**CDH Subsystem Trade Studies**

The Command and Data Handling (CDH) subsystem serves as the backbone of any spacecraft, ensuring the ability to manage operations, process commands, and communicate effectively with mission control. For this design, four key components were evaluated: Command Processing Unit, Communication Interfaces (I2C, UART, CAN), Data Storage (Radiation-Hardened Memory), and Redundant Systems. Each component underwent a thorough assessment based on criteria such as cost, risk, performance, and complexity, enabling informed decisions for a reliable and efficient subsystem.

#### **1. Command Processing Unit Trade Study**

The Command Processing Unit (CPU) is responsible for executing spacecraft commands and ensuring synchronization between subsystems. The three options considered were the RAD750, LEON-3, and Space Cube processors. The trade study evaluated these CPUs based on four criteria: cost, risk, performance, and complexity.

| Command Processing Unit Trade Study | | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| **Criteria** | **Explanation** | **Grade** | **Weight** | **RAD750** | **LEON-3** | **Space Cube** |
| Cost | Overall cost of the command processing unit.  The total cost should not exceed $425M.Total cost of the CPU unit. Lower cost is preferred to remain within budget. | 10 = high,  5 = medium  1 = low  0 = Fail | 20% | 6 | 8 | 4 |
| Risk | Risk associated with potential failures and impact on mission success. | 10 = high,  5 = medium  1 = low  0 = Fail | 35% | 9 | 7 | 6 |
| Performance | Ability to meet processing requirements (1 second command execution).Processing speed and ability to handle complex commands efficiently. | 10 = high,  5 = medium  1 = low  0 = Fail | 30% | 8 | 7 | 9 |
| Complexity | Complexity of integration and operational usage within the spacecraft.Ease of integration with other subsystems. | 10 = high,  5 = medium  1 = low  0 = Fail | 15% | 7 | 6 | 8 |
|  |  | **TOTALS:** | **100%** | 77.5% | 70.5% | 65.5% |

The RAD750 scored the highest overall, primarily due to its strong performance in terms of risk and reliability. Developed by BAE Systems, it is a radiation-hardened processor and has been used in over 200 spacecraft, including NASA's Mars rovers . Its proven track record made it the top choice for missions requiring durability in harsh space environments. While the LEON-3 offers a cost-effective solution and is commonly used in ESA missions , its lower radiation tolerance and higher risk score placed it behind the RAD750. The Space Cube was the most advanced in terms of performance, offering superior data processing speeds, but its higher cost and unproven flight history made it less desirable.*The RAD750, a radiation-hardened processor developed by BAE Systems, has been used in over 200 spacecraft, including NASA’s Mars rovers (Good 2020).* This connects the claim about the processor to the source.

The weighting was influenced by mission priorities: risk (35%) was the most critical, given the harsh radiation conditions of space, followed by performance (30%) to ensure mission objectives could be met in real time. Cost (20%) and complexity (15%) were secondary considerations but still influenced the decision to select the RAD750, which offered the best balance of reliability and performance.

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#### **2. Communication Interfaces Trade Study**

Communication interfaces enable data transfer between different subsystems within the spacecraft. The protocols evaluated were I2C (Inter-Integrated Circuit), UART (Universal Asynchronous Receiver-Transmitter), and CAN (Controller Area Network).

| Communication Interfaces (I2C, UART, CAN) Trade Study | | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| **Criteria** | **Explanation** | **Grade** | **Weight** | **I2C** | **UART** | **CAN** |
| Cost | Overall cost of the communication interface.Total cost of the communication protocol implementation. | 10 = high,  5 = medium  1 = low  0 = Fail | 20% | 8 | 7 | 5 |
| Risk | Risk associated with potential communication failures and data loss. | 10 = high,  5 = medium  1 = low  0 = Fail | 35% | 6 | 7 | 9 |
| Performance | Ability to meet data transfer requirements and latency constraints.Data transfer rate and the ability to meet latency requirements for spacecraft operations. | 10 = high,  5 = medium  1 = low  0 = Fail | 30% | 7 | 6 | 8 |
| Complexity | Complexity of integration and operational usage within the spacecraft. Ease of implementation and compatibility with other subsystems. | 10 = high,  5 = medium  1 = low  0 = Fail | 15% | 8 | 7 | 6 |
|  |  | **TOTALS:** | **100%** | |  | | --- |  | 71% | | --- | | 66% | |  | | --- |  | **72.5%** | | --- | |

The CAN protocol emerged as the top choice due to its robustness and high fault tolerance, scoring 9 in risk. CAN is widely used in automotive and aerospace applications, where reliability and fault tolerance are paramount . Its ability to handle multiple devices while ensuring error detection and correction made it an ideal choice for space missions where communication must be fail-safe.  
I2C, while more cost-effective and simpler to integrate (rated 8 in cost and complexity), scored lower in terms of risk and performance. It is typically used for shorter-range communication between multiple devices on a single bus but may struggle in high-speed or long-range communications . UART, known for its simplicity and moderate performance, lacked the robustness needed for fault-tolerant communication in space, placing it third.  
The weighting for risk (35%) and performance (30%) was prioritized, given the need for reliable data transfer in critical spacecraft operations. Cost (20%) and complexity (15%) were considered secondary, as the robustness and reliability of the communication protocol were deemed more important for mission success.

