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Trends in Space Transportation Systems in Various Countries
— Changes Arising from Retirement of the Space Shuttle —

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1 Introduction

On February 26, 2005, the Ministry of Land, Infrastructure and Transport launched Multi-Functional Transport Satellite-1R (MTSAT-1R) via H-IIA Launch vehicle No. 7. The failed launch of H-IIA No. 6 in November 2003 had idled the launch vehicle developed by the Japan Aerospace Exploration Agency (JAXA) for a year and three months. The successful launch of the MTSAT-1R into geostationary transfer orbit (GTO) is a restart for the program.

Meanwhile, the United States space transport system also was shut down following the in-flight loss of the Space Shuttle Columbia; however, with a new launch scheduled for July 2005, the program is on the road to recovery. Despite this, the Space Shuttle is now expected to be retired within 10 years due to changes in US space policy that took place during the shutdown.

This report will first discuss the move toward retirement of the Space Shuttle. It will then look at post-Shuttle space transportation systems in terms of five broad categories: (1) manned space transportation systems, (2) transport of supplies to the International Space Station, (3) expendable launch vehicles, (4) deep space exploration beyond the Moon, and (5) reusable launch vehicles. Next, it will discuss projects currently either in development or in operation in various countries.

Finally, the report will examine the appropriate policy for Japan on space transportation systems in light of this international competition on development.

2 Move toward retirement of the Space Shuttle Program

Operation of the Space Shuttle began in spectacular fashion in 1980 with the launch of Columbia. The formal name of the Space Shuttle is “Space Transportation System” (STS), with the component that returns to Earth called the “orbiter.” Five orbiters were manufactured. They have flown over 100 missions to date.

As the name implies, the National Aeronautics and Space Administration (NASA) developed the Space Shuttle design as a system for all forms of space transportation. The concept was that it would transport people and cargo into space, that it could be used repeatedly, and that it would be ready for re-launch about one month after each landing. Initial plans envisioned four Space Shuttles, with dozens of launches every year.

Once actual operation began, however, those plans were immediately frustrated. Because heat-shield tiles suffered serious damage during re-entry and their repair was time-consuming, it became evident that re-launch after one month would be impossible. In addition, insufficient thought was given to repeated operation, and costs blew out to nearly 100 times initial estimates. In recent times, NASA’s best achievement has been eight launches in one year, at a cost of US$4 billion. Because it cannot come close to matching the low cost of expendable launch vehicles that can be deployed for between ¥10 billion and ¥20 billion per launch, the Space Shuttle has not undertaken a mission for the sole purpose of launching satellites since 1992.

The Space Shuttle program has suffered two major accidents and lost two orbiters. On January 28, 1986, Challenger self-destructed immediately after launch when burning gas erupted from a crack in an O-ring on the solid rocket booster (SRB) and caused liquid propellant to explode from the opening. The loss of the seven-member crew was a major blow to US space development. Two years and eight months of preparation ensued before the next launch, in September 1988. Challenger's replacement orbiter, Endeavour, made its first voyage in May 1992. On February 1, 2003, Columbia broke up during re-entry flight over Texas, USA, and was lost along with all seven crewmembers. The accident was caused by insulation detaching from the external tank and damaging part of the reinforced carbon-carbon (RCC) panel on the leading edge of the left wing, allowing superheated air to penetrate during re-entry. With the accident investigation and determination of future policy completed, re-launch is scheduled for July 2005.

In the International Space Station (ISS) project being built by the USA, Europe, Japan, Russia, and Canada, component parts (modules, trusses, etc.) are to be launched by the Space Shuttle and Russia's Proton launch vehicle. Of those parts, Japanese and European experimental modules can only be launched by the Space Shuttle. In order to meet its international obligations, the USA must therefore keep the Space Shuttle in operation at least until the ISS is completed. However, once construction of the ISS is finished, the USA plans to retire the Space Shuttle as soon as possible and move to a new, more efficient space transportation system that separates crew transport from cargo transport.

3 Trends in development of manned space transportation systems

3-1 USA Crew Exploration Vehicle (CEV)

Prior to retirement of the Space Shuttle, NASA plans to develop the Crew Exploration Vehicle (CEV) as a manned space transportation system capable of everything from low Earth orbit flight to manned exploration of Mars. The initial goals were to achieve manned CEV test flights by 2014, with manned exploration of the Moon taking place between 2015 and 2020, but NASA Administrator Michael Griffin intends to move test flights up to 2010.

