Power Storage Devices for Satellites
- from satellites to aircraft -

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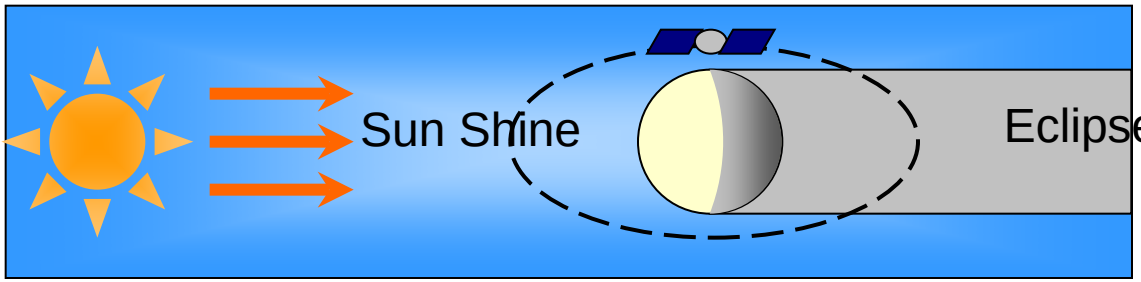
1. Roll of battery(cells) in the Satellites

Power Supply in Satellite



During Sunshine
Power supplied from Solar cells

During Eclipse mode
No power supply from Solar cells

Rechargeable Battery

=Power Supply during Eclipse mode

Charged by Solar cells

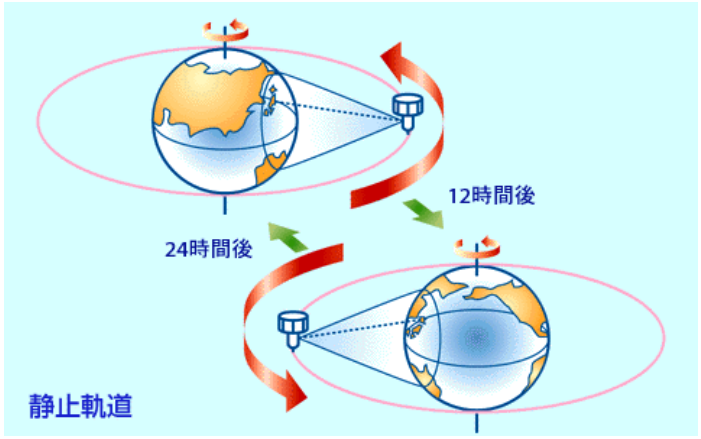
Discharge

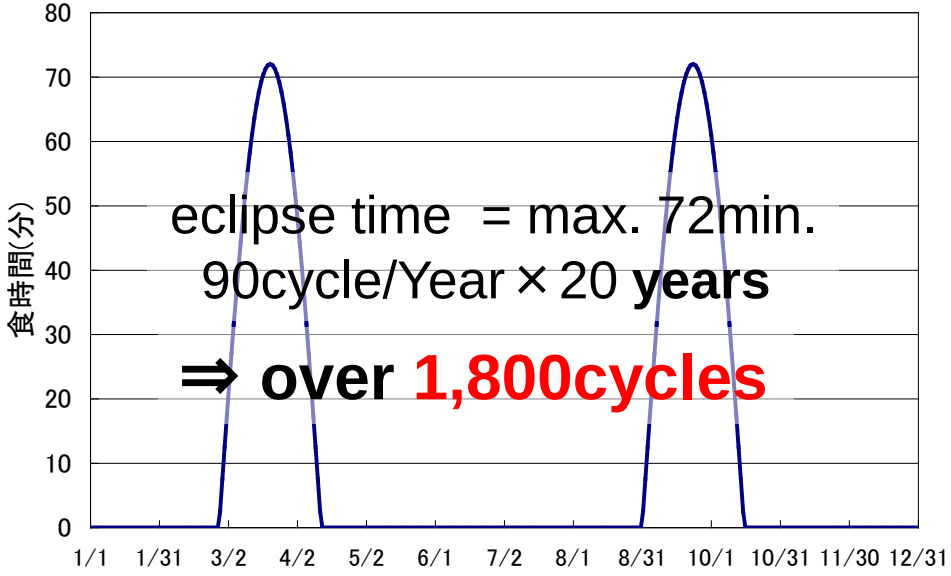
Operation on the orbit

GEO・・・ About 36,000km

high altitude on the equator

1 round in 1 day(24Hr)



