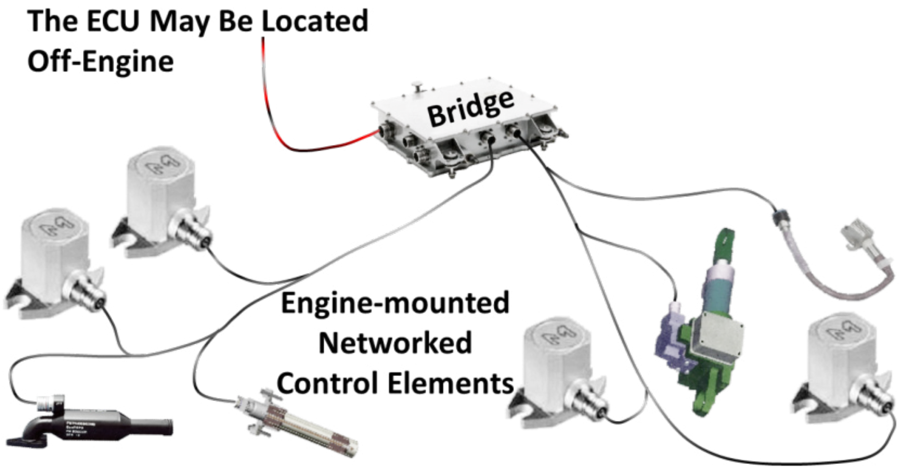
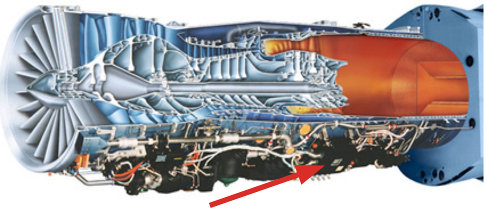
Distributed Control for Turbine Propulsion

Development of a modular, distributed control architecture for turbine propulsion systems is necessary for achieving improved performance and capability in aviation. These high-performance engines and their control systems are expected to perform at peak efficiency for decades while subjected to some of the most severe environmental conditions, implementation constraints, and the constant threat of electronics obsolescence.



Notional high-temperature, networked control elements remaining on the engine in a future distributed control architecture



Currently, the ECU for military aircraft engines is core mounted, requiring fuel cooling. As the core becomes smaller and hotter, both the size and cooling requirements for the ECU become problematic.

From Centralized to Distributed Control

Today's modern full authority digital engine control (FADEC) is based on technology developed in the early 1980s. This architecture features a digital electronic engine control unit (ECU) that also accommodates analog input/output circuitry to operate the control system's sensors and actuators. The present ECU is typically engine-mounted in close proximity to these control elements to minimize the overall impact of weight on the engine, of which the harness accounts for a large percentage. Consequently, the ECU is exposed to the most severe environmental extremes that must be accommodated in its design and then certified to the most stringent safety and reliability requirements.

Unfortunately, the limitations of this architecture are becoming increasingly apparent. The improvements in turbine technology have increased engine operating temperatures and reduced the opportunities to locate control hardware. Likewise, the certification process inhibits the introduction of new capabilities while obsolescence drives the need for unplanned modifications.

Migrating to a distributed control architecture will allow the replacement of complex analog interfaces with digitization at the source, embedded processing, and common network interfaces at the system effectors and the ECU. The modularization of control functionality affords new opportunities to improve turbine capability by increasing the capability of existing control functions or, more simply, expanding the number of elements.

The present ECU for commercial aircraft engines is mounted on the cold fan casing. As the fan diameter increases, the push is to reduce the gap between the casing and the nacelle for weight and drag reduction. The size of the ECU becomes an issue.

