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DEFINING THE FUTURE

Automatic Code Generation at Northrop Grumman

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History of Automatic Code Generation at Northrop Grumman

- **1997**
  - Initial internal project to look at efficiencies of automatic code generation
  - Prototype implementation of Global Hawk guidance and control
- **2000**
  - Fire Scout prototype flight test demonstration utilized automatic code generation for 6DOF, guidance and control
- **2003**
  - First flight of X-47A using automatic code generation
- **2004**
  - Decision made to consolidate on MathWorks Toolset
  - Prototype Demonstration of UCAR guidance on RMAX helicopter
  - DARPA software enabled control flight test utilizes Stateflow for mode control in addition to guidance

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History of Automatic Code Generation at Northrop Grumman

- **2005**
  - SeFAR
  - AEI
- **2006**
  - Expanded Use of Stateflow (not done by GNC but SW people)
    - UUV Logic
    - UAV Logic managing Mode control via Air Vehicle Manager
- **2007**
  - Using Stateflow for CCDL (cross channel data link) voting
  - Demonstrations of UAV and UUV using automatically generated code from Real-Time Workshop Embedded Coder

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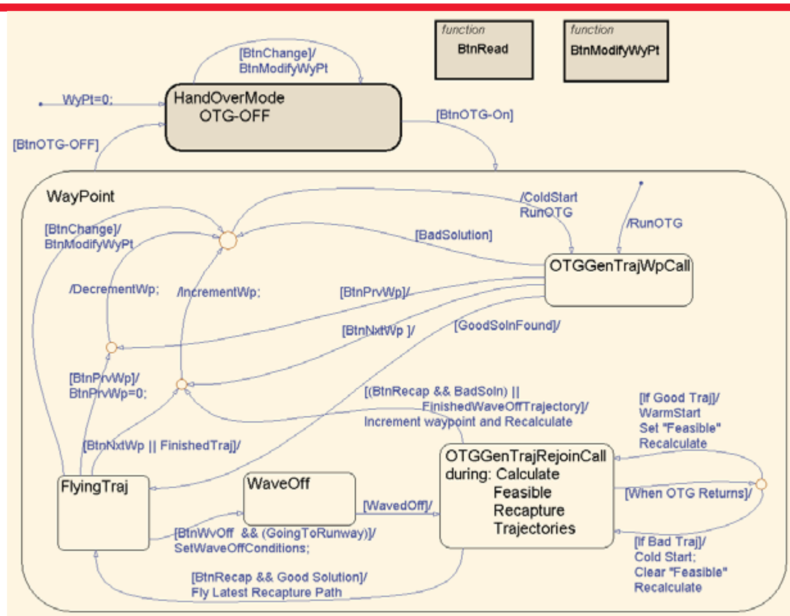
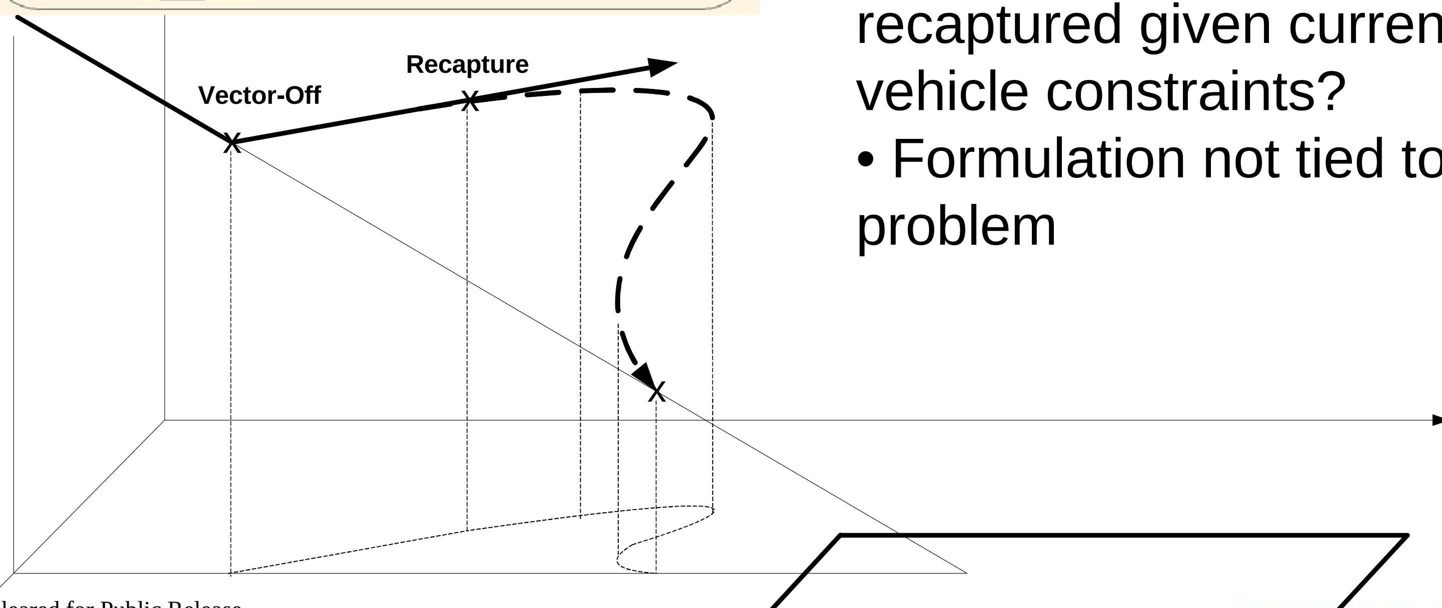
SEC NGC Exp #2 Flight Test
Basic Maneuver





