Implementation of a Real Time GT-POWER model for HIL Simulation

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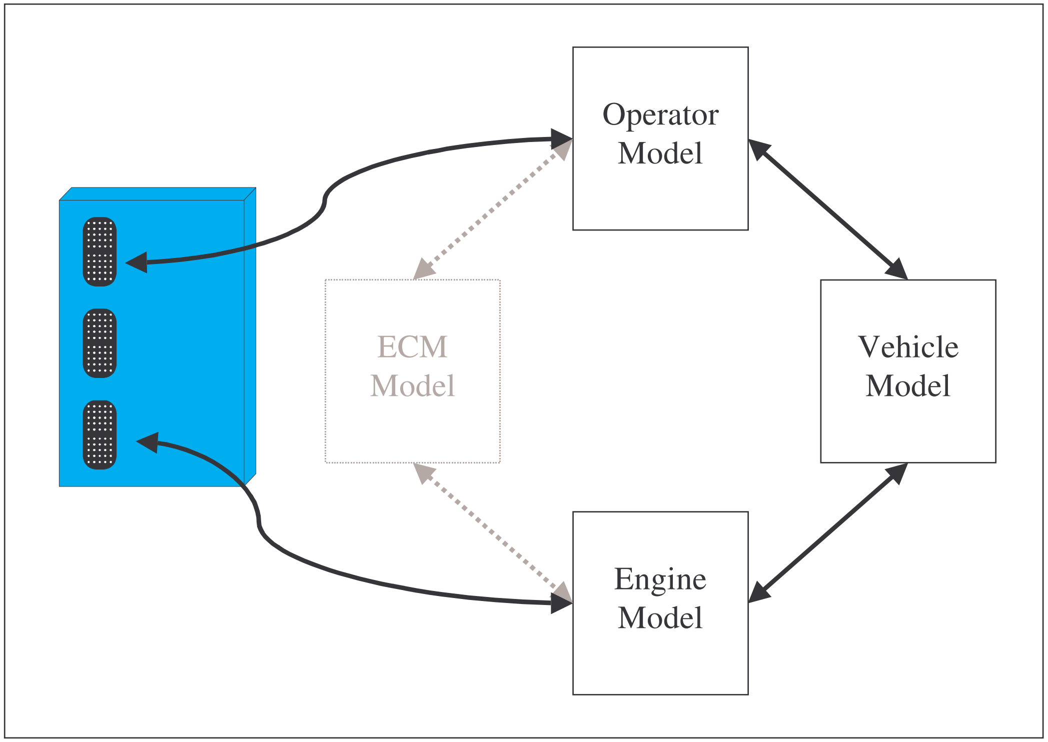
System Simulation

- Cummins uses an internally developed tool for system simulation with capability for:
  - Pure Simulation
  - Hardware In the Loop Simulation (HILS)
- Used primarily for controls development and hardware testing
- Models are built in MATLAB / Simulink
  - Executes in native Simulink or in compiled mode
- HILS is by nature real-time and the available computing power imposes constraints on the complexity of the models used
  - Typically requires mean value engine models

HIL Simulation Overview

- Controller in Loop Simulation
  - Real engine controller with models of engine, vehicle and operator



Need

- Diesel engine air handling system topologies are becoming very complex and more difficult to build / maintain in Simulink

