NASA TM-100919

NASA Technical Memorandum 100919

Overview of NASA Research in Fiber Optics for Aircraft Controls

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Prepared for the
ISA/88 International Conference and Exhibit
sponsored by the Instrument Society of America
Houston, Texas, October 16-21, 1988

OVERVIEW OF NASA RESEARCH IN FIBER OPTICS FOR AIRCRAFT CONTROLS

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SUMMARY

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 components and improving system reliability. A technology that displays promise towards this end is fiber optics. The primary advantages of employing optical fibers, passive optical sensors and optically controlled actuators are weight/volume reduction, immunity from electromagnetic effects, high bandwidth capabilities and freedom from short circuits/sparking contacts. Since 1975, NASA Lewis has been performing in-house, contract and grant research in fiber optic sensors, high temperature electro-optic switches and "fly-by-light" control system architecture. Passive optical sensor development is an essential yet challenging area of work and has therefore received much attention during this period. A major effort to develop fly-by-light control system technology, known as the "Fiber Optic Control System Integration" (FOCSI) program was initiated in 1985 as a cooperative effort between NASA and the DOD. Phase I of FOCSI, completed in 1986, was aimed at the design of a fiber optic integrated propulsion/flight control system. Phase II will provide subcomponent and system development, and system testing. In addition to a summary of the benefits of fiber optics, the FOCSI program, sensor advances, and future directions in the NASA Lewis program will be discussed.

INTRODUCTION

The application of fiber optic/electro-optic technology to aircraft control systems holds much future promise due to 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 a 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). Due to the fact that optical fibers are dielectric, problems with electromagnetic interference, electromagnetic pulse, and lighting are eliminated, which 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.

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Figure 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 shown 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

The design, development and testing of a fiber optic integrated propulsion/ flight control system for an advanced supersonic dash aircraft is the goal of the joint NASA and DOD Fiber Optic Control System Integration (FOCSI) program. Phase I, to assess current technology and provide system design options, was completed early in fiscal year 1987 (Oct. 1986) (refs. 1 and 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 database 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, 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 database on the performance, reliability, and maintainability of fly-by-light control systems.

FIBER OPTIC SENSORS PROGRAM

As was 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 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, i.e., it must perform reliably with repeated temperature cycling and vibration. The most severe overall environments occur in the engine bay areas. Here the highest soaking temperature a sensor may see is 423 K (150 °C) and the lowest is 218 K (-55 °C), while the highest temperature the active surface may see is 1370 K (1100 °C) in penetrating the hot section (ref. 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 (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.

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 (ref. 3). Laboratory prototypes have been developed and tested for measurement of temperatures (218 to 1973 K), pressure, speed, position, flow and blade tip clearance.

Currently work is continuing to improve methods for temperature, pressure and position measurements and has been initiated to develop referencing techniques for intensity modulated sensors, optical sensor multiplexing schemes, and shock position sensors (refs. 4 and 5). Two examples which will be discussed further are a wavelength division multiplexed optical encoder and a semiconductor-etalon temperature sensor (refs. 5 to 8).

A diagram of the wavelength division multiplexed optical encoder is shown in figure 3. 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 LEDs 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 one 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 ten bit resolution. Currently, a prototype encoder is being constructed for future engine and flight tests.

A schematic diagram of a semiconductor etalon temperature sensor is presented in figure 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 rod (GRIN) 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. To permit the measurement of temperatures significantly higher than can be withstood by the fiber and graded index (GRIN) rod lens, an alumina tube positions the sensing etalon a distance of 5 cm from the GRIN 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.

SUMMARY AND CONCLUDING REMARKS

A description of the NASA Lewis program in fiber optics for aircraft control systems has been presented including FOCSI, a NASA and DOD contracted program to design, develop and test a fly-by-light aircraft control system, and an in-house, contract, and grant program to develop and test fiber optic sensors and optically controlled actuators.

NASA intends to continue to aggressively pursue all areas of this technology. Additionally, we are interested in serving as a focus for achieving a 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.

