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Advanced Solid Rocket Launcher and its Evolution

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The research on next generation solid propellant rockets is actively underway in various spectra. JAXA is developing the Advanced Solid Rocket (ASR) as a successor to the M-V launch vehicle, which was utilized over past ten years for space science programs including planetary missions. ASR is a result of the development of the next generation technology including a highly intelligent autonomous check-out system, which is connected to not only the solid rocket but also future transportation systems. It is expected to improve the efficiency of the launch system and double the cost performance. Far beyond this effort, the passion of the volunteers among the industry-government-academia cooperation has been united to establish the society of the freewheeling thinking "Next generation Solid Rocket Society (NSRS)". It aims at a larger revolution than what the ASR provides so that the order of the cost performance is further improved. A study of the Low melting temperature Thermoplastic Propellant (LTP) is now at the experimental stage, which is expected to reform the manufacturing process of the solid rocket propellant leading to an increase in the cost performance by a factor of ten. This paper indicates the direction of the big flow towards the next generation solid-propellant rockets: the concept of the intelligent ASR under development; and the innovation behind LTP

Key Words: Advanced Solid Rocket, Responsive Launch, Mobile Launch Control, Intelligent Avionics System, LTP

1. Introduction

The research on next generation solid propellant rockets is actively underway in various spectra all over the world. The advanced solid rocket (ASR) launcher is under development by JAXA as a successor to the established M-V rocket (Figure 1).[1,2)] It aims at the development of an indispensable next generation technology not only to the solid rocket but also to future transportation systems as it improves the efficiency of the launch system by making the check-out function highly autonomous. On the other hand, the freewheeling thinking "next generation solid rocket society (NSRS)" was established by the zeal of the volunteers among the industry-government-academia cooperation in order to make larger reform that can reduce the transportation cost more significantly.[3)] During 50 years of history of Japanese solid rocket launchers, a rapid improvement and an increase of the rocket performance were brought by the introduction of the composite propellant and composite materials. They finally led to the technology required to directly put spacecraft into a planetary orbit. Then, what is the next evolution? The further reform towards next 50 years greatly depends on what we do at this time. The paper reveals innovative ideas, such as simplification of the launch system, propellant manufacturing process and the ignition method, which will change the rocket history in a drastic way.

2. Advanced Solid Rocket Launcher

2.1. A Small Step leading to a Big Leap

The study on solid propellant rockets of Japan started with a horizontal launch experiment of tiny pencil-size rockets 54 years ago. Such endeavor was finally rewarded and Japan's first artificial satellite "Ohsumi" was launched in 1970 by a four-stage all-solid propellant Lamda-4S rocket. From then on, Japan's research and development of solid propellant launchers were conducted independent of foreign technologies and it was utilized only for space science missions. In mid-90's, the M-V rocket became available to meet the strong demand for 2-ton class full-scale scientific missions planned in late 90's and early 2000's. It was the biggest and best performance all solid propellant launch system in the world that can be utilized for both inter-planetary and solar-synchronous missions.

Figure. 1. Advanced solid rocket launcher on pad.

The M-V vehicle contributed to Japan's

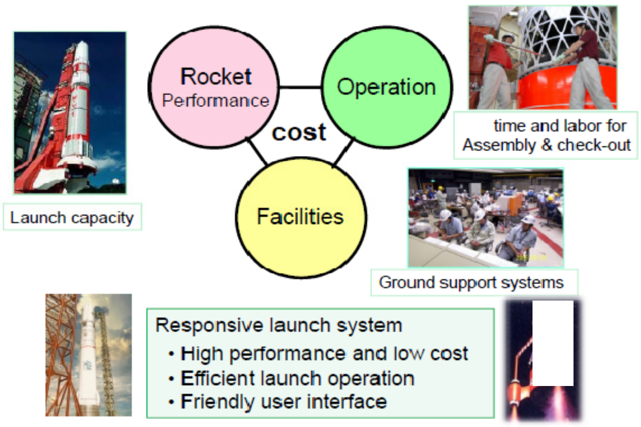


Figure 2. Concept of the ASR launcher.

