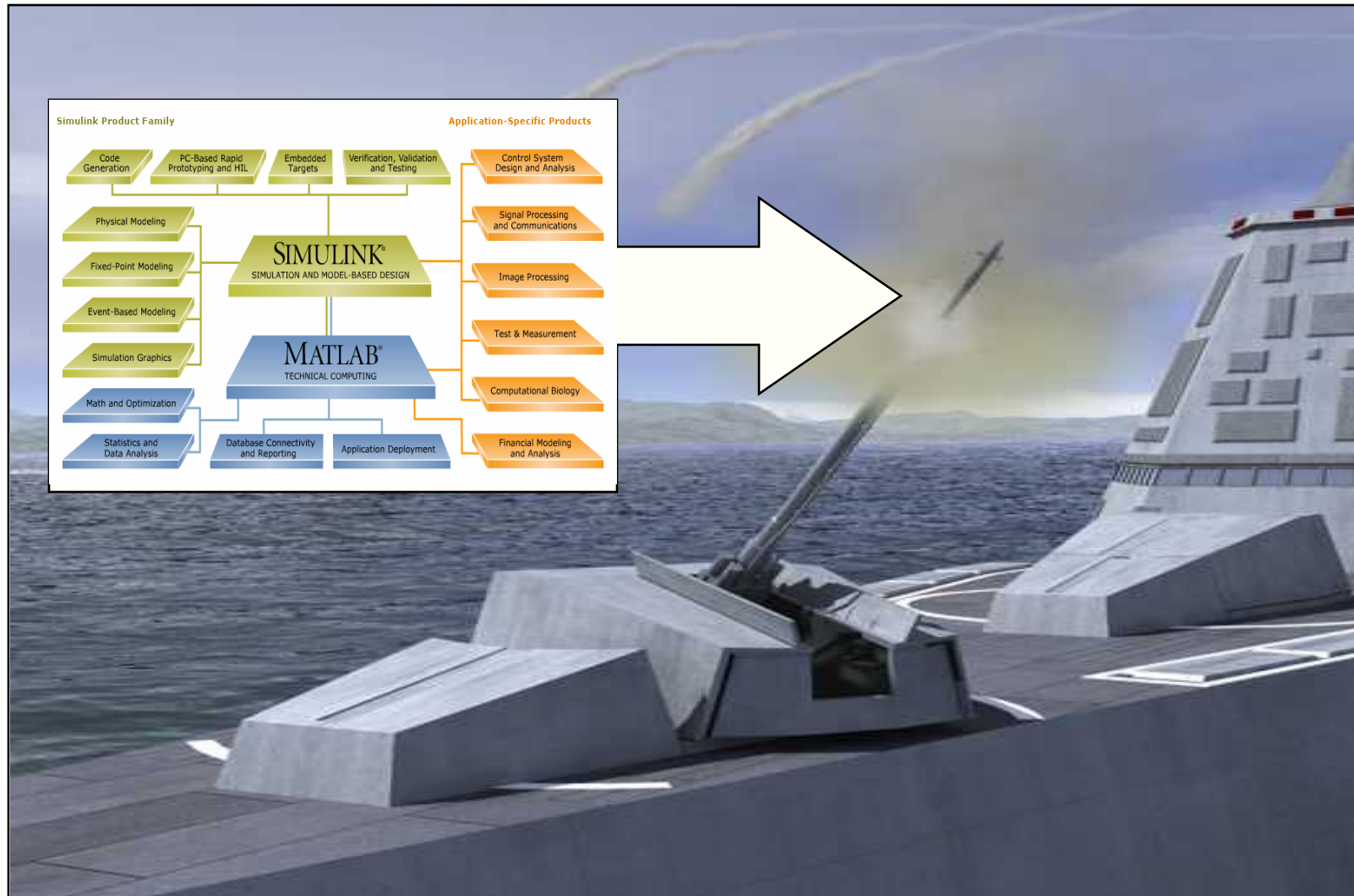


# A User's Experience with Model-Based Design for GNC-Based Systems



*James E. Craft, Lockheed-Martin Missiles and Fire Control*

# Lockheed Martin Corporation

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- 140,000 Employees
- 65,000 Scientists and Engineers
- 23,000 IT Professionals, Systems and Software Engineers

*LMC writes more code than Microsoft*

## ➤ My Experience:

- ✓ MSSE, Software Engineer for 25 years
- ✓ Lean Six Sigma Blackbelt
- ✓ C++ and UML Instructor (UML Subject Matter Expert)
- ✓ Software Developer, Software Development Lead
- ✓ Software Architecture, CMMI Maturity

## ➤ Project Experience:

- ✓ Comanche
- ✓ Sniper/ATP
- ✓ AGS LRLAP
- ✓ MRM
- ✓ MEADS

# Why Do We Model ?

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➤ *The short answer – to avoid spectacular failures !*

- ✓ *Swedish Naval Warship, Vasa (1625)*
- ✓ *NASA Mars Climate Orbiter*
- ✓ *Denver airport baggage handling system*
- ✓ *FBI's Virtual Case File system*
- ✓ *Talking Barbie*



➤ *Modeling gives us a blueprint of the system before we build it*

- ✓ *Sketch*
- ✓ *Blueprint*
- ✓ *Executable Design*



➤ *Modeling provides a shared understanding between the customer, the SME, the Systems Engineer, the Software developer, and the tester*

➤ *Modeling allows us to do Performance Predictions and refine the System Design*

