Developing a CubeSat
Model Based System Engineering (MBSE)
Reference Model

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International Council on Systems Engineering (INCOSE)

Space Systems Working Group (SSWG)

Project Objectives

Prove-out MBSE methodology on a CubeSat

Provide a CubeSat Reference Model and a CubeSat Project Model
that CubeSat teams can use as a
starting point for their mission specific CubeSat model

Team Composition

Aerospace Students and Professors

JPL and NASA Engineers

Engineers and Software Developers from
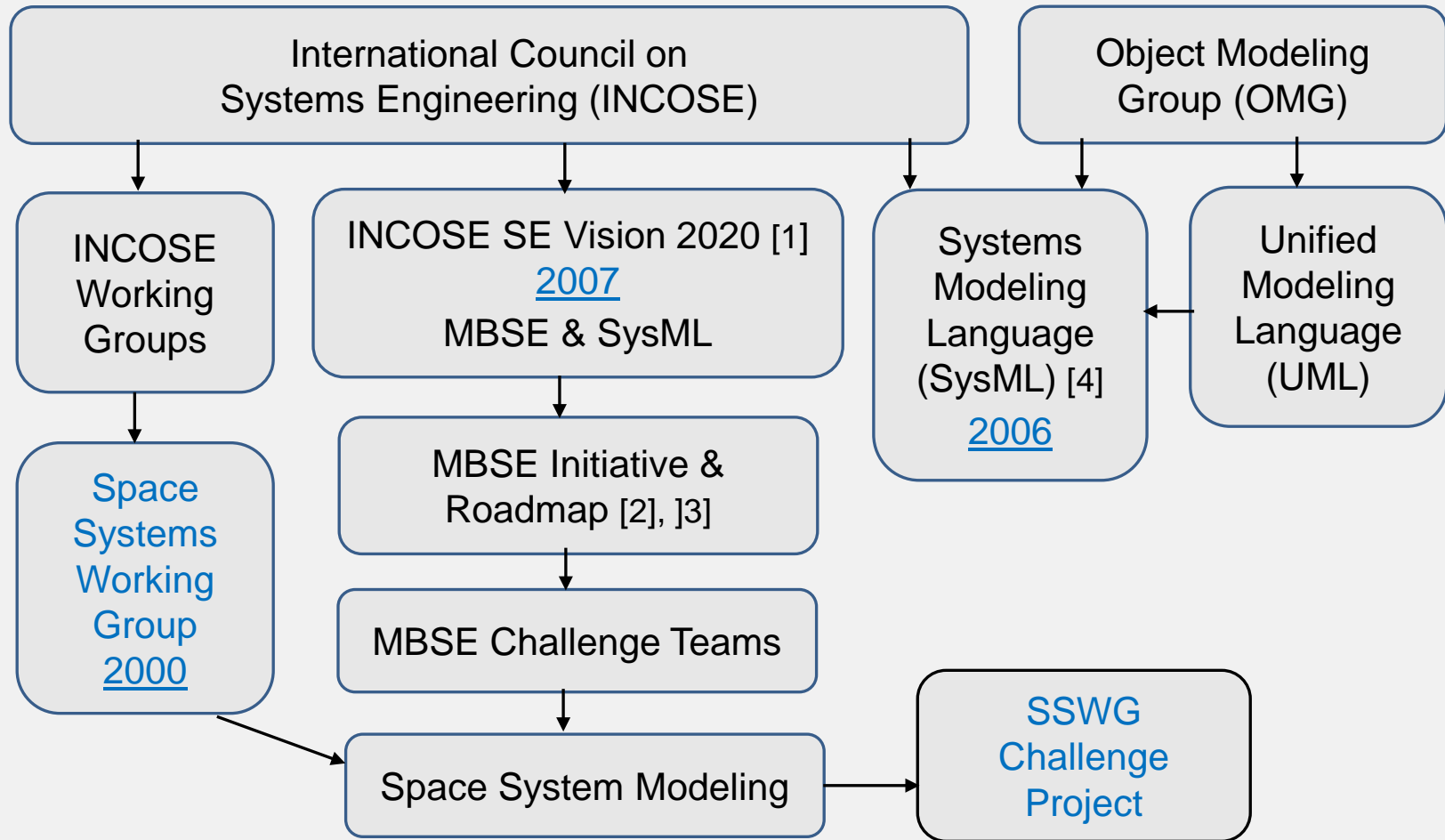Commercial Modeling and Simulation Tool Providers

