Passive Wireless Sensor Technology Workshop

Naval Applications of PWST from the End-user's Perspective

6-7 June 2012

Presented to:
ISA Communications Division
La Jolla, CA

Presented by:
Robert W. Pritchard
NAWCWD China Lake

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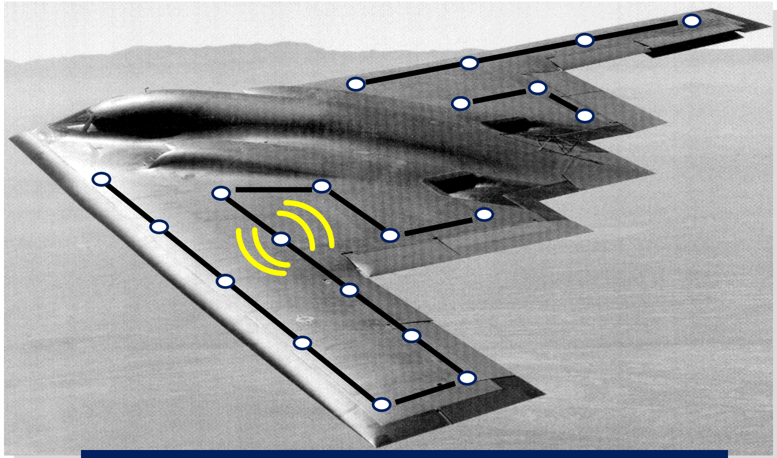
NAVAIR

Passive Wireless Sensor Technology
(Potential Used in Various Applications)

- PWSTs would be invaluable within a number of Navy Applications, including other Services (Army, Air Force, NASA, Marines, Homeland Security, FBI, CIA, etc.) – ***JUST SCRATCHING THE SURFACE***
  - Condition-based Maintenance
  - Health Management/Monitoring
  - Inventory Management
  - System Prognostic/Diagnostic
  - Self- Prognostic/Diagnostic Systems
  - Power Systems
  - Energy Harvesting
  - Energy Management/System Control
  - Event Monitoring & Response Trigger
  - SAF/AFD/ISD and Fuzing systems
  - Anti-Tampering
  - Field Detection/Bomb Disposal
  - Universal Soldier (Bio-monitoring/Biomedical, GPS Locator)
  - Robotic Systems
  - UAV/UGV Systems (Inertia Sensors for UGV Navigation/GPS systems)
  - Seekers … etc.

Condition-based Maintenance

- Energy-Autonomous Sensors for Remote Sensing in Inaccessible Places Simplify Aircraft Maintenance



Courtesy of Prof. FK Chang/Stanford University

Aircraft maintenance will be easier in future, with sensors monitoring the aircraft skin. If they discover any dents or cracks they will send a radio message to a monitoring unit. The energy needed for this will be obtained from temperature difference.

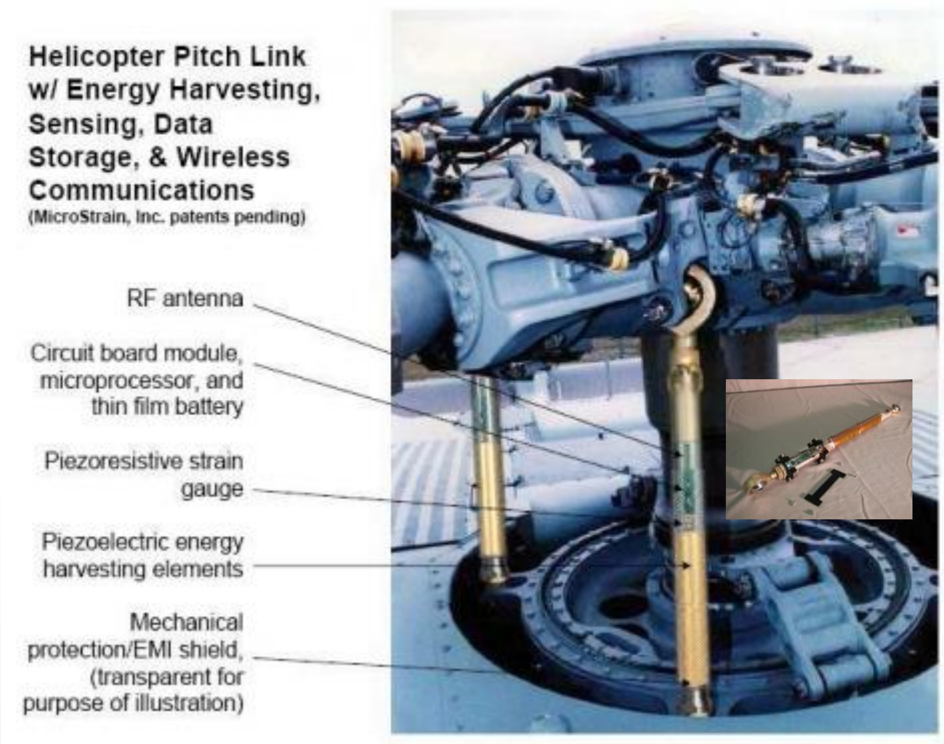
Condition-based Maintenance
(Event Monitoring)

