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mechanical design
composites engineering
structural health monitoring

Wireless Nodes for Active Structural Monitoring in Extreme Environments

Monitoring & Evaluation Technology Integration System

M.E.T.I.-System Suite of Damage Detection Devices

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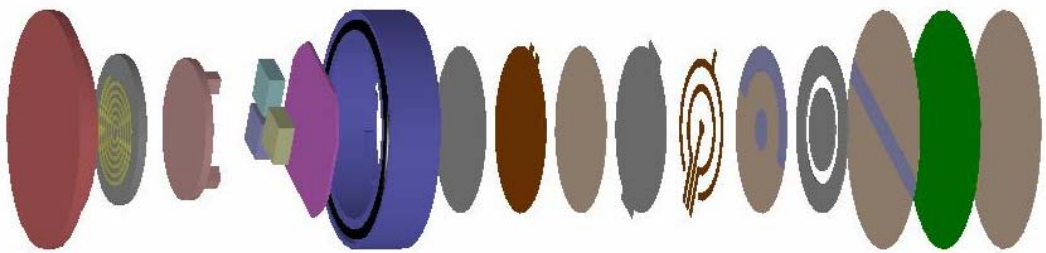
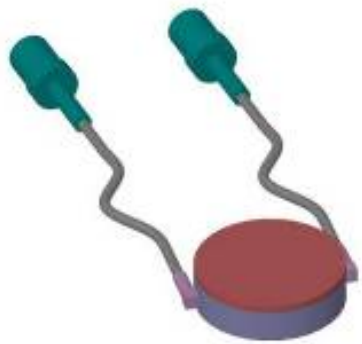
MDC SHM Activities

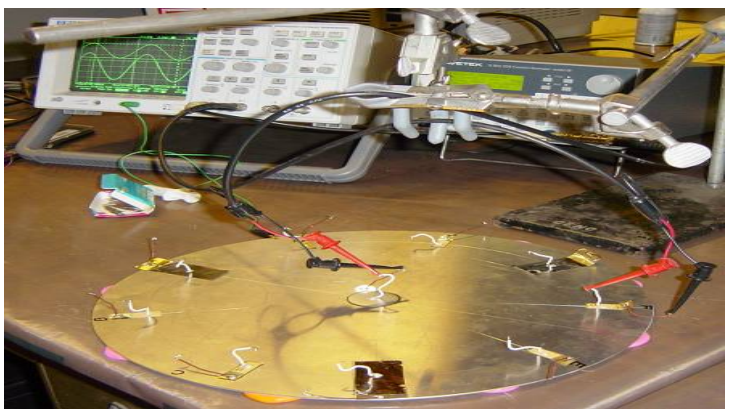
- Much SHM research has focused on detection methods; most demonstrations have been limited to laboratory-scale
- Presently MDC is developing infrastructure for which several methods can be implemented for military or civil applications
- MDC has focused primarily on piezoelectric-based methods
- Several collaborators from industry, government and academia

