SSC18-IX-03

SS-520 Nano satellite launcher and its flight result

YOSHIFUMI INATANI
Japan Aerospace Exploration Agency, Institute of Space and Astronautical Science (JAXA/ISAS)
3-1-1, Yoshinodai, Chuo-ku, Sagamihara-shi, Kanagawa-ken, Japan; +81-50-3362-2518
inatani.yoshifumi@jaxa.jp

HIROHITO OHTSUKA
IHI AEROSPACE Co., Ltd.
900 Fujiki Tomioka-shi Gunma Japan; +81-274-62-4163
h-ohtsuka@iac.ihi.co.jp

ABSTRACT

The SS-520 is a two-stage solid fueled sounding rocket, designed to carry research payloads on sub-orbital missions to altitudes of 1000km (100kg). ISAS/JAXA has modified with the addition of a small third stage and a minimum of attitude control system to insert a 3U-class of small satellite into a low Earth orbit .This 3-staged launch vehicle's specification is 9.54m length, 0.52m diameter and 2.6t of Gross mass at launch. In January 2018, SS-520-5 was launched with CubeSat (TRICOM-1R) after the launch failure one year before. The launch this time was in good shape, and the satellite was inserted into planned orbit. By the quick look, the satellite works as planned. This development program is funded by the Ministry of Economy and, Trade and Industry JAPAN and industry investments.

INTRODUCTION

JAXA/ISAS has been developing a number of sounding rockets since 1955 for the purpose of scientific research. This rocket has a history that has improved in performance with pencil rocket, baby rocket, kappa series, lambda series, MT-135, S-210, S-310, S-520 and SS-520. The number of launch has been proved over several hundred.

On the other hand, rocket private launch demand is expanding worldwide. As a milestone to foster this small satellite launch business, JAXA/ISAS, IHI AEROSPACE Co., Ltd. (IA), CANON ELECTRONICS INC. (CE), and University of TOKYO applied for a program funded by the Ministry of Economy, Trade and Industry (METI) of Japan. It is a development demonstration program aimed at developing small rockets / micro satellites etc. which are price competitive by utilizing Japanese COTS parts/ technology.

The METI budget is about 450 million yen ($4.5M) in 3 years. Within this limited budget and period, our team considered a solution that is most efficient and effective. As a result, we decided that the concept of remodeling the SS 520 sounding rocket and launch Cube-Sat is good, and private investment has also joined, and we began development.

This idea has been examined within JAXA / ISAS in the 1990s.Figure 1 shows its work assignment.

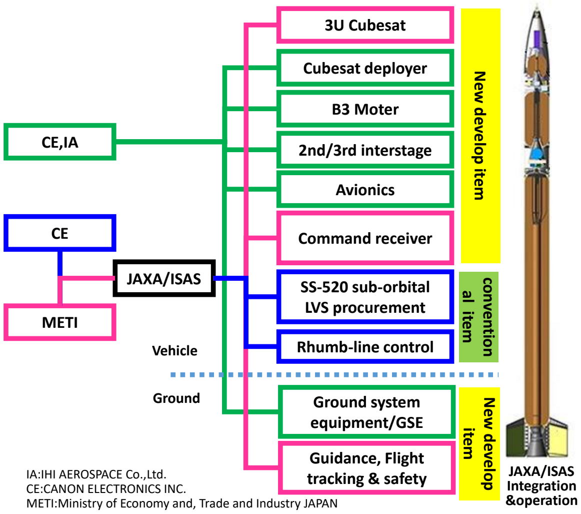

Figure 1: Newly Developed Part and Work Sharing of Joint Developments of SS-520 Satellite LVS

DESIGN & DEVELOPMENT

The small satellite launch vehicle is a three-stage rocket with 'SS-520s two-stage rocket' and a 'small 3rd solid rocket motor housed in a fairing'.

This rocket is based on a sounding rocket with limited capability, it is necessary to minimize the system. In the Navigation Guidance control (NGC) of this rocket, we decided to orbit the satellite in a system with only the "2nd stage launch direction" and "ignition timing" after the first stage separation.

It is judged on the ground whether this second stage NGC system is functioning normally or not. And by making the GO / NOGO judgment of the continuation of the 2nd stage ignition sequence on the ground, it was set as a system to ensure flight safety.

It is necessary to monitor the flight condition from the relation of flight safety. The first and second stages of the rocket are equipped with radar transponders and communication devices. And the third stage is a system based on Space based tracking system that can monitor state by GNSS and Iridium communication. This also serves as a demonstration of autonomous flight safety system (AFSS) technology in the future.

