MATLAB EXPO

Model Based Design Process, Application for National Defense and Space Development

SANGSUL HAN, Agency for Defense Development

MathWorks

Presenter

SANGSUL HAN
Team Leader, Ph.D, Principal Researcher
Advanced Defense Science & Technology Research Institute - Satellite Systems PMO. 3th Team

Contents

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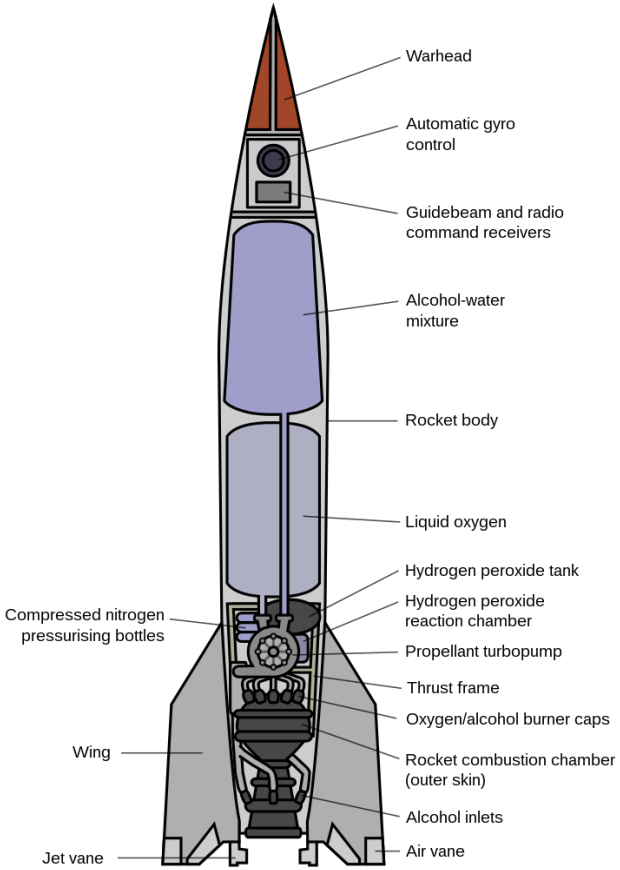
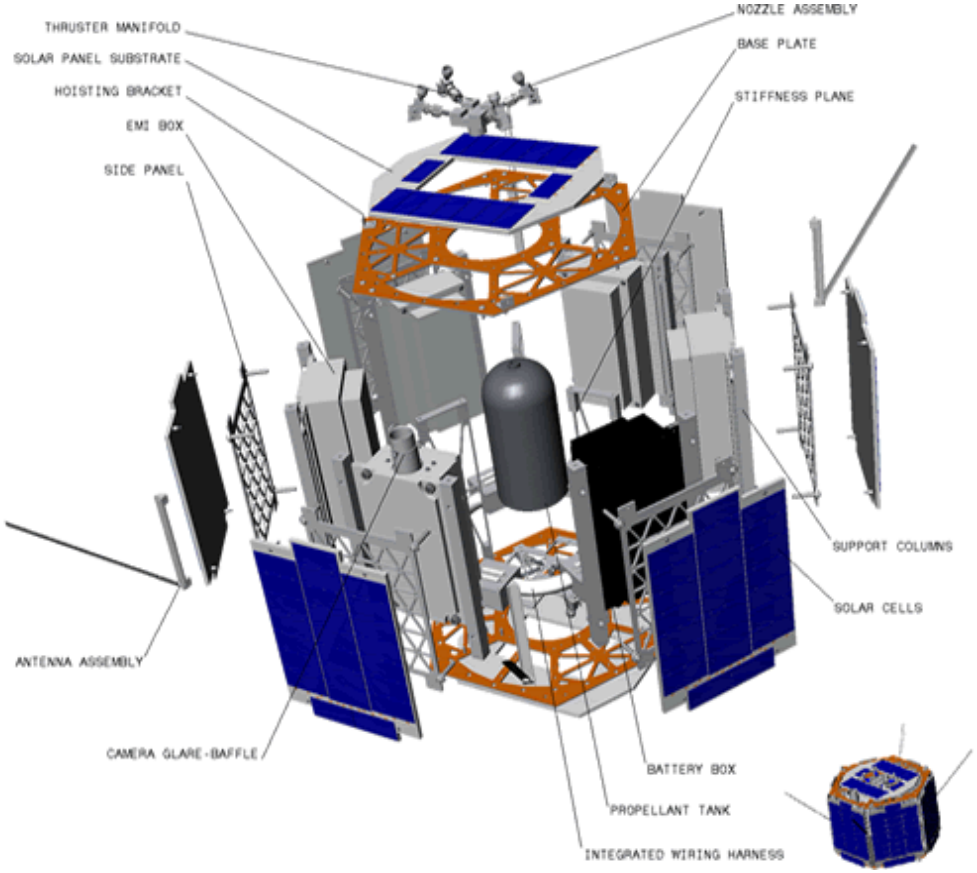
Background considering the Application of MBD

Rocket and Satellite

- Rocket and Satellite are based on similar technologies.



V-2



ARTEMIS

Transformers

- Each car and robot is composed of same components in the Transformers.

Fast Jump Up

- To be an eager pursuer or a bold challenger ?
- Creative new challenging with MBD

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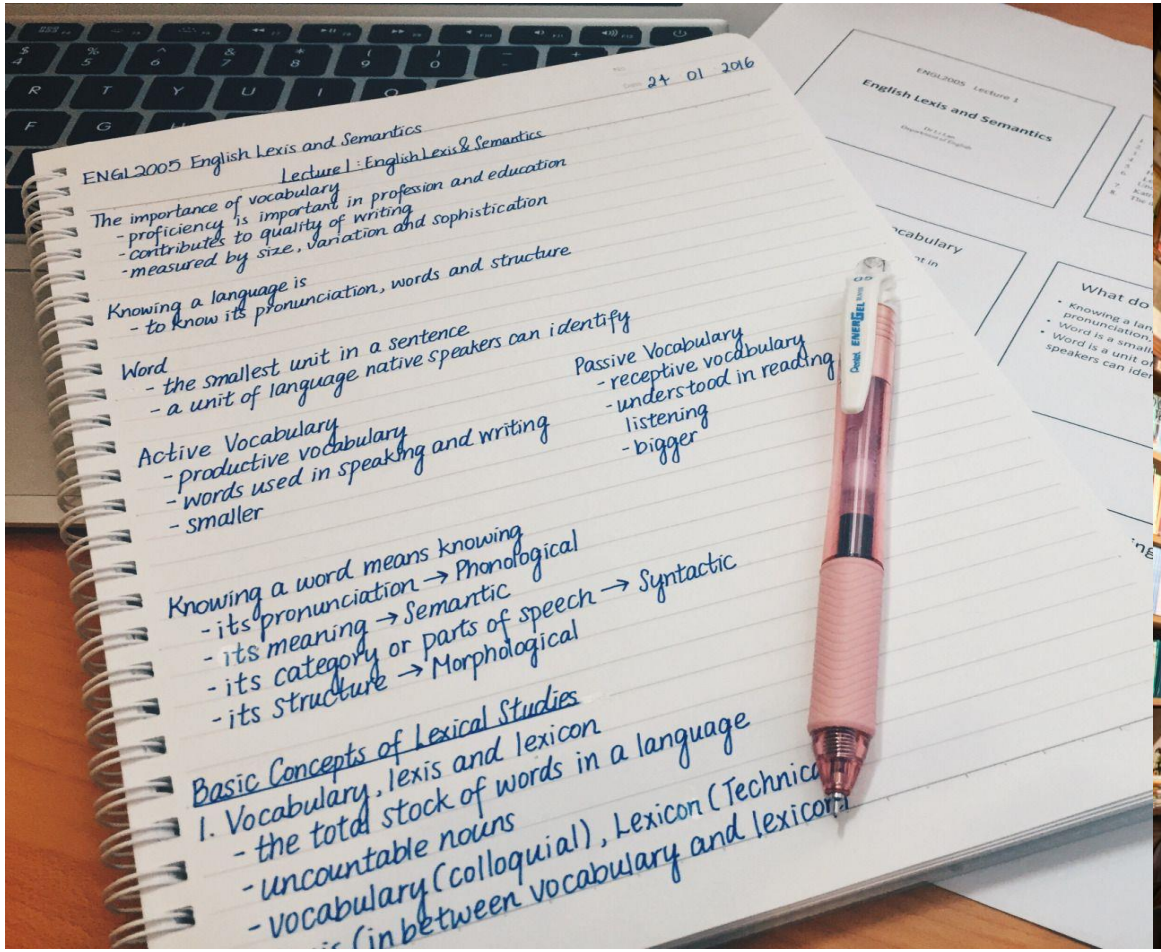
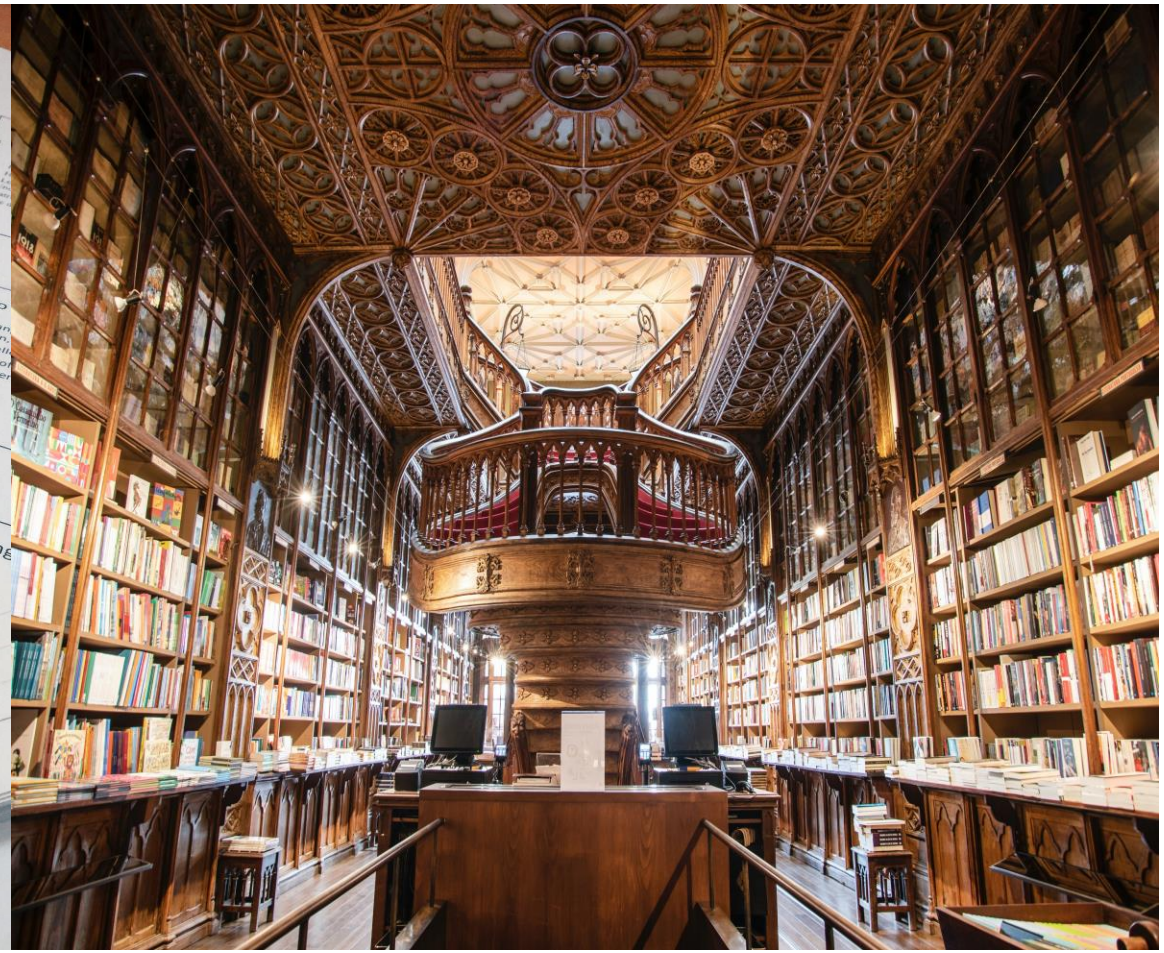
Practical Effects obtained by applying MBD

