LiBDO: The Lithium Ion Battery DeOrbiter

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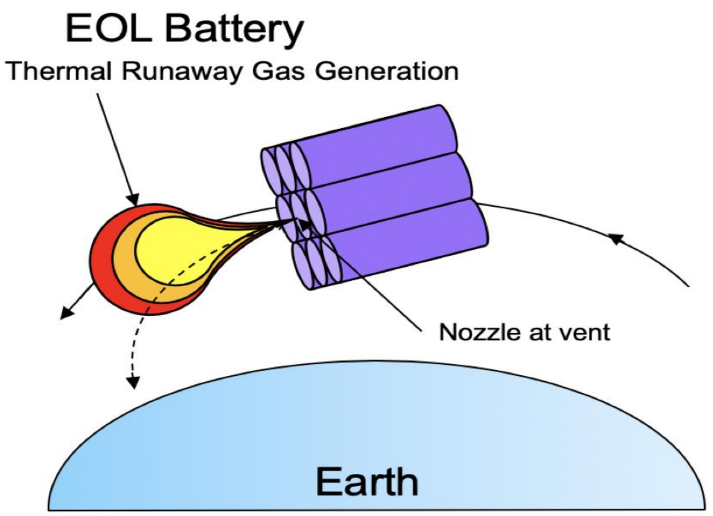
The Lithium Ion Battery DeOrbter

Reducing space debris with the battery

The Lithium Ion Battery DeOrbiter (LiBDO) is a zero additional mass technology that can be added to any spacecraft to shorten residual orbit time and reduce space debris.



- The greatest weakness of lithium ion batteries is their tendency to burst into flames when damaged. This weakness can be turned into an essential new capability by harnessing this reaction to improve disposal of the vehicle.

- At the end of mission life, the spacecraft battery is a large store of energy which can be used to generate thrust to deorbit the vehicle by sending the cells into thermal runaway and channeling the gasses into thrust.

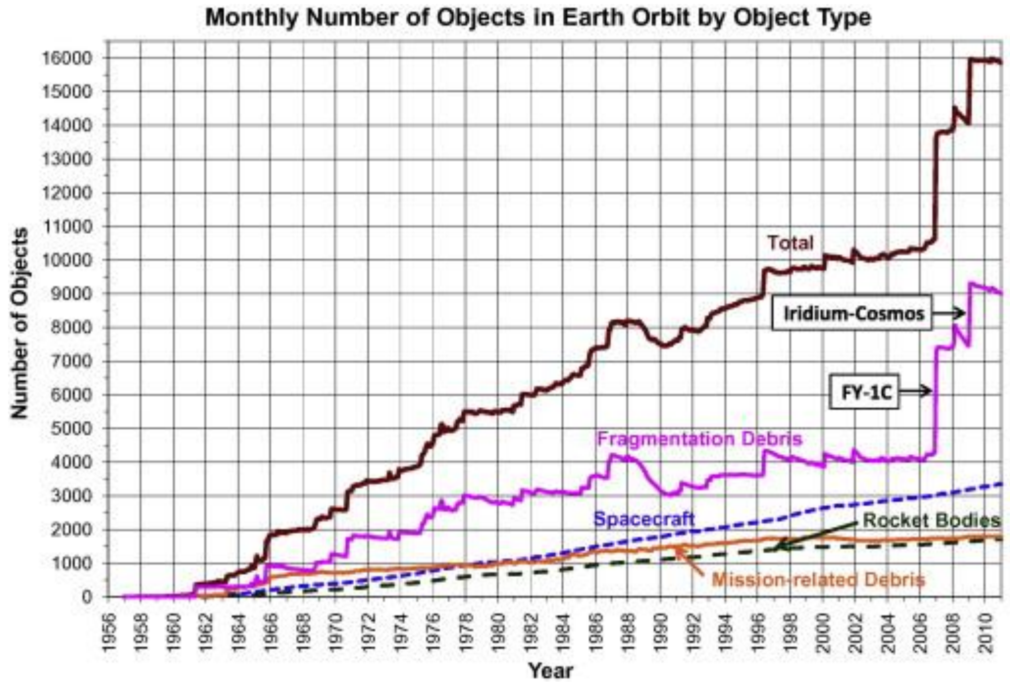
•A commercial Li-ion battery can be used to generate thrust by triggering the battery to thermal runaway.

