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A Concept of International Nano-Launcher

Kazuhiro Yagi, Seiji Matsuda, Jun Yokote
IHI AEROSPACE Co., Ltd. (IA)
900 Fujiki Tomioka-shi Gunma Japan; +81-0274-62-7684
k-yagi@iac.ihi.co.jp ; matsuda-s@iac.ihi.co.jp ; jun-yokote@iac.ihi.co.jp

Takayoshi Fuji, Kenji Sasaki
Institute for Unmanned Space Experiment Free Flyer (USEF)
2-12 Kanda-ogawamachi Chiyoda-ku Tokyo Japan; +81-3-3294-4834
fuji@usef.or.jp ; k.sasaki@usef.or.jp

Mitsuteru Kaneoka
CSP Japan Inc.
2-2-2 Uchisaiwai-cho, Chiyoda-ku, Tokyo Japan; +81-3-3508-8105
kaneoka@csp.co.jp

Shinichiro Tokudome, Yohsuke Nambu
Institute of Space and Astronautical Science (ISAS)
3-1-1 Yoshinodai, Sagamihara, Kanagawa, Japan; +81-42-759-8250
tome@isas.jaxa.jp ; namnyef213@svs.eng.isas.jaxa.jp

Masaaki Sugimoto
Department of Earth and Planetary Science, The University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo, Japan; +81-03-5841-4281
sugimoto.japan@gmail.com

ABSTRACT

NEDO (New Energy and Industrial Technology Development Organization) initiated three-year small satellite technology development program from April 2008 under the sponsorship of METI (Ministry of Economy, Trade and Industry). In the meantime, the team of a private company and an university has conduced a feasibility study of atmospheric observation using mini satellites. Nano space is drawing strong interests from civil and defense agencies, academia and industry in major space fairing nations. It soon will be able to provide many innovative technologies that dramatically change design, manufacturing, operation and, most importantly, economy of the future space systems and applications. Launch opportunity for the nano space system is still limited to mixed loading on current launch vehicles. Dedicated new launcher optimized for this new category of the space system will strongly be requested as missions using nano satellites become more practical. Nano-launcher has to be affordable and available to anyone at any time and launched from the wide variety of locations in land, sea or air. This paper summarizes results of the concept study of Nano Launch Vehicle Systems (NLVS) capable of lifting 1kg-30kg payloads. The combination of US existing rocket system and sounding rockets of Japan is proposed as an example of promising solutions for the cost reduction using international cooperation scheme. Key elements, including maximum use of existing technologies, minimization of ground support facilities, multi-platform launch system, are also discussed.

INTRODUCTION

Technologies in MEMS and advanced material facilitate miniaturization of components and increase in performance and efficiency. Demand for 1kg-30kg nano satellites was relatively limited in universities for hands-on training and education of students. As shown in Figure 1, civil and defense government organizations and even private companies actively employ nano satellites for testing and demonstration of technologies, experiments and practical applications, such as telecommunication.

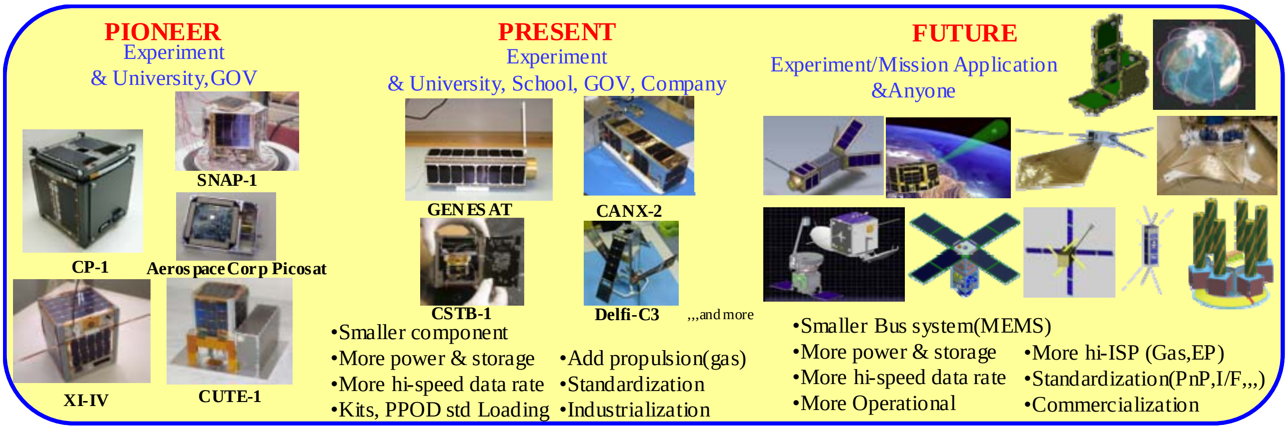

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Figure 1. Nano-sat Revolution