In March 2005, NASA issued a request for proposal (RFP) to develop the CEV from September 2005 through December 2008. Two groups responded by the May 2 deadline. A consortium led by Lockheed Martin proposed a winged vehicle with a crew of six. Boeing joined Northrop Grumman, Europe's Alenia Spazio and others with a proposal for a space-docking vehicle with three modules. NASA will study these proposals and is scheduled to announce its

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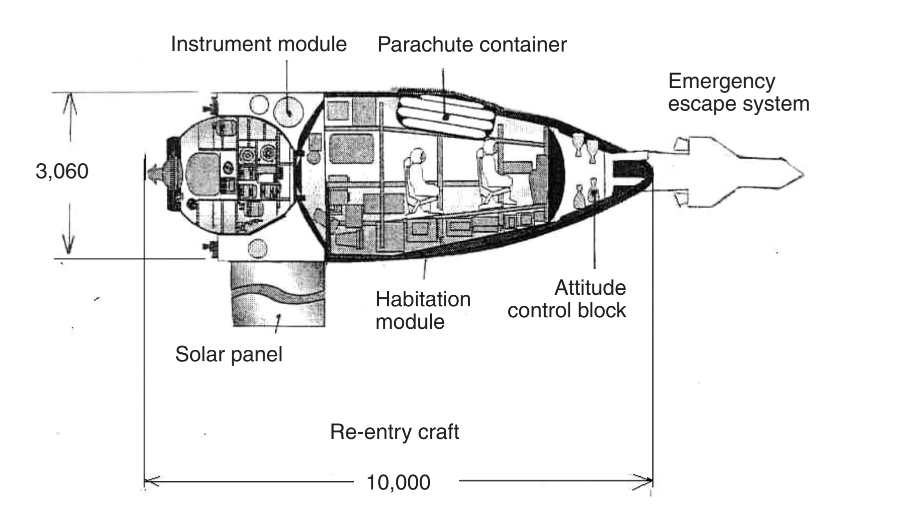
•*Space Shuttle's reusable Solid Rocket Booster (SRB)*

After the SRB completes combustion, it separates and falls back to Earth, where it is collected from the ocean. Because it is made of metal, it can be refilled with propellant and used again. In contrast, Japan's H-IIA rocket utilizes the SRB-A, in which a structure formed by filament winding (FW) is filled with propellant. Once the propellant has burned off, the structure is severely weakened, so it cannot be used again.

•*SRB's oxidizer damages the ozone layer*

The SRB's propellant comprises fuel and an oxidizer, which are blended in a mixer, formed, and solidified. Because the oxidizer contains perchlorate, the SRB's exhaust reportedly damages the ozone layer. In February 2005, the US Environmental Protection Agency (EPA) set the official reference dose of perchlorate at 0.0007 mg per kg of body weight per day.

Figure 1 : Cross-section of lifting body type Kliper[1]



Original diagram © Anatoly Zak

choice of contractor in September 2005.

3-2 Trends in development of new Russian manned spacecraft

In November 2004, Russia's RKK Energia, maker of the Soyuz manned spacecraft, unveiled a full-scale mockup of the Kliper (КЛИПЕР) manned spacecraft, at the KIS experimental station. The model is also scheduled to be exhibited at the Paris Air Show in June 2005. The basic structure and specifications of the current Soyuz spacecraft (3-person crew) differ very little from those of the 40 year-old original, with its cramped and uncomfortable crew space. The Kliper replacement may become the mainstay of crew transport design after the Space Shuttle is retired.

Two configurations for the Kliper have been announced so far. Figure 1 shows a cross-section of the lifting body type. With six-seater capacity (two rows of three), it will not only be able to transport six crew members to the ISS, but can also accommodate four space tourists and a crew of two. The second configuration has wings like the Space Shuttle, but the crew compartment is the same as that of the lifting body type. It is therefore possible that development will proceed in stages, first with the lifting body type and then with the winged type.

The Kliper will be 10 m long, with a diameter of 3 m and a weight of 13 tons. In addition to six astronauts, it will be able to carry about 500 kg of cargo. An emergency escape rocket at the front of the craft similar to that of Soyuz is shown in the published plans. An alternative draft design provides for weight-saving by attaching the escape rocket to the rear of the craft, where it could also be used as a propulsion engine for acceleration. To save development costs, the Ukrainian Zenit launch vehicle is expected to be used as the launch vehicle.

3-3 Competition between European Space Agency member countries on development of manned spacecraft

In Europe, above and beyond national space development programs in various countries, the European Space Agency (ESA) carries out large-scale programs with funding and development input shared among member countries. In the field of manned spaceflight, member countries are engaged in an unprecedented level of competition. This is because the ESA's own manned spaceflight plan has only reached the stage of budget appropriation, and its content is yet to be determined.

The ESA's two largest financing countries, France and Germany, are carrying out technical development for manned spaceflight in their own space development programs. France is developing two manned spacecraft, the Angel and the Pre X, while Germany is developing its own pair, the Phoenix and the Hopper. If development goes well, both countries are thought likely to attempt to have their respective national manned spaceflight programs adopted as the ESA program.

3-4 China's manned spaceflight

In October 2003, China successfully launched Shenzhou 5, becoming the third country to achieve launch of a manned spacecraft. Around September 2005, China plans to carry out a spaceflight of several days with a two-person crew, setting a record by becoming the first country to achieve a multi-astronaut spaceflight within two years of its first solo flight. The Soviet Union took three and one-half years, and the United States three years, to accomplish the same feat. Beginning in 2006, China plans to fly three-person missions, with one member of each complement being a non-astronaut. (See Feature Article 3, July 2004.)

In addition, China plans to dock manned spacecraft with its own space station. The Long March 5 launch vehicle, currently in development, may be ready to launch space station modules by around 2010.

