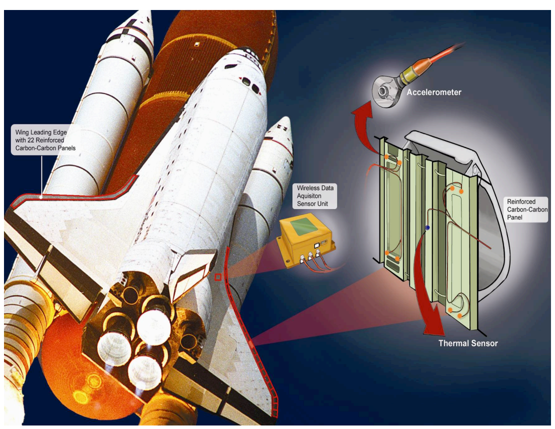
CxP Wireless DFI
Summary Presentation for OTI Flight Test Working Group

NASA/JSC

December 16, 2009

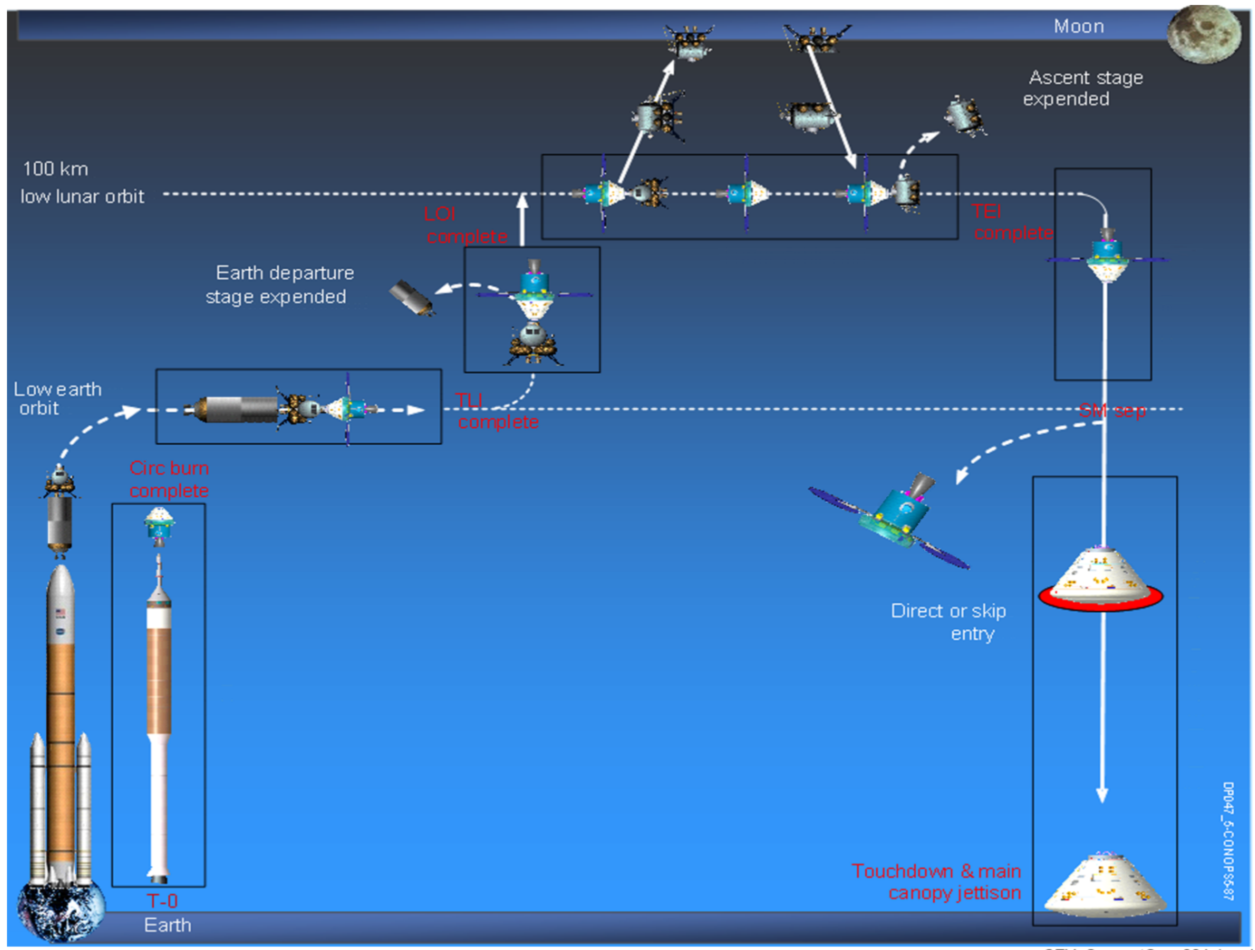


Outline of the Presentation

- **Introduction**
- **Objective and Approach**
- **Wireless DFI Technology Roadmap**
  - CxP Wireless DFI Requirements
  - Common Features and Benefits of Wireless DFI
  - Concept of Operations
  - Common Architecture
  - Enabling Technologies
  - Near Term Roadmap
  - Long Term Roadmap
- **Wireless DFI Return on Investment**
- **Recommendations**

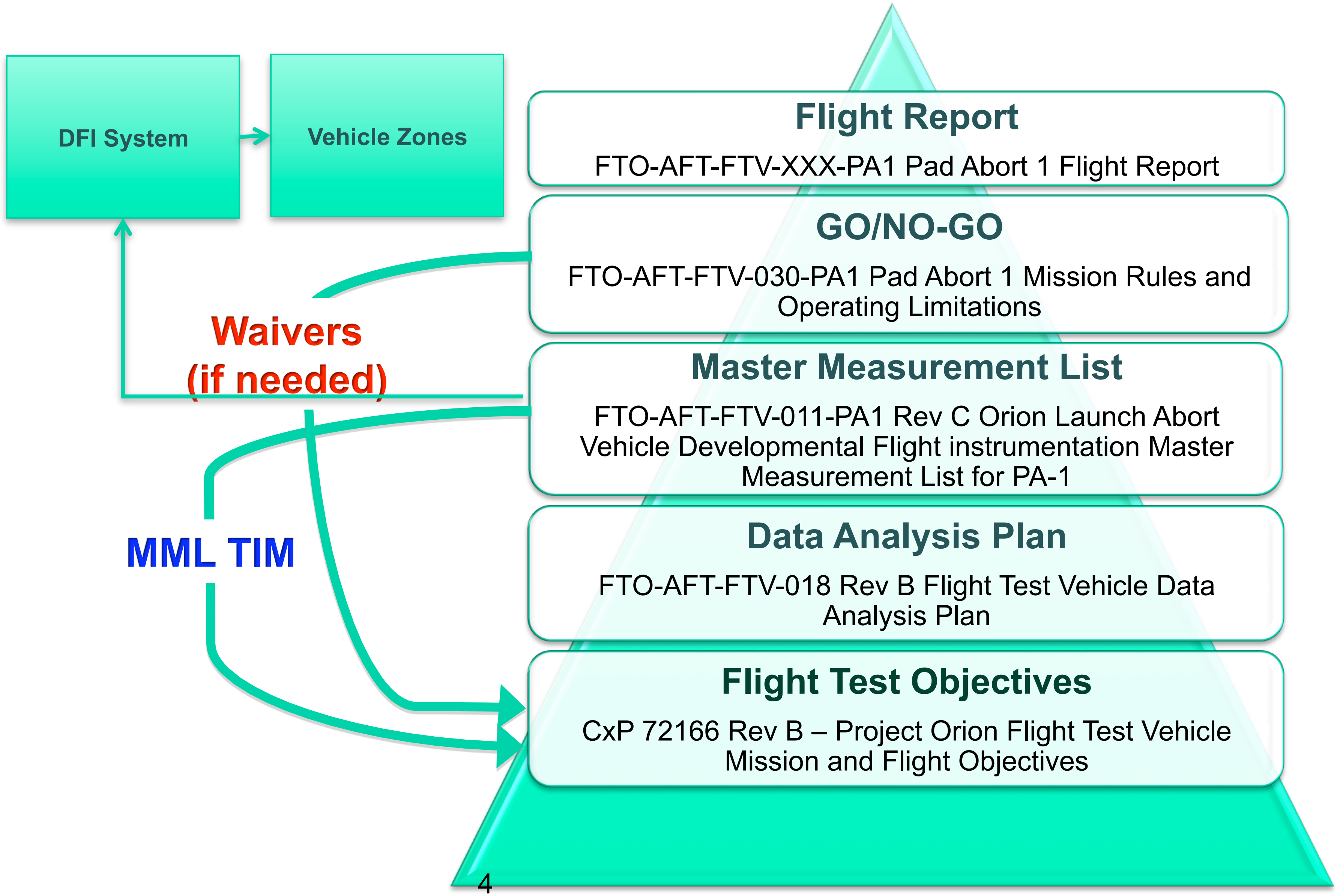
Primary Purpose of this Effort

- The goal is to understand the Altair Lunar Lander vehicle and Ares I, Ares V, the Block II Orion Crew Exploration Vehicle (CEV), instrumentation needs and assess the system requirements for a common wireless instrumentation architecture that is feasible.

