NASA Avionics Architectures for Exploration (AAE) and Fault Tolerant Computing

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Outline

- **Overview of JSC Avionic Systems Division's technology development efforts and their relationship to the NASA Avionics Steering Committee Technology Roadmap**
- **Summary of Avionic Architectures for Exploration (AAE) efforts to date**
- **Future goals and opportunities**
- **Change title, add words reflecting those I sent to Mitch**
  – This presentation will focus on the AAE project, led by Johnson Space Center, and the potential for using it to infuse Fault Tolerant Computing into future Human Spaceflight missions. Other JSC Avionics Technology efforts and their relationship with NASA's Avionics Steering Committee Technology Roadmap will also be described.

The Challenge of Expectations: An Analogy

- **You have just bought a beautiful home in a remote location with a million-dollar view**
- **It's been outfitted with a home office, so you can telework to make the payments**

For the money spent, you expect this:

But you get this:

Computing Power

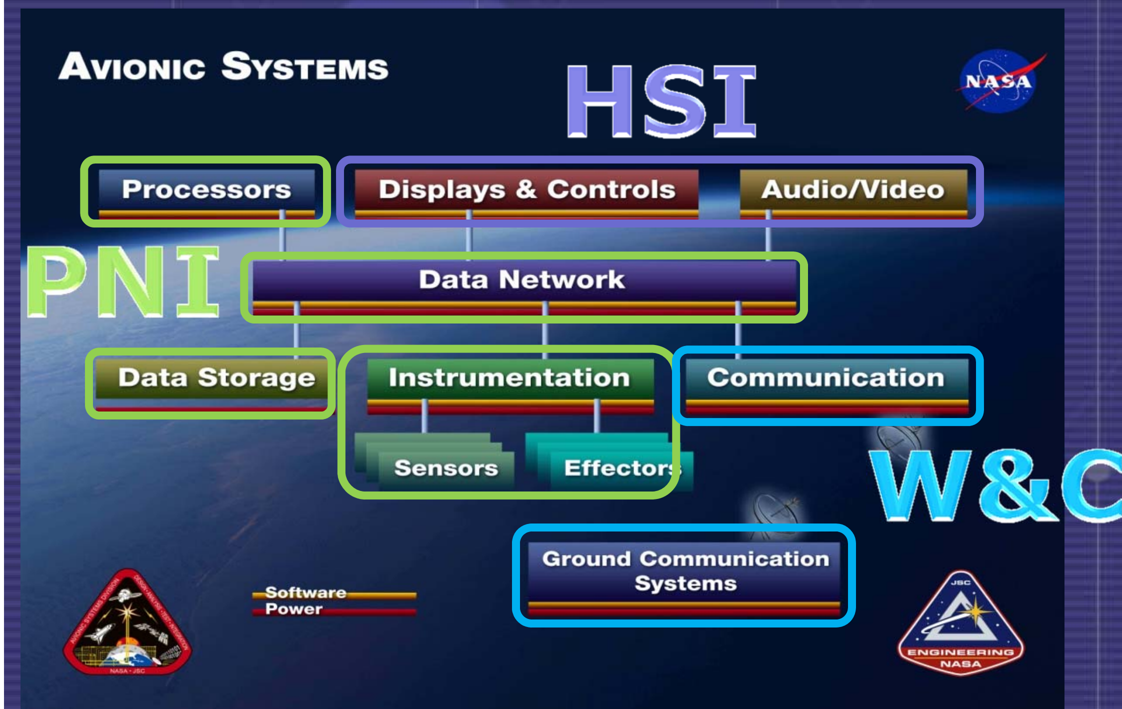
Communications

Data Transfer

Situational Awareness & Entertainment

This is the situation we face today with Avionics beyond LOE

Avionic System Division (ASD)



Other Division Functions:

- Antennas and Wireless Systems; RFID Technology
- Electronic Design and Manufacturing
- Systems Engineering and Integration /Test
- Spacecraft Avionic System and Subsystem Management
- Project Management of in-house flight avionics (GFE, PL, AES)

Rad & EEE Parts

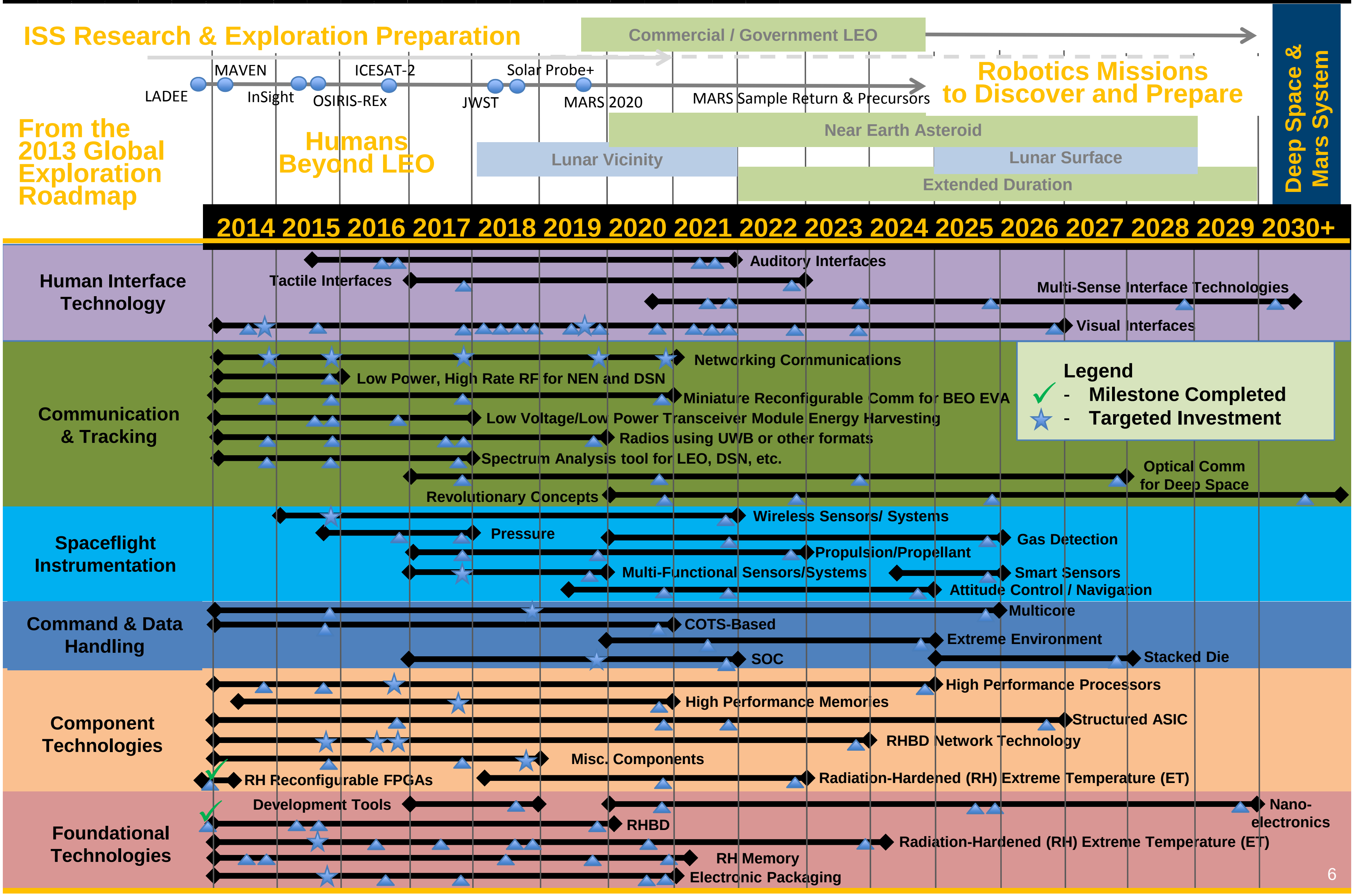
Challenges:

- As NASA missions move farther from Earth and become increasingly more complex, new challenges arise.
- Long-duration crewed missions as well as space-based observatories and solar system tours will require sophisticated reliability and fault tolerance.
- Communication delays and challenging orbital dynamics of NEA and extreme science missions require increased autonomy and on-board decision infrastructure.
- Traditional solutions to reliability and autonomy increase processing demands and redundancy which in turn drives system mass and power.
- Future exploration vehicles are likely to be an aggregate of multiple vehicles from multiple sources. We cannot expect every module of an aggregate vehicle to be the same. This will drive standards, sparing, redundancy, etc.

