Laboratory MOXIE Commissioning and Operations

@ the MIT Haystack Observatory

SPACE RESOURCES ROUNDTABLE
JUNE 2023

Parker Steen for the MOXIE Team

MIT HAYSTACK OBSERVATORY

MOXIE Models

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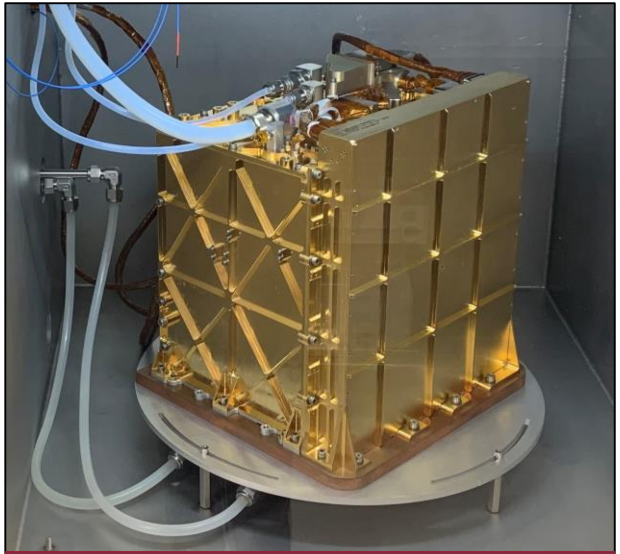
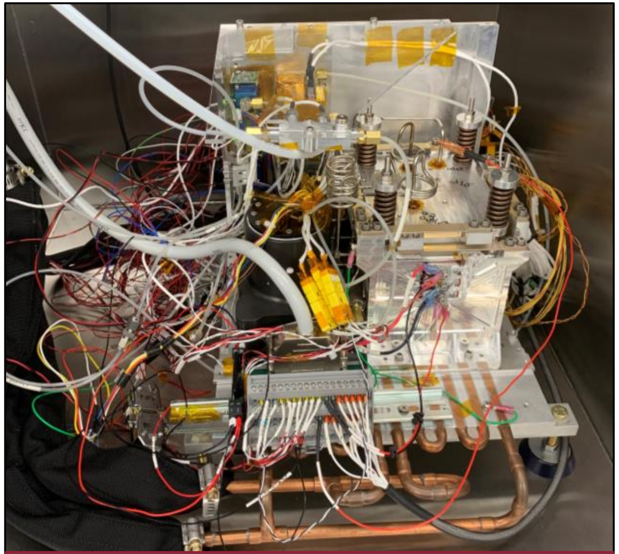
FLIGHT MODEL (FM)

14 runs on Mars



ENGINEERING MODEL (EM)

15 runs in JPL labs, 2 at Haystack to validate FM runs



FLATSAT

6 runs in Haystack's lab

Haystack's Mars Laboratory

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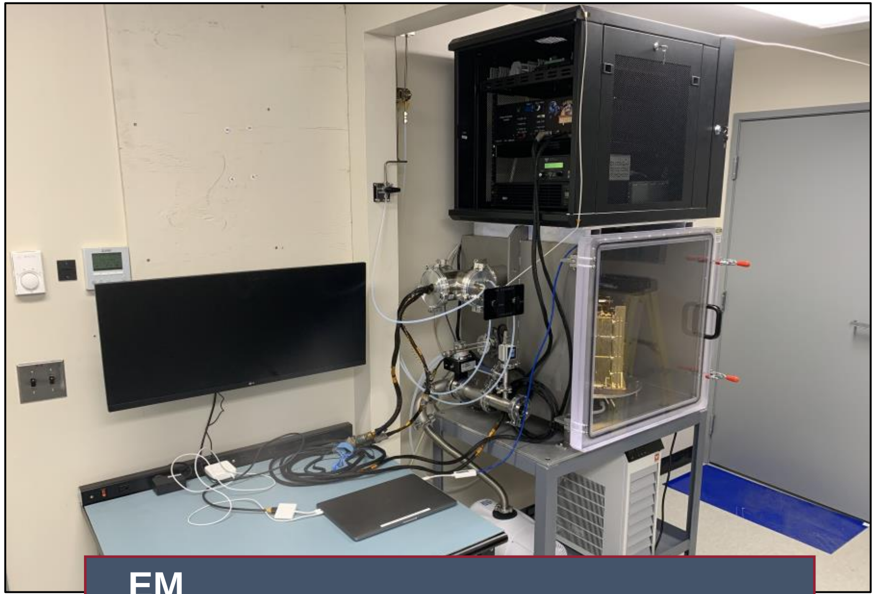


