

Cluster Launch of Hodoyoshi-3 and -4 Satellites from Yasny by Dnepr Launch Vehicle

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Two Earth observation microsatellites, Hodoyoshi-3 and -4 developed by the University of Tokyo, were successfully launched into Sun Synchronous Orbit by Dnepr launch vehicle from Yasny launch base in Russia on June 19th, 2014 in order to demonstrate innovative Japanese microsatellite technologies. The launch was a part of a challenging Dnepr cluster mission of 33 satellites involving 17 countries with a variety of international cooperation. Coordination works on the launch vehicle interfaces started from a Kick-off meeting in June 2012, then PDR to CDR in 2013, and Fit-check/combined tests in March 2014. A special air-gun type shock tester was used for satellite qualification to simulate the separation shock of the vehicle. The launch campaign started with air cargo transportation of the satellites and GSE from Tokyo to Yasny via Europe in May 2014. The launch base support in Yasny proceeded to satellite check-out, installation of Li-ion batteries to the satellites, fuelling of H₂O₂, activation of MIPS, satellite integration onto the Space Head Module of the Dnepr vehicle, and then launch observation. The launch environment and interface constraints of the Dnepr vehicle were modest and gave favorable design flexibility to Hodoyoshi satellites, which enabled remarkable in-orbit challenges. This paper presents the critical steps of launch interfaces and experiences gained from the coordination works and launch campaign.

Key Words: Cluster Launch, Hodoyoshi Satellite, Dnepr Launch Vehicle, Yasny Launch Base, Launch Vehicle Interface

1. Introduction

Today, microsatellites are pursuing advanced missions which used to be realized only by expensive large satellites. For example, Skysat-1, a 90 kg microsatellite developed by a venture company in the US and launched by Dnepr launch vehicle in 2013, provides 1 m GSD high resolution Earth images and motion pictures for commercial applications. However, launch opportunities for microsatellites have been quite limited, and some interface constraints (size, mass, stiffness) for their piggyback launches have been restricting the growth flexibility of microsatellite design.

Hodoyoshi-3 and -4 microsatellites were developed by the University of Tokyo in order to demonstrate advanced technologies and missions with reasonable cost and reliability. They were successfully launched into Sun Synchronous Orbit (SSO) from Yasny in 2014 as a part of a Dnepr cluster mission of 33 satellites involving 17 countries. The launch environment and interface constraints of the Dnepr were modest and gave favorable design flexibility to Hodoyoshi satellites, which has enabled remarkable in-orbit challenges. Two years of the interface coordination works and the joint launch campaign at Yasny provided the participants with valuable opportunities for international cooperation.

This paper presents the critical steps of launch interfaces and experiences gained from the coordination works and launch campaign.

2. Hodoyoshi-3 and -4 Microsatellites

2.1. Mission and major performance

Hodoyoshi-3 and -4 are Earth observation microsatellites using a common spacecraft bus design concept. Fig. 1 shows their in-orbit configurations with solar paddles deployed. Several different



Fig. 1. Hodoyoshi-3 (left) and -4 (right) in-orbit configurations.

mission payloads can be hosted on top of this common spacecraft bus, having excellent design flexibility for various future missions. Table 1 summarizes the major performances and mission payloads of Hodoyoshi-3 and -4.

Table 1. Major performances and mission payloads of Hodoyoshi-3 and -4.

	Hodoyoshi-3 (2014-033-F)	Hodoyoshi-4 (2014-033-B)
Size	0.5×0.5×H0.7 m	0.5×0.6×H0.8 m
Weight	56 kg	64 kg
Mission Payload	Earth Observation using multispectral optical sensor GSD: 38 m (swath 78 km) 3 bands (B1: 520-600; B2: 630-690; B3: 730-900 nm) + GSD: 240 m (swath 500 km) 3 bands (RGB) Store & Forward Data Collection Platform Hosted payloads (10 cm cube) 3 cubes	GSD: 6.3 m (swath: 25 km) 4 bands (B1: 450-520; B2: 520-600; B3: 630-690; B4: 730-900 nm) 4 cubes
	Hetero-constellation experiment	
Communication	Telemetry and Command: S-band uplink:4 kbps, downlink:4/32/64 kbps Mission data downlink: X-band 10 Mbps (demonstrated up to 350 Mbps on Hodoyoshi-4)	
Command & Data Handling	OBC using SOI-SOC technology	
Power	Power generation: max 130 W (GaInP2/GaGa/Ge) Power consumption: average 50 W Battery: 5.8 AH Li-Ion	
Attitude Control	Earth pointing, 3 axis stabilization using star tracker, fiber optical gyro, reaction wheels, GPS	
Propulsion	Monopropellant H ₂ O ₂	Xe Micro Ion Propulsion
Orbit	SSO. 630 km, LTAN 10:30 am	

2.2. Reasonable cost and reliability using innovative Japanese commercial technologies

Hodoyoshi-3 and -4 carry advanced equipment shown in Fig. 2, with reasonable cost and reliability, developed in Hodoyoshi program using Japanese commercial technologies, including:

