Propulsion System Simulation Using the Toolbox for the Modeling and Analysis of Thermodynamic Systems (T-MATS)

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Outline

- Background
- T-MATS Description
- Framework
- Block Sets
- Examples
- Summary
- References and Download information

Background, Modeling Goals

- Requirements for transient gas turbine simulation for academia, research, or industry.
  - Flexible plant model
    - Sets of components that may be used to create custom turbo-machinery performance models.
    - Ability to leverage legacy model design and codes
    - Numerical solvers for system convergence
  - Dynamic operation for transient simulation
    - Ability to easily create a dynamic model from a steady state model
  - Faster then real time operation
  - Easy integration with common design tools
    - Seamless integration with or built in MATLAB®/Simulink®.
    - Parameterized and easily modifiable.
  - Ability to collaborate with international workforce
    - Non-proprietary, free of export restrictions, and open source.

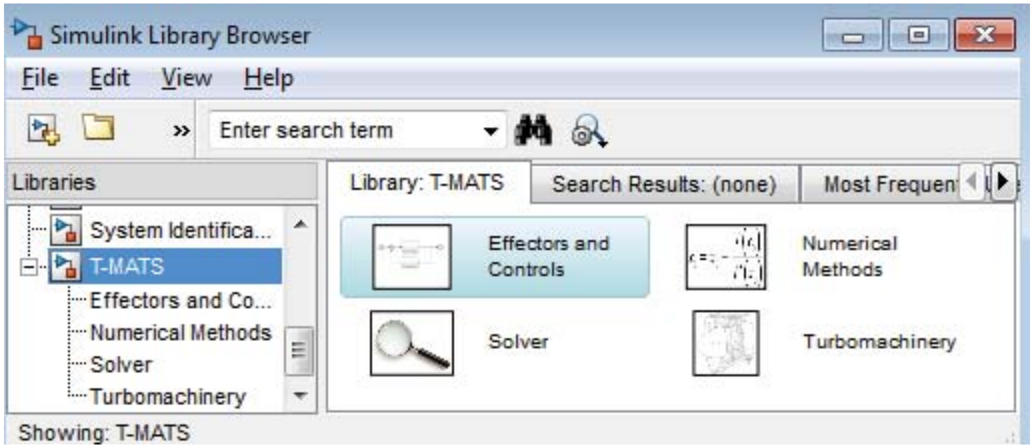
No single software package meets all of these requirements

T-MATS Description

- Toolbox for the Modeling and Analysis of Thermodynamic systems, T-MATS
  - Modular thermodynamic modeling framework
  - Designed for easy creation of custom Component Level Models (CLM)
  - Built in MATLAB/Simulink
- Package highlights
  - General thermodynamic simulation design framework
  - Variable input system solvers
  - Advanced turbo-machinery block sets
  - Control system block sets
- Development being led by NASA Glenn Research Center
  - Non-proprietary, free of export restrictions, and open source
    - Open collaboration environment

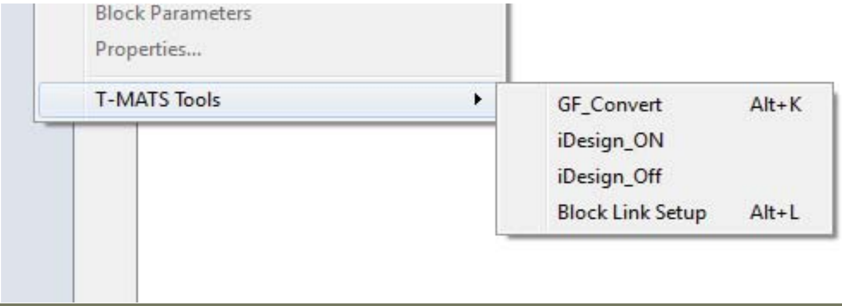
T-MATS Framework

- T-MATS is a plug-in for a MATLAB/Simulink platform
  - additional blocks in the Simulink Library Browser:



Added Simulink Thermodynamic modeling and numerical solving functionality

  - additional diagram tools for model development in Simulink:

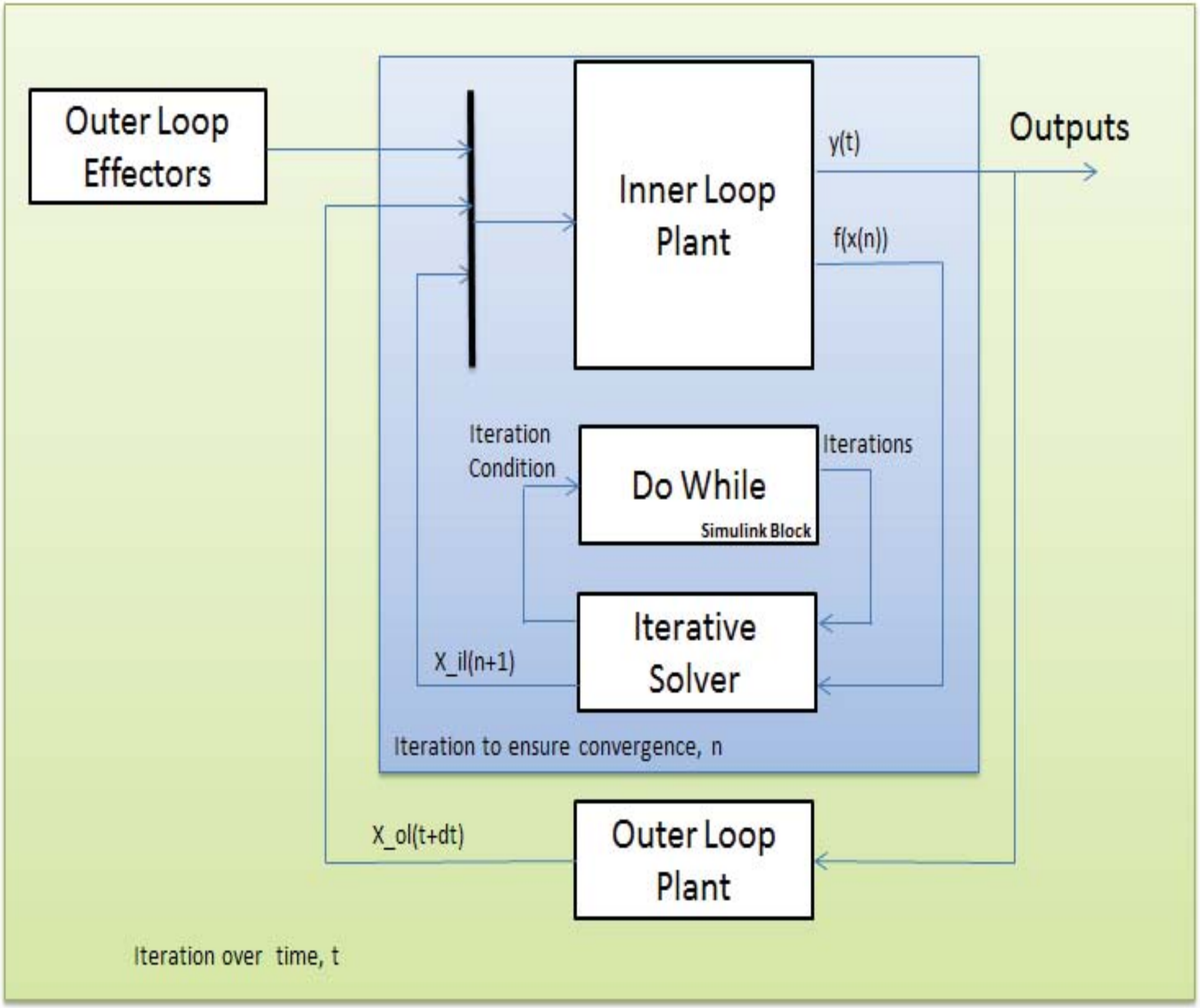


Faster and easier model creation

T-MATS Framework

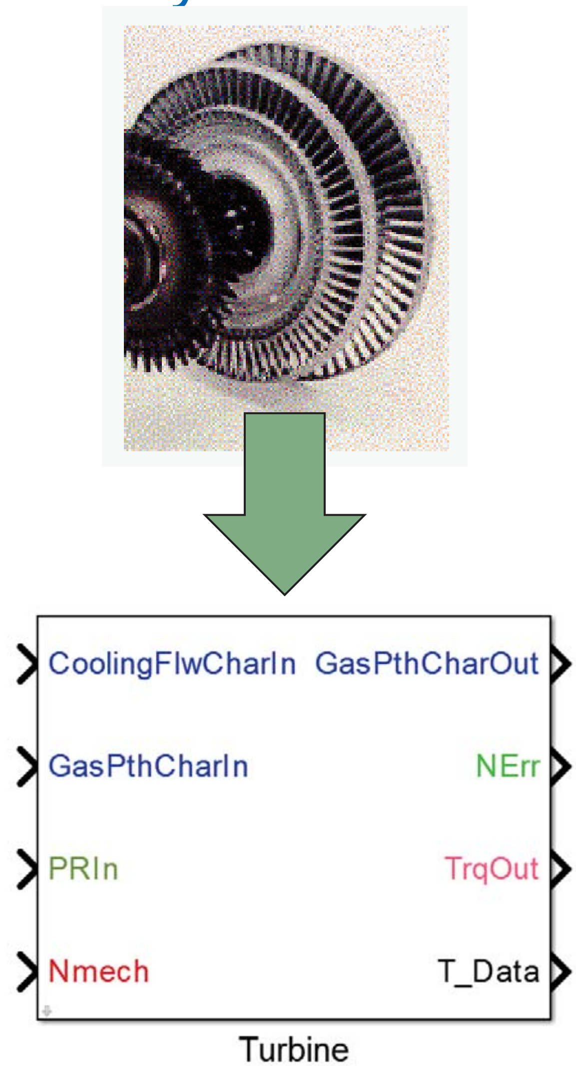
Dynamic Simulation Example:

- Multi-loop structure
  - The “outer” loop (green) iterates in the time domain
    - Not required for steady-state models
  - The “inner” loop (blue) solves for plant convergence during each time step



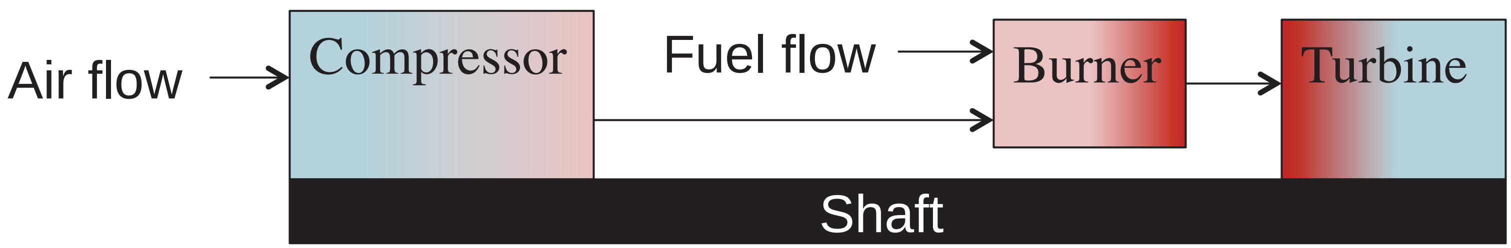
Blocks: Turbo-machinery

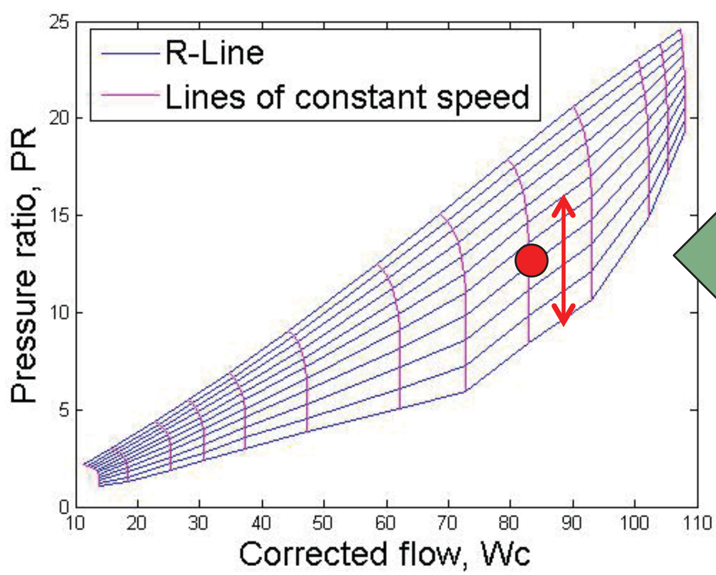
- T-MATS contains component blocks necessary for creation of turbo-machinery systems
  - Modeling theory based on common industry practices
    - Energy balance modeling approach
    - Compressor models utilize R-line compressor maps
    - Turbine models utilize Pressure Ratio turbine maps
    - Single fuel assumption
  - Blocks types; compressor, turbine, nozzle, flow splitter, and valves among others.
    - Color Coding for easy setup
  - Built with S-functions, utilizing compiled C code/ MEX functions



Blocks: Numerical Solver

- Why is an external solver necessary?
  - Many thermodynamic simulations contain variables that are system dependent.
  - In Gas turbine models air flow through the engine is dependent on system architecture.

