January 21st, 2026

STARLINK BATTERIES:

RELIABILITY LESSONS FROM 10,000 LEO SATELLITES

RAY BARSA | PRINCIPAL BATTERY ENGINEER

SPACEX

CUSTOMERS

9M+

COUNTRIES

155+

CONTINENTS

7

SATELLITES IN ORBIT

9500+

SATELLITES DEORBITED

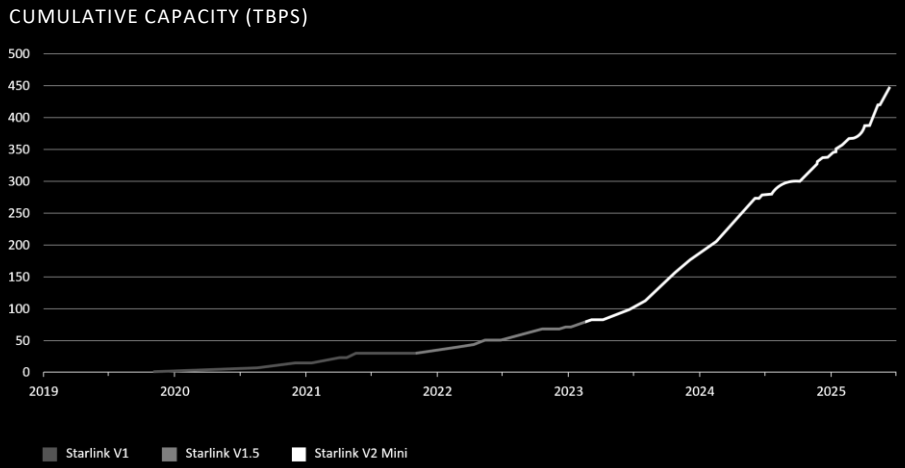
1500+

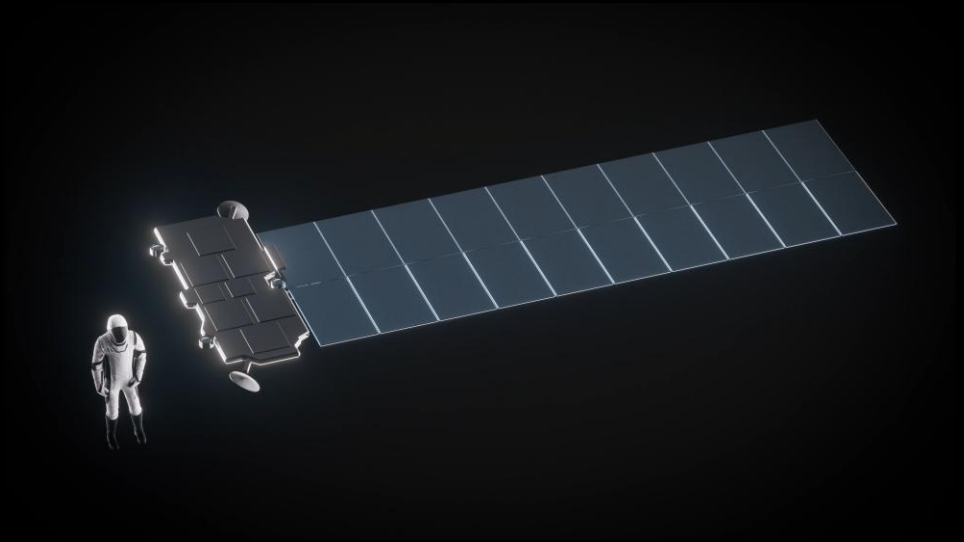
DEAD SATELLITES TODAY

1

CONSTELLATION GROWTH

Starlink V3 satellites - designed for Starship, with each launch adding 60 Tbps of capacity to the Starlink network - more than 20x the capacity added with every V2 Mini launch on Falcon 9





2025

Starlink V2 increased network capacity +50%
123 dedicated launches of Falcon 9

2026

Starlink V3 begins launching on Starship
Each satellite adds >1Tbps down & 200Gbps up

