integrated flight propulsion control system

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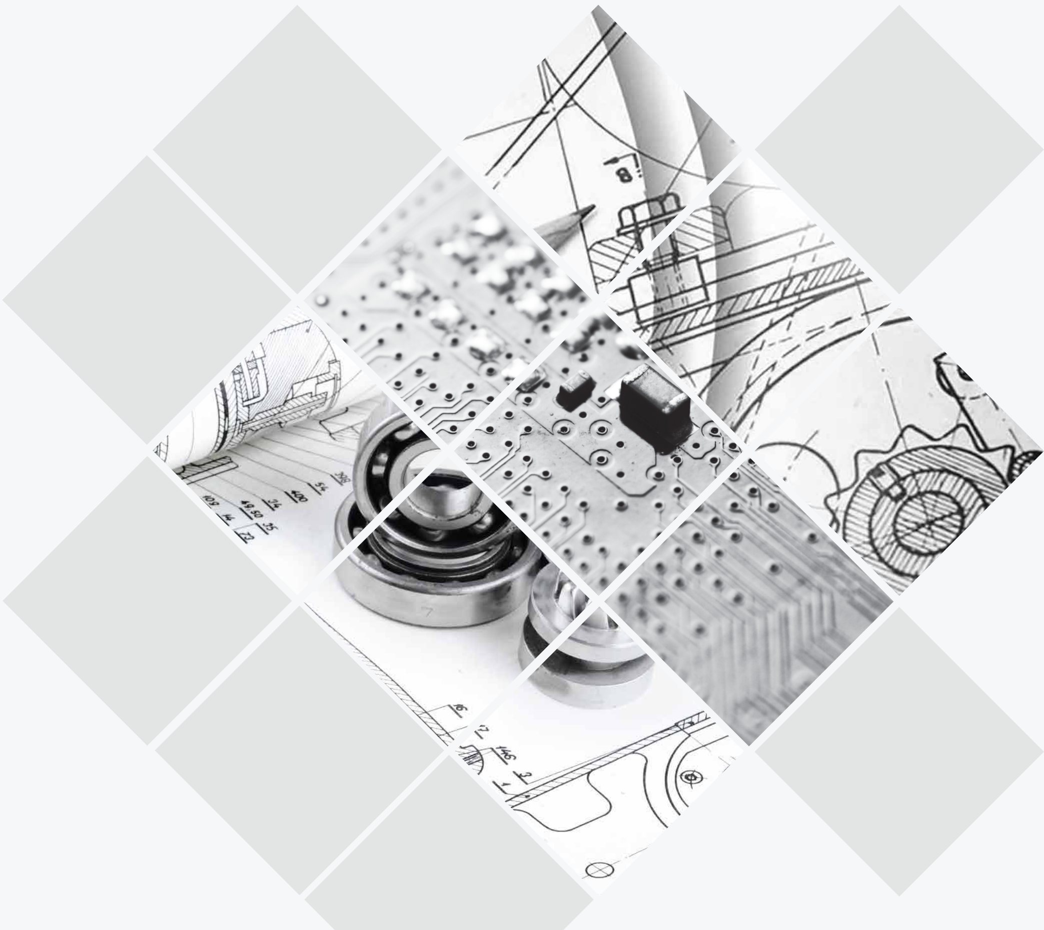

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Abstract

The aerospace industry in the present scenario is very fascinating and motivating, and is set to become an exciting space in the near future with innovations getting better day by day, and immense competition amongst various industry players. R&D investments in emerging markets are on the rise, where investments in new technologies form the core of aerospace growth strategy.

The real challenge lies in making technology more efficient, reliable, and advanced. In this context, Integrated Flight Propulsion Control (IFPC) seems to be intriguing and revolutionary. Also, in the business sense, this is a welcoming aspect since aerospace companies are exploring a range of opportunities to increase revenue, margins, and market share.

Integration of propulsion and flight control systems will provide significant performance improvements for supersonic transport airplanes. Increased engine thrust and reduced fuel consumption can be obtained by controlling engine stall margin as a function of flight and engine operating conditions. Improved inlet pressure recovery and decreased inlet drag can result from inlet control system integration.

