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μLambda Rocket Concept for Micro Satellites

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ABSTRACT

Sophisticated 3U or 6U Cubesats with modular design approach and plug-and-play technology could accommodate a wide range of missions. Small and medium-sized enterprises nowadays develop and sell standardized Cubesat kit to worldwide users. Some of them even become Cubesat one-stop-shop, providing coordination for launch opportunity in addition to kit distribution. Many space agencies use these companies to manage ride share of multiple users.

Current nano/micro satellite users have to rely on piggyback ride and share ride on medium-heavy rocket where they have few choices on launch window and orbit selection. As capability of nano/micro satellites grows and mission utility increases, private ride or dedicated launch becomes more favorable space access tool.

Authors conduct concept study on SpaceSpike rocket capable of lifting up to a 10kg or less to 40kg satellite to LEO. Targeting a commercial air launch system for a 150kg satellite to polar orbit, authors also develop key technologies under ALSET (Air Launch System Enabling Technology) R&D project funded by METI (Ministry of Economy, Trade and Industry).

This paper introduces SpaceSpike rocket series, ALSET and the development of small launcher avionics, and new rocket concept "μLambda". Trade study to make low-cost μLambda launch system and service a reality in short period is also conducted.

INTRODUCTION

Number of spacecraft launched by rocket and launch categories from 1988 through 2010 is shown in Figure 1. Recently, small satellites launch demand has been getting greater than before. Small satellite (100kg~1,000kg) and micro satellite (10kg~100kg) have constant launch demand. Launches of nano satellites (1kg~10kg) are increasing. In addition, launches of pico satellites (1kg or less) are expected to increase.

Number of spacecraft launched by destination orbit and mass categories from 2001 through 2010 is shown in

Figure 2. The figure clearly shows that launch demand to LEO is dominant. Small satellite launches have still depended on larger launches. It needs dedicated launches.

Responding to this trend, the authors have presented SpaceSpike rocket series for 10kg~30kg class of micro satellite (Refs. 2 to 4).

On the other hand, the authors have also conducted ALSET R&D on the air launch system to achieve launch service for 150kg class of small satellite to polar orbit 500km (Ref.5).

In this paper, the authors introduce new rocket “µLambda” capable of lifting up 50kg satellite to LEO 250km x 500km by ground launch and 100kg satellite to LEO 250km x 500km by subsonic horizontal air launch.

The launch capability of them is shown in Table 1.

