DRAGONFLY

A relocatable lander to explore Titan's prebiotic chemistry and habitability

Dragonfly Power Subsystem Architecture (PDR)

Space Power Workshop

Electrical Power Subsystems (EPS)

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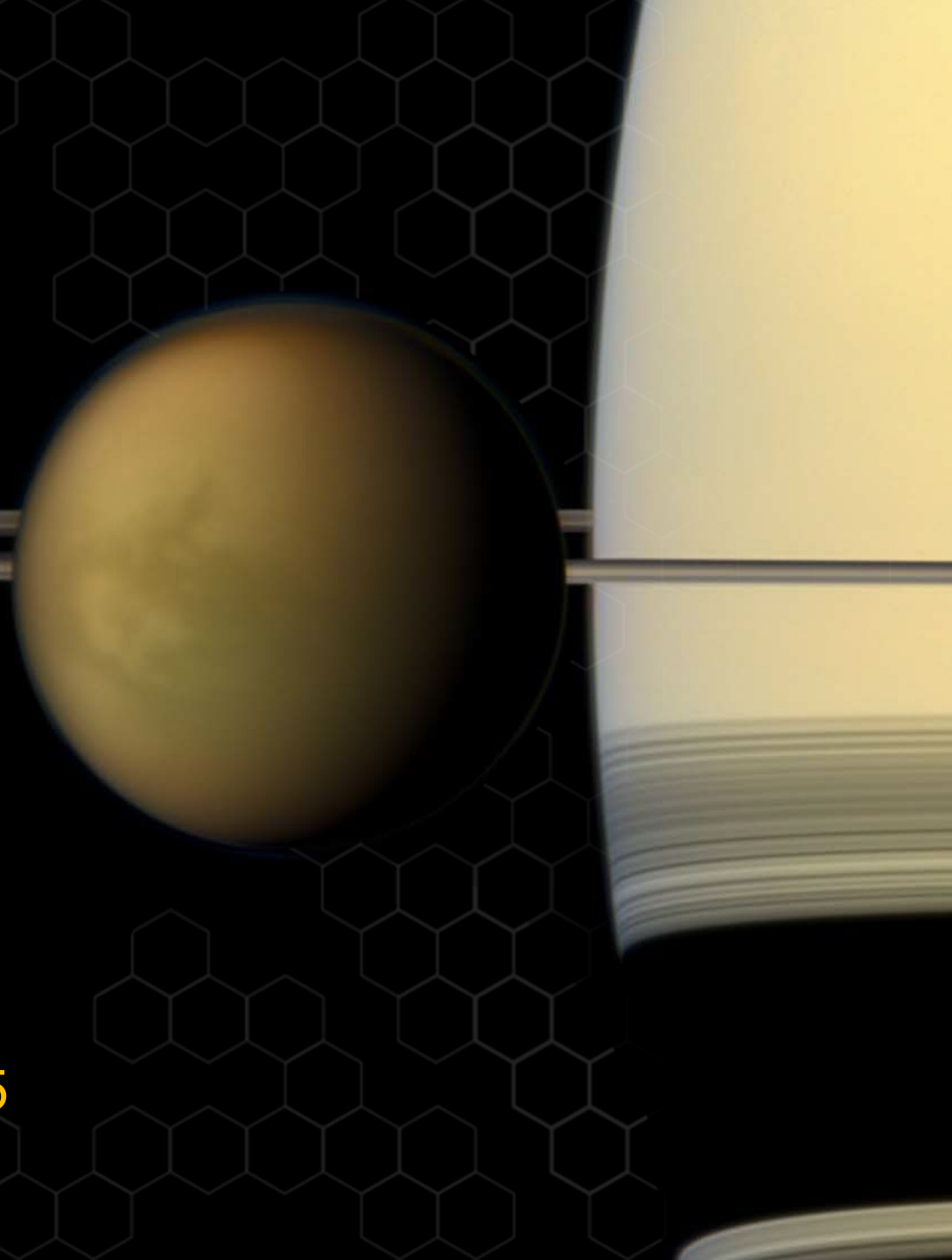


Agenda

- Project Synopsis
- Subsystem Design/Block Diagram
- Lander/EDL EPS Component Locations
- Critical Bus Power Electronics (CBPE) Functions
- Lander Battery Functions
- Current Transducers Functions
- Power Switching Unit (PSU) Functions
- Rotor Drive Electronics (RDE) Functions
- EDL Primary Battery (EPB) Functions
- EDL Battery Controller (EBC) Functions
- Conclusion

Dragonfly Project Synopsis

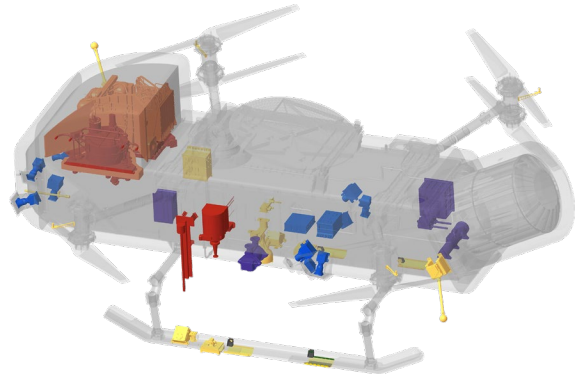
SCIENCE

Prebiotic chemistry
- Analyze chemical components and processes at work that produce biologically relevant compounds

Habitable environments
- Measure atmospheric conditions, identify methane reservoirs, and determine transport rates
- Constrain processes that mix organics with past surface liquid water reservoirs or subsurface ocean

Search for biosignatures
- Search for chemical evidence of water- or hydrocarbon-based life

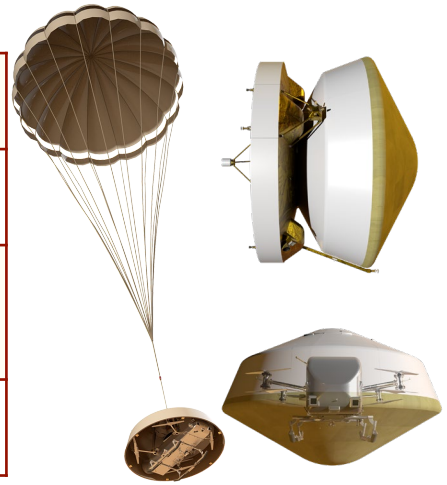
INSTRUMENTS



- DraGMet: Geophysics & Meteorology Package (APL, JAXA)
- DraMS: Mass Spectrometer (GSFC, CNES)
- DrACO: Drill for Acquisition of Complex Organics (Honeybee Robotics)
- DragonCam: Camera Suite (MSSS)
- DraGNS: Gamma-ray Neutron Spectrometer (APL, LLNL, GSFC, Schlumberger)

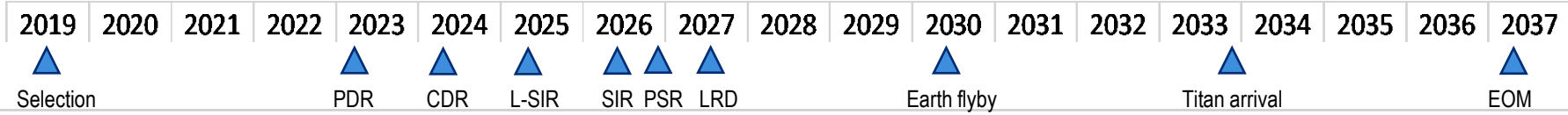
KEY FLIGHT SYSTEM FEATURES

Cruise Stage to get to Titan, with EDL assembly to protect and deliver the Lander during ~120 minute EDL sequence
MMRTG low power charges ~11.5 kW battery system, which is used for flight, science, and data transmission
Pumped fluid loop cools flight system in cruise; insulation protects Lander from cold temps on surface; ducted convective-gas system controls interior components
Direct-to-Earth comms with radial line slot array antenna, tones during critical events