# Fitting MBD into Lockheed's Product Development Process (PDP)

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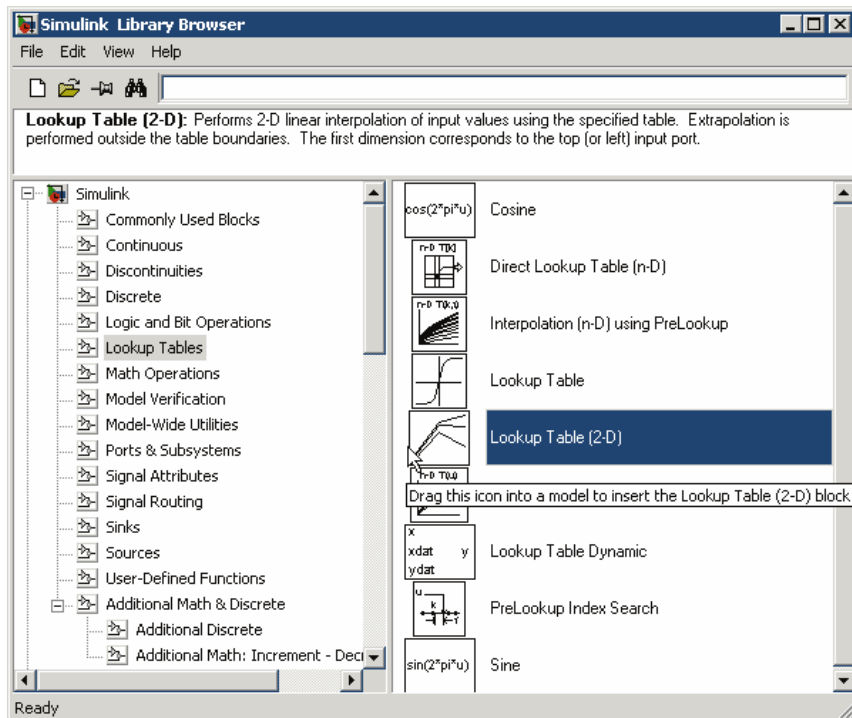
- *Requirements*
  - ✓ *Creating the correct system*
  - ✓ *Use Case analysis*
- *Test*
  - ✓ *Model checking, test coverage*
  - ✓ *Allows validation of requirements without significant investment in implementation*
- *Peer Reviews*
- *Lean Development*
  - ✓ *Separate computational code and behavioral code*
- *Agile Principles (Agile Modeling)*
  - ✓ *Iterative modeling (build a little, test a little...)*
- *Working within CMMI® Level 5 Environment*
  - ✓ *Code reliability, optimization*
  - ✓ *Component based software*
  - ✓ *Code analysis, Metrics*



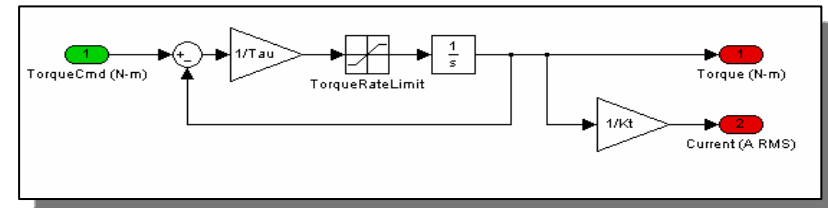
# MATLAB®, Simulink® and Stateflow® Models

## Using the Right Tools

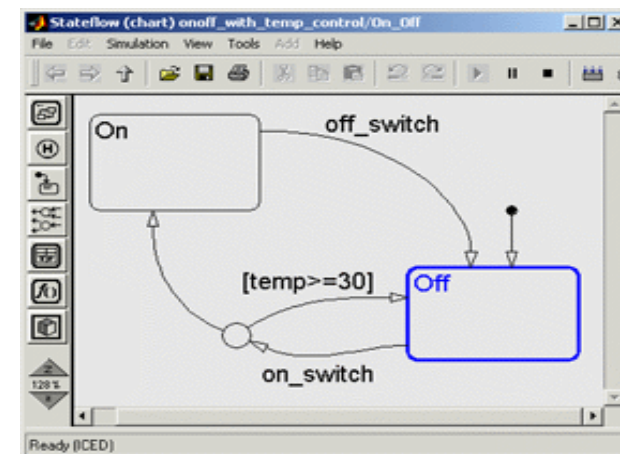
MATLAB® and Simulink® form the core environment for Model-based Design for creating accurate, mathematical models of physical system behavior.



**Graphical Software Building Blocks**



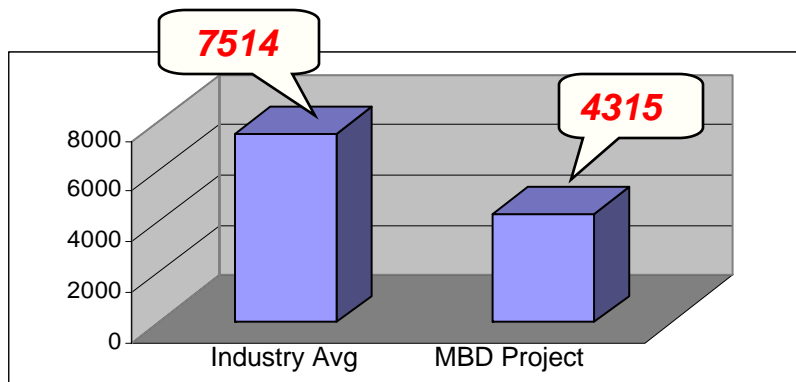
**Simulink® for mathematic/control processes**



