Status, Vision, and Challenges of an Intelligent Distributed Engine Control Architecture

ABSTRACT

A Distributed Engine Control Working Group (DECWG) consisting of the Department of Defense (DoD), the National Aeronautics and Space Administration (NASA) – Glenn Research Center (GRC) and industry has been formed to examine the current and future requirements of propulsion engine systems. The scope of this study will include an assessment of the paradigm shift from centralized engine control architecture to an architecture based on distributed control utilizing open system standards. Included will be a description of the work begun in the 1990's, which continues today, followed by the identification of the remaining technical challenges which present barriers to on-engine distributed control.

Status, Vision, and Challenges of an Intelligent Distributed Engine Control Architecture

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Outline

- Distributed Engine Control Working Group
- Motivation / Goals
- Vision
- Challenges
- Roadmap
- Conclusion

Distributed Engine Control Working Group

Charter

The Distributed Engine Control Working Group (DECWG) is **a forum for the discussion of aero-propulsion systems with a specific emphasis on the future development of engine controls**, including both hardware and software, for military and commercial engines. By examining the current and future requirements of propulsion engine systems, the group will lay the foundation for a future distributed engine control architecture based upon **open system standards**.

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Distributed Engine Control Working Group

The main goals of the DECWG will be:

- Identify, quantify and validate **benefits** from the stakeholder perspective.
- Identify the impact of **new control strategies** on all facets of the user community; including design, fabrication, assembly, supply chain, and operations.
- Identify **regulatory and business barriers** which impede the implementation of alternate control philosophies.
- Identify existing and emerging **technologies** which can be leveraged in the aero-engine control system.
- Identify **technology barriers** which prevent the implementation of alternate control philosophies and provide guidance to industry for their removal.
- Develop an overall **roadmap** with which to guide the successful implementation of alternate control philosophies.

Motivation / Goals

Lower Cost

Technology Push / Pull

Simplify Upgrades

Add Customer Value

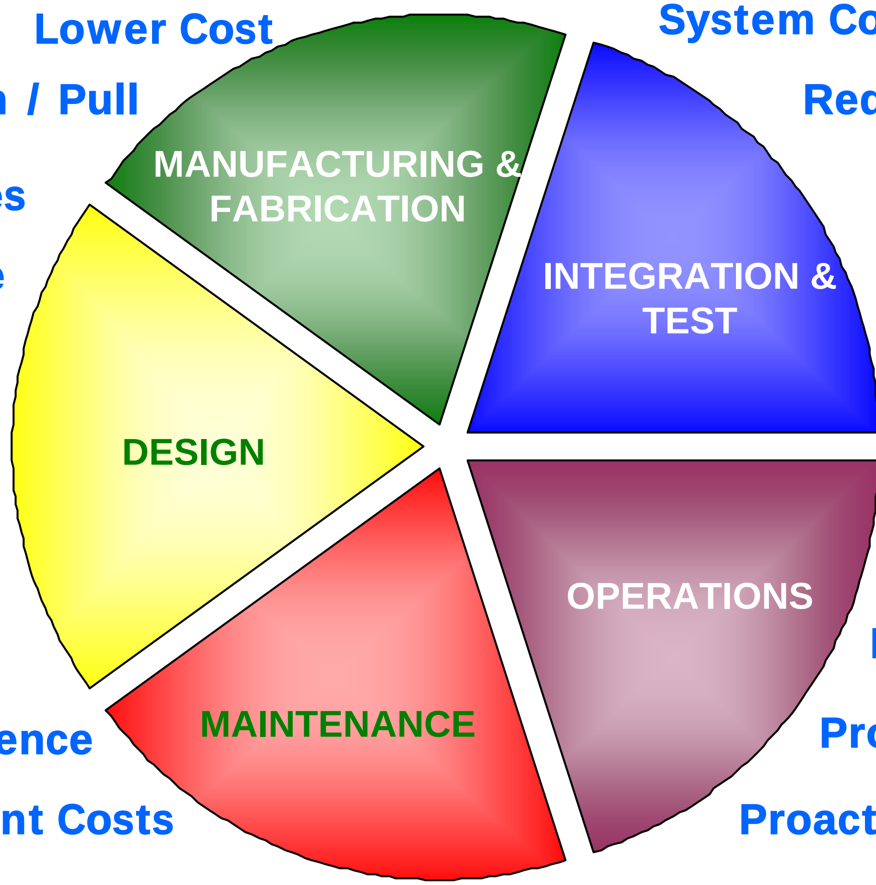
Time to Adapt
/ Add New Features

Adaptive Control
/ Flow Control

Reduce Weight

Mitigate obsolescence

Reduce Sustainment Costs



System Compatibility

Reduce Certification
Cost / Time

Capability Growth

Improve Reliability

Increase Availability

Real-time Life Tracking

Mission Success

Prognostic Capability

Proactive Health Management

Performance, Time & Cost

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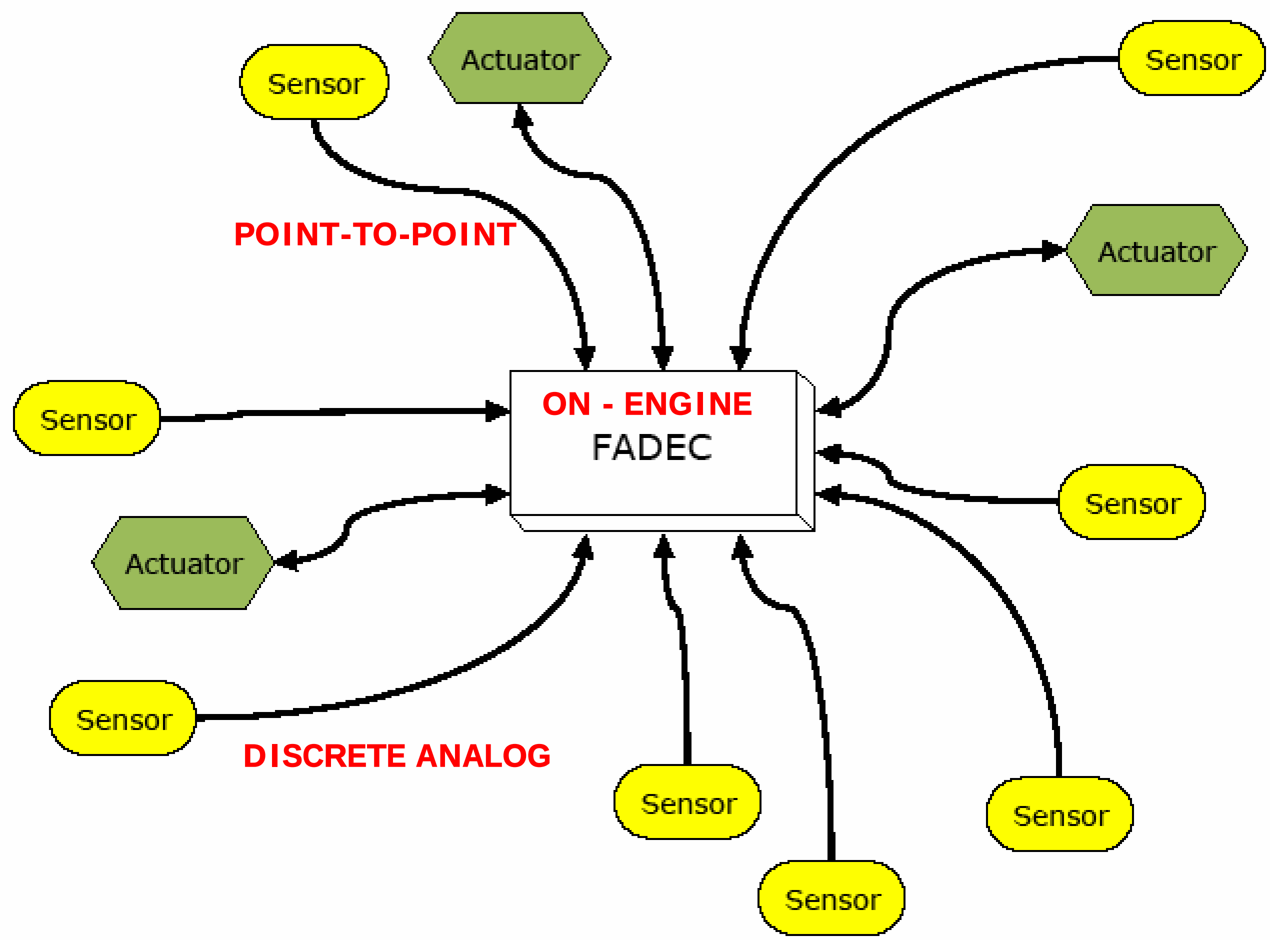
Central Control System Issues