Abundant Library

- Inhouse and own legacy



- Outsourcing and abundant library



Automation

- Hard-working ant and relaxed grasshopper … with automated farm

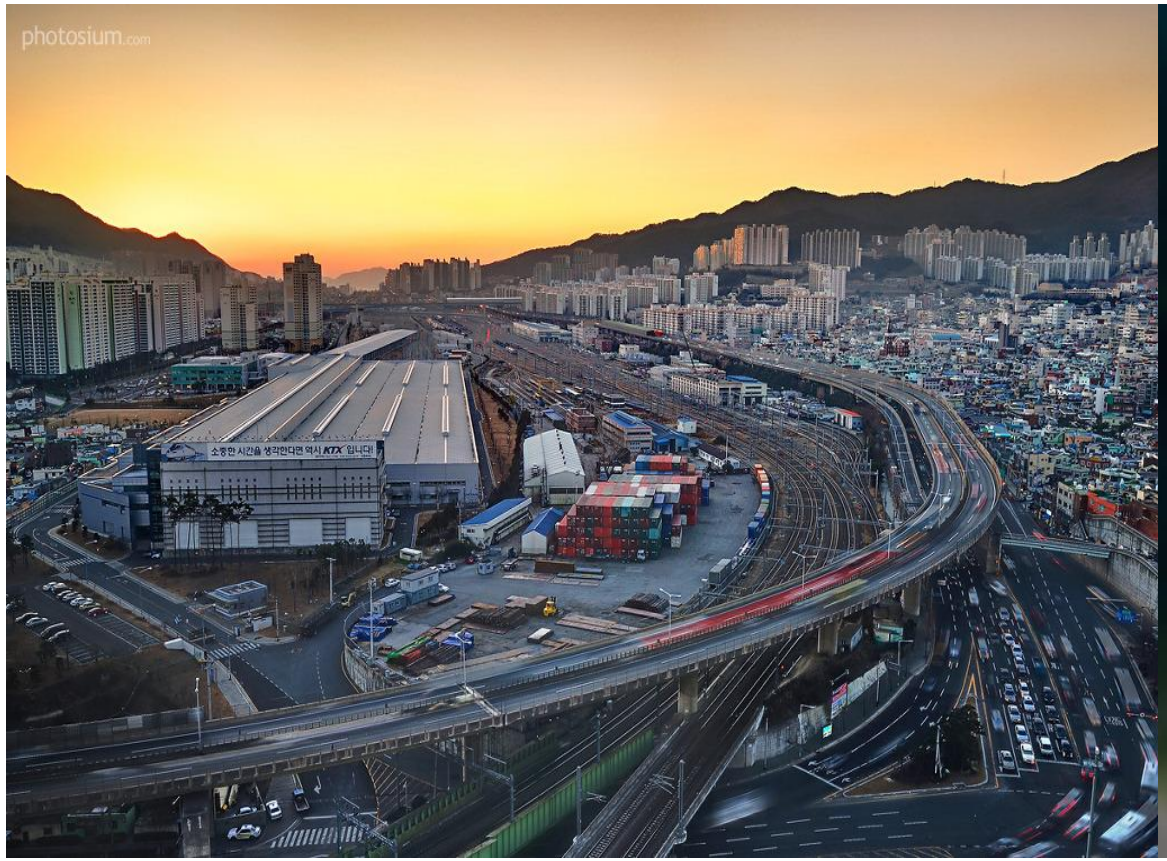
Expert Tools

- Tools are simple and poor.
- But I am an expert.

- I am a beginner.
- But tools are professional and plentiful.

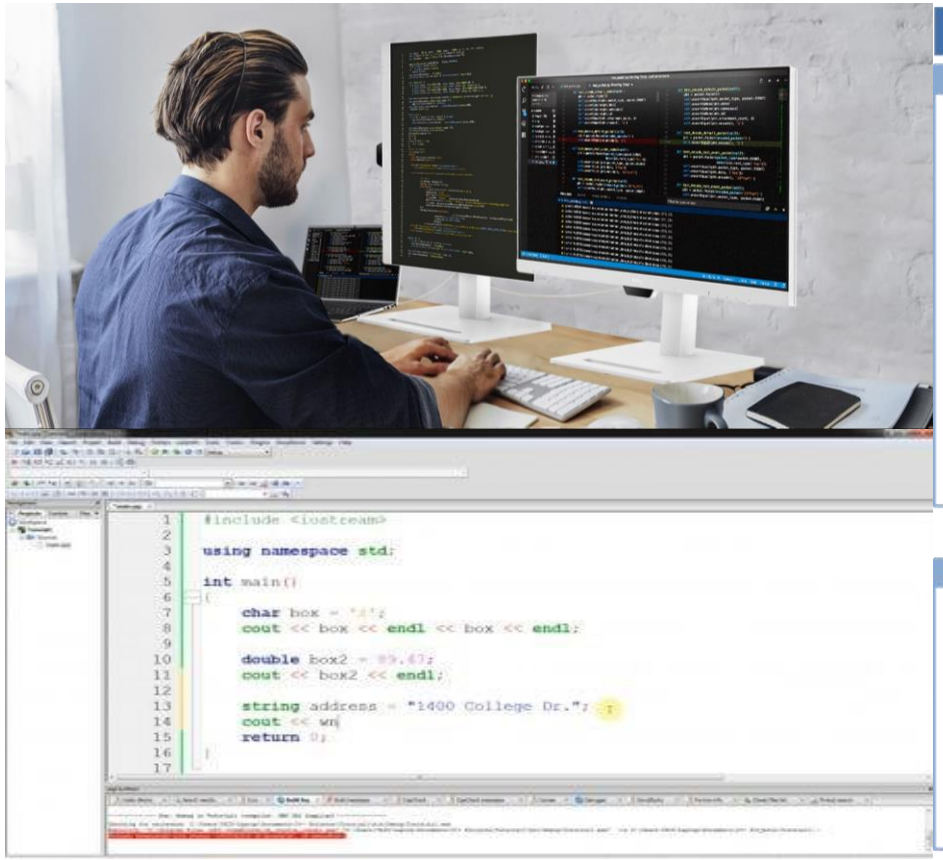
Concentration

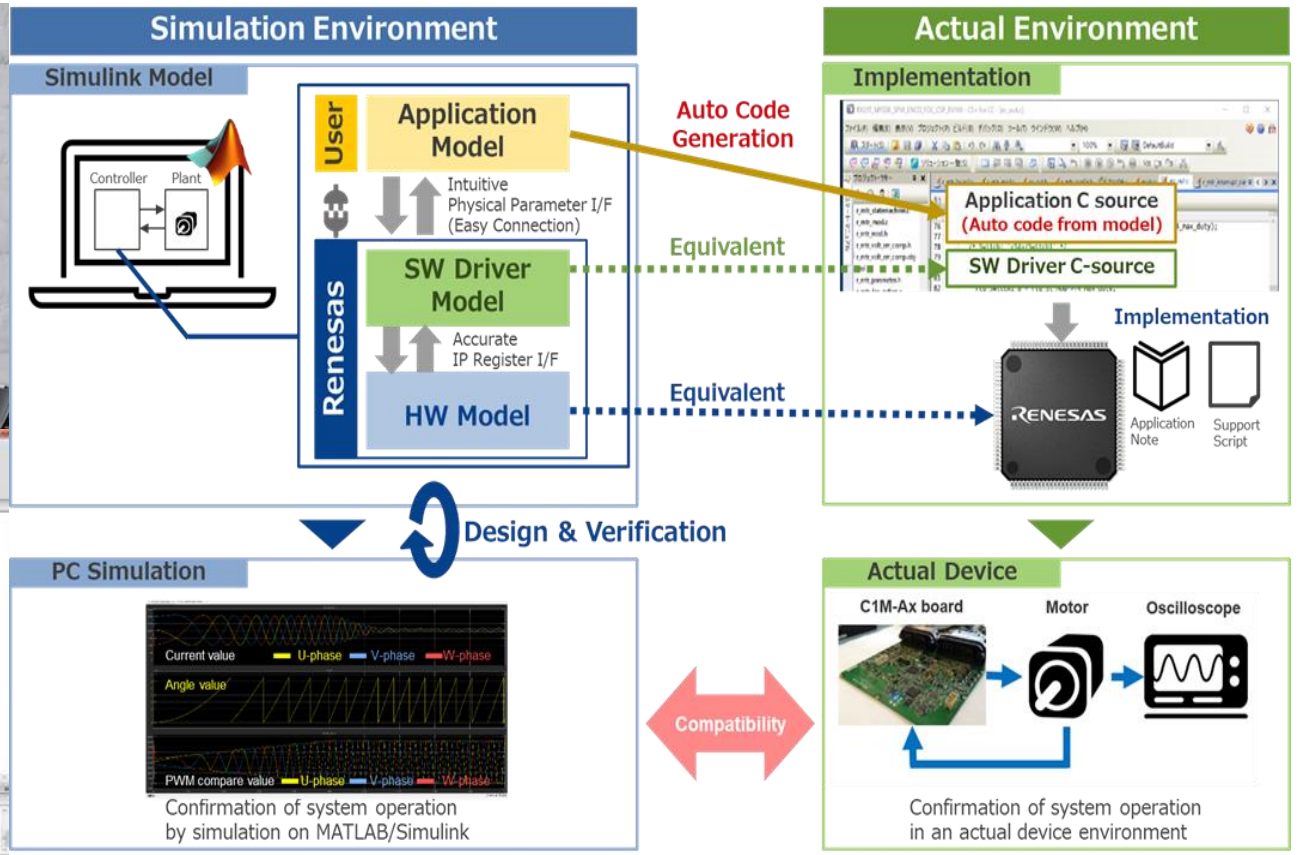
- An engineer should be a super-hero
- MBD allows an engineer to focus on design.