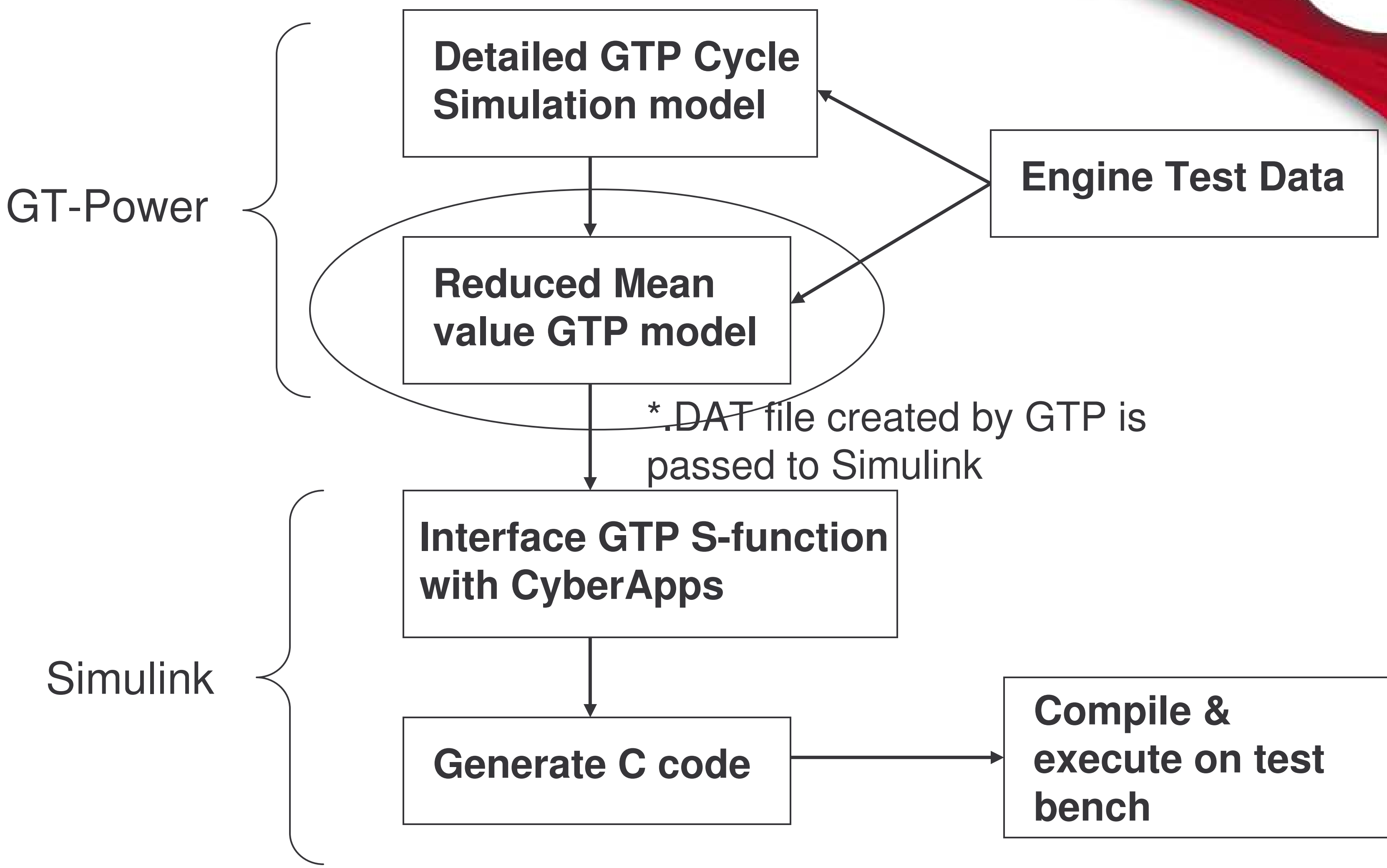
- It is proposed to replace the existing engine models built in Simulink with those in GT-POWER for both pure simulation and real-time HILS

- Advantages
  - More continuity between engine cycle simulation and engine system simulation
  - Arbitrarily complex air handling systems can be built
  - Simpler model calibration processes

