Development of Gas Turbine Performance Models using a Generic Simulation Tool

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- § Object-Oriented Gas Turbine Performance Modelling
- § Features of Simulation Tool
- § Modelling Methods
- § Application Example
- § Engine Dynamics
- § Frequency Response
- § Adaptation to Test Data
- § Conclusions

Object_Oriented Gas Turbine Performance Modelling

Object-Oriented Programming (OOP) Features

- Encapsulation
- Inheritance
- Abstraction
- Polymorphism
- Aggregation

OOP Advantages

- Supports flexible and modular design
- Facilitates code re-use
- Makes code evolution and maintenance easier
- Provides user-friendly interface

Object_Oriented Gas Turbine Performance Modelling

GasTurb

Predefined gas turbine configurations

GSP

Only the developer can create new components

NPSS / Onyx

Restricted availability

Matlab-Simulink

Not fully OO

Use a commercially available general purpose OO simulation tool to model gas turbine components from which to build any engine configuration using a flexible and user-friendly interface

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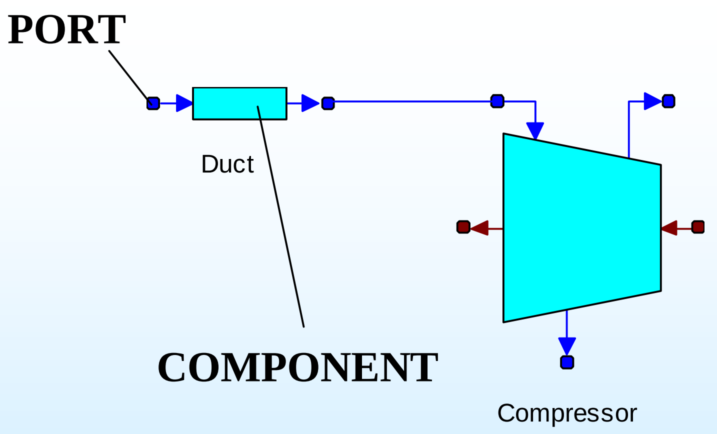
Features of Simulation Tool

- § **Software COMPONENT = mathematical description of engine component**
- § **Components are joined together through their PORTS**
- § **PORTS define the set of variables transferred between connections**

Component Code

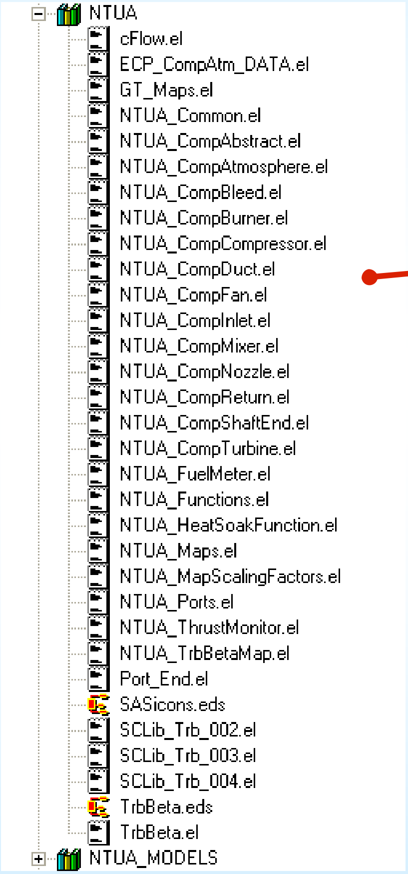
```
COMPONENT Duct IS_A GasChannel
 DATA
        REAL K = 0          "Loss Factor"
        REAL q = 0.         "Heat flux (W)"
 CONTINUOUS
        H_out = H_in + q / g_in.W
        g_out.P = g_in.P * (1.0 - K * M_in1**2)
END COMPONENT
```