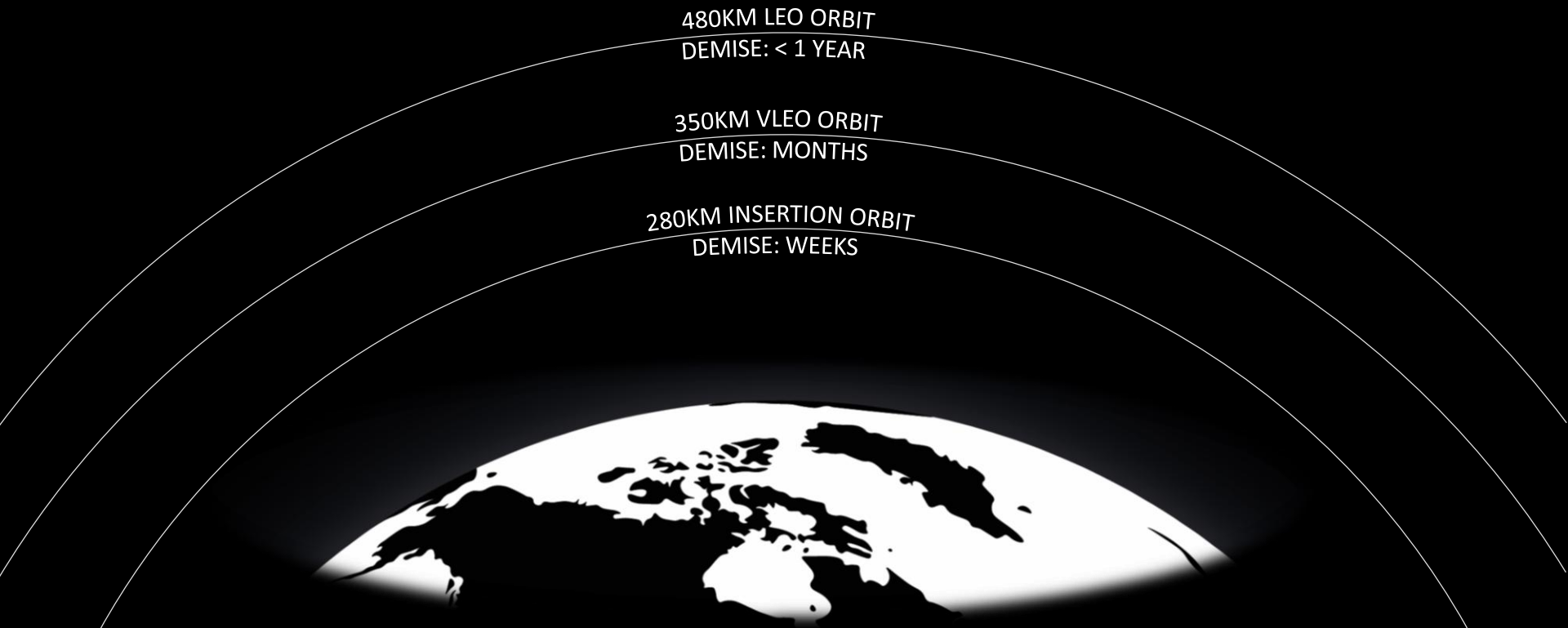
COLLISION AVOIDANCE

DEMISEABILITY

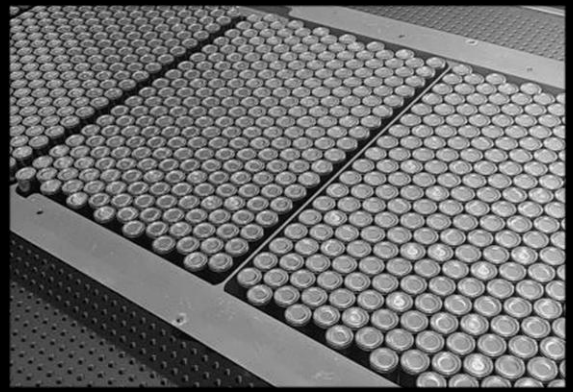
LOW ALTITUDE OPERATION

“Beginning of life" failures happen at low altitudes, and the satellite deorbits quickly — keeping low-Earth orbit free of debris

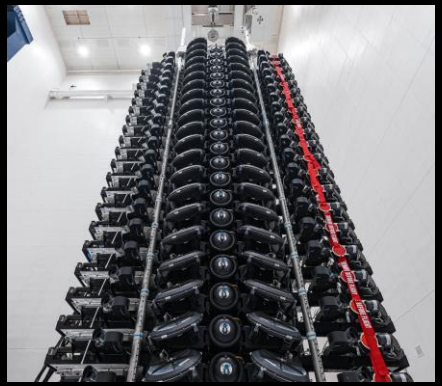
In 2026, Starlink will also undertake a major operation to lower its 550km operational shells down to ~480km