Telecons every Friday at 1pm east coast time

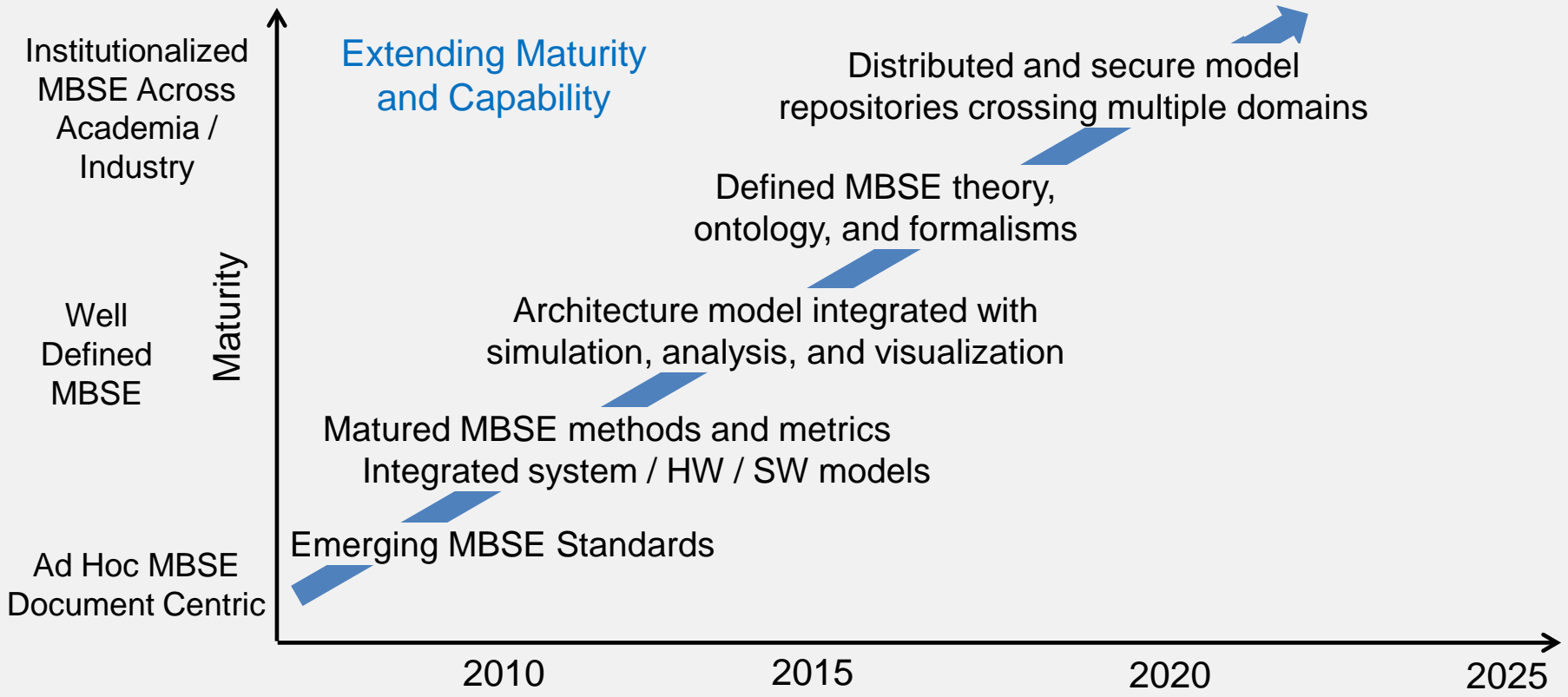Meeting materials and links to meeting recordings in Google docs

Email me to be included on the email reflector list

INCOSE MBSE Initiative - Genesis, Flow, Interaction

International Council on Systems Engineering (INCOSE)

Object Modeling Group (OMG)

INCOSE Working Groups

INCOSE SE Vision 2020 [1]
2007
MBSE & SysML

Systems Modeling Language (SysML) [4]
2006

Unified Modeling Language (UML)

Space Systems Working Group
2000

MBSE Initiative & Roadmap [2],]3]

MBSE Challenge Teams

Space System Modeling

SSWG Challenge Project

MBSE Roadmap

Maturity (vertical axis):
- Institutionalized MBSE Across Academia / Industry
- Well Defined MBSE
- Ad Hoc MBSE Document Centric

Timeline (horizontal axis): 2010, 2015, 2020, 2025

Extending Maturity and Capability

- Distributed and secure model repositories crossing multiple domains
- Defined MBSE theory, ontology, and formalisms
- Architecture model integrated with simulation, analysis, and visualization
- Matured MBSE methods and metrics
- Integrated system / HW / SW models
- Emerging MBSE Standards

Adapted from [3]

MBSE and SysML

INCOSE Systems Engineering Vision 2020 [1]

MBSE: Formalized application of modeling to support system requirements, design, analysis, verification, and validation activities

Survey of Model Based Systems Engineering Methodologies [5], [6]

