Mission Engineering and the CubeSat System Reference Model – Status #1

David Kaslow
DEKaslow Consulting
Newtown Square, PA 19073
610-405-6685
david.kaslow@gmail.com

Alejandro Levi
INCOSE Space Systems Working Group
Alejandro.G.Levi@ieee.org
orcid.org:
0000-0001-8450-8597

Chuck Croney
Consultant
Fort Washington, PA 19034
215 880-4422
chuck.croney@gmail.com

Bradley Ayres
Air Force Institute of Technology
2950 Hobson Way
Wright-Patterson AFB, OH 45433
937-255-3636 x3422
bradley.ayres@afit.edu

David Hurst
Orbital Transports, Inc
965 W Chicago Ave,
Chicago, IL 60642
773-218-6151
dhurst@orbitaltransports.com

Steven A. MacLaird – "Steve"
Object Management Group (OMG), SVP, Gov't & Industrial Strategy
PO Box 549
Quinlan, TX 75474
703-231-6335
MacLaird@omg.org

ABSTRACT

The International Council on Systems Engineering (INCOSE) Space System Working Group (SSWG) has created the CubeSat System Reference Model (CSRM), a representation of the logical architecture of a CubeSat system, intended for use by system architects and engineers as a starting point as they develop the physical architecture of the Space and Ground segments of the CubeSat mission of interest to them.

The CSRM is based on Model-Based System Engineering (MBSE) principles, is System Modeling Language™ (SysML™) compliant, is hosted in a graphical modeling tool, and is intended to foster completeness and economies of scale associated with reusability. The CSRM has been vetted by system engineering professionals and has been introduced to the CubeSat mission development team community with favorable results. The CSRM has been submitted to the Object Management Group (OMG) as a CubeSat specification, and is being evaluated for standardization.

Mission Engineering, a discipline where the mission itself is looked at as a system is being explored as a means to maintain balance between the spacecraft system, operations (including ground systems), and the mission (the integration of needed capabilities). With the CSRM nearing development completion, opportunities exist to extend the CSRM to enable the application of Mission Engineering to modeling a complete CubeSat mission.

A prior paper addressed the overall challenges and approach that the INCOSE SSWG will address when exploring the application of Mission Engineering to the development of a mission-specific CSRM. This paper is the first of several papers on Mission Engineering and the CSRM.

INTRODUCTION

The International Council on Systems Engineering (INCOSE) Space Systems Working Group (SSWG) has been focused on the design and development of the CubeSat System Reference Model (CSRM) since 2014. [1] - [6] That effort was successfully completed in 2020. The CSRM has been submitted to the Object Management Group (OMG) as a specification, and is being evaluated for standardization. The SSWG plans on exploring how the results of the development of the CSRM can be applied to the realm of Mission Engineering.

This is second of several planned Mission Engineering and CSRM papers. The first was [7].

This paper provides the following:

- Overview of the CSRM
- CSRM as an OMG Specification
- Development of a Mission-Specific CSRM
- Defining Mission Engineering
- CSRM and Mission Engineering
- Mission Architecture Activity and Mission Operations
- Conclusion
- Path Forward

OVERVIEW OF THE CUBESAT SYSTEM REFERENCE MODEL

The CSRM is founded on MBSE principles, SysML compliant, platform independent, and hosted in a graphical modeling tool. The CSRM provides a CubeSat logical space-ground architecture. The logical components are abstractions of the physical components that provide the system functionality without imposing implementation constraints. The physical architecture defines physical components of the system including hardware, software, persistent data, and operational procedures, and leads to the actual physical design.

The logical components are a starting point for the definition of a mission-specific CubeSat logical architecture, followed by the physical architecture and the CubeSat development. Using the provided CSRM as a starting point, the mission-specific team is free to adopt a different logical architecture and modify the CSRM to accommodate the change.