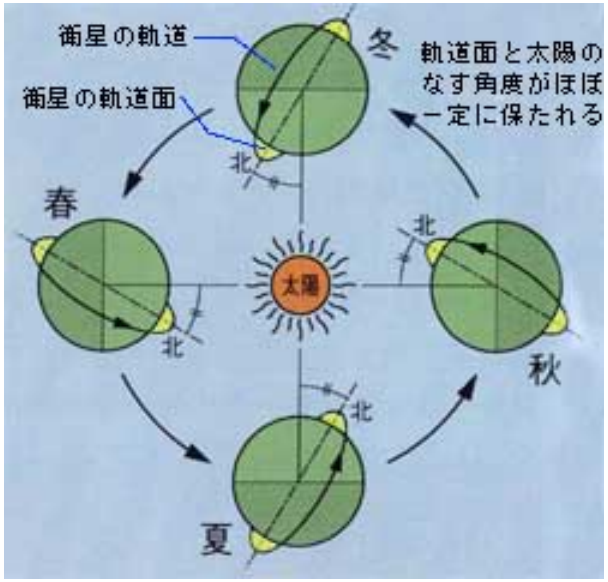


eclipse time = max. 72min.

90cycle/Year × 20 **years**

⇒ **over 1,800cycles**

LEO・・・400-700km high altitude from the earth



Typical Operation

15-16cycles in one day

1cycle : 90-110min.

Sunshining period : 60-70min.

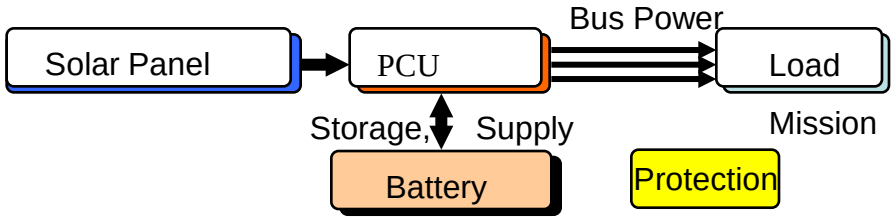
Shadowing period : 30-40min.

⇒ 5,000～6,000 cycles /year

Life time : 7years

more than 40,000cyc

Specifications required for Battery(Cells)



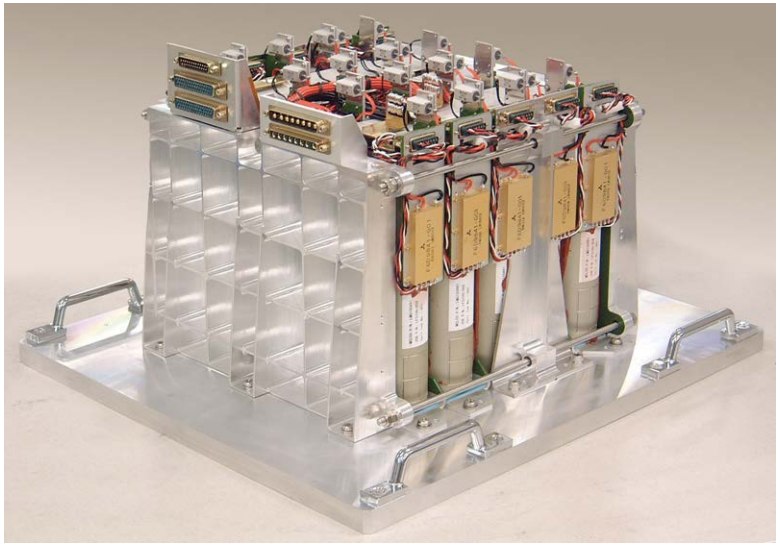
Cell, Battery

- Short term charge/discharge and long cycle life (7 years) for LEO mission（Charge 60-70min., Discharge 30-40min.)
- 90cycles /year and long calendar life(20 years) for GEO mission
- Toughness, High Reliability
- Tolerant to mechanical stress(vibration and shock at launch time, vacuum, microgravity, and so on)