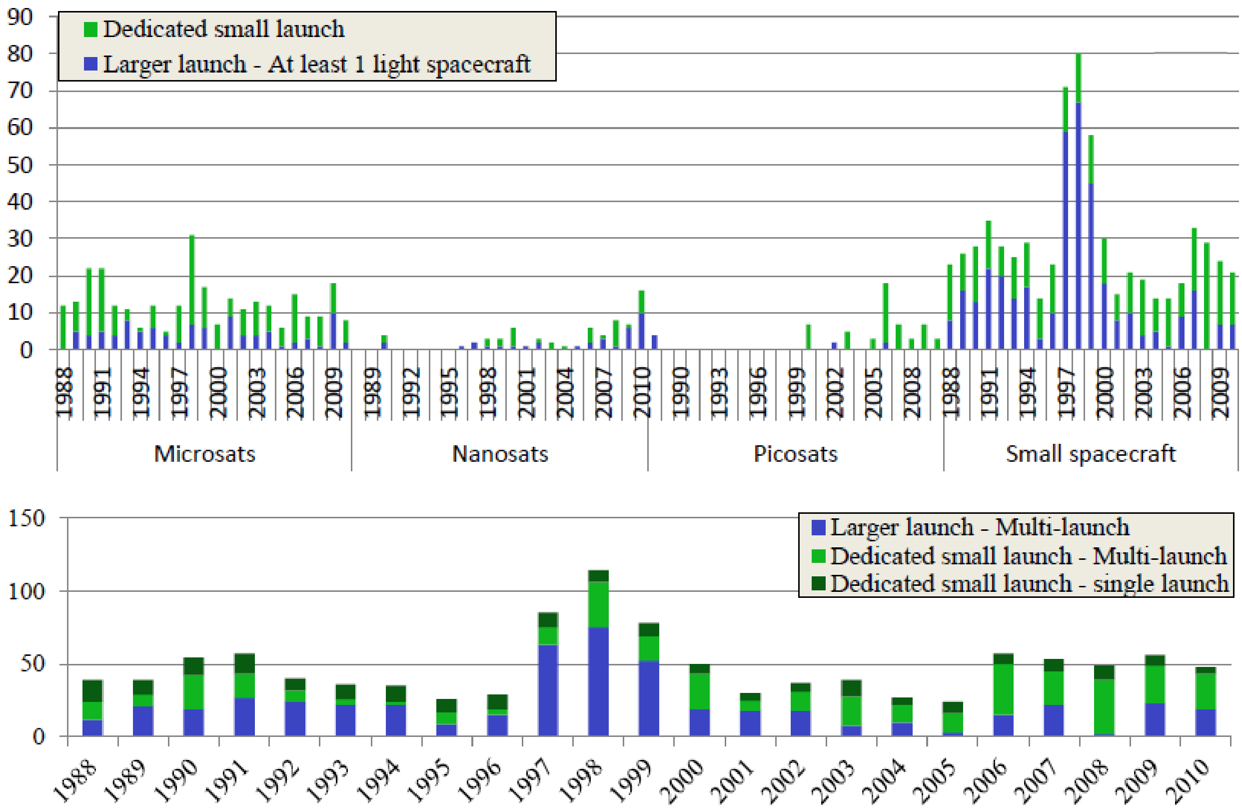
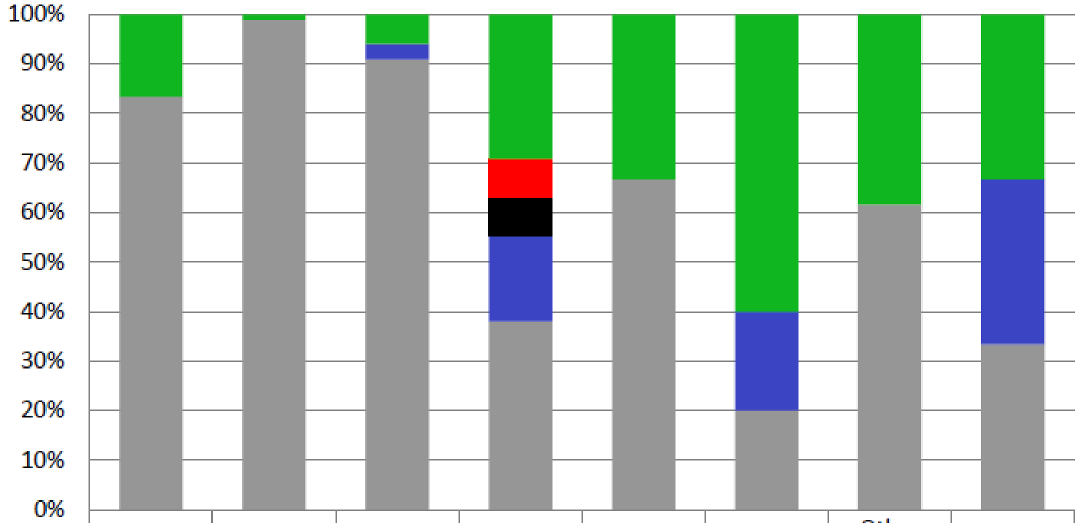


Figure 1: Number of spacecraft launched by rocket and launch categories (1988-2010)

(Source: Ref.1)



	HEO	GEO	MEO	LEO	LPO	Deep space	Other planet orbit	Planet surface
Small spacecraft	4	3	4	183	1	3	5	3
Picosats	0	0	0	48	0	0	0	0
Nanosats	0	0	0	49	0	0	0	0
Microsats	0	0	2	109	0	1	0	3
Larger spacecraft	20	272	60	238	2	1	8	3

Figure 2: Number of spacecraft launched by destination orbit and mass categories (2001-2010) (Source: Ref.1)

Table 1: Launch Capability

Rocket	Launch Capability
SpaceSpike-1	LEO 250km circular: ~10kg
SpaceSpike-2	LEO 250km circular: ~40kg
µLambda	LEO 250km x 500km: ~100kg
ALSET Launcher	Polar Orbit: ~150kg (LEO 250km circular: ~300kg)

MLAMBDA OVERVIEW

μLambda system configuration is shown in Table 2 and Figure 3.

μLambda is three-stage solid rocket system. Fixed tail fins provide aerodynamic spin stabilization during the 1st stage burn. Vehicle spin is decelerated using a yo-yo de-spinner system before 2nd stage ignition. MNTVC/RCS (Movable Nozzle Thrust Vector Control/Reaction Control System) provides three-axis guidance and control for the 2nd and 3rd stage burn. Avionics and RCS thrusters are mounted on the 3rd stage.

