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Using Model-driven Engineering Techniques for Integrated Flight Simulation Development

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Outline

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Introduction of Model-driven Engineering

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- Model-driven Engineering
  - A.K.A. Model-driven Development (MDD)
  - Software development methodology that focuses on creating models rather than algorithms
  - Domain experts maintain more control of the software end product
  - Promotes compatibility and communication between individuals/teams
- One Tool's Role in MDE
  - Simulink® is a Popular tool for domain experts' development of system models
  - Real-Time Workshop® Embedded Coder provides MDE interface to Integrated Flight Simulations (IFSs) through automatic generation of C/C++ code
  - IFS engineer owns process of creating code

Real-Time Workshop® provides an MDE interface to the IFS

History of MDE at Raytheon Missile Systems

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- Initial work
  - Automatic code generation process created to support rapid algorithm development
    - Identified limitations and pitfalls
    - Standardized deployment for incorporation in object oriented simulations
  - Original Processes developed using release Matlab® R11
- Ongoing efforts
  - Process has been implemented on many programs
    - Hardware models
    - Control algorithms
    - Medium and high fidelity
  - Presently using Matlab® Release 2009a
    - Processes updated for current releases

MDE Processes are in place and are being used at Raytheon Missile Systems.

Intentions of Using MDE for Integrated Flight Simulation Development

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- MDE is a powerful process for designing models, both hardware and software, for simulations
  - Because of requirements imposed on IFSs, impractical to develop entire simulation with MDE
- Early development of IFSs requires frequent changes to models
  - Automatic code generation from MDE methods saves time, not only in initial integration of the model into the IFS, but subsequent changes can be made simpler and quicker.
- While much initial model design work done with Simulink®, other MDE tools are used to develop flight software

MDE, when used appropriately, is a powerful tool for IFS development

MDE Tool History Example

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- MDE Tools Evolve Over Time, and so must MDE processes
  - Matlab® R2008a and Previous
    - Would generate only C code
    - C++ option only changed the file extensions from ".c" to ".cpp"
    - Early versions (R11) could only support discrete models
  - Releases Since Matlab® R2008b
    - Includes option to generate "Encapsulated C++" code
    - True C++ class that can be instantiated in the IFS (multiple times if needed)
    - Includes Initialize, Step, and Finalize member functions
    - Additional member functions for setting or getting static input variables