EM

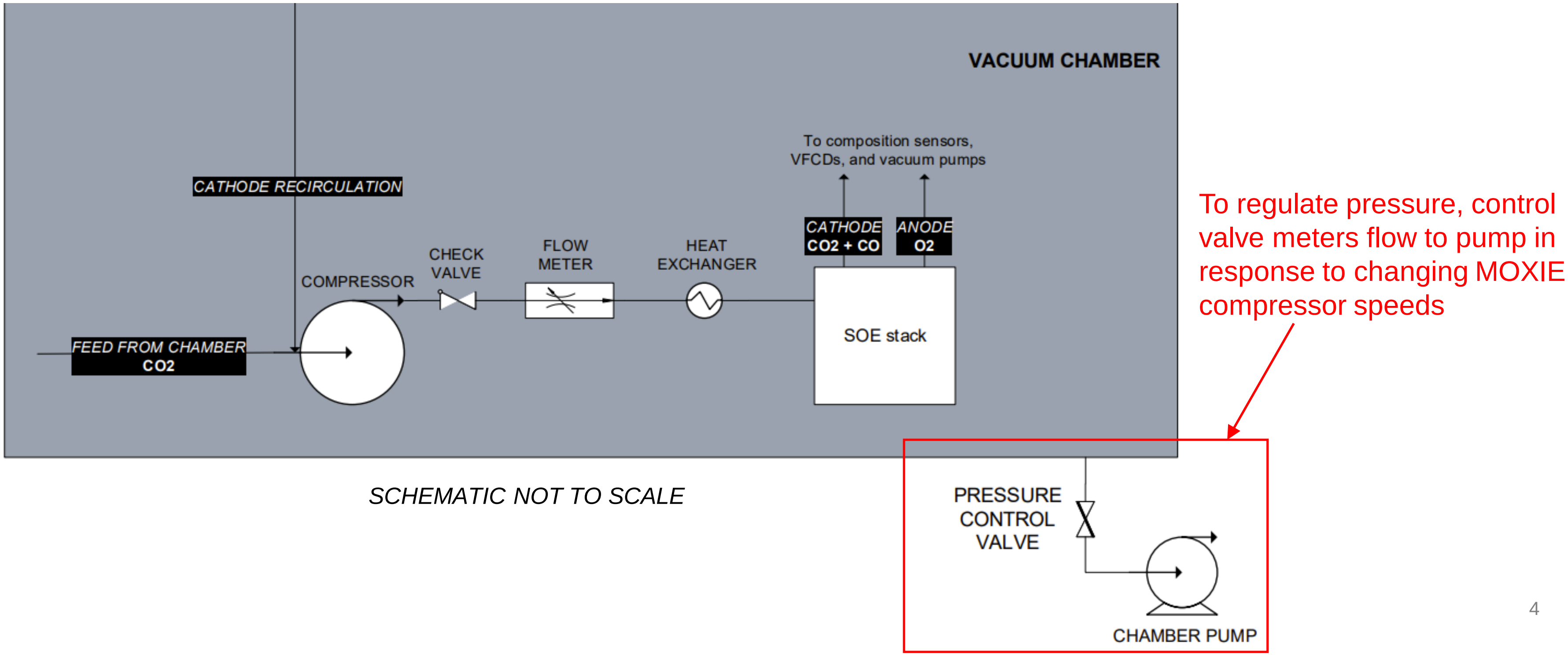
- Validation of FM O_2 runs

FLATSAT

- Validation of EM & FM O_2 runs
- Flight software modifications
- Reconfiguration of flow paths & instrumentation
- **Testbed for novel ISRU operating configurations free of MOXIE rover constraints**