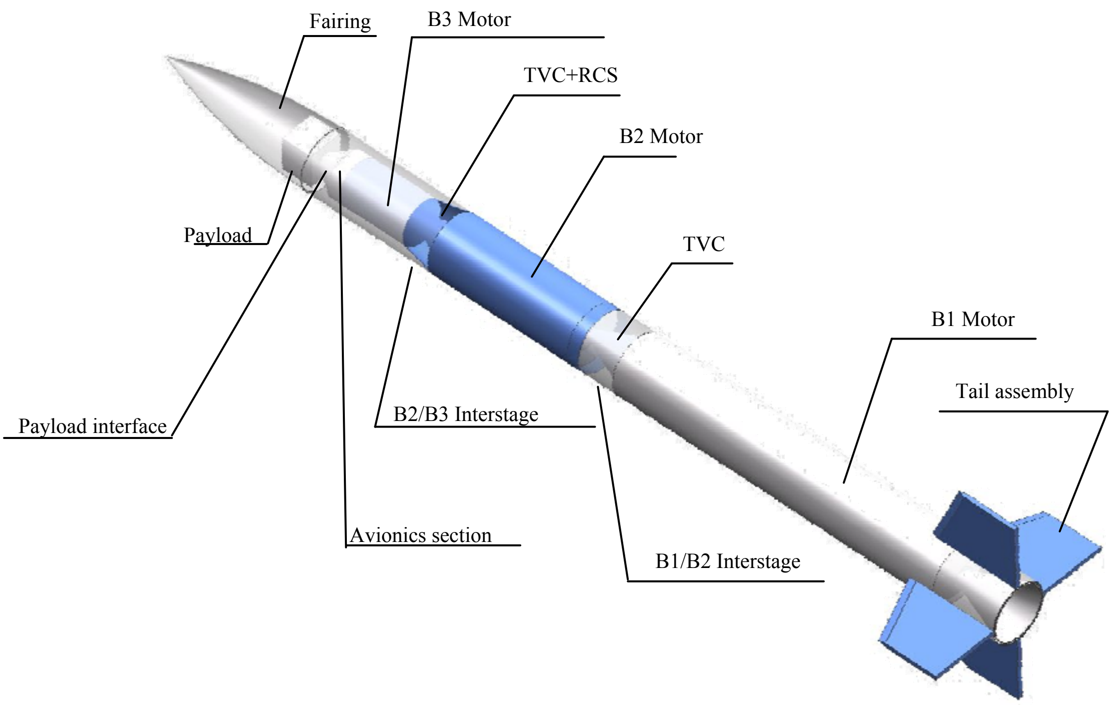
μLambda is capable of lifting up 50kg satellite to LEO 250km x 500km by ground launch. Typical flight sequence is shown in Figure 4.

μLambda has an optional configuration for a subsonic horizontal air launch shown in Figure 3. The wing contributes to improve the performance by avoiding the fall velocity increase after the separation from the airplane and making the attitude stable. However, the performance degradation by wing mass increase must be taken into consideration. The launch capability of subsonic horizontal air launch configuration is about 100kg to LEO 250km x 500km.

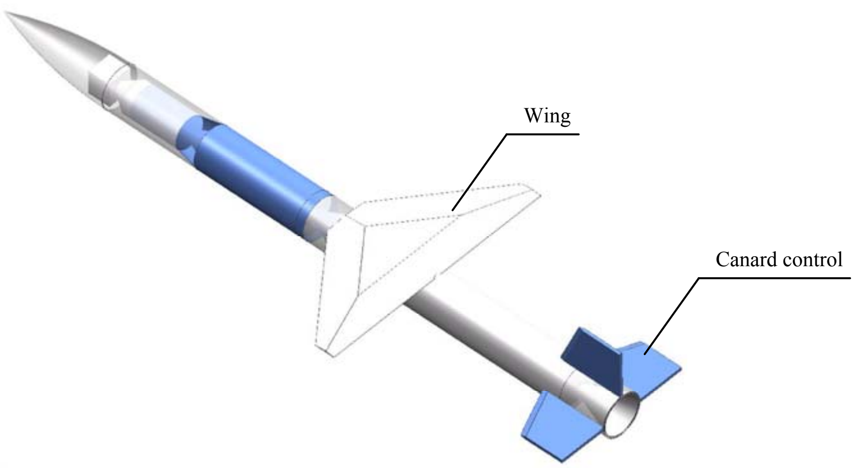
The result of the performance analysis in case of ground launch is shown in Figure 5 ,6 and 7. Maximum dynamic pressure is about 250kPa and maximum axis acceleration is about 270m/s^2. Both of them are within the permitted level.

Table 2: μLambda system configuration

Total length		13.4m
Diameter		φ850mm
Gross Weight (excluding payload)		7,350kg
Propellant Mass	1st stage	4,080kg
	2nd stage	1,800kg
	3rd stage	460kg