- Wireless Instrumentation for Aircraft-Munitions Communication Link Interrogator

Aircraft-Munitions communication link integrity verified by assessing voltage drop-out through the umbilical, at the connector joint. Information needed to assess DUD failures occurring during training/combat.

Condition-based Maintenance
(Energy Harvesting)

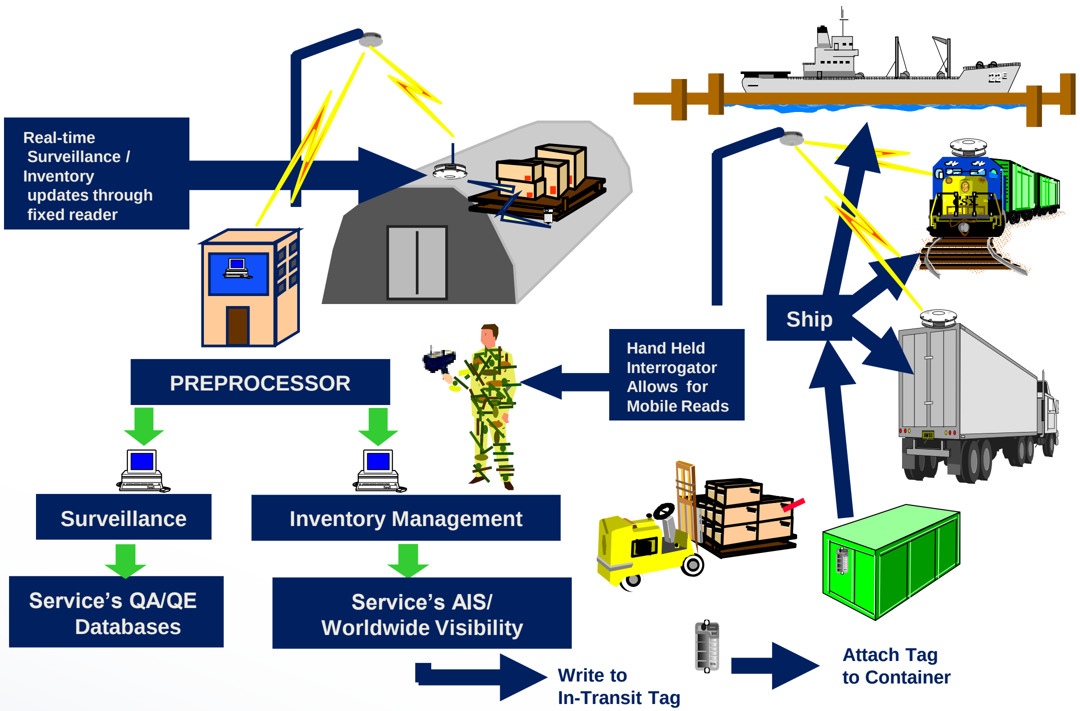
- Energy Harvesting Wireless Sensors for Helicopter Damage Tracking and Tracking Pitch Link Dynamic Loads



Microstrain, Inc.

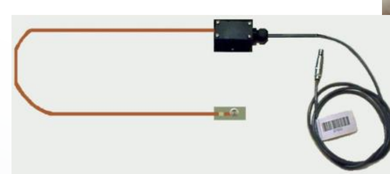
Rotorcrafts are subject to intense and highly variable loading events. The ability to identify and predict the fatigue of structural components before they threaten rotorcraft performance is highly valuable. According to the U.S. Navy, 90% of rotorcraft total life cycle (TLC) costs occur after initial delivery. Understanding the condition of rotorcraft can provide considerable maintenance efficiencies as well as improve the safety of system operators. As a result aircraft platforms can achieve higher availability, safer operation, and reduced maintenance costs.