- Precision and high-agility 3-axis attitude control using compact SOI-SOC on-board computers, reaction wheels, a star tracker, a fiber optical gyro, and a GPS receiver;
- 6.3 m GSD 25 km swath multi-spectrum sensor for Earth observation (Hodoyoshi-4);
- Xenon Micro Ion Propulsion System (MIPS, Hodoyoshi-4);
- 100 M to 350 Mbps 16 QAM X-band data transmitter (Hodoyoshi-4)



Fig. 2. (from top left) SOI-SOC on-board computers, reaction wheels, a star tracker, a fiber optical gyro, a GPS receiver, and Xenon Micro Ion Propulsion System (developed using Japanese commercial technology).

3. Dnepr Launch Vehicle

Dnepr is a satellite launch vehicle converted from a Russian SS18 liquid-fueled strategic missile and operated by International Space Company Kosmotras. Dnepr has a three stage in-line configuration. The first and second stages are standard SS18 stages without any modification. The third stage is a standard SS18 third stage, with a modification of its control system to optimize flight software and electrical links with the spacecraft. Major performances and characteristics of Dnepr Launch Vehicle (LV) is shown in Fig. 3.

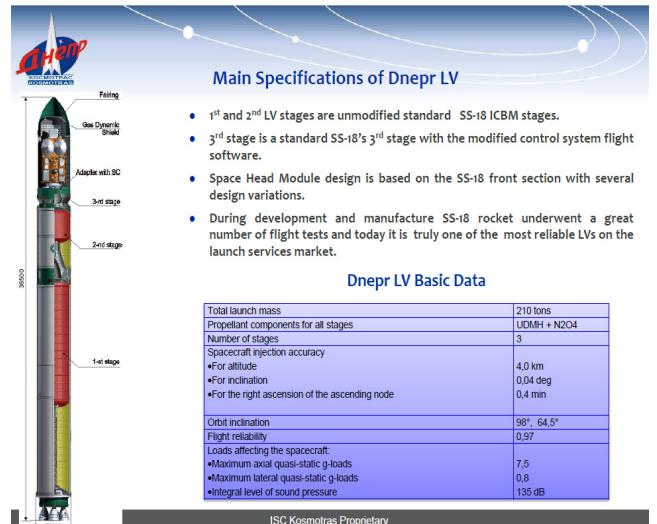


Fig. 3. Dnepr launch vehicle major performance and characteristics.

Dnepr cluster launch for Hodoyoshi-3 and -4 was selected for the following reasons.

- Dnepr has the largest and longest experience on commercial cluster launches of variety of microsatellites from many different countries in the world (21 launches (20 success), and 127 payloads had been injected into orbits as of 2014).
- Dnepr had launched JAXA's OICETS and INDEX satellites in 2005, and its precise injection and reliability together with professional works of the launch provider Kosmotras were well known. In addition, another contract to launch ASNARO + 4 university satellites had already started.
- No hard limitation on mass and size (such as less than 50 kg or smaller than 50 cm cube). Launch environment is modest. Satellite stiffness requirement is very favorable (Lateral: >10 Hz; longitudinal: >20 Hz) and allows excellent satellite design flexibility for various advanced missions.
- Predicted injection orbits (slightly different between Hodoyoshi-3 and -4) were preferable for a team to operate two satellites simultaneously using a single ground antenna.
- Reasonable flexibility and support by the launch provider to microsatellite teams as commercial customers.
- Reasonable launch cost not only for satellite customers but also for the launch service provider, which enables the provider to keep sustainable and dependable commercial cluster launch business.

4. Launch Vehicle Interfaces

4.1. Interface coordination process overview

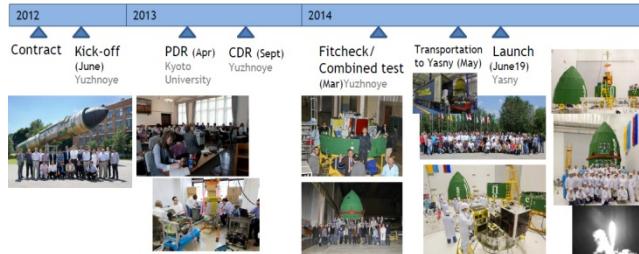


Fig. 4. Interface coordination process overview.

As shown in Fig. 4, the interface coordination with the launch vehicle started at around the launch contract, continued during the Kick-off meeting in Yuzhnoye in June 2012 and the PDR in Kyoto University in April 2013, finished during the CDR in Yuzhnoye in September 2013 and the Fit-check / Combined tests in Yuzhnoye in March 2014, and then proceeded to the launch in June 2014. The results of the above coordination works are described in subsections 4.2 to 4.6.

4.2. Space Head Module accommodating 33 satellites

A total of 33 satellites with a variety of different shapes, sizes and mass were cleverly and cost-effectively (i.e. high density) accommodated on two-story platforms (Platform-A and -B) in Space Head Module (SHM) of the Dnepr launch vehicle by skilled rocket professionals. Fig. 5 shows the configuration of the SHM accommodating the 33 satellites.

