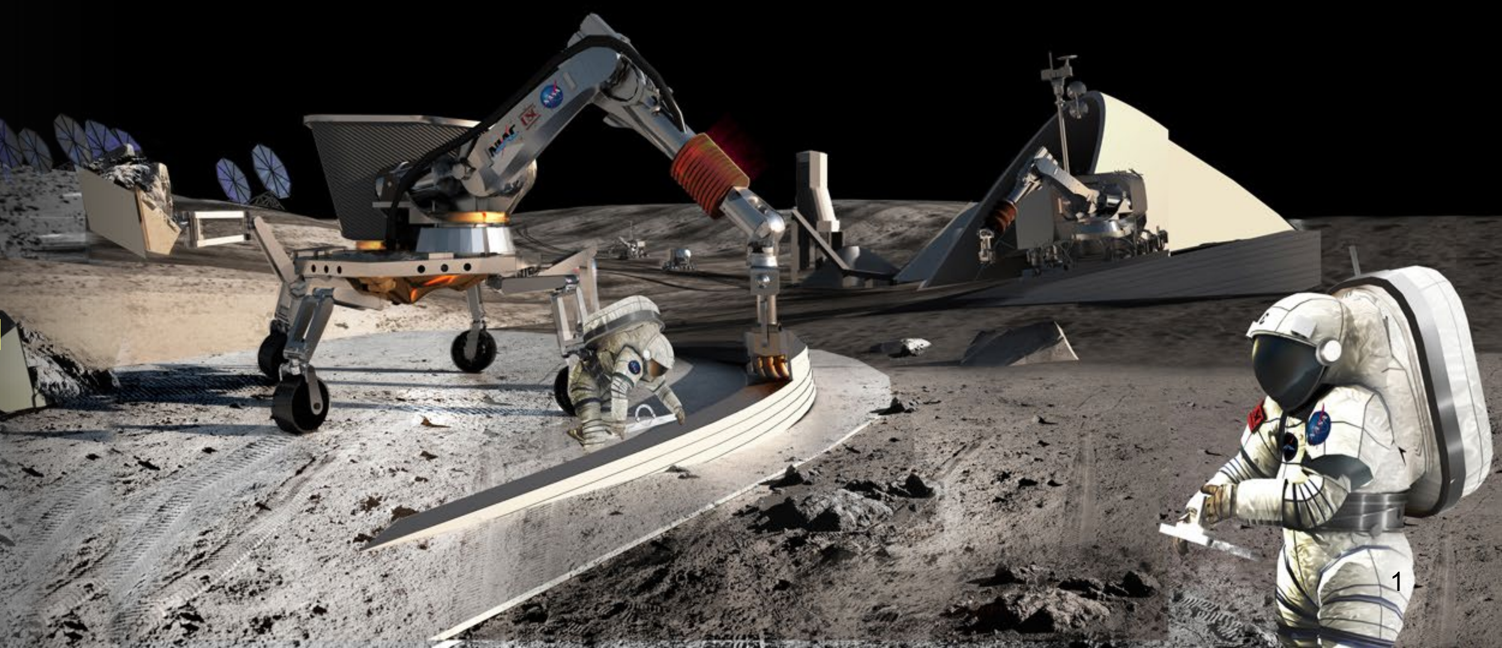
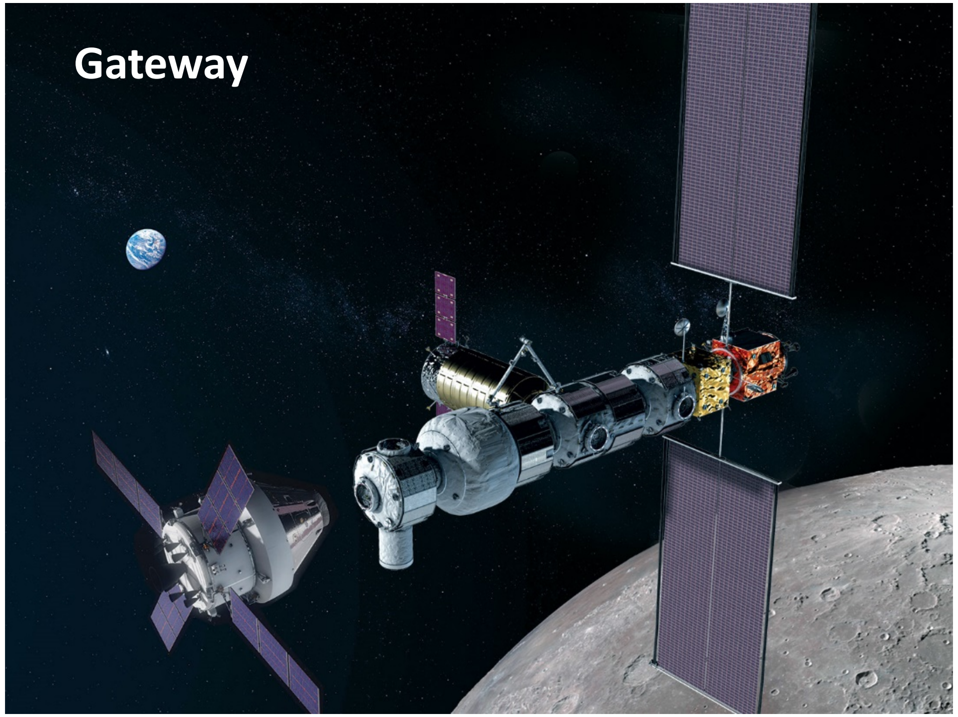
Overview Artificial Intelligence and Machine Learning Power Related Technologies at NASA

