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PREFACE

This issue of the Journal of Space Technology and Science is dedicated to the subject of space tourism.

Space tourism has long been a dream of humankind, but it still remains a dream. However, the fundamental technology required for space tourism is available, so that, if it is well conceived in terms of engineering and economy, it will be realized as a practical step of the next generation of space activities. This is the motivation for the space tourism study undertaken by the Japanese Rocket Society. The first paper, introducing the context of the study and the general approach, was originally drafted by myself for the Society, and used as material for discussion at the Space Tourism Study Conference held as part of the 1993 JRS Annual Meeting at Gakushi-kaikan, Tokyo, April 14, 1993.

This special issue features the second paper and the four papers that follow it, which are based on presentations and discussions by the panel of the conference. The second paper is a revision of a presentation made by Patrick Collins to supplement the first paper and provide the audience and panelists with background information on space tourism, emphasizing its practical aspects. It is the most important opinion of the paper that space tourism will be realized only if it is economically feasible; otherwise it will remain a dream forever.

Different from usual conferences, the panel was the main part of the conference. As its moderator, I wanted to hear the views of specialists of various fields concerned with a practical approach to space tourism study. Fortunately the following four specialists accepted the JRS's invitation to join the panel.

Genyo MITARAI	: Space medicine
Yoshihiro KYOTANI	: Business
Tsuruo TORIKAI	: Transportation
Toyohiro AKIYAMA	: Pleasure of spaceflight

In this list, the specialized field is specified for each panelist. The first half of the two-hour panel was for presentations by the specialists in this order, and the remaining half was for discussion including questions and answers. On editing the opinions and discussions, I did not write an agenda of the meeting which recorded all the proceedings as they took place, but summarized them in a paper for each specialist on the panel as included in this special issue. I should explain that the speech of each panelist is summarized so briefly that only the essence of their opinions and discussions are included here. Thus, any errors or misunderstanding are my responsibility, although each paper was reviewed by the original speaker.

The last paper was presented by myself at the 10th IAA Man in Space Symposium held in Tokyo, in the same month that the JRS meeting was held. Since the ideas expressed in it share a common interest in these topics, I decided to include it in this issue. As stated in the paper, I hope that the study of space tourism can revitalize research activities of related fields of spaceflight.

ACKNOWLEDGEMENTS

In addition to the panelists of the panel, I am grateful to the following people. Before starting this study on space tourism, I was encouraged by JRS President, Ryojiro AKIBA, who also gave me a the chance to participate in the 10th IAA Man in Space Symposium. The JRS Board of Directors arranged the participation of the Space Tourism Conference at the 1993 JRS Annual Meeting. JRS director Kuninori UESUGI played the role of General Chairman of the Conference. Secretary of JRS Committee for Academic Activities and Editor-in-Chief of JSTS, Yoshiaki OHKAMI made this Conference most fruitful.

Finally, I have to thank Patrick Q. Collins for his enthusiasm for space tourism, and his assistance in preparing English manuscripts of the papers for this volume, which gave this issue a good shape and high spirits.

Guest Editor
Makoto Nagatomo
JRS Vice- President
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June 1, 1993

ON JRS SPACE TOURISM STUDY PROGRAM*

Makoto NAGATOMO
for
JRS Committee for Academic Activities

1. Introduction

Space activities are considered to provide people with futuristic expectations and dreams of new frontiers. But on the contrary, the reality of space activities is facing a slowdown of national projects in the former Soviet Union and even in the United States. Generally in the world it is difficult to continue ongoing space projects and to extend space commercialization due to financial reasons. Vague expectations and dreams for the future are not enough to justify government funding to continue space activities further.

2. Background

It was unfortunate for International Space Year (1992) that two major rocket development projects, H-II and M-V were both delayed, and consequently all satellite projects depending on these vehicles had to be postponed. These facts seemed to give evidence of some difficulty that Japanese space activities faced after catching up quickly with advanced nations in the past.

However, the general characteristics of these troubles that caused the delays are technical and happened to take place coincidentally. Thus, the present situation of Japanese space technology development is considered to be favorable in the long term. What is more to be concerned about is the lack of a global perspective of space development, and the loss of power to steer the general direction of space activities.

The space programs of the Soviet Union and United States were planned and implemented as scientific and military projects for national prestige, and related technology development has been the responsibility of government agencies. This pattern of organization also generally prevails in other nations. As a result, space technology has been developed in order to send men to the moon and to explore the entire solar system with scientific probes. The future of this achievement would be followed by a manned Mars flight in the near future.

As seen in the past examples of the aircraft and electronics industries, it is important that such advanced technology should be transferred to civilian sectors as soon as possible, so that industry can commercialize it for civilian space projects. In the sixties in the United States, commercial utilization of space was widely discussed as an opportunity for the post-Apollo space effort. However, among various fields considered, including space factories and space tourism, only communication and broadcasting satellites have been commercialized, and these are limited to the information industry, although such public-use satellites as navigational, meteorological and earth-observation satellites are also included in this category. Accordingly, it is believed that only the information industry can afford the high price of launching satellites.

The current trend of commercial rocket development in the world focuses on competitiveness within a narrow price difference between organizations to meet the demand of the existing satellites business, which increases cost-effectiveness by increasing the capacity and performance of each satellite without increasing the mass, by using high technology. This sort of effort to develop satellite technology would not increase the demand of space transportation but is effective to miniaturize the payload. Such a relation between the present-day rocket and satellite businesses excludes future progress of general space activities due to the high price policy.

3. Perspective of Rocket Research

The Japanese Rocket Society was founded by the Japanese rocket pioneers in 1956 to conduct an experimental study of rockoons for sounding the high altitude atmosphere. With

* Prepared for Japanese Rocket Society (JRS) on September, 1992.

advances in space technology and science, its activities have expanded to a broad extent to cover related subjects. At present, thirty-five years after the first artificial satellite Sputnik, we are now facing a new age of rocket research for the next century, while the future of satellite communication is investigated by the concerned business community.

Thus, we would like to focus our effort on the rocket vehicles to be used in connection with future space programs. As discussed above, one direction of research should be a realistic approach to low cost space transportation with special emphasis on practical aspects to meet the potential demands of prospective commercial customers. The other direction of research is the extension of past rocket research that pursued the highest performance in terms of delta V at the sacrifice of economic performance. This type of rocket will be necessary for development of the new space frontier such as Mars and the Moon, and will be featured by government procurement.

The exploration of the space frontier will be funded and managed by governments, which prefer dedicated mission planning including rocket vehicles. Thus, we will choose the low cost and mass transportation to space for public use as our study subject. Space industrialization involving solar power satellites and space factories, and space tourism represent prospective customers of this type of transportation system.

From the standpoint of rocket design, space tourism will give stricter but more definite targets of development than space industrialization, because space tourism is featured by manned spaceflight, while the main payloads of space industrialization would be cargo which can not be well defined at this time. As shown by the history of aircraft design, most cargo vehicles have been modified versions of passenger vehicles. Accordingly, passenger rockets are likely to be converted to carry cargo for space industrialization. This is the reason for this committee to choose rocket research for space tourism. We will now study the future of space vehicles in the context of space tourism.

4. Space tourism study

Space tourism has long been a dream of many people. Probably they would be willing to pay for the dream, if it became reality. This is the fundamental demand that could provide the tourism industry with a much greater market than conventional space projects. To meet the demand, we have to solve complicated problems of different disciplines interacting with each other. Following are four disciplinary approaches proposed for space tourism.

4.1. Medical assurance of spaceflight for the general public.

At present, selection of astronaut candidates is based on medical standards for aircraft pilots, so that the requirements are very strict. Is it necessary for tourist passengers to satisfy the same standards ? If not, a more difficult design standard than the present one will be applied to rocket vehicles to accept the looser medical standard for passengers. It is suggested that machines used for attractions in playlands should be referred to indicate acceptable levels of acceleration and motion for space vehicles. The length of a space flight may also be an important factor in defining the early space travel.

4.2. Space tourism should be a commercial activity based on a sound demand and supply relationship.

Experienced business practice will be required to start this business. We should learn from the failure of the first space travel project planned by Space Expeditions with the Phoenix rocket. An orbital hotel has also been conceptualized to offer a variety of services to space tourists, but it cannot be operated alone. If a project plan is practical and definite in respect of not only the technical but also the business point of view, it will interest prospective investors, who would respond by suggesting what else is required. It is most desirable that some business group should join this study, probably indirectly if they are serious about it.

4.3. Standards of transportation systems.

Rocket vehicles to be used for space tourism should be designed as transportation systems. This is the main difference of these vehicles from conventional space launch vehicles which are basically designed and operated as ammunition systems. To specify the new characteristics, design and operation standards of transportation systems for space will be required. To simplify the study guideline, the transporters will operate only single stage vehicles, which will be called passenger vehicles here. Such procedures as testing payloads before flight, and use of explosives for routine operations should be precluded from vehicle design. Some precursors like DC-X and Phoenix can be considered as reference systems.

4.4. Passenger services should be studied in more practical detail.

Experience of weightless condition and earth observation will be the main purposes of space tourism. The pleasure of space tours will depend on how passengers can enjoy these two features presented by each passenger vehicle and its flight plan. It is desirable to prepare candidate packages of travel plans and passenger services at various levels of provision.

