Development and Application of the CubeSat System Reference Model

Space Systems Working Group (SSWG)

Co-Chairs

David Kaslow

david.kaslow@gmail.com

Alejandro Levi

alejandro.g.levi@ieee.org

CubeSat System Reference Model Project

- CSRM Project Objectives
- CSRM Foundation
- CSRM Fundamental Elements
- CSRM as an OMG Specification
- CSRM Application
- CSRM Architecture
- CSRM and Mission Engineering
- References

CubeSat unit is 10x10x10 cm and about 1.3 kg

Originated 1999 – Stanford Univ and Cal Poly Univ

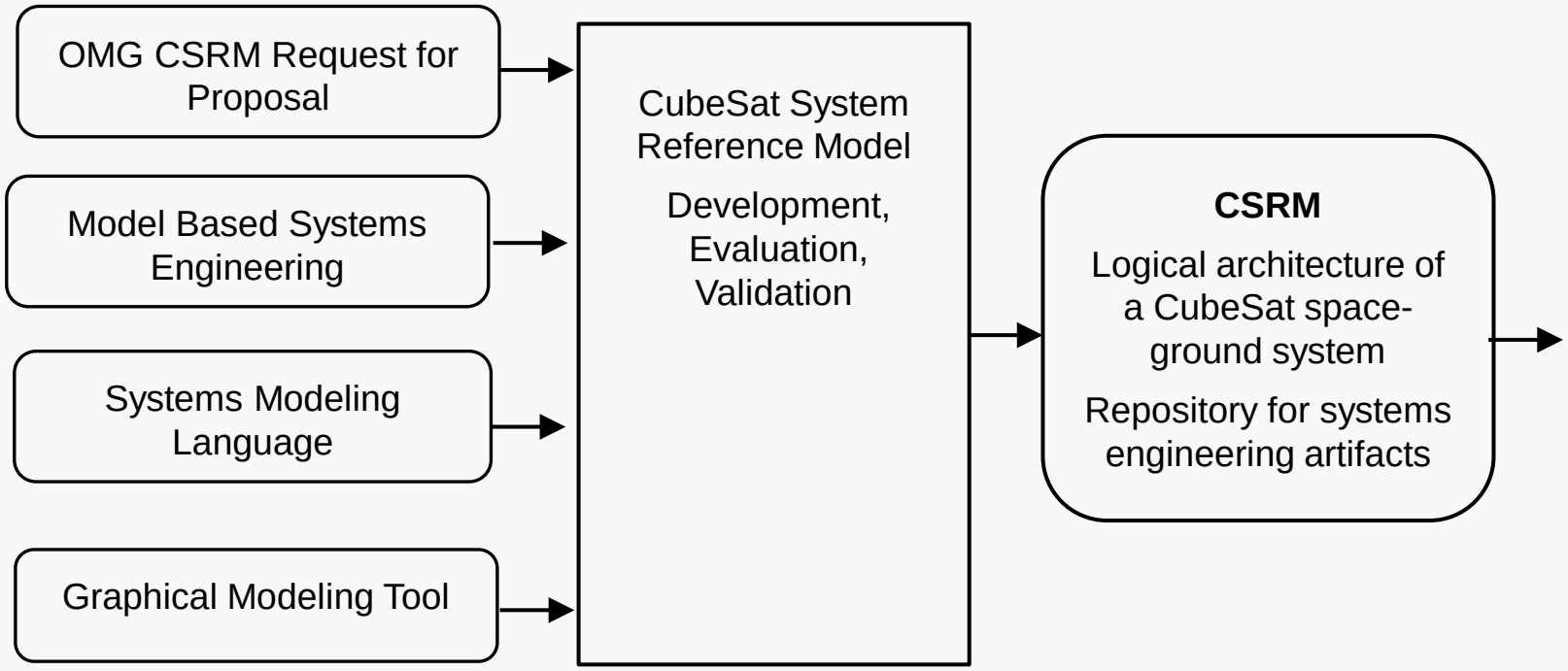
CSRM Project Objectives

- International Council on Systems Engineering (INCOSE) Space Systems Working Group (SSWG) project
- Objectives of CSRM Project
  - Demonstrate Model-Based Systems Engineering (MBSE) as applied to a CubeSat Mission
  - Develop a CSRM that a university team can uses as starting point for their mission-specific model
  - Develop the CSRM as an Object Management Group (OMG) Specification

