34th Annual INCOSE international symposium

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Designing an Artificial Magnetic Field Generator

Model-Based Systems Engineering for Spacecraft Radiation Protection

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Abstract and Introduction

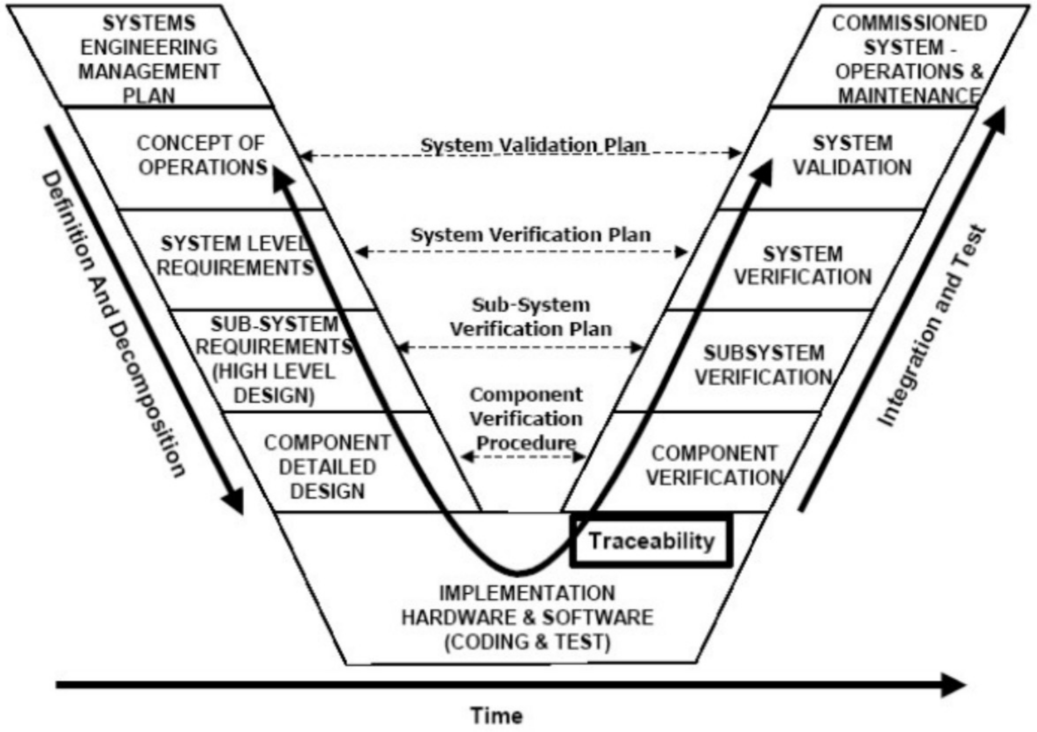
- **Context**: Space exploration faces significant challenges from cosmic and solar radiation, threatening equipment and astronaut health.
- **Solution Proposed**: Develop an artificial magnetic field generator to mimic Earth's protection mechanism.
- **Objective**: Demonstrate how MBSE can optimize the design and integration of advanced radiation protection systems.

Challenges of Traditional Methods

- **Limitations of Passive Shielding**: Heavy materials increase launch costs, limited effectiveness against high-energy particles.
- **Need for Innovation**: Exploring artificial magnetic fields as dynamic, adjustable protection against varied radiation threats.

MBSE Approach

- **Definition**: MBSE uses integrated models instead of traditional document-centric approaches, facilitating comprehensive system analysis.
- **Tools Used**: Employing Cameo Systems Modeler and Systems Modeling Language (SysML) to enhance design precision and stakeholder communication.
- **Benefits**: Unified visualization of complex systems, enhanced communication among stakeholders, streamlined validation and verification processes.



