United Technologies Research Center

System Co-design through Co-Simulation

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ARPA-E Co-design Workshop
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Be Curious℠

UTRC is UTC's innovation engine

Defining what's next:

Define new frontiers

Co-develop new technologies

Solve tough problems

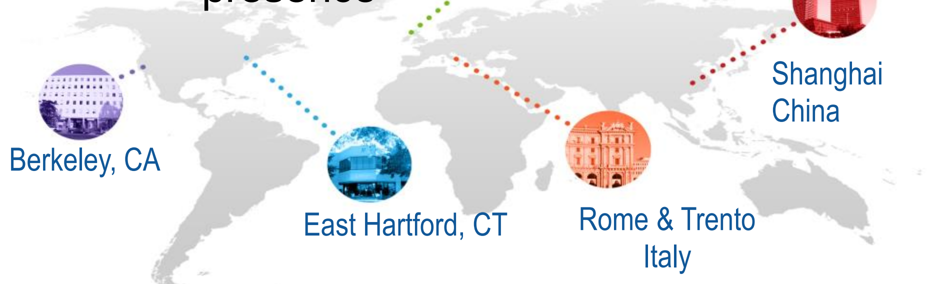
Serve as hub for technical interchange

Leverage global network of innovation

Monetize UTC intellectual property

United Technologies Research Center

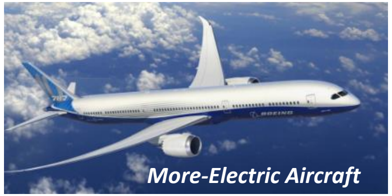
A global presence



Global collaborations

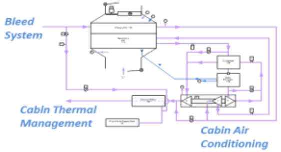
Concurrent System Design – Motivating Example

High performance, next generation systems require increased integration and adaptiveness

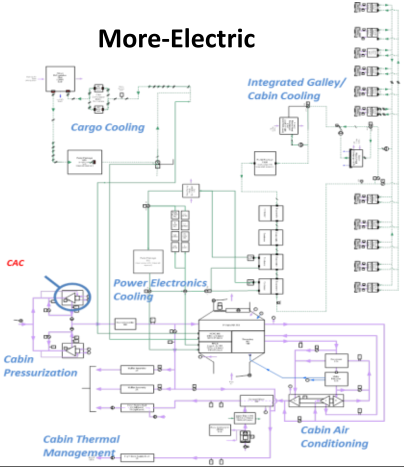


Industry-leading fuel burn achieved through highly integrated and adaptive power and thermal management

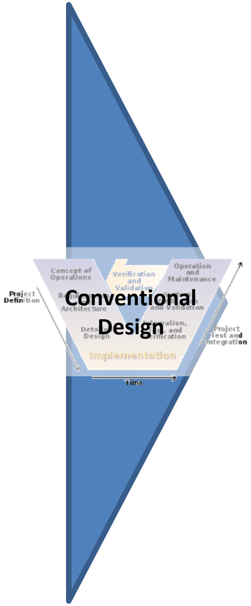
Conventional



More-Electric



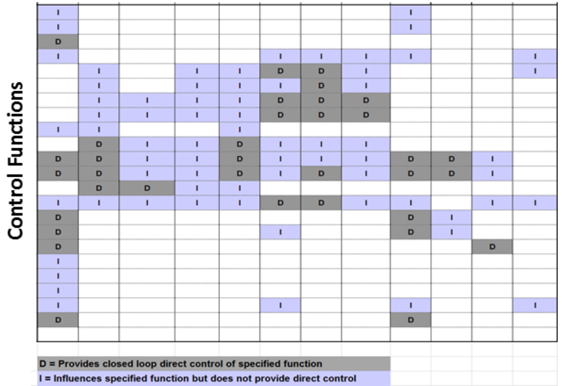
Metric	Conventional	More-Electric
Control Loops	~5	~40
Lines of Code	200k	600k



Control Interdependency Matrix

(1 subsystem shown)

