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FIBER SENSORS FOR AIRCRAFT HEALTH MONITORING

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SAE Avionics Systems Division
Sept 19 - 22, 1999
Sheraton Four Points Hotel
San Diego CA 92123

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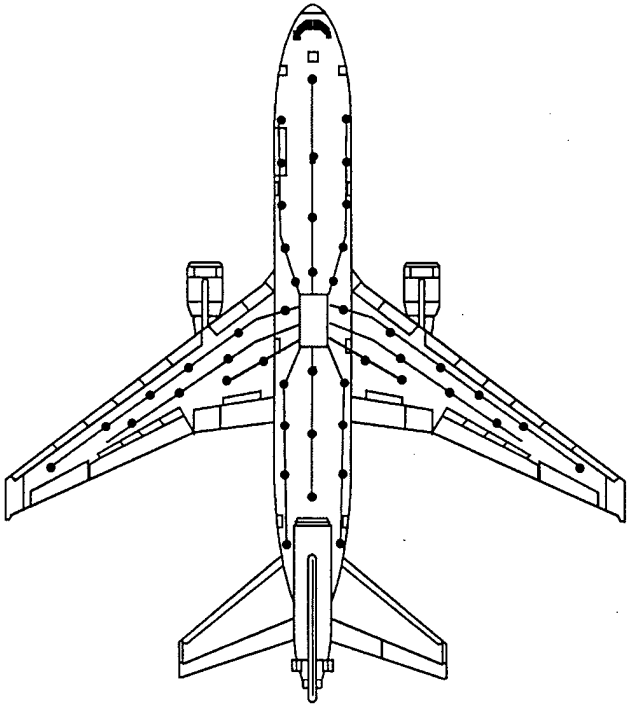
DTIC QUALITY INSPECTED 1

OUTLINE

- Objective
- Why Health Monitoring
- Sensor Requirements
- Fabrication Methods
- Bragg Grating Sensors
  - Strain and temperature monitoring
  - AE Monitoring
  - Bondline monitoring
  - Corrosion Monitoring
- Discussion - Recommendation

OBJECTIVE

- To study, develop and transition fiber sensor technologies for aircraft health monitoring. To develop reliable readout electronics and analysis software



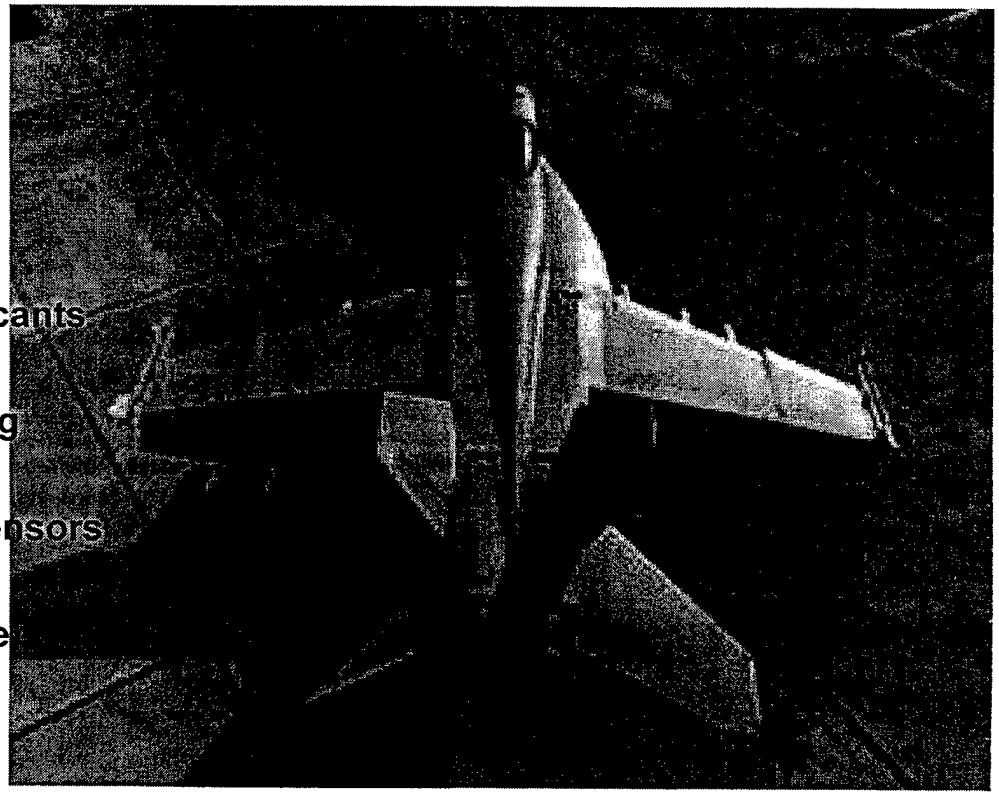
Why Health Monitoring ?

The main purpose of aircraft health monitoring is for reducing maintenance cost and enhancing aircraft useful life

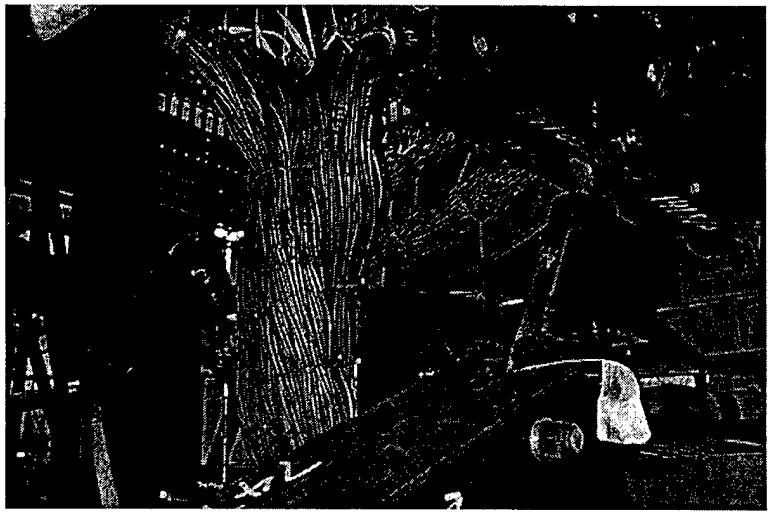
- Health Monitoring of Rotating Engine Parts
- Distributed Bond line Monitoring system
- Distributed Crack Initiation and Growth Monitoring System
- Distributed Corrosion Monitoring System

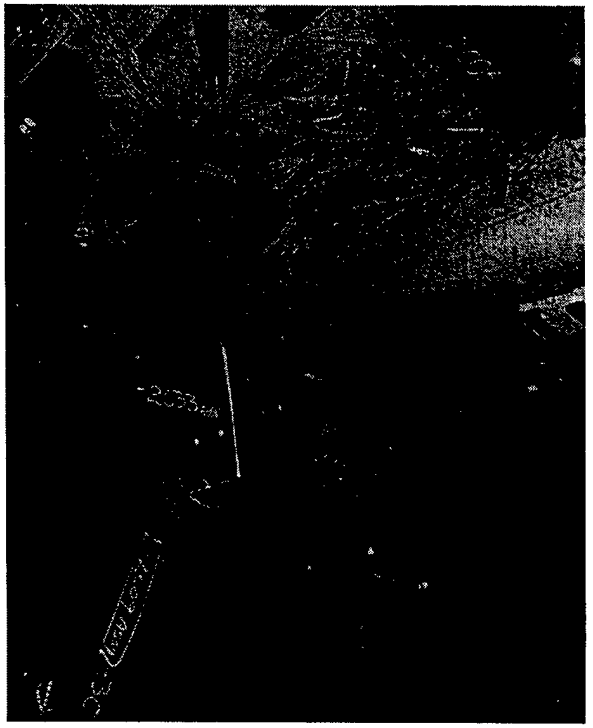
What parameters could be monitored in an aircraft ?