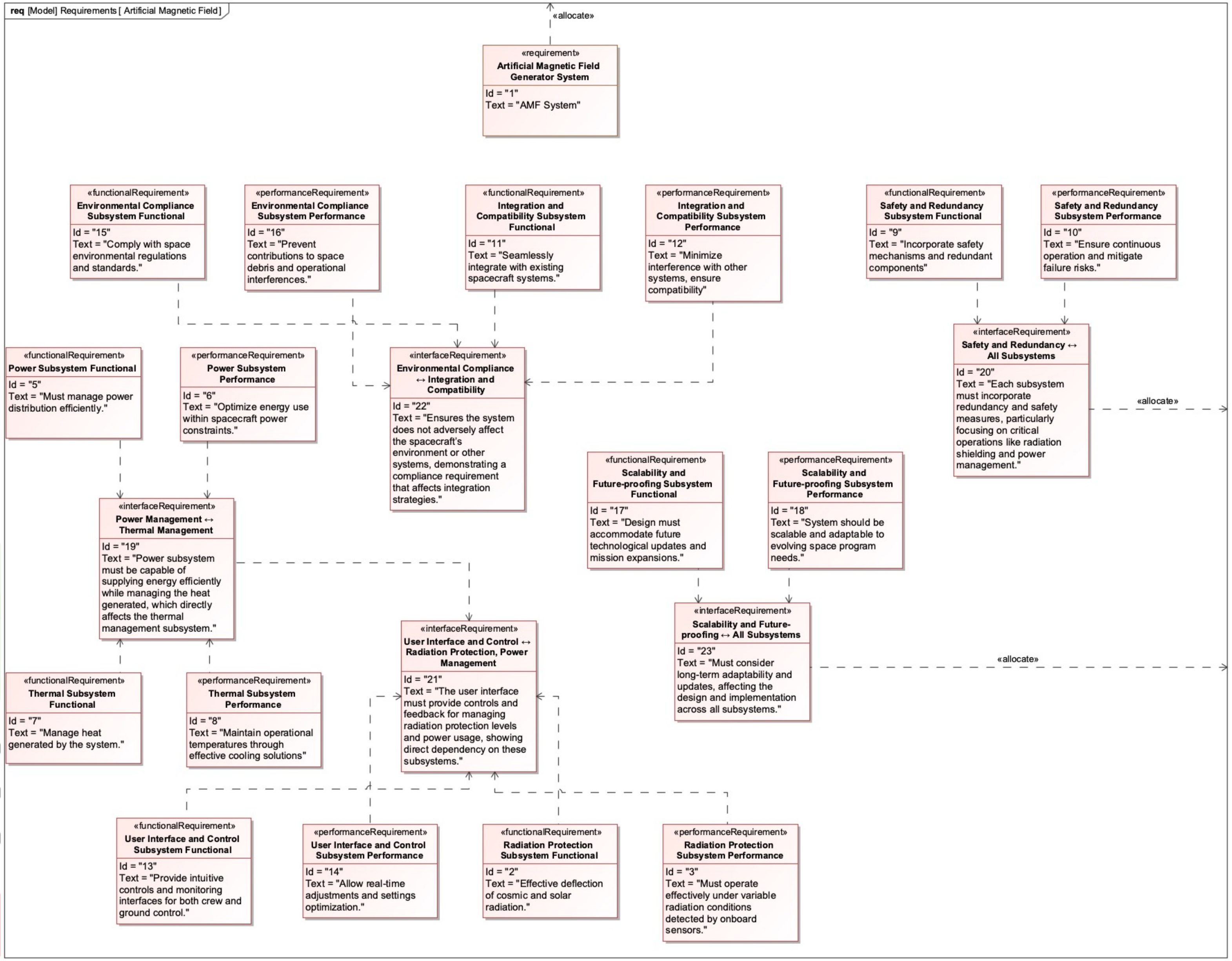
MBSE lifecycle, from requirements gathering through to system validation and operation. (Wasserman, 2014)

MBSE organizes and visualizes system requirements and components.