CCS…Invisible, Static Resources, Centralized Management

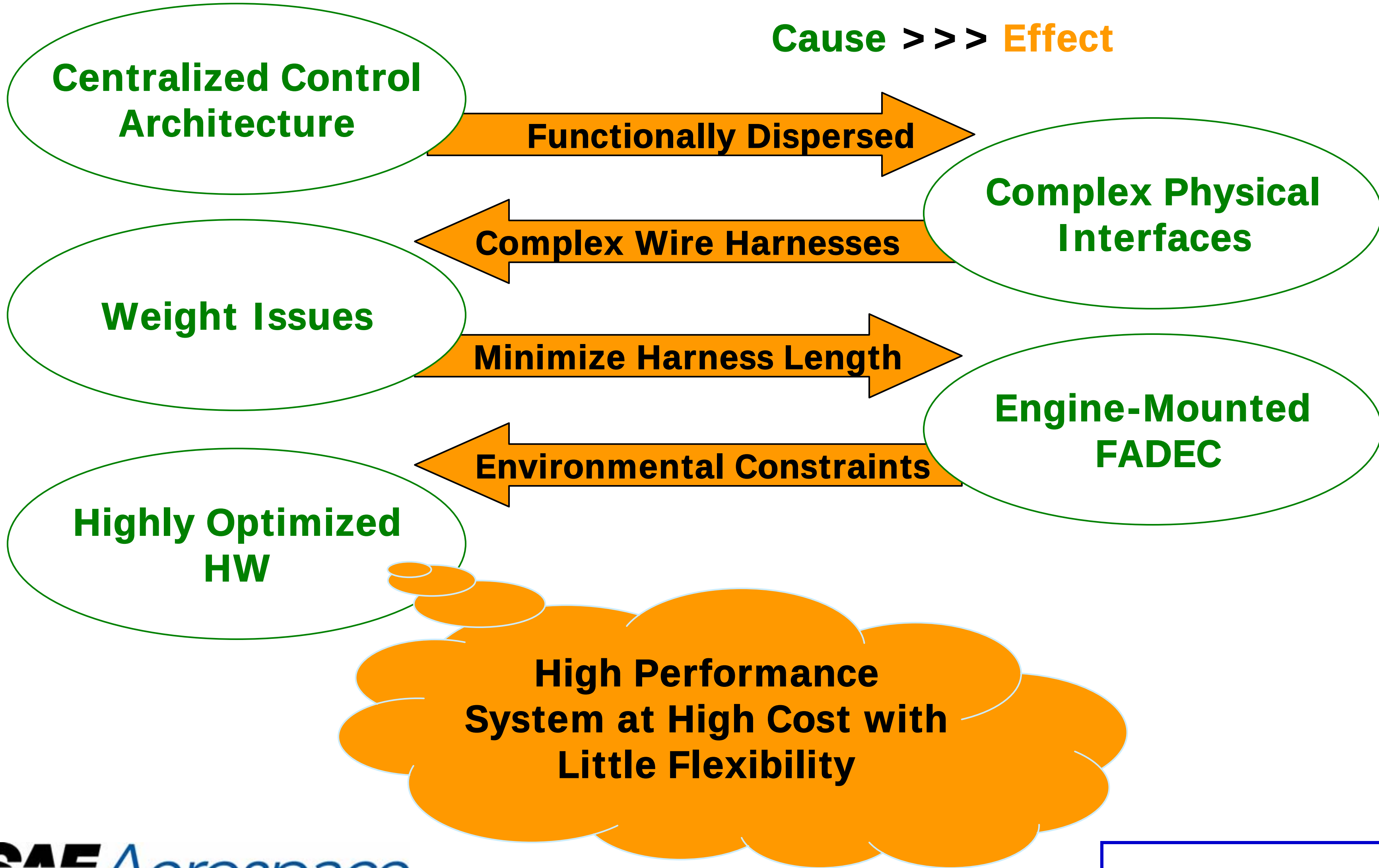


Harness
- Heavy
- Complex
- Reliability Issue

FADEC
- Hostile Environment
- Expensive
- Prone to Obsolescence

System
- Difficult to Isolate Faults
- Difficult to Modify and Upgrade
- How to Implement Advanced Controls?

