Applications of the Lithium-Ion Secondary Batteries to the Space Crafts for the Scientific Missions

ISAS/JAXA

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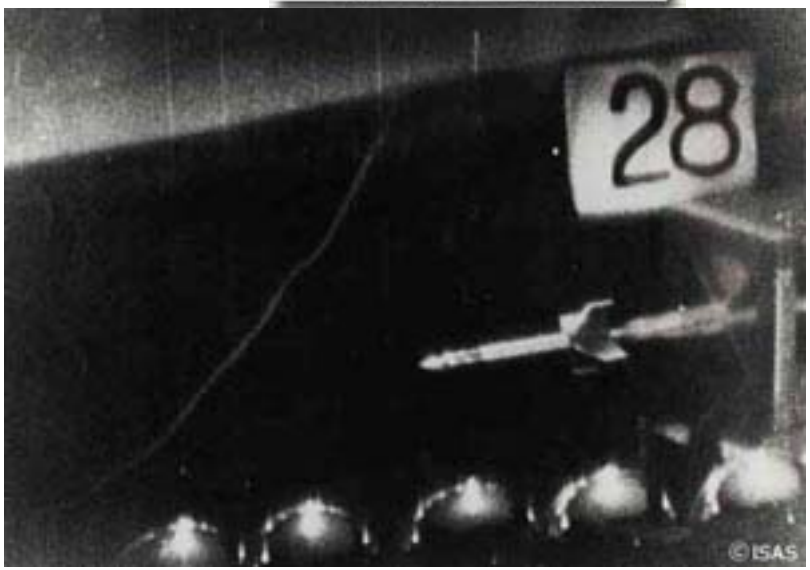
Today's Topics

- Operation of the Lithium-ion Secondary Battery for Interplanetary Space Craft 'HAYABUSA'
- Application of the Lithium-ion Pouch Cells to Piggy-Back Satellite 'REIMEI'
- Application of the HEV Lithium-ion Cells to M-V Launch Vehicle

The outward appearance of HAYABUSA



2003.5.9

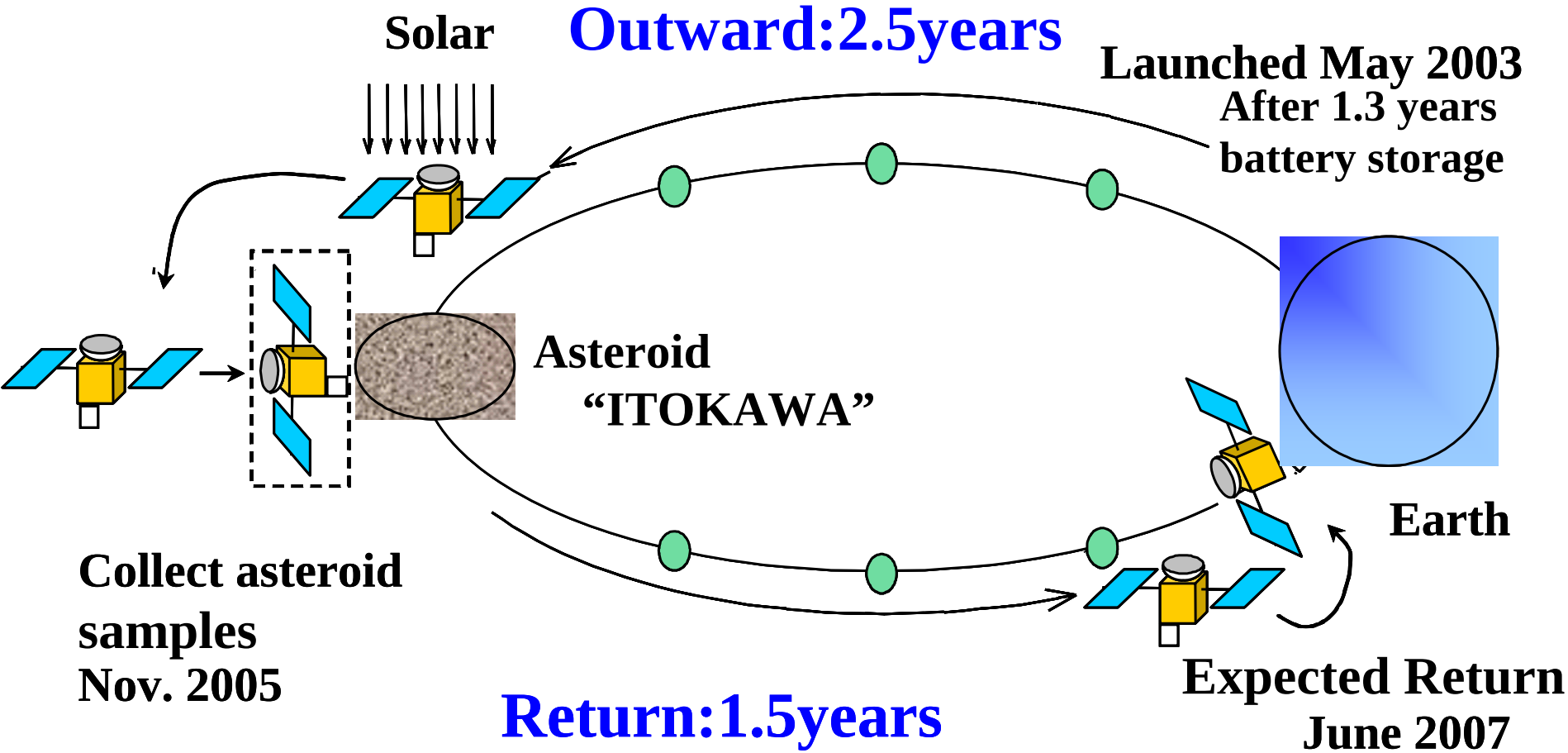
HAYABUSA was launched

Outline of HAYABUSA(1/2)

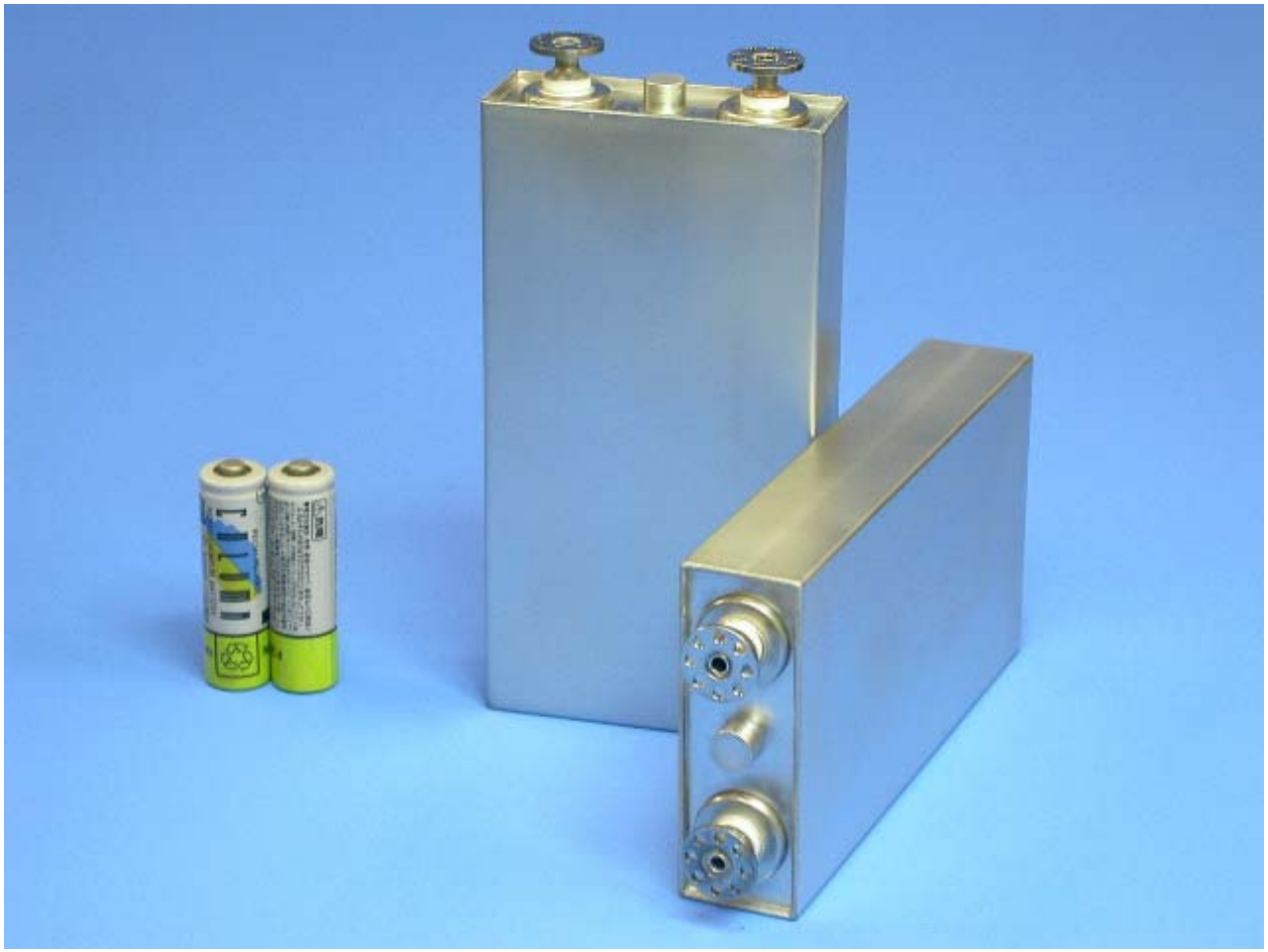
- ‘HAYABUSA’ (called ‘MUSES-C’ before launch) is an interplanetary spacecraft launched in May 2003.
- Destination is an asteroid named ‘ITOKAWA’ (1998SF36).
- Spending the first year to accelerate its velocity with an ion engine, it changed course to the asteroid using Earth’s gravity.