- Engine Monitoring
  - Cracks in disks, blades
  - Flow parameters
  - Temperature
- Gear box
  - Wear and cracks in gears
  - Vibration
  - Viscosity and particulate in lubricants
- Structural Monitoring
  - Full scale fatigue tests monitoring
  - Aircraft validation
  - Acoustic emission monitoring sensors
  - Vibration Monitoring
  - Strain monitoring sensors (usage
  - Impact damage monitoring
  - Bond integrity monitoring
  - Temperature monitoring
  - Humidity monitoring
  - Buffet monitoring



Full Scale Fatigue Test





Wiring for strain sensor instrumentation during a full scale fatigue test. Every sensor requires a minimum of two electrical leads. Each sensor requires a calibration file. Special care has to be taken to avoid EMI.

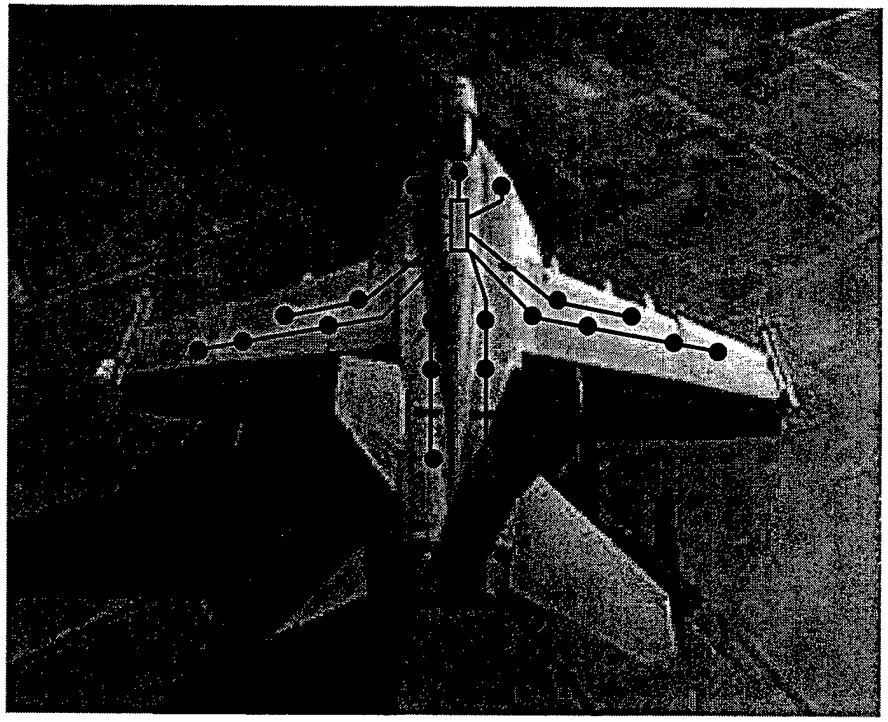
SENSOR REQUIREMENTS

Sensors have to be:

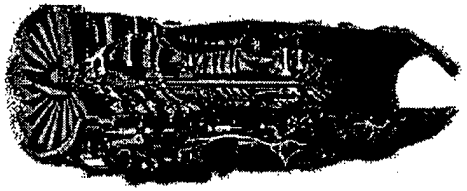
- Small volume
- Light weight
- Easy to connect
- Easy to multiplex
- Temperature resistant
- Rugged
- Reliable
- Easy to interrogate
- Accurate
- Minimum power requirements
- Minimum EM shielding requirements
- Corrosion resistant
- Easy to repair

