Aircraft and Rockets

JUNICHI MAEZAWA
MINORU KOBAYASHI

1. Introduction

There are two basic types of demand in the aerospace field, as described below.

- Demand for transportation systems, including distribution systems
- Demand for air defense systems related to national defense and security

The former type of demand is related to the infrastructure for transportation supporting the globalization of the world economy, while the latter concerns the provision of security as a premise for the growth of the global economy. It is essential to establish a good relationship between the former and the latter. Moreover, from the perspective of changing circumstances in the world after September 11, 2001, it has become necessary to make “globalization and rationalization” and “security” compatible with each other for the future world. From this viewpoint, aerospace products will become increasingly important, because they are major components of these infrastructures.

It is necessary for effective transportation and security that the systemization and the integration of products and services should be the goal.

As the defense industries, it is necessary to establish not only a combat aircraft system itself but also a total air defense system that enables each defense element to operate efficiently and effectively for national defense and security by utilizing the latest information technology. Therefore, system integration and its technical elements must be developed to realize the ultimate needs of national defense and security effectively.

In the civil aircraft industry, MHI has expanded its business activities by selling its products to aircraft manufacturers such as Boeing Company and Bombardier Inc. In the future, MHI also intends to strengthen its business to make that business bigger, so as to sell its products directly to aircraft users who are the end users of the products. MHI has already opened the door towards achieving this goal through the introduction of the MH2000 in the helicopter field. MHI is seeking and taking opportunities to steadily enhance its technical capabilities towards being able to produce entire aircraft in the fixed wing aircraft field.

In the same way, MHI intends to increase its technical capability in the space industry towards achieving the integration of launch vehicles (rockets), seizing the major opportunity presented with the transfer of the H-IIA to the private sector. Further, in the utilization of space, namely the final purpose of launching rockets that serve only as a means of transportation, it is important that MHI develop space system-integrating technology such as space solar power systems, and satisfy various social needs such as supplying clean energy.

In order to realize true progress in the aerospace business, it is essential for MHI to strive in such a way that the systemization and the integration of its products support customers. This report introduces trends of aircraft and space products such as rocket vehicles that are major products of MHI’s aerospace business, with an overview of past, present, and future perspectives of the aerospace products. Some products and technologies are described in detail.

2. Progress of aircraft technology in Japan

Aircraft enterprises in Japan were revived after World War II to support U.S. Air Force aircraft maintenance. Then we learned the manufacturing methods and technology for post-war aircraft through licensed production for Japan Defense Agency. Based on that experience, the basis for designing and manufacturing our own civil aircraft has been established. Our business has grown to undertake the production of large components such as wings and fuselages for U.S. companies. And, our level has reached the stage where we developed the F-2 fighter in cooperation with the U.S. Nowadays, the large-scale civil aircraft market is dominated by two major aerospace powers in U.S. and Europe, while other foreign enterprises have recently spread participation more in this civil aircraft market by supplying aircraft subsystems and components. It is obvious that competition for production share is becoming very tight. That is why

MHI must extend its ability for designing and manufacturing in this aerospace fields.

2.1 Trends of MHI products (**Table 1**)

The full-scale aircraft business of MHI began with the licensed production of F-86F fighters, which was soon followed by the licensed production of F104J supersonic fighters in the 1960s. Through the domestic development of T-2 supersonic trainers and F-1 supersonic fighters in the 1970s, MHI subsequently gained expertise in the design of supersonic aircraft. MHI established its sole national position as a supersonic fighter manufacturer through the development of T-2CCV and the licensed production of F-4EJ and F-15J. F-2 (**Fig. 1**), which receiving technical evolution flight tests by JASDF, is being developed based on U.S. GD (present Lockheed Martin) F-16C by adding Japan's own technologies such as composite wing, phased array radar, and digital fly-by-wire. In the F-2 program, MHI has played the role of a total system integrator. Defense demands to be emphasized for the future include the creation of new products that accommodate the information RMA (Revolution in Military Affairs) and the improvement of fighter technology. More specifically, MHI intends to participate in total air defense systems as a whole including fighters, pilotless aircraft, and ground facilities, and to create new products. Additionally, from the perspective of improving fighter technology, it is important to challenge new technology such as stealth technology, flight control technology, and avionics integration technology aimed at improving operational efficiency.

In particular, in order to ensure any future overall defense system that performs joint operations, the effectiveness of such an element must be evaluated by simulations, with a clearly defined vision. Any future defense system cannot be defined without an adequate information system. Accordingly, MHI has established a new IT laboratory in Tokyo in order to demonstrate the concepts and the operational effectiveness of future overall defense systems by simulations, and define MHI proposals for future products. Using the IT laboratory, MHI conducts activities to make customer-oriented proposals, taking into account the opinions and the ideas of customers. Thus, MHI has taken the first step towards the creation of such a large-scale integrated system, taking advantage of its ability to integrate many activities for air, sea, land, and space. These activities are being completed with the participation of all the related divisions in MHI Nagoya Aerospace Systems Works.

In the field of civil aircraft in Japan, YS-11 was first developed in the late 1950s after World War II. In addition to participating in the development of YS-11, MHI also independently developed the multi-use double turboprop engine aircraft MU-2. This aircraft was capable of achieving short take-offs and landings, and flew at a high speed owing to its high wing loading, which was

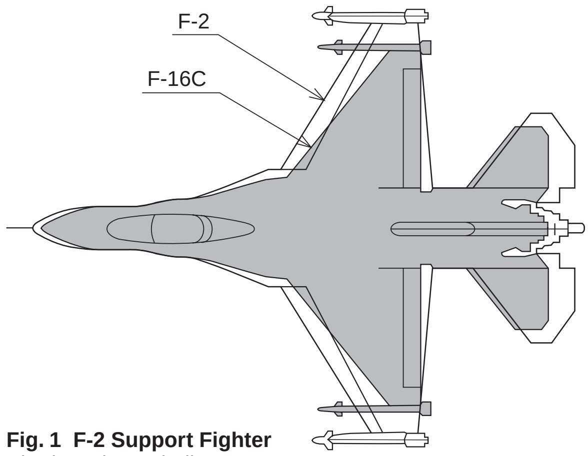


Fig. 1 F-2 Support Fighter
Shadowed area indicates F-16C.

