Wireless Sensor Architecture for Inflatable Spacecraft Health Management

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Richard Alena, Stephen Ellis, Jim Hieronymus, Dougal Maclise, Serdar Uckun

Code TI

Intelligent Systems Division

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Human Systems Division

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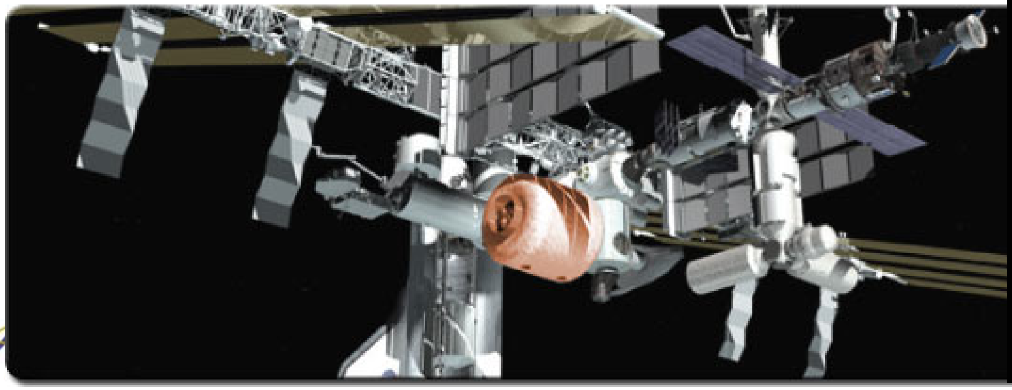
TransHab for ISS (1997-2000)

- Four levels
  - Pressurized tunnel
  - Crew health care
  - Crew quarters
  - Wardroom and galley
- Central core
  - Passageway
  - Mechanical support
  - Machinery



Bigelow Genesis I Space Station

- Used NASA TransHab concept
- Launched in June 2006
- Successful flight demonstration – see photo

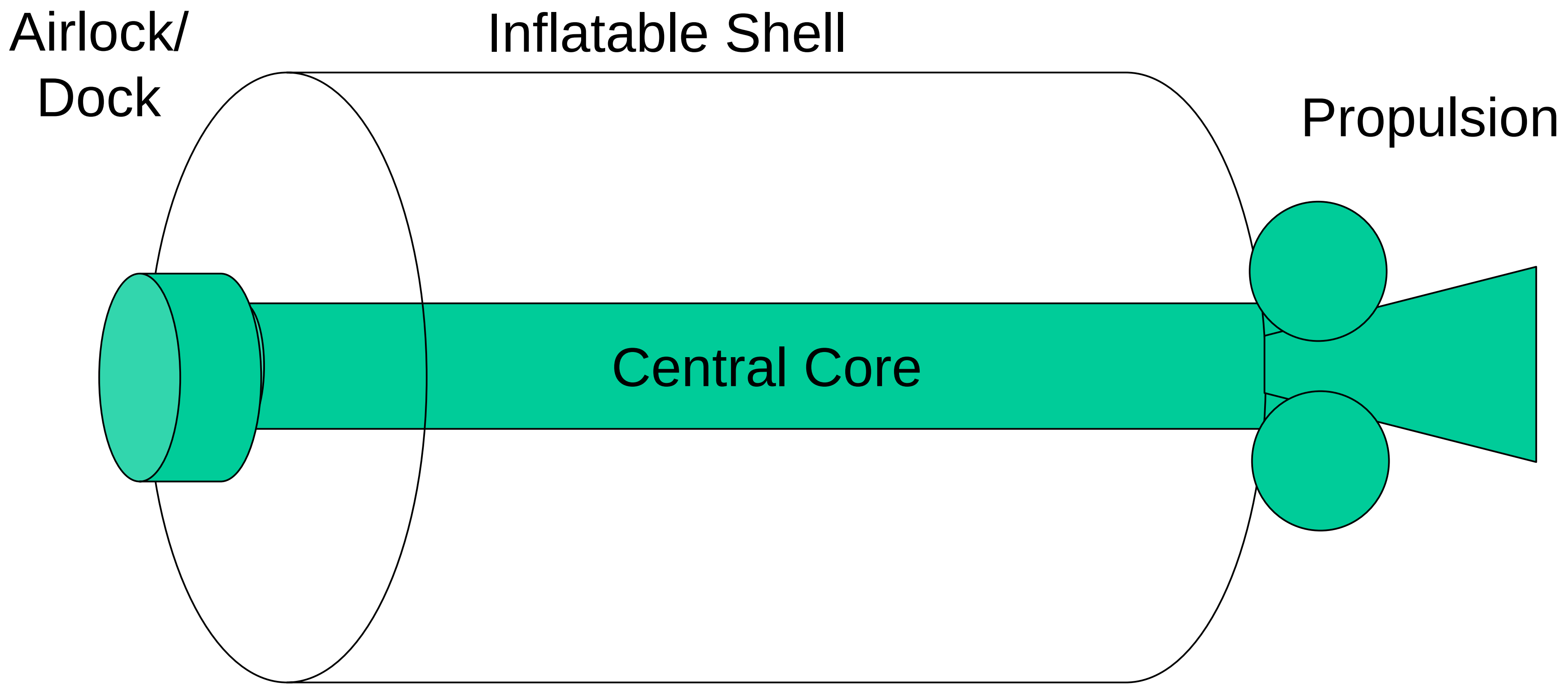
Inflatable Structures for Future Mars Transit Vehicles and Habitats