e.g. INCOSE OOSEM, IBM Telelogic Harmony SE, Vitech MBSE

MBSE: A collection of related processes, methods, and tools
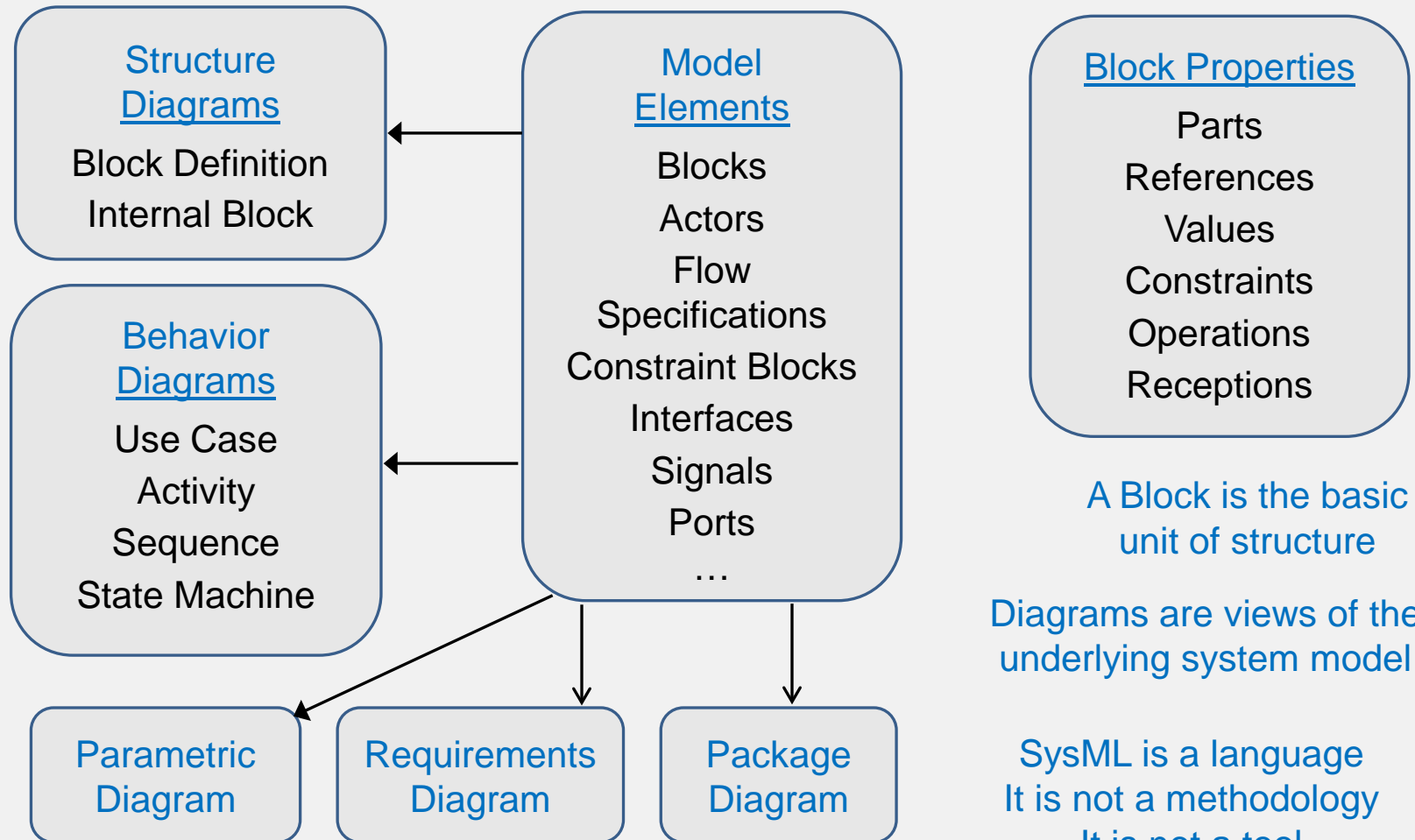
Object Oriented Systems Engineering Method

OOSEM

Top down, scenario driven process that uses SysML

Object Management Group [4]

SysML: A graphical modeling language for modeling complex systems including hardware, software, information, personnel, procedures, and facilities

SysML

Structure Diagrams

Block Definition
Internal Block

Behavior Diagrams

Use Case
Activity
Sequence
State Machine

Model Elements

Blocks
Actors
Flow
Specifications
Constraint Blocks
Interfaces
Signals
Ports
…

Block Properties

Parts
References
Values
Constraints
Operations
Receptions

A Block is the basic unit of structure

Diagrams are views of the underlying system model

SysML is a language
It is not a methodology
It is not a tool

Parametric Diagram

Requirements Diagram

Package Diagram

SSWG Challenge Project

INCOSE MBSE
Challenge Project
Initiated in 2007

INCOSE SSWG
2007-2010

Phase 0

Modeled a Space System
in SysML

Hypothetical FireSat -
SMAD

MBSE CubeSat Project
2011 to Present

Phase 1

CubeSat Framework

Preliminary RAX Model

Phase 2

RAX Behavior Modeling
Power, Comm, State

Recent Efforts (Phase 3)

Enterprise Modeling
for CubeSats
All lifecycle phases

RAX CubeSat Model
Trade Studies

Tools

- No Magic - MagicDraw
    - Graphical SysML modeling tool

- No Magic - Cameo Simulation Toolkit
    - Enables the time-step execution of behavior models within Magic Draw

- InterCAX - Paramagic
    - Plug-in modudle for MagicDraw
    - Enables the execution of parametric models and system trades
    - Wraps external models such as MATLAB/Simulink, Mathematica, or Excel

Tools

- Analytical Graphics - Systems Tool Kit
  - Simulation and visualization of spacecraft behavior

- Phoenix Integration - ModelCenter
  - Graphical environment for creating simulation workflows by integrating various types of simulation models, including Excel spreadsheets, STK scenarios, and MATLAB scripts.
  - Once a simulation workflow is created, PHX ModelCenter executes the workflow, automatically transferring data between the simulators

- Phoenix Integration - MBSE Analyzer
  - Enables the execution of parametric diagrams via ModelCenter

MBSE CubeSat Project

Phase 3

Integrated Model-Based Systems Engineering (MBSE) Applied to the Simulation of a CubeSat Mission

RAX Mission Simulation

State Diagrams

Orbit

Solar

Experiment

Download

Models behavior in response to internal and external events

Activity Diagrams

Run Operation
– Steps through time

Update States

Send Signals
– Controls update of state values

Update State Values

Defines actions in the activity along with the flow of input, output, and control

Parametric Diagrams

Get States

Power Collection

Update Energy

Update Data

Update Download

Mapped to analytical and simulation models that estimate RAX performance

Time step through a scenario and model:
Energy collection and usage
Data collection, storage, and downlink