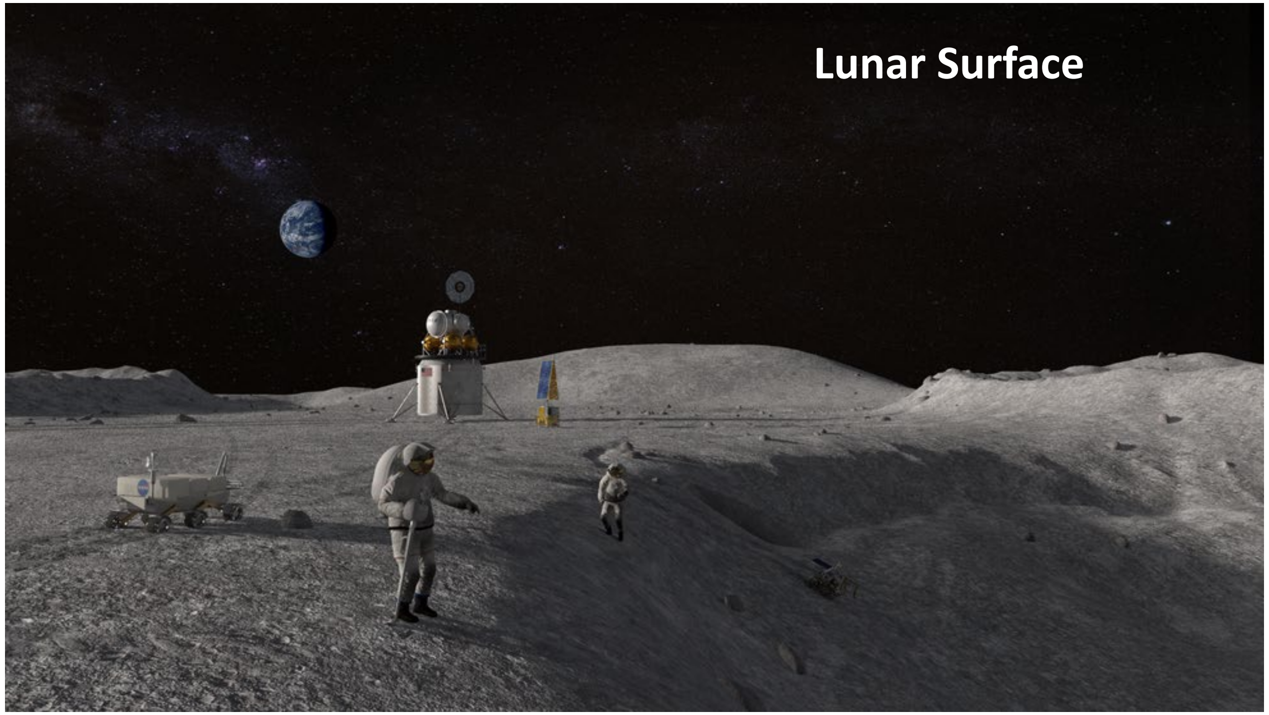
Jeffrey Csank
NASA Glenn Research Center
Cleveland, OH