- Wireless Sensor Systems for Military Applications (i.e., ATOS, ATaRS, RRAPDS, IMLM-DAAS, etc.)



Sporian Microsystems Inc.

Microstrain, Inc.



Micron Instruments, Inc.

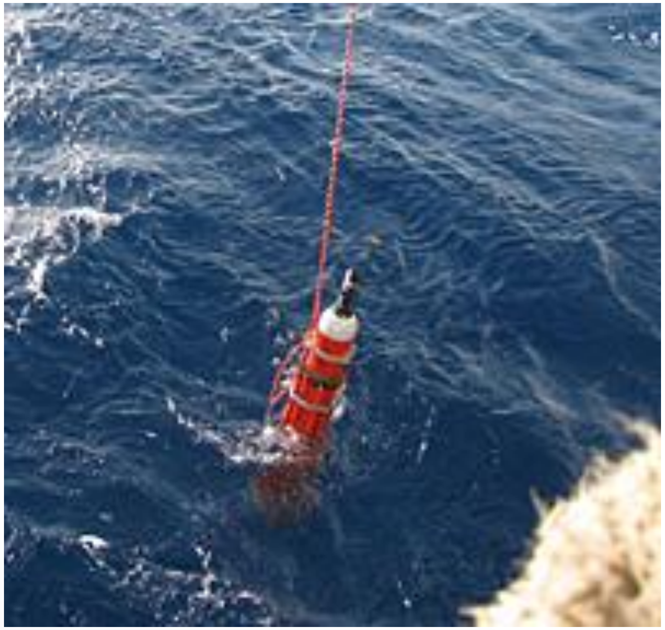
Bnet Corporation, Inc.

Health Management/Monitoring & Inventory Management

- External environmental conditions of where the munitions have been
  - Temperature Cycling (Normal & Shock)
  - Humidity
  - Vibration (Truck, Handling, CATS/TRAPS, Shipboard Shock, Gun Shock, etc.)
  - Impact Shock (Handing, Drop, Bullet, etc.)
  - Chemical Out-gas (NOx/SOx evolution)
  - Integrated Flight Dynamics
  - Corrosion
- Internal conditions/response to environmental stimuli
  - Temperature/Pressure
  - Humidity/Moisture (Weather Seal/O-ring Failure, Nozzle Leakage)
  - Stress/Strain (Composite Casing Delimitation, Propellant & Bond-line Degradation, Bond-line Separation, Slumping, Bore Cracking, etc.)
  - Chemical Species (Plasticizer Migration, Stabilizer Depletion, NOx evolution, etc.)
  - Crosslink Density/Modulus
  - Corrosion
  - Leak Detection
  - Sensitivity Changes (Friction, ESD, Insensitive Munitions related properties)
- Detection, Identification, Location and Remote Sensing *(Encryption for Security)*

Power Systems

- Novel Ocean-Powered Underwater Vehicle

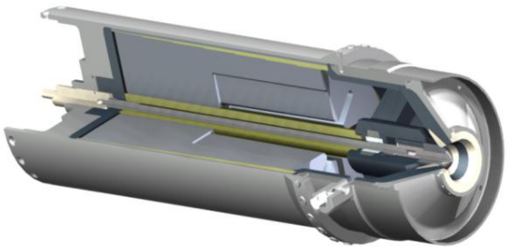


Courtesy of NASA/JPL

NASA, U.S. Navy and university researchers have successfully demonstrated the first robotic underwater vehicle to be powered entirely by natural, renewable, ocean thermal energy. The autonomous underwater vehicle uses a novel thermal recharging engine powered by the natural temperature differences found at different ocean depths. Scalable for use on other applications, this technology breakthrough could usher in a new generation of autonomous powered wireless sensors.