The CSRM architecture can be applied to SmallSats

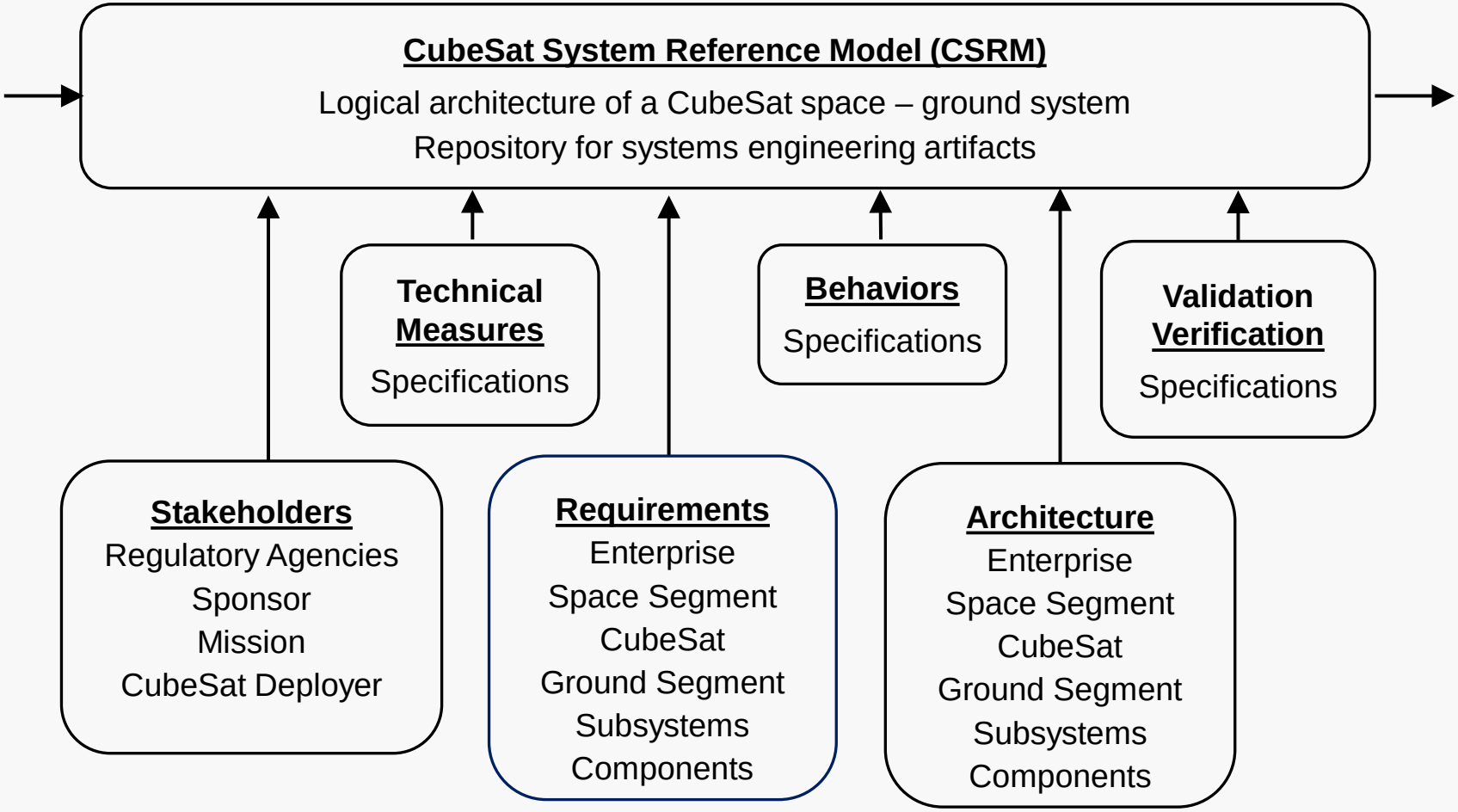
Can the CSRM concept be extended to Mission Engineering?

CSRM Foundation



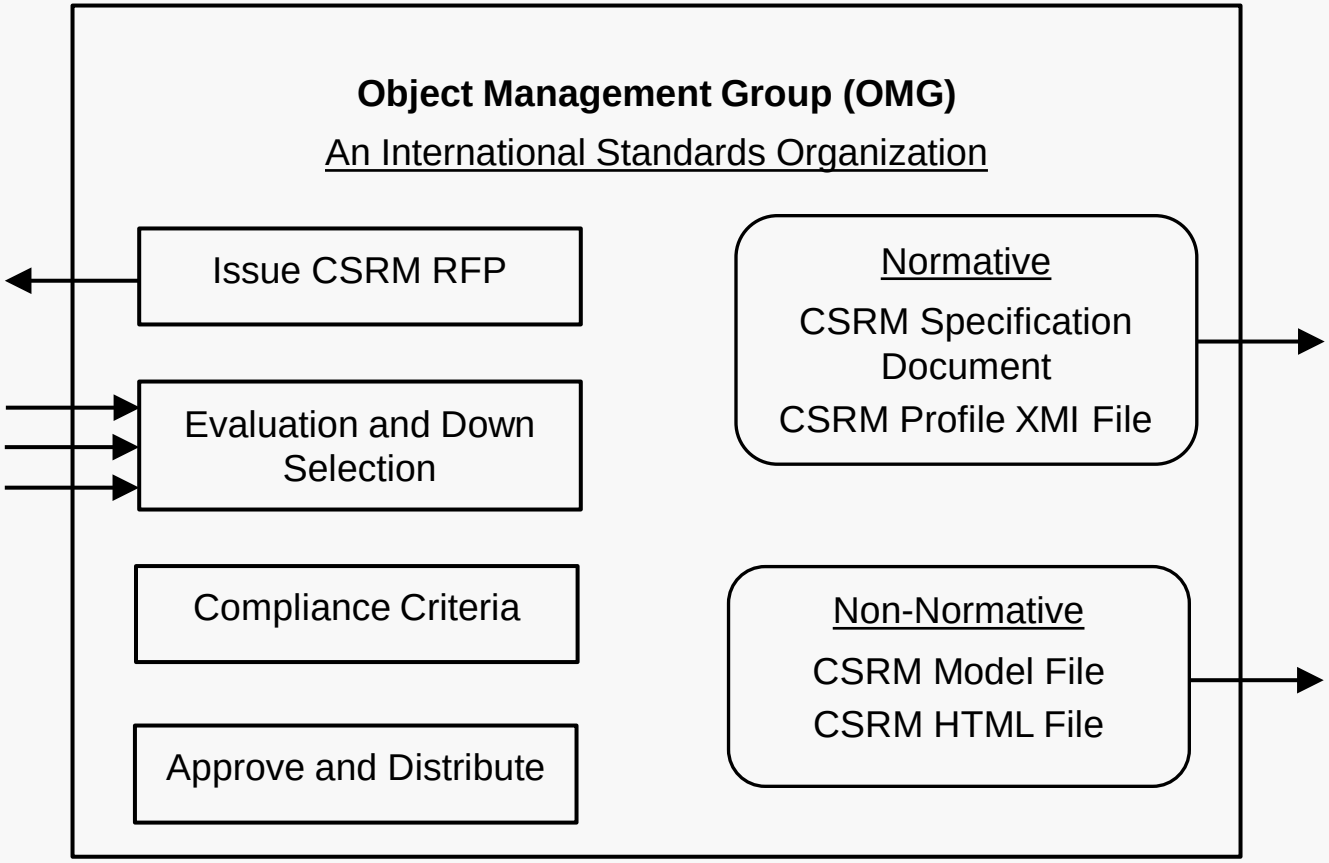
A foundation for a mission-specific logical model