(1) Ground launch



(2) Subsonic horizontal air launch

Figure 3: μLambda system configuration

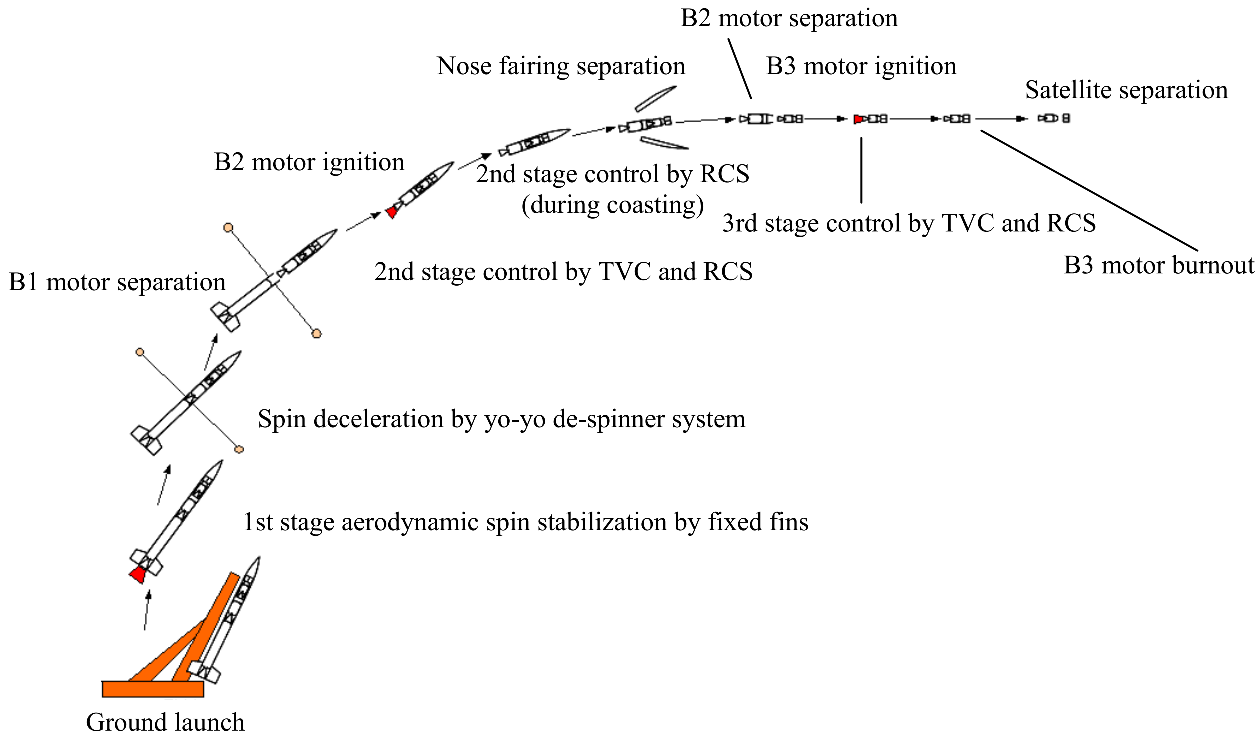


Figure 4: μLambda flight sequence (ground launch)

