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Technology Review of Flight Crucial Flight Control Systems

(Application of Optical Technology)

H.A. Rediess and E.C. Buckley

HR Textron Inc.
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Contract NAS1-17403

September 1984

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NASA Contract NAS1-17403

In accordance with the provisions of NASA Contract NAS1-17403, the attached report is forwarded for your information.

Sincerely,

Herman A. Rediess
Vice President
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Enclosure

Report on "Technology Review of Flight Cruical Flight Control Systems" (Application of Optical Technology)

NASA Contractor Report 172332 (Supplement 1)

TECHNOLOGY REVIEW

OF

FLIGHT CRUCIAL FLIGHT CONTROL SYSTEMS

(APPLICATION OF OPTICAL TECHNOLOGY)

SEPTEMBER 1984

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PREFACE

This report is a supplement to NASA CR 172332 and describes the results of a technical survey in the application of optical technology to aircraft flight controls.

This survey was conducted by HR Textron Inc. under contract NAS1-17403 and the Technical Representative of the Contracting Officer was Mr. Cary Spitzer, NASA Langley Research Center. The material presented herein solely represents the findings and opinions of the authors and is not to be construed as being endorsed by the US Government or representatives of the National Aeronautics and Space Administration.

As part of this survey task, an optics technology questionnaire was forwarded to prominent technologists. The authors wish to acknowledge the contribution provided by respondents, and to note that the conclusions drawn from the questionnaire are not necessarily endorsed by the contributors.

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INTRODUCTION

A survey of technology in flight critical (crucial) flight controls was conducted for NASA Langley Research Center as a data base for planning future research and technology programs. The results of that survey were published in April 1984. As an extension of that task, a complementary survey was conducted to access the state-of-technology in optical devices for application to aircraft flight controls, and is reported here.

There are several motivations for considering optical elements in aircraft flight control systems. Ring laser gyros are being used in some systems because of improved reliability and maintenance. Fiber optical data links have been used for high speed inter-channel data transfer among the digital computers on the Boeing YC-14. The strongest motivation currently for a "fly-by-light" system is to reduce or eliminate the susceptibility to electro-magnetic interference (EMI) and electro-magnetic pulse (EMP) due to nuclear weapons. The term "fly-by-light" (FBL) is not precise but generally means at least that fiber optics are used for the primary data links between the principal elements, i.e., the flight control computers, the sensors/transducers and the actuators. FBL systems could also include other optical elements, e.g., optical position transducer. They generally do not consider optical processing. There are no FBL systems in production aircraft at this time and the technology is in various stages of development.

The survey covers the various optical elements that are considered in a "fly-by-light" flight control system including optical sensors and transducers, optical data links, so-called optical actuators, and optical/electro-optical processing. It also addresses airframe installation, maintenance, and repair issues. Rather than an in-depth treatment of optical technology, the survey concentrates on technology readiness and the potential advantages/disadvantages of applying the technology. The information was assembled from open literature, personal interviews, and responses to a questionnaire distributed specifically for this survey. Not all of the information obtained was consistent, particularly with respect to technology readiness. The body of this report presents the authors' synthesis of information into their perception of the state-of-technology. The basic information from the questionnaire responses is included in Appendix A.

OVERALL ASSESSMENT

While considerable research and development (R&D) has been conducted including component fabrication, laboratory and flight demonstration testing, the general consensus is that optical technology for flight critical flight control system applications is still in the developmental stage. Fiber optic data links are currently being used in production aircraft for certain avionic systems, such as communications, navigation and weapon systems; but, not for flight control. The most extensive flight demonstration of FBL will be conducted by the Boeing Vertol team as part of the Army's ADOCS program. The Army's JVX is the first full scale engineering development program considering a FBL system. The extent to which optical elements will be used in JVX is yet to be determined. There are widely differing views in the flight controls technical community about the technology readiness of full FBL and even the necessity for FBL to avoid EMI/EMP problems. Most technologists agree that fiber optics data busses are beneficial to reduce EMI/EMP effects but are divided over the readiness of other optical elements other than ring laser gyros, of course. Some technologists believe that the technology for a FBL system from sensors/transducers to computer to actuator will not be sufficiently developed for production applications until about the year 2000. It is clear that the use of such elements as position transducers (linear or rotational), fiber optic rotation sensors, optically actuated actuators, and certain other elements in the 1980's will face a number of development problems.

Essentially the data base is incomplete and concerns exist on reliability, temperature effects, and field maintenance/repair techniques among others. These unknowns are being quantified as the military programs and other R&D activities continually nourish the required data base. The Army's Advanced Digital Optical Control System (ADOCS) program was the most frequently cited activity contributing to the application of optical technology in flight control systems.

OPTICAL ELEMENTS

The optical elements and issues associated with the application in flight control systems are discussed below.

TRANSDUCERS -- Developments have been in process for several years and some devices have been flight tested but the technology for flight qualified operational application is still immature. Current designs of both linear and rotational transducers are quite large and considerable development will be needed to produce compact, practical devices.

Among the developments of optical position transducers under the Army ADOCS program were those of Sperry Flight Systems and Boeing Aerospace. Both conceptual developments demonstrated the feasibility.

The Sperry unit consisted of a linear position transducer (LPT), fiber optic link and an electronic interface unit (EIU). As outlined in Reference 1, (Figure 1) the LPT performs the optical position coding function (using a reflective element) and the serial time division multiplexing. The fiber optic transmitter and receiver along with the associated control and timing circuitry are contained in the EIU. The LPT is operated by an optical pulse which is divided among the delay fibers and routed to the optical encoder. The encoding scale is directly connected to the transducer shaft and contains a grey code pattern. As the scale moves under the "read" head, the delayed pulses are reflected back into the fibers or absorbed depending on the code pattern at the particular location. The optical coupler serially combines the time shifted signals onto the output channel and, thus, only two optical fibers are required between the LPT and EIU.

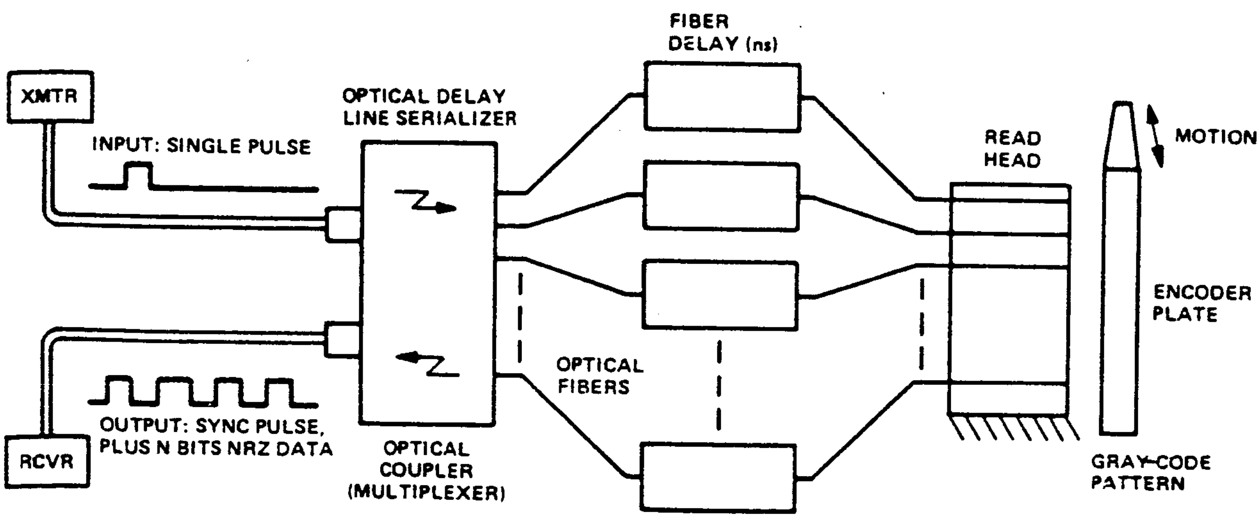

Figure 1 TRANSDUCER OPTICS SCHEMATIC (SPERRY)

After studying four distinct concepts, the Boeing design selected was an analog approach wherein variable-width slits were translated past a pair of viewing apertures to form a position dependent differential signal (Reference 2). As shown in Figure 2, light enters an input mixing rod/prism which provides a uniform rectangular beam across the two tapered slits of the encoder. Two output mixing rods transmit the light to the two output fibers. Position is derived from the difference between the output light levels (Reference 3).

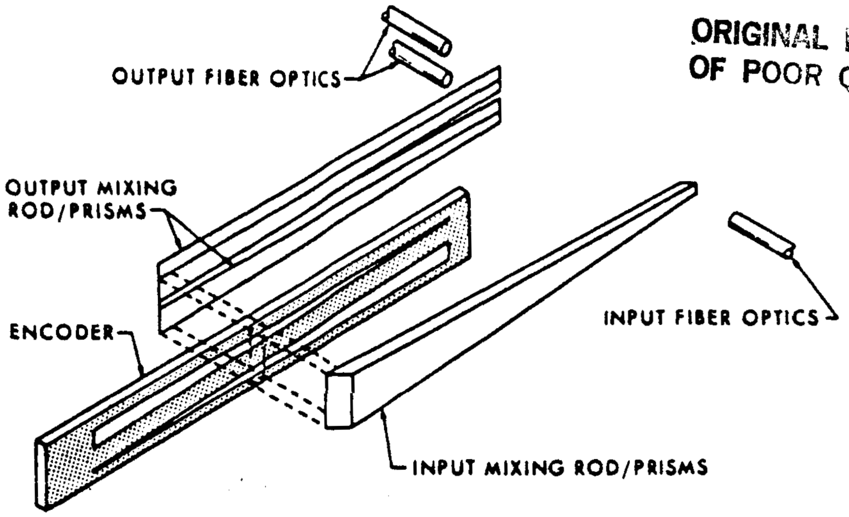

Figure 2 ANALOG LPT CONCEPT (BOEING)

Other linear and rotational transducers have been and/or are being developed under IRAD by several companies, e.g., Marconi Avionics, TRW, and Hamilton-Standard (see Appendix B). Two devices have been successfully flight tested in the Navy T-2C and Army AH-1S aircraft which are discussed in a later section.