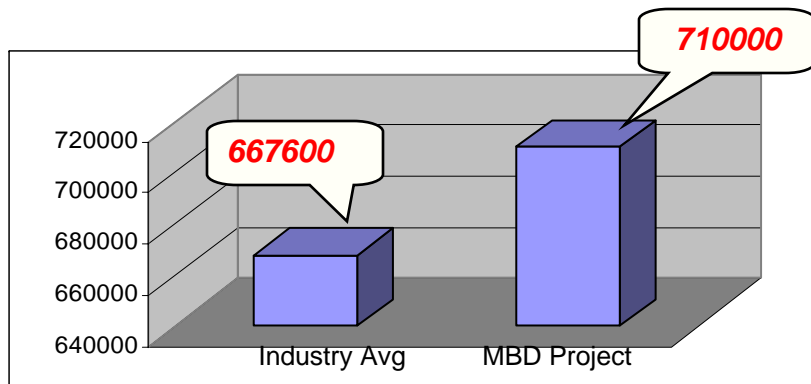
**Stateflow® for logical processes**

# Industry Usage of MBD

Developers that use MBD in their designs are able to manage (year over year) more design starts and completions than the industry average. This translates into higher productivity and greater savings for the organization.

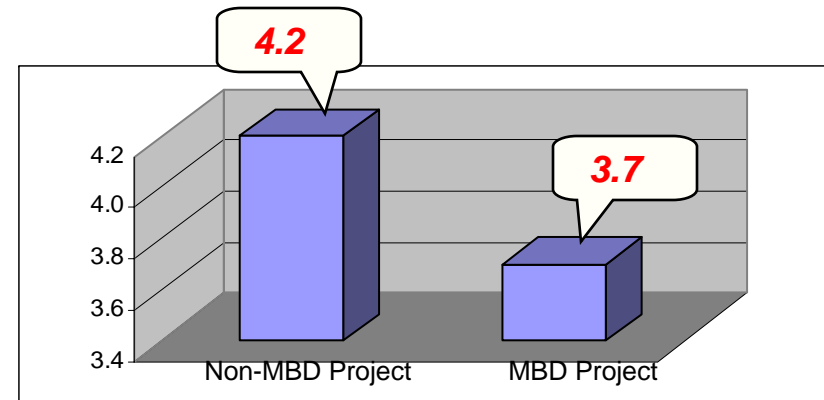


**Avg Lines of Handwritten Code Per Developer**



**Total Lines of Code Per Project**

Recent surveys comparing coding efficiencies and schedule impacts for MBD programs show improved performance factors.