Continuous MDE tool improvements require process improvements

Model Lifecycle Comparison

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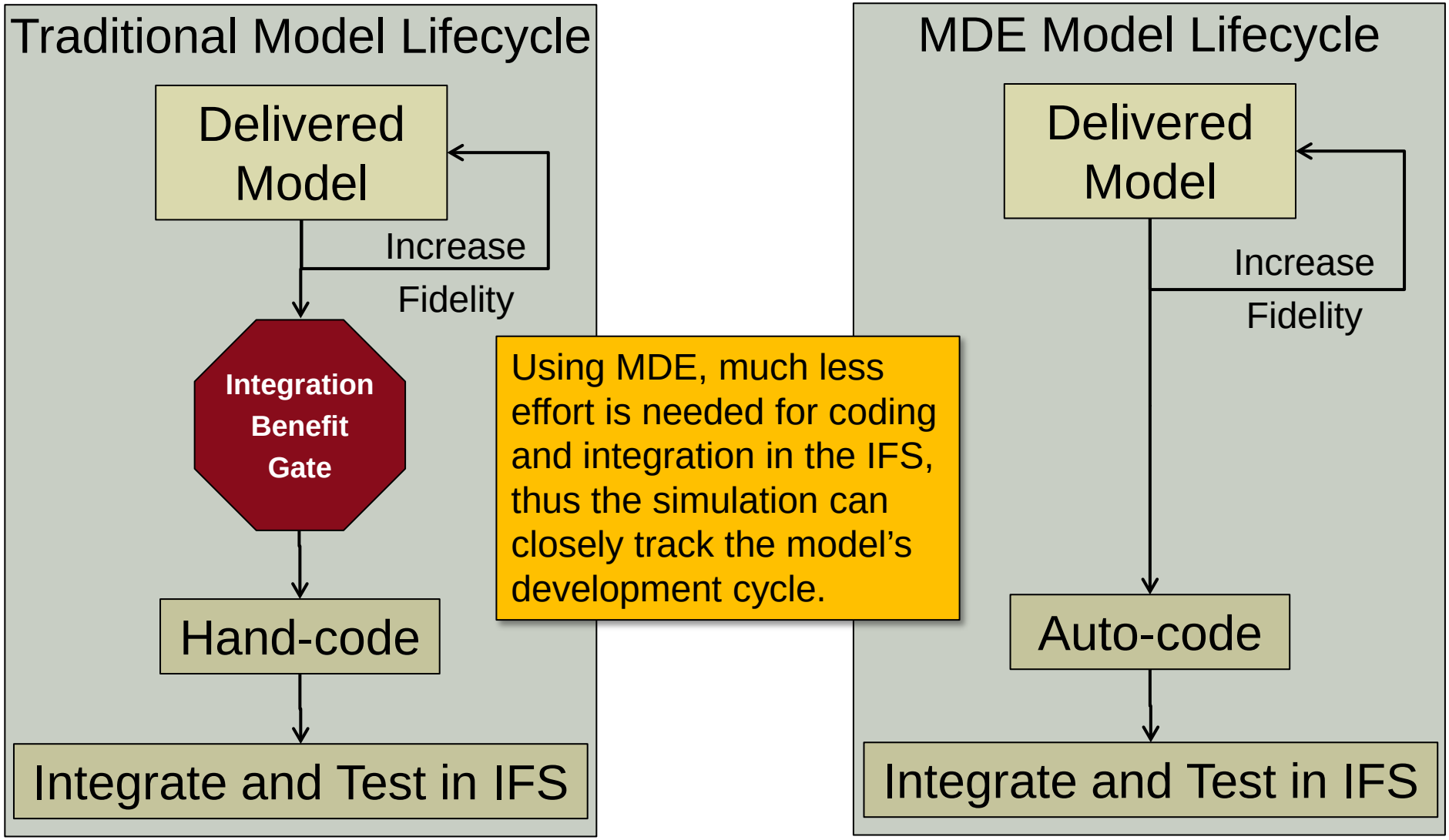

Autocoding can reduce cycle time for integrating updated models

MDE Process Flow

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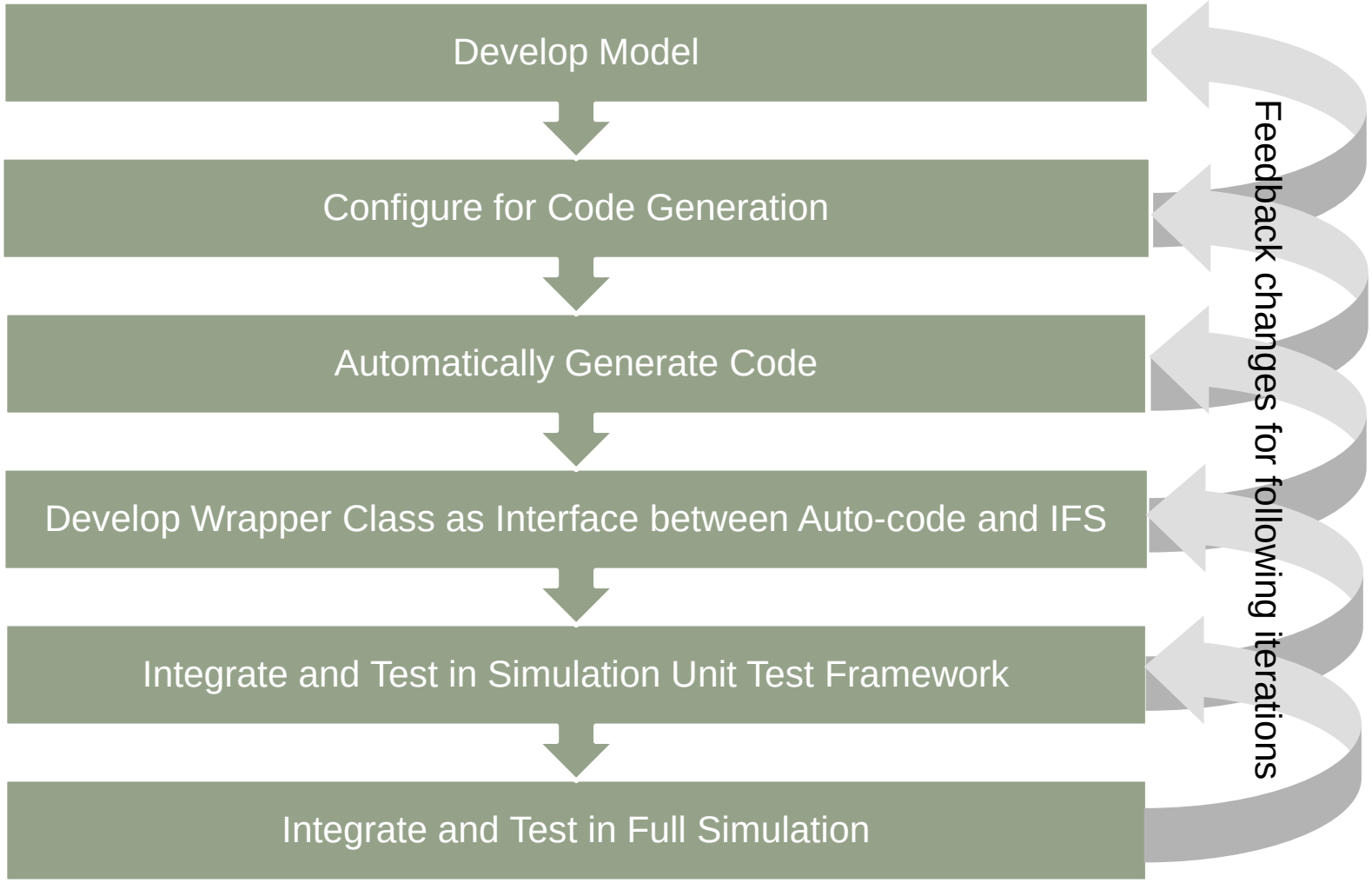