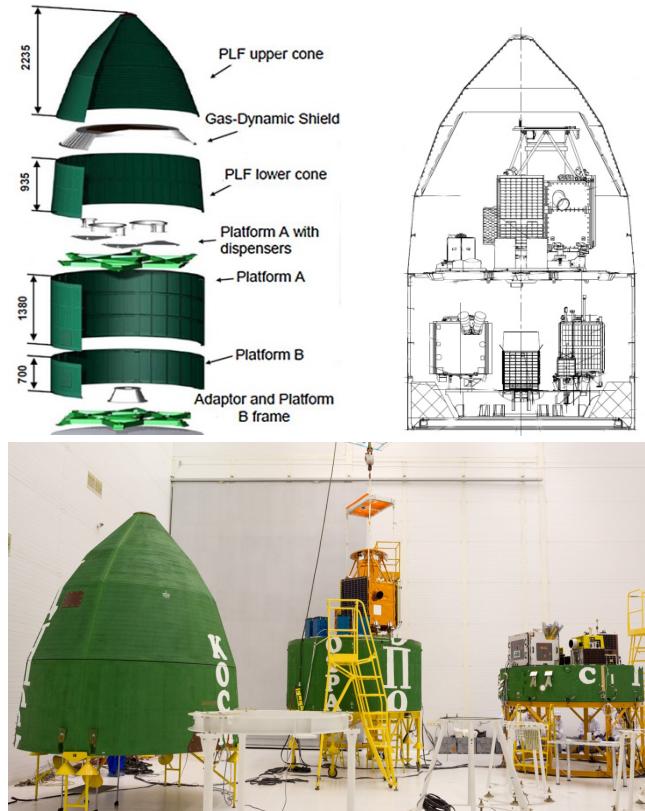


Fig. 5. Dnepr SHM accommodating 33 satellites with a variety of different shapes, sizes and mass (from left to right, Nose-cone, Platform-A, and Platform-B).

4.3. Hodoyoshi-3 and -4 SHM integration interface

Hodoyoshi-3 and -4 were integrated onto the dispenser of Platform-B of the SHM together with several other satellites as shown in Fig. 6.

As shown in Fig. 7, each satellite bottom cylinder flange was fixed onto the dispenser of Platform-B with three “pyro-locks”. No pushing springs were used. Two satellite separation switches and two launch vehicle separation switches were used for each satellite.

Hodoyoshi-3 and -4 were of cold launch, and there were no electrical interconnections with the launch vehicle.

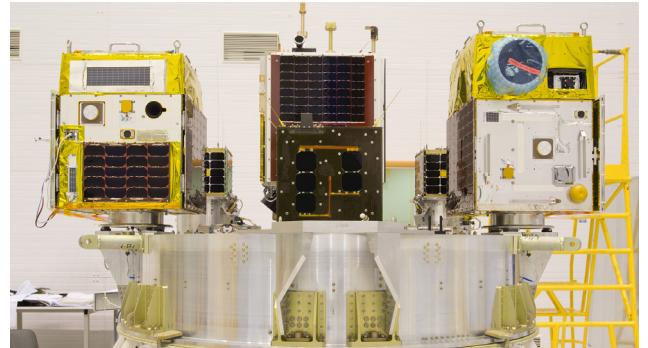


Fig. 6. Hodoyoshi-3 (left) and -4 (right) integrated onto the dispenser.



Fig. 7. (from left to right) 3 pyro-locks at the bottom of Hodoyoshi-4, Hodoyoshi-4 fixed on the dispenser of Platform-B, separation switches.

4.4. Mechanical environment requirements

Major mechanical environment requirements are shown in Tables 2 to 5. The satellite stiffness requirement is very modest (Lateral : >10 Hz; longitudinal : >20 Hz), which provides excellent flexibility in satellite design. Launch environment of the Dnepr is generally modest; however, the separation shock at high frequency spectrum generated by “pyro-locks” is high (4000 G at 5000 Hz) and needs attention for microsatellites. This is addressed in sections 4.5 and 4.6.

Table 2. Quasi static loads during flight (Platform-B).

Operations case	G-load	
	Longitudinal	Lateral
1 st stage flight:- maximum angle of attack - maximum of axial g-load	3.9±0.4	0.47±0.2
	7.7±0.5	0.10±0.4
2 nd stage flight - maximum of axial g-load	7.0±0.5	0.20

(QT factor: 1.3)

Table 3. Sine vibration requirement.

	Longitudinal direction.			Lateral direction.	
Frequency subrange, Hz	5-10	10-15	15-20	5-10	10-15
Amplitude, g	0.4	0.8	0.4	0.4	0.4
Duration, s	10	30	60	100	100
Verification test factors and sweep rates : QT : 1.25, 2 oct./min.					