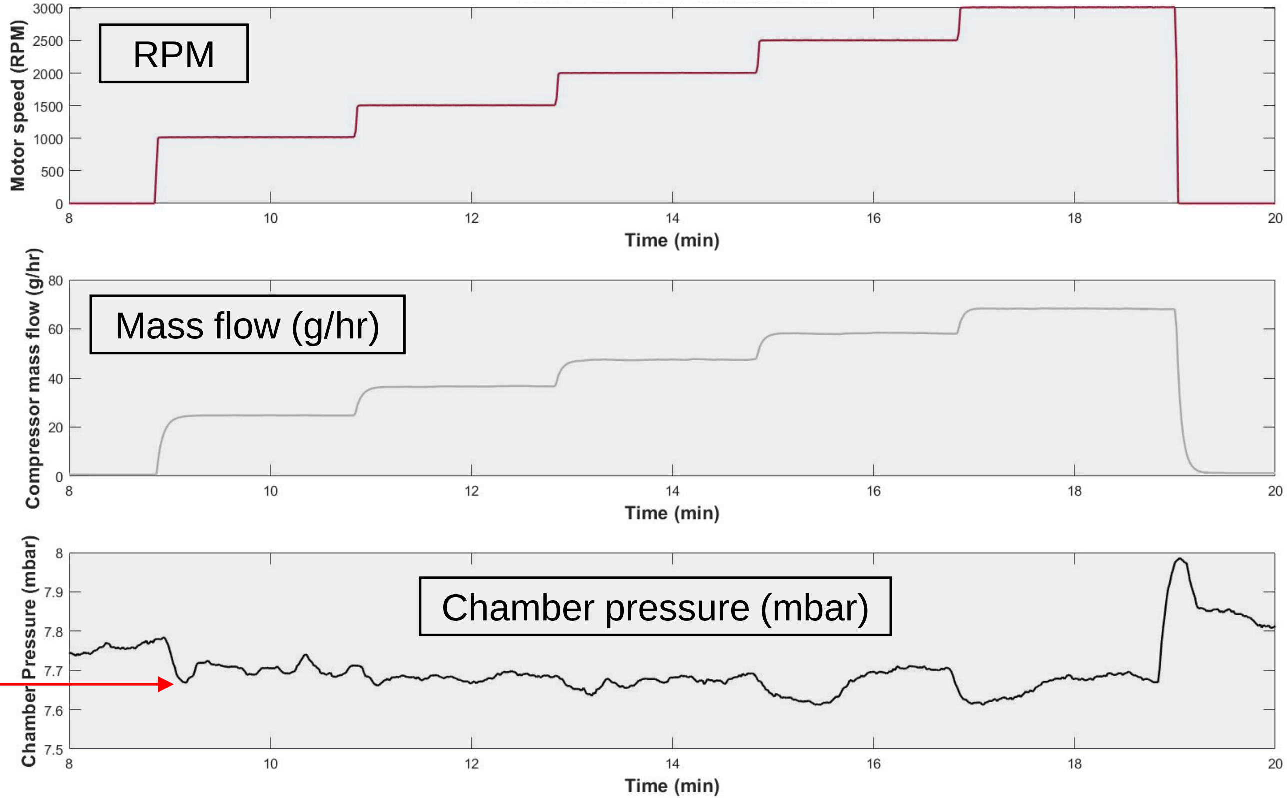
EM & FlatSat – Compressor Feed

- Emulates FM operations via pressure controlled chamber



Chamber Pressure Control

- Experiment demonstrating chamber pressure response to change in speed of MOXIE’s volumetric compressor



Chamber pressure when compressor turns on:

- *ΔP = 0.1 mbar*
- *Response time = ~1min*

FlatSat – Possible Modifications to Flow Paths

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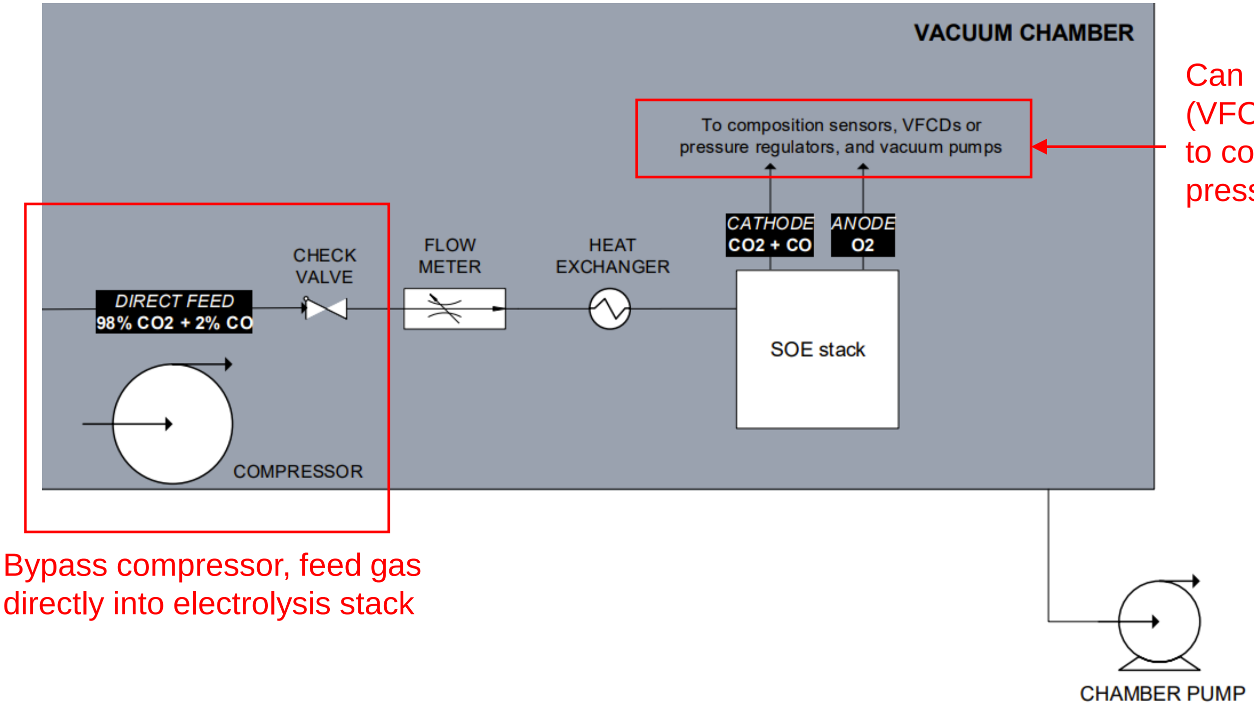


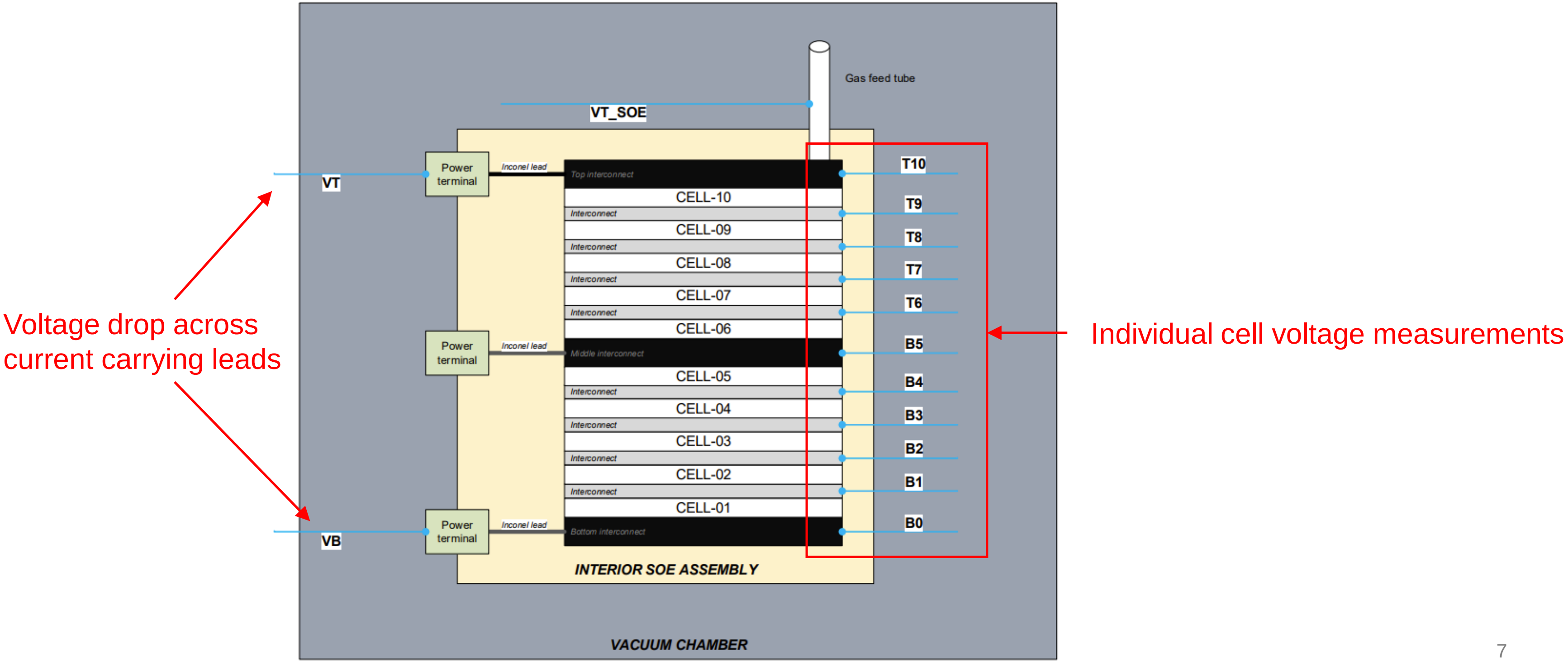
Can bypass fixed apertures (VFCDs) for pressure regulators to control cathode & anode pressure independent of flow rate

