Spacecraft Sensing Needs and the Limitations of Cables

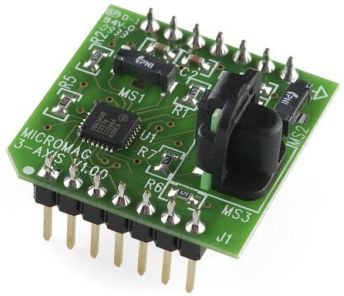
Dr. Derek Doyle

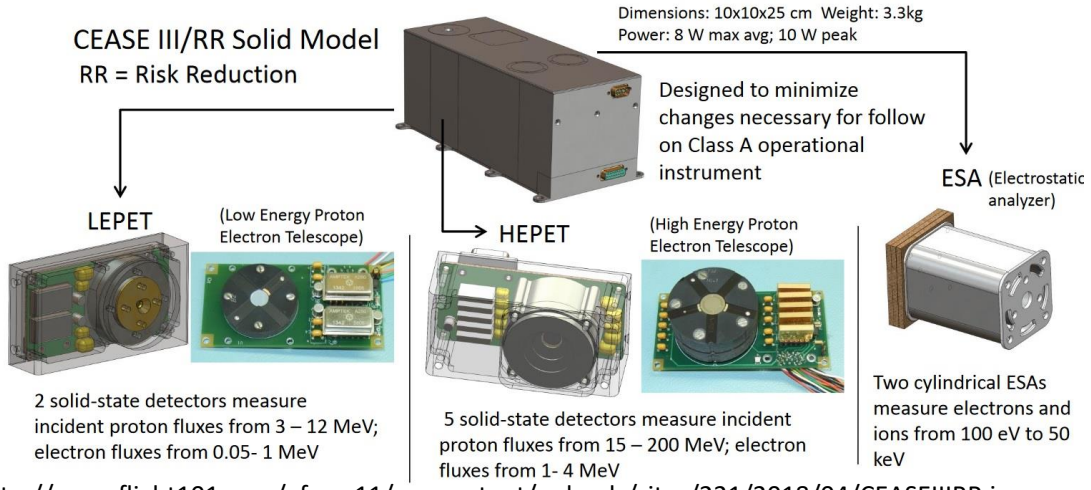
Space Vehicles Directorate|

ISS Program Structure

- Current Spacecraft Sensing Situation
- Next Generation of Satellites
- Development of the Structural Health Monitoring (SHM) Experiment
- Challenges Faced
- Opportunities for the Wireless Community

Current Situation





http://spaceflight101.com/afspc-11/wp-content/uploads/sites/221/2018/04/CEASEIIIRR.jpg

Sensors play a vital role in maintaining a satellite and its CONOPS

Attitude and Controls : horizon sensor, star tracker, sun sensor, magnetometers, inertial sensors.

Thermal management: thermocouples, thermistors

Deployments: strain gauges, load cells, torque sensors, accelerometers

Launch: pressure, microphones, accelerometers, shock sensors

Environmental: Radiation sensors, surface charge, plasma, structural status

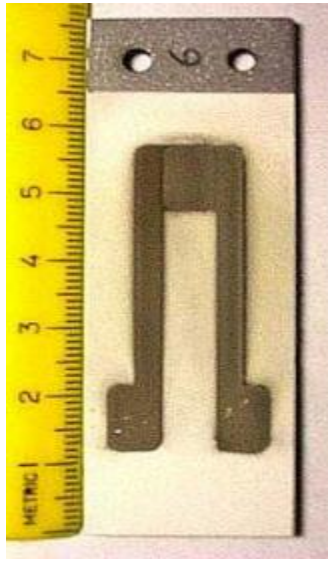
These sensors are utilized to provide critical information to technicians that may influence CONOPS or implemented into on-board autonomous decision making routines

Current Situation

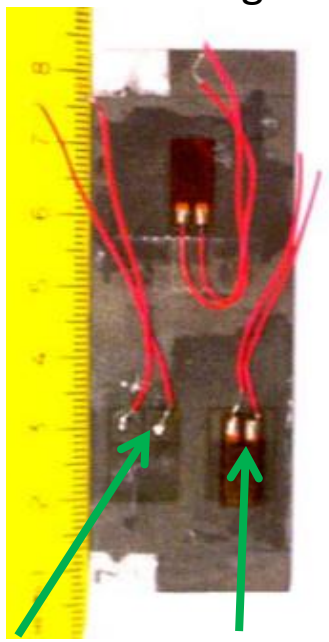
Sensors for SHM

Leveraged Traditional

Thermocouples



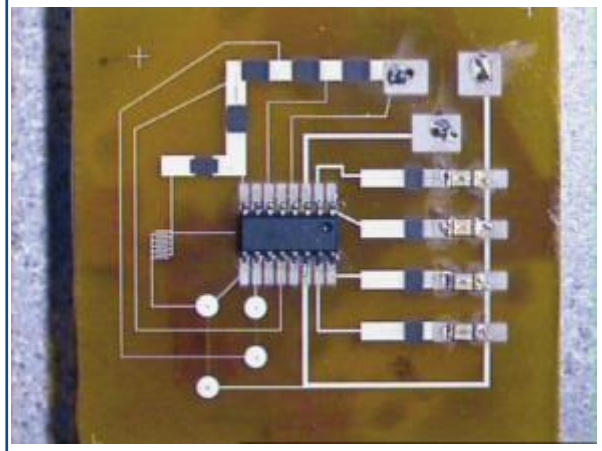
Strain Gauges



Printed Commercial

http://www.darpa.mil/dso/thrusts/materials/novelmat/prognosis/progsite/prognosis_pdf/Stony_Brook-Sampath.pdf

Novel Sensors



Photograph of a working chemiresistor sensor system made by MAPLE DW. The photograph shows
all the elements of the sensor except for the batteries which are mounted on the back.

Alberto Piqu ´ e, Craig B. Arnold, Ryan C. Wartena, Bhanu Pratap, Basavaraju Shashishekar,Karen E. Swider-Lyons, David W. Weir, and Richard A. Kant *Naval Research Laboratory, USA*"Laser direct-write of miniature sensor and microbattery systems " RIKEN Review No. 50 (January, 2003): *Focused on Laser Precision Microfabrication (LPM 2002)*

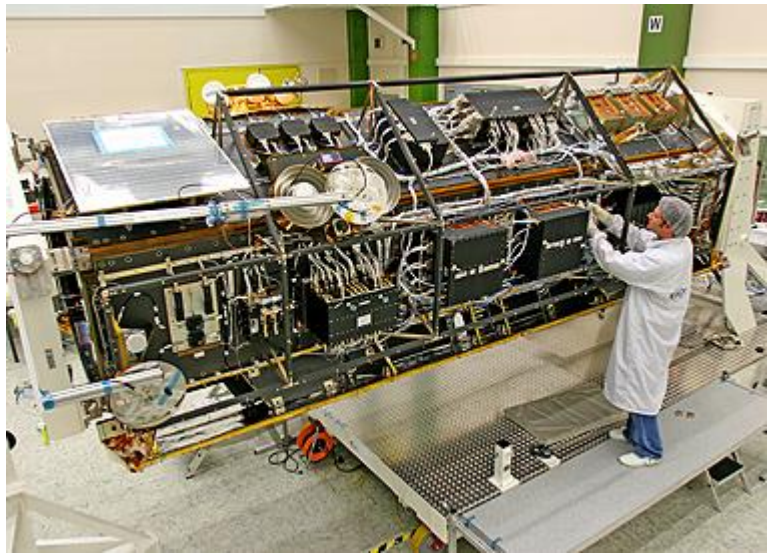
Demonstrated concepts on PnP-Sat

Commercial Developments

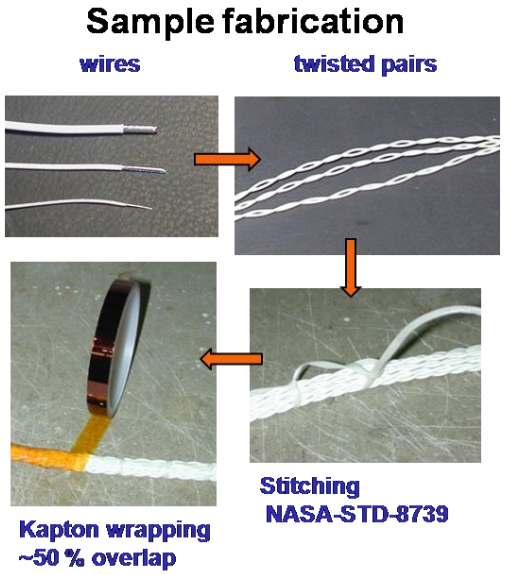
Sensor and wiring integration into the structure From Metis Design

PZTs

Current Situation



- Bundles of twisted pair single-conductor wires stitched and wrapped with Kapton® tape
  - Consistent with spacecraft power and signal cable fabrication
- Cables add damping and can shift modal frequencies