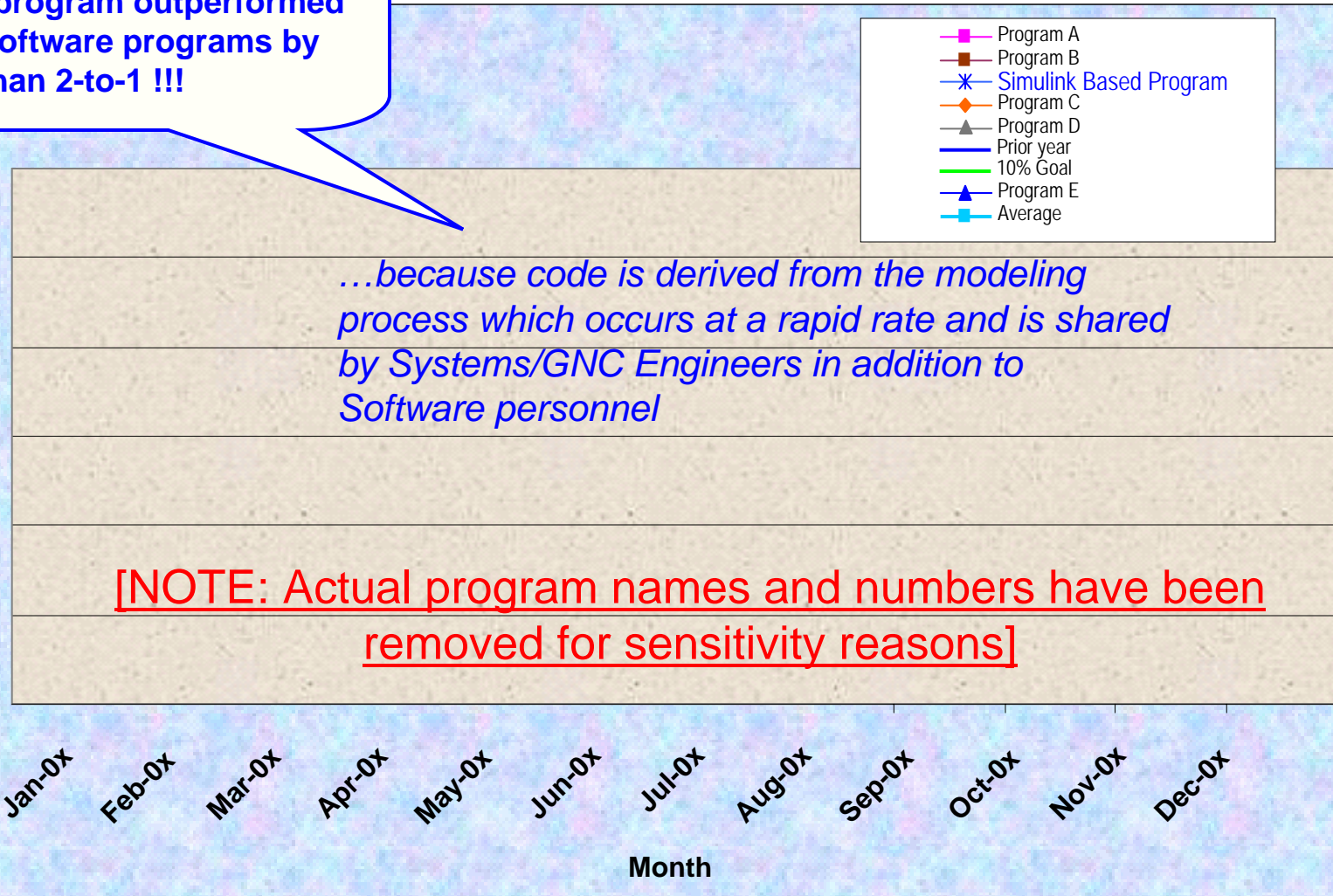
**Avg Months Behind Schedule**

Source: *What Do You Do When the Horse You Are Riding Drops Dead?*, Jerry Krasner, Embedded Market Forecasters, March 2007

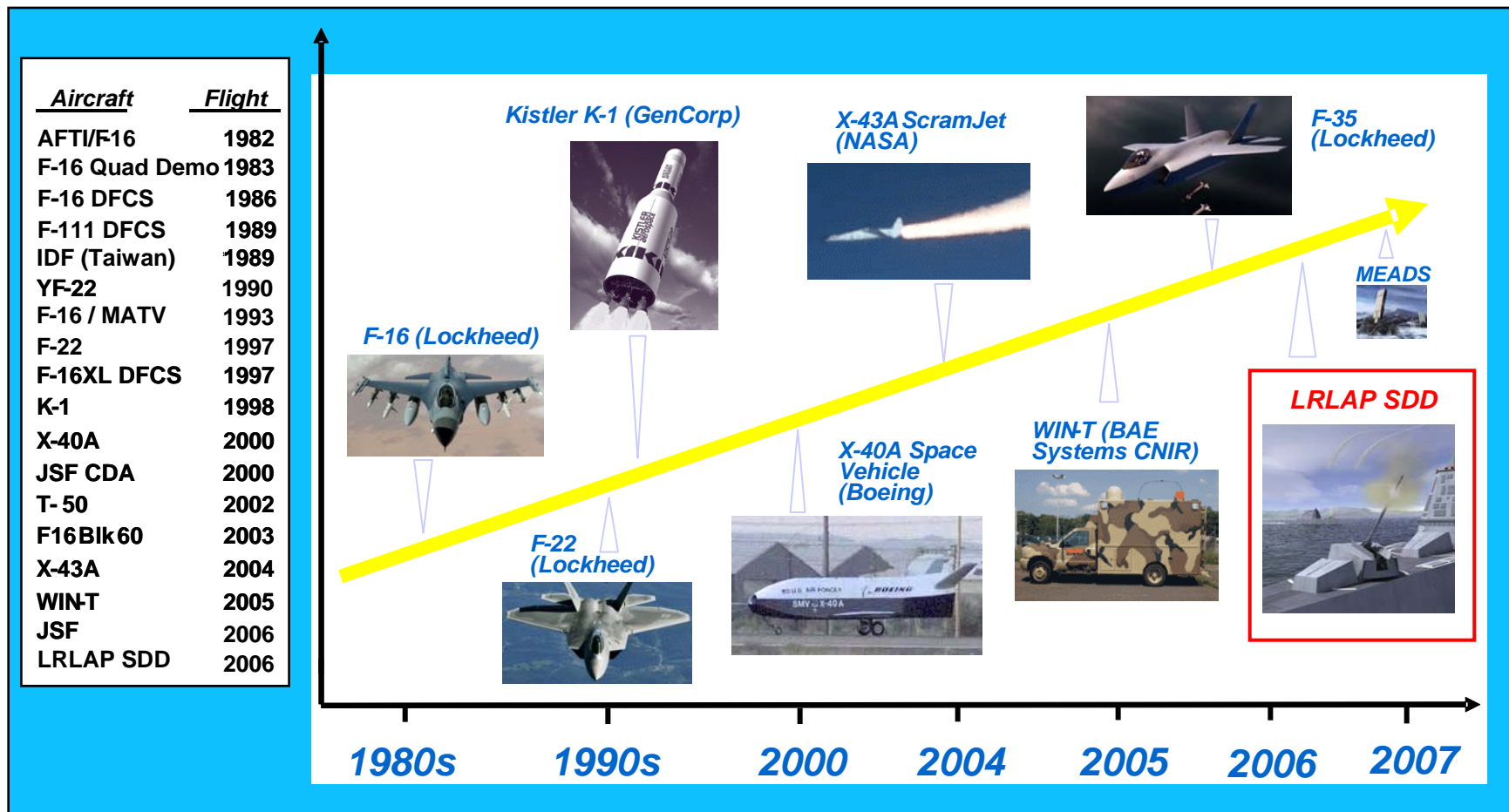
# Software Productivity Using Simulink®

With Simulink®, the model-based program outperformed other software programs by more than 2-to-1 !!!