Interagency Advanced Power Group (IAPG)
Artificial Intelligence and Machine Learning Panel
January 25, 2022
Virtual

NASA Space Related Technology Development





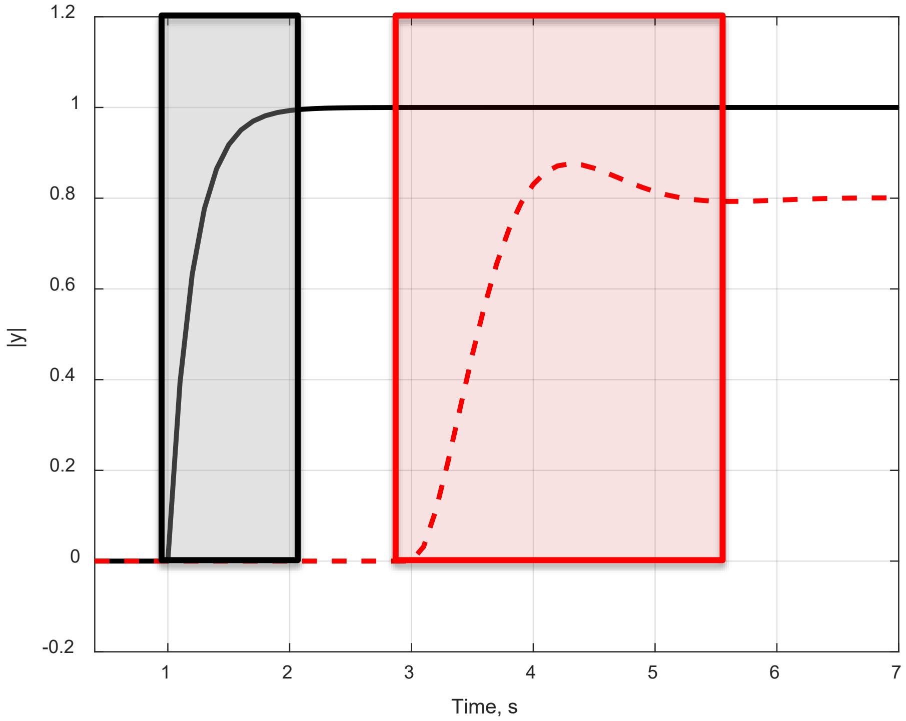
AI / ML in Space Power Systems

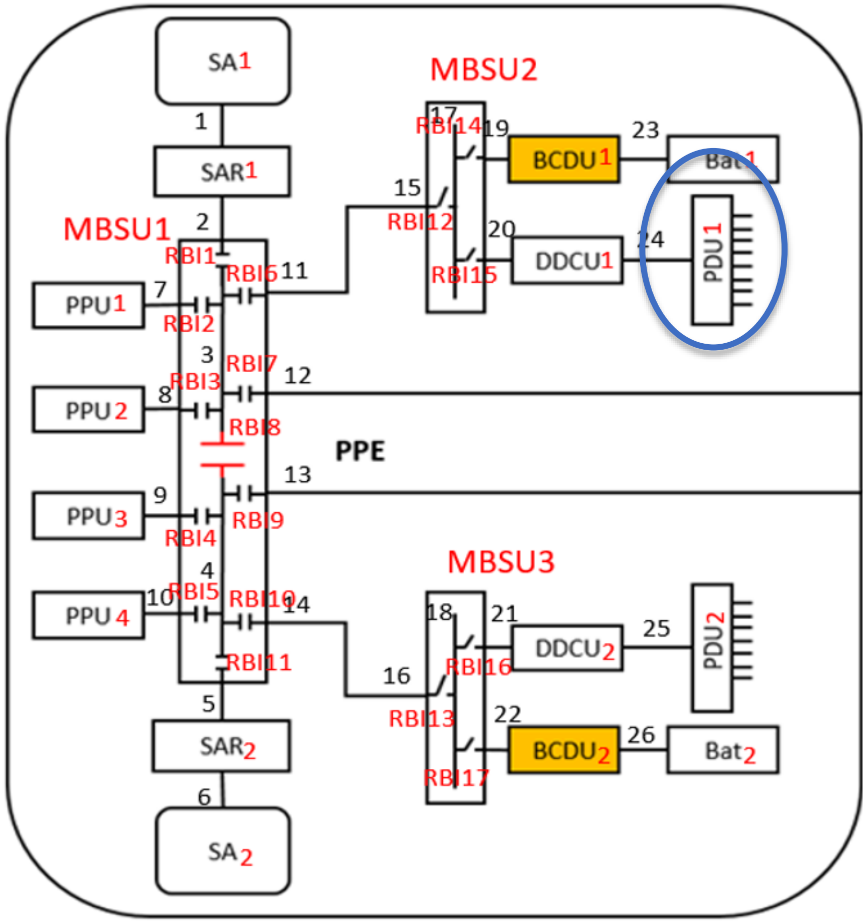
- **Fault Detection and Analysis**
  - Increase the correct classification of faults/failures
    - Distinguish between failures with similar signatures and multiple failures
- **Contingency Management**
  - Help determine the “optimal” architecture after a failure
- **Maintenance**
  - Human Awareness and interaction
    - Provide information to operator to help with repairs/maintenance/etc
  - Determine when equipment is starting to deviate from nominal operation
    - Avoid failures due to component degradation
- **Power/Energy Management**
  - Power system operability / coordination
    - Update system set points to ensure power system stability
    - Coordinate between converters, etc.
  - System monitoring / Intelligent power forecasting and scheduling
    - Update load power demand allocations based on actual usage instead of nominal rating (reduce margins)