superior to other competing aircraft at the time. A total of 765 MU-2 were produced and sold. Fifteen years later, MHI developed a compact business jet aircraft known as MU-300, which achieved high speed performance and low fuel consumption. This aircraft had a wing profile that was designed to maintain the required lift and prevent sudden increases in resistance, even at high Mach numbers. A total of 103 of MU-300 were produced. After that, some civil aircraft were planned. However, they were not produced because of the small size of the market and uncertainty of domestic demand. Due to such circumstances, MHI focused its efforts on designing and producing specific portions of airframes developed by overseas manufacturers under international joint development. Now, MHI is aiming to engage in the entire assembly of aircraft through accumulated experience in developing and manufacturing specific portions. At present, development of compact aircraft is being planned in a public-private partnership. MHI also strove to expand its share of the design and the production of the structural parts for large civil aircraft, mainly two-aisle passenger cabin type aircraft (B767 and B777), in cooperation with the Boeing Company. In the design and the production of regional aircraft including component installation, MHI also strove to improve design and manufacturing capability with shortened delivery times, and reduced costs through the adoption of concurrent engineering techniques in cooperation with Bombardier Inc. MHI also worked to strengthen its ability to acquire type certification based on structural analysis, strength tests, and reliability analysis for component installation. MHI also manufactures parts for aircraft built by Airbus Industrie, as a subcontractor. MHI must advance the development of technologies that strengthen its ability to gain advantages in competition, if the company is to successfully engage in the entire assembly of civil aircraft in the future.

The helicopter business of MHI began from the knockdown production of S-55 helicopters developed by the Sikorsky Aircraft Corporation for the Japan Coast Guard

Table 1 Major aerospace products of MHI and history of development

Year: 1960, 1965, 1970, 1975, 1980, 1985, 1990, 1995, 2000, 2005, 2010, 2015

Product		
[Aircraft]	A-330/340 Cargo door; A-320 Shroud box	Airbus project
Civil aircraft (developed through international joint cooperation)	DC-10 Tail cone; MD-11; 747 flap; B767-200; -300 Aft fuselage, door; B-777-200; -300 Aft fuselage, tail cone, door; B737-6,7,800 Inboard flap; High-efficiency next vehicle; Sonic cruiser	Transonic aircraft, composite design; Boeing Project
(development domestically in Japan)	Fuselage, cockpit YS-11 (mass production); YS-11	
(developed by MHI)	MU-2; MU-300; Compact aircraft (self-/jointly-developed)	
	GX Wing, center fuselage; DASH8- Fuselage, empennage; CRJ-700 Aft fuselage; BO-100 Wing	Bombardier project
Fixed wing aircraft for Japan Defense Agency (Aircraft built under license)	F-86F; F-104J; F-4EJ; F-15J,DJ	Acquisition of manufacturing technology
(Developed aircraft)	T-2; F-1; T-2CCV; F-2 support fighter; Aircraft succeeding F-4; Technology verification aircraft; F-4EJ improved type; F-15 modification for modernization	Supersonic aircraft technology; Digital fly-by-wire, composites; System integration
(Pilotless aircraft)	Pilotless aircraft (super high-altitude endurance type/tactical type, etc.)	Autonomous flight, network technology
Helicopter (Helicopter for civil use)	MH-2000; Future civil Helicopter; S-92	Enhancement of fundamental technology for helicopters; Improvement of product competitiveness; International joint development
(Helicopter for Japan Defense Agency)	S-55/H-19; HSS-2/2B; SH/UH-60J(A) Maritime patrol, Rescue, Utility; SH-60K maritime patrol helicopter; MH-53E; Next generation patrol helicopter	High-performance rotor; Ship landing assist system; Advanced helicopter combat direction system
[Space equipment] Rocket	N-Ⅰ Seven rockets; N-Ⅱ Eight rockets; H-Ⅰ Nine rockets; H-Ⅱ Seven rockets; H-ⅡA; H-ⅡA Robust type	Transference to civil enterprises, improvement of reliability, cost reduction, large-scale tank manufacturing technology
Space station	CAM; JEM; Operation by JEM; HTV	Needs for utilizing station
	SSPS (Space Solar Power System)	Use of solar energy such as SSPS
Space reentry vehicle	HOPE-X development; Development of RLV prototype	Weight reduction, maneuverability, and reentry technology











: License : Joint development(including partial subcontract) : Development for modification : Domestic development in 1953. After that, MHI produced helicopters continuously for Japan Defense Agency under a license contract with the company. Significantly, MHI developed the SH-60J, installing an automatic flight management system originally developed by MHI into the U.S. Navy SH-60B. Based on the success of the SH-60J, MHI expanded its helicopter business in such a way that UH-60J(A), a derivative of the SH-60J was adopted by the Ground, Maritime and Japan Air Self Defence Forces. Furthermore, MHI developed the shipboard maritime patrol helicopter SH-60K (**Fig. 2**). This helicopter has excellent hovering performance capability that is based on the use of all composite main rotor blades, a ship landing assist system, and an advanced helicopter combat direction system. A prototype of the SH-60K helicopter was delivered to Japan Defense Agency last year. MHI is striving to improve the maneuverability and the maintainability of these types of helicopters, as well as reduce vibration with the aim of developing future types of helicopter for Japan Defense Agency. In addition, MHI has developed a multi-purpose civil helicopter known as the MH2000, which has excellent safety features and low noise emissions, and has already begun its delivery to customers. MHI is also participating in an international cooperation development project that is aimed at developing a large S-92 helicopter through the teamwork of six countries. In this project, MHI has fully adopted the three-dimensional CAD (CATIA) approach in the development of helicopters as well.

The aircraft engine business of MHI started with the repair of gas turbine engines for U.S. Air Force after World War II. Then, MHI developed an original engine TS-1 for an observation helicopter for Japan Ground Self Defense Force. Using the accumulated technology applied in TS-1, MHI developed the MG5 engine for the MH2000, and also developed an engine controller known as the FADEC (Full-Authority Digital Electric Control) installed in the MG5 engine. At present, technology for mixed flow compressors is being accumulated as an extension of the technology used in centrifugal compressors, because mixed flow compressors are suitable for making medium-sized engines compact. In the area of large- and medium-sized civil aircraft engines, MHI participates in the production of the PW6000 engines of Pratt & Whitney (P&W) as a risk-sharing partner (7.5%), and is in charge of a combustor module which is a core portion. MHI has received orders for CF34-10 combustor cases from GE. Based on these experiences, MHI strives to become a partner on equal terms and increase the number of customers it serves. MHI was certified as a Full Repair Station for the PW4000 (94-inch type) by FAA (Federal Aviation Administration) in 2002 so that MHI can extend its repair business. MHI is now actively striving to secure more orders to repair airline engines such as the PW4000.

