstand a wide range of environmental conditions, the adoption of duplex circuit systems, and the adoption of effective self-recovery functions.

Efforts are thus underway to develop machines with intelligent processors in keeping with progress being made in the development of autonomous dispersion functions in machine products. The actualization of super-small devices utilizing nanotechnology, as well as of super-small and high functional devices utilizing Radio Frequency Micro Electro Mechanical Systems (RF-MEMSs) is expected in this field.

(4) Power electronics

The need to adopt build in custom motors has been increasing. In this regard, MHI has already developed the exclusive technologies necessary for achieving size-reductions, increased efficiency, and cost-reductions for custom motors and power converters, applications of which have already been realized in various products. One issue confronting both motors and power converters is the need to increase the operating efficiency of the equipment.

Electromagnetic drive mechanisms are fully expected to be integrated in various machine products as a component in the future. No concept of components such as a motor or generator exists in the power electronics field. That is, once a machine is fabricated, the functions of motor and generator are included in the machine. In other areas, the actualization of new types semiconductors such as SiC, which achieves significant energy savings in a device, can be expected.

(5) System control technology

A major area of concern in the field control systems development is compatibility between the machine system and humans and the realization of an effective man-machine interface (placing the human at the core, while establishing a natural and intelligent relation between the computer and human).

In the future, the rapid development of IT technologies including digitization, distributed operation, and remote operation, together with the response to their use will steadily expand into an ever-wider range of fields. On the other hand, with the current tendency towards ever-greater emphasis on service and solution-oriented approaches, maintenance service technologies for machines equipped with operational support and diagnostic capabilities, as well as machines and plants developed based risk assessment will find a greater range of applications as technologies that increase the added value of these and similar products. In addition, the development and application of technologies that realize functions that resemble the five human senses, including the development of innovative technologies capable of changing the intrinsic qualities of a machine, can be expected to proceed centering on Intelligent Transport Systems (ITS) and robots.

In this regard, MHI intends to focus on promoting the introduction of miniature, ultrahigh efficiency, and intelligent (energy saving, time saving, resource saving, efficiency increasing) technologies, along with communication technologies. The focus will be on realizing a sensuality assessment technology capable of dealing with sensitivity and feeling, together with humanoid processing technology.

2.4 IT field

The business of computing and contents supply services that are closely related to living, entertainment, medical treatment, welfare, and security, accelerates in emerging advanced information technologies and broadband generation.

The progressing information technologies (IT) since the 1980s has become a core technology of "Transportation & Distribution," "Environment & Social facility," and "Services," which are major business areas emphasized by MHI, as shown in **Table 1**. The applications of the newest advanced technologies and future technologies to MHI products are described in this section.

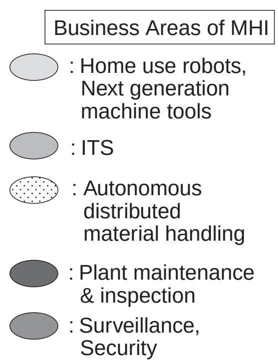
(1) Application to mechanical systems

Technologies related to computers, communication, man-machine interface, and artificial intelligence are the driving forces to create new highly value added products and the creation of service businesses such as machines with operational support maintenance and monitoring services in machines, plants, transportation and logistics systems. The extending effect by the progress of these technologies on the mechanical systems that support MHI's core business areas is extremely large.

Specifically, MHI has already commercialized the real-time operation monitoring technology for plant and

Table 1 Progress of IT-related Technologies and Business Areas of MHI

Technology field	The 1980s	The 1990s	The 2000s	The 2010s
Computers, Communication	PCs (1st period) Low speed modem	PCs (2nd period), Internet	Wearable, Wireless, Broadband	Ubiquitous, Self-repair type
Artificial Intelligence	Knowledge engineering	Probability models, Data mining	Autonomous distributed system, Reinforcement learning	Common sense reasoning
Sensors	Visible ray, X-rays	Infrared ray, Microwaves	Millimeter waves, γ rays	Sub-terawaves
Human I/F	Keyboard, CRTs	VR	AR, Telepresence	Cyber I/F
Robotics	Industrial robots	Harsh environment robots	Personal robots	Intelligent robots
Manufacturing, Materials		Micromachines	Nanotechnology	