Reliable Auto-code … Quality ?

- An engineer is not a programmer.
- MBD allows an engineer to get high-quality code.





Efficient Communication

- Co-workers based on various background

- MBD allows co-workers to discuss using model.

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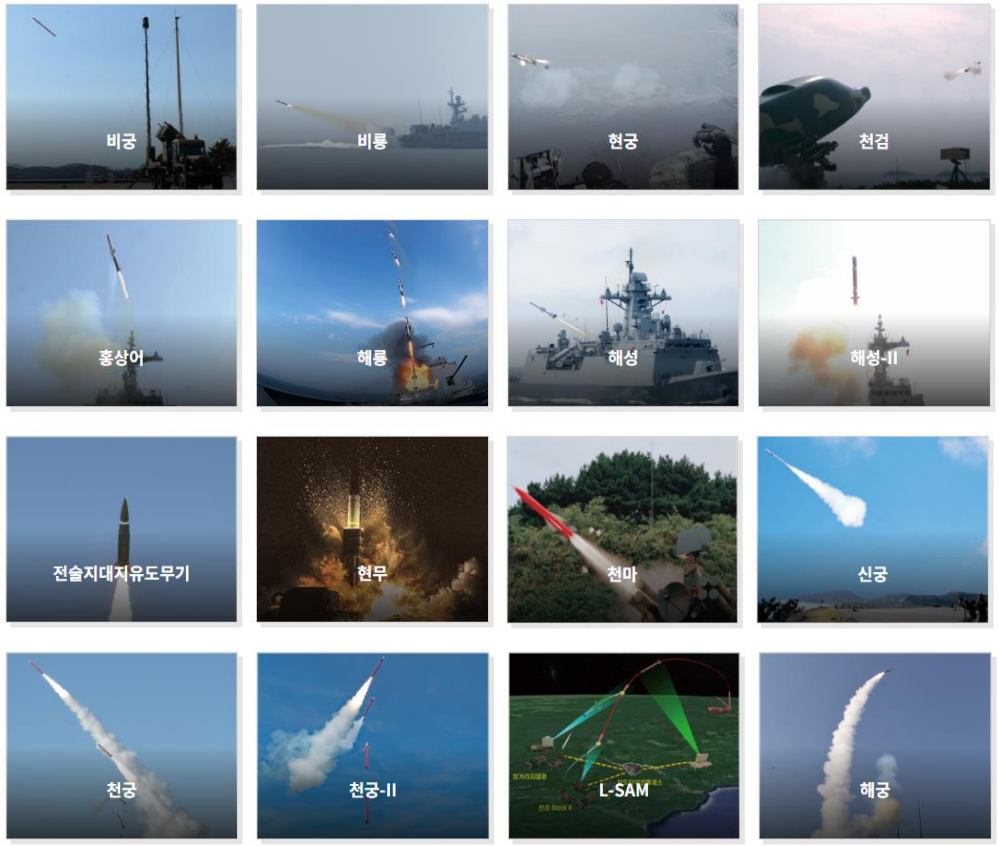
MBD Process applied to National Defense Development

Verified and Validated Legacy

- The legacy of national defense has been accumulated through many developments over long time.



New system … How to ?

Legacy

Verified, Validated, Stable, … High inertia

New system

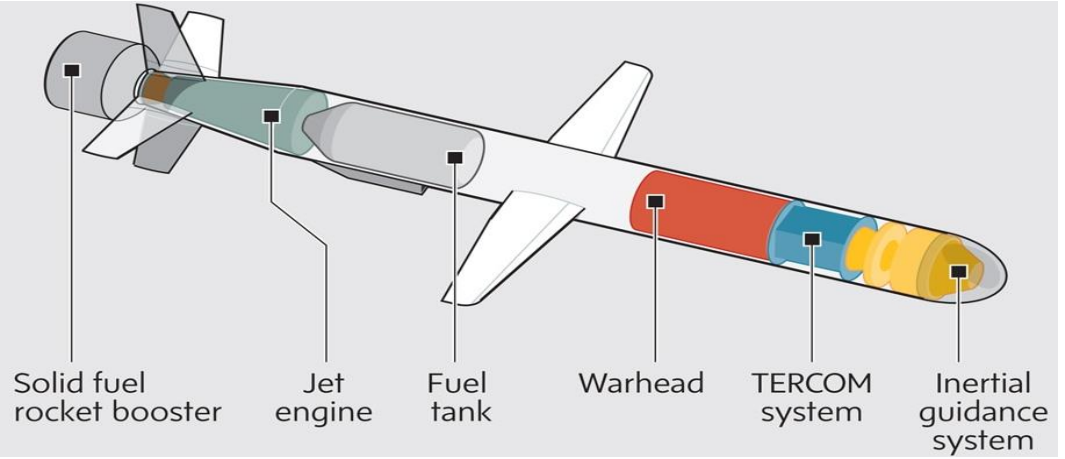
Large, Complex, Long lifetime

MBD Process

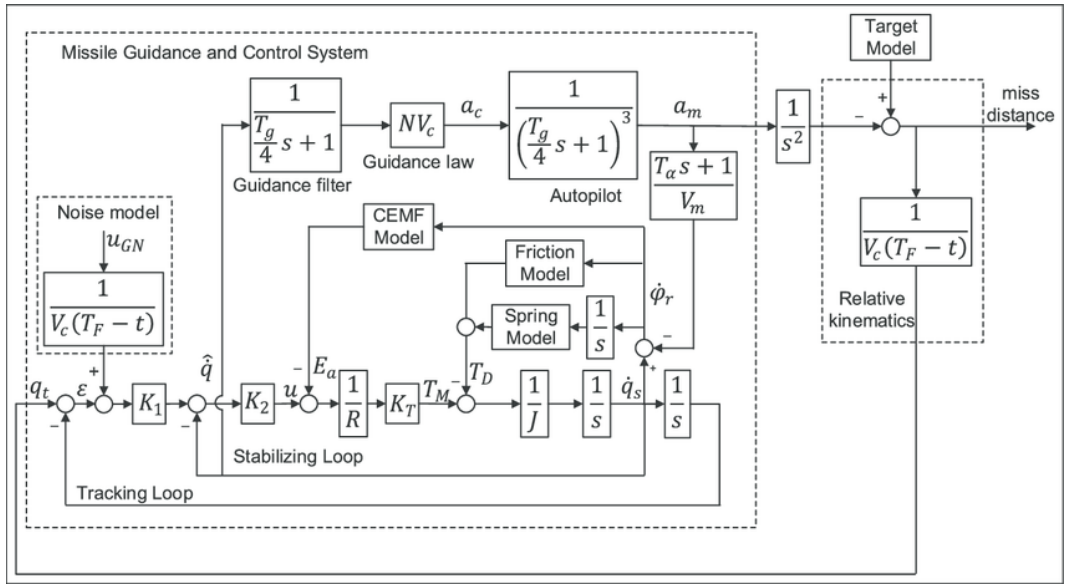
Fast prototype, Efficient Co-working

Complex system

- Properties of missile system
  - Various kinds of units
  - Various kinds of technologies
  - Complex control system



- Properties of missile control system
  - Multiple feedback loops
  - Including dynamic models
  - Linear, non-linear, and complex system



Multiple and Extendable systems

- System of multiple systems with same models should be simulated.

Approach to apply MBD

MathWorks®

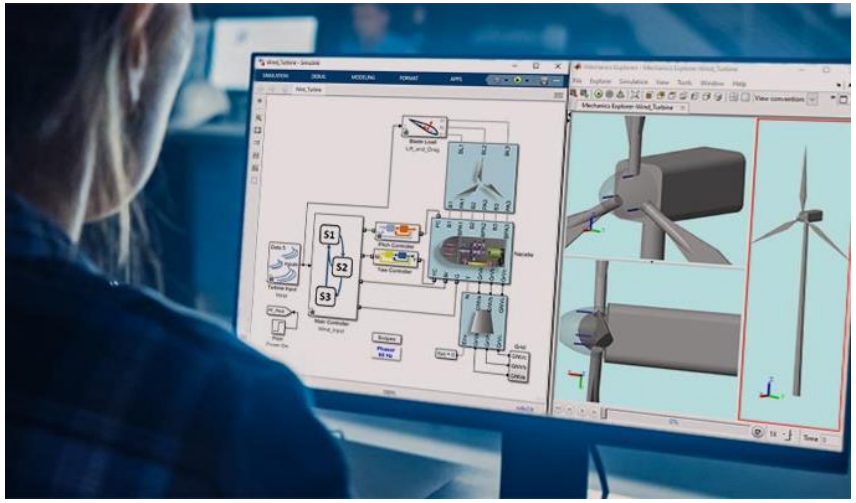
MATLAB® & SIMULINK®

Using MATLAB

- MATLAB

Using Simulink

- Physical Modeling
- Real-Time Simulation and Testing



Workflows

- Reporting and Database Access
- Systems Engineering
- Code Generation
- Application Deployment
- Verification, Validation, and Test

Applications

- AI, Data Science, and Statistics
- Mathematics and Optimization
- Signal Processing
- Image Processing and Computer Vision
- Control Systems