- Inflatable structures can provide superior capability and performance:
  - Increase usable volume
  - Decrease ascent mass and volume
  - Provide superior MMOD protection
  - (radiation protection is an open issue)
- Inflatable structures also require methods to:
  - Allow deployment of subsystems on flexible surfaces
  - Reduce wiring and cabling and piping
  - Provide effective feed through from interior to exterior
  - Monitor for damage or leakage
- Provide improved vehicle/habitat health management
  - Monitor health management of inflatable structure from stowage to full deployment
  - Develop sensors for multiple-layer inflatable structures

Inflatable Habitats, continued

- Use geodesic dome type construction
  - Minimize central core, maximize inflated volume
  - Provides strength and rigidity
  - Provides “channels” for power, data and thermal control
- Use central core for vehicle attachment, propulsion and machinery
  - Attachment, structural integrity and propulsion all require rigid backbone for major elements
  - Machinery requires proper mounting to absorb structural strain and vibration
  - Minimize central core mass, volume and functional dependencies
- Minimize spacecraft infrastructure requirements by using wireless
  - Wireless networks
  - Wireless power transmission
  - Wireless methods minimize deployment issues!
- Incorporate structural health monitoring into structure
  - Strain sensors, accelerometers
  - Thermal sensors, leak detectors

Conceptual Vehicle Physical Layout

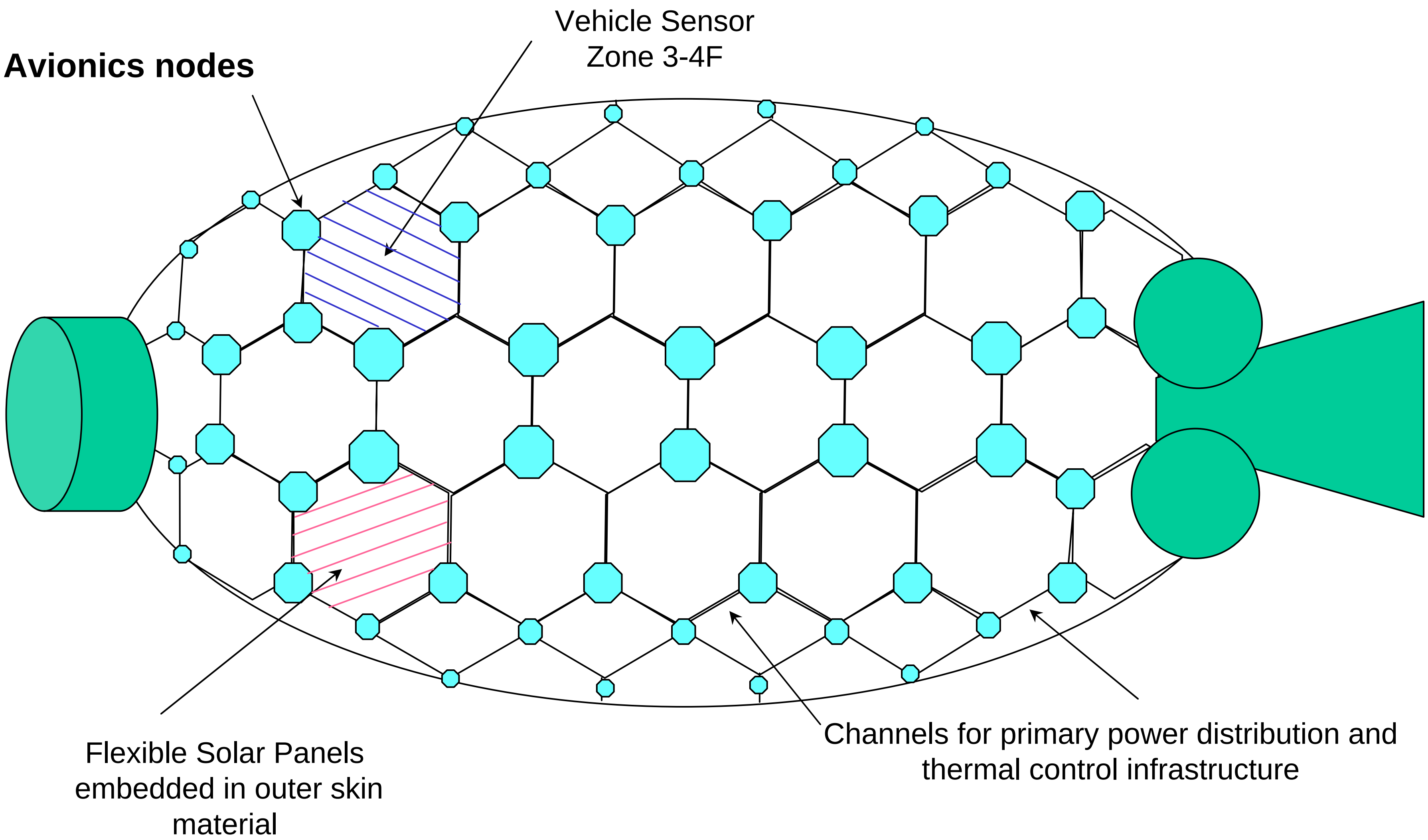


- Central Core is vehicle structural backbone housing all mechanical assemblies
- Other components are distributed within inflatable volume or on inflatable fabric

Health Management Challenge

- Develop advanced technology for inflatable spacecraft for flight in 5-10 year time frame
- Integrate advanced structural concepts with innovative distributed modular sensing and subsystems technology
  - Identify appropriate sensors for chosen inflatable fabric technology
  - Develop embedded sensors for inflatable structures
  - Improve wireless methods for reading embedded sensors
  - Provide simple sensor power distribution
  - Minimize spacecraft systems power consumption
- Anticipate future computer and avionics developments
  - Wireless sensor data communications with bounded time latency
  - Advances in wireless networking protocols (e.g., ad-hoc networking)
  - Robust collaborative computational systems
  - High performance and low power consumption
  - Low mass and small package for sensors and avionics