MBSE CubeSat Project

Phase 4

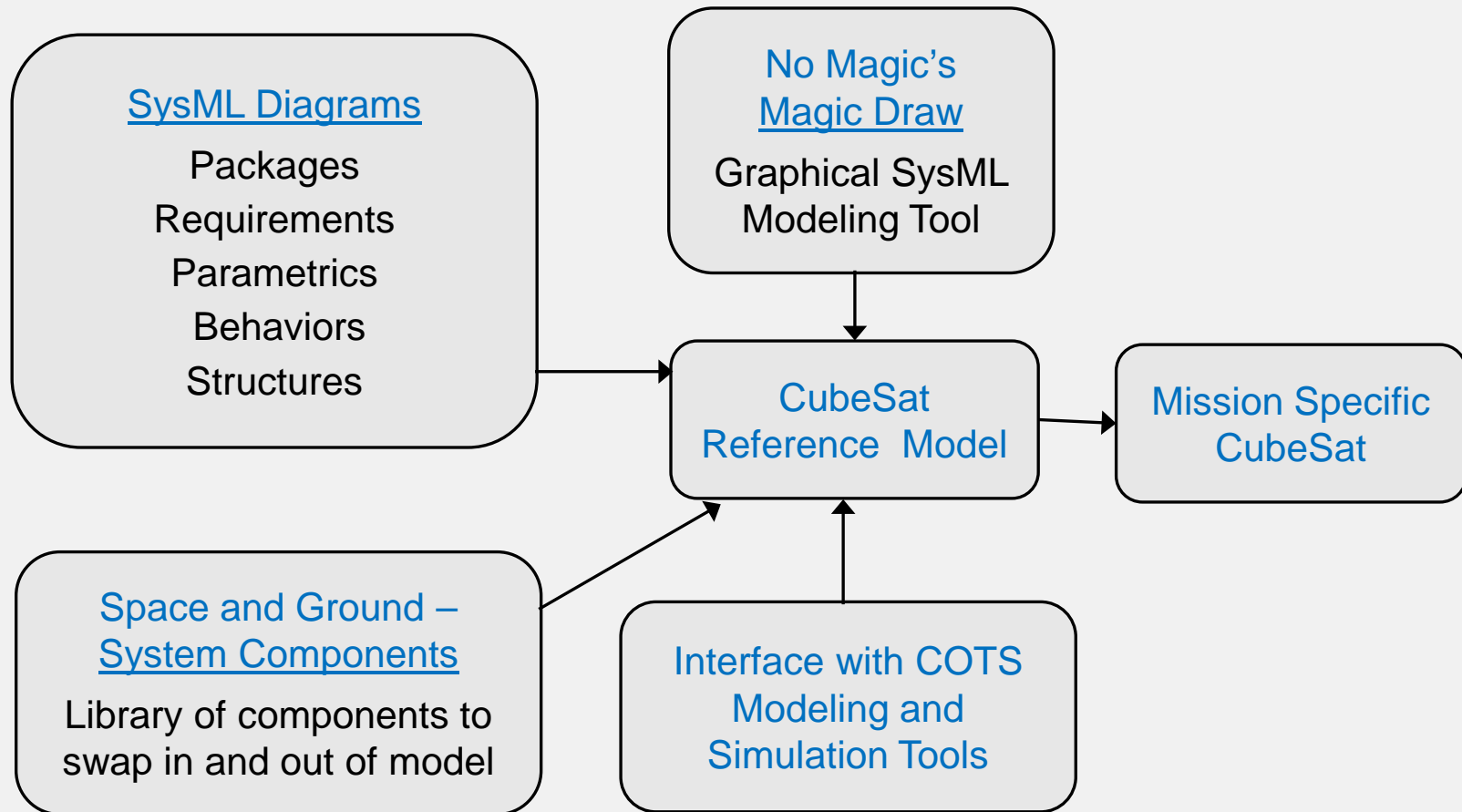## Developing a CubeSat
Model Based System Engineering (MBSE)
Reference Model

CubeSat Reference and Project Models
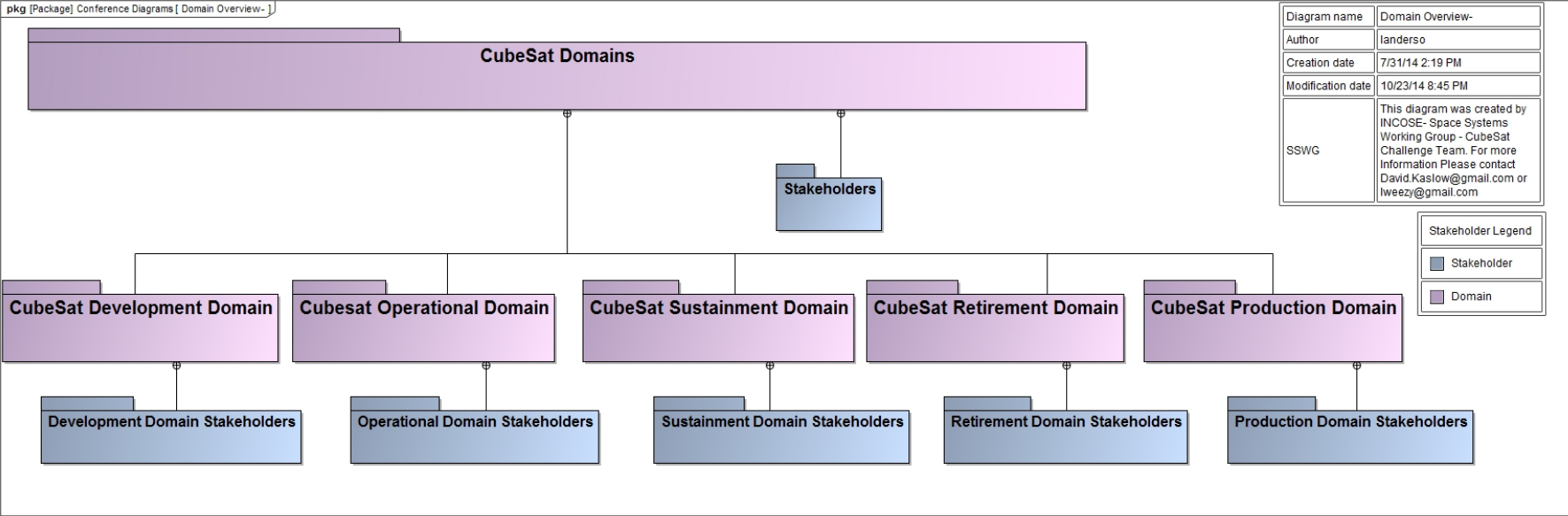
CubeSat System Reference Model