BATTERY RELIABILITY



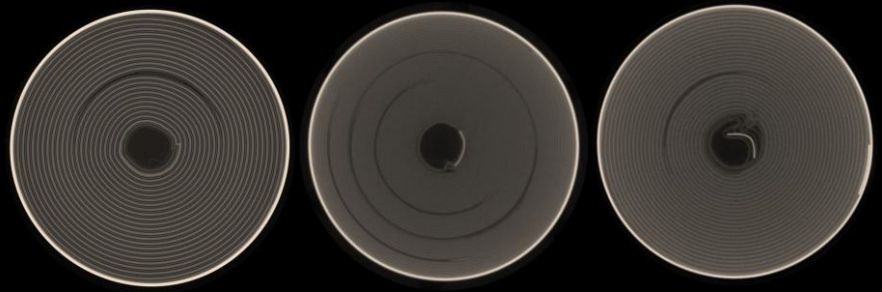
230 Wh/kg Pack Design



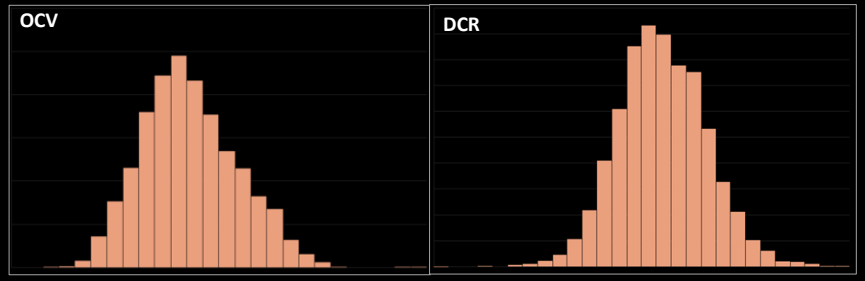
+1000 Satellites Quarterly
>50 MWh Battery Capacity per Year

>100 MWh Battery Capacity in Orbit Today

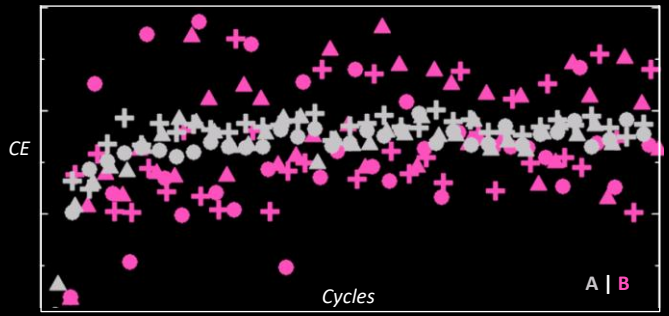
CELL-LEVEL SCREENING & OPERATION



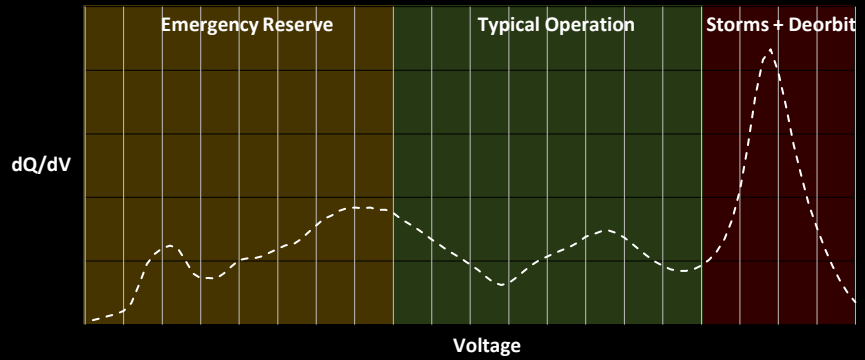
CT Scanning (Qualification) – assess variations in mechanical build quality & monitor long-term cycling phenomena



Cell Screening (Acceptance) – measure OCV Decay, DCR, ACZ, and mechanical integrity at pack builds



Ultra High-Precision Coulometry (Qualification) – assess electrochemical performance variation & infer long-term cycling performance

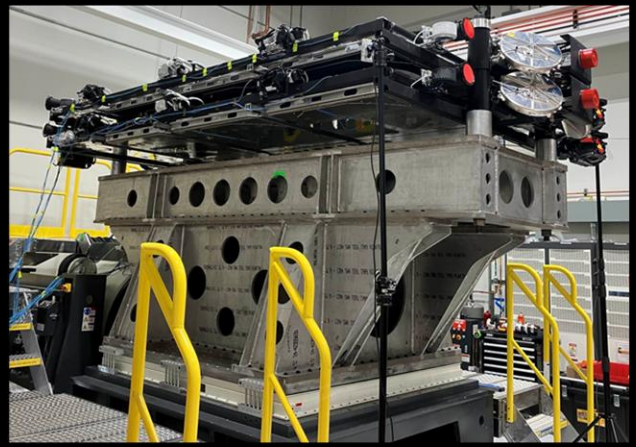


Orbital Operation – tunable SoC windows reduce degradation, reduce sidewall rupture rate, and increase pack homogeneity