Nano satellites have typically launched as secondary payloads, using unused space on an existing mission. While this practice will likely continue in near future, they have to compromise objectives of their missions because the primary payload is entitled to have a priority in mission planning, mission timelines, orbital targeting, launch windows, and overall scheduling. So, it is necessary for nano satellite developers (for example, scientific and engineering researchers) to have some flexible launch opportunities in attempting to develop their new and revolutionary technologies. From this viewpoint, we propose to develop a nano launch vehicle fully exploiting S-520 sounding rocket technologies, practices and hardware to provide low-cost, frequent access to space for nano satellite mission planners.

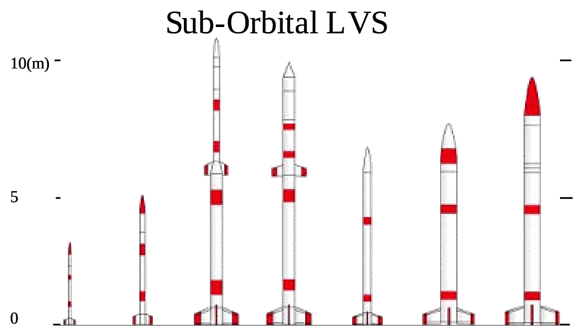
This paper summarizes results of the concept study of Nano Launch Vehicle Systems (NLVS) capable of lifting 1kg-30kg payloads.

This study is carried out by the team of USEF, IHI Aerospace, CSP Japan, and ISAS.

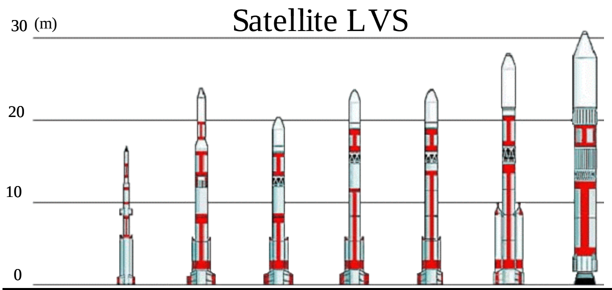
HISTORY OF SOLID ROCKETS IN JAPAN

Japanese space launch vehicle development was started with a Pencil Rocket in 1955. Since then, ISAS developed solid-based sounding rockets and satellite launch vehicles (Figure 2).

M-V, latest model of solid rockets, was the largest all-solid rocket developed for science and exploration missions. Last M-V was launched in September 2006.



	MT-135	S-210	K-9M	K-10	S-310	S-520	SS-520
Total Length	3.3m	5.2m	11.1m	9.8m	7.1m	8.0m	9.65m
Diameter	0.135m	0.21m	0.42m	0.42m	0.31m	0.52m	0.52m
Weight	0.07t	0.26t	1.5t	1.78t	0.7t	2.1t	2.6t
Altitude	60km	110km	330km	240km	190km	430/350km	1000/800km
Payload	2kg	20kg	55kg	132kg	70kg	70/150kg	30/60kg
Flight Year	1964	1969	1962	1965	1975	1980	1998
Launches	1200+	44	88	14	39	24	2



	L-4S	M-4S	M-3C	M-3H	M-3S	M-3SII	M-V
Total Length	16.5m	23.6m	20.2m	23.8m	23.8m	27.8m	30.7m
Diameter	0.735m	1.41m	1.41m	1.41m	1.41m	1.41m	2.5m
Total Weight	9.4t	43.6t	41.6t	48.7t	48.7t	61t	139t
Payload to LEO	26kg	180kg	195kg	300kg	300kg	770kg	1800kg
Flight year	1970	1971	1974	1977	1980	1985	1997
Rate (s/l)	1/5	3/4	3/4	3/3	4/4	7/8	6/7

Image Source

Figure 2. Solid Rockets of Japan

Sounding rocket family of S-310, S-520 and SS-520 is still in use and next generation solid rocket research is carried out.