#### **3. Data Storage Trade Study**

Reliable data storage is vital for spacecraft to handle mission-critical data. The memory options evaluated included Flash Memory, SRAM, and EEPROM.

| Data Storage (Radiation-Hardened Memory) Trade Study | | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| **Criteria** | **Explanation** | **Grade** | **Weight** | **Flash Memory** | **SRAM** | **EEPROM** |
| Cost | |  | | --- |  | Overall cost of the radiation-hardened memory solution. | | --- | | 10 = high,  5 = medium  1 = low  0 = Fail | 20% | 7 | 6 | 8 |
| Risk | Risk associated with data loss and memory corruption due to radiation. | 10 = high,  5 = medium  1 = low  0 = Fail | 35% | 5 | 9 | 7 |
| Performance | Ability to store and retrieve data reliably in harsh conditions. | 10 = high,  5 = medium  1 = low  0 = Fail | 30% | 8 | 7 | 6 |
| Complexity | Complexity of integration and usage in the spacecraft system. Ease of integration with the overall system. | 10 = high,  5 = medium  1 = low  0 = Fail | 15% | 8 | 7 | 6 |
|  |  | **TOTALS:** | **100%** | 66.5% | 76% | 68.5% |

SRAM (Static Random-Access Memory) was selected due to its high radiation tolerance and ability to store data in real-time applications . It scored 9 in risk, reflecting its resilience in space environments, making it ideal for long-duration missions. Although it is more expensive than other options, its performance (7) and complexity (7) were acceptable, and its reliability outweighed the cost concerns.

Flash Memory, while offering high storage capacity at a lower cost (7 in cost), posed significant risks in terms of radiation vulnerability (5 in risk). EEPROM (Electrically Erasable Programmable Read-Only Memory) offered a compromise between cost and risk but lacked the speed required for real-time data processing (scored 6 in performance). Ultimately, SRAM's superior radiation resistance and real-time capabilities made it the preferred choice for the mission.

Given the harsh conditions of space, risk (35%) was weighted heavily, followed by performance (30%) to ensure the storage solution could handle mission-critical data efficiently. Cost (20%) and complexity (15%) were secondary considerations, as reliability and data integrity were the primary concerns.

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#### **4. Redundant Systems Trade Study**

Redundant systems are essential to ensure mission success in the event of hardware failures. Three options were analyzed: Active Redundancy, Standby Redundancy, and No Redundancy.

| Redundant Systems Trade Study | | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| **Criteria** | **Explanation** | **Grade** | **Weight** | **Active Redundancy** | **Standby Redundancy** | **No Redundancy** |
| Cost | |  | | --- |  | Overall cost of implementing redundancy systems. | | --- | | 10 = high,  5 = medium  1 = low  0 = Fail | 20% | 4 | 7 | 9 |
| Risk | Risk associated with potential failures of redundant systems. | 10 = high,  5 = medium  1 = low  0 = Fail | 40% | 9 | 7 | 3 |
| Performance | Effectiveness in maintaining operation during failures of primary systems. | 10 = high,  5 = medium  1 = low  0 = Fail | 30% | 9 | 6 | 2 |
| Complexity | Complexity of integrating redundancy systems into existing spacecraft architecture. | 10 = high,  5 = medium  1 = low  0 = Fail | 10% | 6 | 7 | 9 |
|  |  | **TOTALS:** | **100%** | 79% | 68% | 47% |

Active Redundancy was selected as it offers the highest reliability (scoring 9 in both risk and performance). Active redundancy means that all systems run simultaneously, ensuring that a backup system can immediately take over in the event of failure, which is crucial for long-term space missions where maintenance and repairs are not feasible. Although it comes with higher costs and complexity (scoring 4 in both), the ability to avoid mission-critical failures justifies the investment. For example, in NASA missions, redundancy is often prioritized to ensure uninterrupted operation of essential systems. *According to the NASA Systems Engineering Handbook, redundancy is critical for mission success, particularly for long-duration or high-risk missions (Jackson 2018).* Given the mission's high stakes, active redundancy was deemed the best approach to safeguard the spacecraft against hardware failures and ensure operational longevity. This explains why active redundancy was selected in the trade study, emphasizing its importance despite its higher costs and complexity.

**Summary of Findings**

The trade studies conducted for the Command and Data Handling subsystem revealed a thoughtful and balanced approach to meeting the mission's stringent requirements. Each selected component was carefully evaluated to ensure optimal performance, reliability, and cost-effectiveness. The RAD750 was chosen as the Command Processing Unit due to its proven reliability in demanding space environments. For communication interfaces, I2C emerged as the best option, offering a practical balance of simplicity and cost savings while maintaining effective data transfer. In terms of data storage, SRAM was favored for its capability to handle real-time data processing, ensuring the system can respond swiftly to mission demands. Lastly, the decision to implement Active Redundancy underscores a commitment to mission reliability, ensuring that critical operations can continue seamlessly even in the event of hardware failures. Together, these selections provide a robust foundation for the CDH subsystem, capable of withstanding the challenges of space exploration.

**References**

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