CSRM Fundamental Elements



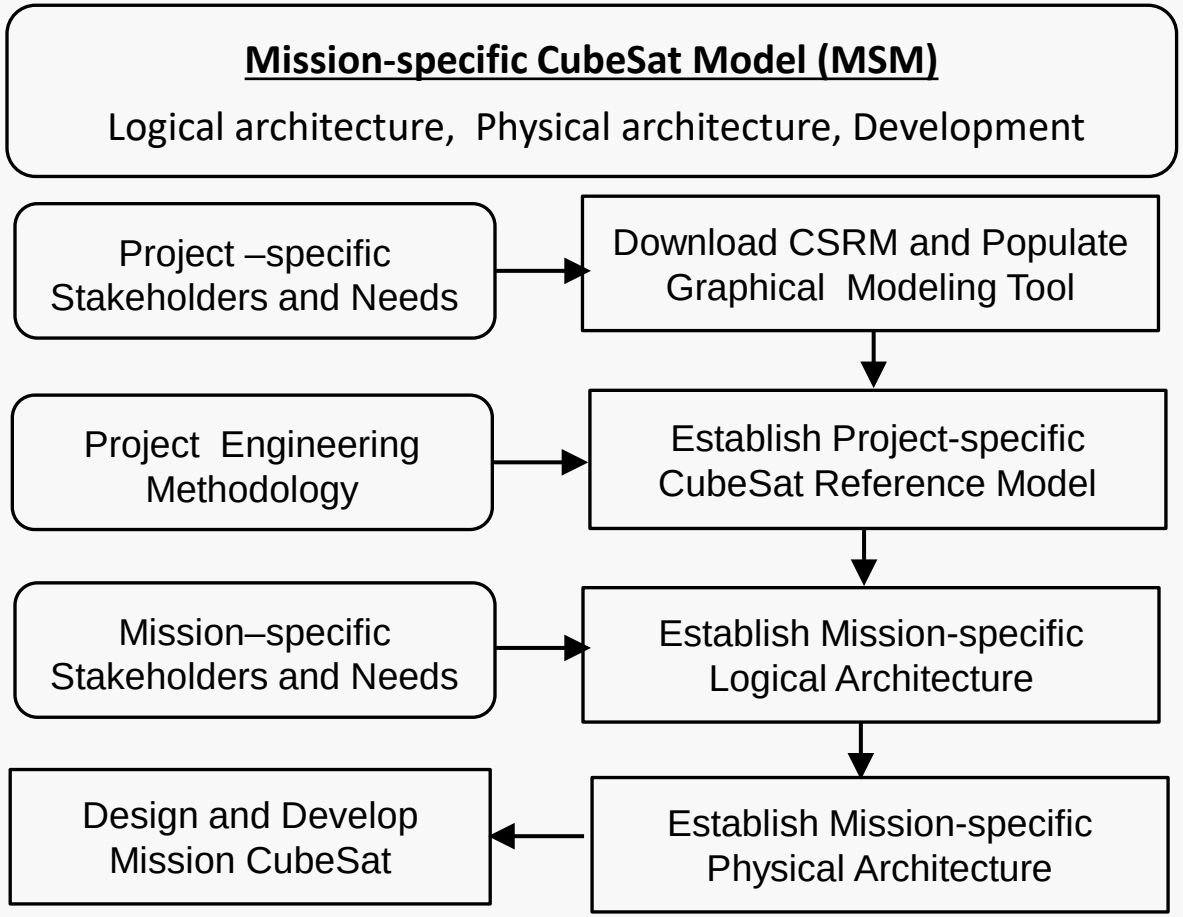
An exo-structure for population with mission-specific elements

CSRM as an OMG Specification



In the past, OMG Specifications have been entirely document-based

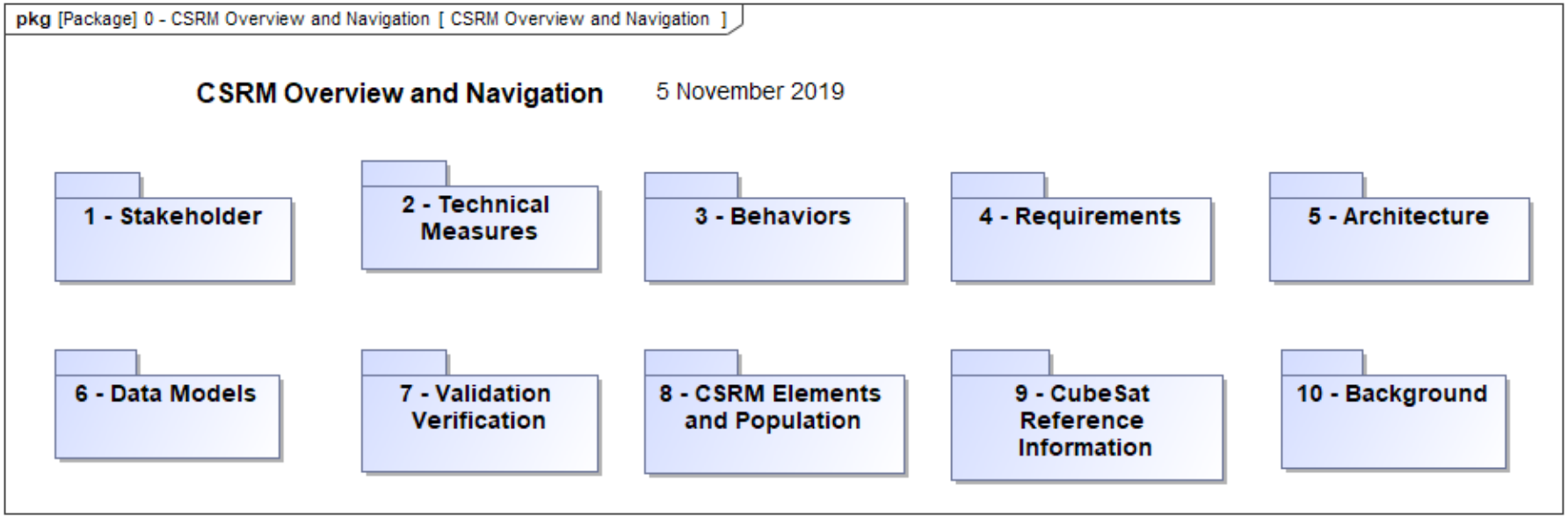
CSRM Application



The CSRM has sufficient flexibility for the mission team to modify the logical architecture for the mission and systems engineering methodology