4 Trends in the development of resupply vehicles for the International Space Station

4-1 Russia's Progress resupply vehicle

On February 28, 2005, the Federal Space Agency of Russia (FSA) successfully launched the Progress M-52 resupply vehicle with a Soyuz U launch vehicle. It was the 17th Progress mission to the ISS. The Progress can carry 2.8 tons of payload per launch, of which about 1 ton goes to fill tanks with fuel, oxygen gas, etc. The remainder is cargo, material needed by the ISS astronauts for experiments, food, etc. Until the US Space Shuttle resumes flights, the Progress is handling ISS supply missions single-handedly. Due to supply delays, ISS crewmembers have even had to ration their food at times. Since its first flight in 1978, the Progress has undergone some improvements, but like the Soyuz, it has undergone no major changes from the original model that supplied the Soviet Union's Salyut and Mir space stations. Even if other countries develop and operate resupply vehicles to rival the Progress, there will probably still be a role for this reliable spacecraft over the near future.

4-2 Japan's HTV resupply vehicle

On January 26, 2005, the ISS Heads of Agency meeting held in Canada discussed space transportation systems with a view to eventual retirement of the Space Shuttle. The joint statement[2] issued there includes utilization of the H-2 Transfer Vehicle (HTV) being developed by JAXA to support the ISS program by transporting cargo to the International Space Station. This can be seen as providing Japan's space transportation system with a platform on which to develop its full capabilities alongside Russia's Progress resupply vehicle and Europe's Automated Transfer Vehicle (ATV).

As can be seen in Figure 2, the HTV is cylindrical and divided into pressurized and non-pressurized sections, with the propulsion equipment and guidance control instrumentation at the rear (at right in the photo), and containers

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•*Manned launch*

When a launch vehicle includes people in its payload, it is called a "manned launch." A manned launch differs from cargo-only launches in that it must reliably return its human payload safely to Earth, it must be equipped with an emergency escape system, and environmental conditions such as vibration and noise must be considered. For the launch of the Shenzhou manned spacecraft, China modified the design of its Long March 2E launch vehicle to produce the new Long March 2F. Major changes included adding redundancy in the control system, a self-diagnostic function for malfunctions, and an emergency escape system. In addition, it is believed that during the four test flights dummies were used in place of astronauts, in order to test medical monitoring and to train support personnel.

for the payload in the center. The HTV can transport a maximum cargo of about six tons. The unmanned automated rendezvous technology developed through the Engineering Test Satellite VII (ETS-VII, Kiku 7) is reflected in its ISS docking capability. Japan will replace its obligation to pay for ISS operation by resupplying the station using the HTV. As long as the ISS is in operation, a certain percentage of resupply demand can be expected.

4-3 Europe's Automated Transfer Vehicle (ATV)

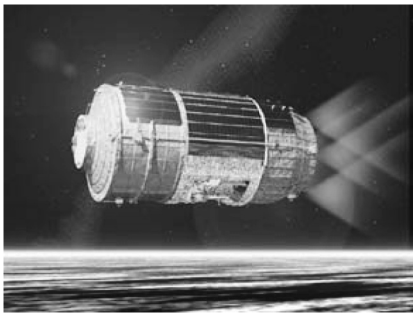
The concept for Europe's ATV has been taking shape since the 1990s. The October 1995 ESA ministerial meeting decided to develop the ATV, and Germany has taken the lead in its development. Current plans call for a 2006 test launch of the Jules Verne as depicted in Figure 3. The development process to date has not always been smooth, with problems such as cost overruns and technical issues arising, but it is currently seen in Europe as a major project that should be continued, even as budgets for other space-related projects are being cut. The ATV is to be launched by Ariane 5 launch vehicle and will automatically rendezvous and dock with the ISS, where it will be able to stay up to six months. About once a year, it will carry experimental equipments, food, and other everyday supplies to the Columbus European experimental module located at the forward starboard section of the ISS. The ATV is designed to carry about 7.5 tons of cargo per launch and to be capable of removing about 6.5 tons of waste from the ISS.

5 Trends in the development of Expendable Launch Vehicles (ELVs)

5-1 USA Evolved Expendable Launch Vehicles (EELVs)

In 1994, the USA announced its national policy on space transportation, with the Department of Defense (DoD) in charge of development of the Evolved Expendable Launch Vehicles(EELVs). Development is based on the Atlas IIAS and Delta II launch vehicles.

Figure 2 : External view of the HTV[3]



Source: Photo by JAXA

Figure 3 : External view of the ATV (Jules Verne)[4]

Source: Photo by ESA

Lockheed Martin has launched five Atlas V (five) launch vehicles since 2003. The weight it can carry into geostationary transfer orbit (GTO) has increased progressively from 3.8 to 8.7 tons. The heavy version aimed for at least 13 tons in GTO, but development has been halted. Meanwhile, Boeing attempted to upgrade the 1.8-ton GTO capacity of the Delta II to 3.8 tons with the Delta III. However, only one of the Delta III's three launches succeeded, and Boeing instead brought to market the Delta IV, which it had been developing along with the GTO 13-ton class. By 2004, the Delta IV Medium had successfully launched three geostationary satellites of about the GTO 3-ton class, and in the sense that it was an upgrade from the Delta II, the launch vehicle was a success. However, the first launch of the Delta IV Heavy (Figure 4) with a GTO 6-ton demonstration satellite in December 2004, was unsatisfactory because of a shorter than expected first-stage burn. According to materials released so far, cavitation (bubbles) in the liquid oxygen supply pipe apparently caused the first-stage burn to terminate. Boeing is already preparing a Delta IV Heavy to launch a DoD Defense Support Program (DSP) satellite.