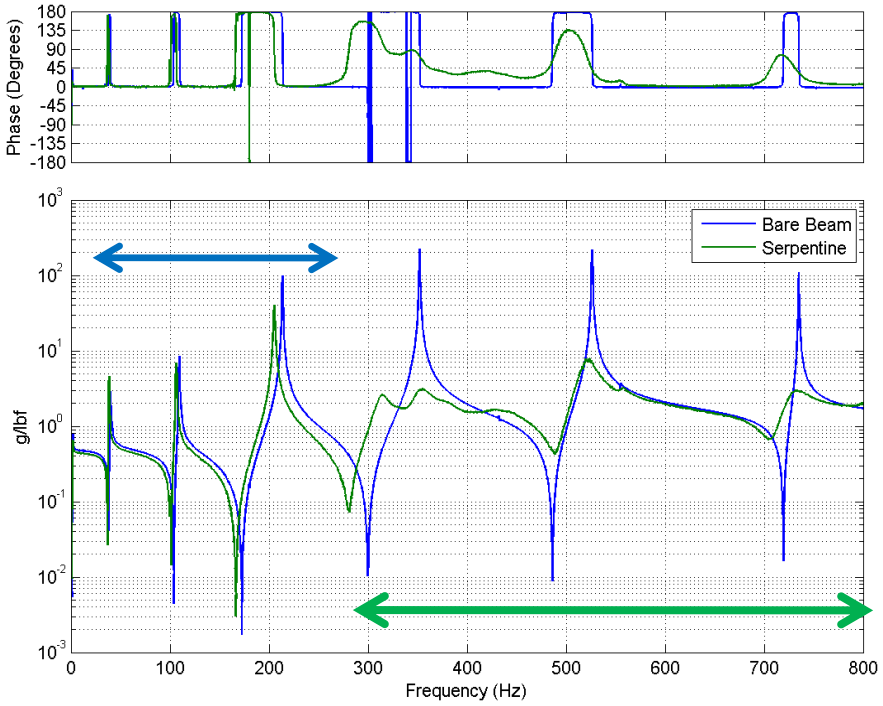


Cables on spacecraft are used for routing data, power, synchronization, light sources, communications, etc.

These harnesses vary per system but can take up to **30% of a systems dry mass**

Cable not resonant

Cable resonant



Next Generation

- Enhanced Assembly Integration and Test
  - configuration management
  - process verification
  - in-situ monitoring during restricted access

- Shipping, handling and storage accountability
  - Identifying problems at time of source

RESPONSIVE

SEV 16-17

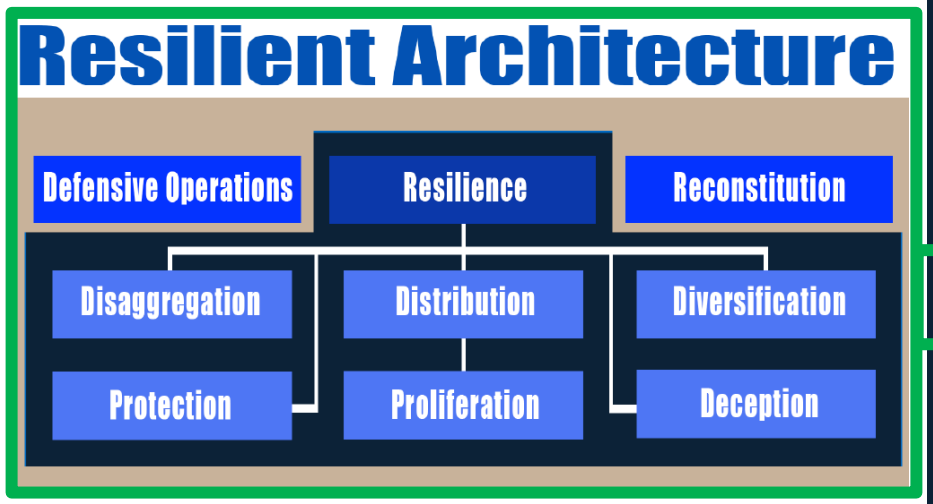
- Monitoring during launch and operations
  - Identify relevant environments

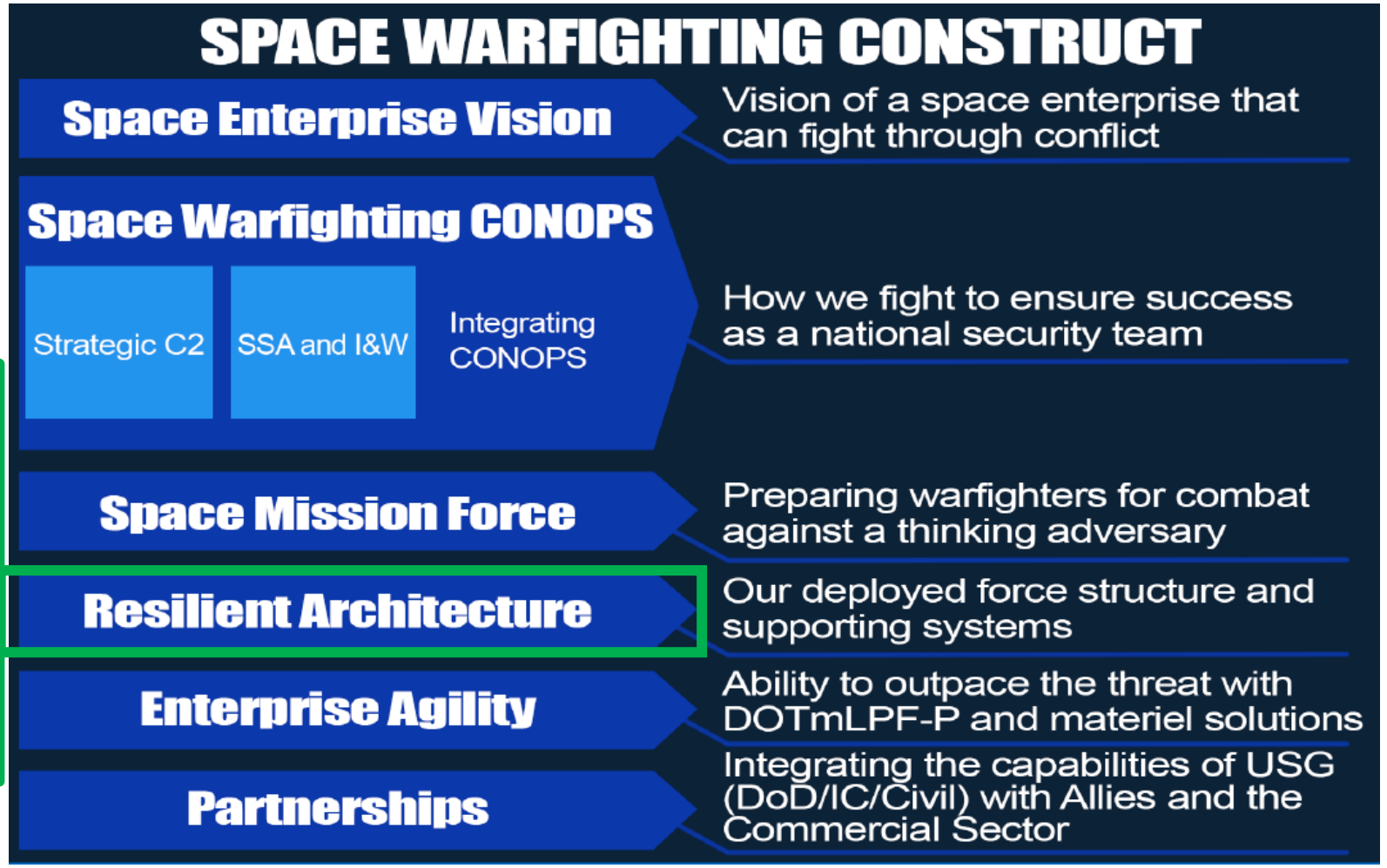
- In-situ and on-demand system assessment
  - Reduced inference
  - Reduced standing army times/costs