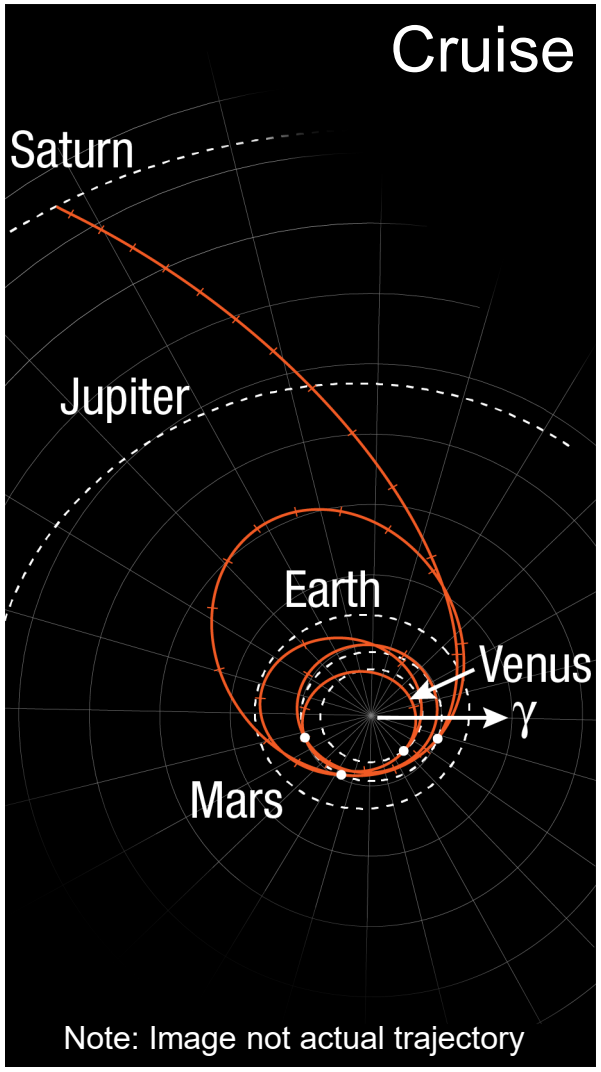


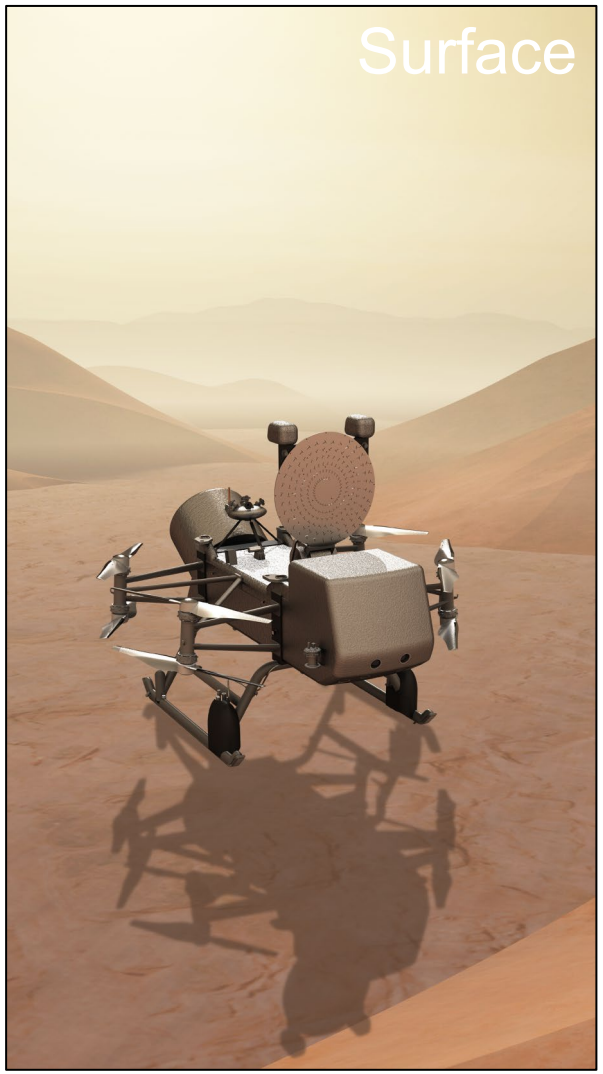
TEAM

Principal Investigator:	E. Turtle (APL); DPIs Trainer (GSFC), Barnes (Idaho)
Project Manager:	R. Fitzgerald (APL); DPM A. Azarbarzin (APL)
Mission Sys Engineer:	K. Hibbard (APL); DMSE: E. Adams
Rotorcraft/Lander:	APL, Moog, Collins, PSU, Sikorsky
Aeroshell & Cruise Stage:	Lockheed Martin
EDL Analysis, Parachutes:	NASA Ames / Langley, Airborne
MMRTG:	DOE / RPS Office
Mission Ops / Navigation:	APL / JPL



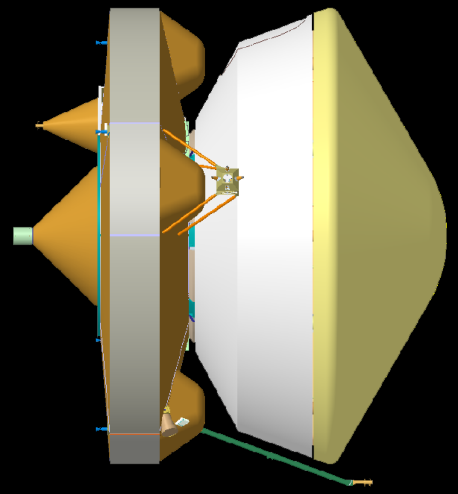
Dragonfly's Implementation Consists of Four Distinct Mission Phases

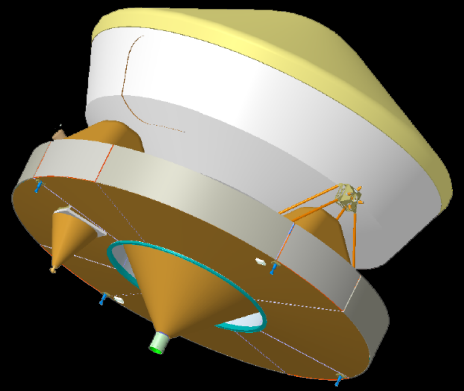




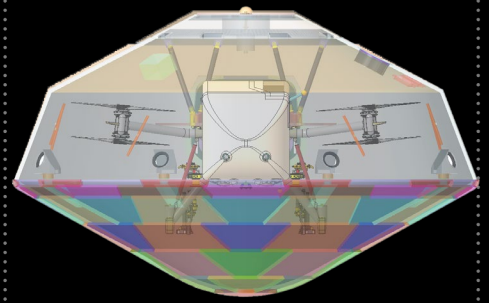
Flight System Elements

Spacecraft =
Cruise Stage + Entry Vehicle

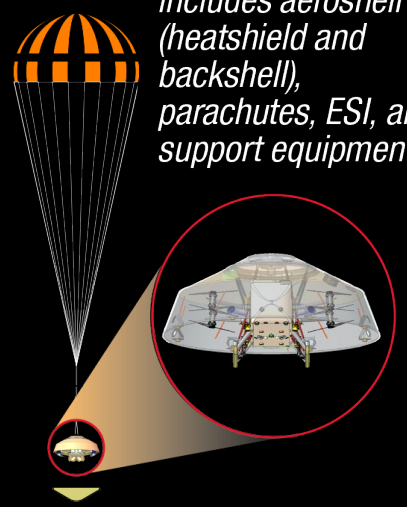




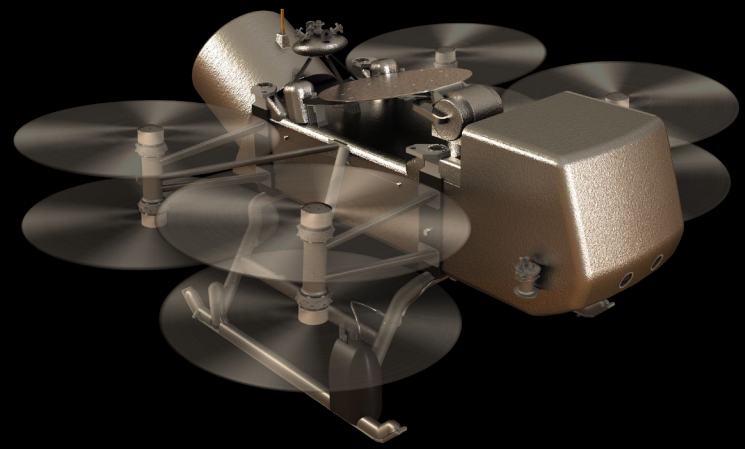
Entry Vehicle =
EDL Assembly + Lander



EDL assembly includes aeroshell (heatshield and backshell), parachutes, ESI, and support equipment.