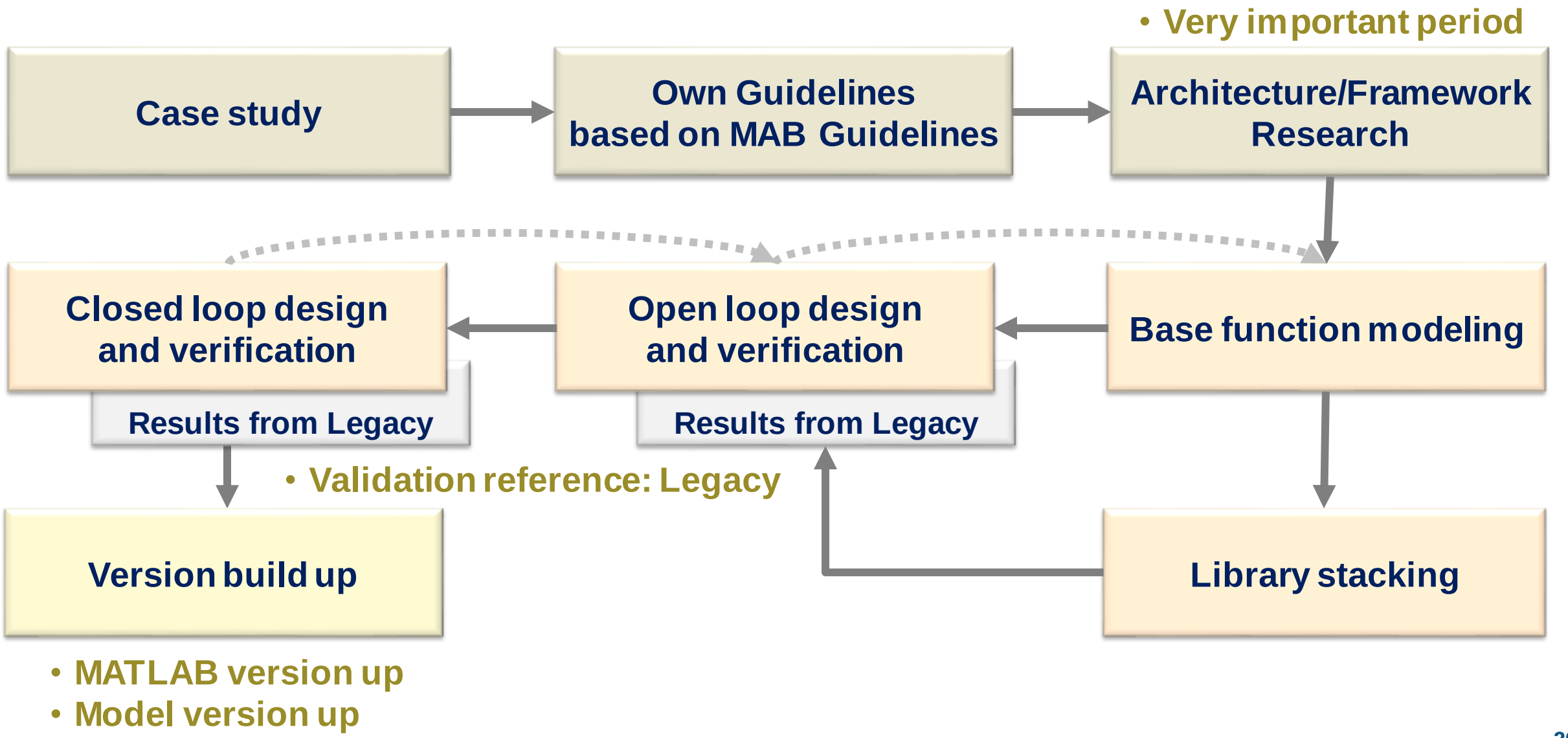
- Test and Measurement
- RF and Mixed Signal
- Wireless Communications
- Radar
- Robotics and Autonomous Systems
- FPGA, ASIC, and SoC Development

- Automotive
- Aerospace

Applications

- AI, Data Science, and Statistics
- Mathematics and Optimization
- Signal Processing

Design, Verification and Validation



Lesson Learn from Case Study

- Good models lead to good auto-code, bad models lead to bad auto-code.

Modeling is difficult. — Hardware Engineer

Readability of auto-code is very poor. — Software Engineer

Sometimes the solution to a problem is ambiguous. — MBD Engineer

Lesson Learning

- **Supplement of Requirements and References from Hardware Engineer**
- **100% inhouse modeling by Software Engineer**
- **Technical assistance from MBD Engineer**

[Policy]

- **Official training**
- **Own guidelines**
- **Inhouse modeling**
- **Automated process**
- **MBD-centered process**

Modeling Guidelines

- Focus: mandatory rules related on code generation

MAB Modeling Guidelines

R2023a

MathWorks® Advisory Board guidelines

MathWorks Advisory Board (MAB) guidelines stipulate important basic rules for modeling in Simulink® and Stateflow®. The overall purpose of these modeling guidelines is to allow for a simple, common understanding by modelers and consumers of control system models.

The main objectives of these guidelines are readability, simulation and verification, and code generation.

If you have a Simulink Check™ license, you can use the Model Advisor to check for compliance with a guideline.

Categories

Naming Conventions
Signal line, block, and subsystem names

Simulink
Simulink model diagram appearance, signals, blocks, and modeling patterns

Stateflow
Stateflow chart appearance, data and operations, events, and patterns

MATLAB
MATLAB® Function appearance, data, patterns, and use

Title	Requirement
Priority	**Mandatory** **Strongly Recommended** **Recommended**
Scope	…
MATLAB Version	…
MA Check	Yes/No
Prerequisites	…/None
Description	…
Rationale	**Readability** **Workflow** **Simulation** **V&V** **Code Generation**

Architecture

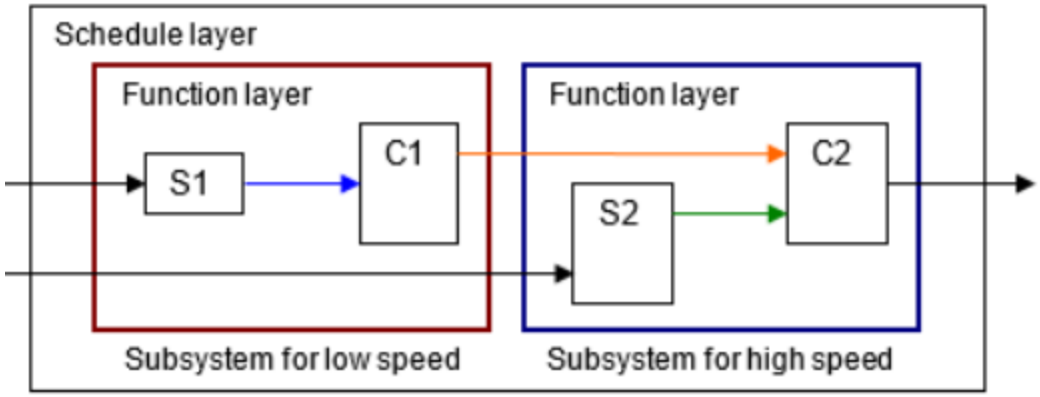
- The designed framework has a hierarchical structure, and certain principles and rules are assigned to each layer.

	Layer concept	Layer purpose
Top Layer	Function layer	Broad functional division
	Schedule layer	Expression of execution timing (sampling, order)
Bottom Layer	Sub function layer	Detailed function division
	Control flow layer	Division according to processing order (input → judgment → output)
	Selection layer	Division into a format that switches and activates the active subsystem
	Data flow layer	Layer that performs one calculation that cannot be divided

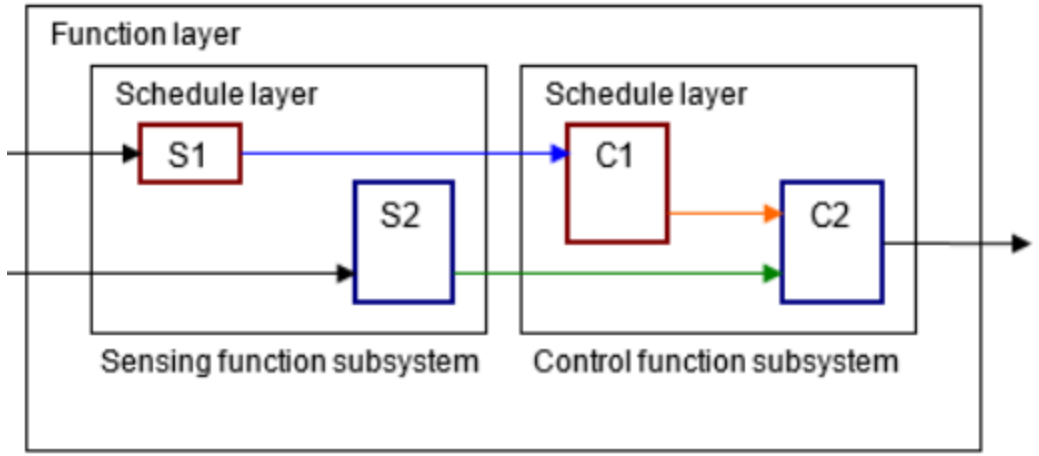
Principle of the Top layer

- The setting range of atomic blocks has a great impact on execution and code.
- Difference: Simple subsystem and Atomic block

- Easy integration
- Poor readability of auto-code

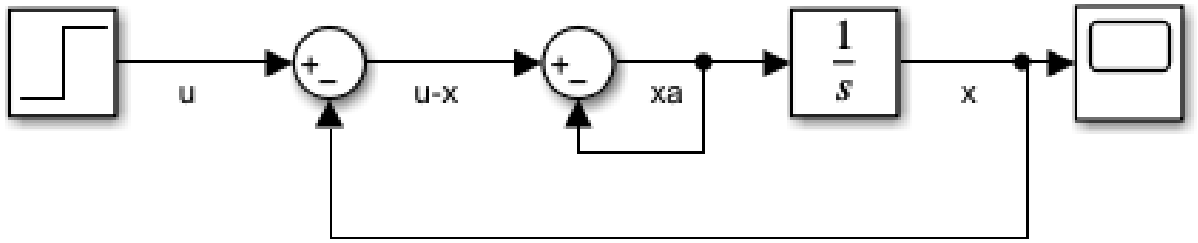


- Good readability of auto-code

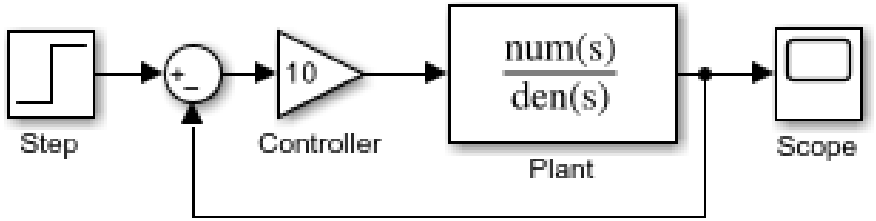


Algebraic loop

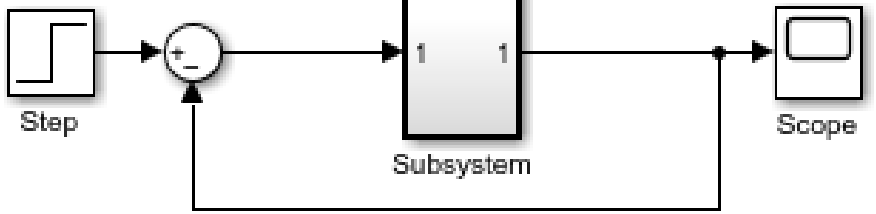
- Inner loop contains an algebraic loop.