      - Allow additional loads to receive power by not allocating extra power to high priority loads
      - Avoid the need to shed loads due to loads consuming more power than allocated

Fault Detection

- **Use a support vector machine (machine learning) to:**
  - Characterize load behavior
  - Detect abnormal behavior
  - Distribute the computation of high-resolution data, easing the computational burden on the EPS
- **Feature Analysis using Clustering**
  - Extract large numbers of features from high-frequency data to characterize transient and steady-state data
  - Use clustering techniques to find relationships between features, finding patterns in the data, producing a list of regular load performance characteristics
  - Identify events outside of regular clusters, indicating abnormal/faulted device behavior
  - Optionally include a system expert in the loop to validate machine learning results and strengthen accuracy

Transient Fault Detection Using SVM





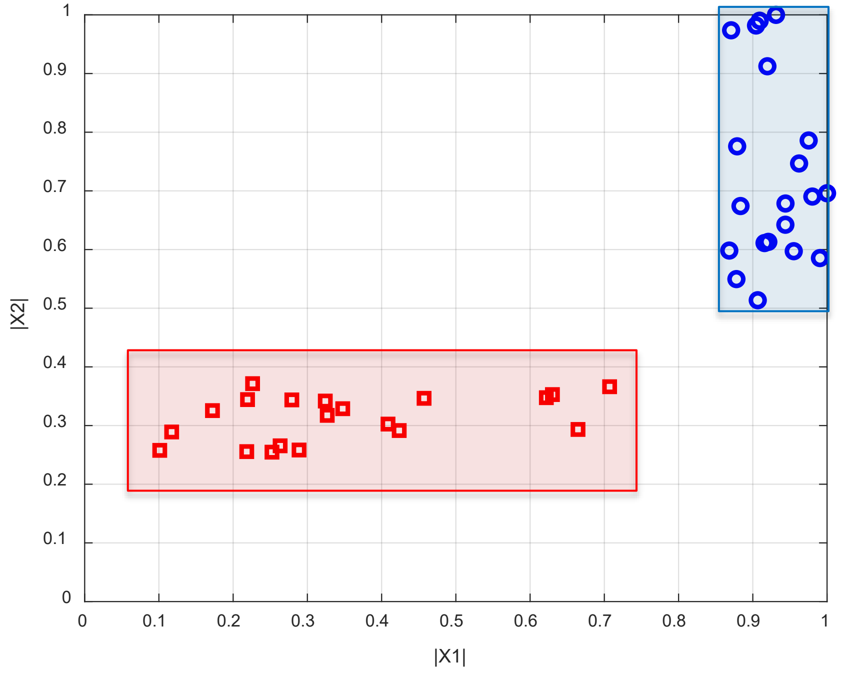
- **Use a support vector machine (machine learning) to:**
  - Characterize load behavior
  - Detect abnormal behavior
  - Distribute the computation of high-resolution data, easing the computational burden on the EPS