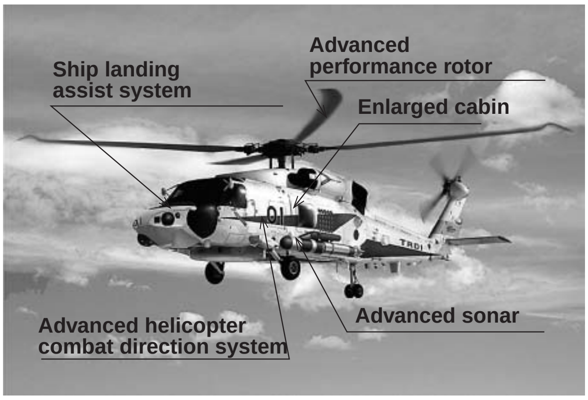


Fig.2 SH-60K shipboard maritime patrol helicopter
The figure shows an outline of the anti-submarine helicopter.

2.2 Trends of aerospace technology

There are two major needs for improving the performance of an aircraft as a system: improvements to the airframe itself and to the onboard systems.

In order to improve the function and performance of the airframe itself, it is necessary to increase the transport efficiency and operational effectiveness of the airframe. In order to increase the transport efficiency of the airframe, it is essential to increase the speed and reduce the weight of the airframe. One of the key technologies used to increase speed is the capability of designing an optimum aerodynamic profile through the use of CFD (Computational Fluid Dynamics). The key to reducing weight is the ability to effectively design and analyze composite structures. In order to improve operational effectiveness, it is necessary to improve the safety and the reliability of the airframe, and extend flight range. This can be done by promoting automation, decreasing pilot work load, and achieving unmanned control, as well as by developing innovative means of improving maneuverability. Flight control technology based on the effective use of computers is necessary to meet these needs. Such technologies are essential for highly integrated autonomous systems, and also serve as an information-connecting platform based on IT. Such technology can be evaluated through the use of flight simulations.

Improvements in the performance of onboard systems are necessary in order to improve mission effectiveness. Thus, it is necessary to focus on the development of cockpit-related systems that integrate internal and external information, since they provide information, support decision-making, and facilitate the pilot's action. These requirements can be satisfied effectively by integrating and improving the functions of avionics.

In order to succeed in the aircraft business, it is essential to develop, produce, and sell the best aircraft at a low price and within a short time, based on a firm understanding of the needs of the customer. Hence, MHI is moving ahead with the introduction of new technologies and improvements in production and support, with

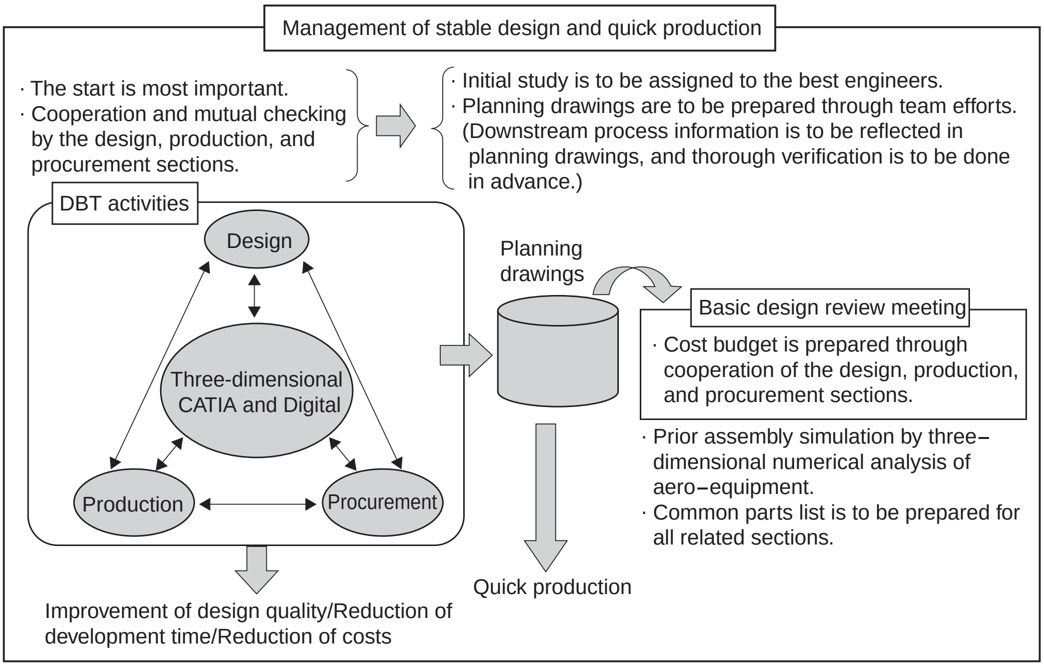


Fig. 3 Concurrent engineering The Figure presents an overview of the content of concurrent engineering by cooperation of design, production, and procurement.

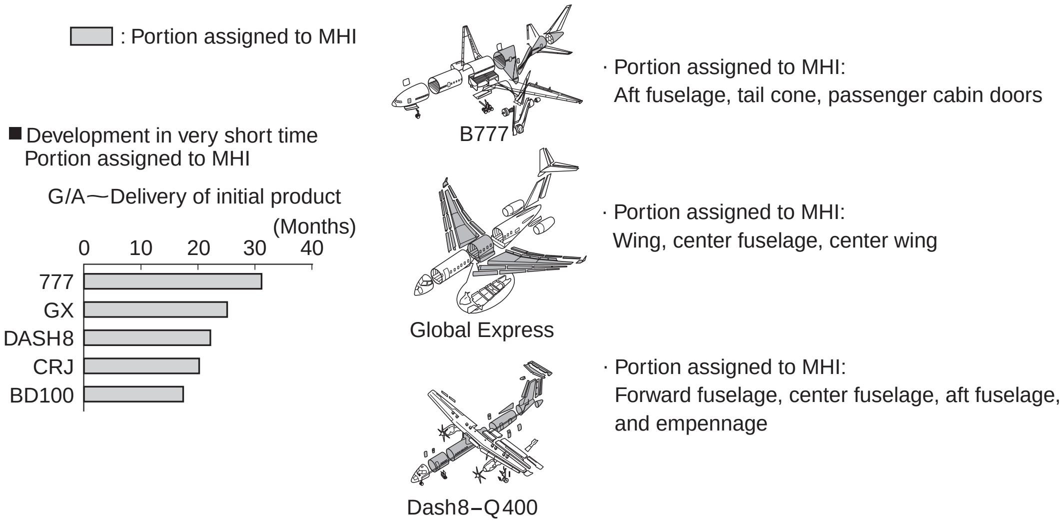


Fig. 4 Airframe portions assigned to MHI and development period
The Figure shows how development time has been shortened for each aircraft by concurrent engineering.

the aim of reducing the life cycle cost of an aircraft.