Energy Management/System Control

- Increase future capabilities of munitions to combat future threats



Solid Propulsion w/ Variable-Area Nozzles

Potential needs for improved, miniaturized sensors

- Axial Pintle Positioning
- Pressure (feedback control)
- Temperature
- Power Cycle Demands & Management

Air Breathing Turbo-Rockets

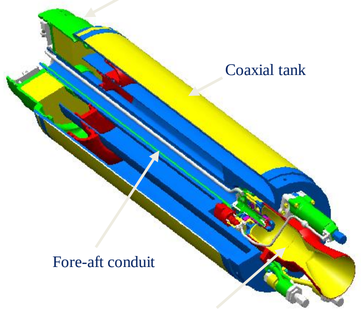
Potential needs for improved, miniaturized sensors

- Fuel flow rate, volume, density
- Turbine RPMs
- Selected T, P (feedback control)

Hypergolic Gel Propulsion Systems

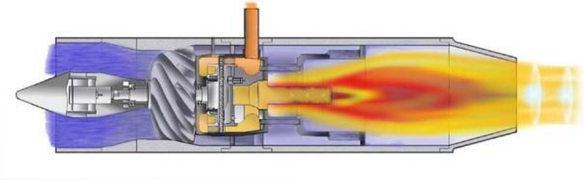
Potential needs for improved, miniaturized sensors

- Oxidizer/Fuel Tank fill levels
- Pressure (feedback control)
- Temperature
- Flow Meters
- MMH & IRFNA Fume Detectors (Safety)



Could more accurate measurements be shown to

- Improve Specific Impulse
- Reduce Mass Fraction
- Reduce Cost, Uncertainty
- Improve Reliability



Anti-Tampering

- Integrate wireless systems that can sense tampering and self-destruct (LIVE/DUD Munitions)
  - Eliminate IEDs or Reverse Engineer of Munitions

DoD & Homeland Security are looking for ways to disable LIVE/DUD munitions, in order to make them useless if acquired by the terrorist cells and/or enemy troops. Utilizing wireless sensor technology maybe one possible way to rendered munitions useless through satellites, radio, or on-board self-destruct systems. This may also be a better way for EOD personnel to achieve proper disposal during combat, without placing them in harms way.

Co-Chairs

Robert W. Pritchard

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China Lake, CA

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Edwards AFB

Planning Team: R. Pritchard/NAWCWD China Lake; G. Studor/NASA-JSC; David Owen/CPIAC

JANNAF Structures And Mechanical Behavior Subcommittee Meeting

Space and Military Wireless Sensor Systems Workshop Series

- Overall Objective
  - Achieve Operationally Responsive Wireless Sensing Systems for Space Launch Vehicles
  - Provide a forum to promote advancement of wireless sensors and development of industry design guidelines to reduce cost and increase reliability for applications to space launch vehicle components
- Overall Focus
  - Assess the current wireless sensor capabilities with respect to applications to space and military systems relevant to JANNAF
  - Develop a combined roadmap for the development and application of desired wireless sensor capabilities among JANNAF participants
  - Develop a vehicle and wireless sensor system engineering approach to better support JANNAF end users in program definition, development, test, anomaly resolution, and operations
  - Develop general design guidelines for development and application of wireless sensors across JANNAF participants

User Integration Challenges for Wireless Sensor Systems

- Today's Focus – TO UNDERSTAND!!!
  - What are the challenges or issues the end-user is having that makes it difficult to integrate this technology?
    - Technology maturity as a whole is ill-defined
      - Sensors and data loggers are TRL 5-6 or higher, yet interfacing with an existing inventory management system or the need to develop a whole new system is yet to be addressed
      - Just now understanding how the data can be used in assessing the health of a system and predict it's "useful life"
    - Too complicated to maintain and use by field personnel
    - Cost too much
      - Sensors and data loggers themselves still too expensive to use on small, inexpensive tactical systems
      - Infrastructure to gather and maintain data, and perform data analysis too expensive
      - Projected increase in production costs maybe too high
      - Certification costs may be too high
      - Cost paradigm at play here – the cost of implementation out weighs the cost of the system

Simply facing an ever shrinking budget and cannot justify the need

- Power strategies may be too limited - batteries need to last much longer, or need to draw power from platform; therefore, re-certification will be a nightmare
- Safety concerns – HERO, EMI, etc.
- Lack of interest – hard to change status quo…

"We've done it the same way for years and invested so much time and money in gathering the information under established surveillance programs… why change!"