5. Guideline 1: Phasing

It is important for such a study to be practical as well as to be fantastic enough to attract people who are interested in the space dream. For this purpose and to avoid misunderstandings between the different disciplinary groups, the following guideline is prepared, which specifies the phases of evolution of space tourism.

Phase 0: Suborbital flight

In this phase, passengers will make a suborbital flight for several tens of minutes. The vehicles will not need to orbit the earth, so the performance requirements will be moderate. However, the services will not be very satisfactory compared with orbital flight. The operational complexity of the vehicles will not be much different from orbital flight, except for taking off and landing within a special range.

Phase 1: Minimum space tour in orbit.

The minimum orbital flight is to circle the earth one time and land at the launch site, as Gagarin made the first manned spaceflight in 1961. The vehicles to be used here are required to have higher performance than ones used for Phase 0. Once a vehicle acquires orbital velocity, it can continue easily to orbit a few more times. Constraints on increasing the time period in orbit will be the physical condition of passengers and the condition of landing at the launch site when it returns to the earth. For example, a two-orbit flight of 3 hours will be a reference trip mode.

Phase 2: 24 hours in space

Considering that in past cases, space sickness did not grow serious in the first 24 hours, and revisiting the favorable condition for landing at the launch site, 24 hours-in-space travel will be the next longer phase. In this phase, the vehicles will need to be provided with facilities for meals and toilets. Larger size of windows and cabin space will be required for accommodation of passengers for longer periods in space. Emergency return capability will have to be considered in the flight plan.

Phase 3: Longer stay in space

It was reported that most astronauts recovered from space sickness after staying for a week in space, and could work more comfortably later. If this is also for space tourists, there is a possibility to stay longer to fully enjoy spaceflight. In this case, the vehicles will be used for transportation only, and hotel accommodation will be necessary.

It is suggested here to use Phase 1 as the reference tour for this study. Thus, the following scenario of a complete tour cycle can be assumed as a baseline.

6. Guideline 2: A basic tour model

The basic idea of this tour model is a group tour, for which four procedural items are given:

Call for participation;

1. Basically tourists join a group tour which includes a spaceflight.
2. One tour group corresponds to the passengers for one space flight.
3. A caution about health requirements similar to that given at attractions in playlands will be announced.

General tour;

1. Each group tour includes travel to the launch site.
2. It will be desirable for launch sites or spaceports to be attached to major playlands where the attraction facilities can be used to check health condition, and especially the endurance of each passenger for spaceflight.
3. Only those satisfying the health conditions will be qualified to join the spaceflight.

Spaceflight;

1. Spaceflight should be considered to be one attraction of the playland.
2. Boarding procedure should be similar to that of airline services.
3. Flight frequency should be two flights in a day.
4. Lift-off and landing will be one of the events of the playland.

Fare rule;

1. Total price of the tour will include spaceflight fare
2. Tourists who are found to be unqualified will be refunded for cancellation of their spaceflights.

7. Study Approach and Organizations

Study will be conducted independently by the four specialized fields, according to the guideline shown above. Study objectives of the first phase will be as follows for each specialized field.

Space Medicine:

To make suggestions on the medical requirements for vehicle design required for space tourism, and for passenger handling procedures.

Business Opportunity:

To develop preliminary information and data which are expected to be requested by prospective business organizations. For example;

1. To show typical relations between performance characteristics of candidate carrier vehicles and required investments, and
2. To participate in market research activities to be conducted by interested organizations.

Transportation:

To materialize candidate vehicles from technical standpoints such as:

1. Investigation of available data on candidate vehicles,
2. Identification of functional requirements, transportation design requirements and operation standards,
3. Conceptual design of reference vehicles, and
4. Identification of interactive requirements with other specialized fields.

Passenger Service :

To clarify sales points of space tourism, and design requirements for passenger vehicles, such as:

1. Define pleasures of spaceflight,

2. Estimation of satisfaction of passengers with progress of the Phasing of space tours,
3. Impacts of tour purposes on vehicles' design, and
4. Development of scenario of the first phase "group package tour".

The Japanese Rocket Society can support this study only partially, focusing on the transportation field. For this purpose, it has set up a reseach committee dedicated to study Transportation. The committee members will be from JRS corporate members on a voluntary basis. The chairman will be Mr. Koki ISOZAKI of Kawasaki Heavy Industry Ltd. The committee is planning to issue its first report by the end of fiscal 1993, that is, March 1994.

Study groups of other specialized fields are expected to build up with progress of the Transpotation committee's activities. Tentatively, Prof. Genyo MITARAI and Dr. Patrick Collins will be contact points for the fields of Space Medicine and Passenger Service, respectively. JRS encourages the members to work together with other societies and organizations.

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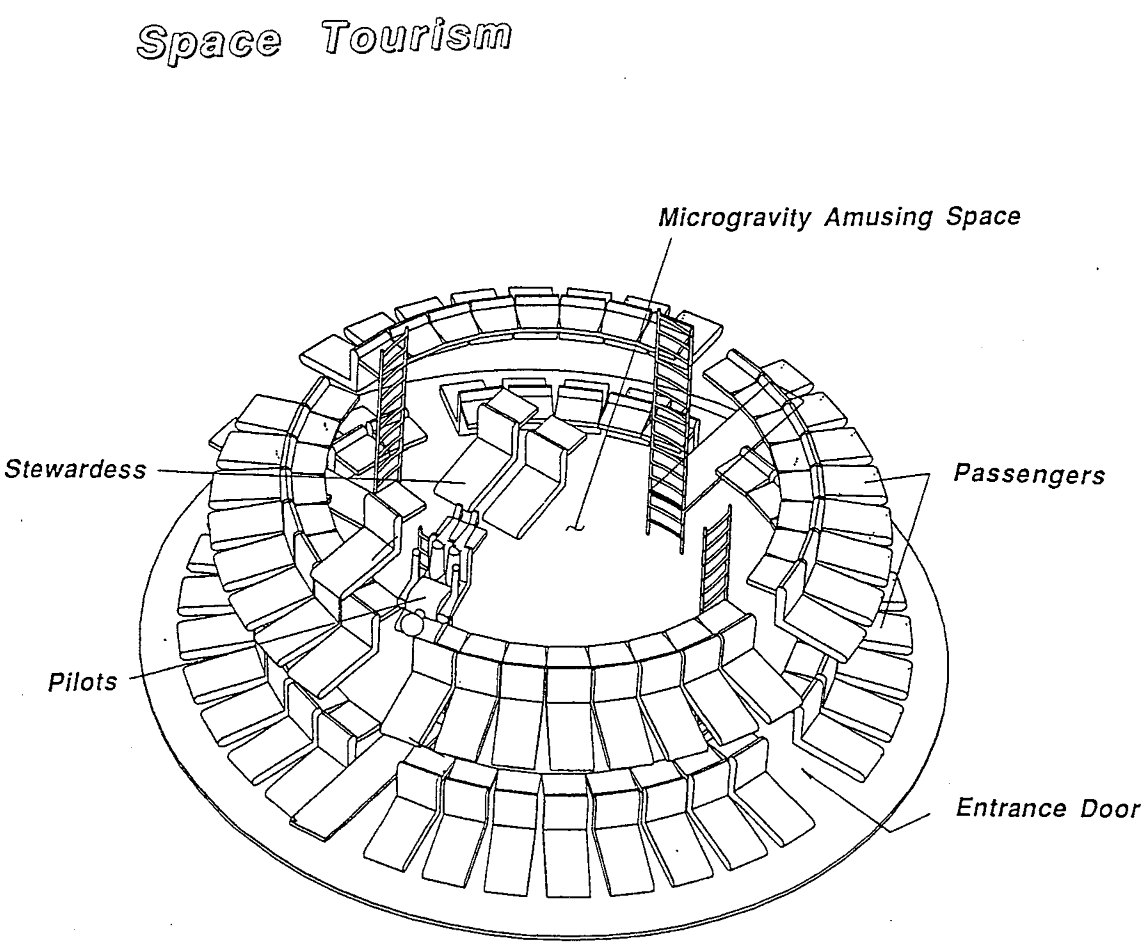

A plan of passenger seat arrangement for space vehicles to be used for space tour.
(Prepared for the JRS Space Tourism Study Conference by Kawasaki Heavy Industry Ltd.)

TOWARDS COMMERCIAL SPACE TRAVEL

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1 Introduction

A good reason for studying the subject of commercial space travel is because most people, when asked, say that they would like to take a flight to orbit. Normal commercial industries, when they discover a service that is apparently so popular with the public, make considerable efforts to commercialize it. However, to date, this desire has had little influence on the space industry, which performs almost exclusively government activities.

Many people would like to experience space travel for various reasons. Since the early days of science fiction in the 1930s, the image of space flight as adventurous and exciting has played a growing role in popular culture. Furthermore, those who have been lucky enough to visit space have all confirmed that it is a highly enjoyable experience. The view of Earth and the stars is spectacular, and the experience of living in "zero gravity" is fascinating. The first American woman to visit space, Sally Ride, said simply that it was the greatest fun of her life.

Of course the actual demand for flights to orbit, if these become commercially available, will depend both on their price and on the details of the "offering". Thus, in order to determine the commercial potential of space travel, research is required both on the technological possibilities of reusable passenger-carrying spacecraft and orbital accommodation, and on the economics of operating a commercial service, including market research.