In addition, digital engineering is necessary in order to improve the efficiency of the aircraft production system, including both design and production. Actual digital engineering techniques, such as concurrent engineering and other methods described briefly below, have been actively used and applied in the development of aircraft recently.

2.2.1 Design

(1) Concurrent engineering

Concurrent engineering (C/E) and front-loading are new methods that are used to enhance engineering capability. In C/E, design and manufacturing data are integrated in a consistent manner, so that material purchase, design, and production work proceed in parallel under well coordinated lateral cooperation in order to reduce dead times due to reworking and to contribute to the reduction of development costs and periods (see **Figs. 3** and **4**). The powerful motive force behind C/E consists of three-dimensional design software as represented by CATIA. Such software applications are not only capable of preparing three-dimension drawings, but can also be used to analyze stresses, design parts and assemblies, design three-dimensional piping and wiring, as well as check for mutual interference and clearances between parts in a product assembly. The use of CATIA makes it possible to reflect manufacturing requirements in a design. For example, when designing and manufacturing a door, the accuracy of positioning for riveting can be improved by increasing the rigidity of the door

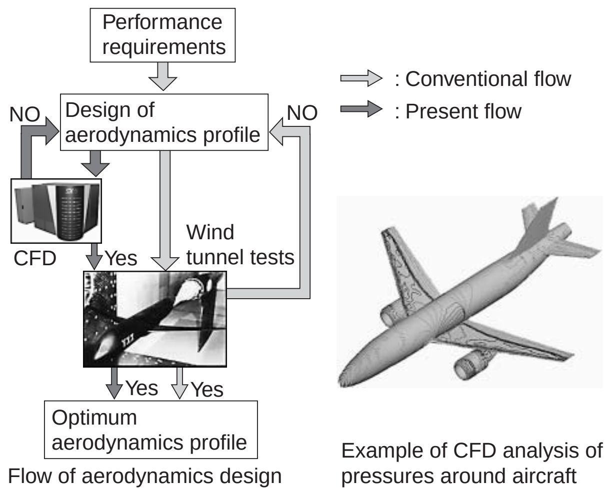


Fig. 5 Aerodynamic design: CFD analysis
Flowchart for obtaining optimum aerodynamic profile and an example of CFD analysis

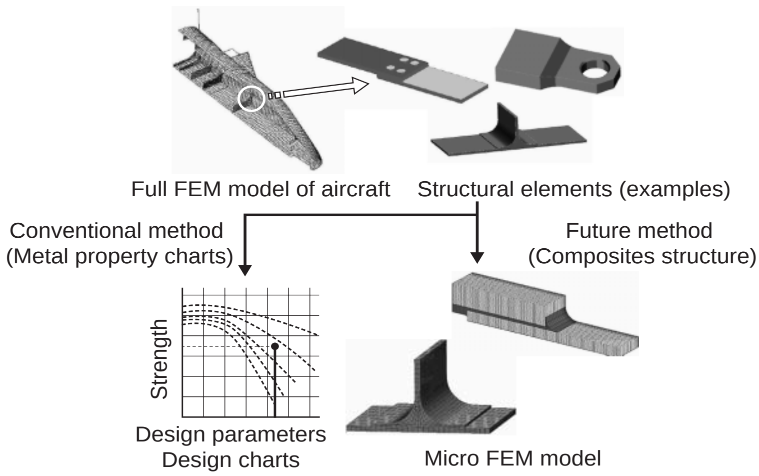


Fig. 6 Example of structural analysis of composites
The image shows an example of the structural analysis of composites using a micro model.

at the design stage, so that the manufacturing need to increase the rate of automatic riveting can be reflected in the design. Future full automation of the production of doors is intended to reduce manufacturing costs.

(2) Simulation

Simulation methods such as CFD (Computational Fluid Dynamics), structural analysis, and flight analysis are positively used for analysis and evaluation in all design phases. At present, these methods are also actively used in the product-proposing phase represented by studies performed in the IT laboratories. MHI intends to extend applications of simulation techniques throughout the overall life cycle of its products, considering such techniques to be an essential technology of digital engineering.

- Aerodynamic design: CFD

Formerly, in order to achieve high performance, wind tunnel tests were carried out in the design of aircraft using models based on drawings prepared at a desk. However, because wind tunnel tests consume much time and money, the number of profiles that can be evaluated is limited. Recently, the progress of computers has made it possible to obtain results based on the numerical analysis of fluid dynamics that are essentially the same as the results obtained by wind tunnel tests. In other words, CFD reduces the number of models and testing cases required for wind tunnel tests, which contributes to reducing the cost and the period of designing. In addition, optimization programs, which not only analyze fluid dynamics for a given profile but also create the best profile for a given set of requirements, have been developed as design tools. As a result, it has become possible to remarkably reduce design manpower (**Fig.5**).

- Composites: Structural analysis

In the strength analysis of aircraft structures mostly made of metals, the strength of each individual structural member is evaluated by inputting the load of the structural member derived from an FEM model of the entire structure into calculation formulas and design charts backed up by experience. On the other hand, in evaluating structures made of composites that have come to be used for primary structures recently, it has been clarified through the development of various products that there are limits to the simple extension of the conventional evaluation procedures used for metallic structures. It is not practical to obtain design charts only from elemental tests, because a great many design variables are required compared to metals. Consequently, it is necessary to establish a special method to analyze the strength of composites. Since the fracture of composites is often caused by internal damage such as delamination, the fracture mechanism has not yet been clarified precisely. However, it has become clear that the fracture process can be clarified to a certain extent by FEM analysis using microstructure models that can indicate differences between layers.