•The cathode material decomposes generating heat and free oxygen. This then consumes the abundant fuels in the cell, and ruptures the vent disk, and is directed out through a nozzle to generate thrust. This thrust then reduces the vehicle orbit to a safe disposal time.

LiBDO reduces LEO missions's residual orbit times

Space debris threatens LEO orbits

Reducing space debris is needed to preserve LEO



The population of LEO objects from the US Space Surveillance Network through 2010. Two events, the FY-1C ASAT and Iridium 33/Cosmos 2251 collision caused large increases in debris in LEO.

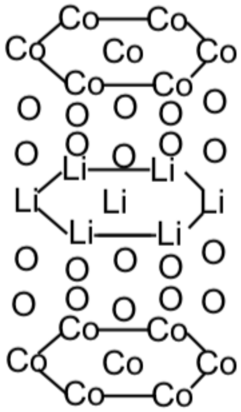
- 22,000 objects tracked by the Space Surveillance Network, and an estimated 900,000 pieces of debris >1 cm.
- 2008: a post-mission Soviet satellite experienced an internal explosion that released 3000+ objects.
- 2009: a Russian satellite collided with an Iridium generating over 1500 pieces of orbital debris. After this event, it was calculated that a vehicle in LEO had a 50% per year chance of being impacted by a piece of debris over 1 cm in size.
- Debris objects in LEO are projected to continue to increase even where there are no additional LEO vehicles.

Liou, J.C. *et. al.*, Adv. Space Res. 47, *11*, 1865-1876, doi:10.1016/j.asr.2011.02.003

Debris is now self perpetuating in LEO due to sheer number of objects

Thermal runaway in the vacuum of space

- A Li-ion battery is a tightly wound bundle of oxidizer and fuel when charged.



(1) $3Li_xCoO_2 \rightarrow Co_3O_4 + 2O + xLi + \Delta$
(2) $2Al + 3O \rightarrow Al_2O_3 + \Delta$
(3) $2LiC_6 + 5O \rightarrow Li_2O + 2CO_2 + \Delta$

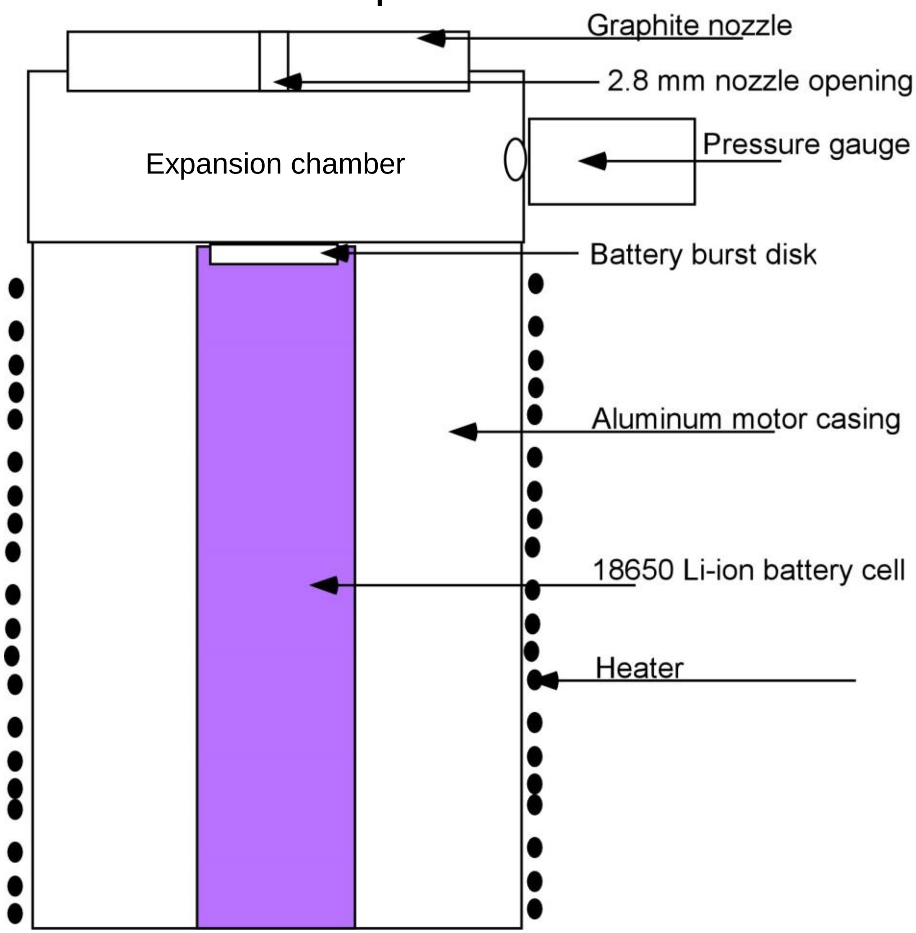
- During charging, the lithium ions are removed from the cathode, creating a very oxidizing substance. Removing lithium destabilizes the cathode material making it a strong oxidizer.