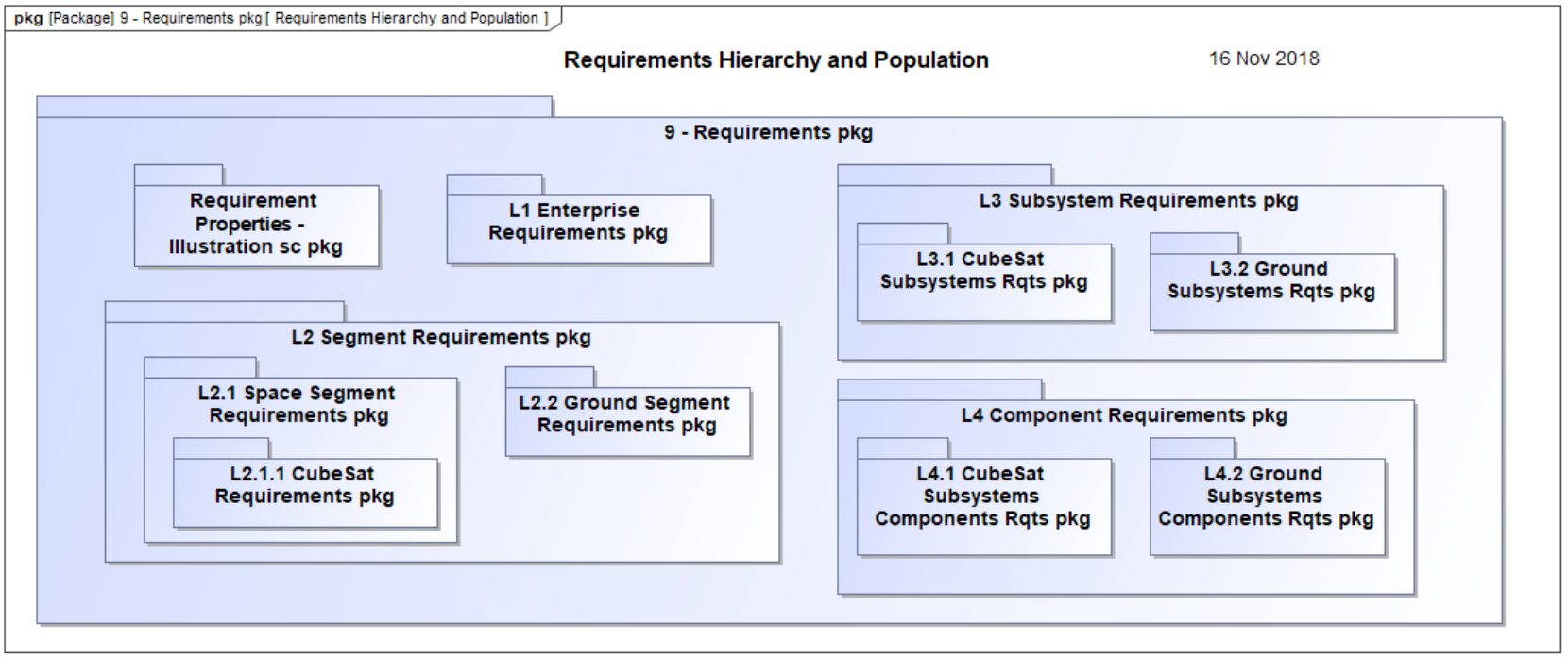
CSRM Architecture

CSRM Landing Page



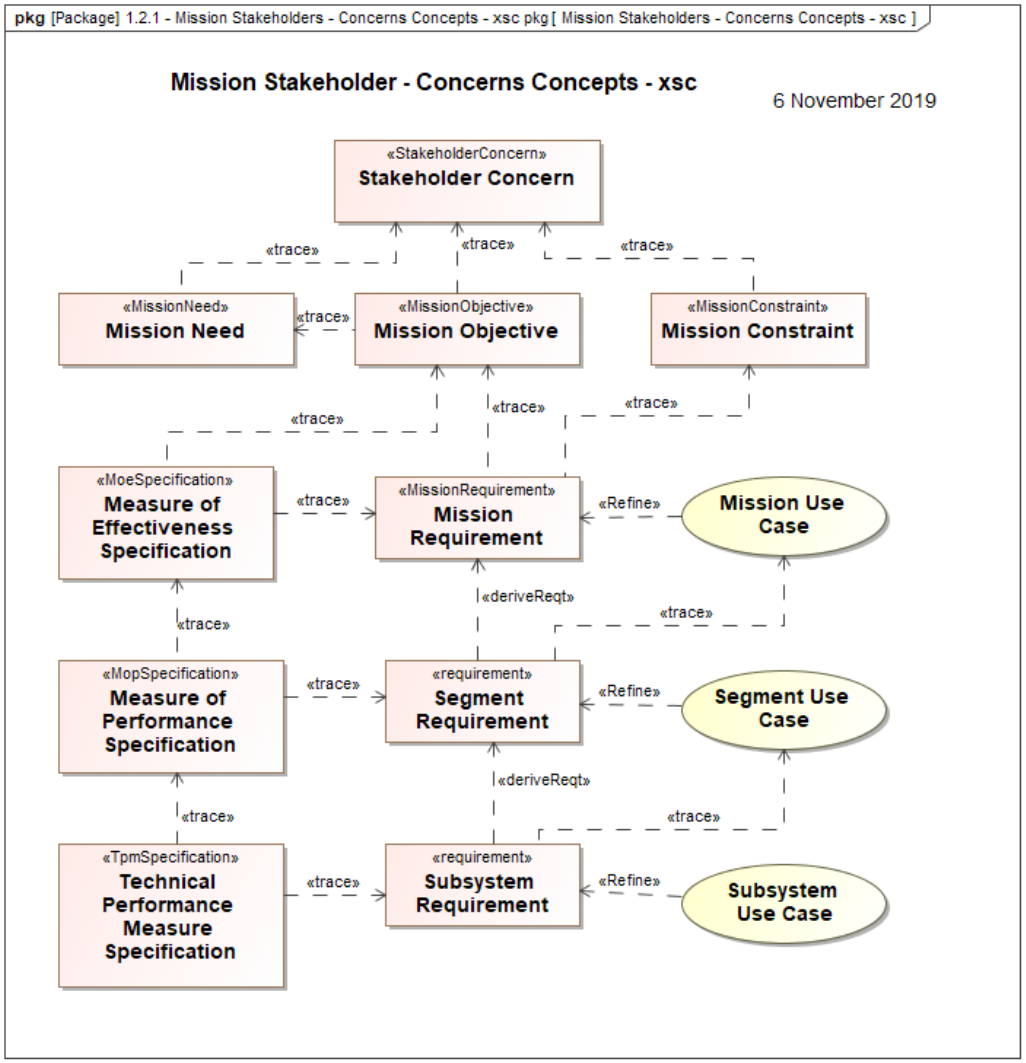
The CSRM landing page provides for an overview and navigation including the requirements and architecture hierarchies