Figure 4 : External view of the Delta IV Heavy

Source: Photo by Boeings

5-2 Europe's augmented Ariane 5

In Europe, the corporation Arianespace operates the Ariane launch vehicle, which has launched about half the world's geostationary communications satellites. The ESA's development program is aiming for the GTO 10-ton class with the Ariane 5E/ESC-A. The first launch, in December 2002, failed to insert the satellite into the prescribed orbit; however, on February 12, 2005, the same type of launch vehicle successfully inserted a communications satellite, proving its ability to launch 7.5 tons into GTO. The Ariane 5E/ESC-A is aimed at reducing costs by carrying two large geostationary satellites in one launch. If costs are lowered, the Ariane will be even more competitive.

5-3 An international joint venture's Sea Launch system

Recently, a new method of marine-based launches has been garnering attention. This method offers the advantage of being able to launch from the high seas on the equator, the optimal location for launching geostationary satellites. This permits maximum use of launch vehicle capability. Because launch vehicle preparation can be carried out onboard ship on the way to the range, work time is also reduced. Four corporations from the USA, Russia, Ukraine, and Norway, founded Sea Launch Co.[5] as a joint venture. The company's ships and a launch vehicle are shown in Figure 5. The sea launch platform is a former ocean oil-drilling platform. The 130-m long Odyssey platform is semi-submersible and self-propelled.

After launching a demonstration satellite into GTO in March 1999, Sea Launch carried out 14 more GTO launches up to March 2005. Of the 15 launches, only one, the March 2000 launch of an ICO satellite into a medium-altitude circular orbit, was unsuccessful. Thus, Sea Launch has successfully launched 13 satellites. Orbit insertion accuracy has improved with each launch.

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•*Multistage launch vehicle*

Launch vehicles use two or three stages to reach the desired speed and altitude, with each stage falling away after its fuel has burned out. These vehicles are called "multistage launch vehicles." The theory was first described in 1929 by the Russian, Konstantin Eduardovich Tsiolkovsky.

Launch vehicles launching geostationary satellites usually have three stages, propelling themselves until they reach geostationary transfer orbit (GTO). The first stage lifts the launch vehicle out of the atmosphere to space altitude, and the second accelerates it to satellite speed. The third stage changes the orbital plane to enter GTO. Then the payload satellite's apogee engine moves the satellite into geostationary drift orbit.

Japan's H-IIA can enter GTO even though it only has two stages. This is because the second-stage engine (LE-5B) can reignite and carry out the role of a third stage. This is advanced technology that stands up against any in the world. Russia's Proton launch vehicle, on the other hand, has four stages. The fourth stage is equivalent to a satellite's apogee engine, so the launch vehicle performs the role of attaining geostationary drift orbit.

Initially, satellites were about 20 km out of place, but recently error has been negligible. According to the Sea Launch work schedule, it takes three to four weeks from the time the satellite is loaded on the Assembly and Command Ship until it is launched, including one week to travel by sea from the Home Port to the range. To date, the shortest period between launches has been 53 days. The most recent launch took place on April 26, 2005, on the equator at 154° west longitude. The payload was a US DIRECTV Spaceway broadcast satellite (GTO weight 6.1 tons). The previous launch was on March 1, so the interval of 56 days was a near record for the company.

Figure 5 : A Sea Launch launch Vehicle (Zenit-3SL) being worked on

Foreground: Odyssey Launch Platform
Background: Assembly and Command Ship
Source: Photo by Sea Launch

5-4 China's next-generation launch vehicle

Trends in China, which is developing launch vehicles in the heaviest classes after those of Europe and the USA, are noteworthy.

At the 54th International Astronautical Convention (IAC), held in Bremen, Germany in October 2003, a Chinese scientist announced the new Long March launch vehicle[6]. The design of China's Long March launch vehicles developed from type 1 through type 4 from a military-use vehicle for missile launch to one that can be used for launching satellites. Because the developers used unsymmetrical dimethyl hydrazine (UDMH)

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• *"Geostationary transfer orbit" and "geostationary drift orbit"*

Geostationary earth orbit (GEO) is a circular orbit about 35,786 km above Earth's surface, with an orbital inclination of 0°. The orbital period is 23 hours and 56 minutes, matching Earth's rotation speed, so the satellite appears to be stationary as it orbits above the equator. In fact, it is traveling at over 10,000 kmph. Geostationary transfer orbit (GTO) is an elliptical orbit that ranges from a perigee of about 200 km to an apogee of about 36,000 km, over a period of around 12 hours. In the case of a launch from Tanegashima (30° north latitude) to the east, with a satellite inserted into GTO by launch vehicle, the satellite must consume a large amount of fuel through its apogee engine in order to transfer to geostationary drift orbit; therefore, the satellite's weight drops by about one-half compared to its weight at GTO insertion. When a satellite is launched toward the east from near the equator, required fuel consumption decreases, so the ratio is higher. Geostationary drift orbit is almost the same as geostationary earth orbit, but a small difference in period and a slight orbital inclination keep the orbit from becoming geostationary. Conversely, the satellite's geostationary position can be changed by controlling it so it drifts. The geostationary position of the US weather satellite GOES 9, which substituted for GMS-5 (Himawari 5) until MTSAT-1R began operating, was shifted from 105° west longitude to 155° east longitude.