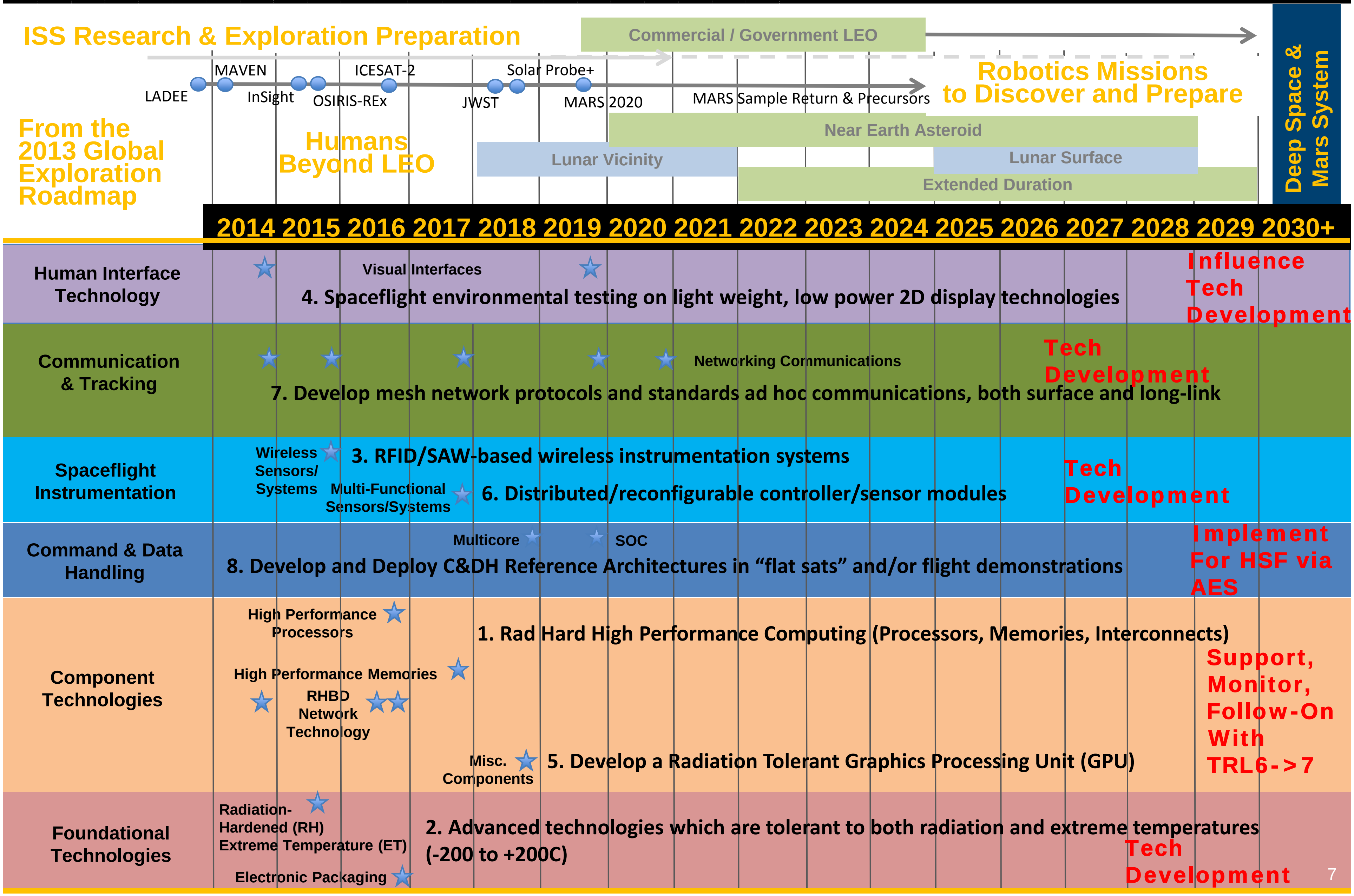
ASD Technology Development Guidelines

- **Improve functionality, reliability, fault tolerance, and autonomy - while reducing size, weight, and power (SWAP) of Avionics.**
- **Leverage terrestrial commercial capabilities to drive down development and sustaining costs.**
- **Stay in sync with Agency efforts (OCT, ASC Road-mapping)**
- **Focus on transition step to make things ready for HSF (TRL-6 to 7)**
  - Use AAE, IPAS, and F.F. to evaluate new technologies, compare them in an objective manner, and mature them to be available for future programs.
- **Use improved avionics to drive down overall vehicle costs, SWAP.**
  - Push towards "Fly-by-Wireless"
  - Give the crew the kind of capabilities they need and want for exploration
  - Enable HSF to benefit from next-generation Rad Hard Avionics (Multicore, SOC)

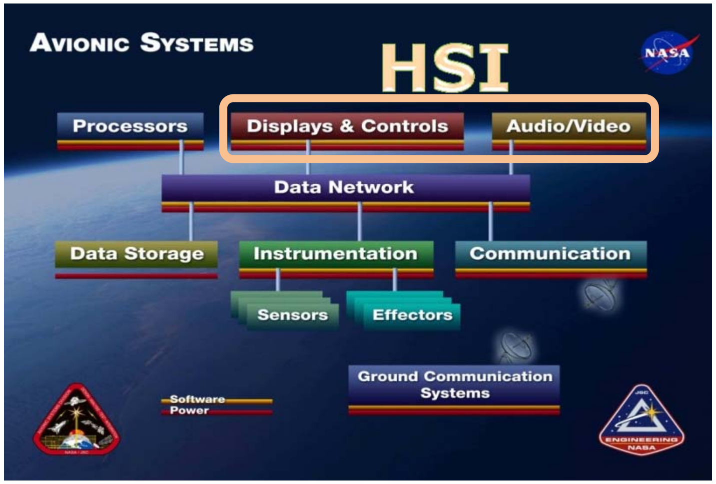
ASC Technology Roadmap – Overview



ASC Technology Roadmap – Key Investment Timeline



Avionics: Human Systems Interfaces



6.1 – Human System Interfaces: Develop prototypes of next generation human system interfaces which can be used to improve ISS crew tasking, reduce Orion costs and SWAP, and support future exploration missions.

- By 2021, Demonstrate prototyped lightweight/low power/radiation tolerant displays using Organic Light Emitting Diode (OLED) technology with software-emulated GPUs (Orion cost reduction of X, mass reduction of X)
- By 2022, Demonstrate the use of advanced commercially available Image acquisition, processing, and distribution techniques, and Audio hardware and speech/voice/text algorithms (Orion mass reduction of X).
- By 2020, Demonstrate onboard ISS wearable sensing and hands-free control (Reduce crew tasking by X%, potentially reduce Avionics mass by X%)

Key Challenges

- Changing expectations set by terrestrial experience
- Increasingly complex automation and crew interfaces as we move beyond Low Earth Orbit.
- Need/desire multimodal human interfaces for efficient and natural integrated vehicle and telerobotic operations
- Requirements change/growth over a long lifetime with multiple missions

Guidelines

- Keep the architecture and design modular so we can launch interface capabilities incrementally (when needed or earlier).
- Strive for "Commonality". Standardize Human Interfaces which translate well between dissimilar modules of an aggregate vehicle.
- Strive for "Mobility". Flexible interface platforms that are body-based or "peel & stick"

Applicable ASC Roadmap Recommendations (EV Role):

4. Conduct early spaceflight environmental testing on new light weight, low power 2D display technologies in order to influence commercial display manufacturing lines toward greater suitability for spaceflight [Ref H08, H25] (Influence Technology Development)
5. Develop a Radiation Tolerant Graphics Processing Unit (GPU) for use as the primary interface between crew and spacecraft data [Ref C13] (Support, Monitor, Follow-On with TRL6→7)

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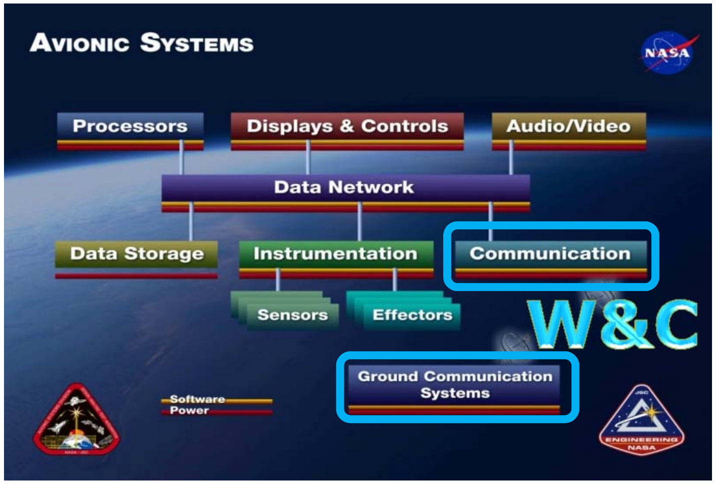
Avionics: Wireless and Communications Systems



Other Division Functions:

- **Antennas and Wireless Systems; RFID Technology**

6.2 – Wireless and Communications Systems: Enhance HSF communications systems to reduce operations costs and improve crew efficiency.

- By 2018, Use RFID/ALM to reduce crew time requirement for onboard inventory and management by ~75% and ground support by ~50%
- By 2019, Use wireless networks and wireless sensor networks and RFID-based sensing to reduce Avionics Mass by X%.
- By 2017, Increase data return efficiency by ~50% and reduce ground-based scheduling ~50% by automating data transmissions through a DTN protocol suite that enable reliable internetworking services in the presence of communication delays and disruptions.
- By 2019, Increase data throughput by a factor of ~2 and improve network reliability by a factor of ~1.5 for proximity and surface communications by developing mesh networking protocols and standards for space applications.