If the strength evaluation for general structures is carried out using micro FEM models previously verified in which design variables can be changed parametrically, it becomes possible to obtain results that are equivalent to conventional design charts. If a design tool could be practically developed that makes it possible to evaluate the strength of any composite automatically simply by inputting design variables and material properties, such a tool will become a strong support for designing the strength of composite structures (**Fig. 6**).

- Flight simulation

Recently, simulations have come to be widely used in research and development, based on a model and simulation concept, and are also being used for de-

Fig. 7 Flight simulation
An example view of flight simulation is shown here.

termining the specifications of a system. The usual aircraft simulator consists of a man-machine interface consisting of a cockpit, computer, and visual simulation system. Inputting the design data of an aircraft newly developed into the computer, the simulator analyzes data concerning the flight performance and characteristics obtained by simulated maneuvering, calculates loads on various maneuvering devices, and evaluates the human engineering of pilot interfaces. Due to recent advances in computer graphics technology, real images can be shown so that a pilot is able to evaluate various maneuvering factors and flight characteristics at high reality. As a result, computer graphics technology has become essential for the development of aircraft (**Fig. 7**).

(3)Integration and functional improvement of avionics

The first avionics systems consisted simply of an aggregation of individual devices. However, they were integrated by various subsystems and connected by multiple data buses. Data processing computers and man-machine interfaces have been integrated since the latter half of the 1980s. At present, the concept of the overall modularization of integrated devices and the unification of specifications is emerging. In the future, it is estimated that analog signal processing hardware and sensors will also be integrated into these avionics systems. As the function and performance of onboard avionics progress, displays in the cockpit will become larger, more multi-functional, and operate with many colors. Recently, new interfaces such as displays with touch sensors, HMD (Helmet Mounted Display), and voice information systems have been added, and automated functions such as an advising function for judgments based on an expert system have been introduced. MHI intends to improve the information network function and develop avionics and information systems that are capable of accommodating such an integrated service environment.

2.2.2 Manufacturing

In order to reduce the development and manufacturing costs of aircraft, CATIA should be used as a common data media for all activities such as design, airframe

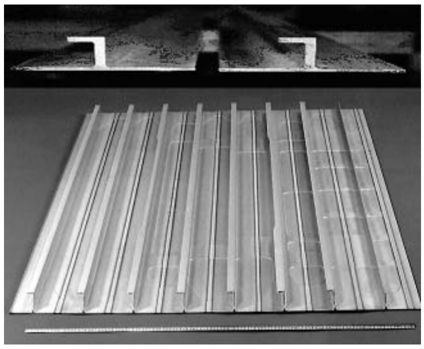


Fig. 8 View of an integral panel produced by FSW
The figure shows a picture of an integral panel produced by friction stir welding.

assembly and parts processing including design and production of jigs and tools. Parts manufacturing costs also must be further reduced through die-less forming such as peening forming, as well as fully automated hole-based assembly systems and integrated parts.

(1) Processing of metallic parts

Assembly costs comprise a comparatively high share of airframe production costs. Reducing the number of parts to be assembled is one of the most effective ways of reducing overall assembly costs. Accordingly, MHI has been accelerating the integration of parts by integral machining from a thick plate, casting, super plastic forming, diffusion bonding, and welding. The latest super high-speed machining is expected to improve efficiency and reduce costs of integral machining. Casting is being applied even to structural parts as a result of making progress in the size, accuracy, and strength. SPF has been used for fabricating the integrated inspection doors of Boeing aircraft to save cost by remarkably reducing the number of parts compared to conventional rivet assembly. MHI has been studying the application of Friction Stir Welding (FSW), which was developed in the United Kingdom, for aircraft. **Fig. 8** shows a prototype of an integral structure of skin and stringers.

Another effective cost-reducing technology is die-less manufacturing. The wing skin plate of the BD-100 business jet aircraft has been formed using a shot-peen forming method, without any dies. At present, MHI is also actively striving to develop a forming method that uses a flexible jig.

(2) Fabrication process of composites

Composite structures for aircraft have come to be used as a method of reducing costs, because the number and weight of the parts can be greatly reduced through co-cure process of composites. Co-cure process consists of first preform, individual laminated structural parts on each mold after heating slightly, and then integrating the preformed structural part with other preformed parts in a co-curing tool. The integrated assembly in the tool is then cured in an

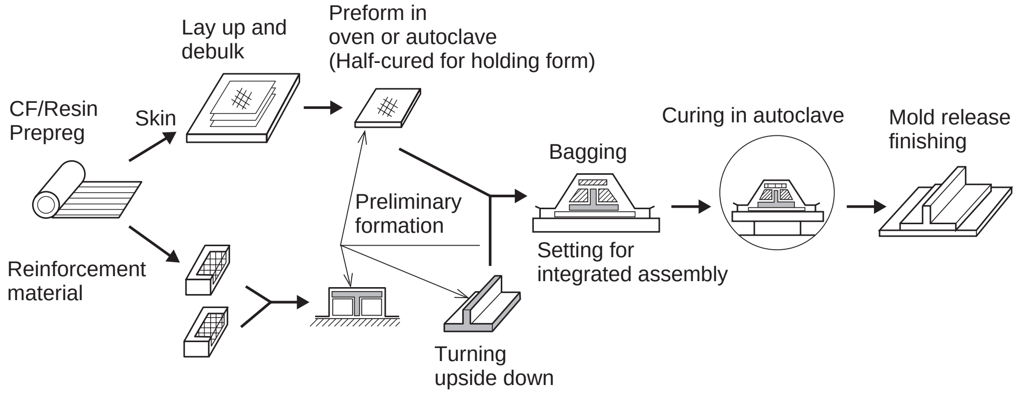


Fig. 9 Concept of co-cure process
A schematic flow diagram is shown here of the co-cure process for composites.

autoclave, as it is (**Fig. 9**). In order to apply the co-cure process to the large and complex wing of F-2, both methods for preventing internal defects and for measuring the pressure applied to complex portions of the structure were developed. The processing condition of the autoclave was optimized by monitoring its dielectric characteristics. As a result, it was possible to produce a co-cure wing box structure consisting of skin, ribs, frames, and caps.

