Power Optimization of Electro-Thermal Systems

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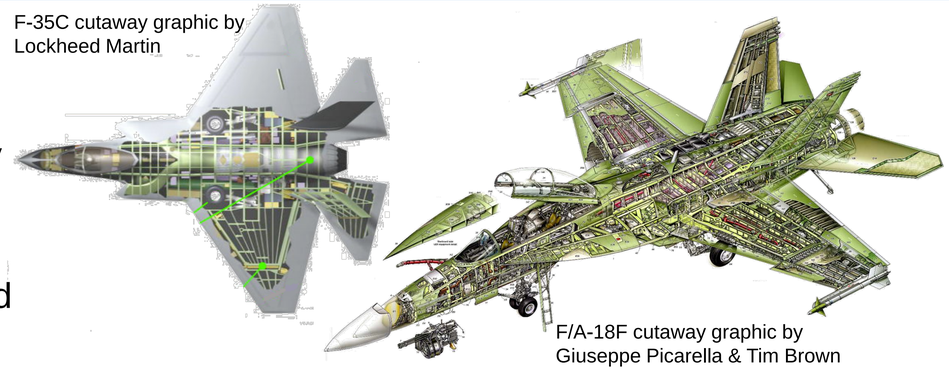
How can modern control techniques and preview be used to improve energy management in constrained systems?

- Modern vehicles are a heterogeneous mix of complex interconnected systems of various energy domains
- Electrification of many systems is resulting in increased power loads and thermal waste heat
- Enhanced optimization of power generation, distribution, storage, and utilization can be achieved using dynamic model-based control to improve performance and efficiency while preventing thermal runaway



Vision: With intelligent decision making the power density of existing electro-thermal systems can be improved by a factor of 2

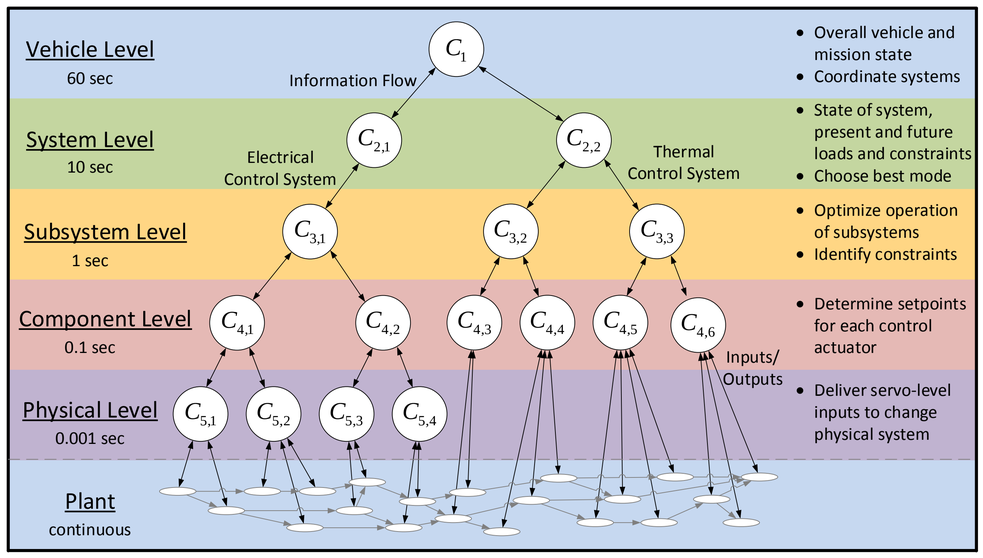
Optimization & Control Methodology

5-Level Control Hierarchy

- Matches the natural hierarchy of many mobile systems
- Handles temporal and functional separation of systems, subsystems, and components

Key Features

- Event-based control updates
- Top-down information flow allows for effective planning of system states
- Bottom-up information flow allows for effective disturbance estimation
- Controllers use robust Model Predictive Control (MPC) or Genetic Algorithms
- Higher-level controllers
  - Plan an efficient path using large prediction horizons
  - Select mode of operation for lower-level controllers
- Lower-level controllers employ fast optimization (i.e. Explicit MPC)