RESILIENT

Next Generation

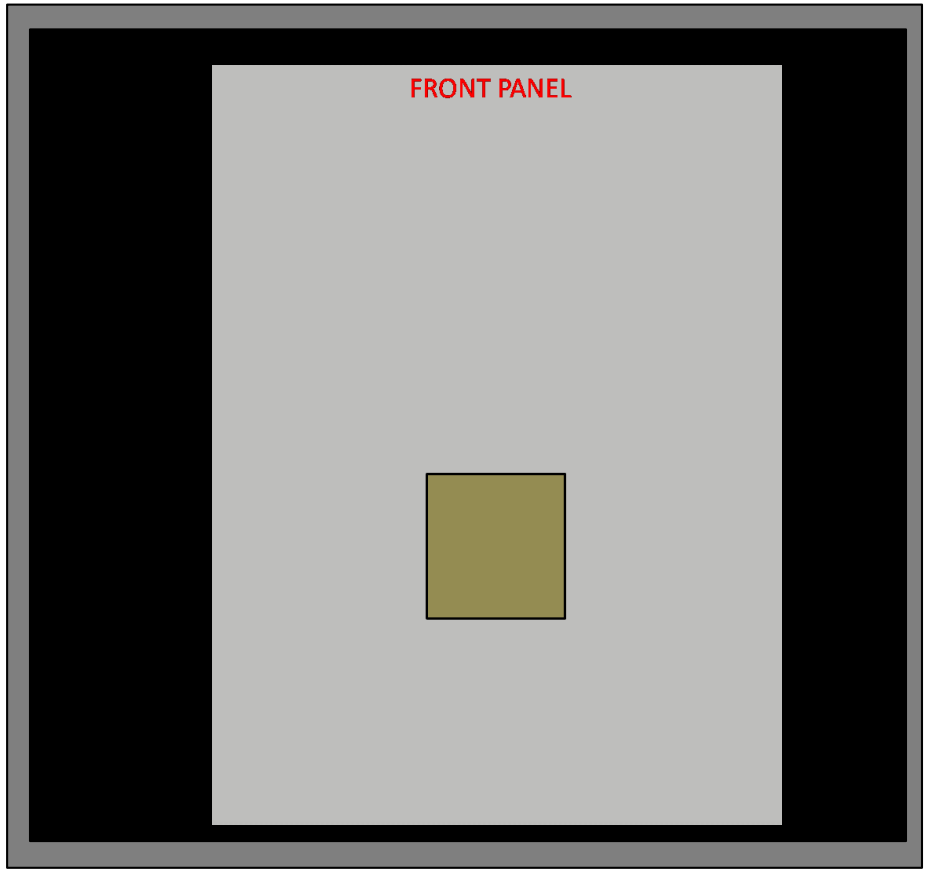
The AF has been exploring what the next generation space architecture would like for over a decade and has recently put more pressure towards change with the Space Enterprise Vision





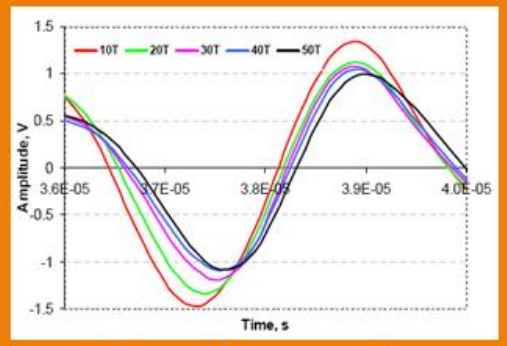
"Our vision is to first normalize space operations as a joint warfighting domain; no different than any other warfighting domain. Only when we think about and talk about space in the same way we talk about operations in the air, on land, at sea, or in cyber will we move in the direction of truly integrating space operations across all warfighting domains"
— Gen. Goldfein, CSAF, 3 Feb 2017

Rise of SHM

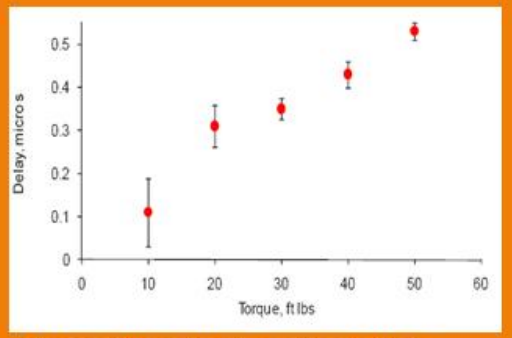


Rise of SHM

PZT Bolted Interface PZT

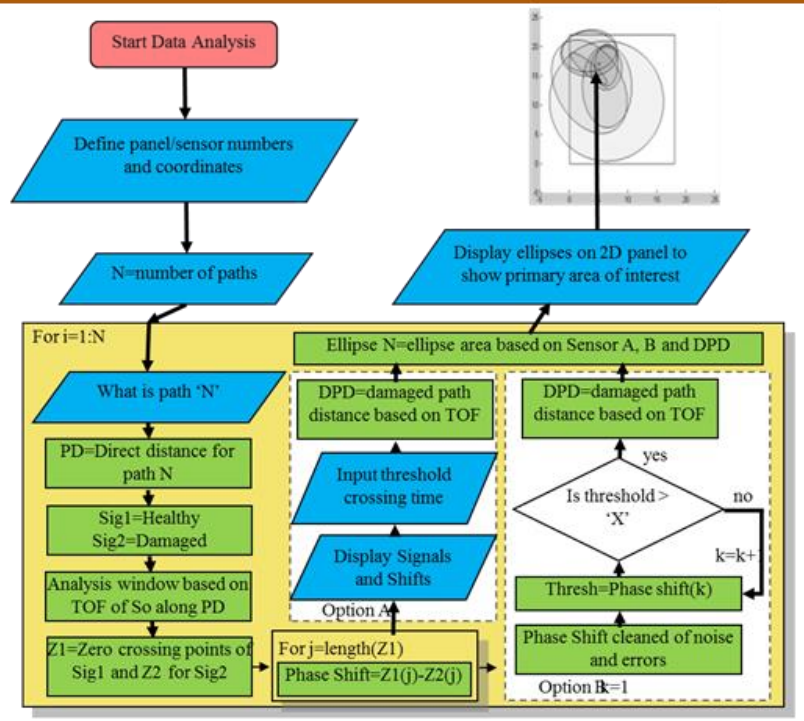


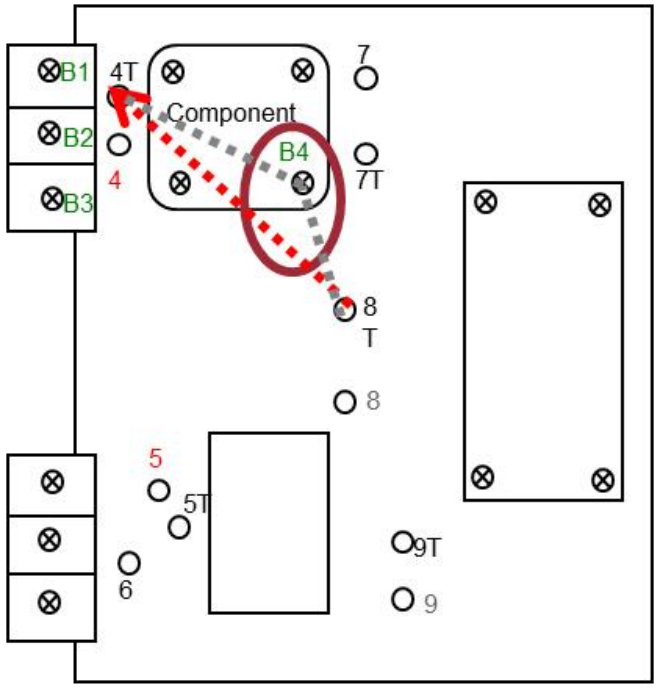
Phase Change with applied load change

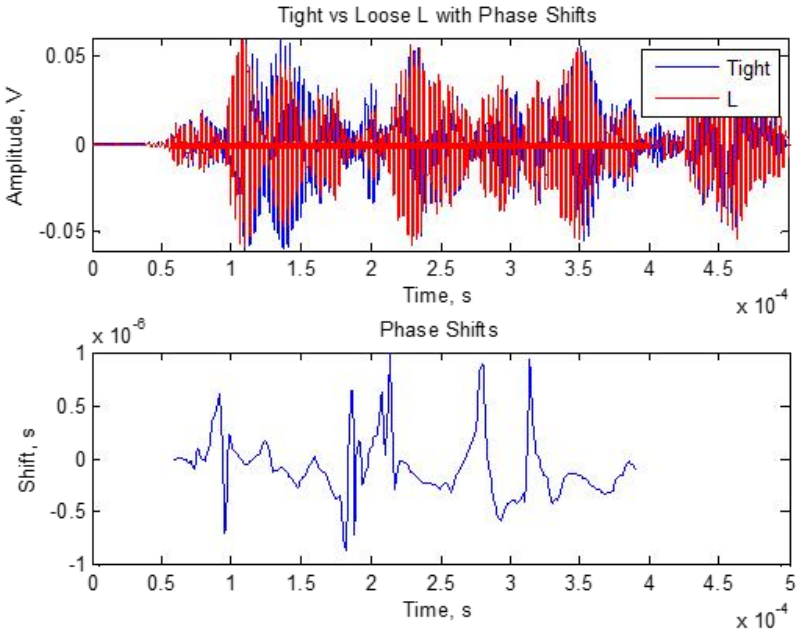


Phase/loading correlation with fastener based uncertainty

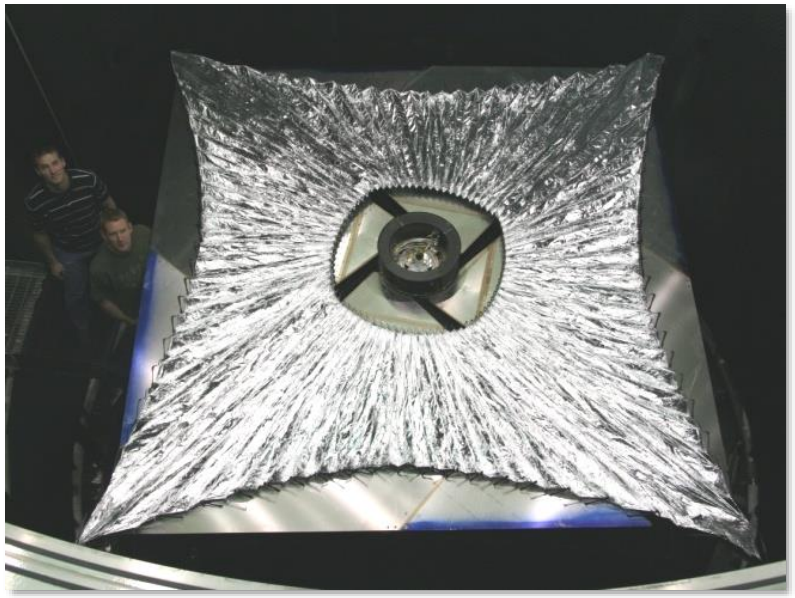
Integrate on complex structures to track change