System Design Decisions



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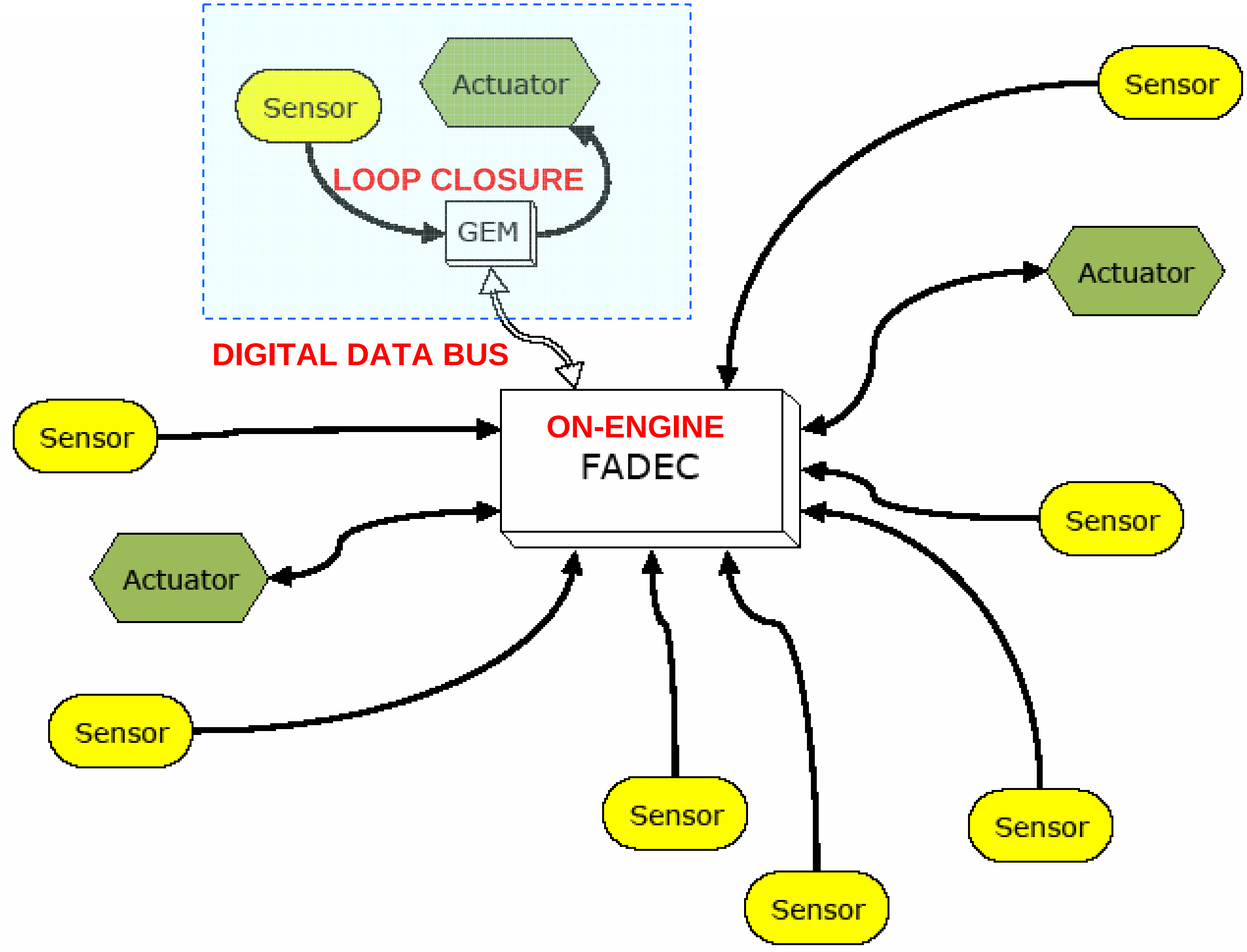
Foundational Development

- Lightweight Distributed Systems (LDS)
- *High Temperature Electronic Components (HiTEC)*
- *COntrolled Pressure-ratio Engine (COPE) Program*
- *Propulsion Instrumentation Working Group (PIWG)*
- *Versatile Affordable Advanced Turbine Engine (VAATE) Initiative*
- *NASA Glenn Research Center Initiatives*

Elements of Distributed Engine Control Technologies have been in development since the early 1990's

Transition to Distributed Control System



Harness

- Reduced Wire Count
- Simplified Mechanical Interface

FADEC

- Simple Loop Closure Off-Loaded to Controller

System

- Limited Fault Isolation
- Functional Segregation

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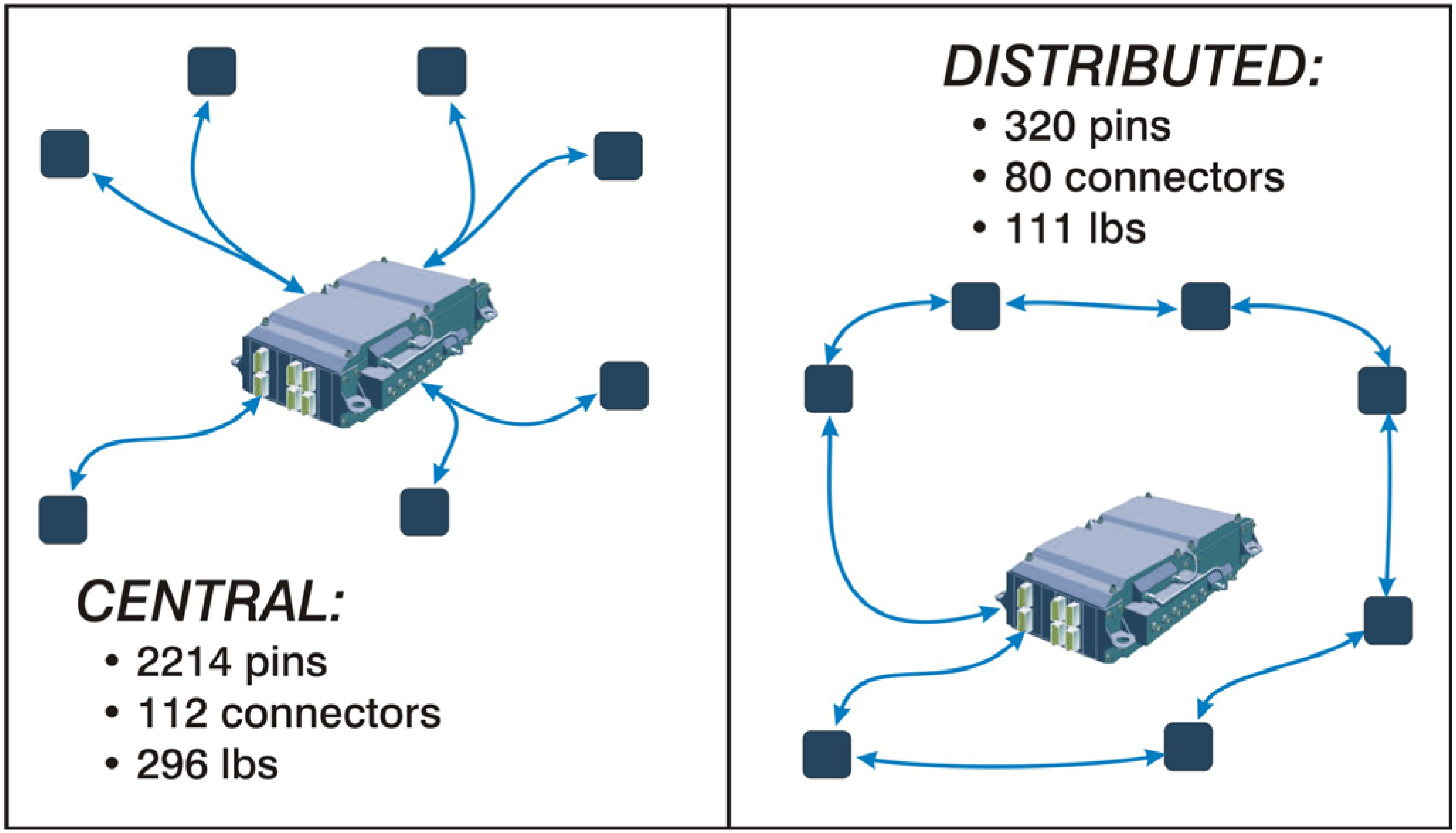
Analysis of Wiring Harness