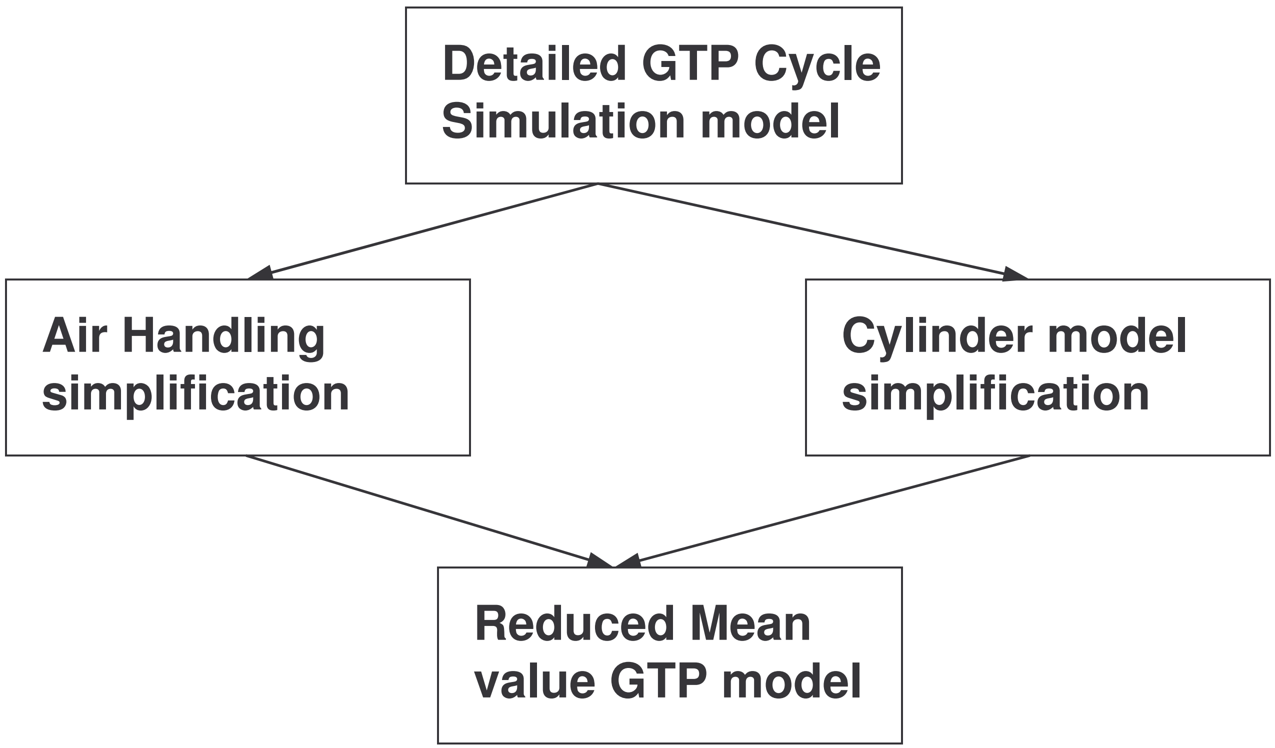
Requirements

- GT-POWER Model Execution Time
  - Need to run faster than real time on current technology computers (to leave CPU cycles for other processes in the system simulation)
  - Mean value cylinder model
  - Simplified 1-D wave dynamics
  - Eliminated disk I/O
  - Optimize computations for speed
- Simulink interface
  - Interface GT-POWER engine model with rest of the model in Simulink
  - Typically S-functions
- Execute under the target operating system
  - GNU/Linux (2.6 kernel) with real-time extensions

Model Workflow



Model Workflow contd..