Rotorcraft Lander
Flight configuration with HGA stowed



- Cruise stage provides functions needed for travel between Earth and Titan
  - Propulsion, guidance & control, (attitude control) and telecommunications
- EDL Assembly provides functions needed for safe descent through Titan's atmosphere
  - Heatshield, backshell, parachute system, separation systems, and LGA
- (Rotorcraft) Lander provides functions needed for surface exploration at Titan
  - Octocopter for mobility (flight) at Titan
  - Science instruments for studying Titan's surface and atmosphere

Note: Images above are used to delineate elements and do not reflect current configuration

EPS Design Drivers

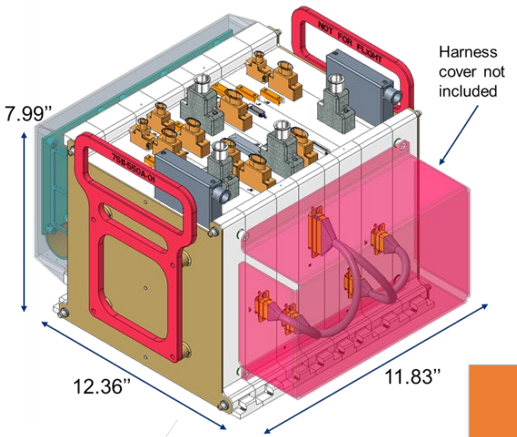
- Dragonfly mission - outer planetary octocopter - drives many specialized power system demands.
- As an outer planetary mission, along with the lander component, solar power is not feasible. Space qualified power source options limited to nuclear power generation.
  - Multi-mission radioisotope thermoelectric generator (MMRTG) was selected and is the design baseline.
  - Limited power generation throughout mission life drives the EPS architecture.
    - Generates about 110 watts of electricity at the start of a mission from NASA's MMRTG website
- Entry, Descent, and Landing sequence drives the need for additional auxiliary power for the lander battery
- In order for the octocopter to fly, high power discharge and significant energy storage are required to drive the eight rotor motors.
  - High power discharge drives need for higher voltage battery/system to reduce IR losses.
    - 23.3kW Take off driven by maximum thrust, 19.3kW continuous for flight, 24.9kW non repetitive peak

EPS Design Drivers

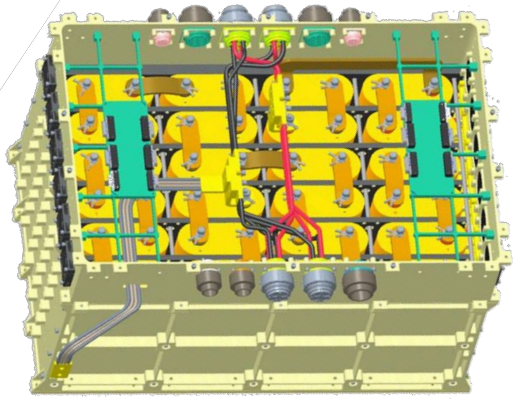
- The remainder of the power architecture is developed within these two overarching constraints.
  - Large energy storage, coupled with limited power generation, drives need for long “hibernation” cycles to slowly charge the high capacity battery.
    - Hibernation Mode
      - Critical Bus Loads powered only from CBPE
      - Battery Charging limited to less than an amp
      - Lander core bus components are OFF: PSU and Avionics
      - Standard mode for Cruise
  - High voltage battery bus drives the need to isolate the MMRTG from the battery with a battery boost charger.
  - Compatibility with existing COTS space qualified components drives need for heritage bus power conversion.