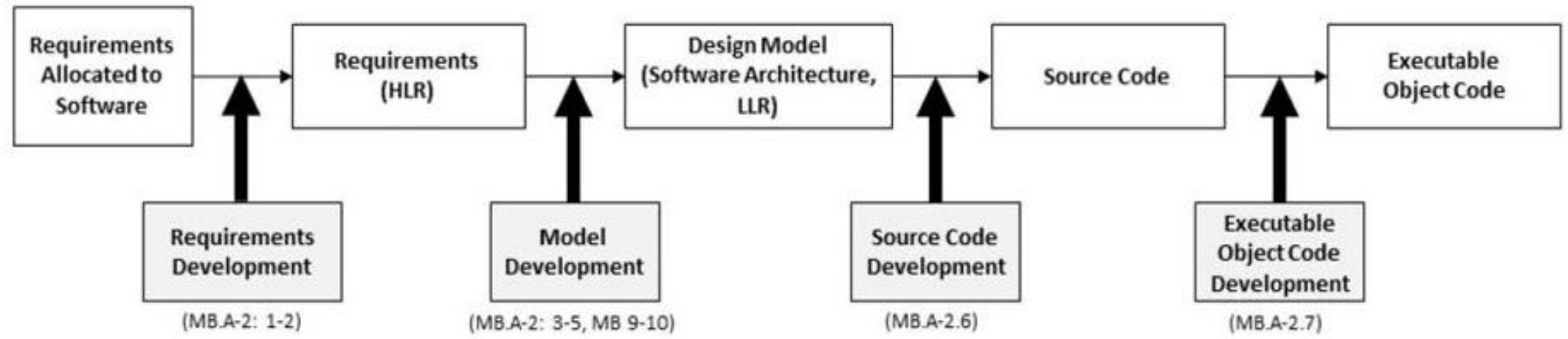
- Model does not contain any algebraic loop.

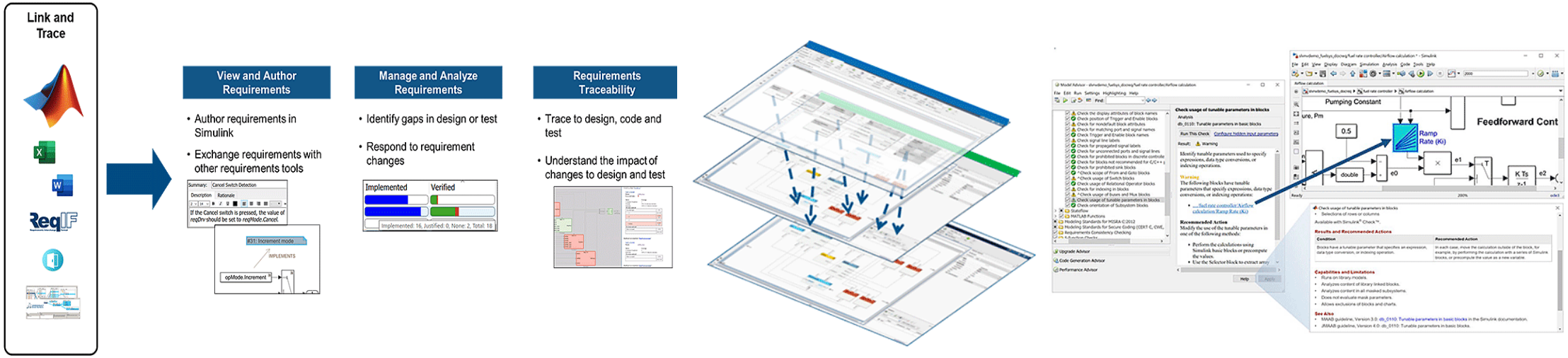


- Model contains an artificial algebraic loop.

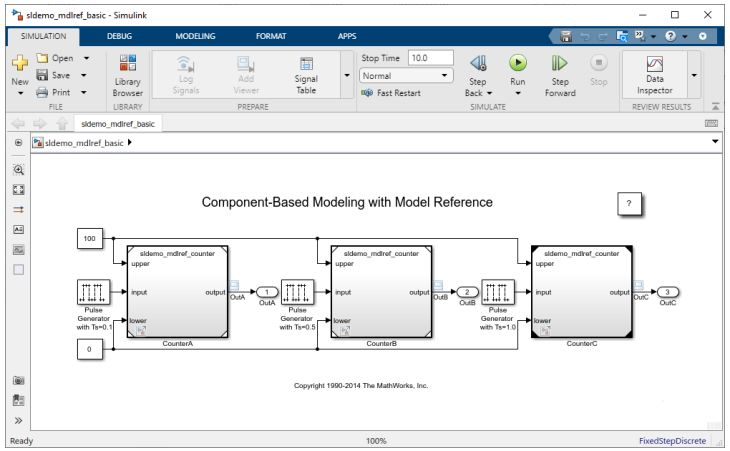


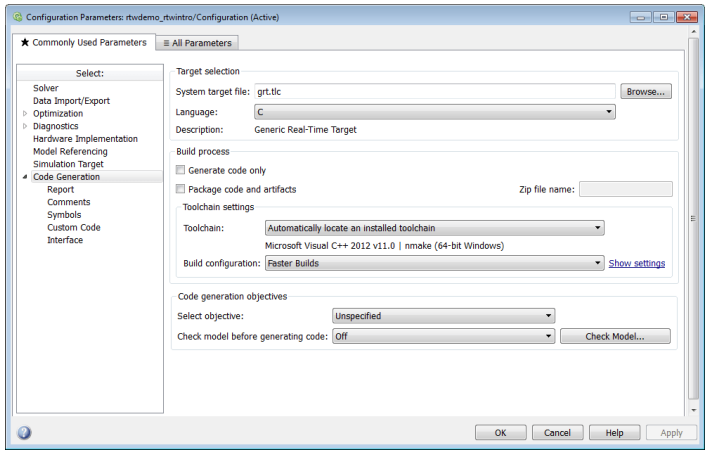
DO-178C Workflow with Code Generation

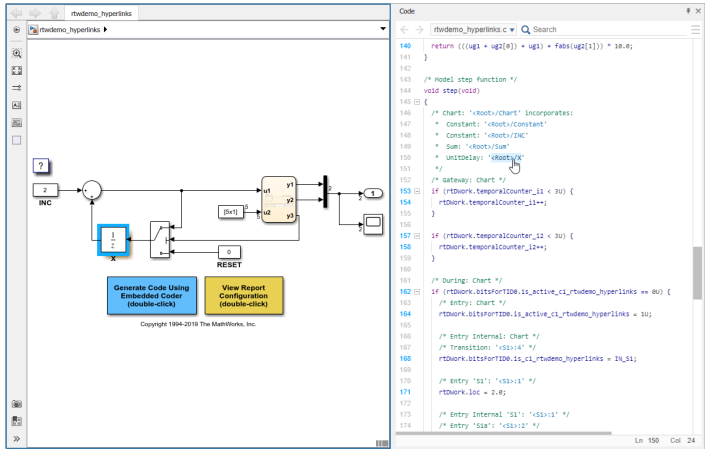




MBD Process with feedback





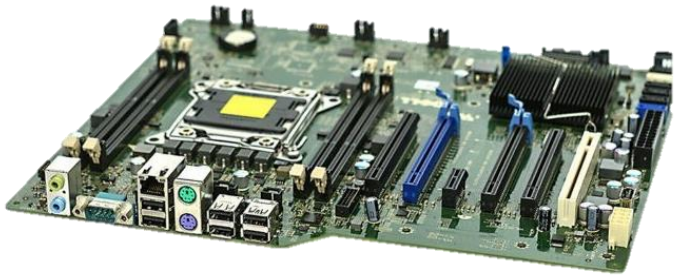


Design(Modeling)

Code Generation

Auto-code / SIL

“Feedback”



PIL / HIL

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MBD Application Plan for Space Development

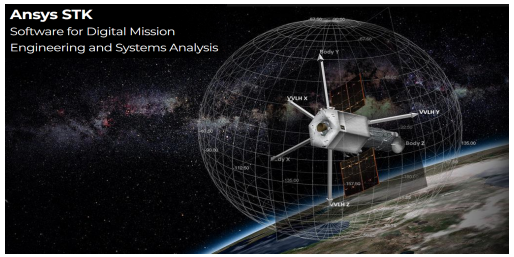
No Legacy

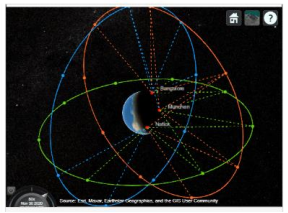
- The legacy of space development in ADD.

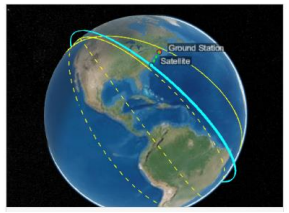
How to develop space control systems ?

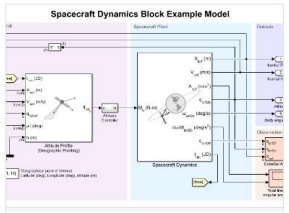
- New project can be developed based on experience in national defense and space field resources.