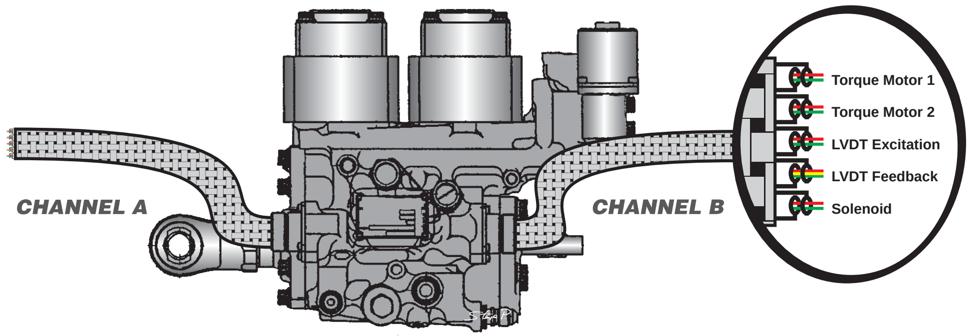
Expected Impact of Distributed Control



HIGH-TEMPERATURE SMART ACTUATOR

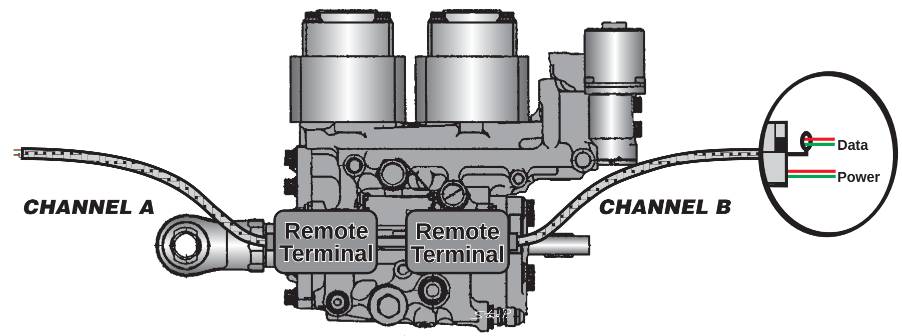
KEY COMPONENT FOR DISTRIBUTED CONTROLS

CONVENTIONAL FAN IGV ACTUATOR



CHANNEL A	11 Wires
	10 Shields
CHANNEL B	11 Wires
	10 Shields
TOTAL	42 Conductors

SMART FAN IGV ACTUATOR



CHANNEL A	4 Wires
	1 Shield
CHANNEL B	4 Wires
	1 Shield
TOTAL	10 Conductors

ADDING COMPACT ELECTRONICS MODULE TO ACTUATOR HAS SIGNIFICANT SYSTEM BENEFITS

- TOTAL WIRE COUNT INTO FADEC REDUCED FROM >500 TO 8
- FADEC COST REDUCTION OF $75K (SUBSTANTIALLY MORE IF FADEC IS OFF-ENGINE)
- FADEC STANDARDIZATION FOR MULTIPLE ENGINES (NEW FADEC DEVELOPMENT IS ~$50M)
- DISTRIBUTED BUILT-IN TEST PROVIDES NEAR 100% FAULT ISOLATION

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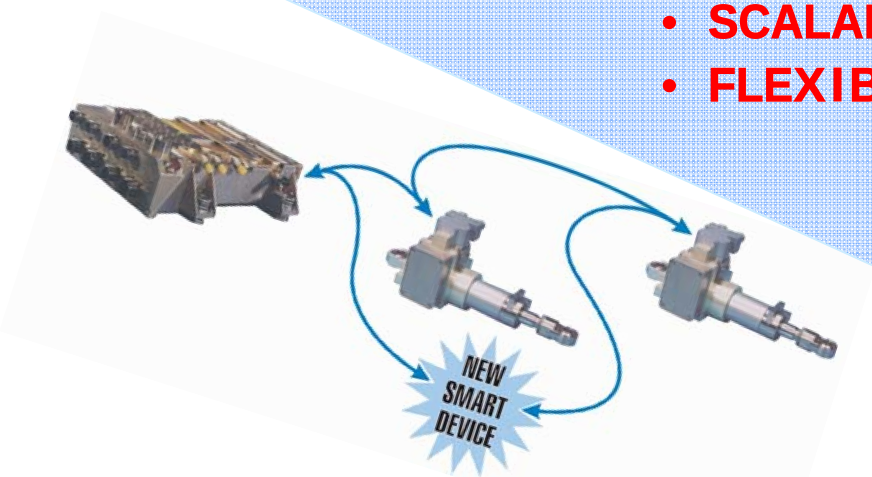
Vision for Distributed Control

Decomposition of the Engine Control Problem into FUNCTIONAL ELEMENTS results in MODULAR components. These components create the building blocks of <u>any engine control system</u>.