SENSORS -- Sensors cover a very broad class of devices but those of most direct interest to flight controls are angular rate sensors and linear acclerometers. Probably the most highly developed optical sensor for flight controls is the ring laser gyro (RLG). RLGs are now being applied in strap-down inertial navigation systems in both military and commercial aircraft. An excellent review of the technology is presented in Reference 4. The technology drivers for RLGs have been low cost and high reliability rather than performance accuracy improvements.

RLGs overcome some problems associated with rotating mass gyroscopes but have other complications such as frequency locking at low rates, high voltage requirements and extremely low scatter optics. Fiber optics rotational sensor (FORS) which have been under development for at least a decade, have excellent potential for low cost and high reliability since they have no moving parts, use all solid-state optics and electronics and require only low-voltage levels. A recent review of the theory and state of the art is presented in Reference 5. R&D activities continue on such issues as sensitivity, linearity, dynamic range, and packaging. A suitable device for use in a strap-down inertial system is expected within the next five years.

Optical linear accelerometers are much less developed. Some company IRAD programs on optical accelerometers and velocity sensors were identified in the survey but none appeared close to being ready for flight controls application.

CONNECTORS -- Technology is relatively mature and many connectors are available. A MIL-STD-38999 multipin connector has been qualified for fiber optics. The use by the tele-communication industry is the driving development force.

DATA BUSSING -- Fiber optics data bussing is fairly well advanced. They are currently being used in some production aircraft for avionic and weapon systems data links. The specification for the MIL STD 1733 Fiber Optic data bus is in the process of being released. This bus has been defined using MIL-STD-1553 protocol. These standards are used for avionics data busses but are not well suited for flight controls applications. Research is underway to define a suitable standard for a flight controls data bus. The standard would apply to optical as well as wire cables. Uses to date have been quite favorable (i.e. YC-14, A-7D aircraft, DIGITAC II) and it is expected that production applications in flight control systems could appear in the next 5 years. Some of the disadvantages are fire/heat susceptibility, cost associated with receive/transmit couplers, and termination/splitting losses.

OPTICAL/ELECTRO-OPTICAL PROCESSING - Optical and electro-optical processing for general purpose computation is probably the least developed of the technologies surveyed. There are several devices for special purpose processing, such as correlations and vector/matrix calculations, for very high speed computations that are in laboratory testing. These devices are likely to appear first in aircraft weapon systems and other avionics rather than flight controls. As gallium arsenide electro-optics become fully developed integrated electronic and optical processing will be possible on the same chip. Experimental chips are being tested in laboratories and are even being used in some fiber optic rotation sensors research. These integrated optics chips may be useful for certain distributed processing functions in flight controls such as electric to optical and optical to electronic conversions, sensor pre-processing, smart actuation systems, and some adaptive control algorithms. This technology will not be ready for use in advanced systems R&D for at least five years and maybe ten.

One of the main features of optical processing that would be attractive to fly-by-light flight control systems would be to make the flight control computer isolated and immune from EMI/EMP. It is not clear when or even if optical computers would be available for that purpose. Responses to the survey questionnaire on this topic were rather skeptical about the possibility of optical flight control computers.

AIRFRAME INSTALLATION ISSUES - Insufficient data currently exists to assess all of the potential problems but some special requirements exist. Cables, for example, must be handled with reasonable care to avoid tension, small radius bends and excessive pressure from clamping devices. The losses from bulkhead connections and the effects of temperature extremes must be considered. Experience with production applications of fiber optics cables for avionics and weapon systems (for example on the AV-8B aircraft) has been excellent. Cables can be produced sufficiently rugged as to be handled in the same manner as coaxial wire cables. Discussions with airframers gave mixed response as to installations concerns. Those who have had experience with fiber optics for avionics systems felt comfortable using them for flight controls. Some airframers indicated that concerns over installing fiber optic cables in the airframe were a major inhibitor to their application for flight critical controls. They will feel more comfortable after gaining operational experience with fiber optics on non-critical applications.

REPAIR/MAINTENANCE TECHNIQUES AND TOOLS -- Since a different medium is involved, special training and tools are needed. Some portable hand-held tools are becoming available. Standardized practices, techniques and tests must be developed along with adequate documentation since the successful implementation of this advanced technology depends upon suitable, practical methods for maintenance and repair. As opposed to electrical systems, connector alignment is critical to avoid reduction in the optically active area. The problems are not insurmountable, it is a question of recognizing the special requirements and addressing them in the proper time-frame. Repair and maintenance on operational systems for avionics data links has been good. One company indicated that it was no more different than repairing coax cables. Airframers and operators will also feel more comfortable with repair and maintenance aspects of fiber optics in flight critical systems after gaining non-critical application experience.

ADVANTAGES/DISADVANTAGES

A major advantage in the use of optics in flight control systems is in the immunity to EMI, EMP and other electrically related disturbances. Since optics do not radiate energy and are electrically isolated, ground circulating currents are avoided and concerns with fault propagation/inter-channel data corruption are eliminated. These benefits are significant considering the trend in more complex, densely packaged designs and the requirement for a high level of integrity for flight critical information. Currently, FBW systems are protected from EMI through shielding of the electronic boxes and wire cables. Substantial shielding comes from the metallic airframes. The use of fiber-optic cabling provides savings in weight and volume which are important in aircraft designs particularly in helicopters. The higher data rates afforded by fiber optics will enhance the system capabilities and design options, particularly in the area of highly redundant, fault-tolerant architectures. Increased use of composite materials in airframes would also motivate use of fiber optics because of the loss of shielding now provided by the metallic skin. Many technologists believe that most of the EMI/EMP immunity benefit will be achieved by using fiber optic cables and it will be adequate to use shielded electronic computer and interface elements.

The disadvantages of using optics are partially temporal and will be minimized as the technology matures and experience is gained. For example, the current high cost will be reduced as more elements are produced in quantities and fabrication techniques improve. The training required for repair and maintenance is temporal and the special tools will become commonplace. Because of the low tensile strength, care must be exercised in handling fiber cables to avoid small bending radii but again this is a learning experience. Cables can be ruggedized for easier handling and installation. Fiber transmission and coupling losses are a current consideration but as the operating wavelengths increase and the technology matures, the losses will be reduced. It should be noted that optical systems contain optical to electrical and electrical to optical converters which are themselves susceptible to EMI. To protect the converters would add weight and cost to the system.

OPTICAL SYSTEMS EXPERIENCE

Over the past eight years several programs have used optical elements in the development of advanced flight control systems. Some of these activities are discussed briefly below.

YC-14 - The USAF YC-14 prototype STOL aircraft, first flight tested in 1976, successfully implemented optical data links to exchange data between the triplex computers. Optical coupling was selected to maintain inter-channel integrity. Figure 3 depicts the sensor data consolidation process and associated optical link designed by Marconi.

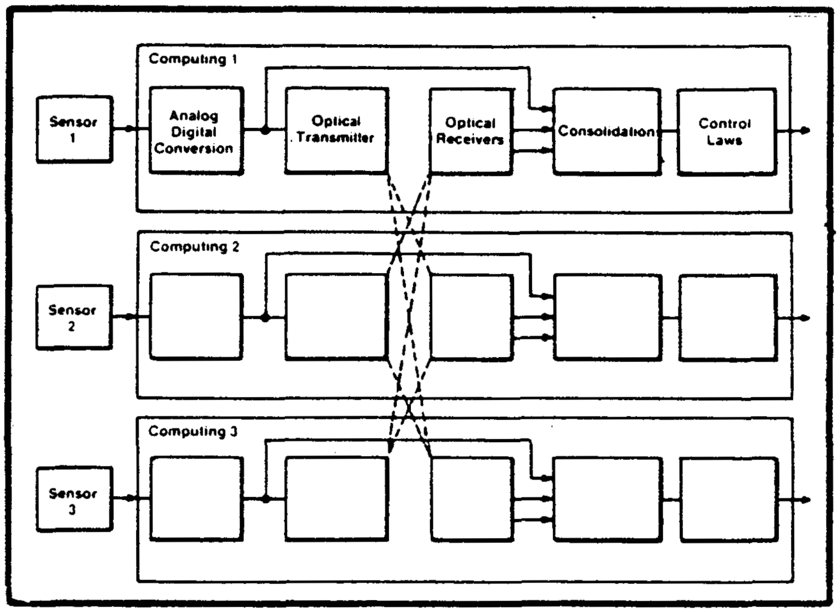

Figure 3 YC-14 OPTICAL DATA LINK

Each sensor output is coupled to the other channels so that each computer has data from each of the sensors. Identical algorithms in each computer consolidate the data enabling equalization and fault detection/isolation of the inputs. The computers are synchronized to avoid sampling time differences and to assure all computers are receiving identical data inputs.

The optical communication medium was used to eliminate electromagnetic interference effects, electrical grounding loop problems, and the potential propagation of electrical malfunctions between channels.

JAGUAR DFBW -- The Jaguar program, initiated in 1977 under the technical sponsorship of the Royal Aircraft Establishment and under contract to British Aerospace, was the first pure digital fly-by-wire with no dissimilar back-up. Marconi furnished the flight control system and included an optically coupled data transmission link (Figure 4) similar to that of their YC-14 design noted above. Based on these experiences, as well as their digital fly-by-light design for the Airship Industry's Skyship 600 mentioned below, Marconi will likely install an interchannel link or possibly a complete fiber optic data bus on the Agile Combat Aircraft technology demonstrator under the United Kingdom's Experimental Aircraft Program. This program, in turn, is geared toward the Future European Fighter Aircraft development which is a joint development program involving the United Kingdom, France, West Germany, Italy, and Spain for a common European fighter for the 1990s.