Bypass compressor, feed gas directly into electrolysis stack

SCHEMATIC NOT TO SCALE

FlatSat – Specific Instrumentation

- Measurements not available with FM or EM, enabling insights in cell-to-cell variation and effective voltage at SOE stack



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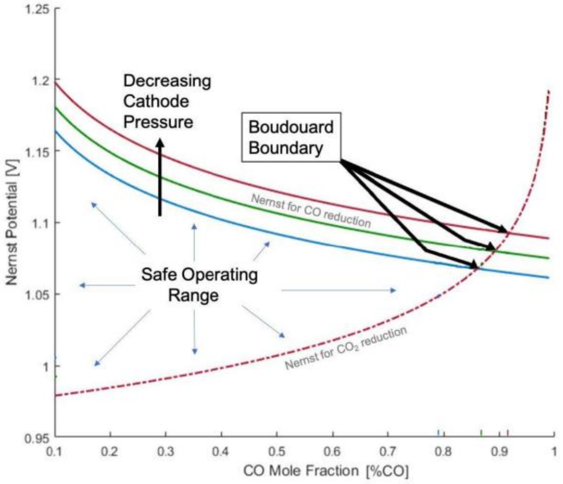
FlatSat Achievements

- **Active control of cathode pressure against atmospheric density variations**
  - Density of inlet gas on Mars changes – especially during dusk/dawn
  - Control loop measures cathode pressure to set compressor RPM to maintain constant flow rate
  - First demonstrated with FlatSat, then with EM and FM
- **Low cathode pressure operations (<200 mbar)**
  - Future scaled versions of MOXIE will preferably run at lower cathode pressures
  - Two driving motivations, experiments:

1. **Compressor performance @ low cathode pressure**
   - Low cathode pressure improves power consumption, volumetric efficiency
   - Compressor metrics characterized as a function of RPM and outlet pressure
2. **Stack safety & O_2 production @ low cathode pressure**
   - Low cathode pressure increases carbon Nernst potential, enabling higher utilization or safety margin
   - Theory validated with FlatSat O_2 run at decreasing cathode pressures



Summary and Planned Work

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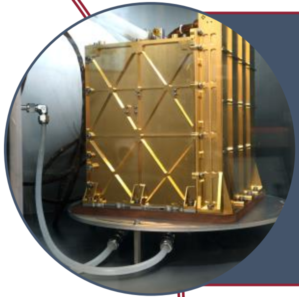
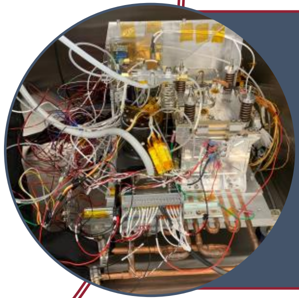


PLANNED WORK

- EM to be used for FM validation
- Continuation of low cathode pressure investigations with FlatSat
- Long duration testing (O_2-production, compressor) with FlatSat



PLANNED UPGRADES

- Remote operations for long duration testing
- Commercial electronics that can run MOXIE flight software

Contributors

Core Laboratory Team: Mike Hecht, Parker Steen, Andy Menching Liu, Shravan Hariharan

Haystack: Chris Eckert, Bob Schaefer, Jason Soohoo, Christine Alcalde, John Swoboda, Alex Burns, Mike Poirier, Tony Bettencourt, Ken Wilson,