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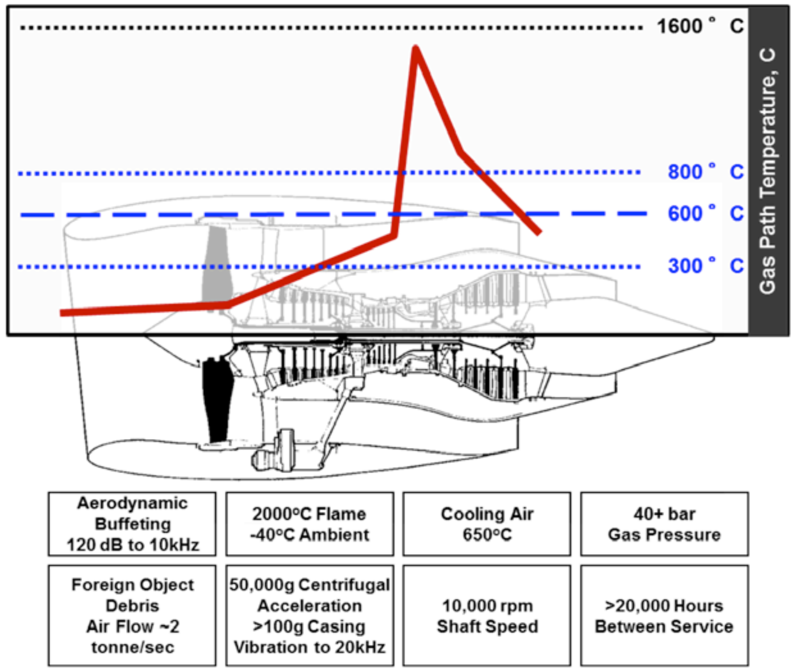
Control System Constraints

- Harness weight can be several hundred pounds on large engines. "Wiring" the harness through the engine structure with multiple connectors adds weight and complexity, as well as raising reliability and fault-tolerance issues.
- The size of the ECU and the cooling requirements pose a challenge as turbine engine technology moves to smaller and hotter cores and larger fans for efficient operation.
- ECUs use commercial electronics, which often become obsolete in a few years, whereas ECUs have a lifetime of 10+ years. This requires complex and costly ECU parts management.
- Unplanned redesign and upgrades are prohibitively costly due to certification issues.
- Emerging active component control concepts for more efficient engine operation cannot be accommodated in the current control architecture.



Temperature extremes and vibration in the aero-engine environment are severe. The minimum temperature is due to ambient conditions at altitude, whereas the maximum temperature occurs in the combustor. Keeping the engine running under most fault conditions is essential.

Challenges Facing Distributed Control for Turbine Propulsion

A fundamental challenge facing implementation of distributed control on turbine engines is the lack of suitable electronics operating at high temperatures. Aircraft engine temperatures typically exceed the ratings of commercially available electronics used in automotive applications. This is especially true at soakback conditions when airflow through the engine is eliminated. Existing commercial electronics capable of operating above 200°C, typically silicon-on-insulator, are prohibitively expensive and have an indeterminate life when operating for extended periods at those temperatures. In response, engine manufacturers and their suppliers have formed a collaboration through the Distributed Engine Control Working Group (DECWG™) to address precompetitive technologies such as high-temperature electronics.

For the long term, significant effort is also being expended to increase the high-temperature capability of electronics for power as well as small-signal analog and digital applications. The progress in silicon carbide has been most notable, especially in the area of power electronics where commercial devices are available.

Additional challenges for distributed control architectures, several of which are posed by the high-temperature electronics issue, include the following:

- High-bit-rate networking in a high-temperature environment
- Robust and deterministic communication protocol
- Engine safety and stability
- Control system integration
- System modeling and analysis
- Verification and validation
- System certification and partial certification
- Supply chain viability
- Engine-airframe integration

For more information: J.D. Cressler and H.A. Mantooth (eds.), Extreme Environment Electronics, CRC Press, 2012; J. DeCastro et al., Analysis of decentralization and fault-tolerance concepts for distributed engine control, AIAA 2009-4884, 45th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, 2009; D. Culley, Transition in gas turbine control system architecture: Modular, distributed, and embedded, ASME Turbo Expo 2010: Power for Land, Sea, and Air, 2010.