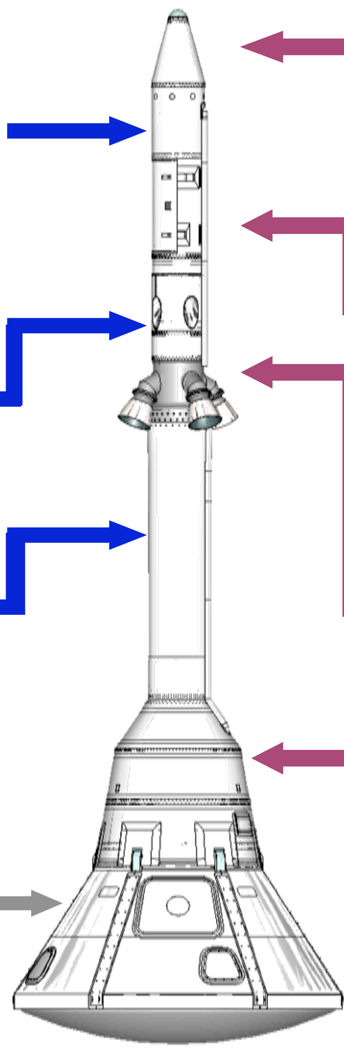


CEV_ConceptOps_004r1.psd

Current DFI Approach



LAS Development
Flight Instrumentation Architecture



Nose Cone Assembly (Orbital)
- RDAU
- FADS
- Accelerometers
- Thermal

Attitude Control Motor (ATK/Elkton)
- Strain Gauges
- Pressure Transducers
- Accelerometers
- Thermal

Canard Assembly (Orbital)
- RDAU (2)
- Strain Gauges
- Accelerometers
- Thermal
- Pressure Transducers
- Micro Switches (Discrete)

Jettison Motor (Aerojet)
- Strain Gauges
- Calorimeters
- Thermal

Abort Motor (ATK/Bachus)
- Accelerometers
- Calorimeters
- Thermal
- Strain Gauges
- Pressure Transducers

Interstage (Orbital)
- Strain Gauges
- Pressure Transducers

Adapter Cone Assembly (Orbital)
- RDAU (2)
- Strain Gauges
- Accelerometers
- Thermal
- Pressure Transducers
- Calorimeters
- Microphones

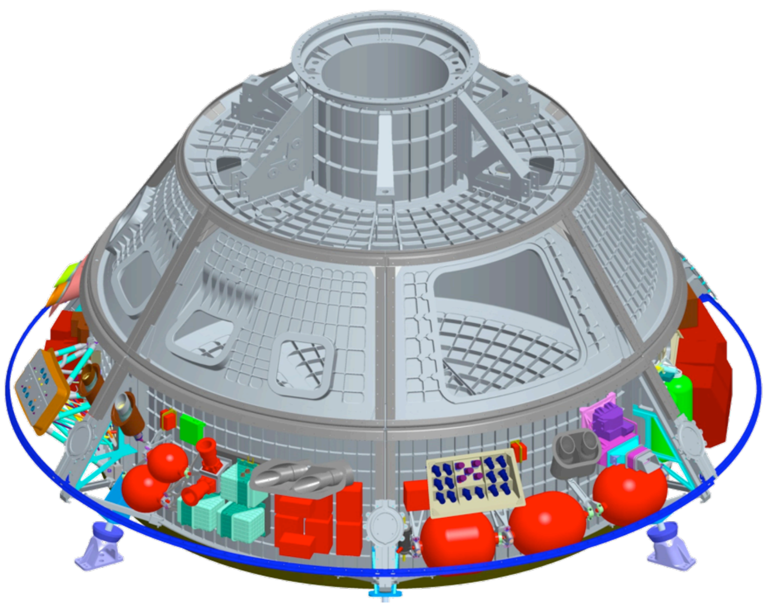
BPC (LASO/DFRC)
- Accelerometers
- Calorimeters
- Thermal
- Strain Gauges

Space Vehicle Zones

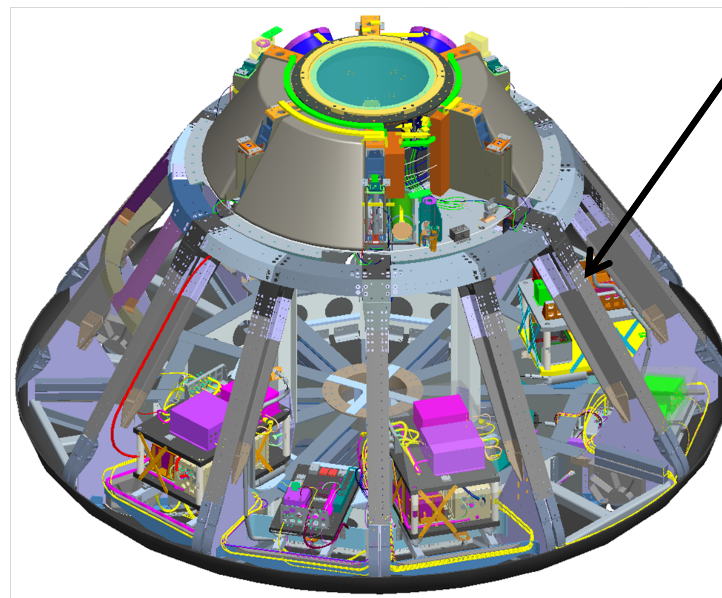
System Overview, DFI Component Locations, CM

Orion Crew Module

270



PA1 DFI Double-shelf Pallet

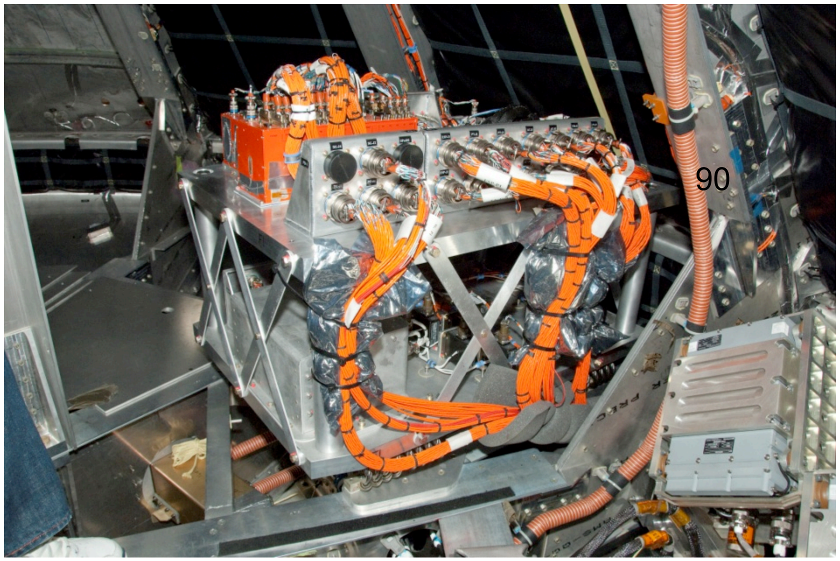


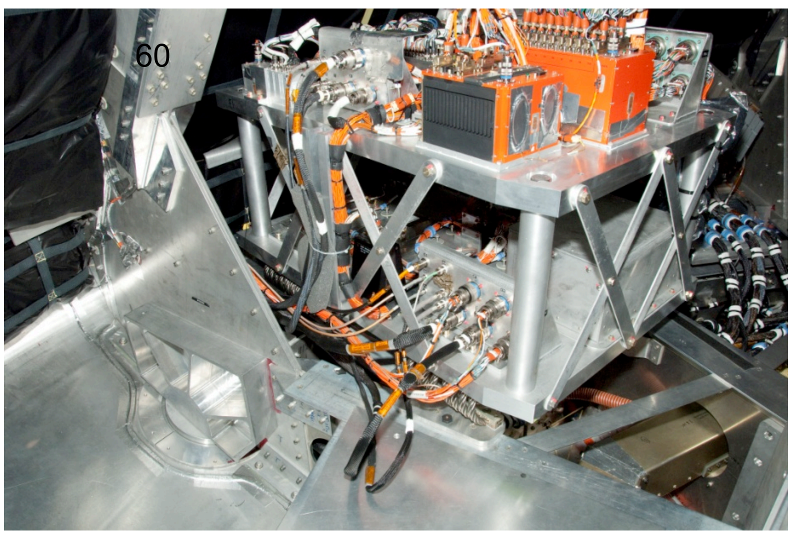
90

FTA clocking angles shown

Why Wireless DFI ?

- **DFI Pallet Installed in CM**





Key Challenges for DFI

where Wireless DFI can provide a lower impact option

Accommodating DFI Change Traffic:

1. **Post CDR** – Mandatory changes resulting from:
   - System/Environment Models,
   - Qual Tests,
   - Integrated vehicle tests,
   - Level II Requirements

2. **Orion 1 and 2** – baselined to be the same

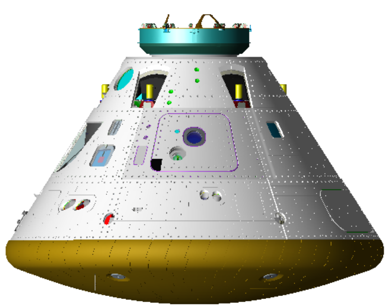
3. **Orion 1 through 5** – Mandatory changes resulting from:
   - **Post-flight** DFI and OFI data evaluations and troubleshooting

4. **Orion 6 and Subs** - Baseline is No DFI provisions:
   - **Any requirements for DFI-like measurements**

Potential Benefits of DFI Wireless Approach

- Costs of Manpower: Lower Engineering, Installation, Maintenance & Logistics
- Cost of Vehicle Weight – Less Weight than cables, connectors, brackets (goal <25%)
- Cost of Parts: Fewer Parts - Wire(Copper is high $), connectors, brackets
- Cost of Change - Changes not required for the wire instrumentation boxes/channels
  - Fewer/simpler Engineering drawings, tech orders
  - Easier access/installation and retest
  - Easier/less impact for add-ons/changes for more complete vehicles
- Physical Restrictions:
  - More Options - fewer structural barriers to where sensors can be located
    - not concerned with wire routing, bundles, brackets
  - Simpler Testing for pre-integration and post integration.
  - Fewer Volume limitations - cables near DAQ connectors, cable bend radius,
    - accommodating large number of wires in a zone
- Failures: Fewer of those typical of Wires/Connectors – bent pins, wire cuts, shorts
- Upgrades: Easier that for wired system
- Flight Test Objectives: – Provides monitoring in remote or extreme environments
  – Ability to adapt to change is greatest benefit

