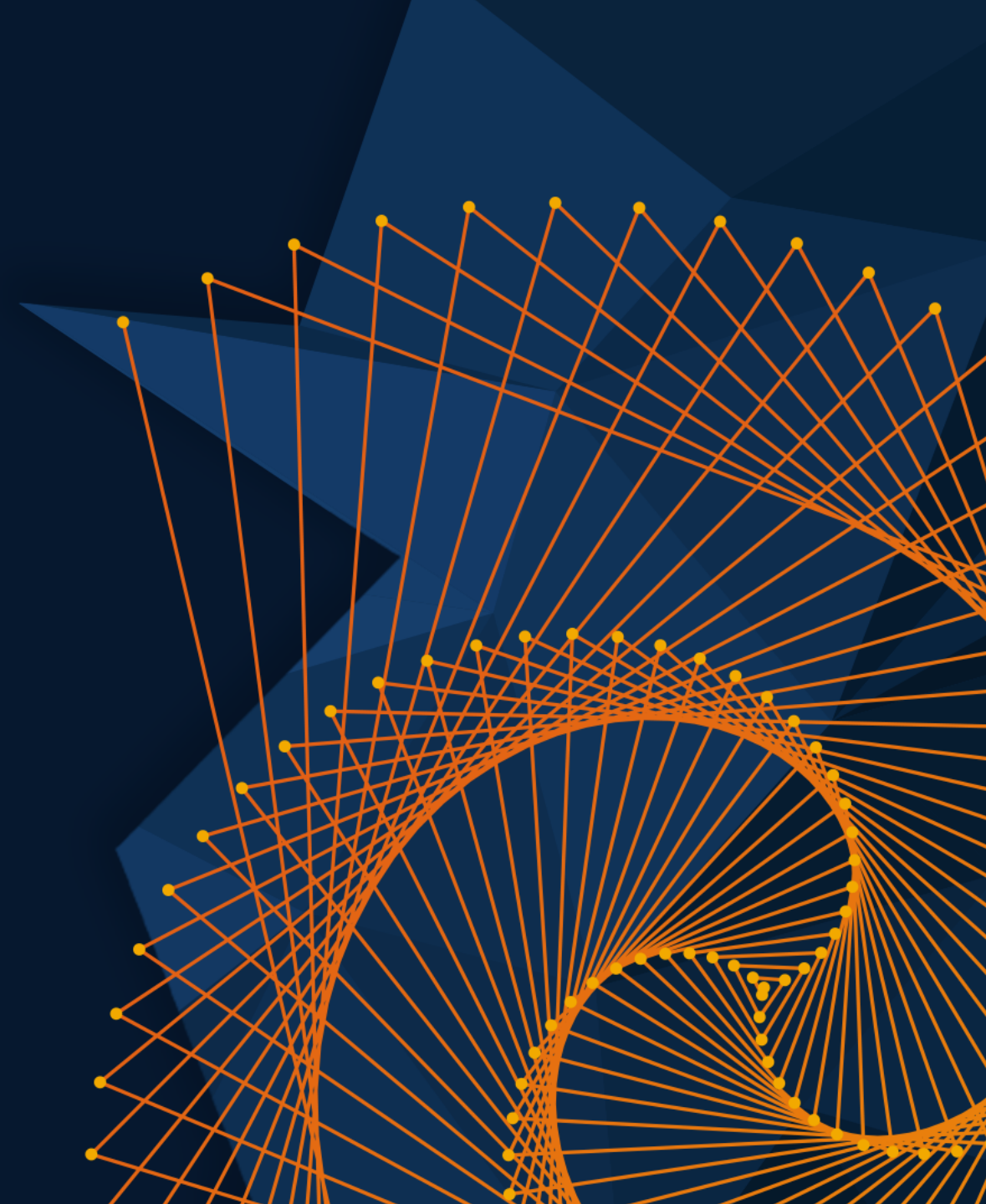


MATLAB EXPO

November 13–14, 2024 | Online

Teaching Model-Based Systems Engineering in Undergraduate Engineering Education

Mehdi Vahab, PhD , MathWorks



Agenda

- What is MBSE?
- Why is it important to teach MBSE to undergraduate engineering students?
- What are the challenges of teaching MBSE concepts and workflows?
- What are the common methods to teach MBSE?
- Why use MATLAB/Simulink to teach MBSE?
- Recourses for teaching/learning MBSE

Agenda



What is MBSE?

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What is Model-Based Systems Engineering (MBSE)?

“The formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases.”

-- INCOSE SE Vision 2020 (INCOSE-TP-2004-004-02, Sep 2007)

What is Model-Based Systems Engineering (MBSE)?

Structured
Documented
Practiced
Supported

“The formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases.”

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What is Model-Based Systems Engineering (MBSE)?

[Physical, Behavioral, Functional, ...]
Modeling is the core practice.

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Practical steps in
product design.

What is Model-Based Systems Engineering (MBSE)?