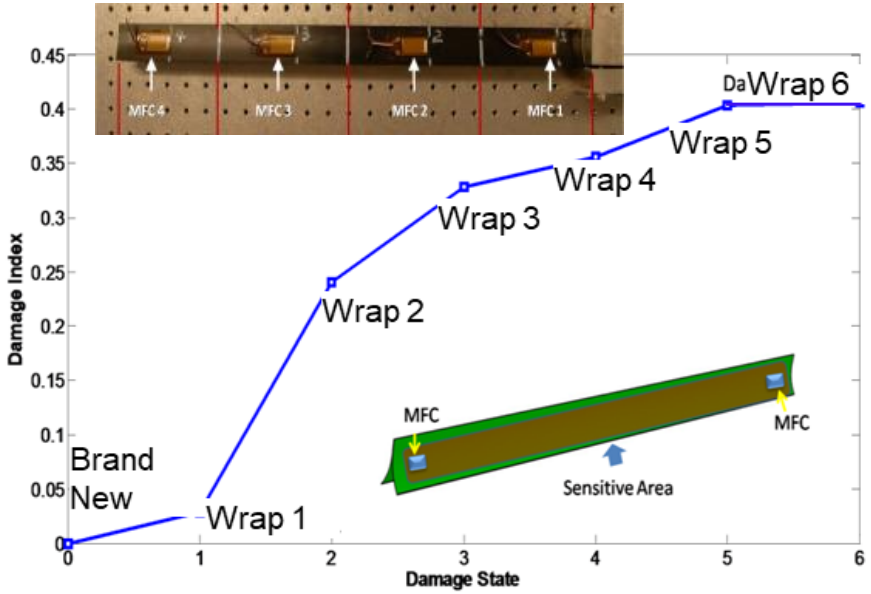


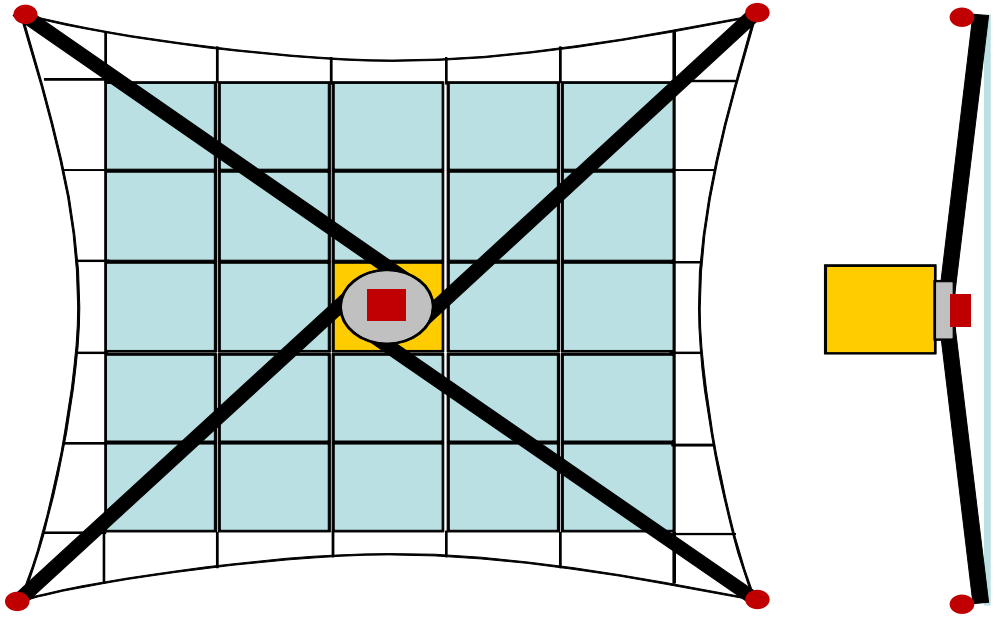




Rise of SHM







Deployable booms:
Track loss of stiffness with build process.

SHM Results consistent with independent structural analyses.

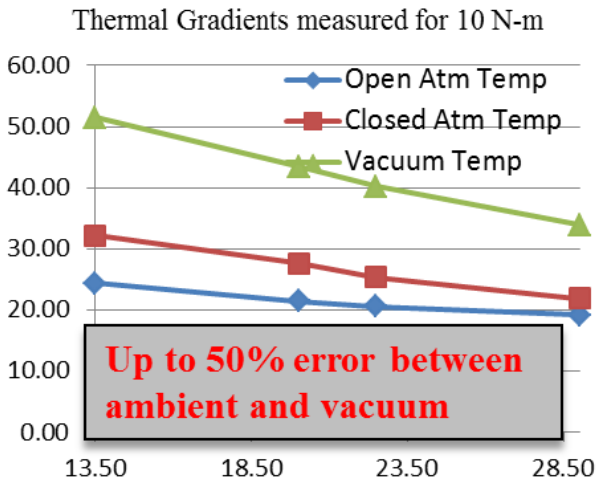
Quantifiable measurement that provides confidence in the component

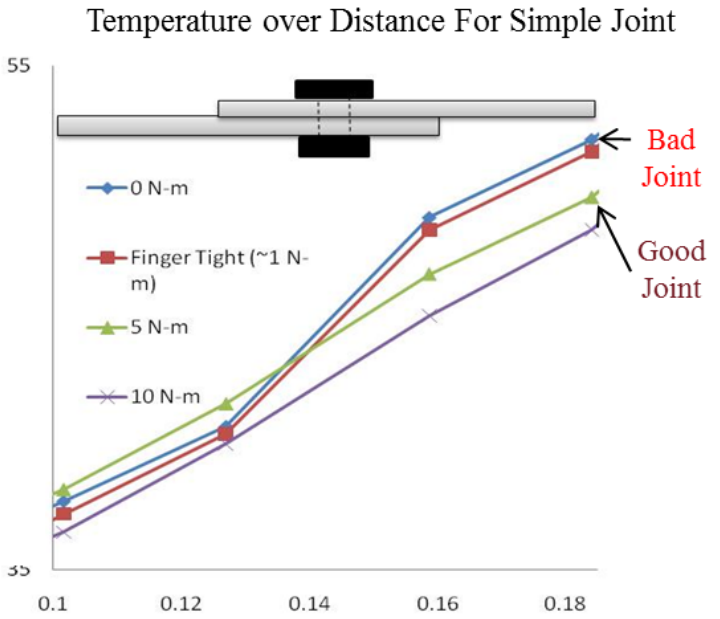
Rise of SHM

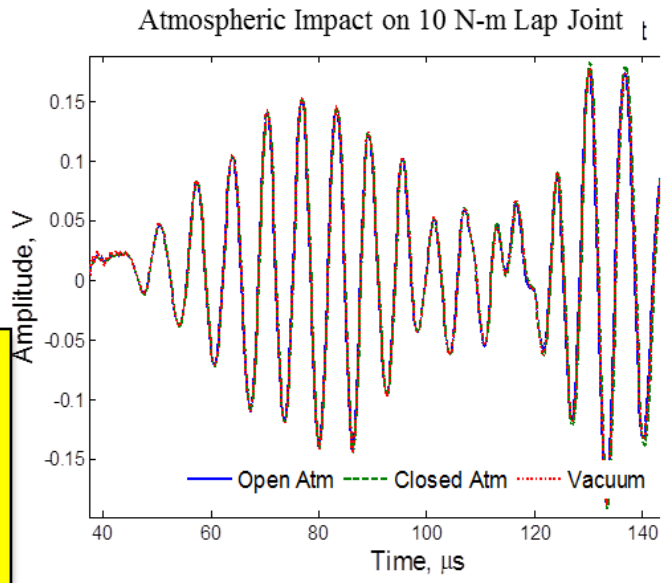
TVac Testing:
-Strict Requirements
-Expensive
-Schedule Intensive
-Difficult to Troubleshoot