Outline of HAYABUSA(2/2)

- Missions of HAYABUSA
  - Observation of the asteroid
  - Bring back samples to Earth
  - Engineering demonstration
    - Ion engine,
    - Triple junction solar cells which generates 100 V-class electricity
      - 100 V-class power is supplied to ion engine
      - 50 V-class regulated power is supplied to bus system and battery
    - Lithium-ion secondary battery
    - etc.



Flight schedule of HAYABUSA



Photograph of a lithium-ion secondary cell used in the HAYABUSA battery

Specifications of the lithium-ion secondary cell used in HAYABUSA.

[1)]The nominal discharge rate is 0.2 C at 20 degrees C

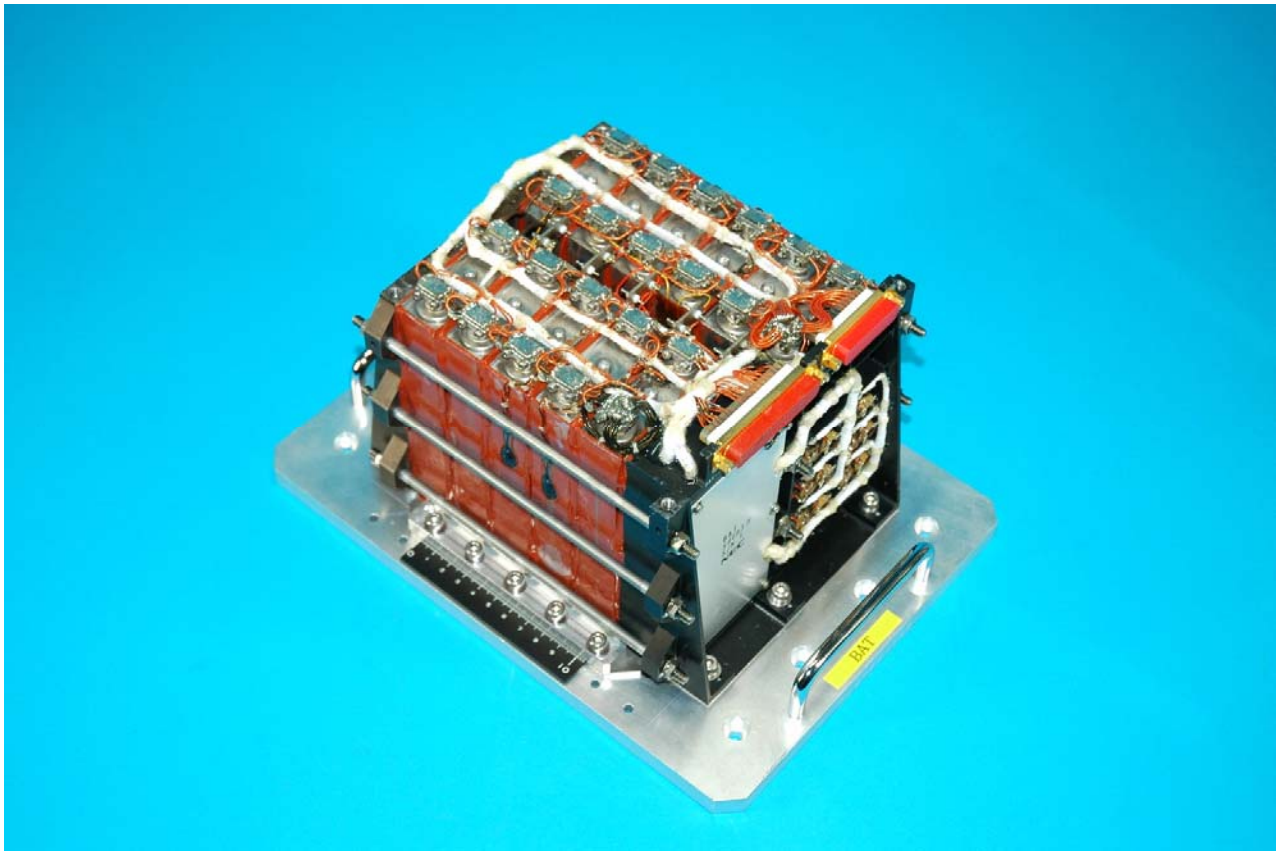
Rated Capacity[1)]		13.2 Ah
Discharge Voltage (Average) [1)]		3.6 V
Size	Width	69.3 mm
	Height	132 mm
	Thickness	24.4 mm
Weight		< 570 g
Energy Density / mass		> 85 Wh/kg
Energy Density / volume		> 215 Wh/L

Expected performance of the battery

1)'Years' was counted starting after preparation of the flight cells.

Event	Years[1)]	Discharge Performance	
		Current/A	Capacity/Ah
Launch	1.34	--	7.03
Earth Swing-by	2.40	14.27	4.76
Touch-down on ITOKAWA	3.71	16.70	2.51
Terminator Observation	3.79	17.61	5.95
Capsule Re-Entry to Earth	5.44	15.23	3.43

The charge current for the operation is 500 mA.
The resistance of the heater used for the discharge is about 8 ohms.



Photograph of the lithium-ion battery

11 cells were connected in series. A balance circuit is installed in this battery stack.

Battery Operation of HAYABUSA (1/3)

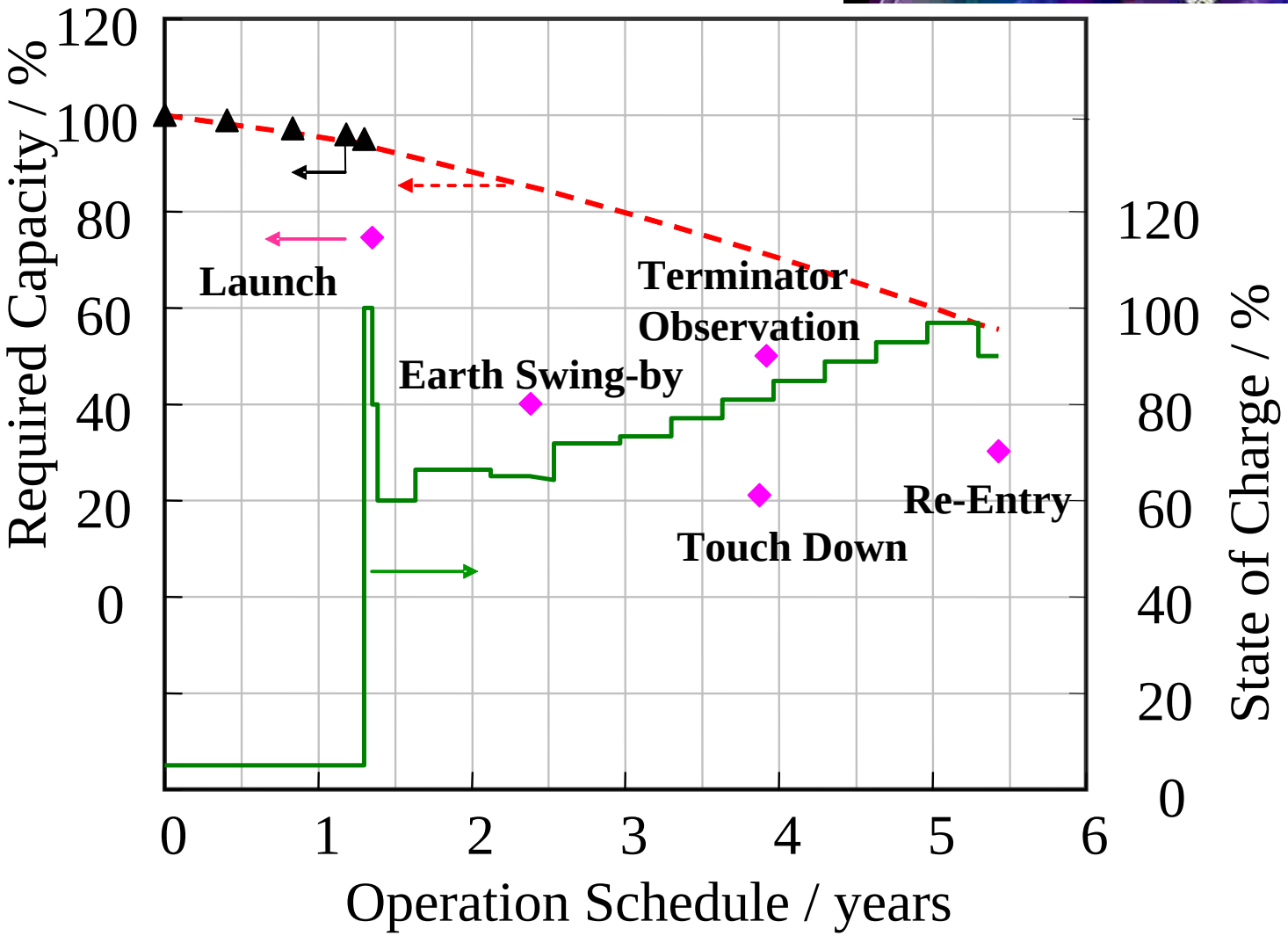
- The battery on the satellite is a 13.2 Ah lithium-ion secondary battery.
- To realize maximum performance of the battery for a long period, the state of charge (SOC) of the battery is maintained at ca. 65% which is required in case of any contingency operation during storage. To maintain the SOC condition, the battery is charged once a week.