Table. 4. Random vibration requirement (5.2Grms, duration 35sec.).

Frequency,Hz	20-40	40-80	80-160	160-320	320-640	640-1280	1280-2000
PSD, g ² /Hz	0.004	0.004	0.004-0.014	0.014-0.022	0.022	0.022-0.011	0.011-0.003

(QT factor: 1.56)

Table. 5. Separation shock qualification test levels.

Frequency, Hz	30-50	50-100	100-200	200-500	500-1000	1000-2000	2000-5000
Spectrum, g	05-10	10-25	25-200	200-500	500-1000	1000-2500	2500-4000

4.5. Hodoyoshi-3 and -4 mechanical environment tests

In order to confirm the design integrity of Hodoyoshi-3 and -4 for the launch by Dnepr, various mechanical environment tests were performed as shown in Table 6. Examples of a vibration test set-up and the sine burst level equivalent to the static load are shown in Figs. 8 and 9.

Table. 6. Hodoyoshi-3 and -4 mechanical environment tests.

Test item	Hodoyoshi-3 EM (common to Hodoyoshi-4)	Hodoyoshi-3 FM	Hodoyoshi-4 FM
Random vibration	QT level (AT level X 1.56)	AT level	AT level
Shock	QT level		
Sine Vibration		AT level	AT level
Sine Burst (equivalent to static load)		AT level	AT level

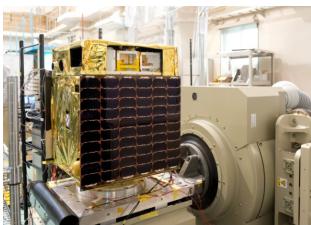


Fig. 8. Vibration test set-up.

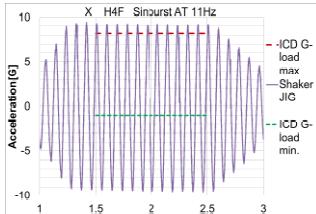


Fig. 9. Sine burst level.



Fig. 10. Separation shock test using a special air-gun shock tester.

To simulate the separation shock, a special air-gun shock tester was developed and used as shown in Fig. 10. This is because conventional shock testers tend to give unnecessary high level shock in lower frequency region in order to provide the high frequency peak. The unnecessary lower frequency shock energy could destroy the satellite being tested, even though the actual high frequency peak generated by the pyro-lock can be alleviated by the satellite structure design.

Measured natural frequencies of the two satellites are

shown below. They satisfy Dnepr cluster launch requirements with more than sufficient margin, but might not satisfy the piggyback launch requirements for other launch vehicles. Hodoyoshi-3: lateral 41.5 and 39.1 Hz; longitudinal 170.9 Hz; Hodoyoshi-4: lateral 35.4 and 31.7 Hz; longitudinal 148.9 Hz.

4.6. Fit-check and combined ground tests in Yuzhnoye

Fit-check

In order to confirm the mechanical interfaces between various satellites and the launch vehicle, a joint fit-check was performed in Yuzhnoye State Design Office in Ukraine in March 2014. Satellite dummies (or structure models) were integrated onto the SHM flight model, and their mechanical interfaces were confirmed. Fig. 11 shows the fit-check in Yuzhnoye and its participants from various countries.



Fig. 11. Fit-check and participants in Yuzhnoye.

Combined ground tests

Mechanical environment tests (vibration and separation shock) of the SHM combined with the integrated satellite dummies (or structure models) were performed to confirm the mechanical design integrity of the SHM. Hodoyoshi and some other satellite teams installed sensors in the structure models and measured their internal environment during the tests.

Figure 12 shows the combined ground tests in Yuzhnoye and the separation shock levels at the pyro-lock ignition measured in the Hodoyoshi-3 structure model integrated in the SHM. The high frequency peak on the top plate of the Hodoyoshi spacecraft bus is considerably lower than that on the bottom plate near the pyro-locks. The high frequency peak was attenuated by the satellite structure. The top plate of the Hodoyoshi spacecraft bus is used as a platform for mission payloads, which was proven to have modest environment suitable for such as Earth observation optical sensors.

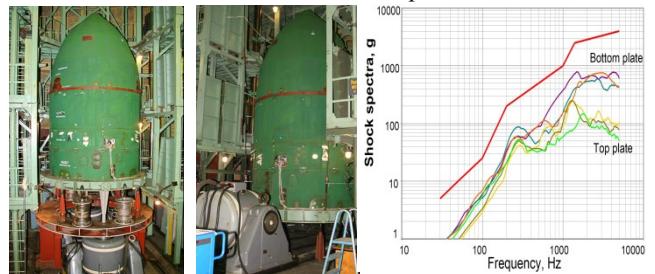


Fig. 12. Combined ground tests in Yuzhnoye (left), and separation shock levels measured in Hodoyoshi-3 structure model in SHM (right).

The joint fit-check and combined ground tests in Yuzhnoye not only ensured the mechanical interfaces but also minimized potential troubles that might have occurred during the launch campaign of the complex 33 satellite cluster mission (i.e. good rehearsal for the SHM integration).