CxP Wireless DFI Technology Roadmap



Objective and Approach

- **Objective – Develop a Technology Roadmap to provide wireless DFI capability for CxP vehicles to optimize the measurements made at a reduced life cycle cost**
- **Approach**
  - Assess CxP stakeholder requirements for wireless DFI
    - Ares I Block II launch vehicle
    - Ares V launch vehicle
    - Block II Orion Crew Exploration Vehicle (CEV)
    - Altair Lunar Lander
  - Identify top-level stakeholder requirements for a wireless DFI architecture
  - Assess readiness levels of wireless DFI enabling technologies
  - Develop a technology roadmap to guide the development of wireless DFI systems
  - Prepare and deliver products
    - CxP Stakeholder Requirements Report
    - Wireless DFI Technology Roadmap Briefing

Source: ARES Corporation

CxP Stakeholders Supported Roadmap Activity

Name	Role	Center
Ricardo Arteaga	NASA Project Mgr	DFRC
George Studor	Technical Advisor	JSC
Mark Prill	Technical Advisor	MSFC
Michelle Rucker	Lunar Lander POC	JSC
Cao Tim	ILS SM SIG POC	JSC
Raymond Wagner	Standards POC	JSC
Ralph David	Orion Blk II POC	JSC
Richard Battle	Ares I POC	MSFC

Source: ARES Corporation

Stakeholder Inputs on Priority of Requirements

- **CxP stakeholders provided general requirements due to early phases of development**
- **Priority is average of ratings assigned by CxP Stakeholder Points of Contact**

5 Very Important (must-have)
4 Important
3 Somewhat Important
2 Somewhat Unimportant
1 Not Important at all
☐ Not rated or mission-specific

DFI Wired & Wireless

Requirement	Priority
Design	
Standards-Based	4.2
Programmability	3.8
Modularity	4.0
Flexibility	5.0
WSN Safety	5.0
Reliability and Robustness	4.3
Accessibility & Serviceability	4.0
Testability	4.0
Interoperability	4.3
Weight	4.8
Size	3.6
Security	4.0
Interface	
Signal Conditioning	2.8
Connectors	
Power Requirements	4.5
Gnd Support Hdw & Swr	4.4

Requirement	Priority
Environment	
Altitude	
Thermal	
Vibration	
Shock	
Steady State Acceleration	
Acoustic	
Electro-magnetic	
Intrinsic Safety	
Performance	
Sensor Types	4.3
Data Rates	3.5
RF Link Capability	3.8
Sensor Identity (Tags)	
Accuracy	4.8
Mission Life	4.5
Service Life	4.5

Source: ARES Corporation

TRL Assessment of Enabling Technologies

- **Majority of the technology needed to support requirements is at TRL 4**
- **Advancement to TRL 7 is primarily an integrated system technology demonstration effort**

Requirement	Current TRL
Design	
Standards-Based	5
Programmability	6
Modularity	4
Flexibility	4
WSN Safety	7
Reliability and Robustness	4
Accessibility & Serviceability	4
Testability	4
Interoperability	4
Weight	6
Size	6
Security	4
Interface	
Signal Conditioning	6
Connectors	7
Power Requirements	6
Gnd Support Hdw & Swr	7

Requirement	Current TRL
Environment	
Altitude	4
Thermal	4
Vibration	4
Shock	4
Steady State Acceleration	4
Acoustic	4
Electro-magnetic	6
Intrinsic Safety	4
Performance	
Sensor Types	4 7
Data Rates	4
RF Link Capability	4
Sensor Identity (Tags)	4
Accuracy	6
Mission Life	4
Service Life	7

TRL
7
6
5
4

Source: ARES Corporation

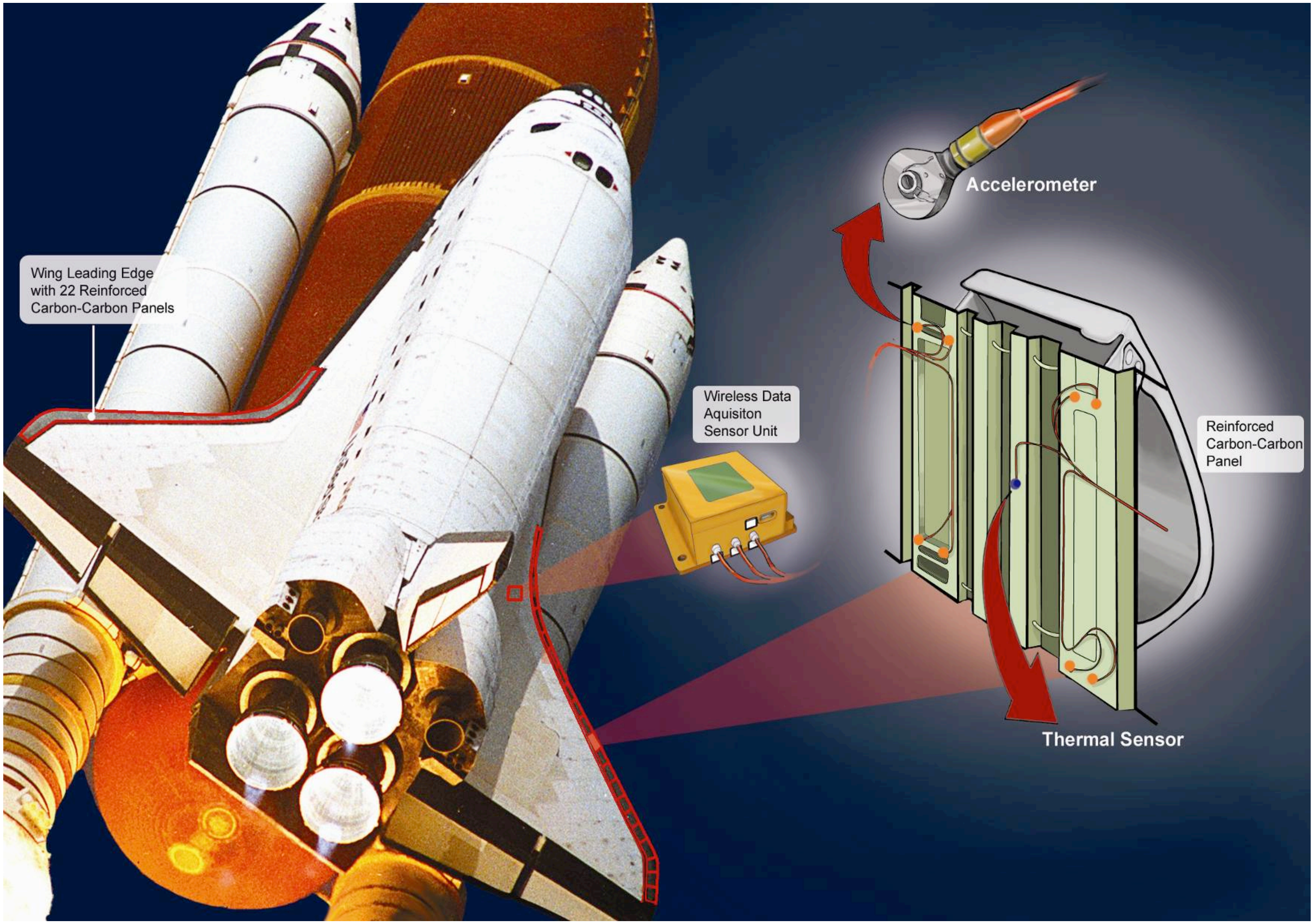
Common Features and Benefits of CxP Requirements-Driven Wireless DFI

Features	Benefits
• **Supports plug and play** – Standards-based – Modular – Interoperable • **Variable service life** • **Battery power** – Single use – Rechargeable • **Variable data latency** • **Transmits data across physical boundaries** • **Limited penetrations of structures** • **Miniaturized components** • **Components tolerate space vehicle environments** • **Fewer connections** • **Fewer and shorter wires** • **Fewer points of required access** • **More options for back-up**	• **Quickly and efficiently adaptable to evolving requirements** – Vehicle design – Measurements – Number/location of sensors • **Flexibility to acquire required data** • **Easy to install** • **Reduced weight of wires/connectors** • **Reduced volume** • **Reduced life cycle cost** – Design – Acquisition – Fabrication/Assembly – Installation – Maintenance/Repair – Removal • **Reduced program safety risk** • **Cost and schedule risk avoidance**

Source: ARES Corporation

Operations Concept:

Use Shuttle Experience, Create a better System



Concept of Operations

- **Both mission preparation and mission execution are enhanced by a Wireless DFI system**
- **A modular wireless DFI architecture allows designers to choose the instrumentation for their need and "plug-and-play"**
  - Wireless Sensor Units will support a wide-variety of sensors and applications
    - Temperature, Shock/Vibration, Stress/Strain, Pressure, Power Monitor, Humidity, Flow, etc
  - Wireless Sensor Unit software supports standard data collection and transmission applications and will be customizable for unique applications
- **A flexible architecture utilizing "smart" wireless sensor units supports a wide variety of operational scenarios such as the example below**
  - Data Needs
    - Time-synchronized data
    - High and low frequency data
    - Event triggered data
  - Data Transmission
    - Real time data transmission
    - Delayed/on-demand intra-mission data transmission
    - Post mission data transmission

Wireless DFI Mission Operations Concept Example

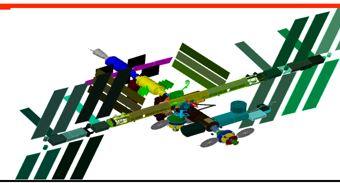
Ground Operations	Launch & Orbit Insertion Operations	On-Orbit Operations	Return/Landing Operations	Post-Landing Operations
• Wireless network checkout • Final wireless sensor unit configuration • Network synchronization • Achieve flight-ready status	• Monitor network for launch event notifications • Transmit real-time and time-critical information • Record most DFI data for post-mission processing • Retrieve expendable vehicle data	• Reconfigurations (stop un-needed recordings…etc) • Wireless network and sensor status verification • Event monitoring • Incremental retrieval of stored data	• Network configuration for return • Monitor re-entry for event notifications • Transmit real-time and time-critical data • Continue recording sensor data	• Crew and systems monitoring • Retrieve all remaining data via hardwire or RF link • Shutdown network as required