Functional and Performance Requirements

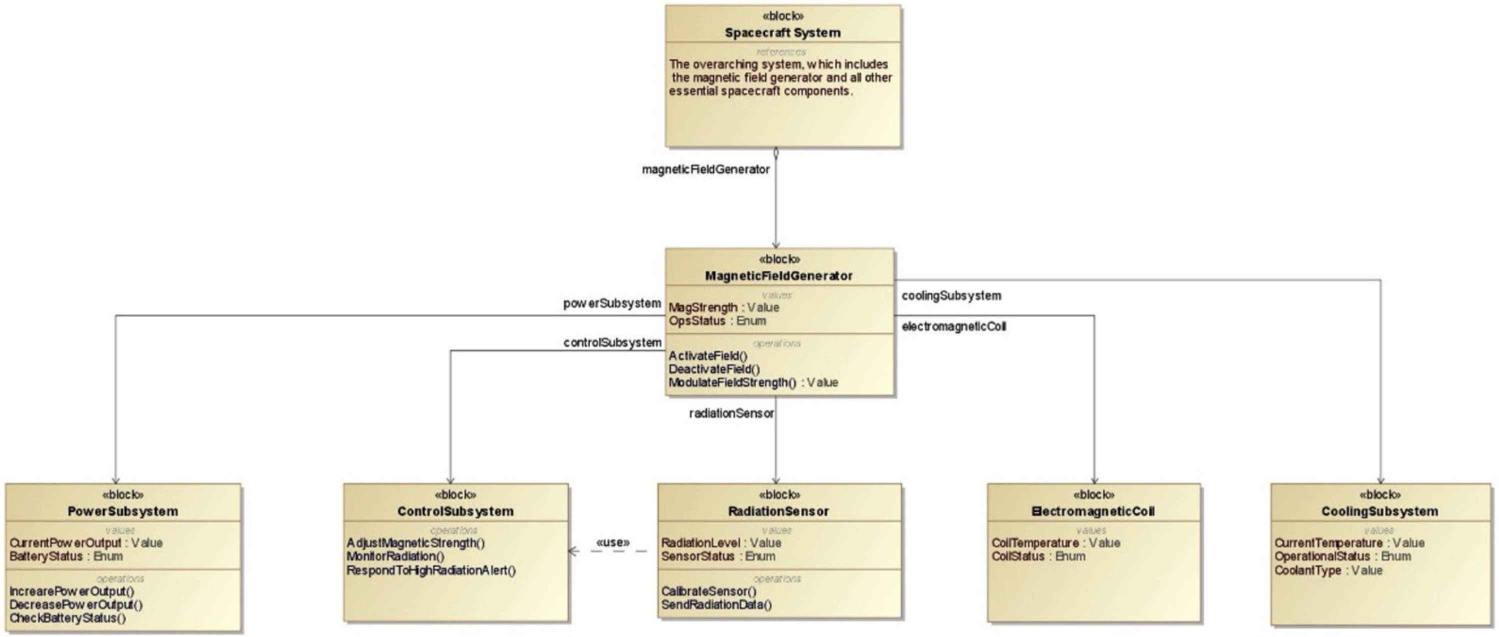
Requirement diagrams illustrate how MBSE organizes and visualizes system requirements and components.

The full listing of Functional and Performance requirements for this project are listed in the backup section.



System Components and Functionality

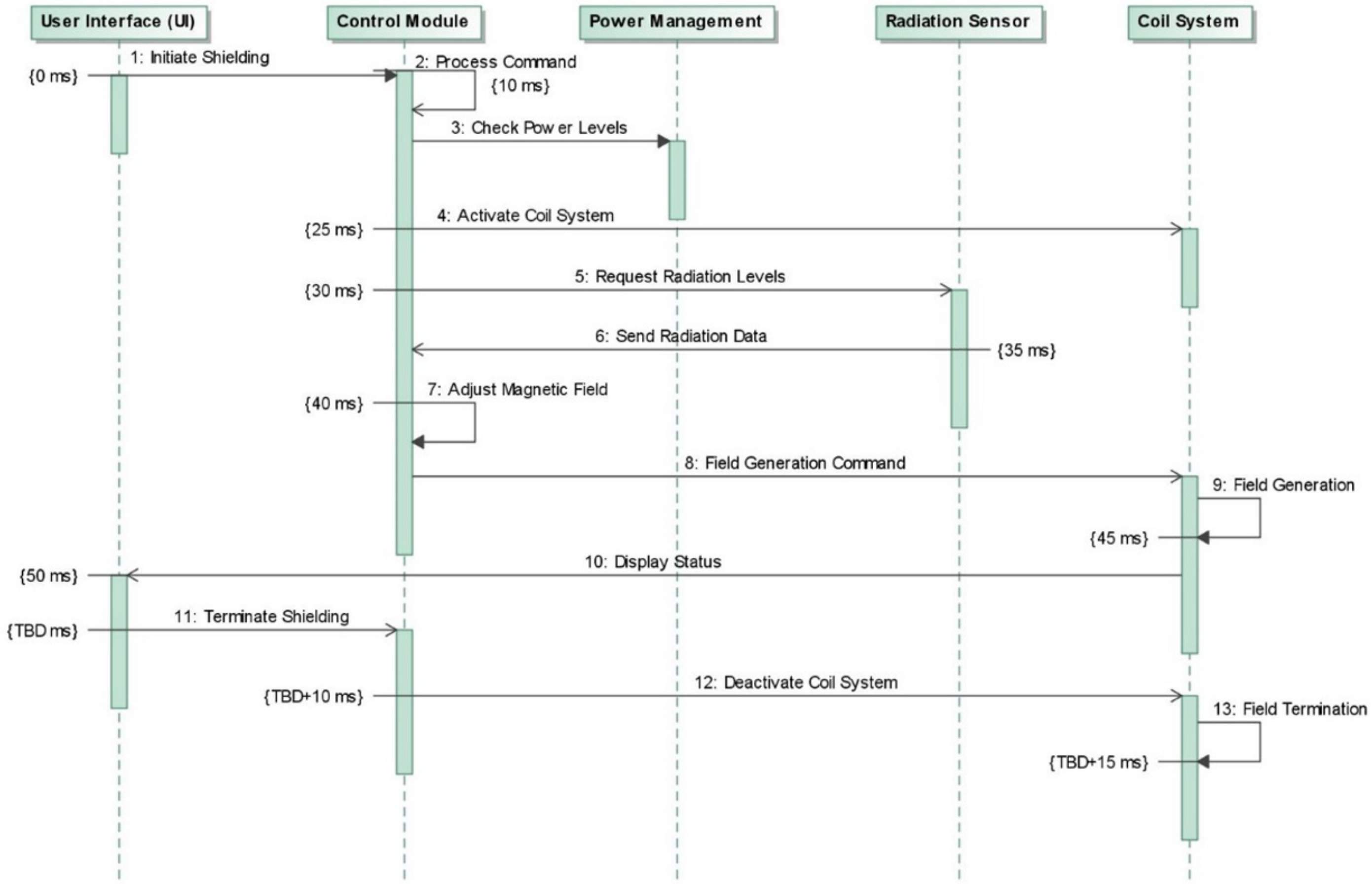
- **Main Components**: Includes Radiation Monitoring, Magnetic Shielding, Power Management, System Health & Diagnostics, Crew Communication.
- **Interactions and Services**: Describes how components such as the electromagnetic coils and control systems interact and the services they provide such as monitoring and power management.



