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V - FIBER OPTICS FOR CONTROLS

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The challenge of those involved in aircraft-control-system hardware development is to accommodate an ever-increasing complexity in aircraft control, while limiting the size and weight of the control system components and improving system reliability. A technology that displays promise towards this end is fiber optics. The application of fiber-optic/electro-optic technology to aircraft control systems boasts a number of inherent advantages over current wire-based systems. Replacing the propulsion and flight control system electrical wiring with optical fibers results in a substantial weight and volume savings. For example, in an F-15 fighter, the weight reduction is estimated to be 57 kg (125 lb) while for transport aircraft, weight savings could reach as high as 680 kg (1500 lb). Because optical fibers are dielectric, problems with electromagnetic interference, and electromagnetic pulse and lightning susceptabilty are eliminated. This, in turn, eliminates the need for shielding and surge-quenching circuits. This is particularly advantageous as modern aircraft move towards the use of composite structures, which provide little inherent shielding. The high bandwidth capability is advantageous for data bus lines and offers the potential for all avionics data to be transmitted over a single line. Fiber optics also eliminates the threat of fires due to insulation failures or short circuits which could cause inadvertent actuation of control hardware.

Figure V-1 shows an artist's conception of a fly-by-light aircraft. In this greatly simplified diagram, the engine control and flight control computers are linked to their respective set of optical sensors and optical actuators using fiber optic cables and an electro-optic interface (not shown).

FIBER-OPTIC CONTROL SYSTEM INTEGRATION PROGRAM (FOCSI)

The design, development, and testing of a fiber-optic integrated propulsion/flight control system for an advanced supersonic dash aircraft (flies at supersonic speeds for short periods of time) is the goal of the joint NASA and DOD Fiber-Optic Control System Integration (FOCSI) program. Phase I, which assessed current technology and provided system design options, was completed early in fiscal year 1987 (Oct. 1986) (refs. V-1 and V-2). Phase I provided a comparison of electronic and optical control systems, identified the status of current optical sensor technology, defined the aircraft sensor/actuator environment, proposed architectures for fully optical control systems, and provided schedules for development. Overall, it was determined that there are sufficient advantages in employing a fiber-optic-based control system to warrant continued efforts to develop such a system. It was also determined that it is feasible to build a fiber-optic control system for the development of a data base for this technology, but that further work is necessary in sensors, actuators, and components to develop an optimum-design, fully fiber-optic integrated control system compatible with advanced aircraft environments.

Phase II, which is to design, construct, and ground-test a fly-by-light control system, has been initiated, with the first task aimed at providing a detailed design of the electro-optic architecture required.

A phase III program for flight test of the system is currently under consideration to establish an initial data base on the performance, reliability, and maintainability of fly-by-light control systems.

FIBER-OPTIC SENSORS PROGRAM

As indicated in the previous section, to implement a fiber-optic control system requires the development of passive optical sensors and optically controlled or powered actuators capable of surviving aircraft environments. Table V-I provides a preliminary list of the set of control and condition monitoring sensors being considered for incorporation into the FOCSI control system. The entire control system must be flight qualified to withstand a supersonic dash aircraft environment. It must perform reliably with repeated temperature cycling and vibration. The most severe overall environments occur in the engine bay areas. For current-generation fighters, the highest soaking temperature a sensor may see is 473 K (200 °C) and the lowest is 218 K (-55 °C), while the highest gas stream temperature that the sensing element may see is 1370 K (1100 °C) (in the hot section, ref. V-1). Fiber-optic cables and connectors in the engine bay area are exposed to a temperature range of 218 K to in excess of 373 K (100 °C). The electro-optics are contained within the protected engine control computer environment and must operate reliably in a temperature range of 218 to 358 K (-55 to 85 °C), although flight qualification requires military specification components which are tested to 398 K (125 °C). Currently, actuators would most likely be of the optically-controlled variety, able to operate reliably in a temperature environment from 218 to 423 K (-55 to 150 °C)

NASA Lewis has addressed this critical area of technology since 1975 by developing a wide variety of optical sensors and a high-temperature electro-optic switch through in-house, contract, and grant efforts (refs. V-3 to V-11). A list of accomplishments in this area is presented in table V-II.