PACK ACCEPTANCE TESTING

Cell Incoming	Pack Outgoing	Satellite Integration	Launchsite	Prelaunch	Orbit Raise	5yr Mission
Cell Acceptance	Pack OCV & GITT Interconnects Sensor Health	Busbars Contact Resistance Thermal Check	Recheck after cross-country transport	Final charge after storage	Low-altitude checks + weeks of thrusting	Weightless, Room Temp, C/2, mid-SoC

Pack Acceptance Testing (HASS-like stress test) performed over auto-dunk tanks

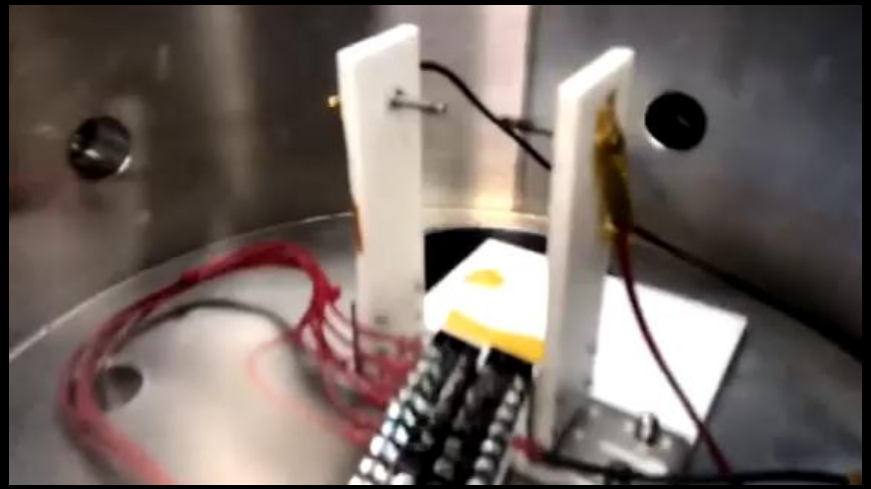


Vibration Qualification performed with stacked satellites

ARC-RESISTANT DESIGN

Spacecraft arcing has destroyed satellites for decades. We find:

- Pack-level arc qualification should take place *after* typical vibe/shock/thermal
- Arcing can catastrophically fail packs given voltages >32V and pressures <1Torr
- Many flightlike tests are required for statistical confidence



Lab-scale testing of Arcing phenomena
Metal Vapor Arc → Cascading Arc → Plasma Arc

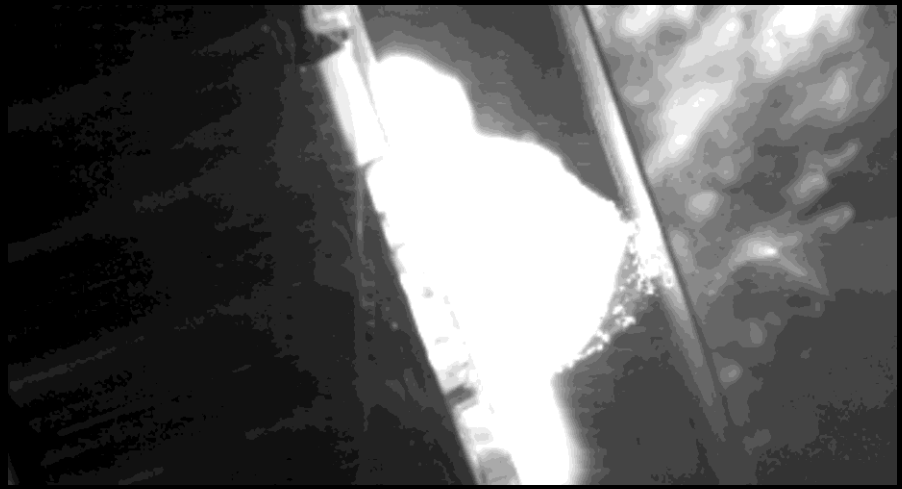
Empirical Testing of Pack Design
Pressure, Venting, Voltage, Distance, & Material Dependent

MMOD STRIKE SURVIVAL

Micrometeoroid and Orbit Debris (MMOD) Strikes are certain to occur with Megaconstellations.