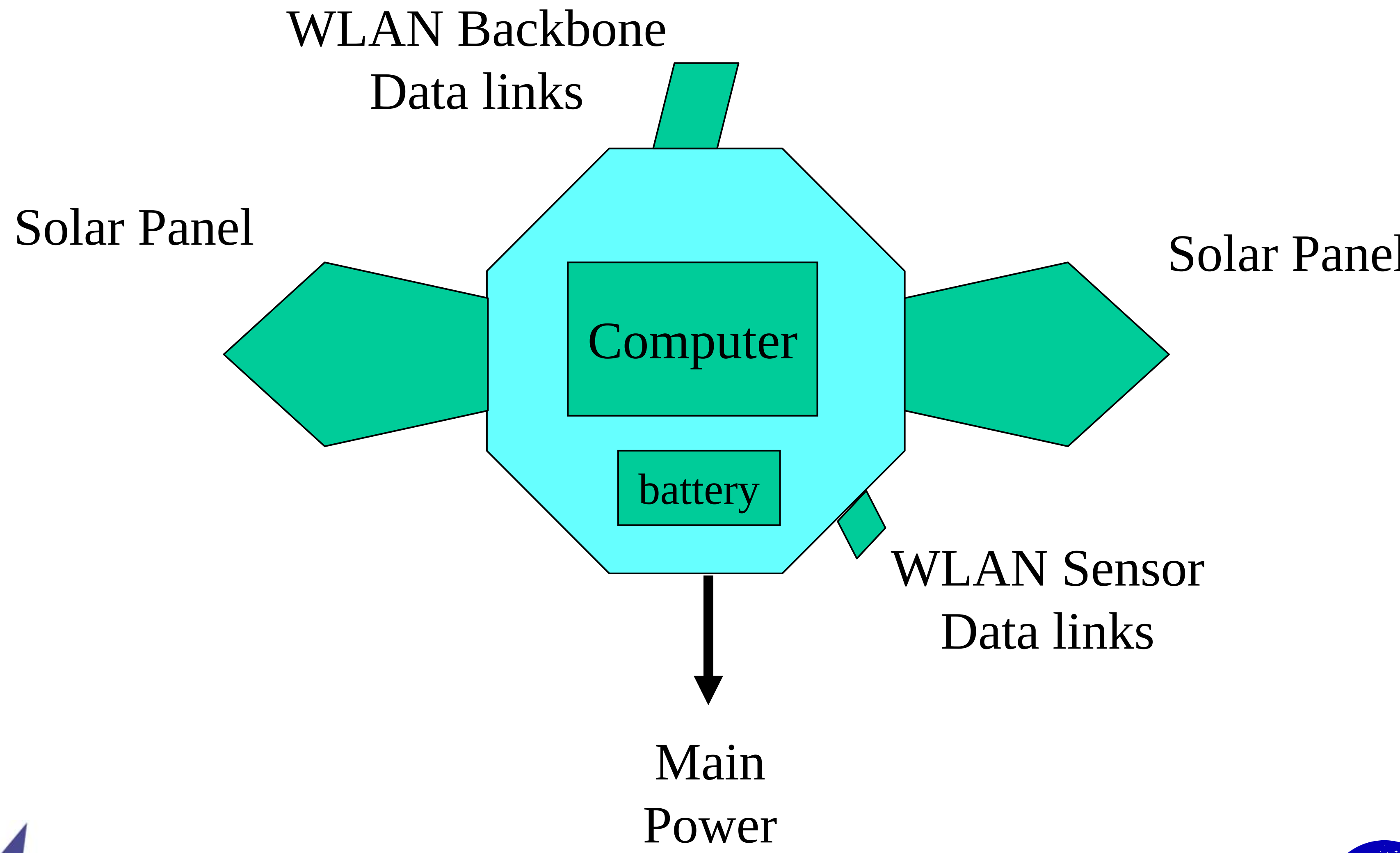
Mars Transit Vehicle Avionics Concept



Sensors for Inflatable Habitat Health Monitoring

- Internal pressure sensors
- Temperature sensors
- Strain gauges
- Accelerometers for deployment and impact monitoring
- Impedance monitoring for multi-layer fabric
- Acoustic Emission or Ultrasonic leak detection

Avionics Node Diagram



Avionics Node Functions

- Management of distributed solar panels providing primary power to spacecraft
- Network management and distribution - wired and wireless
  - WLAN hub for multiple wireless sensor associated with vehicle zone management
  - Mesh WLAN between avionics nodes
- Computing power for fault-tolerant Integrated Modular Avionics (IMA)
  - Based on ARINC 653 IMA Standard
  - Highly-redundant computing for vehicle and mission management
  - Use central fault-tolerant actuator modules for critical functions