Source: ARES Corporation

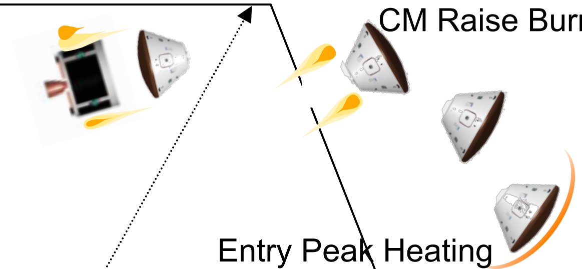
DFI Operations Concept: Mission Profile

ISS Docking Phase
- Event Dynamics
- Configuration Changes

On-Orbit Docked Phase
- Event Measurements
- Incremental Down-load
- Incremental Down-link



ISS Un-Dock Phase
- Event Dynamics
- Configuration Changes



CM Raise Burn

Entry Peak Heating

Initial Astronaut Ops
- Setup Internal DFI Download HW
- RF Download

Orbit Phase
- Stop most DFI recording
Compute summary file event indicators
Download summary files and Raw data as time permits
- Start on-orbit monitor modes

Re Entry Phase
- Monitoring

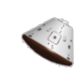
Ascent
- Continuously Store Data in Sensor Units
- Time Synch between units in same RF zone
- Wired Vehicle Buses provide link between Ares and Orion DFI systems
- Expendable vehicles down-load or downlink data

Mission Control

GFE Ops

Engineering

Landing Phase
- Event Monitoring



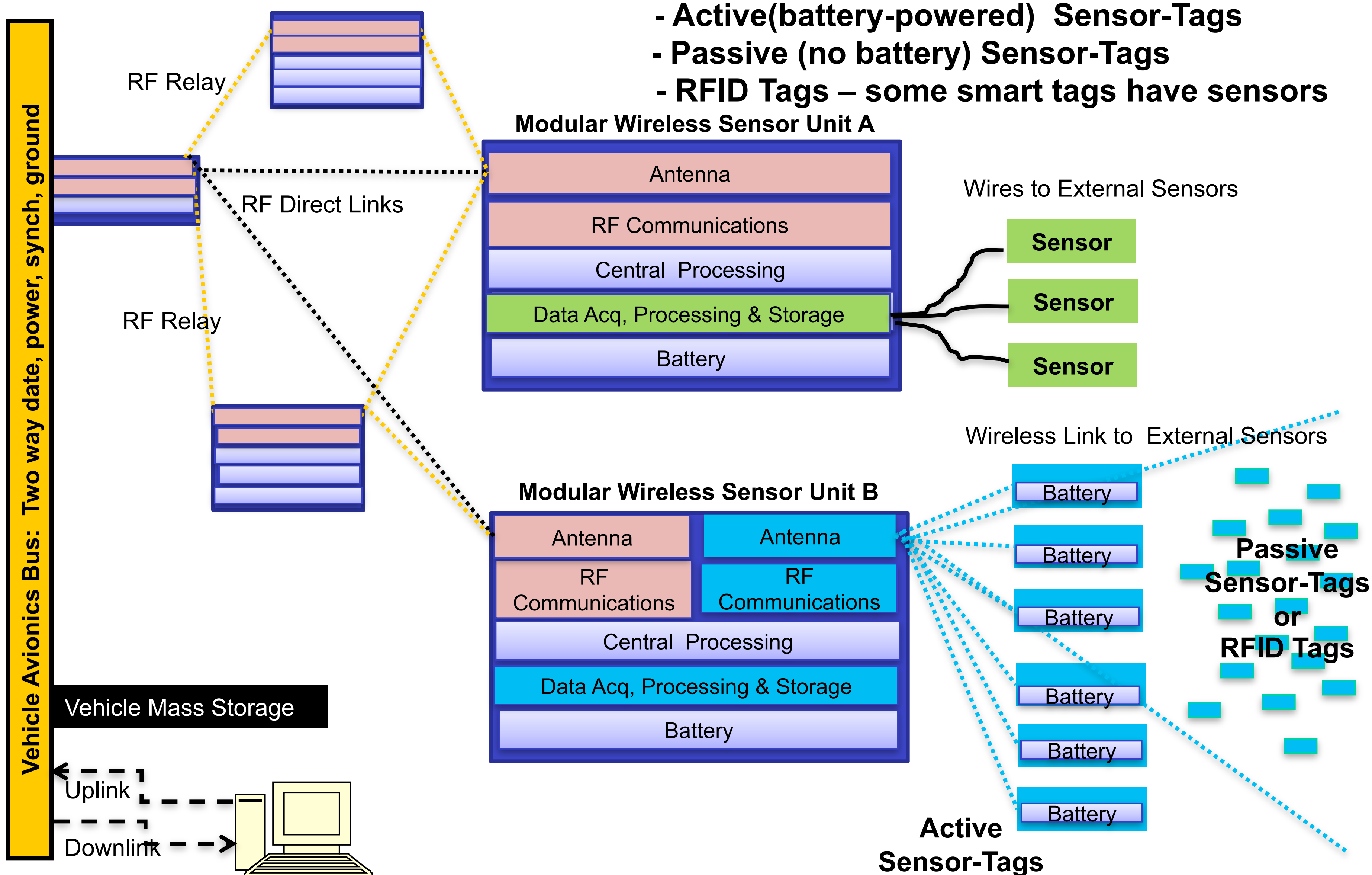
Launch
- Final Ground Synch
-Auto trigger into data collection mode

Pre-Launch Phase
- Checkout
- Programming
- Measurements

Post Landing Phase
- Crew and Systems Monitoring
- Transport and Handling
- Data Download via Hardwire link or high rate RF

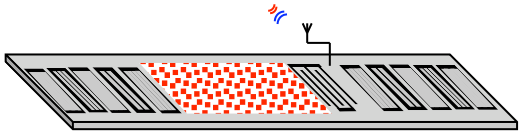
Modular Wireless DFI Architecture:

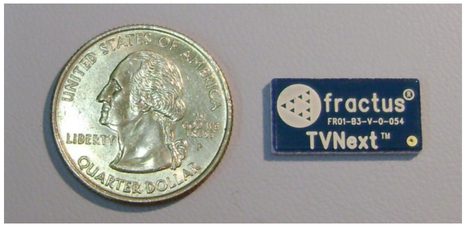
- Wireless Interrogation/Communication with Sensors
  - Active(battery-powered) Sensor-Tags
  - Passive (no battery) Sensor-Tags
  - RFID Tags – some smart tags have sensors

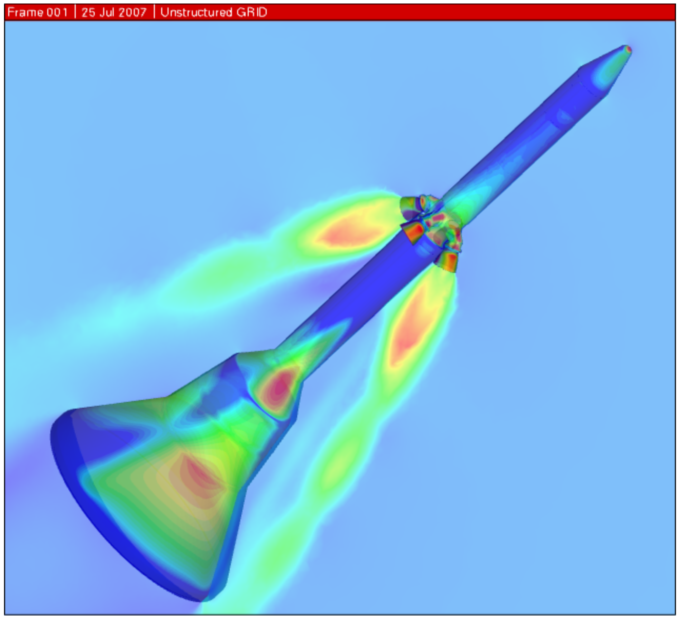


Passive Wireless SAW sensors

- Low cost
- Simple integration
- Small (low mass and low volume)
  - Very lightweight < 1 gram
- Extremely Low power (RF or Ambient)
  - Temperature sensors
  - Strain sensors
  - Pressure sensors
  - Chemical sensors
  - Accelerometers sensors
- Harsh Environments
  - High Temp (+1200º C)
  - Radiation Hard (10 Mrad)
  - Shock & Vibration (20-20Khz)
  - Pressure (500psi)
- Reliable (near wired)



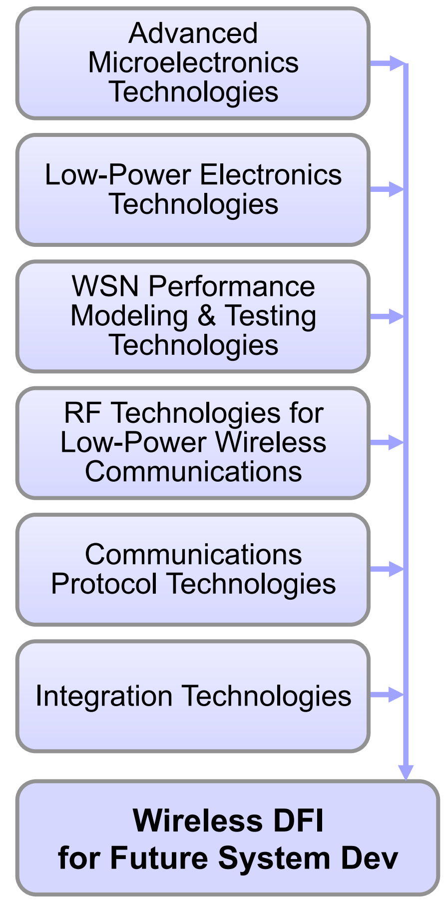




Critical Enabling Technologies

Six technologies are critical to providing the benefits of wireless DFI to future system development activities

- **Advanced Microelectronics Technologies**
  - Small Size & Low Power
  - Environmentally- Robust
- **Low-Power Electronics Technologies**
  - Energy Aware Algorithms
  - Ultra low Voltage Analog Circuits & Low Capacitance & “Sleep” Transistors
  - Passive Wireless Sensors
- **WSN Performance Modeling and Testing Technologies**
  - Reliable Link Analysis in Challenging Environments
  - Reliability & Performance Predictions
- **RF Technologies for Low-Power Wireless Communications**
  - Battery Performance Technologies
  - Harsh Environments
  - Small Size with Long Life
- **Communications Protocol Technologies**
  - Reliability
  - Data Rate
  - Low Power
  - Security
- **Integration Technologies**
  - Integrate RF, Data Acquisition, Low Power, etc.
  - Trade Spaces (e.g.. Power vs. Reliability vs. Data Rates, etc.)
  - Vehicle provisions (physical and functional access)



Source: ARES Corporation

Technology Roadmap (First Steps)

<u>Phase 1</u>: <u>Position Orion to take advantage of Wireless DFI:</u>

1. Add wireless provisions into existing Orion and Ares avionics architecture that allows wireless DFI to be added.
   - Physical and Functional Avionics bus access points.