The CSRM integrates five overarching elements: stakeholders, technical measures, behaviors, requirements, and architecture as shown in Figure 1. The CSRM provides for defining and tracing requirements from stakeholders, to behaviors, with technical measures assigned to subsystems and components.

The CSRM is a repository for systems engineering artifacts. However, it is not pre-populated with specific stakeholders, technical measures, behaviors, and requirements. That is the job of the CubeSat mission-specific development team

CSRM AS AN OMG SPECIFICATION

OMG, a voluntary international standards organization, has a detailed process for identification of the need for a specification followed by the solicitation, development, approval, and distribution of a specification as shown in Figure 2.

OMG released a Request for Proposal (RFP) for a CubeSat specification in September 2018. INCOSE and several others responded to the RFP. The INCOSE CSRM was selected to continue development.

In the past, OMG specifications have been document-based. In this case the CSRM Specification consists of:

- Normative CSRM Specification document that is populated in part from the CSRM Model File
- Normative CSRM Profile XMI file for import into a graphical modeling tool

Supplementing the CSRM Specification are non-normative files:

- CSRM Model file since it is an implementation in a specific graphical modeling tool
- HTML Published file

The HTML file allows for exploration and evaluation of the CSRM without the need to acquire a graphical modeling tool. It provides sufficient guidance for establishing a mission-specific CSRM.

Compliance criteria for implementation of this specification are the retention of:

- Five fundamental elements: stakeholders, requirements, behaviors, architecture, and technical measures
- Architecture levels: enterprise, and space and ground segments and subsystems

Compliance criteria are part of being an OMG specification. Retention of these logical elements provides a common baseline for comparing and evaluating different mission-specific implementations and for the sharing and reuse of design elements.

The CSRM has been thoroughly vetted, as part of the OMG specification process, by system engineering professionals, and introduced to the CubeSat development community.

