Tools and Technology Development for Distributed Engine Control

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NASA Glenn Research Center

Propulsion Control and Diagnostics Workshop
Ohio Aerospace Institute
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Distributed Engine Control Agenda

Time	Topic	Presenter
3:45	Tools and technology Development for Distributed Engine Control	Dennis Culley
4:05	Decentralized Engine Control Simulation System (DECSS)	Oran (Bud) Watts
4:30	Working with High Temperature Electronics: Reapplying a Lost Art	Mike Krasowski
4:55	Silicon Carbide Electronics – Update and Prognosis	Glenn Beheim
5:20	Open Discussion	all

Subsonic Fixed Wing (SFW)
Efficient Power and Propulsion (EPP)

EPP Objective:
Create, advance, and validate technologies and engine component performance prediction tools that will reduce thrust specific energy consumption and contribute to the performance metrics of N+3 vehicle concepts.

Distributed Engine Control (DEC) Technology helps achieve these objectives by creating and advancing the control system *hardware* technology to overcome engine system constraints which prevent the acceptance or optimization of many new engine technologies.

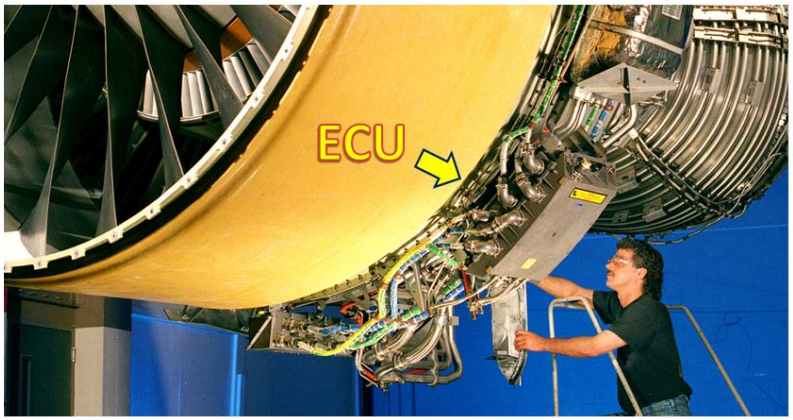
DEC Objectives:

- Create a sustainable high temperature electronics infrastructure which will allow *growth and integration* of new control system technologies thus enabling a pathway to new engine technologies consistent with EPP goals.
- Create new tools which advance and help validate *soft and hard* control technologies which improve vehicle performance metrics and reduce specific energy consumption.

The Turbine Engine Control System Conundrum

- Future engine systems will use as much computational power as they can afford in order to improve system performance, reliability, and safety.

