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Civil Air Transport: A Fresh Look at Power-by-Wire and Fly-by-Light

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CIVIL AIR TRANSPORT: A FRESH LOOK AT POWER-BY-WIRE AND FLY-BY-LIGHT

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Abstract

Power-by-wire (PBW) is a key element under subsonic transport flight systems technology with potential savings of over 10 percent in gross take off weight and in fuel consumption compared to today's transport aircraft. The PBW technology substitutes electrical actuation in place of centralized hydraulics, uses internal starter-motor/generators and eliminates the need for variable engine bleed air to supply cabin comfort.

The application of advanced fiber optics to the electrical power system controls, to built-in-test (BITE) equipment, and to fly-by-light (FBL) flight controls provides additional benefits in lightning and high energy radio frequency (HERF) immunity over existing mechanical or even fly-by-wire controls. This paper will review the program plan and give a snapshot of the key technologies and their benefits to all future aircraft - civil and military.

Introduction

NASA in response to a directive from the U.S. Senate has developed a multiyear technology development and validation plan that will help the United States retain its leadership in aeronautics research and technology and compete in the international marketplace for future civil aircraft. One of the key elements under subsonic transport flight systems technology is power-by-wire (PBW) with potential savings of over 10 percent in gross take-off-weight (GTOW) and fuel consumption compared to today's aircraft (Ref. 1). Fly-by-light (FBL), which is the replacement of electronic data transmission, mechanical control linkages, and electronic sensors with optical components and subsystems, is another key element.

In the NASA Lewis Research Center study reported in Ref. 1 the stated benefits are shown to be possible through the integration of an advanced secondary electrical power system into a civil transport aircraft using a Boeing 767 as a baseline. While the particular benefits may depend on aircraft size and type, engines, and specific electrical and flight control systems, the range of improvements is consistent with available advanced technologies.

The primary weight reduction occurred in the secondary power system when the baseline hydraulic, pneumatic and electrical subsystems were replaced with a single, advanced high frequency, sinusoidal power management and distribution (PMAD) system with controlled energy flow and load management. An advanced fly-by-wire flight control system using electrical actuators and advanced low fixed bleed high bypass ratio engines contribute the remaining major advantages according to the NASA Lewis study. The single electrical power system provides higher component utilization with significant reductions in parts count, weight, failure modes, and cost of ownership.

The PBW technology eliminates the need for hydraulic actuation and for engine bleed air to supply cabin comfort and anti-icing. It enables integral starter/generators for engine starting and power generation to be used with advanced energy-efficient engines without gearboxes. These changes significantly improve fuel efficiency and reduce aircraft weight. Improved safety and dispatch reliability combined with lower maintenance and direct operating costs are additional tangible benefits.

According to the study, eliminating the engine bleed for powering the environmental control system (ECS) and for anti-icing provided the largest single fuel savings of any proposed change. An electric motor driven ECS with electric impulse driven de-icers are the proposed replacements.

Subsequent to the NASA Lewis study, additional technologies have emerged. The application of advanced fiber optics to the electrical power system controls, to built-in-test (BITE) equipment, and to fly-by-light (FBL) flight controls provides additional benefits in lightning and high energy radio frequency (HERF) immunity over existing mechanical or even fly-by-wire controls.

This paper will review the program plan and take a fresh look at some of the key technologies and their benefits to all future aircraft - civilian and military. Figure 1 shows the payoffs and the major tasks planned for the PBW element. Figure 2 summarizes the primary elements of the FBL/PBW 5-yr program plan under the Civil Transport Initiative.

The Electrical Powerplant

The heart of the electrical power system is a multiredundant, fault tolerant, microprocessor controlled, power management and distribution (PMAD) system. It incorporates bidirectional inverters driven through a high frequency, resonant utility bus connected to internal starter-motor/generators, thereby eliminating gearboxes and the need for separate APU's and engine starters. The high frequency utility bus permits all the advantages of ac for stability, fault clearing, differential monitoring and control, as well as significant crew/technician safety because of its low energy per pulse nature and ease of ground fault interruption. Figure 3 shows a typical utility bus architecture for an ac PMAD system using advanced electronic switching for power conditioning, control, distribution, protection and a fault tolerant architecture (Ref. 1).