[1] Y. Zhou, R. Arghandeh, and C. J. Spanos, "Partial Knowledge Data-driven Event Detection for Power Distribution Networks," *IEEE Trans. Smart Grid*, pp. 1–1, 2017.

Feature Analysis Using Clustering

Example Features

Single Stream	Statistics	$\text{mean}(w_t^i), \text{var}(w_t^i), \text{range}(w_t^i)$ $\text{median}(w_t^i), \text{entropy}(w_t^i), \text{hist}(w_t^i)$
	Difference	$u_t^i = \text{Diff}(x_t^i)$; Statistics
	Transformation	$\text{fft}(w_t^i), \text{wavelet}(w_t^i)$
Inter Stream	Deviation	$x^i - x^j \quad \forall i, \forall j \in \mathcal{N}(i)$
	Correlation	$corr(x^i, x^j) \quad \forall i, \forall j \in \mathcal{N}(i)$



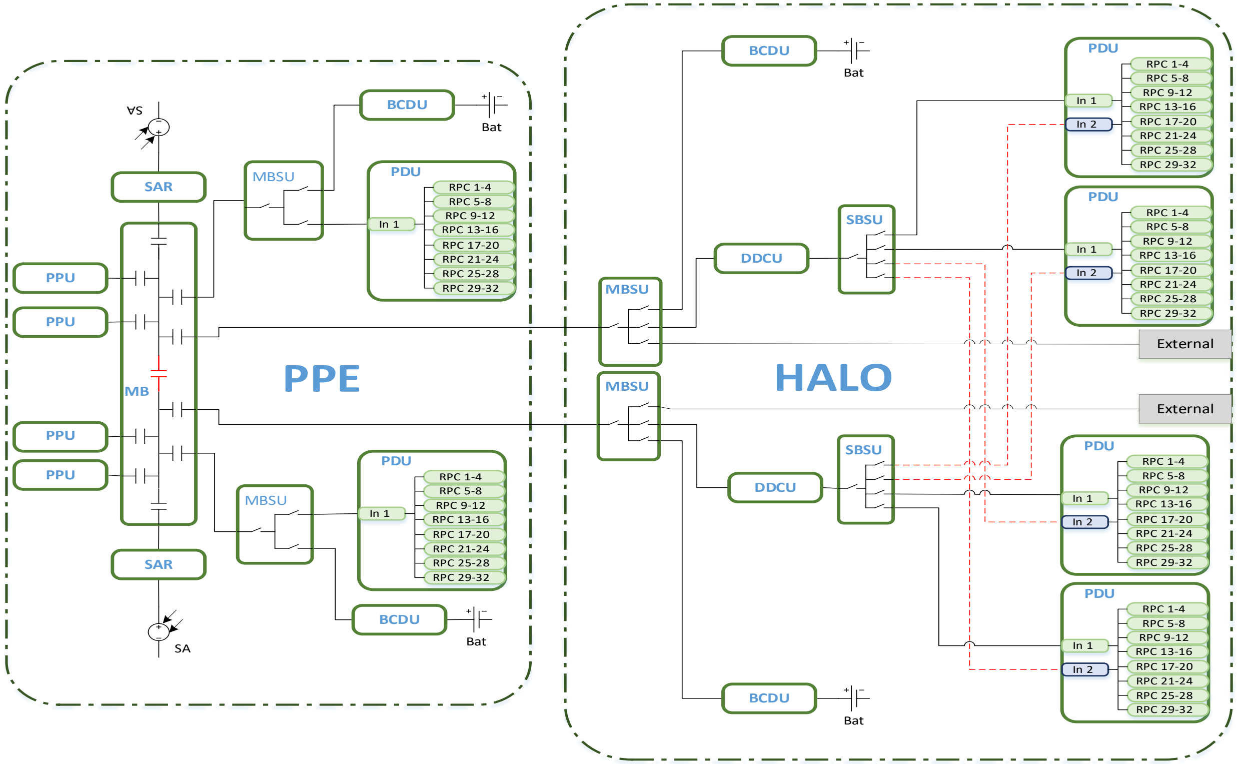
[2]