IHI Aerospace Co., Ltd. has been contributing to these solid rocket developments in Japan as a leading manufacturer of rockets applying the technologies and expertise of the solid propulsion rocket motors.

NANO LAUNCHER EVOLUTION

Sounding LVS is already used for science missions, disaster monitoring, atmospheric research, air breathing engine development, CANSAT and CUBESAT deployment, fly-back LVS technology development in Japan and foreign countries. If upgraded in short period and with low development cost, competitive NLVS will be able to provide flexible launch services to those potential users (Figure 3).

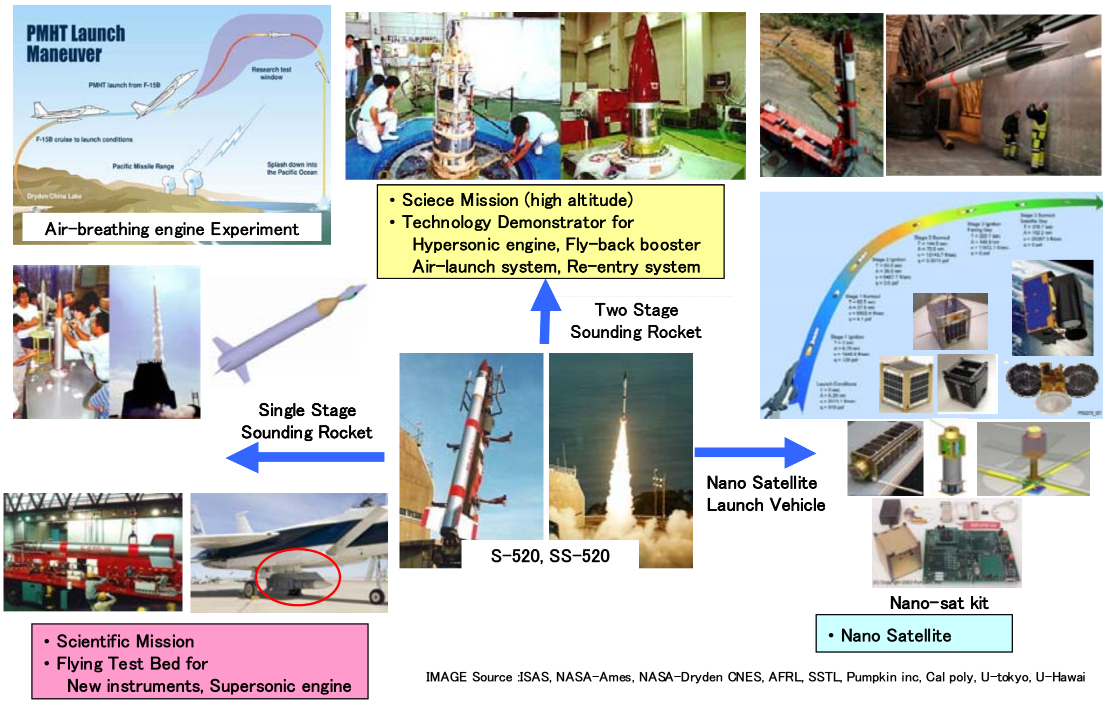


Figure 3. Potential Users of Nano-launcher

S-520 sounding rocket, operated by ISAS and IHI Aerospace, is a powerful single-stage rocket which has a capability for launching 100kg payload far above 300km altitude. SS-520 is a two-stage sounding rocket, the first stage of which comes from S-520. It is 9.65m in length, 0.52m in diameter and 2.6t of total glow mass and is capable of delivering 30kg payload to 1000km sub-orbital trajectory. S-520 has successful launch of 24 while SS-520 launched twice by now. Japanese sounding rockets have been launched from many sites, including Andoya, Norway(S-520, S-310), Showa station, Antarctica (S-310, S-210). NAL-735, which is based on SB-735 booster of M-3S-2 rocket, have been launched from Woomera, Australia for supersonic airplane experiment.