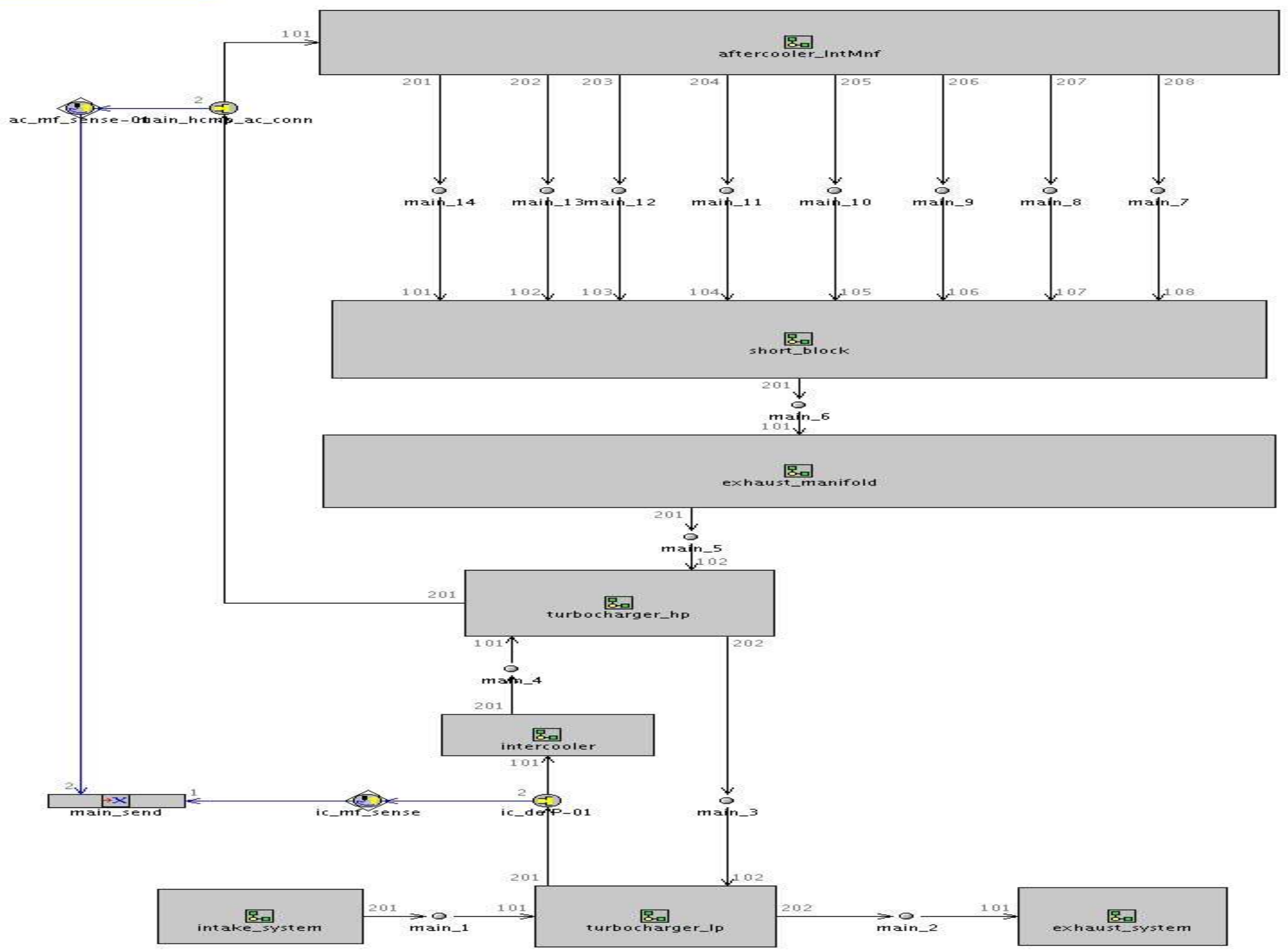


Case Study:
2-Stage, intercooled and aftercooled 16 cylinder engine

Air Handling Simplification

- Combine pipes and flow splits to form bigger volumes
  - This makes the code to take bigger time steps
- Conserve volume
  - Example: simplified exhaust manifold volume should be the same as detailed GT-Power model
- Maintain surface area of critical components for heat transfer
  - All the coolers
  - Exhaust manifold
- Maintain same turbine/compressor inlet/exit area

Reduced Model



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Mean Value Cylinder model

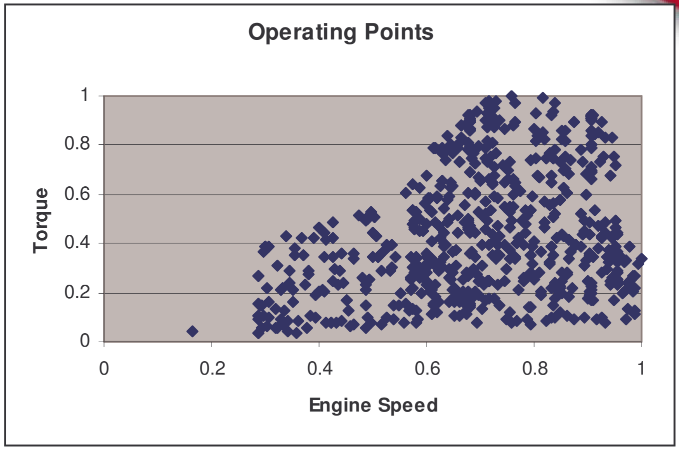
- MVCM essentially contains map based cylinder model that is computationally faster (max time step:20 CAdeg) than a regular cylinder model (max time step:1 CAdeg)

- Three maps define the cylinder performance
  - Net indicated efficiency
  - Volumetric efficiency
  - Exhaust energy fraction

- Neural Network tool is used to develop maps
  - User defines the dependencies and data to train the neural network (NN)
  - An automated NN tool is used in GTP