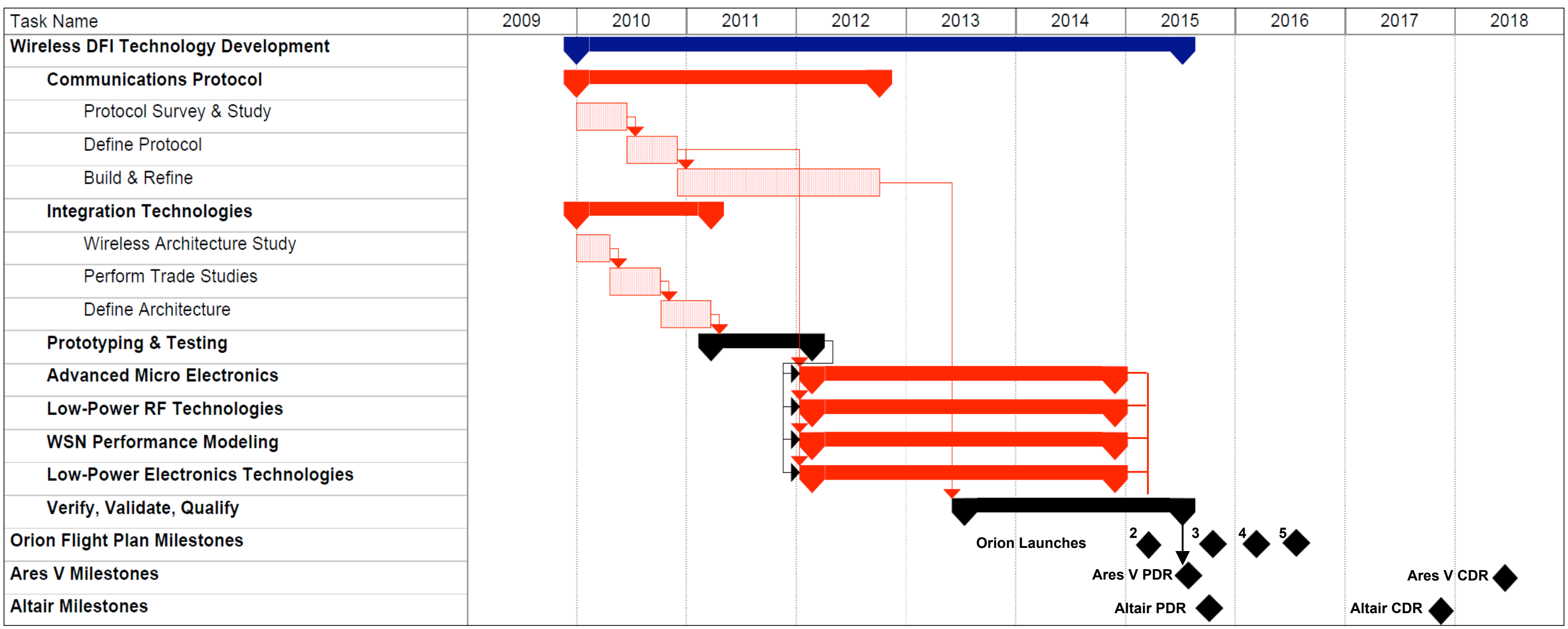
2. Use proven Shuttle/ISS wireless sensors to provide measurements in ground and early flight testing and Orion/Ares missions.
   - WLEIDS Accelerometers/Acoustic Pressure, AE, Strain, Temperature, Pressure and other compatible sensors.
   - **<u>Early targets:</u>**Orion Vib/Acoustics tests & Integrated GVT <u>add-on</u>

3. Develop standard's based wireless DFI sensor system for replacement of/complement legacy systems.
   - New standards hold promise and are being demonstrated in RF Test beds – move forward on other functionality next.

4. Add new system depending on funding and progress in TRL advancement.
   - Passive Sensor Tags, Smart RFID, Data Loggers, etc.

Technology Roadmap

- **Develops architecture and enabling technologies**
- **Prototypes and demonstrates integrated system**
- **Supports implementation in incremental steps**
  - Initial implementation on Orion 5 as warranted
  - Ares V and Altair PDRs



Source: ARES Corporation

Summary

- **CxP wireless DFI stakeholder requirements**
  - CxP stakeholders provided general requirements due to early phase development
  - Priority of stakeholder requirements generally assessed as “important” and higher
- **TRLs of enabling technologies**
  - Majority of the technology needed to support requirements is at TRL 4
  - Achieving TRL 7 is primarily an integrated system technology demonstration effort
- **Common features and CxP benefits of wireless DFI**
  - Supports cost and schedule risk reduction through efficient adaptability
  - Key features include plug and play, reliable power, responsive communication
- **Wireless DFI concept of operations and architecture**
  - CONOPS supports mission preparation and execution
  - Plug and play enabled by flexible modular architecture
- **Technology Roadmap**
  - Develops architecture and enabling technologies
  - Prototypes and demonstrates integrated system
  - Supports incremental implementation on Orion flights, Ares V, and Altair

Source: ARES Corporation

Wireless DFI Return on Investment for Long Term Technology Roadmap

Estimated Life Cycle Cost Savings Per Use

Life Cycle Costs	% of Conventional	Cost of Conventional ($M)	Cost Savings ($M)
Design	50	.5	.25
Acquisition	100	1	0
Fabrication and Assembly	50	1	.5
Installation	25	2	1.5
Maintenance and Repair	25	1	.75
Removal	25	1	.75
Cost of Change	25	5	3.75
Ops and Sustain Engr	150	1	- 0.5

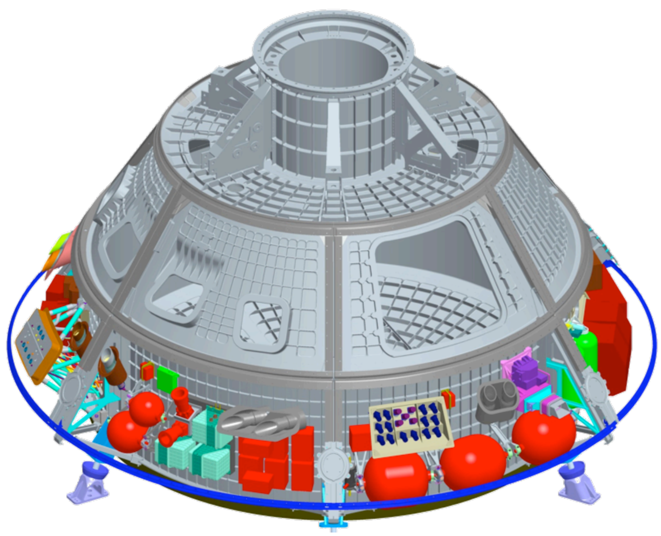
Notional Costs

Total cost savings/use approx. $7 M
Number of uses for CxP = 10
Total CxP cost savings approx. $70M

Source: ARES Corporation

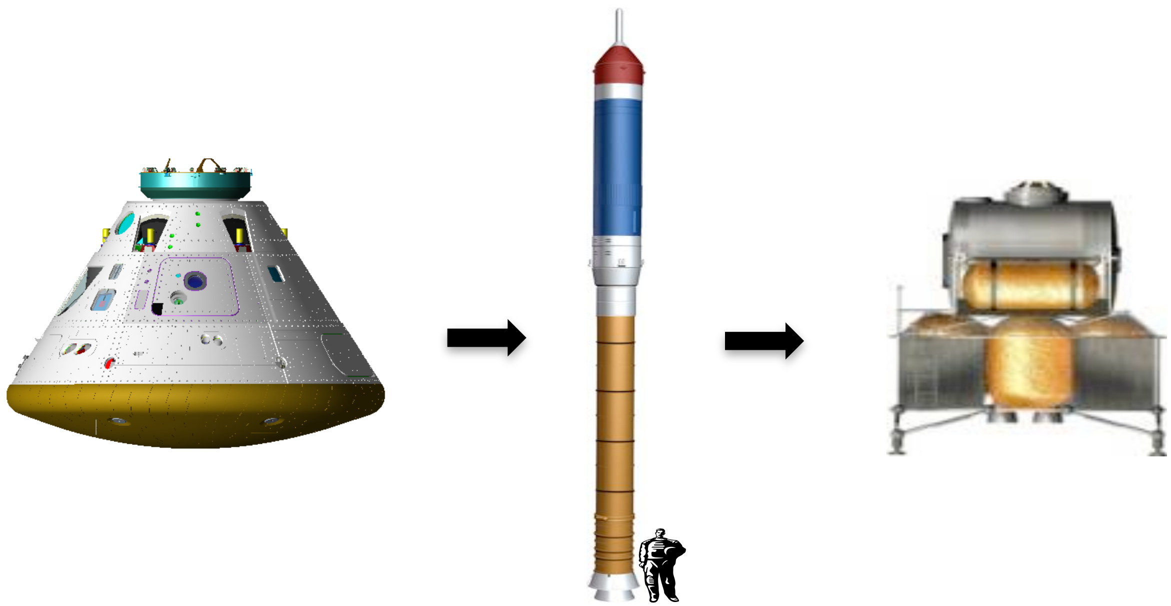
Go Forward Plan

- Archive Products from this and other similar studies.
- Continue Engagement with the External community; Conferences, Site Visits.
- Continued Advocacy for advancement of Wireless DFI applications.
- Prepackage the Wireless DFI task package so it's 'shovel ready' to compete for the next increment of stimulus/other dollars.
- Modular Instrumentation/DFI Working Group for CxP, or under FTWG, needs to be Re-Invigorated with all Projects and some level II orgs supporting it.