Component Icon



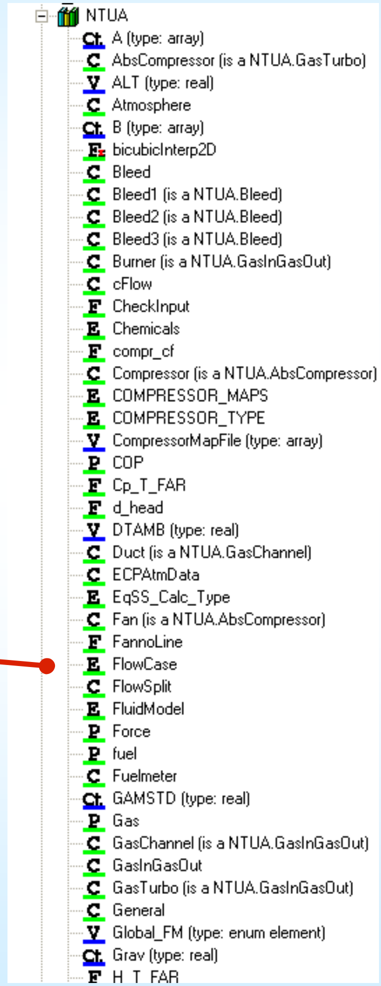
Features of Simulation Tool

COMPONENTS are stored in a LIBRARY

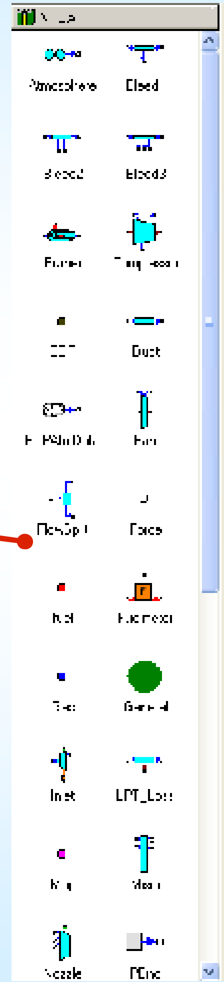


Library files

Library elements

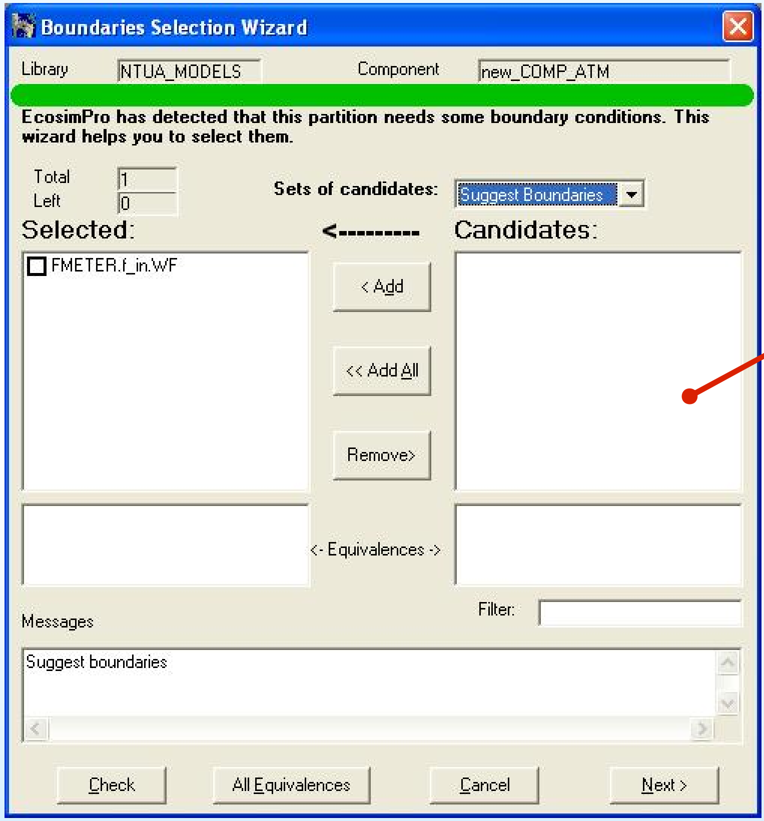


Library icons



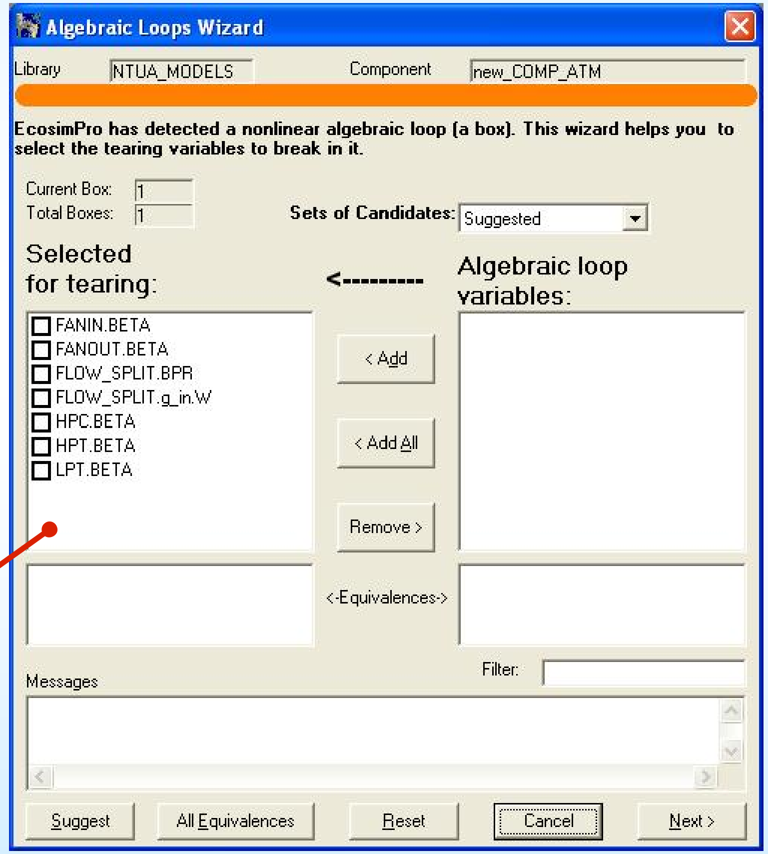
Features of Simulation Tool

A PARTITION is created to define the mathematical model



Selecting Boundary Conditions

Selecting Algebraic Variables



Features of Simulation Tool

```
EXPERIMENT ACCEL ON TURBOFAN_OBIDICOTE_MODEL.TESTS

DECLS
  TABLE_1D fuel_law

INIT    -- set initial values for variables
   -- Dynamic variables
  FANIN.XN = 1740
  HPC.XN = 9785
   -- Algebraic variables
  FANIN.BETA = 0.48
  FANOUT.BETA = 0.69
  FLOW_SPLIT.BPR = 6.0
  FLOW_SPLIT.g_in.W = 150
  HPC.BETA = 0.52
  HPT.BETA = 0.89
  LPT.BETA = 0.29

BOUNDS    -- set expressions for boundary variables: v = f(t,...)
  NTUA__ALT = 0
  ATM.DTAMB = 0
  NTUA__RH = 0
  ATM.XM = 0

BODY
 REPORT_TABLE("*")

 EcoReadTable1D("C:\\EcosimPro\\USER_LIBS\\NTUA_MODELS\\EXP

 FMETER.f_in.WF = 1.0 * timeTableInterp(TIME, fuel_law)

 STEADY()

 INTEG_TO(9,0.02)

END EXPERIMENT
```