HEALTH MONITORING SYSTEM

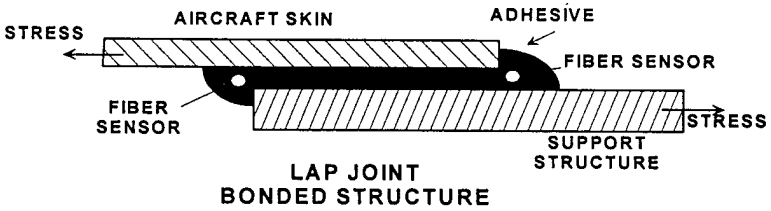
Health Monitoring System



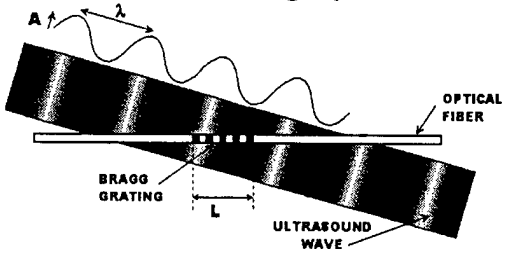
Engine Monitoring System



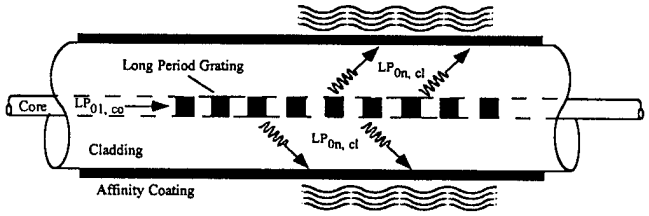
Bondline Monitoring System



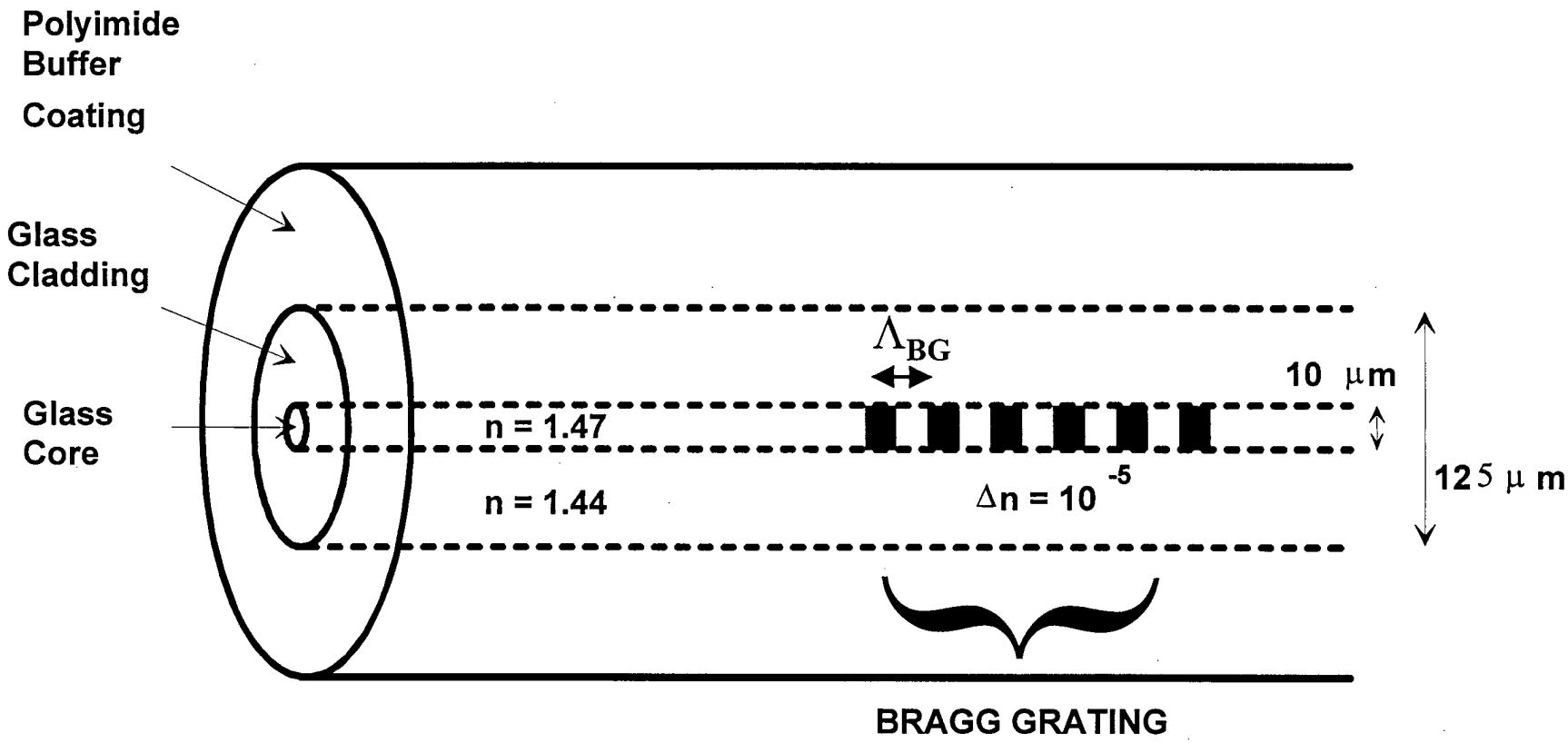
AE Monitoring System



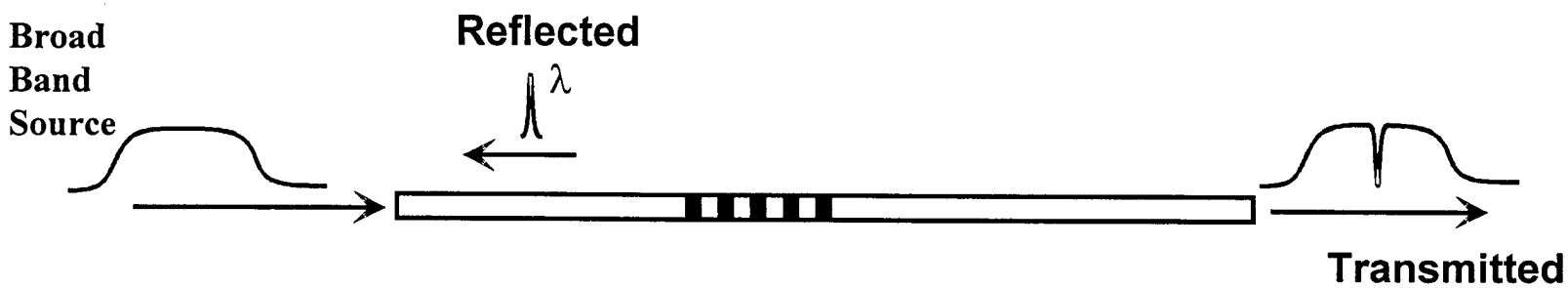
Corrosion Monitoring System



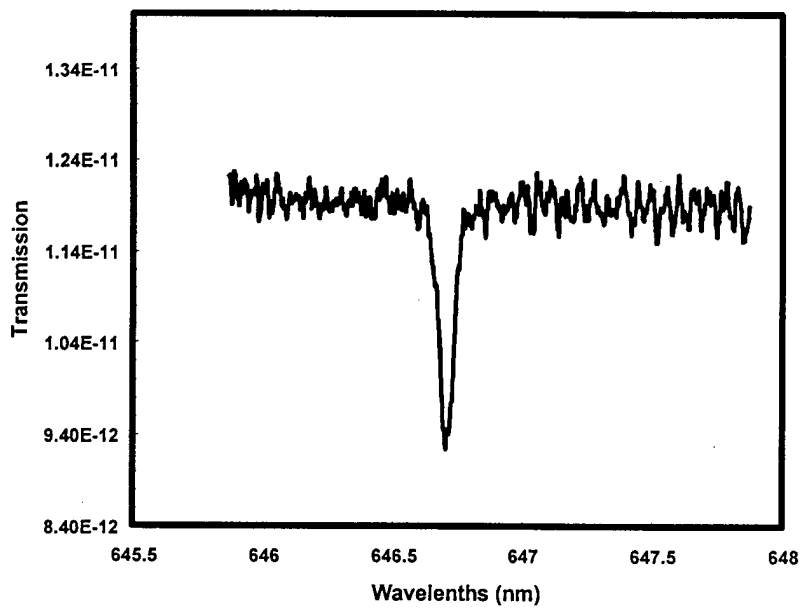
OPTICAL FIBER BRAGG GRATING



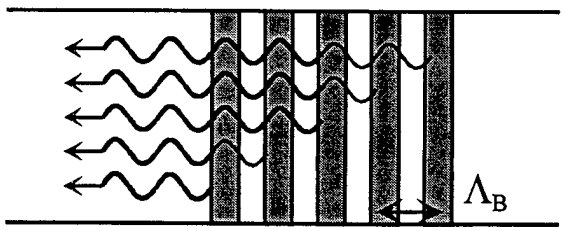
BG SPECTRA



TRANSMISSION SPECTRA