Requirements Hierarchy

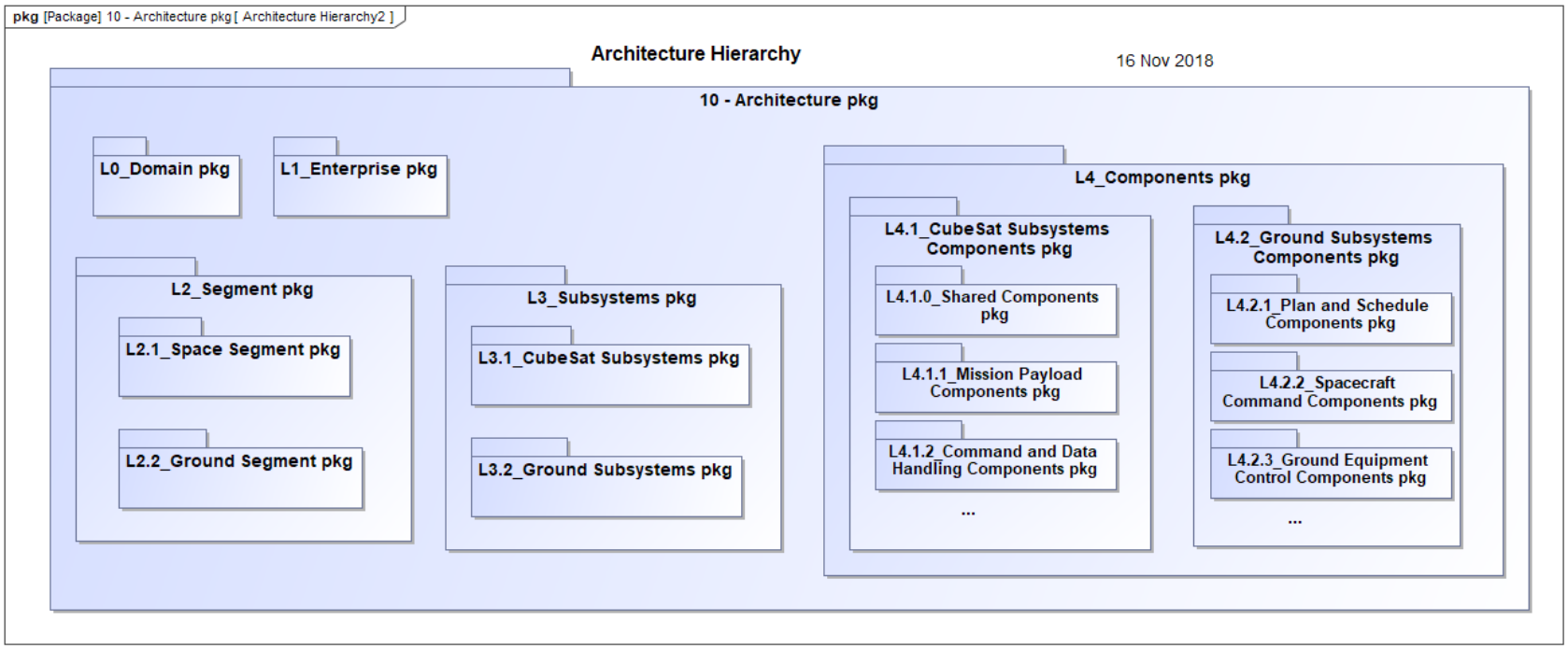


CSRM provides for defining and tracing requirements from stakeholders, use cases, technical measures down to subsystems and components and to validation and verification activities