Interactions between the propulsion and flight control systems (FCS) of an airplane become stronger as the cruise Mach number increases. The integration of propulsion control systems and propulsion flight control systems has shown significantly improved aircraft performance parameters such as range, thrust, and rate of climb. When the systems are not integrated, each system must be able to operate in a worst case combination with other systems and hence large operating margins are required.

Integration of systems studied by QuEST Global allows these margins to be reduced when the full margins are not required, thus resulting in higher thrust, lower fuel consumption, higher range, greater maneuverability, and better safety and reliability. The aspects of integrated flight propulsion control for both civil and military aircraft are studied.

This paper presents some preliminary thoughts on the control requirements for supersonic transport, identifies the key control integration issues, and presents some potentially beneficial integrated control modes, both for normal operations and for emergencies. In the case of fighter engines, the integrated control system involves the inlet, autopilot, auto-throttle, air-data, navigation, and stability augmentation systems. The thrust vectoring integrated flight control system provides enhanced maneuvering at high angles of attack.

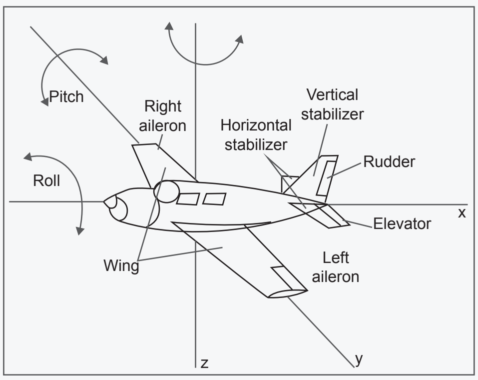
Using propulsion system forces and moments to augment the flight control system and airplane stability can reduce the flight control surface and tail size, weight, and drag. Special control modes may also be desirable for minimizing community noise and for emergency procedures. In addition, an adaptive optimization technique called Performance Seeking Control (PSC) has been studied.

With this whitepaper, QuEST Global aims to demonstrate the incorporation of integrated flight propulsion control system, one of the front line technologies being investigated. It is seen that such control integration can improve performance, reduce environmental impact, and improve safety. The integration of advanced flight controls with propulsion system can have great impact on service transformation, and next-generation product development.

The need for Aircraft Flight Control Systems

Aircrafts require control systems to control the forces of flight, direction, and attitude during the course of flight, using aircraft control surfaces. These flight control systems establish an interaction between the pilot and aircraft control surfaces. The focus has always been on making the interaction more easy and effortless, while making the flying experience a whole lot better.

Aircrafts consist of primary and secondary control surfaces:



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Primary control Surfaces
• Ailerons
• Elevator
• Rudder

Operation of primary flight control surfaces changes the airflow and pressure distribution over and around the airfoil. These changes directly affect the lift and drag produced by control surface

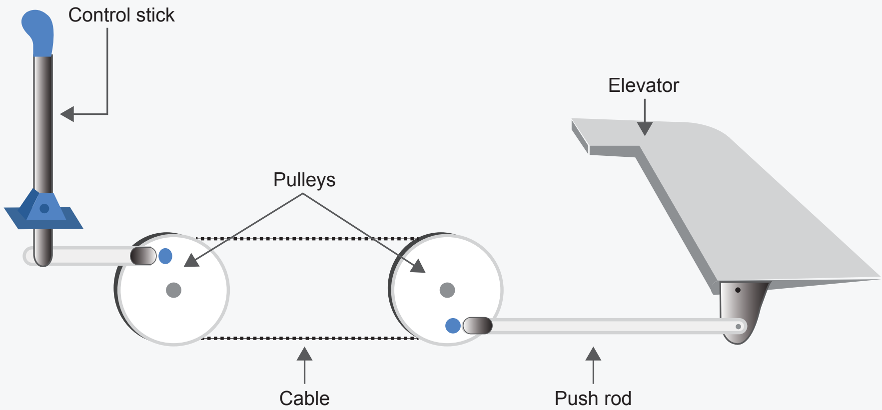
Secondary control surfaces (Assists the primary control surfaces)
• Horizontal and vertical stabilizer
• Wing Flaps
• Spoilers
• Trim Tabs
• Slats
• Winglets

combination, and allows a pilot to control the aircraft about its three axes of rotation. Aircraft control system inputs direct the movement of control surfaces about three axes of rotation.