NLVS will be developed using phased approach. At first, we develop NS-520 (S-520 + B0 boost stage), which is low-cost and performance enhancement version of S-520 rocket family. Next, NLVS " NL-520 (NS-520 + upper stage)" capable of lifting up to 20kg payload to 250km LEO, will be developed and introduced to the international launch market.

AL-520 is air-launched version of NL-520. Air launch is considered as most ideal launch system for small satellites because of its launch capability, minimum ground support, higher flexibility and mobility advantage, and affordable cost. From the safety point of view, any launch from Japanese existing launch site (Tanegasima and Uchinoura) requires dog-leg flight path that results in velocity loss due to vehicle maneuvering. Air launch approach clears off the loss of vehicle performance and, with a large mother ship and a supersonic airplane, high launch performance could be achieved.

R&D roadmap of this upgrade effort is shown in Figure 4.

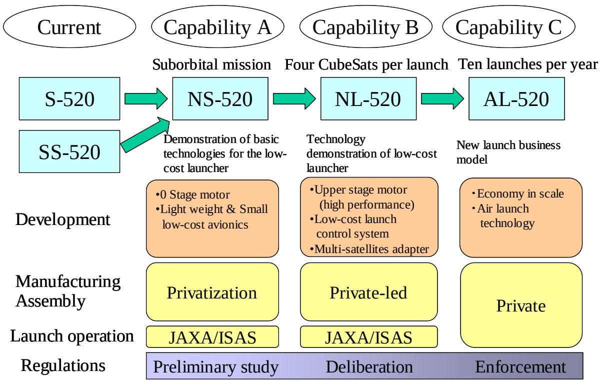


Figure 4. Nano-Launcher Phased Development

A family of Nano-launcher, including NS-520, NL-520 and AL-520, accelerates the use of cost effective Nano space activities. Advanced solid rocket technologies of Japan could contribute to the education, training, small space technology development and testing, disaster monitoring, and weather monitoring in Asia, US, Europe and Russia.

VEHICLE CONFIGURATION AND OPERATION

NS-520 is a two stage sounding rocket and NL-520 is a four stage land launcher NLVS that derived from the S-520 sounding rocket. The overall configurations of these NLVSs are shown in Figure 5.

NL-520

The main objective of developing NL-520 (Nano-sats launcher) is to provide low-cost, frequent access to space for various mission planners. Development strategy of NL-520 is described below;

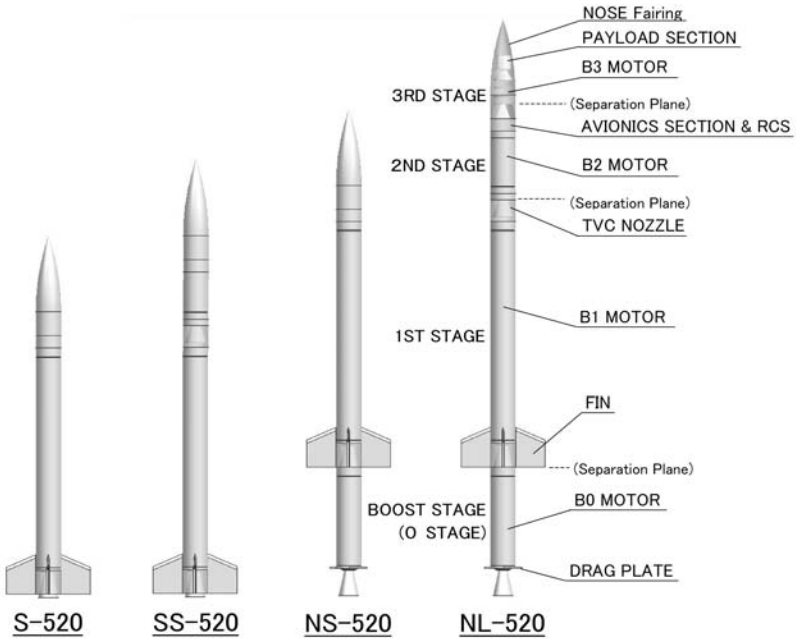
1) Achieve maximum use of existing components and devices of S-520, including the existing launch site facilities (such as Rail Launcher), to minimize cost, reduce risk, and permit early test flight.