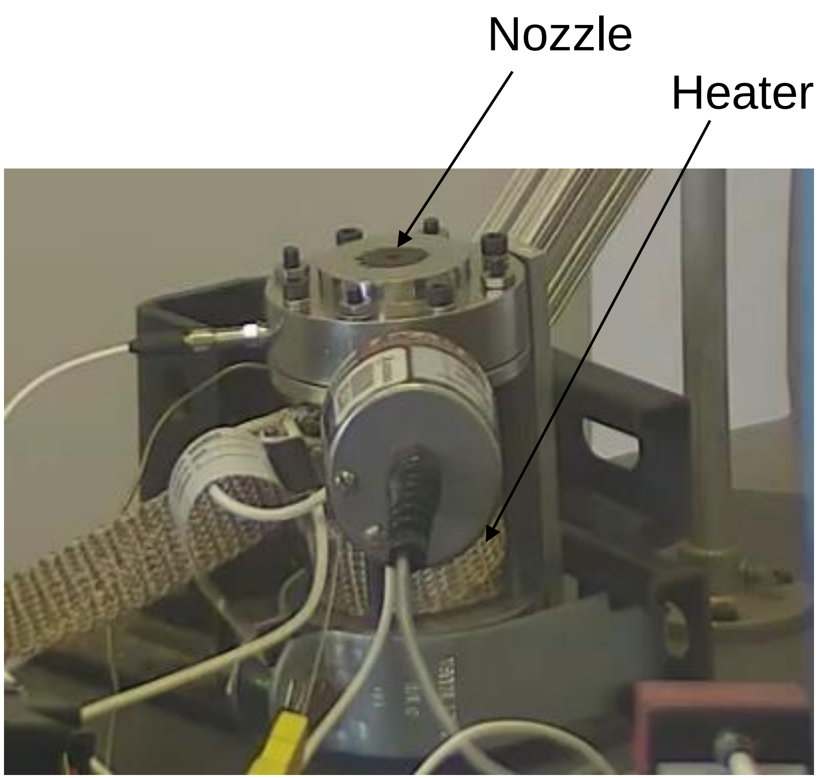
- When heated past ~170˚C the polymer separator keeping the oxidizing cathode and the reducing anode (or fuel) melts. The two materials touch and release their stored 'battery' energy. This then heats the partially delithiated cathode, causing spontaneous decomposition, which rapidly spreads the thermal runaway condition causing *combustion* of the cell contents. The high temperature and intimate contact of the cathode with the aluminum substrate will also ignite the aluminum as an additional source of fuel.

The Li-ion battery has all the necessary components for a vacuum capable solid rocket motor

Test Design for proof of concept for LiBDO

Test setup





Test setup showing heater, pressure gauges, and the nozzle.

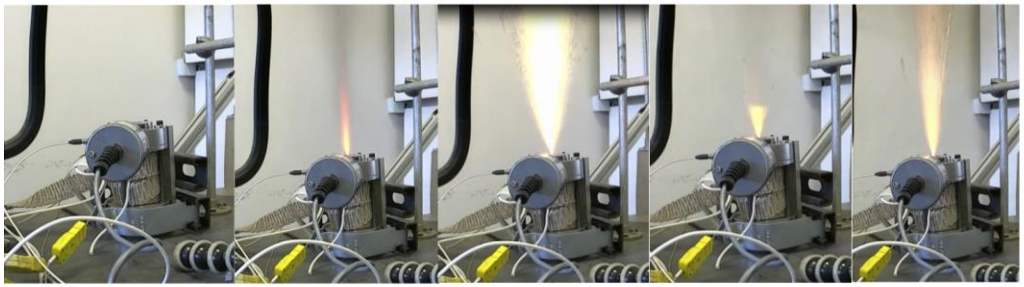
This design measures the pressure generated in an expansion chamber prior to ejection out of nozzle. This allows for measurement of vacuum capable thrust generation.