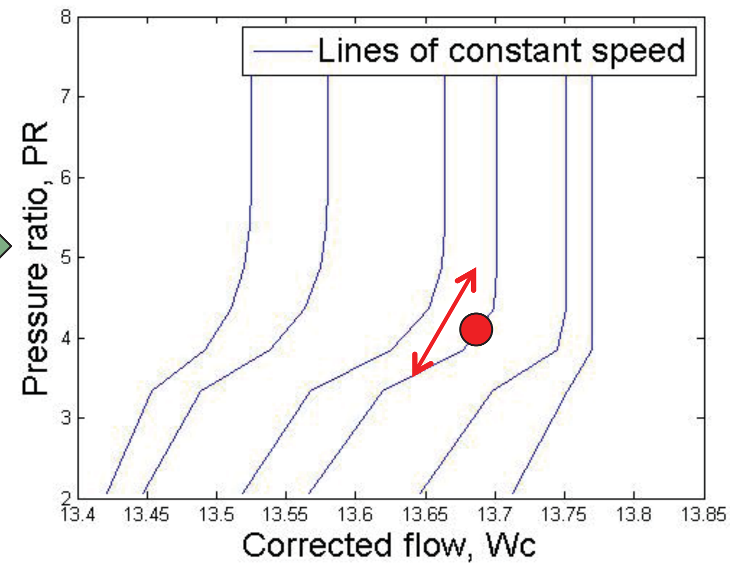




Components must agree on W for the system

Convergence

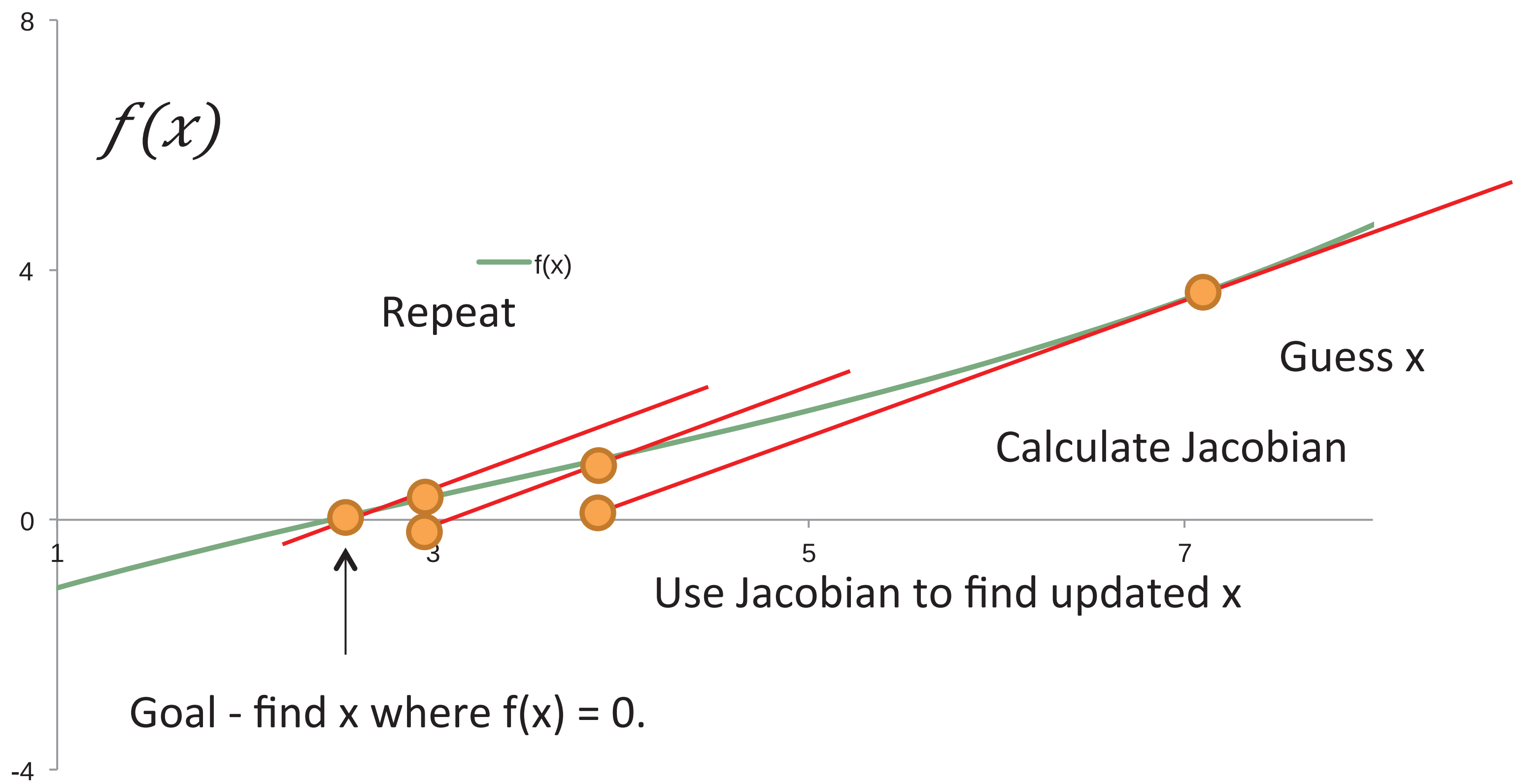
Effectors:
Shaft speed
Pressure
Temperature



Blocks: Numerical Solver

- T-MATS solvers utilize the Newton Raphson method

$x(k+1)=x(k)-f(x(k))/\nabla f(x(k))$ where, $\nabla f(x(k))=Jacobian$



Blocks: Controls

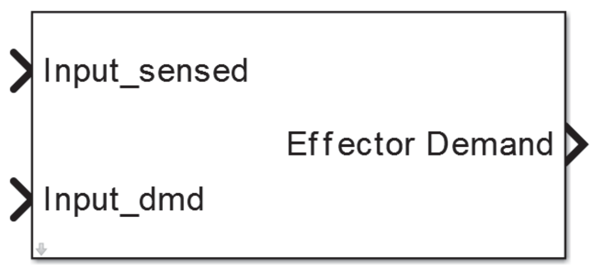
- T-MATS contains component blocks designed for fast control system creation
  - Sensors:

1st order Sensor

  - Actuators:

1st order Actuator

  - PI controllers:



Simple PI controller

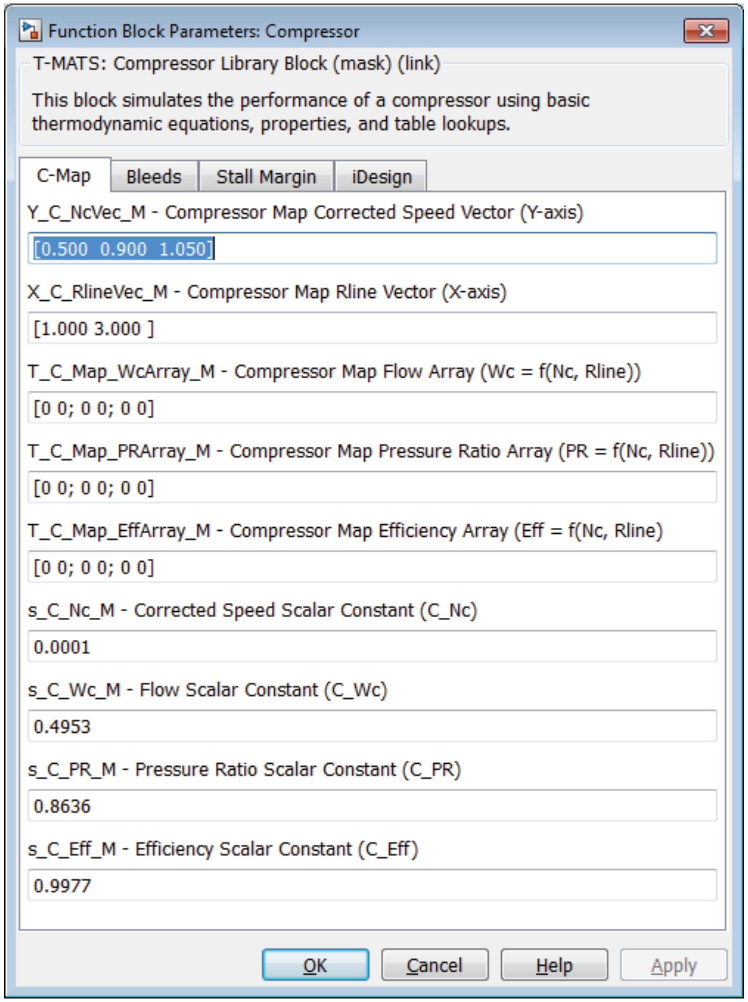
Blocks: Settings

- The T-MATS Simulation System is a highly tunable and flexible framework for Thermodynamic modeling.