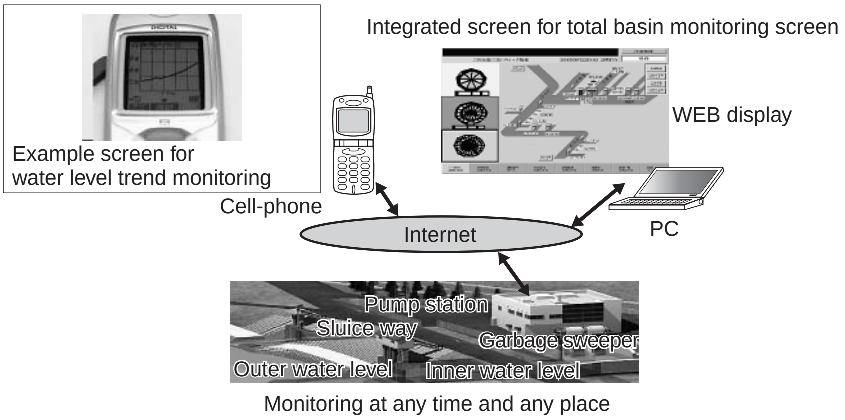


Fig. 3 Wide area remote monitoring and control system for a drainage pump station
IT is applied to realize remote monitoring at any time and any place for laborsaving.

mechanical systems using the high-speed communication of the Internet (**Fig. 3**), the operational support of injection molding machines that apply control technology and intelligent processing technology, and operational technology to prevent unstable combustion in combustors. Autonomous control technology, reinforcement learning technology, and other types of technologies are expected to be developed further to (a) have functions capable of modifying the internal structure of a system by itself and create new structures through interactions with complex and dynamic environments, and (b) achieve evolution toward machines which have functions to conduct self-repair and self-organization as like as organisms. And hence, MHI is actively engaged in promoting technological development under consideration of the progress towards the creation of intelligent-oriented mechanical systems.

(2) Innovation of foundation in information-oriented society and development of robots as an intelligent machine

(a) Ubiquitous network society

A society with an information network that allows people to access at any time and any place by various methods and which allows people to use the network freely in their living environment under unconsciousness is referred to as an ubiquitous network society, shown in **Fig. 4**. In the ubiquitous network society expected to appear within the next decade or so years, the barriers and spatial distance between the real world and the virtual world will be removed, and people will observe and control distant real objects as if they exist right before their eyes. The impact on industry, society, and living such as the operation and maintenance of facilities and plants, medical treatment and nursing, education and art, as well as house automation can be expected to be extremely large.

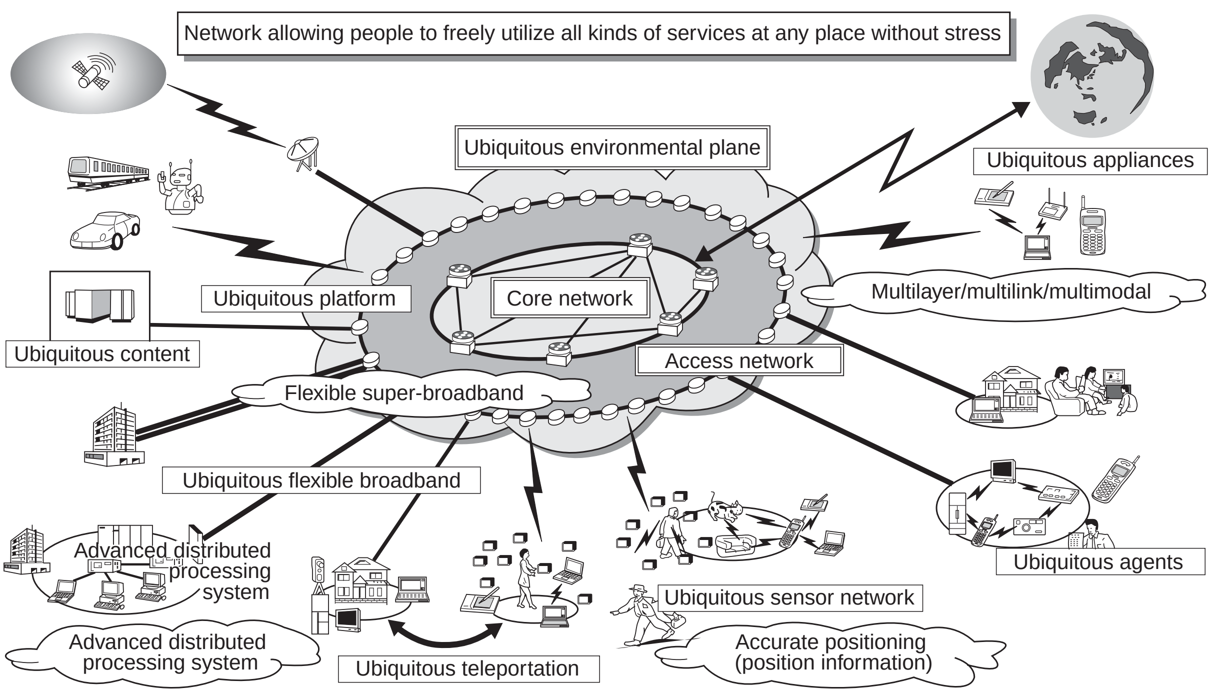


Fig. 4 Concept of ubiquitous network (2010)[2]