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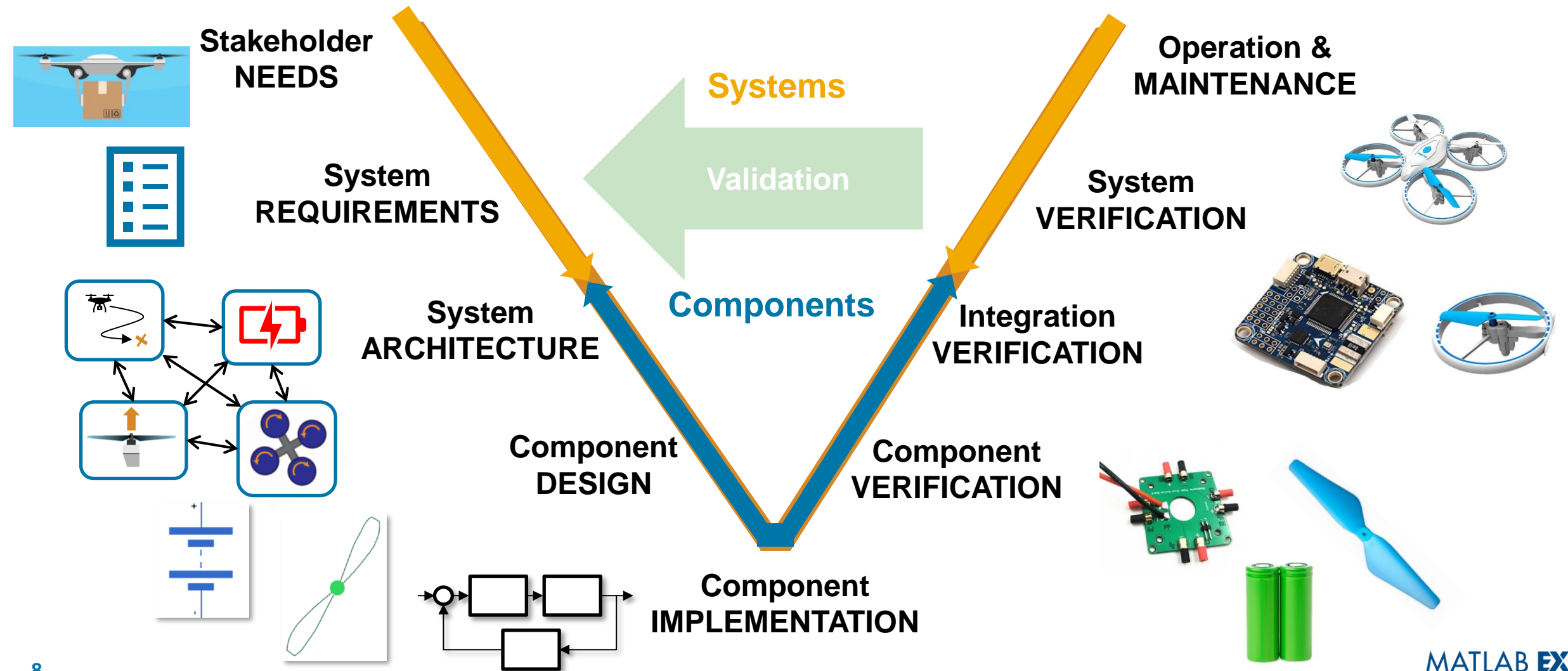
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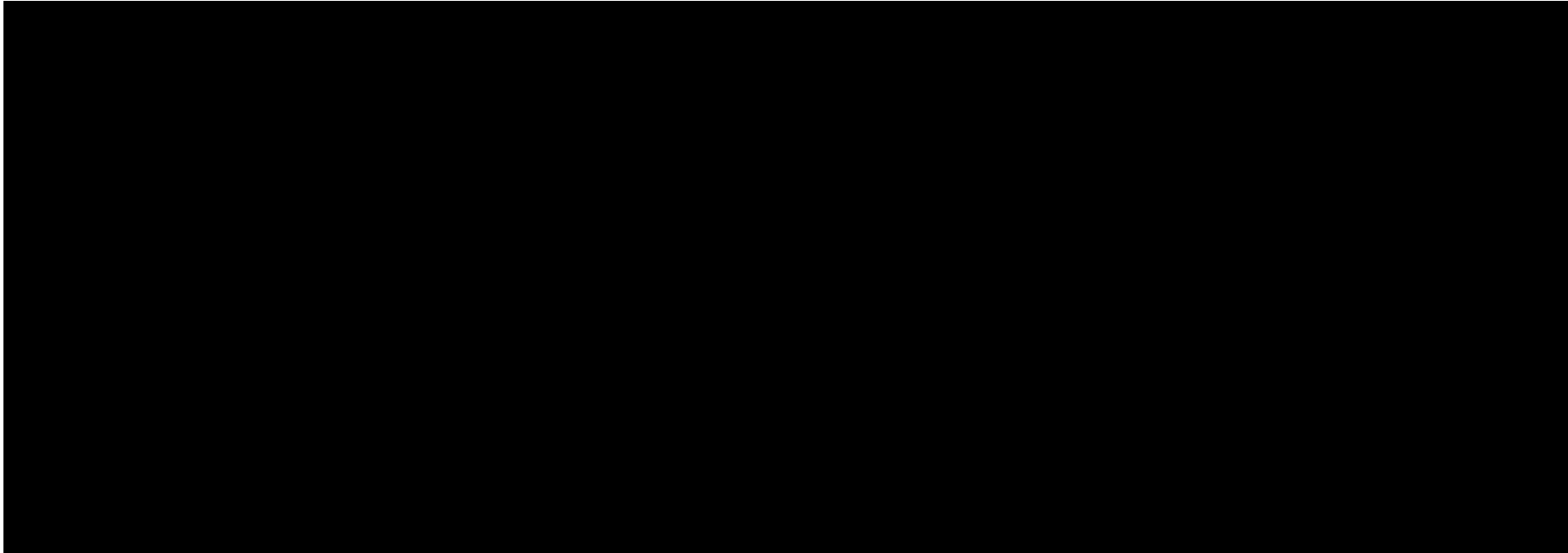
Practical steps in
product design.

Almost every engineer is involved to some degree or form.
Covers many types of products (hardware, software, service)

V-diagram explains the steps in systems development lifecycle



Drone delivery – ship resupply mission example



Index	ID	Summary
SkyzerMissionModel_REQ		
1	#1	Stakeholder Interface
2	#2	Requirement Process
3	1.1.4	Communications Capability
4	1.1.3	Surveillance Capability
5	1.1.2	Imaging Capability
6	1.1.1	UAV Capability
7	SMNeed_2	Imaging Capability
8	SMNeed_3	UAV Capabilities
9	SMNeed_5	Airworthiness
10	SMNeed_4	UAS Control Segment
11	1.3.3	Max Payload Weight
12	1.3.2	Cruise Speed
13	1.3.7	UAV Operation Period
14	1.3.4	Operational Radius
15	1.3.1	Max Speed
16	1.3.6	Operational Altitude

Properties

Filepath: C:\Code_sandbox\MBSE_MBD\incose-is-24-

Revision: 1

Created by: kburns

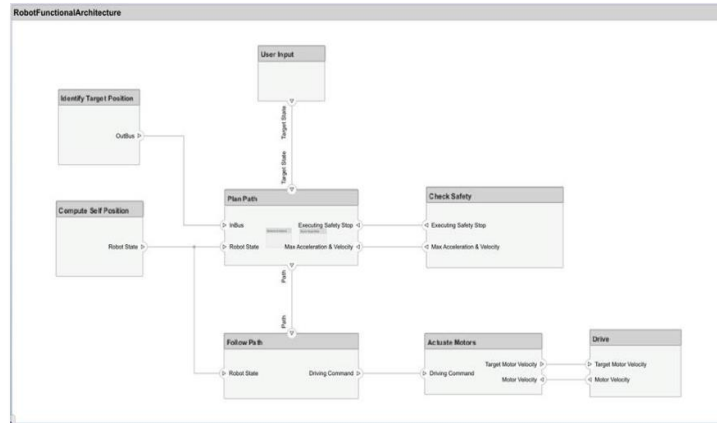
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Modified by: kburns

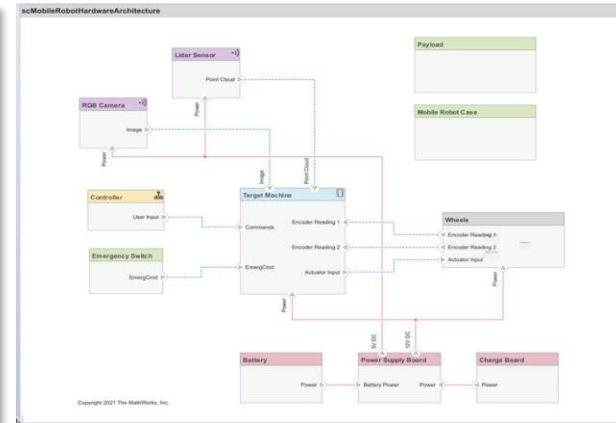
Modified on: 20-May-2024 15:35:55

Description:

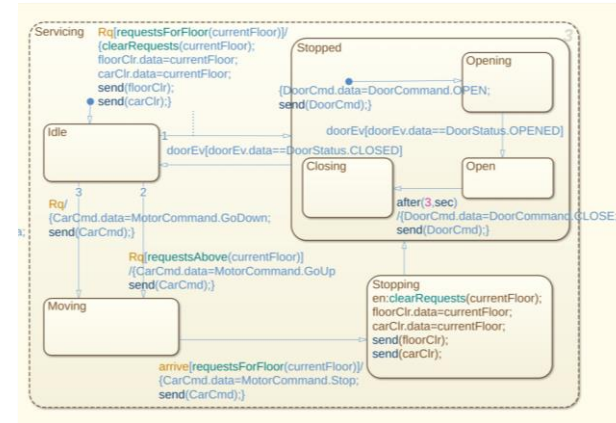
System Requirements



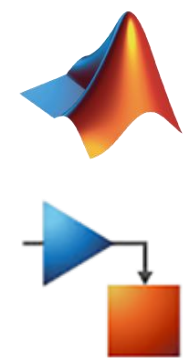
9 Functional Architecture



Physical Architecture



Logical Architecture and Modeling



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Commercial companies are hiring MBSE experts

Use your favorite job search engine and search for Systems Engineer or MBSE.

Model Based Systems Engineer

- **Experience with MBSE tools and processes**
- Comfortable working in a prototyping environment
- Experience modeling or simulating systems
- Experience with the coordination and conducting of design review activities

Principal Model Based Systems Engineer

- Experience with the application of systems engineering, **model based engineering, digital engineering** methods and creative thought-leadership to mature and develop revolutionary digital engineering solutions
- Familiarity with multidisciplinary analysis and optimization tools and digital engineering lifecycle management tool

[X] Systems Engineer

Senior Engineer, Thermal Systems

“... **Preference will be given** to those individuals with experience in a Digital Engineering environment with Model Based Systems Engineering (**MBSE**) **experience** and tools...”

Senior Laser Systems Engineer

- **Experience with** systems engineering and requirements management software tools and model-based systems engineering (**MBSE**)

Commercial companies are hiring engineers with MBSE expertise

Use your favorite job search engine and search for MBSE concepts and workflows (system architecture, modeling, simulation, testing, verification, and validation)

Engineer II Mechanical

“Assist with **designing, developing**, executing, and evaluating fitness-for-use **testing**, product specifications and process **validation** plans for a **variety of moderate complexity products** and/or component”

Design Application Engineer

”Develop new product **designs**, specifications, define product **test** requirements and support testing and **validation** activities”

Verification Validation Engineer

“Understanding of **Model Based SW Engineering (MBSE)**”

Modeling and Simulation Engineer

“Conduct **modeling and simulation** activities that include **analysis, simulation** development, **verification** or **validation**”

Government agencies require MBSE knowledge and practices for their collaborators and contractors

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STATUS OF ADOPTION AND IMPLEMENTATION OF DIGITAL ENGINEERING INFRASTRUCTURE AND WORKFORCE DEVELOPMENT WITHIN THE DEPARTMENT OF DEFENSE

House Report 117-118, page 69, accompanying H.R. 4350, the National Defense Authorization Act for Fiscal Year 2022

CENG 001 – DIGITAL ENGINEERING FOR DoD CONSUMERS

Mr. Thomas V
Acting Principal
Office of the I
October 1, 20

Distribution Statement

- The Digital Engineering for DoD Consumers credential promotes the learning of key digital engineering information and perspectives. It establishes how models, simulations, and digital engineering can be a benefit over the entire system life cycle and how models, simulations and digital engineering support systems engineering processes. It is expected to provide an understanding of the role of Model-Based Systems Engineering (MBSE), the needs for digital artifacts related standards, how to define a finite set of digital artifacts, and the ability to develop constructs for assembling digital artifacts.
- In addition, this credential addresses digital engineering across the Department of Defense (DoD) Acquisition Lifecycle and DoD's digital engineering fundamentals, strategic goals, and policies. Concepts explored include, but are not limited to, DoD's shift toward an acquisition environment that relies on models, simulations, and digital engineering that identify with the DoD Digital Engineering Strategy, DoD Digital Engineering Fundamentals, and DoDI 5000.02. [Approximately 26 hours]
- Made up of two courses:
 1. CLE084 – Models, Simulations, and Digital Engineering
 2. MBSE: Model-Based Systems Engineering (through Coursera)

“...status of the Department’s adoption and implementation of digital engineering, including, but not limited to:

- (1) The workforce skill development required;

a;
ross the

Engineering graduates do not think they are fully prepared in MBSE

American Society for Engineering Education (ASEE)
“2020 Survey For Skills Gaps In Recent Engineering Graduates”

	MBSE	Hard Sciences & Engineering Science Fundamentals	Digital Twin
Very Prepared	16%	44%	3%
Somewhat Prepared	32%	44%	9%
Very Little Preparation	22%	7%	14%
Not Prepared At All	24%	1%	68%
Gained Skill After Graduation	6%	4%	5%

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State of teaching MBSE in undergraduate engineering programs: “MBSE is for graduate school/professional training”