Or simply… "We just don't understand the benefits of changing they way we do business – a better business case is needed"

OPNAV Ordnance RFID Implementation Policy

(as of 4 August 2008)

DEPARTMENT OF THE NAVY
OFFICE OF THE CHIEF OF NAVAL OPERATIONS
2000 NAVY PENTAGON
WASHINGTON, D. C. 20350-2000

IN REPLY REFER TO
5230
Ser N411C4/8U156857
04 AUG 08

From: Chief of Naval Operations (N41)

Subj: NAVY ORDNANCE RADIO FREQUENCY IDENTIFICATION (RFID) IMPLEMENTATION

Ref: (a) USD(AT&L) Memo/Radio Frequency Identification (RFID) Policy of 30 Jul 2004
(b) OPNAV N41 Memo 4600 Ser N413T/5U895210 of 14 Feb 2005
(c) NAVSUP CIO Memo 5230 Ser AIT-5/012 of 14 Mar 2007
(d) NAVSEA OP 3565/NAVAIR 16-1-529 VOLUME 2, ELECTROMAGNETIC RADIATION HAZARDS (HAZARDS TO ORDNANCE)
(e) USTRANSCOM Memo/DOD Automatic Identification Technology (AIT) Concept of Operations (CONOPS) for Supply and Distribution Operations of 11 Jun 2007

1. Reference (a) issues policy and business rules for implementing RFID throughout DOD. References (b) and (c) articulate Navy's implementation plan and acknowledge that RFID tagging of ammunitic
planned RFID equipme
operational environm
Hazards of Electroma
certification of bot
available and under
ordnance. Reference
HERO requirements. R
for compatibility of
of munitions/ordnanc
"recognized that no
and other explosive
baseline AIT for mun
RFID tag."

2. OPNAV N41 chartered a Navy RFID Implementation Initiative Integrated Project Team (IPT) to evaluate current and potential future RFID solutions that comply with certification requirements of reference (d). The IPT, working with the Naval Surface Warfare Center, Dahlgren Division Electromagnetic Environmental Effects Assessment & Evaluation Branch, has determined that there is no viable technology currently available that will enhance inventory accuracy and asset visibility while complying with requirements set forth in reference (d). The IPT's finding reinforces USTRANSCOM's finding as stated in reference (e).

Subj: NAVY ORDNANCE RADIO FREQUENCY IDENTIFICATION (RFID) IMPLEMENTATION

3. This memorandum, therefore, directs that efforts, including resourcing, to field RFID for use with Ordnance be discontinued until such time as technology matures to achieve cost effective fielding of RFID which improves asset visibility and provides a benign environment for ordnance operations. The 2D barcode will be the primary AIT for Naval munitions tracking until then.

4. The OPNAV point of contact is CDR Greg Spangler (N411C4), (703) 604-9915, or email greg.spangler@navy.mil.

[illegible]

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2

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A Better Understanding is *Needed*!

User Integration Challenges for Wireless Sensor Systems

- Today's Focus – TO UNDERSTAND!!!
  - What can be done to ease those challenges or issues?
  - Do we need to change the perception that these systems will be too costly and difficult to use and/or maintain? If so, how?
  - How can we, the technical community, gain the interest needed to get this technology into the hands of the end-users?
    - System designers/developers and eventually, the warfighter in the case of the military
    - Primarily, system health monitoring and condition-based maintenance
  - During the workshop, observations, questions and answers will be compiled into a document to summarize the challenges, requirements, applications, solutions and technology gaps
  - Organized working session in the afternoon to develop a "way-forward" for the integration of wireless sensor systems to get it in the hands of the designers, developers, logistic personnel and ultimately the warfighter
    - Participants and attendees will be divided into smaller groups to address these and other questions that may come up in order to develop the "way-forward."

Questions to Keep in Mind

- What challenges do you have in integrating sensor systems?
- What obstacles do you have to overcome in integration and procurement of wireless sensing systems?
- What are your largest road blocks for implementation?
- How did you approach and solve, or plan on overcoming, these issues?
- Have you done any trade studies, identifying the payoffs?
- What are you measuring, in what environments, and why do you need them?
- What are the critical measurements and what are the low hanging fruit?
- What special sensing technologies would you like to see developed and for what purpose and in what environment?
- After the system is implemented, what do you do with the data and how do you safeguard it?