MODULARITY

- **COMMONALITY**
- **EXPANDIBILITY**
- **SCALABILITY**
- **FLEXIBILITY**

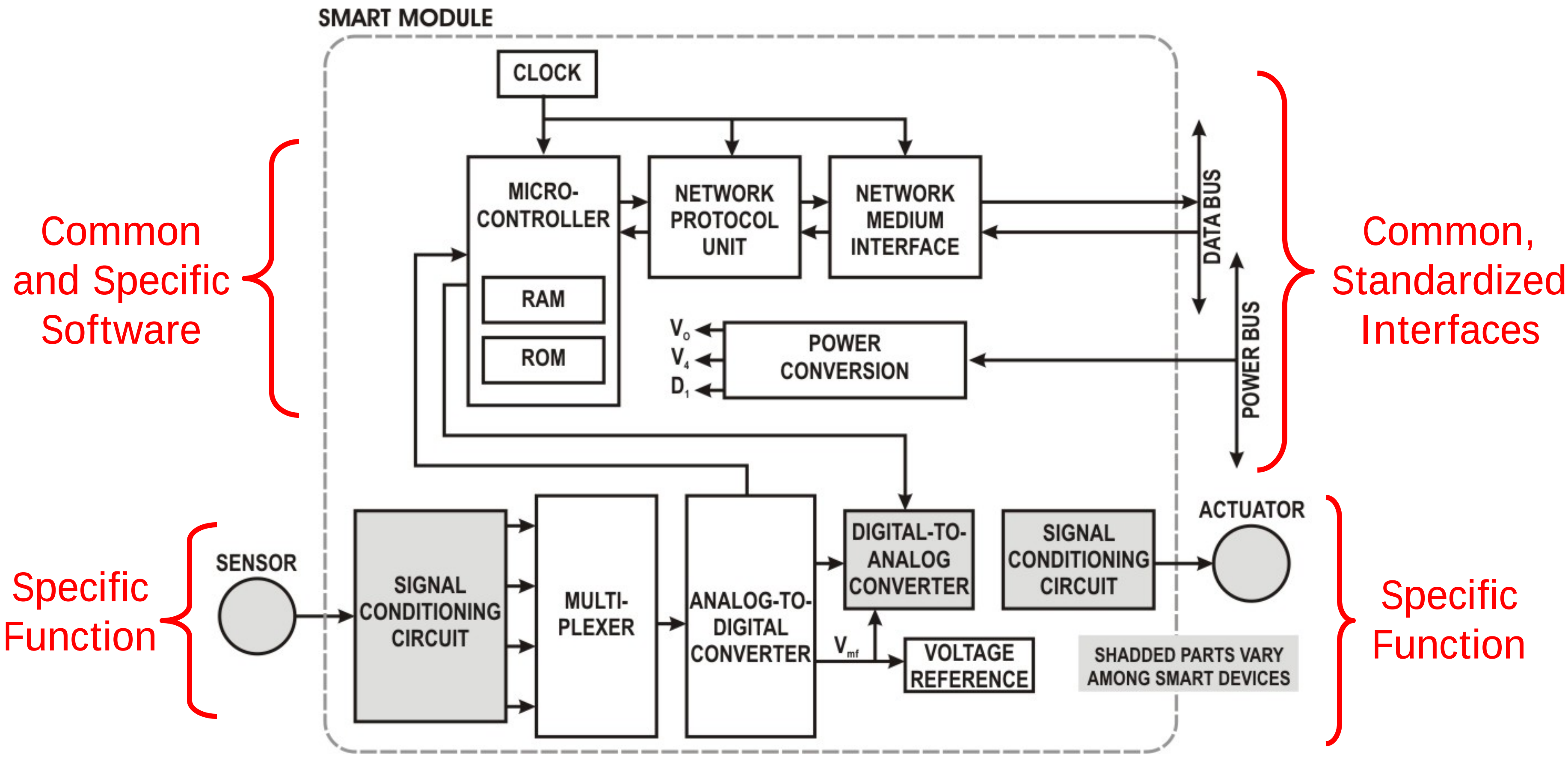
- **OBSOLESCENCE MITIGATION**
- **LOWER PROCESSING REQUIREMENTS**
- **ENHANCED PERFORMANCE**
- **LOWER WEIGHT**
- **REDUCED COST**



The use of OPEN SYSTEM STANDARDS enhances benefits by leveraging the greatest possible market for components .

Modular Design Elements for Engine Control

In Distributed Control much of the Hardware AND Software can be reused in the system AND across engine platforms



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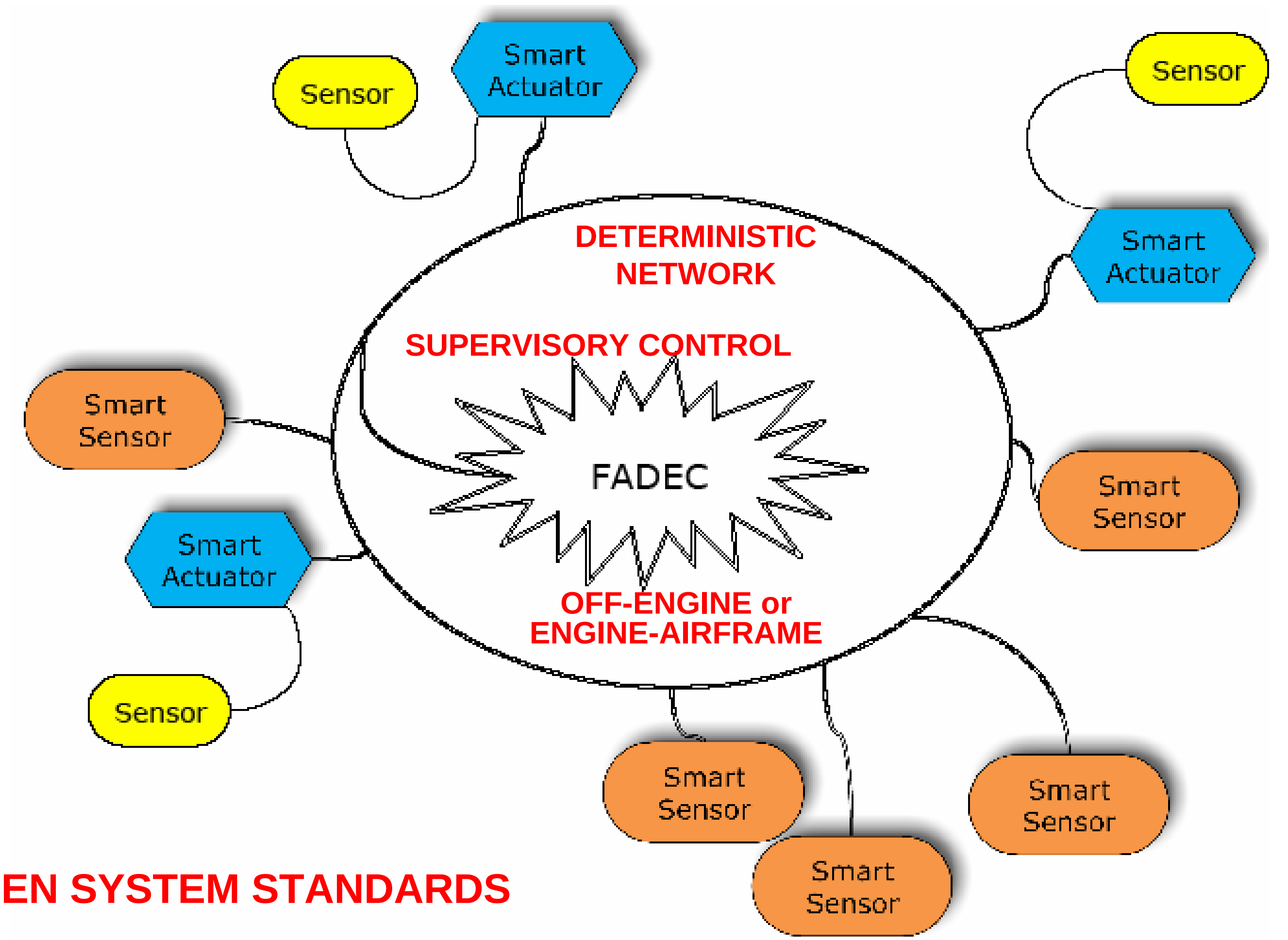
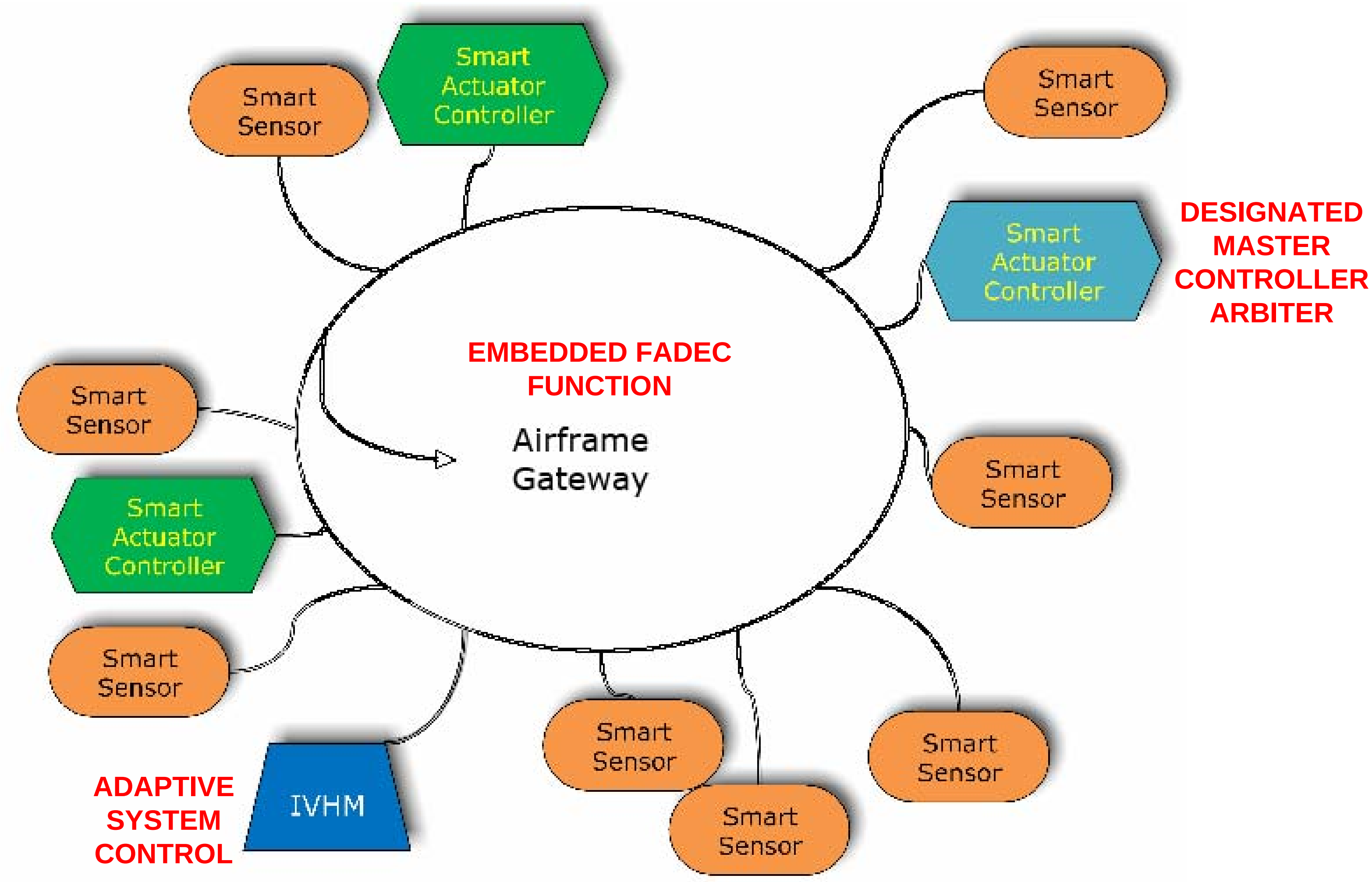
Integrated Distributed Engine Control