SysML elements for specifying requirements, design, development, and operations

Starting point for mission specific CubeSat model

CubeSat Project Model

Processes and methods for design, development. and operations

Includes SysML activity and sequence diagrams

Cal Poly CubeSat Design Specification [7]

Mechanical, Electrical, Communication Licenses, Imaging Licenses, Debris Mitigation, Verification Reporting and Signoff

CubeSat Reference Model - Scope

Lifecycles
Conception through retirement

Phases of Operations
Launch
Early ops
Normal ops
Degraded

CubeSat Reference Model
A model that can be used as a starting point for a mission specific CubeSat model

Mission Stakeholders
Needs
Objectives
Measures of Effectiveness
Constraints

Foundations
INCOSE Systems Engineering Handbook [8]
NASA System Engineering Handbook [9]
Applied Space Systems Engineering [10]
Space Mission Engineering -The New SMAD [11]
CubeSat Mission Design Based on Systems Engineering Approach [12]

CubeSat Reference Model – Goal

SysML Diagrams

Packages
Requirements
Parametrics
Behaviors
Structures

No Magic's Magic Draw

Graphical SysML Modeling Tool

CubeSat Reference Model

Mission Specific CubeSat

Space and Ground – System Components

Library of components to swap in and out of model

Interface with COTS Modeling and Simulation Tools

CubeSat System Reference Model

CubeSat Domains

CubeSat Stakeholders
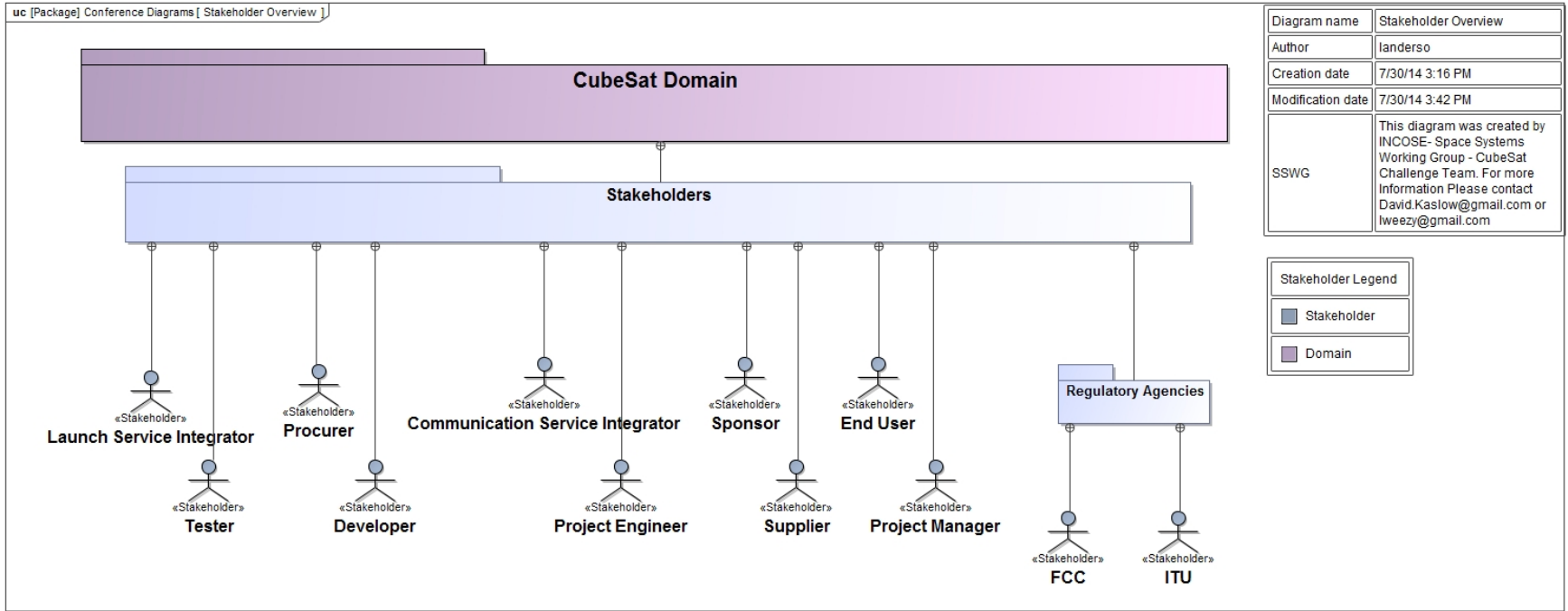
CubeSat Mission Needs, Objectives, Requirements
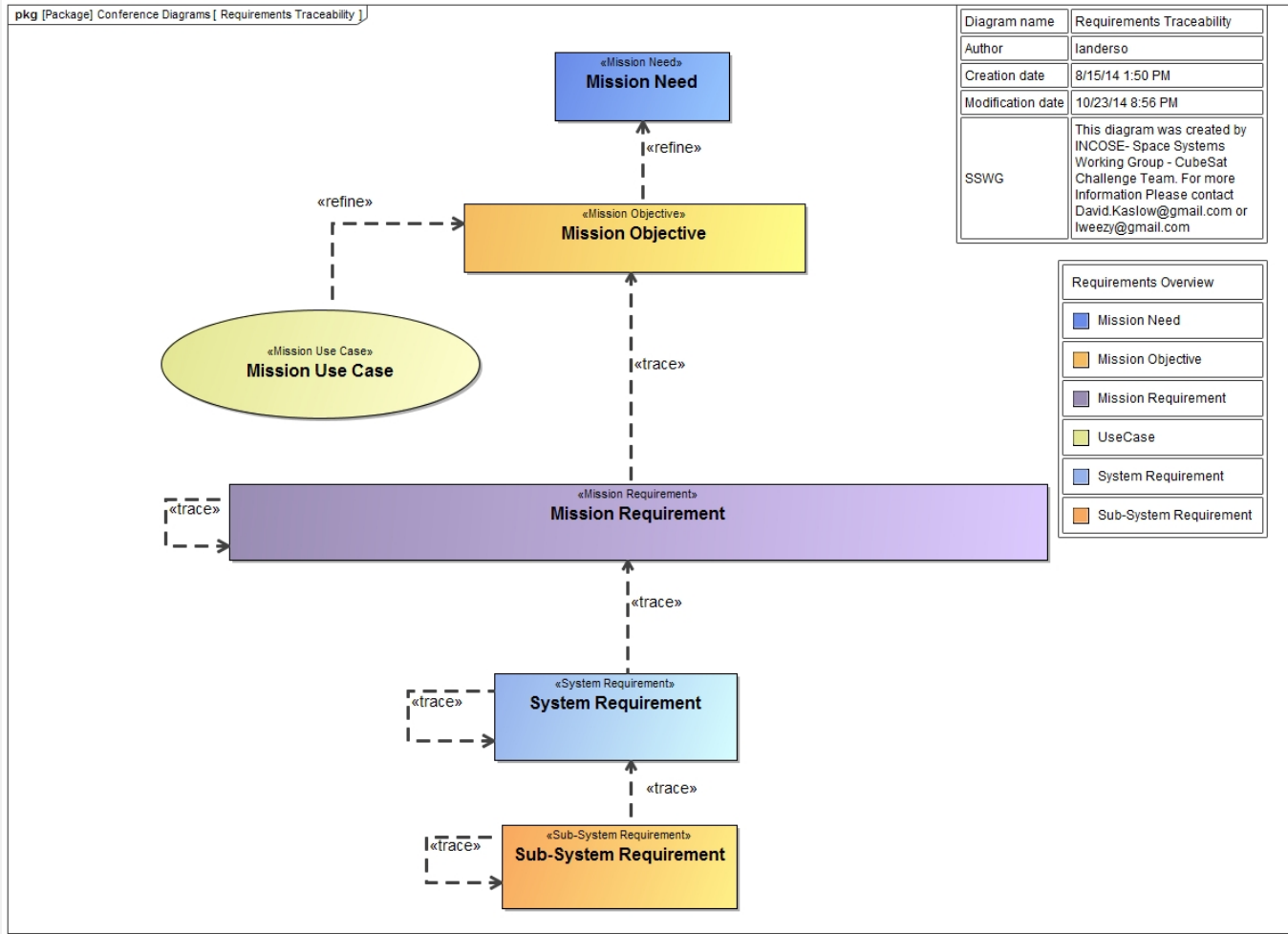
CubeSat Operational Domain
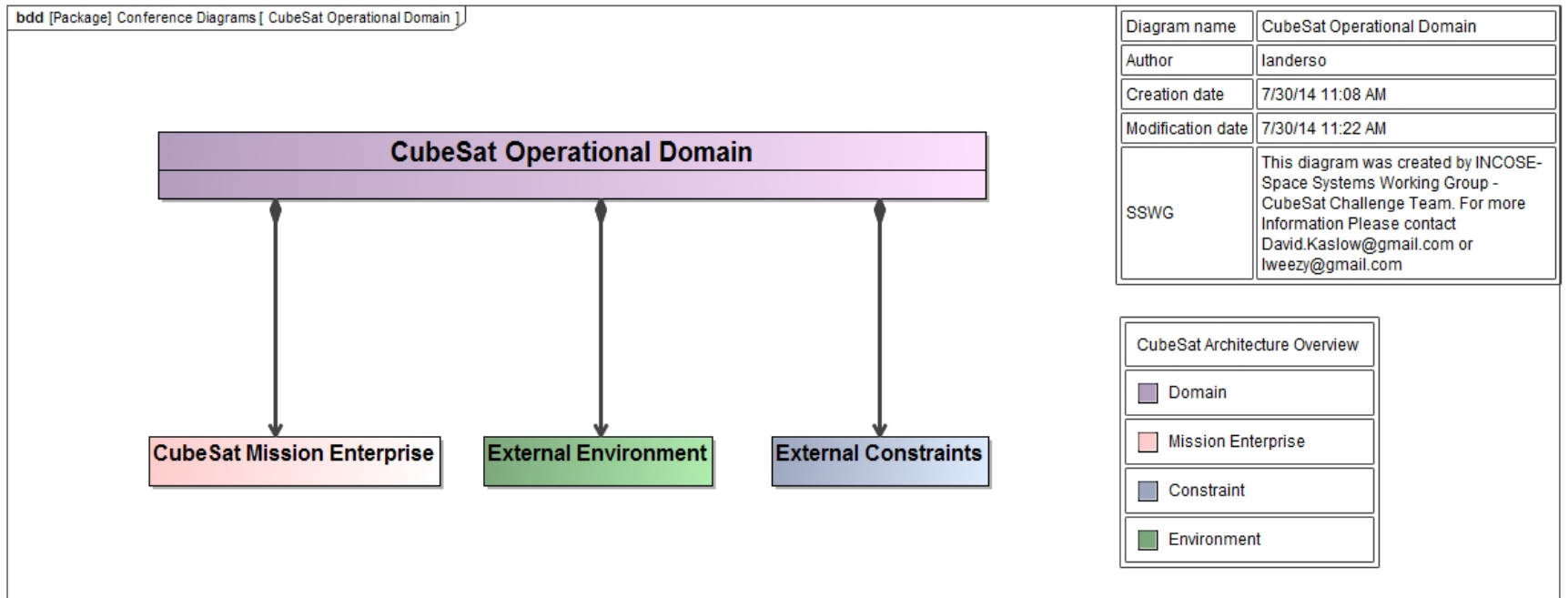
CubeSat External Environment and External Contraints
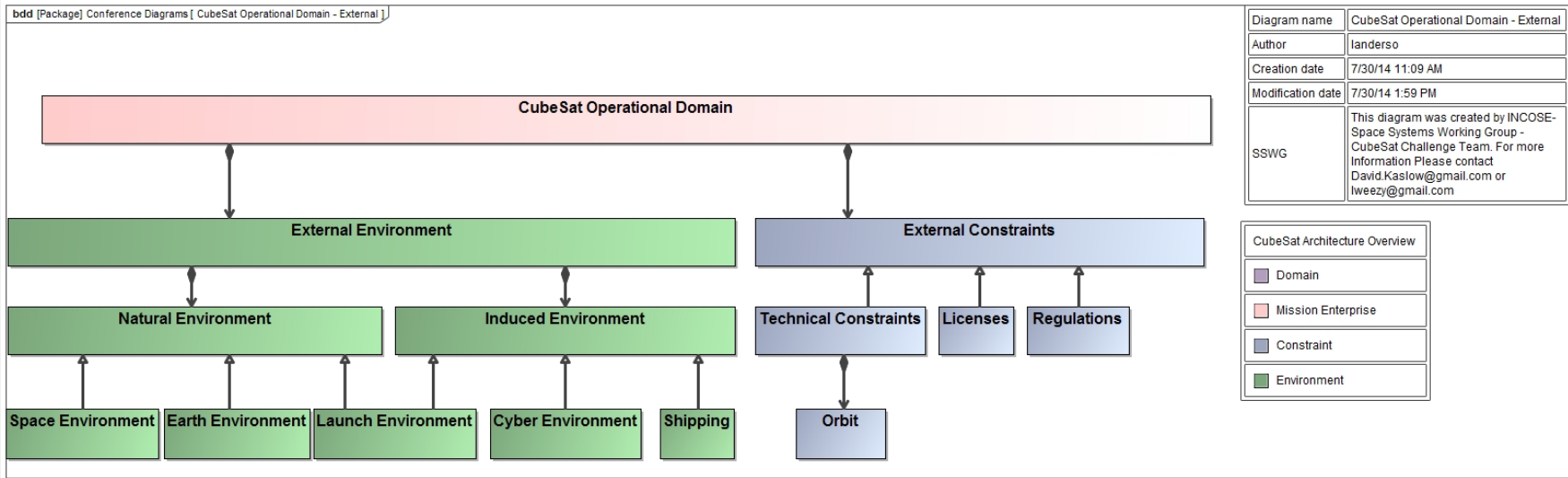
CubeSat Mission Enterprise
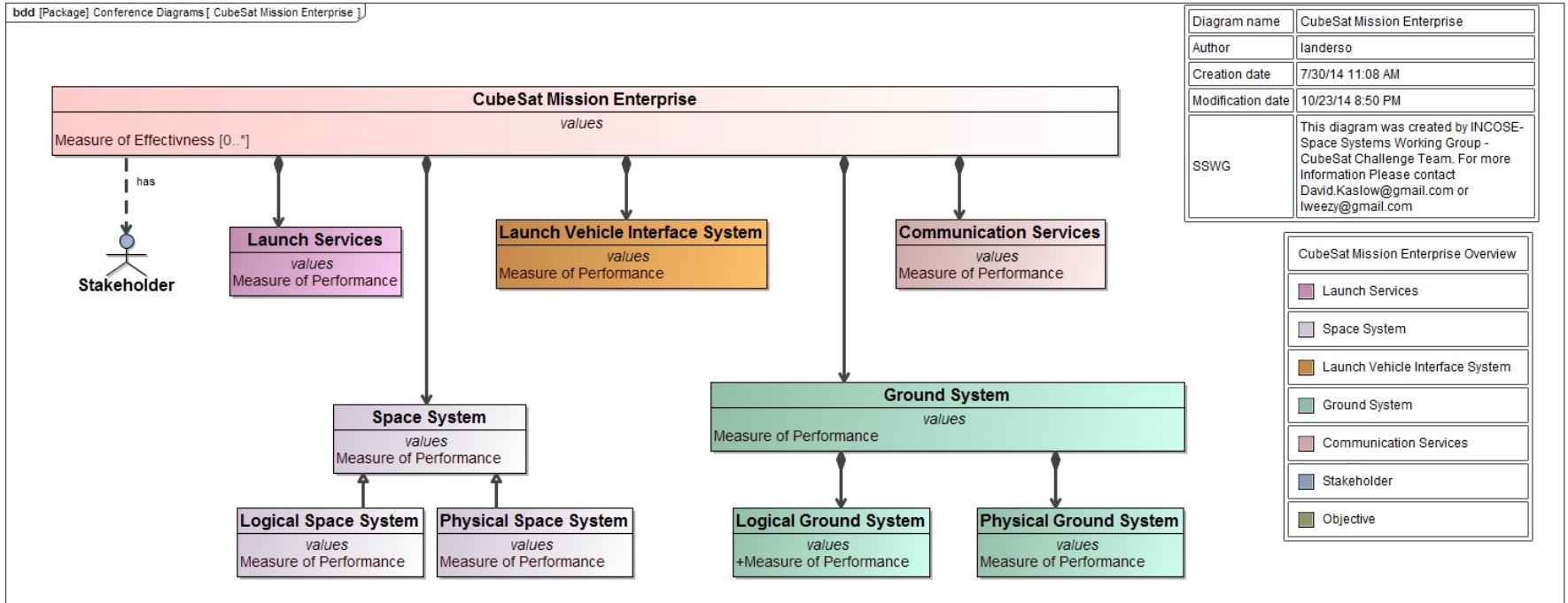
CubeSat Logical Space System