2 The role of government

Spacecraft engineering design is related to aircraft technology, as a result of which the term "aerospace industry" has been coined. However, the development of the space industry to date has been unlike the historical evolution of the aviation industry, notably in that the roles played by government and private industry have been different.

Although government departments, particularly the military services, played very important roles in the development of flight, governments did not establish monopoly organisations to perform aircraft flights "on behalf of the public". The fact that this occurred in the case of the space industry, initially in the USA and subsequently in Europe, Japan and elsewhere, can be seen as a result of the Cold War, and in particular of the challenge of Sputnik and Yuri Gagarin's orbital flight, which stimulated the USA to respond in kind by performing government-sponsored "space projects".

Although aviation research centres were established in many countries, these did not generally have manpower as great as or greater than the companies to which they gave contracts. The USA's Apollo Project was a unique Cold War project which created a widespread popular perception that space activities should be performed by central government organisations. This idea was apparently widely accepted for several decades in the USA, although it is contrary to that country's fundamental ideology. This acceptance was perhaps partly due to the unique aura of space and to the rhetoric of the government-funded space industry which has long claimed that they are "opening the space frontier for humankind".

Nevil Shute, the chief engineer on the very successful British "R100" commercial airship project in the 1920s, described particularly clearly some of the disadvantages of government carrying out advanced technology vehicle development projects (1). The "R101" was a parallel government project with much greater funding than the R100. Not only was the R101's performance very poor, but it crashed disastrously, killing nearly everyone on board. The British government then scrapped the R100, in a further non-commercial decision rather similar to the US government's later decision to scrap the Saturn 5 rocket and Apollo project hardware.

The recent evolution of the US/international space station project is an interesting case in point. Proposed initially to provide scientific research facilities in orbit, the project was of considerable interest to wide sectors of the engineering and scientific communities. However, as the cost mounted progressively to many times the cost of the 1970s Skylab project, and as the legal regime covering operations on board became progressively more complex, almost every scientific and engineering group has withdrawn their support. The current proposal is that the station will provide facilities for the agencies which build it, which is a travesty of the original purpose, and is not surprisingly of limited interest to the politicians who must justify such large expenditure to the public.

Government organisations' objectives and modes of operation are necessarily different from those of private comanies. It might be said that whereas companies are entrepreneurial, government organisations are "procedural", since they must be able to show to the public that their actions are in accordance with established rules. For this reason there are certain things that governments cannot do effectively. Commercial innovation is one of these, and this is required in full measure in order to develop popular space travel.

This difference can perhaps be further illustrated by considering what might be the result if the head of a national air force were asked what it would cost to provide tourist flights to a certain destination. Because they operate a variety of different aircraft it might be thought that an air force could do this. But the way in which an air force operates is completely different from that of a commercial air travel company, and so their estimates would have almost no relation to the actual costs of a commercial company.

Although commercial space travel is not an appropriate activity for government organisations, helping the private sector in various ways to develop the capabilities necessary to create a new and profitable industry is one of the traditional roles of government in every advanced country. In particular, governments in many countries played a major role over several decades in the development of aviation into a commercial industry, and they continue to do so, both directly and indirectly.

Consequently, determining the correct roles for government and private organisations in the development of this field will be very important to its success (2), and may be of considerable economic significance if the commercial space travel industry grows as has been suggested (3). 1992, International Space Year, was the 35th year of the space industry (measured from the first satellite launch in 1957), which is half the traditional western life-span of "three score years and ten". Thus 1993, the start of the "second half", is perhaps an appropriate date for starting a new approach to space development.

3 Perestroika in the space industry

With the end of the cold war forcing the restructuring of the aerospace industry it might be said that we are seeing the beginning of "perestroika in the space industry". Over the decades of the cold war the aerospace industry has developed astonishing technological capabilities. It would be of potentially enormous economic benefit if this could be channelled into commercially valuable activities, rather than allowed to go to waste.

One sign of "perestroika" in the space industry is the recently announced joint venture by Lockheed and Krunichev to market the low-cost Proton launch vehicle. Although western governments are trying to protect the markets for their higher-cost launch vehicles, this development should put pressure on western makers of high-cost expendable rockets to consider developing low-cost reusable vehicles.

Another sign that the space industry is at last beginning to live up to aviation's example was the 1990 flight of Tokyo Broadcasting Service (TBS) journalist, Akiyama Toyohiro, to the orbiting space station, MIR. This achieved a significant place in the history of humans' expansion into space. As well as being the first Japanese, and the first journalist to visit space, Akiyama-san's flight was the first commercial space flight by someone outside the space industry. His flight was also strikingly similar to the many pioneering flights in the early days of aviation sponsored by newspaper companies, primarily for the purposes of publicity.

As an example, the Mainichi Shimbun company (which today is the parent company of TBS) and the Asahi Shimbun company competed continuously through the 1920s and 30s, sponsoring international competitions, such as for the first flight across the Pacific ocean, and long distance flights. For example the 1937 flight of the "Kamikaze-go" from Tokyo to London was sponsored by the Asahi Shimbun company, while in 1939 the "Nippon-go" made an eastward flight around the world, visiting 30 countries, sponsored by the Mainichi Shimbun. These and similar flights, such as Lindbergh's transatlantic flight, that led to the "Lindbergh boom" in US domestic aviation, played a major role in popularizing passenger flight, by demonstrating that aviation technology was mature enough to provide safe passenger operations.

The second such commercial space flight project, the flight of the British Helen Sharman to MIR in 1991, was similar in principle to Akiyama-san's flight, except that it was commercially unsuccessful, leading to a substantial loss on the part of the sponsors. But this is also part of business; investments can lead to losses as well as to profits. After the recent "bubble economy" many companies in Japan are facing unprecedented losses caused by misdirected investment. A small fraction of these losses would be sufficient to pay for the development of a space tourism business.

As and when reusable commercial passenger-carrying launch vehicles are developed, they will surely receive a high level of publicity. For this reason they will be very good vehicles for commercial publicity, and it seems probable that there will be many sponsored space flights emulating the early days of commercial flight. Such a pattern of development in the space industry could well have similar benefits for the industry's commercialisation.

4 Commercialisation

However, the development of reusable launch vehicles, which is needed both to reduce launch costs and to increase their reliability to the level of aircraft, faces a problem of commercial justification. The present day launch market is very small; a few tens of satellites per year. Consequently a single reusable launch vehicle that could fly even once per week, would be able to launch all of these (although due to political interference in the market, this would be unlikely). Unfortunately there is no good prospect that the demand for satellites will grow very much as the price of launch falls. Indeed, such markets as telecommunications and broadcasting seem likely to shrink under competition from more cost-effective terrestrial systems such as optical fiber cables and cellular telephone networks.

Consequently in order to be able to recover the development costs of reusable launch vehicles, the space industry needs a new, much larger market, that would require tens of launches per day. If commercial space travel could become popular enough to reach a scale of the order of one million passengers per year, it could pay for the development of low cost launch vehicles.

	Wide-bodied jet	Passenger launch vehicle
Production run	1000	50
Price (billion Yen)	20	100
Flights per year	720	300
Lifetime (years)	20	10
Amortization* (million Yen)	4.4	43
Fuel per flight (million Yen)	2	16
Miscellaneous (million Yen)	2	20
Total (million Yen)	8.4	79
Passengers per flight	300	50
Cost/person (thousand Yen)	30	1600
Passengers per year	200 million	750,000

*: assuming 5% interest rate.

Table 1: Representative cost targets for space tourism.

Table 1 illustrates the powerful effect of accessing such a large market; the development of such a vehicle might be amortized commercially. To reach this market is the key challenge for the space industry today. If it can reduce costs sufficiently, the industry can grow very large, with such important projects as satellite power stations (SPS) providing environmentally clean electric power on a global scale. This will be the real "space age".

On the demand side, we know from modern popular culture that space travel is a popular idea in many countries (4). For example, in recent years some of the most popular video series and films such as Space Battleship Yamato, Star Wars, Mobile Suit Gundam and Star Trek are based in space. Consequently, if space travel was available at the same cost as air travel, it would certainly become a very large market - many tens of millions of customers per year (which is still only a few percent of air travel). However, we also know that flight to orbit will be more expensive than air travel, because the fuel needed to accelerate a person to Mach 25 is approximately that required to transport them around the world. Thus space travel will be a relatively expensive service, and if it is to become widely popular, it will probably be as a "once in a lifetime" experience for many customers, a unique modern equivalent of a "journey to Mecca" in an earlier age.

Although one million passengers per year would be very large for the space industry, it is quite small by comparison with modern aviation. However, in order to reach this scale, the cost must be low - less than 2,000,000 Yen per person or 20,000 Yen / kg, about 1% of the cost of launch using present-day expendable rockets.

5 Cost reduction

In order to reduce costs to the required extent, we must start to get experience of reusable commercial launch vehicle operations as soon as possible. The only such project currently under way is the McDonnell Douglas DC-X / DC-Y / Delta Clipper project, though a vehicle more like the Pacific American Phoenix would seem more appropriate for passenger travel (5).

It is not uncommon for members of companies building expendable rockets to state that VTOVL SSTO rockets are impossible, but their feasibility has been demonstrated incontrovertibly by Hudson (5 Appendix). The only interesting question is how much it would cost, and how much mass is required, to make an SSTO vehicle fully reusable. In this context it is interesting that, despite government funding of some hundreds of $ billions to date, the space industry has not yet tried to do this in any country.

