Reliability Challenges for Space Missions

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Unique Reliability Challenges for Space Missions

Developing and operating space systems means achieving the lowest possible structural mass at the highest levels of efficiency and reliability under extreme environmental conditions of temperature, radiation and vacuum.

- From "Handbook of Space Technology", edited by N. Allen, American Institute of Aeronautics and Astronautics, Inc., and John Wiley & Sons Ltd, August 2009.

- Unique Reliability Challenges for Space Missions
  - Space environment
  - One-of-a-kind space systems
  - High level of reliability requirements

This tutorial is from electronics application perspective only and is not intended to address other disciplines.

Outline

- Unique reliability challenges for space missions compared to commercial industry
  - Space environment
    - Overview
    - High vacuum: challenges
    - Radiation: challenges and radiation hardiness assurance
    - Extreme temperatures: challenges, technologies and qualification
  - Space system and space technologies
    - Overview
    - Challenges from electronics application perspective
  - Reliability requirements
    - Overview
    - Challenges
- Fundamental processes to ensure mission assurance for space flight program at NASA
- Summary

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Space Environment Overview

- Altitude over 100 km is typically considered as space environment
  - The parameters required for aerodynamic flight are no longer available at around that altitude.
- High vacuum
- Space radiation
  - Solar events, galactic cosmic rays, trapped particles
- Extreme temperatures
  - Low Temperature of space background
  - In-situ extreme temperatures
- Reduced gravity
  - Residual atmosphere in low orbit
- Contamination
- Space debris

High Vacuum: Challenges

- 10^{-7} Pa at 500 km altitude versus 10 Pa^{-15} at GEO 36,000 km altitude.
- Outgassing
  - Involves mass loss and a change in surface properties of the materials; structural problems are not expected.
  - Represent a danger for sensitive components, i.e. optical instruments, thermal coatings and high voltage devices.
  - One of the sources of contamination of spacecraft
  - Bake-out test performed in a thermal vacuum chamber before its launch for planetary protection.
- Negligible convection
  - Radiant heat between spacecraft and environment
  - Radiation and conduction internally
- Changes in material properties
  - Mechanical strength, life space and fatigue
- Cold welding
  - Metallic parts lying close to each other can weld together due to the escape of the intermittent gas layer existing on Earth.

N. Allen, "Handbook of Space Technology", American Institute of Aeronautics and Astronautics, Inc., and John Wiley & Sons Ltd, August 2009.

Space Radiation: Challenges

- Electromagnetic radiation and particle radiation cause change in the atomic structure of the radiated materials or devices.
- The space radiation environment is quantitatively and qualitatively more severe than the atmospheric radiation environment. Peak particle fluxes (mainly neutrons in the atmosphere and protons in LEO) are 2 or more orders of magnitude higher in space than in the atmosphere.
- Even the most benign space environment also poses the threat of the heavy-ion component of galactic cosmic rays, which can cause destructive SEEs with greater probability than protons or neutrons. Space environment also introduces additional threats that are negligible in the atmospheric environments (e.g., destructive SEE, TID, and DDD).
- Extensive references available; e.g. IEEE Transactions on Nuclear Science, NSREC, etc.

After Dr. Raymond Ladbury, NASA GFSC

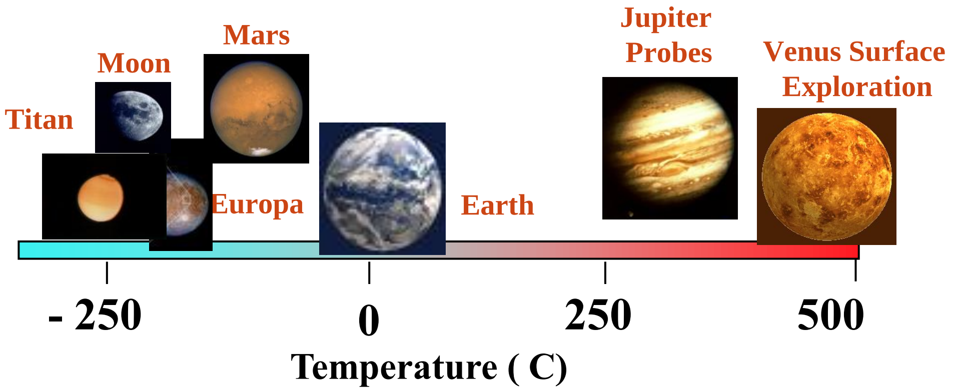
Space Radiation: Radiation Hardiness Assurance

- Reduce radiation risk to acceptable levels while minimizing the costs of such efforts. There are different RHA methodologies.
- The difficulties of providing economical RHA arise from two main causes.
  - First, it is not possible to reproduce with 100 percent fidelity all application conditions a component will encounter during the mission, as this would necessitate SEE testing with very energetic ions over prolonged periods and would preclude such cost saving strategies as accelerated testing.
  - Second, the destructive nature of radiation testing precludes screening the radiation response of flight parts, so one must instead qualify a "lot" including the flight parts and a representative test sample. Thus much of RHA consists of using models to generalize from test results on the qualification sample to worst-case bounds on flight-part performance.
- All of the NASA radiation approaches require the project to evaluate susceptibility to TID, DDD, and destructive and nondestructive SEE as appropriate for the technologies of the parts and the mission environment.

After Dr. Raymond Ladbury, NASA GFSC

Space Extreme Temperatures: Overview

- Low temperature of space background.
- In-situ extreme temperature shown below.
- Thermal influence from electromagnetic radiation: mainly converted to thermal energy and the most important external parameter for the spacecraft's thermal balance.



E. Kolawa, "Assessment of Technologies for Extreme Environments", NASA Technical Publication, 2007

Space Extreme Temperatures: Challenges

- Technology
  - No technology designed for extreme temperatures.
  - Advanced technology: conventional derating may not apply, or less margin for derating.
- Qualification
  - No qualification and reliability methodology existing for extreme temperatures.
  - Mil-Std cannot support the extreme temperature conditions; Different failure mechanisms at extreme conditions;
  - Conventional derating does not work

High Temperatures Technologies

- GaN and SiC technologies are the two most promising technologies for applications above 200°C.
- GaN-based high temperature and rad-hard electronics have been demonstrated.
  - GaN has an intrinsically low susceptibility to radiation-induced material degradation, yet the effects observed in the Schottky diode I-V and C-V characteristics indicate that the total-dose radiation hardness of GaN devices may be limited by susceptibility of the metal-GaN interface to radiation-induced damage.
- SiC-based MOSFETs, IGBTs, JFETs, diodes, SiC-based UV flame sensors, SiC-based Alpha, neutron, X-ray and UV detectors, SiC-based high-frequency RF MESFETs, SiC-based MEMS and sensors, SiC transistor integrated circuits operating at high temperatures have been demonstrated. The reliability of SiC MOSFETs has shown a significant improvement.
- The hardness of SiC is mainly extrapolated from the higher displacement energy and its wider band gap than silicon. Some parameters of interest in SiC FETs and diodes are found to be not greatly affected by radiation. However, several other phenomena have also been observed indicating that SiC diodes are very sensitive to single-event effects (SEEs) and dose effects.

References from IEEE Transactions, conferences, web sites including http://www.grc.nasa.gov/WWW/SiC/, etc.

Low Temperatures Technologies

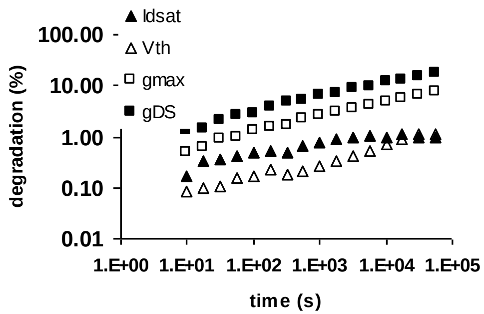
- CMOS, SOI, GaAs and SiGe technologies can operate at temperatures below -55°C.
- Hot carrier effects for CMOS, SOI and GaAs devices are the major long-term reliability concerns for low temperature operations.
- Design-for-reliability approach can be used to generate the design rules to ensure the long term reliability of the devices without any process modifications. A couple of examples on customized SOI electronics for a Mars mission.

