Distributed Engine Control

NASA Fundamental Aeronautics Program
Subsonic Fixed Wing Project

Glenn Research Center
Controls & Dynamics Branch

2009 Propulsion Controls and Diagnostics Workshop
December 8-10, 2009

DEC Session Agenda

10:15 am
Distributed Engine Control Task
Overview and Implementation Roadmap

10:45 am
SiC High Temperature Electronics:
Concepts and Development Timeline

11:30 am
Proposed 5 Year plan:
System Benefits and Implementation Challenges

1:45 pm to 3:45 pm
Distributed Engine Control Breakout Session

Distributed Engine Control
Overview and Implementation Roadmap

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Outline

- Overview of Distributed Engine Control
- Subsonic Fixed Wing Project Objectives
- Technology Roadmap
- Technical Challenges and Approach
- Industry Partnerships

Gas Turbine Engine Controls

- Engine control systems have followed a series of evolutionary / revolutionary development steps based on system requirements and constraints.
  - Prior to 1970: Evolution of Hydromechanical Control
  - 1970 to 1990: Evolution of Electronic / Hydromechanical Control
  - After 1990: Evolution of Full Authority Digital Engine Control (FADEC)
- Present day drivers and constraints (*simply stated*) compelling the next revolutionary step
  - A need for more control and processing capability requiring additional volume, weight, and heat dissipation.
  - More efficient engines resulting in less available mounting envelop and a hotter environment with less capacity to reject heat.

Control systems typically account for 15 - 30% of engine system weight and cost and pace engine system development

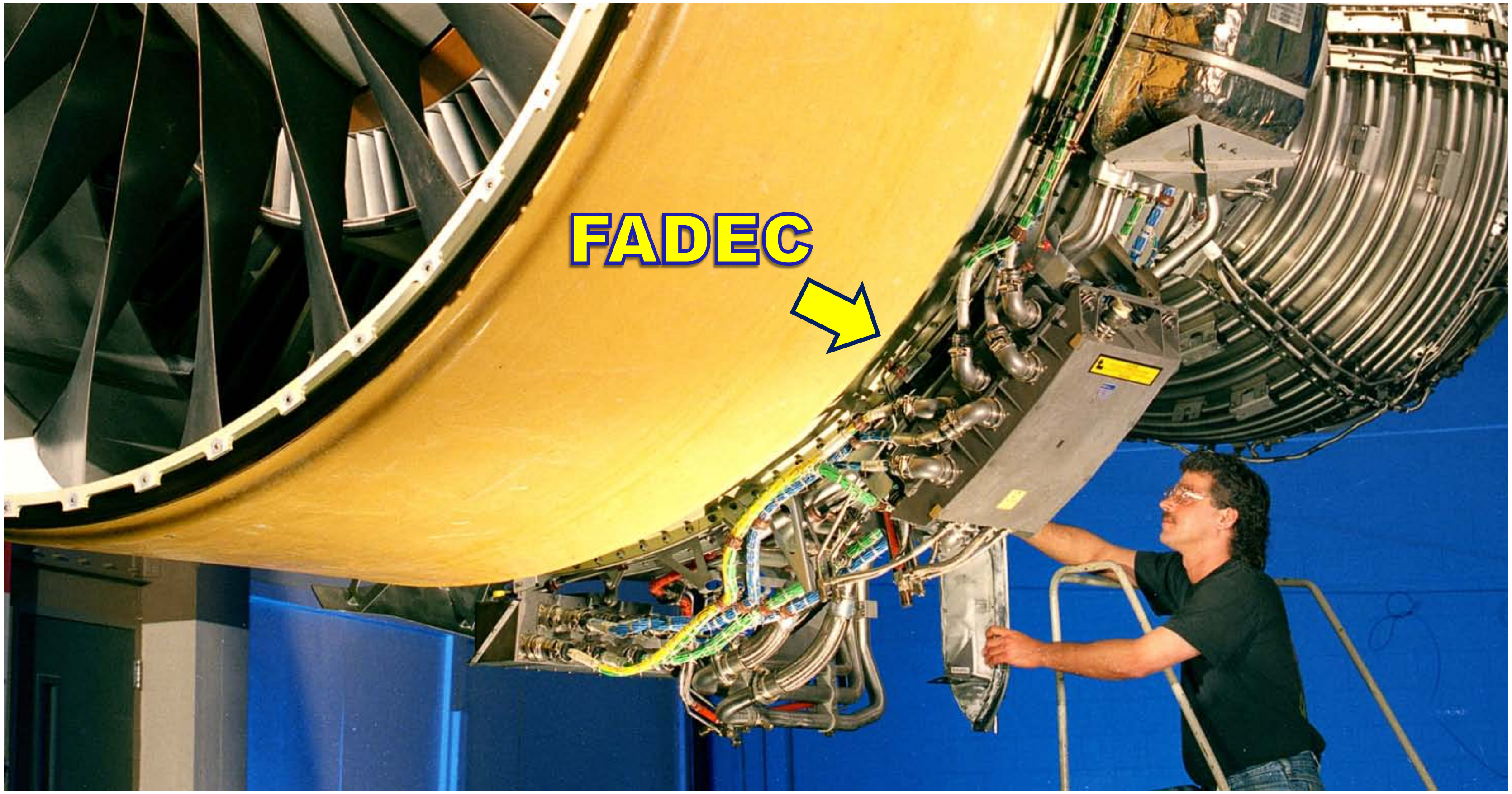
Gas Turbine Engine Controls

More About Drivers …

- Future engine control technologies, such as combustion control, flow control, stability control, etc., are expected to be ***high bandwidth*** technologies which can overwhelm typical FADEC control intervals.
- Engine control laws are highly complex, requiring increasingly large processing burdens, and a reliance on ***commercial*** state-of-the-art processing electronics.
- Propulsion Health Monitoring requirements are expected to significantly increase the data processing needs in the FADEC.