Test design simulates heater triggered LiBDO design.

Demonstration of thrust from a Li-ion cell

Single Cell Test Proof of Concept

Heating | Ignition | Large Discharge | Reduced Discharge | Increased Discharge

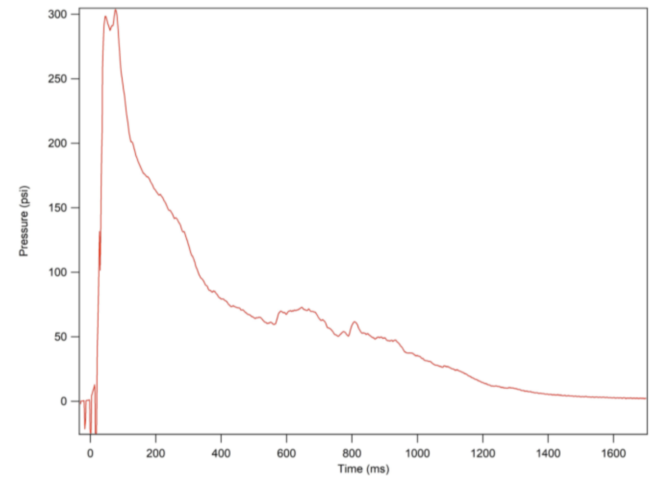


-0.2 seconds | 0.0 seconds | 0.12 seconds | 0.44 seconds | 0.64 seconds

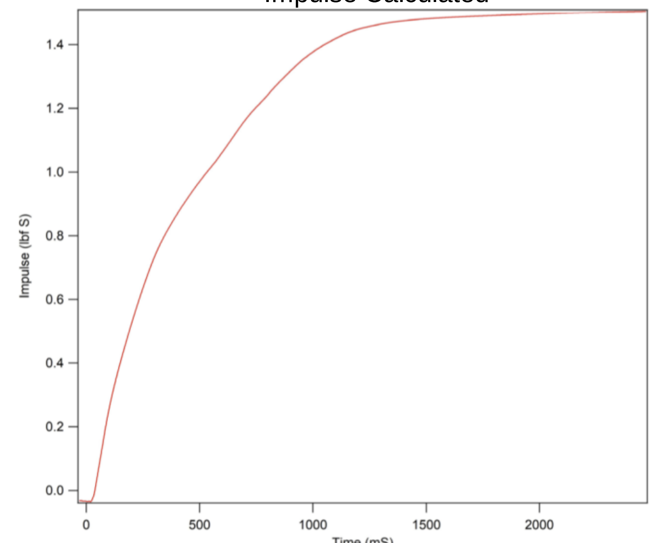
A single Li-ion 18650 sized cell, a Moli-M LCO cell

- The cell was charged to 100% state of charge (SoC) and then placed in a purpose-built motor housing.
- The motor housing was heated until the cell went into thermal runaway.
- A pressure gauge inside the small space between the cell vent and nozzle measured the pressure. The pressure rise from the test indicated that this first attempt of the LiBDO technology generated the vacuum equivalent thrust of 29.3 N and a total impulse of 10.4 Ns.