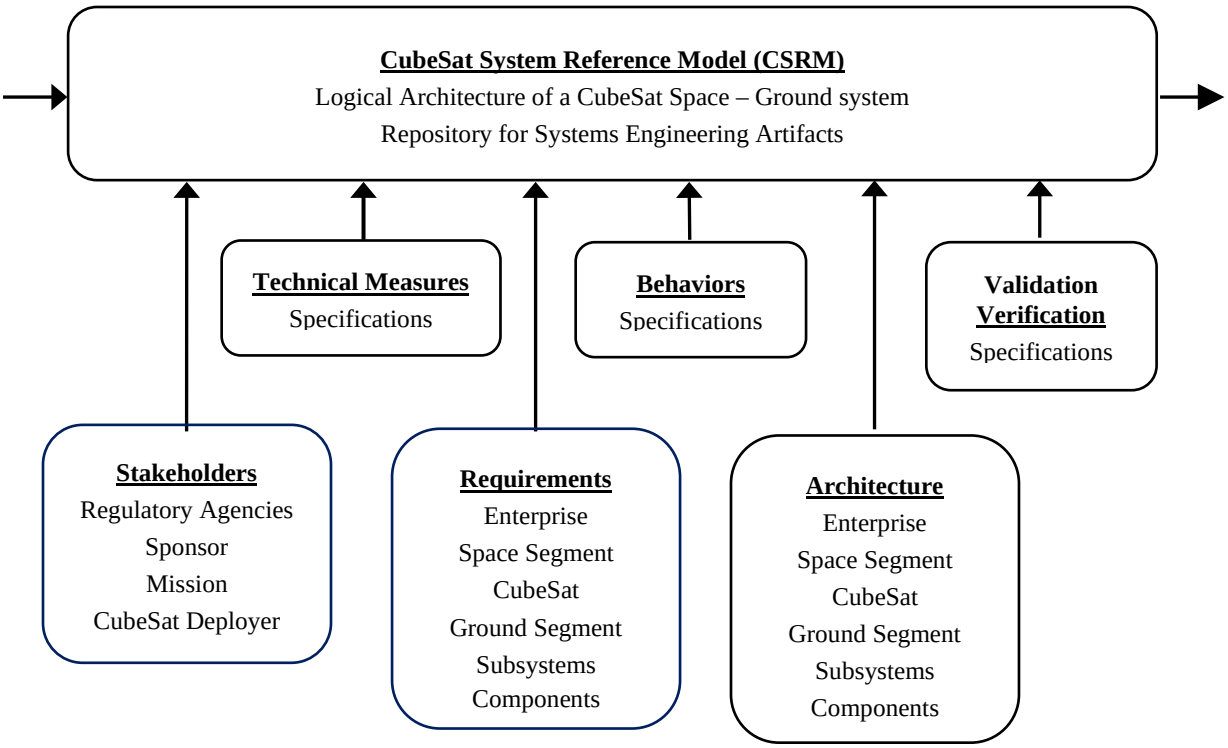

Figure 1. An Exo-Structure for Population with Mission-Specific Elements

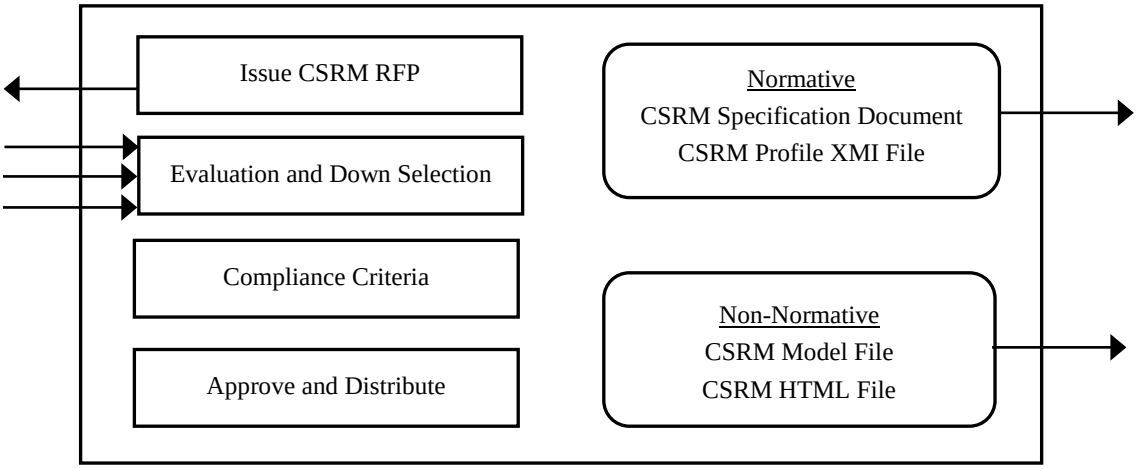

Figure 2. CSRM RFP and CSRM Specification

DEVELOPMENT PROCESS FOR A MISSION-SPECIFIC CSRM

A mission-specific CubeSat team downloads the CSRM specification and files from OMG for import it into their own graphical modeling tool. The mission-specific team is free to adopt a different logical architecture and modify the CSRM to accommodate the change. The mission team identifies the project stakeholders, project systems engineering methodology, and mission-specific stakeholders and needs. This is followed by specifying the mission-specific logical and physical architectures. See Figure 3. The CSRM documentation is internal to and integral to the CSRM.

DEFINING MISSION ENGINEERING

We have built on our preceding paper [7] that provided several definitions of Mission Engineering and associated activities including an initial assessment of where the CSRM supports these activities and where there are areas that require further research.

Mission

A mission describes what the system will do and the purpose of doing it. The mission provides the context for defining measures of effectiveness and for development of the Concept of Operations. The mission is accomplished by operational nodes completing one or more operational activities. An operational node can be an organization, individual, or system. Operational activities are actions that either transform one or more inputs into outputs or change the state of the system. A system provides capabilities through the execution of operational activities. [8]

Mission Engineering

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. [8]

The above definitions of Mission and Mission Engineering emphasize that the mission is the system of interest and the operational accomplishment of the mission should include all phases of operations (from Launch and Early Orbit, through Normal Operations, ending with Decommission Operations). Normal Operation accomplishment includes meeting Technical Measures in the operational environment.