Control Actuators



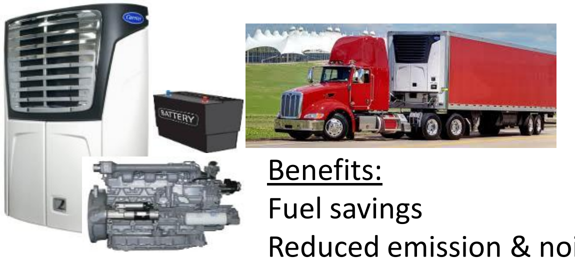
Outcome: Fundamental controllability issues
Late learning & engineering changes
Hardware over-specification

Lesson Learned*:*

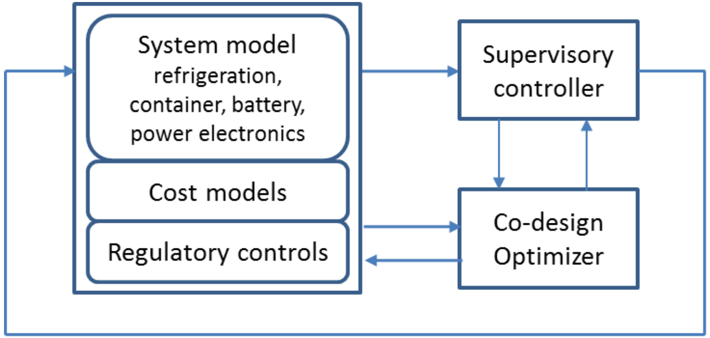
Cannot assess value of new architectures without early consideration of performance, robustness, & controls

System and Supervisory Control Co-design

Hybrid refrigeration for Truck/Trailer

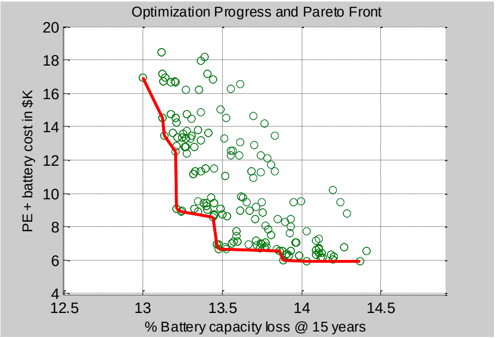


Benefits:
Fuel savings
Reduced emission & noise
Reduced food waste



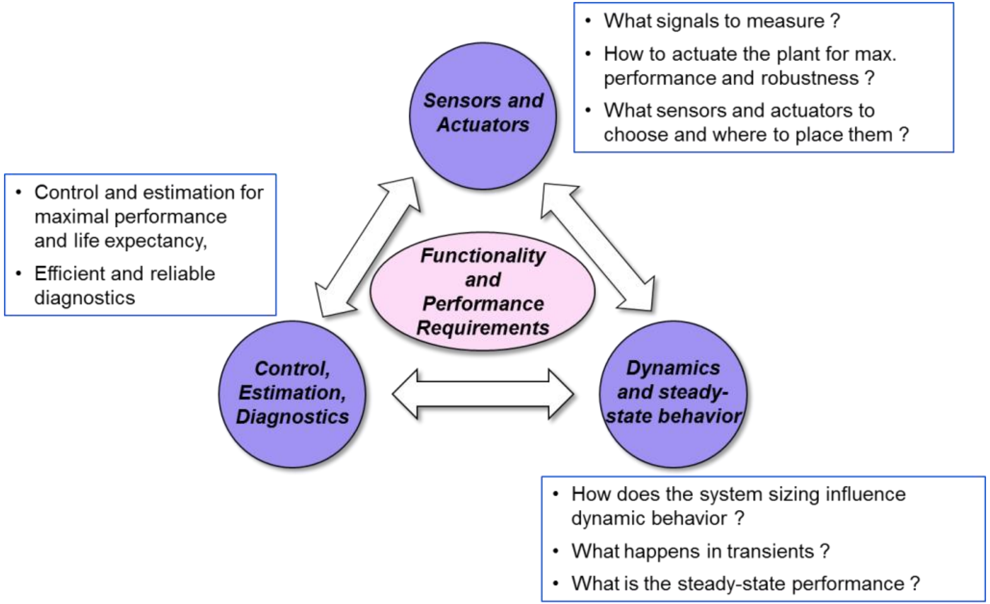
Simulation-based design - Bayesian optimization based on Gaussian process