MBSE illustrates how different system components like Radiation Monitoring, Magnetic Shielding, and Power Management are interconnected.

Methodology

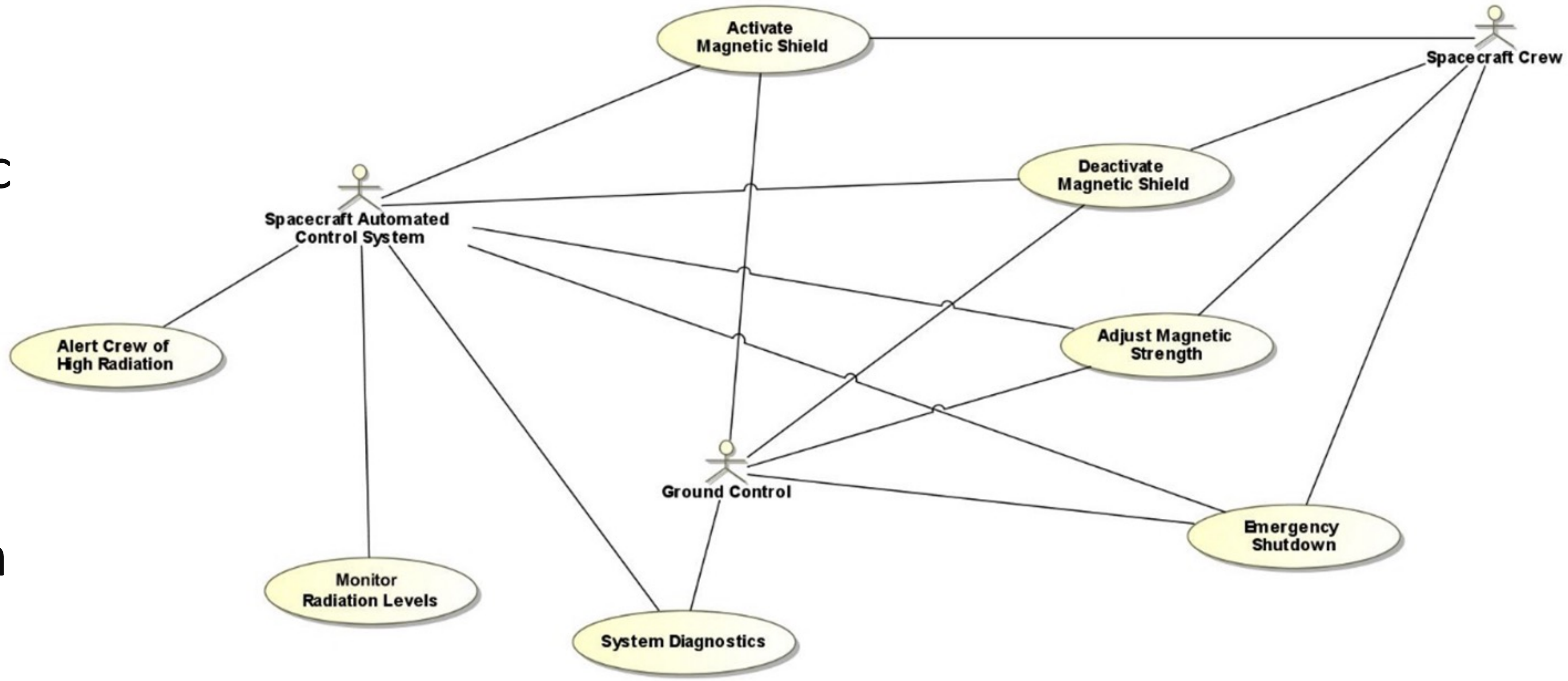
- **Modeling Techniques**: Application of SysML for creating detailed block definitions, activity diagrams, sequence diagrams, and internal block diagrams.
- **Operational Flow**: Illustrates system operations under varying radiation conditions and power scenarios, ensuring adaptive performance.