2) Develop light-weight and small, low-cost avionics system, using commercial technologies and COTS products. The target weight and cost are one-tenth of avionics for conventional heavy lift rockets. The weight and cost of avionics are critical factors for small launcher.

3) Develop a method to integrate standardized satellite deployment system, like P-POD, on NL-520 to provide easy interfaces to Nano-sat mission planners.

Flight Sequence

Typical flight sequence of NL-520 is illustrated in Figure 6. and cited below.



Total Length	8.0 m	9.65 m	10.7 m	12.7 m
Diameter	0.52 m	0.52 m	0.52 m	0.52 m
Weight	2.1 t	2.6 t	2.9 t	3.4 t
Stages	1	2	2	4

Figure 5. NLVSs Vehicle Configuration

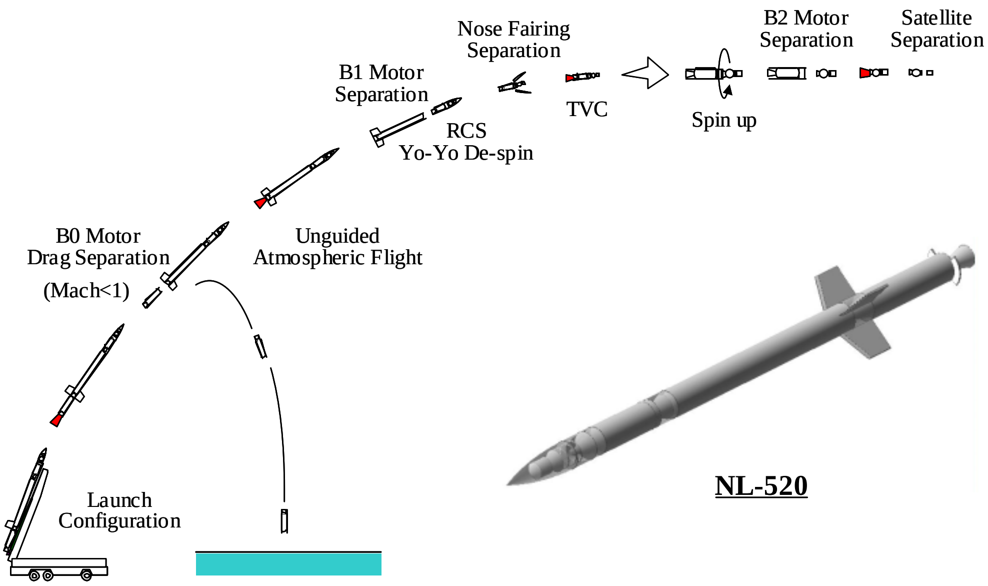


Figure 6. Typical Flight Sequence of NL-520

- NL-520 is launched from a rail launcher at an elevation angle of approximately 80deg. During the boost stage burn, maximum speed does not exceed Mach 1 to stay within the aerodynamic load limit of existing S-520.

- During the boost stage and first stage burn, NL-520 flies through the atmosphere on an unguided trajectory, like L-4S Japanese first satellite launcher. Stability is provided passively through aerodynamics and aerodynamically induced roll rate (~2Hz).

- After B1 stage separation, the Yo-Yo despinner is activated, reducing the spin rate to near zero, and the RCS starts operation for controlling pitch/yaw/roll attitude.

- After Nose Fairing separation, the second stage burn. The TVC device is used for pitch and yaw control. During the second stage, the guidance & control system works, by means of TVC system, in order to compensate the effect of the first two stages unguided flight.

- After the second stage burn out, the vehicle is given a spin of 1 Hz by RCS. Then, the third stage ignites at the appropriate time and the satellite is released in its target orbit.

Performance

The launch capability of NL-520 is about 20kg to 250 x 500km LEO. NL-520 can accommodate 2 P-PODs (i.e. up to 6 CUBESATs) on the single launch.