- Design output: Battery size, voltage, control set-points, parameters and limits
- Multi-objective optimization
  1. Cost (Battery +Power electronics)
  2. Battery capacity loss
- System-level constraints
  1. Maintain cargo temperature:
  2. One hour autonomous battery operation
  3. At least 15 years of battery life
- Variabilities – cooling load, usage
- Model uncertainties



Co-design: Sensors, Actuators and Control

Synergetic system design for maximal achievable performance



Optimal dynamics and control co-design based on numerical optimal control.

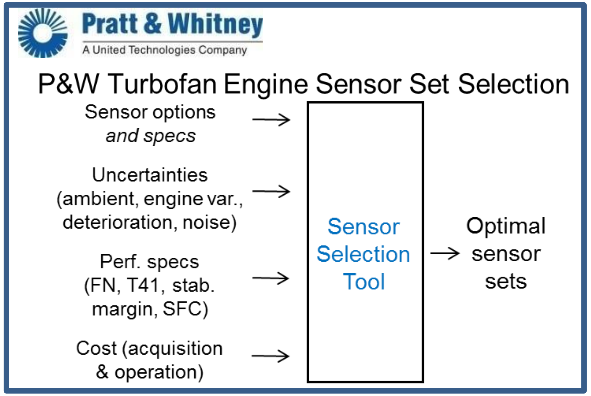
Control objective

Design objective

$$\min_{u,\theta} \; T + \int_0^T \left(\mathbb{U}(x,u,\theta) + \mathbb{E}(x,u,\theta) \right) dt,$$

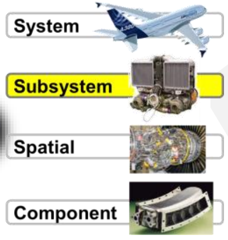
$$\begin{aligned} \text{subj. to} \quad & \dot{x} = f(x,u;\theta), \\ & x(0) = x_0 \;\; x(T) = x_T, \\ & \theta \in \Theta. \end{aligned}$$

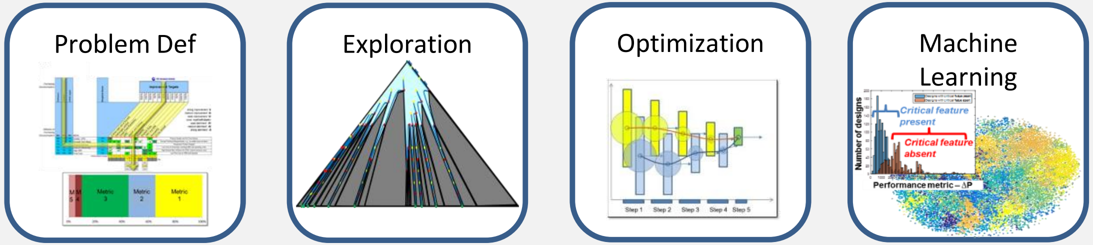
Case Studies: *Helicopter Maneuver Optimization,*



DISCOVER: Computational Intelligence for System Design

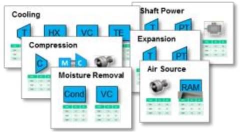
Automated exploration and evaluation of system (plant & control) architectures

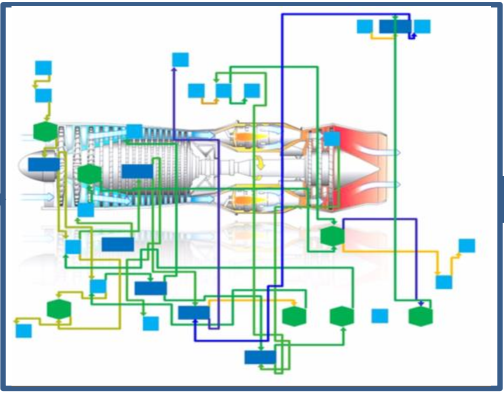




Inputs

- Requirements
- System-level metrics
- Technology options
- Flow types
- Mission segments
- Composition rules