Battery

- Redundant design for reliability,
- 2 Fault Tolerant for safety

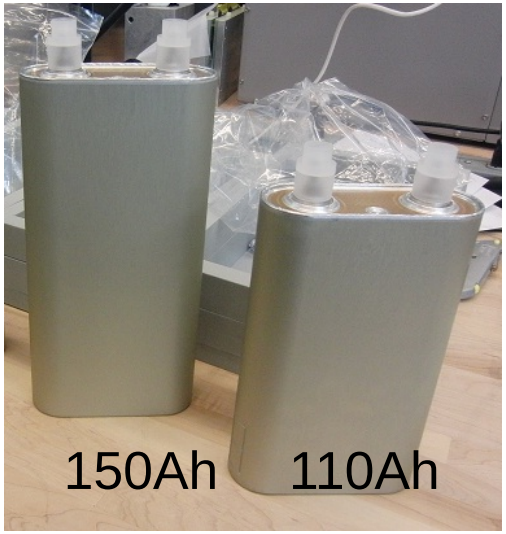
2. Lithium ion Cells for Satellite



Heritage and 2nd Gen. Li ion Cell for Space

Specifications

Item	Requirements
Geometry	Elliptic Cylinder
Dimensions	Same as Heritage cell
Cathode materials	Host materials are the same as Heritage cell ($LiCoO_2$)
Anode materials	
Charging Voltage	4.1V(Heritage 3.98V)
Capacity	10% larger than Heritage cell
Energy Density	> 150Wh/kg
Operating Temp.	QT: -10～+40℃⇒-10～+45℃
	AT: 5～25℃⇒5～30℃
Cycle Life	LEO 5⇒7years
	GEO 15⇒20years