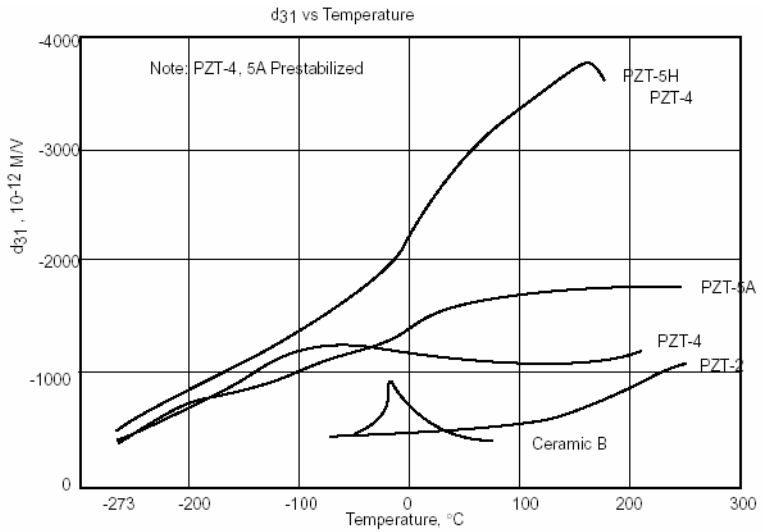




Actuator/Sensor Optimization

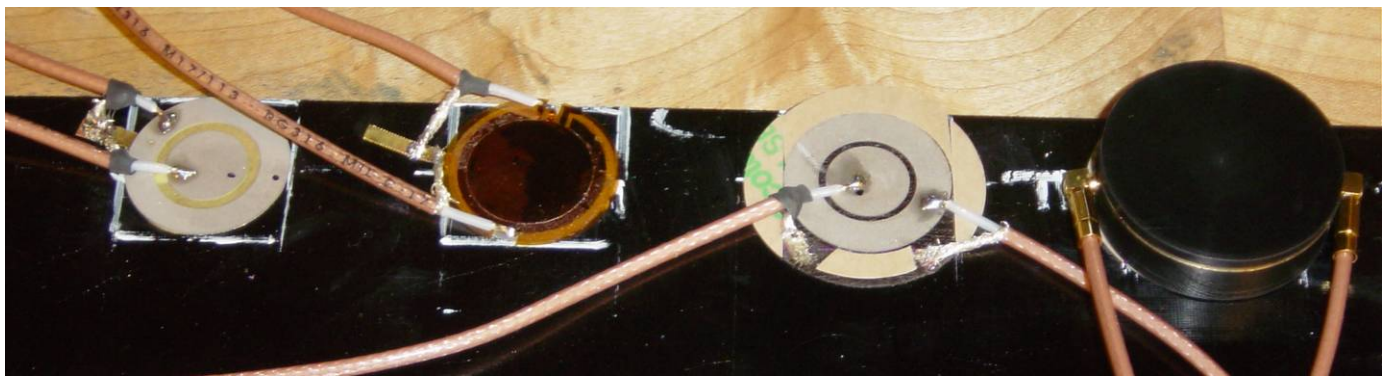
- NRO funded BAA program with MIT A/A as subcontractors
- Optimized piezoelectric actuators and sensors
  - material properties including thermal behavior
  - geometries for target detection methods
  - goal of minimizing power and amplification requirements
- Developed algorithms for data interpretation using Lamb waves
- Experimental validation of optimization and algorithms on plate and sandwich panel specimens





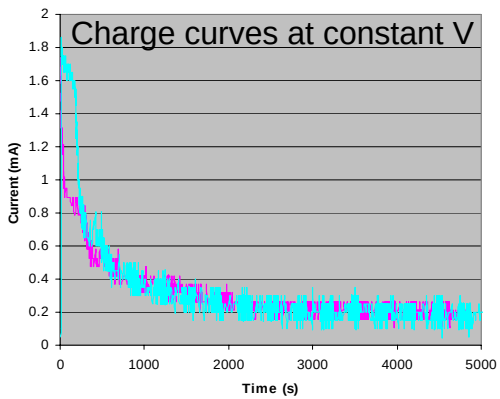
Packaging

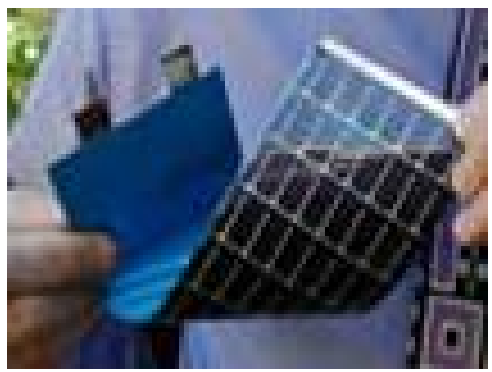
- NSF funded STTR program with MIT A/A as subcontractors
- Developed packaging for SHM component durable operation
  - sealed from moisture ingress
  - shielded against electro-magnetic interference (internal and external)
  - insulated from short-duration extreme temperature exposure
  - provides protection and isolation against incidental impact
- Experimentally proved that packaging scheme could effectively protect components as desired without effecting performance