Fan Case Mounted - Air Cooled



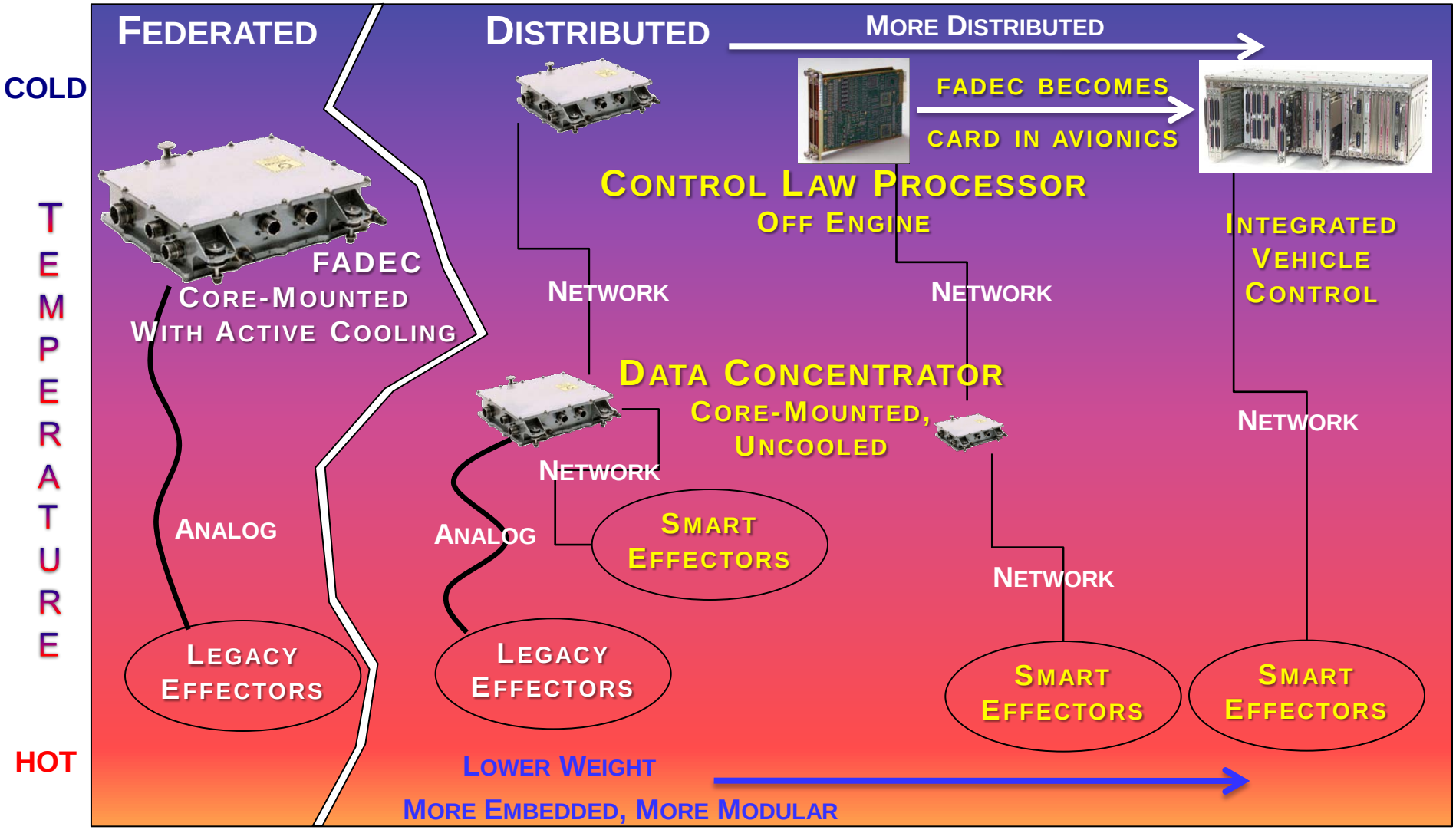
Public Release Photo Courtesy of Pratt & Whitney

Core Mounted - Fuel Cooled

Public Release Photo Courtesy of Pratt & Whitney

- Computational power is almost exclusively a commercial product intended for commercial applications.
- The engine system is one of the most extreme environments for electronics.
- Many engine system performance improvements result in further constraints on engine control system deployment.

Solution: A Break with the Past



The Evolution of Engine Control Architecture

DEC Task: A Multi-Pronged Strategy

Near Term Path >>> Revolutionary

Identify and overcome the significant barriers to technology.

1. Create a sustainable infrastructure for embedded high temperature electronics
   - Work within DECWG to *leverage efforts and expertise*
2. Develop tools to aid design, analysis, and optimization of control systems
   - Extend modeling and simulation tools to include Hardware-in-the-Loop
   - Develop new analysis tools to quantify benefits and optimize performance
   - Assist the development of new smart control effectors

Long Term Path >>> Evolutionary

Extend capabilities to continually improve engine performance and safety

3. Develop high temperature electronics technology to extend the reach and functional capability of embedded electronics above 300 ^{o}C
   - Develop practical Silicon Carbide circuits
   - Develop reliable Silicon Carbide components and packaging

Distributed Engine Control Working Group DECWG

Vision:

*Deliver **affordable** distributed engine controls for dual use gas turbine and aerospace vehicle applications that are environmentally robust, are scalable, provide lower life cycle cost, mitigate obsolescence, reduce weight, support advanced control algorithms, and create an '**eco-system**' that sustains future engine control infrastructure.*

Objectives:

- **To provide a forum** for the US government and aerospace industry to collaborate, in a pre-competitive environment, on the advancement of technologies required to implement distributed controls in aerospace propulsion systems.
- **To align the efforts** of the US government and private industry, both large and small businesses, to provide the technical skills and funding required to design, build and test representative hardware required for these systems.
- **To develop and demonstrate** fundamental high temperature electronics that are required to implement affordable distributed control systems.