Battery Operation of HAYABUSA (2/3)

- The lithium-ion secondary battery is charged with CC-CV control.
- For precise control of SOC, we prepared 256 levels of charge voltage between 35.0 V / 40 degrees C and 47.5 V / 0 degrees C.
- When the charge current starts to taper, the timer cuts off the current in case of over-charging. The period for the taper charge could be alternated from 0 to 9.1 hours.

Battery Operation of HAYABUSA (3/3)

- We perform a balance operation every four months. Through this operation, the cells are charged up to 4.1 V/cell using by-pass circuits to balance SOC levels.
- Along with the operation in orbit, we are simulating the performance of the flight battery using a ground-test battery. Both results showed good correlation.

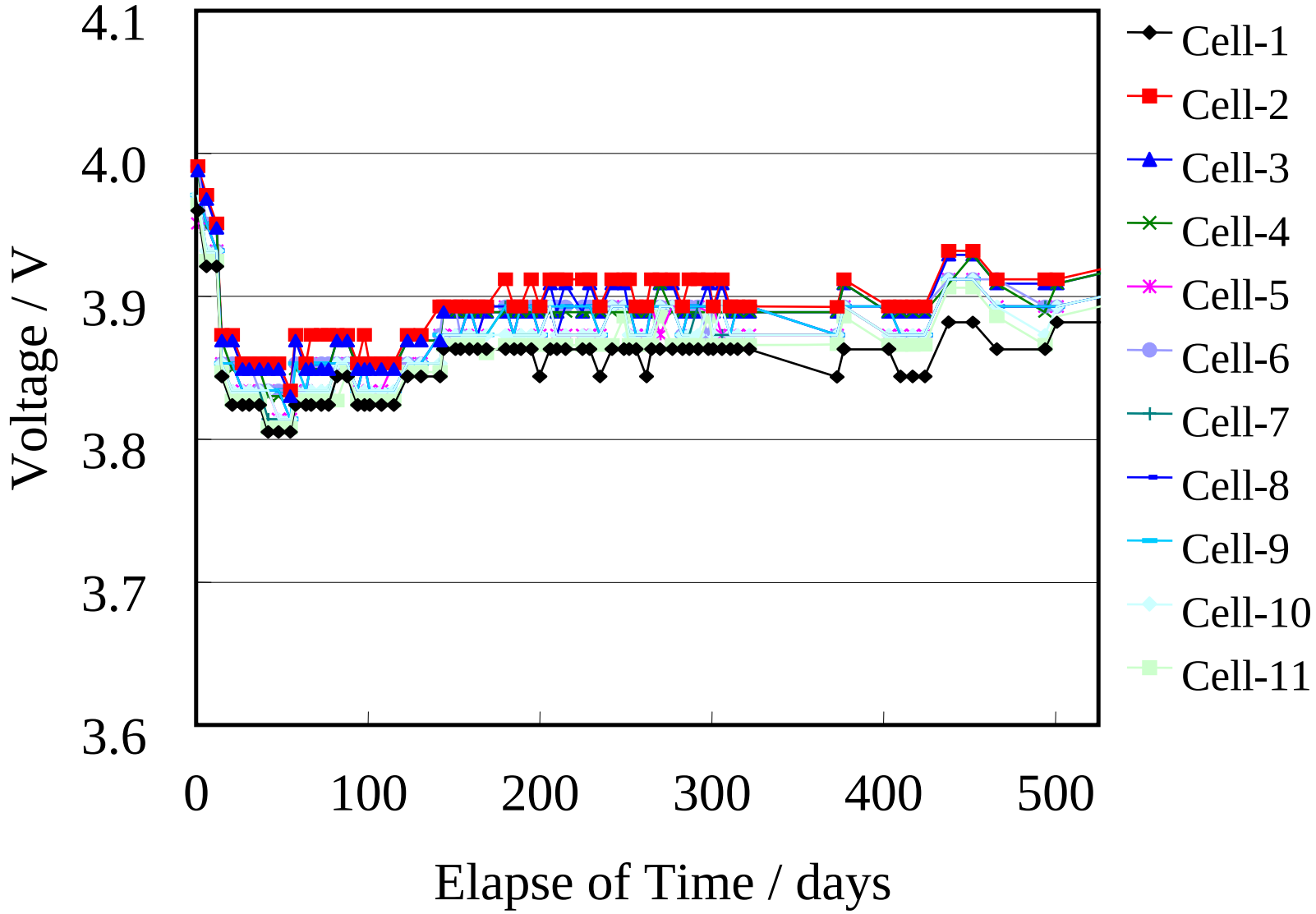


Operation of the flight battery for HAYABUSA

◆ Required capacity for each event ▲ Capacity measured

- - - Decay of the capacity (calculated)

—— Elevated charge condition for events

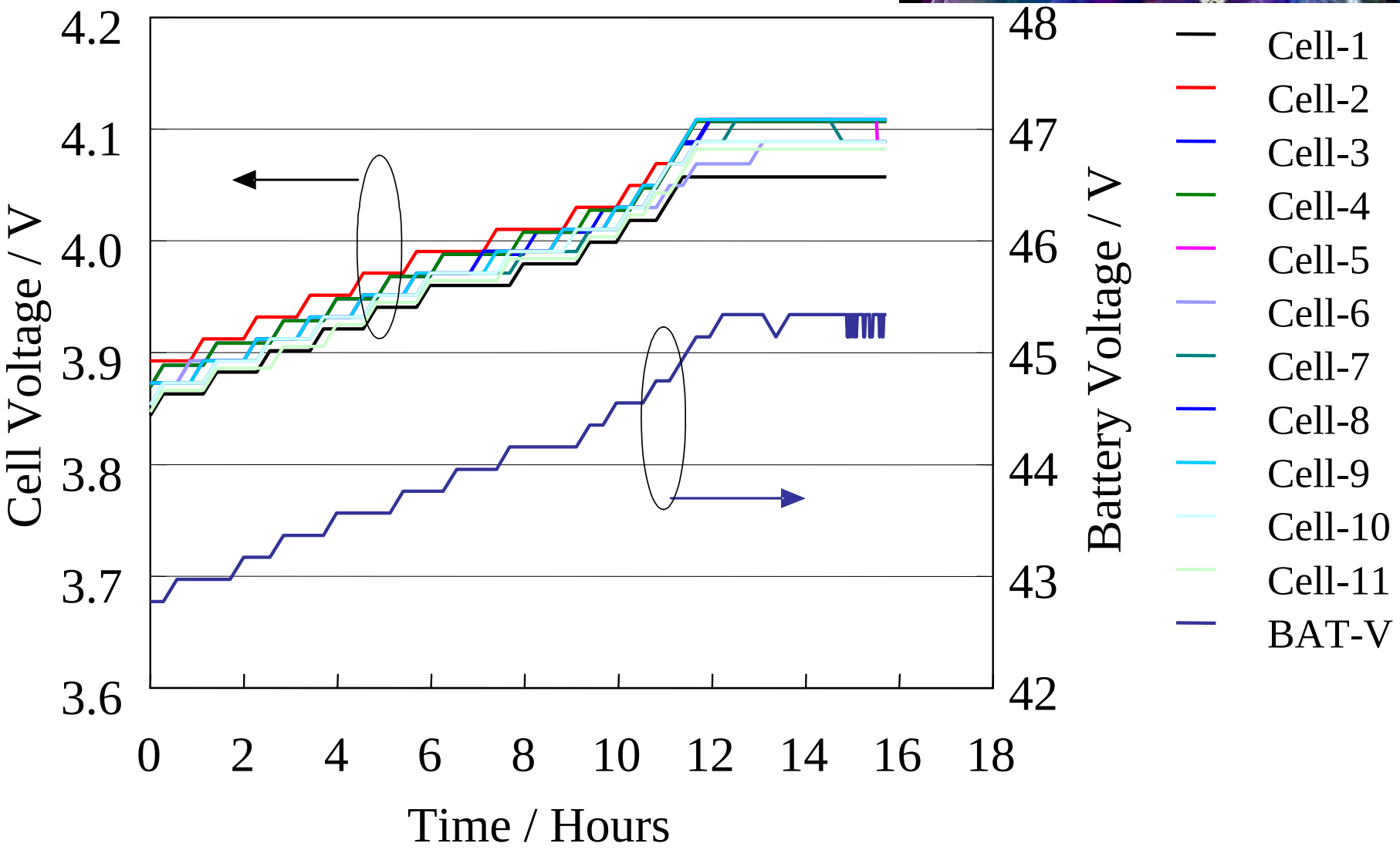


Trend of the cell voltage in flight.