- Extract large numbers of features from high-frequency data to characterize transient and steady-state data
- Use clustering techniques to find relationships between features, finding patterns in the data, producing a list of regular load performance characteristics
- Identify events outside of regular clusters, indicating abnormal/faulted device behavior
- Optionally include a system expert in the loop to validate machine learning results and strengthen accuracy

[2] https://steema.com/wp/blog/2015/06/01/clustering-visualization/

Autonomous Network Reconfiguration

- **After a fault, this service sets the electrical network based on a modified Dijkstra's shortest path algorithm**
  - Computes quickly (<100ms) to minimize load outages
  - Finds a near optimal topology based on the given fault information
  - Current path weights are decided off-line and sometimes leads to higher priority loads not getting power
    - AI/ML could be applied to update path weights in real-time based on anticipated future needs or past priorities/needs

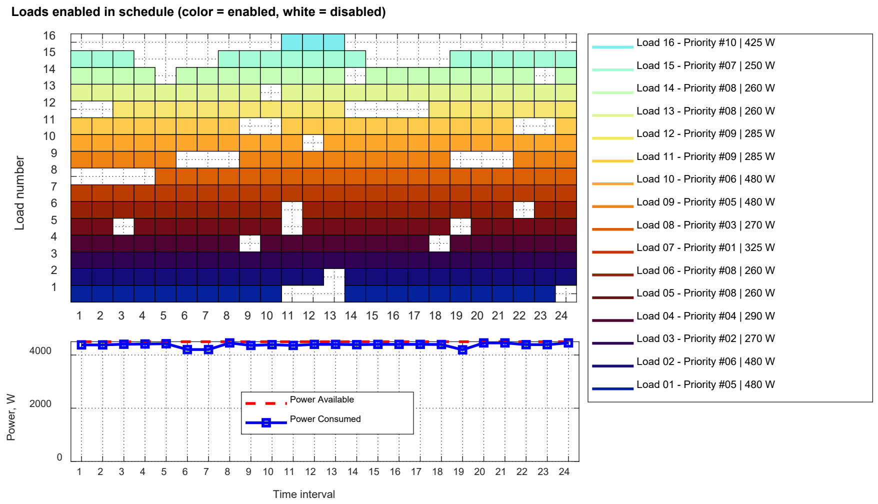


Autonomous Load Scheduling

- **Autonomous power systems must generate periodic load schedules over a given planning interval (e.g., 5 minutes)**

- **Approach: Cast problem as mixed integer linear programming**
  - Constraints
    - Deliver up to max power available
    - Enforce periodicity of schedules
  - Objective
    - Maximize power delivered to loads weighted by priority
  - Lessons Learned:
    - If problem too expensive to solve, break into smaller subproblems

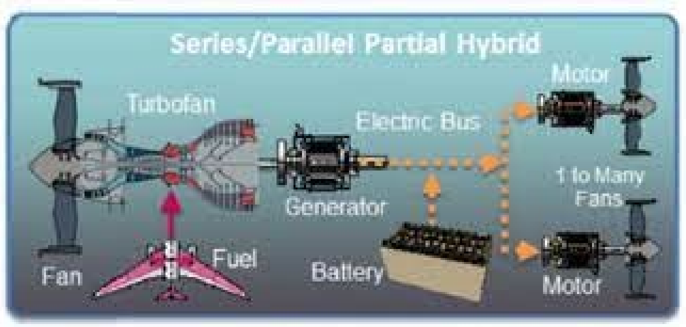
- **Result: Successfully can create locally optimal load profiles for 16 load demo system within planning interval**