MIT AeroAstro: Jeff Hoffman, Andy Menching Liu, Shravan Hariharan, Kyle Horn

JPL: Asad Aboobaker, Alex Perez, Keith Billings, Ike Chi, Gerald Voecks

OxEon Energy: Joe Hartvigsen

Consultation: Don Rapp

Backup

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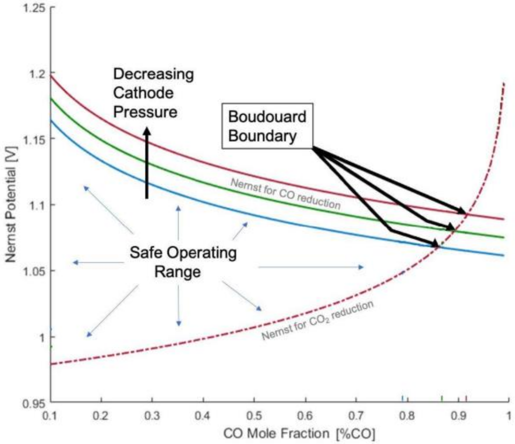
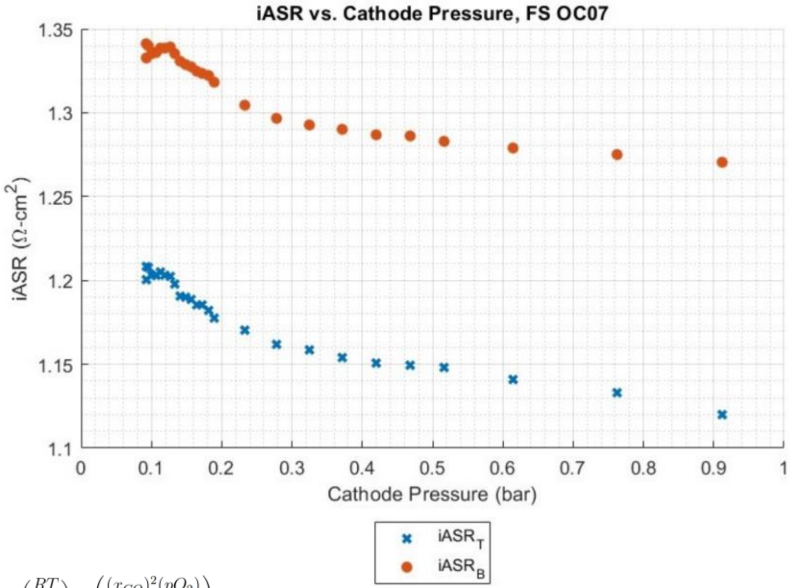
FlatSat Low Cathode Pressure Electrolysis

Shravan Hariharan (M.S. 2023)

- Low cathode pressure increases carbon Nernst potential, enabling higher utilization or safety margin
- Theory validated with FlatSat O_2 run at decreasing cathode pressures
- Experiment
  - Repeated I-V sweep with constant inlet flow rate (22 g/hr, 98% CO_2 + 2% CO)
  - Periodic decrease in cathode pressure setpoint