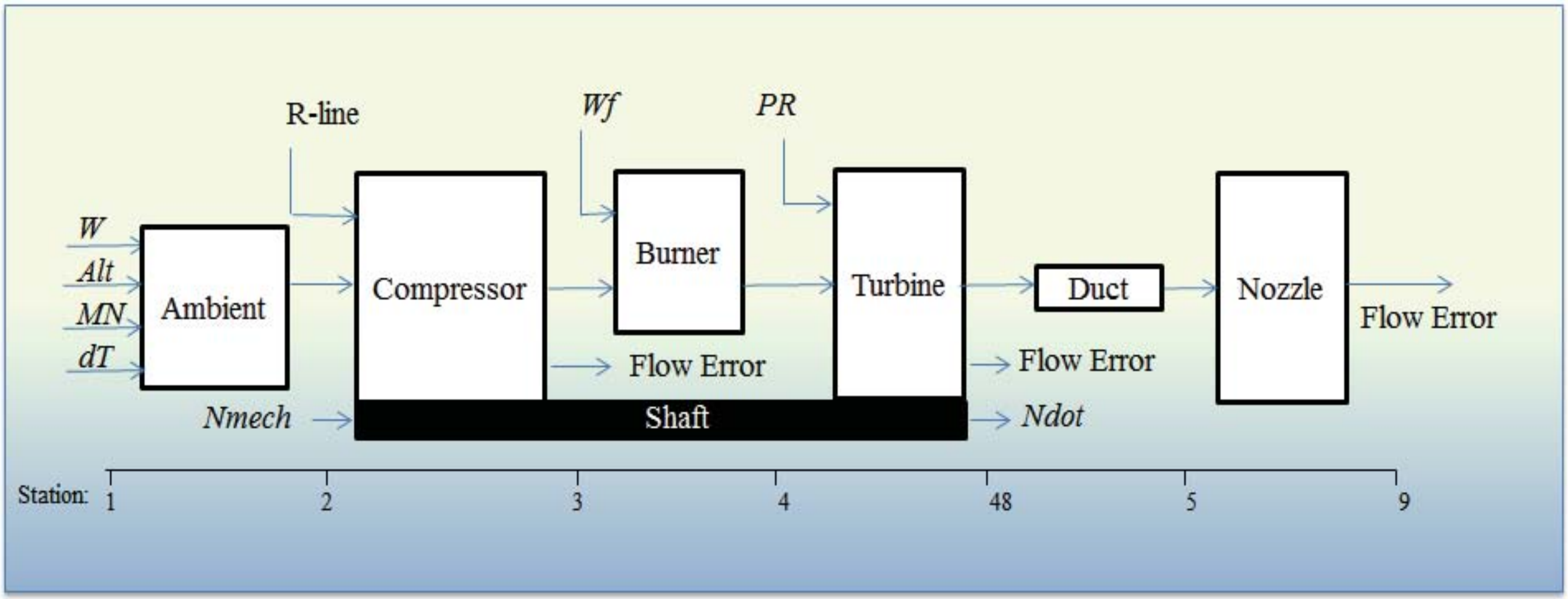
  – T-MATS block Function Block Parameters
    - fast table and variable updates

  – Open source code
    - flexibility in component composition, as equations can be updated to meet system design

  – MATLAB/Simulink development environment
    - user-friendly, powerful, and versatile operation platform for model design