NASA SBIR/STTR Technologies

A2.07-8712 Data Concentrator for Modular and Distributed Control of Propulsion Systems

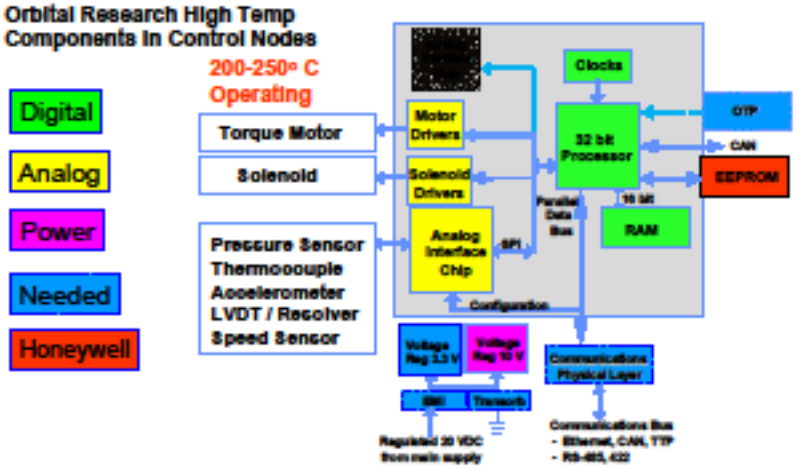
PI: Mike Willett

Orbital Research Inc. -Cleveland Oh

Identification and Significance of Innovation

Orbital Research Inc. proposes in this NASA Phase I/Phase II SBIR project to design, develop, and test a High Temperature (HT) Data Concentrator that will, for the first time, enable the implementation of a modular and flexible distributed control architecture for next generation turbine engines. Orbital will accomplish this significant advance by integrating existing and developmental application specific integrated circuits (ASICs) into a functional high-temperature (200-225°C continuous operation) module ready for high temperature testing

Orbital Research High Temp Components In Control Nodes



Expected TRL Range at the end of Contract (1-9): Phase I - TRL 3

Technical Objectives

- Develop Detailed Specification for the Data Concentrator
- Define Requirements for the OTP, Transorb, and Protocol Driver
- Prepare Documentation and Chip Designs for Phase II

Work Plan

Task 1. Create Specifications for Data Concentrator
Task 2. Design HT Transzorb
Task 3. Design High Temperature OTP
Task 4. Analyze Protocol Options
Task 5. Data and Program Management

NASA Applications

Ground testing of rocket engines; Ground testing of turbine engines (including VAATE); Sensor webs and distributed sensors (non-engine); Highly reconfigurable sensors

Non-NASA Applications

Next generation military and civilian aircraft turbine engines, including rotorcraft, UAS, and land vehicles (very large market potential); Down-hole drilling and geothermal drilling controls; Prognostic Health Management (PHM)/Integrated System Health Management (ISHM); Chemical, nuclear, refinery, and process plant instrumentation;
Powertrain controls for internal combustion engines, gas or diesel.

Contacts

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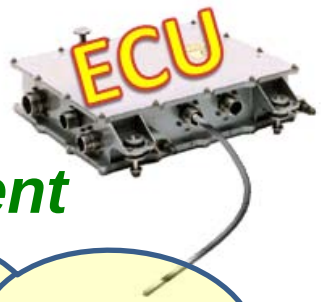
Mr. Dennis Culley COTR, NASA GRC RHC0