From the above, the SS-520-5 was also an experiment to construct a minimum system that can be established with a micro-small rocket and whether future AFSS will be established.

This rocket flies due to spin stabilization in the atmosphere. After the combustion of the first stage is completed, disconnect one stage motor. Then, while keeping the spin state in Rhumb-line Control, maneuver the attitude about 70deg.And then, control the attitude of LVS in the trajectory throwing direction. Only this one-time attitude control, the second and third stages keep the spin while maintaining the spin and suppress the disturbance caused by the combustion, the satellite is being thrown in orbit.

With only this one attitude control, the 2nd stage and the 3rd stage fly with the spin maintained, and the satellite is put into orbit. Conventionally, it is desirable to stop spinning of the first stage, and a three-axis attitude control method for the second stage and the third stage. However, it was difficult for this SS-520 sounding rocket to mount multiple attitude control devices. And it became necessary to reduce the weight of the rocket. Since the launch capability is insufficient also in the existing SS-520 rocket structure, it is necessary to make a significant light design of 2nd / 3rd inter-stage, PAF (payload attach fitting), equipment mount plate.

In addition, it was also necessary to reduce the weight of installed avionics. Also in the avionics using the COTS part, weight reduction and miniaturization were essential conditions. The weight reduction of this rocket structure and the effect of miniaturization and lightening of avionics became an important point to become the world's smallest satellite launch vehicle.

Figure 2 shows composition and developments of SS-520 satellite launch system. This rocket has a total length of 9.54 m (31 ft. 3.5 in), a diameter of 0.52 m (1 ft. 8 in), and a total weight of 2,600 kg (5,732 lb.).

And Table 1 shows main characteristics SS-520 satellite launch system.

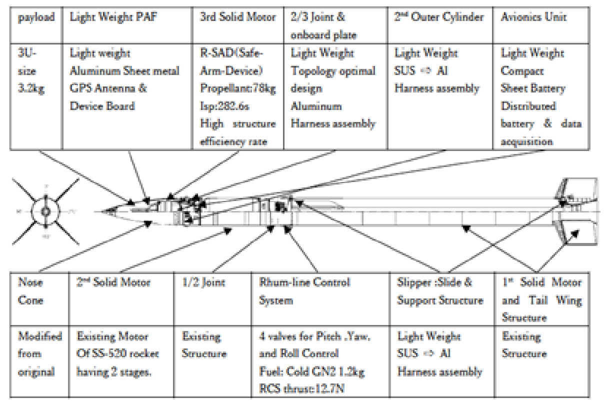

Figure 2: Composition and Developments of SS-520 No.5 Rocket

Table 1: Main Characteristics of SS-520 No.5

Item		Specification
Full Length	@ B1 Ignition	9855mm
Gross weight	@ B1 Ignition	2579kg
Outer diameter	Reference Diameter	Diameter 520mm 1795mm@Tail
1st Motor	Solid Propellant	BP-202J 1594kg
2nd Motor	Solid Propellant	BP-202J 324.9kg
3rd Motor	Solid Propellant	BP-211J 78.7kg
Attitude Stabilization	Spin Stable by Tail Wings	Spin rate 1.6Hz +/-0.2
Attitude Control	Rhumb-line Control & Active Nutation Control (ANC)	Maneuver Angle Max 80 degree
RCS	GN２ Cold Gas ４Unit for R,P,Y	Prop.：1.2kg Thrust:13.7N
Launch Capability	4kg	Target Orbit 180km×1800km

2nd /3rd stage Design

The internal structure of the newly developed head body is shown in Figure 3. In order to have satellite launch capability for the conventional SS-520, the following countermeasures were implemented.

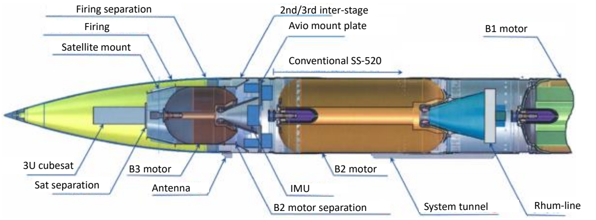

Figure 3: Composition and Developments of SS-520 No.5 Rocket

1, A new 3rd stage solid rocket motor was newly developed. As shown in

Table **2**, it is a high-performance solid motor with greatly improved structural efficiency.

2, The satellite mount plate and separation system is lightweight and needs to be manufactured at low cost, developed with an aluminum sheet metal structure. Its shape has a hexagonal plane. And, by mounting boards such as GPS antennas and receivers directly on the mount plate, the case weight of each equipment was reduced. The plate on which the equipment is not mounted was hollowed out as an access window for access to the internal 3-stage R-SAD (Remote control Safe and Arm Device).