- All guidance performed by OTG at fly time
- Vector-off occurs due to runway-not-ready condition (user set)
- Shortly thereafter runway-clear signal given. (User set)
- Can runway interface point be recaptured given current state and vehicle constraints?
- Formulation not tied to specific problem

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Embedded Coder structure for SEC

- **Effort utilized first flight of R14sp3**
  - Driven by need/desire for EML
- **The SEC code structure contained two subsystems which were each coded "build Subsystem" and compiled into the existing (Boeing) environment for the flight test.**
- **One of the subsystems ran in a real time section of the operating system.**
- **The second subsystem was implemented as an 'anytime' task**
  - Contained optimization codes and interfaces written in both C and FORTRAN
  - Some of the called functions were precompiled and linked in

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Embedded Coder structure for SEC

- **The software solution used to complete this task required an array of tools**
  - Precompiled FORTRAN, C code, precompiled C libraries, Simulink (Block build up, S-Functions, Stateflow)
  - Environments, were varied, Windows, Windows soft real-time, Real-Time Linux.
- **The Test Process for SEC**
  - Almost all design, debugging, validation and testing was done in Simulink with the simulation running much faster than real-time on Windows
    - Coverage analysis utilized to catch Stateflow design bug
  - Code was generated and a brief check was made in a soft real-time windows environment
  - It was then compiled into the Linux real-time HWIL environment used in the flight test
- **The process from code generation to Linux real-time HWIL test was about 5 min. of user time (total time was larger due to environment size)**
- **No hand modifications to code or interface made once ICD established**

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Embedded Coder structure for AEI

- **AEI**
  - Active control of a wind tunnel model
  - Two DSpace control boxes
    - One running at 1000Hz, the other at 200Hz
  - Entire system, two flight computers, and model were built up in Simulink for faster than real time design and analysis
  - The subsystems representing the flight code were libraries
    - The master hardware interface diagram was kept by NASA and would call the same libraries as the simulation
    - The entire model built using Real-Time Workshop Embedded Coder
  - The subsystems contained many Simulink architectures
    - Stateflow was used to manage the many different modes and operation of the code
    - Heavy use of enabled subsystems to reduce computational requirements
  - Iteration time from Simulink modification to the new system loaded in the dSpace controller and running on the hardware was < 10min
  - Allowed for rapid solution iteration and testing
  - Based on the success of this process, the next entry will follow a similar process

Evolution of SAA Simulation Development

PRISM Simulation (Starting Point)