Neural Network training results

- To prove the concept of MVEM, engine test results were used
  - DOE on speed, fuel qty, main timing, other variables (~600 points)
- Future plans: generate data from simulation of calibrated models



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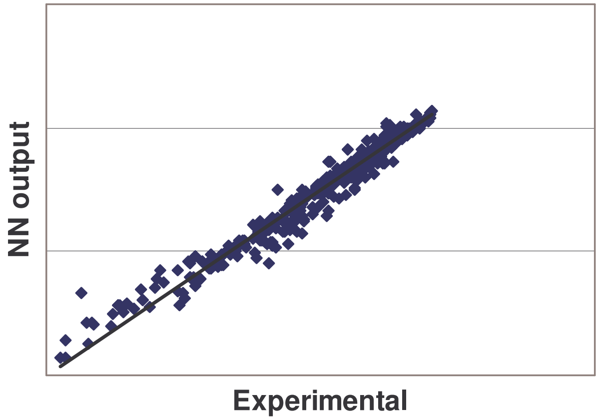

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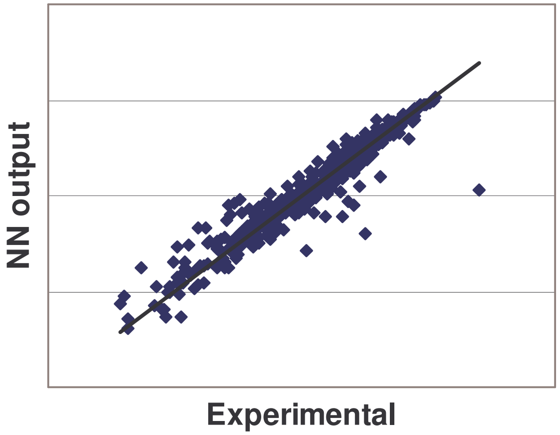
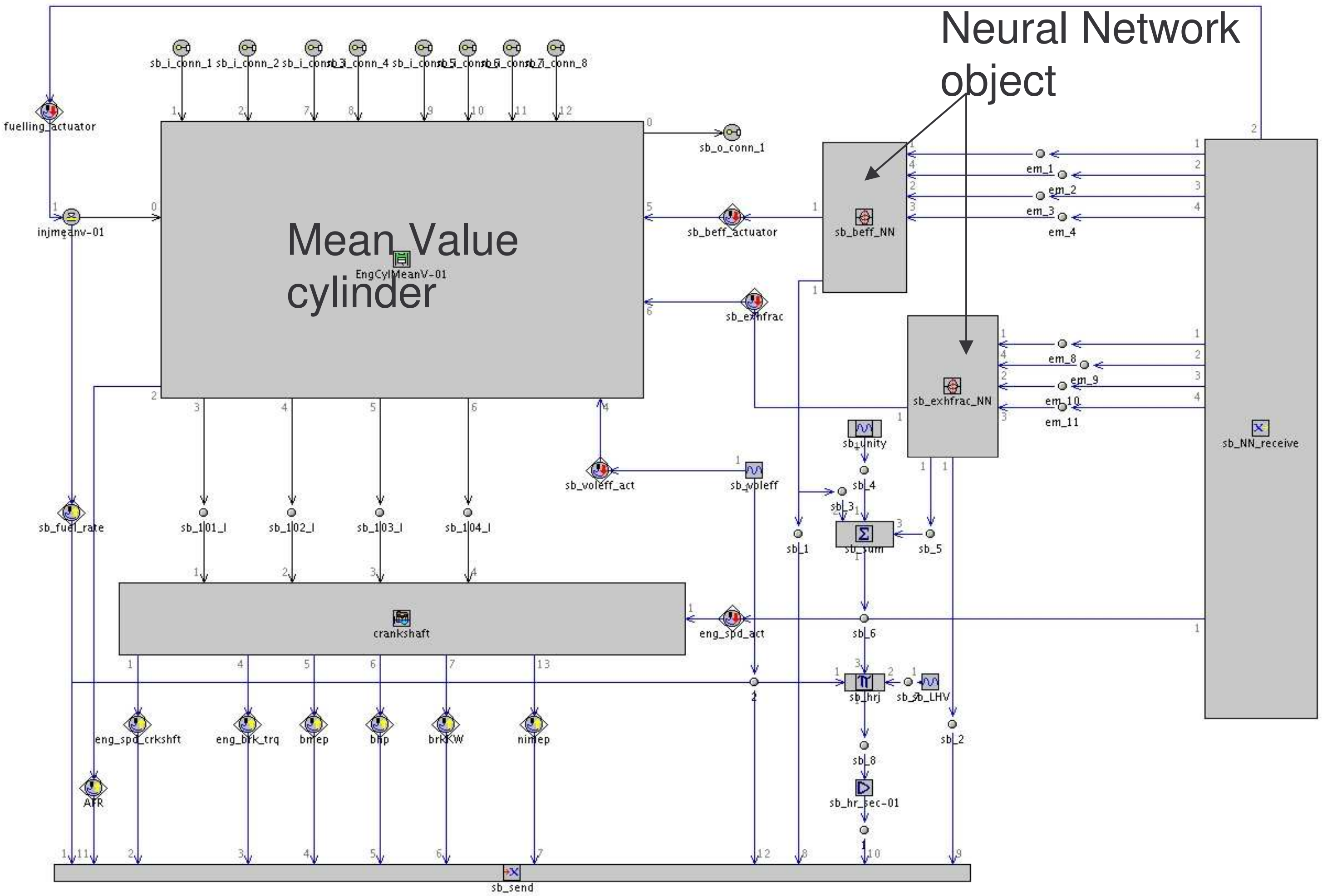
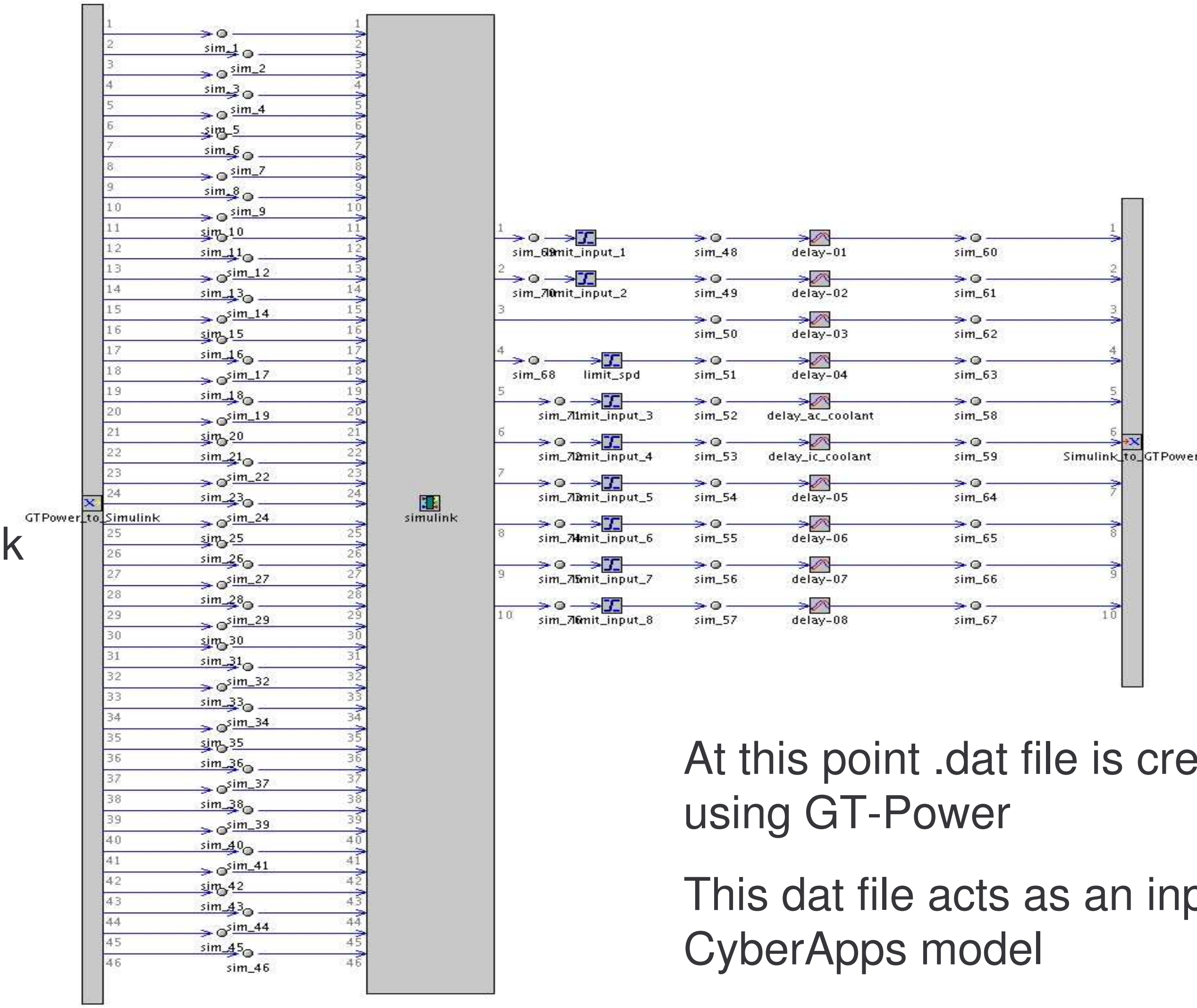