Challenges/Obstacles/Roadblocks

(Tactical & Strategic Point of View)

- **Communication w/ the right decision makers is difficult, boarding on impossible!**
- **Person who benefits is not the payee – takes “too long” to realize ROI**
- **Cultural issues (anti-HMS mindset/perception)**
  - Existing system policies make implementation difficult
  - Misunderstanding or poor information
  - Safety concerns (perceived or real)
  - Incorporation of concepts/requirements during early stages of design is difficult
  - Data interoperability and uniform standards already exists – Why change???
  - Data analysis infrastructure (including training) for two-way warfighter-analyst connection/communication appears costly
  - Information Assurance (Can it be secured?! **BIG CONCERN!!!!**)
  - Long-term reliability of sensor systems (or “repair”-ability/”replace”-ability)
  - Susceptibility to routine environments (x-ray, ESD, etc.)
  - Interactions w/ existing design elements (Will this system cause my weapon to fail?!)
  - Ill-defined data analysis, then why use it and run the risk of integration
  - No solid business case available
  - Overall appears too costly and can’t be integrated quickly – technology just isn’t ready!

Potential Approaches to Resolve Issues
(Tactical & Strategic Point of View)

- **Sponsorship**
  - Decision-maker who "gets it"
  - Who doesn't rotate
  - Hit significant milestone in short time period
  - Keep the momentum going
- **Retrofitting**
  - Foot-in-the-door; look toward external monitoring first, then approach embedded once infrastructure has been established
- **Incremental improvements/ upgrades once TRL has been reached**
- **Aggressive stance on incorporating HMS into early stages of design**
  - Set-up contractual requirements early on in the design phase
- **Competition can provide solutions via uniform architecture**
  - Too many different proprietary solutions (e.g., ISA 100, IEEE 1453)
- **Must build a strong business case**
  - Commercial SRM Failures – Tim Miller (AFRL)
  - USAF NATO/ATaRS – Robert Mueller (Bnet)
  - NASA Space Shuttle – George Studor (NASA)
  - Boeing – George Studor (NASA)
  - Jet Engines – George Studor (NASA)
  - NASCAR/Automobile Industry – Robert Pritchard (NAWCWD-CL)
  - Ejection seats (Loss of Life) – Phil Sturgill/Frank Tse (NSWCIHD)
  - IMLM-DAAS – Erik Weber (AFRL)/Fred Prater (NSWCIHD)
  - Raytheon/ATaRS– James Villarreal (Raytheon)
  - TPO Programs (Loss of Life/Loss of Platform) – Robert Pritchard (NAWCWD-CL)/Frank Tse (NSWCIHD)
  - Test Facilities – Dave Owen (CPIAC)

Critical Measurements, "Low Hanging Fruits" & Specialized Sensing
(Tactical & Strategic Point of View)

- **Critical Measurements**
  - Temperature
  - Relative Humidity
  - Location of Asset (and extra information, e.g., pedigree)
  - Shock/Vibration/Impact History
  - Moisture
  - Contamination (i.e. JP fuel)
  - Bond-line condition
  - Stabilizer depletion
  - Modulus
  - Strength (stress and strain)
  - Crosslink density
  - Burn rate
  - Integrated flight dynamics
  - Acoustic pressure
  - Bore cracks
  - Slump, deformation
  - Case damage (esp. composite casing)
  - Corrosion
  - Component failures (electronics, nozzles, igniters, fuzes, safe/arm devices, o-rings, etc.)
  - IM-related measurements
  - Functional check (self-test)
- **Low Hanging Fruits**
  - Temperature
  - Relative humidity
  - Location of Asset (and extra information, e.g., pedigree)
  - Shock/Vibration/Impact History
  - Functional check (self-test)
- **Desired Future Specialized Sensing Technologies**
  - Strength (bulk and bond)
  - Modulus
  - Crosslink density
  - Stabilizer in NG/NC
  - Liquid Diffusion Sensors (for plasticizer migration)
  - Passive Sensors (Hybrid)
  - IM-related Properties
  - "Intelligent Sensor"
  - Sensors that will assess component failure (e.g., nozzles o-rings)
  - Non-RF Wireless Technologies
  - Very reliable – no drift
  - Self check
  - Encryption or Security

The Big Question at Hand!!!!