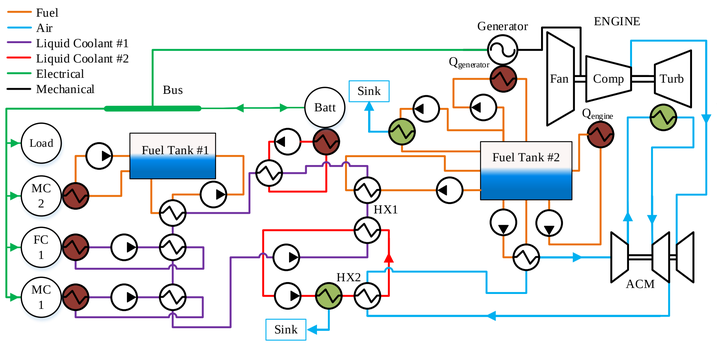
Main Results

Controller Development

- Select candidate architecture
- Represent the architecture as a directed graph by analyzing how power flows through the system
- Partition graph based upon time constants
- Partition graph into various systems & subsystems based upon functional purposes
- Develop individual controllers and determine information flow

Candidate Architecture

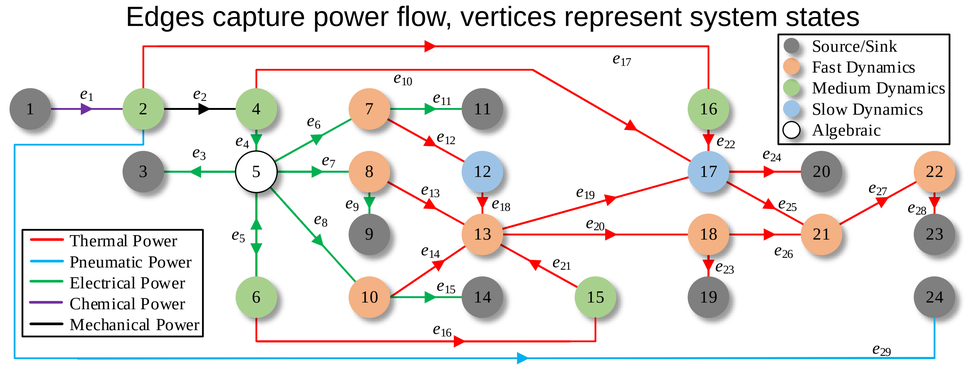
Aircraft electrical, thermal, and engine systems



Applying a graph based modeling approach

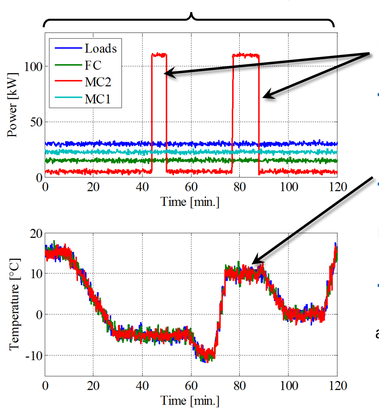
Graph Model of Candidate Architecture

Edges capture power flow, vertices represent system states



System Disturbances

Electrical Loads & Thermal Sink Temperatures



Large electrical loads resulting in significant heat loads

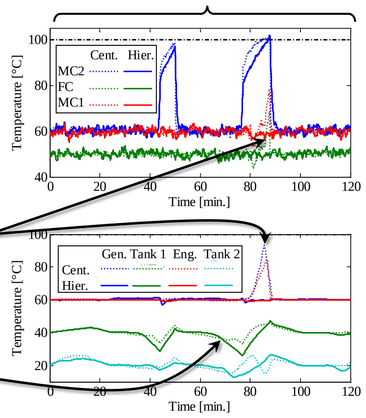
Poor thermal sink availability means heat cannot be easily removed from the system

Hierarchical control performs better than centralized during stressful events

Hierarchical control can take anticipatory action well before centralized control, while utilizing similar amounts of computational resources

System States

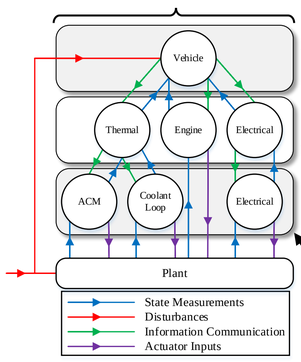
Electrical & Aircraft System Temperatures



Preliminary Results

Control Hierarchy

Vehicle, System, & Subsystem Levels



Vehicle:
Determines state trajectories for slow time scale dynamics and sends those commands to system level controllers. Has some knowledge of disturbances.

System:
Tracks vehicle level commands and determines state trajectories for medium time scale dynamics which are passed to subsystem level controllers.

Subsystem:
Tracks system level commands and determines state trajectories for fast time scale dynamics. Also measures plant states and communicates that information up through the hierarchy.

Developing controllers within the hierarchy

Graph partitioning