The interstage section of the H-IIA launch vehicle, which is 4 m in diameter and 7 m in length, is also manufactured by molding in an autoclave, resulting in a 90% reduction in the number of parts. The prototype of the HOPE-X structure, with a 15 m long integral composite structure of the wings and fuselage, has been manufactured using low-temperature vacuum curing in an oven, instead of an autoclave (**Fig. 10**). A three-dimensional composite-forming method in which the preformed material is made of solid form fabric composed by RTM (Resin Transfer Molding) is expected as a future technology for improving the performance of composites. In addition, MHI is studying the development of new technologies in order to reduce the costs of large composite structures. These include such methods as molding composite by VaRTM (Vacuum Assisted Resin Transfer Molding) (**Fig. 11**), in which resin is impregnated into a woven fabric preform made of reinforced fiber under a vacuum, as well as the combination of ultraviolet- or electron beam-curing and fiber placement auto-lamination.

3. Progress of space technology

In the N rocket project started in line with the establishment of the National Space Development Agency of Japan (NASDA), MHI was assigned the task of developing the N-rocket and its launch. In the development of the LE-3 engine in Japan for the second stage, MHI developed a pipe-structured combustor constructed by noble metal-blazing and a pipe-structured nozzle assembled using electron beam welding and electric discharge machining, with technical guidance from Rocketdyne. These

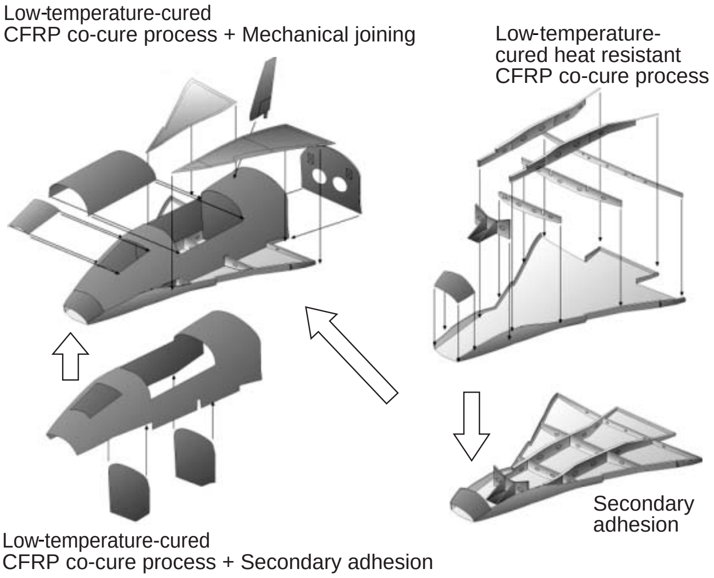


Fig. 10 Original structure of the prototype of HOPE–X

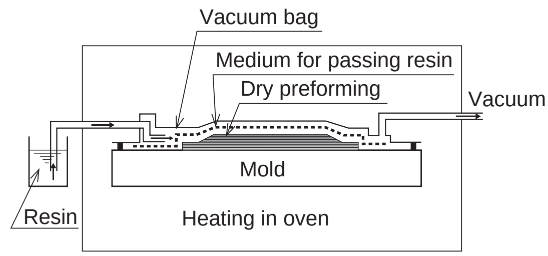


Fig. 11 VaRTM forming
The VaRTM forming method uses vacuum impregnation as a means of molding composites.

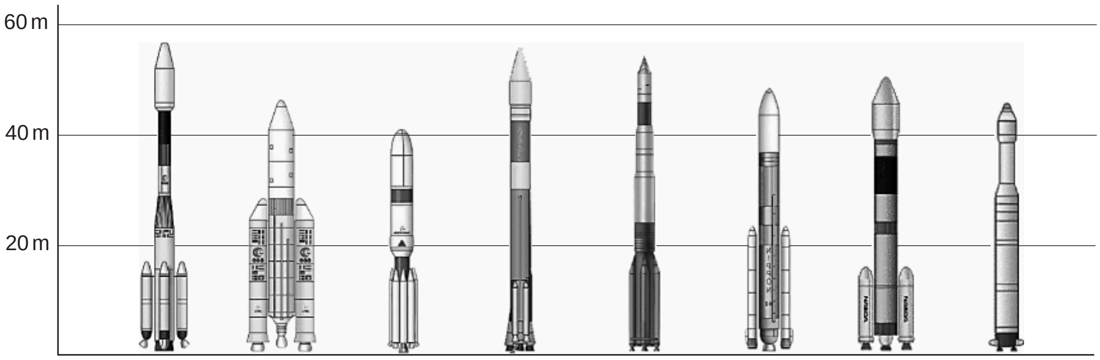
technologies have become the technical basis of current liquid fuel engines. After that, MHI undertook the development of liquefied oxygen and liquefied hydrogen fuel engines, which were completed as the LE-5 second stage engine, after overcoming all difficulties. The H-I launch vehicle equipped with the LE-5 engine was launched in 1986. Further improvements in performance were continued by Japanese domestic technology. In the first stage engine LE-7 for the H-II launch vehicle, MHI completed a two-stage combustion cycle system, which demonstrated that MHI had attained the highest levels of global rocket technology. MHI also strived to actively simplify the structure and remarkably reducing the number of components, aiming at the commercialization of rockets. However, the final launch of the H-II failed, due to failure of the LE-7 engine caused by cavitation of the hydrogen turbo pump. During the three years spent determining the cause and implementing measures to eliminate the problems found, the global satellite launch market changed with an excessive production of rockets, making it more difficult to proceed with commercialization. Nevertheless, MHI succeeded in the inaugural flight of the H-IIA launch vehicle in the summer of 2001, as a result of the overall review performed in design, manufacture, and quality assurance. In the future, providing for the transference of launch vehicles to civil business, MHI intends to concentrate its full power on achieving success in the production and marketing of launch services. In addition, MHI is also actively engaged in developing equipment for use in space other than rockets such as the Japanese Experimental Module (JEM), Centrifuge Accommodation Module (CAM), H-II Transfer Vehicles (HTV), space solar power system, and reusable vehicles related to the international space station, aiming at the future social demand in the 21st century.