(Both Tactical & Strategic Point of Views)

- **After the system is implemented, what do you do with the data and how do you safeguard it?**
  - Existing information secure systems (OIS, CAS, Army; different networks for classified and unclassified)
  - Store data selectively (store information, not data!)
  - Downlink to ground before asset is expended
  - Incorporate into models that assess remaining life
    - Could be very complicated and costly at first until modeling algorithms have been developed and integrated to create an autonomous system
  - Use of encryption
  - Check Engine Light ; the GO-NO GO Scenario

NEEDS OF THE FUTURE!!!

Concerns & Desirable Features Summary of Wireless Sensors *(ALL??)*

- **Design Issues**
  - Operational Range (temperature, pressure, moisture, etc.)
  - Manufacturing Range (temperature, pressure, moisture, etc.)
  - Combustion chamber ingress/egress
  - Optimization criteria and tools for determination of appropriate number and location of sensors (bulk propellant, bond-lines, chemical species, etc.) - System Specific?
  - Available volume, mass, packaging constraints (i.e., system integration to existing platforms)

- **Sensor Type/Measurement Issues**
  - Accuracy
  - Sensitivity
  - Non-intrusiveness
  - Long Term measurement stability
  - Ease of calibration
  - Robustness for Installation
  - Low Power Requirements
  - Sensors that can measure everything
  - Ability to prioritize which chemical reactions to monitor (decoupling higher order, daughter products, etc.)
  - Health Monitoring & Sensors for ACS, gas generators, pyrotechnics, pyrogens, warhead energetics, inerts
  - Material compatibility/low corrosion sensitivity

- **Diagnostics/Prognostics**
  - Maturity of prognostics/diagnostics to accommodate sensor information
  - Parameters
  - Data Volume
  - Codes, algorithms (stress, strain and IM)

- **Data Acquisition and Management**
  - Data inundation - overwhelming storage, assimilation, and assessment burden
  - Manpower, implementation, and automation
  - Volumetric/packaging constraints
  - Reliability of Sensors, Data Acquisition Hardware
  - Data Storage capacity
  - Battery capacity, life
  - Encryption/Security

- **Programmatic Issues**
  - Transition of technology to SRM production environment
  - Demonstration and qualification on production/fielded assets (progress beyond STVs)
  - Safety/Flight Certification (umbilical/aircraft integration)
  - Low cost, COTS-like fabrication and specification
  - Intelligent Sensing - ability to interpret environment change and respond accordingly

    (i.e. automatically swap from low frequency sensing of temperature in dormant storage to high frequency sensing of shock, and vibration in a transportation scenario)
  - Flexibility/adaptability – develop systems and strategies to retro-fit existing systems
  - Platform Integration of sensor suites, communications

QUESTIONS ??

Back-up Viewgraphs

- Design Guideline Outline – Tiger Team
  - Document SOA sensors and user needs from previous workshops and make it available
  - Develop an assessment what we have learned from previous workshops
  - Develop communication means to distributed info
  - Develop cooperative roadmap for wireless sensor technology development and application
  - Develop a draft of design guidelines
- JANNAF Wireless Sensor System Integration Document (Lessons Learned)

Draft Outline of Wireless Sensor Design Guidelines

Section 1. Introduction
State objectives

Section 2. Wireless Sensor Capabilities and Applications
Review current wireless sensor state-of-the-art technology and practical applications

Section 3. Design Considerations
- Sensor Installation
- Sensor Calibration
- Data Acquisition Technologies
- Data Collection and Reduction
- Algorithm development
- Data Security
- Energy Harvesting
- Data Center

Section 4. System integration
Discuss system integration issues and describe the procedure to select sensors, data acquisition, data analysis, and handling procedures specific to the launch vehicle components the sensors to be installed.

Section 5. Verification and Validation Testing
Discuss how the wireless sensing system will be verified and validated by subsystem and full-scale testing

Section 6. Costs Benefit, Logistics, Safety, and Compatibility Issues
Assess the benefits and costs of using wireless sensing system, including impact on acquisition, life cycle, and integration. Review safety and system compatibility relative to the operation of the vehicle of interest and summarize barriers for sensor implementation.

Section 7. Conclusions and Recommendations
Summarize the conclusions and recommendations of wireless sensor applications.