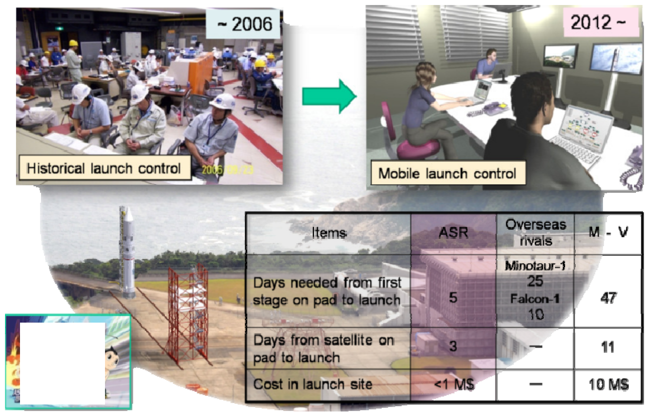


Figure 4. Evolution of the launch system.

space science in almost all its fields from space astronomy to even planetary missions. After it lifted its first payload, the world's first radio-astronomy satellite "HALCA" in 1997, the vehicle launched the world's first asteroid sample-return spacecraft "HAYABUSA" in 2003 directly into its inter-planetary trajectory. In February 2006, the vehicle became the world's first and only solid rocket launcher that can be utilized for both inter-planetary and sun-synchronous missions when it put the sun-synchronous satellite "AKARI" into orbit. Unfortunately, the operation of the M-V rocket was terminated in September 2006 mainly due to its relatively high operational cost after it launched Japan's second solar observation satellite "HINODE" into a solar synchronous transfer orbit. On the verge of extinction of Japan's solid rocket launchers, the next-generation solid propellant launch vehicle called Advanced Solid Rocket (ASR) has emerged, which is aimed at exceeding the established M-V rocket to meet the strong demand of the new era of space science and space transportation.[4)] The vehicle is not just a successor to the M-V rocket but a pioneer to lead the next 50 years of Japan's unique research on the solid rocket launchers by adopting a wide variety of innovative concepts.[5-9)]

2.2. Intelligent Self Check-out System toward the Next Generation

Throughout the 50 years history of the solid rocket launchers, the research and development were executed only to increase the

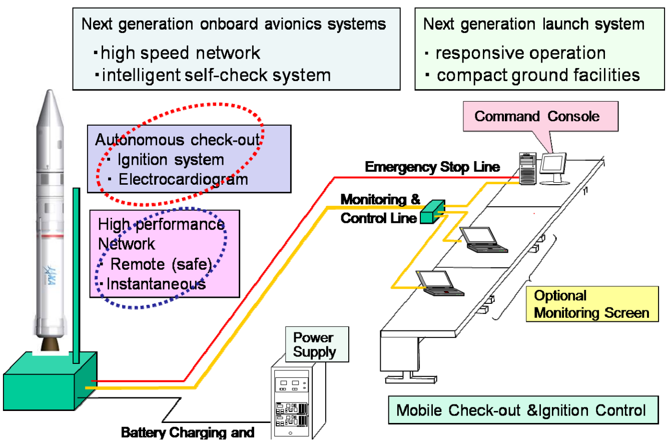


Figure 3. Schematic diagram showing an image of the future launch control.

payload capacity and orbital accuracy. The cost and the efficiency of launch system have not been seriously considered. Note that the concept of launch system involves not only the vehicle itself but ground facilities and operations. The purpose of the ASR launcher requires optimization of the launch system to minimize the associated time and labor necessary for launching and to make the ground support system as compact as possible (Figure 2). This leads to evolution of the launch system from the current launch system into a responsive one. The key to success is the innovation of the onboard avionics system. It is designed to be connected with each other and with the ground facilities by a high-speed serial bus, possibly the Spacewire (Figure 3). In addition, it is designed to be highly intelligent so that the vehicle performs onboard check-out autonomously.[10)] Owing to this endeavor, the check-out of the onboard ignition system will be performed remotely, safely, and instantaneously while it used to take a few days because it required the highest level of safety. It can also eliminate associated ground facilities. Furthermore, ultimately, through the network, it will be possible to check and control rockets anywhere in the world simply by using a single laptop computer. This is called the mobile launch control. Consequently, the time needed for the ground operation is dramatically reduced and the operational efficiency of the ASR launcher can be considered the highest standard of the next-generation (Figure 4). Such an innovative concept for the ASR will open doors for future launch systems.