Currently, work is continuing to improve methods for temperature, pressure, and position measurements; and work has been initiated to develop referencing techniques for intensity modulated sensors, optical sensor multiplexing schemes, and shock position sensors (refs. V-12 to V-30). Two examples which will be discussed further are a wavelength division multiplexed (WDM) optical encoder and a semiconductor-etalon temperature sensor (refs. V-31 to V-34).

A diagram of the wavelength division multiplexed optical encoder is shown in figure V-2. It uses a micro-optical wavelength multiplexer/demultiplexer in conjunction with a reflective code plate. This approach results in a compact, rugged, and potentially inexpensive device. The multiplexer unit consists of a 5-mm-diameter graded index (GRIN) rod lens epoxied to a prism/grating assembly.

Broadband light from two LED's enters the transducer via the encoder input/output fiber. The multiplexer disperses the broadband spectrum across the channels of a reflective code plate. Those wavelengths directed to a channel in the logic zero state are absorbed by the code plate. Those wavelengths directed to a channel in the logic 1 state are reflected by the code plate and retransmitted to the input/output fiber. At the receiver of the WDM optical encoder, demultiplexing is performed by a second grating assembly which disperses the spectrum onto a photodiode array. The pattern of "on"-peaks (logic 1) and "off"-valleys (logic 0) defines the position of the actuator to 10-bit resolution. Currently, a prototype encoder is being constructed for future engine and flight tests. Figure V-3 is a photograph of the current prototype.

A schematic diagram of a semiconductor-etalon temperature sensor is presented in figure V-4. The sensing element is a silicon carbide (SiC) etalon on silicon (Si). Light incident on the etalon is partially reflected from both of its surfaces. Interference patterns from these reflected beams can be related to the optical thickness of the etalon which, in turn, is a function of the temperature. An optical fiber delivers light to the sensor. A graded index (GRIN) rod microlens collimates this light and directs it towards the sensing etalon. Light reflected by the etalon is recoupled into the fiber by the GRIN lens. A dual interferometer (not shown) system is employed to determine the optical thickness. An alumina tube positions the sensing etalon a distance of 5 cm from the GRIN rod lens to permit the measurement of temperatures significantly higher than can be withstood by the fiber and GRIN rod lens. The sensing etalon is a single-crystal film of silicon carbide (SiC) with a thickness of 18 μm. A silicon substrate provides mechanical support to the SiC and serves to protect its surface. A smaller, more advanced version of the sensor is currently being constructed. Figure V-5 is a photograph of an earlier, larger prototype.

CONCLUDING REMARKS

NASA intends to continue to aggressively pursue all the areas of fiber-optic technology presented. Future directions in the program are described as follows:

(1) Continue efforts aimed at achieving FOCSI objectives
(2) Continue development of novel fiber-optic sensor concepts
(3) Develop engine test prototypes of promising fiber-optic sensor systems
(4) Study innovative approaches to actuation device design
(5) Serve as focus for achieving consensus on fiber-optic component specifications for aircraft

One area which deserves attention in the near term is fly-by-light control systems for future generation fighter aircraft and high-speed aircraft such as those flying in sustained supersonic or hypersonic regimes. Such control systems will require fiber-optic components capable of much higher temperature operation than was reported here.

TABLE V-I. - PRELIMINARY FOCSI SENSOR SET

Propulsion	Flight
Control sensors	
Pressure Compressor inlet, discharge Turbine discharge Speed Fan Core Temperature Compressor, turbine inlet Turbine blade Actuator positions Fuel flow Light-off detector	Actuator positions Pressure (total, static) Mach number Angle of attack Total temperature Interface with flight guidance
Condition monitoring sensors	
Oil temperature, level, debris Vibration Fuel temperature	Hydraulic pressure, temperature, level Fuel level