MBSE

One should be a full-fledged engineer before they can learn MBSE

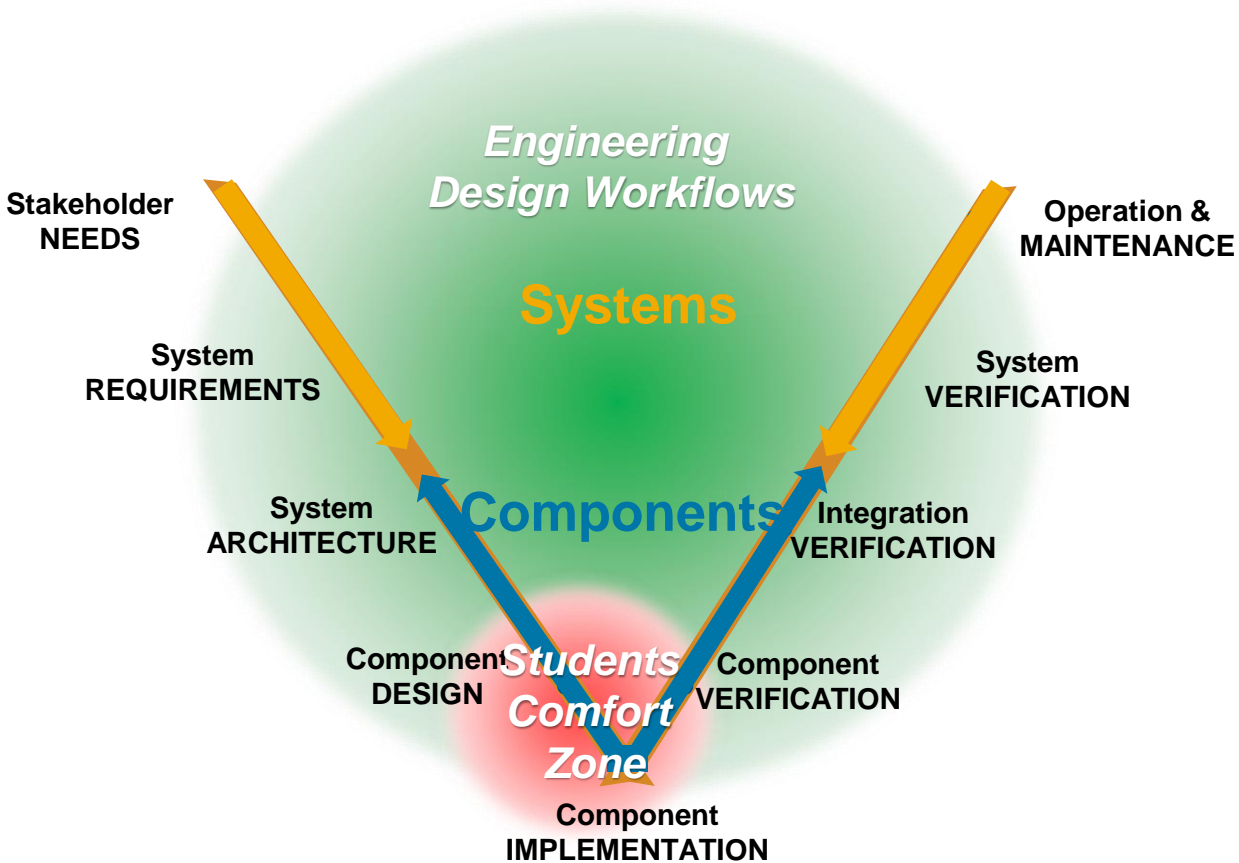


MBSE is too complex to teach to undergraduate students

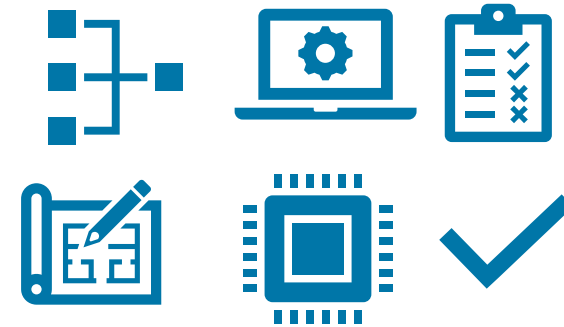


MBSE is for Systems Engineers

Common challenges of teaching MBSE



Students Motivation



Too Many Topics to Teach



Inaccessible Tools

Agenda

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Example 1: CalPoly Pomona – Aerospace Engineering

Freshman

Sophomore

Junior

Senior

Industry Practices and Program Management

SE Fundamentals
Teaming, leadership,
ethics, tech writing

MBSE
Design project

Program Management
Teaming and planning

System Thinking

Intro Astro
Spacecraft system
architecture

SE Fundamentals
Pseudo aircraft design
project

MBSE
System Architecting

**Senior Design
Capstone**
Launch Veh, Spacecraft,
Aircraft

Hands-on, Design, Build, Test Project

**Intro to Aero &
Astro**
5 Hands-on projects

SE Fundamentals
F-22 project: Wind/water
tunnel tests, constraint
diagrams

Wind Tunnel
Wing design optimization

Project Design
Analyze, design, build,
test

◆◆ (Simulate) Industry review

MATLAB EXPO

Example 2: University of Michigan, Ann Arbor

AEROSP 288/388/488 Courses

AEROSP 488

Product Development Leadership

Team Development
Program Management
System Validation
Ethics
Knowledge Capture

Systems

488 Students mentor and coach 288 and 388 students

AEROSP 288

Fundamental of Product Development

- Requirements and Architecture
- CAD and Manufacturing
- Circuits
- Simulation (CFD, CAE)