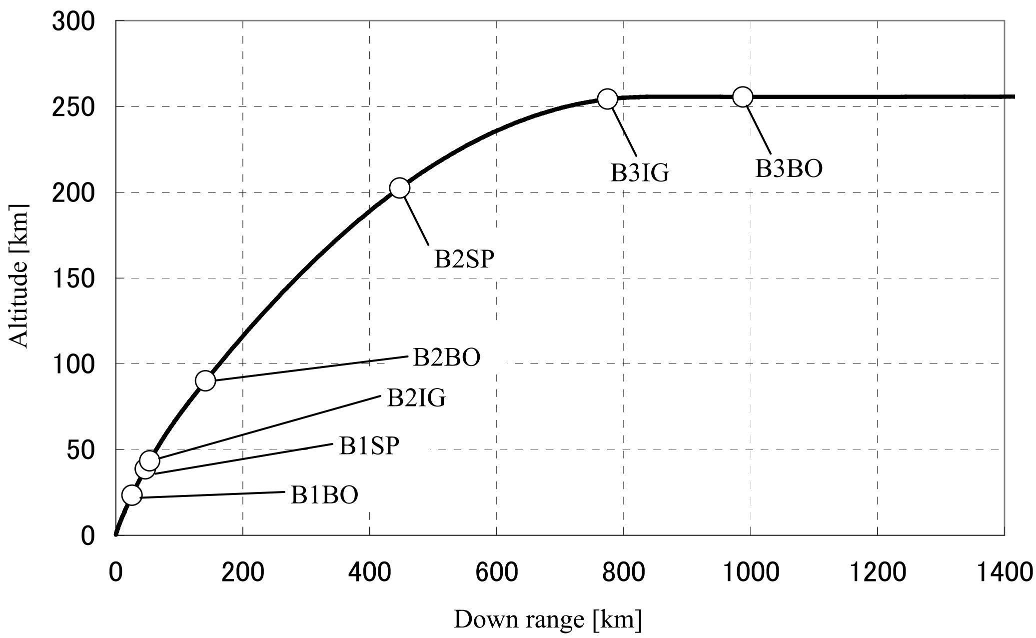


Figure 5: Altitude to down range

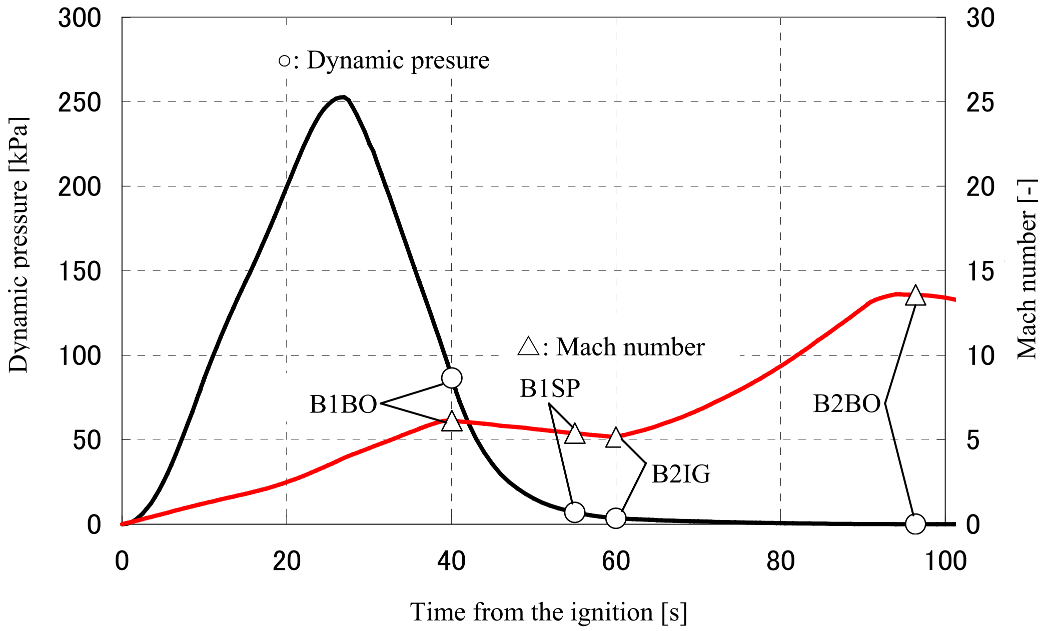


Figure 6: Dynamic pressure and Mach number to time from the ignition

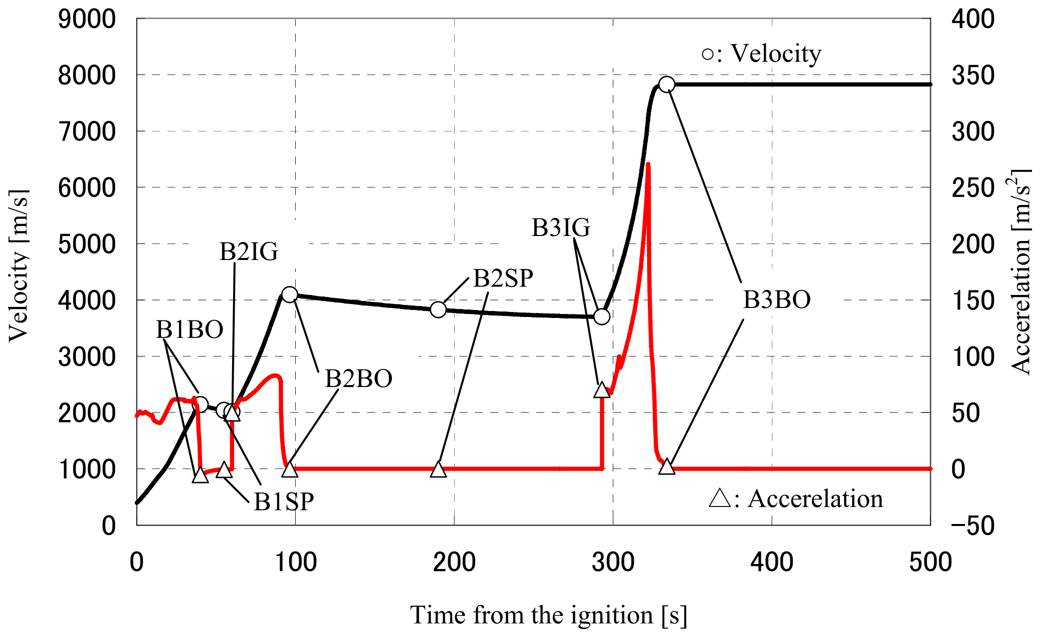


Figure 7: Velocity and acceleration to time from the ignition

SPACESPIKE OVERVIEW

The authors have presented SpaceSpike rocket series. In this section, SpaceSpike-2 of them is introduced.

SpaceSpike-2 system configuration is shown in Table 3 and Figure 8.