SLOC/Hour



# Use of MBD in Defense and Aerospace Applications



*LRLAP builds on heritage of Simulink in Aerospace and Flight Systems ...*



# Long Range Land Attack Projectile

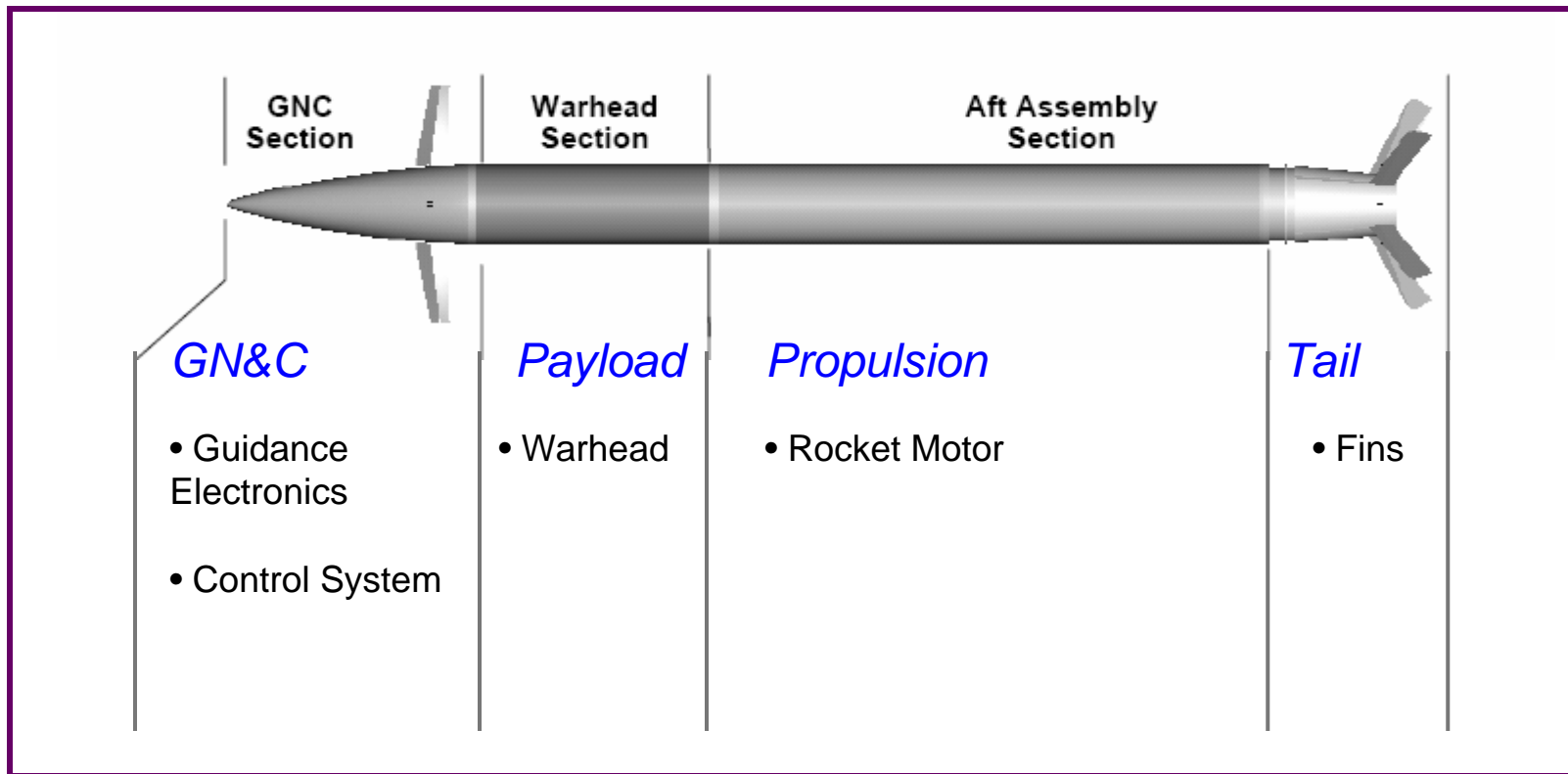


➤ LRLAP is part of a family of 155mm projectiles for the Advanced Gun Systems on the U.S. Navy's next-generation DDG-1000 destroyer

- ✓ *Provides single-strike lethality from offshore against a wide range of targets*
- ✓ *Multiple payloads and multiple guidance approaches*
- ✓ *Initial concept focused on long-range land attack requirement*

# Tactical Design Overview (Generic)

*GPS-guided projectiles give warships the ability to provide interdiction, suppression and other fire support missions to support ground and expeditionary forces.*



# Using Simulink for GNC Applications

- *Guidance, Navigation and Control applications are prime candidates for Simulink modeling and simulation*

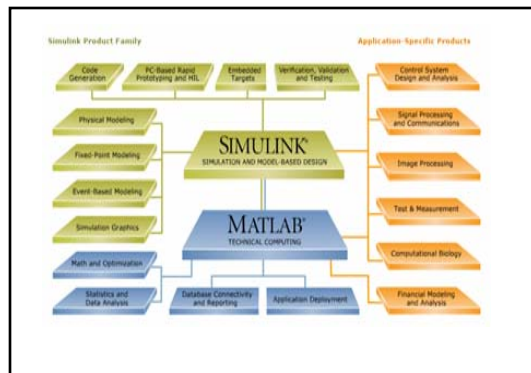


IMU Subsystem	Provides pitch, roll and yaw rates
GPS Subsystem	Detects current position based on GNSS constellation
Autopilot	Provides automated vehicle cmds for guidance and control
Navigation Algorithms	Plans and records position compared to known locations
Guidance Laws	Evaluates sensor readings and course data to determine speed and heading
Control Subsystem	Flight control surfaces used to stabilize and direct the vehicle
Atmosphere Models	Provides mach speed and dynamic pressure