OPEN SYSTEM STANDARDS

Embedded Distributed Control



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A Long Term View

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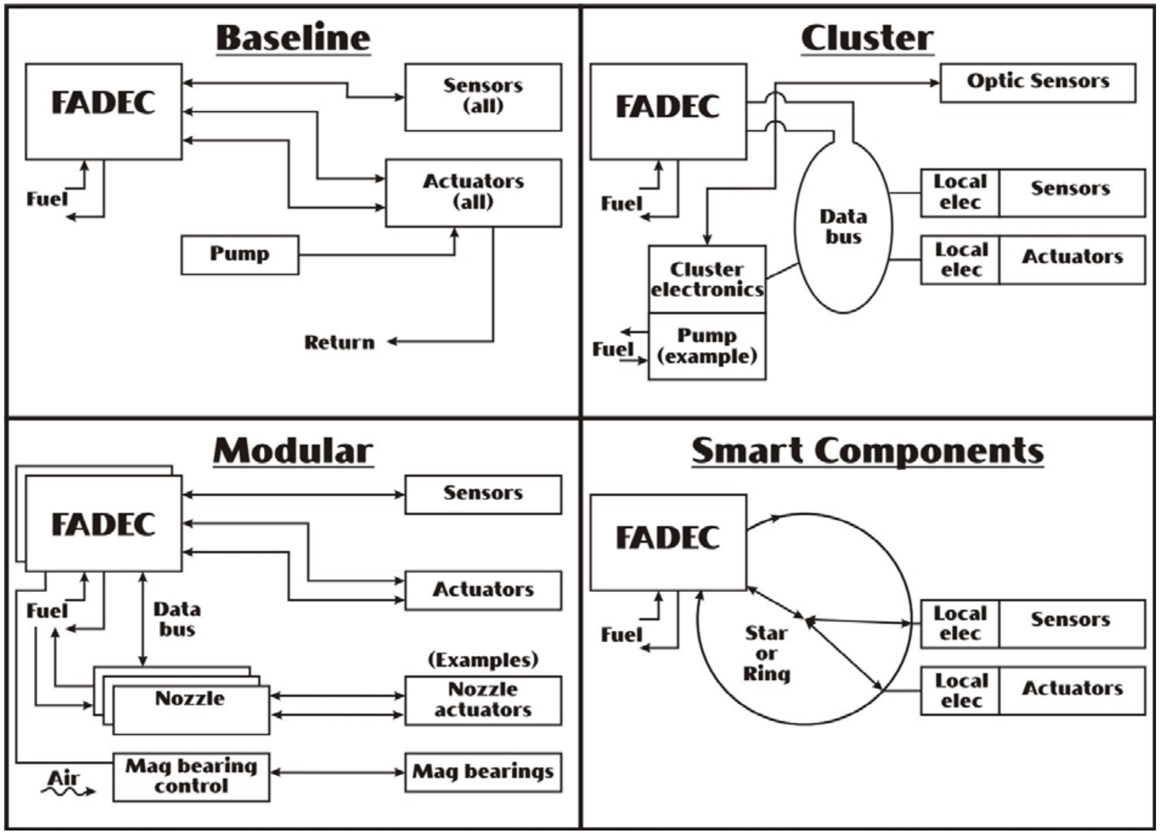
Distributed Architecture Flexibility