Implementation in GTP



Simulink interface in GTP

Signals from GTP to Simulink

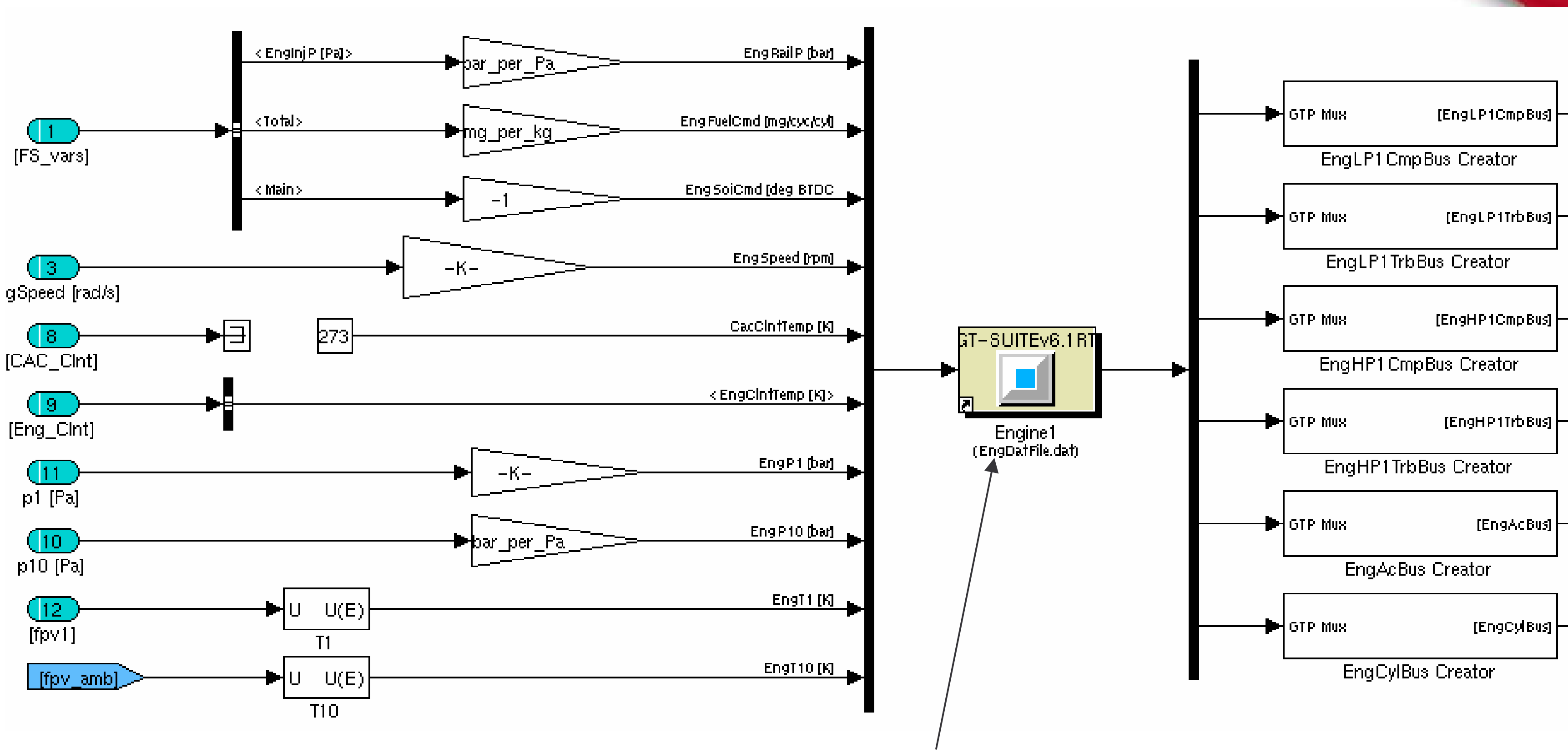


Signals from Simulink to GTP

At this point .dat file is created using GT-Power

This dat file acts as an input to the CyberApps model

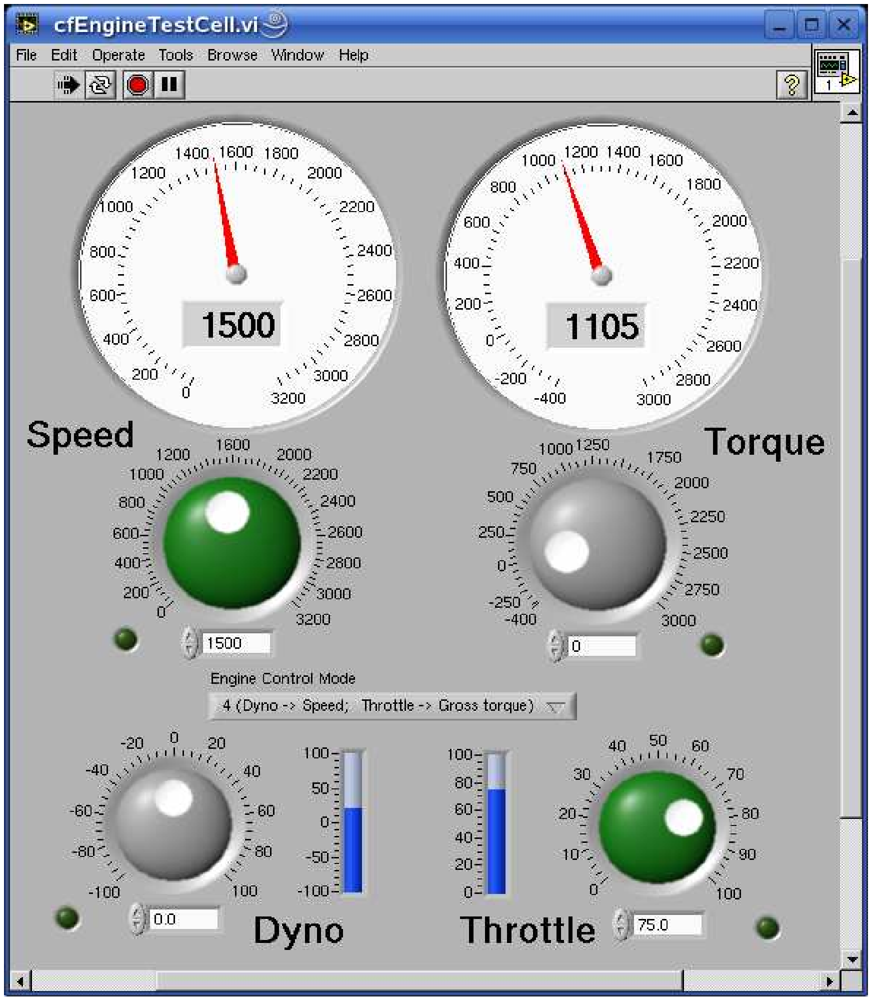
GTP S-function in Simulink



- GTP S function is interfaced to CyberApps
- C Code is generated

HILS : Results

Real Time test system interface



- C code generated from Simulink is compiled under Linux to generate an executable
- On 2.4 GHz Pentium 4 processor, ~ 60% CPU utilization under steady state, ~ 80% CPU under transients (actuals would depend on complexity of model)

HILS: Results Comparison

- Experimental / GT-POWER detailed / GT-POWER real-time
- Engine speed and fueling imposed on the models
- 3 different steady state operating conditions (A, B, C)