• *"Range" and "launch pad"*

In order to launch satellites by a launch vehicle, a location from which to launch the vehicle is needed. This is the "range". At the range, the vehicle's stages are assembled and inspected, and the satellite, fairing, and so on are assembled and integrated with the vehicle so that the launch vehicle can be placed at the "launch pad," from which it will be launched. The range also includes control and supervising facilities.

as fuel, toxicity became a problem. China is currently using its experience in launching more than 80 Long March launch vehicles to engage in R&D on the Long March 5 series, with the aim of simplifying the launch process and increasing reliability.

The Long March 5 is assembled from combinations of seven kinds of modules with diameters of 5 m (stages one and two), 3.35 m (stages one, two, and three), and 2.25 m (stages one and two). The 5-m diameter first stage and second stage, the 3.35-m third stage, and the 2.25-m second stage are each equipped with a pair of engines that use liquid oxygen and liquid hydrogen as propellants to produce 50 tons of thrust. The remaining three modules (the 3.35-m first and second stage and the 2.25-m first stage) are each equipped with two engines that utilize liquid oxygen and kerosene to produce 120 tons of thrust. The fuelled weights of the first stage are 173.5 tons (5-m), 144 tons (3.35-m), and 64 tons (2.25-m). The second stage of 5-m module is only capable of entering low orbit, but adding an HO Module utilizing existing liquid oxygen/liquid hydrogen engines enables GTO insertion. Within the Long March 5 series, the strongest model, the 504/HO, adds four 3.35-m modules around a 5-m module with the aim of being able to insert 15 tons into geostationary transfer orbit. It may become the world's most powerful in terms of launch capability.

Looking at the Long March 5's design concept, it differs from launch vehicles in the Long March 2,3 and 4 series in that it can flexibly adjust its launch capability according to payload for anything from small satellites to heavy ones, and its engines use pollution-free or low-pollution liquids as fuel. Liquid-fuel engines are also desirable from a reliability standpoint, because they can be test-fired before use, and during launch, ignition can be confirmed before liftoff.

China plans to construct its fourth range on Hainan at 20° north latitude, so that island may become the site for Long March 5 launches.

Along with the Republic of Korea building its first range in Oenarodo, Cholla-namdo, China's construction of a new range bears watching.

5-5 India's PSLV and GSLV expendable launch vehicles

The Indian Space Research Organization (ISRO), which leads Indian space development, successfully launched India's first satellite with its own expendable satellite launch vehicle (SLV), in 1980. Subsequently, augmented (ASLV), polar orbit (PSLV), and geostationary orbit (GSLV) versions were also developed. Through 1997, two out of four SLV launches, three out of four ASLV launches and two out of four PSLV launches failed, for a dismal success rate of only 41.7 percent. However, since 1999 India has conducted eight consecutive successful launches of medium-sized satellites, including three geostationary satellites. Launch capacity is roughly one-half that of the Japanese H-IIA.

In 2001, India successfully launched a GSAT geostationary satellite with a GSLV for the first time. India's INSAT operational geostationary satellite carries instruments for communications and weather missions. So far, 13 INSAT satellites have been launched by European and US launch vehicles, but in the future they may be launched by India's own GSLV.

5-6 Japan's augmented-type H-IIA launch vehicle

The mainstay of Japan's launch vehicle, the H-IIA, has launched seven times, all successfully except for 6th H-IIA launch vehicle which failed by malfunction of SRB-A separation. Once the number of successful launches increases and reliability of the H-IIA's design is established, its operation will transfer- from JAXA to Mitsubishi Heavy Industries (MHI). Currently, Rocket System Corp. (RSC) is commissioned by JAXA or customers, and in turn commissions space-related businesses to carry out launch-related work. However, following the shift to the private sector MHI will be the primary actor, bringing together the products and personnel of relevant companies to prepare for launches and ultimately looking to JAXA for launch control only. This is expected to begin with contracts for fiscal 2006. This will provide clear separation between Japan's day-to-day launch operations and new development.

In charge of new launch vehicle development, JAXA has looked at several configurations for the augmented H-IIA and is aiming for the ability to insert 6 tons into GTO by increasing diameter from 4 m to 5 m and equipping two main engines inside of the first stage. If this performance goal is realized, the augmented-type H-IIA will be able to launch an HTV into low orbit and will be able to accept commercial orders to launch the world's heaviest communications satellites, such as Intelsat 10 (GTO 5.6 tons).

6 Deep space exploration beyond the moon

The energy required to reach space altitudes is expressed as “ΔV” (Delta V), or “velocity increment.” Figure 6 shows the ΔV needed to fly from an altitude of 10 km to a distance of almost 1 light year[7].