Commercial Implementation

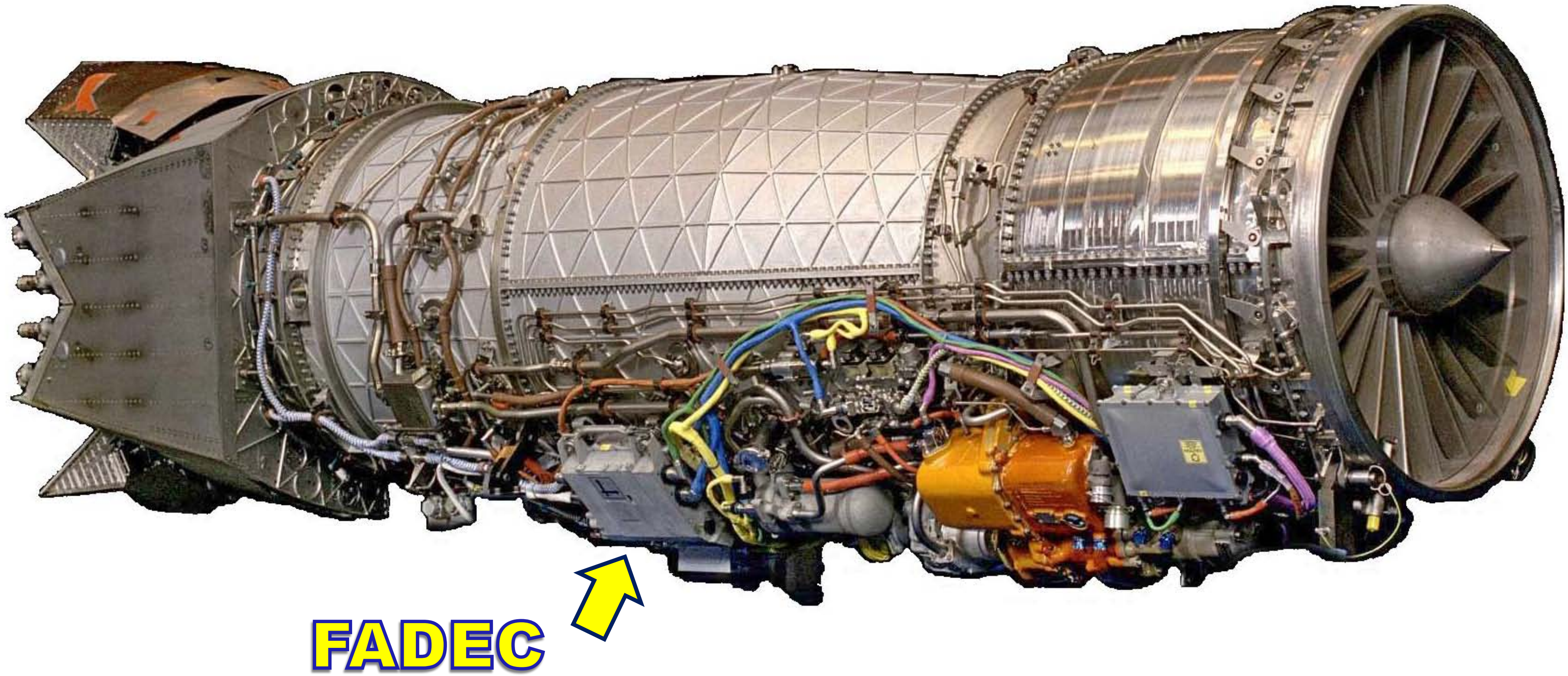
Fan Case Mounted - Air Cooled



Public Release Photo Courtesy of Pratt & Whitney

Military Implementation

Core Mounted - Fuel Cooled



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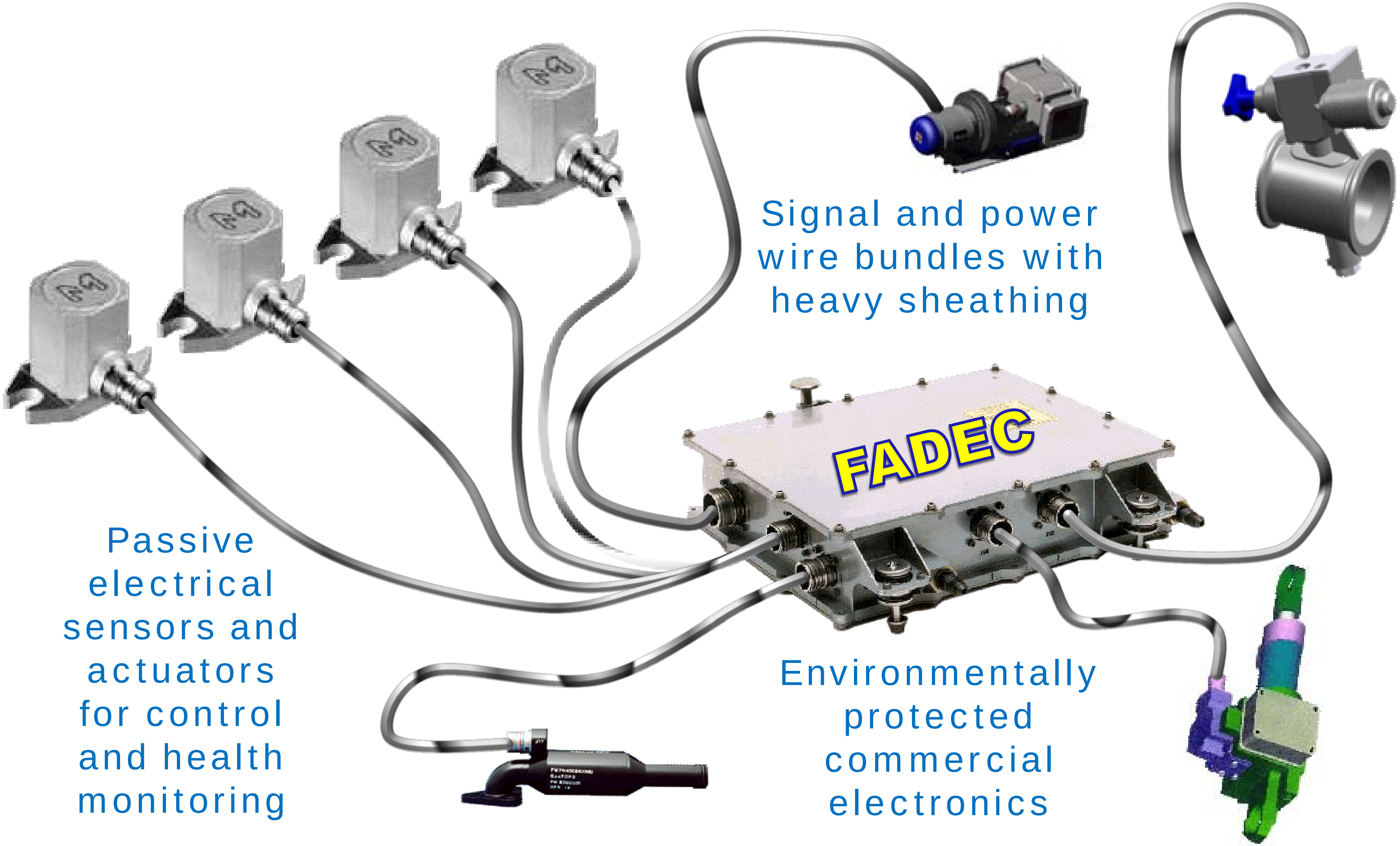
Centralized Control Architecture



NASA Subsonic Transport System Level Metrics

.... technology for dramatically improving noise, emissions, & performance

CORNERS OF THE TRADE SPACE	N+1 (2015)*** Technology Benefits Relative to a Single Aisle Reference Configuration	N+2 (2020)*** Technology Benefits Relative to a Large Twin Aisle Reference Configuration	N+3 (2025)*** Technology Benefits
Noise (cum below Stage 4)	-32 dB	-42 dB	-71 dB
LTO NOx Emissions (below CAEP 6)	-60%	-75%	better than -75%
Performance: Aircraft Fuel Burn	-33%**	-40%**	better than -70%
Performance: Field Length	-33%	-50%	exploit metroplex* concepts

*** Technology Readiness Level for Key technologies =4-6
** Additional gains may be possible through operational improvements
* Concepts that enable optimal use of runways at multiple airports within the metropolitan areas

Enabled with control | constrains control

SFW Approach

- *Conduct Discipline-based Foundational Research*
- *Investigate Advanced Multi-Discipline Based Concepts and Technologies*
- *Reduce Uncertainty in Multi-Disciplinary Design and Analysis Tools and Processes*
- *Enable Major Changes in Engine Cycle/Airframe Configurations*

Propulsion Controls – SFW Objectives

Provide Critical Path Technology for Extremely Efficient Engines (UHB):

- *Combustion Control* - lower emissions
- *Flow Control* - improved aerothermodynamic efficiency, fuel burn
- *Stability Control* - lower weight, field length

Achieve Additional Control System Enhancements Supporting SFW Goals:

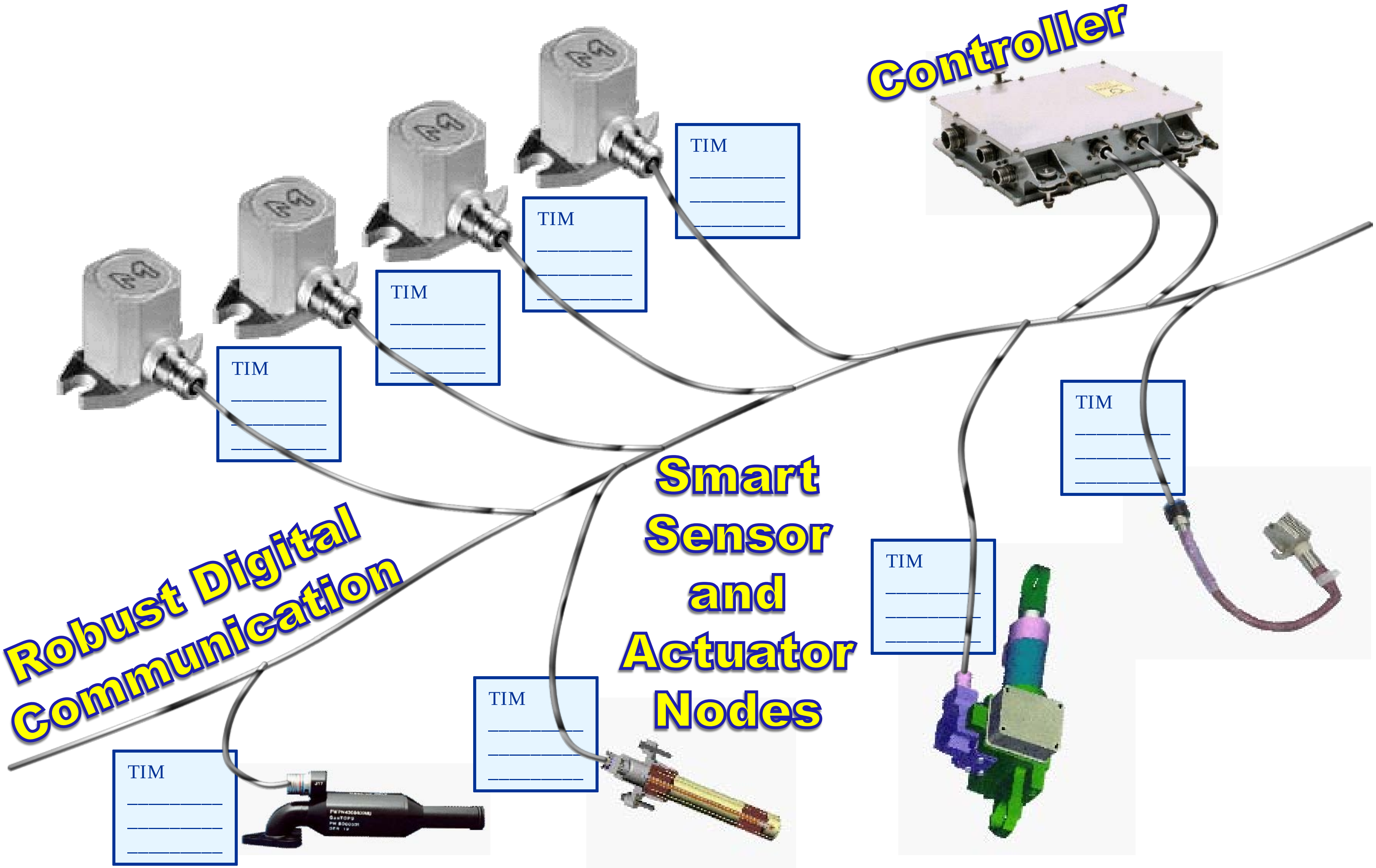
- Directly reduce engine weight (e.g., reduce harness weight)
- Improve propulsion responsiveness (e.g., local control loop closure)
- Increase system performance (e.g., adaptive / intelligent control)

Complement ARMD Objectives:

- Improved vehicle performance by enabling highly integrated propulsion/airframe control – e.g., asymmetric thrust balancing