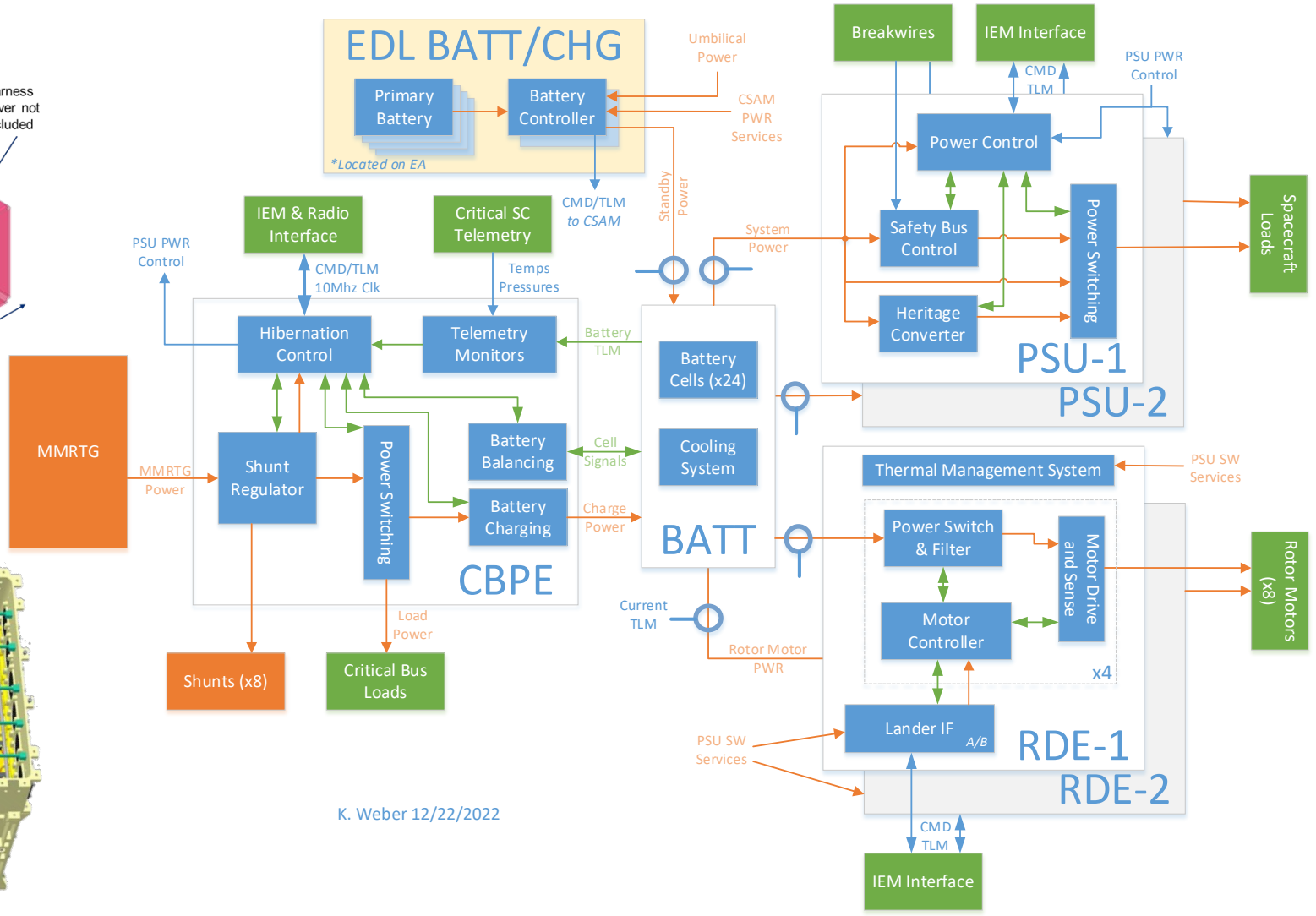
EPS Block Diagram

CBPE



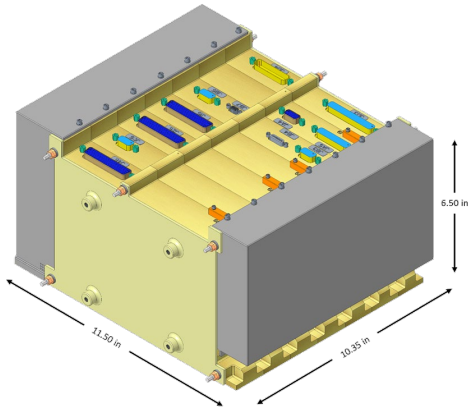
BATT



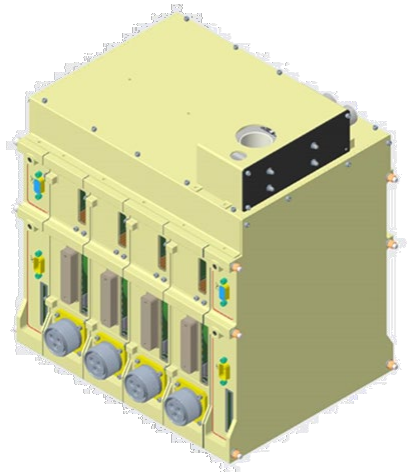


K. Weber 12/22/2022

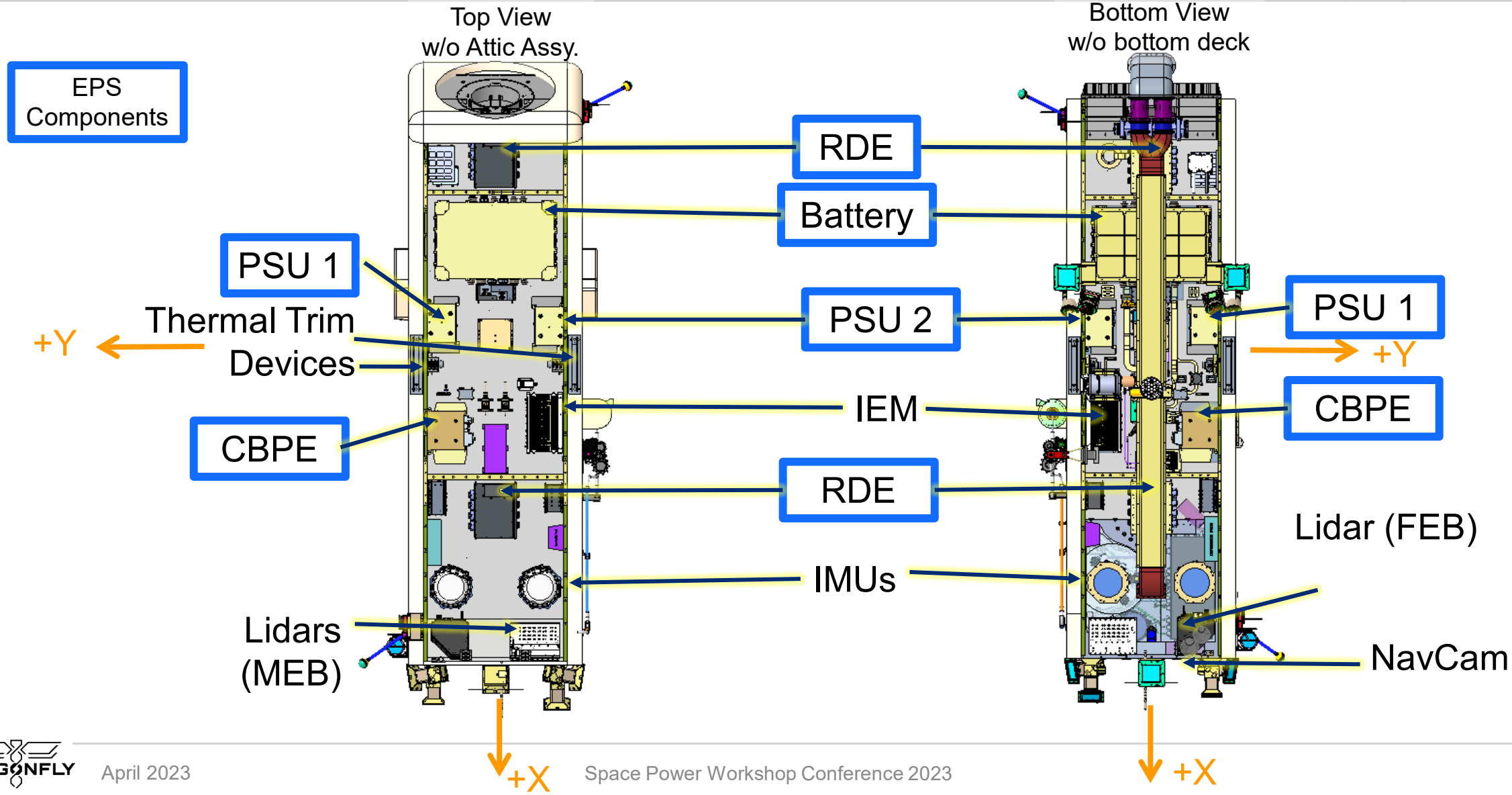
PSU



RDE



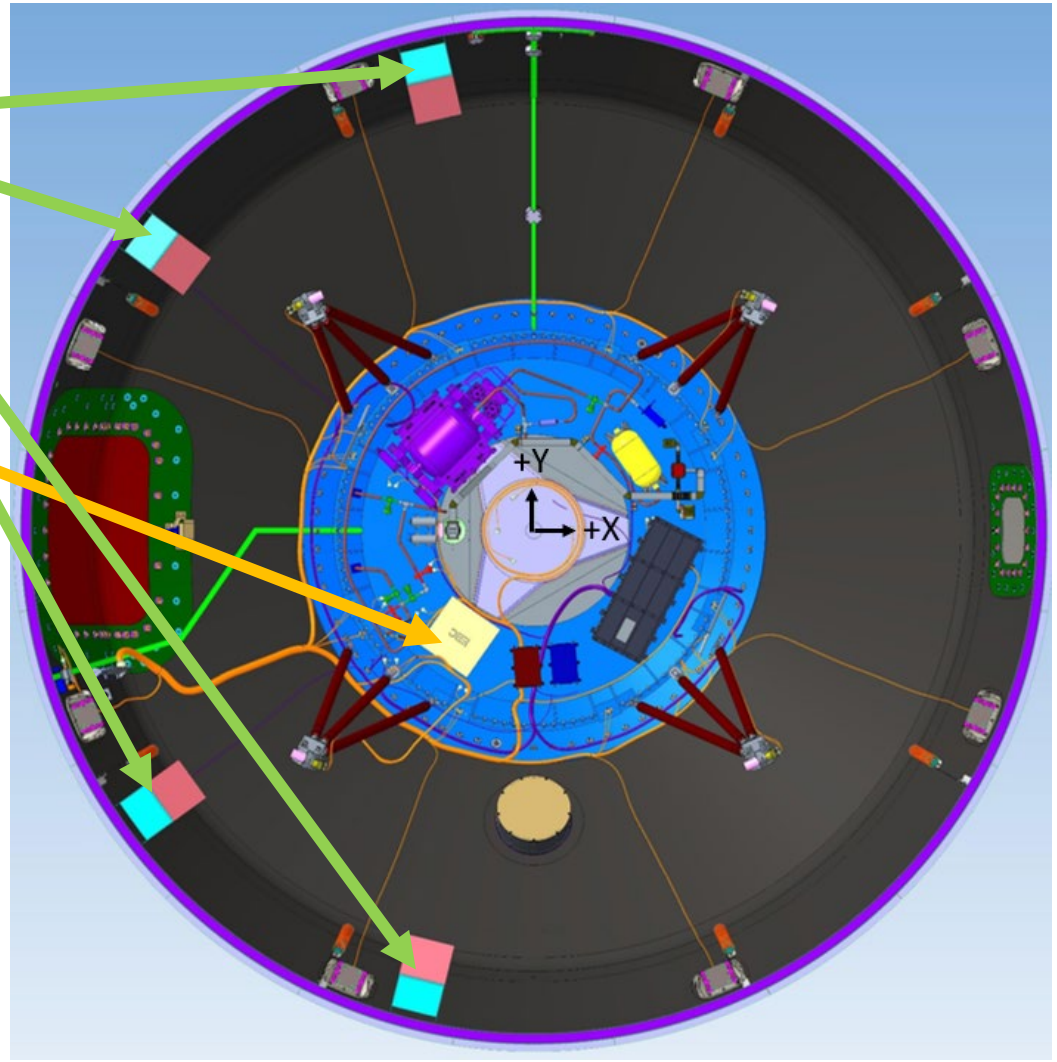
EPS Components in the Lander Layout



EPS Components in the EDL Assembly Layout

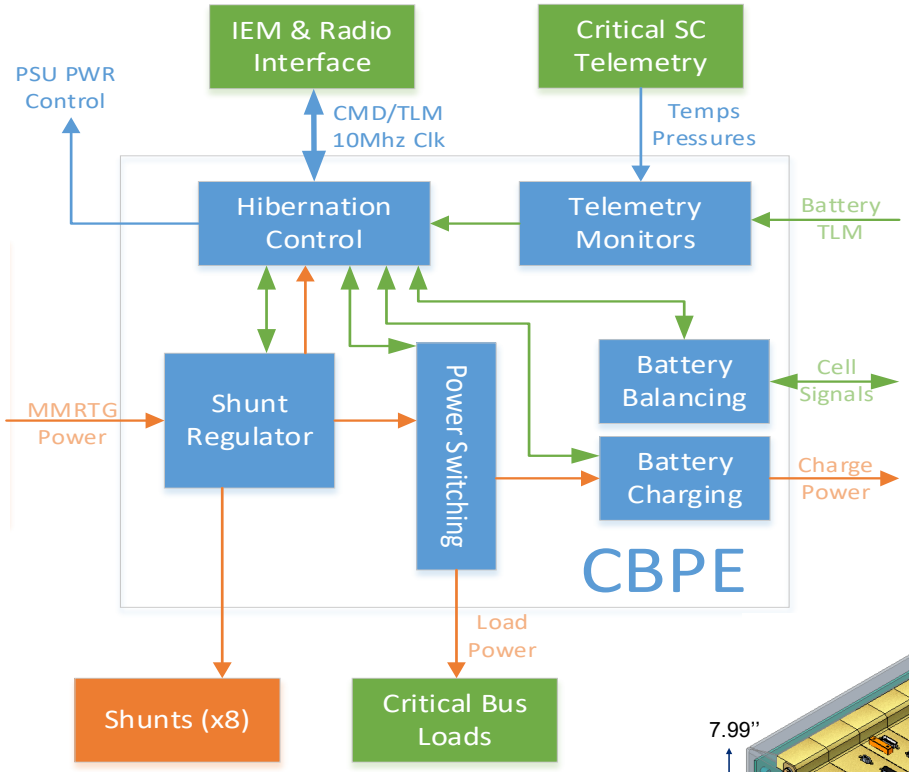
EDL Primary Battery (EPB) (x4)
Around perimeter of backshell
On side containing MMRTG access door

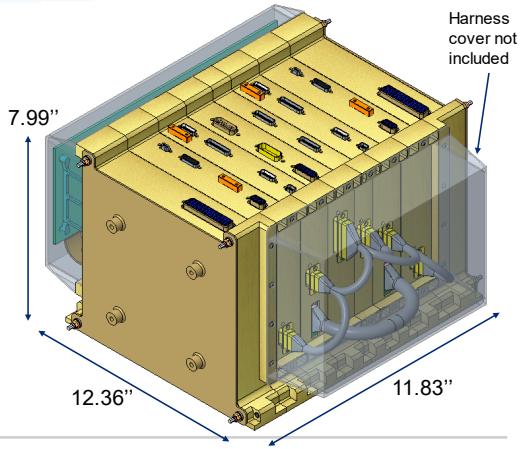
EDL Battery Controller (EBC)
On backshell interface plate (BIP)



EPS CBPE Functions

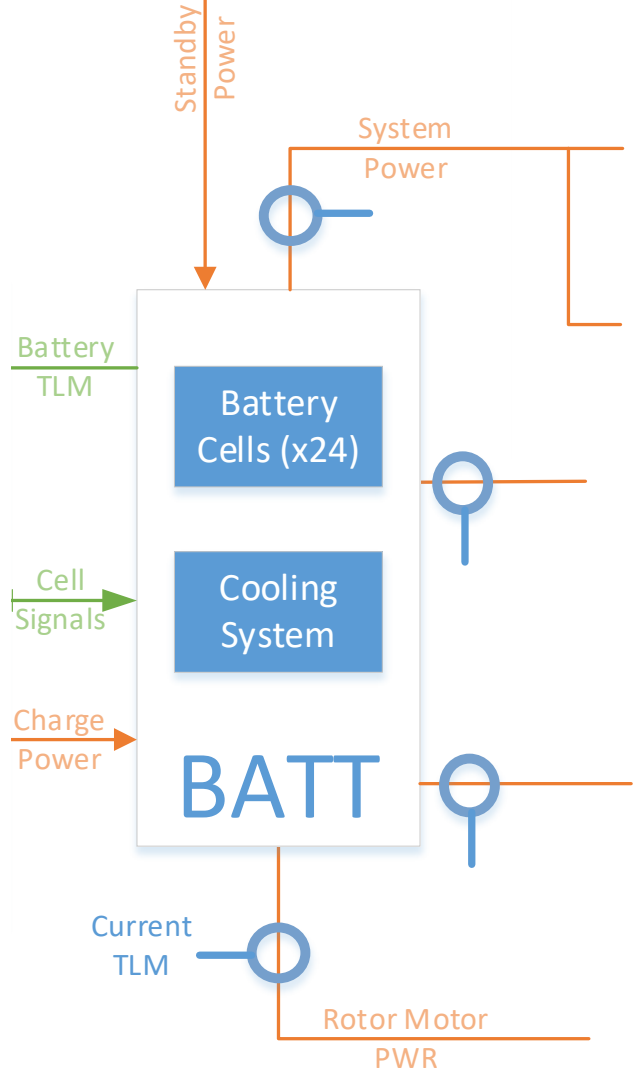
- **Shunt Regulator Unit (SRU)**
  - Regulates power bus at the maximum MMRTG power point, with triple redundant shunt controller and n+1 shunts.
  - Provides bus capacitance for stability/transient response.
  - Provides circuits to accommodate the MMRTG telemetry and chassis short clearing.
- **Battery Charge Cell Balancer (BCCB)**
  - Maximizes charging of the battery with available input power.
  - Implements battery cell balancing.
  - Monitors battery health telemetry.
  - Two (2) Block Redundant Units, nominally one powered
    - Only one can charge battery at a time
- **Hibernation Controller (HC)**
  - Implements hibernation timer for nominal wake up and monitors critical spacecraft telemetry to initiate a wake up in a fault condition.
  - Controls spacecraft hibernation state via power control to the PSUs.
  - Implements spacecraft clock (SCLK).
  - Provides switching and protection for critical bus loads.
  - Control interfaces for hibernation components (pumps/fans/trim device)
  - Provides CMD/TLM interface to IEM.
  - Two (2) nominally active Redundant Units