5. Yasny Launch Campaign

5.1. Yasny launch base

Yasny launch base is located in Orenburg region, Russia. The base is composed of:

- Assembly, Integration and Test Building (AITB), as shown in Figs. 13 and 14, incorporating clean rooms (Zone-A, Zone-B, and Fueling station);
- Launch silos with their block houses;
- Administration and hotel complex including hotels, dining facilities and office premises;
- Necessary utilities supporting the launch base operations.



Fig. 13. Yasny Launch Base location and AITB.

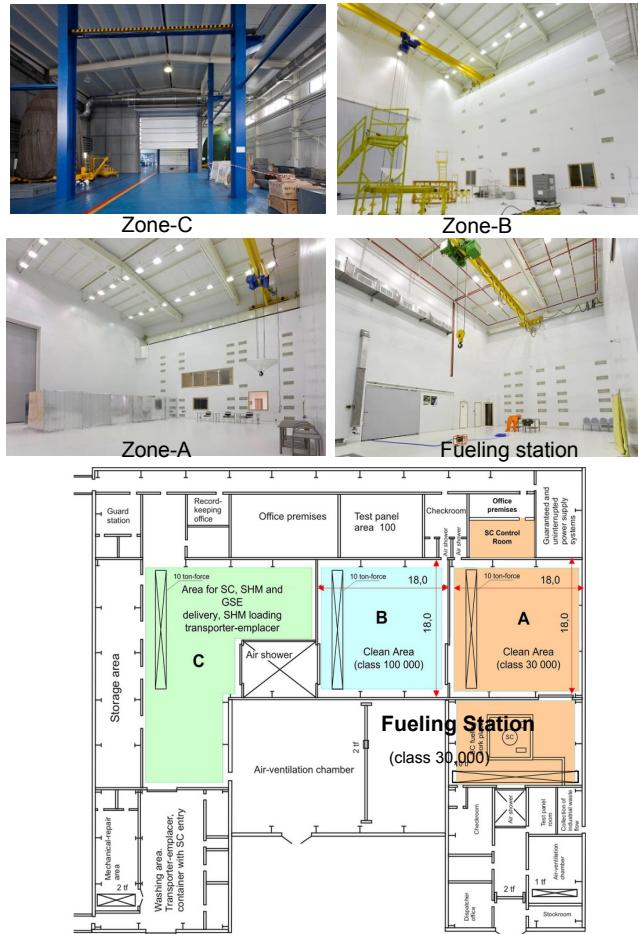


Fig. 14. Yasny launch base AITB facility (from top left to right, Zone-C, Zone-B, Zone-A, Fueling station) and its floor layout.

For this cluster launch, clean rooms of AITB were allocated for the preparation of satellites as shown below:

- Zone-A: Primary satellite KazEOSat, Deimos-2, SaudiSat-4
- Fueling Station: Hodoyoshi-3 and -4, AprizeSat-9 and -10
- Zone-B: SHM and other satellites

5.2. Transportation of Hodoyoshi-3,-4 and GSE to Yasny

For the launch campaign, the following cargo, shown in Fig. 15, was transported to Yasny from Tokyo.

- Hodoyoshi-3 and -4 in each satellite container
- GSE in four “Pelican case” plastic containers
- Li-ion batteries in two UN wooden boxes



Fig. 15. Cargo shipped from Narita.

There were two kinds of Dangerous Goods Declaration (DGD) items (Li-ion batteries and high pressure Xenon) in the cargo; and they were handled as shown below:

- Li-ion batteries: removed from satellites and packed in UN qualified wooden boxes.
- High pressure Xenon (Xe): integrated in Hodoyoshi-4 in a qualified high pressure tank which allows air transportation.

(H₂O₂ and Helium (He) were prepared by Kosmotras in Russia and not transported from Tokyo.)

Forward route from Tokyo to Yasny

Forward route was mainly by air as summarized below.

1. Narita to Frankfurt by commercial cargo flight (05/17 to 18)
2. Frankfurt to Pardubice (Czech) by land (05/19 to 20)
3. Pardubice to Ul’yanovsk by shared chartered flight (05/21)
4. Quick customs clearance at Ul’yanovsk (05/21)
5. Ul’yanovsk to Orsk by shared chartered flight (05/22)
6. Orsk to Yasny AITB by land (05/22)

The cargo was first transported to Europe by commercial cargo flight, and then took a joint charter flight to Yasny shared with other satellites such as KazEOSat and Deimos-2. Customs clearance was made in Ul’yanovsk quickly without opening containers. G’s recorded in a Hodoyoshi-3 container during the transportation was max. 1 g as shown in Fig. 16.