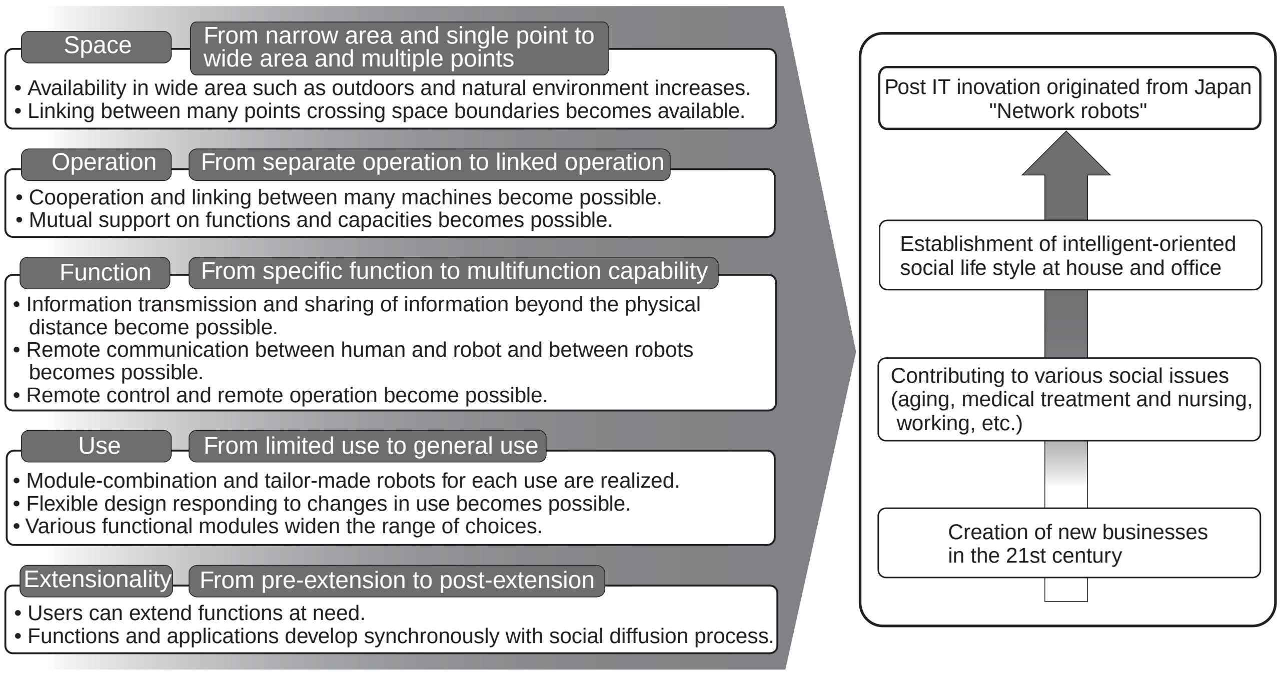


Fig. 5 Effect of realization of "Network robots"(3)

(b) Fusion between networks and robots (intelligent machines)

The term "robot" in this category consist of a broad concept that not only includes what is referred to as physical robots, but also includes various functions that are embedded into the surrounding environment (actual machines and facilities such as rooms and roads) as well as functions such as information-based household electric appliances which deal with information in a virtual space. Accordingly, the concept overlaps the future of intelligent mechanical systems in the ubiquitous network society, which are one of the targets in MHI's products. The effects of realizing such a new robot, called Network Robots are given in **Fig. 5**. As can be seen in the figure, the information owned by individuals can become information commonly shared by society. This can be expected to facilitate the transition from individual robots (intelligent machines) to autonomously cooperative robots as a group (intelligent machines).

(c) Home use robot as a target of MHI

MHI has developed a robot capable of providing support for daily life called “wakamaru,”[4] which is able to live symbiotically with humans. MHI is making an effort to solve such issues as realizing conversation capabilities with humans in various scenes, image and speech recognition technology robust against noise, safety against information-hacking, and communication technologies including real-time receiving and remote operation of dynamic scenes and voices, in order to create a “Network Robot” that is capable of leading the ubiquitous network society described above.

3. Enhancing the level of fundamental core technologies

3.1 Structure, strength, and vibration technologies

Structure, strength, and vibration related technologies are fundamental core technologies for products essential to acquiring the satisfaction of customers. To ensure the prompt and effective delivery of good products to customers, MHI emphasizes three technologies in this field. The following sections presents an overview of how these advanced technologies positively affects products.

(1) Large-scale structural analysis technology

MHI continually strengthens the technologies it uses in the analysis of large-scale structures by linking these technologies with three-dimensional CAD design techniques that are being progressively developed by the design section. By establishing structural analysis models and increasing the speed at which structural analyses are performed, large-scale and precision structural analysis can be conducted at high speed, which serves to optimize products.