3.1 Development of products

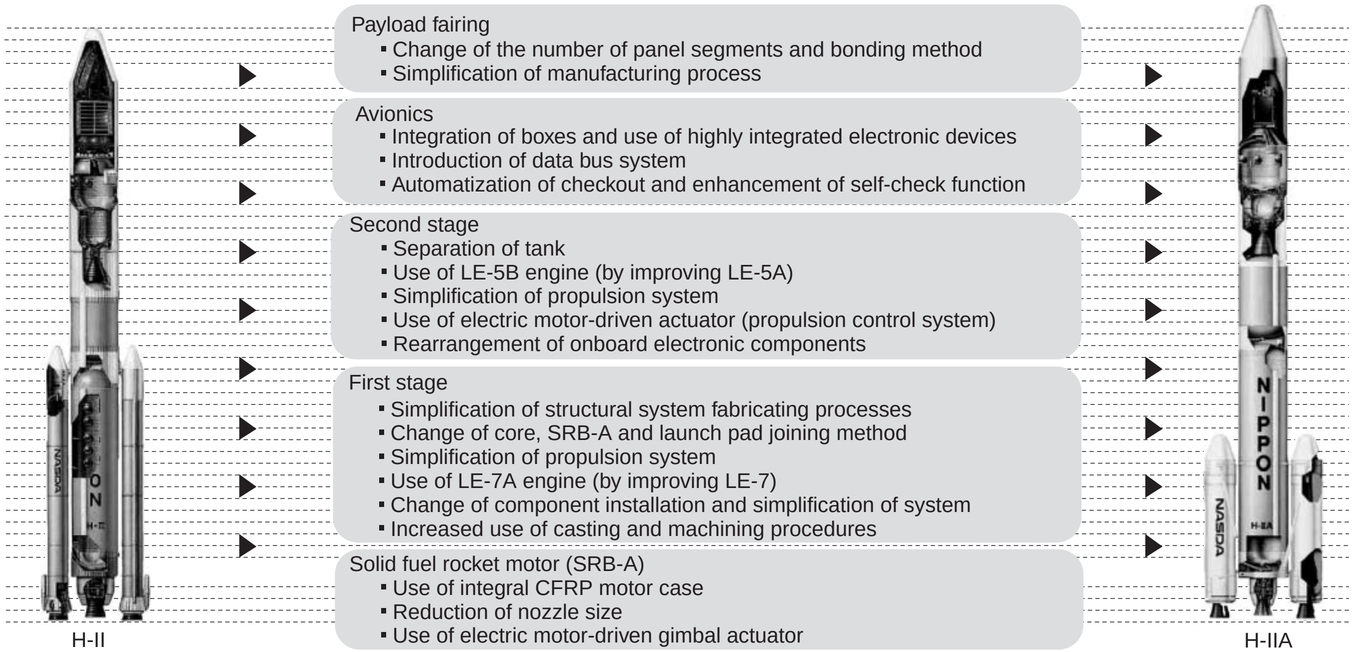
(1) Launch vehicles (rockets)

The No. 1 through No.4 standard-type H-IIA launch vehicles, each of which is capable of placing a satellite weighing about two tons into a geostationary orbit, achieved cost reductions and improvements in reliability through the adoption of various new technologies, towards the privatization of the rocket business. Various improvements have been applied to the H-IIA in order to simplify the construction and launching work involved. These range from improving the first and second stage engines through modifying even the ground facilities as well as construction of the fuselage, based on the technologies and experience gained through work on the H-II. It is no exaggeration to say that almost all components of the system have been improved. As a result, the cost of the H-IIA has been reduced to half that of the H-II, and its capability has now achieved a level that is fully competitive with other commercial launch vehicles in the world (**Table 2**). In the future, MHI intends to accelerate improvements of launch systems and development of enhanced types of launch vehicle, together with measures for the transference of the rocket business to civil enterprises, because launching capacity must be increased in order to participate effectively in the global rocket market.

Table 2 Launch vehicles (rockets) developed in Japan and overseas



Name of rocket	Arian IV	Arian V	Delta III	Atlas	Proton	H−Ⅱ	H−ⅡA	Chang Zheng (Long March)-3
Nationality	Europe		U.S.		Russia	Japan		China
Organization	ESA		MDC	USAF	IPPI	NASDA		CNSA
Total weight (t)	480.0	725	321.8	187	770.0	260	288.0	240.0
Launch to low orbit (t)	9.6	18	8.3	8.6	21	10.0	10.0	8.5
Launch to geostationary orbit (t)	4.5	6.8	3.8	3.8	4.9	4.0	4.1	2.6
Cost of launching (one hundred million yen)	120 to 150	180 to 216	90 to 108	108 to 126	108 to 118	170 to 190	75 to 85	54 to 66



(Courtesy of NASDA)

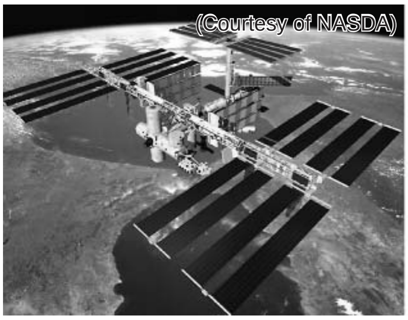
Fig.12 H-IIA improvement
The H-IIA launch vehicle was developed from the H-II with the following improvements.

● Outline of H-IIA launch vehicle (**Fig. 12**)

The H-IIA launch vehicle is equipped with a first stage LE-7A engine and a second stage LE-5B engine. In order to simplify and reduce the number of components used, the first oxygen tank of the propulsion system is pressurized using oxygen that is partially vaporized from liquefied oxygen, instead of cryogenic helium. Function testing work on the gimbal system has been simplified by the blow down hydraulic system in the first stage, and using an electric motor instead of a hydraulic system in the second stage. In the construction of the rocket, the integral tank with a common vacuum heat-insulated bulk head in the second stage of the H-II has been changed to individual tanks joined by a truss structure in the H-IIA. As a result, the tanks have become easier to assemble, and control of temperature and pressure (pressure difference between the tanks) has been simplified when propellant is charged at a cryogenic temperature. The weight of the interstage section that joins the first and second stages has been reduced by changing the material used from aluminum alloy to carbon fiber composites (CFRP). A data bus system is used in the electronic control avionics for controlling the rocket to simplify the connection between the onboard equipment and the ground facility when launching the rocket. In addition, the data bus system makes self-diagnostics of devices easier. As a result, it has been possible to raise reliability of the onboard equipment through self-diagnosis. On the other hand, the most difficult task in the development of N-1 through H-IIA launch vehicles was the development of the engines. However, these difficulties were overcome by the development and adoption of the two-stage combustion cycle system for the first stage LE-7A engine of the H-IIA system. The entire amount of liquefied hydrogen and a portion of the liquefied oxygen system are fed into the preliminary combustor called a pre-burner in order to generate a high-pressure combustion gas that drives both the liquefied oxygen and hydrogen turbo pumps. After driving both turbo pumps, the exhaust gas is then sent to the main combustor to be burned again and output as part of the thrust power. Dividing the combustion process into two distinct stages in this way has made it possible for the LE-7A engine to achieve a high level of efficiency. However, development of the engine has led to the need to continually overcome extremely severe conditions. These include the liquefied hydrogen, which is discharged at a temperature of -253°C and a pressure of 27 MPa from the turbo pump, coming into direct contact with the main combustor with a temperature of about 3 300°C and a pressure of 13 MPa, as well as the generation of extreme levels of mechanical and acoustic vibration at the time of combustion. Despite such conditions, however, each of these various difficulties were overcome one by one as the engine was completed. At present, MHI intends to accelerate its effort to commercialize H-IIA launch vehicle, e.g. further improvement of performance of the LE-7A engine through use of a long nozzle skirt for complete regeneration.