Requirements Hierarchy

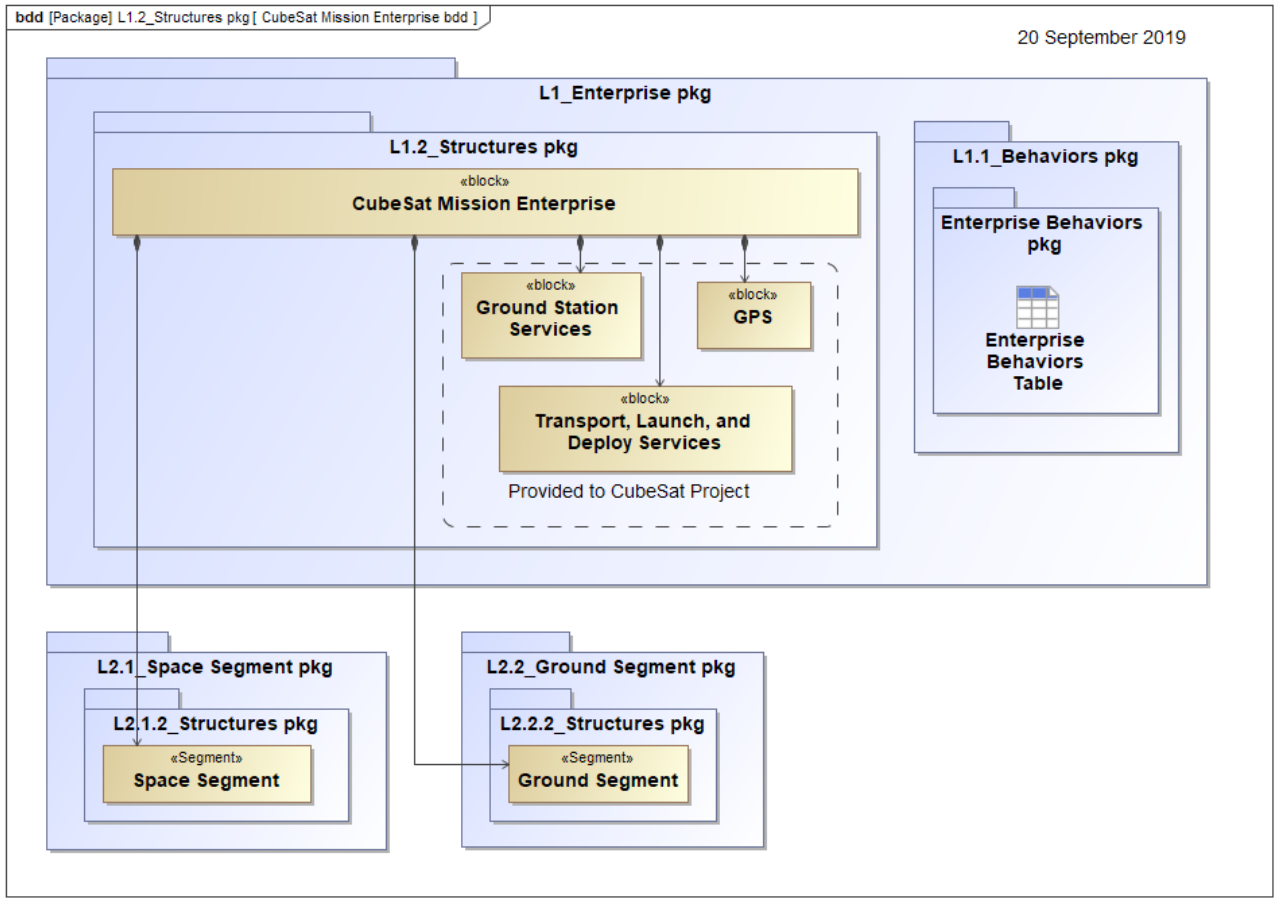


Architecture Hierarchy



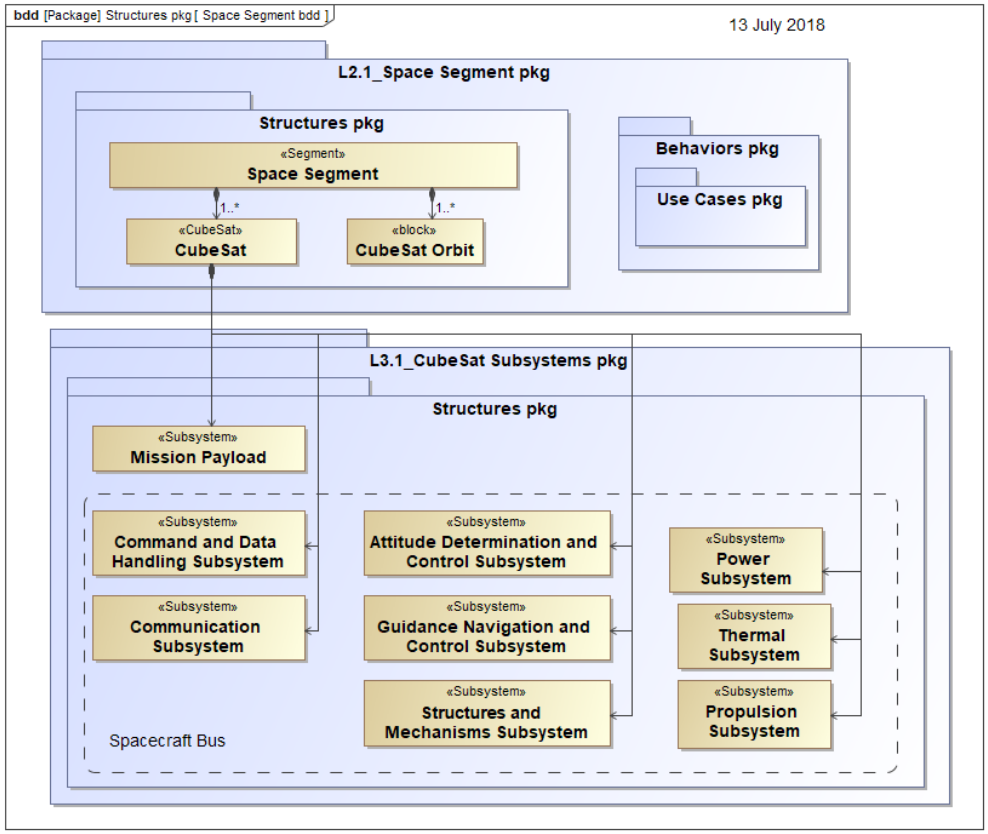
CSRM logical architecture provides the starting point for a mission-specific team establishing their logical and physical architectures

CubeSat Mission Enterprise



CSRM provides for both space and ground capabilities and external services

Space Segment and CubeSat Subsystems



The mission team specifies subsystem capabilities and whether they are provided by software, hardware, persistent data, or operator procedures

Next Steps - Mission Engineering

The SSWG will explore how the approaches and methodologies used in the development of the CSRM can be applied to Mission Engineering.

CSRM and Mission Engineering

- The following activities are proposed:
  - Identify Mission Engineering MBSE methodologies
  - Identify the key elements of terminology, and map/align with the CSRM terminology for each methodology
  - Analyze the CSRM for additional artifacts which could be added to the containment tree for the key elements that do not map to the CSRM
  - Assess whether the CSRM is the right tool to support this aspect of the methodology
  - Provide the results of the above analysis to INCOSE and OMG with recommendations for implementation

Carry-out a CSRM gap-like analysis relative to accommodating mission engineering threads

Identify Mission Engineering Methodologies

Space Mission Analysis and Design

Space Mission Engineering is the refinement of requirements and definition of mission parameters to meet the broad objectives of a space mission in a timely manner at minimum cost and risk

DoD Mission Engineering Handbook

Mission Engineering is the deliberate planning, analyzing, organizing, and integrating of current and emerging operational and system capabilities to achieve desired warfighting mission effects