NON-PROPRIETARY DATA

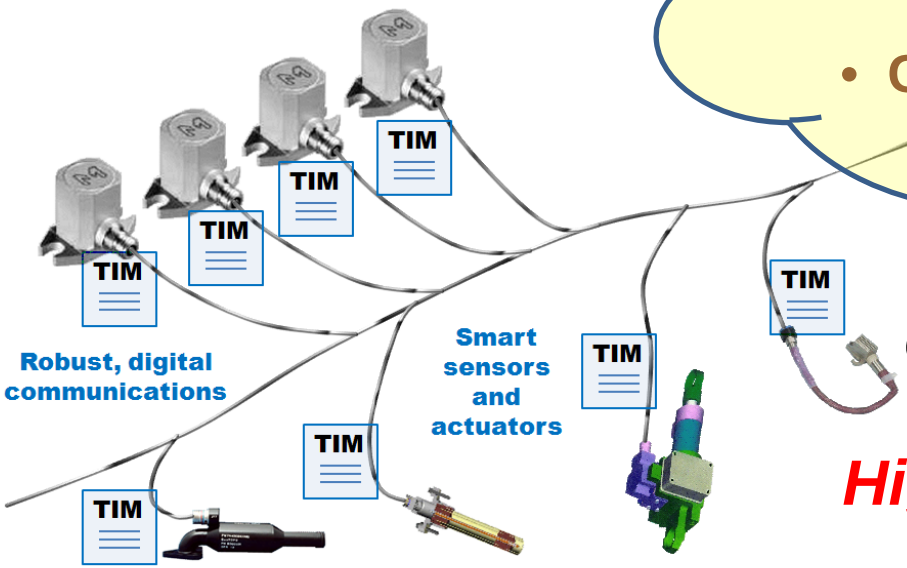
Developing a New Capability Skill Set

Modular
Flexible
Scalable
Architecture

Processing-Intensive functions are
Location Independent



- **Engine System Performance**
- **Control System Design**
- **System Integration**
  - **Controls to Engine**
  - **Engine to Airframe**
- **Certification**
  - **Verification and Validation**



Control Effector functions are
Location Dependent and
High Temperature Capable

NASA Focus Area

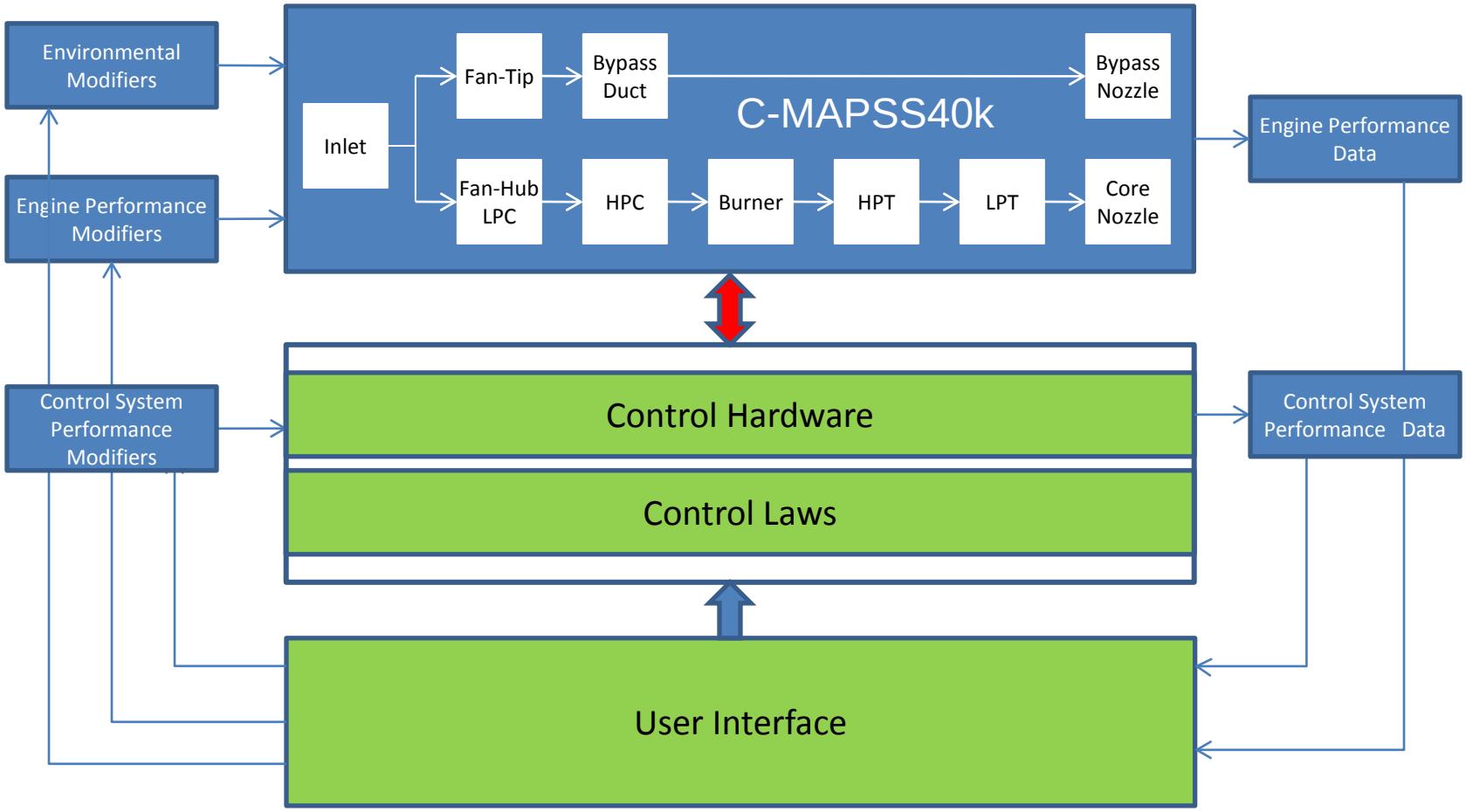
The **NASA** focus for distributed engine control is primarily in the area of **tools and technology** development. Funding is provided through the ***Fundamental Aeronautics Program, Subsonic Fixed Wing Project***