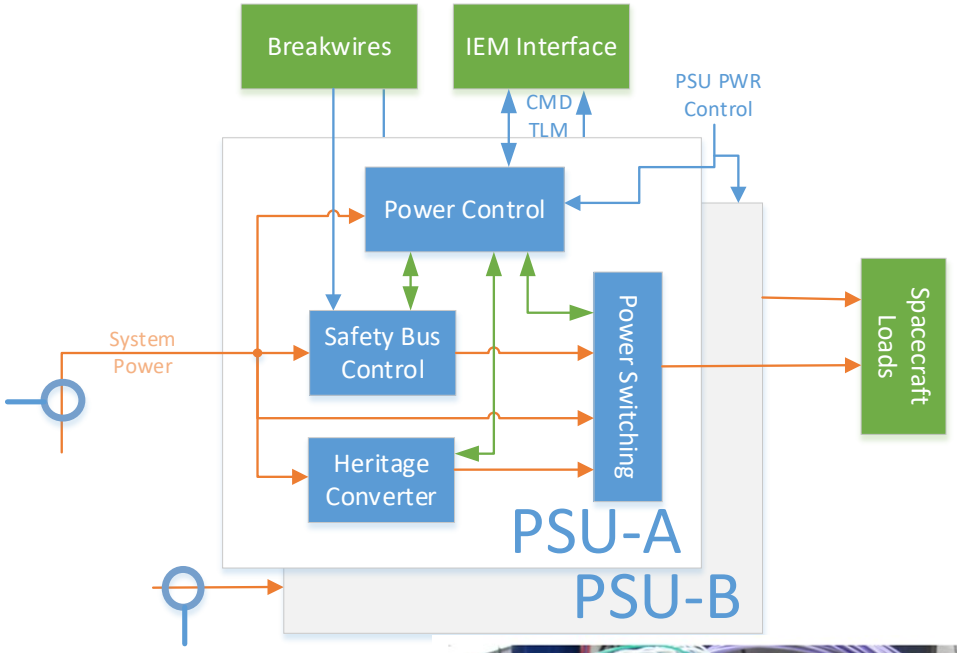
EPS Battery Functions

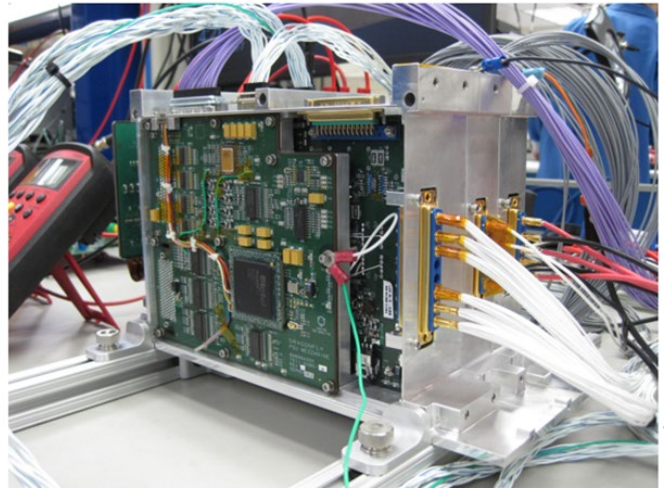
- Energy storage via 24s1p configuration of LSE134 GS Yuasa battery cells
- Supports
  - 330A non-repetitive peak (2.5C)
  - 300A repetitive peak
  - 268A steady state (2C)
- Provides individual outputs for each RDE & PSU
- Supports charging and balancing of cells at low rates via the CBPE
- Supports integration and test (I&T) interfaces for monitoring and faster charging
- Implements thermal management for high power discharge during rotorflight phase, including heat pipes and PCM



EPS PSU Functions

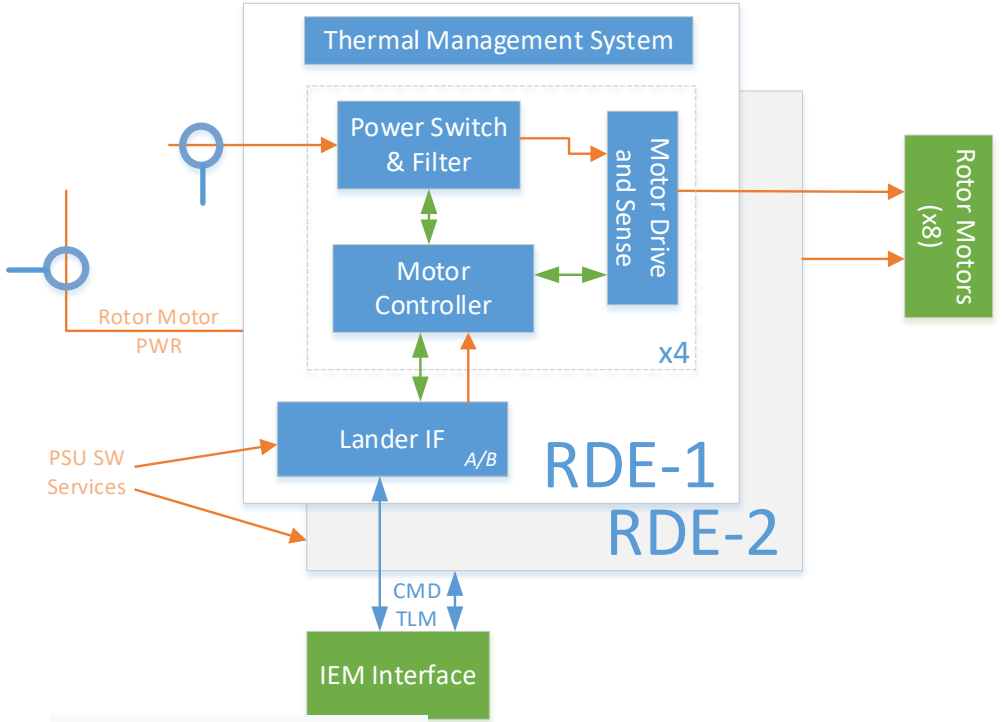
- Provides power switching functions for all lander loads
- Implement battery safety bus - inhibited by sensed breakwire state
- Converts battery bus power to heritage bus with a non-isolated buck converter
- Protects the battery bus from downstream faults
- Supports 4.6kW total peak power throughput
- Implements I&T Hold off for ground testing
- Provides CMD/TLM interface to IEM
- Two non-redundant 7 slice units

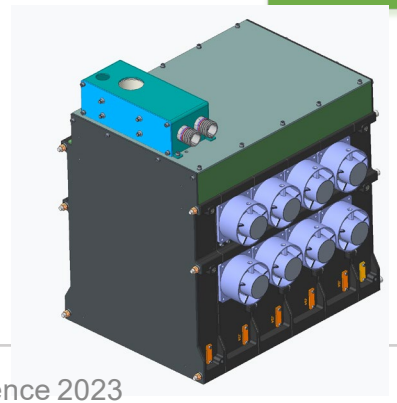


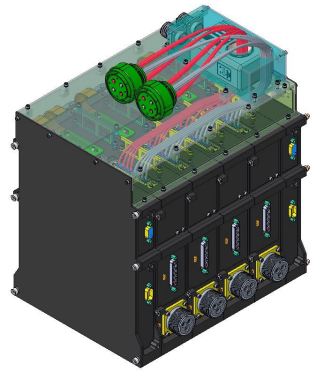


EPS RDE Functions

- Provides BLDC motor control for all eight rotor-motors
- Supports 3.5kW peak power throughput per motor channel
- Protects the battery bus from downstream faults
- Provides cross strapped CMD/TLM interfaces to IEM
- Responds to 100Hz motor control commands from MGNC
- Implements convective thermal management via fans, powered from the PSU
- Internally n+1 redundant by motor controller