CubeSat Logical Ground System
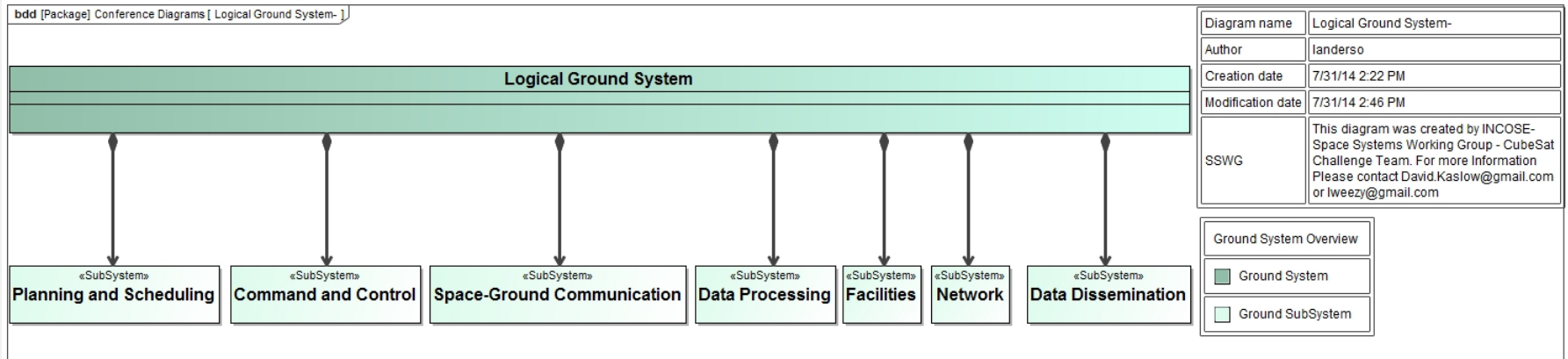
Next Steps and References