Enabled by
Transition to Modular, Distributed, and Embedded Functionality

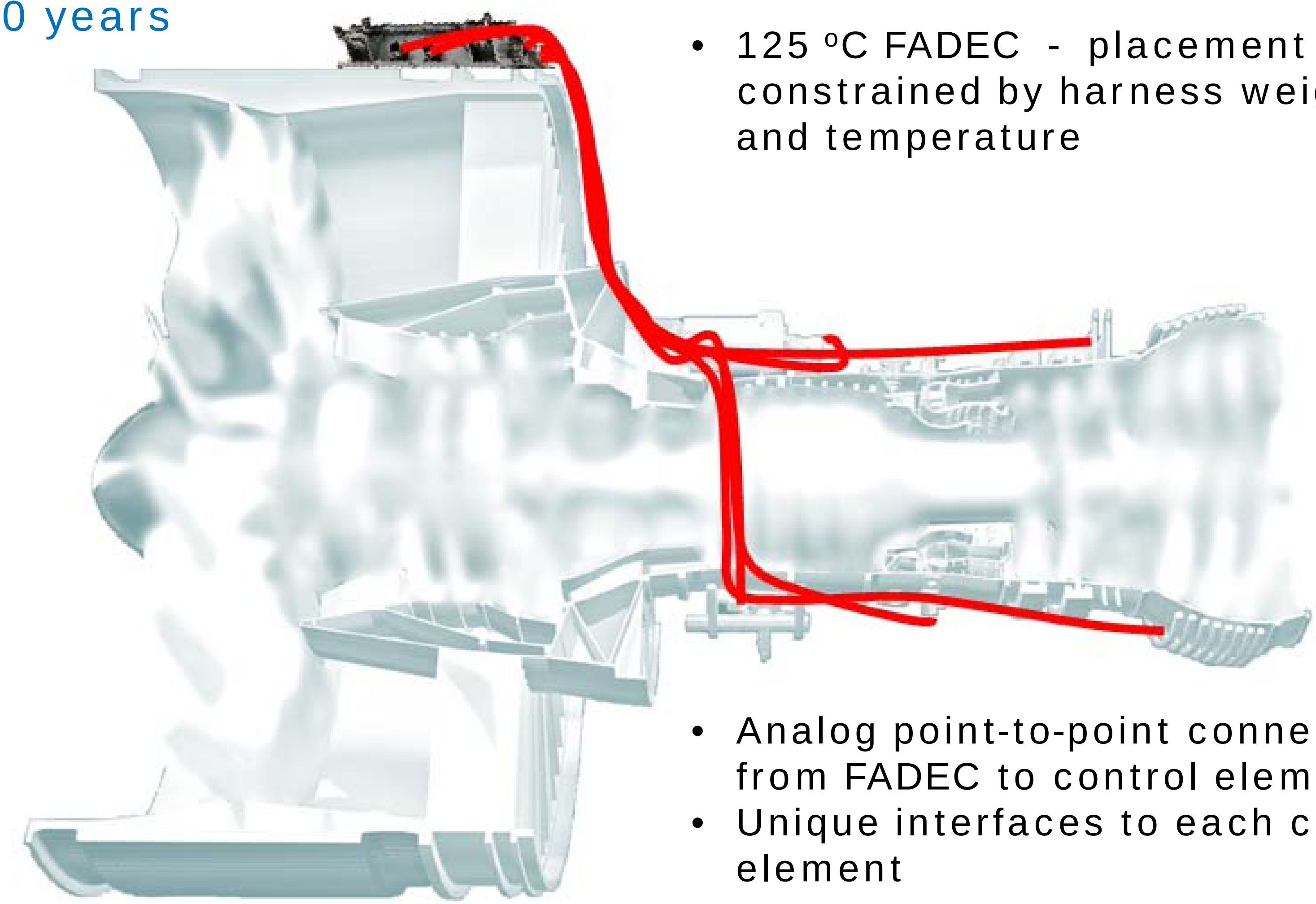
Distributed Control Architecture



TIM – Transducer Interface Module – embedded software specific to each smart device

Transition from Centralized Architecture

T = 0 years



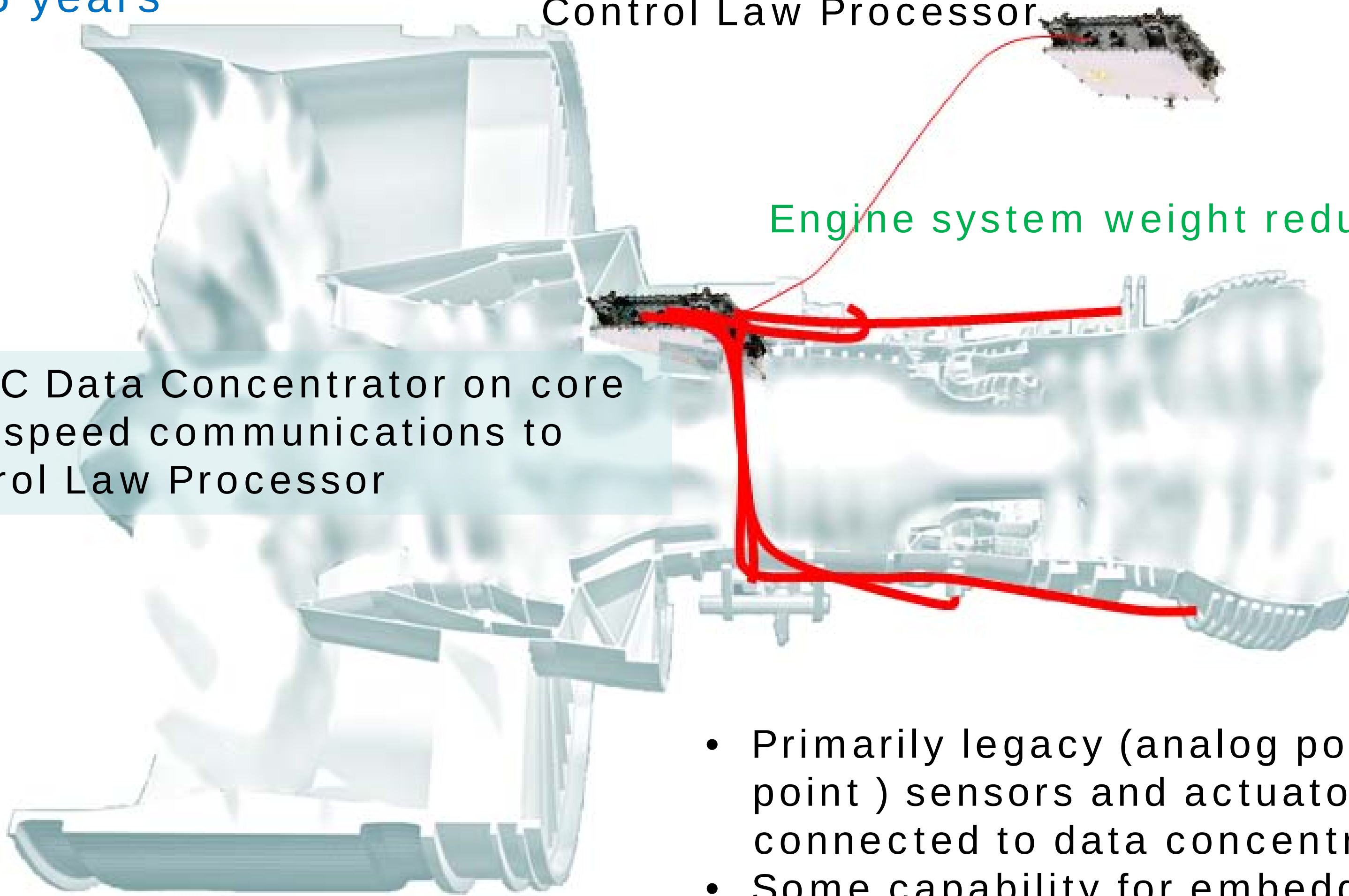
- 125 ^{o}C FADEC - placement constrained by harness weight and temperature
- Analog point-to-point connections from FADEC to control elements
- Unique interfaces to each control element

Transition to Networked FADEC Architecture

… reduced fuel burn

T = 5 years
N+1

- Small, unconstrained 125 ^{o}C Control Law Processor



Engine system weight reduction

- 225 ^{o}C Data Concentrator on core
- High speed communications to Control Law Processor