Distributed Architecture Does NOT Force a Specific Configuration
It Provides for the Best Choice on a Given Platform

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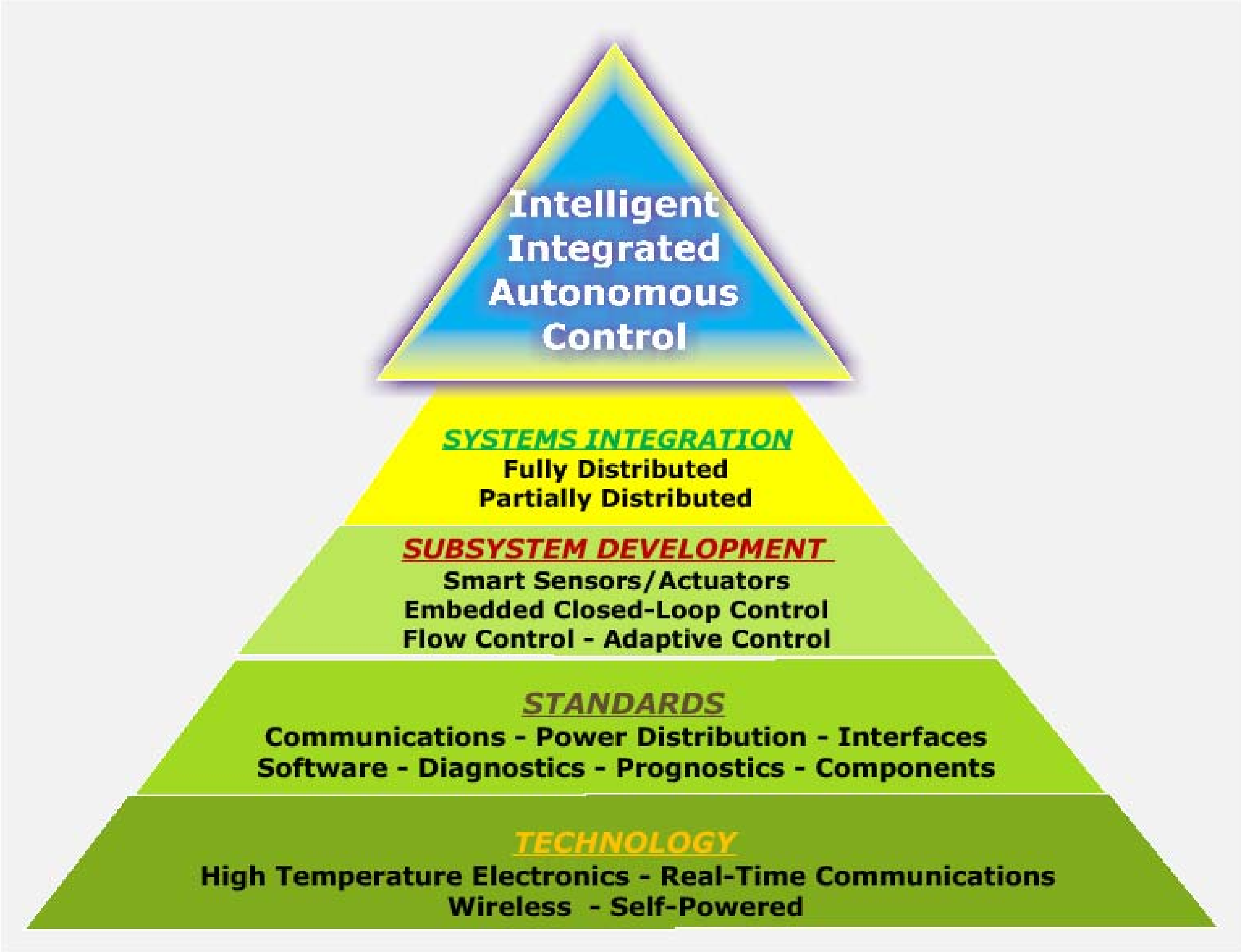
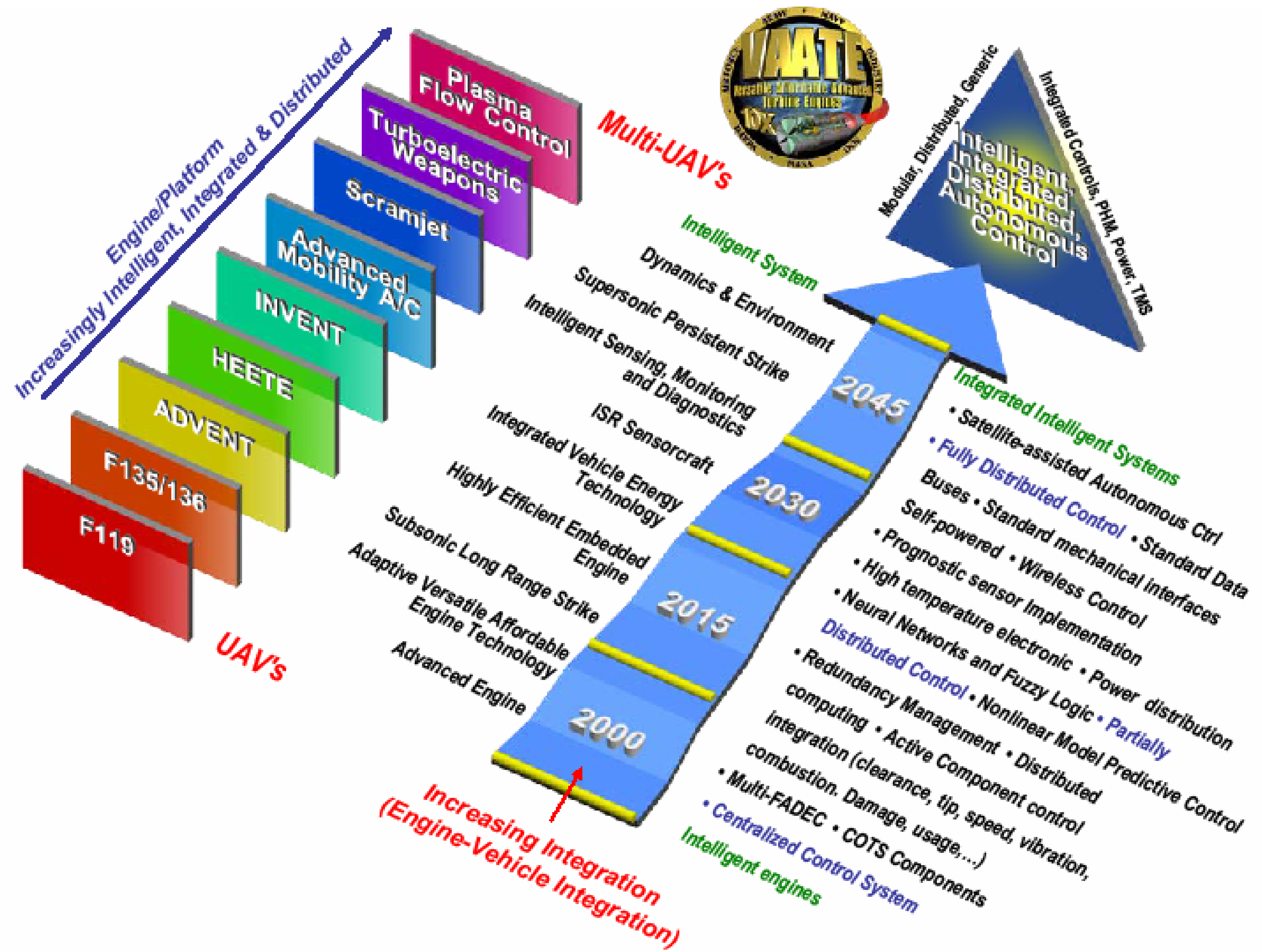
Challenges