Pressure Trace



Impulse Calculated



The total impulse was 1.54 lbf * s

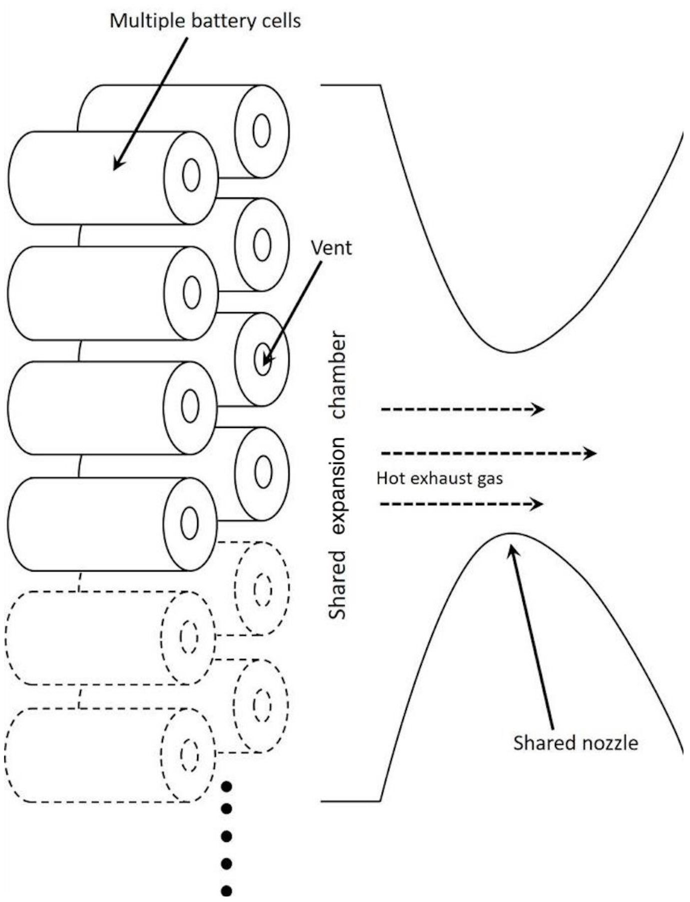
Unoptimized activation data demonstrate baseline capability

A low cost, low mass satellite enhancement

- This technology seeks to leverage the components that all satellites already have to reduce post-mission orbital lifetime. Unlike other competing deorbit technologies such as tethers and thrusters, LiBDO uses existing on board hardware to deorbit
  - *Battery and trigger (heater) are already on board.*

- This technology only requires a nozzle to capture and channel the exhaust and use of the spacecraft's attitude control system to direct the thrust to lower the vehicle orbit.

- It is anticipated that the thrust generated can be optimized by increasing the state of charge of the battery beyond 100%, as LCO chemistry can store more energy and generate more oxidizer.
  - *Typically this reduces life, but triggering LiBDO will shorten life much more!*



Plan for a shared gas expansion chamber connected the the cell vents and the external nozzle. Cells can be triggered individually or collectively to generate thrust.

Minimal mass addition for a substantial capability increase

Mission context

Calculated reduction in residual orbital time using LiBDO

Slingshot 1: at least a 55% reduction in residual orbit

- A 12U vehicle in a 500 km orbit, with a mass of 15 kg. The planned mission life is 2 years, currently with no additional capability to deorbit at end of mission. Slingshot will carry 18 Li-ion 18650 COTS cells.
- At the end of the 2 year mission life the orbit will be 489.9 km with a 10.48 years post life decay orbit time. Based on only the thrust generated per cell from the first benchtop tests, by activating 18 cells on the vehicle the orbit would be reduced to 445.2 km, a 24% reduction in orbital decay time, to 7.95 years.
- The thrust generated from a deployed BDO system (which is anticipated to be at ~2x the measured thrust) will reduce the orbit size to 400.8 km, and have a 4.67 year post orbit decay life, a 55% reduction in residual orbit time.

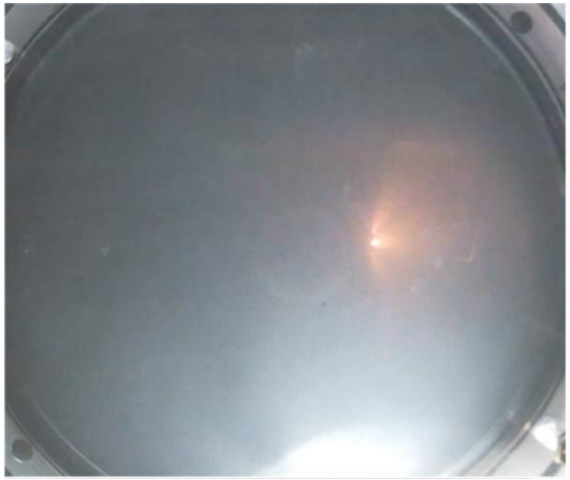
Decrease orbital lifetime by 55% with minimal mass addition