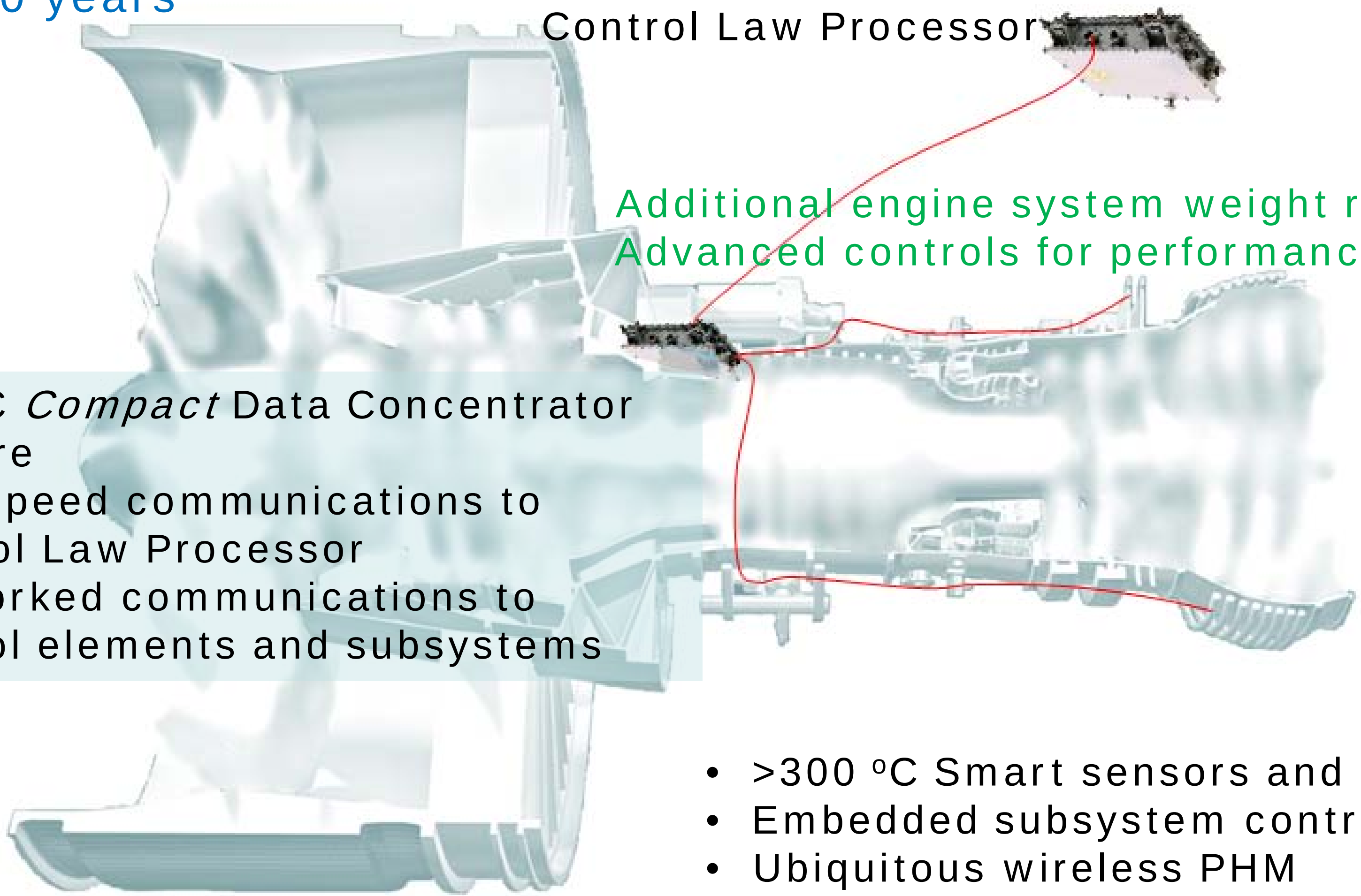
- Primarily legacy (analog point-to-point) sensors and actuators connected to data concentrator
- Some capability for embedded subsystem control and wireless devices for Propulsion Health Monitoring (PHM)

Transition to Networked Control Architecture

... reduced fuel burn, reduced NOx, reduced noise

T = 10 years
N+2

- Small, unconstrained 125 ^{o}C Control Law Processor



Additional engine system weight reduction
Advanced controls for performance & noise

- 225 ^{o}C *Compact* Data Concentrator on Core
- High speed communications to Control Law Processor
- Networked communications to control elements and subsystems