3, 2nd / 3rd inter-stage was designed as a new structure. Figure 4 is shows satellite mount structure. The new setting method used for this weight reduction is the structural design by "topology optimization method". As a result, the mass reduction effect of about 20% was obtained compared with the conventional design.

4, We also optimized the rocket avionics loading structure as well. We realized super lightweight by minimum structural strength part and fastener.

5, For the rocket control equipment, in order to minimize the installation space and maximize the launch capability, only the Rhumb-line control device in the rear two rows was used. Therefore, the attitude accuracy by this control affects the orbit input error. The fuel tank was also arranged on the inner surface of the two-stage nozzle, and the minimum size was set to suppress the tank outer diameter and load only 1.2 kg of fuel. The maneuver capability is up to 80 degrees.

Table 2: 3rd Solid Rocket Motor (B3) Characteristics

Item		Specification
Combustion characteristics	Effective burning time Vacuum thrust MEOP Vacuum ISP	25.6s 12.76kN max 6.22MPa max 282.6s
Motor Case	material	CFRP
Nozzle	material	CFRP
Propellant	Type weight	BP-211J 78.7kg
Gross weight	Without Nozzle	86.27kg
Ignition Device	Type R-SAD with Delay Igniter	Boost Motor Ignition Delay time：5s

Figure 4: Light Weight & Low Cost satellite mount structure composed of the sheet metal of Aluminum

Guidance navigation control system

A guidance control block diagram is shown in Figure 5.and sequence of event is shown in Figure 6.

In the launch operation, the posture maneuver has to be terminated before the top altitude is reached after nosecone separation, after completion of the first stage combustion. The attitude angles that must be maneuvered during this time are up to 80deg required by one stage flight dispersion analysis. Therefore, it is necessary to complete the 80 deg maneuver at a fast speed. On the other hand, in the Rhumb-line control, since the injection is performed at each spin period, the occurrence of the nutation mode cannot be avoided.

However, we were able to suppress the final nutation mode by devising just before the end of the maneuver.

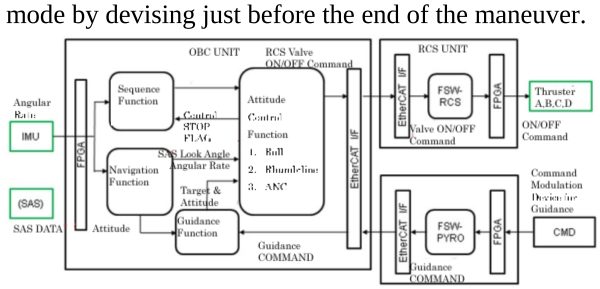

Figure 5: Block Diagram of Guidance & Control System

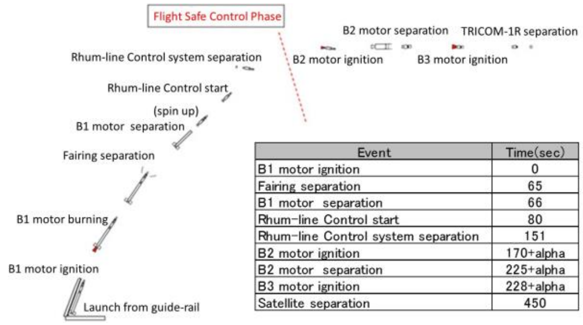

Figure 6: Sequence of event

As a final demonstration test of the guidance & control system, Motion Table TEST (M/T test) shown in Figure 7 was carried out. In this test, we performed End to End test simulating actual flight using onboard avionics, software and IMU on 3 axis Motion Table.

For this test, we used a sun sensor (SAS) to confirm the health of the IMU. Simulated sunlight was installed to simulate the direction of the sun and evaluate the functions of SAS devise.

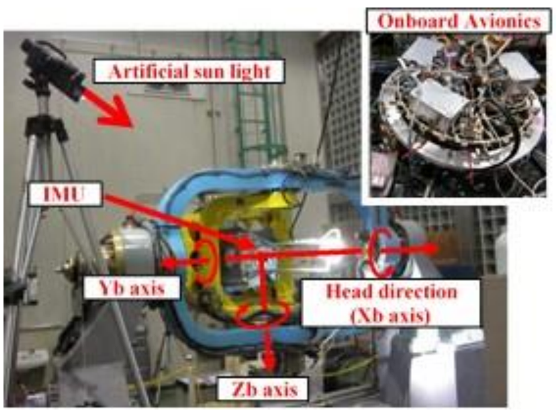

Figure 7: Motion Table Test (Real Time Simulation) with Onboard Avionics

Light weight COTS Avionics

In this development, COTS parts were adopted, and a small and lightweight avionics system was developed shown in Figure 8. HALT test (shown in Figure 9) was conducted as a demonstration of compact and light substrate technology, consumer manufacturing technology, quality assurance technology using COTS technology.We demonstrated technology of Japanese COTS parts companies that can withstand severe launch environmental conditions.