Straightforward process using MDE models to develop Functional Simulations

Time Savings Comparison

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- Hardware model coded
  - Control Actuation System model
  - Representative model for most hardware models integrated in IFS
- Used three methods to obtain time comparisons
  - Hand-coded from Simulink® block diagram
  - Auto-coded using original process using Matlab® R11
    - Can only use discrete blocks and integration when auto-coding
  - Auto-coded using updated process using Matlab® R2008b
    - Continuous blocks and integration supported
- Note that process times are for a first pass through the auto-coding process
  - Subsequent integrations of the same model should show even further process time reductions

Time Savings Comparison

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Task	Hand-coding (hr)	Auto-code without Continuous Block Support (hr)	Auto-code with Continuous Block Support (hr)
Create usable source code from using MDE			
Insert and connect generic I/O port content		2	2
Replace Integrators with ports		2	
Continuous block identification and replacement		8	
Auto-code option selection and code generation		<1	<1
Preparation of generated code		4	4
Handcoding model - Simulation	60		
Handcoding model – Algorithm Design Tools	60		
Subtotal	**120**	**17**	**7**
Common efforts to integrate code into IFS			
Modifying IFS wrapper object, input files, etc	4	4	4
Performing unit Tests for verification	4	4	4
Performing Simulation Tests for verification	10	10	10
Subtotal	**18**	**18**	**18**
Total Conversion Time	**138**	**35**	**25**
% of Hand-coding	**100%**	**25.4%**	**18.1%**

Significant time savings when auto-coding models

Performance in Integrated Flight Simulations

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- Currently using MDE processes in simulations on multiple programs
- Extensive verification of models performed
  - Developed detailed processes for conversion of the model to C/C++ code
  - Verified performance of the models integrated in the IFS match the performance of the original model as a unit test
  - Regression runs of the full simulation completed to verify performance of the model in the IFS
- Processes updated and tested with latest tool capabilities