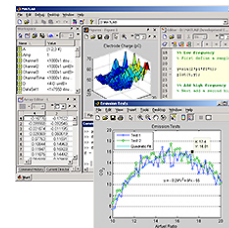
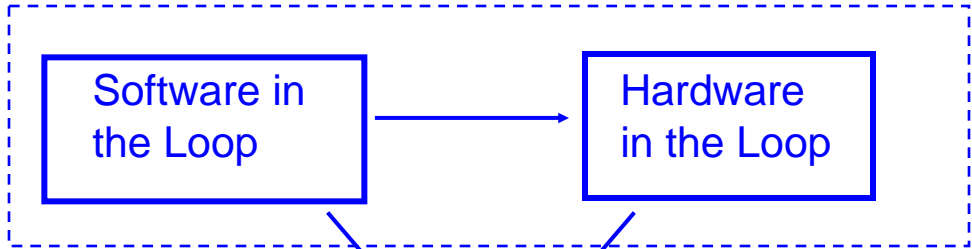
# Use of MatLab and Simulink



- GNC Algorithm development
- PC-based testing (Detailed Sim)
- Monte Carlo runs



Simulink used to generate GNC code

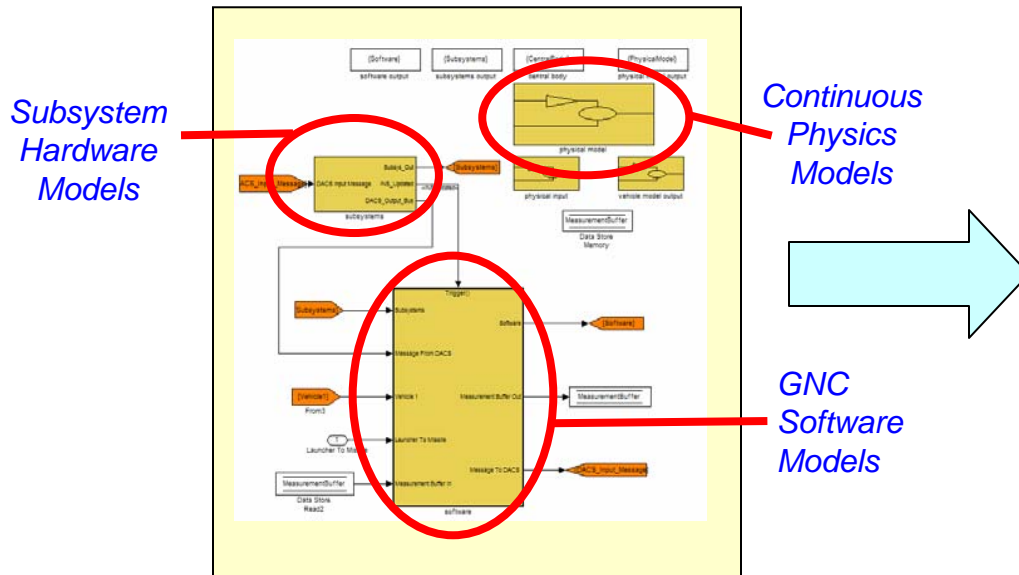


Plot data used for analysis and performance verification

# Simulink® and Auto Generated Code

## Auto Generated Code

## Simulink®



```

/* Stateflow Block: '<S1>/GNC Executive' */
{
  /* Stateflow Block: '<S1>/GNC Executive' */
  if (software5_DWork.GNCExecutive.is_active_c19_software5 == 0) {
    software5_DWork.GNCExecutive.is_active_c19_software5 = 1;
    software5_DWork.GNCExecutive.is_c19_software5 =
      (uint8_T)software5_IN_prelaunch;
  } else {
    switch (software5_DWork.GNCExecutive.is_c19_software5) {
      case software5_IN_postlaunch:
        if ((int32_T)software5_B.Memory[0] > 0) {
          software5_reset_tracker();
          software5_clear_reset();
        }
        software5_save_inputs();
        software5_ownership();
        software5_tracker();
        software5_MKV_guidance();
        software5_autopilot();
        software5_output();
        break;
      case software5_IN_prelaunch:
        if (software5_U.signal1 != 0.0) {
          software5_DWork.GNCExecutive.is_c19_software5 =
            (uint8_T)software5_IN_postlaunch;
        }
    }
  }
}
    
```

### ➤ Simulation

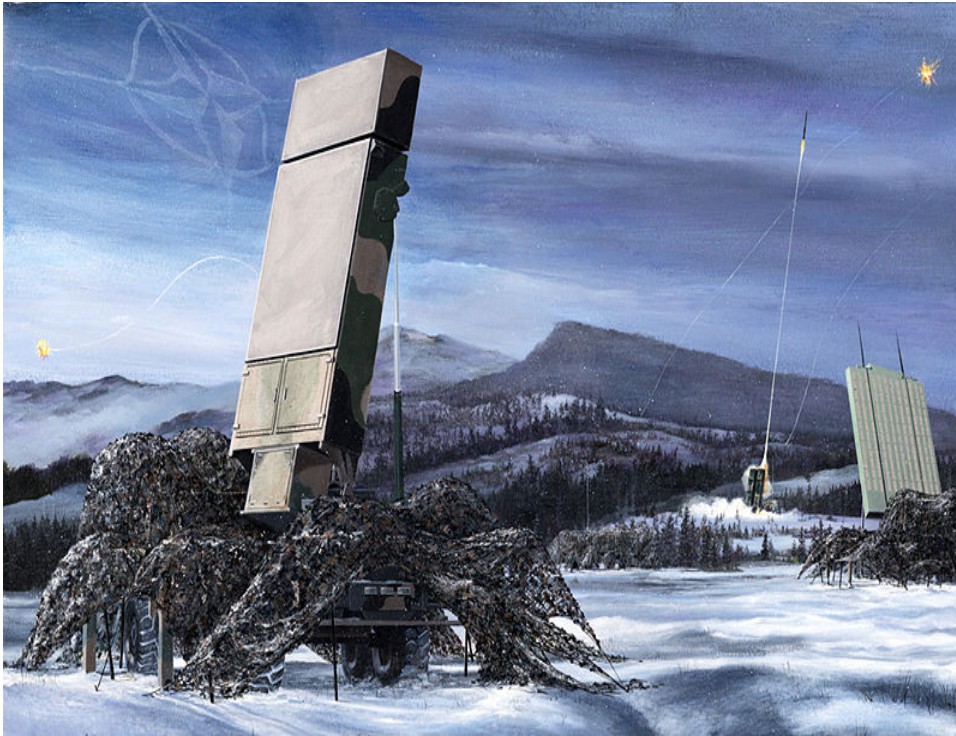
- ✓ *Tool System performance evaluation*
- ✓ *Requirements definition support*