Cost reduction is one of the continual driving forces in commercial industry, since every reduction in cost is a direct addition to profit, and reducing prices below those of competitors is one of the major forms of commercial competition. However, the possible cost of passenger space travel is controversial, with published estimates ranging from $400,000 in 2012 (6); $60,000 in the year 2050 (7); to $10,000 in the 2000s (8). An experienced figure such as Ruppe doubts whether low-cost launch is possible.

However, if the space industry does not succeed in reducing launch costs low enough, then space travel will not become a significant business, and the space industry will probably continue as a small-scale, high-cost activity of government researchers. In that case, space will not be a "new frontier" for humans.

The DC-X project budget is some $60 million, or less than 0.05% of NASA's annual budget. This shows a lack of interest by US politicians, but it is also perhaps a sign that much can be achieved at relatively low cost. Once reusable launch vehicles are in commercial operation, operating companies will learn continually about improving their operation and reducing costs. When the space industry reaches this stage, the early history of aviation will have many interesting lessons for its further commercial development.

6 Space hotels

An interesting aspect of the future development of commercial travel to low Earth orbit is the relation between the cost of flights to and from orbit, and the cost of staying at an orbiting "hotel". At a target price of some 20,000 Yen per kilogram to low Earth orbit, a passenger flight would cost some 2,000,000 Yen. At this price the launch of an orbital hotel weighing some hundreds of tons would cost some tens of billions of Yen. If the demand for trips to orbit was of the order of 1 million passengers per year, and if passengers were to stay in orbit for 2 or 3 days, there would be a demand for accommodation for between 5,000 and 10,000 people in orbit. This scale would certainly provide manufacturers the opportunity to obtain significant scale economies through mass production of accommodation units.

It is worth noting that a "space hotel" would be much easier to design and build than the US/international space station. As an illustration of this, accommodation made from several units of the Skylab space station from the early 1970s, excluding the scientific equipment but including more windows and comfortable fittings, would be satisfactory for an initial hotel. It is difficult to believe that each unit would cost more than a few billion Yen, about the price of a business jet, which is a much more complex vehicle.

The total cost of such a hotel, including launch, should therefore be a few tens of billions of Yen, which is comparable to that of a modern office building. If we assume that such a hotel should earn annual revenues of 10% of its cost, or some billions of Yen per year, then if it accommodated some thousands of passengers in a year, the cost of a few days' stay would be of the order of 1,000,000 Yen, or some 50% of the cost of a passenger flight to orbit. It will be interesting to see whether more detailed future cost estimates support this approximation. If so, then it seems likely that space hotels will be built even in the early stages of space tourism.

7 Conclusion

Provision of low-cost passenger flights to orbit seems to have the potential to become a key opportunity for the space industry to tap a huge new commercial market. It is therefore highly desirable to devote resources to discovering whether it is possible to develop this business in the near future.

Like other large commercial development projects, the development of commercial space travel will require detailed discussion between people from many different areas of business, from manufacturing companies of course, but also from travel and hotel companies, marketing and media companies, insurance and law firms, and banking and finance companies. A successful project will come about only as the result of the combined efforts of these groups.

But in order to succeed, discussion between these groups must begin. It seems surprising that this discussion has not yet begun elsewhere within the world's space industry. Consequently it is beginning in Japan, with the work of this Space Travel Study Group of the Japanese Rocket Society. Let us hope that it will lead to a new, commercial "space race". If it does so, the winners will be the travelling public.

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SPACE TOURISM AND SPACE MEDICINE*

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1. Introduction

Last year, I went to Florida to see off our Space Shuttle mission, Space Lab-J as an ex-Principal Investigator, and the originator of a medical experiment with carp. On that occasion, I visited Disney World together with my wife. An attraction we chose was a big roller coaster called the Space Mountain. We followed the waiting line for an hour. Then I noticed several senior couples left the line when they reached a sign post. Soon I found it said that persons with any one of the following symptoms may not ride on this vehicle; aged, high blood pressure or lumbago. Those who left the line must have obeyed the warning. I myself suffered from all of them, but didn't care. Fortunately, my wife did not read English. When our turn came, our seats happened to be at the front. It was a great experience in both physical and mental terms. My wife had to rest for thirty minutes afterward to recover from dizziness. I was quite all right and felt proud of the exciting experience.

On my return to Japan after this, I found a letter on my desk inviting me to make comments on the space tourism study today. The excitement I experienced in Disney World might have made me more aggressive than usual. I responded to the letter positively.

2. Safety First

I now remember with surprise what made me decide to take a ride on the thrilling Space Mountain. I think I completely trusted in the safety of the attraction; both the vehicle and its operation. When we fly with air lines, we believe the aircraft is absolutely safe, that is why we use it as transportation. This fact is apparently shown by the statistics of general aviation. Therefore, the most important condition for space tourism is safety. This is the premise of my comments to follow.

3. Space Environment and Medicine

At first, I would like to discuss the space environment from the medical point of view.

Atmosphere:

Most aircraft used for transportation are pressurized. The pressure level is equivalent to an altitude of 2700m for transoceanic flights. In the case of space vehicles the pressure program to match the rate of climb will be a key issue. The gas composition will be another issue, since the cabin atmosphere will be made of a mixture of gases carried in bottles.

Acceleration:

This is a special feature of space flight different from aircraft. At first, the high acceleration during ascent to space is inevitable. To our knowledge, the maximum endurable level of acceleration depends on the direction acting on the human body. Four G acting from head to foot will cause blackout, while two G is the maximum in the reverse direction. The relations of endurable G and direction of acceleration are shown by Figure in the next page.

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In this figure, curve A is the case of water immersion, that is the human body in water. In this case, tolerable G levels are higher than 10 and tolerable time is 4 minutes for 10G. Other curves are acceptable if they are out side the solid line which represents a constant acceleration level and duration for typical launching conditions. It is most favorable for the acceleration level to be kept lower than 3 G.

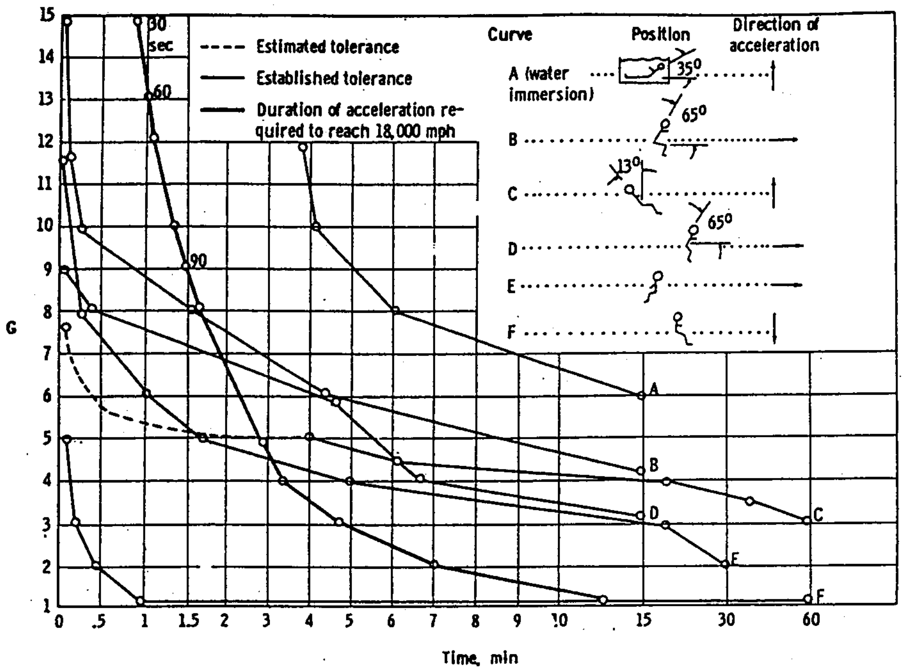

Figure Effect of back angle on tolerance to ± Gz (Reference)

Rotation and Vibration:

Slow pitching and rolling motion will cause air sickness, but I do not know much about the motion of space launch vehicles. Vibration and acoustic noise should be eliminated for passenger transportation. It should be noted that many medical data including the diagram shown here are concerned with physiological limits, which are too severe for tourist passengers.

Weightlessness:

Space sickness is caused by weightlessness. Sea sickness can be compared to space sickness, but the conditions of seasickness which can be defined by the three symptoms of cold sweat, nausea and pale face are not observed in the case of space sickness. A person suffering from spacesickness suddenly throws up without bad feeling. It is necessary to make a medicine to cure the sickness. When one is space sick, it is difficult to eat medicine, so that an ointment type of medicine should be studied.

Spacesickness is the main medical problem for space tourism. In this space tourism study plan, the phase one tour was proposed based on the assumption that three hours flight in weightless condition would not cause spacesickness. I am skeptical about this assumption. At present astronauts undertake various forms of physical training, which seem to improve their durability against space sickness. I am afraid some ordinary people may become sick in several minutes, as in the case of seasickness. Human blood moves to the upper past of the body under weightless condition. This occurs even during the short period of the phase one tour.

Radiation:

The Atlantic anomaly located between the altitudes of 90 and 160 km over the southern Atlantic ocean will be considered to be dangerous to human bodies.