Figure 8: SS-520-5 COTS Avionics

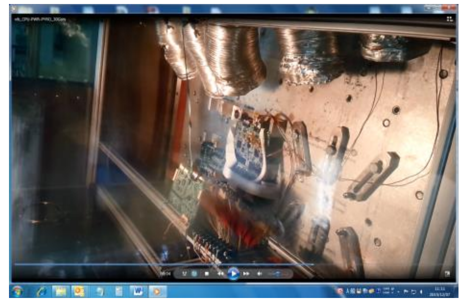

Figure 9: HALT test (Highly Accelerated Life Test)

Features of this avionics system are below

(1) Network system

Reduce harness with "EtherCAT" which is real-time high-speed communication of Ethernet

(2) Redundant system

Redundant processing system has switching function without short break in case of failure.

(3) Power supply system

"Distributed power supply system" which incorporates "sheet battery" for each unit

(4) Ignition system

Compact and light weight pyrotechnic using "Capacitor bank / semiconductor ignition system"

(5) Measurement system

Distribution of measurement functions to each unit, prevention of enlargement of DAU and reduction of harness. All of units are optimally located on the compact board by the unification of component sizes.

Table 3 and Table 4 show the weight comparison of the conventional SS-520 and the new SS-520-5. We achieved weight saving by incorporating new COTS technology and design method.

Table 3: Comparison of electronics mass

Type	SS-520(sub-orbital)	SS-520-5(NEW)
Avionics	4.8kg (CI-AVIO)	Total:2.6kg
		OBC:0.8kg
		PYRO:1.0kg
		DAU:0.8kg
Telemeter	2.1kg	2.0.kg
Radar transponder	RT:1.3kg / x2 Distributor:0.34kg	RT:0.9kg / x2 Distributor:0.254kg
IMU	1.8kg(VG440)	0.9kg(SDI)
Power Source	2.4kg POWER Central Management (CI-BAT)	1.4kg(RF-BAT) Ex: dispersed power source
instrumentation	2.8kg	3.1kg(2nd stage instrumentation)

Total mass of 2nd stage electronics mass	15.5kg	11.1kg
Side jet(SJ) electronics mass	5.0kg（SJ-E）	0.7kg（RCS）

Table 4: Comparison of structural mass

Type	SS-520(sub-orbital)	SS-520-5(NEW)
2nd stage vehicle structure	23kg (SS-520-3)	Lower of outer casing:6.3kg Upper of outer casing:6.8kg
Instrument mount plate	7kg(SS-520-3)	1.9kg
2nd/3rd interstage	-	3.0kg
Total	30kg	17.9kg

Payload (3U CubeSat)

The satellite is TRICOM-1R "Satellite name: TASUKI", which is a 3U size CubeSat developed by the University of Tokyo.

This is the purpose of the space demonstration of satellite functions composed of COTS parts and components.

The purpose of this "TASUKI" is as follows

(1) Demonstration of store & forward (S & F) mission using high sensitivity receiving device: Transmission data transmitted from a fixed or mobile transmitter located on the sea or the ground to the satellite, satellites orbiting the earth will receive and collect these data

(2) Demonstration of orbit of the latest COTS device: Demonstration of earth observation camera adopting consumer device for optical / imaging device.

(3) Demonstration of on-demand autonomous immediate observation function.

(4) Acquisition of flight status data from the rocket Store the sensor data on the 3rd stage and downlink to the ground station

The external view of the satellite of TASUKI is shown in Figure 10, and the specification of the satellite is shown in Table 5.

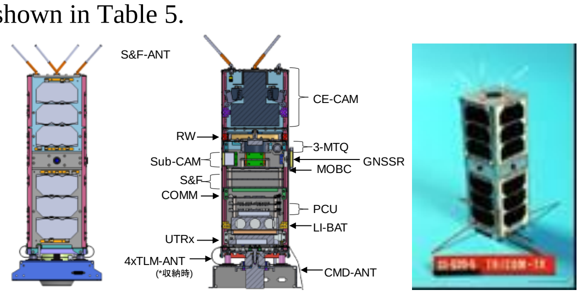

Figure 10: 3U Cube-Sat (TRICOM-1R)