2.3. Enhanced User Interface

The level of user friendliness of the ASR launcher is planned to be enhanced to exceed the already high performance M-V launch vehicle. For more versatile orbital maneuverability and more accurate orbital injection, an optional tiny post-boost stage (PBS) can be installed as a fourth stage rocket atop the third stage motor which utilizes small hydrazine engines (Figure 5)[1, 13).] The engine is planned to be virtually identical to that of the Side Jet (SJ) established for the M-V third stage attitude control. By using this option, a wide variety of orbits that small satellites require can easily be reached including a solar synchronous orbit and even a planetary trajectory. In addition, the accuracy of trajectory can be increased to as high as that of liquid propellant rockets, better than that of the M-V rocket (Table 1). Note that the orbit insertion precision of solid propellant rockets is, in general, less than that of the liquid propellant launchers

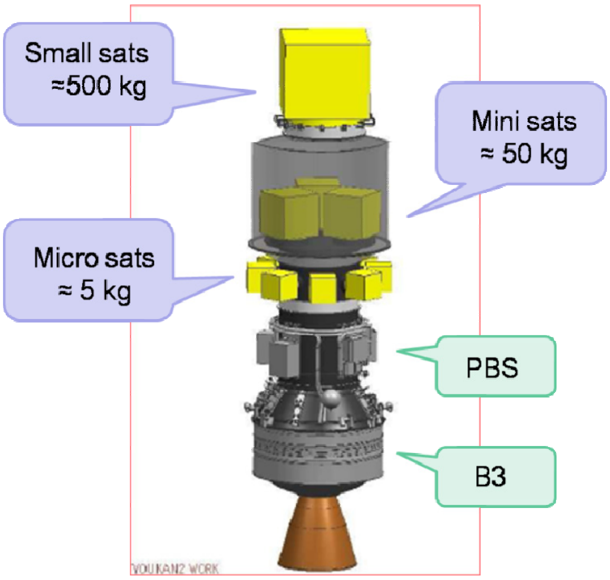


Figure 5. Multi-launch configuration.

simply because their total impulse of the last stage cannot be controlled.

Another service that small satellites most welcome will be the reduction of mechanical environment. Especially, the acoustic environment is designed to be lowered by introducing a special ground facility and utilizing a refined method of numerical analysis[7]. Note that the acoustic environment of solid propellant rockets is relatively severe as compared to that of liquid propellant vehicles due to its higher thrust at ignition.

The first payload to be launched by the Advanced Solid Rocket is a planetary telescope named TOPS and its target of launching is expected to be as early as in 2012. The satellite will be inserted into a low circular orbit at an altitude of about 700 km by use of the post boost stage. Following the TOPS project, there are 5 missions now being under review, which include a space plasma research project and an X-ray observatory mission. Although the second mission remains to be selected soon, it will be launched just after the first mission. In addition to these missions under review, as many as 10 missions have been studied intensively to be onboard ASR launcher. The mid-term plan of JAXA permits the ASR to be launched at a frequency of 3 times par 5 years but we are working to increase the launch opportunities significantly to satisfy the needs of domestic payloads.

Although the ASR launcher is aimed at relatively small satellites having marginal excess capacity, its development involves launching of piggybacks in a multi launch configuration (Figure 5). Note that the maximum capacity of the ASR launcher is approximately 1.2 ton into a low earth orbit and 500 kg into SSO. The current idea is to accommodate multi-satellites ranging from small satellites weighing up to 500 kg through mini-sats of 50 kg scale to micro-sats of below 10 kg c. The multi launch interface is now under study but it will be standardized. The M-V rocket already launched more than 5 micro satellites, which were all university satellites, and of course, the ASR launcher will launch much more to lower the threshold of space utilization..

Table 1 Orbit insertion accuracy of ASR.

Trajectory		Configuration: Standard	Configuration: PBS
SSO@500km	Perigee error	±25 km	±20 km
	Apogee error	±100 km	±20 km
	Inclination	±0.6 deg.	±0.2 deg.