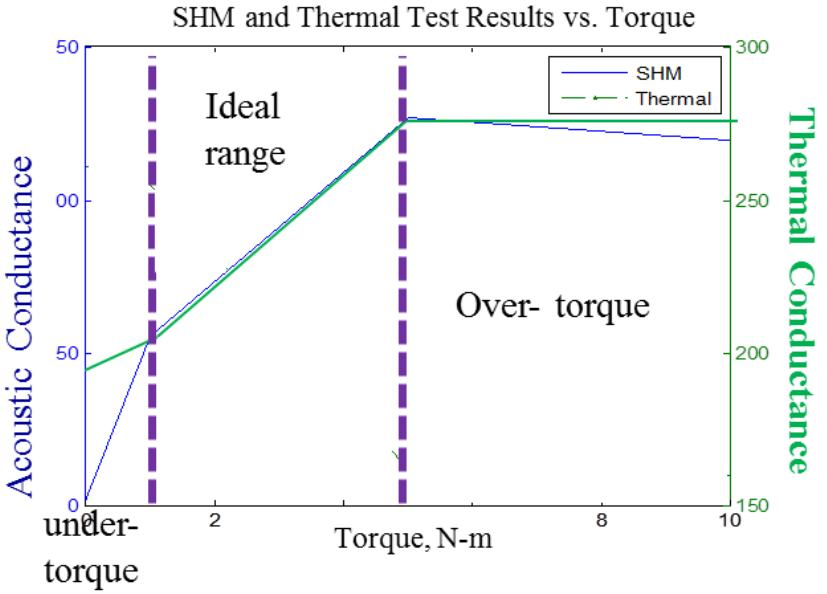
SHM Test:
-No need for vacuum
-Cheap
-Fast
-Easier to troubleshoot

Small Scale Test Times:
Thermal: 8 hours
SHM: 5 Minutes

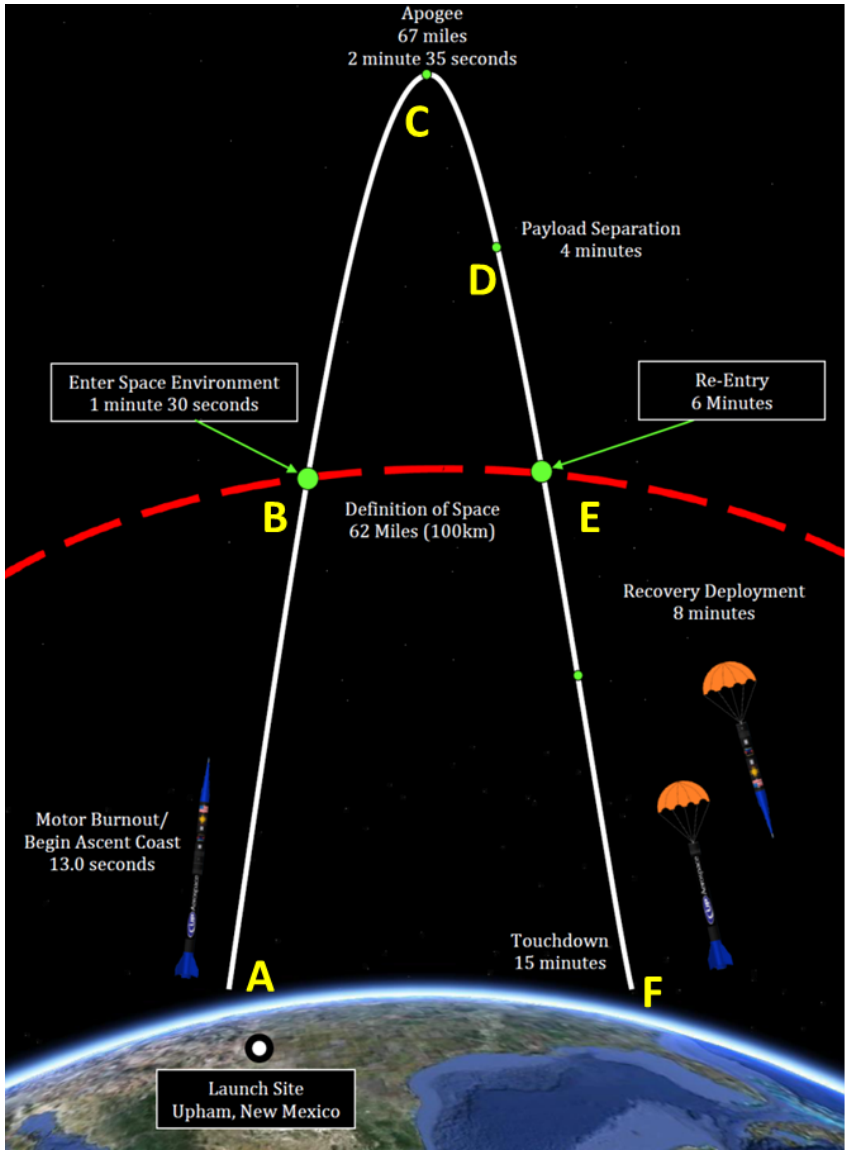


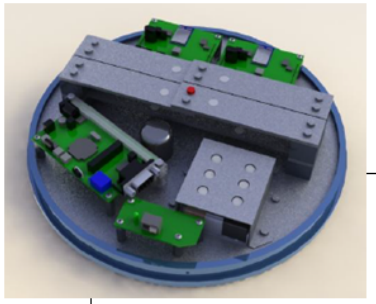






Rise of SHM





Rise of SHM

Experiment 1: STP-H5 on ISS (~2016-2017)

- Track the platform from AI&T through experimental integration onto the ISS
- Assess sensitivity of system to detect acoustic events from thermal/impact events
- Identify hardware limitations in a LEO environment

Experiment 2: AFRL free flyer to GEO (~2017-2018)

- Monitor spacecraft through critical ground testing
- Monitor launch environment
- Assess hardware effectiveness for tracking functions of the spacecraft (deployments, thruster firings, separation events)
- Work with AFRL Autonomy group on in-line processing of SHM tracked events