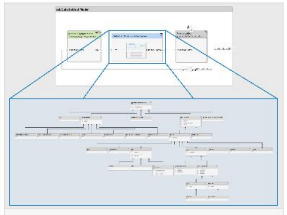
MATLAB® & SIMULINK®

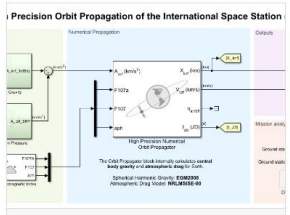


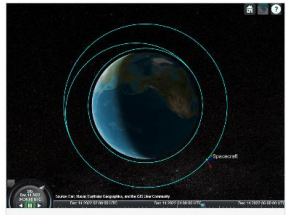


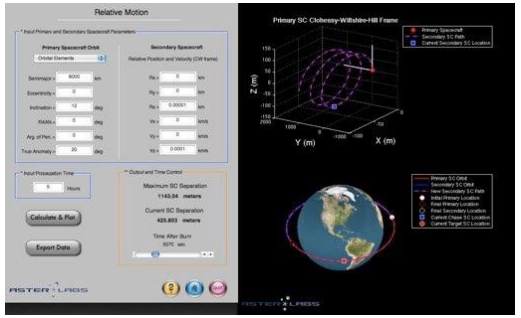




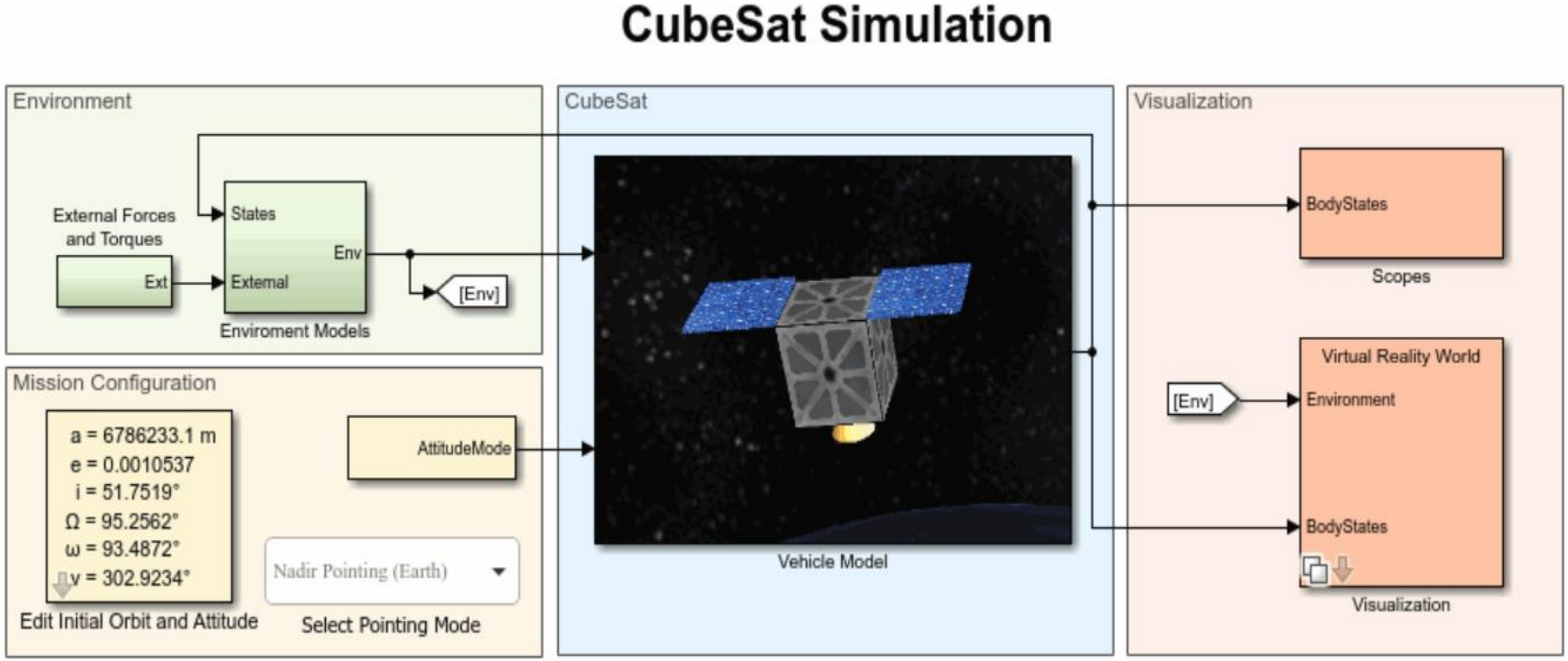




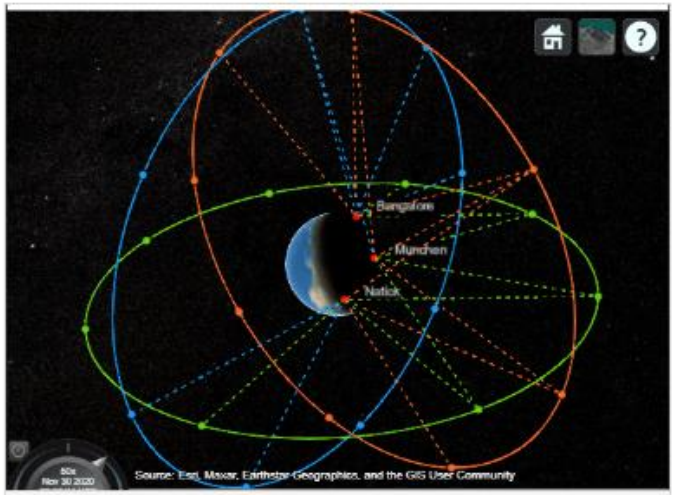




Simulation template: CubeSat

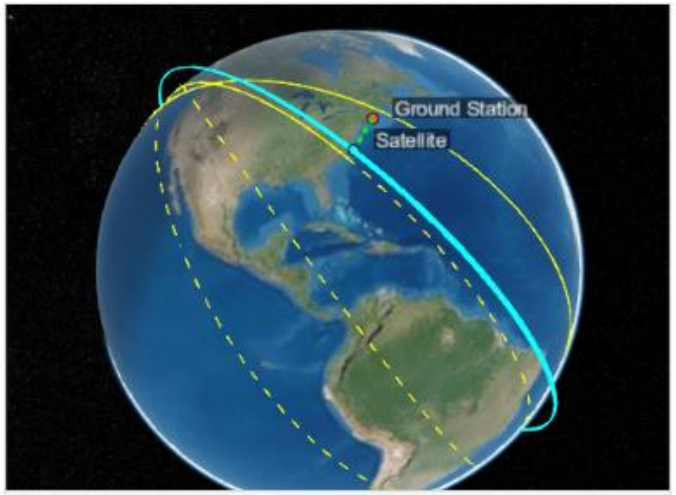


Spacecraft sub-library (1/2)



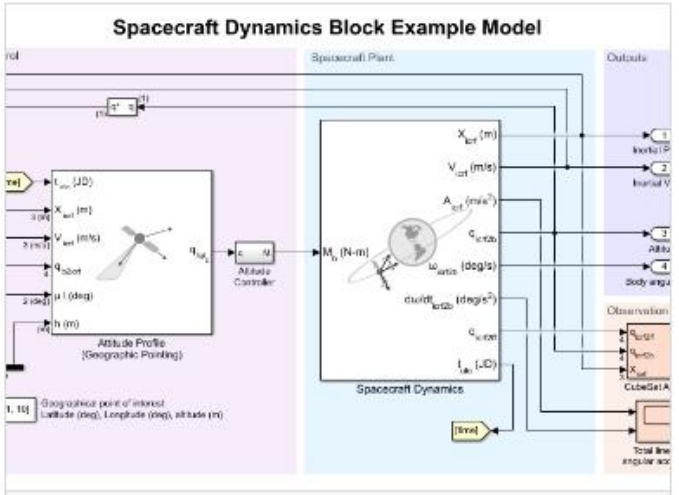
Constellation Modeling with the Orbit Propagator Block

Propagate the orbits of a constellation of satellites and compute and visualize access intervals between the individual



Mission Analysis with the Orbit Propagator Block

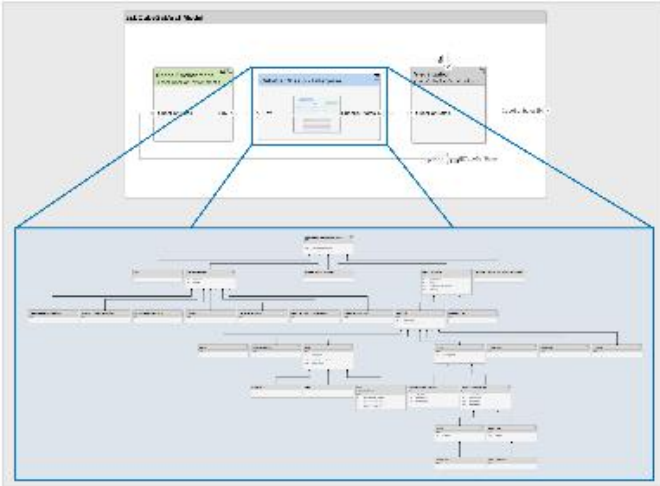
Compute and visualize line-of-sight access intervals between satellites and a ground station.



Getting Started with the Spacecraft Dynamics Block

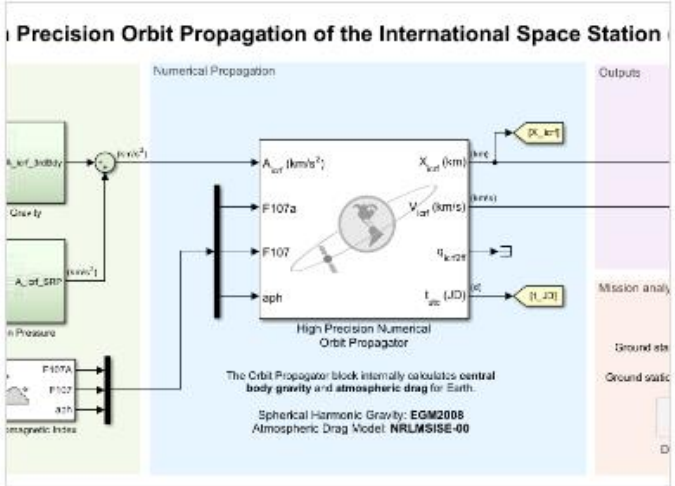
Model six degree-of-freedom rigid-body dynamics of a spacecraft or constellation of spacecraft with the Spacecraft Dynamics block from the

Spacecraft sub-library (2/2)



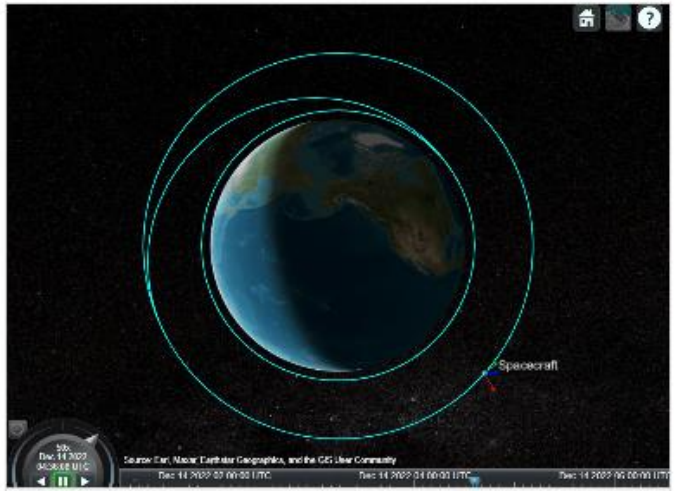
Model-Based Systems Engineering for Space-Based Applications

Explore the **CubeSat Model-Based System Engineering Project** template.



High Precision Orbit Propagation of the International Space Station

Propagate the order of the International Space Station (ISS) using high precision numerical orbit propagation.



Hohmann Transfer with the Spacecraft Dynamics Block

Model a Hohmann transfer of a spacecraft between two circular coplanar orbits.

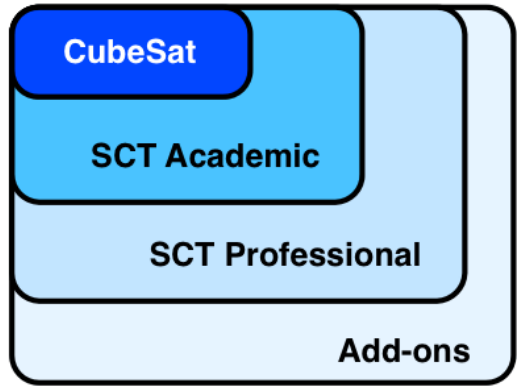
Toolbox related on satellite (1/3)

Spacecraft Control Toolbox

Design, analyze, and simulate spacecraft control systems

Highlights

- Spacecraft control system design and analysis
- Attitude dynamics modeling including multibody spacecraft
- Orbit dynamics analysis and simulation including formation flying
- Environmental modeling: solar, atmosphere, magnetic
- Pointing and propellant budgeting
- Kalman filters and nonlinear estimation



PrincetonSATELLITE SYSTEMS

Princeton Satellite Systems, Inc.