Primary Objective:

A ***Common Environment*** for continuous collaboration among government, industry, small business and academia

- Develop a focal point to integrate the various areas of NASA's control system research portfolio – model based control, adaptive control, prognostics, and diagnostics
- Couple control system research with NASA's research in high temperature instrumentation, wireless, and silicon carbide electronics
- Participate in solving problems for the practical application of controls including design, analysis, integration, and certification
- Innovate for the long-term development of controls by encouraging collaboration and protecting intellectual property

Hardware-in-the-Loop Common Environment



Hardware-in-the-Loop

Goals:

- Develop a modular, open system tool which can be extended over time
- Provide for inclusion of engine simulations beyond C-MAPSS40k
- Function in real-time or faster than real-time depending on configuration
- Incorporate capabilities to design and analyze control system architectures in simulation and then extend into HIL within the same environment, as hardware is developed and made available

Purpose:

- Become a critical tool in the requirements development of distributed systems
- Become a method of analyzing and demonstrating system level benefits
- Become a method of distributing requirements to collaborators
- Perform preliminary verification and validation of control components
- Extend the concept of *controls* to the integrated vehicle system level
- Enable low risk participation by protecting Intellectual Property

NASA SBIR/STTR Technologies

Distributed Engine Control Empirical / Analytical Verification Tools

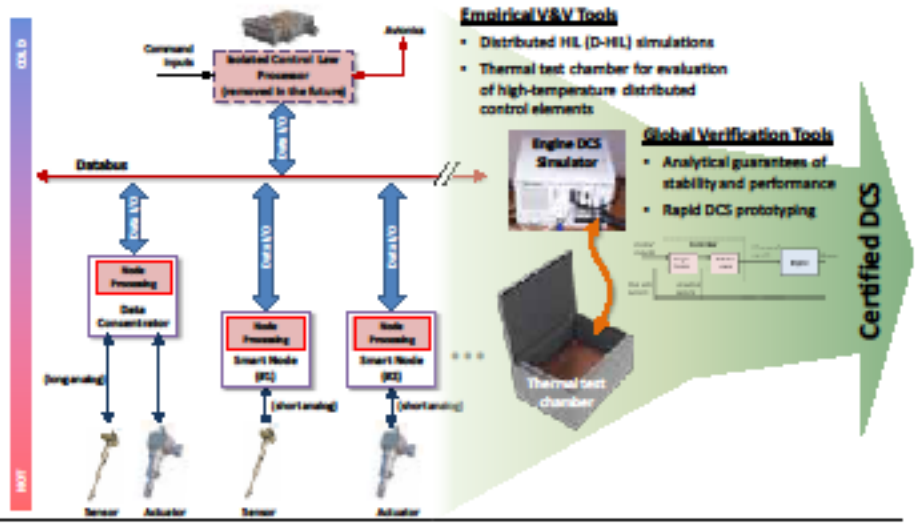
PI: Jonathan DeCastro/ Impact Technologies, LLC. Rochester, NY

Proposal No. A2.07-9372

Identification and Significance of Innovation

Impact Technologies, in collaboration with Prof. R.K. Yedavalli, propose a novel verification environment for eventual rapid certification of distributed engine control systems such as new high-temperature components and control laws. The proposed D-HIL simulator will feature a thermal test chamber capable of subjecting components to harsh engine environments, while functioning as elements in the networked control loop. To verify engine control software, a Global Verification Toolset (GVT) is proposed to assess stability and performance of the assembled distributed engine control system.