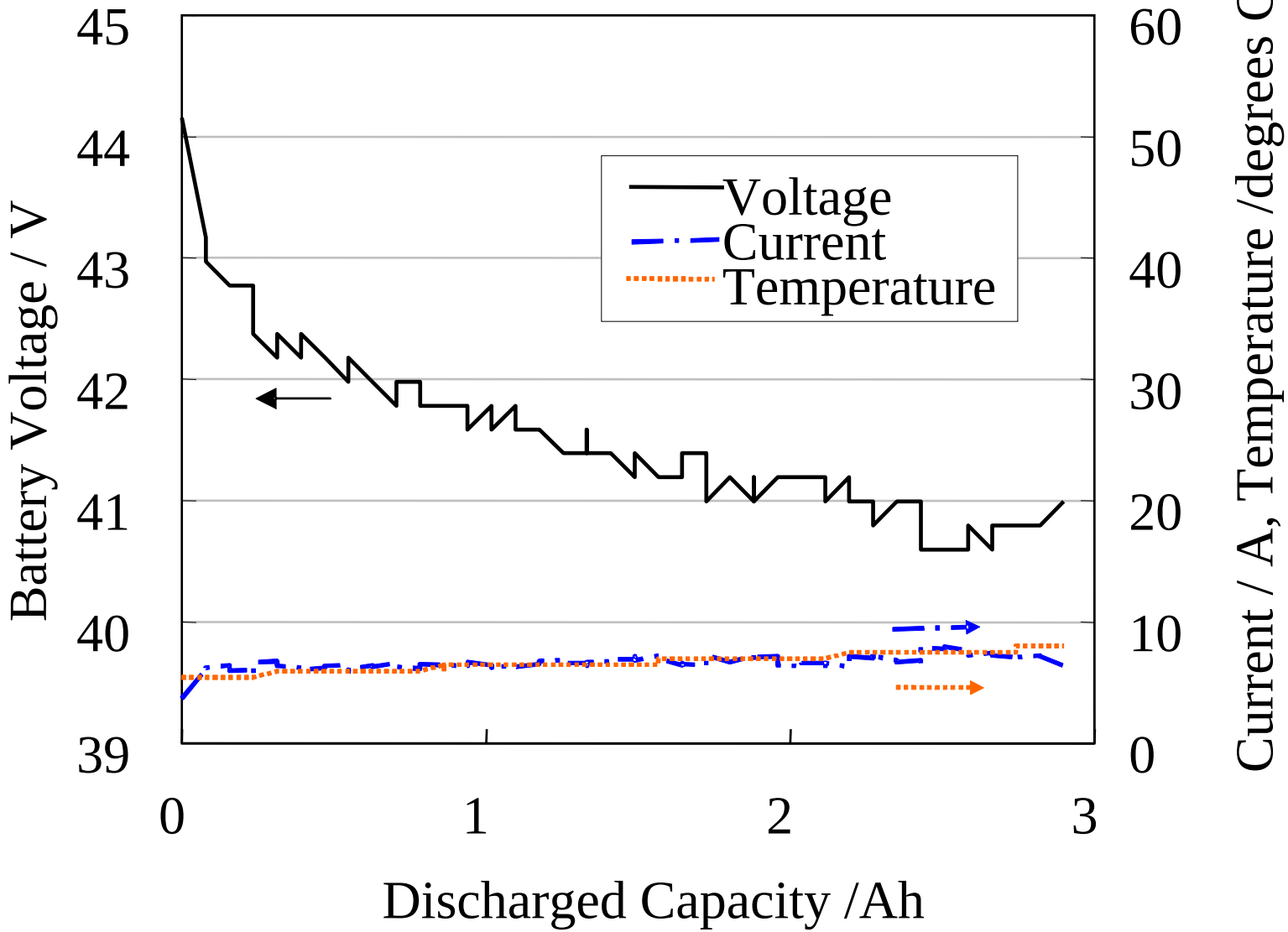
The self-discharge has been compensated by charge once a week. The monitored cell voltages increased with the elevated charge conditions.

Balance Operation

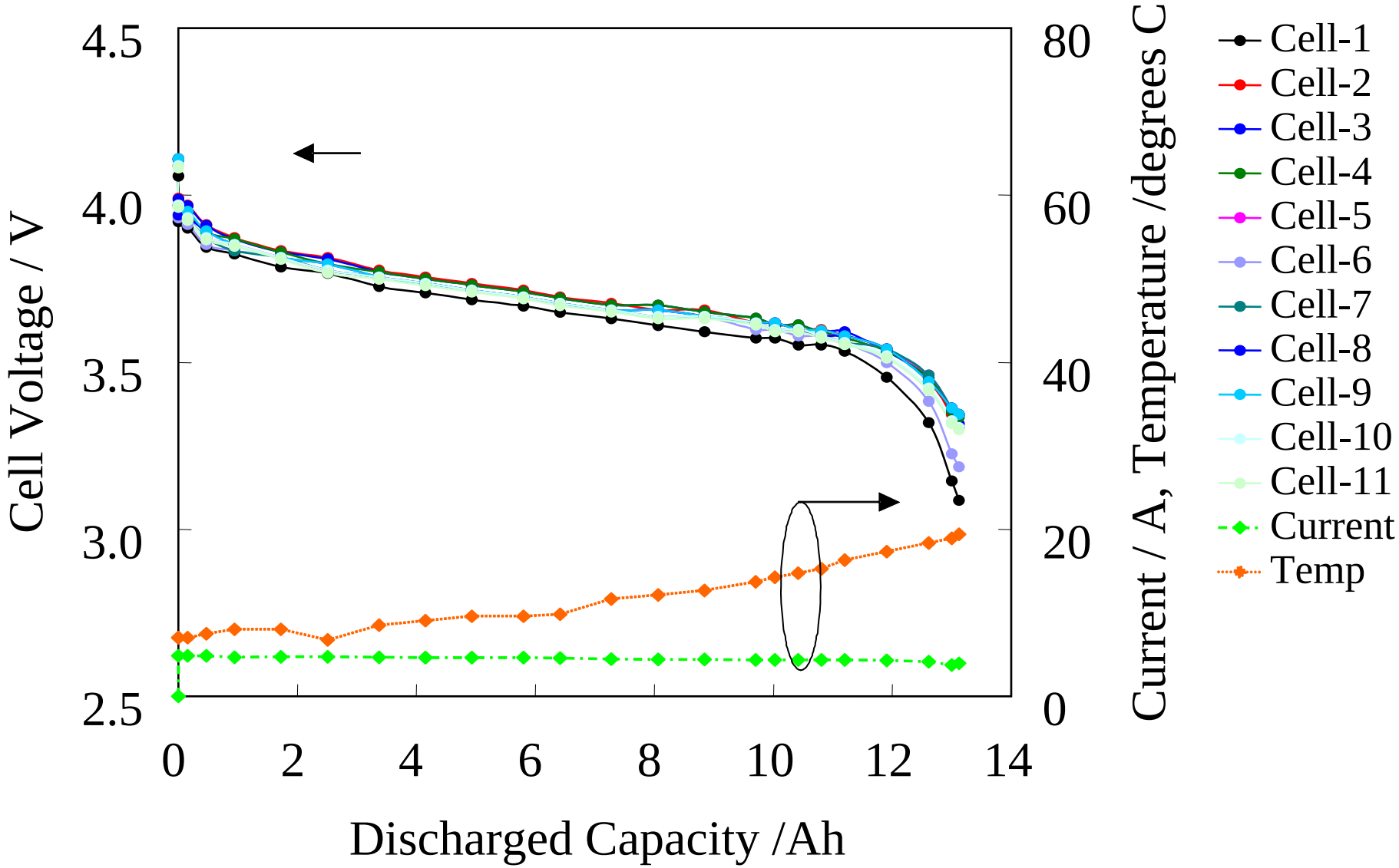
- The charge current for this operation was 500 mA. The resistance of the heater used for the discharge was about 8 ohms.
- By spending 12 hours with charge current of 500 mA, the SOC level of each cell arrives up to the same level stepwise.
- After charged, the battery was discharged down to ca. 50% SOC using a heater-resistance of the satellite.
- Then the battery was charged again up to 65% in preparation for the contingency.