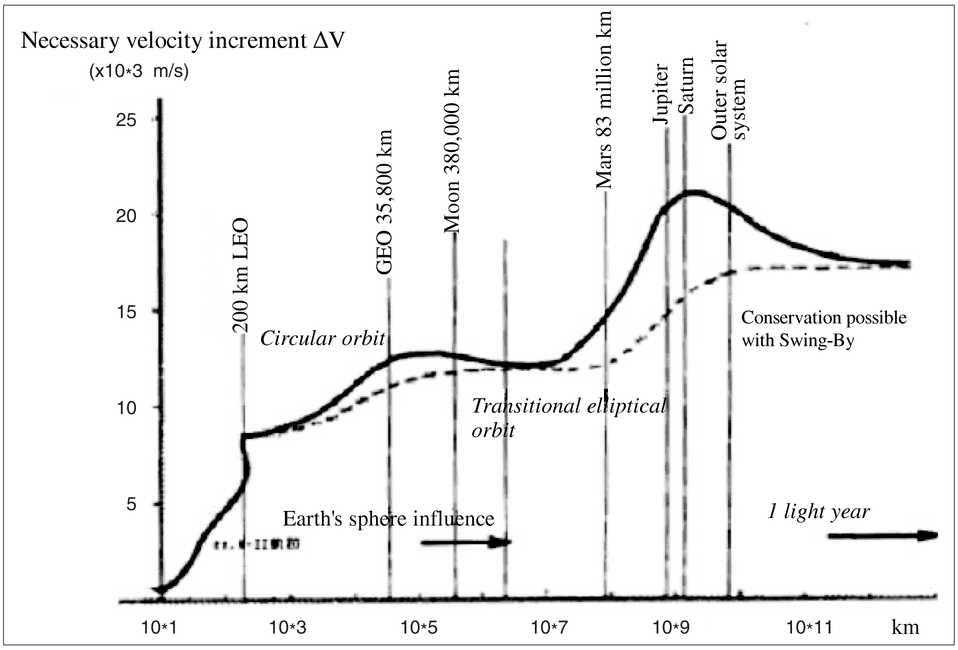
As can be seen in Figure 6, the velocity increment required to reach an altitude of 200 km is 8 km/s, while that needed to reach geostationary earth orbit (GEO) or the Moon is only slightly higher at 12 km/s. The distance to Mars is 200 times the distance to the Moon, while the distance to Jupiter or Saturn is thousands of times greater, but the velocity increment needed to reach them is less than one might expect. In such deep-space flight, rather than the launch vehicle only, propulsion systems installed in the probes handle an important part of the ΔV. In addition, flight plans for planetary probes conserve ΔV by using a method called “swing-by” to utilize the gravity of Earth or other celestial bodies for acceleration.

NASA has launched solar system probes such as Ulysses (Sun), MESSENGER (Mercury), Magellan (Venus), Lunar Prospector (Moon), Mars Observer (Mars), Galileo (Jupiter), Cassini (Saturn), Voyager (now outside the solar system), and Stardust (comet). Cassini made a close approach to Saturn's moon Titan in December 2004, and in January 2005 it released the ESA-developed Huygens toward that moon.

The Soviet Union launched deep space probes such as Venera (Venus), Luna (Moon), Mars (Mars), and Vega (comet).

In Japan, JAXA’s Institute of Space and Astronautical Science (ISAS) used solid rockets (the L-3SII and M-V) to launch Hagoromo (Moon), Nozomi (Mars), Suisei (comet), Hayabusa (asteroid), etc. Nozomi failed to reach Mars because of a malfunction in an oxidizer pressure valve, but Hayabusa reached the asteroid Itokawa, and is due to return with samples during 2005. In order to make that flight, Hayabusa was equipped with its own ion-engine propulsion system. This kind of Sample Return mission,

Figure 6 : Energy ΔV needed to reach from Earth[7]



which brings a small sample back to Earth from deep space, certainly qualifies as a type of space transportation system.

7 Reusable launch vehicle

Reusable launch vehicles are designed so that the vehicle can be recovered and refueled for the next flight. The two main categories of reusable launch vehicle are single-stage to orbit (SSTO) and two-stage to orbit (TSTO). In the case of two-stage reusable launch vehicle, the first stage may be a conventional aircraft, with the second stage fired in the air.

When either a single-stage or a two-stage reusable system is used, the only major recurring costs are the fuel consumed and the work performed. Therefore, costs can be much lower than they are for expendable launch vehicles, which face huge manufacturing investment for each launch. Reusable launch vehicles are especially effective for missions to launch materials for ultralarge satellites that must be assembled in orbit. With all of humanity facing an energy crisis as fossil-fuel resources run out, development of space solar power systems (SSPS) is one potential alternative energy strategy. However, if the costs of launching such systems are enormous, and more energy is required to develop and operate them than they can harvest, such development plans are not viable. When the Space Shuttle appeared it seemed that realization of space solar power systems might be within reach, but because the Space Shuttle uses expendable external tanks (ETs) and thus is not completely reusable, and because maintenance and repair after recovery takes longer than expected, construction plans for space solar power systems quickly faded away.

Not only the Space Shuttle but also the reusable launch vehicles that have been developed in various countries have experienced a series of challenges and failures. Below, I review past projects to develop reusable launch vehicles in several countries:

(1) USA

(i) Based on the 1994 national policy on space transport, NASA was placed in charge of developing a Reusable Launch Vehicle (RLV) as a successor to the Space Shuttle. NASA attempted to develop a lifting-body type X-33 experimental craft, but the composite tanks could not be lightened as expected and development was abandoned.