Fig. 6 shows an example of a structural analysis carried out on a die head of an injection molding machine. The use of such repeated precision structural analyses during the design stage make it possible to attain optimized product designs.

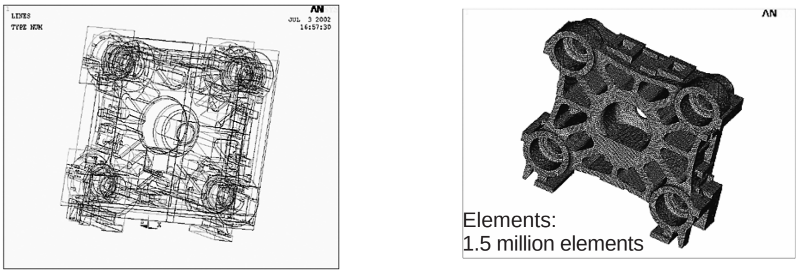
(2) Multibody dynamics technology

Multibody dynamics technology is a technology in which strength assessments are conducted at the component level. It takes into consideration the total dynamic behavior of a product structured by multiple components. Linking with 3-D CAD during the product development stage, a digital mockup of the subject product is fabricated so that the computer can confirm the functions and performance of the product.

Fig. 7 shows a model that was used in the development stage of a forklift. The combined analysis of the hydraulic system and control system made it possible to quickly confirm the driving performance of the subject forklift. Since the verification is done using a digital mockup, the period of experimental verification is shortened by approximately 30%.

(3) Robust design technology

Applying quality engineering using the Taguchi Method, MHI has developed products with highly robust levels, that is to say, which are capable of enduring the variations of actual working environments. **Fig. 8** shows an analytical example of a structure to prevent folding at the edges in a paper-folding machine of a newspaper offset press. A highly robust paper folding machine is attained by combining the analysis technology, which simulates the dynamic behavior of the papers with quality engineering techniques using the Taguchi Method.



3-D CAD model   Structural analysis model

Fig. 6 Die head of injection molding machine
The structure analysis model linked with 3-D CAD data gives precise structural analysis.

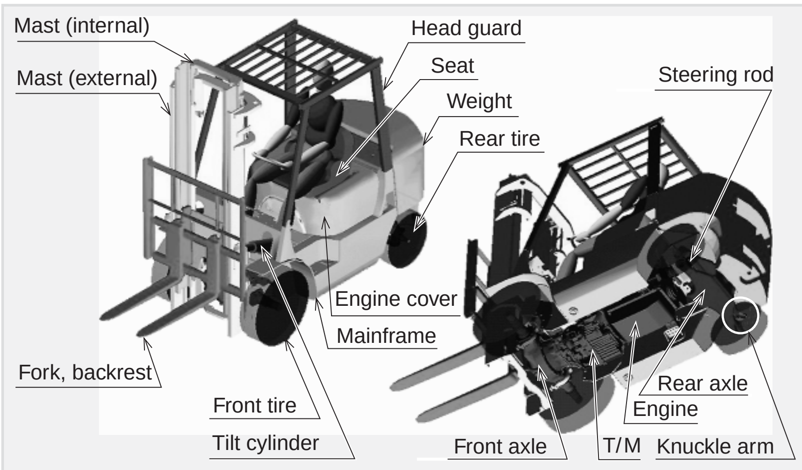


Fig. 7 Multibody dynamics model of forklift truck
Combined analysis of control system and hydraulic system is conducted using a multibody dynamics model, and the performances are verified using a computer.

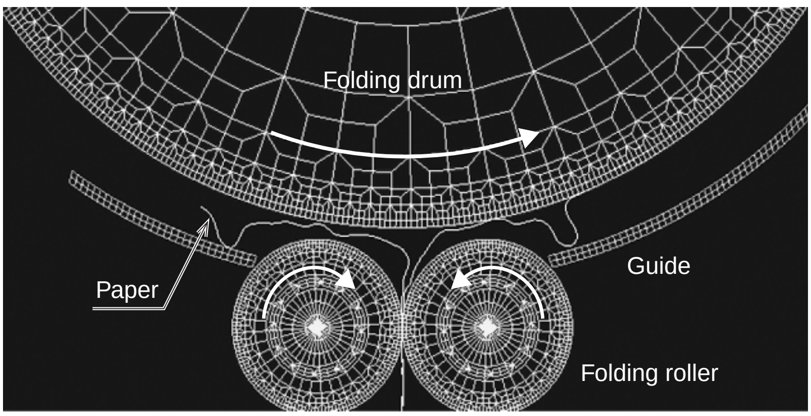


Fig. 8 Analysis of mechanism to prevent edge folding in paper folding machine
Nonlinear dynamic analysis on the behavior of papers in a paper folding machine is conducted using the parameters of fluctuations in paper travel speed and of paper-feed speed at the folding rollers. The data thus obtained are rearranged and evaluated using quality engineering to increase the stability of the operation.