Key Challenges

- Increasingly complex vehicles and mission profiles will drive the need for more communications bandwidth – Uplink, Downlink, "Intra-Space"
- Complex mission profiles will result in intermittent communications windows over vast distances
- Aggregate vehicles will necessitate robust communications standards

Guidelines

- Use wireless technology to drive down vehicle SWAP, improve situational awareness and operations, minimize logistics and maintenance, and provide instrumentation to better test and characterize the structure/environment
- Use innovative communications approaches (e.g., ad hoc comm) to drive down vehicle & operations costs

Applicable ASC Roadmap Recommendations (EV Role):

3. Develop RFID/SAW-based wireless instrumentation systems to reduce weight of spacecraft cabling infrastructure and increase reliability & accessibility of sensors [Ref I06] (Technology Development)
6. Develop distributed/reconfigurable controller/sensor modules in spacecraft to reduce weight and increase reliability while also lowering non-recurring development costs [Ref I08] (Technology Development)
7. Develop mesh network protocols and standards for use in: space-to-space long-link systems with extreme propagation delays and outages; surface wireless systems with proximity-based quality of service and information assurance capabilities; and ad-hoc networking that can provide reliable end-to-end communications without carefully planned and scheduled link operations [Ref CT01, CT02, CT03, CT04, CT05] (Technology Development)

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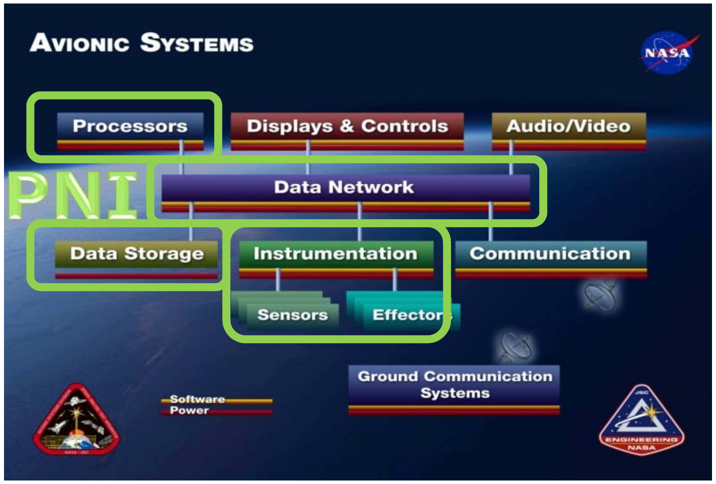


<u>6.3 – Processors, Networks and Instrumentation:</u> Provide a set of radiation-tolerant, reduced SWAP C&DH systems which are capable of supporting processing and throughput equivalent to today's terrestrial state of the art.

- By 2021, Demonstrate in AAE radiation hardened/tolerant, reduced SWAP flight computers capable of running sophisticated algorithms for augmented reality and expert systems to support crew operations
- By 2021, Demonstrate in AAE reduced SWAP, Radiation Tolerant Networks with dynamic network architectures, capable of supporting large data through-put with both deterministic and non-deterministic protocols, and having both wired and wireless components
- By 2021, Develop/Demonstrate Instrumentation systems [in a variety of environments] which are modular, scalable, and reconfigurable for both flight and prototype applications, reducing instrumentation costs by X%.

<u>Key Challenges</u>

- Enhancements are needed in processor performance, increased bandwidth, reduced SWAP, improved "-ilities", etc. to support changing expectations set by terrestrial experience
- Need lightweight robust real time operating systems and middleware.
- Development of scalable architectures to accommodate dynamic system needs.

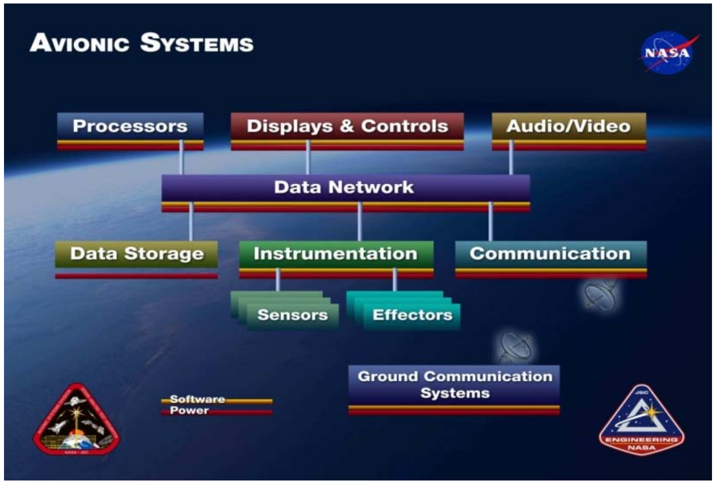
<u>Guidelines</u>

- Maximize the use of Core Flight Software (CFS) to maximize our ability to leverage platforms, resources, and skills.
- Keep the architecture and design modular. Make it scalable and tailor-able to specific missions.
- Strive for "Commonality". Standardize Computer Interfaces between dissimilar modules of an aggregate vehicle. Standardize busses and networks to enable minimal sparing
- Provide Instrumentation to better test and characterize the structure/environment

<u>Applicable ASC Roadmap Recommendations</u> (EV Role):

1. Continue our investments in High Performance Computing, to provide direct dramatic improvements in flight functions and capabilities across the NASA mission classes, to enable new flight capabilities and mission scenarios, and to thus increase science and exploration return, while addressing the unique requirements and architectural features consistent with the energy efficiency and fault tolerance challenges of beyond-LEO, Earth-observing, and human spaceflight missions (Support, Monitor, Follow-On with TRL6→7)
   - Rad Hard Multicore Processor [Ref C01]
   - Rad Hard High Capacity Memories – Volatile and Non [Ref C04]
   - Rad Hard High Speed Interconnect – multi mode (copper, fiber, wireless) [Ref C08, C09, C10]
5. Develop a Radiation Tolerant Graphics Processing Unit (GPU) for use as the primary interface between crew and spacecraft data [Ref C13] (Support, Monitor, Follow-On with TRL6→7)
6. Develop distributed/reconfigurable controller/sensor modules in spacecraft to reduce weight and increase reliability while also lowering non-recurring development costs [Ref I08] (Technology Development)
8. Develop a C&DH Reference Architecture which employs advances in Rad Hard High Performance Computing and Extreme Environment Electronics and deploy it in NASA "flat sats" and a flight demonstration project [Ref CD01, CD04] (Implement for HSF via AES)

Avionics: Radiation and EEE Parts



Other Division Functions:

- **Electronic Design and Manufacturing**

Rad & EEE Parts

<u>6.4 – Radiation and EEE Parts:</u> Reduce the overall cost of electronics parts and improve performance by using a combination of new test, analysis, and manufacturing techniques combined with enhanced shielding.

- By 2018, Reduce the cost of deep space radiation testing of complex parts X% by using Variable Depth Bragg Peak (VDBP) techniques to rapidly screen parts for destructive errors.
- By 2020, Reduce the cost of electronics parts X% by expanding manufacturing techniques to allow the use of state of the art electronic components in critical HSF applications.
- By 2017, Employ the Badhwar-O'Neill Galactic Cosmic Ray (GCR) radiation model to better analyze GCR effects in deep space on both crew and avionics, reducing the cost of testing required to find and certify parts by X%.

<u>Key Challenges</u>

- Radiation Hardened Avionics must be provided which will meet changing expectations set by terrestrial experience, and requirements change/growth over a long lifetime with multiple missions
- Processing requirements already exceed that which can be provided by existing Space Hardened Avionics (e.g., Power PC-based Rad750)
- Because of the radiation environment, we cannot rely on COTS hardware for additional processing capabilities as we have done on Shuttle and ISS (i.e., laptops aren't likely to work reliably beyond LEO)

<u>Guidelines</u>

- Ensure new components & systems will function in space environments (LEO and beyond). Develop more sophisticated radiation models to ensure optimal performance in the harsher radiation environment of HEO and deep space.