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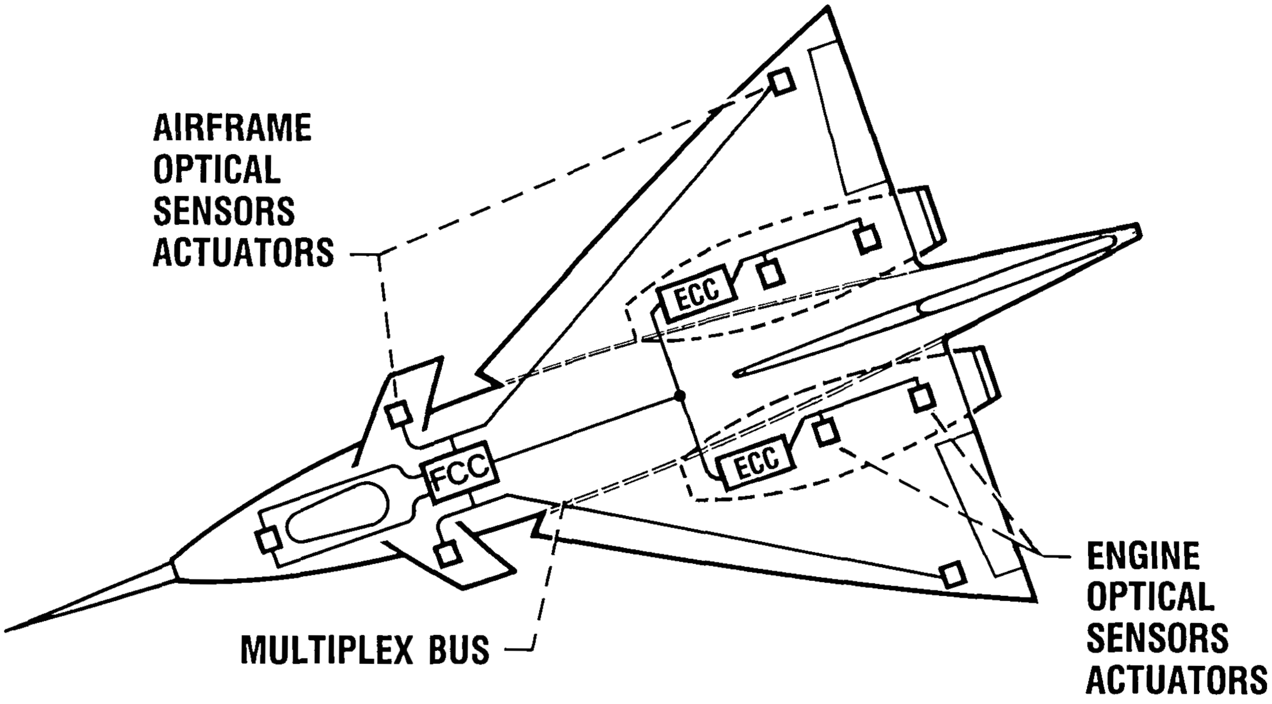
TABLE I. - PRELIMINARY FOCSI SENSOR SET

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



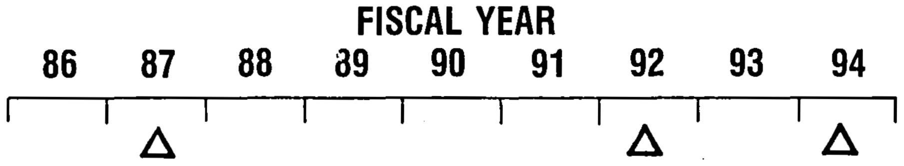
ECC—ENGINE CONTROL COMPUTER
FCC—FLIGHT CONTROL COMPUTER

FIGURE 1. - FLY-BY-LIGHT AIRCRAFT.

OBJECTIVE

DEVELOP THE TECHNOLOGY NECESSARY TO INCORPORATE A FIBER-OPTIC INTEGRATED PROPULSION/FLIGHT CONTROL SYSTEM INTO AN ADVANCED SUPERSONIC AIRCRAFT

SCHEDULE



PHASE I: PROPULSION/FLIGHT CONTROL DESIGN

PHASE II: SUBCOMPONENT/SYSTEM DEVELOPMENT
ENGINE/IRON BIRD TEST

- NASA/DOD COOPERATIVE EFFORT
- RESULTS APPLICABLE TO FUTURE ADVANCED ROTORCRAFT

FIGURE 2. - FIBER OPTIC CONTROL SYSTEM INTEGRATION PROGRAM.