3.2 Tribology

Tribology is a field that handles machine elements such as bearings, gears, and seals, which are utilized in MHI products. Tribology plays an important role in supporting the performance and reliability of the products.

Since MHI produces a large variety of products and most of them are tailor made, it is difficult to verify products of each kind by the repeated fabrication of prototypes. Consequently, MHI has developed analytical models for evaluating performance of machine elements based on theoretical model of fluid and solid dynamics, and validates them with experiments. Then MHI adopts the analytical models to simulate the actual machine. By maintaining the analysis technology at the most advanced level, tribology contributes to effective product development.

In the sliding bearings inside an engine, for example, analysis was applied in a practical manner taking into account the effects of fluid, heat, and structural deformation. Furthermore, consideration of the relation between the bearing gap and the amount of lubricant present, both of which vary with time, has made it possible to predict the peak value and the peak position of local high pressure, as illustrated in **Fig. 9**. Such analysis contributes to the improvement of engine reliability.

In the case of roller bearings, MHI has developed an analysis model that considers the 3-D motion of balls, which is owned by only a limited number of bearing manufacturers. Integral analysis of the bearing and the peripheral structures makes high speed and high face pressure limit design possible (**Fig. 10**). Adding to common standard computational methods such as those specified by American Gear Manufacturers Association (AGMA), MHI has also developed an exclusive analytical method for gears to predict actual damage limits, thus allowing compact limit design (**Fig. 11**).

As described above, MHI has been quite successful in extending analysis to areas where only experience could previously make predictions.

Continued progress in these fundamental technologies is expected to play an essential role even more intensively in improving the performance and reliability of products both now and in the future.

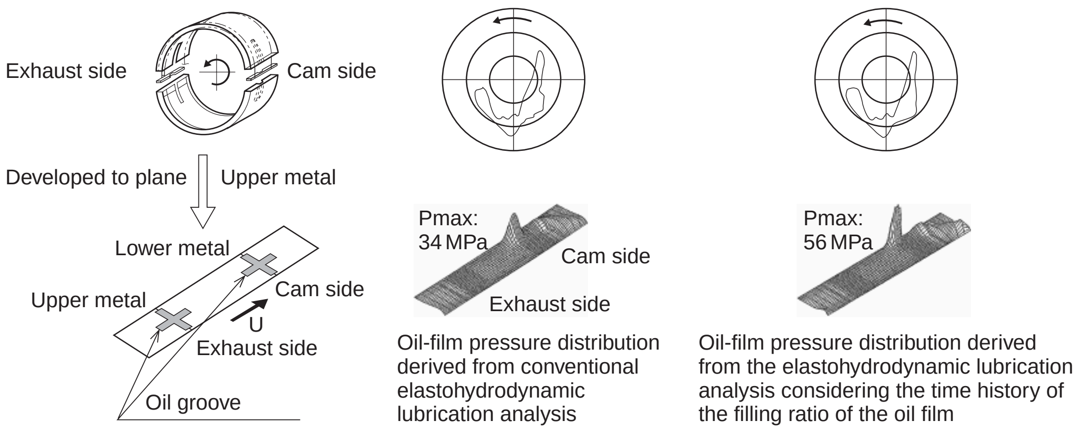


Fig. 9 Computation of oil-film pressure distribution in an engine bearing
Conventional EHL analysis gives only 34 MPa of the maximum oil-film pressure. Considering the time history of oil filling ratio, however, actual local high pressure of 56 MPa is predicted.

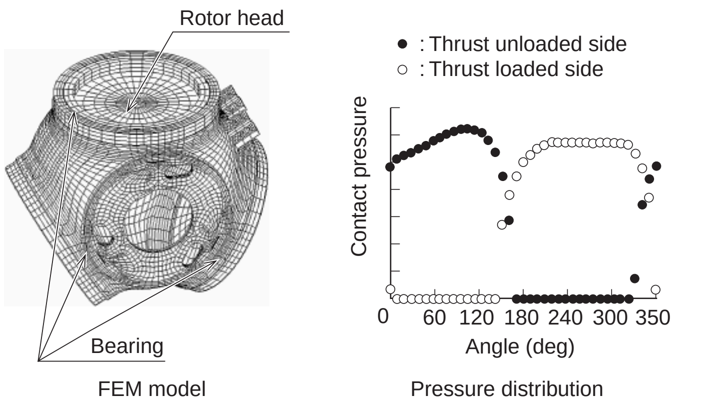


Fig. 10 Structure of windmill bearing and rotor head; pressure distribution derived from the combined analysis of FEM of the structure with the numerical model of the bearing
Elastic deformation in the structure around the bearing distorted contact pressure distribution and the maximum contact pressure significantly increased compared to the pressure calculated for the bearing installed in a rigid housing. However, the structural optimization design using the combined analysis of FEM and the bearing model made only 7% of maximum pressure deviation from the pressure in the rigidly supported case.