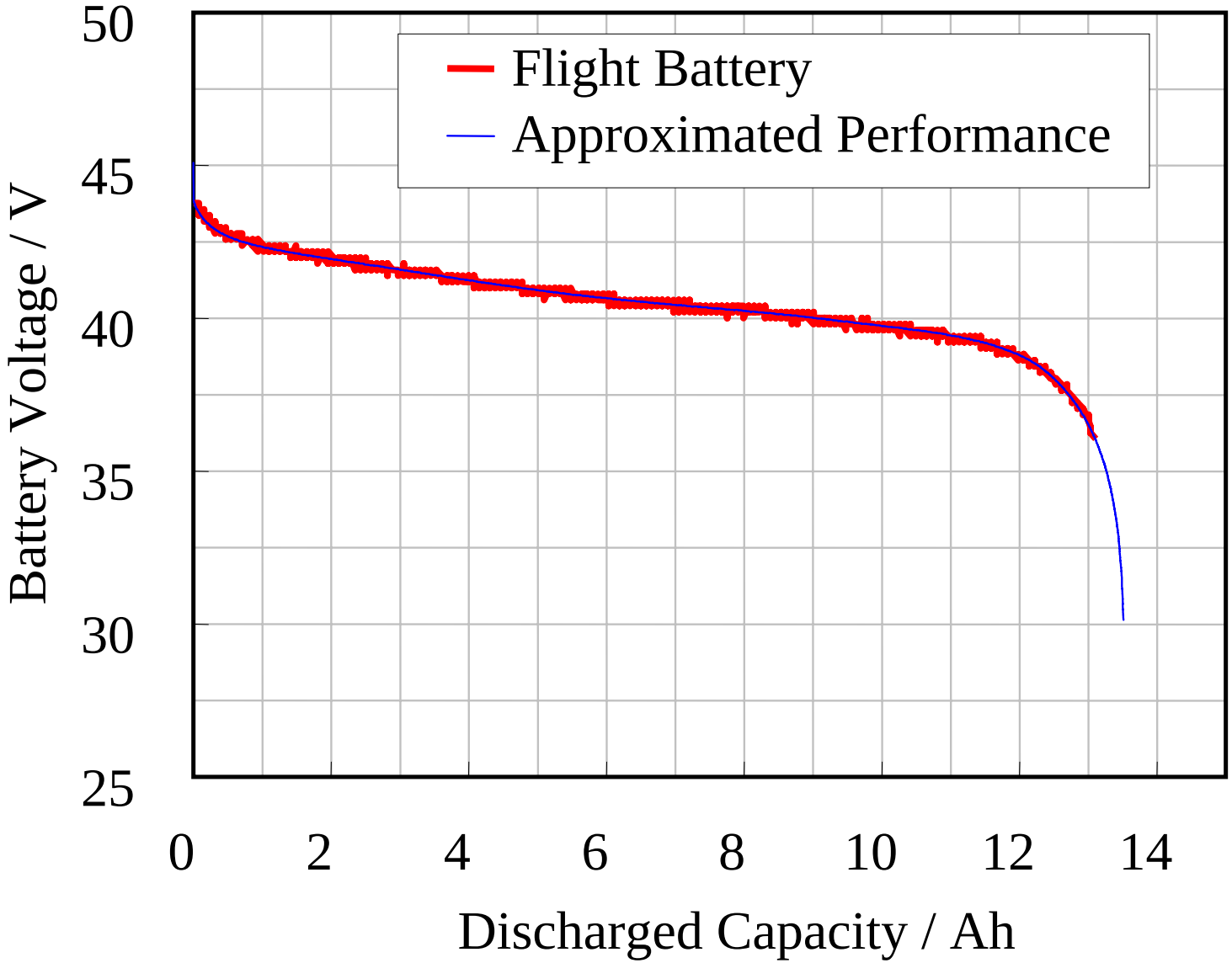
Charge curves of the battery/cell voltage during the balance operation. The difference of the cell voltages is within 50 mV, which means the cells keeping a balance.



Discharge performance of the lithium-ion battery during the Earth swing-by



Discharge performance of the lithium-ion cells during the on-orbit capacity measurement



Discharge curves of the flight battery during the on-orbit capacity measurement

Expected Performance of the Lithium-ion Secondary Battery to touch down on ITOKAWA

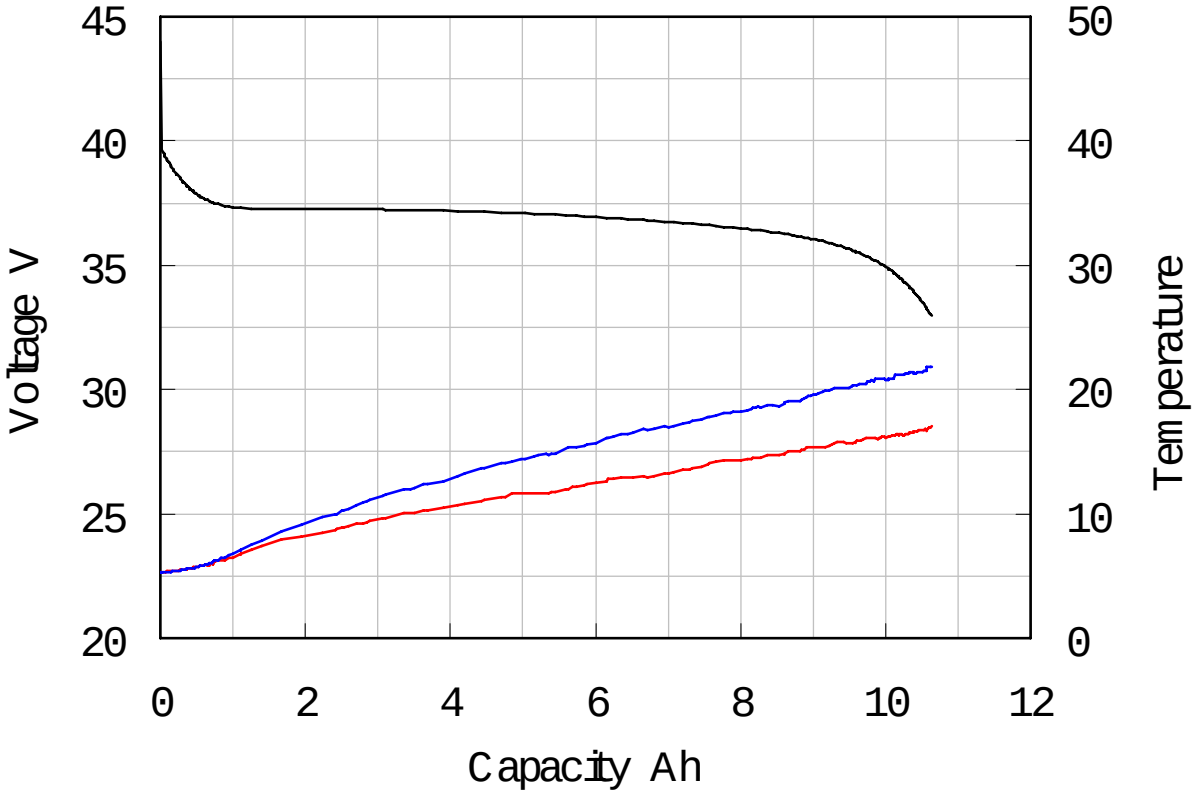
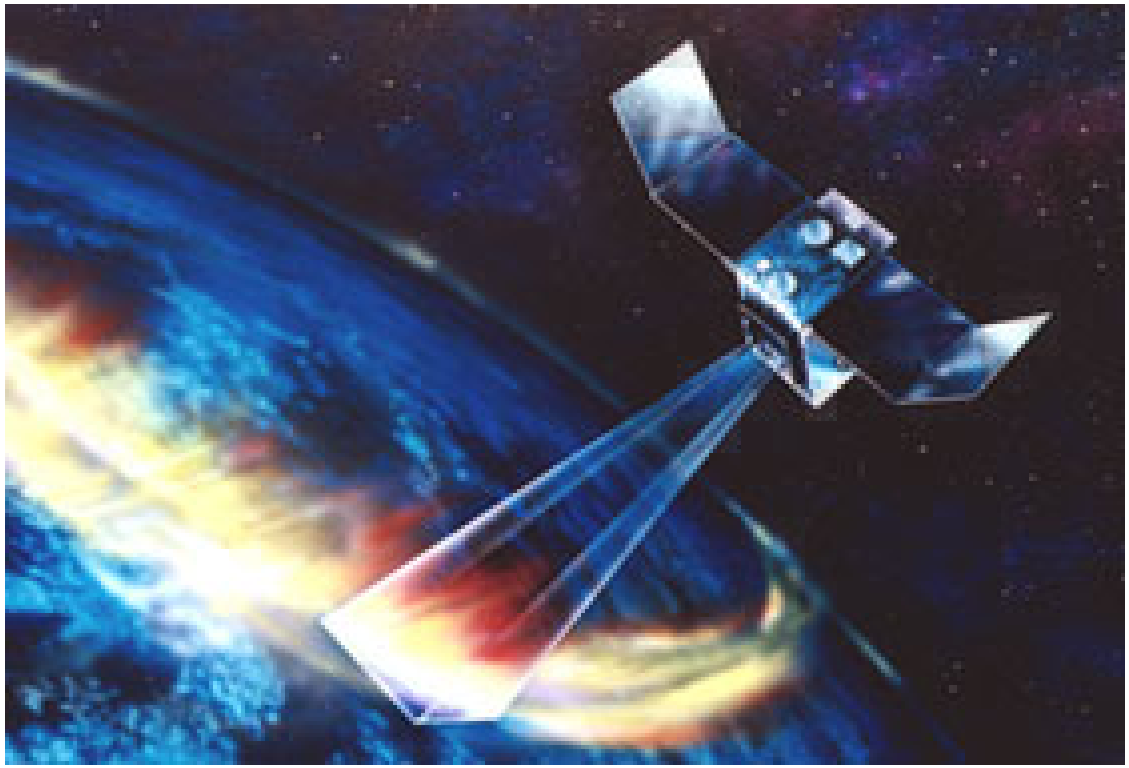


Fig. Expected performance of the HAYABUSA battery
Discharged by CP mode..570W.33V cut-off.
Charged up to 43.989 V.