4. Physical Requirements of Space Tourists

In the scenario prepared for the proposed study, passengers are assumed to take a health inspection while they are enjoying rides on various types of attractions. This reminded me of my father's case. When he flew with airlines, there was a rule to reject aged persons who were older than seventy years old. But he always lied about his age. To make sure of this, I asked Japan Air Line if they had such old documents, but the answer was no.

For the future space tours, I hate to hang a sign to reject those who are "aged", and have "high blood pressure" and "lumbago". But we have to be careful of such a people who are determined to make their last tour to space. Actually the airlines have a simple criterion to check such a passenger. One such rule specifies warning against disease of the heart, low blood pressure, hypoxia and so on. However, some of these criteria are not clear, and so not useful. Thus, this is just an information for discussion.

5. Concluding Remarks

In conclusion, medical aspects of space tourism can be discussed in such a frame work like this, but I would like to emphasize that only a few accidents can damage the dream of space tourism. In this respect, we should study practical themes such as the best angle of reclining seat or the attitude of passengers during flight, based on the phase one tourism described in the scenario.

Reference

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Genyo MITARAI graduated in 1946 from Nagoya University where he also received his M. D. degree in 1954. From 1967 he was a Professor in the Department of Aerospace Physiology, at the Research Inst. of Environ. Med., Nagoya University, until 1984 when he retired as the Director of the Institute. Then he was invited to Chukyo University as Professor, and was appointed Dean from 1989, retiring in 1992. He is now a lecturer of the University. His major fields have been electrophysiology of the retina, and equilibrium physiology. He proposed a medical experiment for the Japanese First Material Processing Test (FMPT) mission. After it was accepted, he worked for preparation of the flight as the Principal Investigator until his retirement from Nagoya University. Later the experiment was successfully carried out by his colleagues onboard Spacelab/Space Shuttle in 1992. Since 1962, he was a councillor of Japan Society of Space, Aviation and Environ. Med, for which he serves as Chairman of Board of Directors. He is member of many academic societies including the Japanese Rocket Society.

BUSINESS DEVELOPMENT FOR SPACE TOURISM*

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1. Introduction

I am pleased to talk about my own experiences of being involved in various technology development projects. However, I am wondering why I am here to comment on the space tourism study to be conducted by the Japanese Rocket Society. I just guess I am expected to talk about the secret of making money to start a new business developing advanced technology.

2. A Lucky Start

My first project concerned the development of the so-called Linear-Motor-Car (Magnetically levitated transportation system) whose key technology was superconducting currents for magnets. In 1968, super-conductivity was not so widely known as nowadays. It belonged to knowledge of specialists as a physical phenomena called "persistent current mode" in English. When I used to explain my plan to apply this principle to make strong magnetic fields to levitate and accelerate train cars, many people would not believe me. I remember, some said to me, "What did you learn in the university? You seem to be ignorant of a basic theory of physics". Under such circumstances, I was saved by just good luck.

In 1970, a Japan-US specialist conference on transportation was held in Washington DC. The participants from the two nations found that both were interested in high speed transportation systems exceeding a speed of 400 km/h. The Japanese proposed a joint project to develop superconducting mag-lev transportation, and the US responded to the proposal. We discussed various issues concerning the development of superconducting technology, such as US secrecy policy for technology. The discussions were so serious that representatives of the Japanese government began to change their view on this new technology, and also on the value of my proposed plan. This was another example of the bad Japanese tradition; To hear a translation from American sounds better than to hear the original from a native Japanese. This has not changed even now.

3. Cash in hand is better than any promise

Returning to Tokyo after the conference in Washington, I was hurrying to get the study started by the ministry of transportation. I was working for the Japanese National Railway (JNR) which had no special funds to take care of such a sudden decision. I said, "We have no money. I cannot do anything without money." "How much do you want?" "About one hundred million yen (approximately one million US dollars)" was the answer, which was a fairly large amount of money in those days. Even so, the money was prepared in a week, probably because of its urgent situation. This decision awakened a samurai-man in JNR who stopped my action saying "Don't get that money from the government, I will get it for you". But I always like cash in hand rather than a promise for the future, so I said this to the man. Then he called a special directors' meeting to decide the funding necessary for my plan. Thus, the first super-conducting technology project was officially begun.

* A comment presented at JRS Space Tourism Study Conference held on April 14, 1993. Edited and translated into English from taped transcript originally in Japanese.

4. Important Visitors to the Project

After considerable efforts, the maximum speed exceeding 500 km/h was achieved by an unmanned test vehicle. On the other hand, we developed the 002 model that could carry passengers onboard in order to study various problems associated with passenger accommodation. This vehicle was often used to provide honorable guests with opportunities to be familiarized with this high technology transportation. We took advantage of these guests for publicity of the new transportation system.

One day, such a guest train operation was suddenly interrupted by "emergency stop" because of sickness of a passenger. Later it was found that the sick passenger had claustrophobia, from being confined in the test car. He was used to flying only on jumbo jets. Thus, you will learn that vehicles for space tourism should be as large as possible.

5. Human relations : Space

As an extension of technology for the mag-lev transportation, I proposed a linear motor assisted take-off (LMATO) for a winged space launch vehicle, together with Prof. Nagatomo. A sled carrying a space vehicle is a modified version of the 002 model that I showed before. The maximum velocity required for this sled was 600 km/h which was within then available technology. So, I have been waiting for completion of our customers, the space vehicle, and I am now wondering what relation there is between that concept and space tourism.

While I was waiting for space vehicles, I started research on the practical application of the linear motor system for elevators. Its principle is the same as linear motor cars, but the direction of acceleration is vertical instead of horizontal. Looking for several institutions to have an interest in developing this system, I found sponsoring groups at the Power Reactor and Nuclear Fuel Development corporation. As a result of tests conducted at Toyama University, we were encouraged to think about applying this to launching rockets. These ideas were products of a group study with members of the committee for the Geotopia project supported by the Science and Technology Agency. Recently, I was invited by American colleagues to join their company established for electromagnetic launching system development. Thus, I am pending between various human relations. Now I dare say to you, "If you are serious about space tourism, you need a dedicated company.

6. Human relations : Shipbuilding

Another research field of superconducting technology has been propulsion for ships. This is a kind of electric propulsion that uses the force caused by the interaction of electric currents flowing in water and magnetic fields applied outside the hull. This project has been sponsored Mr. Sasagawa. When he visited to ride on the linear motor car as a guest, he surprised all of us by shouting loudly "Start! Let's go" at the moment of the operator's counting zero. He is always a man of commander. After the test ride, he asked me "How about Japanese marine technology?" I frankly answered "There has been no effort to develop new technology in this field. I know because I was engaged in this field during the war. The technology was all imported. Do you know any engine designed by Japanese?" This time he was surprised by my answer, and quickly ordered me to do something. So I proposed my idea to propel ships by means of superconducting magnetic force. He responded " Does it work well?" "I don't know. It is the purpose of research to find out. You already know a business of which the risk is fifty-fifty." "What's that?" "Your motor boat racing, sir" "You're right!" Anyway, he sponsored my research project of 'superconducting ship', which is known as Yamato-1. It was successfully tested last year. On the day of the completion ceremony, I heard that he had been advised by someone not to believe me because an American technical paper was negative to my idea. By the way, the superconducting ship can be used best for submarine type of cargo vessel.

7. Inner space trip

In February this year, I had a chance to join a sightseeing cruise in a submarine in Maui Island, Hawaii, which is one of three places providing this kind of service in the States. The submarine was 30m in length. Passengers took seats in a line on each side, and could look out through each window. The crew members were three. One of them is a scientist guide and another one is an interpreter. Batteries to power the vessel were stored under the seats of passengers. The batteries warmed the seats during operation. Oxygen bottles were installed to supply breathing air. There was no toilet. After the trip, they issued a certificate to each passenger. This will be an important service for space travel too.

I enjoyed the submarine trip very much, and was interested in the price. I did not know what it was exactly, because it was included in the payment for the hotel fees. According to a pamphlet on the trip, 5 dollar-off price was 39.95 dollars. But it rose to 79 dollars if you are Japanese. Why? Because, they explained, Japanese translation required additional cost. I envied the interpreter's high salary!. However, I wonder if space travel can be as cheap as this.

Later, when I boasted about this experience to my friends, someone showed me a pamphlet of a Mitsubishi-made submarine for sightseeing. He said I could make a similar sightseeing trip with this ship in Okinawa. But I found the price was more expensive than in America. The reason is that the submarine is built to meet Japanese laws which are stricter than American laws. The laws may concern seaworthiness. Is there any difference of the seas in Japan?

8. Decide Upper Limit of Investment

Before making a company, you should learn one important thing, that is the upper limit of investment. Generally speaking, the railway people are loose in spending money. But I suppose the space people may be one order of magnitude more, or probably much more loose than the railway people. Say 500 million yen is allotted, then it will be easily exceeded up to 5 billion yen and even 50 billion yen for projects of developing new space systems, I guess. This approach cannot be used for a business project. Any business needs an upper limit of investment. And it is most important to manage the entire project within this limit.