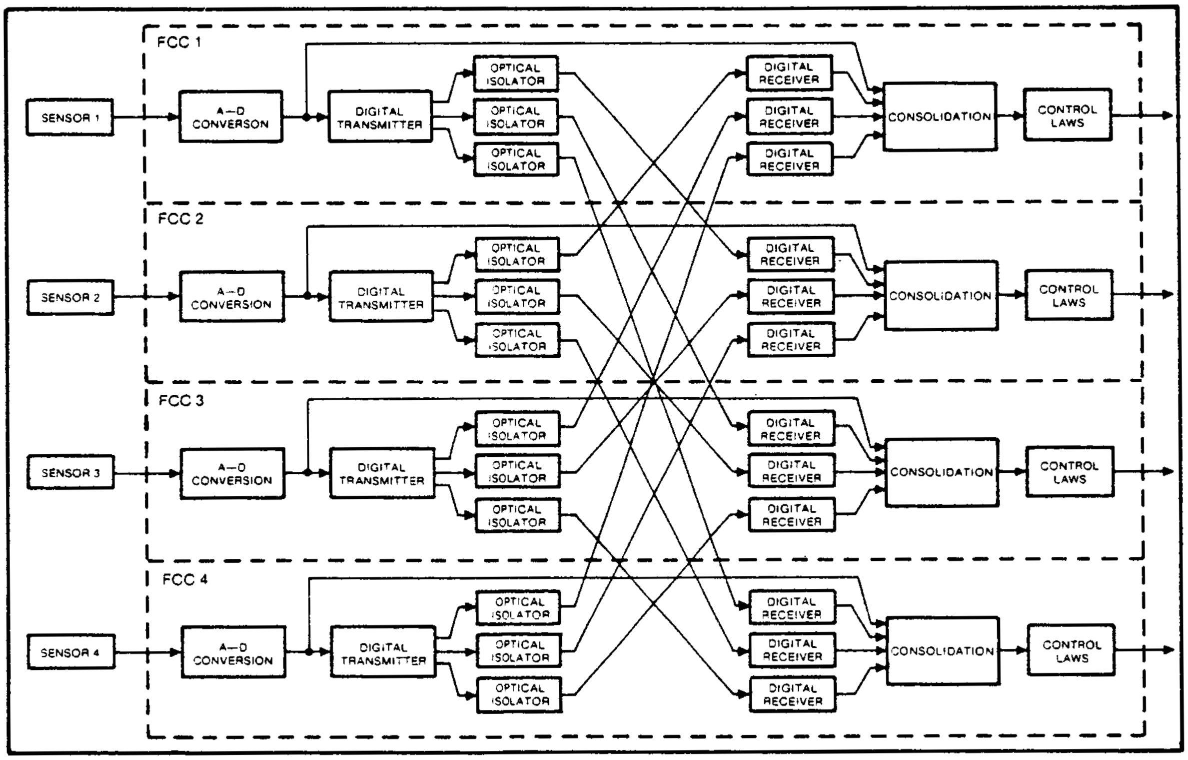

Figure 4 Jaguar Optical Data Link

DIGITAC II - The DIGITAC II flight control system currently installed in the DIGITAC YA-7D test aircraft at Edwards AFB, California uses MIL-STD-1553A data busses to transfer flight control data. It is the only known "fully up" three axis system that transmits all aircraft flight critical control data between computers and between computers and remote terminals. The system performance and reliability has far exceeded expectations. Based on the trouble free results, it appears that technically this approach is ready for consideration for use in production aircraft.

The data busses are dual channel wire and dual channel fiber optic ("fly-by-light") and are selectable in the cockpit by the pilot to "fly-by-wire" or "fly-by-light" or alternatively to implement one wire channel and one fiber optic channel. The "fly-by-light" system has flown 290 flights over a period of 3 years. The system has performed flawlessly with virtually no maintenance. The "fly-by-light" system has achieved such a reliable status that it is now used exclusively to fly the aircraft in all routine test missions. Experience gained with this system shows the single fiber channel to be totally trouble free. The channel with the multifiber (210 fibers) cables has suffered numerous fiber breakage problems due to normal aircraft maintenance handling. The multifiber cable approach has been replaced by single fiber cables having improved transmission qualities and tough protective shields that offer considerable overall improvements.

LODT TESTS -

1) A prototype MIL-T-85289 Linear Optical Displacement Transducer (LODT), developed by Hamilton Standard under a Naval Avionics Center contract, was successfully flight tested by Rockwell International (RI) in a Navy T-2C "Buckeye" trainer aircraft (Reference 6). RI had developed an advanced flight control actuation system for the Navy and conducted several flight test projects in the T-2C, one of which focused on the LODT.

Consisting of displacement transducer, fiber optic link and computer interface unit, the LODT was implemented as a rudder position feed-back sensor with error command and position signals transmitted by optical fibers. A fly-by-wire system had originally been incorporated in the test aircraft and was modified to accommodate the LODT. A simplified diagram of the major components is shown in Figure 5 with shaded areas denoting the changes for the digital fly-by-light (DFBL) system.

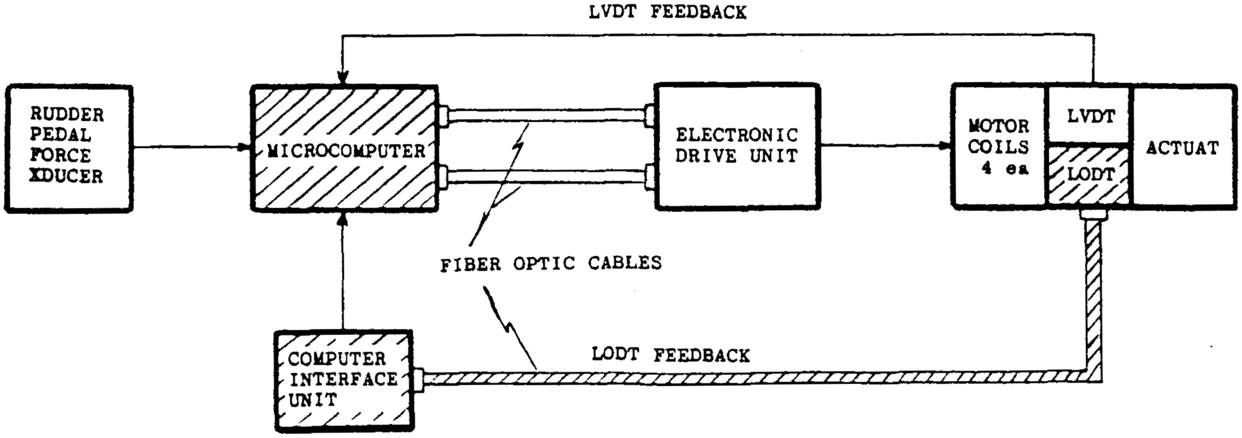

Figure 5 SIMPLIFIED DFBL SYSTEM FOR T-2C TESTS

In the flight tests, two system operational modes were provided as depicted in Figure 6 - the digital fly-by-light (DFBL) and the analog back-up (ABU). In the DFBL mode, the LODT rudder position feed-back signal is summed with the pedal force command signal to produce an error command. This signal is optically transmitted to the electronic drive unit (EDU), restored to an electrical signal, amplified and power converted for energizing the torque motor coils. In the ABU mode, a linear variable displacement transducer (LVDT) provides the rudder feed-back position signal which, with the pedal force command, by-passes the microcomputer and connects directly with the EDU. The ABU mode may be selected manually and is automatically engaged when the microcomputer senses abnormal DFBL system operation.

Prior to the flight test operations, laboratory tests were conducted on the integrated system to verify performance. Actual flight hardware was used extensively, except where impractical such as the hydraulics, not only to exercise the flight articles but to eliminate potential problems. The tests were able to verify the LODT performance by comparing it with the conventional LVDT data. The results were nearly identical.

A total of 3.6 flight test evaluation hours were attained in three flights during which all planned objectives and data acquisitions were realized without

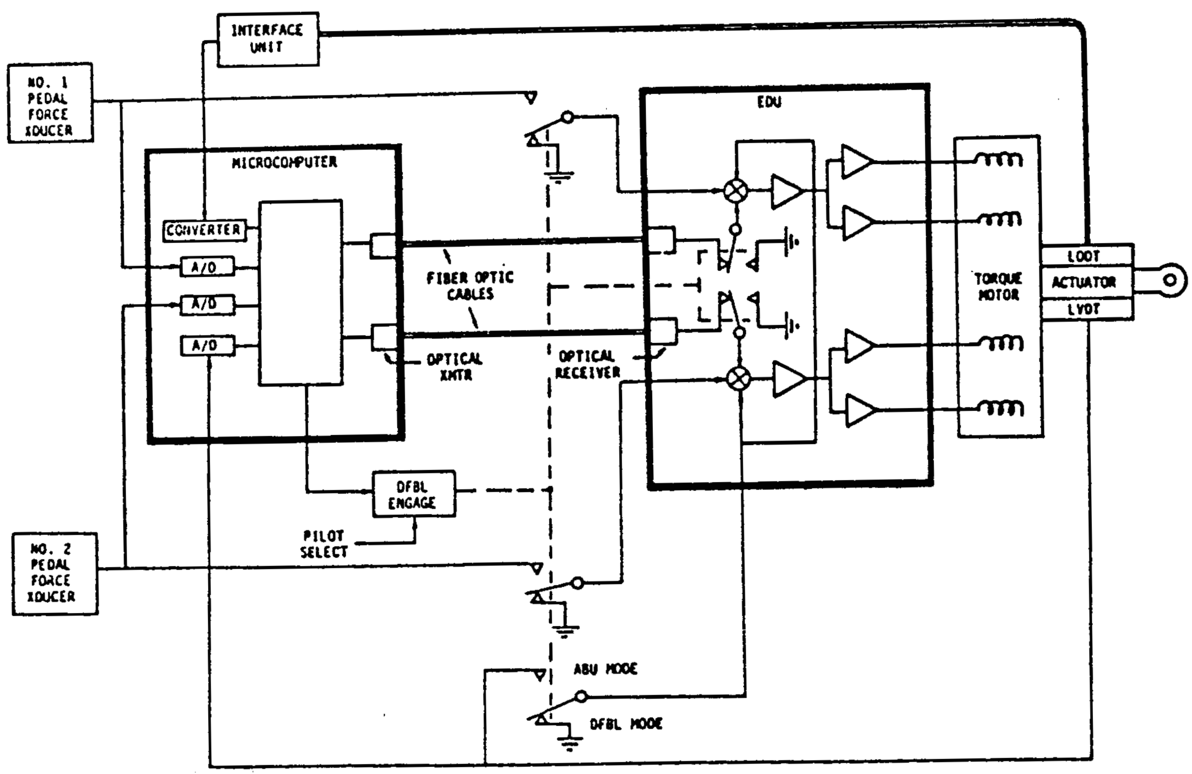

Figure 6 T-2C FLIGHT TEST OPERATIONAL MODES

malfunctions. Flights were conducted at altitudes from 10,000 to 30,000 ft., at various speeds (150 - 340 Knots) and maneuvers. Both the DFBL and ABU modes were flown under each flight condition and for direct comparison of the two transducers, the microcomputer converted the LODT digital output to an equivalent analog signal for the data recording instrumentation. Excellent correlation of LODT and LVDT outputs was achieved indicating that the LODT is a viable approach.