CxP Wireless DFI Recommendations

- **Continue funding a Wireless DFI Initiative under CxP O&TI/FIT Office leadership.**
  - **Near Term**: Wireless DFI benefits hold great promise for effectively addressing data collection challenges.
  - **Long Term:** Post Orion 5, DFI architecture solution that is standardized, common, and compatible with Orion and Altair such that data can be shared.
  - The approach used for Orion and Ares will pave the way for Lunar Vehicles.



Backup Charts

Bottom Line Results

- **Level II DFI Requirements are lacking**
  - More work needed to generate crisp Level II language
  - Level II Orgs/SIGs need to weigh in on Project DFI
- **Key Benefits are to reduce impact for:**
  - Weight and cost of certain known measurement requests
  - Changes/Additions to the baseline vehicle wired DFI systems.
- **Wireless DFI is of significant interest to most stakeholder**
  - Priorities and Applications vary widely
- **One "size" will not fit all needs, but that doesn't negate the benefit of standardization of RF and power with provisions for "bring your own" system**
  - Systems are in use/available: Shuttle, ISS, other agency and COTS
  - Standards-based systems are in work, need TRL work
- **Key Next Steps:**
  - <u>Level II Requirements</u> and specific needs reflected in Level III/IV req
  - <u>Level II Metrics</u> for features and benefits that can't be written as req
  - <u>Vehicle Provisions</u>: Physical and Function accessibility by zone
  - <u>Tech Development</u>: identify most bang for buck tech for future systems
  - <u>Applications</u>: transition from early use of existing assets to next system

NASA Technology Strategy

Year One - CxP Office: CS = 0.75, Cont = 1.0, Travel = $15K

1. **Increased Involvement in Funded Technology Development**
   - **Existing SBIR/STTR/other Technology Developments**
   - **Develop and sustain dedicated SBIR/STTR subtopic(s).**

2. **Develop and Propose CxP DFI Requirements & Metrics: Including Wireless**
   - **Resolve clear Level II Requirements for Synchronization, SIGs, Mission Operations, Ground Operations, Maintainability/Supportability.**
   - **Work with Vehicle Projects to establish a wireless standard(req)for DFI.**

3. **Work with Projects to develop requirements documents for Wireless DFI for Altair, Habitat, Pressurized Rover, Ares V and Orion for Lunar missions.**

4. **Participate in various Test and Design activities(like CDR) to assure compliance with requirements, valuations using metrics, and suggested applications.**

5. **Participate in Wireless Sensor Systems "Community of Practice.**

NEAR TERM STRATEGY: DEVELOP A WDFI TEAM TO ASSESS AND APPLY WDFI "TOOL KIT"

Note: This is very similar to what JSC/EV has done on an individual basis for Shuttle and ISS, except the approach uses other resources more effectively. Similar to earlier proposals.

YEAR ONE:

1. Assemble Core Team

Core Team grows to Wireless Sensors "Community of Practice"

→ Add other CxP Organizations → Add NASA Centers → Add other Gov Agencies → Add COPs from other Industries

CS: .5, Cont: .5, Travel $20K

2. Integrate Available Sensor System Info/docs

WDFI "Tool Kit" Grows to a WDFI "Cooperative" with many options

CS: .5, Cont: .5, Travel $10K

3. Investigate Options with Stakeholders

- Contact Ground Test and FTO - DFI stakeholders for match-making
- Conduct site visits as required to investigate needs and develop proposals
- Engineering Eval for Functional and Environmental Performance

CS: .5, Cont: 2.0, Travel $30K

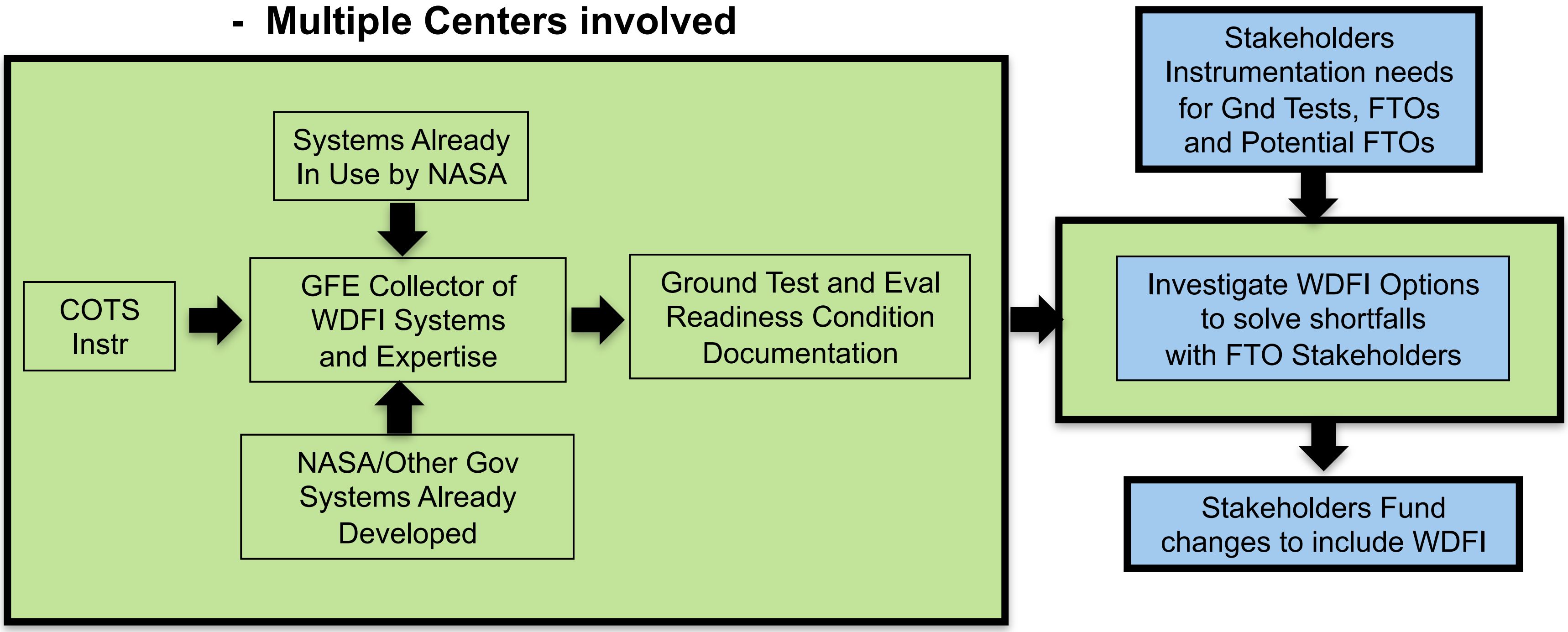
4. Develop Agreements with Stakeholder for Application at various facilities and vehicles

CS: .5, Cont: 1.0, Travel $10K

Near Term Strategy: Apply WDFI "Tool Kit"

Build Up the Wireless DFI "Tool Kit" with Experienced JSC GFE Team - Multiple Centers involved

Stakeholder Selects Solutions from WDFI "Tool Kit"



<u>Current Examples:</u>

- JSC: Lunar Electric Rover, Desert Rats Hab (HDU), COPV monitoring , Impact Test monitoring with available systems
- Ares Composite Monitoring with COTS/SBIR

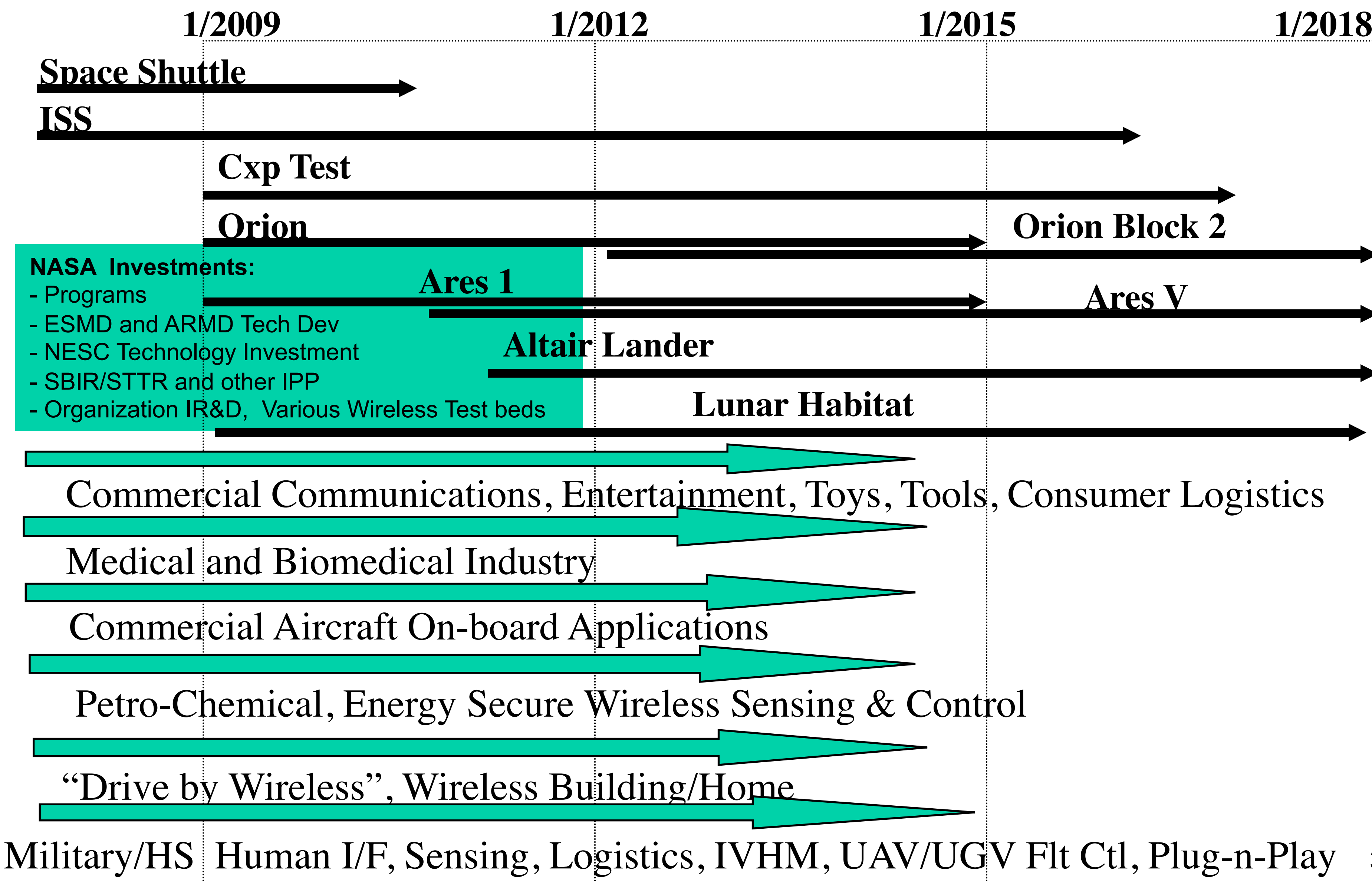
<u>Future (Multi-center) Specific Examples:</u>