Different EXPERIMENTS can be made for a PARTITION

Initial Values for Dynamic & Algebraic Variables

Boundary Condition Values

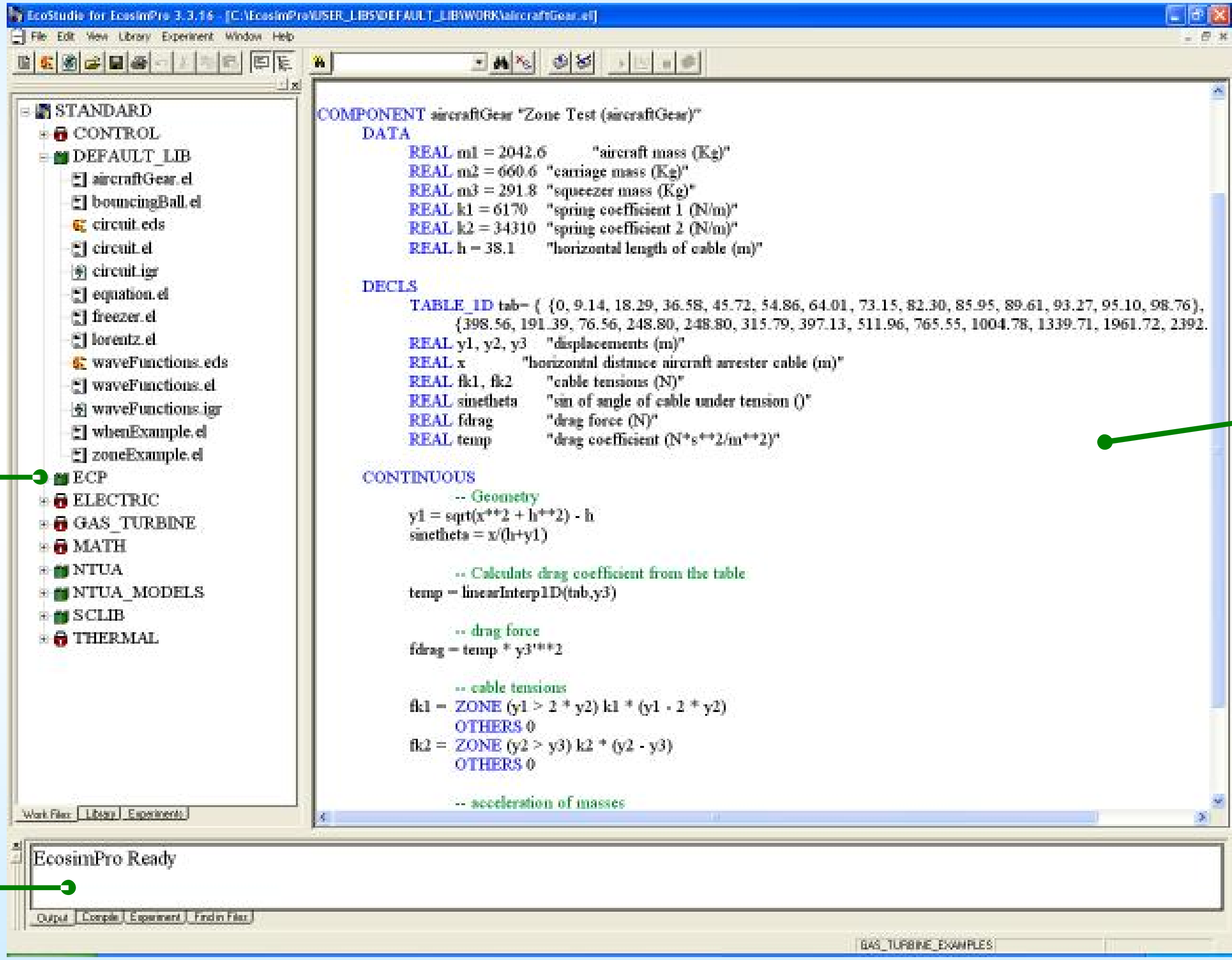
Reporting

Steady State Calculation

Integration

Main Window of Simulation Tool

Workspace Area

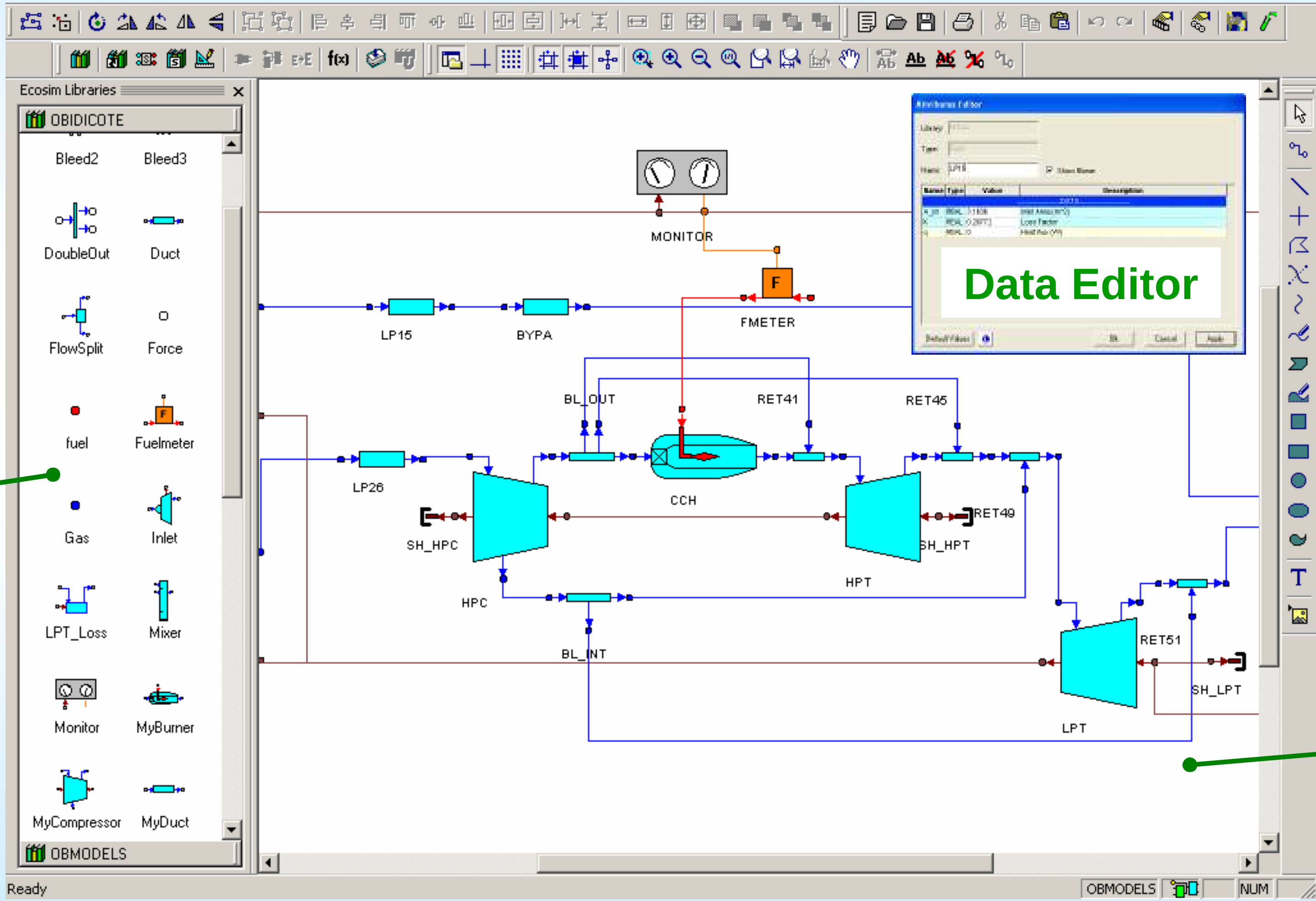


Editing Area

Output Area