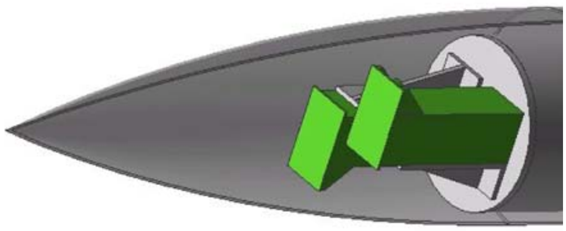


Figure 7. 2 P-PODs integrated on NL-520

Trajectory

Typical trajectory that achieves 250 x 500km elliptical orbit with an inclination of 31deg is shown below (Figure 8, 9 and 10). Maximum dynamic pressure is about 200kPa, and maximum axial acceleration is about 200m/s^2.

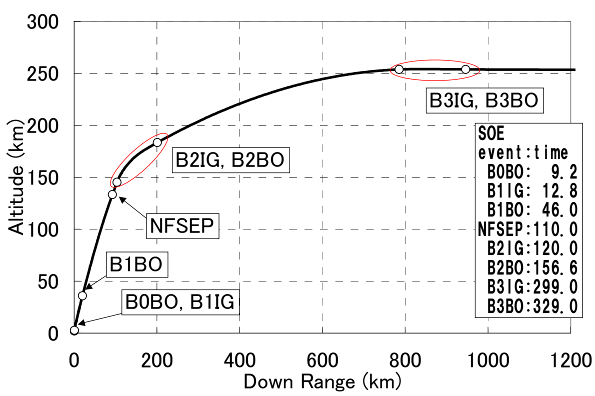


Figure 8. Down Range vs. Altitude

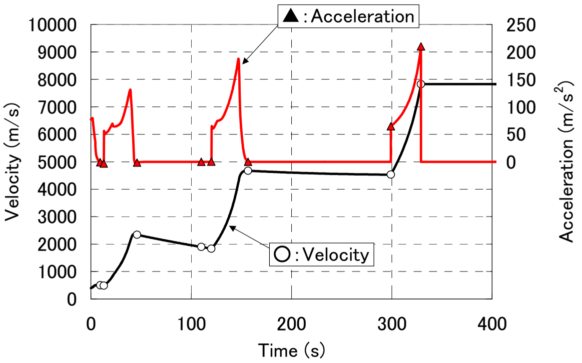


Figure 9. Time vs. Velocity, Acceleration

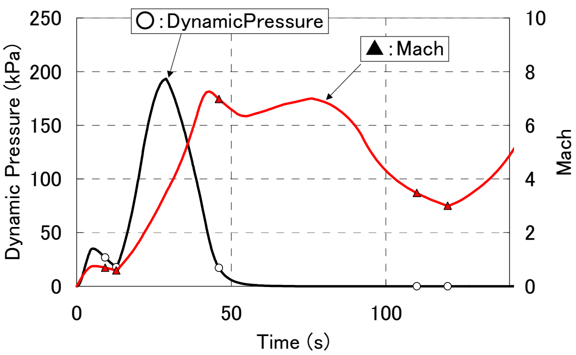


Figure 10. Time vs. Dynamic Pressure, Mach

NS-520

NS-520 development is the first step to achieve NL-520 Nano-sat launcher. The boost motor (B0 motor) dramatically increases the payload capability of NL-520. The new development component is B0 motor, B0/B1 separation system, and light-weight and low-cost avionics (excluding GN&C).

Our target cost of NS-520 is less than S-520, while it can launch twice the amount of payload to the same altitude in comparison with S-520 (Figure 11).

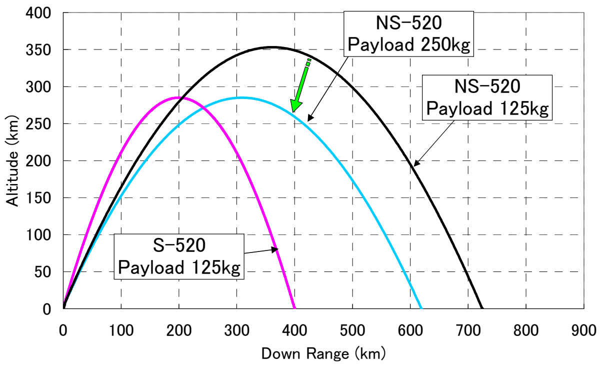


Figure 11. Performance of NS-520

INTERNATIONAL COOPERATION

Representative sounding rocket sites are listed in Table 1. NL-520 will be designed to be adaptable to sounding rocket launch sites in the world. One of major constrains on the launch site selection is the traditional range safety that postulates the usage of a ground station for ranging, monitoring and flight termination (command destruction) under anomaly conditions. Using GPS ranging and telemetry/command via communication satellites in the launch operation can be a solution to alleviate the need for range safety ground station.