-Orion Loads and Acoustics Investigate applying WLEIDS Accelerometer and Acoustic Pressure Measurements for Ground and Flight tests.

- Thermal, Vib, Acoustic for Orion and Integrated GVT, roll-out needs for Orion/Ares
- Lander Prototype: Additional Instrumentation for performance evaluations

NASA Wireless DFI Technology Strategy

Get Smart, Evaluate and Partner, <u>Leverage</u> what we can



Technology Impacts on Key Requirements

Requirement	Priority	Technology Drivers					
		Communications Protocol Technologies	Advanced Microelectronics Technologies	RF Technologies for Low-Power Wireless Communication	WSN Performance Modeling Technologies	Low-Power Electronics Technologies	Integration Technologies
Design							
Standards-Based	4.2	TRL 5		TRL 5			
Programmability	3.8		TRL 6			TRL 6	
Modularity	4.0	TRL 5	TRL 6			TRL 6	TRL 4
Flexibility	5.0	TRL 5	TRL 6		TRL 4		
WSN Safety	5.0			TRL 7			
Reliability and Robustness	4.3	TRL 5	TRL 5	TRL 4		TRL 5	TRL 4
Accessibility & Serviceability	4.0			TRL 4			
Testability	4.0	TRL 6	TRL 6		TRL 4	TRL 6	TRL 4
Interoperability	4.3	TRL 4					
Weight	4.8		TRL 6			TRL 6	
Size	3.6		TRL 6	TRL 5		TRL 6	
Security	4.0	TRL 4		TRL 4			TRL 4
Performance							
Sensor Types	4.3		TRL 4			TRL 4, 9	
Data Rates	3.5	TRL 6					
RF Link Capability	3.8	TRL 5	TRL 4		TRL 5	TRL 4	TRL 4
Sensor Identity (Tags)			TRL 4				TRL 4
Accuracy	4.8		TRL 6			TRL 6	
Mission Life	4.5		TRL 6			TRL 4	
Service Life	4.5		TRL 7			TRL 7	

Source: ARES Corporation

Technology Impacts on Key Requirements

Requirement	Priority	Technology Drivers					
		Communications Protocol Technologies	Advanced Microelectronics Technologies	RF Technologies for Low-Power Wireless Communication	WSN Performance Modeling Technologies	Low-Power Electronics Technologies	Integration Technologies
Interface							
Signal Conditioning	2.8		TRL 6			TRL 6	TRL 6
Connectors							TRL 7
Power Requirements	4.5					TRL 6	TRL 6
Gnd Support Hdw & Swr	4.4						TRL 7
Environment							
Altitude							TRL 4
Thermal							TRL 4
Vibration							TRL 4
Shock							TRL 4
Steady State Acceleration							TRL 4
Acoustic							TRL 4
Electro-magnetic					TRL 6	TRL 6	TRL 6
Intrinsic Safety						TRL 4	TRL 4

Source: ARES Corporation

Priority of Requirements and TRL of Enabling Technologies

Requirement	Current TRL	Priority	Barriers and Gaps	Steps to Overcome Barriers
Design				
Standards-Based	5	4.2	Although some work has been completed on an open standard for aerospace applications, considerable development and testing remains.	1. Identify common standard to be used. 2. Implement & Test
Programmability	6	3.8	Several families of sensors have proven programmability in flight application. Has not been applied specifically to WSN space applications.	1. Design standard programming hardware, software & interfaces 2. Implement & Test
Modularity & Flexibility	4	4.0	Industrial sensors have been proven to be capable of both flexible & modular architecture. However, has not been applied to WSN space applications.	1. Select industrial design concept & adapt to flight WSN 2. Functional Test using chosen Architecture 3. Qual Test Demonstrating Environmental Suitability 4. Flight Test and/or piggy back test.
WSN Safety	7	5.0	WSN has been proven safe on shuttle & other past space missions.	1. Standard safety and hazard analysis required.
Reliability and Robustness	4	4.3	Industrial sensors have been proven to be capable of reliable & robust architecture. However, has not been applied to WSN space applications.	1. Select industrial design concept & adapt to flight WSN 2. Functional Test using chosen Architecture 3. Reliability & Link Analysis, Verification & Test 4. Flight Test and/or piggy back test.
Accessibility & Serviceability	4	4.0	Industrial sensors have been proven to be accessible & serviceable. However, has not been applied to WSN space applications.	1. Develop plug-n-play concepts as well as mounting features that enable quick & easy installation/removal. 2. Functional Test 3. Demonstrate accessibility features on flight vehicle 4. Flight Test and/or piggy back test.
Testability	4	4.0	Industrial sensors have been proven in this area. However, has not been applied to WSN space applications.	1. Develop test and self-test features that enable quick & easy verification of operating & performance integrity. 2. Functional Test 3. Demonstrate features on flight vehicle 4. Flight Test and/or piggy back test.
Interoperability	4	4.3	Industrial sensors have been proven in this area. However, has not been applied to WSN space applications.	1. Identify systems that interface with existing standard hardware interfaces. 2. Verify design interfaces (hardware & software) 3. Functional Test 4. Demonstrate 5. Flight Test and/or Piggy Back
Weight & Size	6	4.8	Miniature, Low mass sensors and electronics have been routinely flown in space. However, light weight electronics for a space-applied WSN have not been developed.	1. Identify systems that electronics have be miniaturized. 2. Verify design 3.Prototype if required 4. Functional Test using chosen design 5. Qual Test Demonstrating Environmental Suitability 6. Flight Test and/or piggy back test.
Security	4	4.0	Industrial sensors have been proven in this area. However, has not been applied to WSN space applications where additional security measures may be required.	1. Identify existing proptocol & necessary security features 2. Incorporate security measures into protocol 3. Functional Test 4. Flight Test and/or Piggy Back Test

Source: ARES Corporation

Priority of Requirements and TRL of Enabling Technologies

Requirement	Current TRL	Priority	Barriers and Gaps	Steps to Overcome Barriers
Performance				
Sensor Types	4, 9	4.3	A few sensors have been developed and flow. Most have not.	1. Identify sensors required for flight missions. 2. Design & Prototype 3. Functional Test using chosen design 4. Qual Test Demonstrating Environmental Suitability 5. Flight Test and/or piggy back test.
Data Rates	4	3.5	Wide range of data rates have been identified for use with unique sensors. Some low data-rate sensors have been flow, but high-rate sensors have not been utilized in a WSN space application.	1. Select industrial design concept that has appropiate data rates to meet bandwidth requirements & adapt to flight WSN 2. Functional Test using chosen Architecture 3. Qual Test Demonstrating Environmental Suitability 4. Flight Test and/or piggy back test.
RF Link Capability	4	3.8	Industrial sensors have been proven in this area. However, has not been applied to WSN space applications.	1. Identify systems that incoporates appropiate RF Link interface with including standard hardware interfaces. 2. Verify design interfaces (hardware & software) meets requirements 3. Functional Test 4. Demonstrate 5. Flight Test and/or Piggy Back
Sensor Identity (Tags)	4		Industrial sensors have been proven in this area. However, has not been applied to WSN space applications.	1. Identify protocal techniques that incorporates sensor identity 2. Functional Test 3. Demonstrate 4. Flight Test and/or Piggy Back
Accuracy	6	4.8	All accuracy requirements have been achieved in space flight environments. However, not all have been applied in a WSN space-flight application.	1. Use proven technology and hardware to maintain accuracy requirements. 2. Functional Test 3. Demonstrate 4. Flight Test and/or Piggy Back
Mission Life	4	4.5	Past missions using instrumentation systems have demonstrated the ability to operate at least as long as required mission life. However a long mission life for a space flight WSN under battery power has not been demonstrated.	1. Identify techniques and hardware that meets the mission life requirements 2. Incorporate into system design 3. Functional Test 4. Demonstrate 5. Flight Test and/or Piggy Back
Service Life	7	4.5	There is no reason to believe that WSN electronics would not have a service life comparable to a hardwired system.	1. Incorporate proven technologies into system design 2. Functional Test