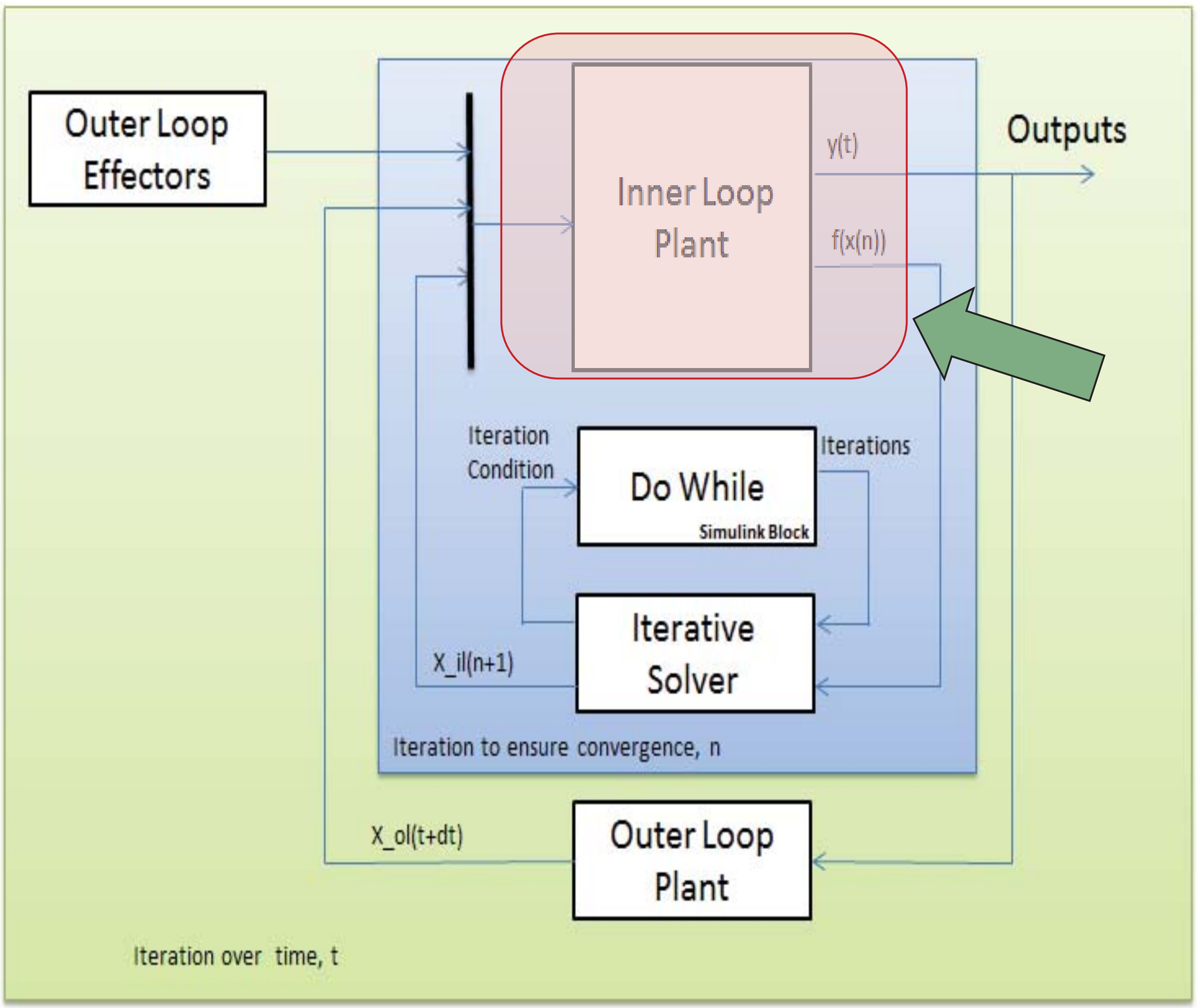


Dynamic Gas Turbine Example: Objective System

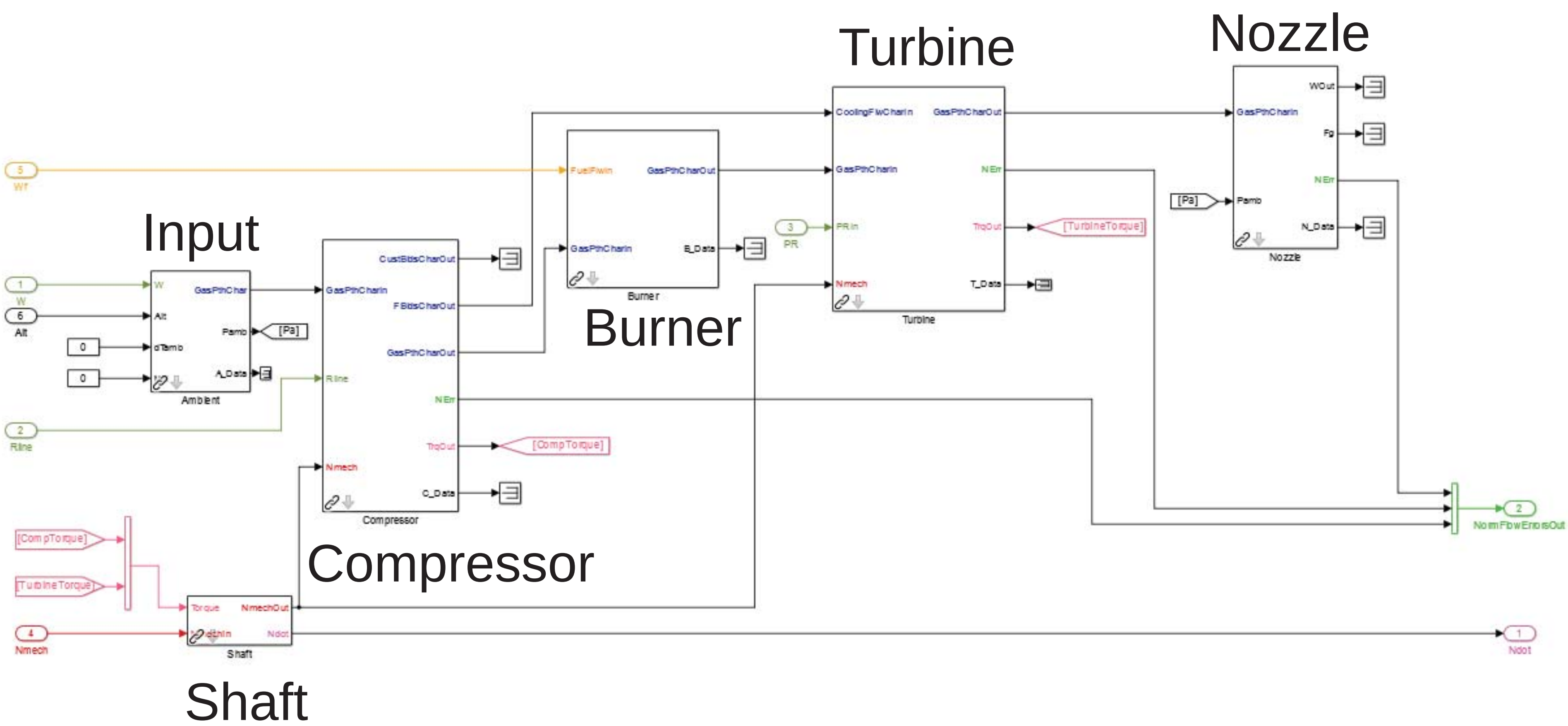


Simple Turbojet

Dynamic Gas Turbine Example: Creating the Inner Loop

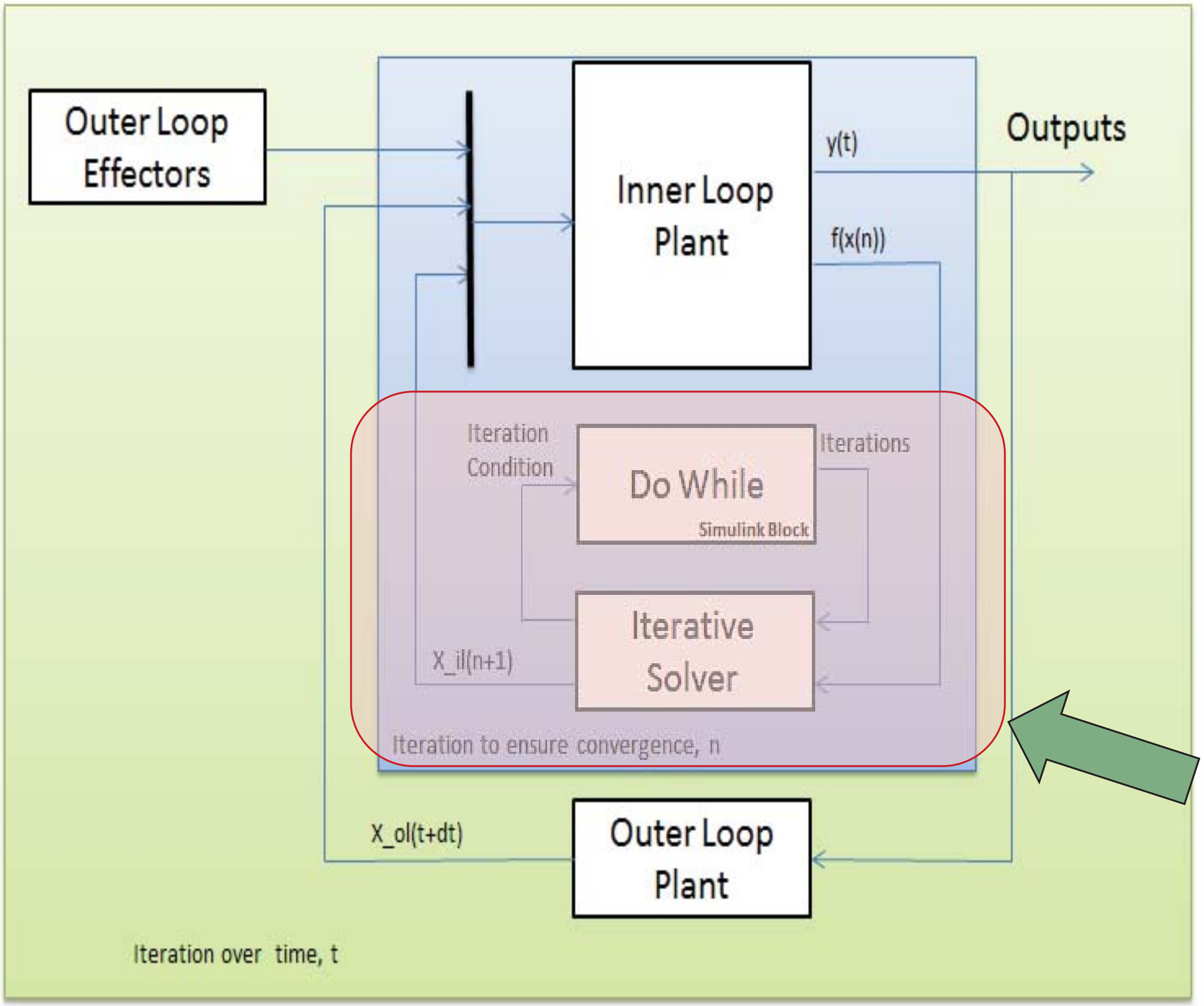


Dynamic Gas Turbine Example: Inner Loop Plant

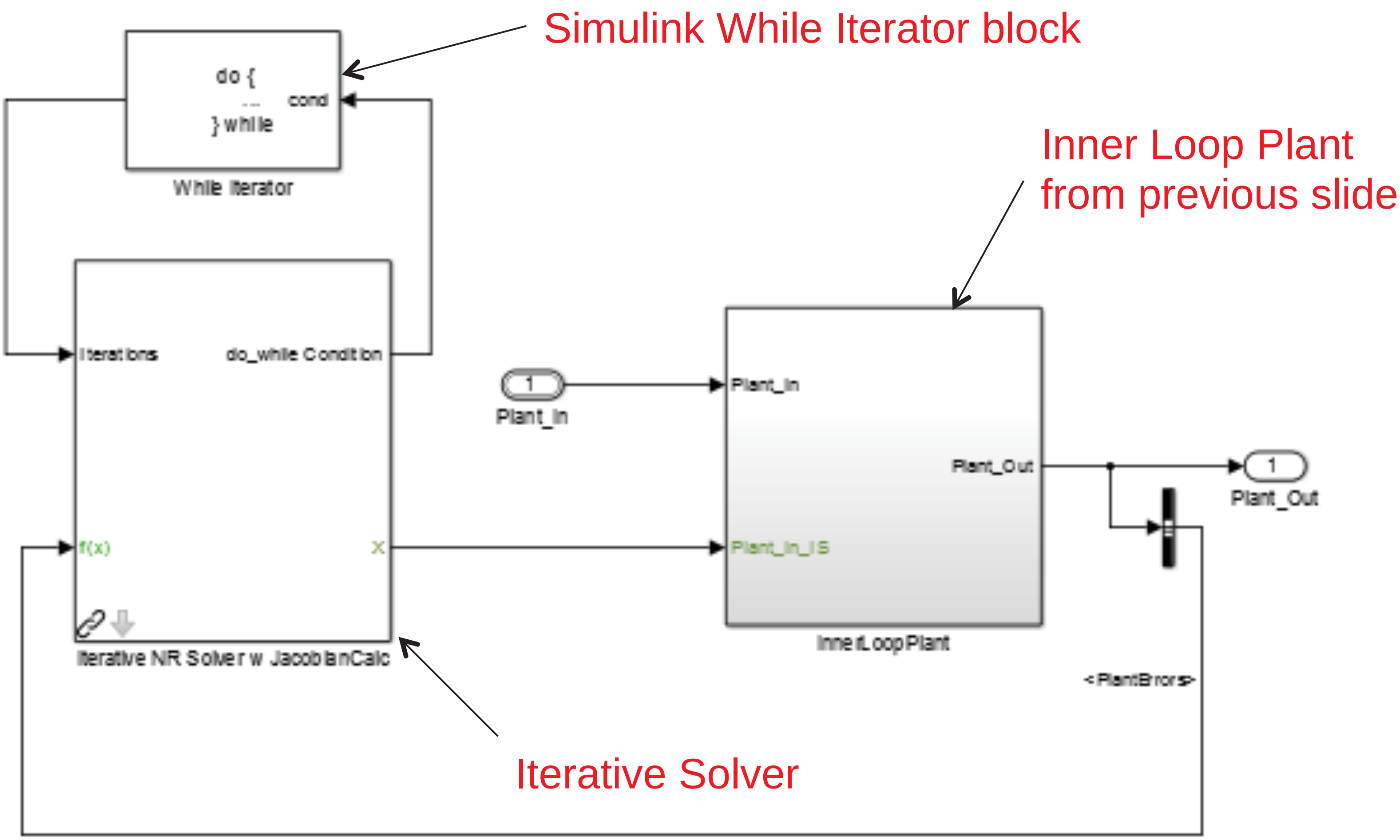