Operations of HAYABUSA

- Sample capture on 19 and 25/Nov, 2005.
- Return to Earth and drop the capsule with the asteroid samples in the Earth's atmosphere.

INDEX = INnovative technology Demonstration EXperiment

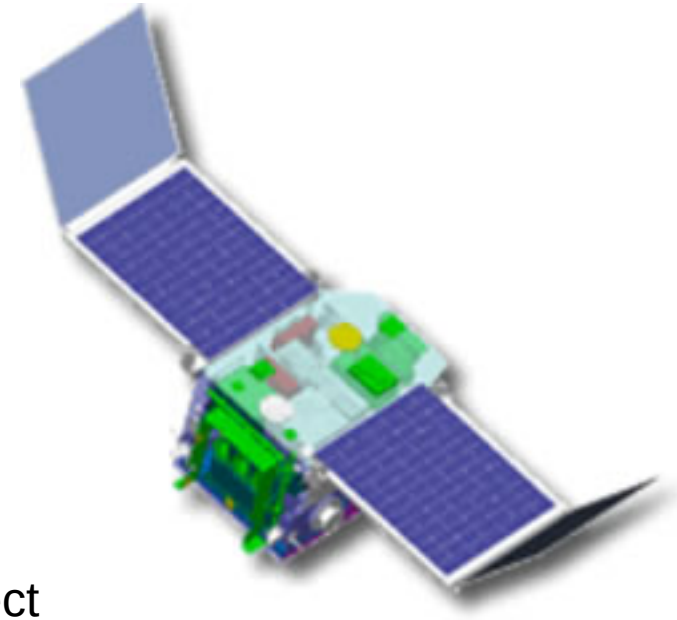


INDEX will be launched this summer as a piggyback satellite of OICETS.

Mission Period > 3 months

- In-Orbit Demonstration of Advanced Technologies.
- Frequent Opportunities using Small / Piggyback Satellite System.
- Aurora observation.

Electrical Power Sub-Systems of INDEX



Application of Multi Junction Solar Cell

27% conversion efficiency

Application of Solar Reflector

Improvement of power generation by solar reflector

Application of Lithium Ion Battery

High voltage, high energy density and no memory effect

Off-the-shelf lithium-ion cells will be applied.

- Tolerance against radiation
- Life Cycle Performance.3months = 1300cycles.
- Performance under the vacuum condition
- Battery Structure .Potting material, Case/Housing.
- Vibration

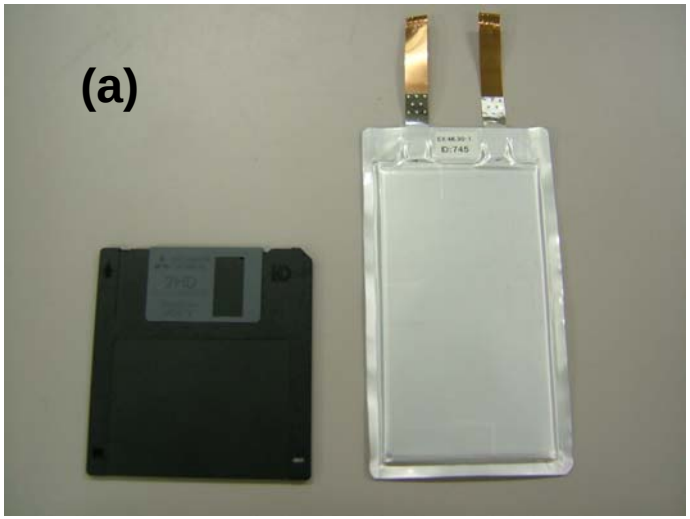
must be developed / tested.

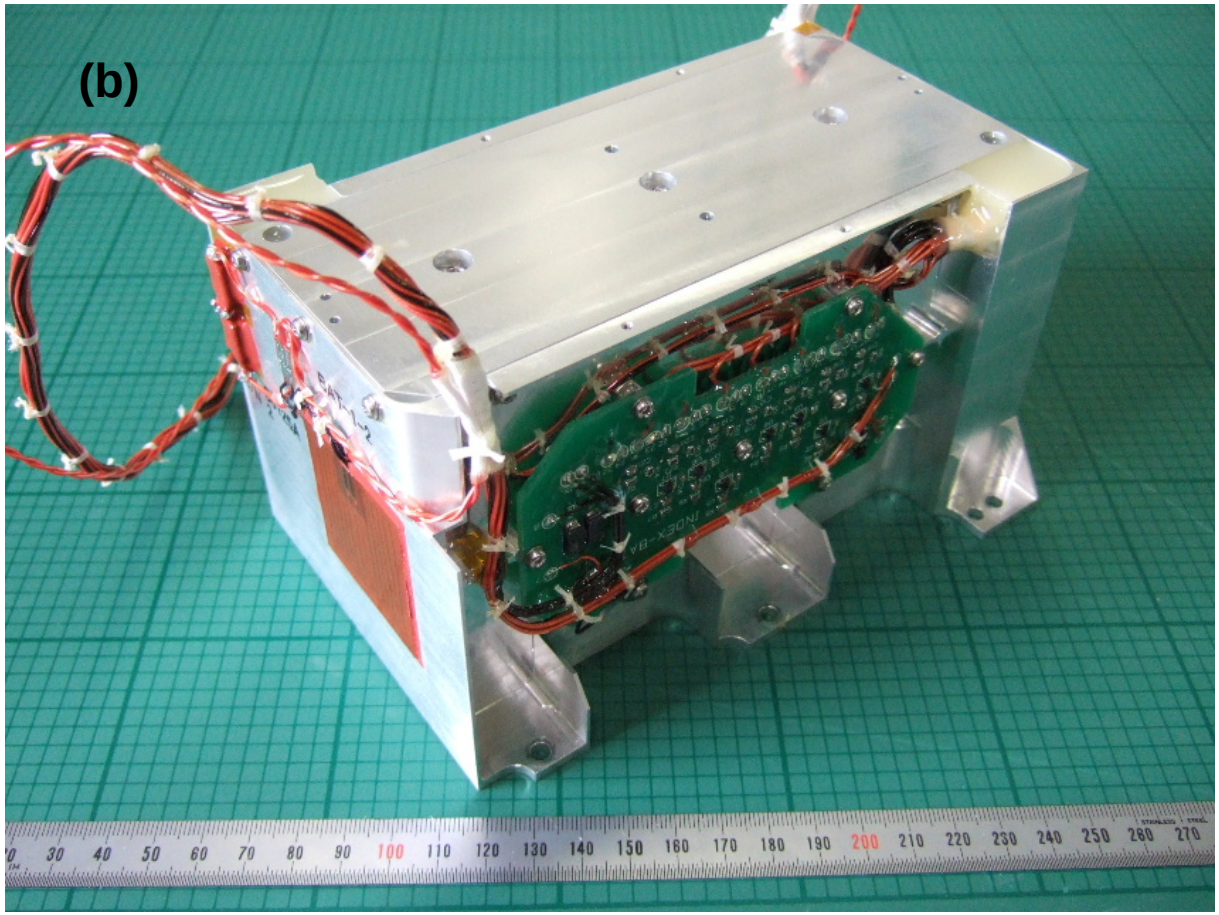
Specification of Lithium-Ion Cell

Electrode	Positive	$LiMn_2O_4$
	Negative	Graphite
Rated Capacity		3 Ah
Weight		75 g
Dimension		145 x 80 x 4 mm
Energy Density	Mass	158 Wh/kg
	Volume	340 Wh/L
Charge Voltage		4.1 V
Lower Limited Voltage		3.0 V

Specifications of the lithium-ion secondary battery for REIMEI

Configuration	7 series of the cells 2 parallels of the batteries	
Potting Material	Epoxy Resin	
Case Material	Al	
Dimension	168×102×96 mm^3	
Weight	2.42 kg	
Energy Density	Weight	70 Wh/kg
	Volume	102.2 Wh/L