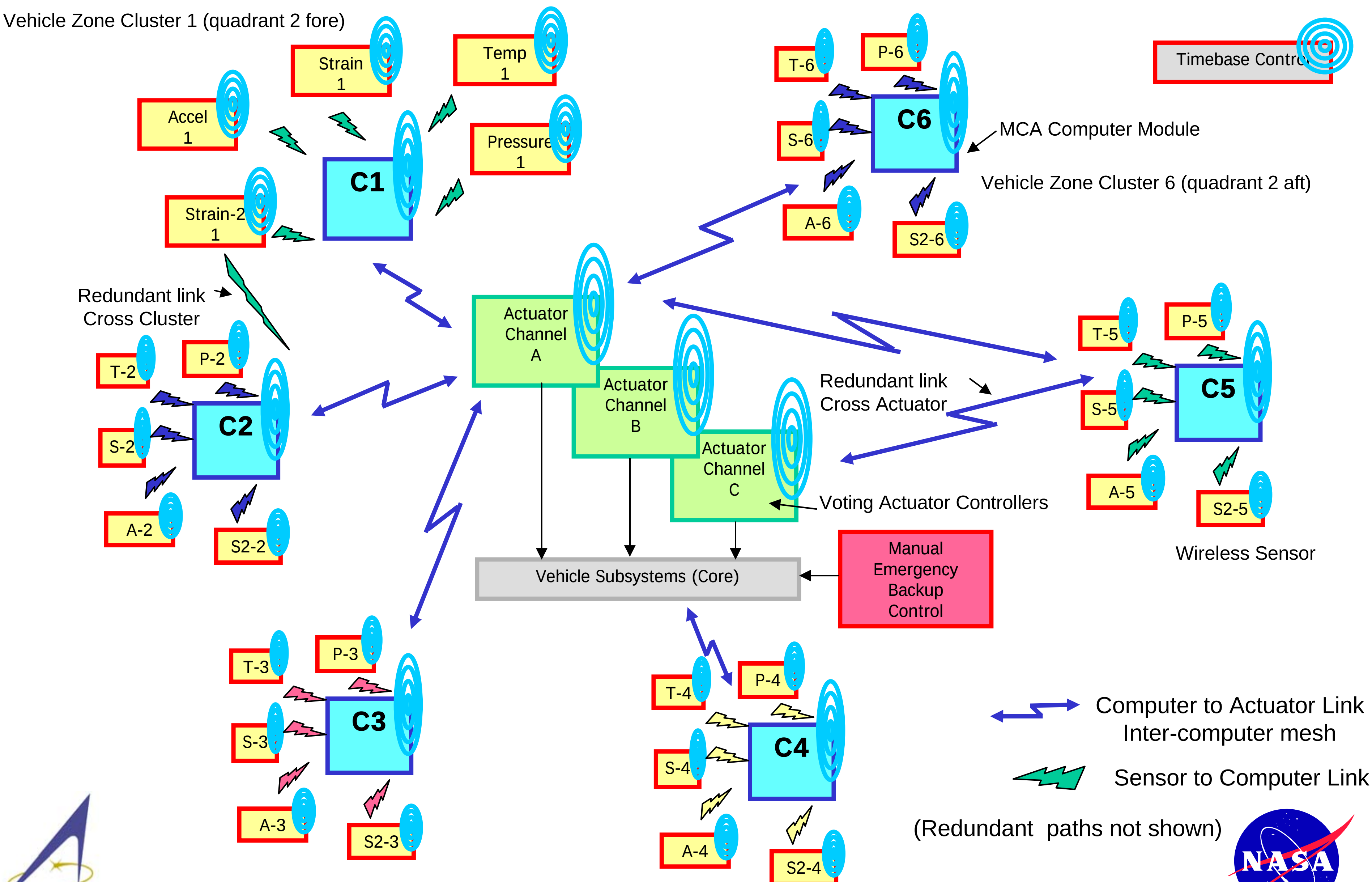
Heterogeneous Wireless Networks

- Baseline command and control RF network
  - Low bandwidth (Mbps) but high availability
- Optical utility network
  - Provides reliability against EM disruption
  - Requires direct line-of-sight
  - Backup for RF networks
- Wireless high-speed RF network
  - General computing and instrument support
  - Backup for baseline C&C network
- Supplementary short-distance wireless links
  - Support embedded sensors
  - Minimize sensor data communications hardware and overhead
- Wireless links cannot interfere with each other
  - Different frequencies and modulation
- WLAN requires bounded latency
  - Currently not supported by standards

Modular Collaborative Avionics (MCA)

- Many nodes provide time synchronous commands to smart controllers and actuators
- Plurality-based voting by smart controllers provides high confidence margin
- System relies on computation and mesh data communication performance that are orders of magnitude beyond that required for spacecraft control
  - Allows implementation of complex time synchronization and critical decision-making algorithms
  - Allows facile reconfiguration for fault tolerance
- Nodes reconfigure their functions based on required operations, current status and sensor data availability
  - Use IMA partitions to host rapidly-reconfigurable software processes
  - IMA's temporal and spatial partitioning of processes is key