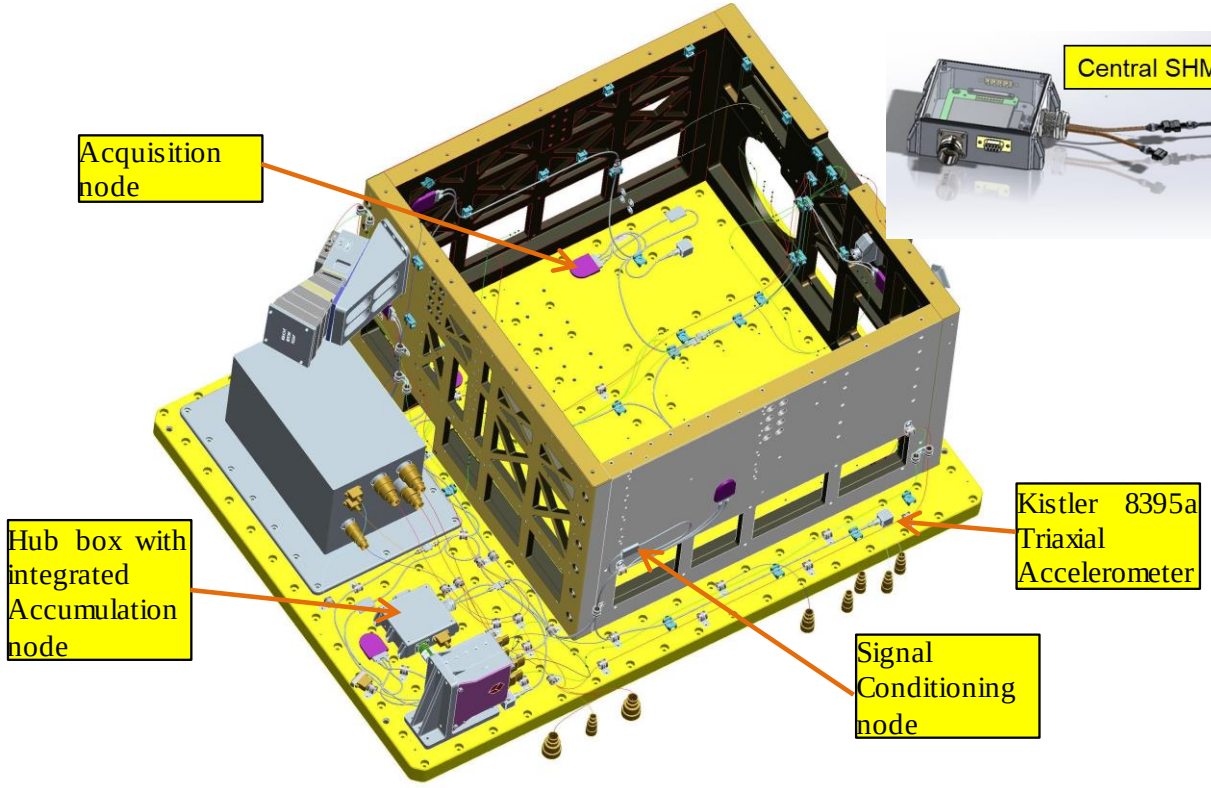
Rise of SHM

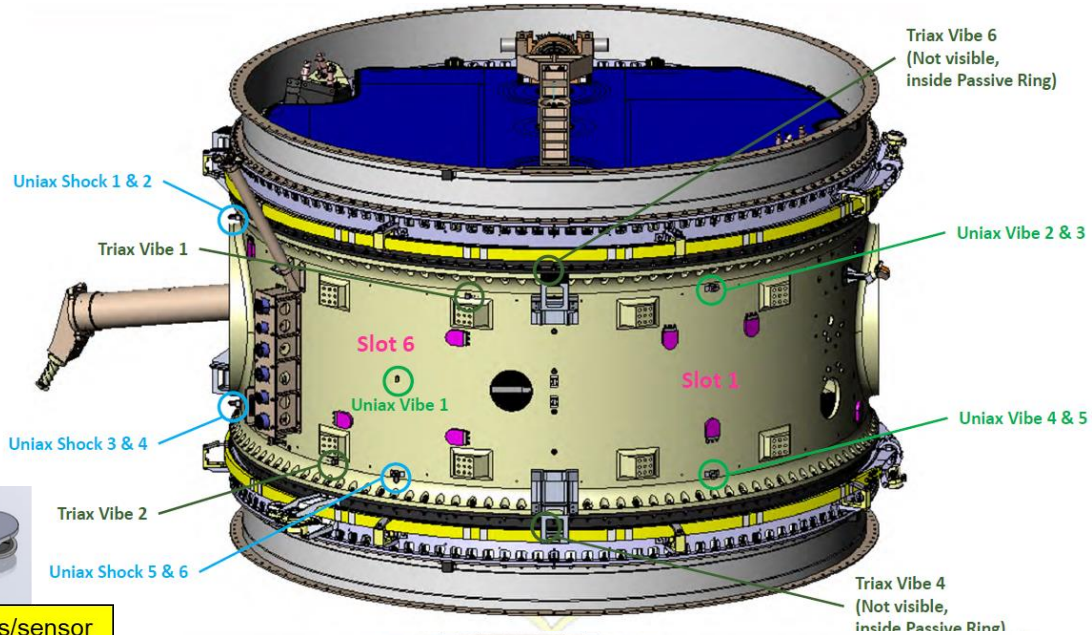
STP-H5

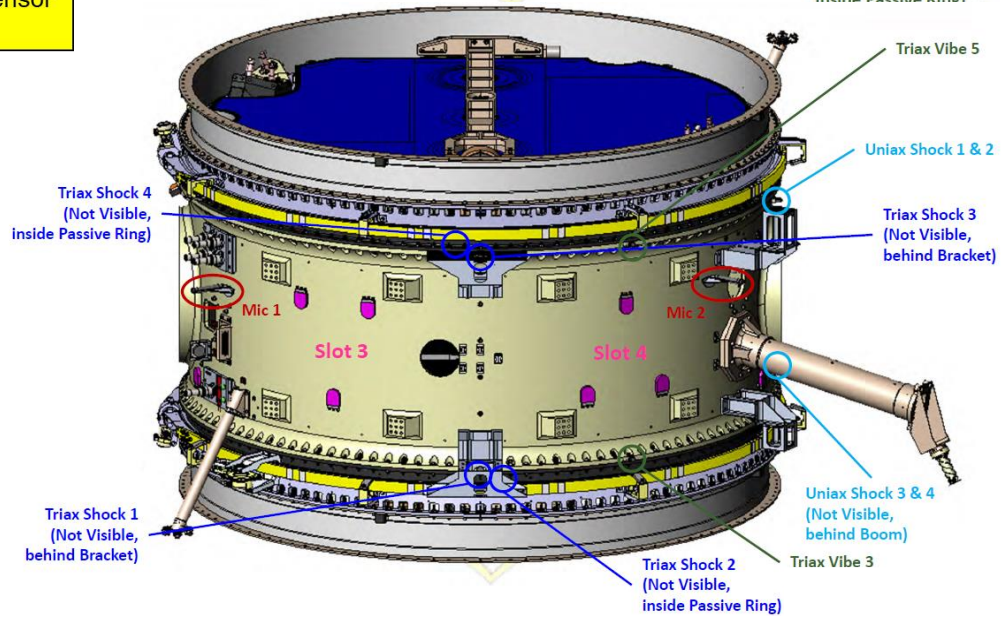
- 8 SHM nodes
- 30+ feet of cable harness
- 9 channels of accelerometers
- 1 Hub

EAGLE

- 24 SHM nodes (24 pzt actuators and 144 pzt sensors)
- 100+ feet of cable harness
- 24 channels of accelerometers, shock and microphone sensors
- 1 central Accumulation node to serve as the interface hub

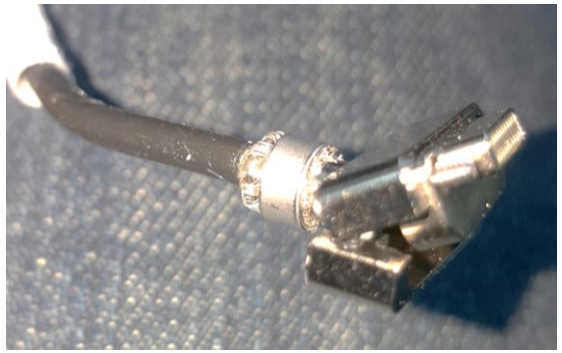




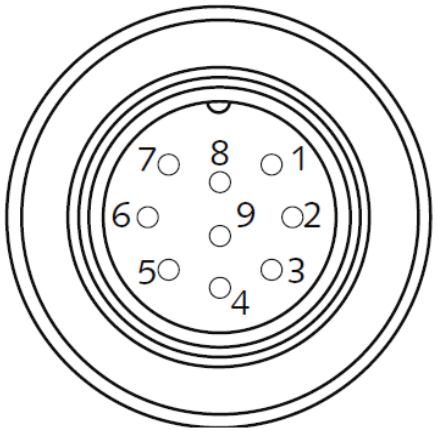


Challenges Faced

Integration

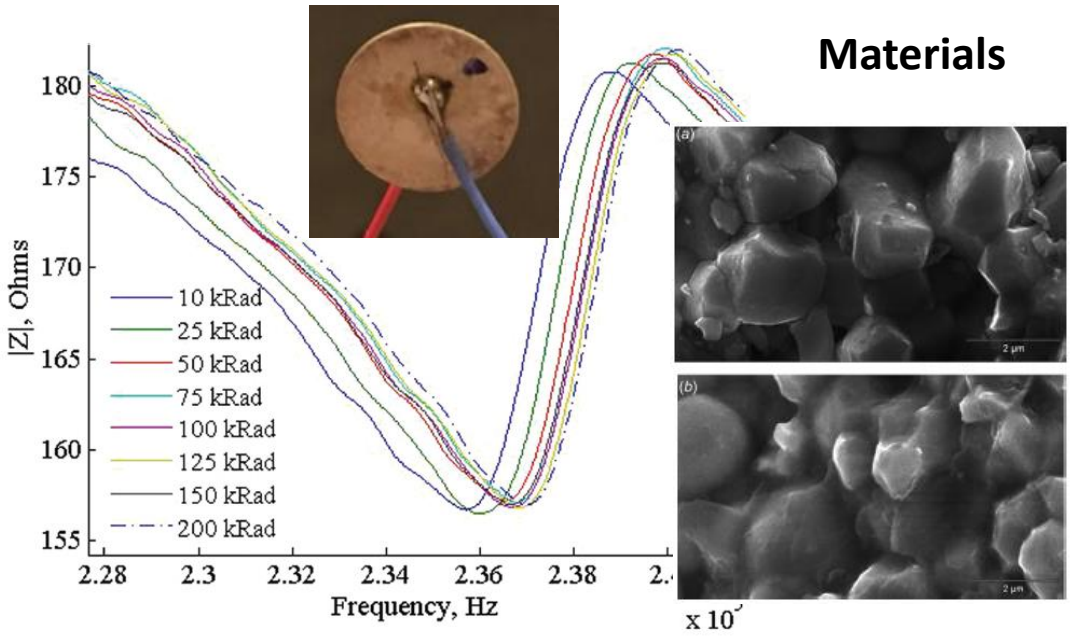


Sensor Connector	Function output		Integral cable TB vrs. or cable Type 1792A... K00/KB00	Integral cable TC vrs. or cable Type 1792A... K01/KB01
Mini 9 pin female	AT, BT version	CT, DT versions	pigtail (color)	9 pin D-Sub
1	Power	Power	Red	1
2*	Ground	Ground	Black	2
3	X DC output	X DC output +	White	3
4	Y DC output	Y DC output +	Yellow	4
5	Z DC output	Z DC output +	Blue	5
6	Temp. output	Temp. output	Orange	9
7	N/C	X DC output –	Brown	6
8	N/C	Y DC output –	Green	7
9	N/C	Z DC output –	Violet	8
-	Case	Case	Shield	Shield