Turbojet plant model architecture made simple by T-MATS vectored I/O and block labeling

Dynamic Gas Turbine Example: Creating the Solver

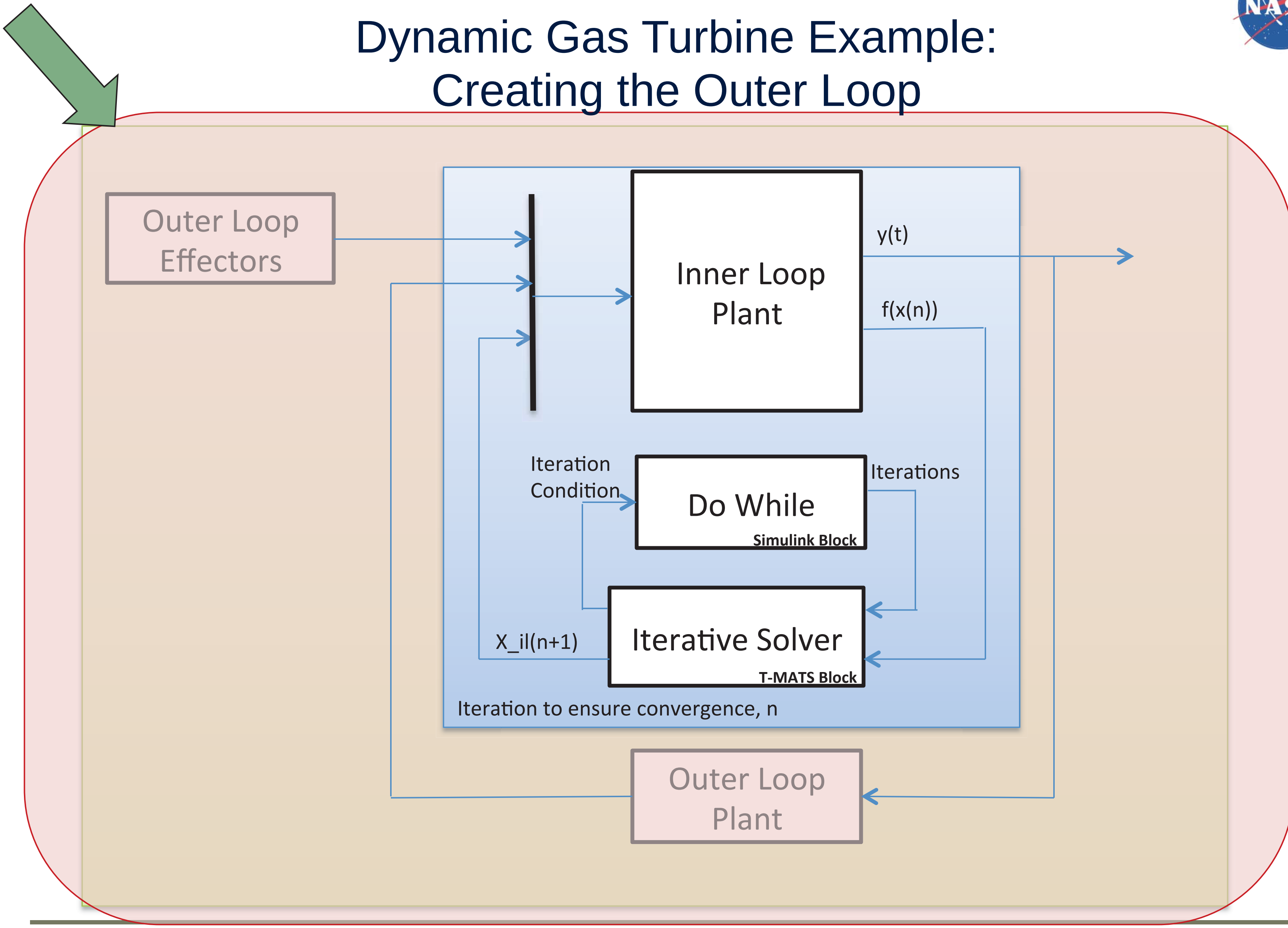


Dynamic Gas Turbine Example: Solver



Plant flow errors driven to zero by iterative solver block in parallel with While Iterator