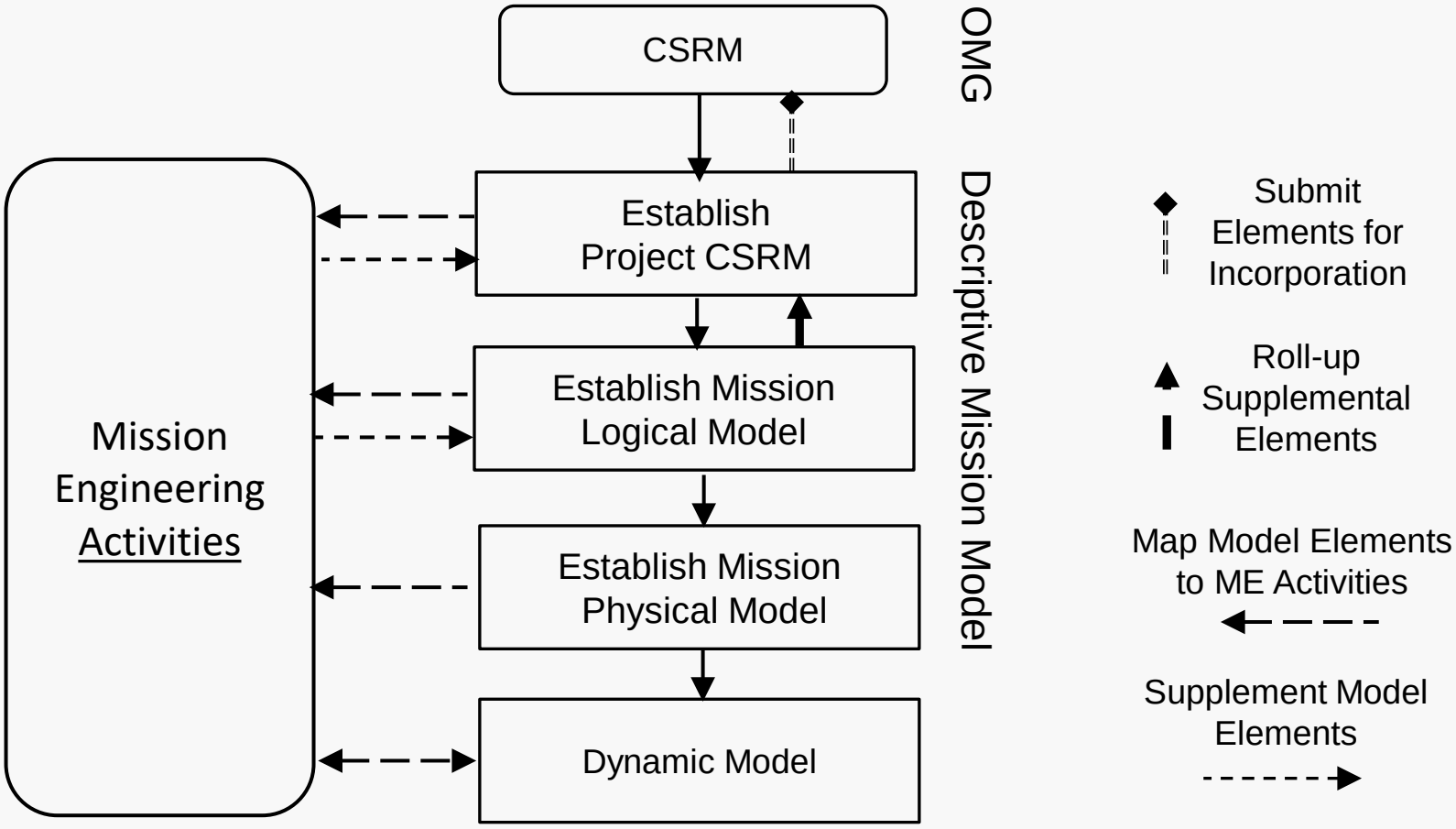
INCOSE Systems Engineering Book of Knowledge

Mission Engineering describes the application of systems engineering to the planning, analysis, and designing of missions where the mission is the System of Interest

Mission Engineering analyzes the mission goals and threads, analyzes the available as well as emerging operational and system capabilities, and designs a mission architecture to achieve the mission goal

Different domains have different mission engineering methodologies

Mission Engineering Scope



Architecting for Mission Engineering

INCOSE Mission Engineering

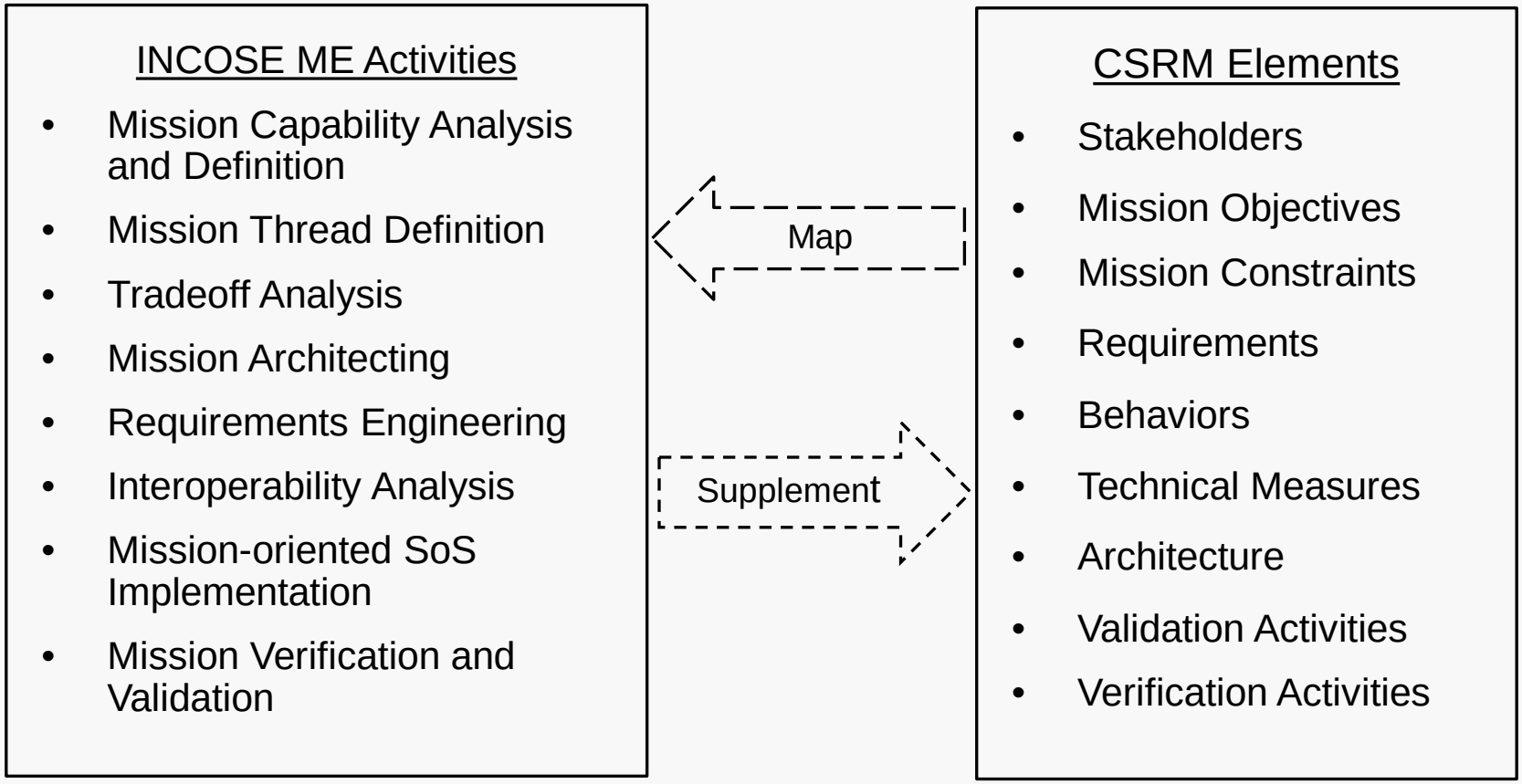
- The INCOSE Systems Engineering Body of Knowledge (SEBoK) defines Mission Engineering as:

  "the application of systems engineering to the planning, analysis, and designing of missions where the mission is the system of interest".

- Where Mission Engineering:
  - Analyzes the mission goals and threads
  - Analyzes the available as well as emerging operational and system capabilities
  - Designs a mission architecture to achieve the mission goal

INCOSE Mission Engineering Activities will be used to kick-off this process

Map and Supplement CSRM Elements



The focus is on logical model that will be populated as a physical model

Mission Engineering – CSRM and System of Systems

- Two of the mission Engineering Activities will be particularly challenging to explore
  - Interoperability Analysis
  - Mission-oriented SoS Implementation Activities
- Our paper outlines the SoS issues as presented in the INCOSE SoS Primer
- SoS architecture issues can be broadly categorized as to the roles of the constituent system
  - The constituent system provides technical data and an interface must be established
  - The constituent system provides a capability that needs to be modeled and integrated with the operations of other constituent systems.

Mission Engineering - Next Steps

- Outreach for additional Mission Engineering Methodologies:
  - 2021 INCOSE International Workshop
  - 2021 IEEE Aerospace Conference
  - 2021 Small Sat Conference

- Coordination with INCOSE Working Groups:
  - Enterprise Systems
  - System of Systems
  - Model-Based Conceptual Design

References

References

- D. Kaslow, S. Spangelo, L. Anderson, E. Fosse, C. Delp, B. Cole, B. Gilbert, L. Hartman, T. Kahn, and J. Cutler, “Applying MBSE to a Standard CubeSat,” *Proceedings of IEEE Aerospace Conference*, Big Sky, MT, March 2012.
- D. Kaslow, S. Spangelo, G. Soremekun, L. Anderson, E. Fosse, R. Yntema, M. Bajaj, C. Delp, B. Cole, J. Cutler, and L. Cheng, “MBSE Applied to RAX CubeSat Mission Operational Scenarios,” *Proceedings of IEEE Aerospace Conference*, Big Sky, MT, March 2013.
- D. Kaslow, G. Soremekun, H. Kim, and S. Spangelo, “Integrated Model-Based Systems Engineering (MBSE) Applied to the Simulation of a CubeSat Mission*,” Proceedings of IEEE Aerospace Conference*, Big Sky, MT, March 2014.
- D. Kaslow and A. Madni, “Validation and Verification of MBSE Compliant CubeSat Reference Model,” *Proceedings of 15th Annual Conference on Systems Engineering Research*, 2017.
- D. Kaslow, B. Ayres, P. Cahill, L. Hart, and R. Yntema, “A Model-Based Systems Engineering (MBSE) Approach for Defining the Behaviors of CubeSats,” *Proceedings of IEEE Aerospace Conference*, Big Sky, MT. 2017.
- D. Kaslow, B. Ayres, P. Cahill, L. Hart, Croney, L Hart, A. Levi. “Developing a CubeSat Model-Based Systems Engineering (MBSE) Reference Model – Interim Status #4,” *Proceedings of AIAA Space Forum.* Orlando, FL. 2018

References

- D. Kaslow, B. Ayres, P. Cahill, and L. Hart, “A Model-Based Systems Engineering Approach for Technical Measurement with Application to a CubeSat,” *Proceedings of IEEE Aerospace Conference,* Big Sky, MT. 2018.
- D. Kaslow, P. Cahill, and R. Frank. “Developing a CubeSat System MBSE Reference Model – Interim Status #5,” *Proceeding of AIAA/USU Conference on Small Satellites,* Logan, UT. 2019.
- D. Kaslow, P. Cahill, and B. Ayres, “Development and Application of the CubeSat System Reference Model”, *Proceedings of IEEE Aerospace Conference,* Big Sky, MT. 2020.
- D. Kaslow, A. Levi, P. Cahill, B. Ayres, D. Hurst, C, Croney, “Mission Engineering and the CubeSat System Reference Model”, *Proceedings of IEEE Aerospace Conference,* Big Sky, MT. 2021.
- J.R. Wertz, D. Everett, and J. Puschell, Eds., *Space Mission Engineering: The New SMAD*, (Space Technology. Library, Volume 28), Hawthorne, CA, Microcosm Press, 2011.
- INCOSE Guide to the Systems Engineering Body of Knowledge v. 2.3, October 2020.
- INCOSE Systems of Systems Primer, INCOSE-TP-2018-003-01.1, 2018
- *Mission Engineering Guide*, Office of the Under Secretary of Defense for Research and Engineering, November 2020.

Thank You

If you have any questions,
please feel free to contact us

David Kaslow
david.kaslow@gmail.com

Alejandro Levi
alejandro.g.levi@ieee.org