### ➤ Automatic code generation

- ✓ *Model blocks translated to comparable code constructs*
- ✓ *Embedded software & real-time simulation software can be generated*

*Effective Simulink® Usage Produces Software From Model-based Design*

# Medium Extended Air Defense System



<http://www.meads-amd.com/video4.html>

Source: LM PRESS RELEASES FOR 2008

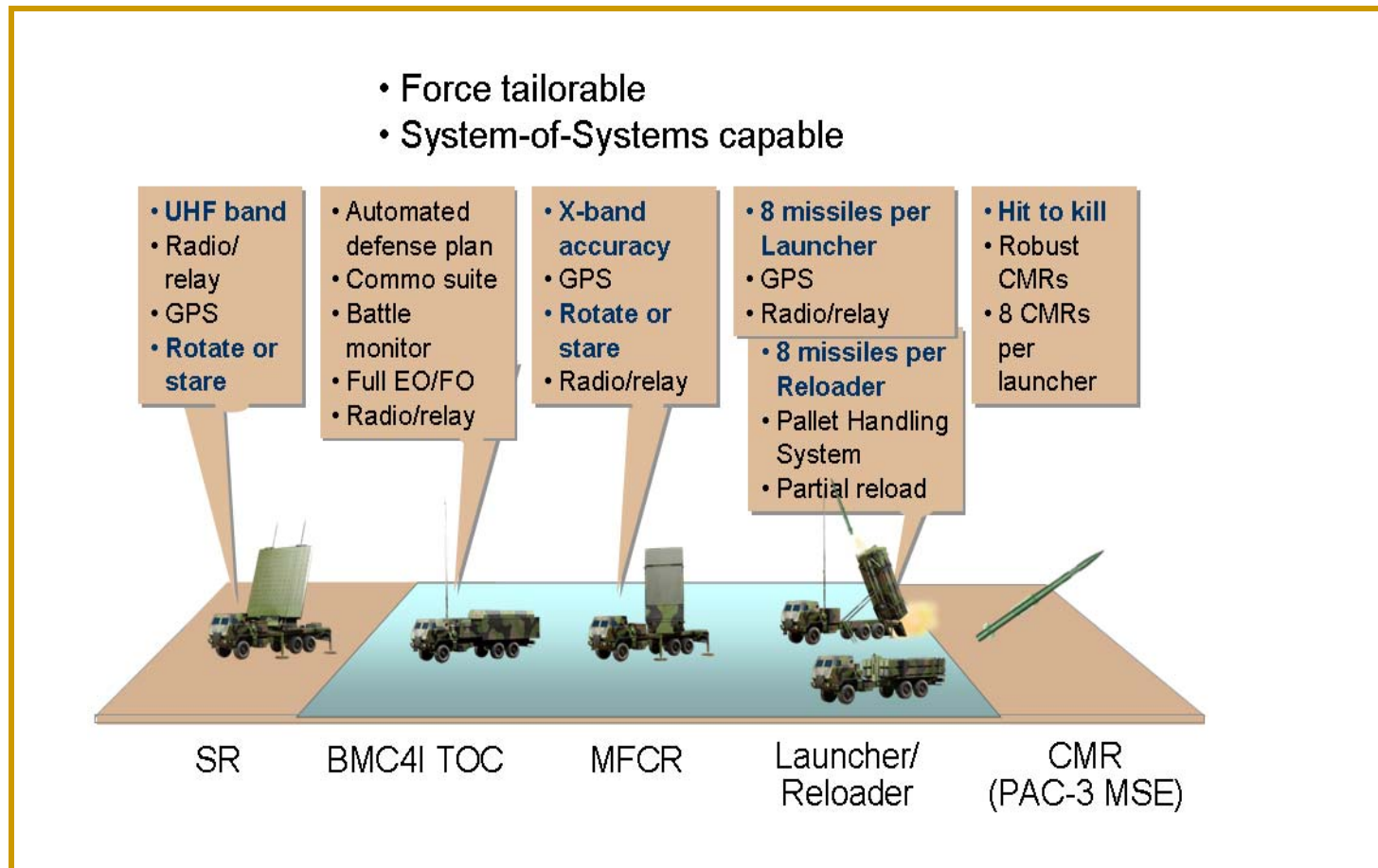
[http://www.lockheedmartin.com/news/press\\_releases/2008/021108MEAD\\_SCompletesPreliminaryDesignReview.html](http://www.lockheedmartin.com/news/press_releases/2008/021108MEAD_SCompletesPreliminaryDesignReview.html)