Components

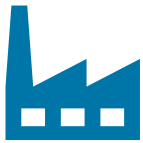
AEROSP 388

Aerospace Tools and Methods

- Statistical Modeling
- Multi-Domain Systems Modeling
- Physical Implementation

Industry-suggested full-year projects and reviews

Commonalities between examples



Industry need, expertise, and advice

Professors of practice

Industry advisory boards

Industry partners



Topic breakdown

Project management

System thinking and design

Implementation



Practicing real-world problems

Hands-on projects

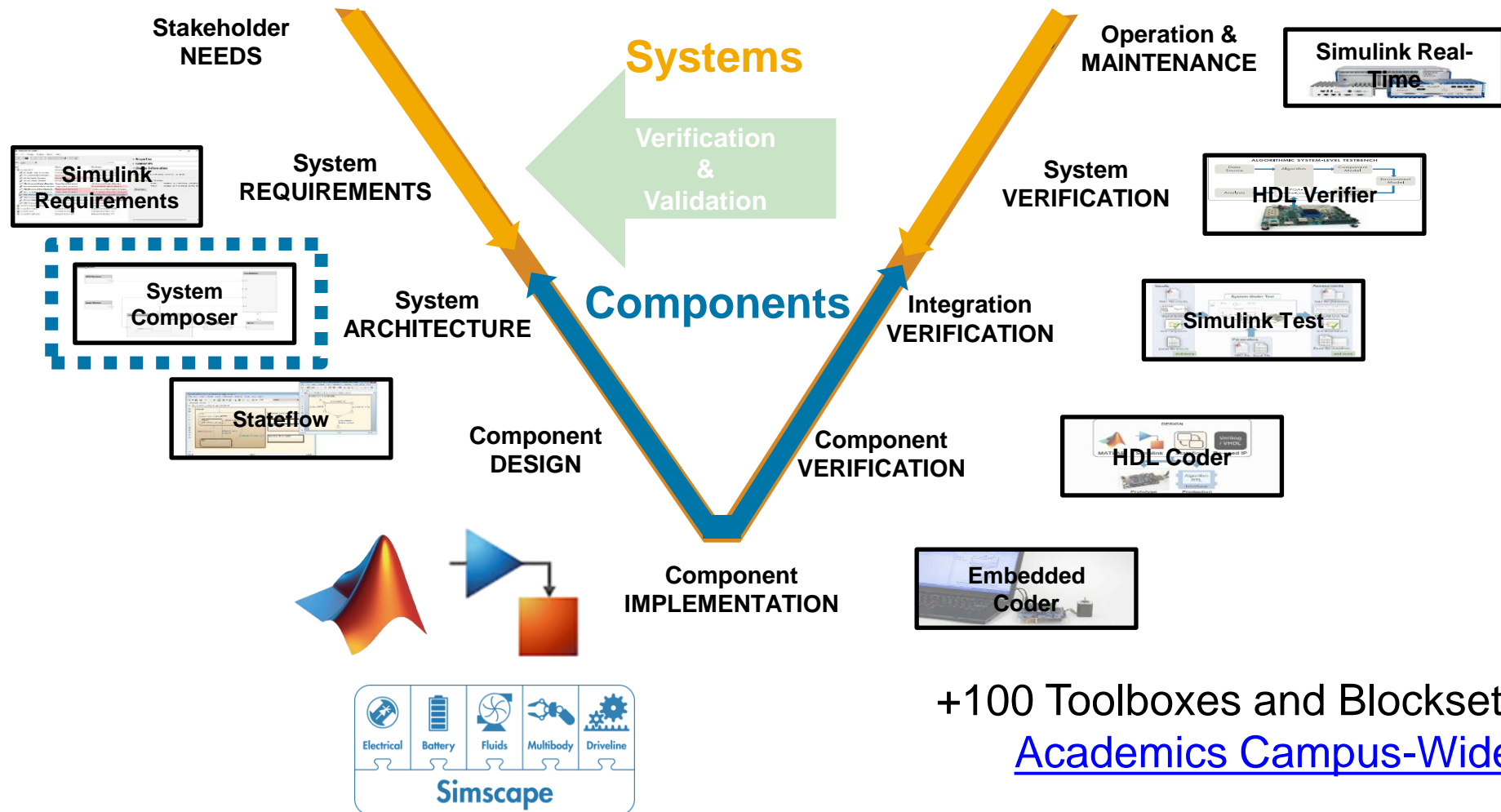
Design reviews

Longer-term projects
(e.g., student competition)

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MathWorks offers dedicated tools for every step of MBSE workflows

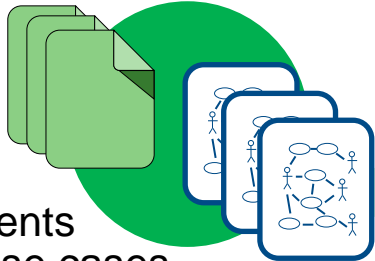


+100 Toolboxes and Blocksets included in [Academics Campus-Wide License](#)

Model-Based Systems Engineering at MathWorks

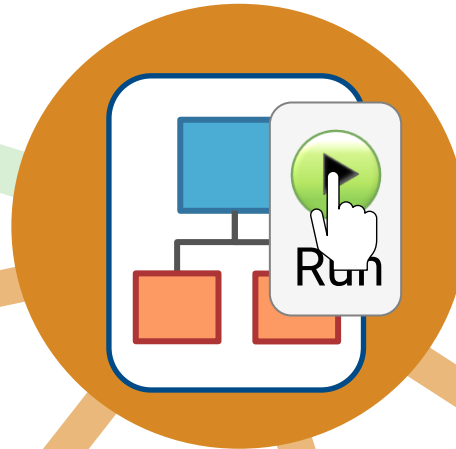
Requirements

Toolbox

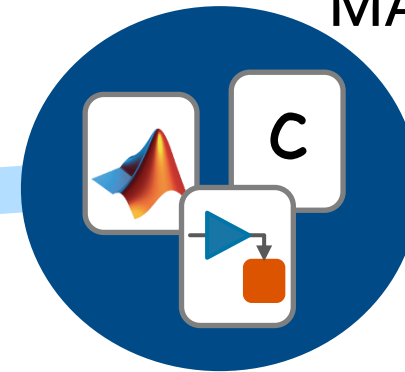


requirements and use cases

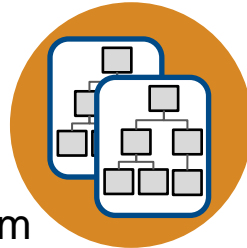
System Composer



MATLAB, Simulink,
Hand Code, FMU,
and more



implementation and test



system decomposition

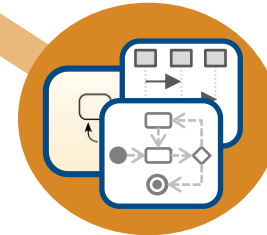
MATLAB
+ Python



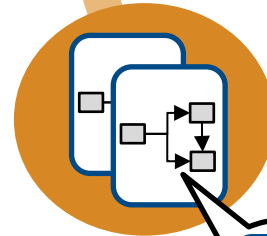
system analysis and optimization

PhysicalStereotype	
cost	800 USD
weight	2 lbs
power	150 W

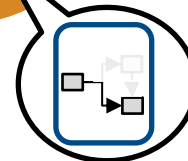
extensible properties



behavioral modeling



connectivity and data flow



query-based views

Gulfstream chooses System Composer for their Electronic System Architecture Modeling method

"System Composer adds additional capabilities for modeling integration between systems, ...capturing important system and component properties, ...directly connecting system architecture models to software functional models, and flowing data down into specialized design tools."

System Architecture Modeling for Electronic Systems Using MathWorks System Composer and Simulink

Christopher B. Watkins
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Savannah, GA, U.S.
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Jerry Varghese
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Becky Petteys
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Jordan Ross
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jordane@mathworks.com

Abstract—Electronic system architectures have traditionally been documented as static block diagrams in tools such as Microsoft® Visio® or through a richer modeling approach such as Systems Modeling Language (SysML). These approaches did not fully meet the modeling needs for the Gulfstream authors, which led to an alternative approach.

This paper introduces the Electronic System Architecture Modeling (eSAM) method, which leverages a new system architecture modeling tool called System Composer™. eSAM was created by the authors to define a standard method for applying the generic System Composer modeling constructs to build functional, physical, and logical architecture models of electronic systems. The eSAM methods are applied to an example avionics architecture to demonstrate capabilities needed for system modeling, collaborative OEM-supplier workflows, data management and ICD generation, systems integration activities, generation of system architecture deliverables for the avionics certification standards governed by SAE ARP4754A, and a Model-Based Design approach that connects a software function to its system-level ICD.

System Composer is built on MATLAB® and Simulink® and leverages the modeling, analysis, and simulation capabilities of these well-established tools. System Composer adds additional capabilities for modeling integration between systems, filtering large models into manageable views, capturing important system and component properties, allocating between different descriptive architecture models, directly connecting system architecture models to software functional models, and flowing data down into specialized design tools.

This paper summarizes desirable features in system architecture modeling tools. When applying design tools to system architecture models, two gaps of interest are identified. Gap #1 is the specification and the implementation of the system architecture models. Gap #2 is the implementation of the system architecture models. The eSAM method addresses these gaps by providing a simplified view of the V-diagram and design activities.

When applying design tools to system architecture models, two gaps of interest are identified. Gap #1 is the specification and the implementation of the system architecture models. Gap #2 is the implementation of the system architecture models. The eSAM method addresses these gaps by providing a simplified view of the V-diagram and design activities.

Figure 1: Simplified development process showing Early concepts, Gap #2, Design Specs, Gap #1, and Implement.