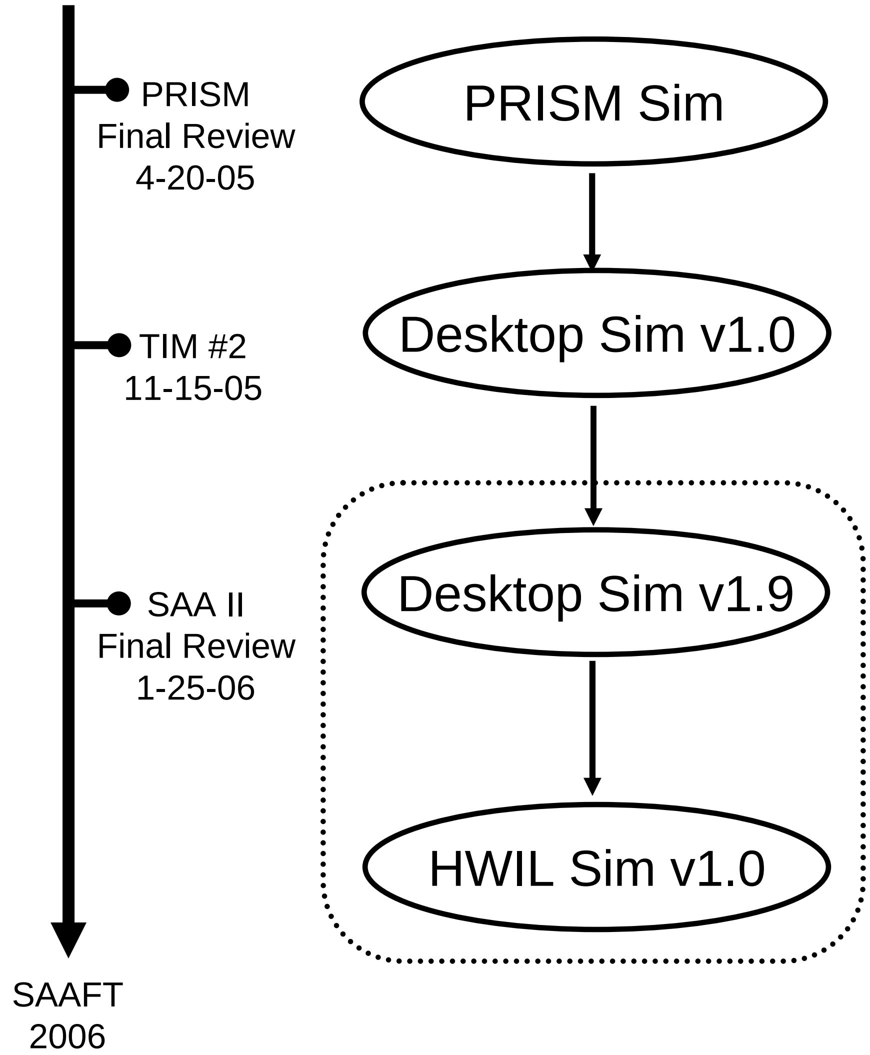
- Passive Ranging EKF
- Auto-ACAS Collision Avoidance

SAA II Desktop Simulation

- Fully Integrated Closed-loop Simulation
- Hosted In Simulink Environment With HWIL Support

SAA II HWIL Simulation (Current)

- Real-time Closed-loop Simulation
- X-Plane Display Environment
- Multiple Processors
- IEEE 1394 Data Communication