<u>**STTR Phase 2 – *Intelligent EPS Scheduling***</u>

- **Stottler Henke Associates, Inc and Montana State University**
- **Creates AI reasoning modules for planning, scheduling, characterization, machine learning, and fault detection/diagnosis/reconfiguration in core flight software (CFS)**
- **Leverages Stottler Henke Associates Aurora software that has been applied for Unites Space Alliance Space Shuttle Orbiter, Air Force Satellite Control Network (AFSCN) and other government applications.**

NASA Aeronautics Technology Development



Hybrid-Electric Aircraft / Aircraft Electrification

Revolutionary Vertical Lift Technologies
Urban Air Mobility

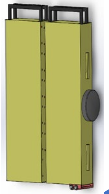
AI / ML in Aeronautics Power and Energy Technology

- **Fault Detection and Analysis**
  - Increase the correct classification of faults/failures
    - Distinguish between failures with similar signatures and multiple failures
- **Digital Twins**
  - Used for performance monitoring, life/degradation, and fault detection
  - AI/ML used to update model and increase accuracy
- **Power/Energy Management**
  - Power forecasting
    - Vehicle performance based on state of charge, fuel, etc.

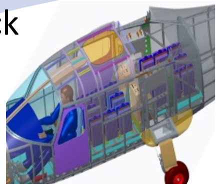
Aeronautics - Batteries

The NASA GRC Photovoltaics and Electrochemical Systems Branch is working towards the advancement of battery safety and performance for hybrid and all-electric air vehicles

AI/ML will be used as a predictive tool, using prior performance, safety and design data to help predict future materials and designs to meet future needs.

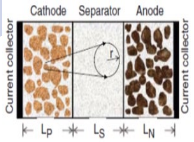


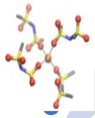
Vehicle Integration



Module to Pack Design

Microstructure to Cell Design





Chemical and Material Design

Battery Pack Level

Design, Demonstration and Vehicle Integration

BORING - Optimize performance, safety and thermal control at the pack level.

X-57– Flight Demonstrator for distributed electric propulsion technology

SUSAN - Subsonic Single Aft Engine Electrofan concept for hybrid/electric propulsion

EPFD –Demonstration of practical vehicle-level integration of MW-class electrified aircraft propulsion systems

Cell Level

Materials, Design and Safety

SABERS –Solid state cell chemistry and design to improve performance and safety

SPARRCI - Improved battery safety and performance via sensor development, cell integration and modelling for early detection and prevention of cell level failures.

NASA Sustainability Base

NASA Sustainability Base

- **Located at Ames Research Center (Bldg. N232, Collaborative Support Facility) is working with Verdigris Technologies via an Non-Reimbursable Space Act Agreement (NRSAA).**

<u>Technologies offer 3 unique capabilities:</u>

- **An intelligent electrical metering network**
  - AI/ML improves the data quality of each system
  - Verdigris validates load signatures and ensures consistency of end-use load categorization for each building or at scale for a portfolio of buildings.
- **Intelligent HVAC optimization**
  - AI learns building patterns and combines real-time, high-frequency meter data with local weather, utility pricing, and building management system (BMS) data to develop forecasts.
  - Continuously optimize baseline efficiency for the HVAC equipment, and automatically shed or shift loads for demand management.
- **Sensors that can produce 8 kHz signatures which can be used for fault detection and diagnostics of motor signatures.**

Lessons Learned & Opportunities

- **Obstacles**
  - Consistent funding for AI/ML in power applications
  - Identifying the correct project, focus, and personnel

- **Opportunities for Interagency Collaboration**
  - Lunar Surface
    - Microgrid development
      - Power system fault management, power management, reconfiguration
  - Aeronautics
    - UAM / Electrification
      - Power system fault management, digital twins
      - Battery development
        - » Determining battery designs and materials to meet future needs