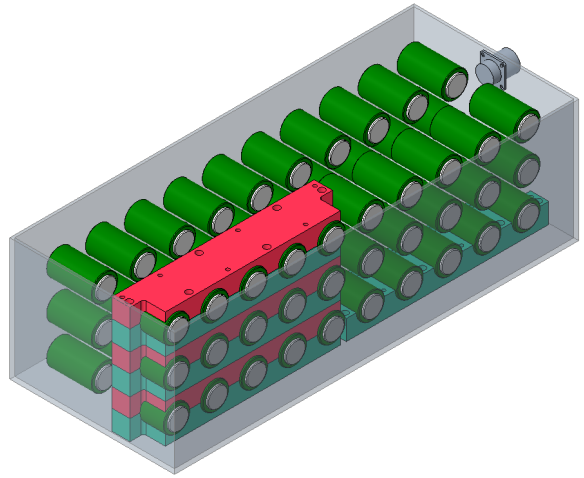


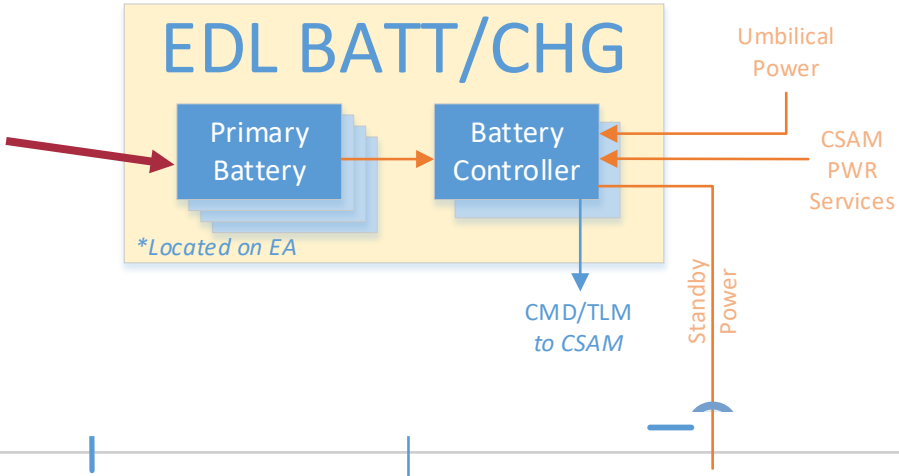


EPS EDL Primary Battery (EPB) Functions

- Four Li-ion primary battery packs, two connected to each EBC
- Primary cells are non-rechargeable devices with higher energy density than secondary cells
  - Do not require charging during cruise
- Internal block diodes preclude accidental charging
- Mounted on the EDL Assembly
- Procured component

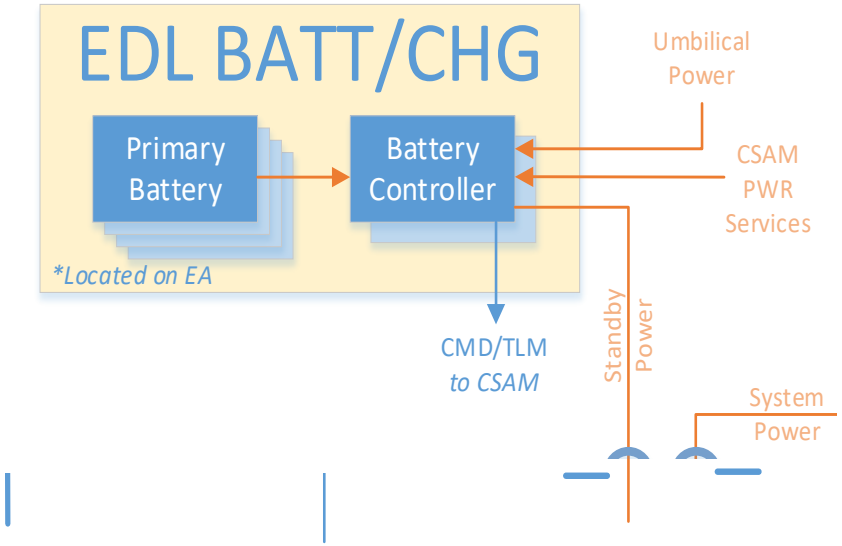
NOTE: CAD developed for volume reference only.





EPS EDL Battery Controller (EBC) Functions

- Controls discharge of the EPB and charging of the lander Battery
- Implements safety checks for ground operations
- Ensures reliable, predictable energy delivery to the lander during EDL
- Mounted on the EDL Assembly Backshell Interface Plate (BIP) thermal control region
- Two non-redundant controllers, operating in parallel for nominal power delivery capability
  - In the event of an EBC fault, ~half of the power delivery would continue to support the lander



Conclusion

- EPS responsibilities for this mission create more integrated system functions within the EPS scope of work than is typical.
  - Hibernation Controller – Hibernation operation, fault monitoring, timekeeping, hibernation telemetry record
  - Drive Train – Battery/RDE/Motor/Rotor tightly coupled to flight performance, demand high power delivery
  - Higher Data Rates – RDE CMD/TLM for flight control, CBPE TLM for battery current limiting & hibernation record
  - Convection Cooling – Interaction with Thermal for RDE and Battery high dissipation during rotoflight
  - EMI/EMC – Bus topologies and high noise from RDE lead to power system pushing EMI/EMC
- EPS has made significant progress in Phase B developing and reviewing detailed designs
- Multiple components are starting into EM Fabrication & Test phase and EM/FM procurements are in RFP/RFQ
- Significant risk reduction efforts have been completed, and others continue to make progress
- The team is excited to deliver specialized, robust EPS hardware for the Dragonfly Mission!

EPS team has made great progress and is prepared to move into Phase C!