Power Systems

- AFOSR funded STTR program with MIT M/S as subcontractors
- Development of wirelessly rechargeable batteries
  - thin film Lithium polymer battery, high energy/power density
  - flexible, durable, and environmentally stable
  - quickly recharge via conventional or wireless methods, no memory effect
- Devised requirements and approach for DAQ components
  - datalogger with ~1 MHz acquisition, A2D, and quick data bus
  - microprocessor to command detection methods, excite actuator, storage
  - wireless transmitter/receiver for commands and data upload





More Current Research

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- Software engineering
  - developing third-generation software to collect and interpret results from frequency response and Lamb wave tests
  - neural-net characteristics, some fuzzy-logic
  - customizable to application
- Microfabrication
  - working with subcontractor to implement sensors/actuators in MEMS
  - some electronics will also be miniaturized
  - increase consistency, lower size and production costs
- Electrical components
  - working with subcontractor to develop micro-electronics suitable for SHM
  - embedded multi-channel datalogger, ~1MHz 16-bit
  - embedded function generator ~1MS/s 16bit
  - will allow unique node address for data/power bus, reduced complexity

Introduction to M.E.T.I-Disk

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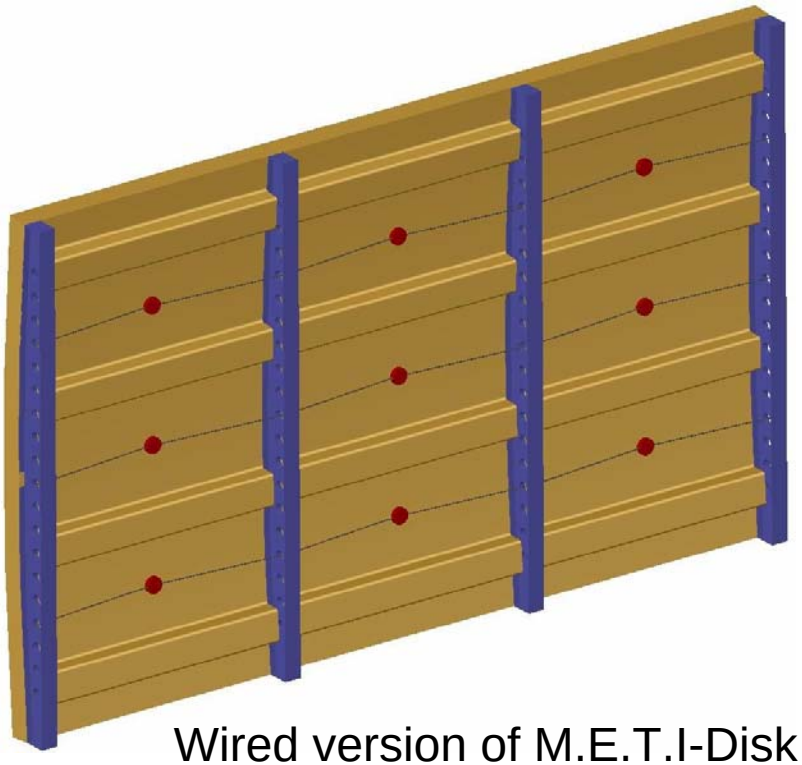
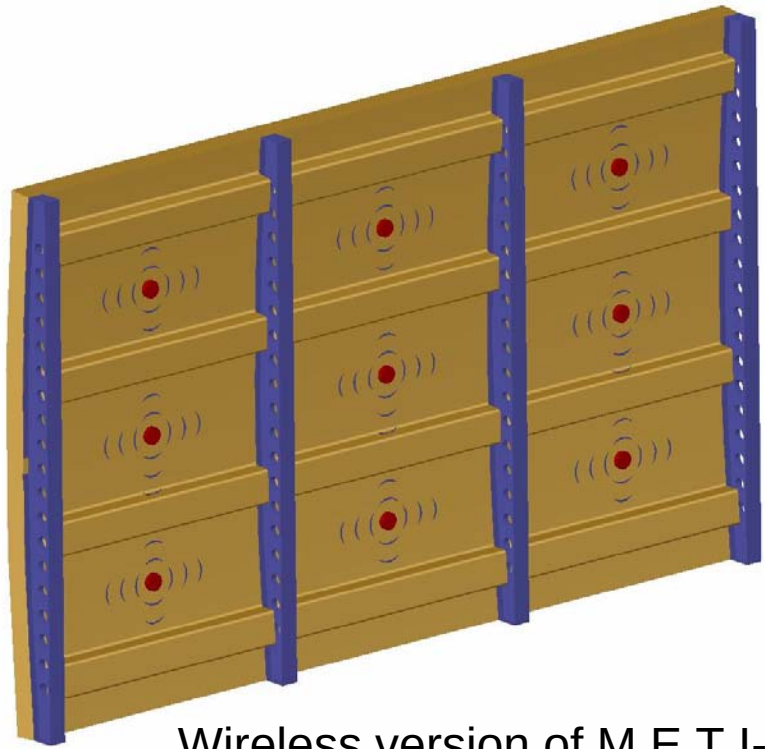