(ii) Then McDonnell Douglas (now merged to Boeing) developed the vertical takeoff and landing Delta Clipper for the US Department of Defense (DoD). Following its first flight in 1993, the Delta Clipper flew more than 10 successful test flights, but in 1996 it tipped over when landing because of a faulty strut, and was destroyed by fire.

(2) Russia

The Soviet Union in 1988 launched the Buran

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• *"Solid propellant rockets" and "liquid propellant rockets"*

A "solid propellant rocket" is a multistage launch vehicle in which where the propulsion equipment for every stage is a solid rocket motor. A "liquid propellant rockets" is a launch vehicle propelled by a liquid propellant engine.

During the Cold War "space race" between the USA and the USSR, almost all US and Soviet launch vehicles were liquid propellant rockets propelled by liquid propellant engines only. A typical example is Russia's Soyuz launch vehicle, which has five liquid engines (20 combusters) per vehicle. Including the Soviet era, more than 1,000 have been launched over a 40-year period. The largest type in Europe's discontinued Ariane IV series, the 44L, used eight liquid propellant engines for the first stage.

In Japan, the University of Tokyo succeeded in horizontally firing a solid-propellant pencil rocket in April 1955. Since then, the ISAS has developed the all-stage solid K (kappa), L (lambda), and M (mu) rocket series.

unmanned recoverable spacecraft with an Energia launch vehicle and successfully recovered it, but financial difficulties led to abandonment of the program.

(3) Europe

The ESA was attempting to launch the Hermes small recoverable spacecraft atop of Ariane 5 launch vehicle, but budget cuts led to development being aborted.

(4) Japan

During the 1990s, then National Space Development Agency (NASDA) and then National Aerospace Laboratory (NAL) collaborated to research and develop the horizontal-landing, recoverable H-2 Orbiting Plane (HOPE), launched by H-II launch vehicle. They also carried out test flights of the related Hypersonic Flight Experimental (HYFLEX) and Automatic Landing Flight Experimental (ALFLEX). The HYFLEX flew successfully, but it was lost into sea and could not be recovered. This prevented detailed analysis of changes in the craft's materials after re-entry. In 2003, High Speed Flight Demonstration (HSFD), in which the craft was released and landed under its own power, was carried out on Christmas Island in the Republic of Kiribati. However, the project remains frozen without an actual HOPE having been manufactured. In March 2005, JAXA announced its long-term vision. This includes not only continued operation and development of the H-IIA launch vehicle that is the basic of Japan's space transportation system, but also assertion of the need to develop a reusable launch vehicle transportation system. The basic concept is to work on new initiatives to improve the reliability of manned launches to the extent possible by carrying out small-scale reuse[8].

In the USA, the Ansari X Prize Foundation's prize scheme has stimulated private-sector competition in manned spaceflight. (See February 2005 "Topics.") The US company, SpaceX, is attempting not only to launch satellites but also to launch a private-sector space station, and to develop a manned spacecraft that can rendezvous and dock with the station. The group includes scientists who have previously worked in launch vehicle development in other space-related companies. It is possible that the free thinking of the private sector may race ahead of stagnating government projects and realize a true reusable launch vehicle. Expectations are high for the creation of spacecraft based on novel ideas.

In addition, research on "space elevators," a space transportation system concept that is completely different from all the chemical launch vehicles mentioned above, is proceeding apace. (See April 2005 "Topics 8.")

8 Conclusion: Discussion of how to proceed with development of Japanese space transportation systems

The time has come for Japan to clarify its basic strategy for ongoing research and development in the technical field of space transportation systems. In light of the trends in various countries described above, this report offers the following suggestions:

Supplement

•*Costs of reusable launch vehicles*

The development of reusable launch vehicles requires vast amounts of funding. This kind of funding is called "nonrecurring costs." In contrast, the funds needed to regularly operate a completed system are referred to as "recurring costs." Nonrecurring costs are lower with expendable launch vehicles than with reusable systems, but recurring costs can be more than 10 times as great. For example, overall costs would be approximately even for 100 launches with either type of system, but in the case of construction of a giant structure in space, such as a space solar power system (SSPS) which would require 200 or 300 launches to supply parts, costs would be much lower with a reusable launch vehicle.

(1) Implement use of the H-2 Transfer Vehicle (HTV)

Following retirement of the Space Shuttle, the HTV may be assigned a portion part of supply transportation to the International Space Station. The HTV is only a load at launch; but when it approaches the final destination it arrives under its own power and can fulfill an important role in space transportation. Japan should apply the robot technology that is its specialty to develop its own automatic rendezvous technology, starting with a focus on efforts to bring the HTV into practical use and secure a position in the International Space Station project.