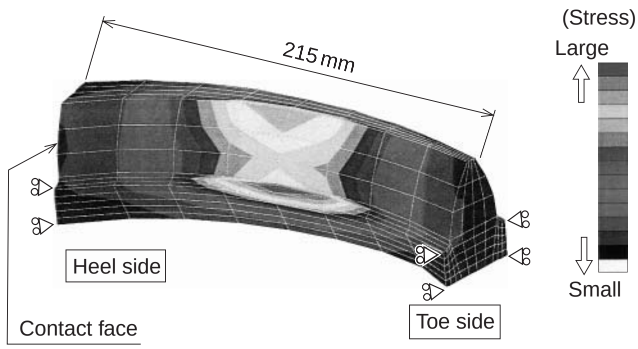


Fig. 11 Bending stress analysis on a spiral bevel gear
Contact computation on the created tooth profile was given by FEM considering the dynamic load effect during high-speed meshing. The bending strength can be estimated on the basis of the stress actually applied to the tooth.

3.3 Fluid technology

Fluid technology is essential to develop many of the 700 kinds of MHI products that are currently available. In particular, owing to the rapid progress in the recent development of computational fluid dynamics (CFD), which is a kind of numerical simulation technology, the analysis of complex flow states has become possible. Such analysis was not possible just a few years ago.

Fluid technology has progressed "from two dimension to three dimension," "from non-viscous fluids to viscous fluids," "from steady states to unsteady states," "from parts to whole structures," and "from simple shapes to complex shapes." This section introduces several examples which apply the technology in order to further understand current advanced technologies. **Fig. 12** shows an example of a kind of supporting system for disaster countermeasures, or a system for evaluating gas diffusion and exposure utilizing a weather prediction model. The system is currently used in Comprehensive Nuclear Emergency Response Training, National Disaster Prevention and Countermeasures, and other programs in Japan. **Fig. 13** shows a precision analytical method that takes into account the influence of the hull, ladder, propeller, and free surface of a ship. The method is applied in the design of high fuel-efficiency ship shapes. **Fig. 14** shows an analysis technique that can grasp weak compression waves inside a nozzle utilizing an advanced precision numerical method. The analysis develops a nozzle that generates decreased fluctuations. **Fig. 15** shows a 3-D analysis of the heat flow inside an automobile cabin. The analysis computes the temperature, humidity, and air velocity around a passenger from the sense of heat and cold, thus evaluating the comfort level of the passenger.

As shown in Figs. 12 to 15, fluid technology is applied in a broad range of fields from weather prediction on a global basis, to ships, supersonic wind tunnels, and vehicles. MHI will continue to develop its Center of Excellence (COE) with the aim of maintaining and advancing CFD technology at the highest level in the world.

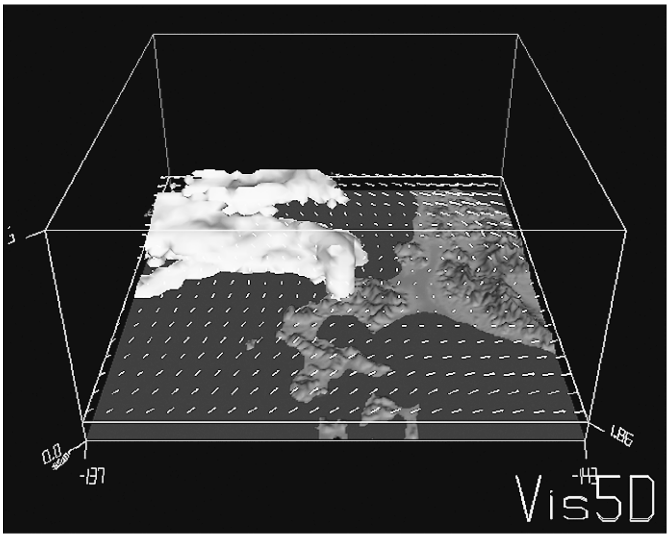


Fig. 12 Prediction of smoke diffusion from Mt. Usu.
MHI developed a system for evaluating gas diffusion and exposure utilizing a weather prediction model as a supporting system for disaster countermeasures. The system is being used in Comprehensive Nuclear Emergency Response Training, National Disaster Prevention and Countermeasures, and other similar programs.