2) Bell Helicopter Textron under contract to the Naval Air Development Center, conducted flight evaluations of a 4-valve fly-by-wire/fly-by-optics actuation system using a model 249 Cobra helicopter. The collective control system was specially configured to accommodate the 4-valve system using quadruplex electrical and simplex optical control links. A mechanical back-up mode was provided and reversion could be initiated by either pilot or automatically under certain "failed" conditions. FBW was in the normal mode of operation since parts of the FBO mode were single string and, thus, during the tests the FBO mode was only flown after attaining altitude.

A simplified functional block diagram of the collective control system is shown in Figure 7 (Reference 7). In the FBW mode, the controls are quadruplex redundant electrical. The four LVDT transducers on the front seat collective lever are linked to the actuator servo valves through the mode selector and electronic control unit (ECU) and position

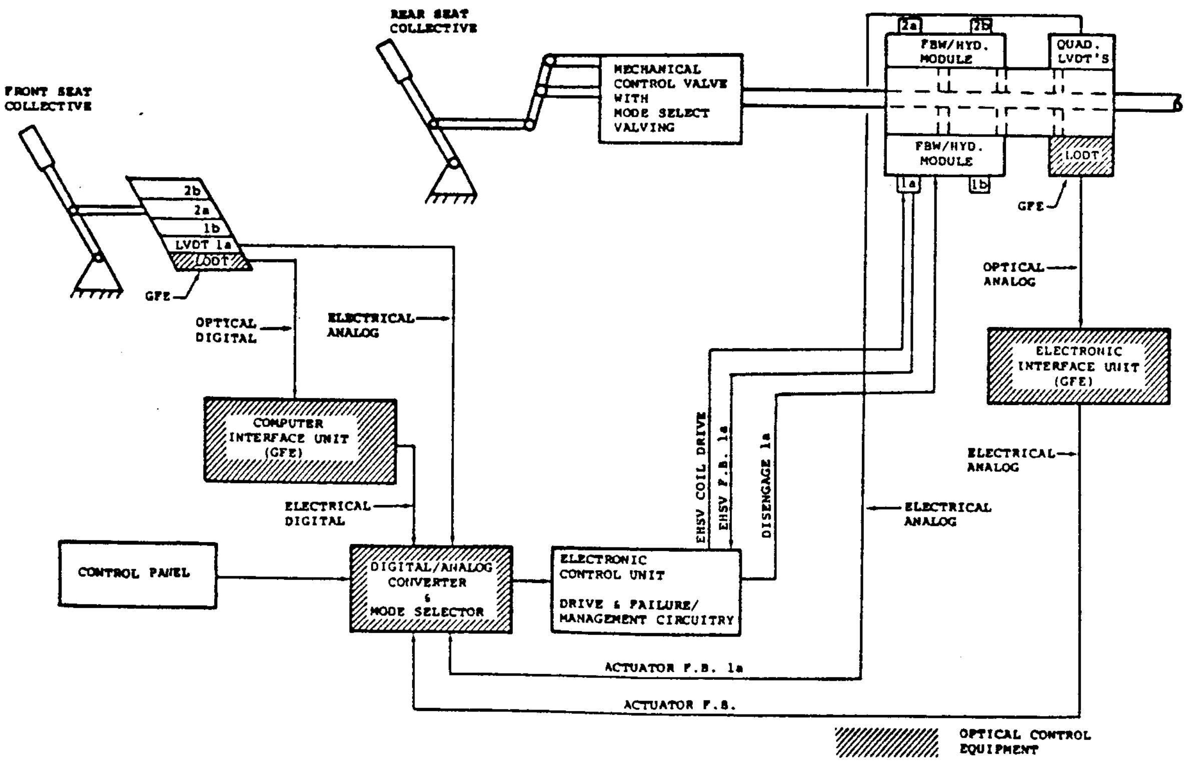

Figure 7 COBRA TESTS COLLECTIVE CONTROL SIMPLIFIED DIAGRAM

feedback is provided by the four LODTs to effect a closed loop. In the FBO mode, a single LODT provides parallel optical signals to the computer interface unit for conversion to a serialized digital grey code which in turn is converted to an analog signal in the digital/analog converter. The signal is summed with the actuator feedback LODT analog signal and the resultant signal applied to four control inputs of the ECU.

The tests successfully demonstrated the optical technology concept. A report detailing this activity and results is currently in process. (Reference 8)

SKS-600 - Marconi Avionics has designed and fabricated an optically signalled flight control system for Airship Industries Skyship 600 airship. The flight control system, illustrated in Figure 8, controls the four tail surfaces and includes a high level of self-monitoring. Duplicate systems will be employed with pilot changeover in the event of a failure. High inherent immunity to electromagnetic interference is achieved by a 1553 optical data bus between the flight control computer (FCC) and the actuator drive

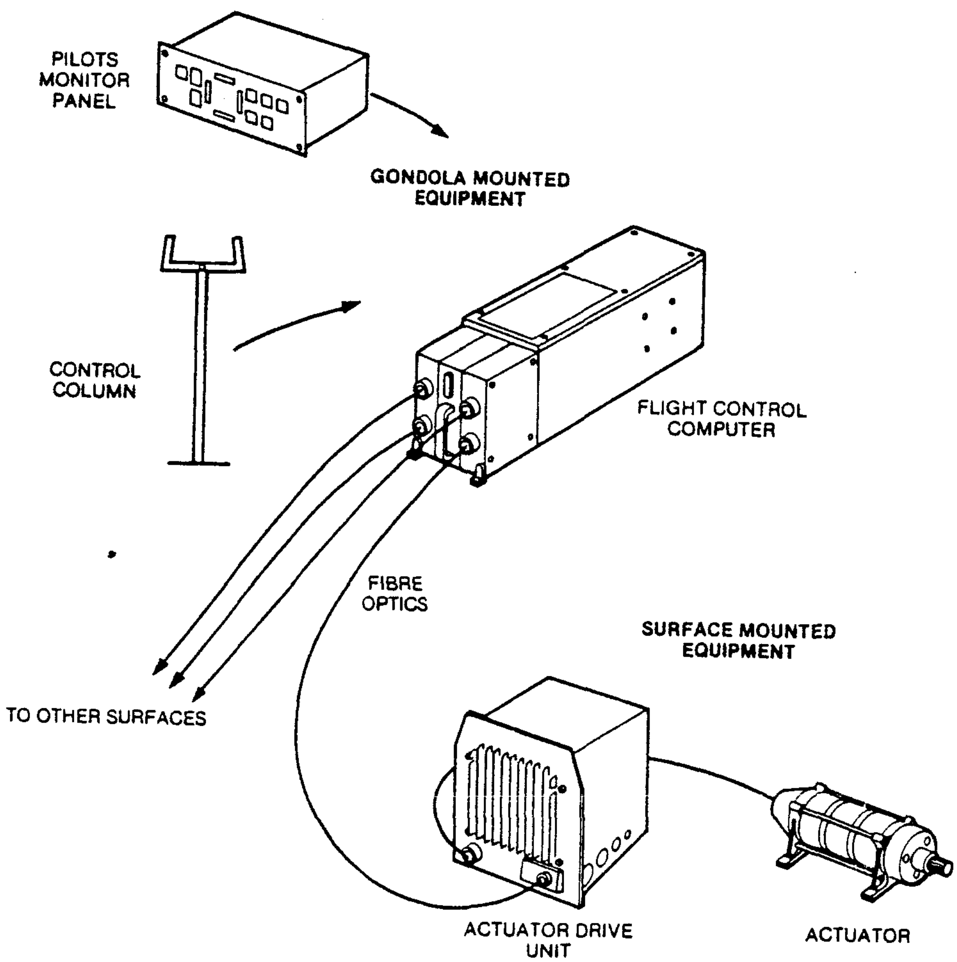

Figure 8 SKS-600 FLIGHT CONTROL SYSTEM

unit (ADU) and by providing local dedicated electrical power at the ADU from a hydraulically driven electric generator. The ADU was made "intelligent" by including a microprocessor for locally handling failure detection and isolation. The FCC, located in the gondola, monitors the "health" and status of the actuation system and can be extended to provide autopilot modes by interfacing the appropriate sensors.

ADOCS - The US Army Applied Technology Laboratory, Ft. Eustis, Virginia is sponsoring an advanced digital/optical control system (ADOCS) program which is scheduled to start flight demonstration tests in early 1985 using a UH-60A Black Hawk. The goal is to provide a redundant digital/optical control system demonstrating the feasibility of helicopter control solely by optical signal paths and to generate supporting data for future production systems. The fly-by-light design provides a medium to enhance survivability of aircraft under battlefield environments and, thus, improve mission capability. In addition, the use of passive optical systems impervious to electrical interference could negate the requirement for back-up controls with attendant savings in weight/cost and increase in systems reliability. The basic architecture, shown in Figure 9, uses separate primary and automatic flight control systems; the former replacing the normal mechanical control linkages and the latter providing improvements in handling qualities and pilot workload (stability/control augmentation and automatic mode selection). Pilot inputs from the four-axis sidearm controller are sent optically through the primary flight control side of the digital flight control processor to three rotor and one tail directional control actuators. The system contains three flight control processors (FCP), each of which can control all system functions and they are physically dispersed in the airframe for added safety from ballistic damage.