<u>Applicable ASC Roadmap Recommendations</u> (EV Role):

2. Work in conjunction with the NASA Electronic Packaging Program (NEPP) to provide for advanced packaging technologies to support analog and digital electronics which are tolerant to both radiation and extreme temperatures (-200 to +200C) [Ref F04, F14] (Technology Development)

AAE Overview

- **The Avionics Architectures for Exploration (AAE) project is chartered by NASA's Advanced Exploration Systems (AES) Program**
  - Evaluate new avionic architectures and technologies
  - Provide objective comparisons of them
  - Mature selected technologies for flight and for use by other AES projects.
- **The AAE project team includes members from most NASA centers, and from industry.**
- **For JSC's Avionic Systems Division, AAE provides a mechanism to achieve technology goals**

AAE Goals for 2013

- **Demonstrate a plausible avionics architecture for a notional space station located at the 2nd Earth-Moon Lagrange point (hereafter referred to as an "L2 Station").**
  - Provide a reasonable set of capabilities using avionics hardware that was either flight ready, or that could be made flight ready within 2 to 3 years.
- **Provide a flexible avionics architecture that can be used to evaluate future concepts/architectures/components for both an L2 Station and other vehicles/mission profiles.**
  - Accommodate equipment from multiple vendors
  - Leverage both re-use and new technologies
    - "Legacy" systems (e.g., MIL-STD-1553B)
    - NASA's Office of Chief Technologist (OCT) Roadmap
    - Avionics Steering Committee (ASC) Roadmap
    - Space Communications and Navigation (SCaN) Roadmap

AAE High-Level Challenges

- **Future exploration vehicles are undefined, but are likely to be an aggregate of multiple vehicles from multiple sources. This will drive sparing, redundancy, etc.**
- **Processing requirements exceed that which can be provided by existing Space Hardened Avionics (e.g., Power PC-based Rad750)**
- **The Radiation Environment at HEO and beyond is much worse than it is at LEO (the environment with which HSF has the most operational experience).**
- **Because of the radiation environment, we cannot rely on COTS hardware for additional processing capabilities as we have done on Shuttle and ISS (i.e., laptops aren't likely to work reliably)**
- **Exploration vehicle requirements will change/grow over the vehicle's lifetime, as will the expectations set by Terrestrial State-of-the-Art. We need to accommodate these changes without undue expense.**

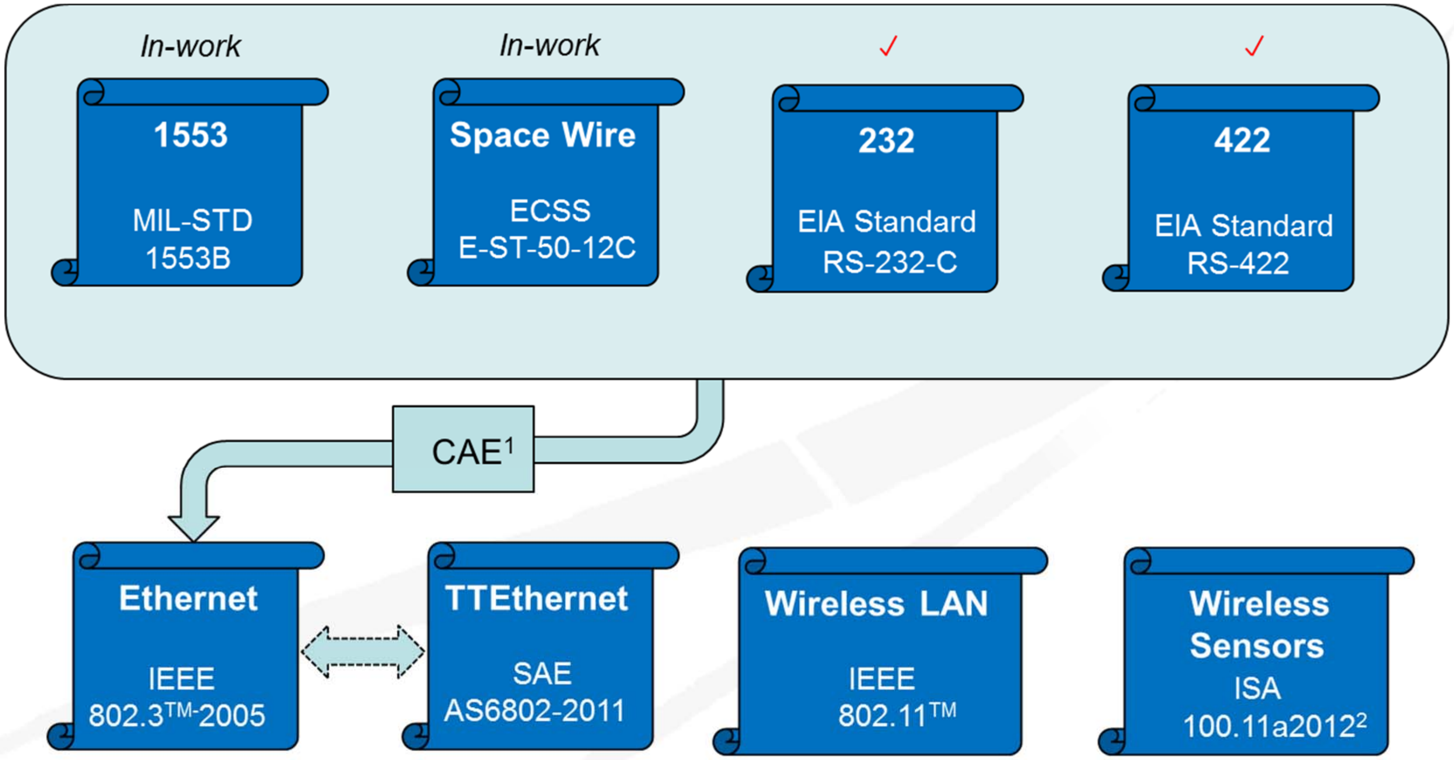
AAE High-Level Guidelines

- Minimize Avionics SWAP in the Flight Vehicle.
- Keep the architecture and design modular, scalable, and tailor-able.

- Minimize Cost.
- Minimize Risk.
- Minimize logistics and maintenance.
- Support Heterogeneity.
- Strive for “Commonality”.

- **Provide Ethernet on the vehicle for crew support.**
- **Maximize the use of Core Flight Software (CFS).**
- **Use the Integrated Power Avionics and Software Lab (IPAS) and Flight Deck of the Future (F.F).**

AAE Interface Standards and Specifications



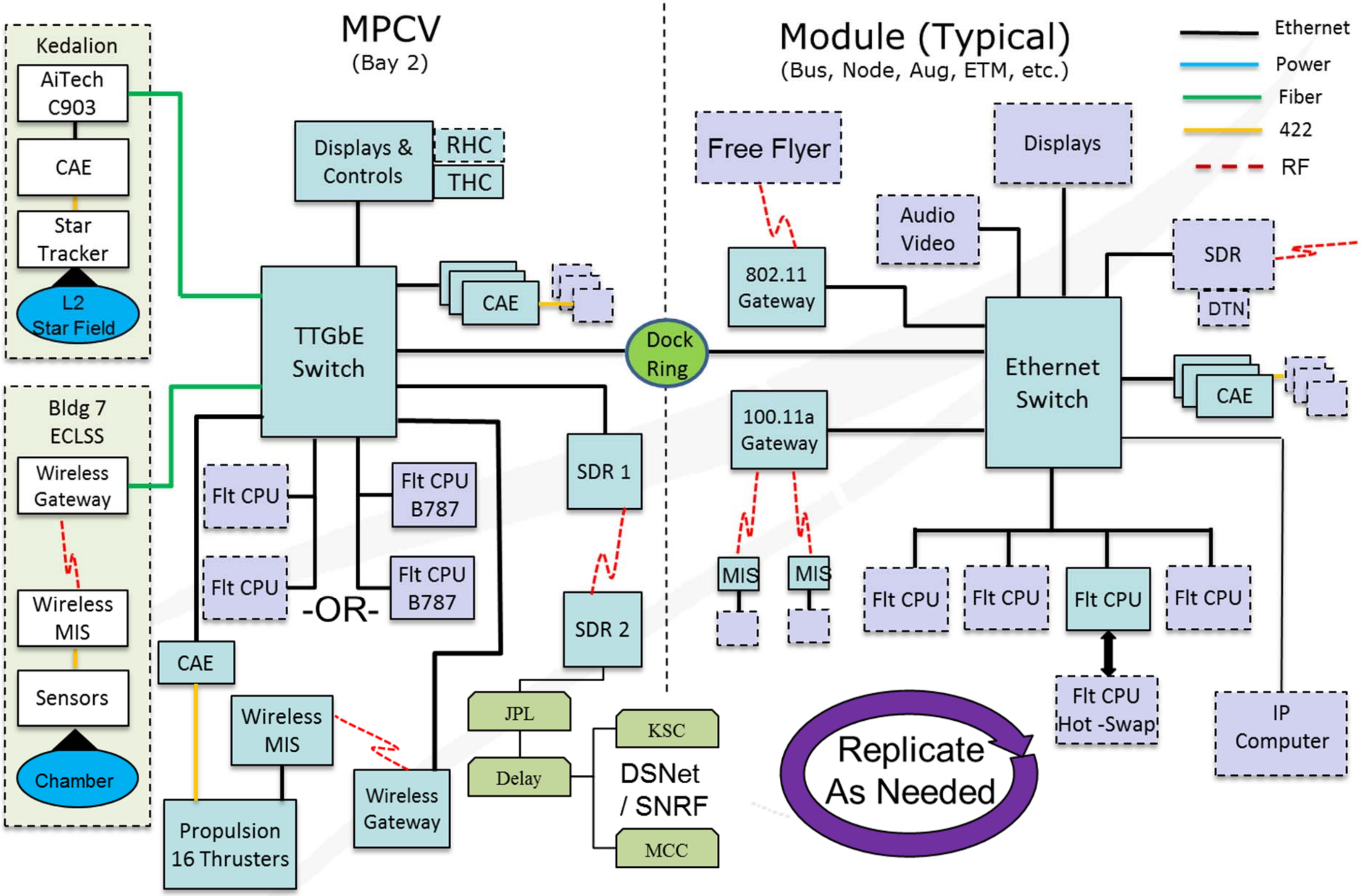
[1] Common Avionics Enabler (Bus converter)

[2] International Society of Automation (ISA) standard for wireless industrial process control and automation.