The list of Mission Engineering Activies in Figure 4 is from [7] and [8]. The Mission Architecting Activity will be addressed below.

CSRM AND MISSION ENGINEEERING

We have been discussing two CSRMs. One is the OMG normative specification in Figures 1, 2, and 3. The other is the mission-specific CSRM in Figures 4, 5, and 6.

Figures 4 and 5 illustrates the architecting of the mission-specific CSRM to support Mission Engineering (ME) activities. they show the mapping of model elements to ME activities at the mission, logical, physical, and dynamic modeling level.

The following steps should be carried out for each of the ME activities listed in Figure 4:

- Identify the key elements of the ME activity
- Identify the ME key elements that align with the mission-specific CSRM elements
- Identify and incorporate elements that supplement the mission-specific CSRM and align with ME key elements
- Provide the results of the above analysis to INCOSE and OMG with recommendations for addition to the OMG resident CSRM Specification
- Review both the ME activities and the development activity to optimize shared information to for meeting technical measures and carrying out mission operations

MISSION ARCHITECING ACTIVITY IN SUPPORT OF MISSION OPERATIONS

Mission Architecting Activity is defined as the development of an operational architecture describing the capabilities, operational activities, operational nodes, and other relevant elements to model the mission. [7] [8]

A Space Mission Architecture includes the space segment, ground segment, mission operations, launch segment, orbit, end user, and command, control, and communications architecture. [7] [9 p62]

Mission Operations includes the people, hardware, and software that control the system a day-to-day basis. This includes spacecraft operations, payload operations, ground operations, and mission management. [9 p903]

Mission Operations are not part of the CSRM as shown in Figure 1. However, they should be included in the mission-specific CSRM as shown in Figure 6 below.

Mission Operations can be captured in activity diagrams and could follow the progression of the logical to physical definition of the resulting system.