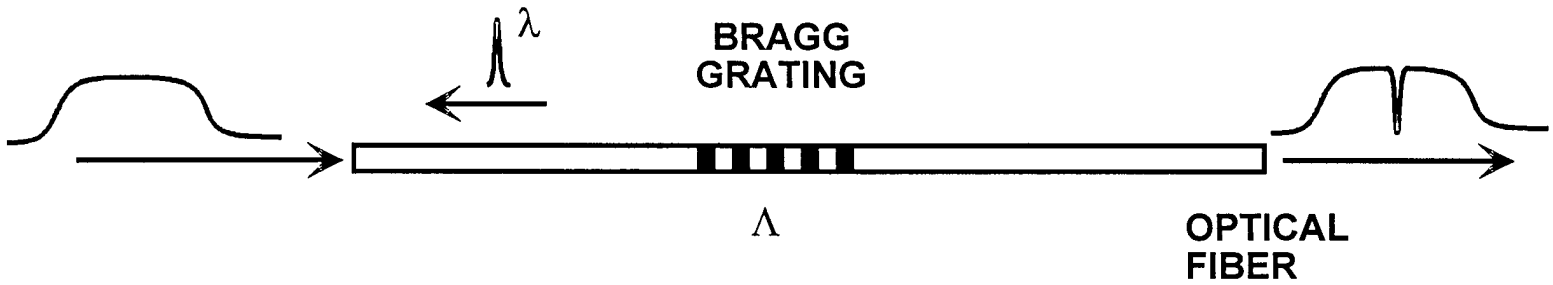
BRAGG GRATING



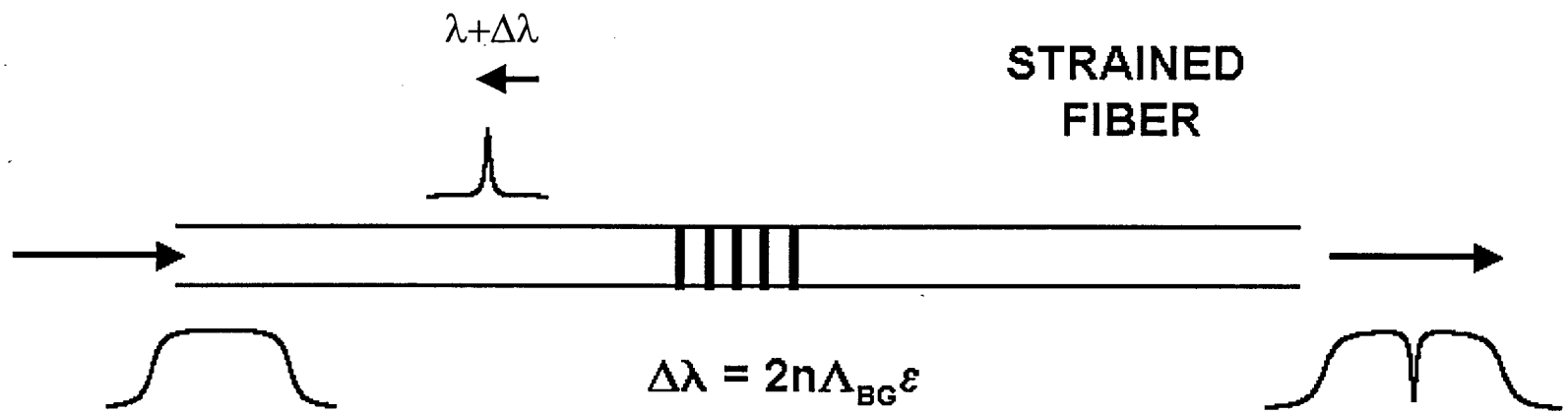
CONSTRUCTIVE INTERFERENCE

$$\lambda = 2\,\mathbf{n}\,\Lambda_B$$

BRAGG CONDITION

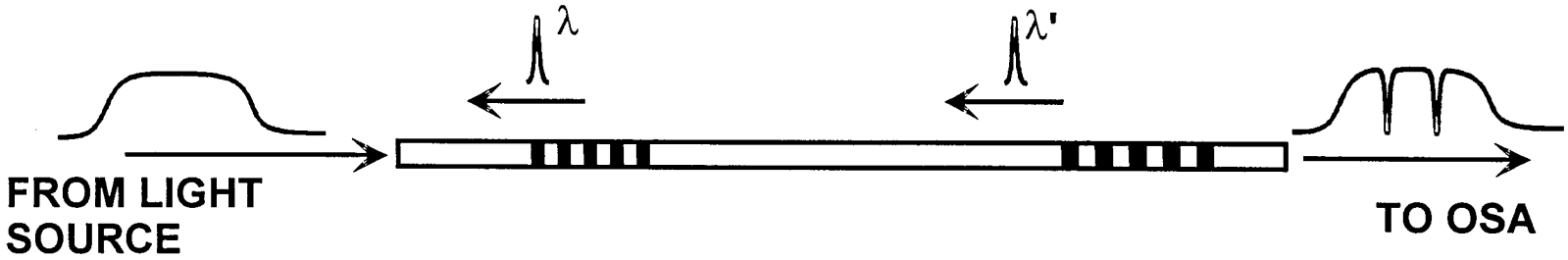


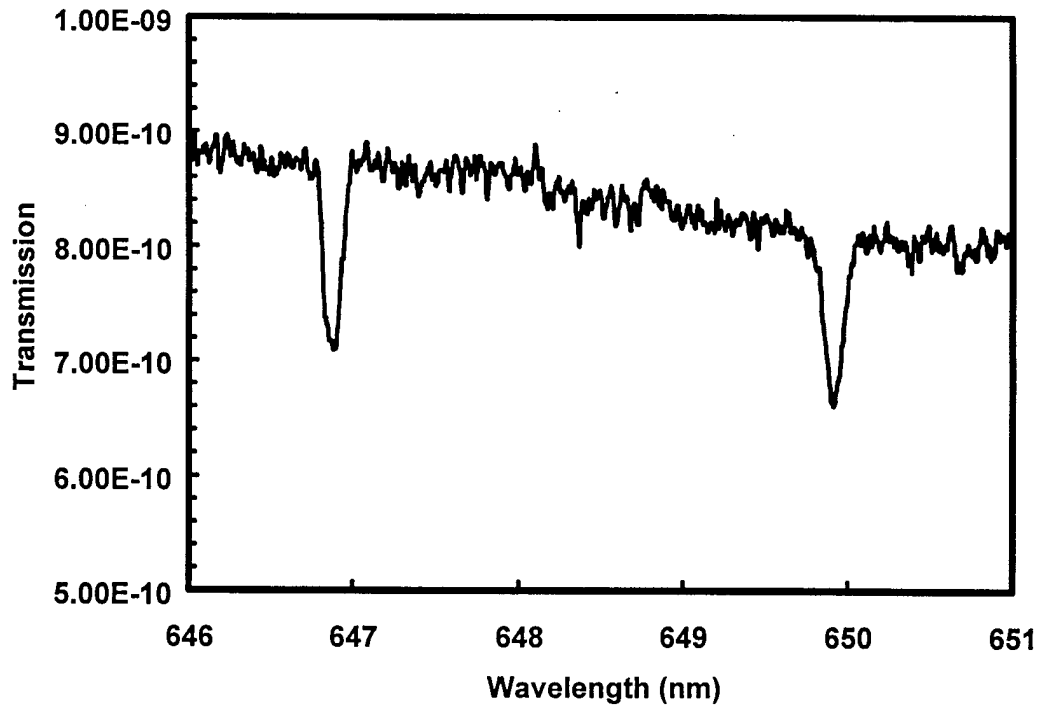
$$\lambda = 2\,\mathbf{n}\,\Lambda$$



Absolute strain sensing capability

ABSORPTION SPECTRA FROM TWO BRAGG GRATING

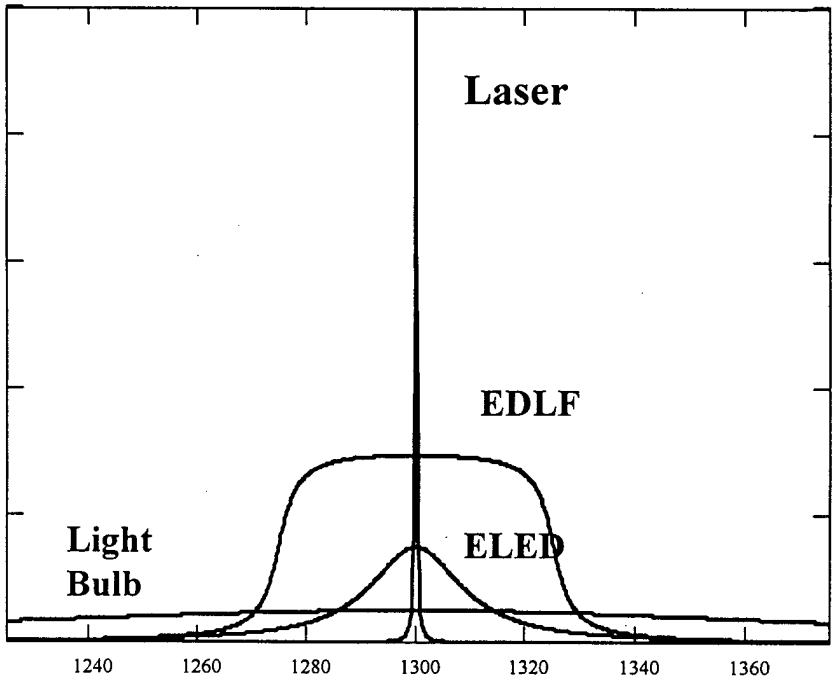




Multiplexing capability (large number of sensors in a single fiber)