The characteristics of the advanced PMAD system provide the conduit to the benefits for PBW in civil transport and perhaps certain military aircraft. The resonant, high frequency (>10 kHz) link drive enables either multiphase low frequency ac sources or dc sources to operate at their optimum voltage and frequency at the input. Since the main inverters switch at the zero crossing of either current or voltage, they minimize power losses, component stress, EMI/EMC and the need for heavy, bulky filters. The high frequency bidirectional conversion and synthesis significantly reduces the size and mass of the electronics components, controls and systematics.

The key benefit, however, comes in the ability to drive all kinds of motors (including rugged induction motors with high temperature capability) in either direction with independent control of torque, speed and maximized, efficient operation over the entire speed range. In effect, all load control including variable speed motor drive is accomplished by sorting and steering the high frequency sinusoidal pulses to the appropriate power switch, motor winding or energy storage element. Voltage regulation, power quality and energy flow are determined and managed at all times and within specified limits. Multiple levels of redundancy are easily accommodated in the system, providing fault containment, fault recovery, and maximized end-to-end efficiency.

Electrical Actuation

Existing electrical actuation technology in the 5- to 50-hp range will be adapted to the flight control and other actuation requirements on an aircraft. Prototype electrical actuators operating from the distributed power bus will be built and demonstrated in a full avionics control environment.

The electric actuators would replace hydraulic actuators, servovalves, and mechanical control linkages. An advanced electrical actuation system includes electromechanical and/or electrohydraulic actuators, load receivers, redundant digital data buses, and remote terminals. Electrical actuators perform the same functions as hydraulic actuators with lower weight, higher efficiency and without sizing restrictions.

The digital data bus and electro-optical sensors and controls promise to be a much lighter weight, more reliable and EMI immune approach than fly-by-wire or mechanical controls. Also, many functions previously done with hardware can now be done with software. This may include such functions as control surface damping and trim.

Status and Health

Microchip level BITE will be built into the hardware to provide a "fingerprint", which may include component characteristics, test information and validation parameters. Such smart BITE chips could provide health self-testing for pre-flight checkout, for in-flight status and for maintenance assistance and records.

The keys to autonomous, growable power and control systems are simple, smart, replicative logic structures. Pushing the intelligence down to the power switch and circuit level enables easy verification, validation, status, and maintainability. It provides step-by-step transitions from manual to autonomous controls. Integrated health monitoring, incipient fault prediction and a controlled evolution of power and avionic systems are readily accommodated with each node communicating with other nodes via simple, common words. This enables distributed intelligence for fault containment, fault tolerance, and autonomous control without massive software investments.

Electro-optical Controls

The fly-by-light (FBL) controls are proposed as a replacement of electrical data transmission, mechanical control linkages and electronic sensors with optical components and subsystems. They circumvent electromagnetic interference (EMI) concerns in applying digital controls by providing lifetime immunity to signal EMI without need for shielding. The FBL technology will demonstrate optical sensors and interfaces with improved lightning and HERF immunity.

The FBL program will identify, develop, and evaluate an optical sensor suite. The sensors will be integrated into innovative electro-optical based fault-tolerant architectures using optical networks and multiplexer/demultiplexer techniques. Performance and reliability assessments of the fault tolerant processors and architectures will provide a basis for developing hardware and software for flight test and inservice evaluation.

Several ongoing activities will feed technology into the FBL program: the fiber optical control system integration (FOCSI) program, the optical propulsion management interface system being designed into the advanced transport operating system aircraft, and a fiber optical transmitter/receiver with a dc 4-GHz bandwidth. An extensive data base and experimental investigation of lightning effects on digital electronics will serve as a baseline for assessing FBL enhancements to the flight control system.

Summary

The goal of the FBL/PBW program is to accomplish credible flight tests and demonstration of full authority, all digital FBL/PBW transport aircraft systems. Performance will be evaluated in the stress of flight environments. The program will use the NASA advanced transport operating system aircraft. Using parallel operation of experimental equipment on the basic aircraft will maximize flight test safety.

