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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An SAE International Group
Outline

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

The main goals of the DECGW 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**
Central Control System Issues

CCS...Invisible, Static Resources, Centralized Management

POINT-TO-POINT

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

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

Centralized Control Architecture

Functionally Dispersed

Complex Wire Harnesses

Complex Physical Interfaces

Minimize Harness Length

Engine-Mounted FADEC

Weight Issues

Minimize Harness Length

Environmental Constraints

Highly Optimized HW

High Performance System at High Cost with Little Flexibility

Cause >>> Effect

High Performance System at High Cost with Little Flexibility

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**Foundational Development**

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

ON-ENGINE
FADEC

Harness
- Reduced Wire Count
- Simplified Mechanical Interface

FADEC
- Simple Loop Closure Off-Loaded to Controller

System
- Limited Fault Isolation
- Functional Segregation
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>
<thead>
<tr>
<th>CHANNEL A</th>
<th>11 Wires</th>
<th>10 Shields</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHANNEL B</td>
<td>11 Wires</td>
<td>10 Shields</td>
</tr>
<tr>
<td>TOTAL</td>
<td>42 Wires</td>
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</table>

<table>
<thead>
<tr>
<th>CHANNEL A</th>
<th>4 Wires</th>
<th>1 Shield</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHANNEL B</td>
<td>4 Wires</td>
<td>1 Shield</td>
</tr>
<tr>
<td>TOTAL</td>
<td>10 Wires</td>
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</tbody>
</table>

- TOTAL WIRE COUNT INTO FADEC REDUCED FROM >500 TO 8
- FADEC COST REDUCTION OF $75K (SUBSTANTIALY 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.

<table>
<thead>
<tr>
<th>Modularity</th>
<th>Commonality</th>
<th>Obsolescence Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Expandability</td>
<td>Lower Processing Requirements</td>
</tr>
<tr>
<td></td>
<td>Scalability</td>
<td>Enhanced Performance</td>
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<tr>
<td></td>
<td>Flexibility</td>
<td>Lower Weight</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reduced Cost</td>
</tr>
</tbody>
</table>

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.
Integrated Distributed Engine Control

Superior Control

Deterministic Network

Off-engine or Engine-Airframe

Open System Standards
Embedded Distributed Control

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
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

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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…

Processes | Documented | Hardware | Software

Configures

Constrains

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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.