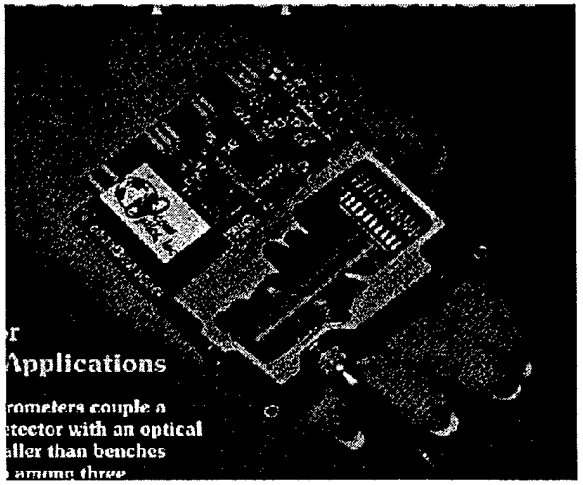
LIGHT SOURCES

- Incandescent light source
- Light emitting diode(LED)
- ELED
- Super luminescent diode
- Erbium Doped Fiber laser
- HeNe Laser



DEMODULATORS

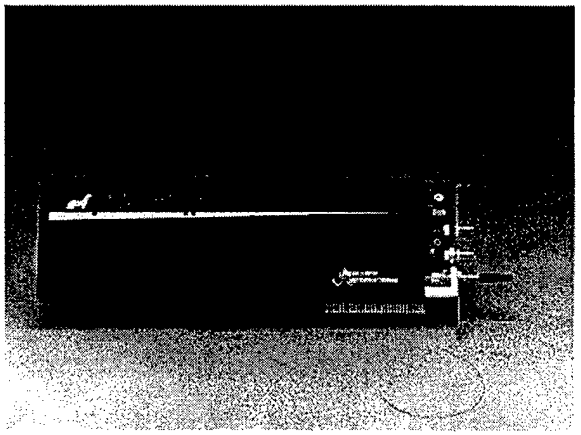
Ocean Optics Inc.



Diffraction grid

Resolution = 0.5 nm
Range 200nm - 11000nm
Refresh Rate = 50 Hz

Research International Inc.

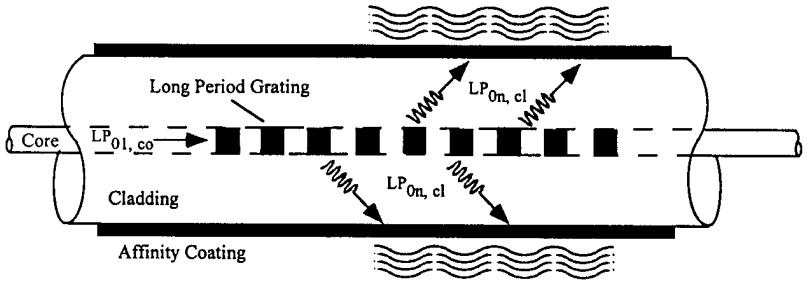


Fabry-Perot Cavity

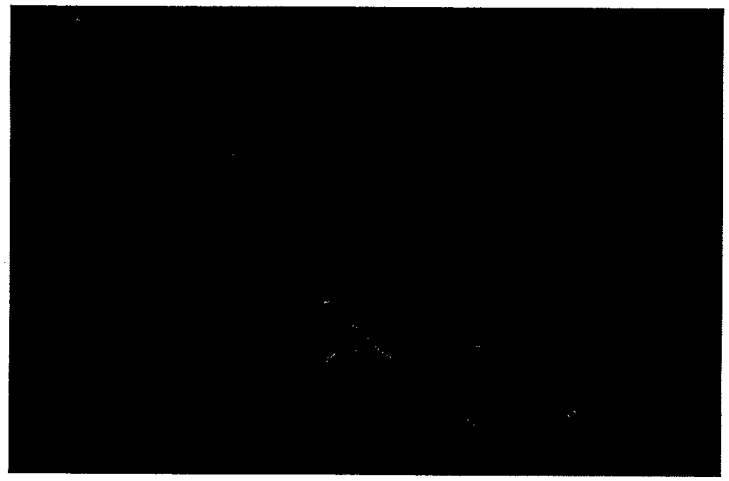
CORROSION MONITORING

FIBER OPTIC LONG PERIOD GRATING

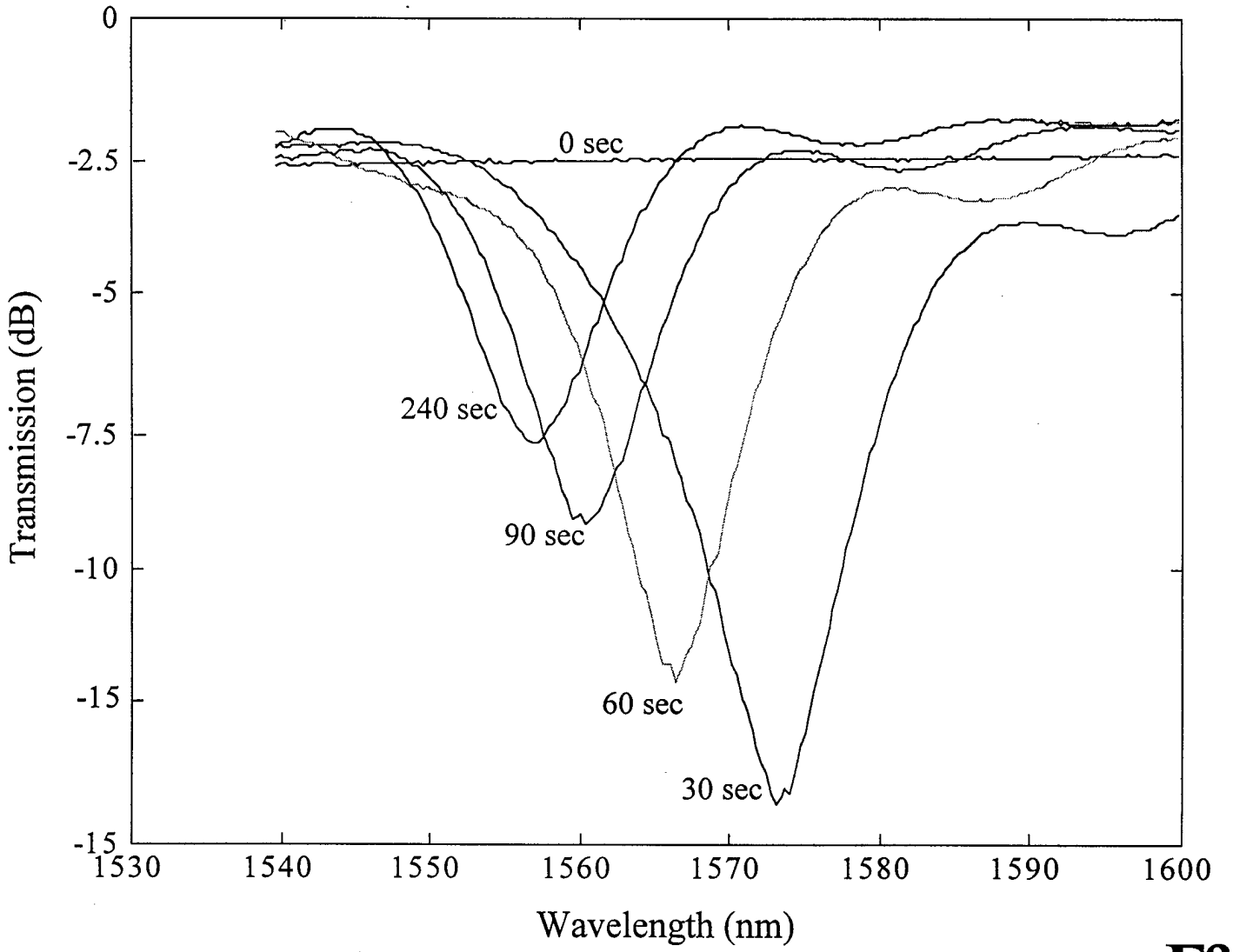
- <u>OBJECTIVE</u>: TO DEVELOP A DISTRIBUTED FIBER OPTIC SYSTEM TO MONITOR THE DEVELOPMENT OF CORROSION
- <u>ADVANTAGES</u>:
  - IN A SINGLE FIBER MANY SENSORS CAN BE PLACED
  - EACH SENSOR CAN BE INTERROGATED INDEPENDENTLY
  - SENSOR CAN BE CAN BE TAILORED TO SPECIFIC COMPOUNDS
  - NO OR MINIMAL ELECTRONICS ARE REQUIRED FOR MONITORING
  - SENSOR IS SMALL AND LIGHT
  - SENSOR IS INSENSITIVE TO EMI
  - SENSOR IS WAVELENGTH (NOT INTENSITY) BASED
  - CAN BE EMBEDDED OR SURFACE MOUNTED
- <u>TRANSITION POTENTIAL</u>: P-3C, JSF