TABLE V-II. - FIBER-OPTIC SENSORS PROGRAM ACCOMPLISHMENTS

Accomplishment	Date
Tachometer demonstrated on engine	1976
Position encoder demonstrated on compressor guide vane	1976
Tip clearance sensor demonstrated on compressor stage	1980
800 °C temperature sensor developed (absorption)	1980
1000 °C temperature sensor developed (Fabry-Perot)	1983
Gallium arsenide photoswitch developed (260 °C operation)	1985
High-temperature pressure sensor developed (microbend)	1985
1700 °C gas temperature sensor developed (blackbody)	1986
Intensity sensor referencing techniques developed	1987

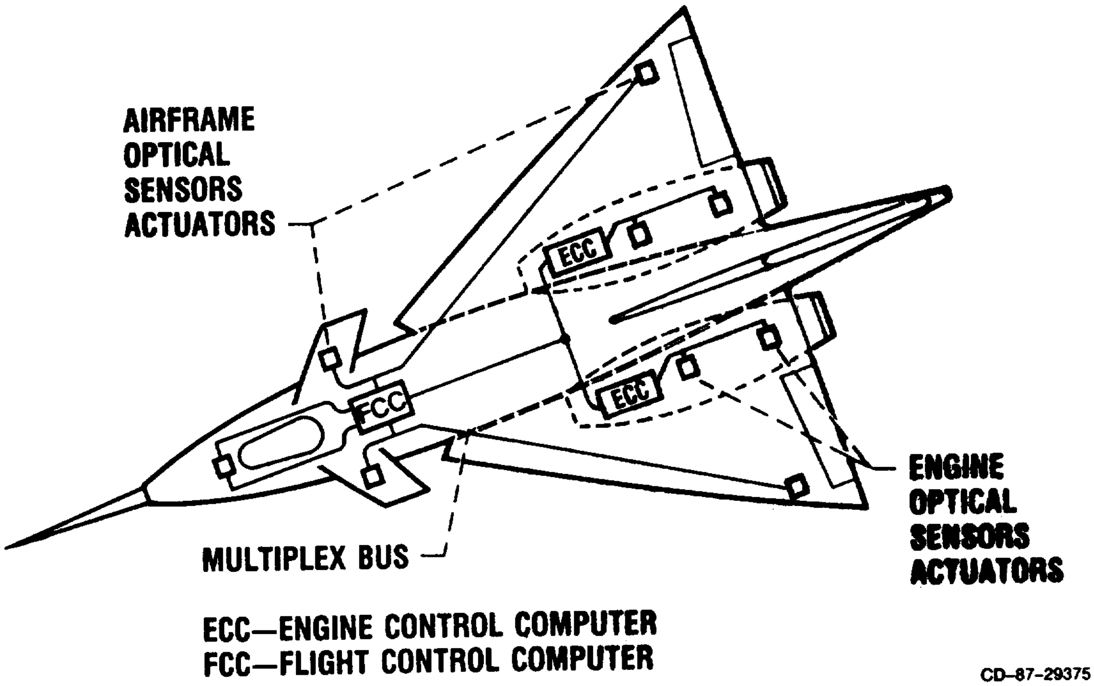

Figure V-1. - Fly-by-light aircraft.