(2) Maintain and develop technology for medium-sized expendable launch vehicles

Demand for commercial geostationary satellite launches amounts to only 20 to 30 annually. Furthermore, with the USA, Europe, Russia, and China all competing fiercely for market share, it is very difficult for the H-IIA to win orders. However, maintaining launch operations and the manufacturing technology needed for the 280,000 parts used in launch vehicles can still play a role in terms of technical development and transmission of industrial techniques such as materials development and manufacturing technologies. In addition, it can also make direct and indirect contributions to the creation of knowledge through space experiments in fields such as life science and environmental research. Japan should not only pursue world-leading launch capacity for the augmented version of the H-IIA, it must also maintain the basic launch vehicle technology that can reliably and flexibly launch the many medium-sized payloads that exist.

One possible direction for development is to equip the augmented version of the H-IIA with a propulsion system comprising liquid propellant engines only, as with the USA's evolved expendable launch vehicles and China's Long March 5 series. This technology might also enhance reliability. Another direction is to aim for technology that allows stage-two engines to be reignited multiple times for satellite insertion into geostationary drift orbit, without needing to use the satellite's apogee engine. This would lower the manufacturing costs of geostationary satellites and allow the weight of instruments loaded on the satellite to be increased. Alternatively, multiple satellites could be launched with a single launch vehicle, lowering launch costs per satellite. Such a space transportation system could be very competitive internationally.

(3) Foster basic technologies through development of reusable launch vehicles

In the development of space solar power systems, projects in which the energy invested in development and operation would be greater than that harvested by the system are not viable. A reusable launch vehicle must be developed, so that the power system can be assembled in orbit while conserving resources and energy, and reducing launch costs. However, based on past failures in other countries, certain technical aspects are not yet mature: development of lightweight structural materials that can bear the heat of re-entry (a particular issue with reusable systems), innovative propulsion systems, etc. Until now, "accumulating basic technologies" and "demonstration through repeated operation" have been considered completely different categories. However, the complexion of reusable launch vehicle development differs from that of conventional expendable launch vehicle development, and it is possible to foster basic technology to improve the system's reliability, life, and overall toughness while carrying out repeated demonstrations. Preparing a system to foster realistic basic technology through repeated demonstrations may also be very significant.

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Abbreviations

•*ALFLEX*	Automatic Landing Flight Experimental (Japan)
•*ASLV*	Augmented Satellite Launch Vehicle (India)
•*ATV*	Automated Transfer Vehicle (Europe)
•*CEV*	Crew Exploration Vehicle (USA)
•*DoD*	USA Department of Defense
•*DSP*	Defense Support Program (USA early warning satellite against missiles)
•*EELV*	Evolved Expendable Launch Vehicle (USA)
•*ELV*	Expendable Launch Vehicle
•*EPA*	USA Environmental Protection Agency
•*ESA*	European Space Agency
•*ET*	External Tank (Space Shuttle)
•*ETS*	Engineering Test Satellite (Japan)
•*FSA*	Federal Space Agency of Russia
•*FW*	Filament Winding (A method of manufacturing composite materials. Bundles of plastic impregnated with carbon fiber are wound around a form and hardened to create structures of various shapes.)
•*GEO*	Geostationary Earth Orbit (circular orbit approximately 35,786 km above Earth's surface)
•*GSLV*	Geostationary Satellite Launch Vehicle (India)
•*GTO*	Geostationary Transfer Orbit (elliptical orbit ranging from 200 km to 36,000 km)
•*HOPE*	H-2 Orbiting Plane (Japan)
•*HSFD*	High Speed Flight Demonstration (Japan)
•*HTV*	H-2 Transfer Vehicle (Japan)
•*HYFLEX*	Hypersonic Flight Experimental (Japan)
•*IAC*	International Astronautical Convention (An annual conference sponsored by the International Astronautical Federation [IAF]. The 2005 convention was held in Fukuoka.)
•*ICO*	Intermediate Circular Orbit
•*ISAS*	Institute of Space and Astronautical Science (part of the Ministry of Education, Culture, Sports, Science and Technology until September 2003; now a part of the Japan Aerospace Exploration Agency)
•*ISRO*	Indian Space Research Organization
•*ISS*	International Space Station
•*JAXA*	Japan Aerospace Exploration Agency
•*KIS*	**Контрольно-Испытательная Станция** Kontrolno-Isptatelnaya Stantsiya (Complex Integrated Stand)
•*MHI*	Mitsubishi Heavy Industries
•*MTSAT*	Multi-Functional Transport Satellite(Japan)
•*NASA*	National Aeronautics and Space Administration(USA)
•*PSLV*	Polar Satellite Launch Vehicle (India)
•*RCC*	Reinforced Carbon-Carbon
•*RFP*	Request for Proposal (a method for fairly selecting contractors)
•*RKK*	**Ракетно-Космицеская Корпорация** Raketno-Kosmicheskaya Korporatsiya (Rocket Space Corporation [Russia])
•*RLV*	Reusable Launch Vehicle (USA)
•RSC	Rocket System Corporation (http://www.rocketsystem.co.jp)
•*SRB*	Solid Rocket Booster
•*SSC*	Shirako Space Consulting (http://www2s.biglobe.ne.jp/~gshirako/)
•*SSPS*	Space Solar Power System
•*SSTO*	Single Stage to Orbit
•*STS*	Space Transportation System (formal name of the Space Shuttle)
•*TSTO*	Two Stage to Orbit
•*UDMH*	Unsymmetrical Dimethyl Hydrazine

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