<http://www.meads-amd.com/presentations>

- MEADS is a highly mobile, low-to-medium air and missile defense system
- ✓ *Multinational joint venture headquartered in Orlando, FL, participating companies are MBDA Italia, LFK in Germany and Lockheed-Martin in the United States*
- ✓ *Protects maneuvering forces and fixed locations against tactical ballistics missiles, cruise missiles, unmanned aerial vehicles and aircraft*
- ✓ *360-degree surveillance and fire control sensors*
- ✓ *Netted-distributed plug-and-fight battle management network architecture*

**CLEARED FOR PUBLIC RELEASE**

# Medium Extended Air Defense System



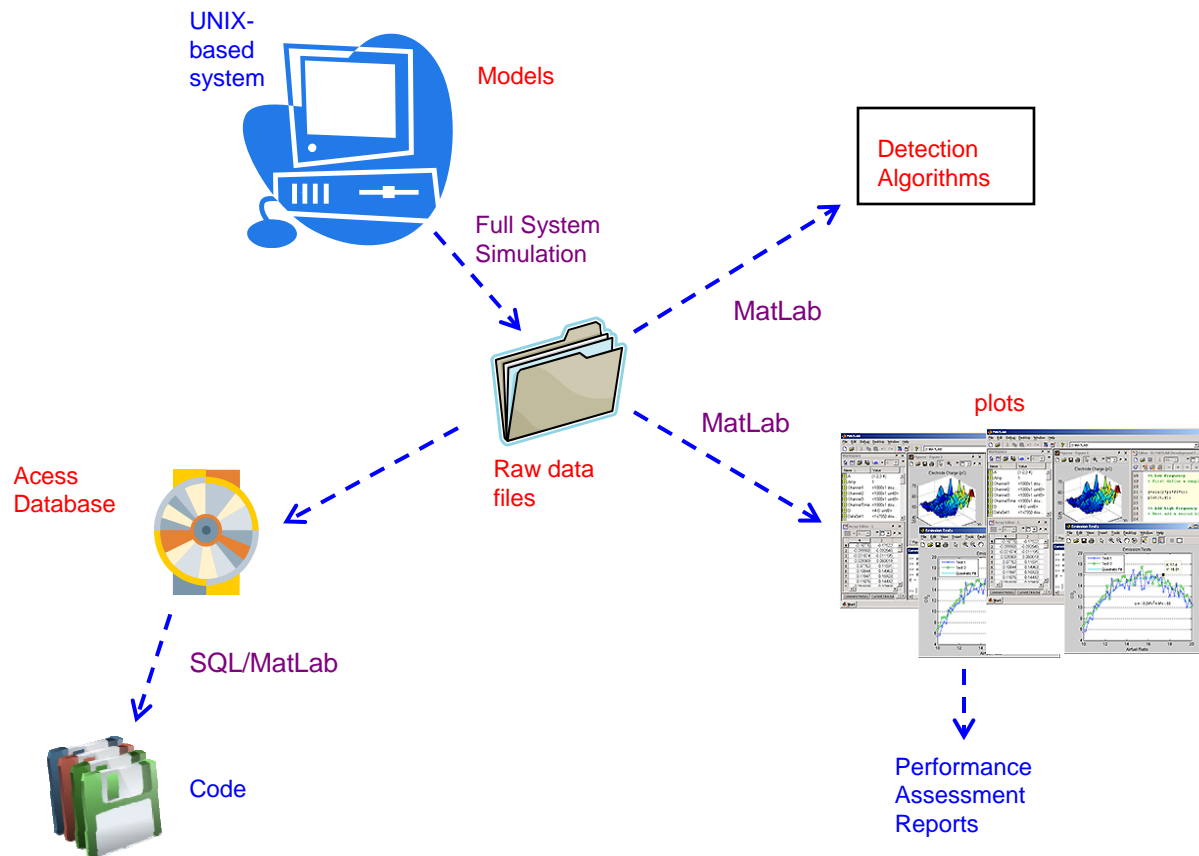
Source: <http://www.meads-amd.com/presentations/presentation1.pdf#page=1&view=Fit>

**CLEARED FOR PUBLIC RELEASE**

# Potential Applications

MatLab is used for verification (for example):

- System Performance Analysis
- Classification, Discrimination and Identification (CDI) algorithms
  - Full system simulations are run to generate raw performance data
  - MatLab scripts used to generate Contour Plots
  - Performance Assessment Reports presented at reviews





# Simulink® Auto Code Quality

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- LMMFC Simulink® Modeling Style Guide ensures readable, maintainable software is generated
- Characteristics of Simulink® generated software
  - ✓ *Generated software structurally matches Simulink® model*
  - ✓ *Comment-to-Lines of Code ratio is developer controlled*
    - Simulink® comment blocks
    - Comment fields with model blocks
  - ✓ *Developers can control variable names*
    - Unique model block names
    - Unique model block input/output port name
- Well-styled Simulink® models become part of the Software Design Document (SDD) and Algorithm Description Document (ADD)

# Summary

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- Significant Reduction in Software Anomalies Through Early Prototyping and Evaluation
- Significant Reductions in Manhours/Source Lines of Code with Model-Based Software and Automatic Code Generation
- Produced Excellent Flight Test Results in Very Complex Development Effort with No Compromises to Flight Safety
- More Requirements-Focused Development Process
- Leveraging Off Heritage Relationships with MathWorks to Mature Modeling Environment and Code Generation