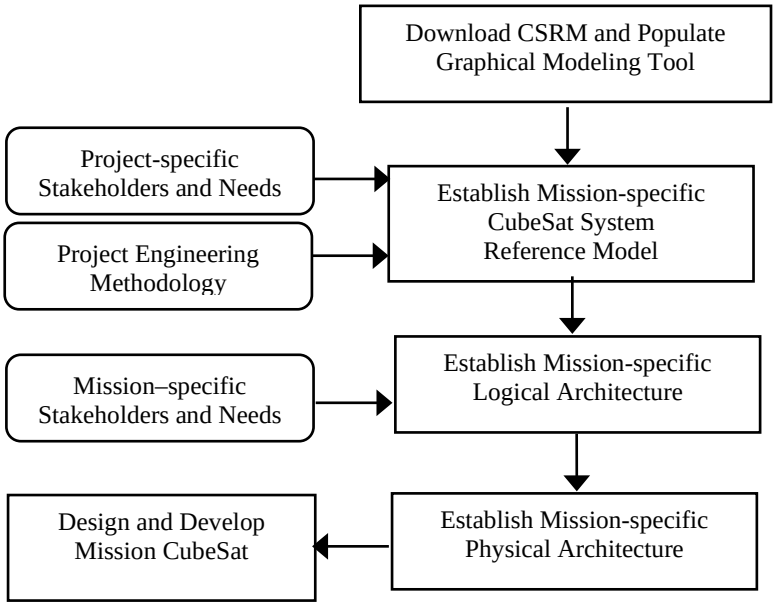

Figure 3. Engineering of a Mission-Specific CSRM

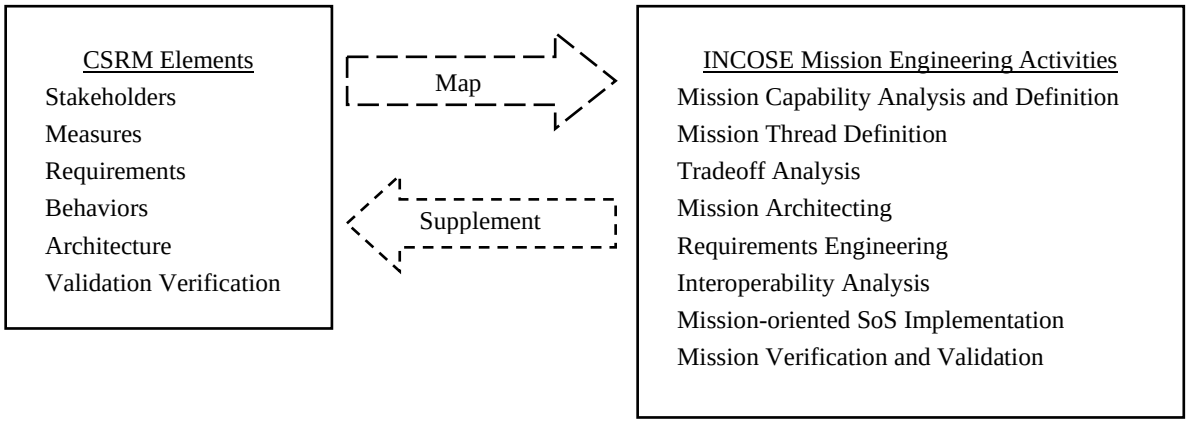

Figure 4. INCOSE Mission Engineering Activities

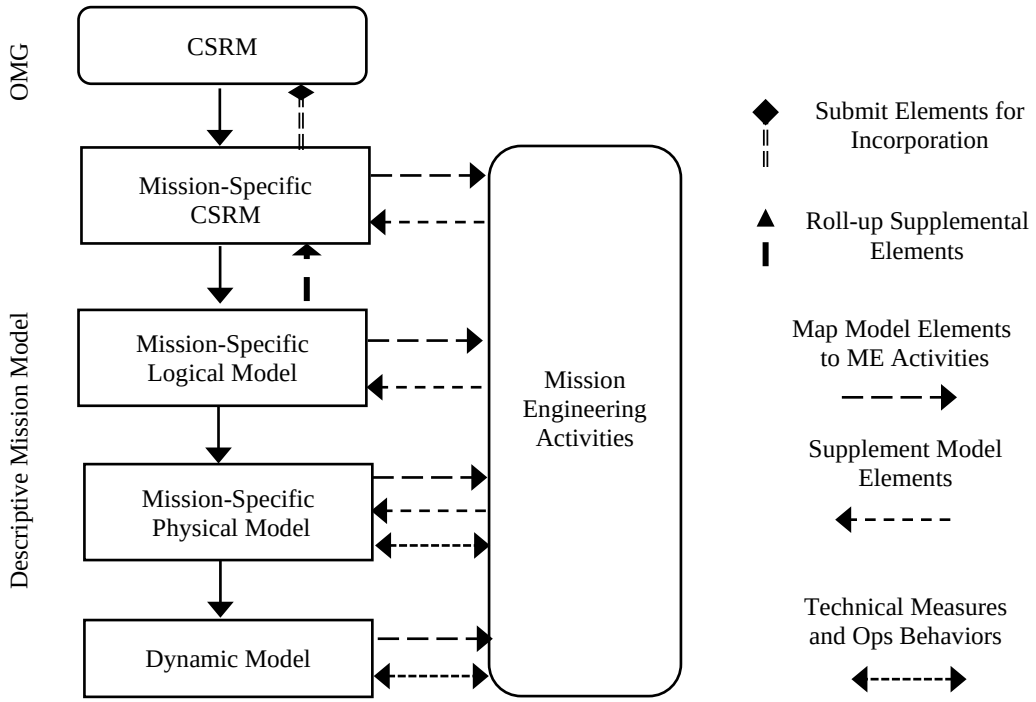

Figure 5. Architecting the Mission-Specific CSRM According to Mission Engineering Activities