Many people hated my strict attitude to control costs within this limit, but the strictness of Mr. Shima, the chief engineer in charge of the Shinkansen development was very famous. "Why do you need it ?" was the answer to every proposition of new studies or tests. It is well known that the oldest Shinkansen line is affected easily by snowy weather. This is a result of his tight control. He predicted this drawback but ignored it because such troubles would take place only once or twice in a year. After completion, people understood the real value of the transportation system, so that newer lines constructed later were fully protected against snow with more investment. This amount of money was not available for the first challenge.

9. Decide Responsible Leader

Finally, I would like to request you to decide who is responsible for the new business. Only a person assigned to a responsibility can be sufficiently serious to achieve it. In the case of Linear Motor Cars, JNR was responsible as I said. In Germany, an insurance company took responsibility for the same kind of transportation system development. They visited our office to ask for our advice, concerning which prospective customers we would have. I admired their attitude and enthusiasm. Therefore, my conclusion on this subject is that you should find someone who is responsible like this insurance company.

Yoshihiro KYOTANI graduated from Kyoto University in 1948, and joined the Japanese National Railway (JNR) as engineer. After working in administration at the Ministry of Transportation and at several JNR firms, he joined the JNR Technology Development Department, as deputy Director (1968- 1976) and later as Director (-1983). During this assignment, he proposed a new high speed train system based on the principle of magnetic levitation and acceleration, and after approval of the proposal, directed the special project team dedicated to related technology development. He received national awards for this achievement including the Purple Ribbon Medal in 1988. After retirement he was invited to join TECHNOVA Inc. in 1987 as President, and has been Chairman since 1989. He is still actively promoting the government project for the Linear Motor Car train system as advisor of the Central Japan Railway company (JR Tokai).

SPACE TOURISM AND TRANSPORTATION*

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1. Barnstormers in Space?

When I was invited to talk about various issues concerning space transportation for space tourism, I remembered the early aviators called barnstormers. They were veteran pilots who got aeroplanes which were used and disposed of by the government after World War 1. They took to the road with these air planes for acrobatic flight shows and entertainment of passenger flights. It was the good old days of early aeroplanes. Space tourism sounds to me like a revival of such old dreams of flight. Wondering if the Japanese Rocket Society agrees with my idea, I would like to comment on the subject around this theme.

There may be two different views on the early aeroplane business. The enthusiasm of people curious about flying excited with a strong smell of castor oil drive the progress of American civil air transportation to become the world's largest airline business. Another view is that it was a sort of poetic description of natural scenery of early America. These two different views may affect thinking on space tourism.

Even in Tokyo, sightseeing flight tours were operated, using deHavilland Dove and Helon, in the late 50's when commercial airlines were not yet as popular as nowadays.

2. Safety of Passenger Planes

At the present, sightseeing flight is impossible without assurance of safety. Various standards to assure safety can be considered. The most typical standard I would choose is that insurance companies will have to insure space tourists as they are now doing for overseas travelers. If the safety of space rockets is assured at the same level as the Concorde supersonic transport, insurance companies will be willing to insure space tourists.

To assure the safety of rockets to the same level as that of present-day aircraft might be a difficult problem. But if this is not solved, it will be impossible to make daily business flights because of frequent interruptions by damage and expenditure for compensation.

As represented by the Apollo program, the reliability of space rockets has been very high. But the meaning of reliability is different for space rockets and aeroplanes. One is expendable, and the other is repetitively used for an extended period. Thus, the terminologies of safety and reliability are used on different technical bases for space and air craft.

It is assumed in the case of passenger airplanes that any potentially predicted failures, such as damage or cracks always exist, even if they cannot be found by preflight and periodic inspections. Thus fail-safe design is the basic philosophy. It is required for aeroplanes to be able to fly even if an additional failure or crack takes place, or an old crack is enlarged.

Fail-safe design cannot be accomplished by making systems or structures in duplicate. The same type of failure can happen simultaneously in both when one fails. This is the basic idea of passenger aircraft design.

Let's consider an autopilot system using fly-by-wire as an example. Considering failure modes of semiconductor microchips might be the same for same manufacturing process, products of different manufacturers should be combined for a redundant system design. The same idea is applied in software design. You should anticipate that a software developer makes the same bugs in his software products, so different people are needed to make redundant software. Even if some ideas are commonly used for aircraft and space systems design, operational conditions are

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different, especially in repetition rates and time length. It is most important to specify the philosophy of designing reliability and safety for space passenger vehicle.

3. Feeling safe but paying for thrill

A lot of controversies may be necessary over the applicability of the safety design standards used for passenger aircraft design for designing spaceplanes for space tourism. But in the case that the general public participate in space tours, we have to consider that they will want to feel as safe as when they use airlines.

Feeling safe is different from understanding safety by statistical data or design data. Feeling is not a matter of numerical quantities but is based on personal experience. In this respect, I myself would not like to be launched into space in a wingless capsule. On the other hand, the current airlines provide their passengers with no parachutes but only safety jackets for emergency. Aircraft are designed to make an emergency landing in case of accidents. This is accepted by passengers as a standard procedure without complaints.

The method of landing vertically, firing rocket engines, will not be comfortable even though I know the reliability by statistics and theory. I had a similar feeling whenever I saw the Harrier fighter land vertically by means of vertical thrust of engines, instead of lifting forces of the wings.

Use of multiple engines for such vertical take-off landing vehicle can avoid accidents caused by engine failure, and the control system can be provided with complete fail-safe capability. However, individual modes of accidents and possible rescue operations might be concerns of not only the passengers but also the government agency in charge of its safety.

However, it will be a question if spaceplanes are made as safe as the elevators of Tokyo Tower, the Shinkansen (the bullet train) and taxis, whether they would be attractive to space tourists. If the purpose of space tourism is to challenge something unusual that is not necessarily safe, excessive safety might lessen the interest of people.

In other words, the space tourism planner should study what is the motivation of those people who can not be satisfied with the most precise computer-simulated experience and want to go to space. What can they expect to experience during the tour? What makes them feel proud when they return and talk with their friends? These questions are concerned with the value and consequently the price of the space tours.

The price of tourism is a key factor affect in the success of the business, and will pursue the lowest price. But, in my opinion, the lowest price will not be the best price. Wrist watches give a good example of this view. Precision of watches was once the key factor of quality. But now it has improved remarkably using quartz movements, and is no longer a factor determining the price. On the contrary, old mechanical movements are sold at a higher price. Likewise, space tourism for the general public may not be so attractive if the price is too low to limit the entertainment opportunities.

5. Barnstormers revisited

The barnstormers that I introduced at the beginning disappeared with stricter regulation of air transportation by the government. But, I thought I saw a revival of the barnstormers with a supersonic aircraft at an air show held in America. At the site, I saw a large hanging sign across a road, which called for passengers to experience a short supersonic flight. The operation was busy with many people signing up. The flight time is thirty minutes or a little longer. The fee was several thousand dollars, which might be a little expensive, but every one enjoyed the flight and was satisfied with a light meal during the flight and a special keyholder souvenir in hand.

It will be the minimum requirements for a passenger on a space flight to take a meal and to watch the earth through an individual window.

Tsuruo TORIKAI graduated from Yokohama National University in 1953. Starting his professional career at Fuji Heavy Industry (FHI), he participated in various aircraft design teams organized for national projects, such as T-1 Trainer, YS-11, C-1and T-2 Trainer, as a designer. From 1971, he was the general manager of FHI's aircraft division, until he was assigned to his present position of managing director of Japan Aircraft Development Corporation. He is a government registered consultant engineer, and member of several academic societies including the Japanese Rocket Society.

THE PLEASURE OF SPACEFLIGHT*

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1. Introduction

I was introduced as the first fare-paying passenger to travel to space. But I would like to add a few comments about this view. In the case of the Space Shuttle, satellite companies that are the customers pay for Shuttle missions to launch their satellites, which usually include expenses required for payload specialists who go to space accompanying the satellites. In my case, the main mission that I accompanied was a broadcasting business project instead of a satellite launch. In this respect, I was not the first fare-paying passenger in space, but rather my flight was unique because it was a private enterprise outside the space industry.

My flight to the Mir space station was followed by the British, Helen Sharman. In the next year and later, a Korean, a Netherlander, and a Belgian are planned to fly on Mir. These people are from small countries, which have little chance to be serviced by NASA. The Austrian who flew to Mir second after me said to me that since even Japan had been waiting for her turn for seven years, so Austria could not fly for 25 years, and so would be left behind European space activities. This represented the background of commercialization of Russian spaceflights. Obviously there had been demands for space flights.

2. Everyone wants to fly to space

The previous speaker talked about spaceflight comparing it to flying in airplanes. The spirit shared by both kinds of flight might be the dream of flying. Everyone likes to fly. I was invited to more than 200 schools to deliver speeches on my experience of spaceflight. I was asked many questions every time. Among them, the question, "when will ordinary men or women be able to fly?" was the most common. I was sorry to answer that probably not before the 2010s. Because I learned at meetings of the Space Activities Commission that the H-2 rocket under development will launch the HOPE in unmanned mode first until 2010. This would mean that my generation will have no chance to go to space. I am really sorry to say this, because I am not a special person but exactly the same as those who asked me the question. I have just luckily happened to be involved in the event to celebrate the 40 anniversary of the TBS company.

3. Physical Requirements

The second most common question is "what are the physical requirements for astronauts?" The present physical tests are very strict, in order to select a few astronauts from many candidates. But in my case, I think the test was a kind of aptitude test. Accordingly, my answer to such questions is that almost every one may clear the requirements.