3. Next Generation Solid Rocket Society

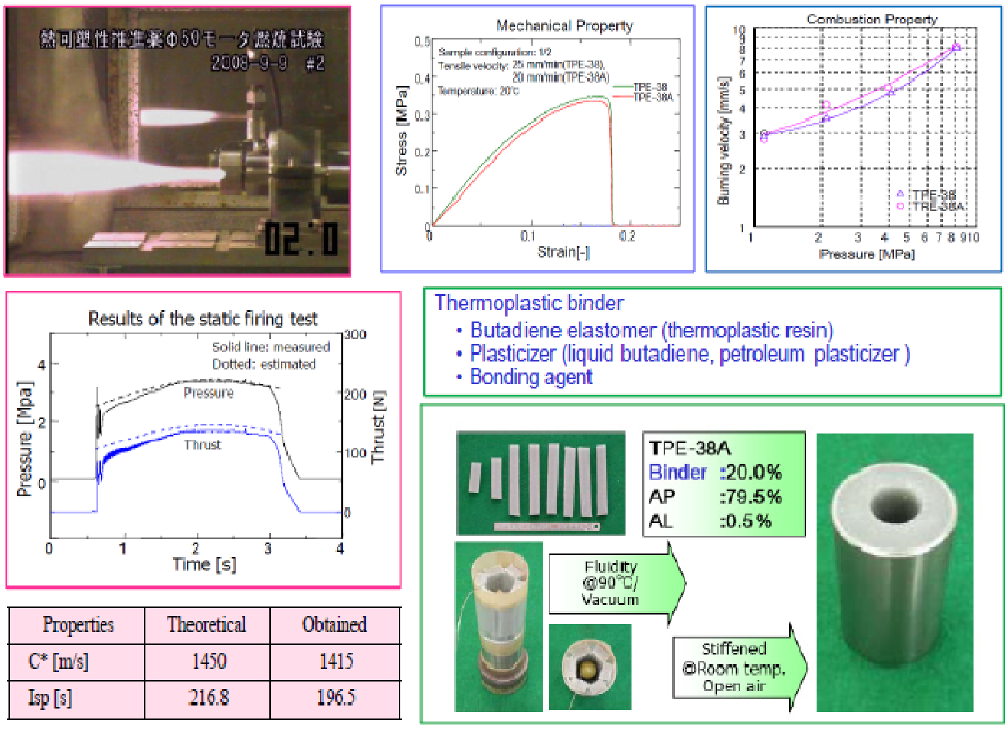
This is how we reform the launch system through the JAXA's ASR launcher. Then, what is the further evolution towards the next 50 years? Beyond the JAXA's ASR launcher, the freewheeling thinking "next generation solid rocket society" was established in May 2006 by the zeal of the volunteers among the industry-government-academia cooperation, and the society now has more than 20 members from agencies, institutes, universities, and private companies. Its purpose is to reform the space transportation systems and make a Copernican change of the cost performance in order to break the current state that the expansion of the space science and the space utilization is restrained by the high cost of space transportation. After graduating from the carnival-like old-fashioned launching of big guns of the Apollo age, let's bid farewell to large-scale and low utilization frequency of manufacturing process. Let's lower the threshold to space and open the door to various missions. The target is a smaller, cheaper and more versatile system. This will lead to the decentralization of the risk, and the idea of reliability will change completely. How can such a big vision be achieved then, and what strategy to pursue? The key technologies to realize the innovation concept can be summarized in Table 2. First of all, a new propellant that completely changes the concept of the current composite propellant, a Low melting temperature Thermoplastic Propellant (LTP), is considered a key player to make the manufacturing process of propellant dramatically simple. On the other hand, the achievement of the fly-by-wireless will be expected more in the future avionics systems.

3.1. Revolution of the Solid Rocket Propellant

Historically, the performance and the manufacturing process

Table 2. Innovative ideas for next generation launch systems.

Propulsion Propellant, Insulation, Nozzle	・Low melting temperature Thermoplastic Propellant (LTP) ・Green propellant ・Multi-nozzle(grating nozzle)
Structure /Material Motor case	・Commercial based low cost materials ・Film wrapping (simpler process)
Avionics Guidance & Control, Wiring	・Fly-by wireless (wireless ignition system) ・Power Line Communication(PLC) ・more applications of GPS
Launch System	・Air Launch & on-orbit assembly ・Fly back boosters ・Space pigeon
Operation Ground operation Telemetry & command	・telemetry & command using satellites ・Autonomous operation



Properties	Theoretical	Obtained
C* [m/s]	1450	1415
Isp [s]	216.8	196.5

Figure 6. An representative example of LTP and its static firing test.

of the solid propellant improved significantly by the introduction of the composite propellant and it made more powerful and larger solid propellant rockets into reality. This almost established the solid rocket technology and enabled all solid propellant rocket launchers to conduct even planetary explorations. Whether it stagnates as it is or it leapfrogs is strongly dependent on what can be taken at this time. What is the next evolution following the composite? Among the factors pushing up the price of rockets is the manufacturing process of large-scale and low utilization frequency, thus it is now aimed at that the process be converted to the one of small-scale and high frequency for a significant cost reduction. The current manufacturing process of the solid propellant consists of: the stir mixture of a binder (HTPB), an oxidizer (ammonium parchlorate: AP) and aluminum powder with the mixer; and molds them into the motor case. Then, the whole motor case is heated so that the elastomer becomes stiffened. This final process, heat stiffening, is a one-way reaction that makes the entire process become a quite sensitive no-return process and cannot be stopped once started. Therefore, the manufacturing facilities, even the mixer, become gigantic although their utilization rate is very low, leading to an inefficient facility and labor skill cost.