During the scheduled flight demonstration tests, the UH-60A mechanical control system will be retained as a back-up.

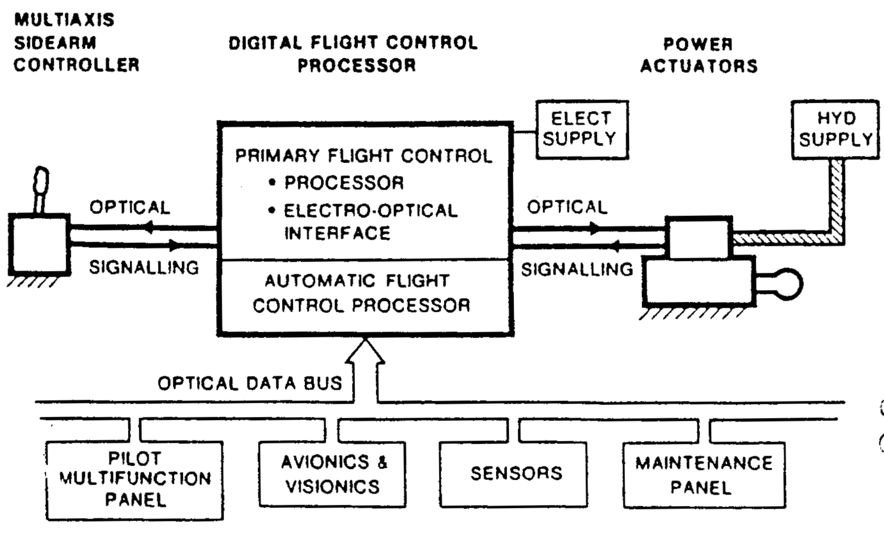

Figure 9 SIMPLIFIED ADOCS CONCEPT

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ABBREVIATIONS

ABU	Analog Back-Up
ADOCS	Advanced Digital Optical Control System
DFBL	Digital Fly-By-Light
DFBW	Digital Fly-By-Wire
ECU	Electronic Control Unit
EDU	Electronic Drive Unit
EIU	Electronic Interface Unit
EMI	Electromagnetic Interference
EMP	Electromagnetic Pulse
FBO	Fly-By-Optics
FBW	Fly-By-Wire
FORS	Fiber Optics Rotational Sensor
IRAD	Independent Research & Development
LPT	Linear Position Transducer
LODT	Linear Optical Displacement Transducer
LVDT	Linear Variable Displacement Transducer
nm	Nanometers (10^{-9} meters)
R&D	Research and Development
STOL	Short Take-off and Landing

APPENDIX A

Response to Optics Technology Questionnaire

As part of the survey, a questionnaire was forwarded to prominent individuals experienced in the field to solicit their thoughts and opinions on the state of optics technology for application to flight control systems. The questionnaire requested that the following items be addressed:

- Transducers
- Sensors
- Conductors
- Data Buses
- Optical/Electro-optical Processing
- Airframe Installation Issues
- Repair/Maintenance Techniques and Tools
- Overall Assessment of Application Status

As expected, the responses covered a wide spectrum of opinions from "technology ready" to pessimistic outlooks on its implementation. For completeness, the individual responses are included, with only minor editing to exclude those not addressing flight control applications for example. Depending upon their personal experience, not all items were addressed by each respondee. The responses represent the thoughts and opinions of the individuals and in no way are to be construed as reflecting a company "position" or outlook. To assure anonymity and inadvertent attribution of particular opinions to specific companies, no names are associated with the responses.

TRANSDUCERS AND SENSORS

- o No knowledge about specific fiber optic transducers. High temperature operation would probably be a problem such as conversion from the transducer output to a drive for an LED or laser application.
- o Most vendors of rotary position or speed sensors offer an optical device. The optics are used for the detection, and the interface to the control is by hard-wire voltage signals. Not aware of any optical rotary detectors that are available which meet military specifications.

- High radiance LEDs and high responsivity silicon PIN diodes (820 nm) are available from several sources.

- Have not identified any potentially mature fiber optic transducers suitable for flight control applications. There is potential, but still find existing candidates deficient when compared with redundant transformer type devices.

- Have a definite interest in the development of a redundant fiber optic angle-of-attack sensor. These devices are vulnerable to direct lightning strike effects due to lightning attaching to the grounded probe. A prototype fiber optic rotary sensor was built under an IRAD program in 1976. The approach used for that study did not lend itself to a compact redundant assembly. The approaches recently reported in the literature could lead to the development of a practical sensor.

- Flight worthy optical position transducers having excellent accuracy and resolution are presently being designed for the Army's ADOCS program.

- Because of the extreme sensitivity of a fiber optic angular rate sensor, its simplicity, and projected low manufacturing cost as opposed to a ring laser gyro, fiber optic rate gyros will probably replace the ring laser gyro in five to ten years when they become available off-the-shelf. Fiber optics acceleration and velocity sensors are presently under development but probably won't be available for another four to six years.

- A linear optical displacement transducer developed for the Navy was successfully flight tested in the directional control loop of a Navy T-2C airplane. The position feedback signals were transmitted via optical fibers.

- The implementation of optical flight control systems will be paced by the development of reliable, small size (comparable to electrical counterparts) optical sensors. Optical sensor technology is in its infancy, requiring substantial remote electronics to interrogate the sensor and interface it with a computer. Optical flight control development programs are presently using optical sensors built by several manufacturers.

- The choice between LEDs and laser diodes appears to remain unresolved. A high-intensity, stable light source, capable of operation between $-50^{o}C$ and $150^{o}C$, is required for future aircraft engine optical systems. The device must consume relatively little power, require minimal cooling, and operate for at least 10,000 hours. We are not aware of a laser diode with this life capability. We have heard of a few for which long life is claimed, but we have not evaluated them. At the present time, development of a 1- to 2-amp optical power switch for use with a direct-drive hydraulic actuator is being sponsored by NASA.

- The current state of the art of optical sensors, as represented by the status of the Army's ADOCS program, is not yet competitive with electrical sensors. They tend to be large, heavy, and expensive. Primary needs are for position, proximity, speed, temperature, and pressure sensors. Position and speed sensing technology is in hand but requires further development to become competitive with electrical devices. An optical proximity sensor for measuring rotor blade-to-case clearance in test-bed engines has been developed under a NASA contract and the extension of this technology to engine control system applications is being explored. Companies are investigating the application of fiber optics to a range of sensing applications, including temperature, pressure, strain, acceleration, etc. The results in the area of temperature sensing are encouraging. The rare earth-doped fiber and self luminous black body sensing techniques appear promising for future engine control system applications. The application of optic technology for pressure sensing is not currently encouraging.

- Military flight control type devices are not available. Future availability will depend on the demand which probably will only come as a result of Government funded programs.

- Early laboratory experiments/developments are now taking place. Feasibility appears to have been demonstrated. Practicality is still an issue, but looks promising. Production application appears to be 10-15 years away.

- A large amount of development effort is being expended in the sensor area but requires much more effort before reliable fiber optic sensors are available for flight control applications. The Army's ADOCS program will generate the required reliability test data of these sensors in the environment.

- Optical transducers have been around for years, are well developed and understood. They are simple, reliable and accurate. The main advantage is the lack of physical contact.

- o The sensor/transducer work reported to date has been fairly primitive, with an optical pick-off featured. Typical devices include an open loop (non-rebalanced) pendulous accelerometer with pendulum motion (and, therefore) acceleration is measured as an optical coupling variation between fibers. Other sensor concepts are based on fiber bending (stress), and moving grating. The ultimate optical sensor family is based upon the Sagnac interferometer principle which breaks down into ring laser gyros, passive tuned cavities, and multiturn passive interferometers.

- o One company's IR&D program is leading to the development, design and product introduction of a fiber optic gyroscope for use in strapdown inertial reference systems in the latter part of the 1980's. The motivation for developing such a product is twofold:

  (a) This type of "Solid State" optical sensor is free from the classical errors introduced in traditional spinning wheel gyros from the functioning angular rate and acceleration operational environments.

  (b) A potential exists for significant sensor cost savings when the fiber optic gyro includes new technologies such as low labor content integrated optics devices.

The particular design approach employs a multi-turn single mode fiber optic gyro ring with a solid state laser diode source feeding the ring through fiber and integrated optics beam splitters, polarizers, depolarizers and phase modulators. The optical concept itself is generally defined as a passive Sagnac interferometric gyro. The proprietary approach to this concept is to scan the phase modulator at a high rate through the dynamic range of the sensor and with modern signal processing concepts to calibrate the sensor at a frequency exceeding the Nyquist rate as established by the sensor performance measurement regime. The concept is currently implemented in various breadboard constructions in the lab with the signal processing embodied in a bit slice processor with parallel architecture. It is felt that the processing problem will be solved using VLSI and/or VLSIC technology when a product design is made. A brassboard sensor is being designed and will be built. Of necessity it will incorporate a mixture of fiber and integrated optics devices ahead of the fiber ring, but the ultimate product will likely employ integrated optics for all devices outside of the fiber ring. The current work involves the use of 0.85 micron wavelength devices, but preliminary experimental evaluation and studies have also been done using the low loss 1.3 micron wavelength under USAF sponsorship.

- Some linear transducers have been developed, but, while they exhibited good characteristics, the physical size is large compared to standard transducers. These devices require considerable development.

- LEDs in the 820 nm range are available and 1300 nm units offering good improvements are in the horizon. One company is producing a 4-axis passive optical hand controller for a helicopter application as well as procuring optical linear position transducers for servo valve and servo ram position measurements.

- Photo detectors are progressing but just by their nature of operation are susceptible to radiation damage. To fulfill the need of a "rad hard" application requires a detector with reduced sensitivity from the beginning, which requires stronger drivers and minimal losses within the system.

- A number of direct mechanical/optical transducers have been developed through the Army's ADOCS program.

- Am not aware of any direct optical rate/acceleration sensors and am not sure one would want them.