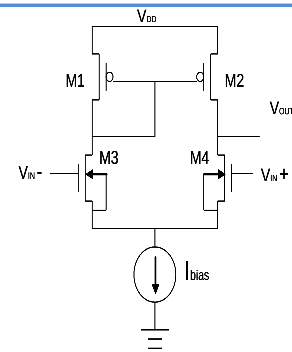
Y. Chen, et al, "Design for ASIC Reliability for Low-Temperature Applications", IEEE TDMR Vol. 6, No. 2, June 2006.
R. L. Greenwell, et al, "5-V Compatible Radiation-Hardened SOI Rail-to-Rail Input/Output Operational Amplifier for Extreme Environments," GMACT, Mar. 19-22, 2007

- SiGe:
  - Potential enabling technology for a wide variety of extreme environment operational conditions, including cryogenic temperatures as low as -273°C, high temperatures up to 300°C, wide temperature ranges from -273°C to 300°C.
  - SiGe HBTs have a very favorable built-in total dose and displacement damage tolerance to multi-Mrad levels. SiGe HBT digital circuits are very SEU sensitive. Further work is needed in this area.

J. D. Cressler, "Silicon-Germanium as an enabling technology for extreme environment electronics", IEEE Transactions on Device and Materials Reliability, Vol. 10, No. 4, December, 2010

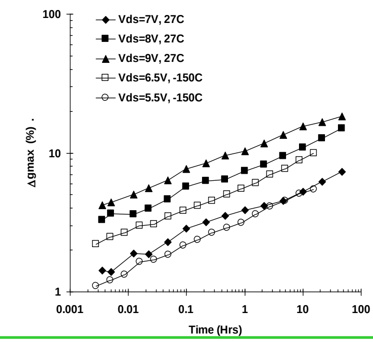
Example: Design for Reliability at Transistor Level



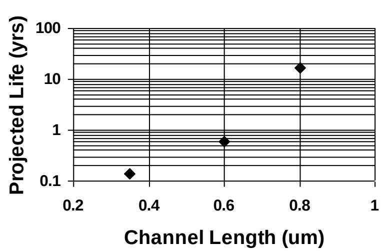


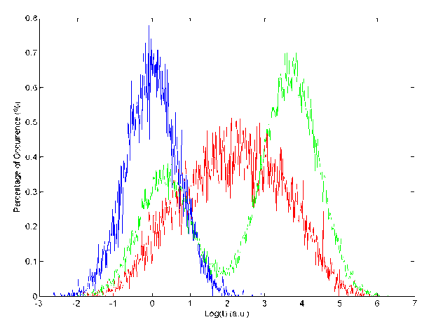
$$\beta = g_{m4}/(g_{ds4}+g_{ds2})$$

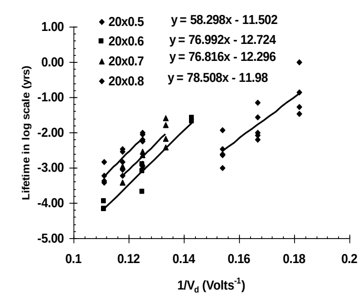
$$V_{Offset} = \Delta V_{th(3-4)} + \Delta V_{th(1-2)}\left(\frac{g_{m1}}{g_{m3}}\right) + \frac{(V_{gs}-V_{th})_{(3-4)}}{2}\left(\frac{\Delta \frac{W}{L_{(1-2)}}}{\frac{W}{L_{(1-2)}}} - \frac{\Delta \frac{W}{L_{(3-4)}}}{\frac{W}{L_{(3-4)}}}\right)$$



Device Reliability Characterization → **Circuit and Board Performance and Design Requirements** → **Failure Criteria Determination** → **Device Reliability Assessment** → **Statistical Approach for Device Reliability** → **Design Rules/Guidelines**

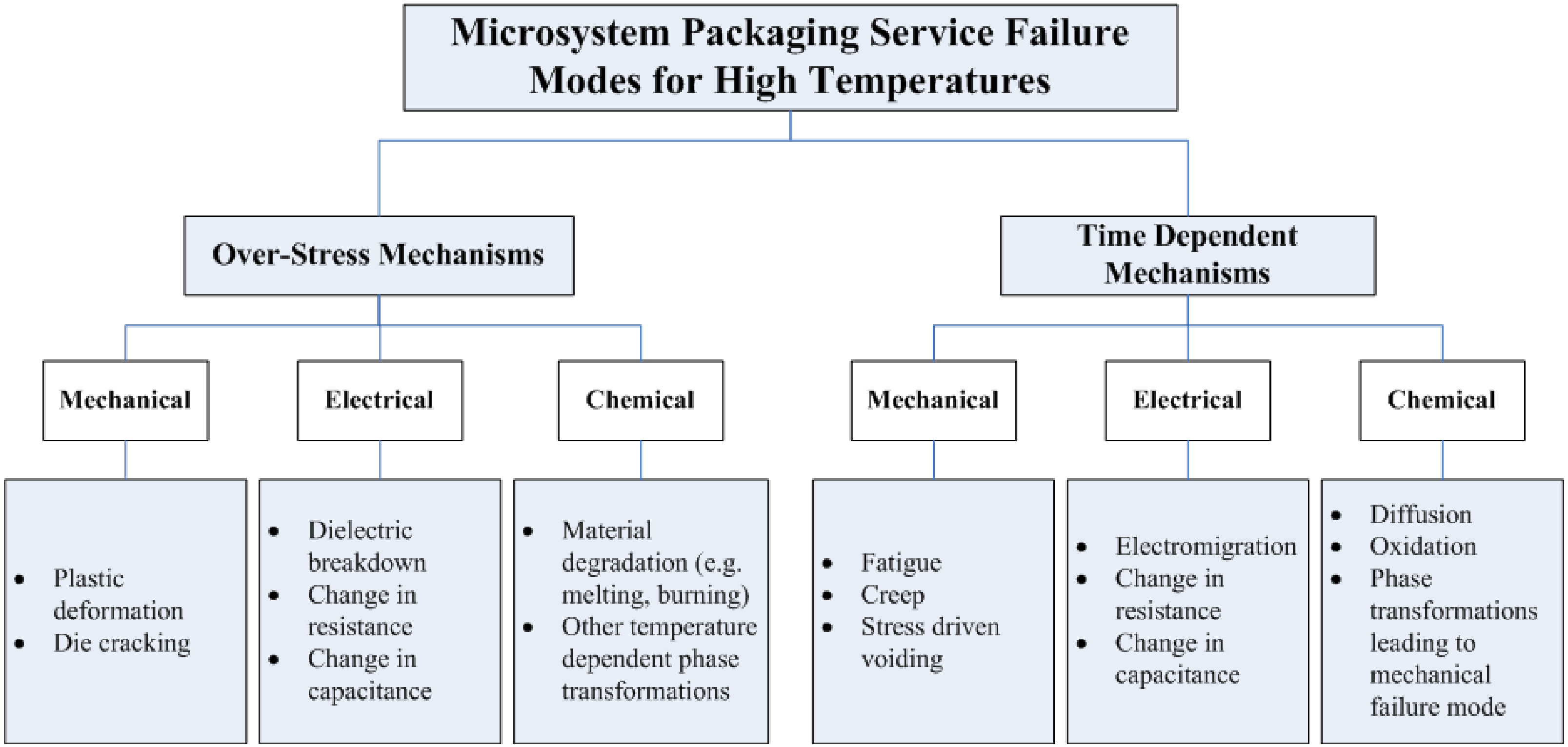






Y. Chen, et al, "Micro- and Nano-Electronic Technologies and their Qualification Methodology for Space Applications under Harsh Environments", Micro- and Nanotechnology Sensors, Systems and Applications II, Proceedings of SPIE Vol. 8031, 2011

Electronic Packaging for High and Low Temperatures

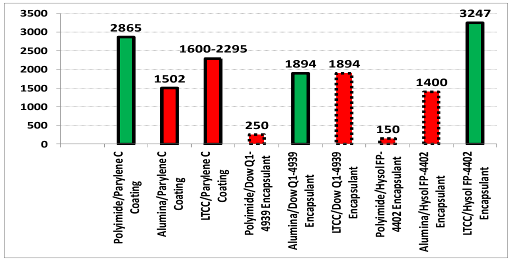


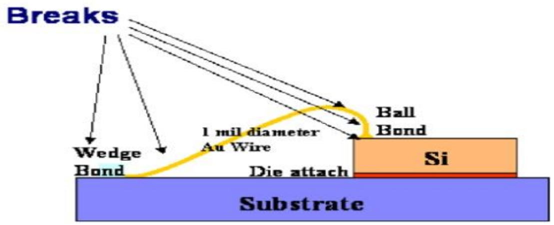
- Electronics and electronic packaging for space applications are generally qualified within the Mil. Std. temperature range of -55 to 125°C.
- The operation of electronic subsystems outside of the temperature range requires the development and detailed evaluation of application specific electronic packaging configurations

From "Extreme Environment Electronics", edited by J. D. Cressler and H. A. Mantooth, CRC Press, 2011.