Methodical and Thorough Process Used in Development of IFSs using MDE Methods

Performance in Integrated Flight Simulations

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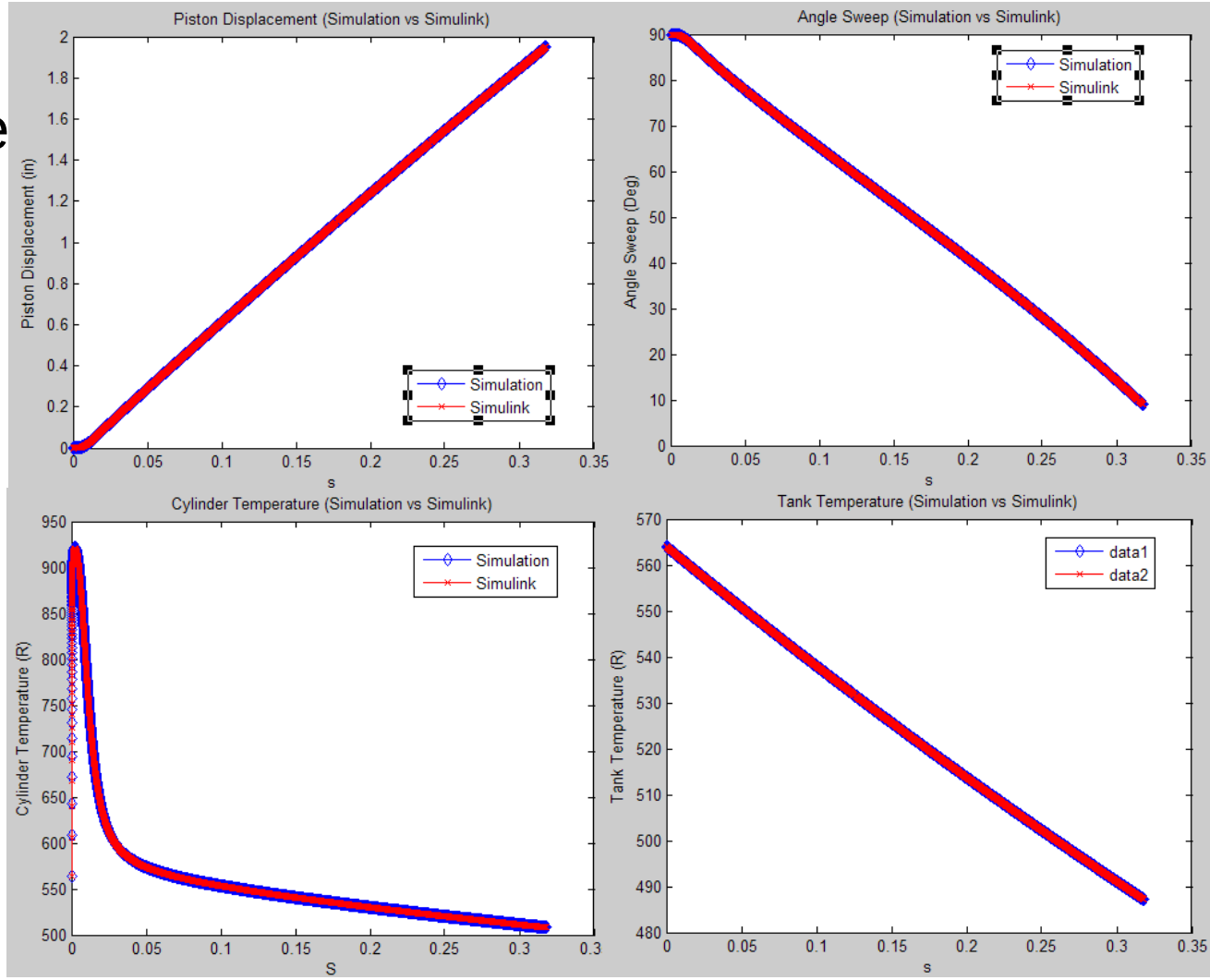
- Wing Actuation System Hardware Model