$$\lambda = (n_{co} - n_{cl})\Lambda_{LPG}$$

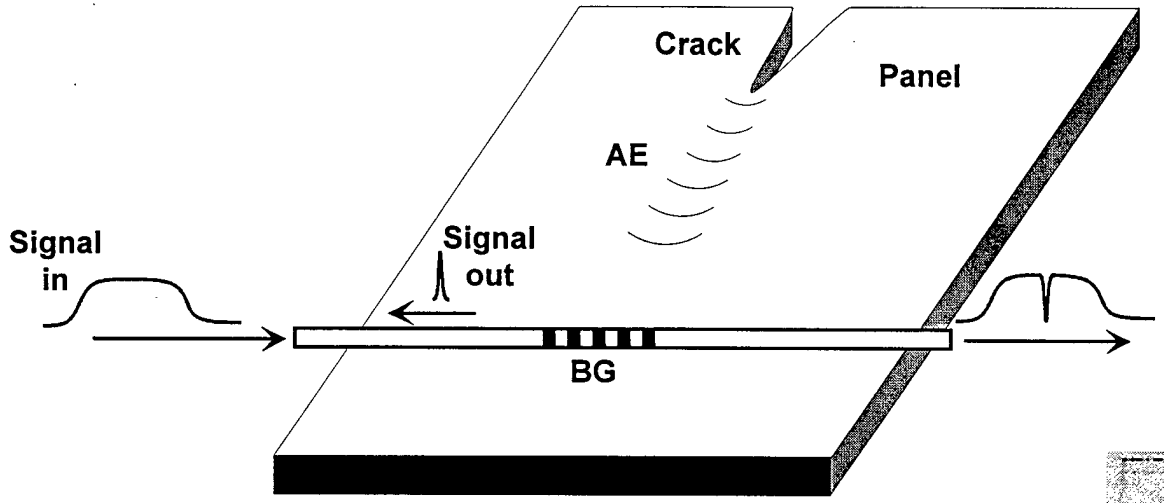


LPG SENSOR SPECTRUM DURING WATER IMMERSION



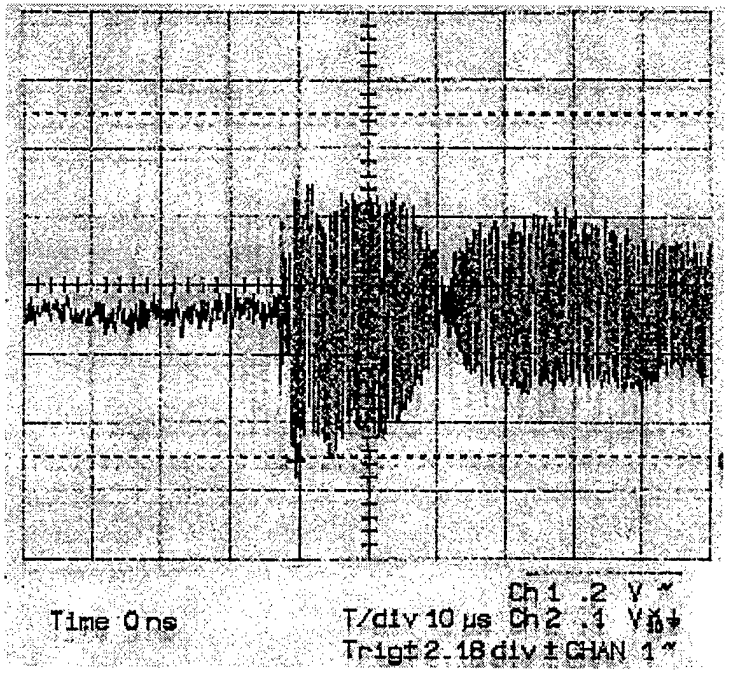
F&S, Inc.

AE Event



- Acoustic Emission event detected with a single fiber-optic Bragg grating

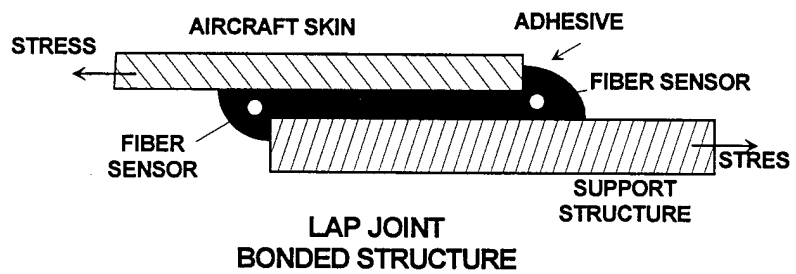
AE Event

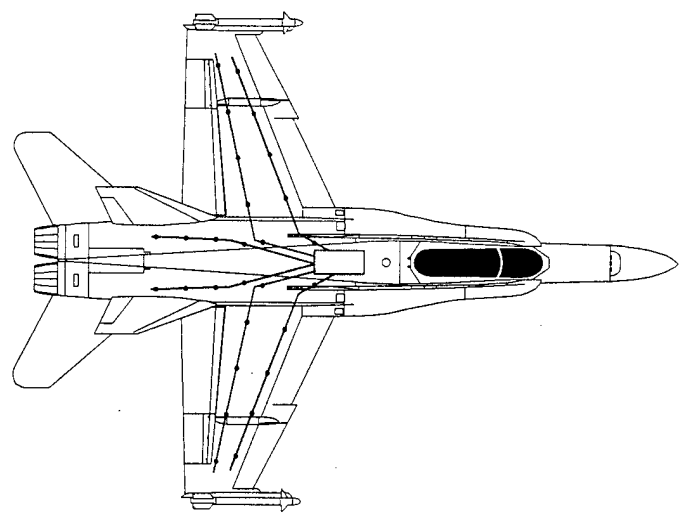


BONDLINE MONITORING SYSTEM

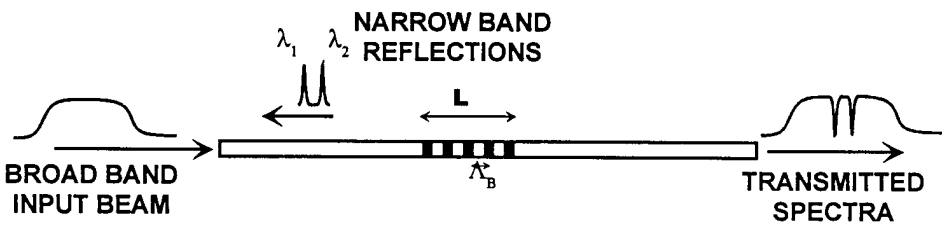
MULTI-AXIS FIBER OPTIC STRAIN MONITORING SYSTEM

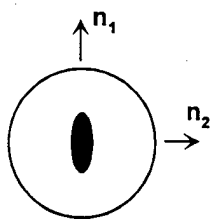
- OBJECTIVE: TO DEVELOP A DISTRIBUTED FIBER OPTIC SYSTEM TO MONITOR BOND-LINE INTEGRITY
- ADVANTAGES:
  - IN A SINGLE FIBER MANY SENSORS CAN BE PLACED.
  - CAN SENSE AXIAL AND TRANSVERSE STRAINS.
  - EACH SENSOR CAN BE INTERROGATED INDEPENDENTLY
  - SENSOR IS SMALL AND LIGHT
  - SENSOR IS IMMUNE TO EMI
  - SENSOR IS WAVELENGTH (NOT INTENSITY) BASED
  - CAN BE EMBEDDED OR SURFACE MOUNTED
- TRANSITION POTENTIAL: P-3C, JSF, CBM, Aging Aircraft