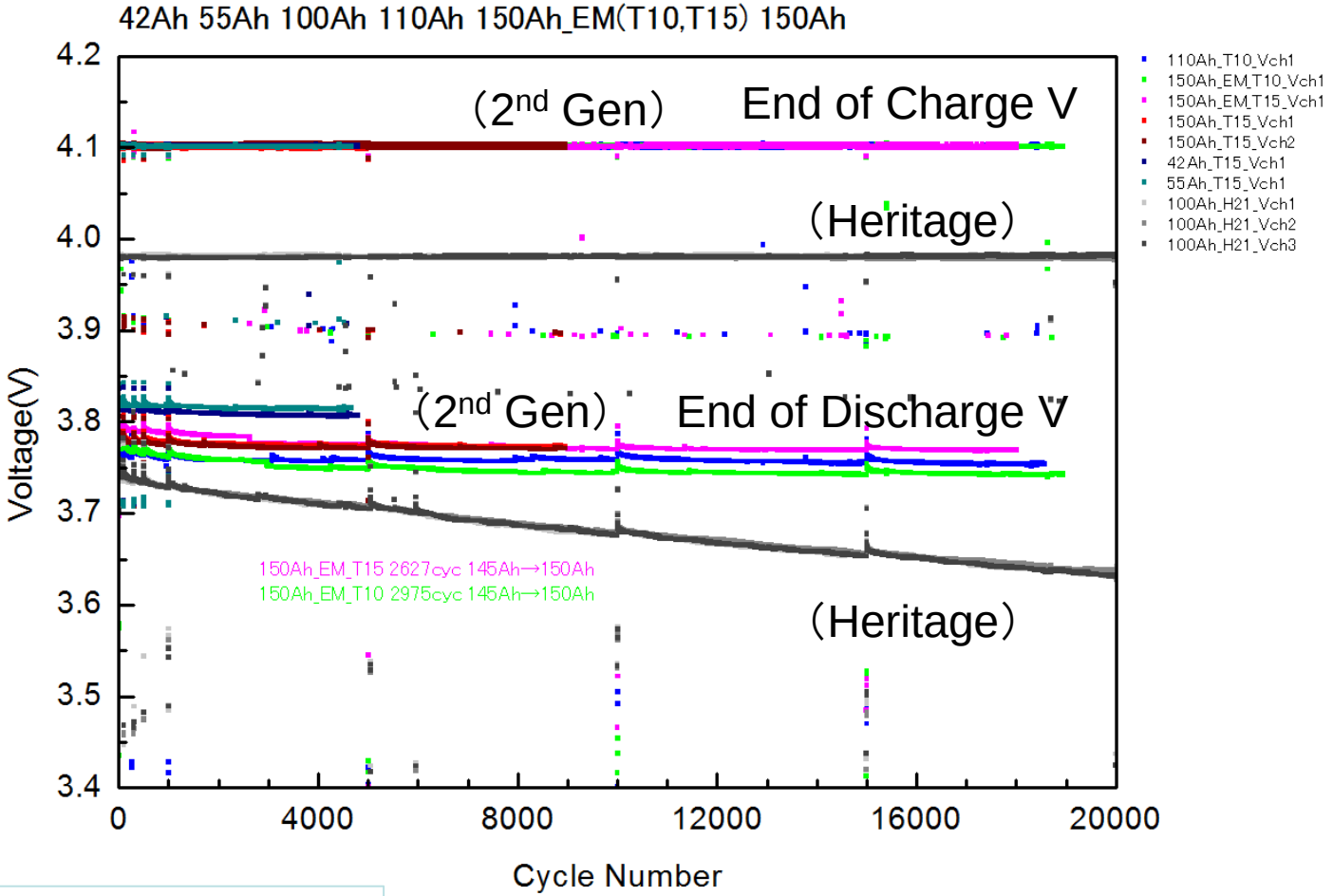


Item	150Ah	110Ah	100Ah*
Geometry	Elliptic cylinndorical		
Cathode	$LiCoO_2$		
Anode	Graphite		
Nominal Capacity	161Ah	122Ah	109Ah
Rated Capacity	150 Ah	110 Ah	100Ah
Nominal Votage	3.7 V		
mass	3,550g	2,770g	2,800g
Size* (W x D x H)	130 x (52) x263(mm)	130 x (52) x 216(mm)	
Energy Density	168Wh/kg 348Wh/l	163Wh/kg 333Wh/l	145Wh/kg 298Wh/l

*Heritage cell

LEO 2nd Gen cell＋Heritage cell

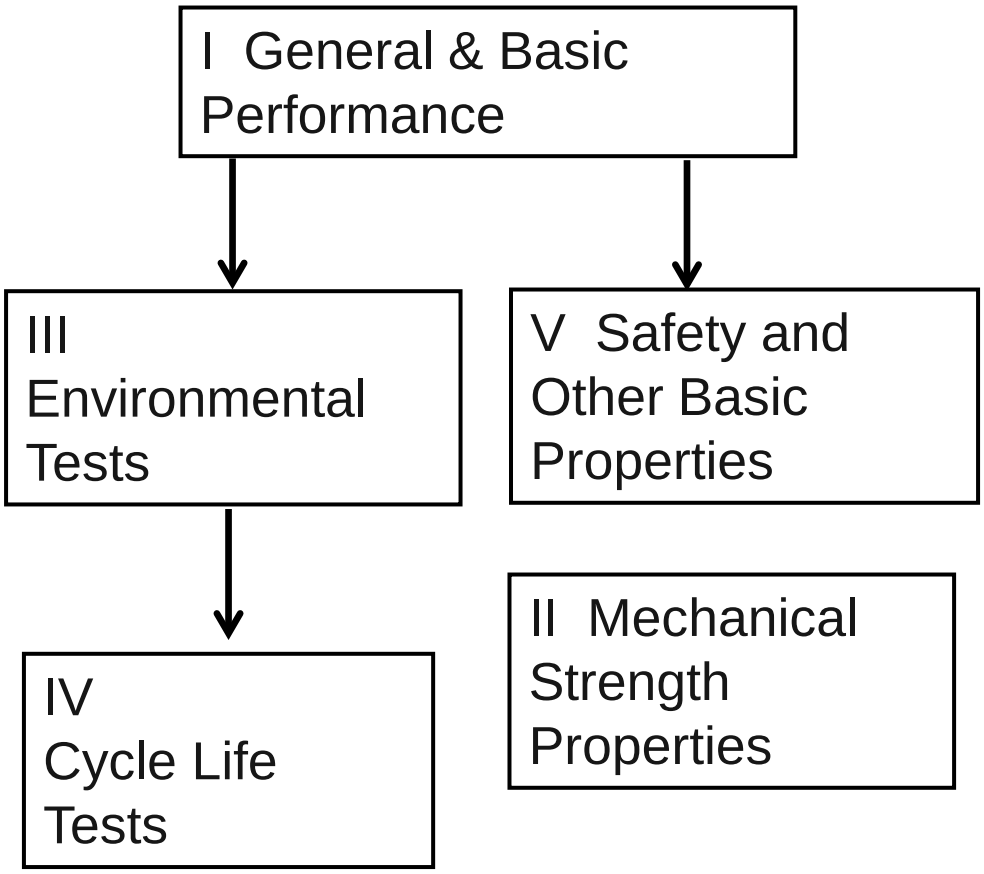
Example of the cycle-life test for LEO simulation(DOD25%)



Charge: 0.3CA CC/CV 60min.
Charge Voltage: 4.10V
Discharge: 0.5CA, 30min..
Temp.: 10 or 15℃

High reliable :
Real time testing is required.