SpaceSpike-2 is three-stage solid rocket system. Tail assembly provides aerodynamic spin stabilization during 1st stage flight. Vehicle spin is decelerated using a yo-yo de-spinner system before 2nd stage ignition. TVC/RCS control 3-axis attitude of the 2nd stage. Before 3rd stage motor ignition, initial attitude for ignition is controlled by RCS on 2nd stage. Vehicle will be spun up and 3rd stage motor will be burned under spin-stabilized condition. Critical avionics components will be mounted on 2nd stage. 1st and 3rd stages have minimum functions of avionics.

SpaceSpike-2 is capable of lifting up maximum 40kg satellite to LEO 250km circular by the zoom flight air launch (Ref.2).

Table 3: SpaceSpike-2 system configuration

Total length		11.5m
Diameter		φ520mm
Gross Weight (excluding payload)		3,200kg
Propellant Mass	1st stage	1,590kg
	2nd stage	650kg
	3rd stage	190kg

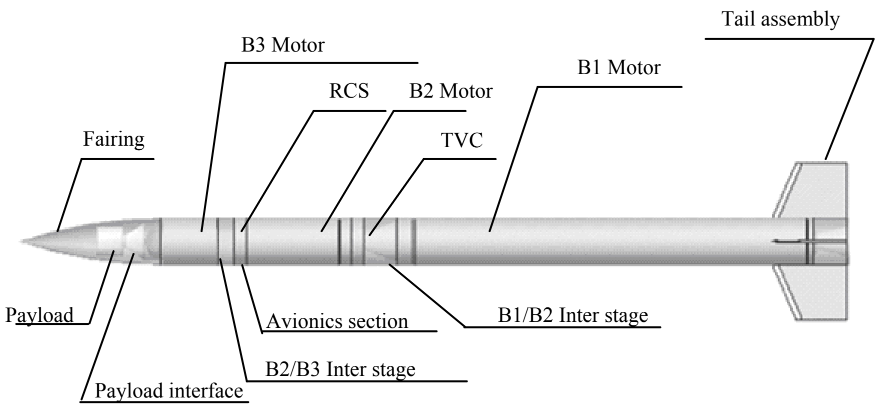


Figure 8: SpaceSpike-2 system configuration

ALSET LAUNCHER OVERVIEW

ALSET launcher system configuration is shown in Table 4 and Figure 9.

ALSET launcher system is three-stage solid rocket system. TVC and RCS control attitude of all the stages. Avionics components are mounted on 3rd stage.

ALSET launcher system is capable of lifting up 150 kg satellite to polar orbit 500km by the air drop air launch.

Table 4: ALSET Launcher system configuration

Total length		11.6m
Diameter		φ1.5m
Gross Weight (excluding payload)		16,700kg
Propellant Mass	1st stage	11,000kg
	2nd stage	2,780kg
	3rd stage	1,050kg

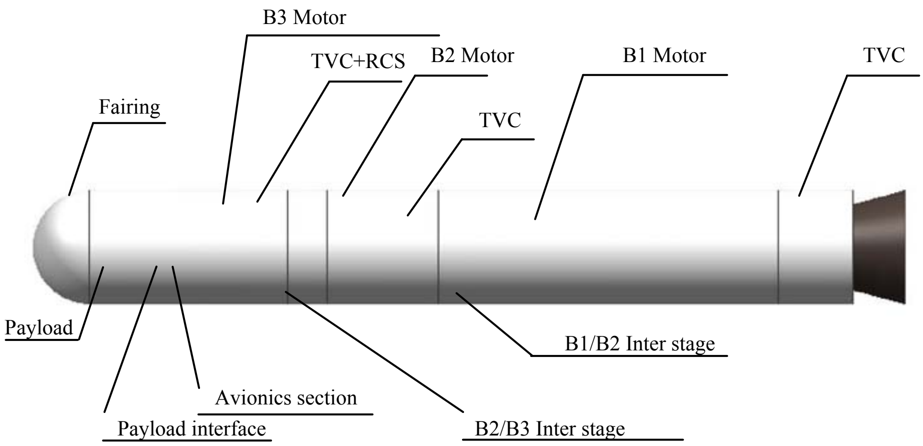


Figure 9: ALSET Launcher system configuration

SMALL LAUNCHER AVIONICS

To achieve the configuration shown above, avionics components must be miniaturized. In this section, the summary of the small launcher avionics development is shown.

One of the key technologies to achieve affordability for the small launcher service is small/lightweight avionics systems. The specific avionics systems envisioned have been developed from 2009 to 2010, supported by subsidies by NEDO/METI in Japan. The result has been presented (Ref.2 and 4). Lightweight and low-cost avionics is under development in ALSET R&D program (Ref.5).

Development of lightweight and low-cost avionics has emphasized the following.