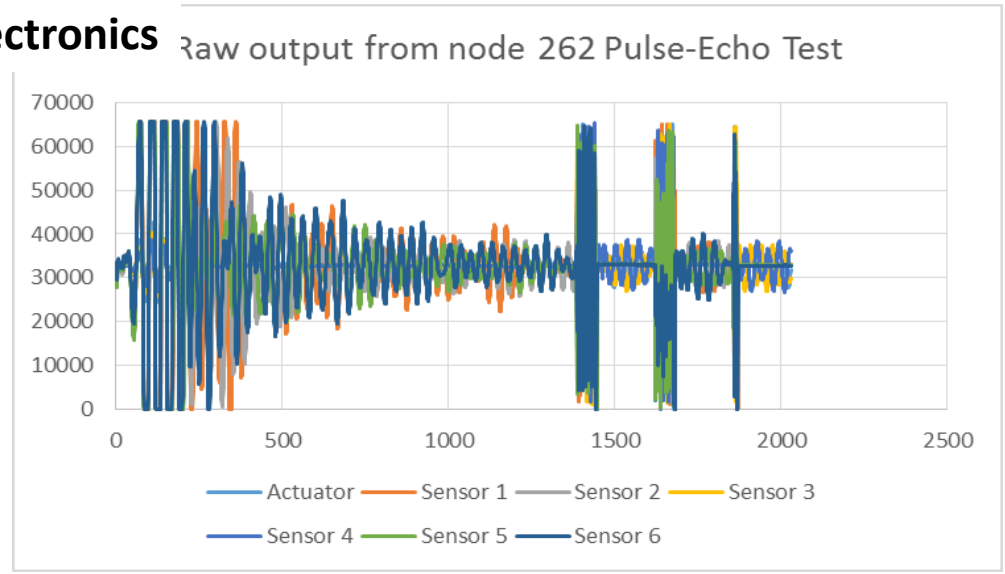


9 pin circular male connector sensor view

Materials

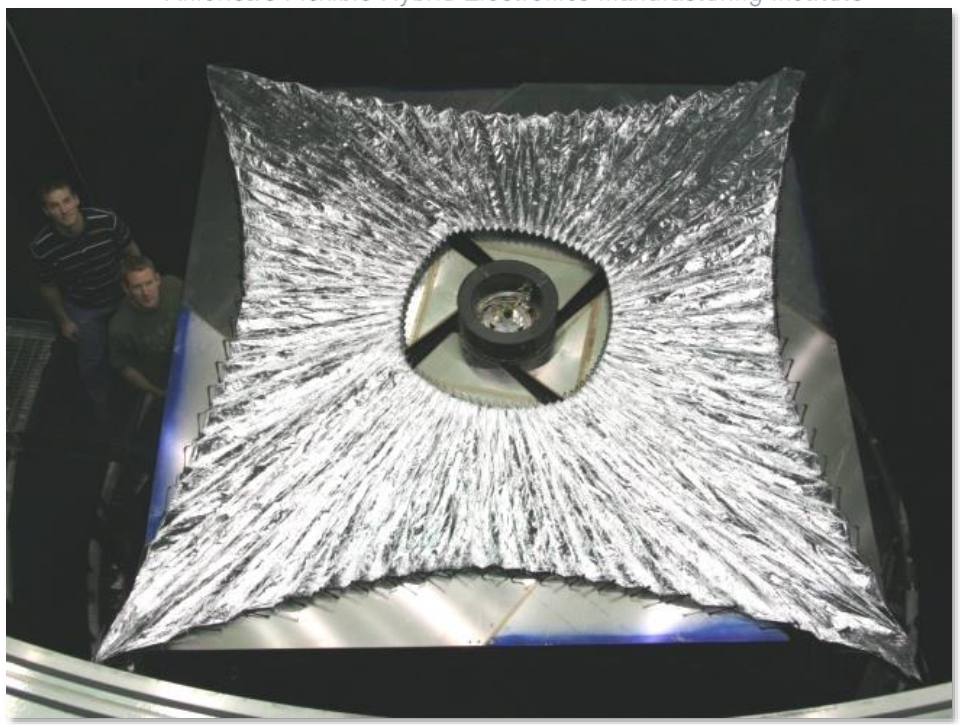


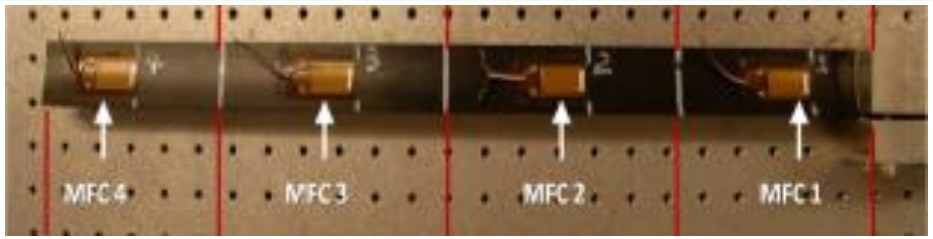
Electronics



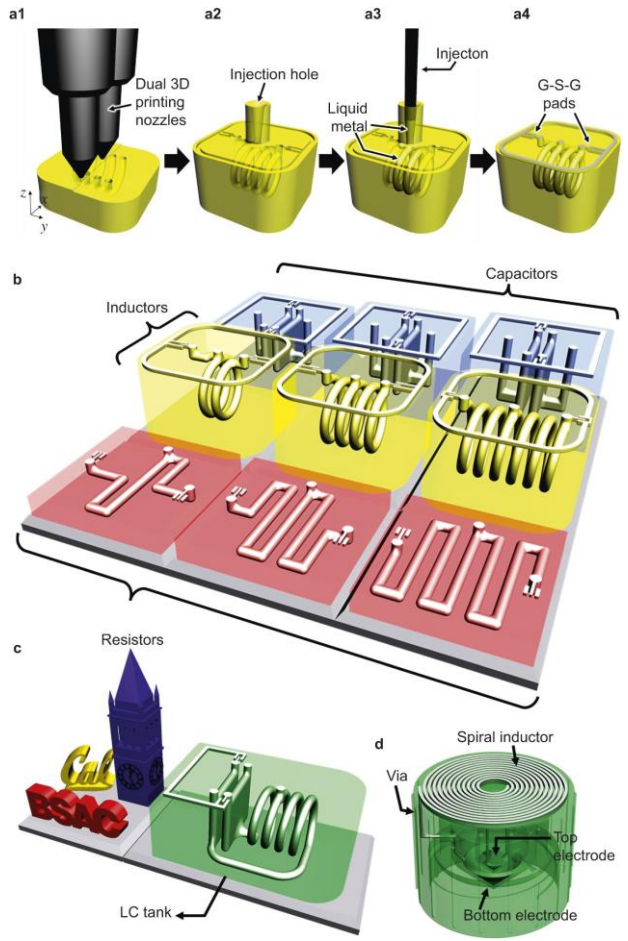
Opportunities

NEXTFLEX
America's Flexible Hybrid Electronics Manufacturing Institute





America Makes



Integration

DoD has invested in manufacturing centers focused on Flexible Hybrid Electronics and Additive Manufacturing.

Techniques are needed for integrating wireless sensing components into structures that are **loadbearing, conformal, and flexible**:

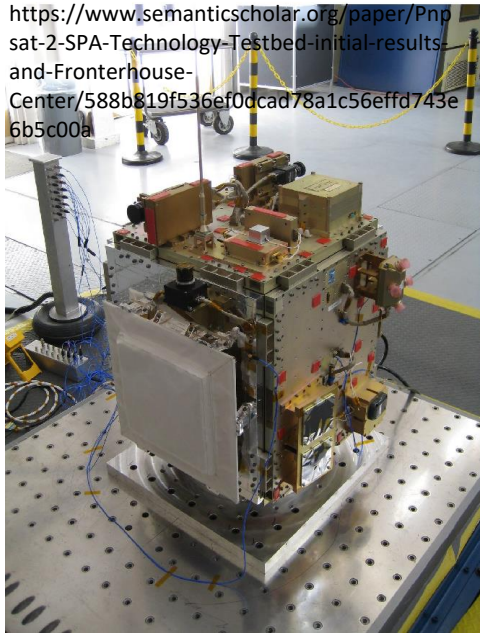
-Sensors
-Antennas
-Power Management
-Logic and Integrated Circuits

Opportunities


https://phys.org/news/2012-06-trial-vacuum-galileo-satellites-closer.html

Ground Test

Several activities occur on the ground that can benefit from temporary and permanent sensor options.


https://www.semanticscholar.org/paper/Pnpsat-2-SPA-Technology-Testbed-initial-results-and-Fronterhouse-Center/588b819f536ef0dcad78a1c56effd743e6b5c00a