- Engine Environment and High Temperature Electronics
- Certification / Safety / Regulatory Environment
- Data Bus and Communications
- Functional Partitioning
- Redundancy and Resource Management
- Market Size
- Increased Maintenance Cost
- Distributed Systems Competencies

Elements of the Development Roadmap





Increasingly Intelligent, Integrated & Distributed
Engine/Platform
F119
F135/136
ADVENT
HEETE
INVENT
Advanced Mobility A/C
Scramjet
Turboelectric Weapons
Plasma Flow Control
UAV's
Multi-UAV's
VAATE
Intelligent System
Dynamics & Environment
Supersonic Persistent Strike
Intelligent Sensing, Monitoring and Diagnostics
ISR Sensorcraft
Integrated Vehicle Energy Technology
Highly Efficient Embedded Engine
Subsonic Long Range Strike
Adaptive Versatile Affordable Engine Technology
Advanced Engine
2000
2015
2030
2045
Increasing Integration (Engine-Vehicle Integration)
Intelligent, Integrated, Distributed, Autonomous Control
Modular, Distributed, Generic
Integrated Controls, PHM, Power, TMS
Integrated Intelligent Systems
• Satellite-assisted Autonomous Ctrl
• Fully Distributed Control • Standard Data Buses • Standard mechanical interfaces
Self-powered • Wireless Control
• Prognostic sensor implementation
• High temperature electronic • Power distribution
• Neural Networks and Fuzzy Logic • Partially Distributed Control • Nonlinear Model Predictive Control
• Redundancy Management • Distributed computing • Active Component control integration (clearance, tip, speed, vibration, combustion. Damage, usage,...)
• Multi-FADEC • COTS Components
• Centralized Control System
Intelligent engines

Expectations for Future Engines

CURRENT ENGINES:

- Mechanical / Structural / Aerothermodynamic design provides a fixed optimum operating point
- Large, fixed safety margins accommodate worst case deterioration and operating conditions
- Inflexible engine response to changing operational & environmental conditions
- Maximum performance compromised for wider operability
- High support costs

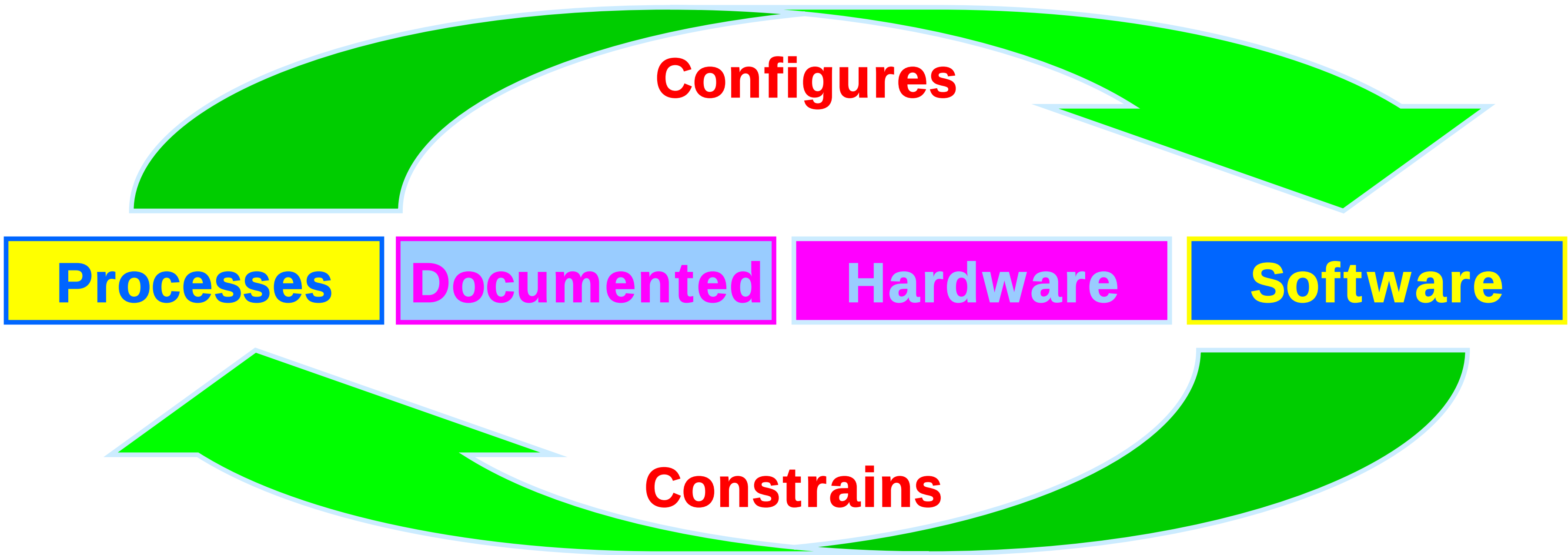
FUTURE INTELLIGENT ENGINES:

- Intelligent control maintains optimum engine operation through adaptive response to all changing conditions while maintaining safety margins
- Accommodation for internal (engine health) or external (new/changed missions) conditions
- Performance requirements met through End-of-Life
- Increased knowledge of flowpath and mechanical conditions enable optimization, self-diagnosis, self-prognosis

Integrated System Design Process

Evolutionary Development Process…

Deploying COTS as much as possible …



Define and Refine the Process and Configuration Design H/W and S/W simultaneously...

Conclusion

- Aero-engine control systems will decide the success of future aeropropulsion systems; Transforming the control system into a distributed architecture, based on open system standards, is necessary to meet the challenge.
- High temperature electronics is the enabling technology for aero-engine distributed control.
- The DECWG perceives the benefits of distributed engine control as:
  1. Reducing the size/weight/cost of wiring harnesses
  2. Simplification of system upgrades,
  3. Distribution of computational burden,
  4. Increased robustness against faults/damage
  5. Mitigation obsolescence issues.