- Technology is here today as witnessed by the developments available.

- A full range of sensors offers new flight control system design potential, including consolidating electronics. Much more work is required in this area although the feasibility has been established for all flight control system sensed quantities.

- Work sponsored by the Army and by NASA Lewis to develop optically activated actuators is currently underway. NASA's interest is to develop actuators for engine control that can either be controlled by a low level optical signal, (which would be used to control locally generated power to the actuator) or actuators that can be operated directly by the optical power transmitted to them.

- Optical position encoders (rotary and linear) and optical tachometers are the furthest along in terms of design, fabrication and testing. NASA Lewis was among the first to build and test a passive optical rotary encoder and an optical tachometer on an engine. Army/Navy cooperative efforts on building and testing a linear optical encoder came to fruition last year with a flight test of the encoder. Army programs for helicopter applications have substantial efforts in the design and development of both rotary and linear, passive, optical encoders. Subsequent flight test are scheduled for these optical sensors.

- Optical temperature sensors for propulsion control applications are being actively pursued by NASA Lewis and two contracts are nearly completed. One is an intensity type sensor (Rare Earth) and the other is a wave length modulating sensor (Fabry-Perot). An additional contract for design and development of an optical temperature sensor capable of measuring gas temperatures to 1700°C has recently been awarded. Pressure sensors lag further behind in terms of development. Optical pressure sensors have been designed but aggressive funding for development and testing of optical pressure sensors has been lacking.

- The Sagnac effect has been pursued using spools of optical fiber for rotation sensing since 1976. To date, no products are available and none are known to be in any prototype stage. The principal problem has been drift stability. The potential benefits of ruggedness (no moving parts), lightness of weight, and low cost in production are believed realizable. Cost is an issue at present due to the expense of small quantities of the fiber and light source - a GaAlAs edge emitting diode. Low parts count, and lack of mechanical adjustments and expected clean room requirements are favorable to low cost. The drift problem is caused by the enormous difference between the wavelength of light and the required optical path length in a reasonable volume to obtain reasonable rate sensitivity. Phase stability required is the order of 1 part in 10^{12} to 10^{15} or more depending upon the drift requirement. Fortunately, the measurement is of relative phase between two light beams which travel the "same" path in opposite directions. At the above stability tolerances, the equality of the path for the two directions is affected by many factors. Investigation of these factors within the optical path materials and methods to minimize the difference is in progress now at a number of facilities. To date, there are few fiber optic gyros existing. Most work has been on laboratory setups which are not functionally gyros nor packaged as gyros. Two companies are known to have built functioning gyro models. Both have built small diameter bulk optics fiber optic gyros with all components packages together. Work is in progress on developing and packaging all fiber gyros which promise to be more stable than the bulk optics approaches which are limited by mechanical stability.

- A fiber optic gyro concept has been developed under Army sponsorship. The current device is a single axis sensor 3.5" diameter by 1.25" high which was built and tested to a rate of ± 150°/sec. Development is continuing.

- Company funds are supporting the development of a small, "low-cost," modest performance fiber optic gyro. Performance results of breadboard testing are expected in late 1984.

- A digital linear optical displacement transducer (LODT) has been flight tested in a Navy T-2C trainer and both a digital and analog LODT in an Army AH-1S helicopter. The units operated satisfactorily but were much to large for practical application.

- Other than the ring laser gyro which is electro-optical, am not aware of any available flight control sensors. Optical sensor technology is a long way off.

CONNECTORS

- Most electrical connector vendors produce fiber optic connectors. There are also about as many standards for fiber optic connectors as there are major connector manufacturers. Some of the manufacturers are trying to develop an industry standard for fiber optic connectors, since no military standard exists. Temperature is one of the main problems. Many connectors require an epoxy to hold the fiber and since the temperature coefficient of the epoxy, fiber, and connector is different, increased losses result at high temperature.

- Fiber optic connectors used on military programs are available from many companies. One company manufactures a multiple box connector holding 8 fibers. It uses a MIL-STD-28876 shell and the butt joint method to interface fibers. Development is underway to lower connector losses using various lens approaches. Some companies are investigating expanded beam connectors.

- Connector technology was developed under the YC-14 program. It is hoped that the connector technology will be resolved by the work directed toward a proposed MIL-STD governing this issue.

- Flight worthy, MIL Spec qualified connectors are already becoming available. Epoxyless connectors requiring no fiber polishing will be the preferred type for aircraft use. A cost effective connector will probably never achieve a lower attenuation than about 1.0 db with excellent repeatability.

- Connector technology is maturing at a good pace with typical connector losses around 1 or 2 db. At present it seems that the telecommunications industry is driving the bulk of connector development.

- None of the many optical connectors currently available are practical for use in the aircraft engine environment. The need is for a standardized, rugged connector, capable of handling temperature extremes of -50°C to 550°C, engine vibration, and multiple matings. While aware of the efforts of the EIA-P6 committee to develop a MIL-STD-38999 optical connector, engine-mounted electronics are already beginning to be sized by the EMI-tolerant electrical connectors now used (including 38999). If optics is to become a viable technology for use in propulsion control systems, it must offer a significant connector size reduction.

o Rugged, low cost connectors are available today. Some users say they are reliable and don't pose a maintenance problem. Others who have experience with them say they have more problems and are less reliable than electrical connectors.

o Excellent new designs are now available at a more reasonable cost than previously. Ready for flight control application.

o Continuous development over the past few years. Problems still exist in having the fiber(s) line up for continuity of the transmitted signal.

o Until recently connectors were bulky, unique and not applicable to flight control "black boxes." Recent data indicates that connector manufacturers are addressing the multi-pin circular, bayonet or threaded, box mounted interface connector.

o Connectors for terminating optical fibers are plentiful especially for multimode (large core) fibers which for the most part are butt type. Metal connectors will be used for engine control applications.

o Connectors are state-of-the-art. Many companies make flyable connectors which meet MIL standards.

DATA BUSSING

o A high speed data bus has been developed for use in the Submarine Acoustic Combat System (SubACS). This system utilizes fiber optic transmitters and receivers to link many units together via a Distributed System Data Bus.

o The specification for the MIL-STD-1773 fiber optic data bus is in the process of being released by the Tri-services. This fiber optic data bus, which operates at 1Mbit/sec, has been defined using the MIL-STD-1553 protocol. The primary group responsible for the development of the specification was the SAE-9C Fiber Optic subcommittee.

o Optical data buses will find extensive use in aircraft within the next ten years. Their integration will be paced by the availability of flight worthy/MIL Spec qualified bi-conical and star couplers. Present fiber optic cables are good enough but can be vastly improved.

- The existing MIL-STD-1773 (1 MHz) optical data bus appears to be adequate for engine controls application.

- Optical data buses are now under development. Production applications are probably 10 years away, perhaps less if higher priorities are established but probably more than 10 years at the normal pace of development.

- Excellent results on various government aircraft applications to date (i.e., A-7D aircraft). Very high speed data uses still need a large development and validation program to prove digital bus network designs and protocols covering the range of 2 to 300 Mbps data transmission.

- Advantages are high data rates, noise immunity. Disadvantages include cost associated with optical receivers/transmitters, couplers, etc., when applied to other than single point to point links.

- Unlike electrical, it is difficult to add connections to optical busses. They are limited by the existing MIL specs to baud rate of serial data. The length of busses in an aircraft is so short that fiber losses are negligible. Termination and splitting losses along a buss quickly eat up reserve transmitted power. Active (vs. passive) splitters should be investigated.

- Although optical data busses will not be required for engine control applications as long as the control remains on the engine, the need for high temperature optical fiber links should be recognized. These fibers will be required to withstand temperatures that can reach 500°C around the turbine case region. A number of different materials are being investigated for possible use with optical fibers. In the event the control is located off engine the communication data link between the control and engine components will use the 1773 optical data bus standard.

- Optical data buses are state-of-the-art and widely used by Bell Telephone. Marconi is developing fiber optic links for the Skyship 600 blimp. A 1553B optical data bus is feasible but optical data transmission is very susceptible to fire/heat.

OPTICAL AND ELECTRO/OPTICAL PROCESSING

- Many aircraft companies, primary flight control companies, missile manufacturers, aircraft jet engine manufacturers and various non-aerospace companies are involved in the development of fiber optic systems. Each company usually has applications that require processing to meet specific needs. Most developments are proprietary to the company.

- o In reviewing the literature on optical actuators, it is felt that the approach is not justified because of the induced transient voltage levels identified. In addition, the review did not identify a practical approach applicable to a direct drive valve type of actuator.

- o Optical processing for flight controls is at least eight to ten years away. The attractiveness of optical processing for flight controls resides more in the total isolation and immunity from external disturbances to be gained rather than the extremely high computational speeds which could only be properly utilized in a flutter suppression system.

- o Now in early stages of development. There are some low level, limited applications appearing now, but the real flight control application in combination with optical sensors and data buses is probably 10 or more years away.

- o Needs extensive R&D before application.

- o Talk about monolithic optical integration circuits has been around but not much otherwise. There does not seem to be much advantage to it, except EMI.

- o Under development. The Army's ADOCS program is probably the most advanced in this respect.

- o Does not appear necessary. Optical processing seems more appropriate to signal processing where 10-50 picosecond limit of electronic gates can be overcome.

- o Don't see much use. VHSIC (shielded if necessary) will be dominant.

- o Not being seriously considered for use in either propulsion or flight control applications. Optical processing for control applications still in the early stages of research. NASA Lewis is currently sponsoring two grants in optical processing research.

- o Some work on optical computers exits, but am not aware of any optical processors for flight control or any other avionics applications.

AIRFRAME INSTALLATION ISSUES

- Fiber optic (F.O.) cables can result in advantages or disadvantages depending on the installation. Some advantages are: lighter weight; no problem with noise pick-up or interference - so it can be routed with power cables; no radiated energy; and very low attenuation. Some of the disadvantages are: connector assembly time is longer; F.O. cables may require larger radius bends; personnel must be trained to understand the differences between F.O. and metal cables.