- Proactive use of COTS (Commercial-off-the-shelf) components/parts including semiconductor relay and MEMS
- Reinforcement of system integration technology
- New functional and environmental testing methods for lightweight avionics
- Simplified vehicle health check using self-diagnosis systems

The system block diagram of a potential miniaturized and low cost avionics architecture is shown in Figure 10. Major avionics systems are centralized in the upper stage and rest of avionics are distributed to avoid excessive weight increase in the wire harness. The development target is high-performance, lightweight and low-cost devices by applying COTS technology to each system.

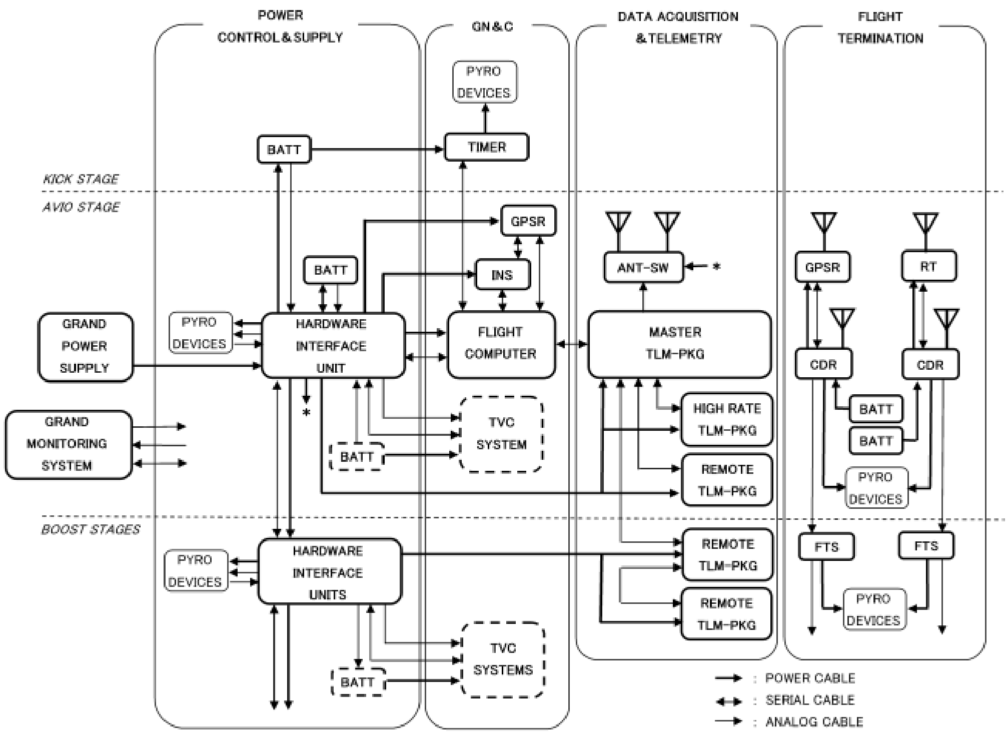


Figure 10: System Block Diagram of Miniaturized and Low-cost Avionics

The avionics mass employing the current devices is shown in Table 5 with the target mass. The current devices are used for larger launch vehicle avionics in Japan. They are too heavy to apply to small rocket system.

As shown in Table 5, Power Control and Supply mass is dominant. To reduce it, the device must be downsized. Electrical power saving is necessary as well to employ smaller cells.

The current PSDB (Power Sequence Distribution Box) adopts mechanical relays to distribute power and has very large body to avoid failing their operation because of in-flight vibration and shock.

Smaller PSDB concept is shown in Figure 11. To solve this problem, semiconductor relays (MOSFET) are adopted instead of mechanical relays. They can make PSDB smaller, thinner and lighter. In the future, the semiconductor is replaced to IC with self-diagnosis function.

To make Data Acquisition and Telemetry mass lighter, the interface must be replaced with serial signals. The result of harness mass estimate is shown in Figure 12. According to it, the replacement of the signal interface makes harness mass about 50% reduced.

Table 5: Avionics Mass Breakdown

Item		Target Mass [kg]	Mass employing current devices [kg]
GN & C		8	43
Data Acquisition and Telemetry		11	45
Power Control and Supply		8	132
Flight Termination	RT & Command	19	Including above
	Power Supply	6	
Total		52	220

[Now]