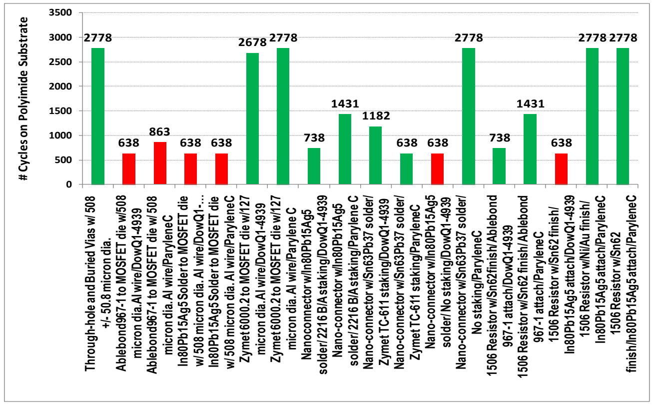
Example: Design for Reliability at Packaging Level

Substrate	• Polyimide (Organic) • Alumina/Al2O3 (Ceramic) • Low Temperature Co-Fired Ceramic (LTCC) (Ceramic)
Die Attach	• Ablebond 967-1 (Silver-filled Epoxy) • Pure Indium (Solder) • Zymet TC-611 (Silicone Based Adhesive)
Encapsulant/ Coating	• Hysol FP-4402 (Epoxy) • Dow Q1-4939(Silicone) • Parylene C (Polymer)
Wire Type	• Au 25.4 µm in diameter (99.9%)
Bare Si Die Size	• 2.2mm², 5mm², 10mm² with wire bonds • 22 mm² x 22 mm² without wire bonds
Through-hole Vias	• 508 µm +/- 50.8 µm diameter • Vias on Polyimide with a minimum Cu thickness of 25.4 µm • Vias on thick-film alumina filled with Dupont Au 9591 or 5727 • Vias on LTCC filled with thick-film Au, Kyrocera 30-065VM2





Material selection → Design of Experiments and Testing → Failure Analysis → Re-design and Second Testing/Pre-Qual → Design of Experiments and Results Analysis

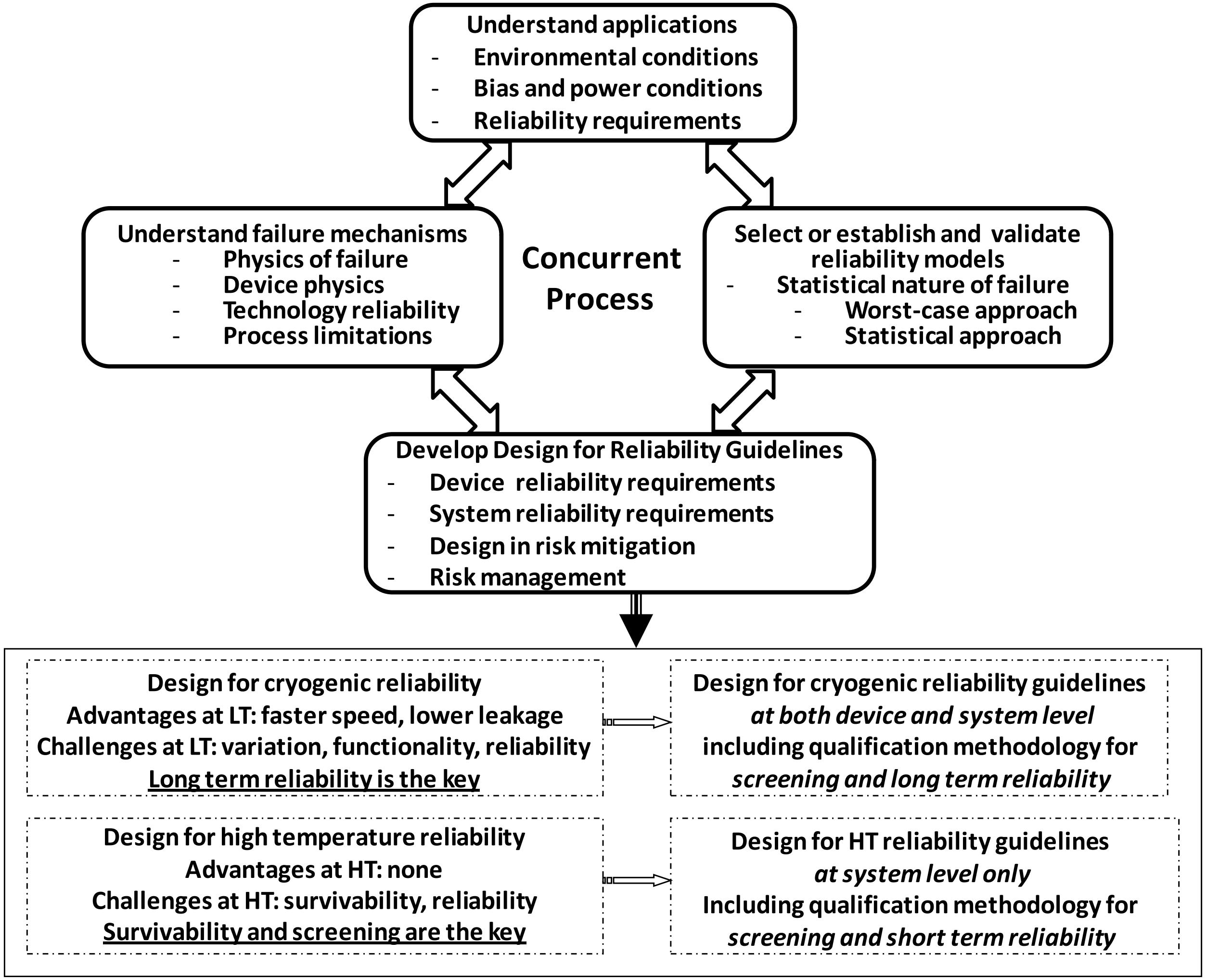


Substrate	• Polyimide (Organic); • Low Temperature Co-Fired Ceramic (LTCC) (Ceramic)
1506 Resistor Attach	• Ablebond 967-1 adhesive • In80Pb15Ag5 solder
1506 Resistor Encap Finish	• Ni/Au • Sn62Pb36Ag2
MOSFET Die Attach	• Ablebond 967-1 adhesive • In80Pb15Ag5 solder • Zymet 6000.2 adhesive
MOSFET Die Heavy Al Wire	• 99.999% Al 508µm in diameter • 99.99% Al 127µm in diameter
37- pin Nanonics Dualobe® connector (nano-connector) with surface mount BeCu lead attach	• Sn63Pb37 • In80Pb15Ag5 • Sn60Pb40 lead finish
Nano-connector staking	• Zymet TC-611 • 2216 B/A
Through-hole and buried Vias	• 508µm +/- 50.8µm in diameter • Minimum Cu thickness of 25.4µm.
Encapsulant/Coating	• Dow Q1-4939(Silicone) • Parylene C (Polymer)

Y. Chen, et al, "Micro- and Nano-Electronic Technologies and their Qualification Methodology for Space Applications under Harsh Environments", Micro- and Nanotechnology Sensors, Systems and Applications II, Proceedings of SPIE Vol. 8031, 2011