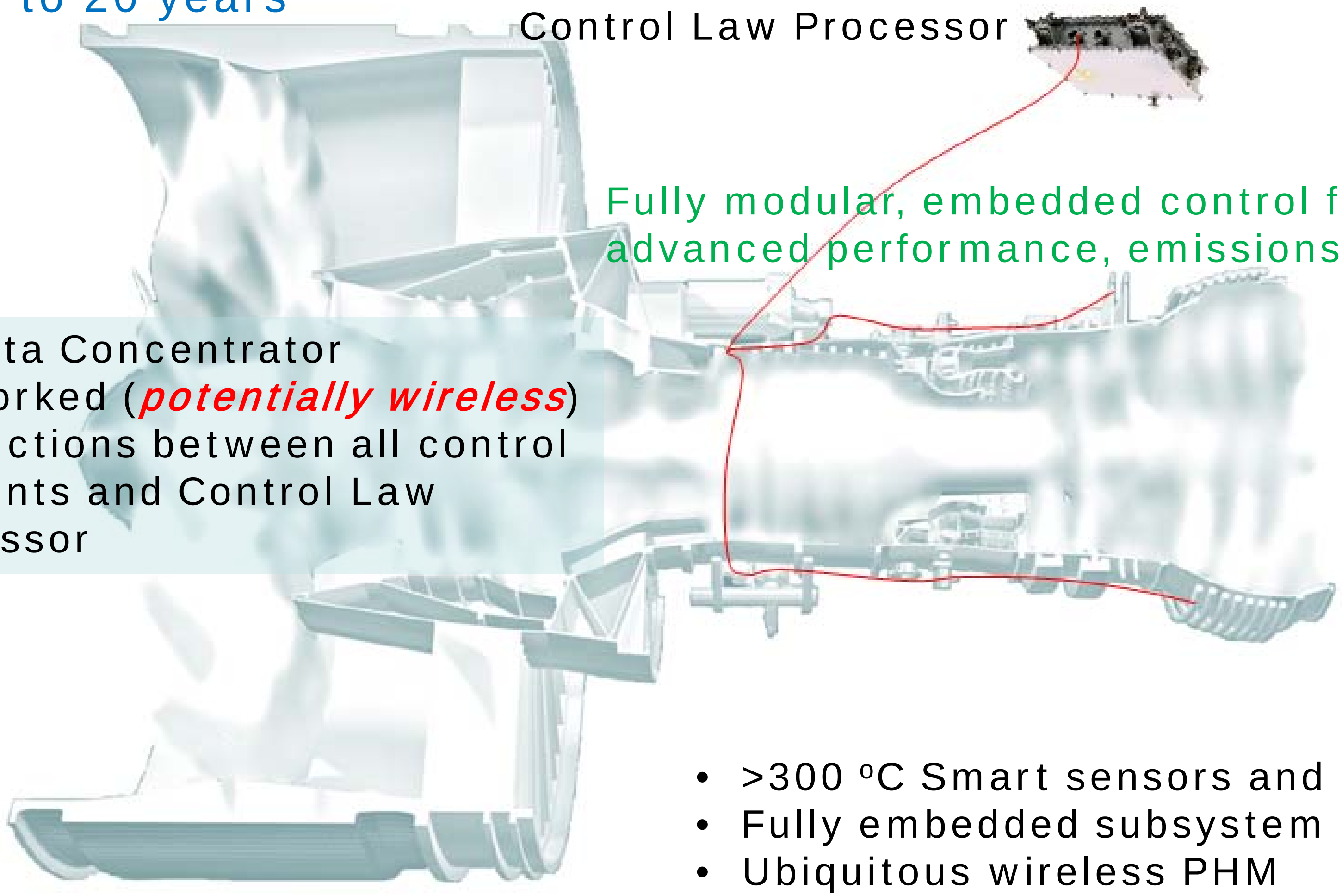
- >300 ^{o}C Smart sensors and actuators
- Embedded subsystem control
- Ubiquitous wireless PHM

Transition to Fully Distributed Architecture

... reduced fuel burn, reduced NOx, reduced noise

T = 15 to 20 years
N+3

- Small, unconstrained 125 °C Control Law Processor

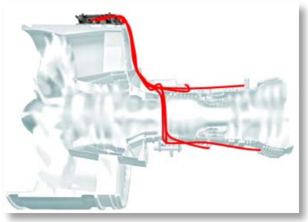


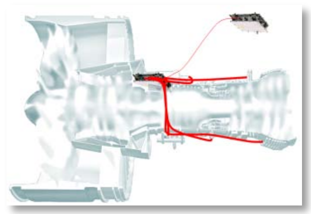
Fully modular, embedded control for advanced performance, emissions & noise

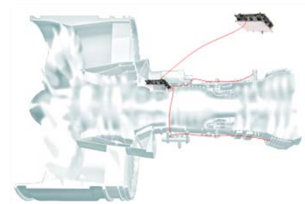
- No Data Concentrator
- Networked (*potentially wireless*) connections between all control elements and Control Law Processor

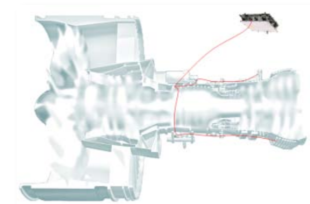
- >300 °C Smart sensors and actuators
- Fully embedded subsystem control
- Ubiquitous wireless PHM
- Power scavenging technologies

Technology Roadmap









T=0 years | 5 N+1 | 10 N+2 | 15 N+3 | 20

Centralized Networked FADEC

225°C Data Concentrator
225°C CLP/DC Comm
225°C Distributed Power

COTS SOI µP, logic, analog
COTS SiC power

Hardware-in-the-Loop Facility

Networked Control

>300°C Engine Network
>300°C Smart Nodes
>300°C Power Distribution

SOI µP, logic, analog   MSI SiC µP, logic, analog
enhanced SiC power

Fully Distributed

>300°C Network Communications
>300°C Embedded Control
>300°C Embedded Power

SOI µP, logic, analog   LSI SiC µP, logic, analog
Enhanced SiC power

Architecture Capability Electronics

Technical Challenges

Identified through the support of the Distributed Engine Control Working Group (DECWG)

Distributed Control enables off-engine mounting of the FADEC but drives several tall-pole issues:

1. Communication pathway from FADEC to engine system – what are the bandwidth requirements and how is it affected by the engine environment?
2. Power distribution to sensors and actuators – previously performed by FADEC – how is it affected by the engine environment?
3. System controllability – functionality distributed from FADEC to local subsystems) – how is system affected by network latency, software partitioning, etc.?
4. System modularity – system engineering, integration, verification, and certification paradigm changes