The flight tests will be designed to verify and evaluate the integrated system. FAA participation and coordination will be integral to developing a prototype certification model.

Reference

1. Hoffman, A.C. et al., Advanced Secondary Power System for Transport Aircraft, NASA TP-2463; May 1985.

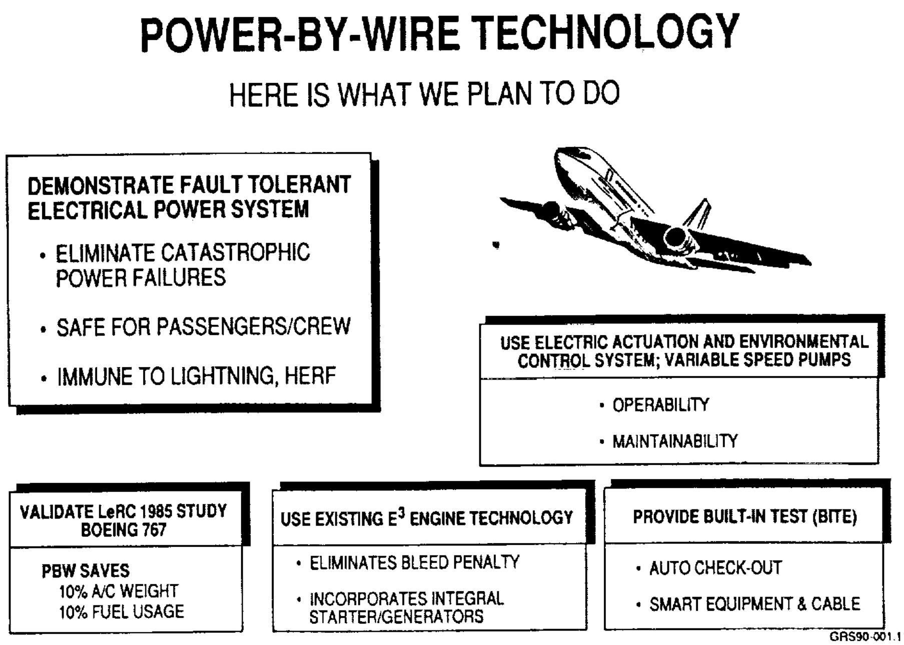

FIGURE 1. - MAJOR TASKS AND BENEFITS OF POWER-BY-WIRE TECHNOLOGY.

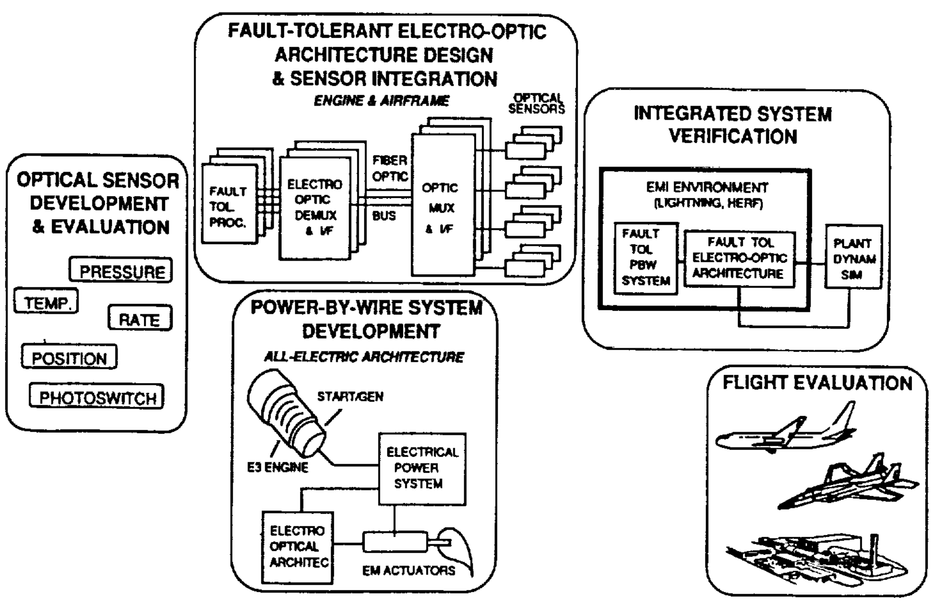

FIGURE 2. - ELEMENTS OF FLY-BY-LIGHT/POWER-BY-WIRE PROGRAM.