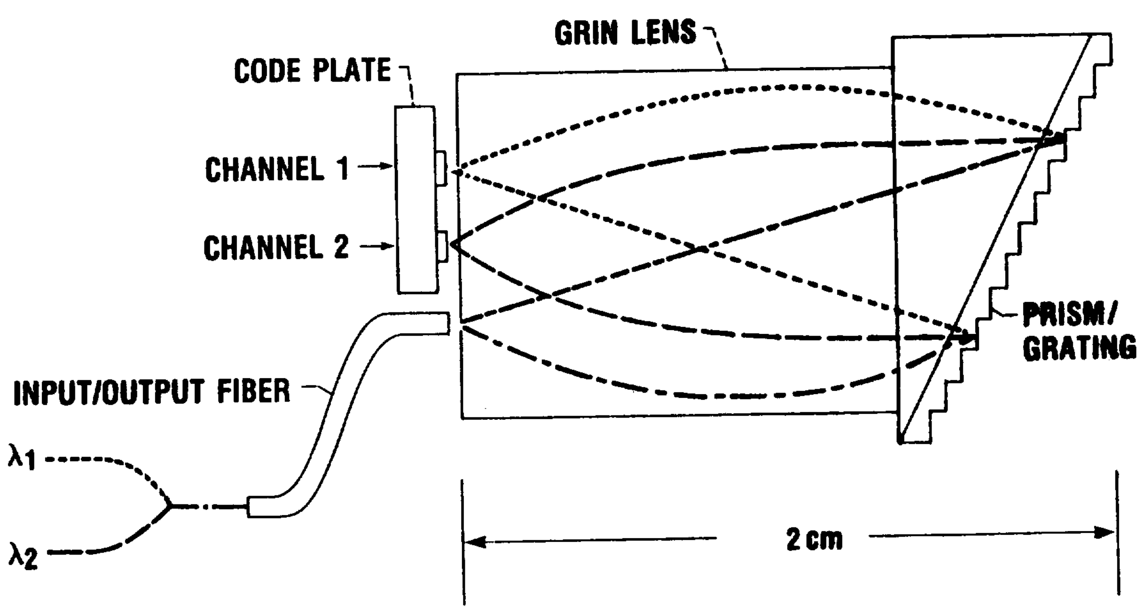

Figure V-2. - Wavelength division multiplexed (WDM) optical encoder.

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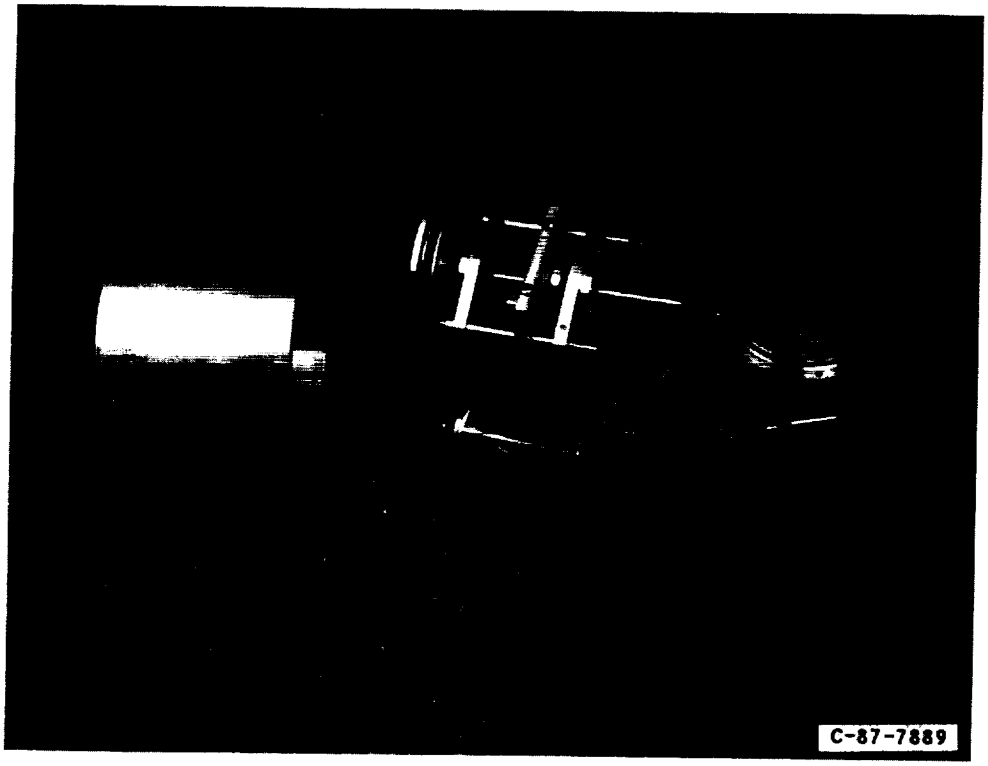

Figure V-3. - Prototype WDM optical encoder.