Spectral Changes with Loading





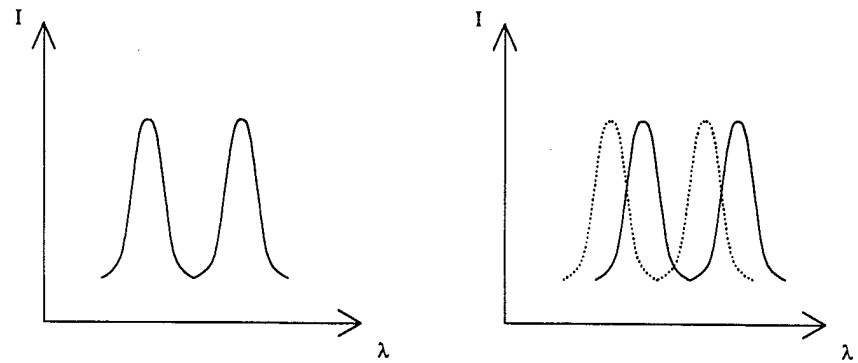
ELLIPTICAL CORE
OPTICAL FIBER

$\lambda_1 = 2\Lambda_B n_1$

$\lambda_2 = 2\Lambda_B n_2$

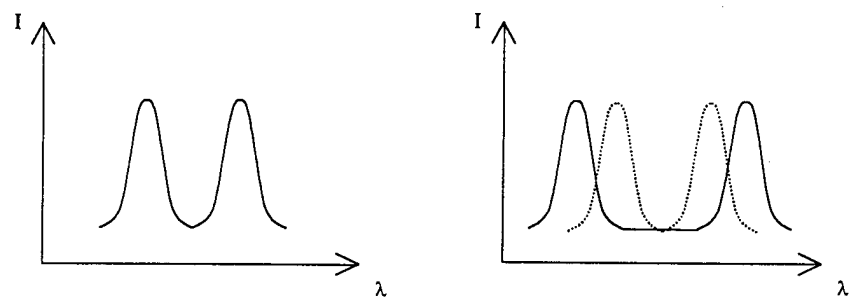
- Sensitivity is orientation dependant

Wavelength shifts due to axial strain



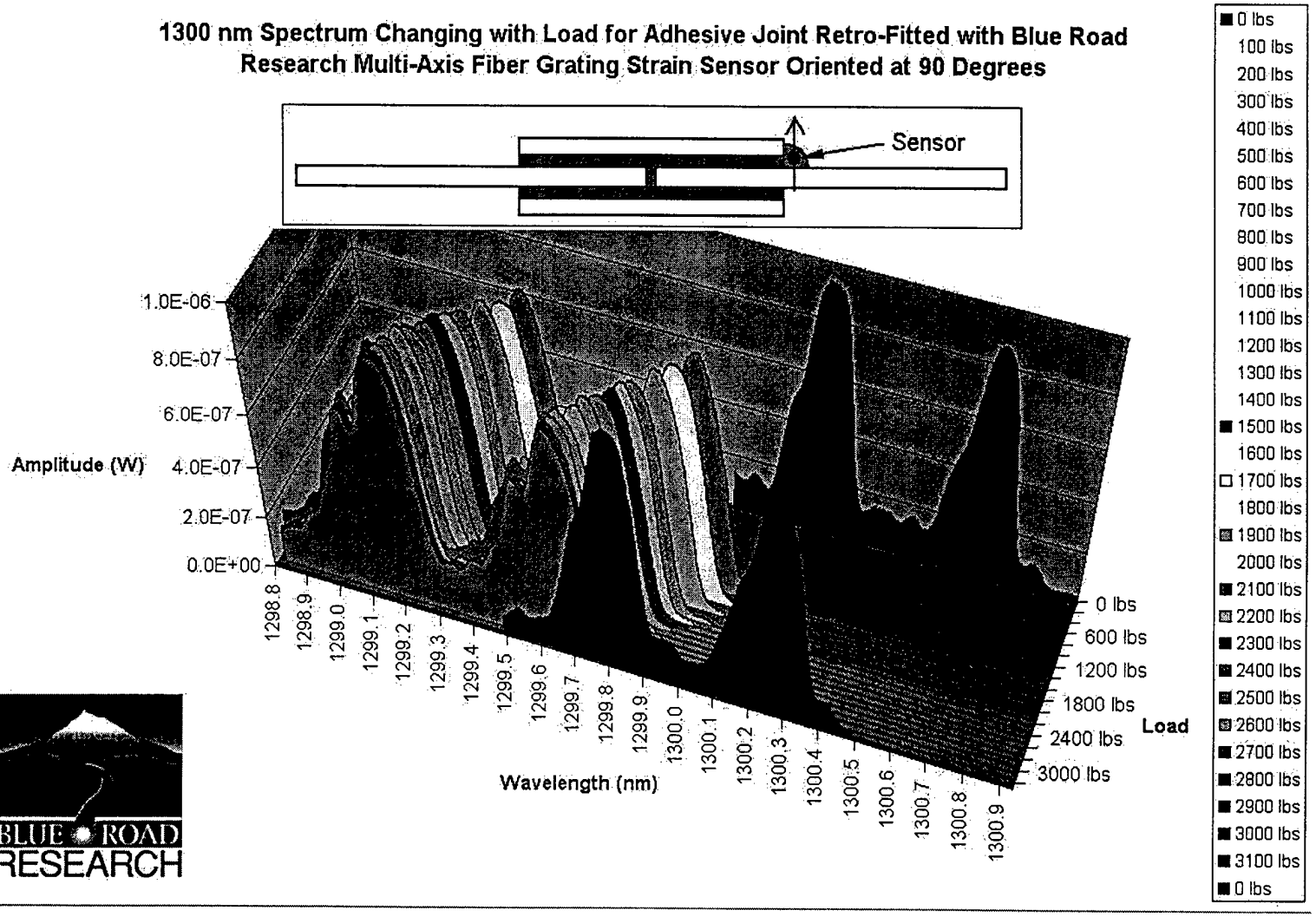
Increasing axial strain →

Peak to peak separation due to transverse strain



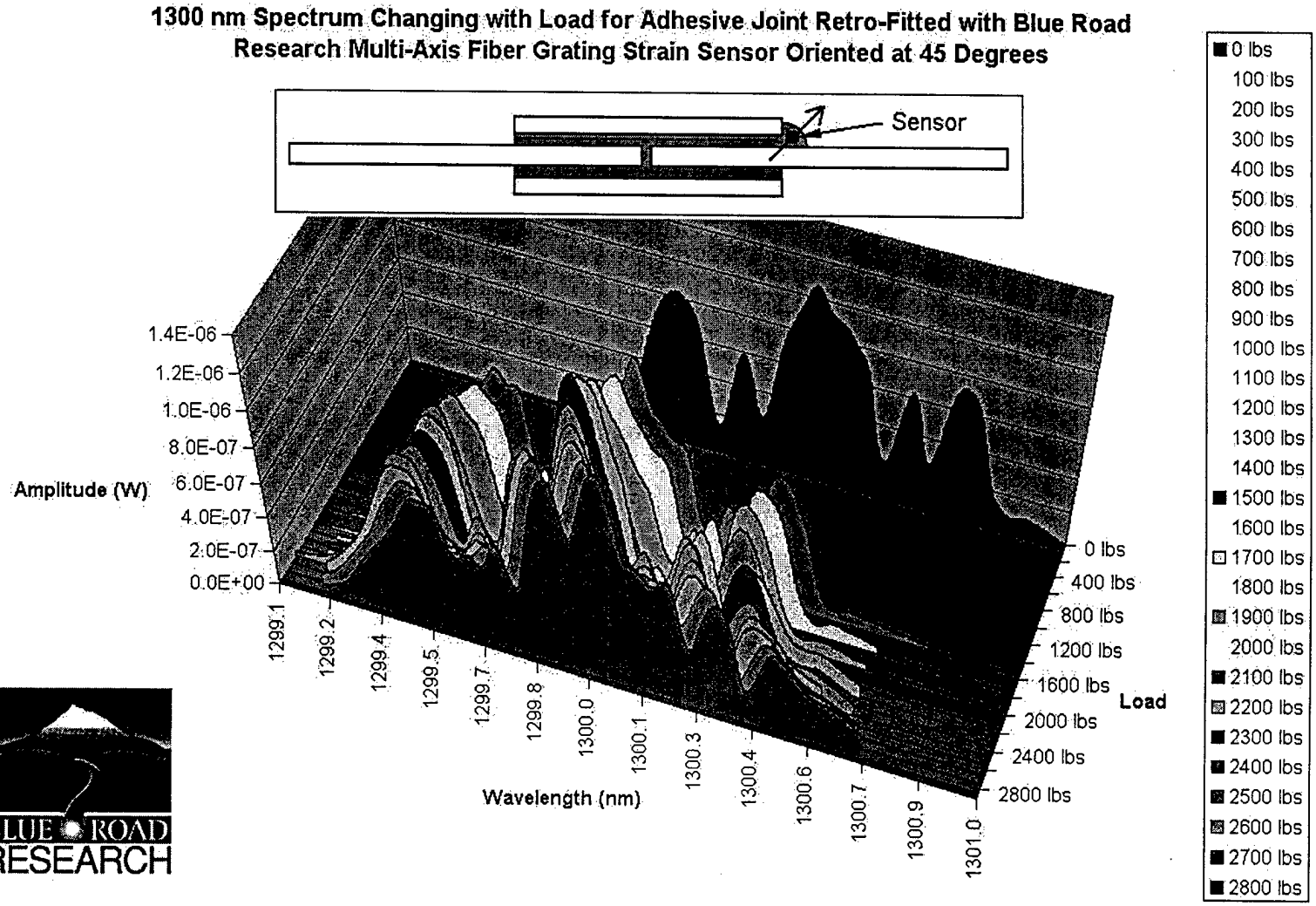
Increasing transverse strain →

Peak Separation vs. Load



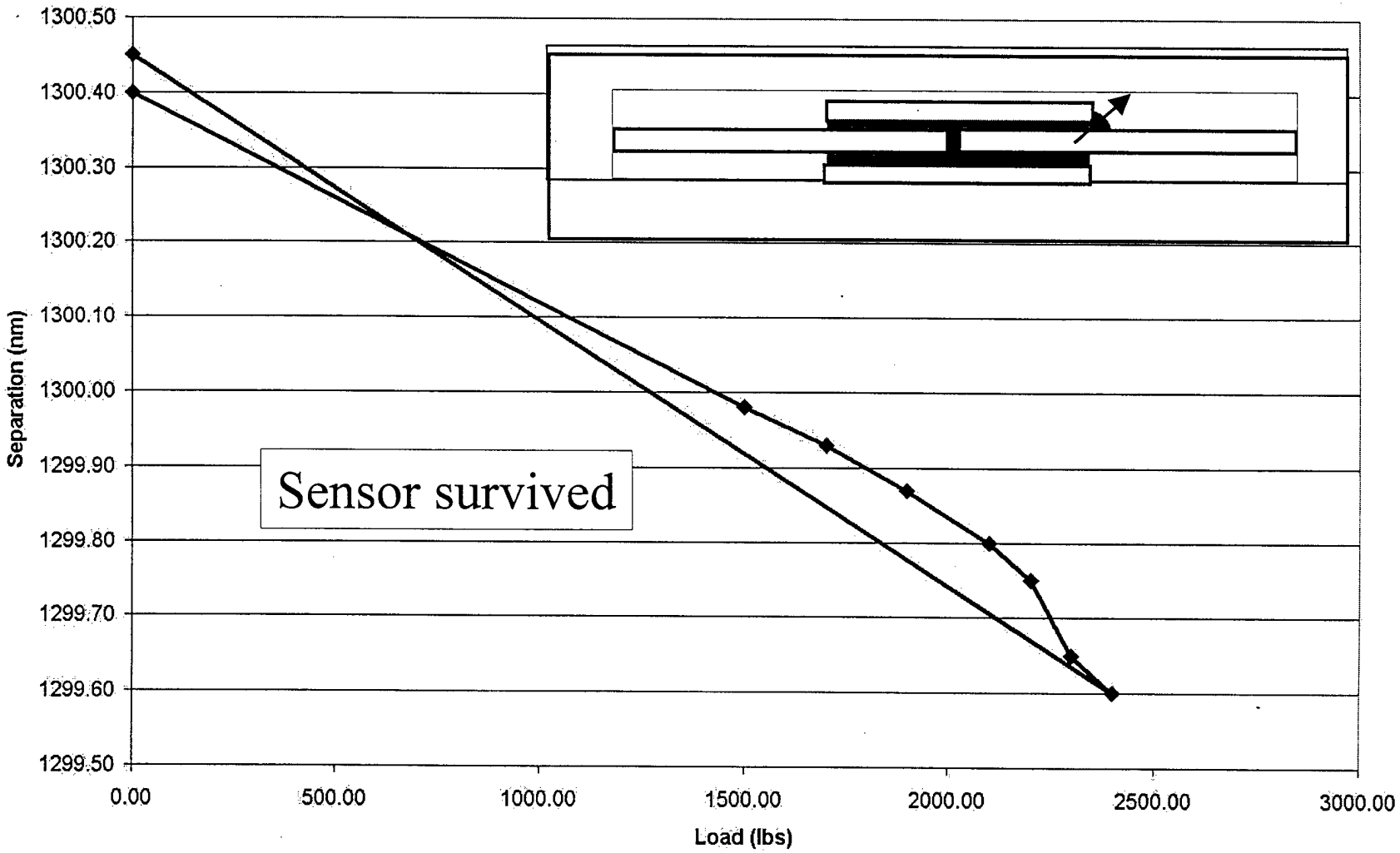
Peak Separation vs Load

high sensitivity orientation



Peak Separation vs Load

high sensitivity orientation



Fiber Sensors are Enabling

- Smart skins
- Smart patches
- Smart Materials
- Functional Materials (ex. Conformal antennas)
- Chemical and Biological detection in paints
- Designs for Inspection and LO materials: New and advanced structures and materials make NDI inspections very difficult
- Flight change due to combat or system damage
- Testing and Validation of structures and components
- Real-time in-flight testing and validation
- Waste Monitoring