- Fiber optic system installation in aircraft structures present special requirements that are not normally encountered in wire installations. Fiber optic cables are not necessarily delicate (current designs), but should be handled with reasonable care such as: minimization of tension on cables, avoidance of small radius bending and undue pressure caused by cable clamps. High and low temperatures may affect the cable transmission characteristics. Connectors should be minimized to avoid excessive signal attenuation. Environmentally qualified fiber optic hardware is important to successful operation in aircraft and includes all projected mission conditions expected of the aircraft. The fiber optic hardware must meet Mil-Spec qualifications since flight critical data will flow over data busses. Since flight control reliability and safety are prime concerns in any manned aircraft application, any fiber optic system approach must by necessity maintain a high level of reliability to be acceptable.

- The electronic circuits for the receivers and transmitters are sensitive and can be adversely affected by other electrical/electronic circuits, therefore, shielding may be needed. Temperature, vibration, g-loading, EMP, EMI and radiation hardening are considerations that need to be addressed for current and future systems, particularly for military applications. Fiber optic cabling for flight control applications such as data busses are likely to involve redundant channels. Appropriate distribution (spacing) should be provided to minimize combat damage in military applications. Cables routed in the vicinity of jet engines need thermal shielding and contamination protection and those passing through pressurized compartments will require special connectors.

- Present state-of-the-art fiber optic components, except for the bi-conical and star couplers, do not present any particular installation issues different from a fly-by-wire implementation. It is important, however, to provide entry ports into the signal transmission system so that no disconnecting is required for test purposes.

- Harnesses are typically used in aircraft wiring for ease of installation and to provide breakpoints between major aircraft assemblies. This implies several bulkhead connections between signal sources and end users. Optical connector losses must, therefore, be reduced even further. Bend radii of optical fibers could be a problem where "tight" equipment installations are encountered. Unique connector designs will be required to provide cable routing configurations comparable to those of conventional wiring.

- Optics is viewed as a system issue. Introduction of optics into propulsion control will be paced by its introduction into the airframe/flight control system interface. There could be isolated cases of optics used completely within the propulsion control system, but intersystem applications will most likely be led by airframe considerations.

- Termination and splitters are one source of losses. Others are passing the fiber through multiple bulkheads with a connector at each bulkhead which will induce losses; bending fiber around tight corners; fiber strain relief; and, environment heating and cooling. (Example: U2 aircraft have sensors on the ends of the wings. The wing tips can flex up and down 6 to 10 feet in flight).

- Size of optical components could become a major issue since optical accuracy is a function of size. Fiber optic cabling susceptibility to heat/fire requires extraordinary protection methods. New fiber development may be required.

- Equipment boxes need an optical interface. The probable and logical first step is to provide a conventional electrical/electronic connector and an optical connector on each box. Second generation boxes could eliminate the electrical/electronic connector. Personnel training is required to handle, install and service fiber optic equipment. Reliability and life of lines, connectors, etc., particularly in the military environment is an unknown.

- Not much data available but feel that airframe installation will be easier using fiber optics. The issue of prefabricated wings using composites, however, needs careful study and review since fiber splices or connectors at the mating interfaces will effect the power budget.

- The advantages are smaller cable bundles, reduced cable weight and immunity to EMI. Among the disadvantages are low tensile strength, smaller bending radii and the fact that power cannot be transmitted.

REPAIR/MAINTENANCE TECHNIQUES AND TOOLS

- Experience with the dual channel fiber optic data busses on the DIGITAC II program indicates that maintenance and repairs have been minimal. This dual channel system has two different fiber optic cables, one channel consists of a multifiber type and the other channel utilizes single fiber cables. Maintenance personnel should be trained in the proper handling and the art of repair and maintenance of fiber optic cables and connectors. Repair and maintenance of the electronics of the transmitters and receivers present no special problems. Bus test equipment and cable end finishing tools are available from various companies specializing in the field of fiber optic technology. Current tools for end finishing cables have limited capabilities; however, techniques are being rapidly improved.

- The time required to make a fiber optic connection is greater than an electrical connection. Care must be exercised in stripping the cable. Square cuts at the fiber ends could be difficult to achieve and care must be taken in polishing the fiber ends (although some new connectors do not require as much effort in polishing). Alignment in the connector is also critical. Therefore, special maintenance personnel or training will be required to repair and maintain fiber optic links.

- There is a need to standardize on test methods, fibers, wavelengths, data rates, and connectors to ease the maintenance task.

- Good portable hand held tools for field repair of fiber optic signal transmission systems are becoming available. However, this subject must continue to receive close attention because the successful integration of fiber optics in operational military or commercial systems depends greatly on ease of repair.

- For implementation, it would seem that requirements be established that optical equipment (connectors, cables, etc.,) be no more difficult to repair than present electrical counterparts and that skill levels be similar.

- Tools, training devices, overhaul facilities, and maintenance manuals have to be developed and distributed. Training programs must be developed and implemented and maintenance personnel must be trained.

- It should not be a difficult problem if the latest fiber optic test equipment and techniques are implemented. Standard techniques will have to be developed and the proper training of personnel will be mandatory.

- Repair, maintenance techniques and tools are currently available.

- Most of the time the military will replace from spares and not repair. Tools, techniques, requirements are not very applicable to field maintenance due to special training and control required for good quality. A splice induces one to two more areas of greater loss where there was negligible loss.

- Procedures for handling fiber optic sensors must be developed and will require training of personnel to field test, field repair, and handle the fiber optic sensors. Tools of a portable nature are required to test optical circuits in a system and to repair components such as connectors and fiber optic cables in non laboratory conditions.

- Fiber optic cabling can be readily spliced (T-joints, etc.). However, connector alignment is very important and could be a maintenance problem. Special training in handling of fiber optics will be required.

OVERALL ASSESSMENT OF APPLICATION STATUS

- The DIGITAC II flight control system currently installed in the DIGITAC YA-7D test aircraft at Edwards AFB California uses MIL-STD-1553A data busses to transfer flight control data. The data buses are dual channel wire and dual channel fiber optic ("fly-by-light") and are selectable in the cockpit by the pilot to "fly-by-wire" or fly-by-light" or alternatively one wire channel and one fiber optic channel. The "fly-by-light" system has flown 290 flights over a period of 3 years. The system has performed flawlessly with virtually no maintenance. The "fly-by-light" system has achieved such a reliable status that it is now used exclusively to fly the aircraft in all routine operational test missions. Experience gained with this system shows the single fiber channel to be totally trouble free. The channel with the multifiber (210 fibers) cables has suffered numerous fiber breakage problems due to normal aircraft maintenance handling. The multifiber cable approach is now considered to be obsolete by industry and has been replaced in single fiber cables having improved transmission qualities and tough protective shields that offer considerable overall improvements. The DIGITAC II "fly-by-light" system is the only "fully up" three axis system that transmitts all aircraft flight critical control data between computers and between computers and remote terminals. The systems performance and reliability has far exceeded our expectations. Based on the trouble free results over the past two years of operations it appears this approach is ready for consideration for use in production aircraft, and this confidence is reinforced in view of the current availability of much improved state-of-the-art components. Some development programs have used fiber optic busses as part of the aircraft systems to control flaps, spoilers, armament stores and communications via a simple single channel bus. Since these applications do not meet flight critical/safety requirements, they are not burdened with complexities of redundancy required in safety of flight systems. The Army's ADOCS, currently being developed for helicopter applications, represents the most extensive development of any known optical approach directed toward aircraft flight controls. Many companies are actively developing a wide variety of optical techniques that are applicable to the aerospace industry. Such application areas as navigation and rate gyros, position sensors, fuel gages, voice activation, data busses, control sticks, etc., to mention only a few that are currently under development.

- The lack of MIL-STDS has limited the application of fiber optics. When the units become qualified and the temperature problems are solved, more applications will appear. Most of today's applications are for communication links. For a small imbedded system, the communication link is not the area where development is required, but rather in the multi-fiber control lines for digital control. (Multi fiber connectors, light to electric converters with TTL output and switching times of 100-400 nanosec.)

- The trend in the cockpit is to put all instrumentation on the displays and to use electromechanical indicators only for emergencies. As the requirements on the aircraft become more complex, and the need to decrease the flight personnel workload more urgent, the use of electro/optical processing for flight control will expand rapidly. It will likely appear in the next generation aircraft. Fiber optics has made in-roads in military applications for ground based systems such as Ground Launched Cruise Missile (GLCM) and ship systems such as SubACS. In the next five to ten years it is expected that airborne applications such as aircraft, missiles and satellites; and fixed locations such as communications, security applications, radar and video multiplexing will increase significantly. The problem to be solved by users of fiber optics in the military environment is the unavailability of transceivers and components compatible with military hardware requirements. The commercial telecommunications industry has fostered the rapid development of fiber optic components and technology for their unique applications but has left some significant voids in the capability needed in military systems, in particular, nuclear radiation resistance, high speed bus applications, and reliable operations in temperature extremes.

- It is considered that a clear cut advantage of fiber optic technology to flight controls has not been identified. The potential high bandwidth data handling capability of fiber optics is not generally a requirement. A requirement for a fiber optic angle-of-attack probe does exist. The need for fiber optics could increase if new architectures require significantly faster data rates or are subjected to much worse electromagnetic hazards. It should be emphasized that these comments are based on a fighter aircraft flight control system perspective. Those involved in other areas and aircraft may have different opinions.

- Based on the present rate of component development, a highly fault tolerant and reconfigurable fly-by-light/flight-crucial flight control system utilizing bi-conical and star couplers will probably not appear before 1986 and only then in a prototype or experimental form. Although the Army's ADOCS is scheduled to fly in 1984 on a Sikorsky Black Hawk helicopter, it does not utilize the kind of fault tolerant and reconfigurable system required by a transport aircraft. Present indications are, however, that future military aircraft will utilize fly-by-light (FBL) controls.

- While optical encoders are used in spacecraft, other applications appear to be in the experimental stage.

- Needed standards for optical flight controls and data transmission systems are just now in the process of being generated by some airframe manufacturers in conjunction with fiber and connector manufacturers. It appears that the flight control application status is developmental.

- The technology is great if properly applied. Currently, that translates into use in transducers and data transmission links.