Table 5: Tricom-1R (TASUKI) Specifications

Size	116 mm×116 mm×H346 mm
Mission	Store and forward (S&F) Earth observation Immediate observation operation
Life	Over 30 days (Estimated 5 month+)
MASS	3.2kg
Attitude control	Passive stabilization By Bdot Attitude sensor: 3-axis geomagnetic sensor(x2), 3-axis MEMS Gyros(x2), GNSS sensor Actuator :3-axis MTQ, 1-axis RW(despin)
Power	Body mounted solar array Generation power: 8W(MAX) Power consumption:5.27W(nominal ave) Lithium ion battery:18650cell x4
Communication	UHF

FLIGHT RESULT

In order to raise the possibility of successful launch, wind data by Doppler lidar was observed at an altitude of 1 km or less in addition to the normal balloon wind observation data before the flight, and more accurate orbit prediction was carried out.

This observation data was used to define the optimal attitude target corrected with the wind data and the optimal target was uploaded to the onboard OBC. At the same time, prediction orbit was predicted, using the avionics equivalent to the real machine (the same specification as the FM item) in conjunction with the real-time flight simulator, in ten minutes before the launch .

Especially, we performed GO / NOGO judgment 5 minutes before from the point of view of safety and mission success by carrying out drop stage of 1 stage and 2 stage, response of Rhumb-line control, input trajectory prediction. By raising the orbit error prediction system, reliability to surely put it on the track by the control system before the two-stage combustion or the guidance system was secured.

2:03 p.m. (JST; 05:03 UTC) on 3 February 2018, SS-520-5 launched from Uchinoura Space Center.

Figure 11: SS520-5 Launch

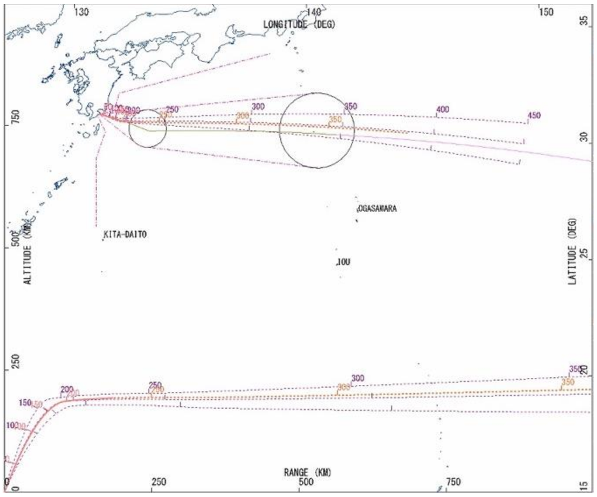

Figure 12: SS-520-5 flight trajectory

SS-520-5 flew along the flight plan (Figure 12). The Rhumb-line control necessary for orbital injection also worked as shown in Figure 13.And the 2nd stage and the 3rd stage also flew to nominal, and TRICOM - 1R was put in orbit 450 sec after launch (Table **6**). Also confirmed the TRICON - 1R communication, and confirmed that all fallen objects of the rocket also dropped within the scheduled area.

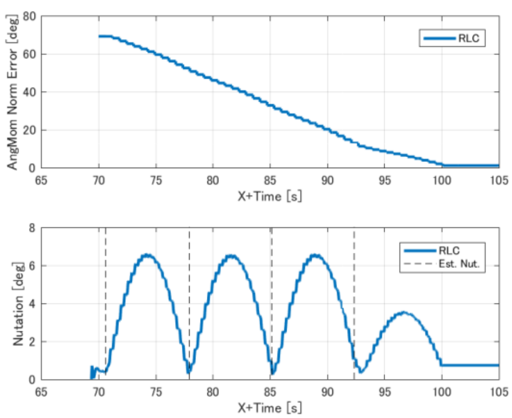

Figure 13: result of Rhumb-line control (Flight data)

Table 6: SS-520-5 Flight Plan & Result

	Plan	Result※
apogee alt (km)	1910	2010
perigee alt (km)	181	183
inclination (deg)	30.76	30.78
semi-major axis (km)	7425	7475
eccentricity (--)	0.1164	0.1222

※space-track.org

As a by-product of this successful launch, on April 2018, SS-520 No.5 was certified by GUINESS WORLD RECORDS(R) as the Smallest Orbital Rocket

CONCLUSION

Based on the SS-520 sounding rocket, our team developed the world's smallest orbital launcher and successfully launched.

Through this development we were able to confirm that the COTS parts made in Japan function with satellites and rockets.

This affordable technology can be used for the development technology of low cost rockets.

Acknowledgments

This development program is funded by the Ministry of Economy and, Trade and Industry JAPAN and industry investments.