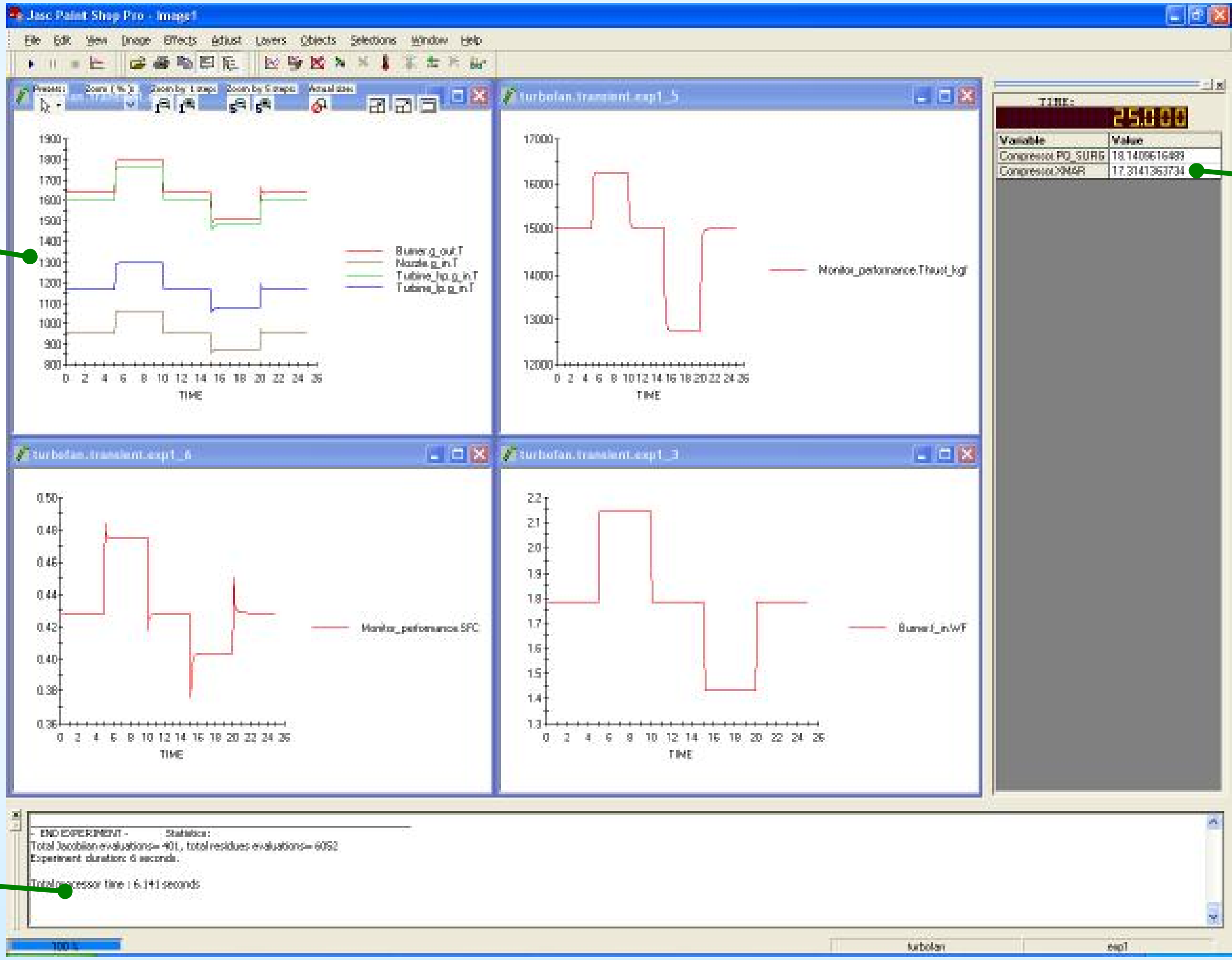
Graphical Component Creation

Symbol Libraries Palette



Edit Area

Graphical Output from Simulation



Plotting Area

Watch Variables Area

Output Area

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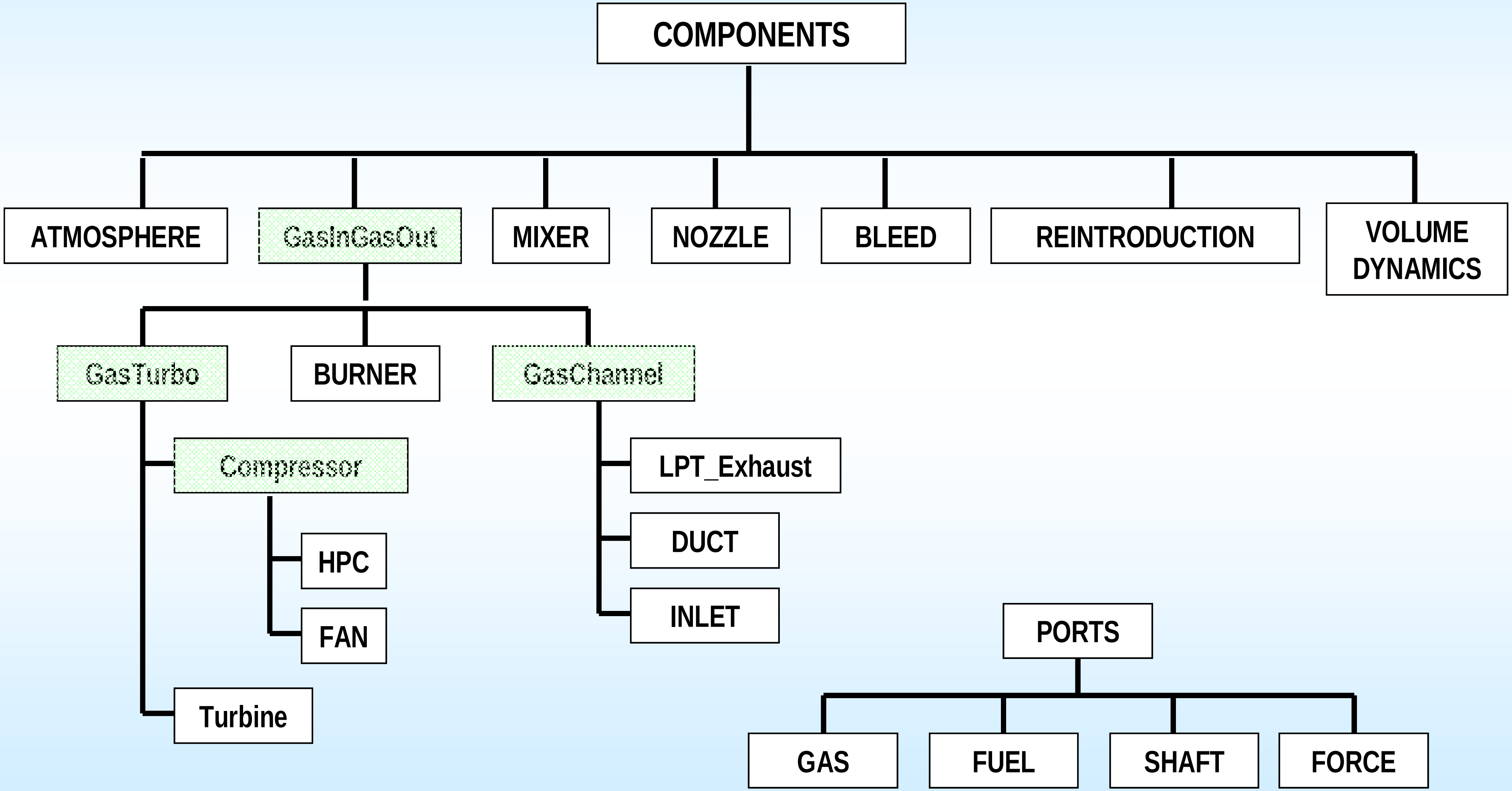
Modelling Methods: Component Hierarchy