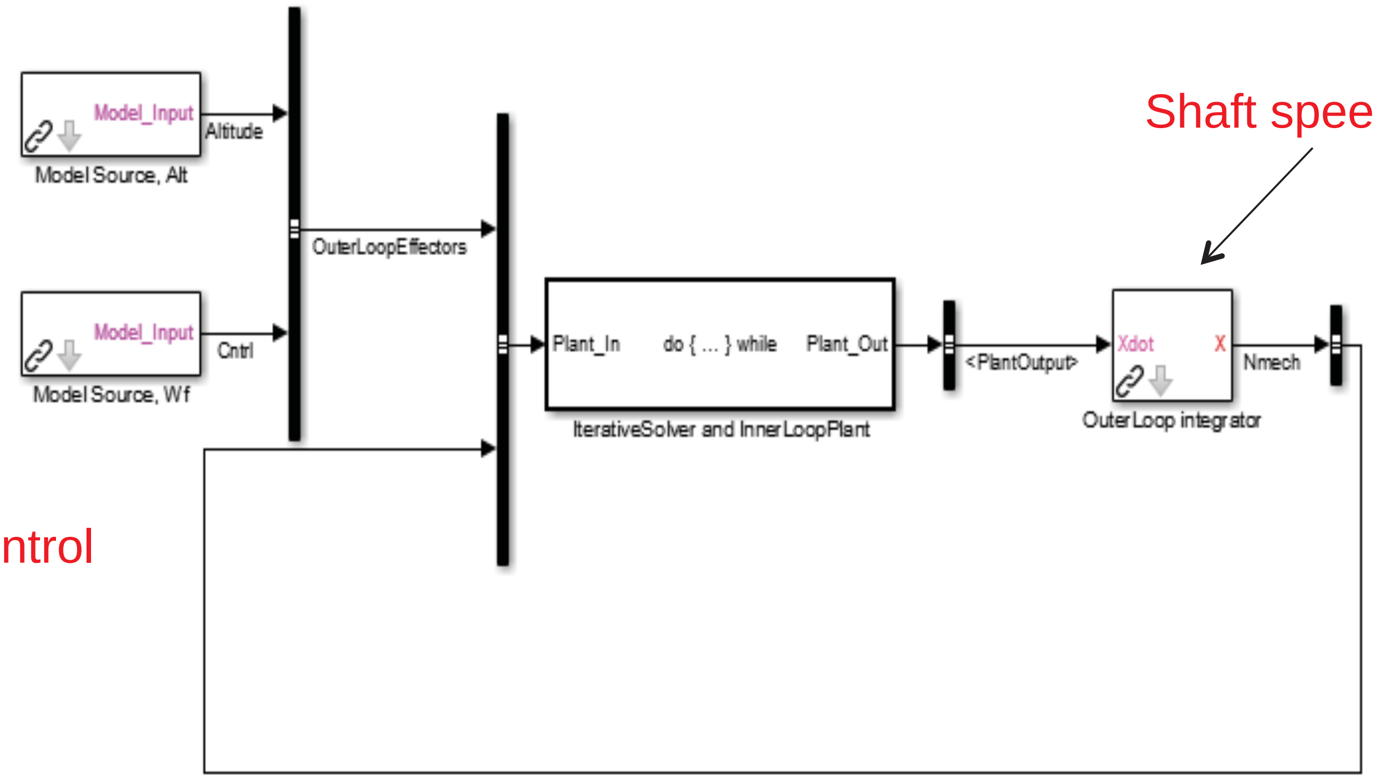
Dynamic Gas Turbine Example: Creating the Outer Loop