MCA Architecture – Structural Health Example



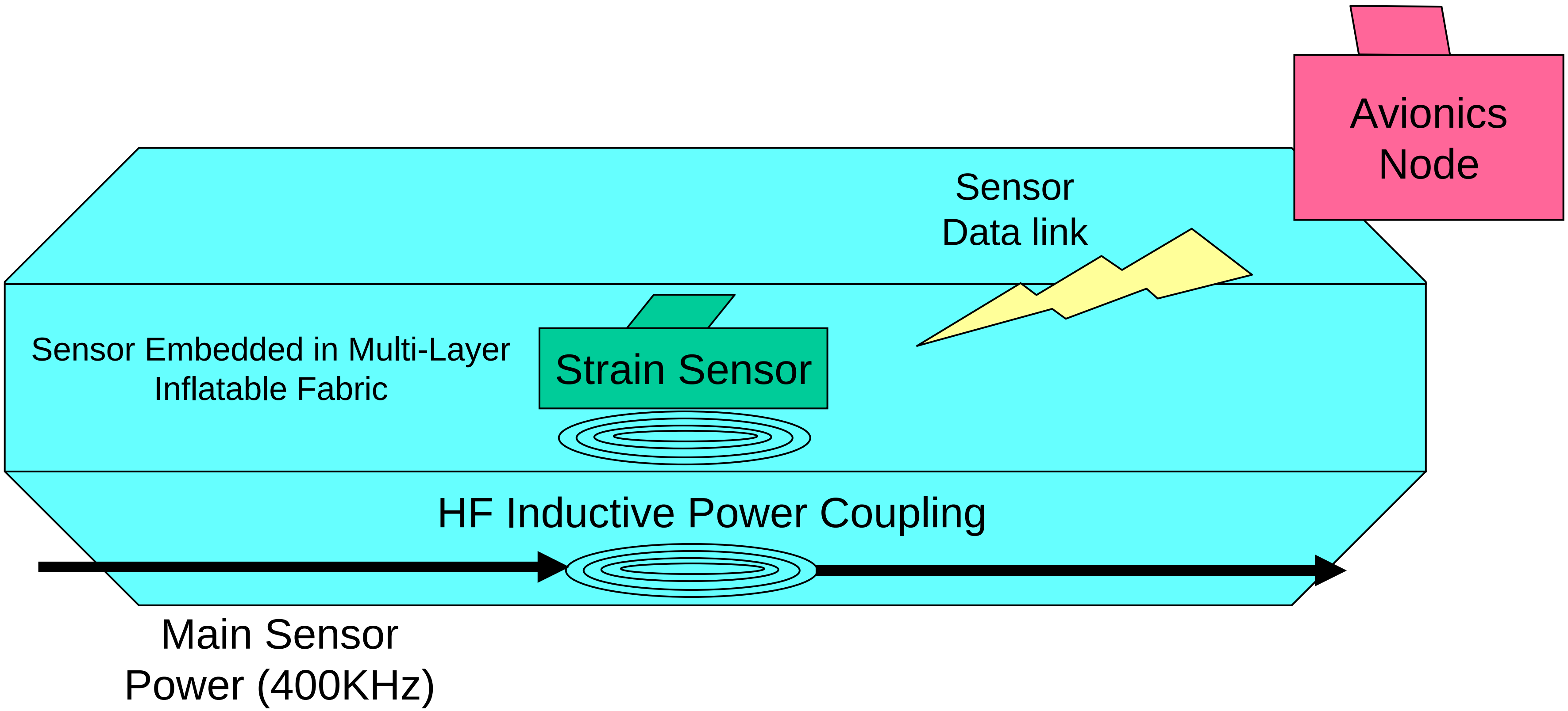
MCA Design Challenges

- Integration of multiple functions in cost-effective and mass/volume/power-effective way
- Optimization of functional complement
  - Homogeneous vs heterogeneous modules
  - Handover or integration of operational functions
- Radiation and environmental tolerance
- Design of power distribution methods
  - Cable plant
  - Wireless backup methods (inductive, optical, RF etc.)
- Integration of multiple RF systems
- Algorithms for collaborative control

Power Generation and Transmission

- Flexible embedded solar panels on exterior
  - If sufficient area is covered, then no need for pointing
  - Must develop very light-weight, thin, low-cost flexible solar cells
- Baseline cables, with backup batteries for reliability
- Magnetic inductive power transmission for sensors and other low-power loads
- Use high-frequency switching power supply technology to provide “through the fabric” power transmission.
  - Eliminates all physical feedthroughs which compromises reliability
  - Can be highly-efficient and part of avionics nodes

Wireless Structural Sensor Diagram



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General Recommendations

- Inflatable spacecraft provide many advantages but will require development of innovative sensing, data and power transmission and deployment technologies.
- Modular avionics can significantly aid the development of inflatable spacecraft systems
  - Can be active and move with fabric during stowage, deployment and operational phases
  - Provides distribution for power, data sensing and control, which follows the deployment profile
  - Allows other innovations in collaborative computing function
- Wireless sensors enable effective inflatable health monitoring
  - Power provided via inductive coupling - no feed throughs
  - Data provided via multiple wireless connections allowing connection to multiple avionics nodes
    - Provides high degree of connection reliability
  - System can reconfigure dynamically for load balancing and fault tolerance