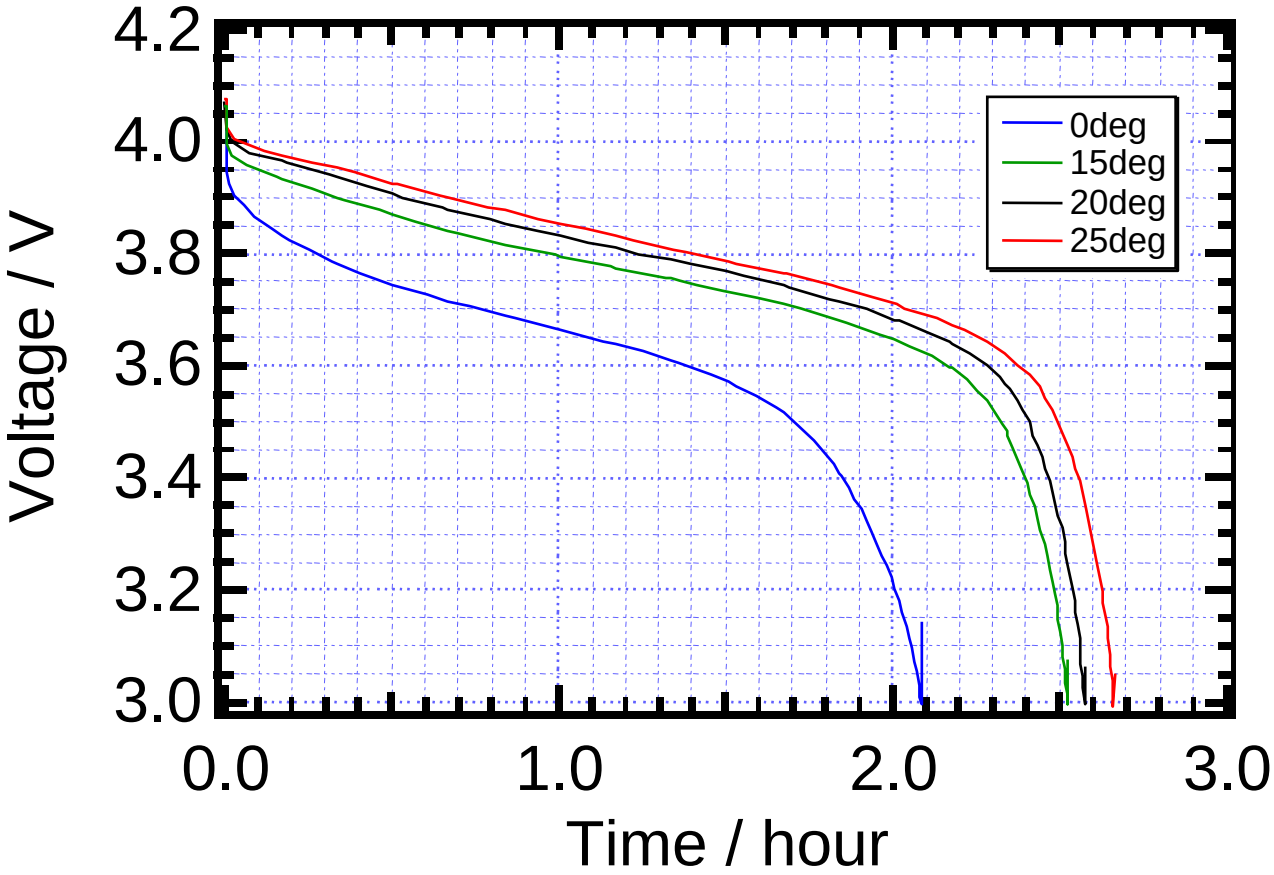




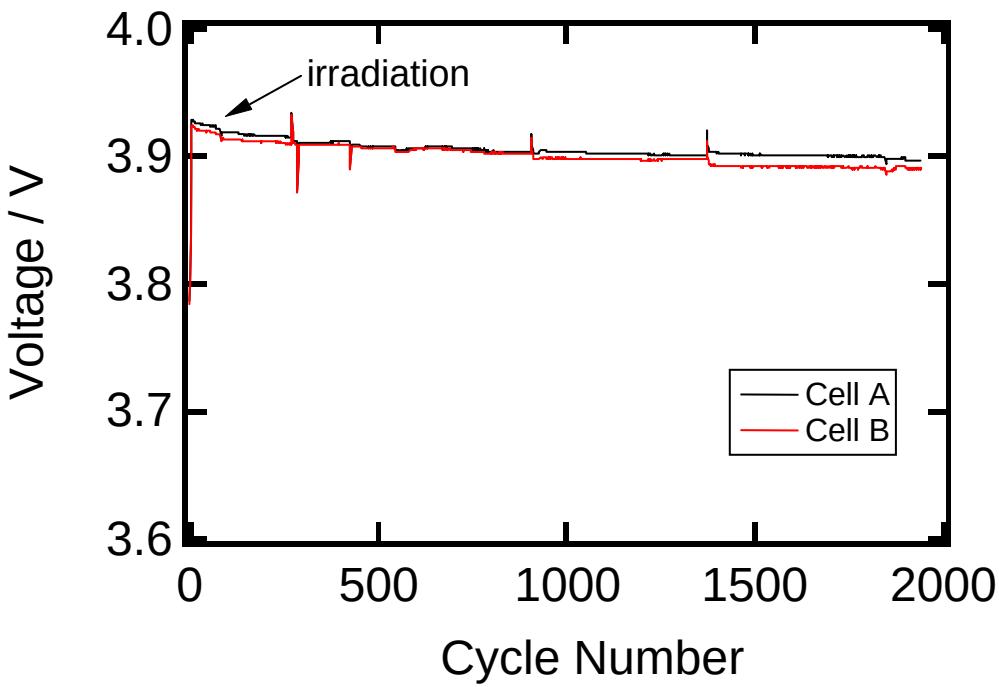
Photograph of the lithium-ion cell (a) and battery (b).

The rated capacity of the cell was 3.0 Ah. The pouch cells were potted with resin and reinforced by the aluminum housing to enhance the tolerance against the vacuum environment.

Lithium-Ion Cell Performance



Radiation Tolerance of the Bare Cells

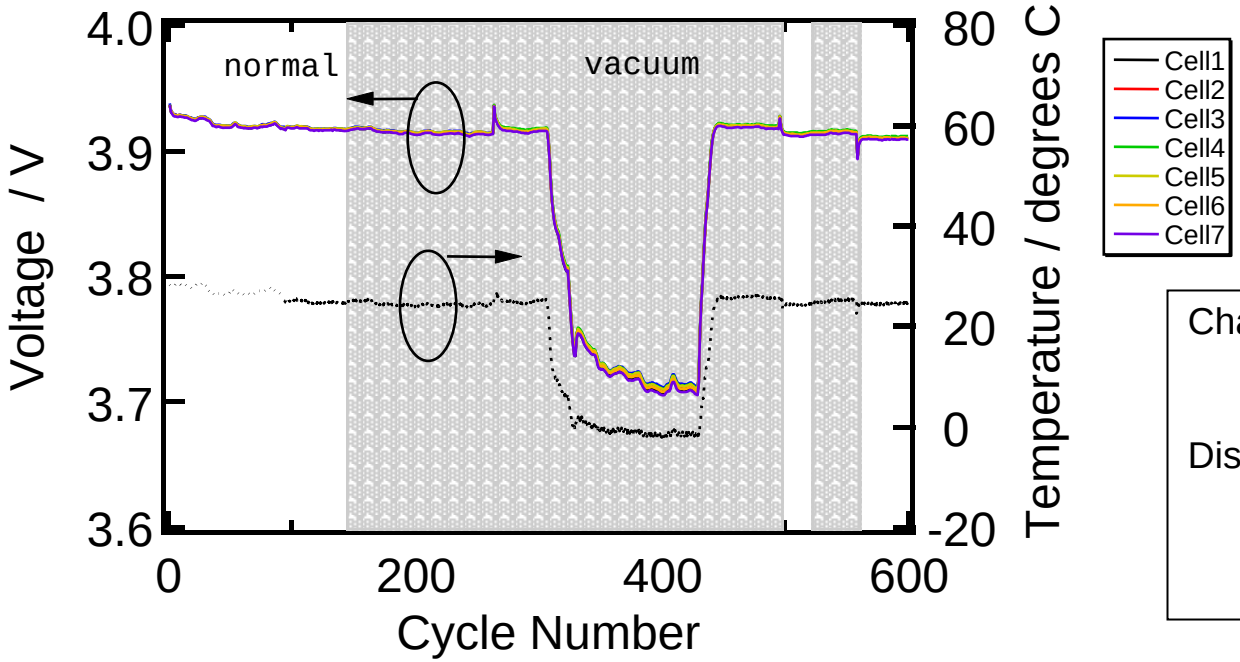


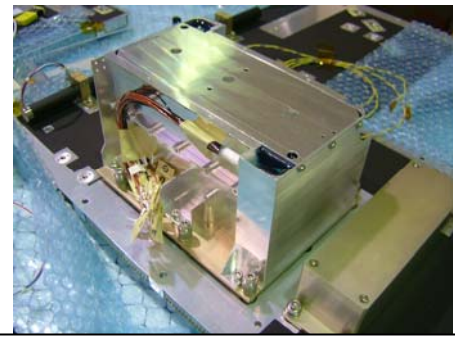
1.5×10^4[rad] Cell A
1.0×10^4[rad] Cell B

Charge : CC/CV
1500mA / 4.1 V
for 65min.
Discharge : CC
1000mA for 35min.
DOD=20%
@ 27 degrees C

- EoDV did not degrease after the radiation tests.
- The EoDV of the cells were still over 3.9 V, which is higher than UVC level of 3.75 V after 2,000 cycles (= 5 months > minimum criteria for the missions)

Trend of EoDV (End of Discharge Voltage) Uralane-Potted Cells with Aluminum Housing under Vacuum Conditions