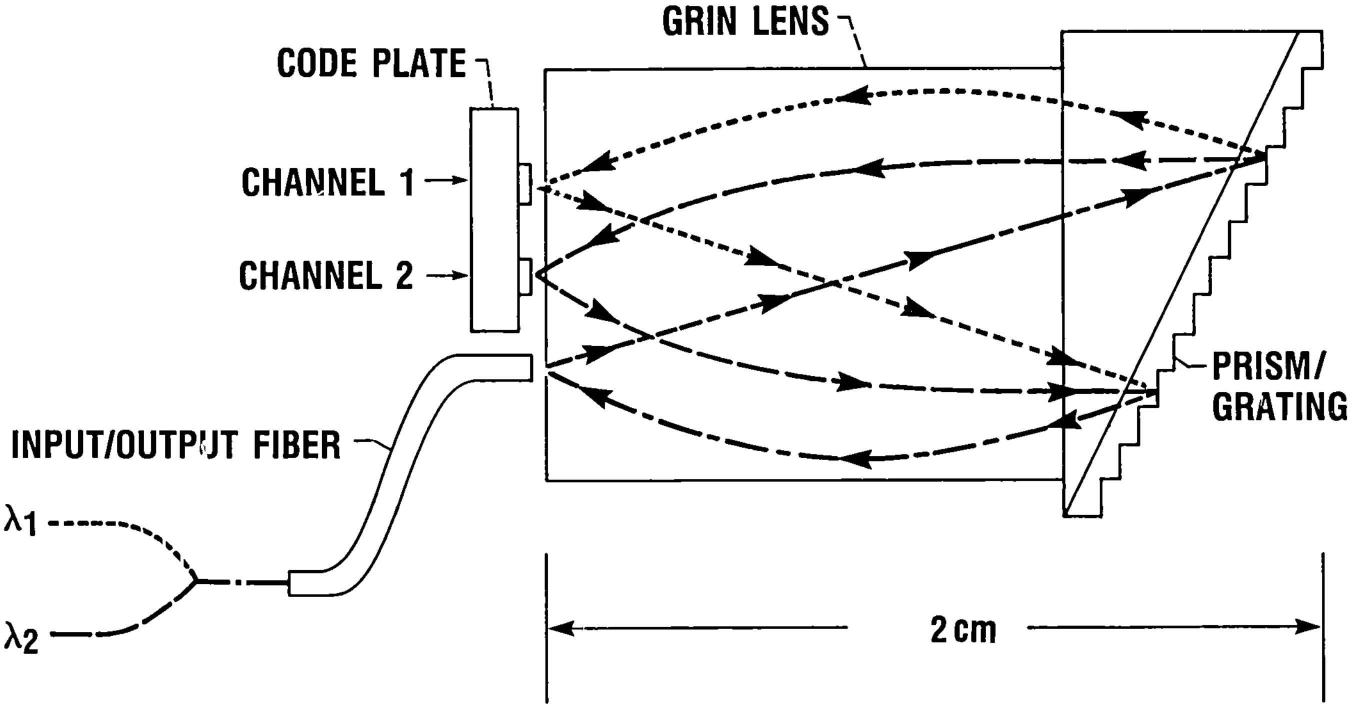


FIGURE 3. - WAVELENGTH DIVISION MULTIPLEXED OPTICAL ENCODER.

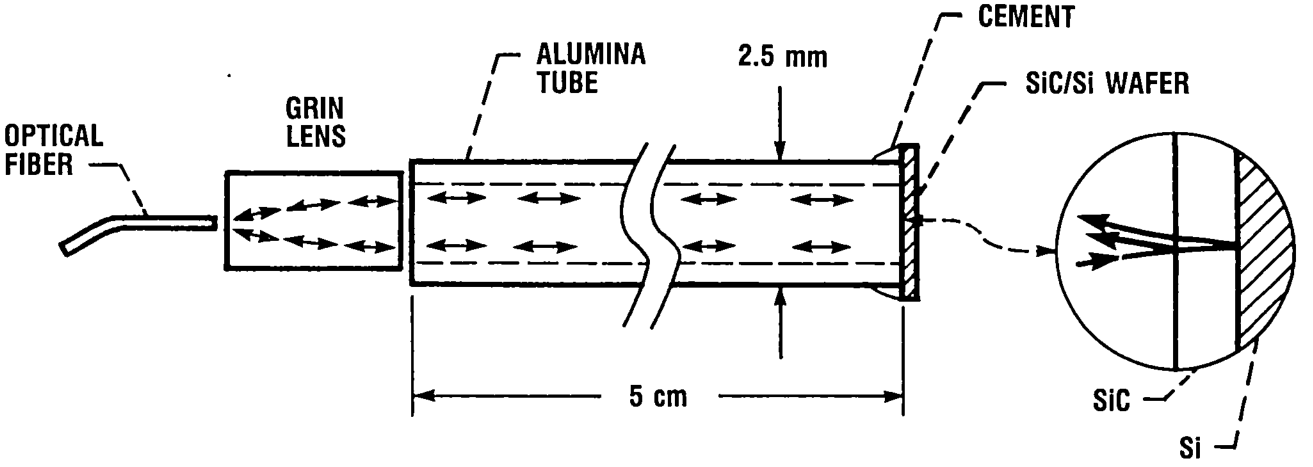


FIGURE 4. - SEMICONDUCTOR-ETALON TEMPERATURE SENSOR.

CD-87-29382

NASA
National Aeronautics and Space Administration

Report Documentation Page

1. Report No. NASA TM-100919	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle

Overview of NASA Research in Fiber Optics for Aircraft Controls

5. Report Date

6. Performing Organization Code

7. Author(s)

Gary T. Seng

8. Performing Organization Report No.

E-4156

10. Work Unit No.

505-62-01

9. Performing Organization Name and Address

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135-3191

11. Contract or Grant No.

13. Type of Report and Period Covered

Technical Memorandum

12. Sponsoring Agency Name and Address

National Aeronautics and Space Administration
Washington, D.C. 20546-0001

14. Sponsoring Agency Code

15. *Supplementary Notes*

Prepared for the ISA/88 International Conference and Exhibit sponsored by the Instrument Society of America, Houston, Texas, October 16-21, 1988.

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17. Key Words (Suggested by Author(s)) Fiber optic sensors; Fiber optic control systems; Aircraft control systems; Aircraft controls; Fiber optic-based controls; Optical sensors	18. Distribution Statement Unclassified - Unlimited Subject Category 07

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No of pages 8	22. Price* A02

NASA FORM 1626 OCT 86

*For sale by the National Technical Information Service, Springfield, Virginia 22161

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Space Administration

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