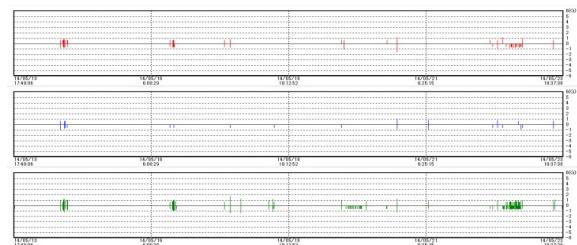


Fig. 16. G's recorded in Hodoyoshi-3 container during the transportation.

Return route from Yasny to Tokyo

Return route was by land and sea as shown below.

1. From Yasny to St. Petersburg by land (via Ul’yanovsk for customs clearance)
2. St. Petersburg to Tokyo by cargo ship (arrival 2014/10/23)

5.3. International peaceful space cooperation in Yasny

Launch Campaign Schedule Overview

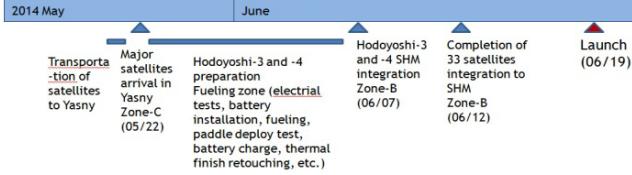


Fig. 17. Launch campaign schedule overview.

The launch campaign in Yasny started from late May, 2014 with the launch scheduled for June 19th as shown in Fig. 17. Major satellites and teams arrived in the Yasny AITB on May 22nd (Fig. 18). The following days, after cleaning, they were carried into clean rooms, and satellite preparation started.



Fig. 18. Arrival of satellites and teams in Yasny AITB (05/22).



Fig. 19. Opening ceremony of Yasny launch campaign (05/26).



Fig. 20. Cooperation of 17 countries.

In spite of world political difficulties, the following teams participated in the opening ceremony of the 33 satellite cluster launch campaign hosted by Kosmotras on May 26th (Fig. 19).

- Launch vehicle team: about 30 specialists from Ukraine
- KazEOSat team: total of 10 from Kazakhstan and England
- Deimos-2: 6 from Spain
- Saudisat-4: about 10 from Saudi Arabia
- Hodoyoshi-3, -4: 9 from Japan
- Others: 4 from Canada

Other specialists from Italy, Korea, Holland, the United States, etc. arrived on later dates.

International peaceful space cooperation of the 17 countries

shown in Fig. 20 started in the Yasny launch base.

5.4. Preparation of Hodoyoshi-3 and -4

The preparation of Hodoyoshi-3 and -4 were performed in the Fueling station of Yasny AITB. Major preparation works were electrical checks, installation and charging of Li-ion batteries, fueling of H2O2, activation of MIPS, solar paddle deployment tests, and rehearsal for SHM integration as shown in Figs. 21 to 25.

Hodoyoshi-3 was fueled with one liter H2O2 after Helium leak test. H2O2 and He were prepared by Kosmotras in Russia. Hodoyoshi-4 MIPS were activated by simply opening the valve of the Xenon tank in the satellite (already filled in Japan) without using any fueling equipment. The Hodoyoshi-4 MIPS demonstrated its unique user-friendly design compared with any other satellites fueled during the launch campaign.



Fig. 21. Battery installation (05/24). Fig. 22. H2O2 fueling (05/26).



Fig. 23. Hodoyoshi-4 MIPS activation and electrical tests (05/27).



Fig. 24. Battery charge (05/29) and paddle deployment tests (05/29-30).



Fig. 25. Separation sequence simulation test (left) and rehearsal for SHM integration (right) (06/04 to 06).

Working environment in the Yasny AITB Fueling station for the preparation of Hodoyoshi-3 and -4 was clean (class 30,000), spacious, and very comfortable.

5.5. Integration of Hodoyoshi-3 and -4 to SHM dispenser

Integration of various satellites onto the SHM of the Dnepr

launch vehicle started in Zone-B on June 4th.

Hodoyoshi-3 and -4 were integrated onto the dispenser of the SHM Platform-B on June 7th by Yuzhnoye specialists under the supervision of the Hodoyoshi team. At 9:30 three pyro-locks were installed to the Hodoyoshi-3 bottom interface flange. Next, the satellite was hanged by crane and its mass was measured using a crane scale, then transported onto the dispenser. Three pyro-locks were fastened to the dispenser, and then separation switches were adjusted. Hodoyoshi-4 was integrated in the same procedure after Hodoyoshi-3. In the afternoon, Hodoyoshi team removed non-flight items from the satellites and inserted flight plugs for arming. Figs. 26 to 29 show the integration process of Hodoyoshi microsatellites.



Fig. 26. Installation of pyro-locks (left), crane operation (right) (06/07).



Fig. 27. Fastening to dispensor.

Fig. 28. Arming by flight plug.



Fig. 29. Removal of non-flight items from Hodoyoshi-4 (06/07).

The integration of Hodoyoshi-3 and -4 onto the dispenser finished at 16:00 without any trouble. The joint tense integration work with the launch vehicle experts provided young satellite specialists with valuable opportunities to build practical experience in the international launch campaign.