33 Witherspoon Street
Princeton, NJ 08542
UNITED STATES
Tel: 609-279-9606
Fax: 609-279-9607
info@psatellite.com
https://www.psatellite.com/

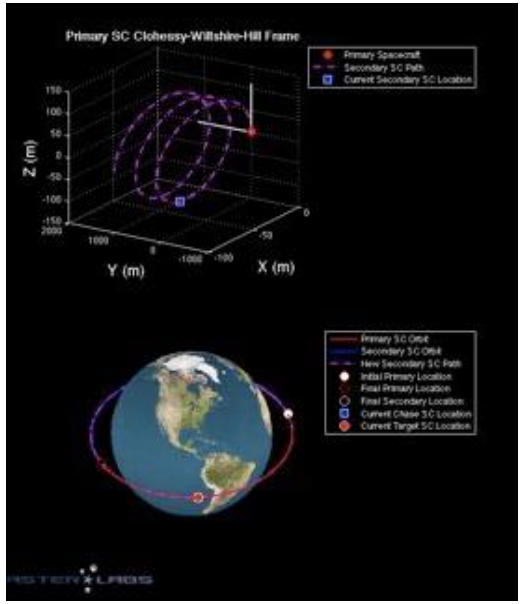
Toolbox related on satellite (2/3)

Orbitus ED - Orbital Mechanics Simulator

MATLAB-based software tool for quick spacecraft orbit visualization and analysis

Highlights

- Offers a user interface written in MATLAB
- Displays satellite orbits, orbit transfers, and rendezvous
- Generates usable data associated with trajectories and maneuvers
- Generates satellite ground track and trajectory
- Offers three-dimensional graphics
- Useful in visualizing the three-dimensional attributes of orbits



ASTER Labs, Inc

155 East Owasso Lane
Shoreview, MN 55126
UNITED STATES
Tel: 651-484-2084
info@asterlabs.com
http://www.asterlabs.com

Toolbox related on satellite (3/3)

Constellation Toolbox

A comprehensive simulation and analysis package for satellite constellations

Highlights

- Provides GPS error models including SA, troposphere, ionosphere, and receiver
- Provides GPS navigation simulations, including attitude visibility restrictions
- Has DGPS capabilities for navigation and component error analysis
- Models complex or arbitrary antennae patterns
- Is highly vectorized for maximum execution speed

Constell Inc.

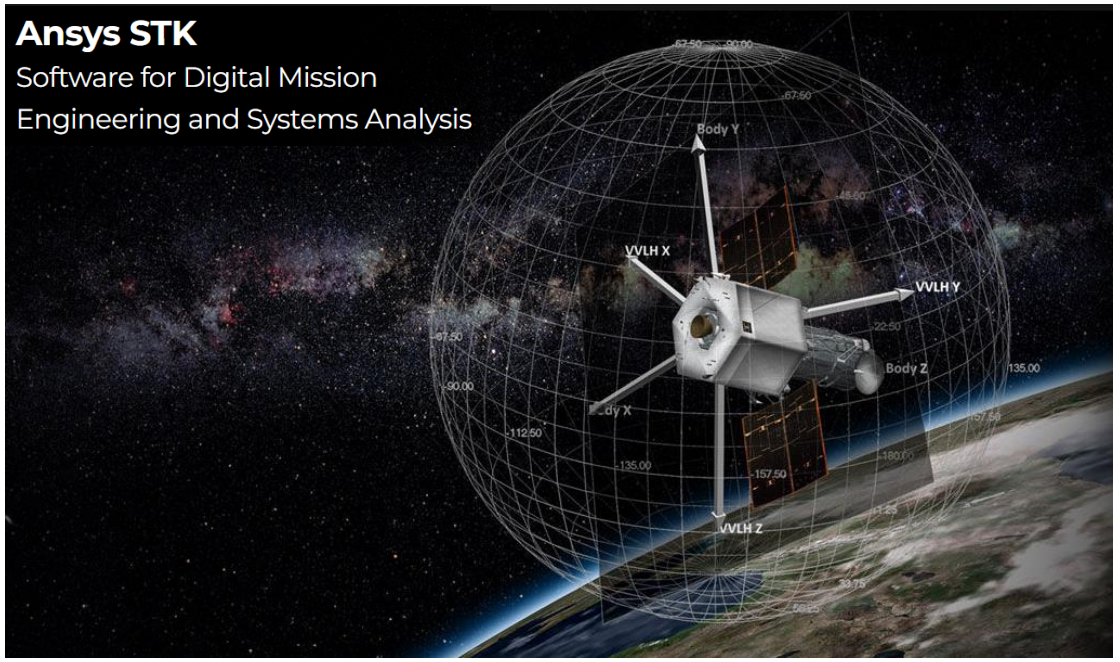
PO Box 433
Philomont, VA 20131
UNITED STATES
Tel: 540-338-0289
Fax: 540-338-0293
info@constell.org
http://www.constell.org

Co-simulation or Inter-simulation

FreeFlyer®

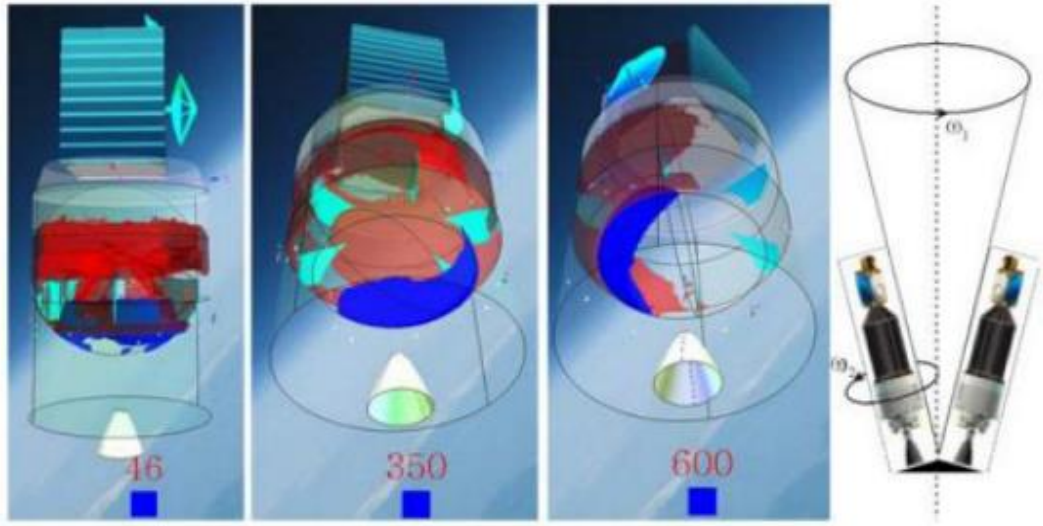
MATLAB® & SIMULINK®

FreeFlyer®, a commercial-off-the-shelf (COTS) application, is a feature-rich astrodynamics tool that supports all phases of the mission lifecycle, from initial design trade studies through automated on-orbit operations. Powered by industry-proven astrodynamics algorithms accessed through a flexible scripting environment, FreeFlyer is unmatched in its versatility to solve the toughest problems of today's space missions.



[White Paper] MBD for space control systems (1/6)

Case Study: *ESA & Airbus Defense and Space*



Propellant motion in spinning upper stages at 46, 350, and 600 seconds. Distribution after 350 seconds becomes uneven.

"Model-Based Design enabled us to create a framework for designing flight controllers with state-of-the art robust control design algorithms, creating multidomain physical models, tuning the design through optimization, and generating code for PIL testing on target hardware—all in the same environment."

— Hans Strauch, Airbus D&S

[White Paper] MBD for space control systems (2/6)

Case Study: *Tessella*

Artist's rendition of the Solar Orbiter.

"We saw the benefits of Model-Based Design on several previous projects. On this project, MATLAB and Simulink enabled us to create a detailed specification that minimized deviation between the prototype algorithms we developed, tuned, and tested in Simulink and the final software implementation."

— *Andrew Pollard, Tessella*

[White Paper] MBD for space control systems (3/6)

Case Study: *Lockheed Martin*

NASA's Orion spacecraft.

"With Simscape Electrical we created an integrated power system model that connects electrical and thermal domains, so we get the whole picture during our mission-level simulations. If we need to model the motors that turn the solar arrays, we have the capability to integrate those mechanical components, too."

— *Hector Hernandez, Lockheed Martin*

[White Paper] MBD for space control systems (4/6)

Case Study: *Lockheed Martin Space Systems*

The IRIS observatory.

The Interface Region Imaging Spectrograph (IRIS) observatory is currently in Earth orbit, where it is capturing ultraviolet spectra and high-resolution images of the sun. These images will help scientists better understand the flow of energy and plasma in the lowest levels of the solar atmosphere.

"A team of about four engineers designed, integrated, and tested the GN&C system in just 23 months. We were more efficient because we used the same tools for both analysis and code development, and generated 20,000 lines of defect-free code. For us, that makes a compelling case for Model-Based Design."

— *Vincentz Knagenhjelm,*
GN&C engineer,
Lockheed Martin Space Systems

[White Paper] MBD for space control systems (5/6)

Case Study: *The Apollo 11 Moon Landing: Spacecraft Design Then and Now*

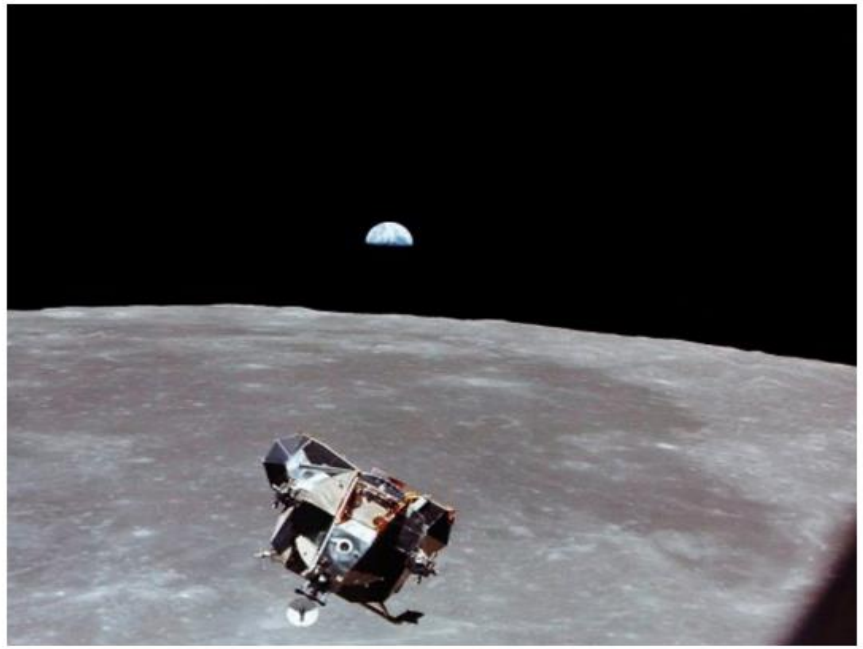


Image courtesy NASA.