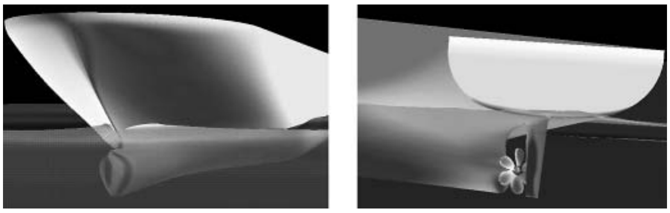


Fig. 13 Integrated fluid analysis of hull and propeller
Analysis to determine the effect of the hull, ladder, propeller, and free surface significantly improve the accuracy of flow field computation. The method is applied here to the design of a high fuel-efficiency ship shape.

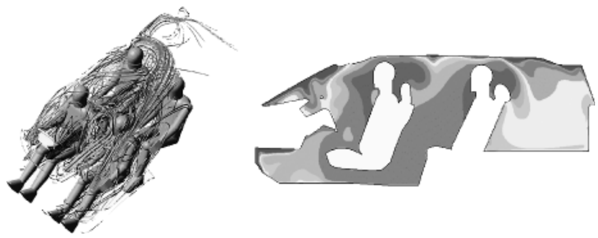


Fig. 15 Evaluation of comfort levels for air-conditioning in an automobile
A method for evaluating comfort levels was established by focusing on the sense of heat and cold for a passenger. Through the 3-D analysis of heat flow in the cabin, the temperature, humidity, and air velocity around the passenger are computed, which are then entered into the evaluation method to determine the level of comfort.

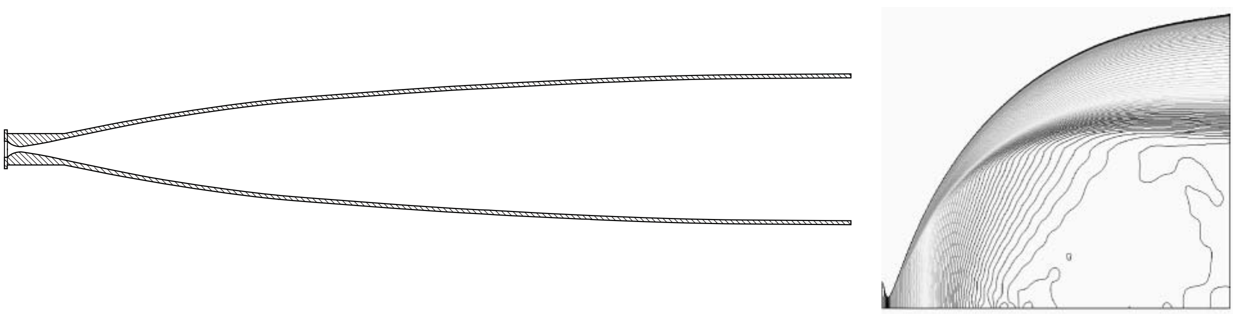


Fig. 14 Mach-number contour in a supersonic wind tunnel (the scale in the radial direction is magnified by a factor of ten)
MHI has developed a nozzle that generates decreased fluctuations by grasping the weak compression waves inside a nozzle using an advanced precision numerical method, and utilizing CFD.

3.4 Combustion and heat transfer technologies

Combustion and heat transfer technologies are core technologies that support MHI products in the energy and environment fields. Among these technologies, energy transfer technology converts thermal energy into higher efficient electric power. The thermal energy transfer has been at the forefront of the structuring of new cycles, new product development combined with conventional cycles, and new energy development including the solar cells and fuel cells mentioned earlier.

Combustion is an important technology for responding to global environmental problems. For example, the operating temperature of industrial gas turbines has raised from the 900°C level to the 1 500°C level in order to increase the thermal efficiency. In this case, MHI has achieved a decrease in NOx generation levels from conventional levels of several hundreds of ppm to several tens of ppm applying the fuel lean premixed combustion technology. MHI was the first company in the world to successfully apply the fuel lean combustion technology to a commercial combustion system. The development of this technology required the establishment of a technology for securing a stable combustion state under a fuel lean premixed combustion condition through a careful analysis of the flow dynamics and chemical reactions occurring in the combustor. **Fig. 16** shows an example of the direct measurement of the distribution of NOx generated in a combustor by means of the laser-induced fluorescence (LIF) method. Although diesel engines are driven in an intermittent combustion state, MHI has successfully attained reduced emission combustion through the refinement of heavy oil droplets and the optimization of flow inside the cylinder, as described in detail in a separate article. In addition, MHI has been engaged in the study of artificial liquid fuels such as DME (dimethyl ether), and the environmentally compatible combustion technologies for various fuels including coal, which has the largest reserves among fuels currently in use.