Modelling Methods: Dynamic Modelling

$$\Delta PW = J * XN * \frac{dXN}{dt} * \left(\frac{2\pi}{60}\right)^2$$

Shaft Dynamics

$$h = 0.0201 * C * Re^{0.8} * K / L$$

$$c_p * M * \frac{dTm}{dt} = h * As * (Tg - Tm)$$

Heat Soakage

- HP compressor (blades and casing)
- Combustion (casing)
- HP turbine (blades and casing)

$$\frac{d\rho}{dt} = \frac{W_{in} - W_{out}}{Volume}$$

$$\frac{dw}{dt} = \frac{1}{L} * \left[(W * V + p * A)_{in} - (W * V + p * A)_{out} + F_{body}\right]$$

$$\frac{d}{dt}(\rho * H - p) = \frac{1}{Volume} * \left[(W * H)_{in} - (W * H)_{out} + PW + Q\right]$$

Gas Dynamics:

- Conservation of Mass
- Conservation of Momentum
- Conservation of Energy

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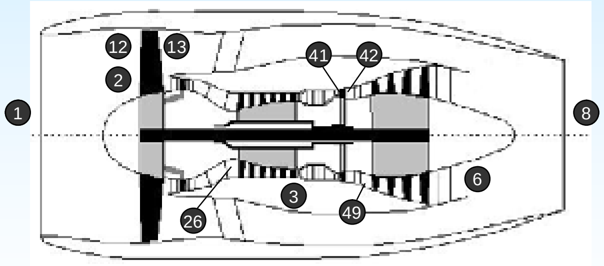
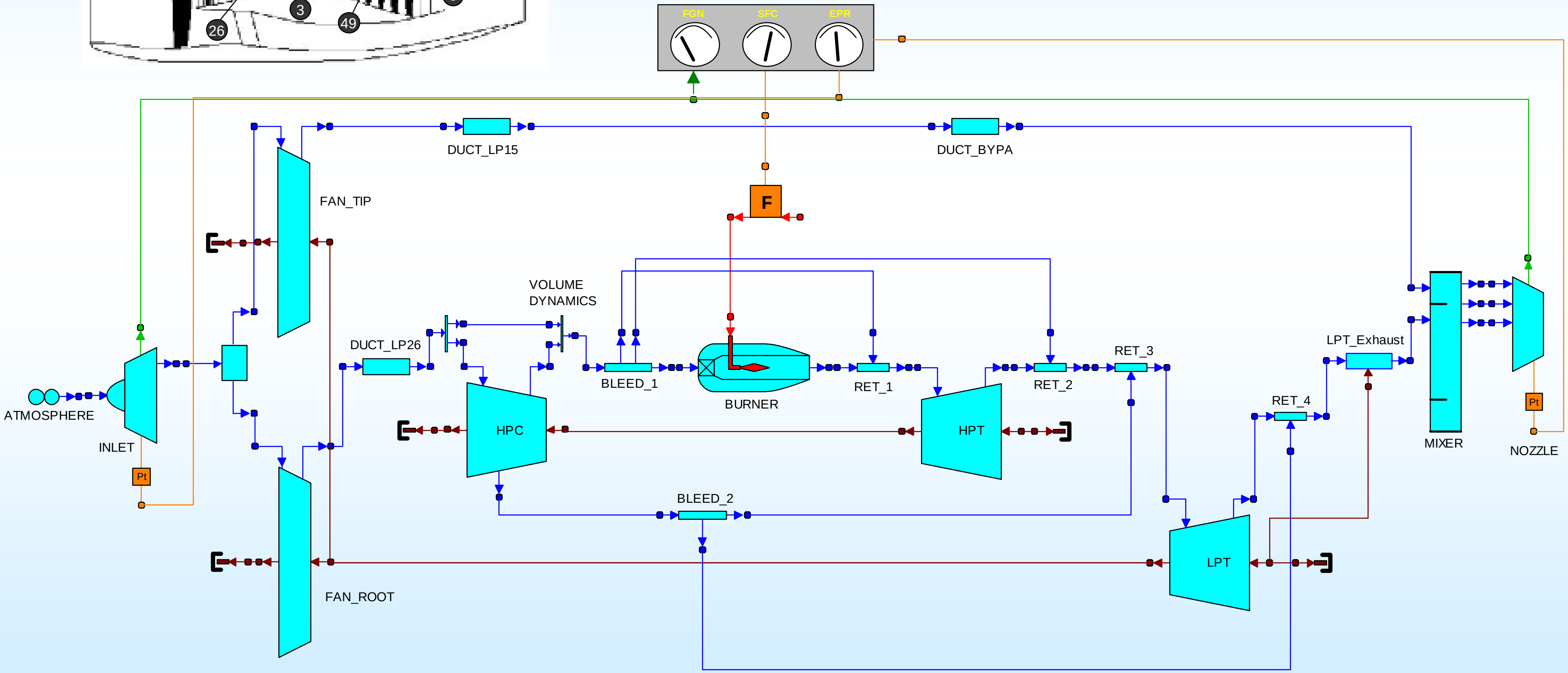
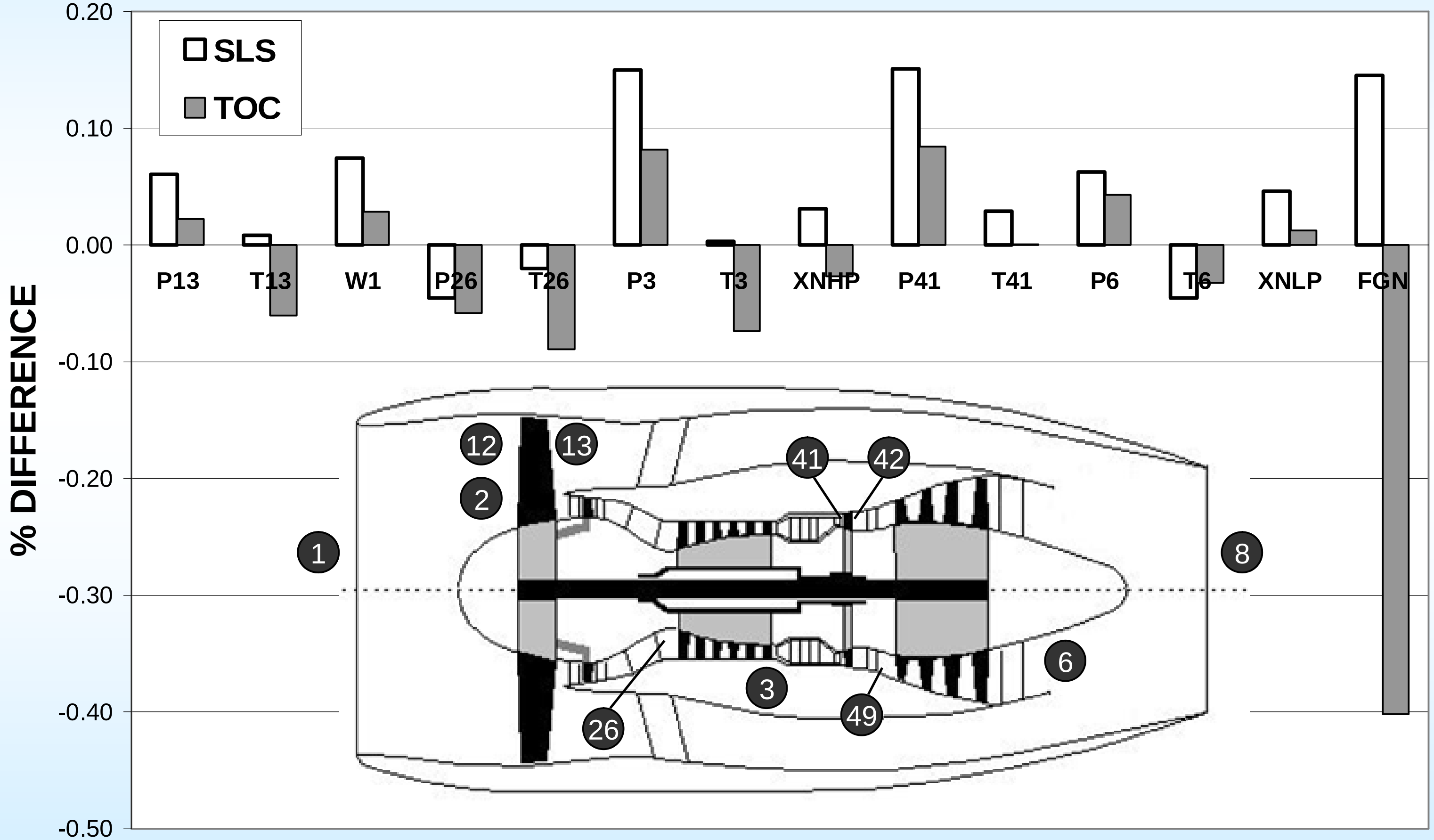
Specific Application Case: Turbofan Model