The most basic flight control system dates back to the 18th century, consisting of a collection of mechanical parts such as rods, cables, pulleys, and chains to transmit the forces of the flight deck controls to the control surfaces. Modern day aircrafts use a variety of flight control systems. Yet an interesting fact is that the basic functionalities and operation of flight control systems till today remain the same regardless of their technological advancements.

Different types of flight control systems in use:

- Mechanical flight control system
- Hydraulic-Mechanical flight control system
- Fly-by-wire/Electronic flight control system



Mechanical Flight Control System	Hydraulic-Mechanical Flight Control System	Fly-by-wire/Electronic Flight Control System
Mechanical flight control systems are primarily made up of cables, pulleys, rods, and chains. It helps aircrafts recover during system failures and land safely. It is not advisable on large aircrafts as the pilot's strength becomes a major decision factor in times of emergency. These mechanical flight control systems cannot handle large stick forces.	In addition to mechanical flight controls, Hydraulic-Mechanical flight control systems include hydraulic lines, actuators, pumps, and a linkage between the hydraulic system and mechanical cockpit controls. It makes flying less demanding and allows high loads on physically larger control surfaces.	In Electronic flight control systems, the cockpit controls generate electronic signals that are interpreted by a computer system and are then converted into outputs that drive the hydraulic system connected to the flight surfaces. Engine control is also mediated by the FCS computers. Electronic flight control systems should be fault-tolerant and fail-safe during the course of flight.

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Benefits of Fly-by-wire/Electronic Flight Control Systems

- Ability to configure system characteristics at any point during the flight
- Benefits related to aircraft performance
- Ease of aircraft handling, reduces pilot workload
- The system ensures that the pilot doesn't put the aircraft into a state that stresses the airframe or stalls the aircraft
- Reduced maintenance costs

Aircraft Engine Control Systems and their types

The beating heart of an aircraft i.e., the engines are built in a large range of performances and types; it is compulsory to assist the engines with automatic control systems in order to achieve the desired performance and safety levels during the course of flight.

In modern day aircrafts, when engine is considered as a controlled object, there are a number of controlled parameters which in turn result in a large number of possible control programs in order to make the engine a reliable component. In most of the modern day aircrafts, engine fuel flow rate is used as an important parameter in control programs. The control system also receives a large number of items of real-time data about the status of various aircraft components and systems, and the conditions through which the aircraft is flying. The data on conditions in the engine is also transmitted to the aircraft.

It is impossible to assure an appropriate coordination of these multiple command laws, so it is compulsory to use some specific automatic control systems (controllers) to maintain the output parameters according to the desired range and performance.

Based on the type of engine and its performance, aircraft engine control systems can vary from simple hydro mechanical to super computing devices.

Hydro Mechanical Engine Control	Electronic Engine Control	Full Authority Digital Electronic Control (FADEC)
Mechanical controls between the throttle and engines fuel control unit (FCU) FCU is a hydro mechanical RPM governor that utilizes engine RPM, engine pressures, and temperatures to control engine thrust to the desired power setting selected by the pilot moving the throttles The throttles must be adjusted as per the changes in temperature and barometric pressure/altitude to maintain a constant thrust	The system is an upgrade of the basic cable, rods, and hydro mechanical FCU and plus an electronic engine control Electronic engine control will control the engine parameters to produce steady thrust during various courses of flight It monitors multiple engine parameters	FADEC is an engine control via "fly-by-wire"/completely electronic There are no mechanical controls between throttle and fuel controls FADEC receives the complete set of input parameters based on flight conditions at all instances Active health monitoring of all engine components

The future inclines towards a more electrical aircraft, backing up or replacing the hydraulic circuits feeding the flight control actuators with electrical power. The direct mechanical linkages between the cockpit controls and the control surfaces are removed and replaced with electrical signalling with direct motion commands.