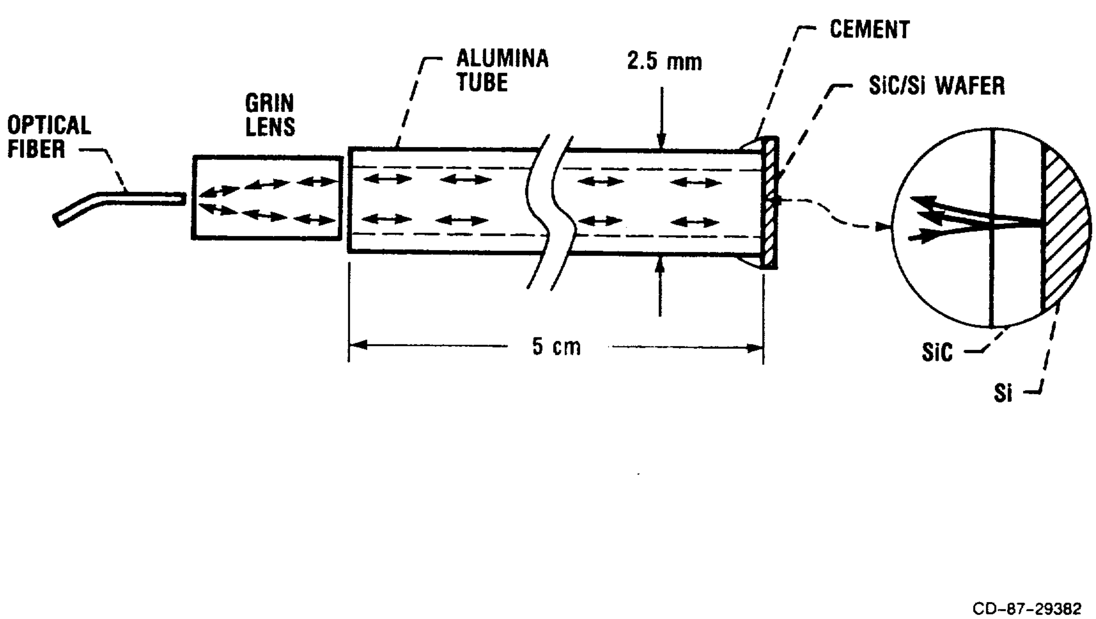

Figure V-4. - Semiconductor-etalon temperature sensor.

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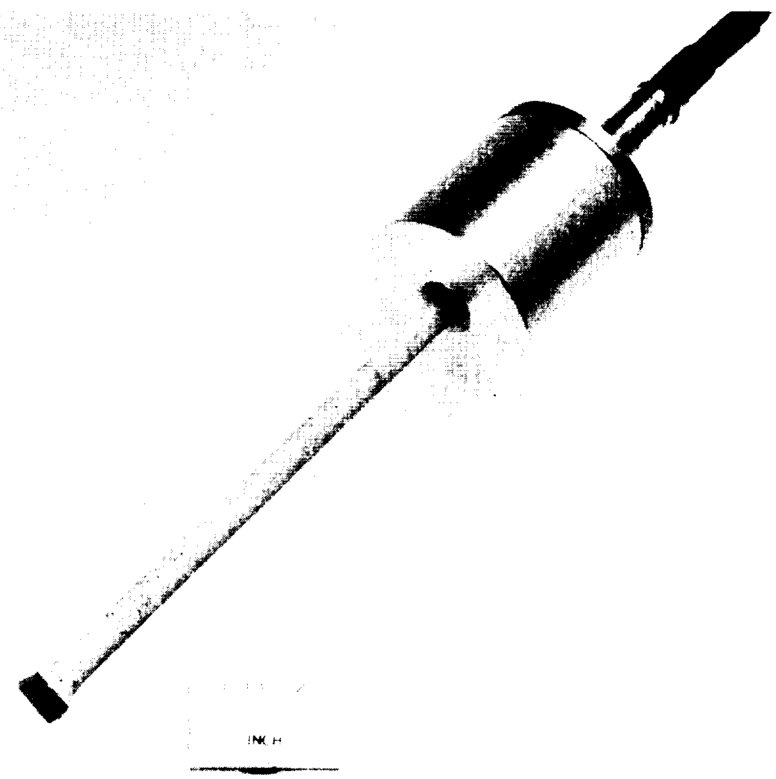

Figure V-5. - Prototype temperature sensor.