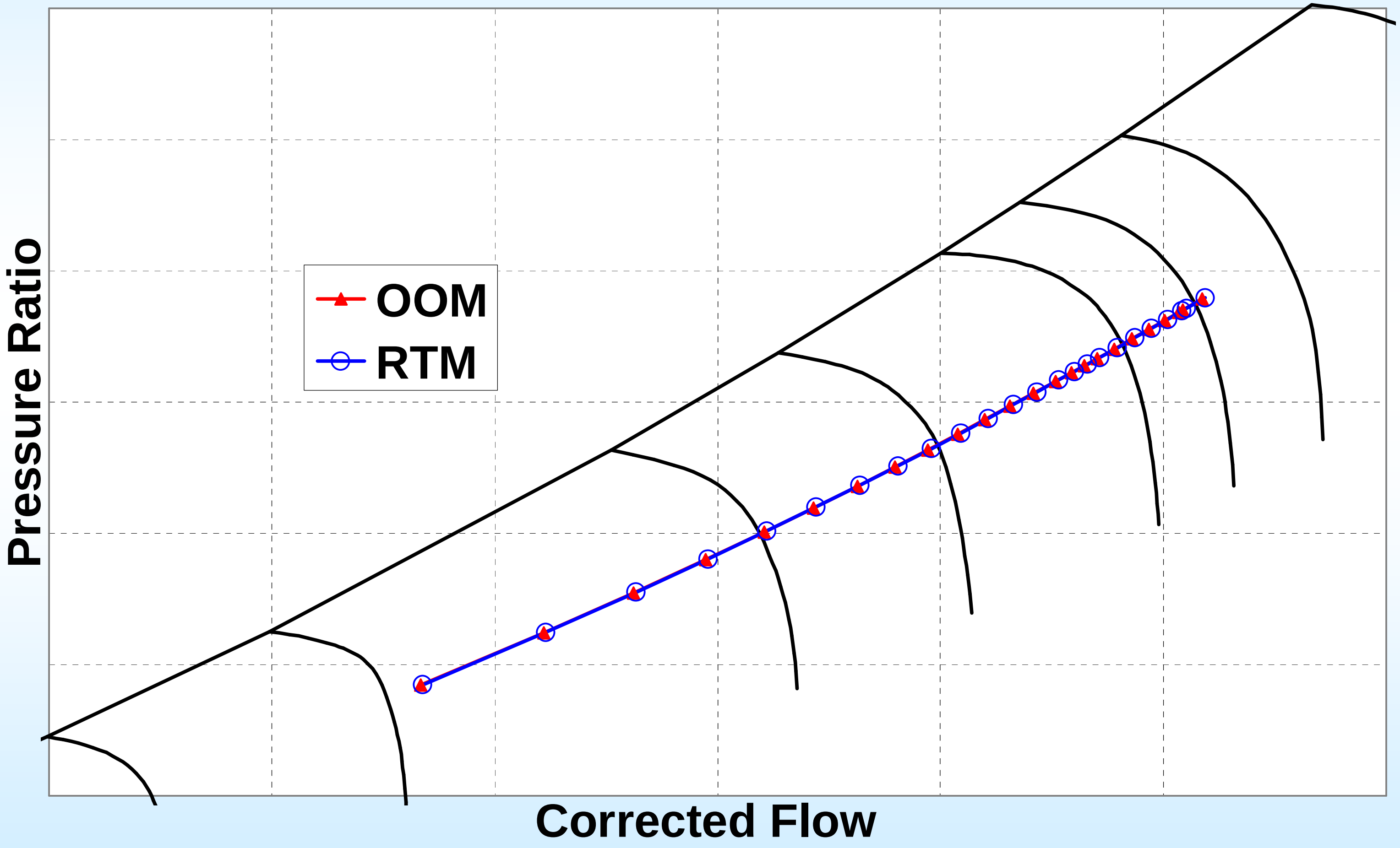




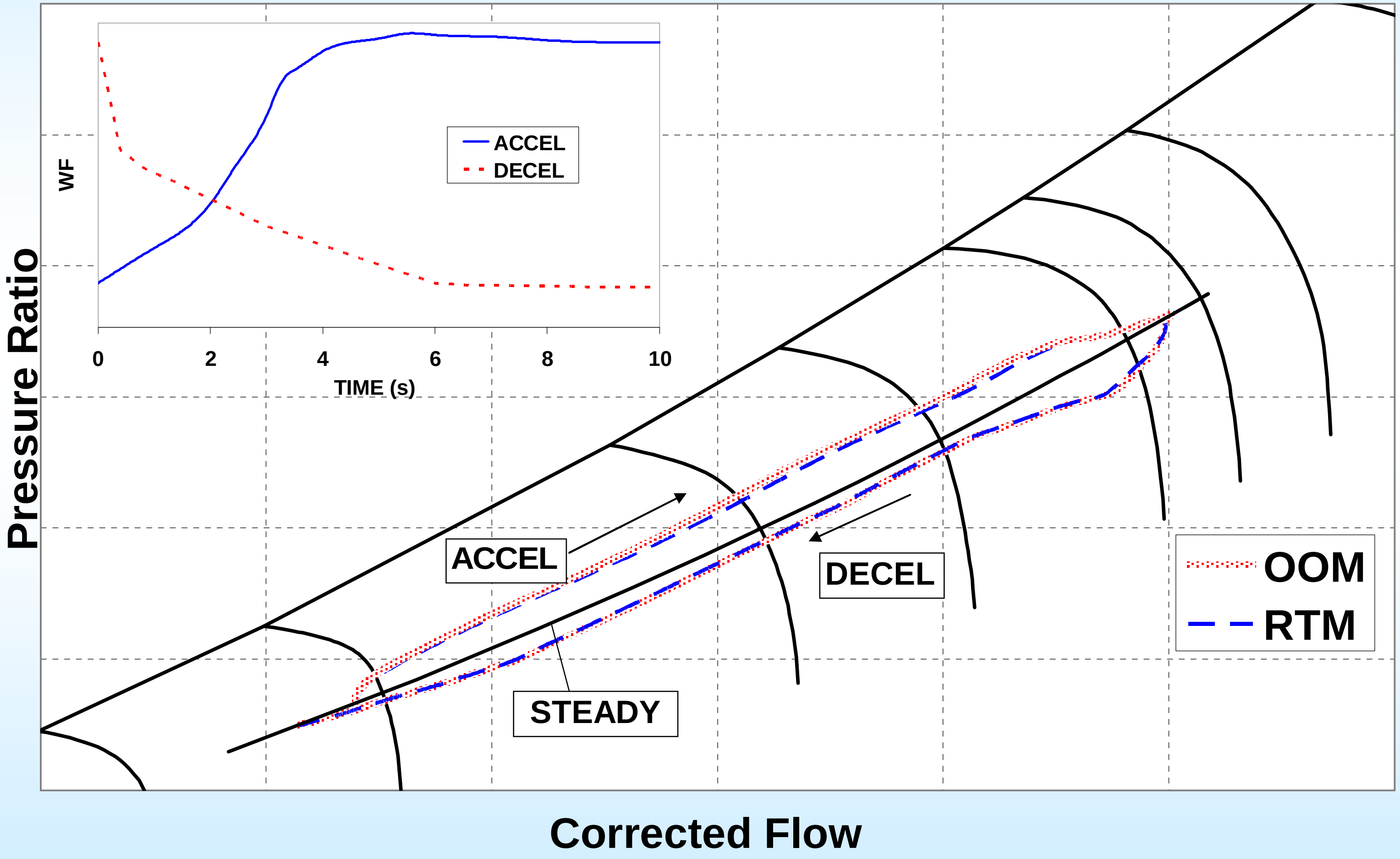
Model Comparison for SLS and TOC Cases



Model Comparison for Steady State Cases at SLS



Model Comparison for Transient Cases



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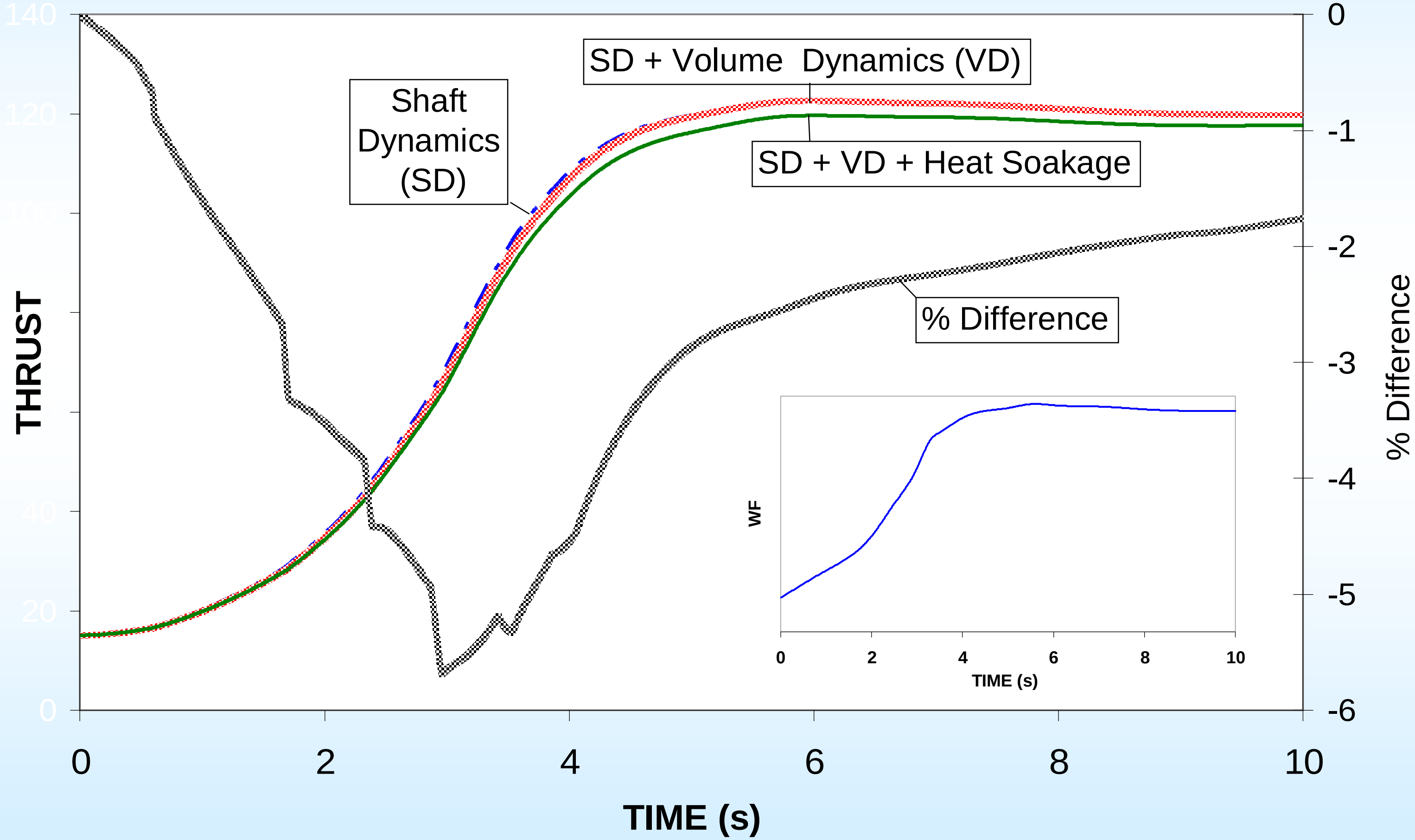
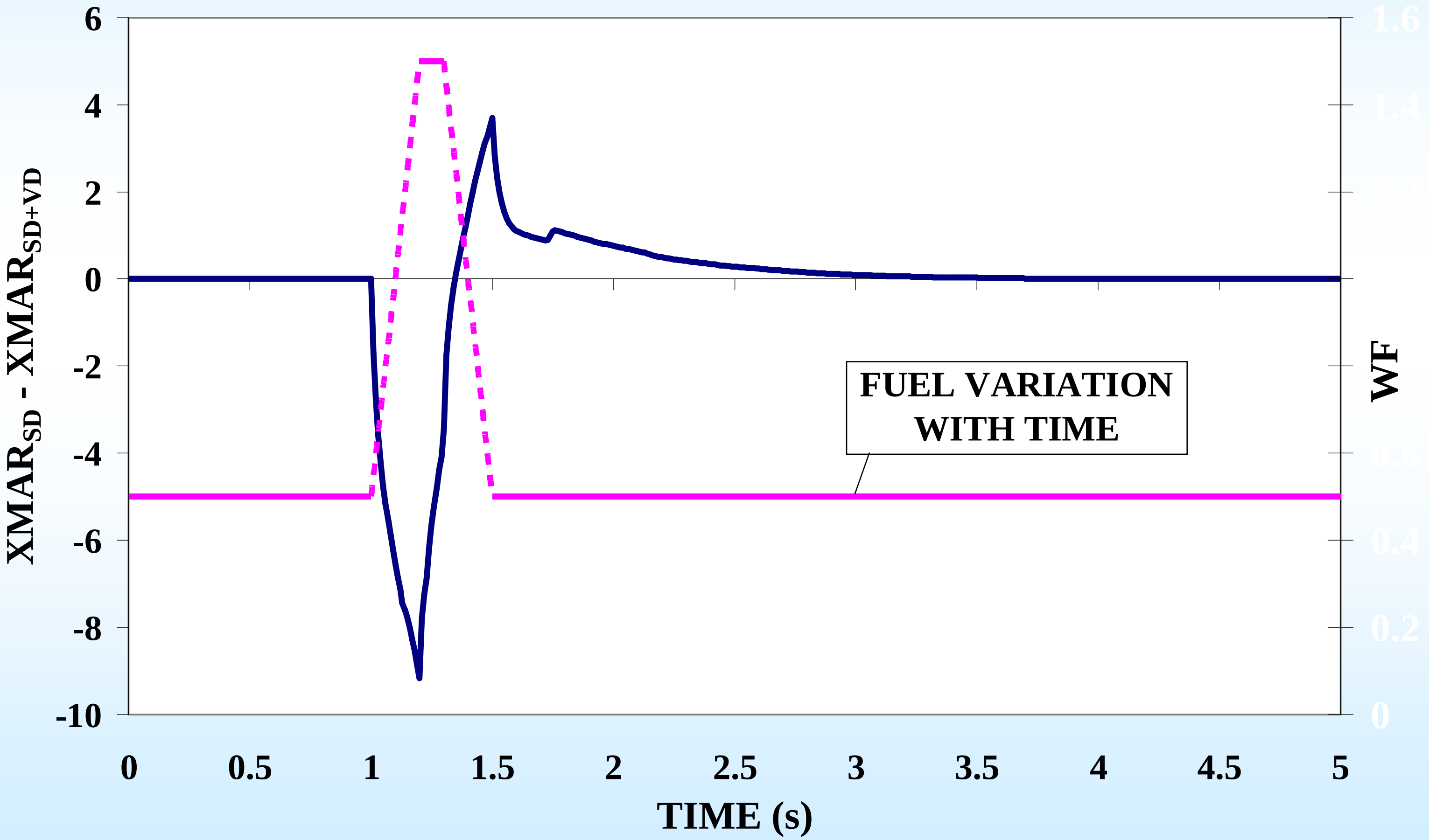
Engine Dynamics: Effect on Thrust