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Insights on recent advancements in Flight Control Systems

- Implementation of flight control system architecture, in terms of number of actuators per surface, number and distribution of power sources and flight control computers, primarily driven by safety considerations
- During loss of control, the flight control actuation system will be supplied from several redundant power sources
- Primary flight control actuation systems controlling 21 flight surfaces
- Implementation of a mix electrohydraulic (EH) and electromechanical (EM) servo actuators and all associated control electronics
- Electrohydraulic servo actuators with remote loop closure electronics for the ailerons, flaperons, inboard and outboard spoilers, elevator, and rudder
- Usage of advanced materials and composites for weight-performance optimization
- Introduction of high lift systems to complete Flap and Slat Actuation Systems
- Adoption of two hydraulic and two electronic power sources to increase power source redundancy from three to four, providing further protection against common failures, such as maintenance errors, which may affect all the hydraulic systems
- Towards more electric propulsion system driven IFPC

Integrated Flight Propulsion Control System

Fly-by-wire is leading the way forward and is being incorporated in all modern day aircrafts. With aircraft manufacturers showing interest in going all electric, it has given way to the idea of developing an integrated flight propulsion control system. This idea is also the next logical step in moving forward into the future. If implemented, this integration could bring in a sea of change in the design and development of next generation aircrafts.

The system is a high performance digital flight controller that provides fly-by-wire flight control, integrated flight and propulsion control, aircraft centre-of-gravity computation for stores and fuel contents, structural air loads alleviation, and superior handling performance.

A generic integrated flight propulsion control system consists of separate blocks for mission management, coupling units for optimized flight, and control logic and feedback systems interfaced effectively to attain the best possible performance throughout the flight envelope.

The key factor is the synergistic effect of digital computers and associated high-speed data links, engine condition monitoring, diagnostics, and shared power systems (hydraulic and electrical), thus providing potential improvements in reliability, life cycle cost, weight, and maintenance actions.

In the integrated flight propulsion control system, the integration control laws are developed as an off-line process and stored in an on-board computer for implementation. Also real-time optimization improves the performance further compared to pre-programmed optimization. This results in an optimum integrated flight propulsion control.

- Integration of propulsion and flight control systems will provide significant performance improvements for supersonic transport airplanes
- Increased engine thrust and reduced fuel consumption can be obtained by controlling engine stall margin as a function of flight and engine operating conditions
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- Using propulsion system forces and moments to augment the flight control system and airplane stability can reduce the flight control surface and tail size, weight, and drag
- Special control modes may also be desirable for minimizing community noise and for emergency procedures. In addition, an adaptive optimization technique called performance seeking control (PSC) has been studied

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When considered early in the design phase, control integration can result in a lighter, lower-drag, safer, and less expensive airplane. It is therefore a logical progression that the demonstrated benefits of digital flight control and engine control systems has instigated development programs that are examining the next level of integration – that of Integrated Flight Propulsion Control (IFPC).

The IFPC employed on fighter aircraft has resulted in the following advantages:

- Stall free throttle transient operation
- Increasing the ceiling altitude
- Increasing the supersonic dash range
- Increase in thrust
- Faster throttle response from idle to maximum rating
- Enhanced aircraft manoeuvrability

Conclusion

The integrated flight propulsion control system will ensure best-in-class operations for the next generation aircraft, built on optimal architecture that is sufficiently robust to failures so as to ensure flight safety while minimizing the weight of the control system. Continuous advancements in redundancy management, fault-tolerant design, health monitoring systems, and failure mode analysis have increased control system reliability and integrity.

The use of digital control systems and their ability to share information and act on that shared information in an intelligent manner allows for optimum control of the engine and the overall aircraft. The level of integration and automatization can be greatly improved through the integration of systems, which significantly improves the efficiency of the aircraft. The potential gains of integrated flight propulsion control have started emerging and will be the next generation technology, inspiring research activities in the years to come.

Further area of research will be the aeroservoelasticity, which mainly deals with the study of the interaction of automatic flight controls on aircrafts and aero elastic response and stability.

The research and development of integrated flight propulsion control systems is further set to bring in bigger collaboration and active participation among industry players. It will evince keen interest among all the segments of the aerospace industry.