This sequence diagram highlights the interactions between system components over time, and is especially useful for showing dynamic behavior in response to changing radiation levels or power statuses.

Relevance to Project

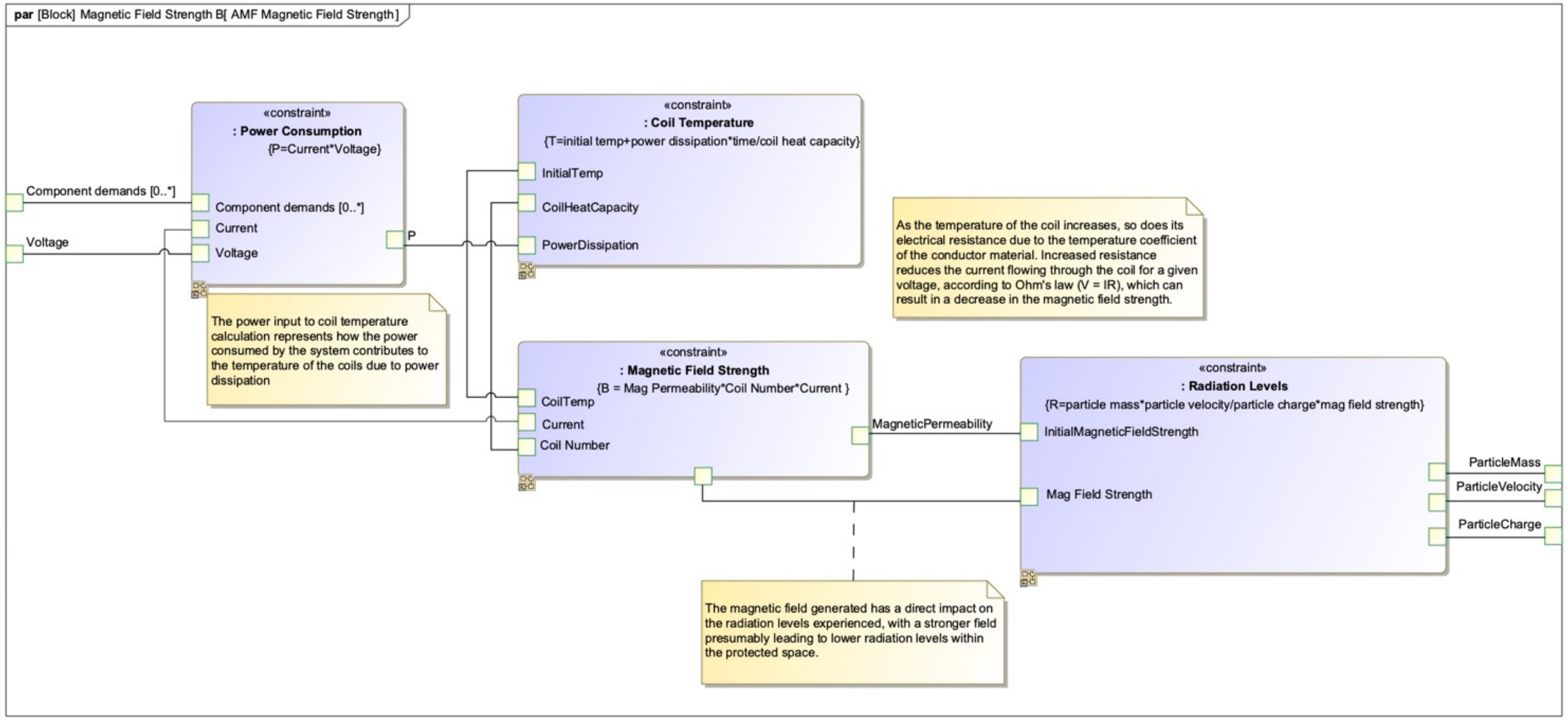
- **Specific Application**: Focus on designing electromagnetic coil systems capable of generating protective magnetic fields around spacecraft.
- **Predictive Capability**: System simulations help refine designs preemptively, identifying potential issues before they arise in real-world applications.