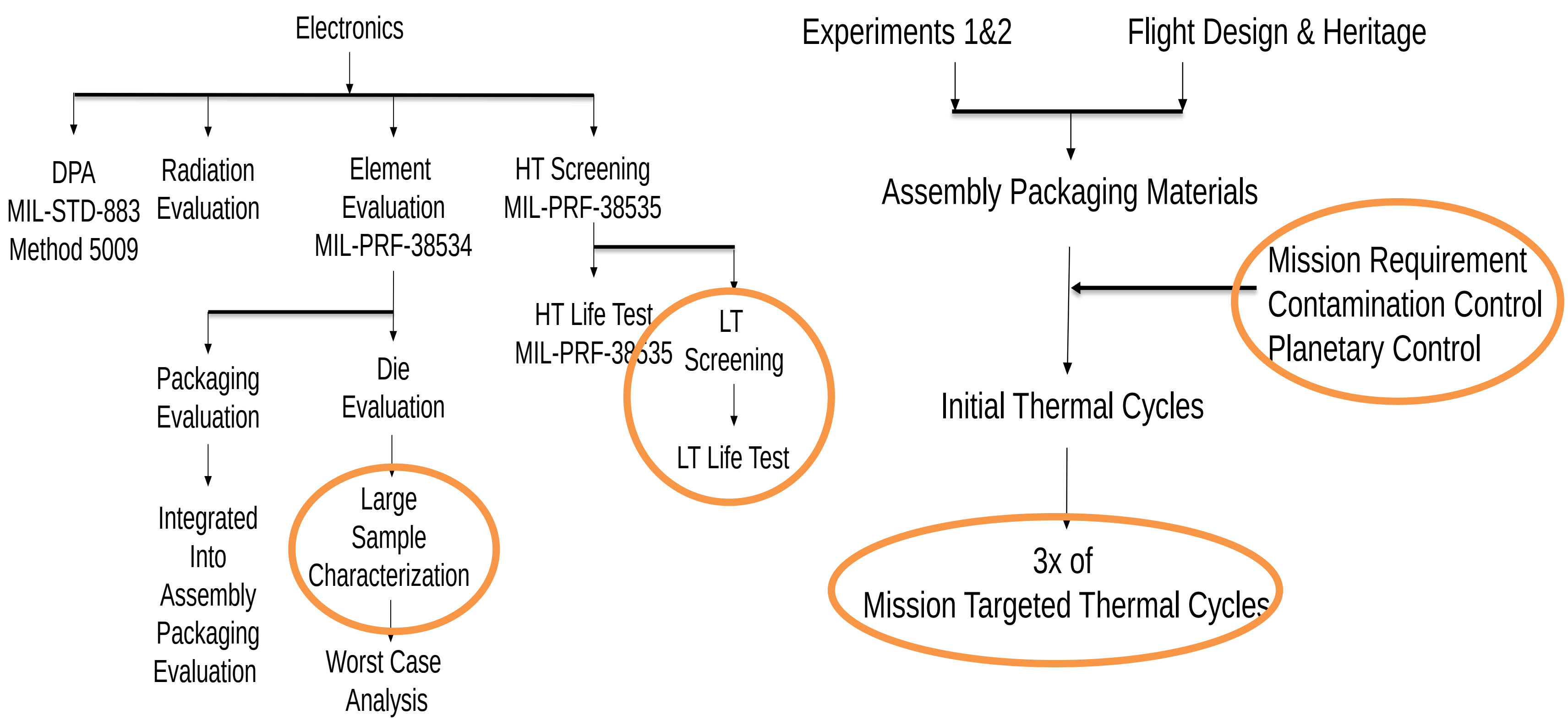
Space Extreme Temperatures: Qualification

- Characterize technologies, understand the failure mechanisms and limitation of the technology, and mature technologies.
- Develop design for reliability guidelines, utilize reliability model with statistical nature
- Mitigate the risk by building-in component reliability into the system.
- Apply large sample size, element evaluation, 3x mission length



From "Extreme Environment Electronics", edited by J. D. Cressler and H. A. Mantooth, CRC Press, 2011.

Example: Qualification for a Wide Temperature Application



E. Kolawa, et al, "A Motor Drive Electronics Assembly for Mars Curiosity Rover: an Example of Assembly Qualification for Extreme Environments", IRPS, 2013.

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Space System

- Space system segments
  - Space segment
    - System element: Spacecraft, Orbit, Payload
    - Spacecraft and its payload in orbit
  - Transfer segment
    - Transport the spacecraft into space
    - Launch vehicle
      - Boost stages
      - Propulsive stages including engines
      - Equipment bay
      - Payload adaptors
      - Multiple payload launch system
      - Payload fairing
  - Ground system
    - Control and monitor the spacecraft and its payload; distribute and process payload data
    - System element: Mission Operations and Ground Station Network

Space Segment: Spacecraft

- Mechanical structure: Defines the fundamental and basic characteristics of the spacecraft; housing all other systems.
- Power supply: Power source such as solar arrays, batteries, fuel cells or radio-isotopic thermoelectric generator (RTG); conversion and distribution of electric energy within spacecraft.
- Propulsion: Allows spacecraft to change its orbit by fairing thrusters; chemical propulsion; electric propulsion; etc.
- Thermal subsystem: Ensure that the temperatures of all mechanical, electrical and electronic unites in a spacecraft are within specific operating temperature ranges during all mission phases.
- Attitude control: Monitors and controls the orientation of the spacecraft in space.
- Communications: Telemetry for spacecraft monitoring, commands for control and payload data to be transmitted to and from Earth and to spacecraft.
- Data processing: Process data generated on the spacecraft.
- Life support system for human space flight: Guarantees physical integrity and appropriate living conditions for humans in space.

Space Segment: Orbit and Payload

Orbit	Characteristic
LEO (Low Earth Orbit)	Altitude of 300 up to 1500km
MEO (Medium Earth Orbit)	Altitude of several thousand km
HEO (High Elliptical Orbit)	Altitude of a few hundred up to 100,000 km
GTO (Geostationary Transfer Orbit)	Altitude of a few hundred up to 35,786 km
GEO (Geostationary Orbit)	Altitude of 35,786 km
Lagrange points	Distance > 1 million km
Interplanetary orbits	Distance up to several billion km

Payload	Applications
Cameras Radar	Earth observation, weather monitoring, planetary exploration, astronomy
Sensors (non imaging)	Earth exploration, atmospheric research, planetary exploration
Experimental components,	Validating new technology
Transponder	Television, internet, telephony
Signal transmitter Atomic clock	Navigating, positioning
Lander In-situ analysis instruments Rover	Analyses of planet surfaces

Adapted from "Handbook of Space Technology" edited by N. Allen, American Institute of Aeronautics and Astronautics, Inc., and John Wiley & Sons Ltd, August 2009.