The following are critical requirements in the checklist that would be applied for applicants for spaceflight.

Heart disease:

This is checked because hearts have to endure increased loads due to gravity when an astronaut returns to earth.

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Calculus:

A stone in the bladder or renal calculus is considered to cause trouble if it floats under weightless conditions. Calculus is common to people older than forty years. I have had none, perhaps because I have a good habit to like drinking alcoholic drink made of malt after working every day.

Detached retinas:

I was checked for detached retina. Physicians explained that high acceleration may cause blindness due to detached retina. Accelerations acting on astronauts in the Soyuz capsule are 3 to 4 G during the ascent and 7 to 8 G maximum during the return phase. Especially the pilots are required to be free from the disease. I guess it might be a serious trouble if a pilot answered back to the earth, "I am blind now, so I can't see if the earth is blue."

Blood vessels:

Blood distribution in a human body changes during space flight. Under weightless conditions, about two liters of blood move to the upper body by filling enlarged blood vessels, which causes the swollen face, or the well-known moon face. I could see this symptom in the face of Dr. Mouri when his activities in space were monitored at the control center. Usually astronauts feel sick at this period of flight.

In Russia, allergy and dental health are also items for inspection. I was specially interested in their evaluation of teeth occlusion of astronauts. They explained, that astronauts' training was so expensive that they wanted each astronaut to fly about ten times. Since good teeth and occlusion are signs of good health, every astronaut had their teeth inspected, just like a horse.

Another thing I remember concerning clenching teeth was the sign given by the Commander just before touch-down on the ground. At the final landing moment, the capsule impacted on the ground. To reduce the shock, rocket motors were fired to decelerate the capsule at an altitude between 0.7 m to 1.5m. The number of rockets to be fired depends on the final velocity. In our case, the velocity was normal and was less than 9m/s, so that four engines were used. Just before firing the rockets, the commander shouted warning to prepare for the shock by clenching the teeth.

Thus, these would be special requirements for spaceflight, to be added to those of airflight.

4. Joy of space flight

The Soyuz is a capsule type of spacecraft accommodating three crew members. Eight minutes and fifty seconds after lift-off, you can leave your seat to move and float under weightlessness. The feeling of this experience is just special like Peter Pan flying in the sky or entering a new world of sensual pleasures.

We can experience weightlessness on a parabolic flight in an aircraft. I took training to be familiarized with weightless conditions in Russia. They used Ill-76 aircraft for this purpose. At first, it started with level flight at an altitude of 6,500m, and then it climbed up to 8,500m while throttling its engines back to make a parabolic flight, and returned to the first altitude. The length of weightless condition was 23 seconds.

Thus, weightlessness is the first joy of spaceflight. The next is earth observation. The earth was a wonderful object for sightseeing. At first we were in an orbit at an altitude of 200km, with the orbiting period of 88 minutes. Then we climbed up to 400km high, firing rockets several times. The difference of altitude was not remarkable as far as the scenery was concerned.

Sightseeing the earth is very special. The colors mixed and combined with the movement of the spacecraft around the earth from daylight to the night side were very beautiful. But the special feeling was more than the beauty of the scenery, I thought. I might say it was a psychological experience. The lights and colored seemed like music. This is a special sales point.

Sightseeing the earth and experiencing weightlessness are the basic commercial values of space tourism. And I would like to stress another important aspect of tourism, that is recognition of participation. A tourist enjoys not only the tour itself, but also speaking to friends about his or her own experience during the tour. I tried in Mir to fly with fans just as in the slide which was shown by the first speaker to illustrate flying with wings under no gravity. It will be necessary to reserve sufficient cabin space to make this kind of play possible, even in the first phase of tourism.

5. Living in space experience

I would like to point out that spaceflight is living in space. According to log records of my flight, I vomited at 17:45 after the lift-off at 11:13. At this moment, I felt nothing bad to cause vomiting, but it came out by itself with a slight motion of my body. When I threw up, it smelt bad and felt bad. Thus I was well until then, perhaps for five hours.

Another problem might be waste disposal. In the case of the Soyuz, I was given an enema the day before departure to space. We had urinals, but I never used it between two and half hours before launch and several orbits in space. For space tourists, to use a urinal for themselves could be a great experience to be proud of later. But from the practical viewpoint of operation of tours, management of urinals will be a serious point of discussion which will require technical data of waste disposal.

For the same reason, tourists will want to take a meal in space, even if it is not necessary for such a short flight time as defined by phase one of this study project.

6. Price and Prospective customers

To conclude my comments, I should like to speak about the price of the joy of space tour. Although the target price of the proposed reference space tour has been suggested to be one million plus yen per tourist, I rather think that people would pay more. For example, among the audience at Lions Clubs where I have given speeches, many liked to pay 10 million yen for such experiences. They already might have been to the Antarctic to see penguins, or ate meat of piranhas from the Amazon river. Some did not want to climb mount Everest, but preferred spaceflight. I suppose these kinds of people will be prospective space tourists.

Thus, there are a great number of tourists for space, but the question is when and what vehicles will be available.

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SPACE TOURISM : SPACEFLIGHT FOR THE GENERAL PUBLIC*

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Abstract

The "Space Frontier" is the main context of Man in Space for this discussion. In the history of manned space flight, we find that the human population on the new frontier of space increased rapidly in the seventies, but remained almost constant through the eighties and until the present. This stagnation seems to have been caused by the financial difficulties of every national space program. Possible implications of this fact are that the general public, that is taxpayers, have lost interest in supporting the elite space society, but wish to both pay and participate in space activities. The most probable solution to this should be space tourism. Tourism is a big business which can build much larger and cheaper space infrastructure than the space station. It is essential for space tourism that passengers' health and safety are assured by appropriate medical standards. To date, medical science has been used mainly for selection of superman astronauts. On the other hand, in future it will be expected to accept all people as space tour passengers, in cooperation with engineers who develop comfortable space tour vehicles.

1. Introduction

Gagarin's flight of thirty two years ago was a surprise for people. Later, with progress in manned space flight, various attitudes toward "human in space" evolved. A typical question asked by scientists who were satisfied by unmanned space missions concerned the usefulness of human beings in space in comparison with automated systems. However the question, man or robotics, was not constructive for discussing the future of space activities. Thus, I thought the idea of productivity in space would be a better context to discuss the engineering of space systems requiring human beings and robotics.

More recently, I consider the context of the "space frontier" is the most important in my thoughts on "humans in space". The usefulness of human beings and the importance of productivity in space are only one aspect of "humans in space". In history it has been the frontier that motivates people to take action for new opportunities. And it will be so in the future. My view on Man in Space is that human beings will go to space because they want to be there, rather than in order to work under weightless conditions.

2. Steps taken for the space frontier

Generally speaking, new frontiers should be the new territory for people to visit and live in. To make it possible in outer space, high technology is essential in location of the living places, assurance of living environment in space and transportation to and from there. Fundamentals of the essential technology were efficiently and successfully developed by governments in the past space programs. These can be considered to be mature enough to be applied for development of the space frontier in various ways in future.

To develop the space frontier, we made unmanned survey and then exploration with robotics, followed by brief manned stays. At present, the first step has extended as far as the entire space of the solar system. The second step has been taken in near earth space including the moon. And now we are at the threshold of permanently manned space existence. What actually happens will be more complicated, since there are many target places and routes to which this evolution of steps can be

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applied. A space station is considered the next step toward the space frontier among various options. The reason is that it should be a key element of space infrastructure for permanently manned lunar activities and a manned Mars expedition. We have arrived at the crossroads to the next steps: lunar bases, manned Mars expedition, as well as the international space station.

All of these are proposed as government-funded programs. In this respect, every scenario is an extension of past space programs. However, political and economical crises in the world seem to endanger these programs which were justified as national programs by old standards. Furthermore, evidence of the stagnation of existing space activities can be observed in the trend of population growth in space, as follows.

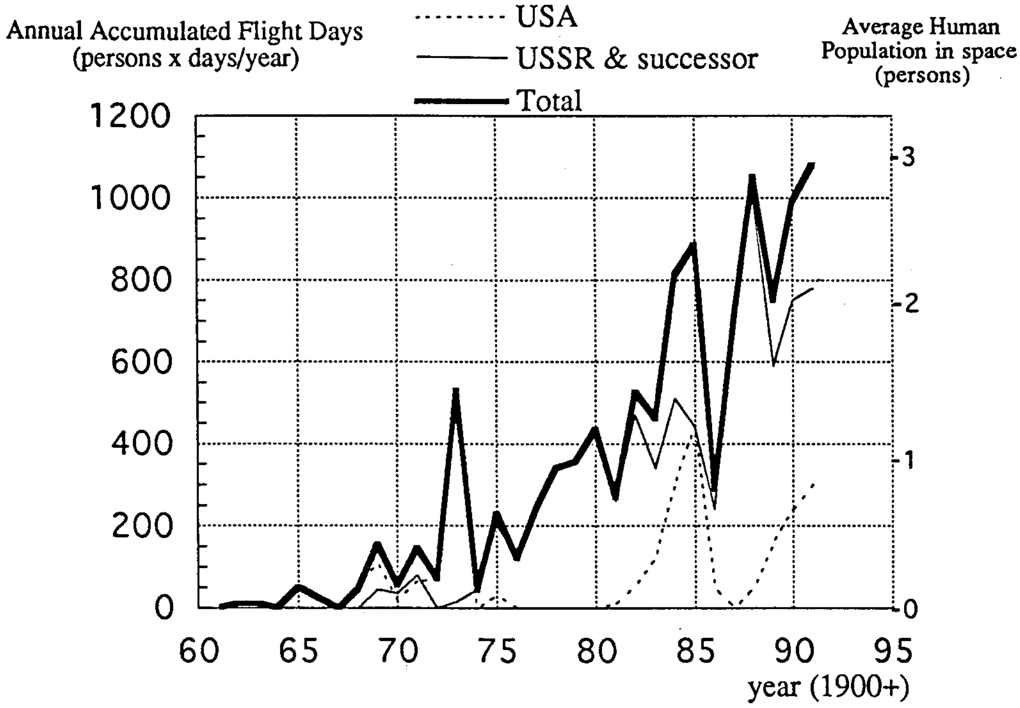

Fig. 1. History of the average number of human beings in space.