Data-Message Modeling for Multi-Lane Architectures on an IMA Platform

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chris.watkins@gulfstream.com

Jordan Ross
The MathWorks, Inc.
Natick, Massachusetts, U.S.
jordane@mathworks.com

The Electronic System Architecture Modeling (eSAM) method has been developed as a novel approach to modeling of system components interconnected across an open Modular Avionics (IMA) platform. Fundamental Based Systems Engineering (MBSE) approach, eSAM system integration models to be constructed independent of the system allocation to the IMA platform to traditional logical/physical model separation, eSAM hybrid modeling method where both logical and physical exist in the same model. Hybrid model components connected, similar to traditional federated architectures though components are physically connected through platform. This improves the clarity of the functional integration, while correctly segregating the role integration and IMA platform allocation. In this paper, a key challenge to modeling IMA system architecture is addressed: the eSAM data and message model. This paper focuses on the eSAM data and message model. This includes the re-use of related data/message definitions in multi-lane architectures supporting high integrity and high availability solutions managed using template-instance modeling method. A system part is defined as a template that can be instantiated in the system models. eSAM has been implemented in System Composer™ tool, which provides capabilities including model analysis functions. This paper for the purposes of illustrating the modeling, system architecture, data message engineering, MBD, model based design, Electronic System Architecture Modeling.

Figure 1: Traditional Point-to-Point System Architecture Modeling. Shared Hosted Application.

Figure 1: Three men standing together, each holding a green award plaque. They are in a professional setting, likely at a conference or awards ceremony.

Functional Flow Block Diagrams using the eSAM Method

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Becky Petteys
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challenges and has begun improving SE methods by leveraging Model-Based Systems Engineering (MBSE). MBSE offers many benefits:

- SE data managed as a single source of truth, thereby eliminating duplication and need to manually sync
- Reduced systems engineering design errors
- Model analysis capabilities that were not possible with disconnected systems engineering data artifacts
- Improved understanding of system design via graphical representation of system architecture and system integration

eSAM is a novel MBSE approach developed by the authors which is tailored for modeling IMA system architectures. System integration activities and systems allocation to the IMA platform is traditionally managed across thousands of Extensible Markup Language (XML) files. eSAM provides a dynamic, interactive graphical model helping system architects and system integrators more effectively manage their development workflows.

The automatic derivation of Functional Flow Block Diagrams (FFBDs) is this paper's focus and is an example of how an MBSE model can improve managing and understanding a complex system. An FFBD depicts system functions and the dependencies between those functions as defined by functional information flows. For example, Figure 1 generically depicts functional dependencies between Functions A, B, and C. If Function A is lost, then there is a direct impact on Function B, which is missing a functional input from Function A. Additionally, there is a cascading impact on Function C if Function B can no longer produce Functional Flow 2 due to losing Functional Flow 1.

Figure 1: Functional Flow Construct. A diagram showing three functional blocks: Function A, Function B, and Function C. Function A is connected to Function B via 'Functional Flow 1'. Function B is connected to Function C via 'Functional Flow 2'.

David Lubkowski Memorial for Advancement in Digital Avionics Best Paper Award
SPONSORED BY MITRE

DASC 41st
Digital Avionics Systems Conference
Portsmouth, VA, USA - September 18-22, 2022

Data-Message Modeling for Multi-Lane Architectures on an IMA Platform Using the eSAM Method

Co-Authored between Gulfstream and Mathworks

explore.ieee.org/document/9925816

<https://ieeexplore.ieee.org/document/10311180>

Researchers at TU Hamburg picked System Composer for novel aircraft systems architecting

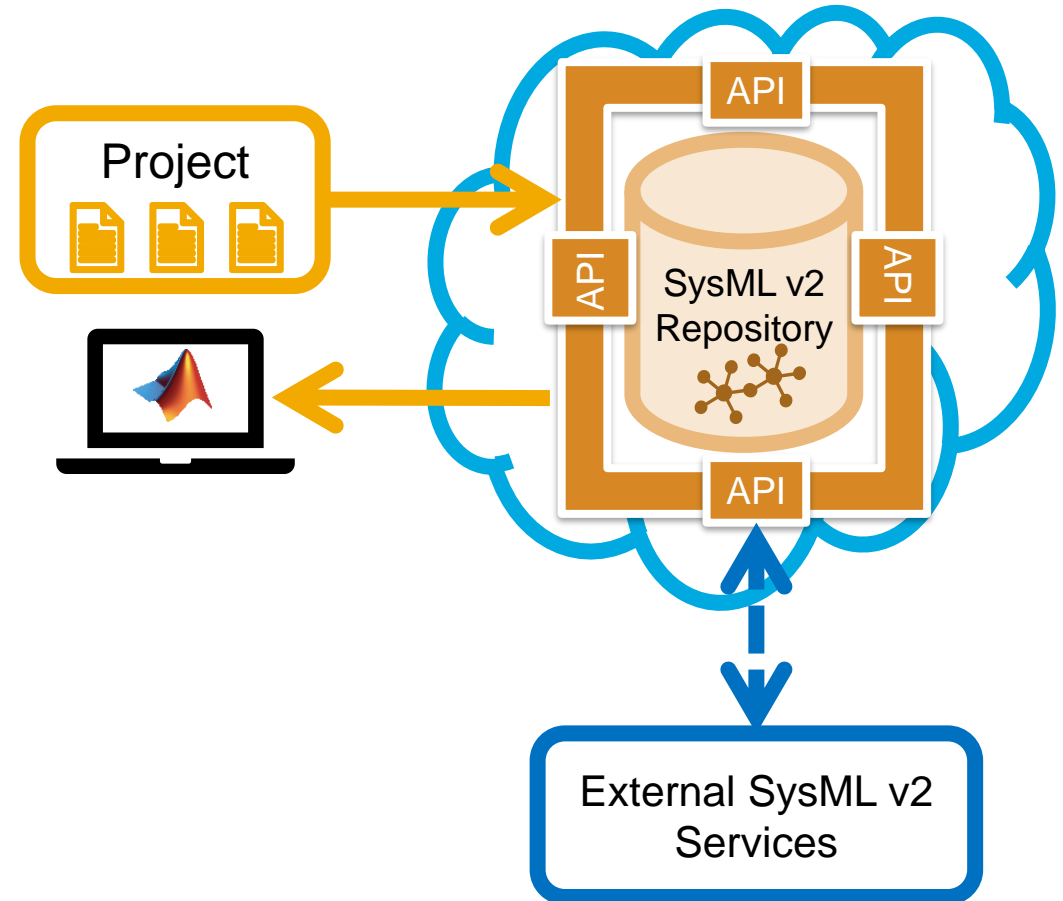
“Model-Based Framework for Data and Knowledge-Driven Systems Architecting Demonstrated on a Hydrogen-Powered Concept Aircraft” [Kuelper, Nils, et al. *INSIGHT* 27.1 (2024): 47-60]

- Accelerate the development cycle to **reduce the time-to-market** and **costs** of novel aircraft
- Comparison between System Composer and three other tools in 18 criteria

“Based on evaluating different modeling languages and tools, MathWorks System Composer is selected as most suitable tool for knowledge-based systems architecting.”