Dynamic Gas Turbine Example: Outer Loop Plant

Environmental conditions

Shaft speed integration

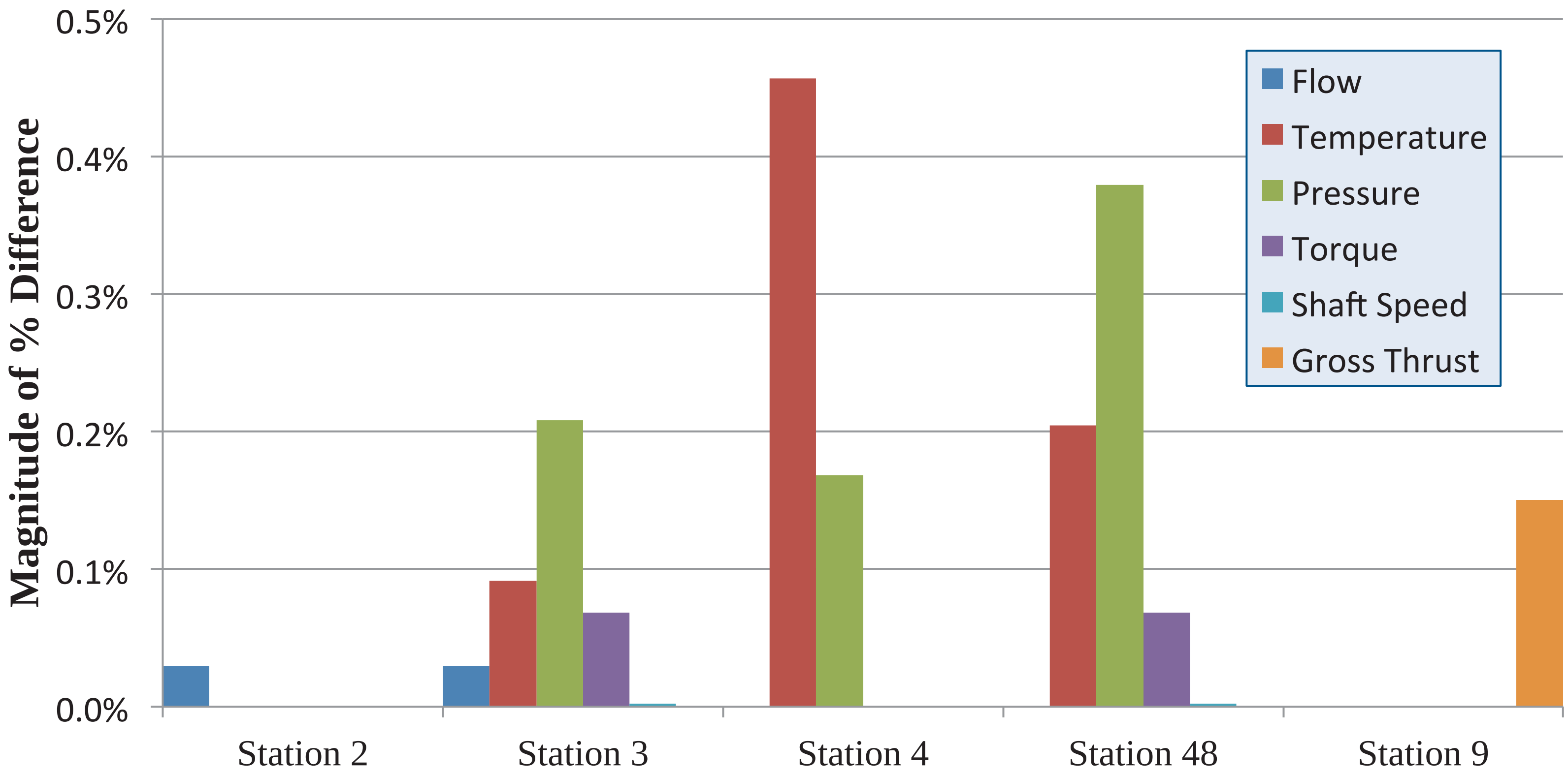


Simple Control System

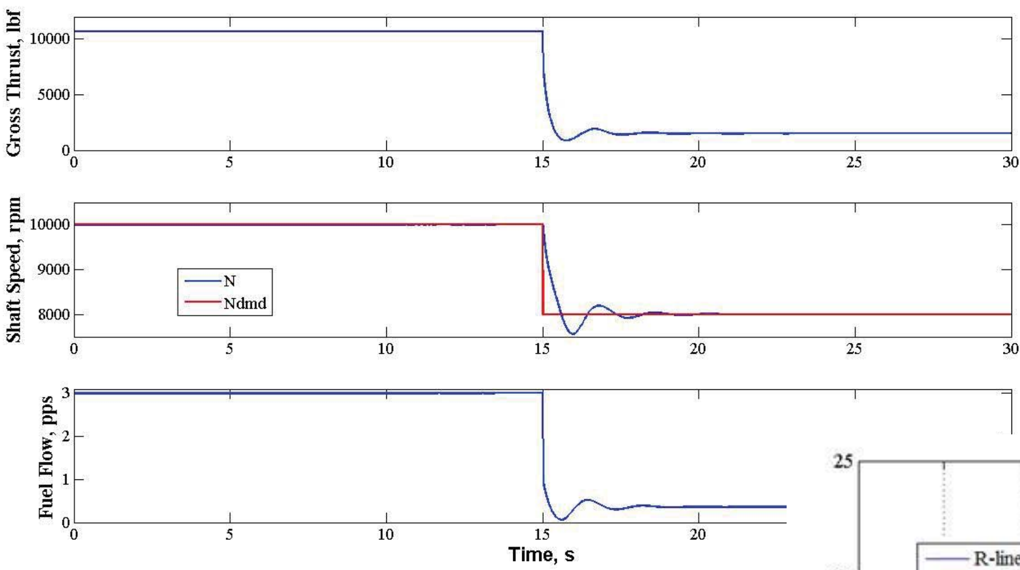
Shaft integrator and other Outer Loop effectors added to create full system simulation

Example Model Match

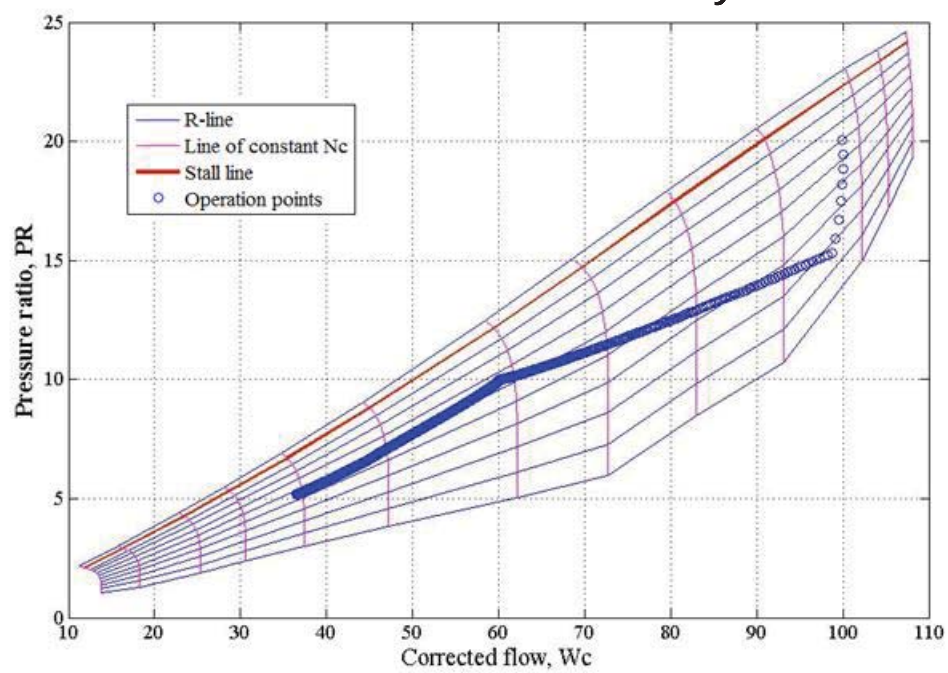
- Data generated from the example T-MATS turbojet compared to a steady state "truth" model developed in NPSS.
  - All difference values less than 0.5%



Example Dynamic Operation



- Simulation of real time system.
  - Engine maneuvers
  - Control system performance
  - Sensor delays



- Dynamic Events
  - Engine response times
  - Stall margin modeling capability
  - Simulation of fault transients

Summary

- T-MATS offers a powerful and user-friendly simulation environment for propulsion system modeling
  - Thermodynamic system modeling framework
  - Automated system “convergence”
  - Advanced turbo-machinery modeling capability
  - Fast controller creation block set
  - Capable of running faster than real time
  - Plug-in for Simulink

References and Download Information

- Download information may be found at: https://github.com/nasa/T-MATS/releases/

- References:

1. Chapman, J.W., Lavelle, T.M., May, R.D., Litt, J.S., and Guo, T.M., "Toolbox for the Modeling and Analysis of Thermodynamic Systems (T-MATS) User's Guide," NASA/TM-2014-216638, January 2014.
2. Chapman, J.W., Lavelle, T.M., May, R.D., Litt, J.S., Guo, T-H., "Propulsion System Simulation Using the Toolbox for the Modeling and Analysis of Thermodynamic Systems (T-MATS)," 2014 AIAA Joint Propulsion Conference, Cleveland, OH, Jul 28-30, 2014.
3. Lavelle, T.M., Chapman, J.W., May, R.D., Litt, J.S., and Guo, T.H., "Cantera Integration with the Toolbox for the Modeling and Analysis of Thermodynamic Systems (T-MATS)," 2014 AIAA Joint Propulsion Conference, Cleveland, OH, Jul 28-30, 2014.
4. Chapman, J.W., Lavelle, T.M., Litt, J.S., Guo, T-H., "A Process for the Creation of T-MATS Propulsion System Models from NPSS Data," 2014 AIAA Joint Propulsion Conference, Cleveland, OH, Jul 28-30, 2014.
5. Zinnecker, A.M., Chapman, J.W., Lavelle , T.M., and Litt, J.S., "Development of a twin-spool turbofan engine simulation using the Toolbox for the Modeling and Analysis of Thermodynamic Systems (T-MATS)," 2014 AIAA Joint Propulsion Conference, Cleveland, OH, Jul 28-30, 2014.