Vehicle disposal using battery thermal runaway

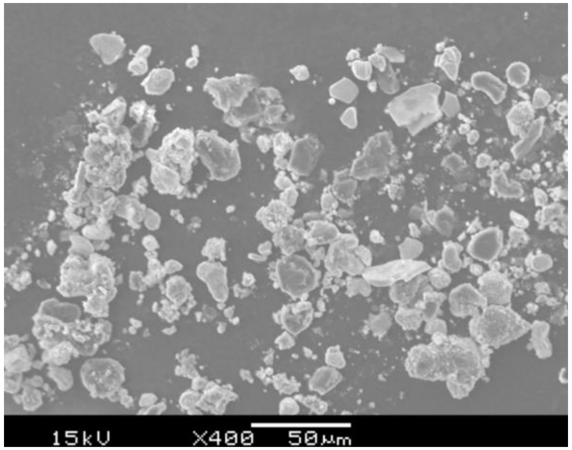
- Many small sats in LEO use drag to dispose of the vehicle at end of life, which can take upwards of 25 years even for low orbits, risking collisions and debris forming events, threatening access to space and critical orbits.
  - *LiBDO can both reduce residual orbit time, as well as eliminate the battery as a source of stored energy.*

- Li-ion cells have been demonstrated to enter thermal runaway in vacuum, and the released debris from this is very small, typically less than 50µm.
  - *Triggering LiBDO will not generate external debris.*

- Thrust generation can significantly impact residual orbit times.



Heater triggered thermal runaway in vacuum.



SEM of the particulates generated from a thermal runaway event in vacuum, and were typically 50µm or less.

Drag is no longer a sufficient deorbit mechanism given the surge in small satellites

Mission design considerations

A functional LiBDO capability on a vehicle will require some considerations beyond current battery needs.

- Sequential cell activation capability or ability to reliably trigger cells simultaneously.
- Large enough heater to trigger the cells into thermal runaway.
- During activation the vehicle will need active ACS control to keep thrust aligned with the orbital direction to maximize orbital reduction.
  - Close to C_g to minimize ACS requirements and a port on the outside of the vehicle.
- Thermal protections for any adjacent residual system.

Demonstration of proof of concept. A COTS Li-ion cell used in the Aerocube satellites was heated to thermal runaway, and the gasses were focused through a nozzle to generate thrust.

Proposal Timeline

White paper
- evaluation of LiBDO technology and capability
- 3U up to 100kg vehicle concepts
- Requirements and impact

Tech Demo
- Demonstration of thrust control and enhancement
- Trigger demonstration
- String level testing

Full Scale Demo
- Battery level demonstration
- Independent module control

Vehicle Battery
- Design and build of a demonstration 6U vehicle battery with LiBDO capability

Year 1

Year 2

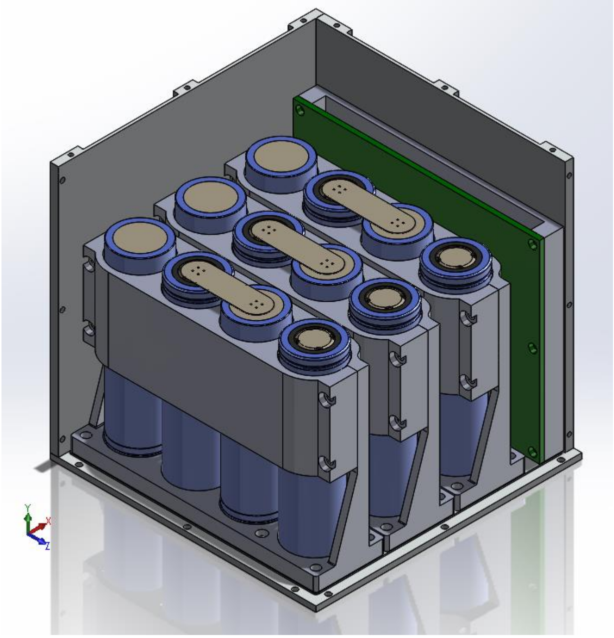
Year 3

Advancing the TRL of a capability to meet a critical need

The Intelligent Battery Group

The Aerospace Intelligent Battery Group (IBG) is a cross organizational team dedicated to developing advanced power system capabilities through new hardware, software, and unorthodox concepts. The IBG is creating and expanding power system technology and capability to enable optimized control and flexibility and new functions.

- Major Projects in addition to LiBDO
  - Radiation Hard and High Temperature Batteries for RTG applications with Oak Ridge National Labs.
  - Project Dynamo: a modular power system for small sats.
  - Smart Wrapper: Wireless battery monitoring and cell balancing hardware.
  - Digital Twin: Vehicle system simulator.



Project Dynamo, a modular supplemental power payload for commercial vehicle bus. Dynamo seamlessly supports bus power needs by optimally using power or energy modules. This payload is targeted for deployment on the Aerospace Slingshot vehicle.