MathWorks is preparing to support the SysML v2 standard

- Work in System Composer today and be ready for SysML v2 tomorrow!
 - System Composer is well-aligned with the concepts of SysML v2
- Interoperability is our top priority.
 - We plan to provide access to System Composer model data through SysML v2 RESTful APIs



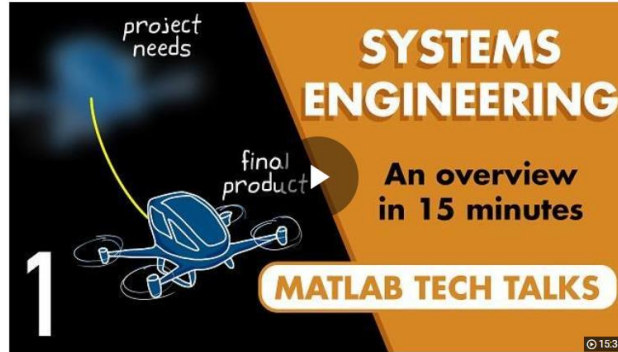
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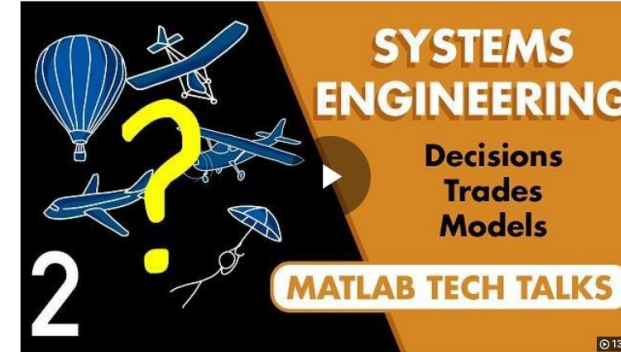
 Recourses for teaching/learning MBSE

Motivate your students with short videos on MBSE

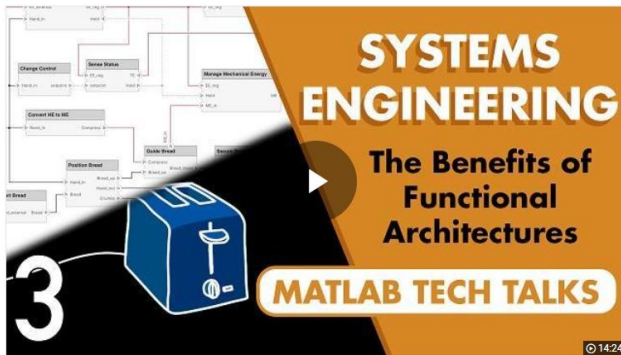
Video series: Managing System Complexity



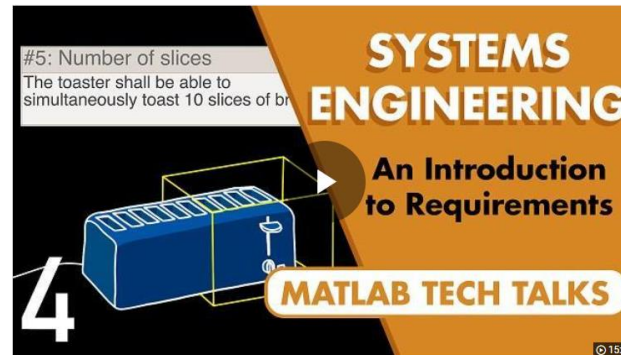
What Is Systems Engineering?



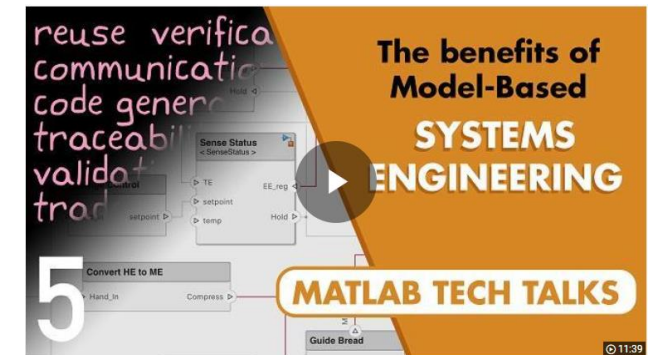
Towards a Model-Based Approach



The Benefits of Functional Architectures



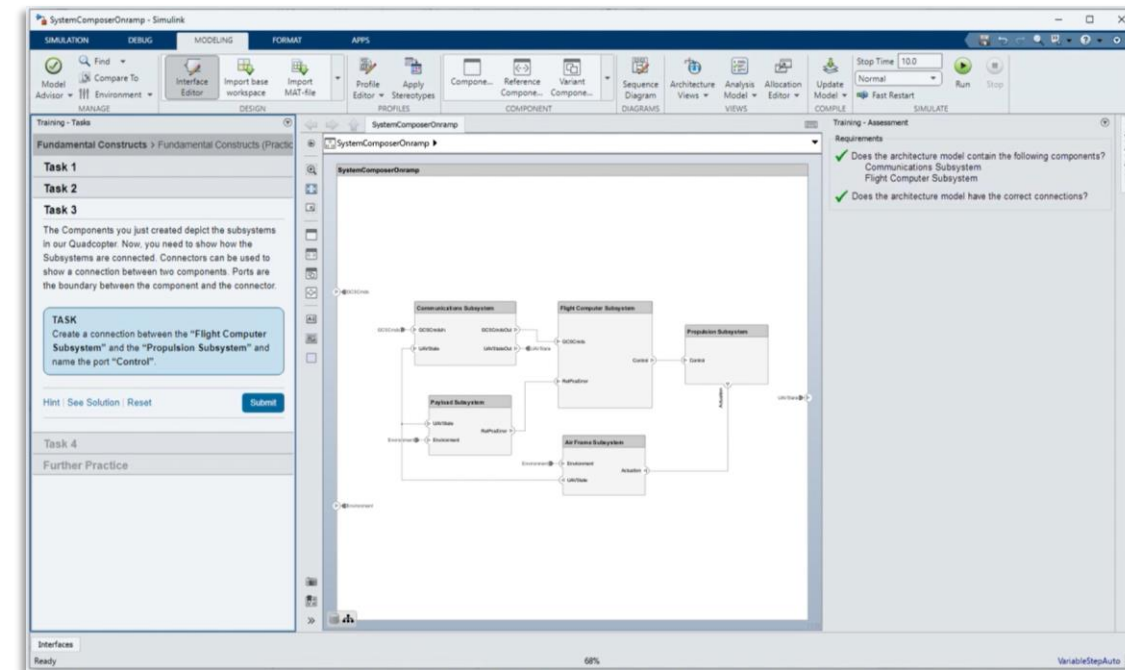
An Introduction to Requirements



Some Benefits of Model-Based Systems Engineering

Reduce barriers to learning systems architecture design by System Composer Onramp