3. Stagnation of population growth in space

I would like to look at the trend of the human population in the near-earth space which is the sum of every astronaut's flight time in each year, and can be defined as the average number of human beings in orbit. (Fig. 1)

The population increased rapidly in the seventies to reach an average level of one person in space, and kept increasing in the early eighties until it reached two people. Then, the growth rate should through the present. Obviously outer space is large enough to accommodate many more people. The reason can be explained by the delay of the international space station. If the original version of the space station was constructed in the early nineties, the population would have been growing continuously.

To see the trend in more detail, we will examine the flight time of individual astronauts. In this case, a population of one person equals various combinations of number of astronauts and their flight time. Recently, Russian astronauts flew mainly in their space station for longer periods than American astronauts flew in the Space Shuttle, which means that fewer Russians than Americans experienced space flight if the average numbers are equal. This will also apply in the case of the international space station, where several crew members with stay for periods longer than a month.

As a result, it is predicted that even if the international space station is built, a relatively small number of astronauts will be employed, and they will be more specialized to aim at higher productivity. Eventually, manned space flights remain a special territory supported by governments for a few elite groups of "superman" astronauts. Nevertheless, if the station had been built as planned, the space population would have kept growing in the nineties high enough to be counted by two digit numbers.

However, the project implementation has been delayed and the population growth has stooped. Among various reasons to explain the delay, financial difficulty is the largest one. This implies that

the proposed budget is considered to exceed the amount that tax payers are willing to pay. In other words, people may be questioning whether to continue to pay their own money to support the elite groups.
Taxpayers generally think that a certain portion of their money can be allotted to maintain the national prestige, but more money should be used for their benefits.

4. Breakthrough for the next century

To get much stronger support for space programs, we have to carry not only a few influential politicians but many more public visitors to space. The only possible way to realize this is commercialization of manned space flights, that is, space travel for the general public. However, the currently planned space systems will not work effectively for this purpose, because they are based on the traditional space technology and engineering which supported scientific and military missions, ignoring economy and passenger service.

Although space tourism was a dream of spaceflight for people, actual manned spaceflights were far from space travel as it had been expected. What is urgently required is to give a definite concept of space tourism to the general public, which will be used as a guidebook to the space frontier. To challenge this route to the space frontier, the Japanese Rocket Society has just started a study on space tourism, which consists of four study areas; space medicine, finance, transportation and passenger services. This first study aims to identify the most practical approach to this new business, and to come up with a definite concept of engineering design, and hopefully a business framework.

Table 1.

SPACE TOURISM
- AN INDUSTRIAL PERSPECTIVE

TOTAL NUMBER OF VEHICLES	100	
PASSENGERS / VEHICLE	50	PERSONS
ANNUAL FLIGHTS / VEHICLE	400	
AVERAGE TRAVEL TIME	0.125	DAYS
ANNUAL TOTAL PASSENGERS	2,000,000	PERSONS
AVERAGE SPACE POPULATION	685	PERSONS
FARE / PASSENGER	10,000	US$
TOTAL ANNUAL SALES	20 B	US$

An example of an industrial perspective of space tourism is shown by Table 1. The industry involves space vehicle manufacturers which might be interested in production of at least one hundred vehicles which carry fifty passengers on each flight. Flight frequency should be two times per day, and in average four hundred flights in a year. If passengers enjoy spaceflight briefly for as short a time as three hours, the total number of passengers will be two million, which corresponds to more than six hundred population in space. Thus, the contribution of space stations to the space population will be negligible.

The effects of space tourism will be enormous in two respects. One is that faster progress may be expected for the advanced space activities to be conducted by the government elite groups. I expect these future programs would get much stronger and wider support from those space visitors who experience the new environment for themselves.

The other is that the demand for mass transportation will change the situation of high cost space transportation, which is now the obstacle blocking the way to the space frontier. If the price of earth to space transportation is reduced by two orders of magnitude as indicated by Hunter (ref.1), not only more and longer space travel will become feasible, but also the most basic infrastructure for industrialization of space to develop extraterrestrial energy and mineral resources will have been completed.

5. Space medicine at large

Considering these possibilities for people in space in the coming century, space medicine seems to have focused its main effort on the specific purpose of assuring the safety of astronauts flying on early space vehicles. From my view point as an engineer, there are two features of the achievements of space medicine in past space programs.

One is that space medicine was life science in the space environment, and especially in weightless condition. It inevitably included the environment of space vehicles to carry astronauts to and from space. Consequently the study was closely related to the design engineering of space systems and vehicles. The study results were often compromises between medical allowances and design criteria. In early projects, technical difficulties of vehicle design seemed to be overcome by tough medical standards for the crew.

The other feature of space medicine was concerned with labor science, perhaps together with human engineering. To justify manned space missions, it was preferable to demonstrate the superiority of human beings to automatic systems. In addition to the important human factors of creativity and adaptability, astronauts are expected to work cooperatively with machines. Thus, taking various lessons and training, astronauts become extremely able workers in space. Space medicine is very important in the selection of tough "superman" and "superwoman" astronauts.

An appropriate medical standard to assure passengers' health and safety is essential for space tourism to open the space frontier to the general public. The medical standard should be much looser than the present one, since ordinary people have to be accepted as passengers. This will reduce rocket performance, due to, for example, additional mass and lower acceleration. In addition to this requirement, rocket vehicles for this use will be required to fly repeatedly like aircraft. Both of these new requirements would impose more difficult design problems on designers of such passenger rocket vehicles. Fortunately, new materials and technology are available to improve vehicle performance. Fig. 2 is a picture of one of the Phenix series vehicles, which was designed for the first attempt of sightseeing space flight.

It will be very important for engineers and medical specialists to work together to find the best compromise between safety assurance and practical vehicle design. In this respect, space medicine is expected to provide appropriate new directions to engineers. To achieve the most positive aspect of tourist services, space medicine will indicate what is the best design for passengers to watch the earth or to enjoy weightlessness from the medical viewpoint. Health management of the space crew will necessarily involve space medicine, while public health in space flight will be an important field of research as well as of practice. It should be stressed that medicine will be more influential on the design and engineering of space systems than before.

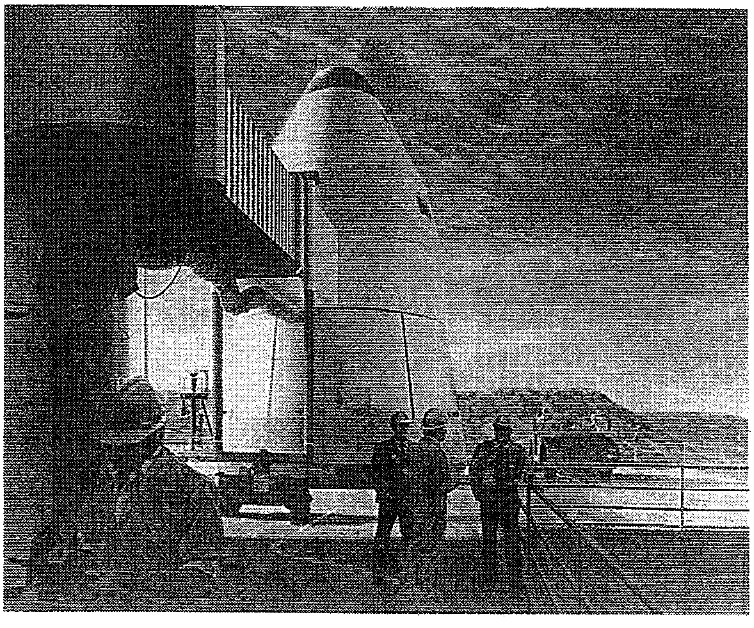

Fig. 2 . 1985 Phoenix design, mixed mode, single-fuel version (Ref.2)

6. Concluding remarks

In this discussion, space tourism is considered to be a breakthrough to open the space frontier to the general public, and consequently to strengthen support for ongoing advanced space programs.

To realize space tourism, space medicine is expected to indicate clear directions for designing new space systems and vehicles to be used for tourists from the general public. The medical standard for tourists and onboard crew is expected to be similar to that for the current airline business.

It will be essential for engineers to closely cooperate with medical specialists to develop new space systems, new medical and engineering standards, and finally a new culture in the space frontier.

7. References

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投　稿　規　定

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