Apollo 11, carrying astronauts Neil Armstrong and Buzz Aldrin, landed on the moon over 50 years ago. To commemorate that momentous event, and to celebrate current programs working on the next moon landings, we revisit Richard J. Gran's firsthand account of designing the Lunar Module digital autopilot, published in 1999. In that article, Richard described the approach he used in the 1960s and compared it with the way Model-Based Design with MATLAB and Simulink could be used to design GN&C systems in 1999. In the 20 years since Richard wrote his article, Model-Based Design has evolved significantly. To highlight this evolution, we describe how MATLAB and Simulink can be applied to GNC system design today.

Read the article to learn more, and see the Simulink system model Richard Gran developed when revisiting the LM digital autopilot.

[White Paper] MBD for space control systems (6/6)

Case Study: *Swedish Space Corporation*

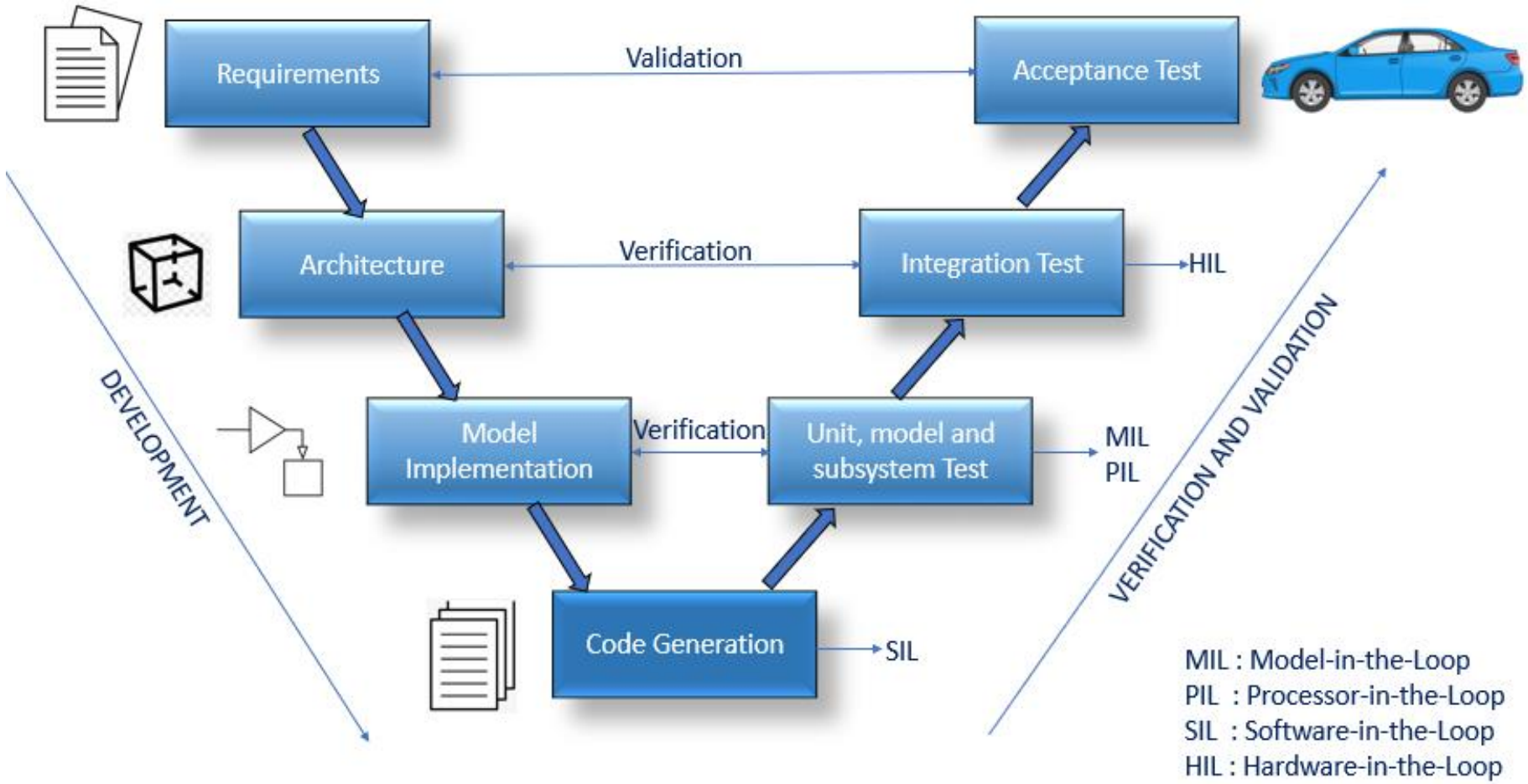
Artist rendition of SMART-1 traveling to the Moon.

"We successfully developed the SMART-1 AOCS in a very short time frame and with a very low budget. MathWorks tools for simulation and flight-code generation played a key role in this success and will serve as the foundation for future satellite programs, such as Prisma."

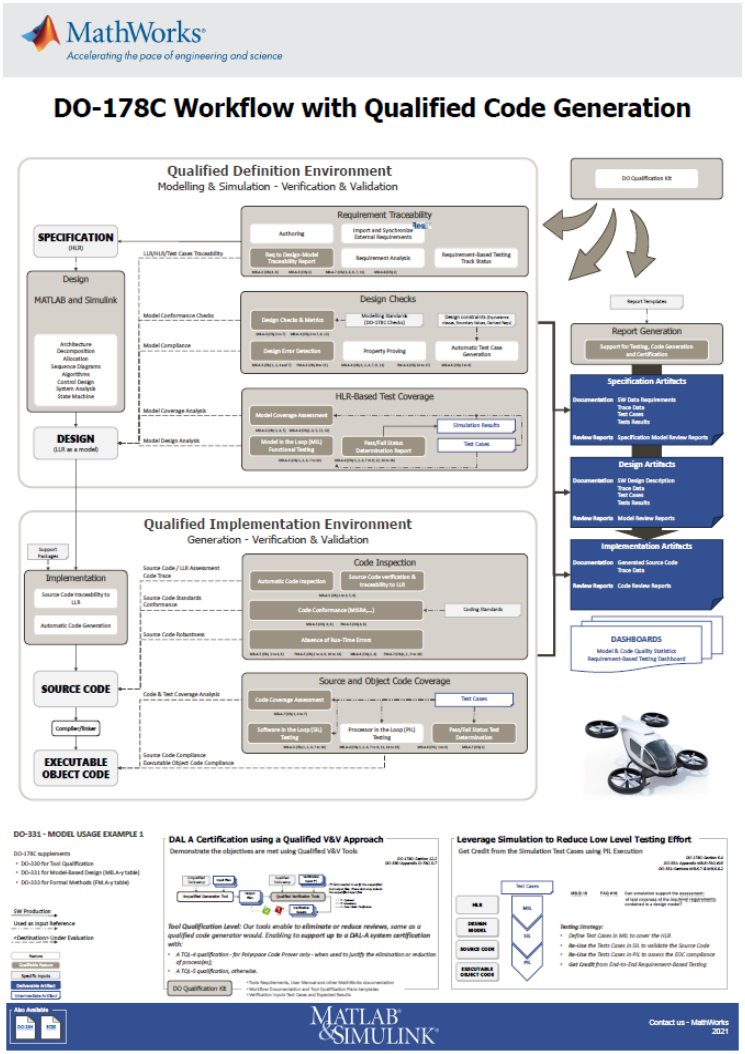
— *Per Bodin, Swedish Space Corporation*

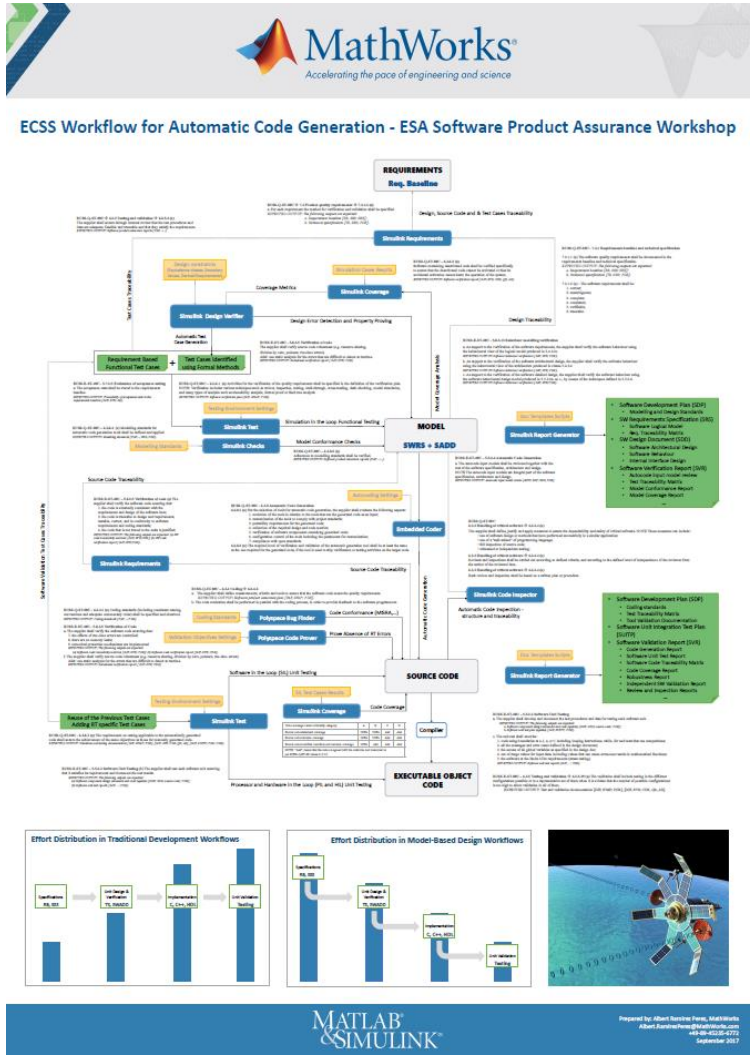
MBD Process

- MBD Process: DO-178C and ESA ECSS



DO-178C and ECSS Workflows with MATLAB & Simulink





MATLAB EXPO

Conclusion

Potential value of MBD Process

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Thank you !!

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