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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Distributed Engine Control Working Group

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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.
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

- Mitigate obsolescence
- Simplify Upgrades
- Add Customer Value
- Technology Push / Pull
- Time to Adapt / Add New Features
- Adaptive Control / Flow Control
- Reduce Weight
- Mitigate obsolescence
- Reduce Sustainment Costs

MANUFACTURING & FABRICATION

INTEGRATION & TEST

DESIGN

OPERATIONS

MAINTENANCE

Performance, Time & Cost

Performance, Time & Cost

Lower Cost

System Compatibility

Reduce Certification Cost/Time

Capability Growth

Improve Reliability

Increase Availability

Real-time Life Tracking

Mission Success

Prognostic Capability

Proactive Health Management

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Central Control System Issues
CCS...Invisible, Static Resources, Centralized Management

**POINT-TO-POINT**
- ON-ENGINE

**DISCRETE ANALOG**
- FADEC
- Hostile Environment
- Expensive
- Prone to Obsolescence

**Harness**
- Heavy
- Complex
- Reliability Issue

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

“Put all your eggs in one basket and watch that basket!” -- Mark Twain

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System Design Decisions

- Centralized Control Architecture
- Functionally Dispersed
- Complex Wire Harnesses
- Minimize Harness Length
- Complex Physical Interfaces
- Engine-Mounted FADEC
- Weight Issues
- Highly Optimized HW
- Environmental Constraints

High Performance System at High Cost with Little Flexibility
Foundational Development

- Lightweight Distributed Systems (LDS)
- High Temperature Electronic Components (HiTEC)
- COntrrolled 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

**CENTRAL:**
- 2214 pins
- 112 connectors
- 296 lbs

**DISTRIBUTED:**
- 320 pins
- 80 connectors
- 111 lbs
HIGH-TEMPERATURE SMART ACTUATOR
KEY COMPONENT FOR DISTRIBUTED CONTROLS

CONVENTIONAL FAN IGV ACTUATOR

SMART FAN IGV ACTUATOR

<table>
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<th>CHANNEL A</th>
<th>CHANNEL B</th>
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<td>11 Wires</td>
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<td>42 Wires</td>
</tr>
<tr>
<td>10 Shields</td>
<td>10 Shields</td>
<td>10 Shields</td>
</tr>
</tbody>
</table>

• 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 any engine control system.

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.

Common and Specific Software

Specific Function

Common, Standardized Interfaces

Specific Function
Integrated Distributed Engine Control

DETERMINISTIC NETWORK
OFF-ENGINE or ENGINE-AIRFRAME

SUPERVISORY CONTROL
FADEC

OPEN SYSTEM STANDARDS
Embedded Distributed Control

EMBEDDED FADEC FUNCTION
Airframe Gateway

A Long Term View
Distributed Architecture Flexibility

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

**Intelligent Integrated Autonomous Control**

**SYSTEMS INTEGRATION**
- Fully Distributed
- Partially Distributed

**SUBSYSTEM DEVELOPMENT**
- Smart Sensors/Actuators
- Embedded Closed-Loop Control
- Flow Control - Adaptive Control

**STANDARDS**
- Communications - Power Distribution - Interfaces
- Software - Diagnostics - Prognostics - Components

**TECHNOLOGY**
- High Temperature Electronics - Real-Time Communications
- Wireless - Self-Powered

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The Distributed Engine Control Technology Roadmap

Increasingly Intelligent, Integrated & Distributed
- Engine/Platform
- INVENT
- HEEETE
- ADVENT
- F135/136
- F119
- UAV's

UAV's
- Advanced Mobility A/C
- Plasma Flow Control
- Turboelectric Weapons
- Scramjet
- Multi-UAV's

Increasing Integration (Engine-Vehicle Integration)

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

Integrated Intelligent Systems
- 2045
- 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 computing
- Active Component control integration
- Redundancy Management
- Distributed combustion
- 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 …

Configures

Processes  Documented  Hardware  Software

Constrains

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.