Selected Accomplishments

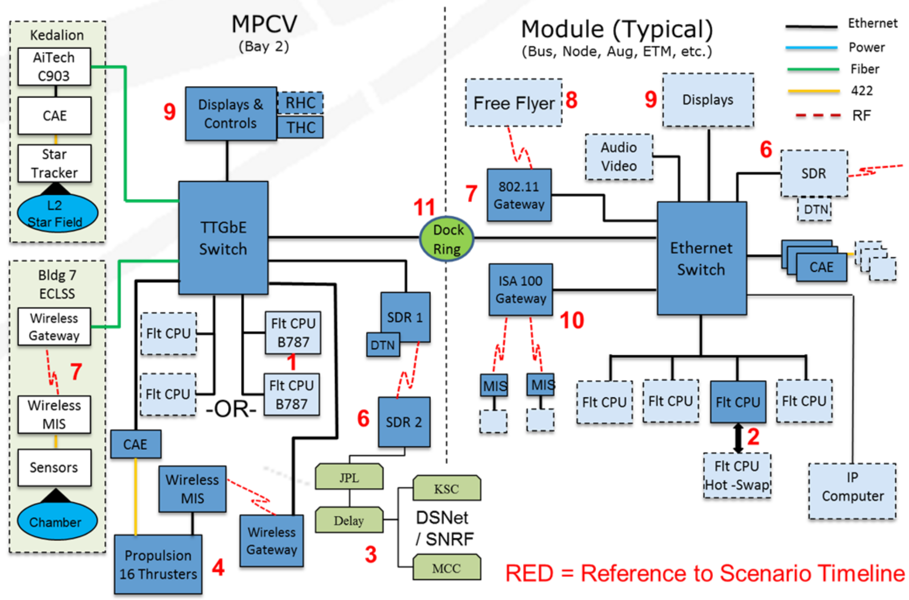
- **Human Interfaces**
  - Initial implementation of a Software GPU on a C903
  - Active Matrix Organic Light Emitting Diode (AMOLED) display evaluation
    - Partnered with Honeywell
    - EMI, Thermal/Vac, Radiation testing
    - Report available at http//ntrs.nasa.gov -- Search for “AMOLEDS”
- **Processors, Networks, and Instrumentation (PNI)**
  - Use of Dissimilar CPUs / OS’s From Multiple Vendors
- **Wireless Sensor Network (WSN)**
  - Evaluated RFID for both Asset Tracking and Remote Sensing
- **Communications Architecture and Disruption Tolerant Networking (DTN)**
  - AAE personnel worked with Representatives from SCAN, AES, MOD, and multiple NASA Centers to baseline a Beyond Earth Orbit Human Exploration Communication Architecture for FY13
  - Demonstrated DTN (using Bundle Protocol and Licklider Transmission Protocol via an external router)
- **Initiated us of Model-Based System Engineering (MBSE)**

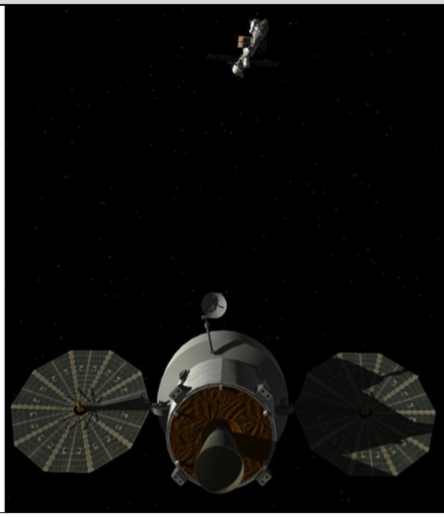
Resultant AAE Rev 2.0 Core Architecture

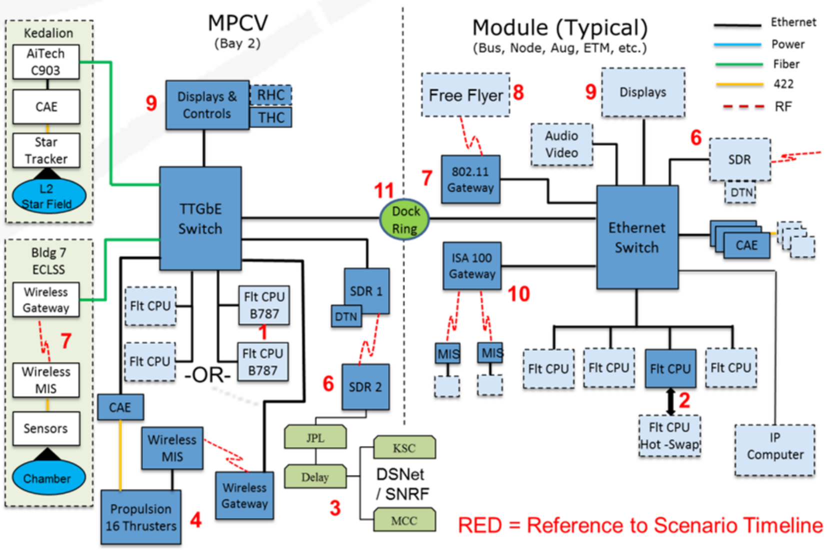


Integrated Test #3 Mission Scenario (1 of 3)

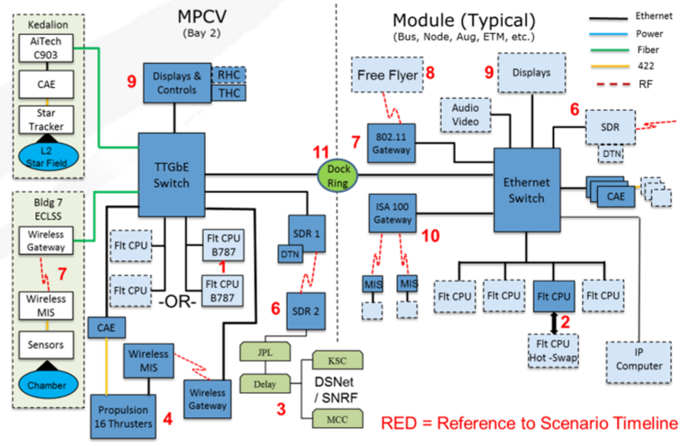
Phase A: Orion Launch to 2000m Separation between MPCV and L2 Station		Ref #
	"Pre-Flight": Simulation places MPCV 2000m from L2 Vehicle and give JSC MCC vehicle control	
	KSC LCC has vehicle control and powers up vehicle, JSC MCC monitors vehicle	3



Phase B: Rendezvous & Docking, 2000m to 300m between MPCV and L2 Station		Ref #
	Demonstrate MPCV power system	4
	Demonstrate MPCV propulsion with power and wireless pressure sensor telemetry	4
	Fail and Hot swap primary flight computers	2
	Space-to-Ground Communications Demo	
	Command MPCV ECLSS fan "on" from MCC through JPL with DTN	3
	Display MPCV telemetry on MCC display	3
	Display MPCV video in MCC	3
	Command MPCV ECLSS fan "on" from MCC through SDR with DTN and communications LOS	6



Phase C: Rendezvous & Docking, 300m to 0m between MPCV and L2 Station	Ref #
Range: 300m – 10m	
Observe L2 Vehicle low cabin pressure on MPCV display through 802.11 proximity communications link	**7**
Send Free Flyer from MPCV to L2 Vehicle to investigate prior to docking	
Navigate Free Flyer to L2 Vehicle via 802.11 network	**7**
Stream video from Free Flyer to MPCV over 802.11 link and to MCC via SDR	**8**
Demonstrate RFID interrogation of autonomous sensor node and passive tags	**8**
Demonstrate 3D position tracking with Ultra Wide Band wireless system	**9**
Demonstrate wireless monitoring of solar panel perturbations from propulsion jet plumes	**10**
Range: 10m – 0m	
Manual docking of MPCV to L2 vehicle	
Use MPCV cockpit to fly vehicle and dock	**9**
Demonstrate MPCV displays	**9**
Automatically establish wired networking between vehicles after docking	**11**