Qualification Test(Initial performance test)



Section	Item
I General & Basic Performance	General (Mass, Dimensions, Leakage, Hermeticity, etc) BOL Capacity Pulse Discharge Internal Resistance Case Isolation
II Mechanical Strength	
III Environmental Tests	Sine Vibration Random Vibration Shock Acceleration
IV Cycle Life Test	LEO Sim.(DOD25%) GEO Sim(DOD80%) Storage
V Safety and Other Basic Properties	Self Discharge Abuse tests Discharge efficiency

3. Safety Control

Lithium ion cell is strongly required for safety control!!!

The major Hazards of Battery(Cell)

- due to Energy :
  Personnel injury (during ground operation)
  Damage to equipment
  due to high temperatures, fire or explosions
  (may caused by Overcharge, External/Internal short, chaging after overdischarge)

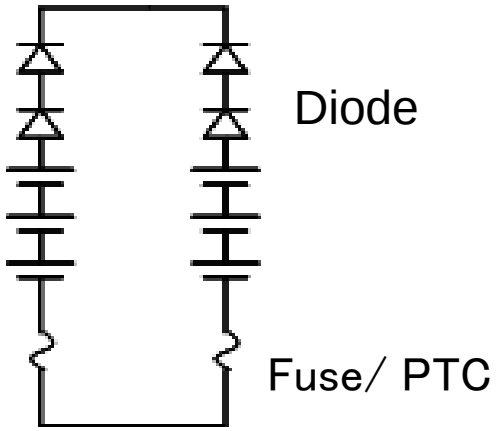
- due to Toxicity (Tox) :
  Personnel injury(during ground operation)
  Corrosion
  Contamination
  (may caused by Overcharge, External/Internal short, workmanship error (leakage))

Top Level Requirement is Two-fault tolerance to all catastrophic failures.

Controls(protective devices)

Protective devices outside the cell/battery
(in a circuitry)
- Diode (especially for primary cell)
- Fuse
- PTC (outside)
- MOSFETS

etc.



Example of Safety control

Protective software
- Temperature monitoring
- Each cell voltage monitoring
- Current monitoring

Tests/ Inspections (Screening process)
- Vibration test : for internal short, workmanship error
- Vacuum test : for Tox hazard
  (leak check)

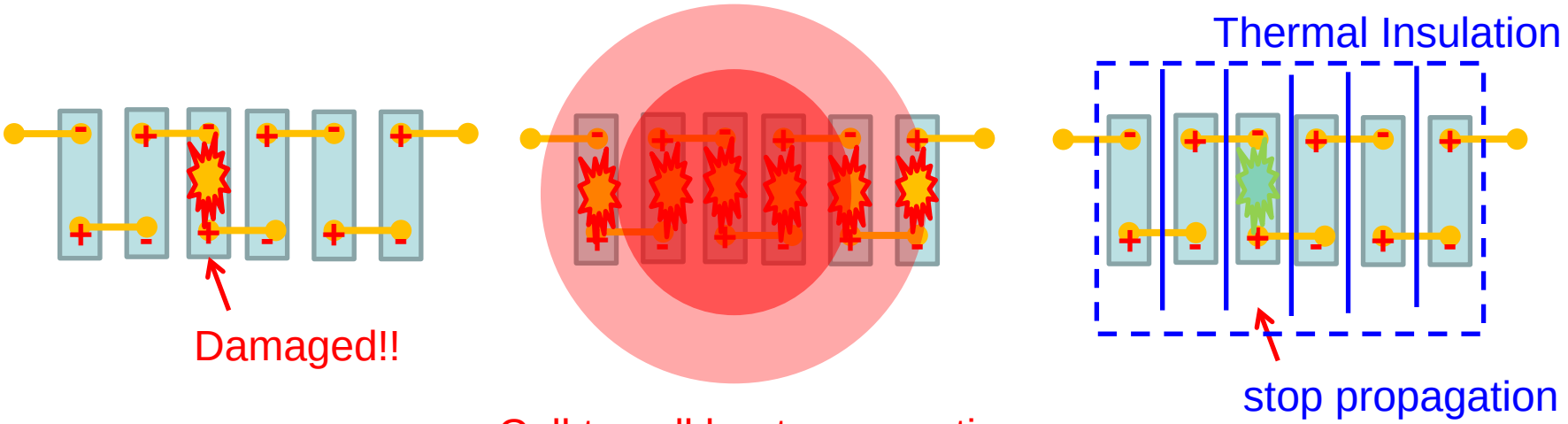
Battery level Control(protection)