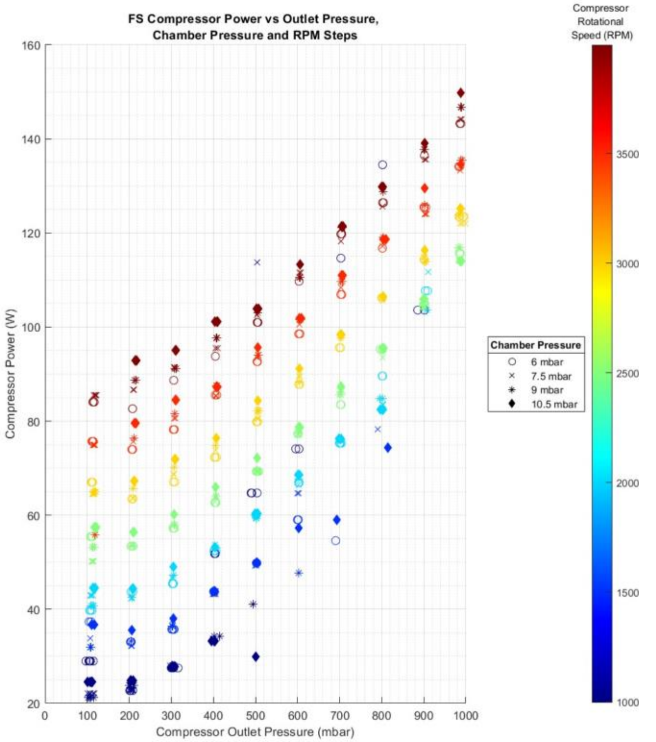


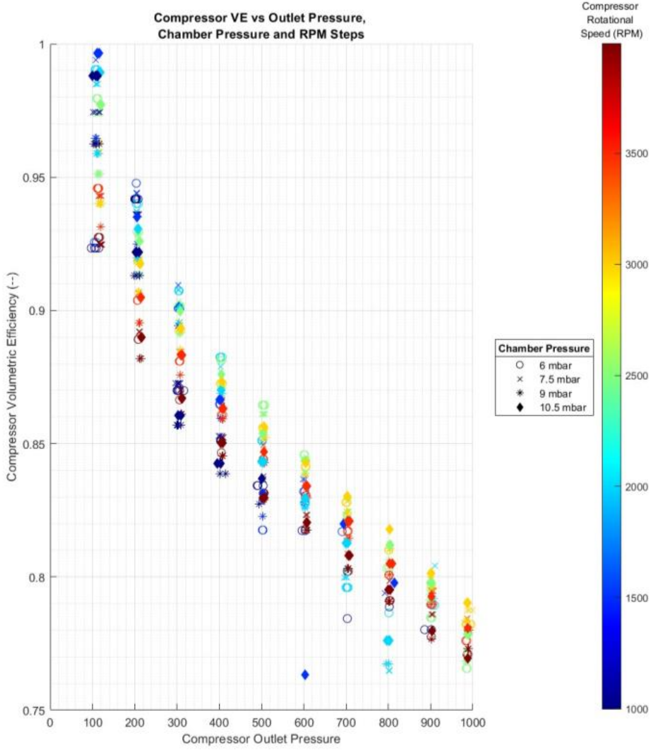
$$V_N(2CO_2 \rightarrow 2CO + O_2) = V_{rev} + \left(\frac{RT}{4F}\right) \ln\left(\frac{(x_{CO})^2(pO_2)}{(x_{CO_2})^2}\right)$$

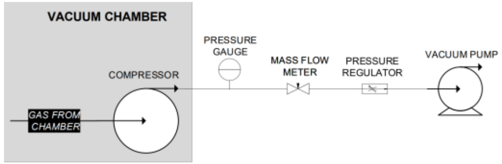
$$V_N(2CO \rightarrow 2C + O_2) = V_{rev} + \left(\frac{RT}{4F}\right) \ln\left(\frac{pO_2}{(P_{ca})^2(x_{CO_2})^2}\right)$$

FlatSat Compressor Characterization

- Low cathode pressure improves power consumption, volumetric efficiency
- Compressor metrics characterized as a function of RPM and outlet pressure







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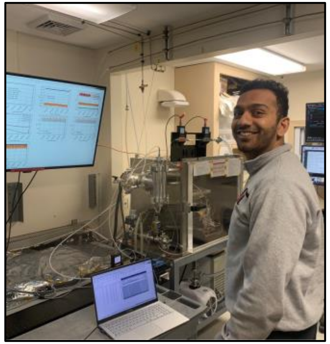

Shravan Hariharan (M.S. 2023)

Active Compressor Flow Rate Control

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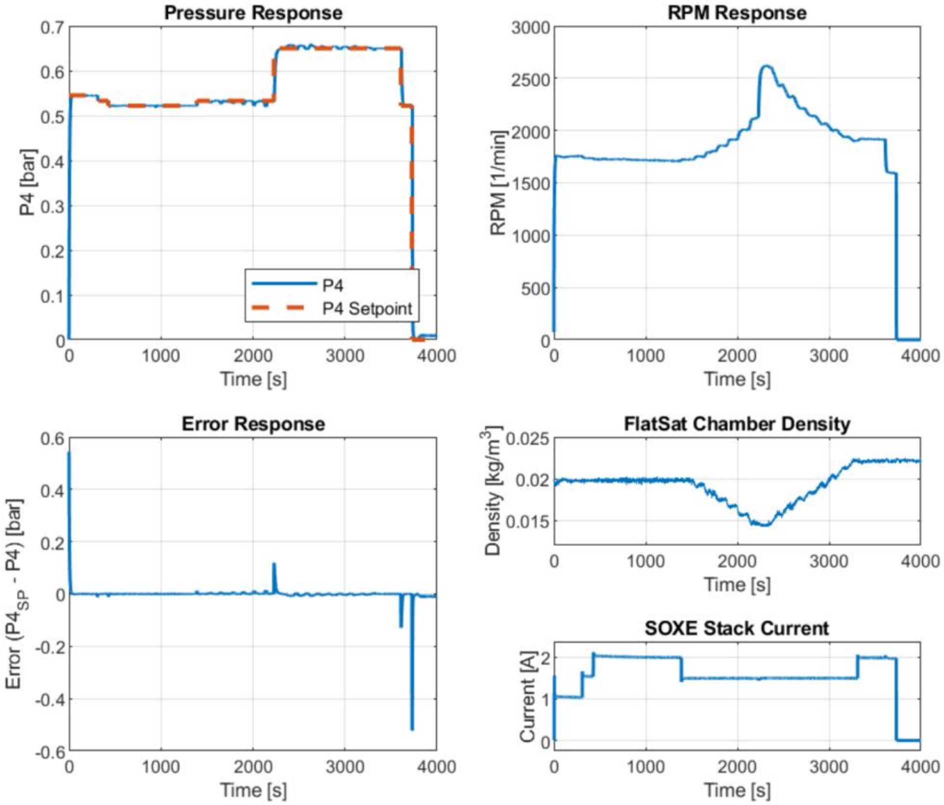
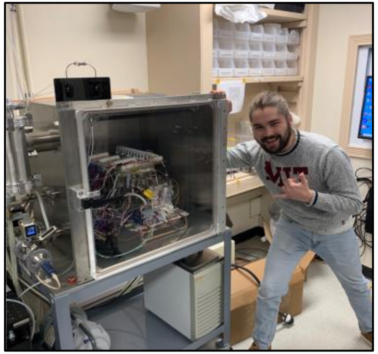