Source: ARES Corporation

Priority of Requirements and TRL of Enabling Technologies

Requirement	Current TRL	Priority	Barriers and Gaps	Steps to Overcome Barriers
Interface				
Signal Conditioning	6	2.8	Signal conditioning requirements have been achieved in space flight environments. However, not all have been applied in a WSN space-flight application.	1. Incorporate proven technologies into system design 2. Functional Test 3. Demonstrate 4. Flight Test and/or Piggy Back
Connectors	7		Standard connectors have been flown for decades.	Use standard, off-the-shelf, space-qualified connectors
Power Requirements	4	4.5	Power source requirements have been achieved in space flight environments. However, not all have been applied in a WSN space-flight application.	1. Identify power requirements for system 2.Incorporate proven technologies into system design 3. Functional Test 4. Demonstrate 5. Flight Test and/or Piggy Back
Gnd Support Hdw & Swr	7	4.4	It is anticipated that there would be no new or unique technologies required in the ground support system.	Use standard, off-the-shelf components to create GSE required.
Environment				
Altitude	4		Flight qualification will be required after the WSN components have been developed. These systems will use a unique combination of low-power electronics, miniaturization and RF equipment that has not been flown. The environmental requirements may be very difficult to achieve for some sensor requirements, depending on the application.	1. Identify most promising environmental hardening techniques 2. Incorporate into system design 3. Qual Test to MIL STD 810
Thermal	4			
Vibration	4			
Shock	4			
Steady State Acceleration	4			
Acoustic	4			
Electro-magnetic	6		The industrial EMI environment is similar to MIL STD 461 space requirements for radiated emissions and radiated susceptibility.	1. Identify most promising protocol for the EMI environment 2. Incorporate into system design 3. Qual Test to MIL STD 461
Intrinsic Safety	4		Industrial sensors have been proven in this area. However, has not been applied to WSN space applications.	1. Identify most promising techniques and hardware 2. Incorporate into system design 3. Functional Test 4. Demonstrate 5. Flight Test and/or Piggy Back

Source: ARES Corporation

Observations Drawn from Stakeholder Inputs

- **Stakeholders provided general requirements**
  - Still in early phases of DFI development for most CxP flights
    - Researchers & system designers do not have not firm data requirements
    - Number of sensors, bandwidth, accuracies, etc. not yet established
  - Often stated Goals were %Savings, %Weight or Volume Reduction, etc.
  - Design & Interface requirements usually stated by comparison to hardwired
    - Example: Shall be at least as reliable as hardwired sensor…
  - Environmental & Performance requirements tend to be mission specific
- **Majority of technology needed to support requirements is at TRL 4**
  - Technologies and concepts have been validated in lab & Industry environment
  - The combination & application of required technologies has not been fully demonstrated in a flight or relevant environment
- **Relatively low-risk to mature technology to meet CxP requirements**
  - Required technologies are well established
  - Have operated individually in a wide variety of environments
  - Little or no research required to prove feasibility
  - Requirements satisfied through the integration of existing technologies
  - Advancement to TRL 7 is primarily a Technology Demonstration Effort

Source: ARES Corporation

Technology Readiness Levels

- **For each technology gap, assess efforts required to achieve TRL-7**

- **System Test, Flight and Operations**

  Shuttle Impact Detection

- **System/Subsystem Development**

- **Technology Demonstration**

- **Technology Development**

  NESC Technology Investment

- **Research to Prove Feasibility**

  SBIR SAW Passive Tag

- **Basic Technology Research**

9 - Actual system "Flight Proven" through successful mission operations

8 - Actual system completed and "Flight Qualified" through test and demonstration

7 - System prototype demonstration in an operational environment

6 - System/Subsystem model or prototype demonstration in a relevant environment

5 - Component and/or breadboard validation in relevant environment

4 - Component and/or breadboard validation in laboratory environment

3 - Analytical and experimental critical function and / or characteristic proof-of-concept

2 - Technology concept and/or application formulated

1 - Basic principles observed and reported

Wireless System potential cost savings

Example for operational Load Monitoring using strain gauges – Black Hawk

Wired system

- 20 meters per channel
- Installation and materials cost = $40 per meter
- 250 Strain sensors
- **Sensors & cabling instrumentation = $200,000**
- Computer cost $ = 5,000
- Amplifier and signal conditioner cost = $100 per channel
- **Total cost for strain survey using 250 Gauges = $230,000**

Wireless system

- Cost per 1 channel = $150 (3 channel device)
- Installation cost = $100 per device (3 channels)
- 250 Strain sensors
- **Sensors and instrumentation cost = 46,000**
- Data storage cost = $100 per device ($8,300)
- Computer cost $ = 5,000
- **Total cost for strain survey using 250 Gauges = $60,000**

- Much of the cost is installation of the wiring looms if these were to be attached to the airfram components additional cost is required to clear any engineering modifications to the airframe

Wired system cost = $230K (4x)

Wireless system cost = $60K

Space Shuttle Orbiter
Main Engine Ignition
Acoustic Pressure Loads Issue
Recent Actions to install Wireless Instrumentation on STS-129

NASA/JSC/EV/George Studor
and Nathan Wells

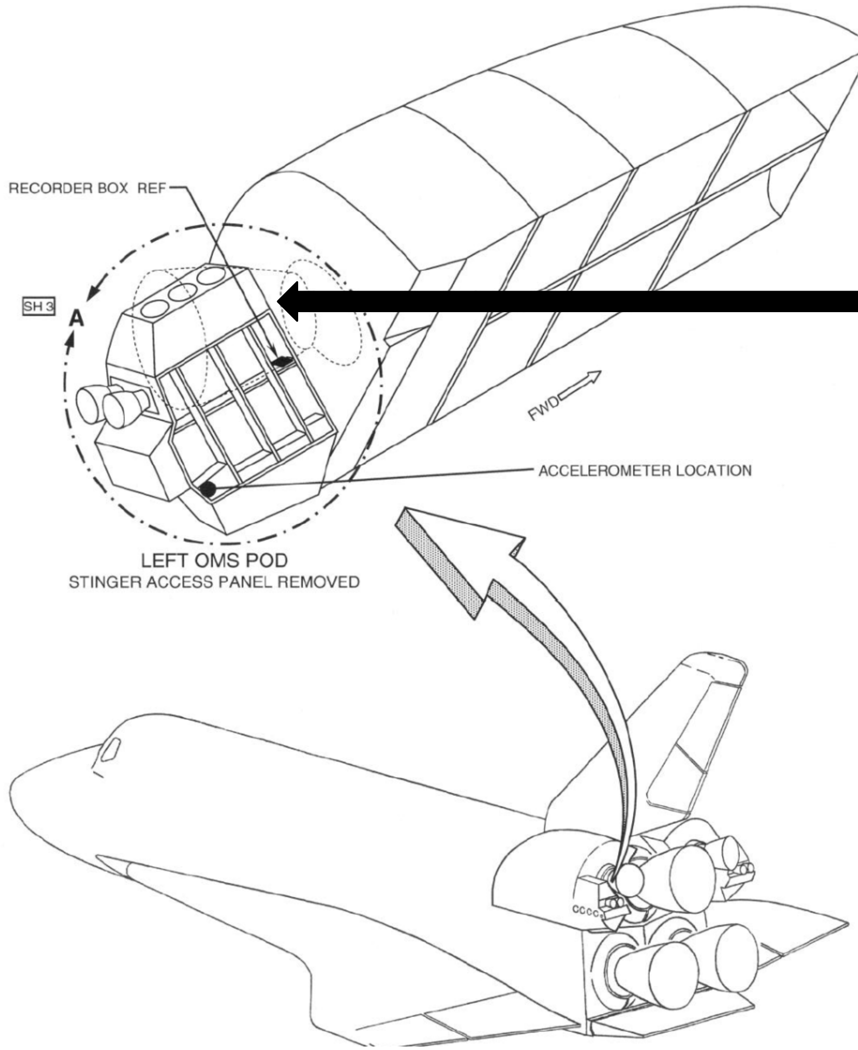
December 10, 2009

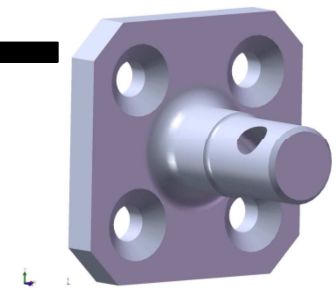
JANNAF Wireless Sensors Workshop

MEI GFE Instrumentation "As-Run" Schedule for STS-129

10/28	STS-129 FRR Issues Actions
10/30	Sensors and Acquisition parameters determined, Vehicle Instr Options ruled out.
10/30	KSC/Structures captures Photos of potential locations for sensors and DAQs
11/1	Inventories checked and initial test plans determined
11/2	KSC shipped Accoustic Pressure Sensor overnight to JSC for testing.
11/3	JSC/EV tests Accoustic Pressure sensor range compatibility with WLEIDS DAQ
11/3	Orbiter/EV present Instrumentation Options and Status to Orbiter
11/3	Safety Cert Approach acceptable based on delta from previous cert in same zone.
11/4	JSC Engineering Approves integrated Orbiter and EA GFE Plan
11/4	KSC Engineering and Ground Ops reviews options and schedules
11/4	Boeing HB provides Engineering Assessment and Hardware Configuration Input
11/4	JSC/EV Management (GFE Flt HW Rvw) agrees to ship flight hardware with minor open certifications.
11/4	JSC/EV Purchases Accelerometer Mounting blocks from Endevco – overnight shipping
11/5	Space Shuttle Program Manager approves triax accel only for STS-129, no Launch slip
11/5	JSC/EV and Safety reviews updated Flight Hardware Certification and Safety Cert Packages
11/6	JSC/EV ships most Flight Hardware for start install of cables and accels NLT 11/9
11/7-9	JSC/EV fabricate Flight Mounting Plates
11/8	KSC receives non-flight mounting block for fit checks and final locating
11/9	JSC/EV GFE Operations expert hand-carries accel blocks and mounting plate to KSC for installation
11/9	KSC installation begins, estimated completion is 11/11 .
11/10	Obiter Project reviews Safety Issue Brief (Hazard Analysis Summary)- Multiple Safety Orgs participate
11/10	Orbiter signs GCAR Certification & CR
11/12	Space Shuttle Program Change Board approves Safety Issue Briefing
11/13	KSC Instrumentation group wirelessly uploads WLEIDS flight instructions (like other WLEIDS sensors)
11/14	L-2 Review – final questions answered concerning safety of installation
11/16	Launch of STS-129

Left OMS/RCS Stinger Monitoring Location for STS-129





Part with highest concern
RCS Stinger Attach Fitting
(P/N 73A310072)