Integrated Test #3, Summary Results

System	Objective	Summary Status
Vehicle	Dock MPCV to Waypoint at L2	Complete.
	Route data between vehicles using wireless and hardline connections	Complete.
	Display spacecraft status on other spacecraft during rendezvous	Complete.
C&DH	Hot swap dissimilar flight computer during rendezvous	
	Network load balancer	Complete. Used SNMP command to switch for implementation
	Port mirror/SNMP heartbeat	Deferred to FY14. Resource issue.
	Use Maxwell CPU in DSH	Deferred to FY14. Awaiting new chassis.
	Provide local boot capability for all flight computers	Complete.
	Network Appliances	
	Use Raspberry Pi appliance as network monitor	Complete.
	Use Raspberry Pi to develop network map	Deferred to FY14. Resource issue.
	Fly MPCV with Honeywell FMC	Complete. GN&C software running with flight dynamics sim and can fire jets.
Networks	Use routers to dock vehicles	Complete.
	Automatically route spacecraft data across wireless during prox ops and hardline once docked	Complete.
	Use TT-E protocol for Honeywell FMCs	Deferred to FY14. Resource issue.
	Route DSH data to L2	Tested. Not fully implemented due to limited resources
Human Interfaces	Displays	
	MPCV ECLSS	Good data from B7 chamber and with ECLSS sim, still integrating MIS data to display
	MPCV thrusters (pwr & MIS)	Lingering issues with display of MIS data
	MPCV TRAJ display (improvements)	Complete.
	L2 power (DSH/AMPS)	Complete except for crew display
	L2 ECLSS (from sim)	Complete.
	MPCV out-the-window view	Complete.
	MPCV centerline camera view	Complete.
	"God's eye" camera view	Complete.
	Manual docking from F.F with displays and THC	Complete.
	Complete AMOLED testing	Complete.
	Test sGPU	Complete. Preliminary tests show improvement when running on C925 vs. C903.
	Telepresence comparison	Complete.

System	Objective	Summary Status
Wireless Systems	Complete CFS ISA 100.11a gateway	Complete.
	Expand ISA100.11a network with more MIS units	Deferred to FY14, will coordinate with other AES Projects.
	Connect B7 ECLSS chamber with MIS and CFS gateway	Complete.
	UWB tracking of free flyer	Complete.
	Integrate 802.11 MIS for high rate sensor data	Deferred to FY14. Resource issue.
	Demonstrate interference tolerance	Deferred to FY14. Resource issue.
Commun - ications	Space-to-ground link using new baseband processor and USRP	Complete.
	Integrate new radio with new baseband processor	Almost complete. Deferred to FY14 due to limited resources
	Integrate DTN into baseband processor	Complete.
Free Flyer	Teleoperate from L2/MPCV	Complete.
	Stream video to MCC	Complete.
	RFID interrogator for passive sensors and inventory	Complete.
	Add wireless actuation capability	Deferred to FY14. Resource issue.
Software	Executable for Proton CPU	Complete.
	Use c903 as star tracker computer	Deferred due to lack of resources
	MPCV Telemetry app (Magic Sensor)	Complete.
	Add CFDP to FC load	Endian compatibility issue between CCSDS packet header and CFS. Deferred due to lack of resources
	AMPS telemetry app	Complete except for crew display.
	Fix Star Tracker CFS app	Deferred due to lack of resources
Ground Systems	Start MPCV from KSC LCC	Complete.
	Transfer DOLILU file from KSC LCC to MPCV	Deferred. Awaiting CFDP
	Add telemetry and displays in MCC OTF	Deferred due to lack of resources
	Receive free flyer video	Complete.
GN&C	Improve star tracker video processing	Requires c903 computer. Deferred due to lack.
MBSE	C&DH models	Ongoing work to improve fidelity of existing models
	Network models	Ongoing work to improve fidelity of existing models
	Human interface models	Ongoing work to improve fidelity of existing models
	Wireless models	Need models for WAP and MIS
	Communications models	Need models for BBSP and radio
	Free Flyer models	Complete.
	System diagram	Complete.

AAE Accomplishments & Objectives

- **During FY13, the AAE Project was able to successfully demonstrate a plausible avionics architecture for a notional L2 Station. We were also able to make significant strides toward our goal of a flexible avionics architecture that can be used to evaluate future concepts/architectures/components for both our nominal L2 Station and other vehicles.**
- **Our FY14 efforts have been centered around incremental architectural upgrades applied to different mission scenarios.**
  - **Mission to an asteroid**
  - **Mission to another planet (e.g., Mars)**
  - **Finish and Demonstrate Hot Spare Methods/Configurations**
  - **Deterministic network (Time triggered Ethernet)**
  - **Distributed fault tolerance processing**
  - **Enhanced DTN capabilities**
  - **Demonstrate a distributed quad computer voting architecture (in partnership with CFS)**

Future Goals and Opportunities (AAE Centric)

- **In FY15, we are planning to merge the AAE project with the CFS project, the DTN project, and some aspects of the Autonomous Mission Operations (AMO) project, all funded from AES.**
- **We recognize the need to widen participation from NASA and other government agencies, add more industry and academic partners, and begin discussions with potential international partners during the coming years. We look forward to engaging these future stakeholders.**
- **Current FY15+ "Intentions"**
  - Evaluate additional vendor products
  - Evaluate additional architectures: Redundancy with dissimilar hardware, Fault Management & Advanced Caution & Warning, More Dynamic Environments
  - Set up for NGSP/HPSC Maturation
  - Use AAE/iPAS as a testbed for Orion and ISS
  - Conduct Focused Radiation Testing (COTS CPUs, GPUs, Displays)
- **Future progress is dependent on funding and resource constraints, along with the priorities set by the Agency for Human Spaceflight.**

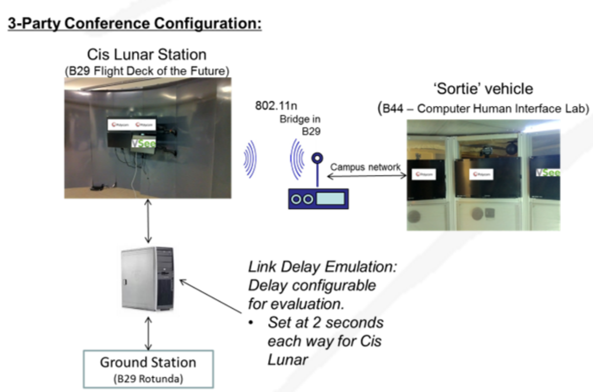
BACKUP

AAE Requirements

- **Spacecraft Vehicle Avionics…**
  - Shall be capable of functioning in deep space (e.g., beyond LEO)
  - Shall be capable of supporting crewed missions
  - When uncrewed, shall be capable of autonomous operations for TBD duration
  - When uncrewed, shall be capable of being remotely operated from Earth, or elsewhere
  - Shall provide capabilities to support science, technology, and research payloads
  - Shall support visiting vehicles, both crewed and robotic
  - Shall support logistics resupply
  - Shall support expansion of vehicle capabilities
  - Shall support TBD EVR/EVA proximity operations
  - Shall support planetary/surface human/robotic operations

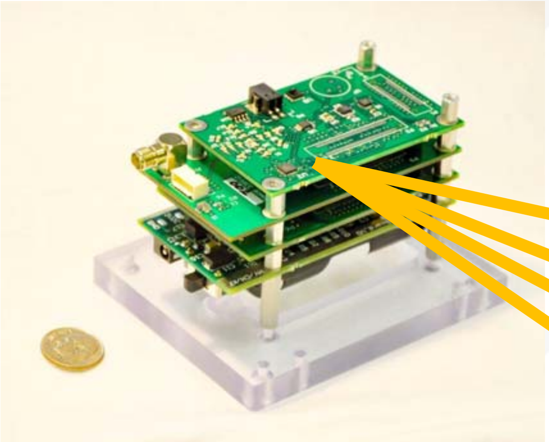
Human Interfaces

- **Initial implementation of a Software GPU on a C903**
- **Active Matrix Organic Light Emitting Diode (AMOLED) display evaluation**
  - Partnered with Honeywell
  - EMI, Thermal/Vac, Radiation testing
  - Report available at http//ntrs.nasa.gov -- Search for "AMOLEDS"
- **Added "Orion-like" and L2 Vehicle Displays**
- **Added Manual control via Translational Hand Controller (THC)**
- **Began Telepresence architecture definition**
  - Evaluated modalities for task support
  - Explored communication delay impacts on 3-way conference effectiveness



Dissimilar CPUs / OS's From Multiple Vendors

Vendor	Type	Model	Operating System	Established Path-to-flight
Honeywell	CPU	B787 VMC	Integrity	Yes
AI Tech	CPC	S950	VxWorks	Yes
AI Tech	Network	S750		Yes
AI Tech	CPU	S950	VxWorks	Yes
Space Micro	CPU	Proton400	VxWorks/ Linux	Yes
Maxwell	CPU	SCS750	VxWorks/ RTEMS*	Yes
Raspberry	CPU	PI	Linux	Not Yet