Use case diagrams show how different users (like astronauts and ground control personnel) will interact with the system, highlighting the system's functionality and user interfaces.

Results and Validation

- **Simulation Results**: MBSE models confirm the system's ability to meet predefined operational criteria and adapt to changing space radiation environments.
- **Adaptability and Scalability**: Demonstrates the system's flexibility to incorporate future technological advancements and mission-specific requirements.



Parametric diagrams show how parameters are linked within the system and how simulations are used to validate system performance against requirements.

Conclusion

- **Summarization of Benefits**: MBSE offers a systematic approach to managing complex system designs, improving reliability and performance in hostile environments.
- **Future Applications**: Potential expansion of MBSE applications in other aerospace projects and complex system integrations.
- (MBSE) provides frameworks and methodologies for quantitatively assessing the benefits of its application to aerospace projects, such as the design of systems like artificial magnetic field generators.

References

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Backup Slides

Requirements

Functional Requirements:

1. **Radiation Protection Effectiveness**: The system must generate a magnetic field strong enough to deflect solar and cosmic radiation effectively, mimicking Earth's magnetosphere.
2. **System Integration and Compatibility**: The magnetic field generator must integrate seamlessly with existing spacecraft systems without causing interference or requiring significant modifications to other systems.
3. **Operational Reliability**: The system should have high reliability, maintaining functionality with minimal maintenance over long-duration missions.
4. **Power Efficiency**: The generator must operate within the spacecraft's power budget, optimizing energy consumption without compromising performance.
5. **Safety and Redundancy**: Safety mechanisms must be in place to protect the spacecraft and its crew from system malfunctions or failures. Redundant systems should ensure continuous operation in case of component failures.
6. **Weight and Space Constraints**: The design must consider the weight and space limitations of spacecraft, ensuring that the generator does not adversely affect launch and operational parameters.
7. **Thermal Management**: Efficient cooling systems must be designed to manage the heat generated by the system, maintaining optimal operating temperatures.

Performance Requirements:

1. **Adaptability to Varying Radiation Conditions**: The system must adapt its protective measures in response to fluctuating radiation levels, providing dynamic protection based on real-time environmental data.
2. **User Interface and Control**: An intuitive user interface should allow crew members and ground control to monitor and control the magnetic field generator system, adjusting settings as needed for different mission phases or in response to specific threats.
3. **Environmental Compliance**: The system must comply with space environmental standards and regulations, ensuring that it does not contribute to space debris or interfere with other spacecraft operations.
4. **Scalability and Future-proofing**: The design should allow for updates and scalability based on future technological advancements and mission requirements, supporting a long-term, evolving space program.
5. **System Diagnostics and Health Monitoring**: Integrated diagnostics should monitor system health, automatically detecting, reporting, and addressing potential issues before they lead to system failures.
6. **Interoperability with Communication Systems**: The magnetic field generator must not disrupt onboard communication systems; design considerations must include electromagnetic compatibility (EMC) to prevent interference with data transmission.
7. **Documentation and Traceability**: Comprehensive documentation must be maintained for all system aspects, ensuring traceability from requirements through to design, implementation, and operation. This documentation is essential for system certification and future upgrades.