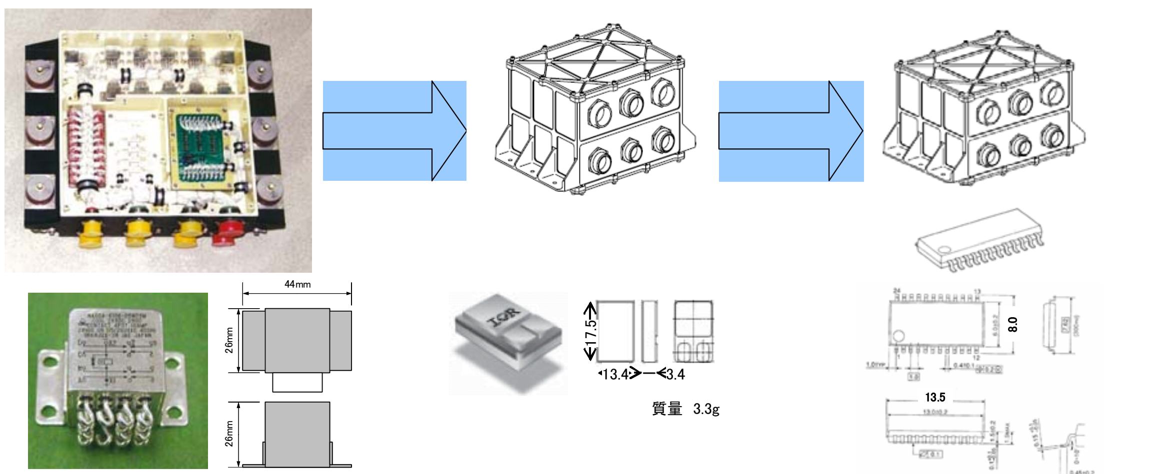
- mechanical relay

[Downsizing]

- semiconductor relay
- high-density mounting

[Future concept]

- self-diagnosis function
- efficient operation



Mechanical relay

Semiconductor relay (MOSFET)

IC with self-diagnosis function (ex.: for automobile airbags)

Figure 11: Smaller PSDB Concept

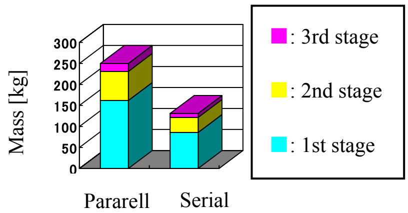


Figure 12: Harness mass estimate

AIR LAUNCH SYSTEMS TRADE STUDY

In this section, air launch systems trade study for µLambda, SpaceSpike-2 and ALSET launcher, and M-V Lite is conducted. It gives the priority of them on the view of future business.

Airplanes are selected by launcher mass compatibility and easiness to assign. Consequently, MD-80 for µLambda and Spacespike-2, C-130 for ALSET launcher and B-747 for M-V Lite are selected each. These airplanes have been manufactured a lot.

As supersonic zoom flight launches have already been presented before by the authors (Ref.2), they are removed from consideration in this trade study.

The result of the trade study is shown in Table 6.

In next 10 to 15 years, Option 2 is earliest to achieve it at the point of technology. Option 1 and Option 3 are necessary to develop hanging structure. To realize them, international cooperation including airplain manufacturers, engine manufacturer and so on is indispensable.

Table 6: The result of air launch systems trade study

	Option 1	Option 2	Option 3
Air launch system	 *1		 *1
Method	Horizontal air launch	Vertical air launch (Air drop by PDS*3)	Horizontal air launch
Launch capability	LEO 250km x 500km ~100kg and LEO 250km circular ~20kg	Polar orbit 500km ~150kg (LEO 250km circular ~300kg)	LEO 250km circular ~1.2ton
Launcher	μ Lambda and SpaceSpike-2	ALSET Launcher	M-V Lite*4 (w/o wings)
Airplane	MD-80(Boeing)	C-130(LM)	B-747(Boeing)
Engines	JT8D-209(P&W)*2 x 2	T56-A-15(RR) x 4	PW4062(P&W) x 4 or RB211-524H2-T(RR) x 4 or CF6-80C2B5F(GE) x 4
Maximum payload	18.2ton	18.9ton	aprox. 63ton
Totals manufactured	1,191	more than 2,000	more than 1,400
Priority	○: responding to small launch vehicle demand, it is necessary to realize earlier	◎: most possible to realize earlier	△: lower priority because of existing alternatives
	・micro satellite dedicated rocket system demand is big ・the airplanes are easily available ・it needs longer DT & E term because of no rocket system hanging experience	・mini satellite dedicated rocket system demand is big ・the airplanes are easily available ・existing platforms for air drop are available	・there are existing alternatives ・the airplanes are easily available ・it needs longer DT & E term because of no rocket system hanging experience

*1: Image souce: Boeing , *2: MD-81, *3: PDS: Platform Delivery System, *4: The launch vehicle removing B1 stage from M-V

SUMMARY

Responding to increasing demand for dedicated small satellite launcher, the authors have introduced μLambda capable of lifting up 50kg satellite to LEO 250km x 500km by ground launch and 100kg satellite to LEO 250km x 500km by subsonic horizontal air launch.

To achieve small launcher system earlier, the authors have presented some air launch systems and have given them their priority on the view of future business.

At the end of this paper, the authors have emphasized that international cooperation is necessary to realize them.

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