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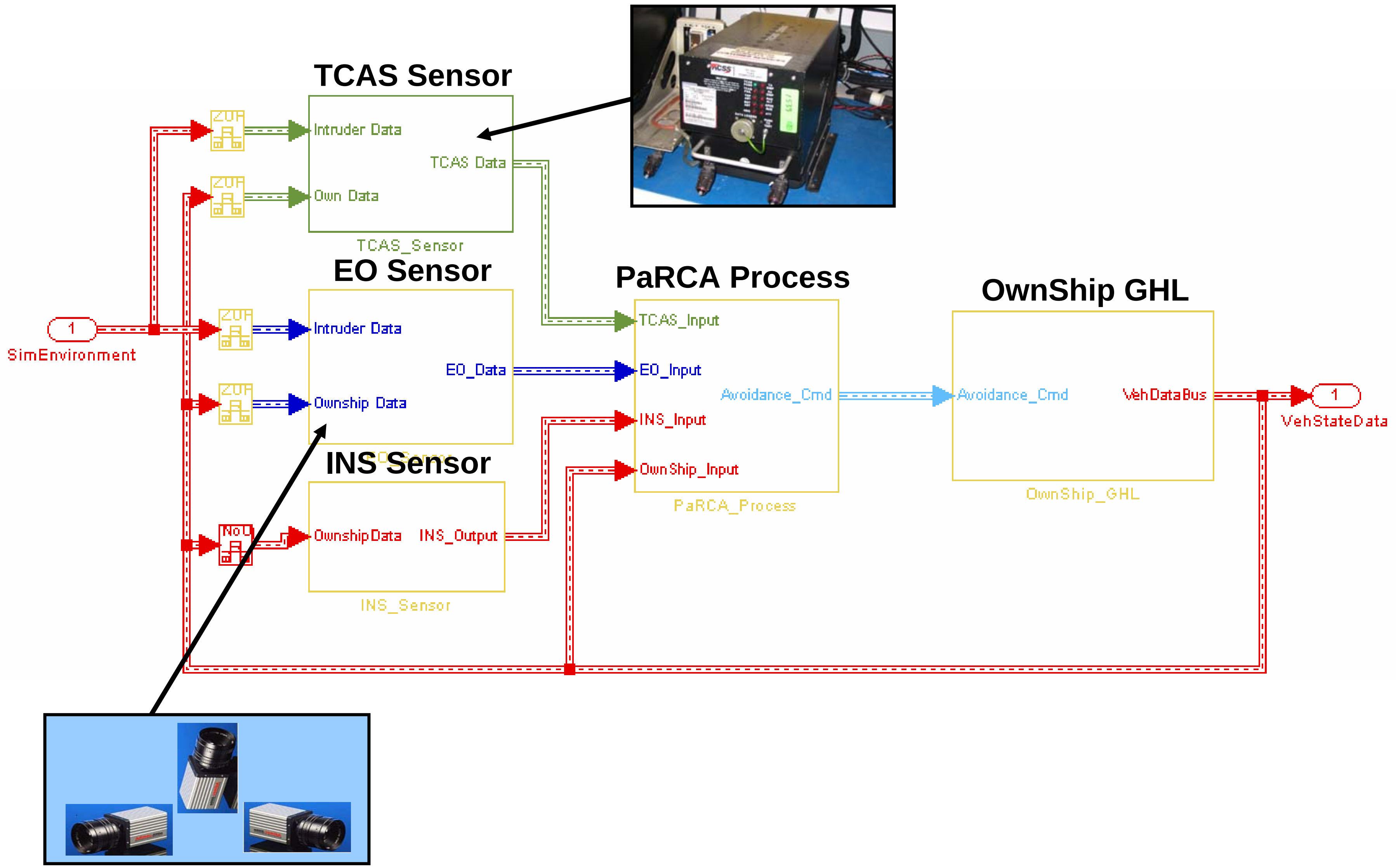
Simulation Architecture Facilitates Transition from Desktop to HWIL



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Desktop Simulation Bus Objects

Data Structure that Specifies Key Attributes of Block Outputs (data type, tunability, value range, etc…)

- Benefits
  - Helps Encapsulate Inputs and Outputs of Each Module
  - Platform Independent Reusable Data Structure
  - Seamless Conversion From Simulation Data Structure to IEEE 1394 Data Packet
  - Implements ICD between Modules
- Overhead
  - Require Detailed Definition and Attentive Maintenance in Desktop Simulation