Good Agreement in Time Domain Performance

Performance in Integrated Flight Simulations

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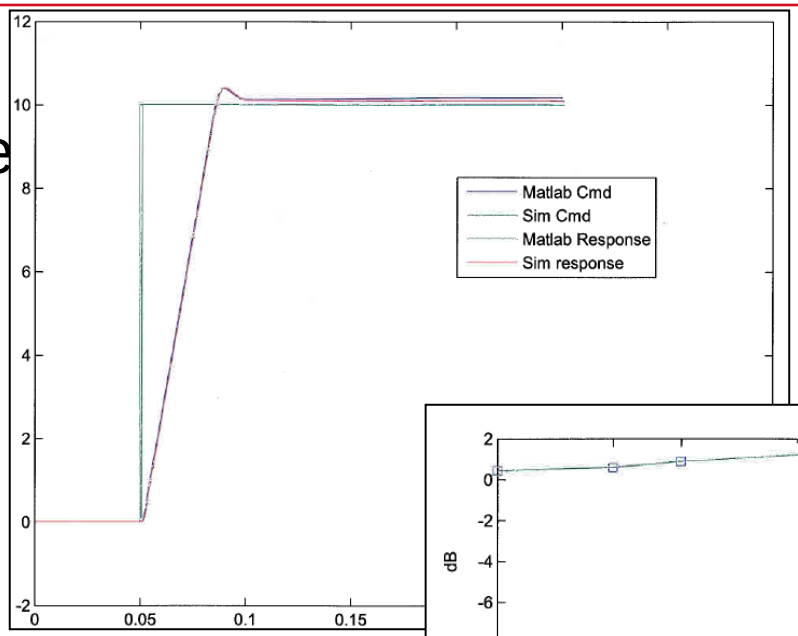
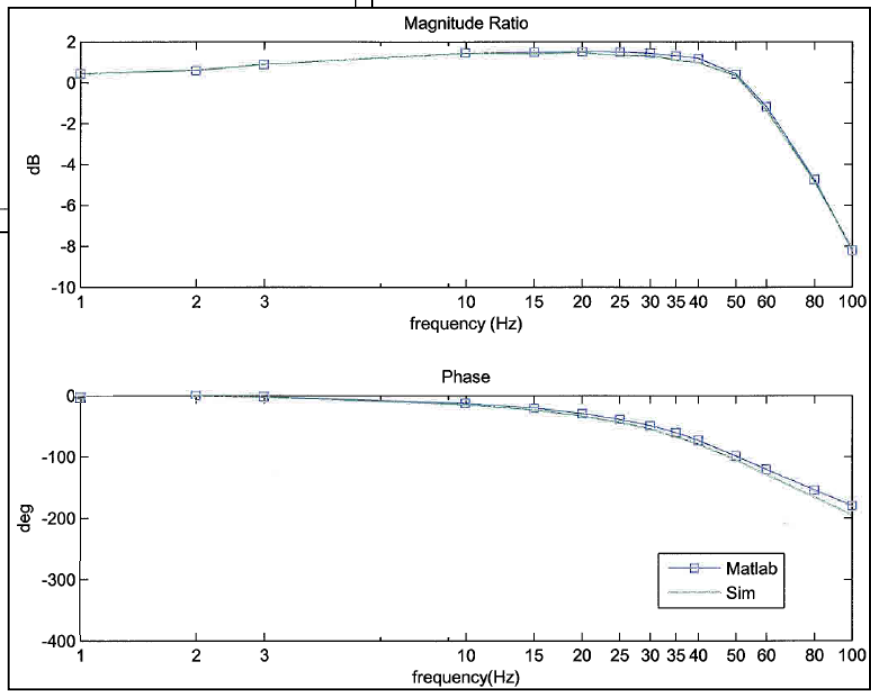
- Control Actuation System Hardware Model
  - Step response
  - Bode Plot





Good Agreement in both Time and Frequency Domains

Common Pitfalls

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- Model Configuration
  - Every model is different, new configurations produce new problems
  - Common model design standards needed for developers to streamline integration into the simulation
- Tool Capabilities
  - As with any tool, user must understand process, model, and MDE tool, not a “push-button” process
  - Common areas to watch
    - Timing – no time shift present
    - Does auto-code accurately represent the system? Auto-code should identically reproduce outputs given identical inputs
- Integration Schemes
  - Internal
    - Continuous – Only available in later releases of Matlab®
    - Discrete – Not always the choice of model developers for representing system
  - External
    - Tie into simulation numerical integration schemes
    - Reduces ability to verify against original model

While MDE tools are useful, care must be taken in model development

Conclusions

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- Raytheon Missile Systems has successfully used MDE processes to incorporate models into IFSs
- Full set of procedures developed to aid personnel cross-program and to train new users
- Procedures verified with multiple models on multiple simulations
- Procedures are updated as new features become available in MDE tools
- Generating code automatically using MDE processes can save significant amounts of time preparing models for incorporation in simulations, and can be completed with confidence