DRAGONFLY

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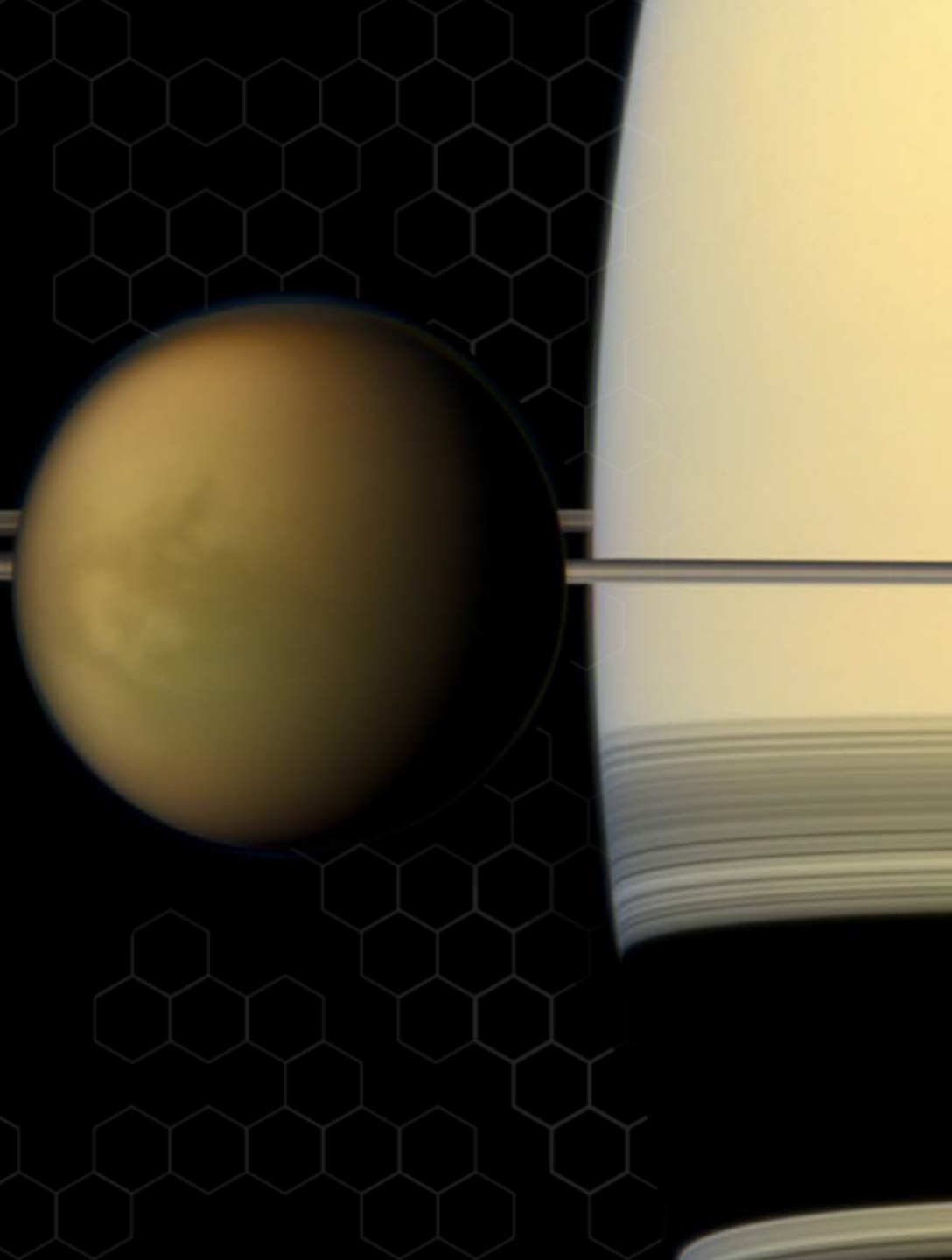
A relocatable lander to explore Titan's prebiotic chemistry and habitability

Dragonfly Power Subsystem Architecture (PDR)

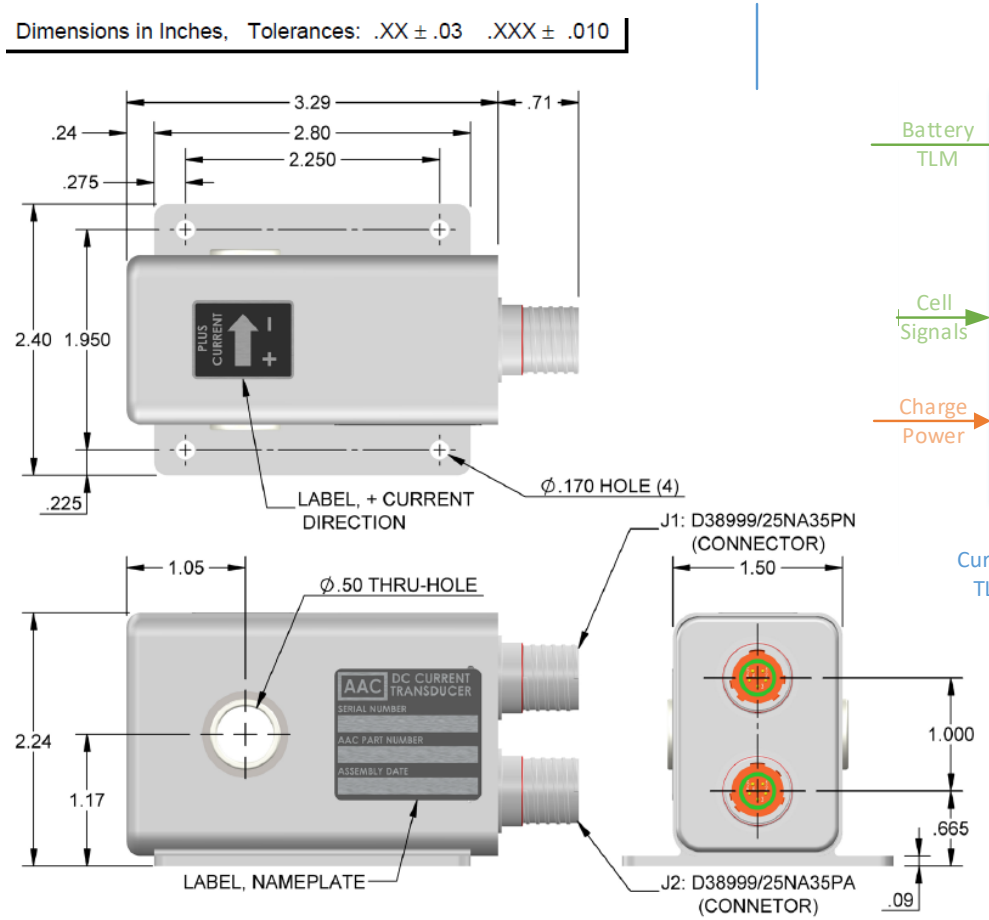
Electrical Power Subsystem (EPS)

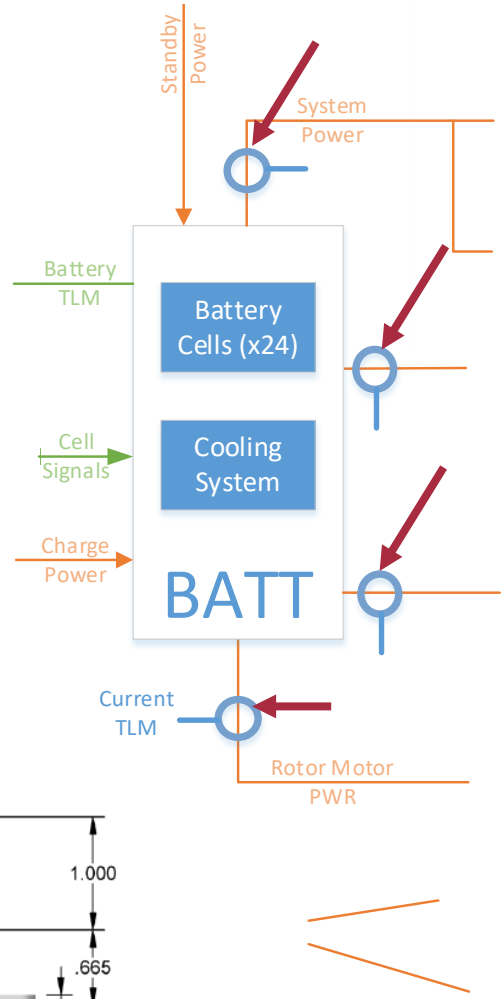
BACKUP



EPS Current Transducer (IXDC) Functions

- Three internally redundant procured components
- Measures current in/out of the battery to the PSUs and RDEs without insertion losses
- Measurements by the CBPE/BCCB are utilized in order to implement the coulometer
- Sensor ranges and directionality are tailored to the PSU or RDE interface specifications





Acronyms List

Acronym	Defined
APL	Applied Physics Laboratory
BCCB	Battery Charge Cell Balancer
BIP	Backshell Interface Plate
BLDC	Brushless DC
CBPE	Critical Bus Power Electronics
CMD/TLM	Command and Telemetry
COTS	Commercial of the shelf
EDL	Entry, Descent, and Landing
EPB	EDL Primary Battery
EBC	EDL Battery Controller
EPS	Electrical Power Subsystems
HC	Hibernation Controller
IEM	Integrated Electronics Module
IXDC	Current Transducer
MGNC	Mobility Guidance and Control
MMRTG	Multi-mission radioisotope thermoelectric generator
PSU	Power Switching Unit
RDE	Rotor Drive Electronics
SRU	Shunt Regulator Unit