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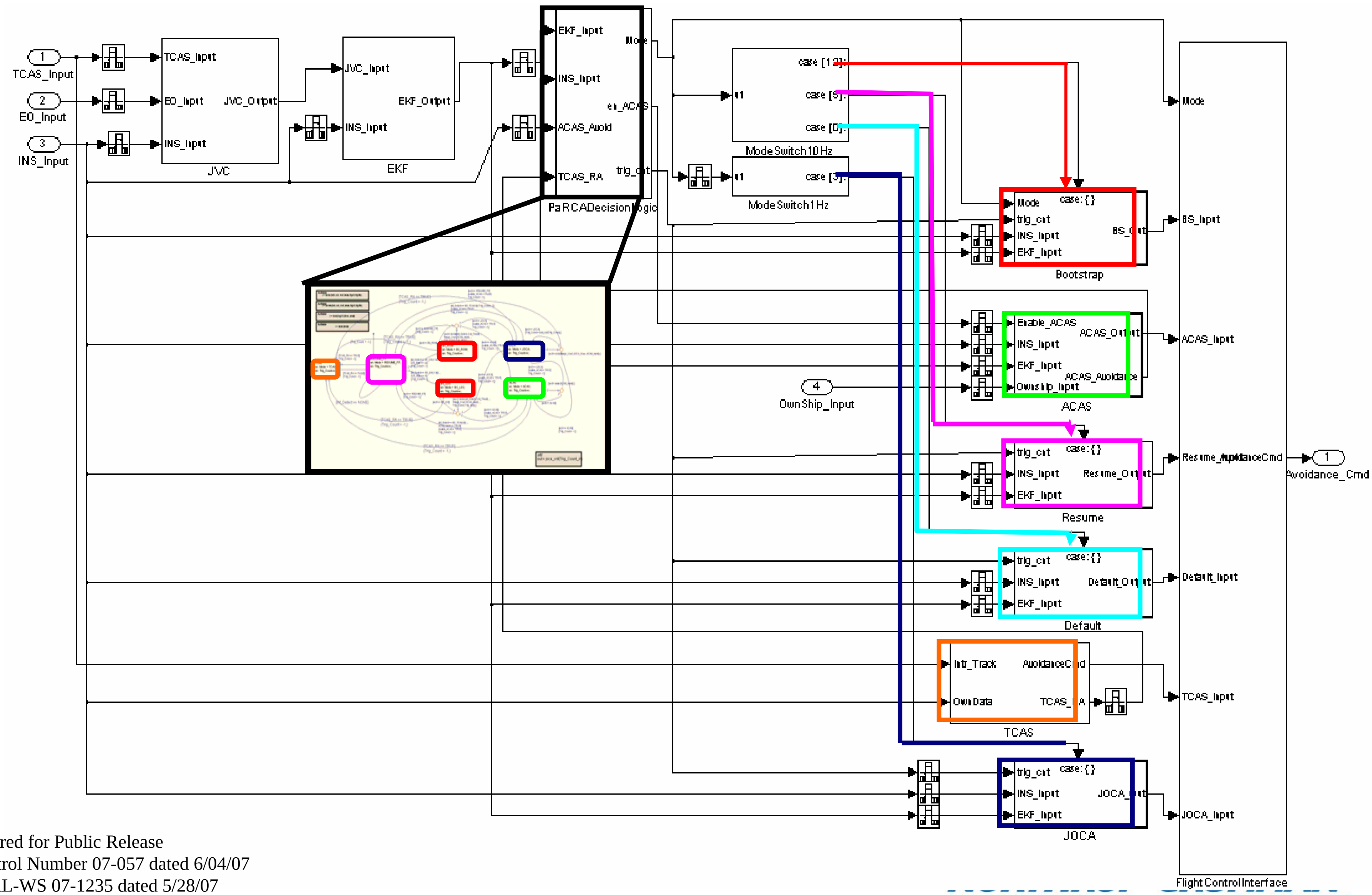
PaRCA Decision Logic



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SAA Desktop Simulation Module Updates

- **Sensor**
  - TCAS **1 Hz** **SFun**
  - EO **25 Hz** **EML**
  - INS **100 Hz** **Sys**
- **Vehicle**
  - Ownship **100 Hz** **Sys**
  - Intruder **100 Hz** **Sys**
- **PaRCA Decision Process**
  - EKF **25 Hz** **EML**
  - PaR **10 Hz** **EML**
  - JOCA **1 Hz** **SFun/EML**
  - ACAS **10 Hz** **SFun**
  - Data Association **25 Hz** **SFun**
  - Decision Logic **10 Hz** **EML**
  - Track Manager **25 Hz** **EML**
  - Flight Control IO **10 Hz** **Sys**

Sampling Rate
Module Type

Sys	Simulink
EML	Embedded MATLAB
SFun	S-Function
SFlow	Stateflow

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Desktop To HWIL Build Up Process

- Each module in desktop simulation is partitioned into individual simulink models

- Real-time Software was generated for each module
  - C/C++ code was generated using MATLAB/Simulink Real-Time Workshop embedded coder for specific target:
    - RTOS VxWorks-based VMS
    - Linux-based Ownship model

- Custom wrapper function developed for target code
  - Scheduling, data communication

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Conclusions

- **Lessons learned**
  - MATLAB/Simulink/Stateflow design process is a powerful toolchain which facilitates real-time HWIL and flight code generation
    - Desktop directly to flight code on flight hardware
  - Bus objects drastically reduce HWIL transition and data communication
  - Coverage analysis facilitates debugging and verification
  - Stateflow extensively used for mode control

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Future Issues

- **Large scale modeling**
  - More than 30,000 blocks
  - Aerospace model more complicated than models typically used in other industries
  - More extensive use of trim and linearization features
  - Model reference
  - Version control

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