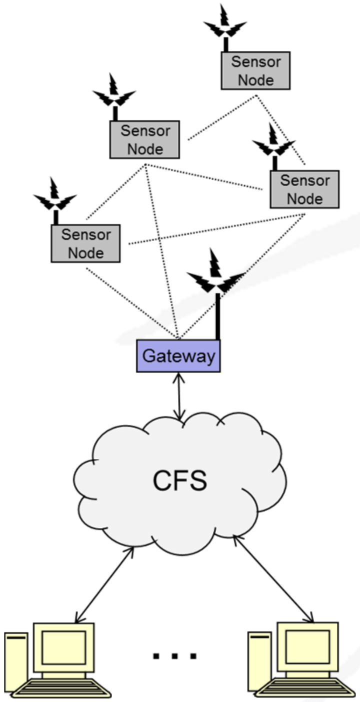


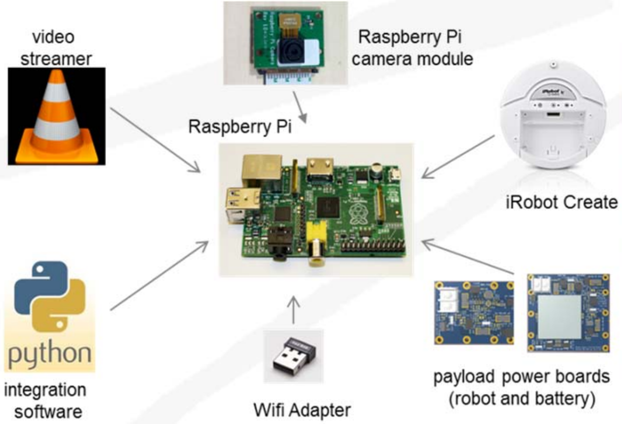
Common Avionics Enabler (CAE)
interfaces Ethernet with "legacy" protocols:

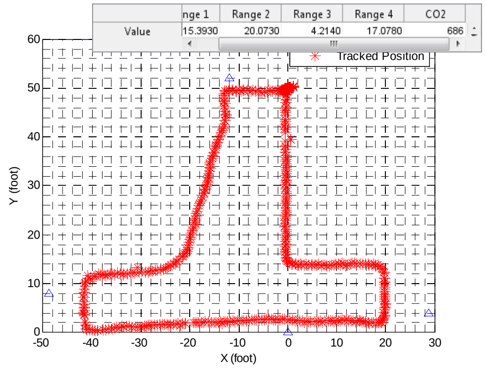
- RS-232
- RS-422
- Space Wire (in work)
- 1553B (in work)

Wireless Sensors/Networks

- **Built CFS interface for ISA100.11a WSN gateway (recommended by CCSDS)**
- **Deployed, Tested, Demonstrated ISA100.11a network**
- **Developed 802.11 (Wi-Fi) Tele-Operated Free-Flyer analog**
- **Evaluated RFID Interrogator Payload**
- **Evaluated Ultra-Wideband (UWB) location tracking Payload**



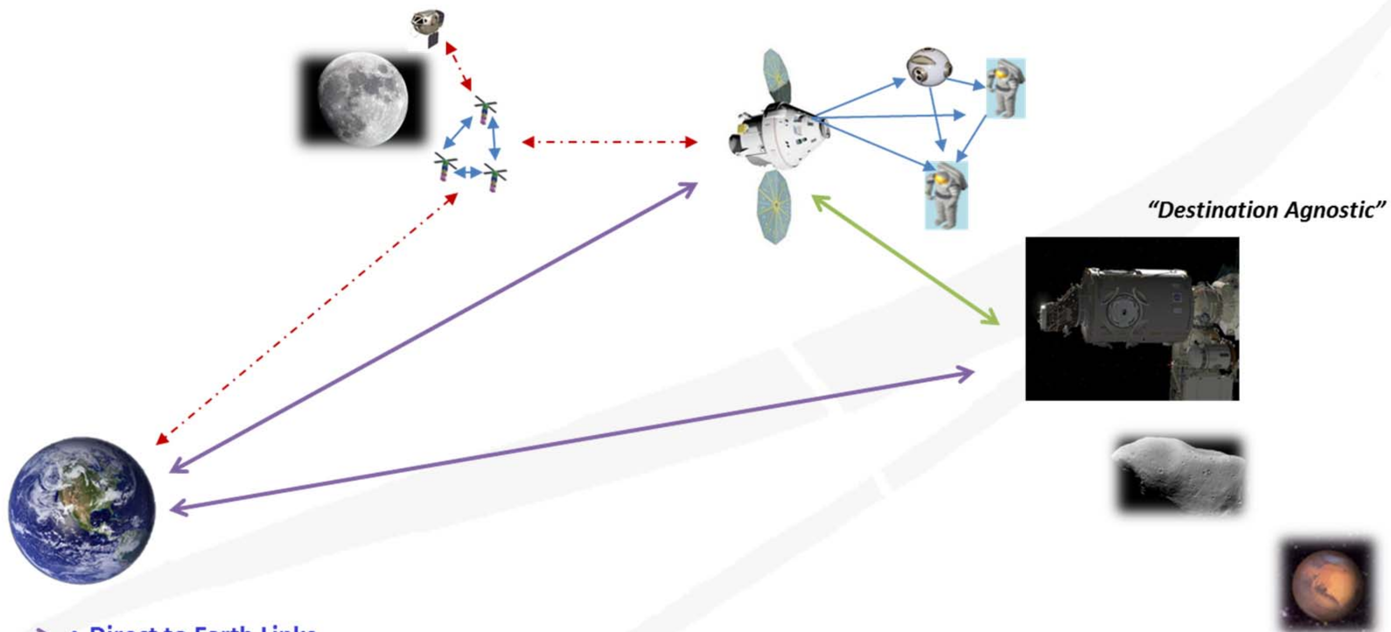




Target Position (feet)			Tracked Position (feet)			Bias (feet)			Standard Deviation (feet)		
x	y	z	x	y	z	x	y	z	x	y	z
0	14	2.5625	-0.0452	14.0346	2.768	0.0452	0.0346	0.2055	0.0631	0.0663	0.1472
-8	38	2.5625	-8.0394	37.9153	2.6532	0.0394	0.0847	0.0907	0.0701	0.0737	0.1951
-16	30	2.5625	-16.0383	29.9854	2.6812	0.0383	0.0146	0.1187	0.0697	0.0744	0.2337
-16	12	2.5625	-15.9962	12.1353	2.9072	0.0038	0.1353	0.3447	0.0749	0.0793	0.1822
-10	26	2.5625	-9.993	26.0337	3.0386	0.007	0.0337	0.4761	0.0596	0.1002	0.2344

Communications Architecture

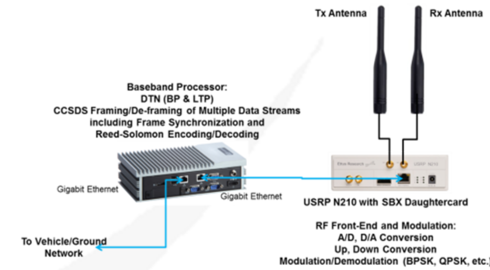
- **AAE personnel worked with Representatives from SCAN, AES, MOD, and multiple NASA Centers to baseline a Beyond Earth Orbit Human Exploration Communication Architecture for FY13**

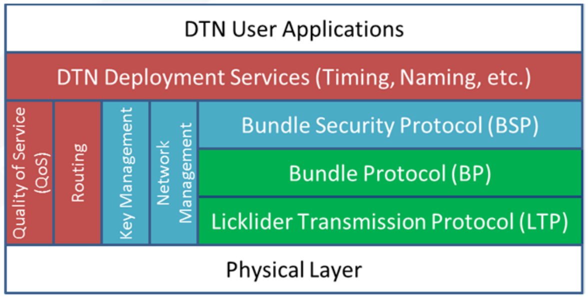


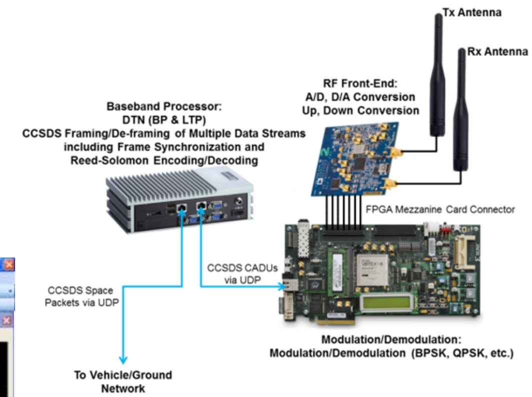
- Direct to Earth Links
    - IOAG Service catalog for the mission phase (LEO, Near Earth and Deep Space) – some variant of QPSK and BPSK
- Proximity (vehicle to vehicle) and Surface Communications
    - Determine capabilities needed
    - look at CCSDS Proximity-1 and see if that is acceptable or if we need to develop Proximity-2
- Wireless local area, mesh network -- 802.11 family variant
- Potential Lunar Relay using Cubesat/Microsat

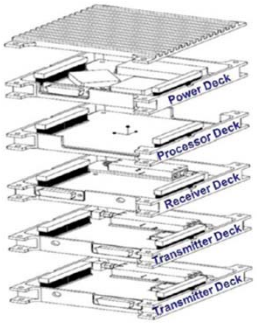
Communications and Disruption Tolerant Networking