Launch site	Location	
Wallops Island, VA, U.S.	37.8 degN	75.5 degW
White Sands, NM, U.S.	32.5 degN	106.5 degW
Spaceport America, NM, U.S.	33 degN	107 degW
Poker Flat, Alaska, U.S.	65.2 degN	147.5 degW
Kiruna, Sweden	68.0 degN	21.0 degE
Andoya, Norway	69.3 degN	16.0 degE
Svalbard, Norway	78.9 degN	11.9 degE
Alcantara, Brazil	2.3 degS	44.4 degW
Woomera, Australia	31.1 degS	136.8 degE
KS Center, Uchinoura, Japan	31.3 degN	131.1 degE
Takesaki, Tanegasima, Japan	30.6 degN	130 degE

Table 1: Sounding Rocket Launch Site

Cost reduction is one of the most significant problems to develop NLVS. One of promising solutions for the cost reduction is to make best use of international cooperation. Various configurations could be designed to achieve cost competitive Nano-launchers by a combination of US existing rocket systems and sounding rockets of Japan (Figure 12.). The thrust of the boost motor is high enough to carry about 1 ton upper stage above the B1 motor.

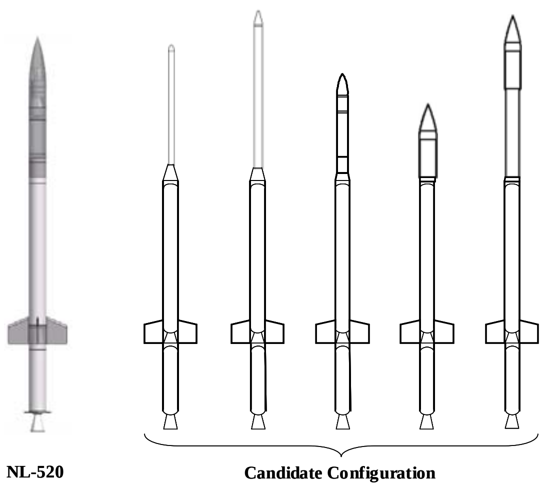


Figure 12. US-Japan Cooperative Nano Launcher

SMALL LAUNCHER EVOLUTION PLAN

Recently, JAXA (Japan Aerospace Exploration Agency) has undertaken the research on the next generation solid propellant launch vehicle called the Advanced Solid Rocket as a successor to the M-V launch vehicle. Technologies and know how of flight control, operation and avionics derived from the development and operation of NSLV will be transferred and applied to this advanced small launch vehicle. Launch performance will be increased by weight saving while launch cost will be reduced by efficient operation. Small launcher evolution plan is shown in Figure 13.