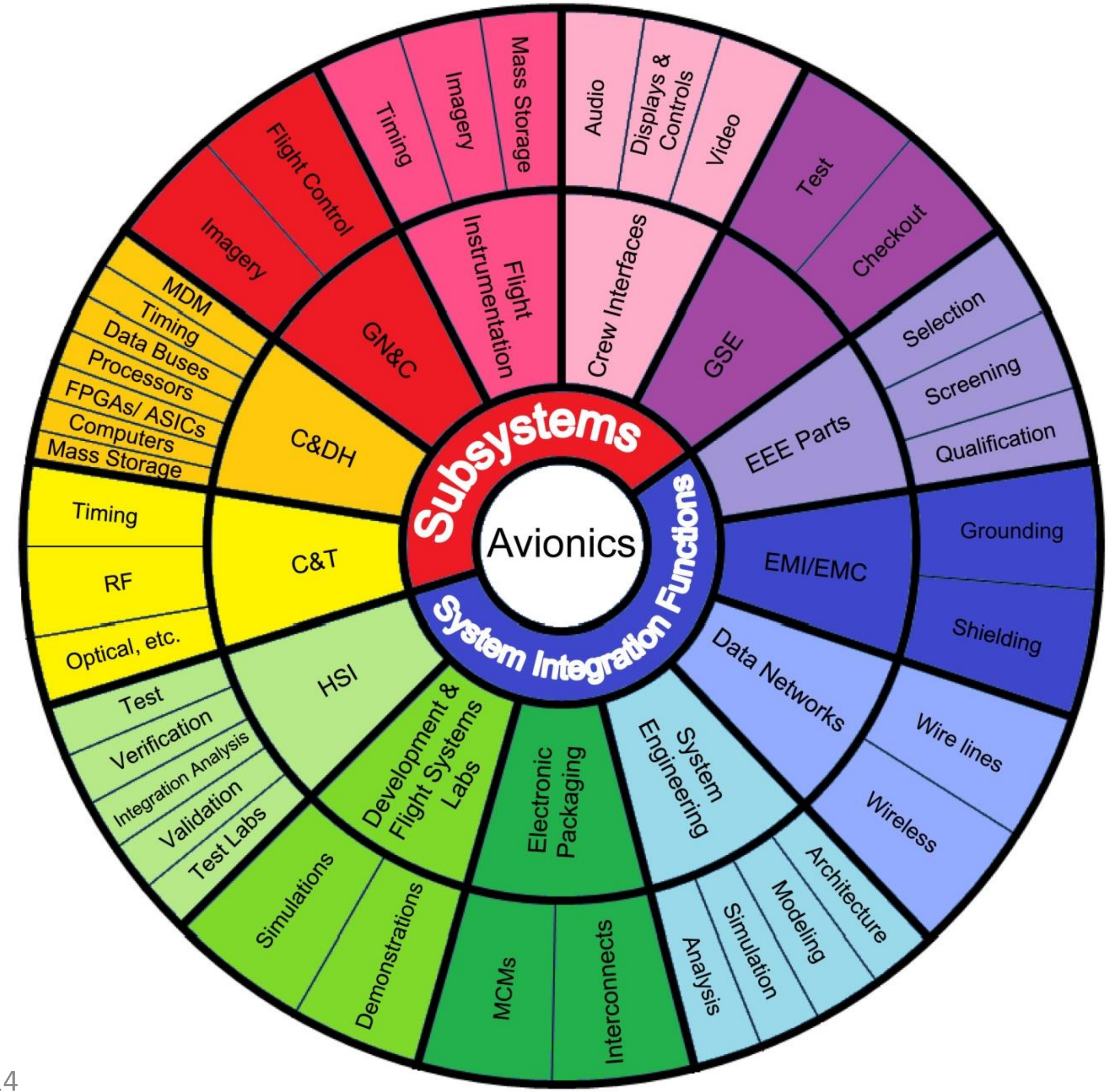
Space Technology

Wide Range of space technologies: snap-shot of NASA Space Technology Roadmaps

Technical Area	Pace Technology Roadmaps	Technical Area	Pace Technology Roadmaps
TA01	Launch Propulsion Systems	TA08	Science Instruments, Observations and Sensor Systems
TA02	In-Space Propulsion Systems	TA09	Entry, Descent and Landing
TA03	Space Power and Energy Storage	TA10	Nanotechnology
TA04	Robotics, Tele-Robotics and Autonomous Systems	TA11	Modeling, Simulation, Information Technology and Processing
TA05	Communication an Navigation Systems	TA12	Materials, Structures, Mechanical Systems and Manufacturing
TA06	Human Health, Life Support and Habitation Systems	TA13	Ground and Launch System Processing
TA07	Human Exploration Destination Systems	TA14	Thermal Management Systems

http://www.nasa.gov/offices/oct/home/roadmaps/

Avionics



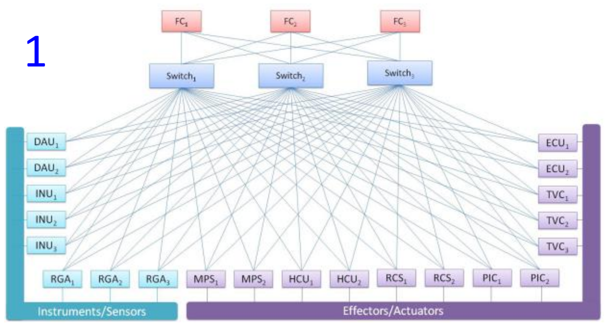
Avionics
Subsystems
System Integration Functions
GN&C
Flight Control
Imagery
Flight Instrumentation
Timing
Imagery
Mass Storage
Crew Interfaces
Audio
Displays & Controls
Video
GSE
Test
Checkout
EEE Parts
Selection
Screening
Qualification
EMI/EMC
Grounding
Shielding
Data Networks
Wire lines
Wireless
System Engineering
Architecture
Modeling
Simulation
Analysis
Electronic Packaging
MCMs
Interconnects
Development & Flight Systems Labs
Simulations
Demonstrations
HSI
Test
Verification
Integration Analysis
Validation
Test Labs
C&T
Timing
RF
Optical, etc.
C&DH
MDM
Timing
Data Buses
Processors
FPGAs/ ASICs
Computers
Mass Storage

Challenges from Avionics Electronics Perspective

- Mission, Environment, Application, Lifetime
  - Same for all disciplines
- Utilize advanced technologies
  - Technology Readiness Level (TRL)
  - Space qualification
    - Not designed for space environment
    - High reliability requirement but low volume (one system in most cases)
- Size, weight and power (SWaP) constraints are much more stringent
  - Challenges for architecture and design
  - Less level of redundancy compared to commercial industry
- Multi-disciplinary
  - Requirements may be different

Example: Trade Study on Launch Vehicle Avionics Flight Computing Architectures (I)

1



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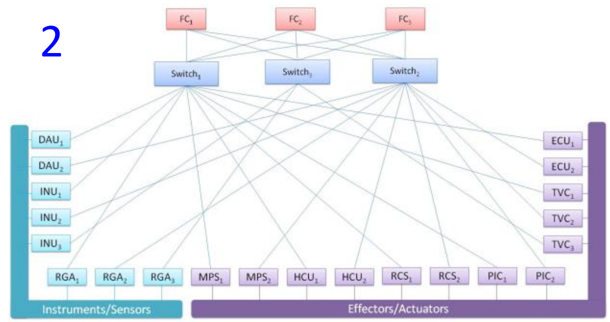

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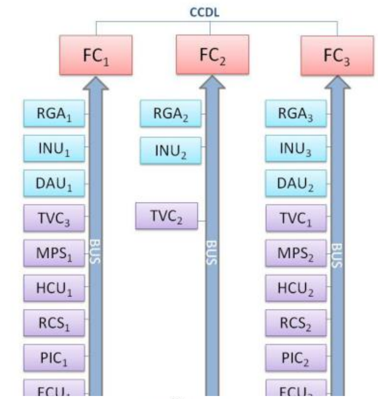

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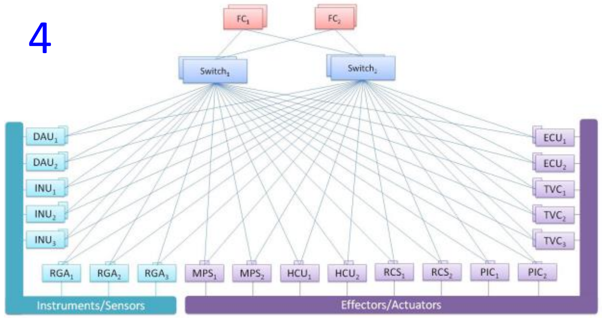

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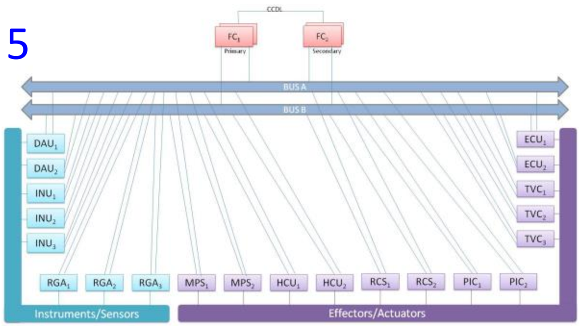

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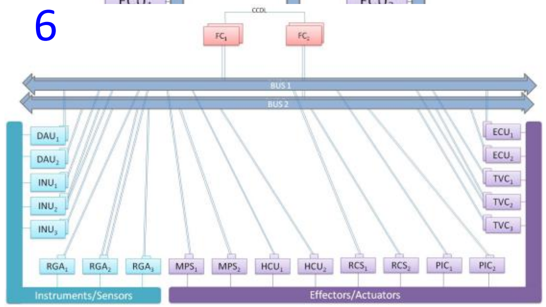

1. FCSSTV: Fully Cross-Strapped Switched Triplex Voter
2. PCSSTV: Partially Cross-Strapped Switched Triplex Voter
3. CBTV: Channelized Bussed Triplex Voter
4. FCSSC: Fully Cross-Strapped Self-Checking
5. FCSBSC: Fully Cross-Strapped Bussed Self-Checking
6. CBSC: Channelized Bussed Self-Checking

R. F. Hodson, et al, "Heavy Life Vehicle (HKV) Avionics Flight Computing Architecture Study", NASA/TM-2011-217168, August 2011.

Example: Trade Study on Launch Vehicle Avionics Flight Computing Architectures (II)

3 Voter, 3 Self-Checking
3 Switched, 3 Bussed
Highly Channelized, Partially & Fully Cross-Strapped Architectures

- **Reliability**
  - Multiple architectures (self-checking/voting, switched/bussed) approaches appear suitable for a short duration HLV mission
  - For long duration mission (9 month), channelized architectures have significantly lower reliability
- **Power**
  - Architectural differences result can result in up to 7% difference in power
  - No significant power difference between self-checking and voting systems
- **Flight Data Network Harness Mass**
  - Mass ranges were determined to be between 16 lbs to 105lbs, which is 2% to 9% percent of the total estimated cable/harness weight for a heavy lift vehicle (assuming ~1200lbs – single stage)
  - Cable weight was a function of cross strapping and not a function of the Flight Computer (Self-checking vs Voter)

R. F. Hodson, et al, "Heavy Life Vehicle (HKV) Avionics Flight Computing Architecture Study", NASA/TM-2011-217168, August 2011.