Wired version of M.E.T.I-Disk



Wireless version of M.E.T.I-Disk

- Monitoring & Evaluation Technology Integration: M.E.T.I.-Disk
- Two versions of M.E.T.I.-Disk are in parallel development
  - wired version nearly finished, finalizing software and testing by late 2004
  - wireless version shares many components, need to integrate electronics
- Single sensor can cover ~12 foot diameter, structure dependant

Technical Highlights

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- Utilizes several piezoelectric damage detection methods
  - Lamb waves are primary means to detect, locate, and interpret damage
  - modal analysis is used to evaluate set damage threshold levels
  - acoustic emission is used to detect impact events
  - passive methods are used to record strain/stress
- Three separate physical phenomena used to interpret data
  - energy integration
  - wave speeds arrival times
  - frequency spectra
- Embedded intelligence/logic in software
  - self-calibrating, uses adjacent sensor to calculate wavespeed
  - self-compensating for hygral/thermal changes using updated wavespeed
  - self-diagnostic, uses impedance to confirm piezoelectric functionality

Advantages to M.E.T.I-Disk

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- Software-centric design
  - uses customized software to tailor the system to any application
  - allows generic hardware to be mass-produced cheaply, installed easily
  - flexible infrastructure accepts multiple sensor types, detection methods
  - hardware-centric designs add complexity, time, cost and risk
- Lamb waves methods
  - can efficiently quarry a larger area on a vehicle than other methods
  - lower sensor density requirements
  - reduced costs, weight, complexity and computational needs
- Analytically-based software
  - can accurately model interaction since only the Ao Lamb mode is excited
  - better understanding of the resulting data, richer results
- Surface mounted sensors
  - devices can be retrofitted onto ageing aircraft
  - allow for easy removal without damaging the structure
  - embedded sensors can initiate damage themselves, repairs are difficult

Concept of Operations

Starting from taxi, passive monitoring methods begin collecting data on state of structural health.

In flight, passive monitoring is used with intermittent active method acquisitions. Up to 16 hours of data collection.

Upon landing, flight data is collected during normal pre-flight servicing time. Complete active method diagnostic is also performed for on time, safe take-off.