Gas Dynamics Effects on Compressor Surge Margin during a Fuel Spike



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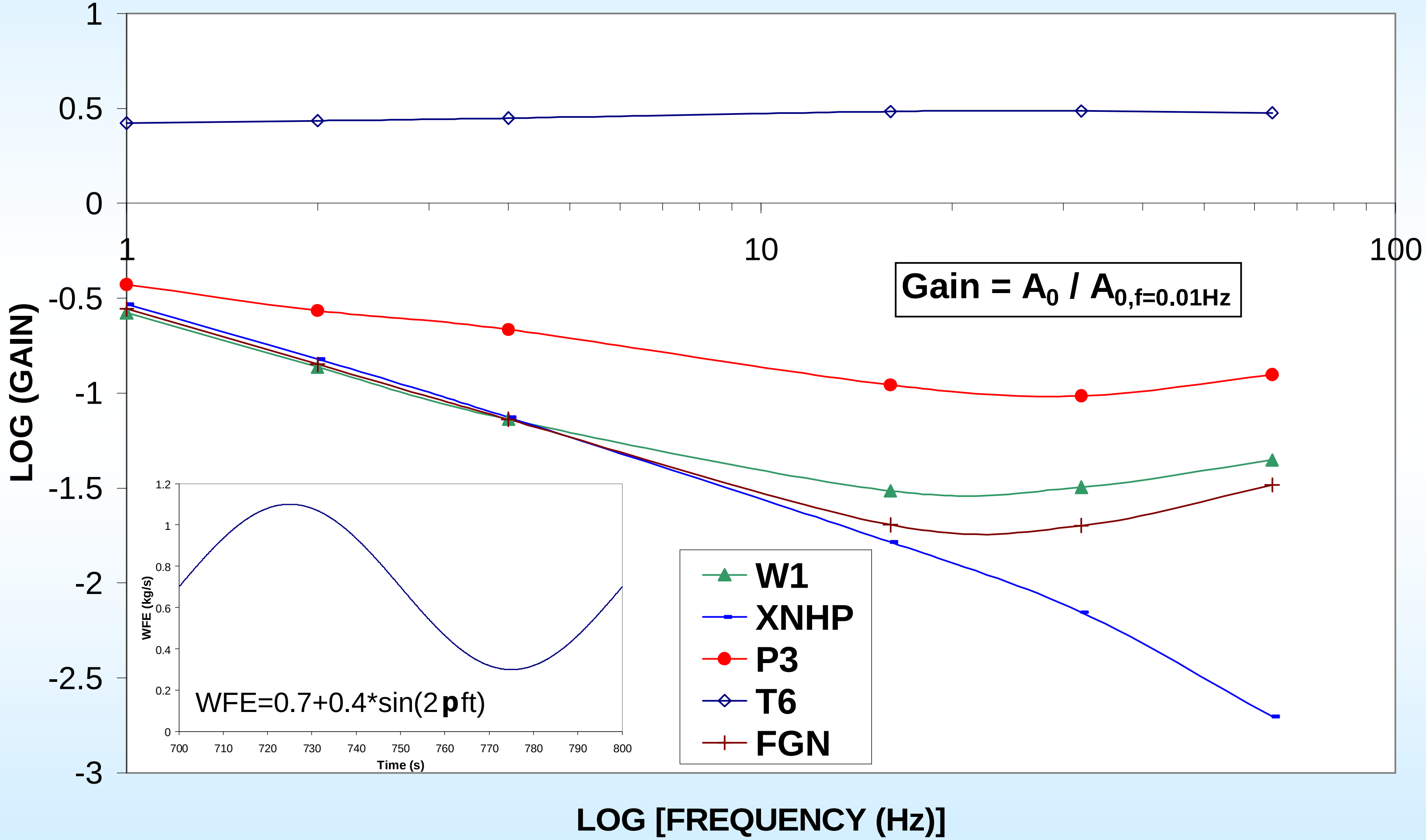
Gain Variation with Frequency for Sinusoidal Fuel Input



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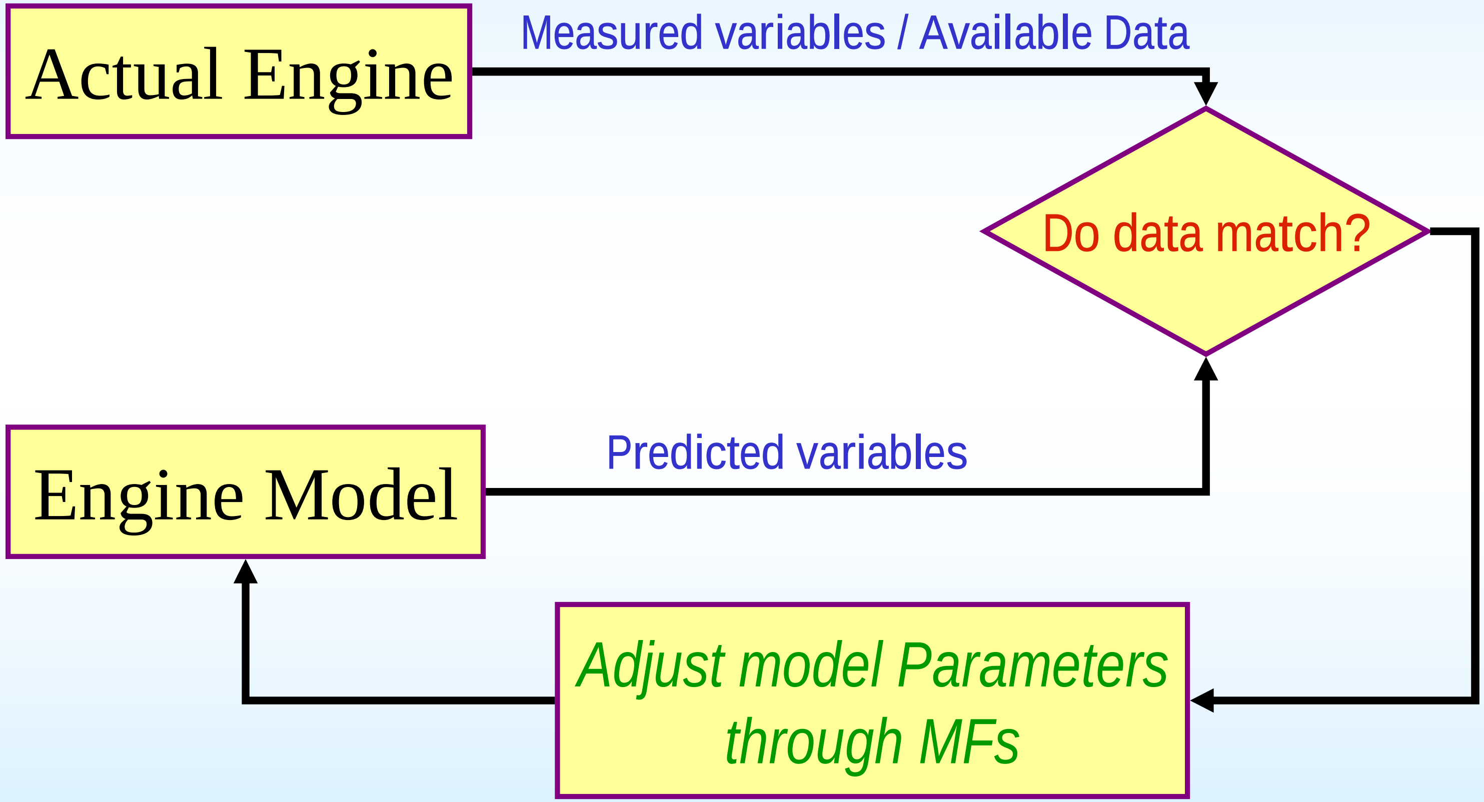
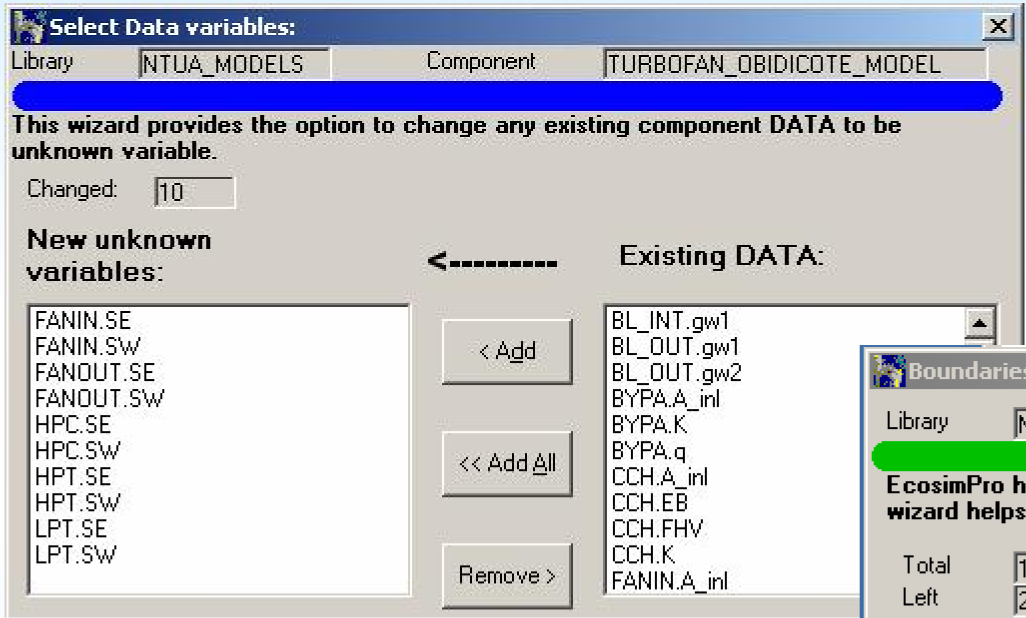
Adaptive Performance Modeling: Principle