- Refining estimates of particle size, velocity, and incoming vector helps protect the most vulnerable areas
- Empirical hypervelocity testing is needed to understand pack-level response
- PPR testing may include multiple initiator cells to represent MMOD strikes
    - *Thought experiment: is it better to penetrate a single cell, or dent multiple cells?*

Hypervelocity Impact Testing
Pack design, orientation, and altitude dependent



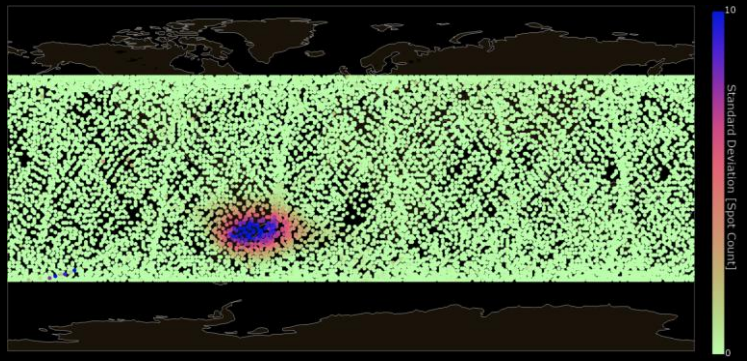
Resulting Cell Damage informs PPR Strategy
Vulnerable locations + initiator cell quantity

RADIATION TOLERANCE

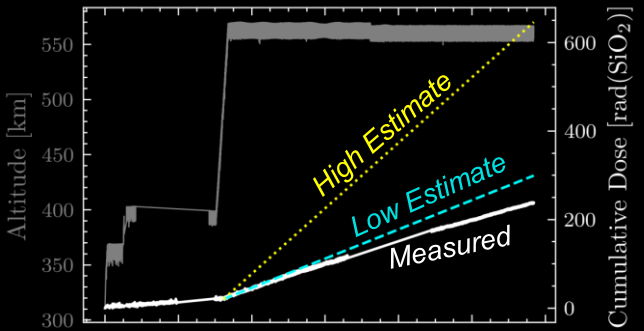
Typical radiation upsets cause latch-ups and railed telemetry; FDIR is straightforward. But what if failures aren't binary?

- Understand nominal time-constants & telemetry magnitudes.
  - Can cell voltages ever truly be at rest (dV/dt flagging)?
  - Can cell temperatures truly change ±5°C/min (dT/dt flagging)?
  - Do failed thermal sensors present as an impossible -200°C, or a possible -5°C?
- Megaconstellations offer a unique opportunity for data collection with COTS sensors & clever software (below)

CMOS Imager under high proton flux irradation



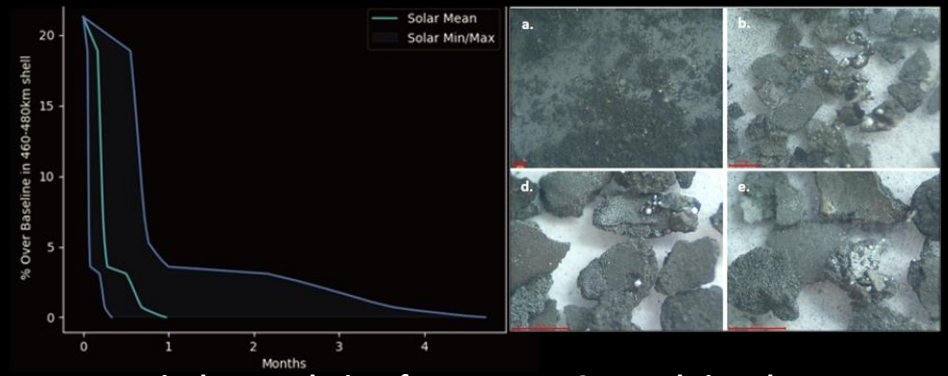
Ten minutes of constellation-level mapping to find & measure the South Atlantic Anomaly (SAA)



Total Ionizing Dose (TID) Measurements are below estimates

PASSIVE PROPAGATION RESISTANCE

- Test conditions are critical
  - Powered vs Unpowered systems
  - Nominal vs faulted thermal conditions
  - Vacuum level heavily influences outcome
- Vary initiation modes to represent different faults
  - Nail Penetration may represent MMOD
  - Simple heaters may overtest or force SWR
  - Arc initiators should use flightlike materials
- Fault Detection, Isolation, and Recovery (FDIR)
  - If single-cell runaway is detected, determine the appropriate response – lower SoC? lower temperature?
- Design Considerations
  - Vent sizing for debris must prevent plasma ingress
  - Cell-adjacent materials and coatings all heavily iterated upon for PPR & arcing



Particulate Analysis Informs Worst-Case Debris Release

Inadequate Pack-Level Test Setup

Q&A