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Overview

Priority Level	Life Cycle Cost <$250M	Life Cycle Cost >$250M	Life Cycle Cost >$1M, significant radioactive material, or human space flight
High	Category 2	Category 2	Category 1
Medium	Category 3	Category 2	Category 1
Low	Category 3	Category 2	Category 1

Characterization	Class A	Class B	Class C	Class D
Priority (Criticality to Agency Strategic Plan) and Acceptable Risk Level	High priority, very low (minimized) risk	High priority, low risk	Medium priority, medium risk	Low priority, high risk
National significance	Very high	High	Medium	Low to medium
Complexity	Very high to high	High to medium	Medium to low	Medium to low
Mission Lifetime (Primary Baseline Mission)	Long, >5years	Medium, 2-5 years	Short, <2 years	Short < 2 years
EEE Parts	NASA Parts Selection List (NPSL)* Level 1, Level 1 equivalent Source Control Drawings (SCDs), and/or	Class A requirements or NPSL Level 2, Level 2 equivalent SCDs, and/or	Class A, Class B or NPSL Level 3, Level 3 equivalent SCDs, and/or requirements	Class A, Class B, or Class C requirements, and/or requirements per Center Parts
Reliability NPD 8720.1	Failure mode and effects analysis/critical items list (FMEA/CIL), worst-case performance, and parts electrical stress analysis for all parts and circuits. Mechanical reliability, human, and other reliability analysis where appropriate.	FMEA/CIL at black box (or circuit block diagram) level as a minimum. Worst-case performance and parts electrical stress analysis for all parts and circuits.	FMEA/CIL scope determined at the project level. Analysis of interfaces. Parts electrical stress analysis for all parts and circuits.	Analysis requirements based on applicable safety requirements. Analysis of interface.

Challenges

- High level of reliability
  - High visibility
- One system (in most cases)
  - Engineering Module
  - Flight system
  - Statistics?
- Low volume for parts and boards
  - High cost
  - Statistics?

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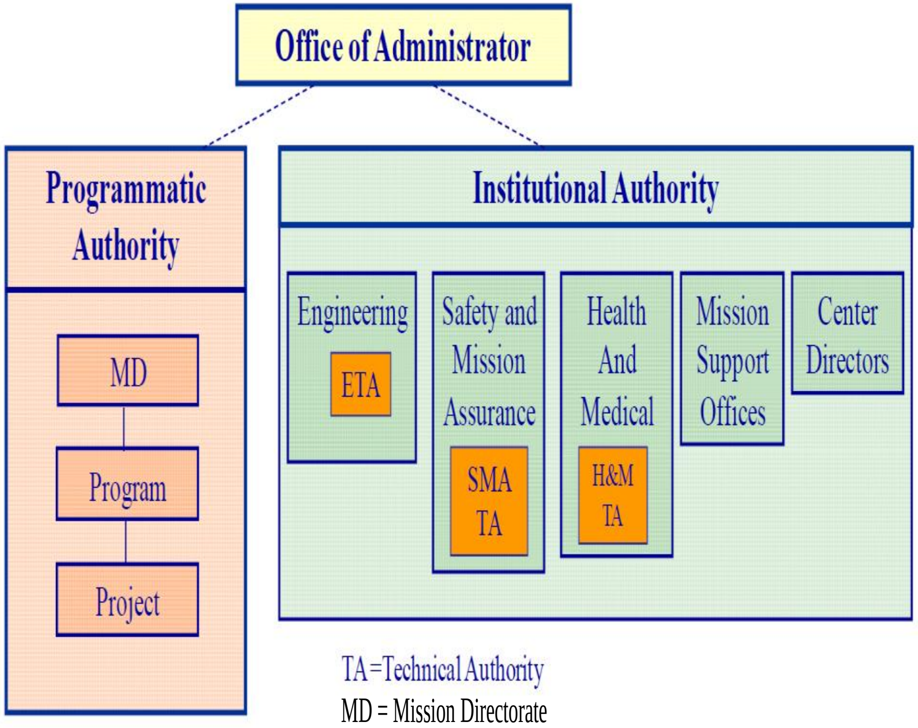
Programmatic and Institutional Authorities

- Two authorities: Programmatic and Institutional.
- Programmatic Authority: Mission Directorates and their respective programs and projects.
- Institutional Authority: not in the Programmatic Authority.
  - As part of Institutional Authority, NASA established the Technical Authority (TA) process as a system of checks and balances to provide independent oversight of programs and projects in support of safety and mission success.



Adapted from NASA Procedural Requirements (NRR) 7120.5E, "NASA Space Flight Program and Project Management Handbook and Standing Review Board Handbook", August 14, 2012.

Programmatic and Institutional Requirements

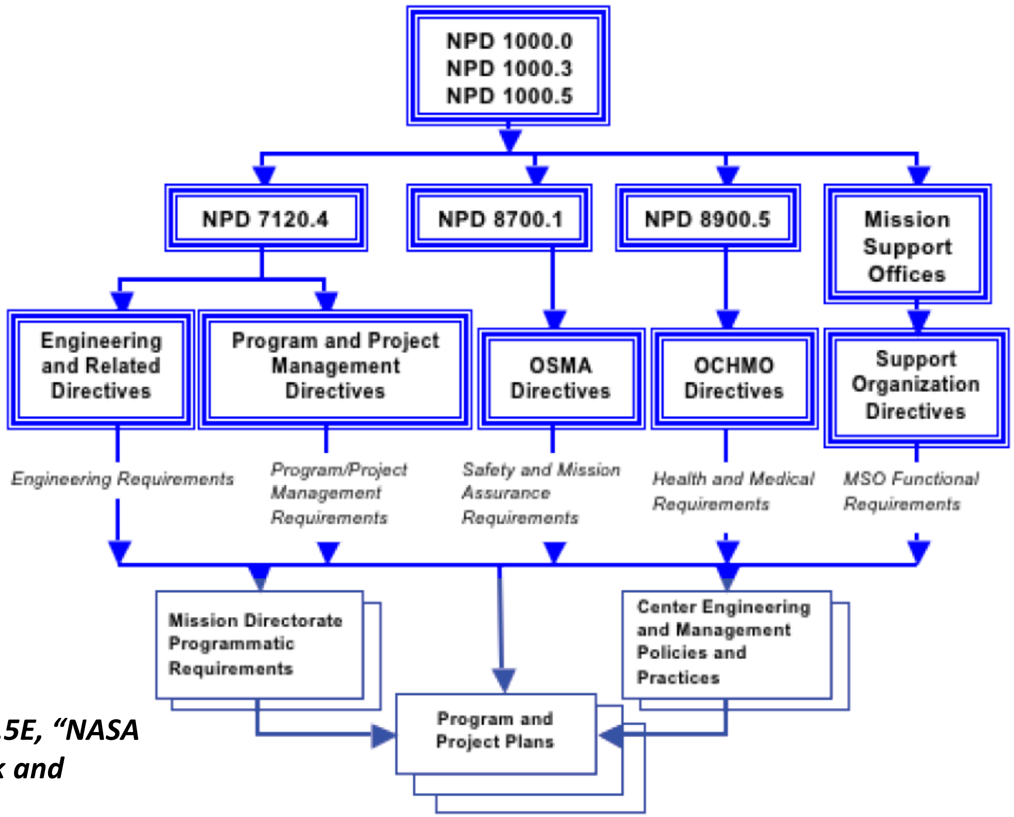
Both "programmatic requirements" and "institutional requirements" need to be satisfied in program and project Formulation and Implementation.

Programmatic Requirements Hierarchy

- **Strategic Goals (NPD 1000.0)**
- **Agency Requirements (Architectural Control Document (ACD))**
- **Mission Directorate Requirements (Program Commitment Agreement (PCA)**
- **Program Requirements (Program Plan)**
- **Project Requirements (Project Plan)**
- **System Requirements (System Requirements Documentation).**

Adapted from NASA Procedural Requirements (NPR) 7120.5E, "NASA Space Flight Program and Project Management Handbook and Standing Review Board Handbook", August 14, 2012.