Expected TRL at beginning and end of contract (1-9):
Begin: 2; End: 3 to 4



Technical Objectives and Work Plan

Objective: Develop a distributed HIL facility and an associated set of Global Verification Tools useful for certification.

Months 1-2: Configure C-MAPSS real-time engine simulator
Months 2-5: Develop the Distributed HIL simulation and design and fabricate the thermal test chamber
Months 1-5: Develop the Global Verification Toolset
Months 4-5: Develop user interface for the hardware/software toolsets
Months 5-6: Final demonstration and commercial/government transition planning

At the conclusion of Phase I, the new verification facility and software tools will be demonstrated in a system test using the C-MAPSS engine.

NASA and Non-NASA Applications

The proposed tools will enable the development of distributed aircraft propulsion control systems and flight control avionic systems. The verification toolset will also benefit fly-by-wire systems and the automotive, energy, and manufacturing industries. Impact Technologies will position the hardware simulator for inclusion in future planned NASA/DoD-led Distributed Engine Control demonstrations.

Firm Contacts

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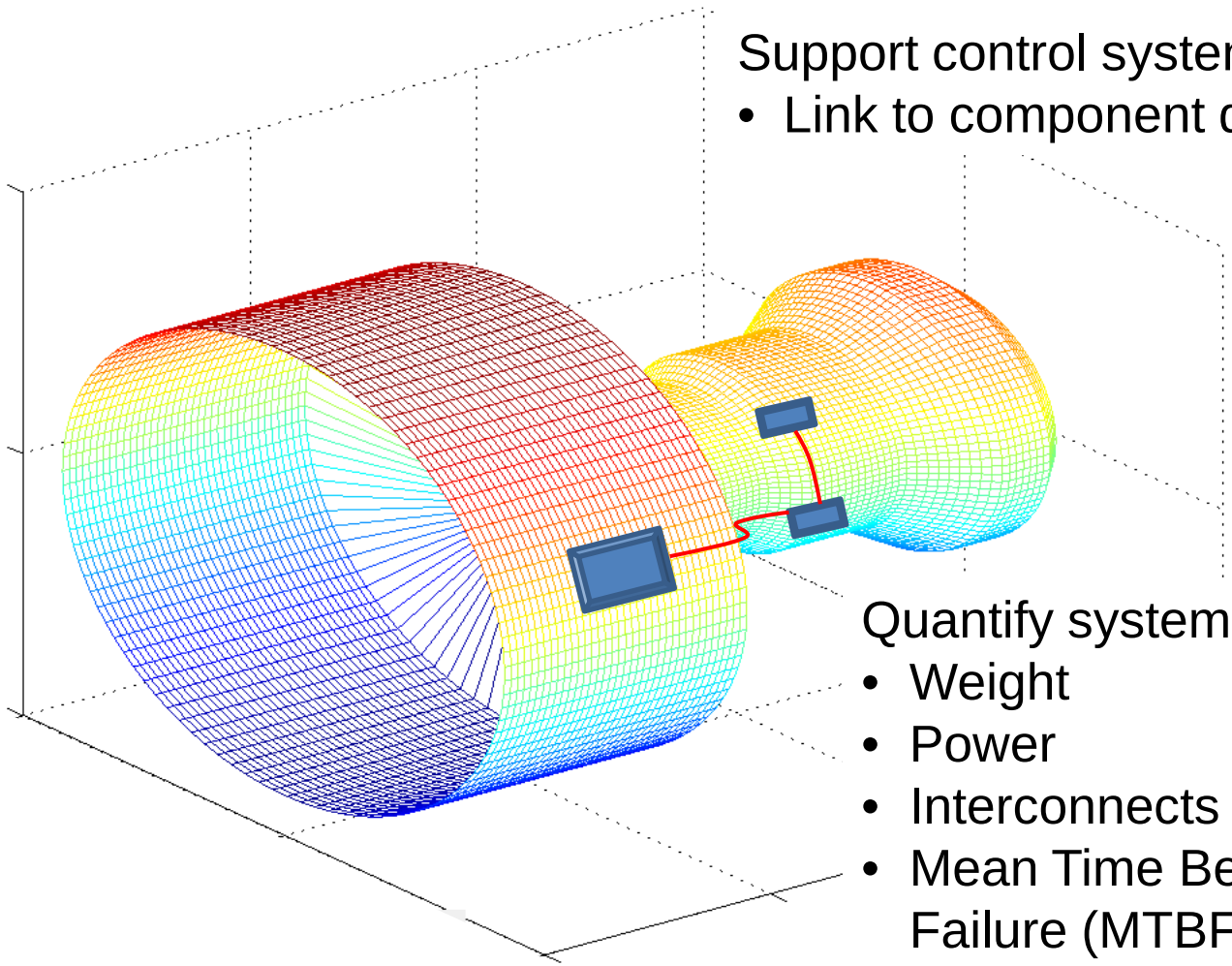
NON-PROPRIETARY DATA