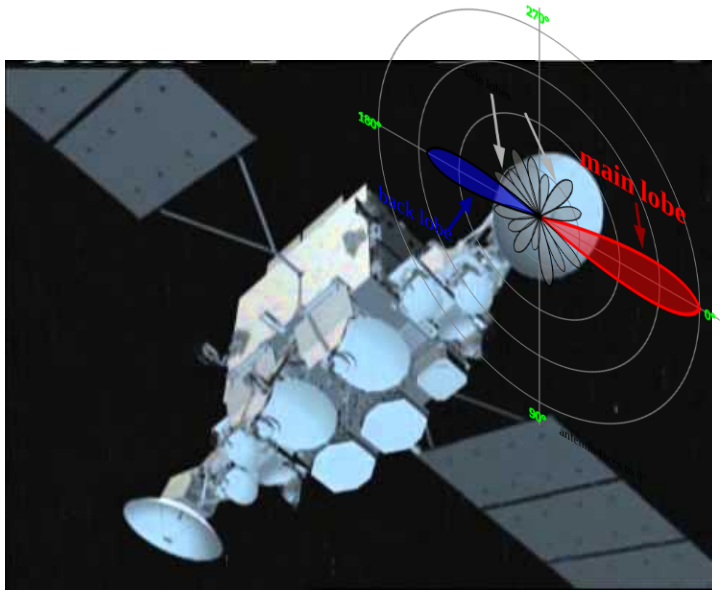

https://en.wikipedia.org/wiki/Direct-field_acoustic_testing

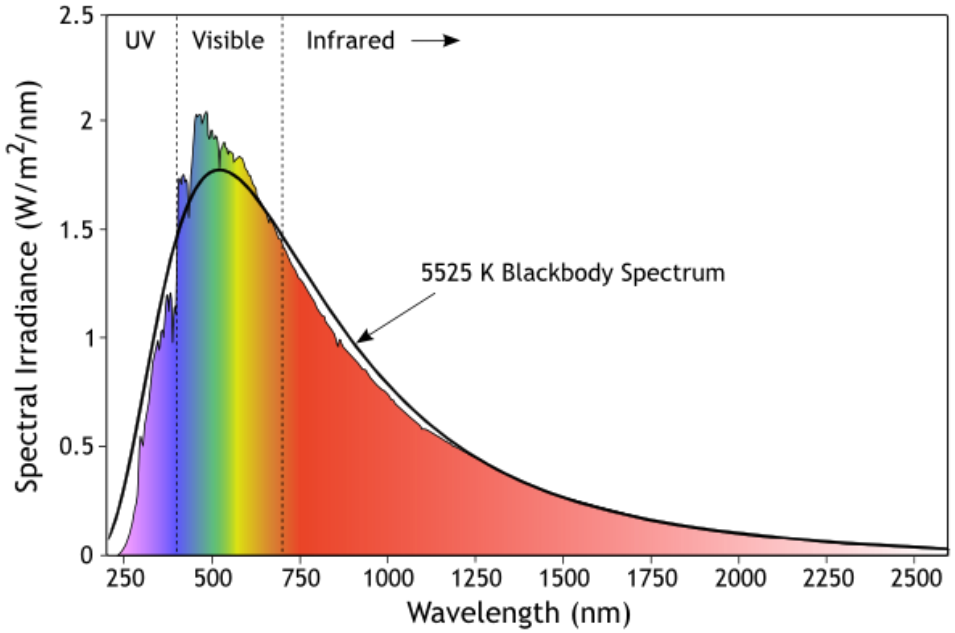
Opportunities

Energy Harvesting

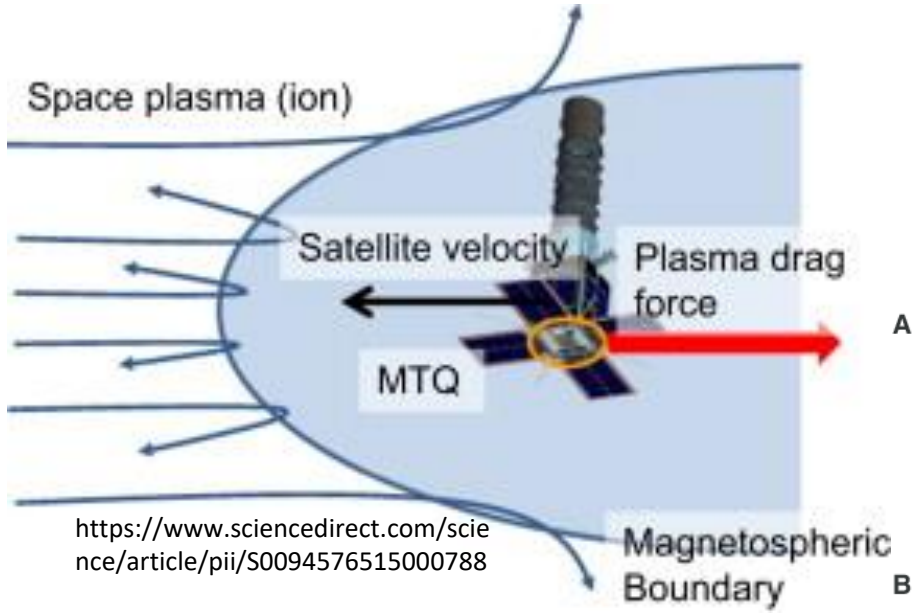
Satellites and other spacecraft have a variety of energy sources that can be captured and utilized:

-Launch environment
-Spurious emissions
-Natural environment

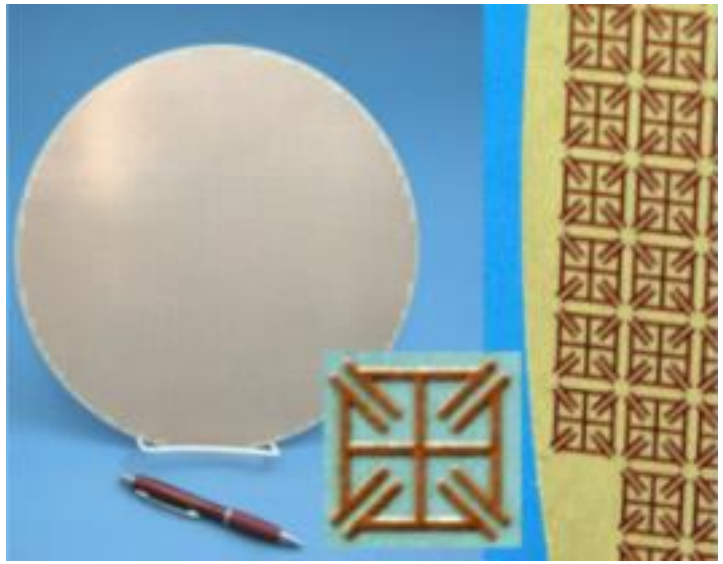




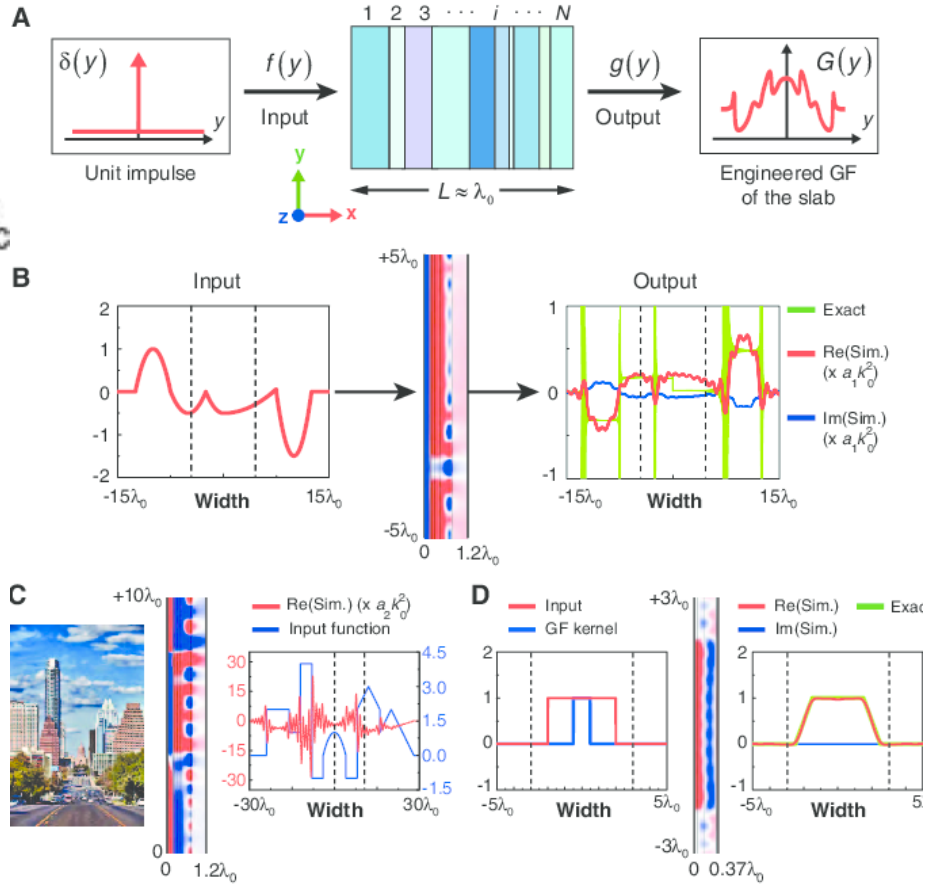
Opportunities



https://www.sciencedirect.com/science/article/pii/S0094576515000788



Modelling/Simulation/Implementations



Other general areas of interest for wireless sensors and spacecraft include

-modelling/simulation of wireless setups and propagation for spacecraft

-utilization of metamaterials / metasurfaces in aiding wireless transmissions

-novel methods of data size mitigation such as metamaterial calculators or other in-line data processing approaches

Questions?