Intuitional Requirements Flow Down



Requirements Framework for Flight Programs/Projects

Program/Project Management Directives
- NPD 1280.1 NASA Management System Policy

Program/Project Management Requirements
- NPR 7120.5 NASA Space Flight Program and Project Management Requirements

Program/Project Management Standards

Health and Medical Directives

Health and Medical Requirements

Health and Medical Standards

Engineering Directives
- NPD 7120.4D NASA Engineering and Program/Project Management Policy

Engineering Requirements
- NPR 7123.1 NASA Systems Engineering Processes and Requirements
- NPR 7150.2 NASA Software Engineering Requirements

Engineering Standards
- NASA/SP-2007.6105 NASA Systems Engineering Handbook
- NASA-STD-8739.4 Crimping, Interconnecting, Cables, Harnesses, and Wiring
- GSFC-STD-1000 GSFC Rules for Design, Development, Verification, and Operation of Flight Systems

Safety and Mission Assurance (S&MA) Directives
- NDP 8700.1 NASA Policy for Safety and Mission Assurance
- NPD 8730.2 NASA Parts Policy
- NPD 8730.5 NASA Quality Assurance Program Policy

S& MA Requirements
- NPR 8000.4 Agency Risk Management Procedural Requirements
- NPR 8705.2 NASA Human-Rating Requirements for Space Systems
- NPR 8705.4 Risk Classification for NASA Payloads
- NPR 8705.5 Technical PRA Procedures for Safety and Mission Success
- NPR 8715.3 NASA General Safety Program
- NPR 8715.5 Range Flight Safety Program

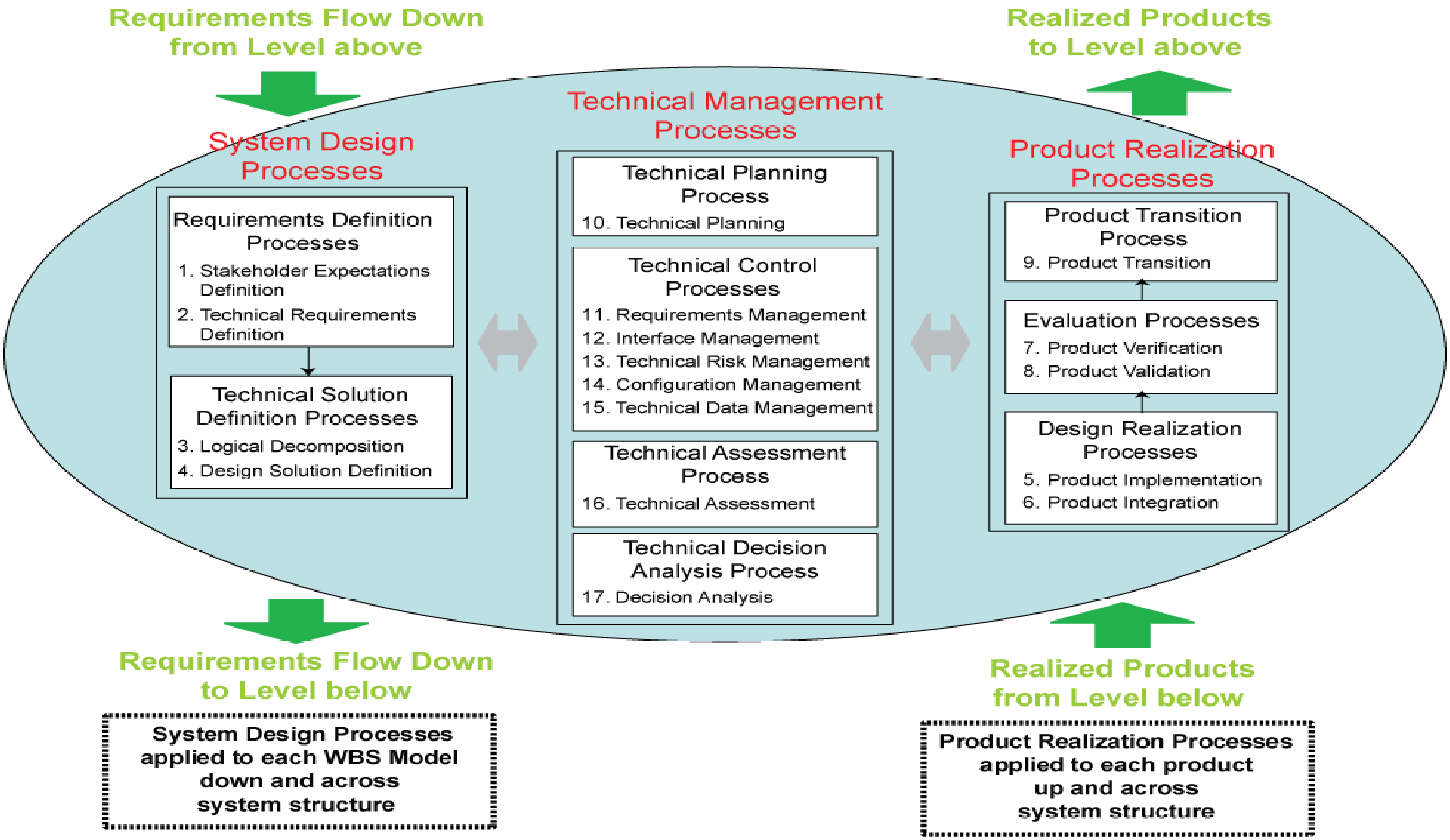
Safety and Mission Assurance Standards
- GSFC-STD-7000 General Environmental Verification Standard for GSFC Flight Programs and Projects
- MSFC-STD-3012 EEE Parts Management and Control for MSFC Space Flight Hardware

NASA Policy Directives (NPDs)—Agency policy documents that describe what is required by NASA management to achieve NASA's vision, mission, and external mandates and who is responsible for carrying out those requirements.

NASA Procedural Requirements (NPRs)—NPRs provide Agency-mandatory requirements to implement NASA policy as delineated in an associated NPD.

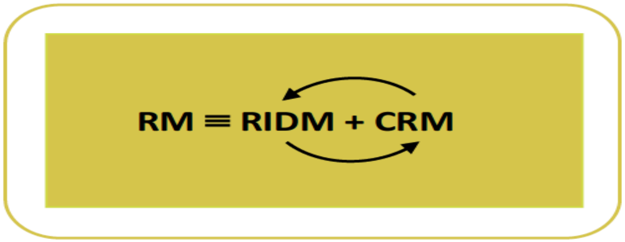
NASA Standards—Formal documents that establish a norm, requirement, or basis for comparison, a reference point to measure or evaluate against. A technical standard, for example, establishes uniform engineering or technical criteria, methods, processes, and practices. NASA standards include Agency-level standards as well as Center-level standards.

System Engineering Processes and Requirements



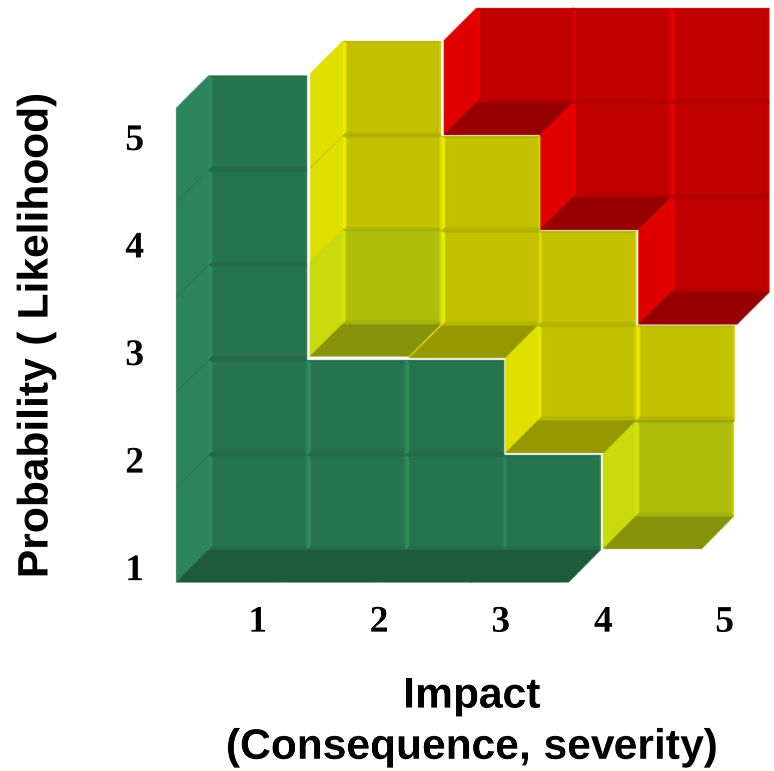
From NASA Procedural Requirements (NPR) 7123.1B, "NASA System Engineering Processes and Requirements", April 18, 2013.