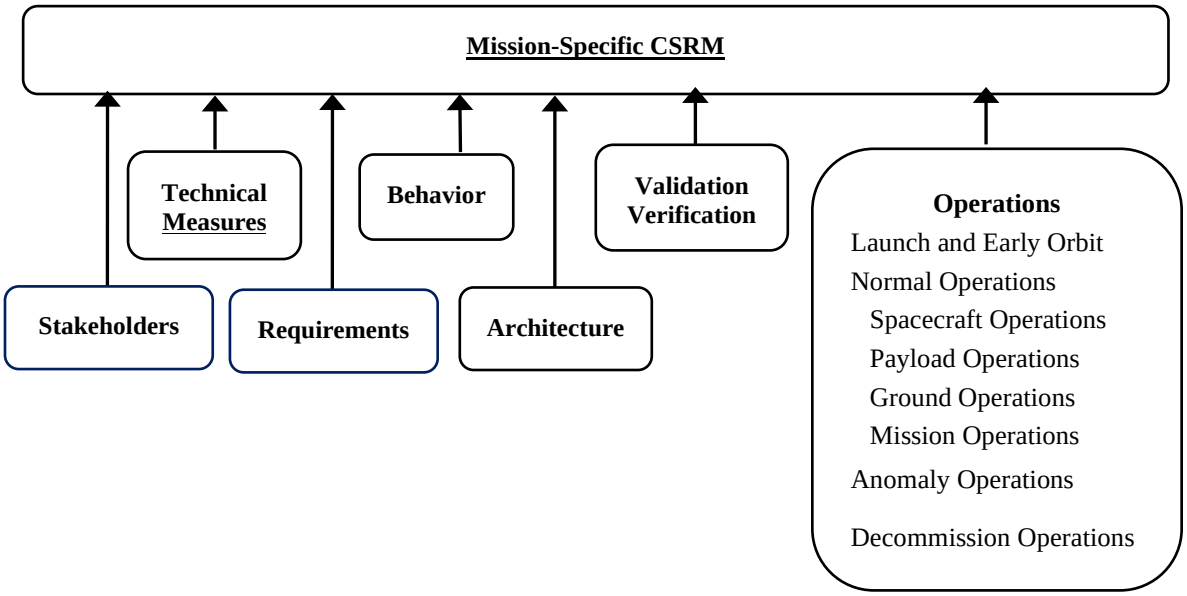

Figure 6. Mission-Specific CSRM

CONCLUSION

The Mission Engineering Activities listed above and follow-on papers will provide guidance for mission-specific team to develop a mission-specific CSRM according to the principles of Mission Engineering.

FOLLOW-ON

The SSWG will continue to evaluate the above list of Mission Engineering Activities. Additionally, the SSWG is soliciting input from stakeholders on possible methodologies, conceptual frameworks, evaluation criteria, or any other strategies that we should consider during this early stage of our work.

References

[1] 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

[2] Kaslow and A. Madni. "Validation and Verification of MBSE Compliant CubeSat Reference Model." Proceedings of 15th Annual Conference on Systems Engineering Research. 2017.

[3] 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.

[4] 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.

[5] 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.

[6] 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.

[7] D. Kaslow, A. Levi, P. Cahill, B. Ayres, D. Hurst, and C. Croney, "Mission Engineering and the CubeSat System Reference Model", *Proceeding of the IEEE Aerospace Conference*, Big Sky, Mt, 2021.

[8] INCOSE Guide to the Systems Engineering Body of Knowledge v. 2.3, October 2020. https://www.sebokwiki.org/

[9] J. Wertz, D. Everett, and J. Puschell. Space Mission Engineering: The New SMAD