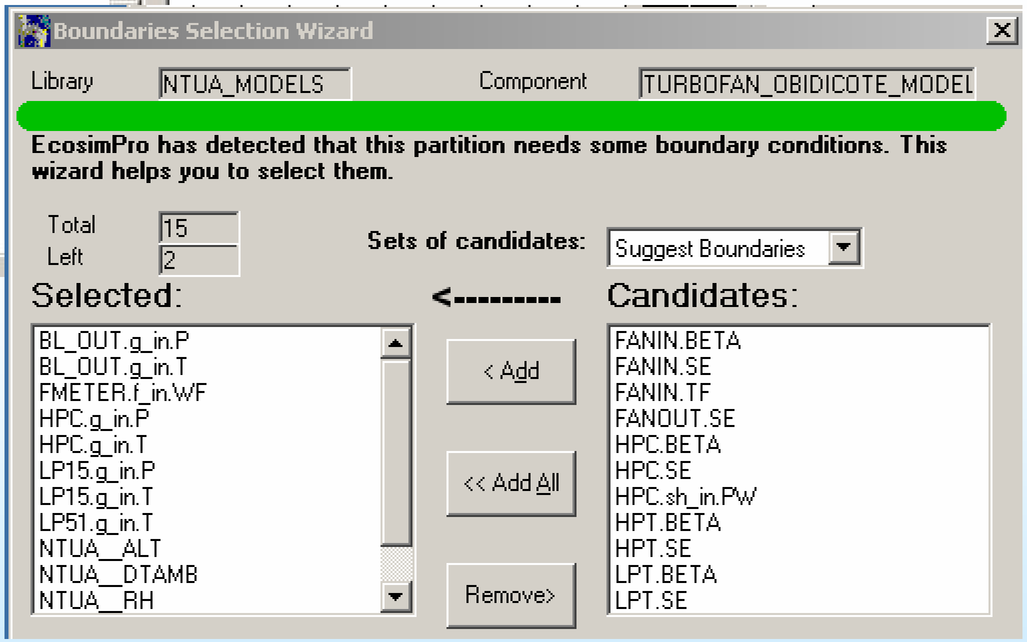


Adaptation to Test Data: Implementation in OOP

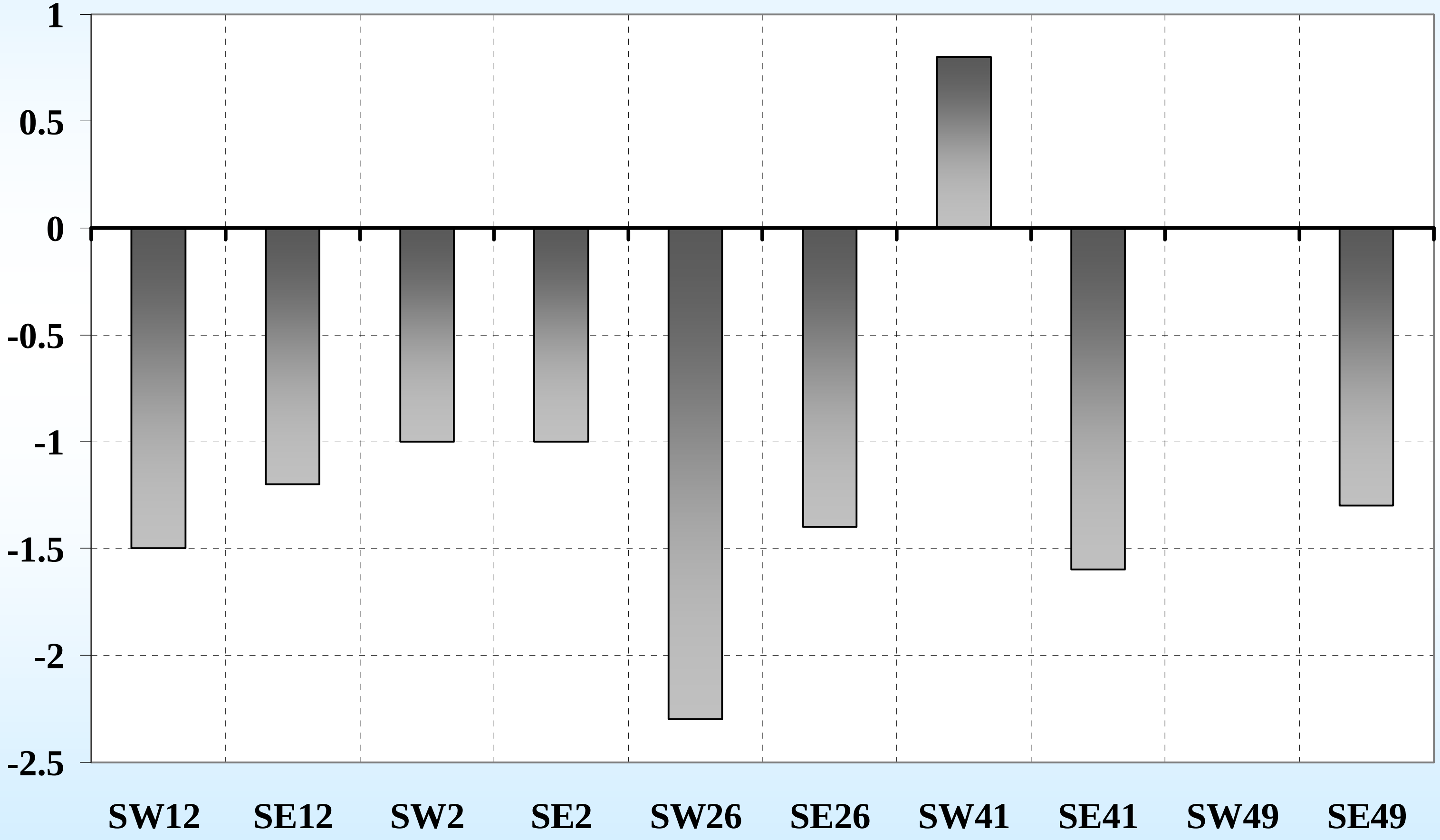


Specifying Adaptation Factors

Specifying Measured Quantities



Sample Results: *Estimated Values of Adaptation Factors from Measurements Simulating a Deteriorated Engine*



Conclusions

- **An Object-Oriented simulation environment was used to create a re-usable library of gas turbine components**
- **A model of a typical civil two-spool turbofan engine was developed by connecting the appropriate components from the library through an advanced graphical user interface**
- **Both steady state and transient simulation results agreed well with those produced by an industry-accepted model**
- **The ease of incorporating dynamic effects into the model and implementing adaptation factors (for matching a model to given measurements) was demonstrated**
- **The approach presented allows for quick implementation of new models and rapid analysis of results**