Cell balancing

each cell voltage is control to be equal.

if imbalance : some cells in the battery are overcharged.
(even if the battery voltage shows normal value!!)
⇒ *Overcharging hazard*

Heat resistant (thermal insulation) between cells (, and/or between cell and other equipment)
in order to prevent cell-to-cell heat propagation
(thermal runaway)

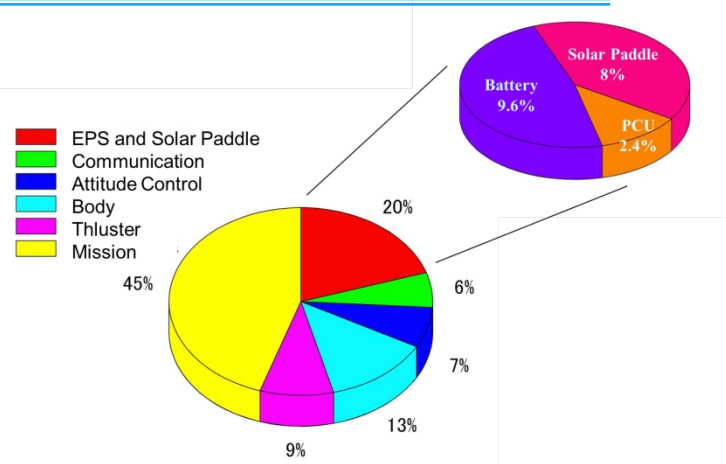


4. Future Energy Storage Devices for the Satellites and for the Aviation

Requirements for Energy Storage Devices for Satellites

Battery is one of the heavy components in satellite.
Lightweight is always required!!
Safety is also required.

Requirement for mid to long term:
over 200Wh/kg with long life
(LEO7-10years, GEO 20years)



Mass ratio of a Satellite (Alkaline cell)

Approach: Short term

- extension of existing cell (safety level is not improved).
- Si,Carbon anode (high energy, Safety level is not improved)
- For safety: non-flammable electrolyte (ionic liquid etc.), $LiFePO_4$ cathode (not lightweight)

Approach: Mid to Long term:

- Thin film cell (Surpressed temperature rising→ improved safety)
- all solid , Lithium-sulfur , and so on (lightweight and safety)

Requirements for the Aviation

(cited from "Dear Speakers of the Europe_V3.docx")

Aspects for batteries

The potential requirements are derived from short to mid-term applications, which require very high C-rates at lowest possible mass, sometimes with very limited cycle numbers. The more we move to the future, the more we are putting high energy to mass ratio in the focus. Values beyond 500Wh/kg are desired.

Batteries	**Key performance Indicators:**	
	Energy/Mass ratio	C-Rate
Short term (5-10 years)	150 - 350 Wh/kg	3 - 100 C
Mid Term (10 to 15 years)	350 - 600 Wh/kg	1 - 10 C
Long Term (>>15 years)	500 - >>1000 Wh/kg	0,5 - 5 C

Energy density of the existing cell for satellite : upto 170Wh/kg
(～200Wh/kg for COTS cell)

C-Rate of the existing battery for satelllite : 3C in 5sec.

Assumed another requirements for the Aviation

	required performance :	(Satellites)
Life	longer life is desirable but battery is replaceable.	battery is not replaceable.
Safety	same as that of satellites.	
Operating temperature range	Wider than that of satelllites	10-30℃
Operating pressure	vary from on the ground to in the air periodically	ca.10^{-6}Pa
Environmental conditions (mechanical)	gentle but long time compared to satellite.	sustained at lauch period

...How long battery discharge by high C-rate?
...How much the capacity required in one cell/battery?
...How many cycles/how long do you want to use?.

Depends on these conditions, there is a cell (not battery) which meets requirements (short/mid term) mentioned in previous sheet (for satellite).

5. Summary

- Battery/ cells for spacecraft (especially satellites) are introduced.
- The lightweight, safety and high reliability are the common requirements for both spacecraft and the aviation.
- The high level requirements of energy density and C-rates are the very challenging, but promising devices are believed to be demonstrated soon.
- Accumulative and continuous R&D shall be performed in order to realize the battery with such high requirements.