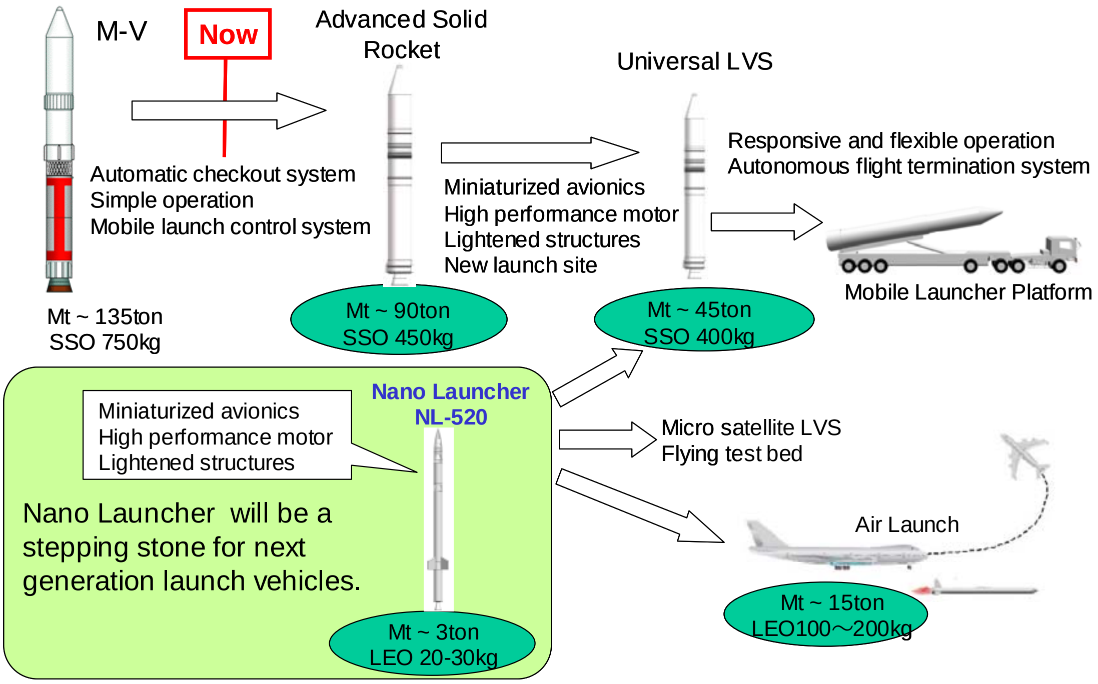


Figure 13. Small Launcher Evolution Plan

CONCLUSION

Nano Launch Vehicle System concept, using existing S-520 sounding rocket, is presented. NL-520 will be capable of placing about 20 kg payload into 250km LEO. It is confirmed that NL-520 would be responsive and affordable launch system for Nano-sats. Cost competitive Nano-launchers will be achieved through the successful development of the international cooperation scheme.

The incremental approach of developing Nano-launcher family is also presented. NS-520 (new sounding rocket) will be developed first and will successively be evolved into NL-520 (NLVS).

NLVS has high potential to provide low-cost and flexible opportunity for technology demonstration, education and training. It will also foster developers and users of space systems, and stimulate space business. Nano launchers and satellites will be the key to successful innovation in space technologies and their applications (Figure 14.).

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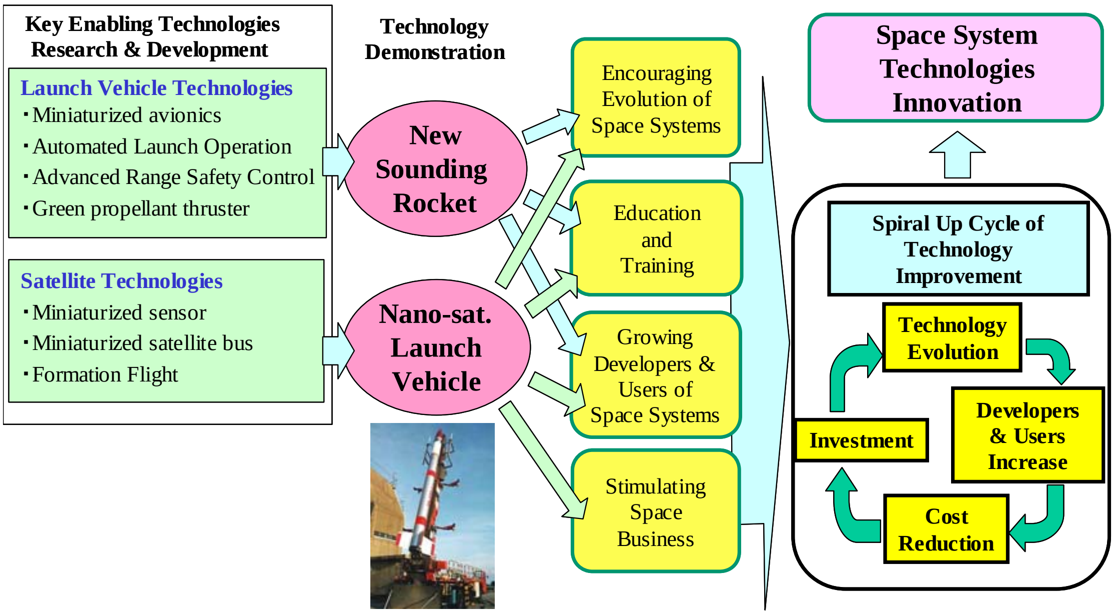

Figure 14. Positive Effect of Nano-Launcher Development