Benefit Analysis Tools

Common Environment Add-Ons



Support control system trade studies

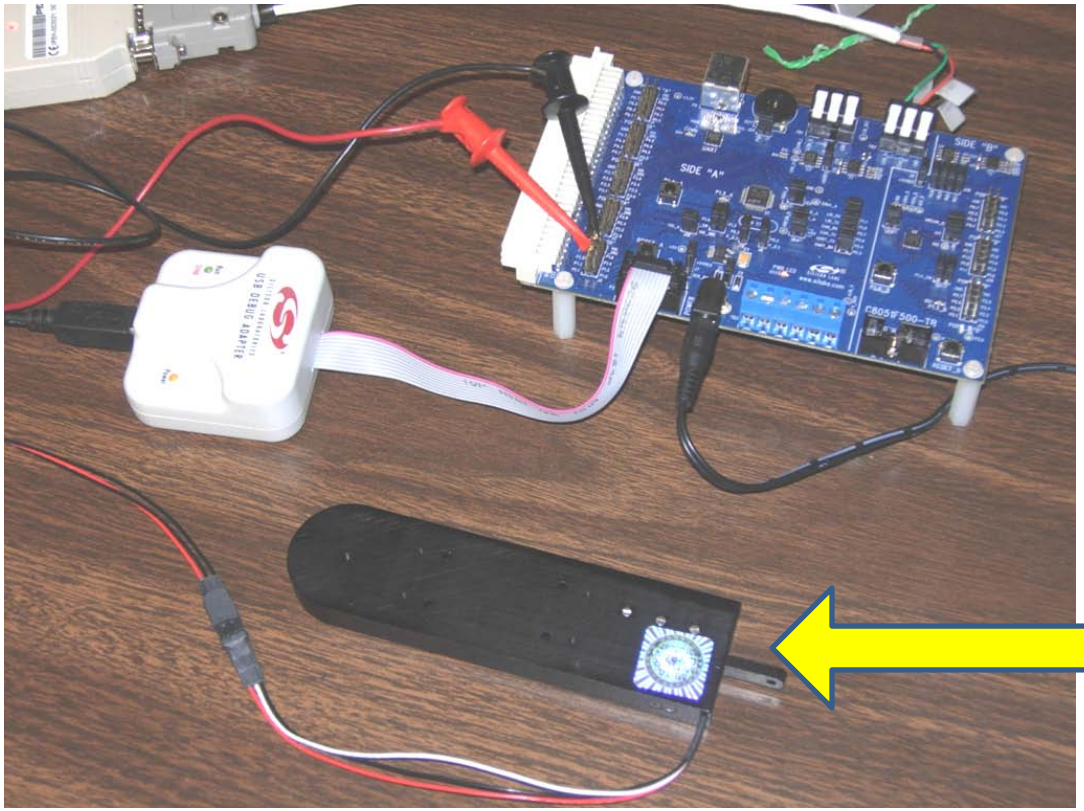
- Link to component design libraries

Quantify system metrics

- Weight
- Power
- Interconnects
- Mean Time Between Failure (MTBF)

Smart Component Development

Common Environment Add-Ons



High Temperature Shape Memory Alloy (SMA) Actuator with Smart Interface

- SMA material developed at NASA GRC
- Actuator developed at MIGA Motors under NASA SBIR

Develop an intelligent actuator with integral feedback

- SMA alloy to function as actuator and sensor
- Minimize actuator power by sensing material mode change

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