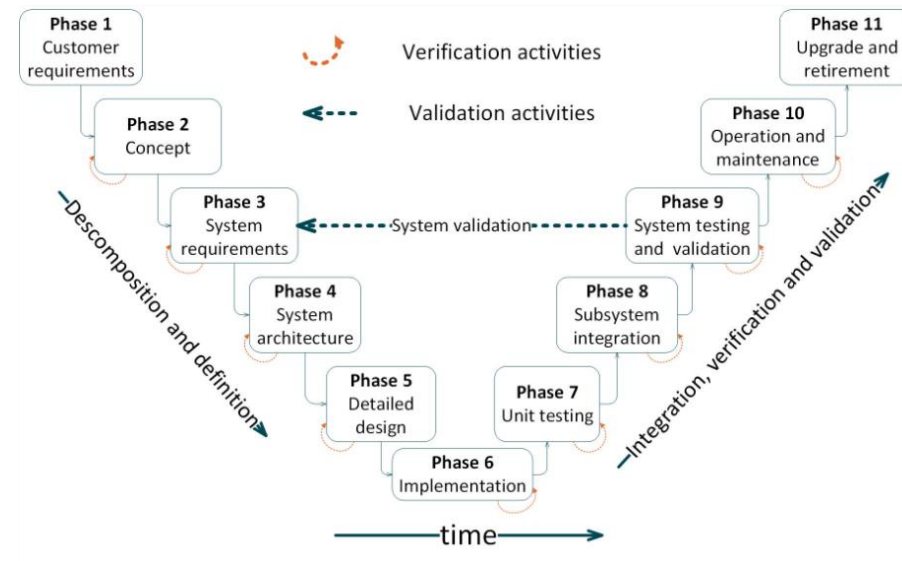
- Free self-paced online training
- Learn how to perform **model-based systems engineering** by creating architecture models + simulations using **System Composer** in **2 hours**
- Short video demonstrations and hands-on exercises with immediate feedback
- Learn by **doing**:
 - Build a descriptive architecture
 - Generate views with filters
 - Link requirements to the architecture
 - Elaborate the architecture with behavioral models
 - Simulate and test the architecture



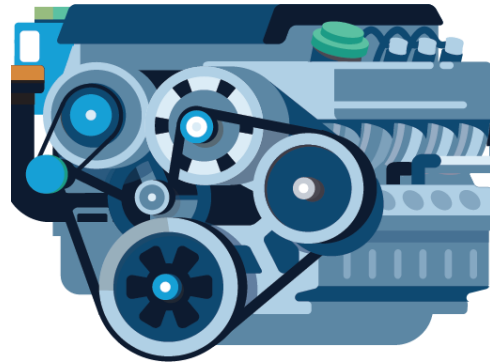
Teach with a MBSE modular courseware

Model-Based Life-Cycle with MATLAB and Simulink

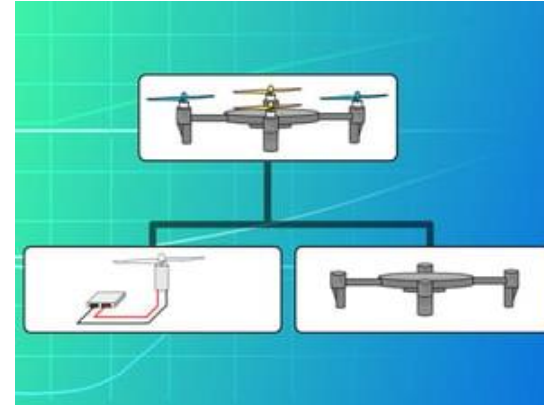
- Prof. Jon del Olmo [Mondragon University]
- Main topics
 - Requirements
 - Architecture
 - Design
 - Validation
- Course modules
 - Presentations
 - Codes and models
 - Exercises



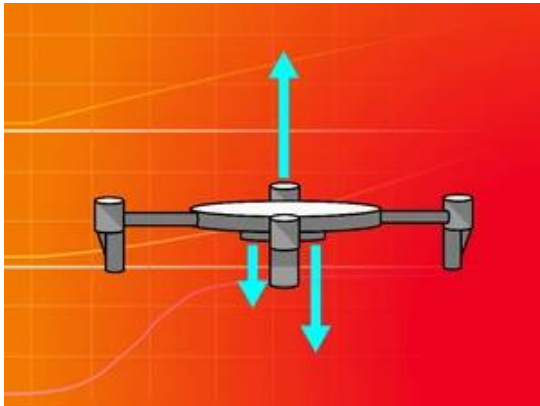
More educational resources are available for MBSE subtopics



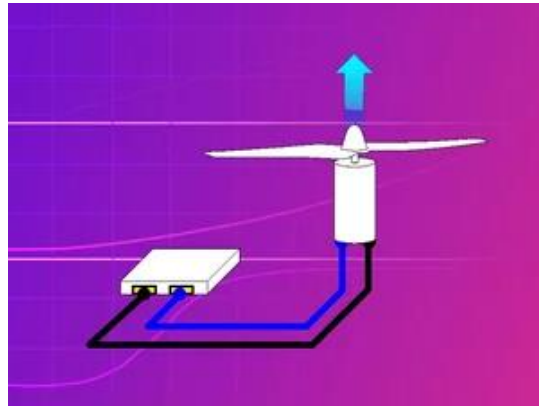
[Introduction to Engineering with Arduino \[Course Modules\]](#)



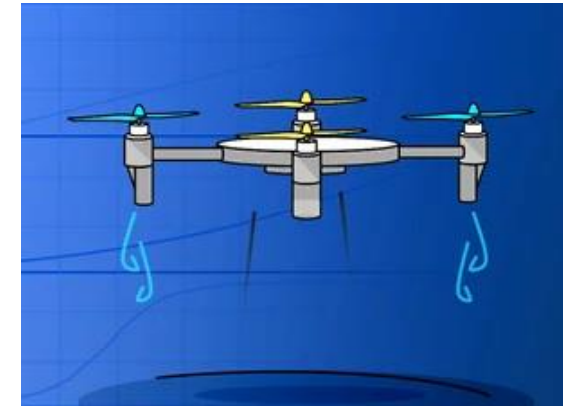
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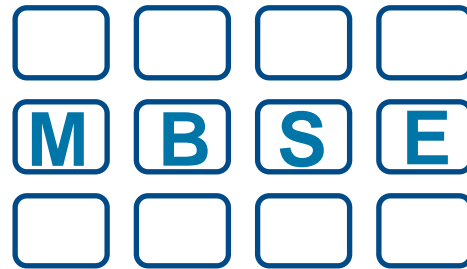
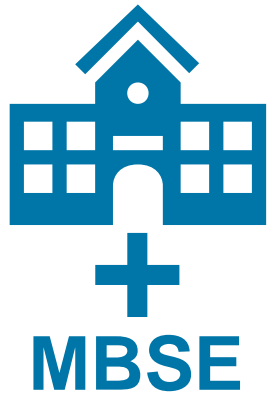


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Summary



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Thank You



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