5.6. Integration of dispenser onto Platform-B

KazEOSat was integrated adjacent to Hodoyoshi-3 and -4, and the day after (June 6th) the dispenser was integrated onto Platform-B as shown in Fig. 30. High density integration of 9

satellites on the Platform-B is shown in Fig. 31.



Fig. 30. KazEOSat integration (left 06/07) and the dispensor integration onto Platform-B (right 06/08).



Fig. 31. High density integration of 9 satellites on Platform-B (06/09).

5.7. Completion of satellite integration onto SHM

In parallel, the integration of other satellites to Platform-A continued simultaneously and finished with that of Deimos-2 on June 10th as shown in Fig. 32. The following day, SHM fairing nose cone was first put on Platform-A, and then the Platform-A with fairing was put on Platform-B as shown in Fig. 33. The completed SHM was loaded on a special vehicle and transported to the launch silo from Zone-C on June 13.



Fig. 32. Integration of Deimos-2 (left), all satellites integrated (right).



Fig. 33. Fairing closure (left, 06/11), completed SHM (center, 06/12), before the transportation to launch silo from Zone-C (right, 06/13).

6. Dnepr Cluster Launch

6.1. Pre-launch briefing and launch observation

Pre-launch briefing was held at 14:30 of June 19th (Fig. 34) with the presence of VIPs including Heads of space agencies of Ukraine and Kazakhstan, and Presidents of Kosmotras and Yuzhnoye. The launch schedule was confirmed.



Fig. 34. Pre-launch briefing (06/19).

Satellite team observed the launch in a conference room of AITB by TV from the launch silo and simulated animation together with verbal announcement of real time telemetry data as shown in Fig. 35. Go-Inertial time was 19:11:10.717 UTC.



Fig. 35. Lauch (left) and its observation in a conference room (right).

6.2. Orbital injection

Satellites were separated every about two seconds from the third stage by the third stage taking away from the satellites by means of throttled-back operation of its motor. Separation of each satellite was confirmed by real time telemetry data from the launch vehicle. The orbit injection profile and parameters are shown in Fig. 36. All the satellites were injected within only 17 minutes after the liftoff. A simulated illustration of the injection of Hodoyoshi-4 and -3 is shown in Fig. 37.

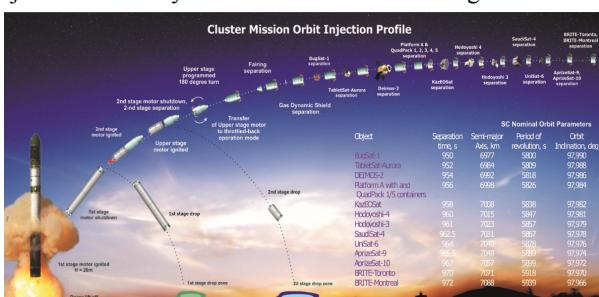


Fig. 36. Orbit injection profile of cluster launch.



Fig. 37. Simulated illustration of the injections of Hodoyoshi-4 and -3.

6.3. Hodoyoshi-3 and -4 injected orbits

Major parameters of the orbit injections of Hodoyoshi-3 and -4 given from the launch provider are summarized below.

- Go-Inertial date and time: 19.06.2014 19:11:10.717 UTC
- Hodoyoshi-4 separation time: 953,084 sec from Go-Inertial (19:27:03.801 UTC)
- Hodoyoshi-3 separation time: 954,585 sec from Go-Inertial (19:27:05.302 UTC)
- Hodoyoshi-4 state vector at separation:

t, sec	X, m	Y, m	Z, m	V _x ,m/sec	V _y ,m/sec	V _z ,m/sec
953.084	4461613	5369152	485317	1137.938	-276.205	-7465.508

- Hodoyoshi-3 state vector at separation:

t, sec	X, m	Y, m	Z, m	V _x ,m/sec	V _y ,m/sec	V _z ,m/sec
954.585	4463315	5368730	474107	1129.460	-287.042	-7470.671

- Hodoyoshi-4 osculating orbital parameters at separation:

Semi-major axis, km	Eccentricity	Inclination,
7015.57	0.0026	97.98

- Hodoyoshi-3 osculating orbital parameters at separation :

Semi-major axis, km	Eccentricity	Inclination, deg
7023.47	0.0037	97.98

6.4. Injection accuracy of major satellites

The orbit injection accuracy of the Dnepr cluster mission was very high as shown in Table 7. Errors in Hodoyoshi-3 and -4 semi-major axes were less than 1 km, and those in eccentricity were less than 0.0002.

Table. 7. Injection accuracy of Dnepr cluster mission June 2014.