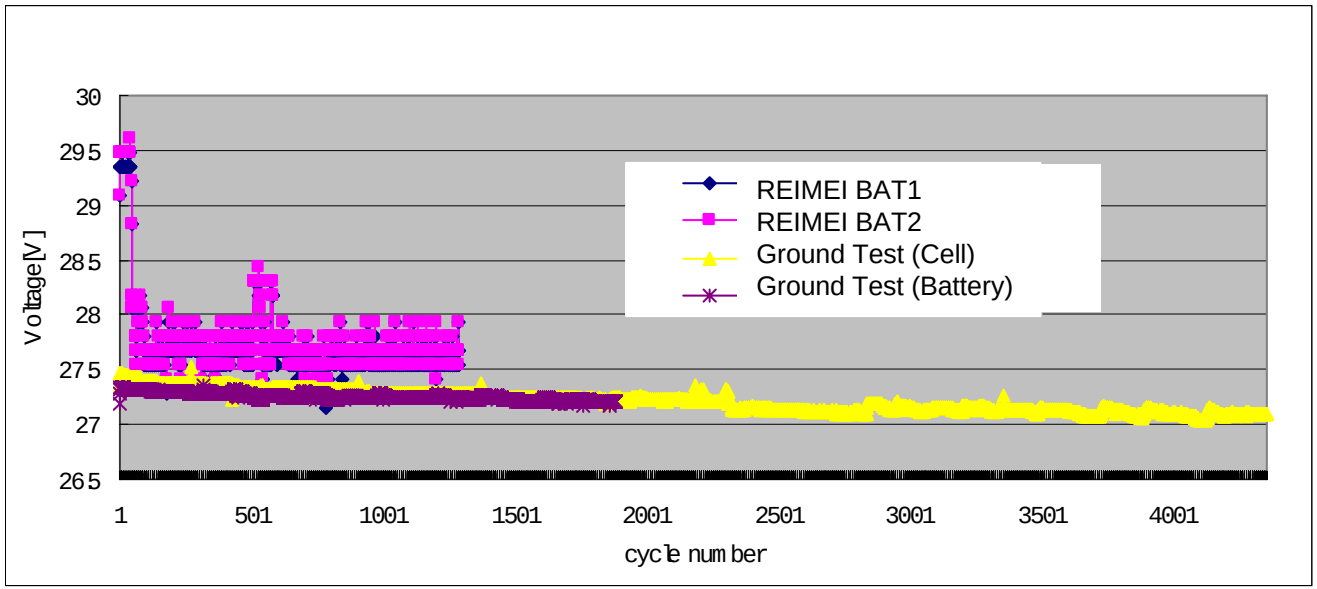
Charge : CC/CV
1500mA / 4.1 V
for 65min.

Discharge : CC
1000mA for 35min.
DOD=20%
@ 20.

- EoDV did not decrease under the vacuum condition.
- The leakage of electrolyte was not detected by the off-gas test.

- Cells were sealed appropriately

In-Orbit and Ground Test Data of the Lithium-ion Secondary for REIMEI



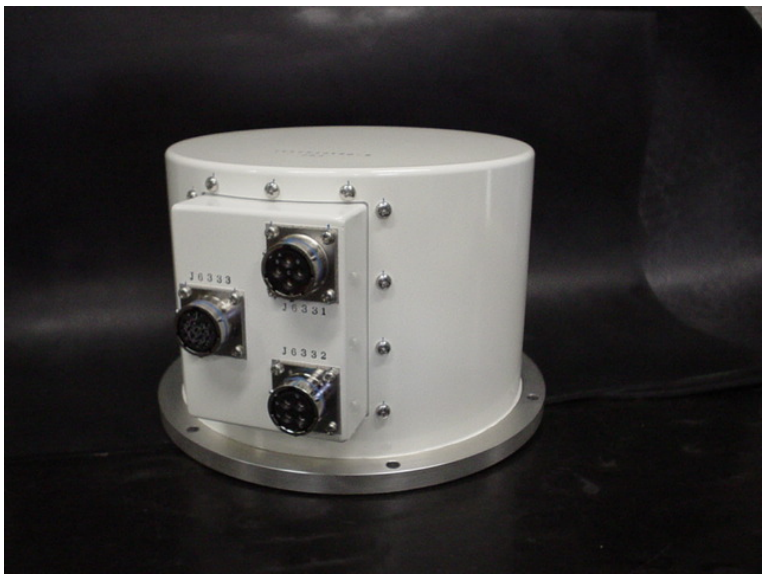
Test Conditions for Ground Tests

Charge	1500mA 65min
Discharge	1000mA 35min
Temperature	25.

Lithium-ion Secondary Cell/Battery for M-V Thrust Vector Control

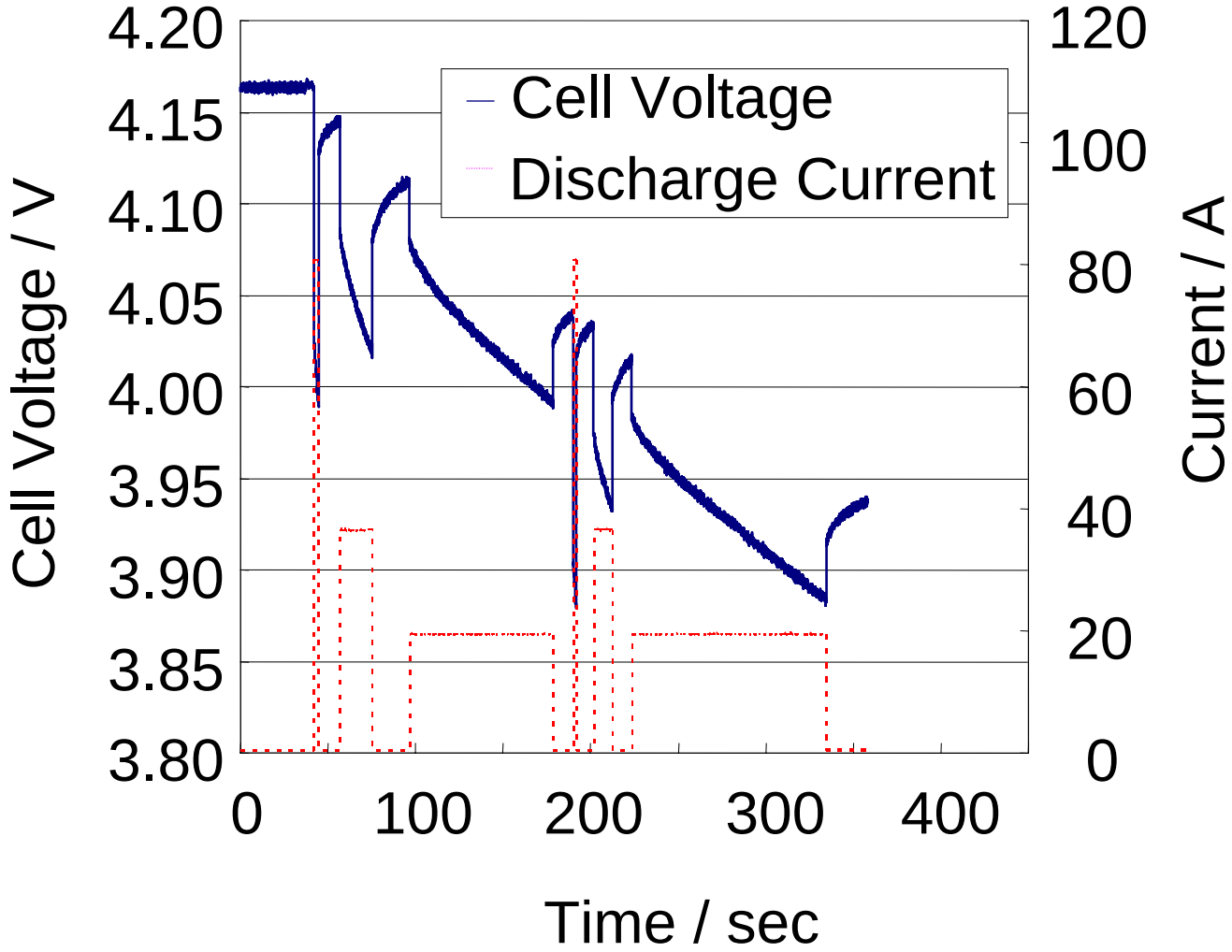
Specifications of the cell

Size	40 mm × 108 mm
Weight	300 g
Rated capacity	6 Ah
Maximum current	90 A



Specifications of the battery

Size	216 mm × 141 mm
Weight	6.3 kg
Number of the cells	10 cells in series
Rated capacity	6 Ah



Discharge performance of the HEV lithium-ion cell during simulation testing for a M-V third-stage thrust vector control.

Summery

- The HAYABUSA satellite is currently using a 13.2 Ah lithium-ion battery system. The performance of the battery was confirmed under micro-gravitational conditions in an interplanetary orbit.
- The REIMEI satellite had 3 Ah lithium-ion pouch cells for the battery system. Lithium-ion pouch cells perform well in the low Earth orbit.
- The M-V launch vehicle has also started to use HEV lithium-ion cells to control its thrusting system. Based on these applications, it is clear that lighter weight battery systems are now being realized for space missions.