This is why a propellant of a quite novel type is introduced here. It has a reverse nature to the conventional composite propellant: thermal elasticity and low melting temperature that can make an evolution in the solid propellant.[11] This propellant remains solid at room temperature while it melts when heated at a relatively low temperature of below 100℃ and it is most important this nature is a two-way reaction like a chocolate bar. Now that the manufacturing process can be intermitted between mixing and molding, the chocolate bar-type small pieces of propellant can be mixed by a laboratory-scale small mixer and can be produced continuously day and night. Finally, they can be stored in a stock house, thus raising utilization rates of the mixer up to 100%. Then, the final loading of the propellant into a motor case can be easily done by melting pieces of propellant bars and molding them into motor case at an automatic mass-production style. In this way, the manufacturing process can be converted to one of a much smaller scale and high utilization frequency, leading to a reduction of personnel expenses. As it is natural that the resin melts at high temperature, there can be many candidates potentially, and we're searching for the characteristic that has affinity with AP, dissolves at moderate temperature and of course has enough mechanical strength and burning velocity. The LTP consists of AP, aluminum powder and thermoplastic binder, which is currently a combination of Butadiene elastomer, Plasticizer and bonding agent. A series of static firing tests have already been done with satisfactory results and the practical use can be expected soon (Figure 6)[12]. Throughout the entire history of the solid rocket launchers in Japan, the endeavors have been paid steadily only in performance enhancement, but from now on, an evolution is aimed at a significant cost reduction based on improving the manufacturing process that will change the history.

3.2. Revolution of the Onboard Avionics

There is also another factor pushing up the price of rockets and it is the electrical systems that are expensive because of special specifications and the wiring between them is so complicated. The onboard wiring can be eliminated by making communication between the onboard electronics wireless, that is, fly-by-wireless. If such an idea can be realized, the world of pyrotechnic of rockets will change dramatically. It is so-called "wireless pyrotechnic" and the effect will be significant because expensive detonation tubes become redundant. In addition to the miniaturization and lightening, it is a big charm that a free layout is possible. The practical use is expected quite soon because the trial manufacture examination has been done, which has demonstrated the effectiveness of the wireless ignition system in the aspects of: multi-communication; simultaneous command; obstacle-proof; and resistance against hacking (Figure 7).

4. CONCLUDING REMARKS

This paper deals with novel designs of next generation solid-propellant rockets in a wide spectrum: the concept of the Advanced Solid Rocket launcher (ASR), now under development at JAXA, which doubles the cost-performance over the previous rocket and is loaded with the highly intelligent autonomous check-out system to reform the launch system into an efficient responsive one; and a study of the Low melting temperature Thermoplastic Propellant (LTP), now at the experimental stage, that is expected to convert large-scale and low utilization frequency manufacturing process to be of small-scale and high utilization frequency resulting in a significant cost reduction. The study indicates the direction of the big flow toward the next generation of solid-propellant rockets: revolution in launch system and manufacturing process.

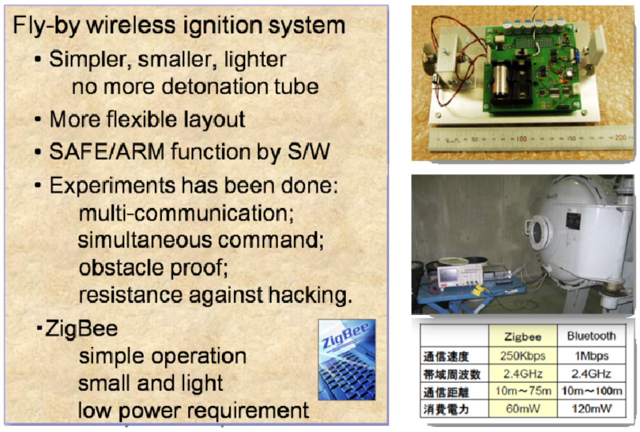


Figure 7. Fly-by Wireless.

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