Object	Orbital parameter divergence					
	Semi-major axis, km		Eccentricity		Inclination, deg	
	Estimated (3σ)	Actual	Estimated (3σ)	Actual	Estimated (3σ)	Actual
Bugsat-1	2.5	0.03	0.00045	-0.00003	0.040	0.0009
ТаблётСат-Аурора	3.0	0.07	0.00050	-0.00004	0.040	0.0008
Delmos-2	3.5	0.18	0.00055	-0.00006	0.040	0.0010
Platform A	2.5	0.20	0.00040	-0.00002	0.040	0.0010
KazEOSat-1	3.0	0.74	0.00045	0.00015	0.040	0.0006
HODYOYOSHI-4	4.0	0.60	0.00050	0.00014	0.040	0.0001
HODYOYOSHI-3	4.5	0.82	0.00055	0.00018	0.040	0.0001
SaudiSat-4	5.0	0.63	0.00060	0.00019	0.045	-0.0005
UNISAT-6	5.5	1.13	0.00070	0.00024	0.045	-0.0011
Aprizise-9	6.5	1.25	0.00080	0.00026	0.050	-0.0016
Aprizise-10	7.5	1.47	0.00090	0.00030	0.050	-0.0023
BRITE-Toronto	11.0	-11.45	0.00140	-0.00154	0.055	0.0002
BRITE-Montreal	12.0	-11.17	0.00150	-0.00148	0.055	-0.0009

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6.5. First acquisition of signals in Tokyo

1 hour 13 min. after the injection, a Hodoyoshi-4 S-band signal was captured by KSAT in Norway.

Hodoyoshi satellite team in Tokyo captured the S-band telemetry signals from Hodoyoshi-3 and -4 from 8:38 to 8:49 of June 20th (Tokyo time) as shown in Figs. 38 and 39.



Fig. 38. Hodoyoshi-3 and -4 at first accusion in Tokyo.

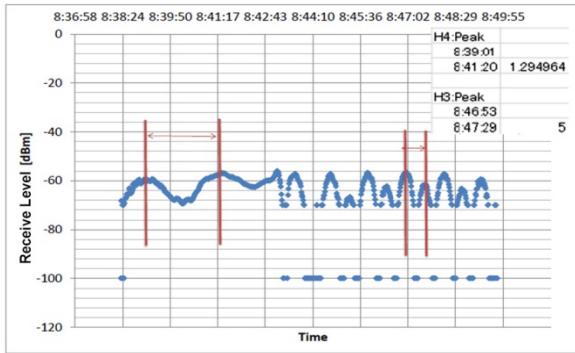


Fig. 39. First accusion data of Hodoyoshi-4 (first half) and-3 (second half) in Tokyo (06/20).

Two satellites were in slightly different orbits, and a single Hodoyoshi operation team with a single receiving antenna first captured Hodoyoshi-4 and then switched to Hodoyoshi-3.

The variations of solar cell output recorded in the computer of Hodoyoshi-4 showed that the satellite was rotating once per three minutes just after the separation (angular velocity about 2 deg/sec.). This rotation period was confirmed by Received Signal Strength Indication (RSSI) at the first contact in Tokyo. Also the RSSI of Hodoyoshi-3 at the first contact indicated that its angular velocity at the separation was 3 to 5 deg/sec.

During the 1st to 4th Acquisition of Signal (AOS) within the first day after the orbit injection, most critical operations including the followings were successfully completed.

- Initial health check
- Solar paddle deployment
- Initial attitude acquisition
- Spin stabilization towards the sun

7. Conclusion

Hodoyoshi-3 and -4 were successfully launched into SSO with very high accuracy by Dnepr launch vehicle from Yasny as a result of the two years of intensive interface coordination works and the launch campaign. The launch environment and interface constraints of Dnepr were modest: the pyro shock issue was solved by using a special air-gun type shock tester, and the flight proven Hodoyoshi spacecraft bus has excellent design flexibility for future growth and challenges. Also the very simple activation of Hodoyoshi-4 MIPS at the launch base demonstrated its unique user-friendly design.

During the Yasny launch campaign, a total of 33 satellites with a variety of different shapes, sizes and mass were integrated onto the SHM of the Dnepr vehicle. The joint works for the cluster mission involving 17 countries provided the participants with valuable opportunities to learn different satellites and teams as well as to experience variety of international cooperation including joint transportation of satellites to Yasny using a shared charter flight.

Hodoyoshi-3 and -4 in-orbit have been demonstrating remarkable innovative Japanese microsatellite technologies including the followings:

- Miniature Ion Thruster Propulsion System, In-flight first operation of an ion thruster on a small satellite (less than 100

kg) : 2014/12/12

http://www.tu-tokyo.ac.jp/etpage/release/2014/141212_01.html

● First in-flight operation of liquid Li-ion battery: 2014/12/16

http://www.kansai-u.ac.jp/mt/archives/2014/12/post_1235.html

● Micro satellite "Hodoyoshi-4" success in acquiring high resolution images : 2014/12/26

http://www.tu-tokyo.ac.jp/etpage/release/2014/141226_4.html

● Micro satellite "Hodoyoshi-4" success in the world-fastest down link communication of 348 M bit per second as a 50 kg class satellite : 2015/02/18

http://www.tu-tokyo.ac.jp/etpage/release/2015/150218_01.html

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