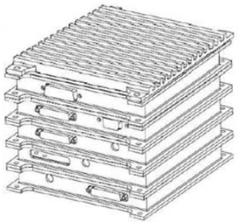
- **Demonstrated prime Space-to-Ground link using the USRP (COTS) SDR platform**
- **Demonstrated the framing/unframing of CCSDS Space Packets (in/out of AOS frames with the addition of Reed-Solomon forward error correction)**
- **Demonstrated DTN (using Bundle Protocol and Licklider Transmission Protocol via an external router)**
- **Added additional DTN capability to the SDR baseband processor using the Interplanetary Overlay Network (ION) from JPL**
- **Began development of RIACS (Reconfigurable, Intelligently-Adaptive Communication System)**
  - The RIACS platform is a combination of a software-defined radio and a signal processor
- **MSFC initiated the build of a PULSAR SDR for delivery in FY14**

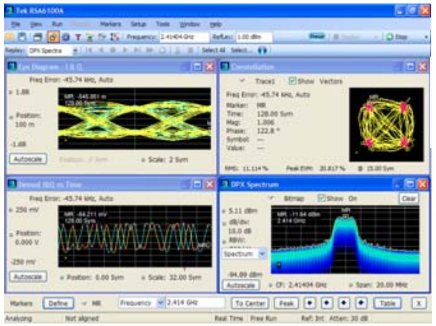






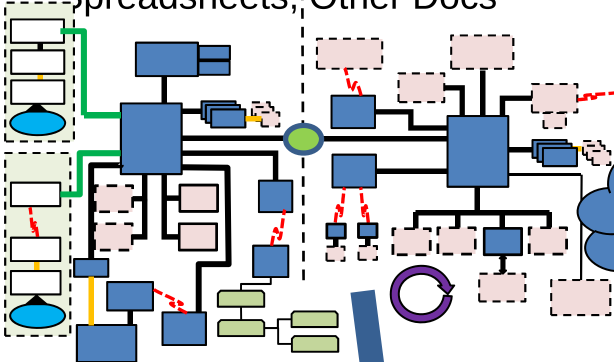






AAE Perspective of MBSE

Power-Point Diagrams, Spreadsheets, Other Docs



Agency-initiated effort to replace our current document-based approach

More than Avionics

Add Knowledge, Relationships

Display
THC
RHC

Human Interfaces

Processors

MPCV HI
Proton
Maxwell

Networks

TTGbE
CAE
RS 422

Interrogator
Wirele antennae
WAP

Wireless Comm

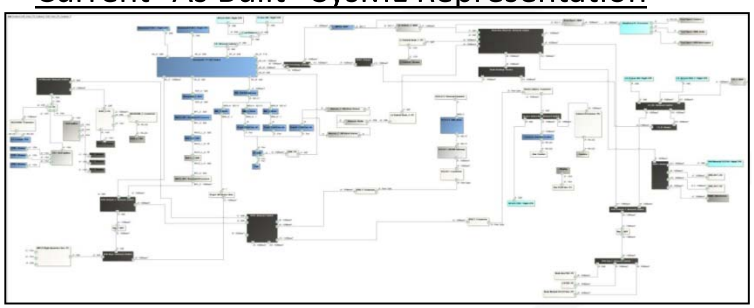
RF Comm

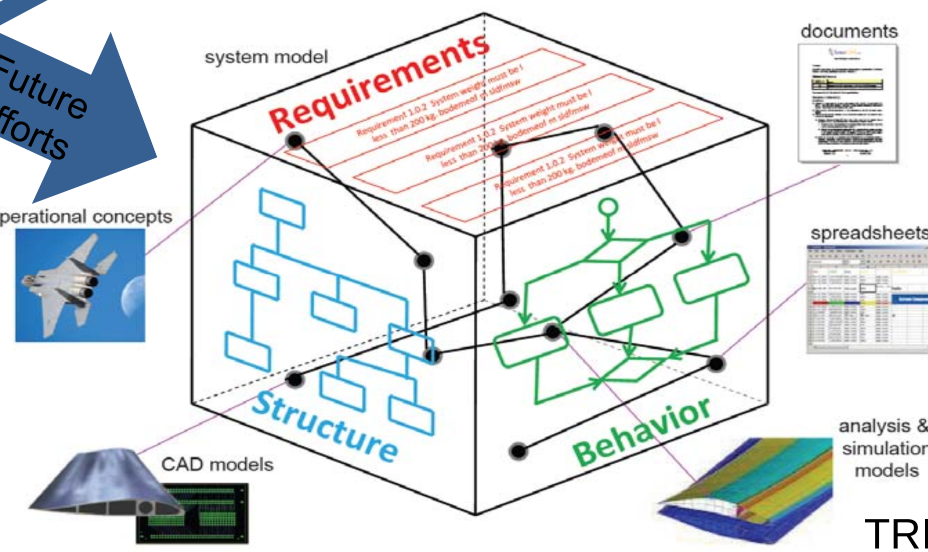
S-band
Ka-band
SDR

Component Libraries

Future Efforts

Current "As Built" SysML Representation





AAE is using SysML to implement MBSE

- Learn by doing
- Add future flexibility

3-D Printing

Automated T&V

TRICK SIM

CFS Project

- **Objectives**
  - **The Core Flight Software Project's objective is to evolve and extend the reusability of the Core Flight Software System into human-rated systems, thus enabling low cost, and rapid access to space.**
    - **Provide a *reusable* software architecture suitable for human-rated missions**
      - **Reduce/offset per-project software development, test, and certification costs by performing that work *once* serving multiple projects**
      - **Address software and hardware issues unique or typical to human-rated systems**
    - **Provide software products, tools, and artifacts directly usable by Class A projects/programs, and for general use across NASA**
    - **Support AES projects as they develop toward flight missions**
- **Accomplishment Extract**
  - **Developed a Quad-Voting CFS System**
    - **CFS Instantiation on VxWorks Partitioned Operating System with Quad-redundant synchronous software voting computers**
- **CFS Project Future Opportunities**
  - **Human Spacecraft Support Activities**
    - **Support for Redundancy**
      - **Symmetric (same OS & shared mem) or Asymmetric Multiprocessor (SMP) support (Dual core, 4 core, 36 core)**
      - **Open source Quad voting layer + External Ethernet**

AMO Project – ACAWS Demonstration

- **Orion Fault Management**
  - Orion Spacecraft has hundreds of spacecraft components, 20K telemetry points, and flight controllers must be able to detect 1K faults.
  - Fault messages may mask the root cause of the fault, and fault consequences may be difficult to understand.
- **Challenge**
  - Demonstrate automated spacecraft fault detection and isolation based a suite of health management technologies previously developed by ARC and industry.
- **ACAWS**
  - Advanced Caution and Warning (ACAWS) detects and isolates faults and fault consequences across the entire spacecraft.
  - Systems Engineering Analysis of the spacecraft design efficiently modeled and analyzed faults and fault propagation using spacecraft design artifacts.
  - Advanced Caution & Warning System (ACAWS) will be demonstrated for mission operations during the Exploration Flight Test-1 (EFT-1) of Orion in December 2014.
- **ACAWS exploits a systems model together with associated software modules to process telemetry and display information to controllers about:**
  - The "root-cause" failure behind a C&W event.
  - Components affected by the failure.
  - Components at increased risk due to loss of redundancy
  - Insight into FDIR activity:
    - FDIR algorithms that have run
    - System components implicated in FDIR activities.
  - Decision-making assistance with nominal operations
    - "At-a-glance" GO/NOGO Flight Rule Tables
      - E.g., Extended Power-Down Decision at Entry Interface
  - ACAWS also provides a "what-iffing" capability that allows operators to introduce failures and explore effects and impacts.
- **The ACAWS Development Project includes a human factors evaluation of ACAWS.**
  - The evaluation will:
  - Provide an empirical test of ACAWS-related performance-based benefits to flight controllers under a variety of off-nominal EFT-1 flight test scenarios.
  - Allow ACAWS developers to determine whether ACAWS benefits scale with scenario complexity and decision-making requirements.
  - Provide an opportunity for an extensive usability analysis of the ACAWS tool set in order to improve upon the current version.
- **EFT-1 flight demonstration**
  - Monitor live downlink for faults or anomalies
  - Experienced flight controllers observe and assess ACAWS throughout the mission
  - Assess ACAWS performance under actual operational conditions
- **Orion EFT-1 ACAWS Evaluation**
  - Live downlink will be used for EFT-1 Flight
  - Data from Orion testing supports ACAWS test and evaluation but does not provide breadth and flexibility to test the several hundred failure modes in the ACAWS model
  - IPAS provides high quality simulated data for ACAWS test and evaluation
  - Battery fault scenarios provide accurate fault signatures
  - Data is merged with nominal data recorded from Orion tests with MCC
  - IPAS simulations provide for insertion of failure signatures over a wide range of conditions to greatly increase confidence of the ACAWS models and logic