Research Approach

Near Term Application <5 Years

- Identify fundamental electronics requirements/capability for high bandwidth communication technology in the hot engine environment.
- Identify fundamental electronics requirements/capability for distribution of electric power in a distributed control system.
- Hardware-In-The-Loop testing (unfunded)
  - Leverage industry/govt interest and collaboration developed from DECWG
  - Leverage Silicon-On-Insulator (SOI) electronics for SFW applications
  - Broaden objectives from hardware to system level control issues

Long term Application >5 Years

- Develop fundamental high temperature SiC electronics capability >300 ^{o}C in support of fully-distributed, fully-embedded electronics on the engine core and ready to transition to industry
  - Full array of digital logic capabilities including large scale integration (LSI), processors, and memory.
  - Full array of analog functions including amplifiers, comparators, power devices, A/D, and D/A
- Develop high reliability packaging of SiC high density (system-on-a-chip) circuits.

Proposed Hardware-In-The-Loop Test

A Hardware-In-The-Loop (HIL) test capability is proposed for the near time frame. The vision is to develop a *common* facility to solicit broad participation from industry/government/academia for the development of the next generation of control systems.

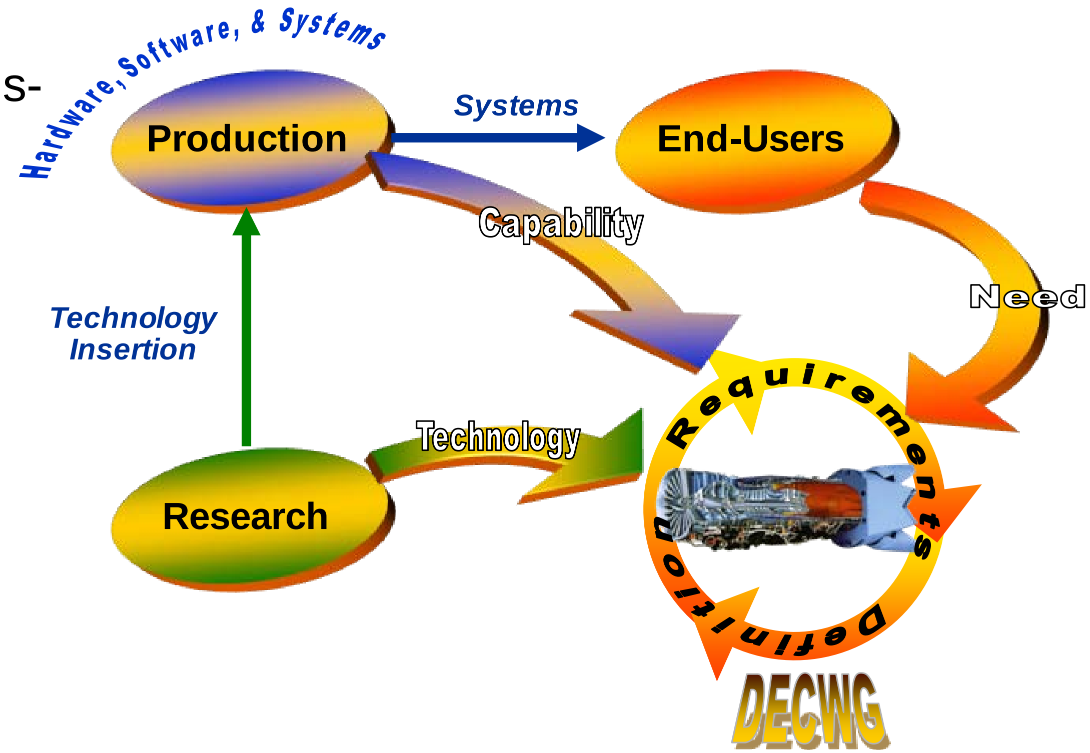
- The concept of a common test facility is based on the *use of open standards* for the interconnection of distributed control element components. The components themselves, and their embedded intellectual property, being unique.
- DECWG activities are being focused on requirements definition …
  - for this facility, and
  - for a common set of electronic functions to be fabricated in 225 ^{o}C Silicon-On-Insulator (SOI) technology to enable construction of a data concentrator and power distribution system.
- HIL will enable investigations of distributed control system stability and performance not currently included in this task.
- HIL will enhance understanding of distributed controls with regard to system integration, verification, and certification.
- HIL will be complimentary to and provide a means to verify simulation capability currently being developed through SBIR.

Industry Partnership

Distributed Engine Control Working Group (DECWG)

- A consortium of government, industry, and (soon) academia investigating the underlying issues and fundamental technology needs for future engine control systems implementation and architecture.

- Government: NASA, AFRL, Army, Navair
- Engine OEMs: GE, P&W, Rolls-Royce
- System Integrators: Hamilton Sundstrand, BAE Systems
- Suppliers: Woodward, Eaton, Goodrich, Honeywell, Parker
- Small business: SMI, Haric, Luraco, Embedded Systems, Impact Technologies, Inprox Technology



Industry Collaboration at 2009 JPC

an DECWG initiative

2009 AIAA Joint Propulsion Conference and Exhibit collaborators: BAE Systems, Eaton Corp., Embedded Systems LLC, General Electric, Goodrich Corp., Hamilton Sundstrand, Honeywell, Impact Technologies LLC, Inprox Technology, Luraco Technologies, NASA, Pratt & Whitney, Scientific Monitoring Inc / Haric LLC, Woodward Governor Company