U.S. AIR FORCE

UTC Aerospace Systems
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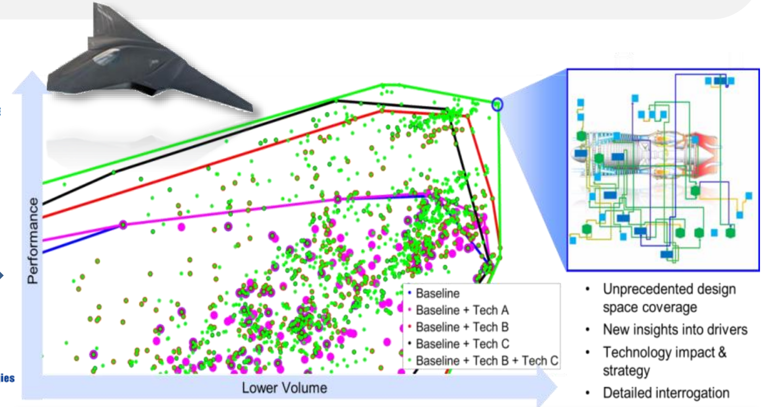


- Unprecedented design space coverage
- New insights into drivers
- Technology impact & strategy
- Detailed interrogation

Improvements: 5X Performance, 2X Volume, >15X Cycle Time

DISCOVER: Computational Intelligence for System Design

Model-Based Exploration of Safety (FHA), Protective Controls, and Reconfigurability

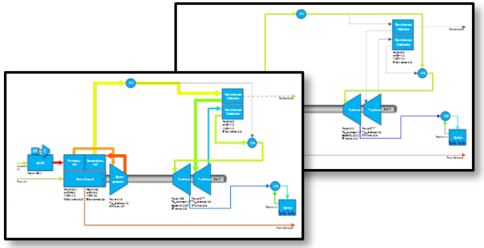
Discrete Supervisory Control Exploration

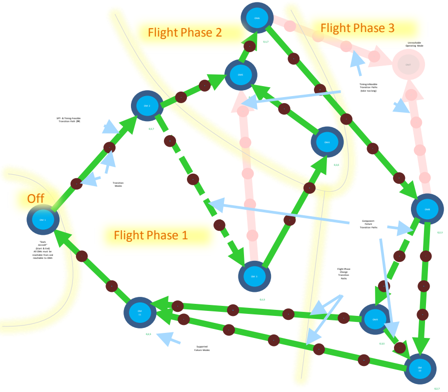
Compliance by Construction
Generates only safety-compliant system architectures

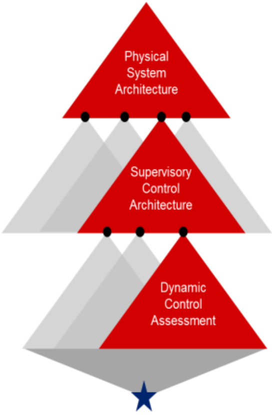
Source Priorities
Finds all Operating Modes and the Transition Paths between them

Architecture = Union(OMs)
Builds Operating Mode Graph, spanning all of the mission's flight phases.

Reconfigurability: Operating Modes



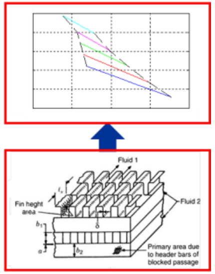




Dynamic Controls Assessment

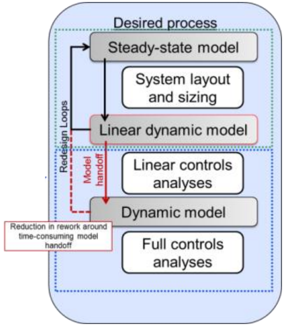
Simple HX Parameters
Hotside map parameter
Coldside map parameter
Height ratio (hot to cold)

Detailed HX Parameters
Hotside fin type
Hotside fin thickness
Hotside fin height
Hotside fpi
Coldside fin type
Coldside fin thickness
Coldside fin height
Coldside fpi



Off-Design
Models need to capable of sizing, off-design performance, and dynamics

Dynamics
Auto generation of piecewise-defined linear dynamic models



Linear Model & Dynamic RGA