- Motivation: density of inlet gas on Mars changes rapidly during dusk/dawn
- Control loop measures cathode pressure to set compressor RPM to maintain constant flow rate
- First demonstrated with FlatSat, then with EM and FM



Kyle Horn (M.S. 2023)

Flight Software Upgrade Testbed

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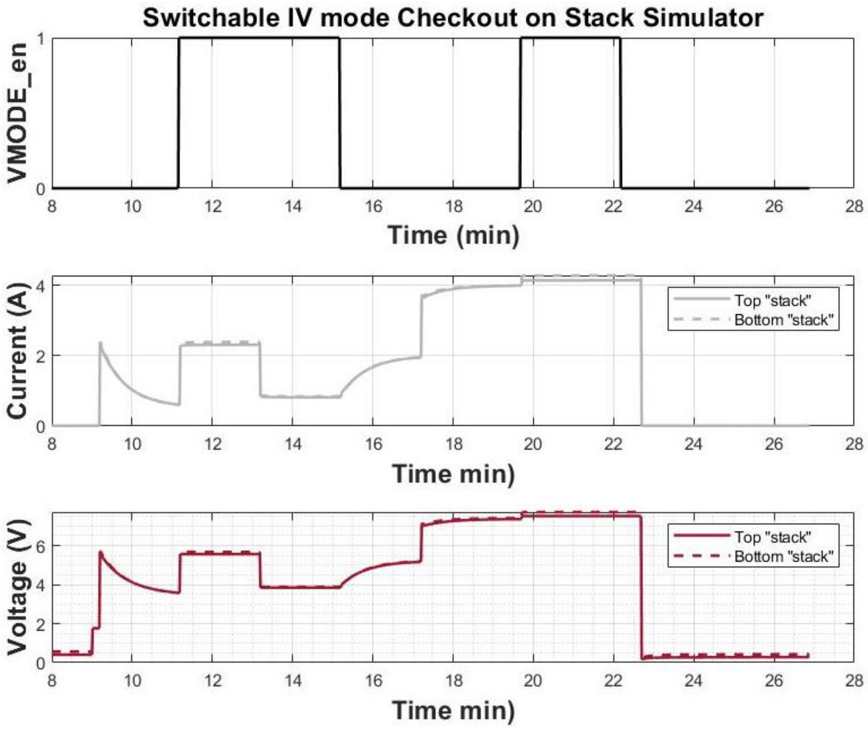
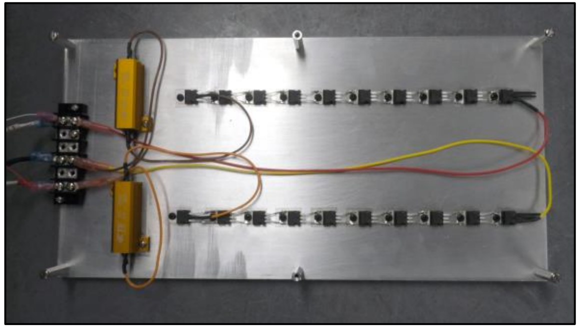


- FSW updates first demonstrated with FlatSat
- Major update: enable bit for toggling between constant voltage and constant current mode during a run



SOXE Simulator Circuit