Down the line, the integrated flight propulsion control system is set to empower the commercial aircraft industry and revolutionize the mode of aircraft transport.

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Author Profile

Sundararajan

Sundararajan retired as Director of Gas Turbine Research Establishment (GTRE), Ministry of Defense, in 2002, after 37 years of service (20 years in Senior Management positions). Post retirement, for six years, he served as Advisor-Technology at Honeywell Technology Solutions Lab. (HTSL) Pvt. Ltd., Bangalore, where he supported competency development and technology enhancement. He joined QuEST on March 2, 2009.

His core areas of technical expertise include:

- Conceptual design and engine performance prediction and analysis
- Gas turbine engine, its components and sub systems
- Engine simulation and modeling
- Engine control system including D&D of FADEC system for Kaveri Engine
- Engine testing and performance evaluation
- Afterburner design and development
- Airframe-engine integration and integrate performance
- Engine model specification and ICD preparation
- Engine certification and qualification

Sundararajan is highly respected in the aerospace industry and academic circles for his knowledge, simplicity, and enthusiasm. He has been a focal point for a number of industry-university collaborations. He has also driven a number of technology initiatives in his previous assignments. An accomplished trainer, he has successfully mentored many engineers during his career. The Gas Turbine course delivered by Sundararajan is a must-do for every engineer in the aerospace domain. At QuEST, Sundarajan is the Head of the Technical Excellence Group.

Sundararajan's accomplishments:

- Responsible for the indigenous design, development, testing, and integration of a contemporary fighter aircraft
- Published more than 50 papers in national and international journals, seminars, and symposiums
- Chairman of the Propulsion Panel of the Aeronautical Research & Development Board (AR&DB), DRDO, and Ministry of Defense
- Indian Representative of the International Society for Air breathing Engines (ISOABE)

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Author Profile

Janakiraman

Janakiraman specializes in aerospace engine thermodynamic synthesis and performance analysis, computational modelling, analysis and experimental aerodynamics.

He graduated with a Bachelor of Engineering (Aeronautical) degree from Tagore Engineering College, Anna University with a University Rank in the year 2010. He was a research fellow at the Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR) and worked at the Indian Institute of Science (IISc) briefly. After his stint at IISc, he joined the Indian Institute of Technology, Madras (IITM) as a Project Associate and worked on experimental aerodynamics till April 2011. While working at IITM, he pursued a program in Project Management at the Loyola Institute of Business Administration (LIBA).

Janakiraman joined the Performance team at QuEST as a Trainee Engineer in April 2011 and supported Rolls-Royce plc. He is currently working as a System Design Engineer supporting Honeywell Aerospace. During his under graduation, he had worked as a part time content writer and had written a number of scientific articles.

Janakiraman is credited with the following achievements:

- A Six Sigma Green Belt, certified by Micro, Small and Medium Enterprises (MSME), Government of India
- Published two international papers on Ornithopter design and development at the Asian Congress of Fluid Mechanics (ACFM) and Fluid Mechanics and Fluid Power (FMFP) conference

At QuEST, his current role includes:

- Supporting Honeywell Aerospace in systems design, verification and validation
- Data mining, root cause analysis, system level problem solving and troubleshooting
- Integration of component design, analyses, performance and manufacturing teams
- Team building and knowledge sharing

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About QuEST Global

QuEST Global is a focused global engineering solutions provider with a proven track record of over 17 years serving the product development & production engineering needs of high technology companies. A pioneer in global engineering services, QuEST is a trusted, strategic and long term partner for many Fortune 500 companies in the Aero Engines, Aerospace & Defence, Transportation, Oil & Gas, Power, Healthcare and other high tech industries. The company offers mechanical, electrical, electronics, embedded, engineering software, engineering analytics, manufacturing engineering and supply chain transformative solutions across the complete engineering lifecycle.

QuEST partners with customers to continuously create value through customer-centric culture, continuous improvement mind-set, as well as domain specific engineering capability. Through its local-global model, QuEST provides maximum value engineering interactions locally, along with high quality deliveries at optimal cost from global locations. The company comprises of more than 7,000 passionate engineers of nine different nationalities intent on making a positive impact to the business of world class customers, transforming the way they do engineering.

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