Risk Management Processes and Requirements



- Two complementary processes, Risk-Informed Decision Making (RIDM) and Continuous Risk Management (CRM).
  - RIDM process addresses the risk-informed selection of decision alternatives to assure effective approaches to achieving objectives
  - CRM process addresses implementation of the selected alternative to assure that requirements are met.

Risk Assessment Report Matrix



Adapted from NASA Procedural Requirements (NPR) 7123.1B, "Agency Risk Management Procedural Requirements", December 16, 2008.

Mission Assurance (I)

- Infrastructure + Processes + Requirements
  - No shortcut to ensure mission success and mission safety
- System Engineering + Implementation Requirements
  - Mission assurance can only be addressed comprehensively
  - Requirements from agency level, center level, program level and project level
    - Formal waiver process

Mission Assurance (II)

- Balance between schedule, cost and sample size selection
- Ensure homogenous population
  - Traceability
  - Representative of flight parts
- Space qualification and screening at parts level, boards level, boxes level, subsystem level and system level, which includes the steps below:
  - Parts selection, conduct derating and worst-case-analysis, board inspection and acceptance, box inspection and acceptance, qualification or protoflight test.

NASA Risk Matrix (Inherent Risk)

Part Groups	Low	Medium	High	Unknown
General	NPSL Level 1 975 Grade 1	NPSL Level 2 975 Grade 2	NPSL Level 3 Vendor Flow	COTS
Actives	MIL Class S,V,K ESA/ECSS JAXA Class I	MIL Class B,Q,H ESA/ECSS JAXA Class II	MIL 883B QML M,N,T,D,E	COTS
Passives	MIL S/R Failure Rate ESA/ECSS JAXA Class I	MIL P Failure Rate ESA/ECSS JAXA Class II	MIL M/L Failure Rate DSCC Drawing	COTS

NPSL = NASA Parts Selection List, http://nepp.nasa.gov/npsl/npsl_toc.htm

From NASA EEE Parts Assurance Group

NASA Knowledge of EEE Parts

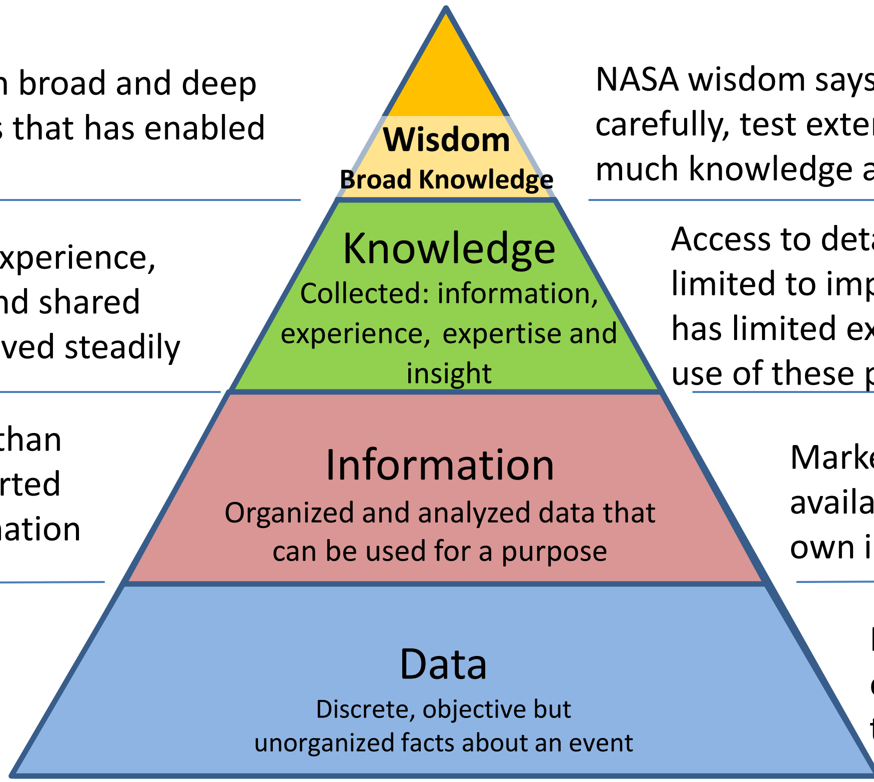
MIL/AERO/Hi Rel

NASA wisdom is based on broad and deep knowledge of these parts that has enabled reliable use for decades

Extensively documented experience, good and bad, collected and shared about parts that have evolved steadily

Data generated over more than 40 years analyzed and reported to provide extensive information

NASA has ready access to mandated data, common to all suppliers



COTS/Auto/Enhanced COTS

NASA wisdom says: use these parts very carefully, test extensively and gather as much knowledge as possible

Access to detailed information generally limited to important customers. NASA has limited experience with large-scale use of these parts

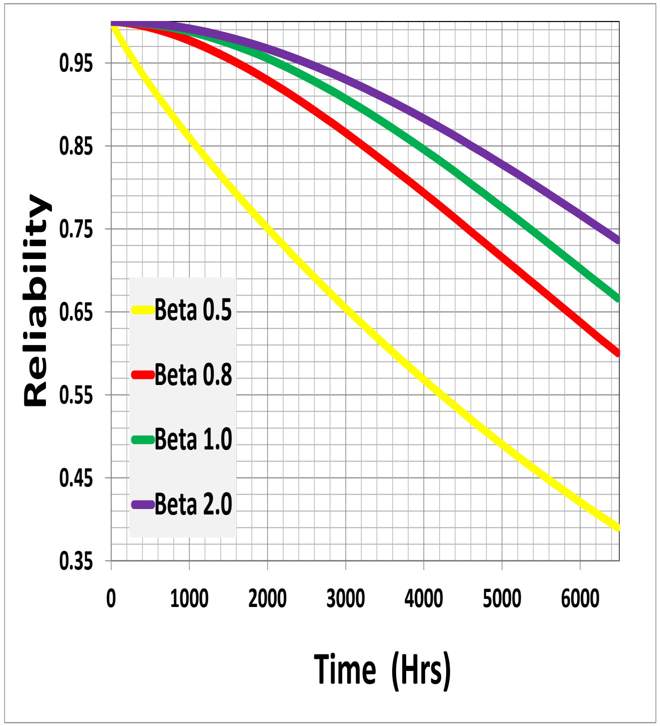
Market-focused reports available. NASA must generate own information

Manufacturers supply extensive data aimed at their target market

After Michael Sampson, NASA NEPP

Parts Level versus Boards/Boxes Level Testing

- Testing/screening/qualification at boards/boxes level cannot achieve the same level of confidence versus at parts level; some failure mechanisms cannot be appropriately or sufficiently accelerated.
- It has been demonstrated that even with the *same* MTTF, parts operating in infant mortality region yield *lower* level of the system reliability compared to the parts operating in the constant failure rate region.
- Boards/boxes level screening/qualification may replace parts level screening/qualification to a certain degree.
  - Criticality of the assembly
  - Level of uncertainty of technologies
  - Reliability requirement or risk acceptance level
- When a high level of reliability is required and/or the electronics and materials are not designed for the environment or the applications, which is the case for non-mil electronics, space qualification on both parts and boards/boxes level is typically required to minimize the risk and ensure mission assurance.



Y. Chen, et al, "On Component Reliability and System Reliability for Space Missions", IRPS 2012.

Summary

- Unique Reliability Challenges for Space Missions
  - Space environment
  - One-of-a-kind space systems
  - High level of reliability requirements
- Fundamental processes have been implemented and demonstrated to ensure mission assurance for space flight program at NASA.
  - Infrastructure + Processes + Requirements
    - No shortcut to ensure mission success and mission safety
  - System Engineering + Implementation Requirements
    - Balance between schedule, cost and sample size selection
    - Ensure homogenous population
      - Traceability
      - Representative of flight parts
    - Space qualification and screening at parts level, boards level, boxes level, subsystem level and system level

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