- Fiber optics is widely accepted as a new technology and except for the usual development and technology transfer problems, is finding increased applications in aircraft, missile and space vehicles.

- The application of fiber optics is in its infancy but growing and progressing.

- While optical data buses are an appropriate use of the technology, have reservations relative to sensors and transducers. The biggest pay-off in optical processing will likely be in signal processing applications which could include missile seeker guidance but not flight controls.

- Optics appears to offer significant advantages over electrical systems in such areas as EMI/EMP/lightning immunity, bandwidth; and, on paper, size and weight. However, when compared to current electrical/electronic technology, these advantages tend to dissipate, if not disappear. Optics will only be introduced when its advantages become real--when it can buy its way in. While the exploration of optics technology in future engine control systems is continuing, the advantages continue to be elusive at the present time.

- Within the next five years, there will be few production applications of the technology. It will probably be used in relatively non-critical applications and perhaps to transfer information between flight control computers; but advanced state-of-the-art optical data buses connected to optical sensors with optical signal processing is at least 10 to 15 years away, and more probably 15 to 20. A dedicated effort, driven by some significant benefit or problem to be solved could shorten the time. A need to solve EMI/EMP problems could accelerate the schedule. In this case, the overall cost would be high since all affected equipment/boxes would have to be modified/redesigned. Fiber optic equipment and transmission lines do not easily interface with digital electronic equipment.

- The use of the latest fibers and components in flight control applications is considered both feasible and desirable. The results of military experience to data is very encouraging. However, further development work is required in optical sensor technology, redundancy management techniques and optical multiplex bus architectures.

- The potential in-flight control applications is strong largely because of EMI/EMP and weight saving advantages.

- Optical technology for application in the area of engine/airframe control applications requires more design and testing under actual conditions to develop a good data base to establish the reliability of these systems. This includes all components of the system; sources/detectors, fiber optic waveguides, connectors and sensors. Until this is done, fiber optic technology will not gain wide-spread acceptance by either the military or commercial industry.

- The benefits of optical technology to flight control are questionable at this time. Current efforts such as ADOCS are essentially hybrid systems with analog sensors and actuators and extensive electrical interfaces. The major rationale for optical flight control is in its immunity to electro-magnetic threats. However, since a total optical system is not even on the horizon at this time, the benefits of partial protection have yet to be qualified. Extensive shielding and radiation hardening will still be a requirement under these conditions and electrical power transmission will continue to be a major issue.

- It is clear that the many advantages offered by the electro optical medium for signal generation and transmission in a flight crucial flight control system can eliminate in a cost effective manner the potential hazards of environmentally induced interference to which the conventional fly-by-wire control system is sensitive. For this reason, government and industry should work together more closely to achieve a more orderly and timely introduction of fiber optics to aircraft flight controls.

APPENDIX B

Industry Points of Contact on Optical Components

Respondees to a technical questionnaire included the names of companies and, in some cases, affiliated individuals involved in the development and/or manufacture of optical components. This listing of contacts is provided for information, recognizing that it is representative of only a small number of the many companies associated with optical technology and/or products. Thus, no significance is intended in either the inclusion or omission of any names.

TRANSDUCERS/SENSORS

- Rotary Transducer

Hamilton-Standard
ATTN: Philip Lefkowitz
Bradley Field Road
Windsor Locks, CT 06096
(203) 677-3021

TRW Electronics Group
ATTN: Malcom Hodge
401 N. Broad Street
Philadelphia, PA 19108
(215) 922-8900

- Linear Transducer

Boeing Aerospace
ATTN: Art Van Ausdal
P.O. Box 3999
Seattle, WA 98124
(206) 773-1375

Sperry Flight Systems
ATTN: Larry Gardner
P. O. Box 9200
Albuquerque, NM 87119
(505) 822-5155

- Pressure Transducer

Parker Hannifin
Bertea Division
ATTN: Roy Cass
18001 Von Karman
Irvine, CA 92715
(714) 833-1424

Teledyne-Ryan
Electronics
ATTN: John C. Moore
8650 Balboa Avenue
P.O. Box 23505
San Diego, CA 92123
(619) 569-2412

- Optical Servovalve

Boeing Military Airplane Co.
ATTN: Norm Huffnagle
220 Wynn Drive
Huntsville, AL 35807
(205) 532-8179

Sperry Flight Systems
ATTN: Larry Gardner
P. O. Box 9200
Albuquerque, NM 87119
(505) 822-5155

- Sidearm Controller

Boeing Vertol
ATTN: Bruce Bloke
P.O. Box 16858
Philadelphia, PA 19142
(215) 522-3618

- Gyroscopes (Includes ring laser and passive gyros)

Gould Inc.

Honeywell, Inc.

Lear Siegler, Inc.

Litton Industries

Martin (Orlando)

McDonnell Douglas

Northrop (Precision Products)

Raytheon

Rockwell (Autonetics)

Singer (Kearfott)

Sperry

Sundstrand

Thompson CSF

- Flight Demonstration of Optical Transducers

Bell Helicopter-Textron
ATTN: M.R. Murphy
P.O. Box 482
Fort Worth, TX 76101
(817) 280-2153

McDonnell Douglas
Astronautics
ATTN: Dr. R. Wood
Huntington Beach, CA 96241

Boeing Aerospace Co.
ATTN: A. W. Van Ausdal
P. O. Box 3999
Seattle, WA 98124

Rockwell International
ATTN: E. J. Solomon
4300 East 5th Avenue
P. O. Box 1259
Columbus, OH 43215

Delco Electronics
6767 Hollister Avenue
Galeta, CA 93117

Sperry Corporation
Flight Systems Division
2111 North 19th Avenue
Phoenix, AZ 85027

- Other Companies Noted in Transducer/Sensor Area

Hewlett-Packard

Plessey

ITT

United Technologies

Motorola

CONNECTORS

AMP Inc.
Eisenhower Blvd.
Harrisburg, PA 17105

Amphenol Connector
2801 So. 25th Ave.
Broadview, IL 60153

Bendix Corp.
1000 Wilson Blvd.
Arlington, VA 22209

Deutsch Co.
Electric Components Div.
Municipal Airport
Banning, CA 92220

GTE Products Corp.
2401 Reach Road
Williamsport, PA 17701

Hughes Aircraft Company
17150 Von Karman Ave.
Irvine, CA 92714

ITT Cannon
666 E. Dyer Road
Santa Anna, CA 92702

Motorola Inc.
P.O. Box 20912
Phoenix, AZ 85036

Optical Fiber Tech.
14 Fortune Drive
Billerica, MA 01821

Plessey Connectors
Limited
Northampton, England

TRW
Connectors Division
1501 Morse Avenue
Elk Grove Village, IL 60007

CABLES

American Optical Corp.
14G Mechanic
Southbridge, MA 01550

Bilden Fiber Optics
2000 South Batavia Ave.
Geneva, IL 60134

Ealing Optics Corp.
2225 Massachusetts Ave.
Cambridge, Ma 02140

Edmund Scientific Co.
101 East Glaucester Pike
Barrington, NJ 08007

Fiberphotics
2257 Soquel Drive
Santa Cruz, CA 95060

Galileo Electro-Optics
Corporation
Galileo Park
Sturbridge, MA 01518

Valtech Corporation
99 Hartwell Street
West Boylston, MA 01583

OPTICAL DATA BUSSES (Developments Largely for Company Product Applications)

Boeing Aerospace Co.
Engineering Technology
ATTN: Mr. G.E. Miller
P. O. Box 3999
Seattle, WA 98124

Georgia Institute of
Technology
Engineering Experiment
Station
ATTN: Dr. M.A. Richards
ATTN: Dr. Powers Garmon
Atlanta, GA 30332

Honeywell, Inc.
Systems & Research Center
Minneapolis, MN 55431

Hughes Research Lab.
3011 Malibu Canyon Rd.
Malibu, CA 90265

IBM Federal Systems Div.
Bodle Hill Road
Owego, NY 13827

ITT Electro-Optical
Products Division
7635 Plantation Road
Roanoke, VA 24019

McDonnell Douglas
Astronautics
Huntington Beach, CA 92641

Spectronics, Inc.
830 E. Arapaho Road
Richardson, TX 75080

Sperry Corporation
Flight Systems
2111 N. 19th Avenue
Phoenix, AZ 85027

OPTICS FOCUSING ON ENGINE CONTROLS

Babcock & Wilcox
Mr. John Berthold
Alliance Research Ctr.
1562 Beeson Street
Alliance, OH 44601

General Electric Co.
Mr. Paul Mossey
MS-H-78
P. O. Box 6301
Cincinnati, OH 45215

Radiation Monitoring Devices
Mr. Gerald Eutine
44 Hunt Street
Watertown, MA 02172

TRW
Dr. Madan Sharma
Fiber Optics Instruments
Redundo Beach, CA 90277

Boeing Military
Airplane Company
Mr. Richard Bartholomew
P.O. Box 1470
Huntsville, AL

OPOCA, Inc.
Mr. Ken James
1202 N. Broadway
Santa Ana, CA 92701

Simmonds Precision
Mr. Dennis DeFreitas
150 White Plains Road
Tarrytown, NY 10591

United Technologies
Research
Silver Lane
E. Hartford, CT 06108
Dr. Bill Glenn
Mr. James Berak
Mr. Elias Snitzer

GENERAL

McDonnell Douglas Corporation
Mr. Gus Weinstock
P. O. Box 516
St. Louis, MO 63166
(314) 233-4343

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16. Abstract

This report is a supplement to a technology survey in flight crucial flight controls conducted for NASA Langley Research Center. This complementary survey was conducted to assess the state-of-technology in optical devices for application to aircraft flight controls. It covers the various optical elements that are considered in a "fly-by-light" flight control system including optical sensors and transducers, optical data links, so-called optical actuators, and optical/electro-optical processing. Airframe installation, maintenance, and repair issues are also addressed. Rather than an in-depth treatment of optical technology, the survey concentrates on technology readiness and the potential advantages/disadvantages of applying the technology. The information was assembled from open literature, personal interviews, and responses to a questionnaire distributed specifically for this survey.

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