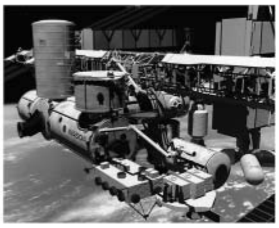
(2) Development of Japanese Experimental Module (JEM)

Tests on the Japanese Experimental Module



International space station

(Courtesy of NASDA)



Japanese Experimental Module (JEM) "Kibo"

Fig. 13 Development of international space station
Overall view of the international space station

Fig.14 Concept of reusable launch vehicle
An external view is shown here of an RLV (Reusable Launch Vehicle).

Table 3 Outline of reusable transportation vehicle for space

Requirements for maneuvering system		Main specifications of rocket body	
Payload capacity:	LEO 3 ton	Overall length:	29.0m
Probability of losing rocket body:	1/400	Gross weight:	98.0ton
Operating period during flight:	7 days	Propellant:	Liquefied oxygen/ liquefied hydrogen
Number of operating crew during flight:	100 man- day		

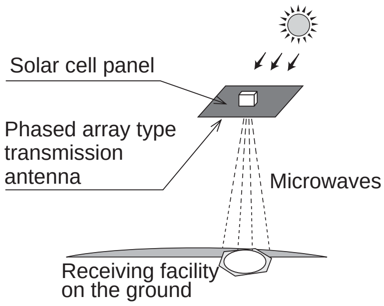
LEO: Low Earth Orbit

(**Fig. 13**) for the international space station have been completed with respect to the combination of the payload and the ground system at the Tsukuba Space Center of NASDA as the final test in Japan. The module will be transported to the Kennedy Space Center of NASA in 2003. It will be launched after it is prepared for launching by NASA at the launching site. In addition, MHI is developing CAM (Centrifuge Accommodation Modules), a centrifuge facility (for research in life science) to study the effects of the gravity environment on life, and an H-II Transfer Vehicle (HTV), one of the transporting vehicles to be used as a supplier vehicle for the space station.

(3) Reusable launch vehicles

MHI is studying the feasibility of utilizing reusable launch vehicles as a means of space transport, instead of conventional expendable vehicles. One of the aims of this study is to realize significant extensions in future space activity through substantial cost reductions, while at the same time achieving levels of safety and reliability that are equivalent to those of conventional aircraft.

Several concepts are being examined for reusable launch vehicles; vertical launching and horizontal landing type such as space shuttles, horizontal takeoff and landing type such as general aircraft, and vertical launching and landing type. **Fig. 14** shows an example of a horizontal takeoff and landing type, which is the first step toward the development of future manned space vehicles and fully reusable space vehicles. These studies, summarized in **Table 3**, aim at establishing design procedures for achieving high reliability and the acquisition of basic technologies for developing robust engines and lightweight structures, as well as service. In order to further reduce costs and improve reliability, MHI is studying the feasibility of reusable vehicles, based on the use of basic technologies such as composite structures, heat resistant material, and guidance and control technologies fostered through the development of the reentry vehicle, and rocket-propelling technology, cryogenic propellant management technology, and launch and service technology fostered through the development of the H series of rockets. MHI considers these efforts to be a program that will build the basis for future space transportation systems following vehicles currently in use.



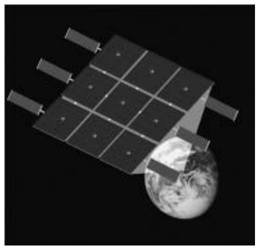


Illustration of system in orbit

Fig. 15 Space solar power system (SSPS)

(4) Space Solar Power System

The space solar power system (SSPS) is a system that sends electric power generated by solar power generation to the ground via microwaves that are received by a microwave-receiving facility on the ground, and which are then converted into electric power (**Fig. 15**). The generation of solar power in space will achieve a generating efficiency that is ten times higher than that possible on the ground, because it is not affected by day and night, or even by weather. It is a clean source of energy that does not consume any fossil fuels, thereby making an ideal means of coping with global warming. In order to send the space generated electric power to Japan, it is necessary to build a power station in space in a geostationary orbit (orbital altitude: 36 000 km) close to Japan. In order to realize the potential of power generation in space and power transmission facilities, a wide range of technologies such as power transmission control using microwaves, power receiving facilities on the ground, and low-cost transport of materials from the ground to space are required. Accordingly, MHI is currently carrying out research and development into each of these areas. Fig. 15 shows an illustration of a large scale SSPS in orbit. The capacity of the space power station in this case is several hundred thousands to one million KW, while the diameter of the power transmission antenna is several hundreds to one thousand meters, and the diameter of the space solar power-receiving facility on the ground is several kilometers. MHI is planning to demonstrate a solar power generation in space with a technical verification satellite and a pilot plant for the verification study of these technologies, with the aim of realizing a practical solar power station. In order to establish a full-scale system, it is essential to develop effective space transportation systems. Hence, further activities in the development and the implementation of space transportation systems, MHI's strength, are expected to expand even more in the future.

4. Conclusion

The aerospace business is a fundamental business, which supports "Transportation systems" and "Defense systems" fields that MHI deems even more important in the future. MHI intends to strive to advance and expand its own technologies for designing and manufacturing aircraft and rockets, to support this business activity. The authors would like to extend their sincere appreciation for all the guidance and encouragement being offered now and in the future to MHI in these endeavors.

AEROSPACE HEADQUARTERS

Managing Director,
General Manager,
Aerospace Headquarters

Junichi Maezawa

Minoru Kobayashi