Next Steps

- Determine the level of model definition at each of the lifecycle stages

- Create models for the concept and development stages

- Validate the models by applying them to a hypothetical CirrusSat mission

- Provide the models to a university aerospace engineering program

References

[1] Systems Engineering Vision 2020, INCOSE –TP_2004-004-02, ver. 2/03,September 2007. [Online]. Available: http://www.incose.org/ProductsPubs/pdf/SEVision2020_20071003_v2_03.pdf

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[3] MBSE Roadmap. MBSE Wiki, INCOSE MBSE IW 2012. MBSE Wiki. [Online} Available: http://www.omgwiki.org/MBSE

    http://www.omgwiki.org/MBSE/lib/exe/fetch.php?media=mbse:mbse_iw_2012-introduction-2012-01-21-friedenthal-c.pptx

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[6] *Additional Methodologies Identified as Gaps since 2008 INCOSE Survey*. MBSE Wiki, Metrics and Methodologies [Online]. Available: http://www.omgwiki.org/MBSE/doku.php?id=mbse:methodology

[7] *CubeSat Design Specification*, rev. 13, The CubeSat Program, Cal Poly SLO, February 2014

[8] *INCOSE Systems Engineering Handbook,* v. 3.2.2, October 2011, INCOSE-TP-2003-002-03.2.2.

[9] *NASA Systems Engineering Handbook,* rev. 1, December 2007, NASA/SP-2007-6105 Rev1.

[10] W. Larson, et. al., *Applied Space Systems Engineering*, (Space Technology Series), McGraw Hill, Boston, MA, 2009.

[11] 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.

[12] S. Asundi and N. Fitz-Coy, "CubeSat Mission Design Based on Systems Engineering Approach," *Proceedings of IEEE Aerospace Conference*, Big Sky, MT, March 2013.