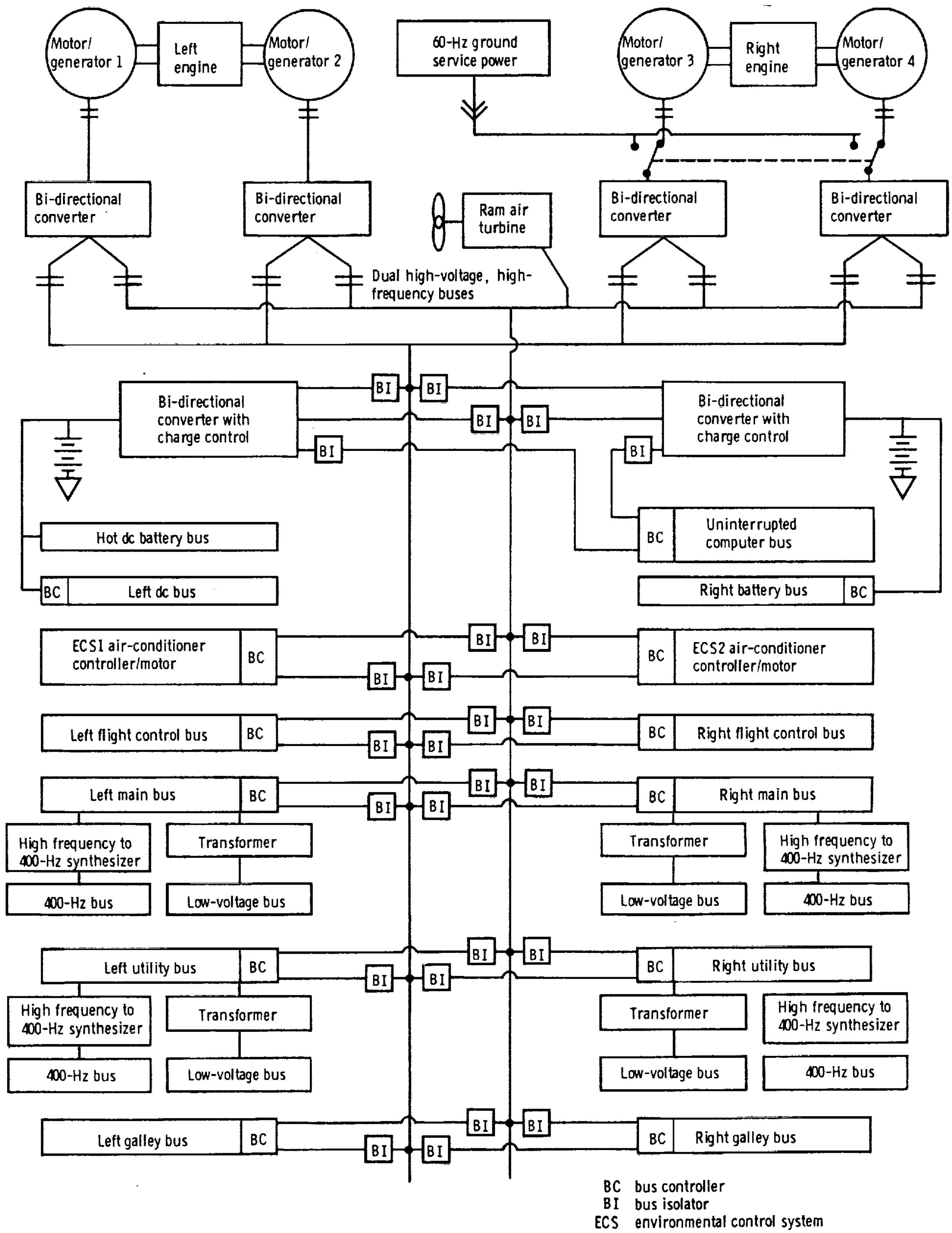

FIGURE 3. - ADVANCED POWER DISTRIBUTION SYSTEM.

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