System Data Utility

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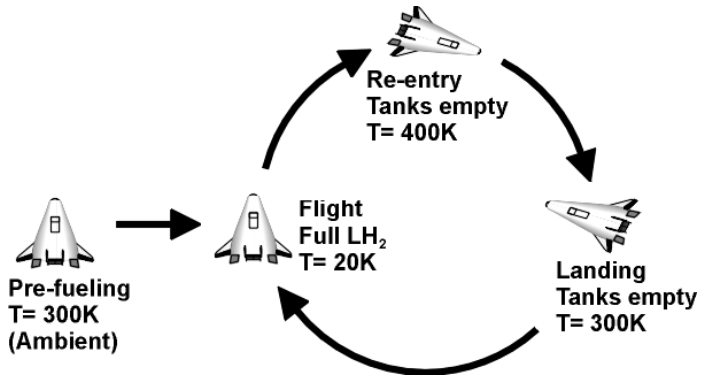
- Black box augmentation
  - record additional critical data in the event of an accident
  - witness maximum strain/stress in vehicle for future design/analysis use
- Maintenance checks
  - expedite scheduled inspections, reduce manual labor with in-situ system
  - offer surface penetrating methods without tear-down of sub-structure
- Ground support
  - continuously monitor vehicle in-flight for threshold stain/stress values
  - perform complete pre-flight diagnostic inspection for safety assurance
- Supply/demand
  - provide component data for state-based maintenance and replacement
  - Smoother, quicker and cheaper supply and demand of components

SHM in Extreme Environments

- Applications
  - reusable launch vehicles (RLV)
  - space exploration vehicles
  - hypersonic aircraft
  - marine vehicles



- Anticipated environments
  - temperatures >350°F under TPS, <-70 °F outside of cryotanks
  - low pressures and radiation for space applications
  - saturated salt water in marine applications
- Fault locations
  - wires for data and power
  - electronics and power sources
  - packaging

Wireless Data and Power Transfer

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- Concerns
  - wires, cables, connector, etc., are most fault prone location on an aircraft
  - add complexity, cost, weight, manufacturing time
  - wires can corrode, short, overload, fatigue
  - cables can melt or crack, exposing wires, absorb fluids
  - connectors can bend, break, fatigue
- Solutions
  - reduce wire count and complexity with local data acquisition, unique ID
  - reduce internal electrical connections with integral circuitry, MEMS
  - eliminate need for data wires with wireless data transmission
  - eliminate need for external power, recharge battery via RF or harvesting

Energy harvesting circuit

Inductive loop recharger

Packaging for SHM

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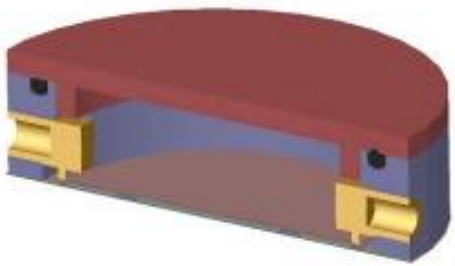
- SHM is predicated on the ability to integrate sensors
  - system reliability must be increased, i.e. sensors cannot initiate damage
  - sensors are sufficiently reliable so that they do not require replacement at intervals less than the economic lifetime of the part being monitoring
  - packaging of sensors is a major consideration
- Packaging must perform multiple functions
  - provide an interface between sensors and structure (eg. to ensure that generated waves can be transmitted with minimal power loss)
  - protect sensors from natural, mechanical and electrical environments, including temperature, moisture, EMI, radiation vibration, and impact
  - avoid durability issues for sensors such as fatigue and creep



Current M.E.T.I-disk packaging with flanged cable connectors

Summary

- Present MDC system suitable for many applications
  - infrastructure in place that can integrate multiple detection methods
  - in-house developed methods and software provide critical information
  - software-centric design allows for generic hardware, custom applications
  - commercialization work in progress

- Continued research to adapt system for harsh environments
  - local data acquisition and reduction; some embedded logic capabilities
  - wireless data transmission, command reception and reprogramming
  - suitable packaging, sealing, shielding and installation process
  - ability to recharge remotely through RF or harvesting vibrations