Heat transfer is an important technology closely related to the thermal efficiency and reliability of boilers, steam generators in atomic power plants, and other facilities. In this regard, MHI promotes experimental and analytical studies to analyze such phenomena as increasing the performance of high performance of heat transfer in the tubes, the prediction of critical heat flux, and solving flow instability. As shown in **Fig. 17**, which is an example of the CFD results, MHI has been conducting various studies to analyze the behavior of bubbles using the particle method aimed at the microscopic approach in order to predict the boiling phenomenon that appears in the tube bundles of steam generators. The inlet temperature of a high temperature gas turbine of the latest design reaches levels as high as 1 500°C. The reliability of the turbine blades operated in such a high temperature gas environment is ensured through the use of high grade cooling technologies. An example of the cooling technology is film cooling, in which the cooling air is guided to flow along the surface of the turbine blade. Efficient film cooling hole configuration is required to minimize the mixing of cooling air with the main gas stream on the blade surface. In this regard, optimization of air ejection is attained by detailed analysis of the mixing between the film-cooling air and the main gas stream, as shown in **Fig. 18**. One example of exposure to

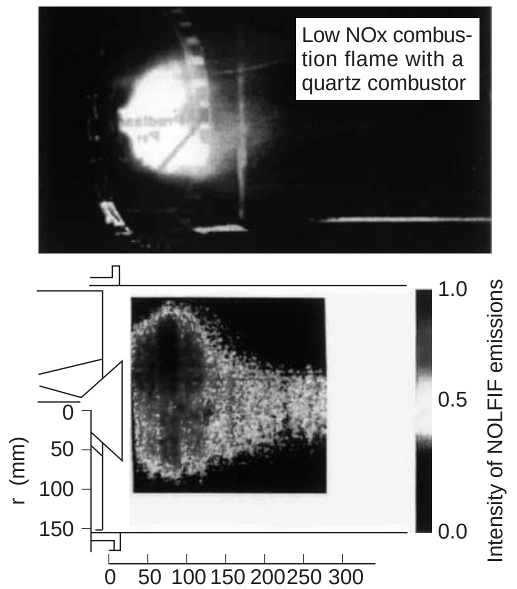


Fig. 16 Distribution of NOx in a premixed Low NOx combustor

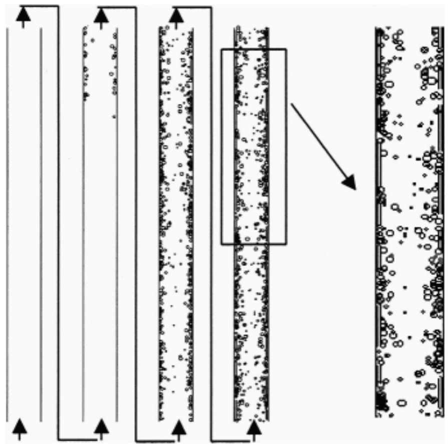


Fig. 17 Particle method analysis of Weatherhead experimental data

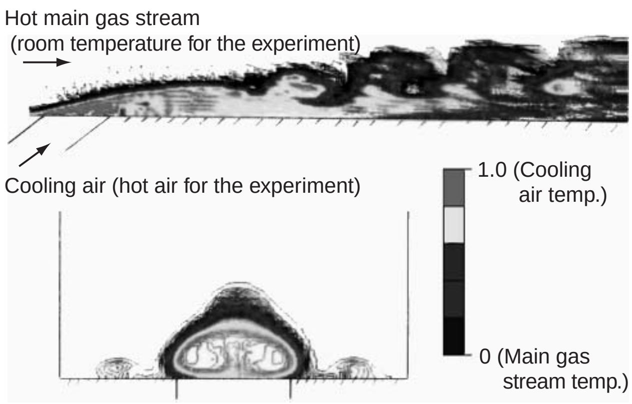


Fig. 18 LES analysis of film cooling: mixing of air-film with main gas stream

higher temperatures is the case of a reusable launch vehicle (RLV). On returning to the earth, the airframe of the RLV is exposed to high temperature plasma. The body of space shuttle is provided with a thermal protection system, in which it is covered with thermal insulation tiles to protect the airframe from the high temperature plasma. Heat transfer technology contributes significantly to the aviation and space fields through the application of tests simulating the state of heating of the airframe in a surrounding high temperature fluid flow, and through the use of CFD predicting the heating state. As described above, MHI is continually making efforts to contribute to the conservation of the global environment and the development of energy conversion/thermal-control technologies ranging from very low temperatures to ultrahigh temperatures using combustion and heat transfer technologies.

4. Conclusion

This article has presented a brief review of some of the prospects for technological innovation proceeding in new technological fields such as nanotechnology, IT, and the like. This has included a review of some of the applications of the resulting technologies to the development of products by MHI in new fields such as solar cells, robots, amongst others, as well as further for the future development of these technologies. The article also briefly described the leading-edge fundamental core technologies including structural, fluid, combustion, and heat transfer technologies, and described the application of these core technologies in the 700 kinds of products produced by MHI.

Placing these advanced technologies as a first step, MHI will continue to create new fields and new products, and deliver the world's top-level core products to customers by successively adopting innovative advanced technologies occurring around the world.

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