Gas Turbine Engine Performance Model Applications using an Object-Oriented Simulation Tool

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Paper Objectives

Demonstrate the use and advantages of general purpose object-oriented simulation environments for the following applications:

1. **Build an engine model from existing engine components and run steady state and transient calculations**
2. **Develop and integrate new components in existing engine models**
3. **Access an engine model from external applications**
4. **Use external routines (FORTRAN, C, CPP) in simulations**

Presentation Contents

- **Building & Running an Engine Model**
- **Developing &Using a New Component**
  - **Component Syntax**
  - **The Cooled Turbine Component**
- **Accessing a Model from an External Application**
- **Using External Code in an Engine Model**
- **Conclusions**

Simulation Environment

The commercial simulation environment presented in ASME GT-2005-68678 is used to implement the applications described in this paper.

The tool uses a high-level object-oriented language (EL) for modeling physical systems.

The most important concept in EL is the component which contains a mathematical description of the corresponding real-world component.

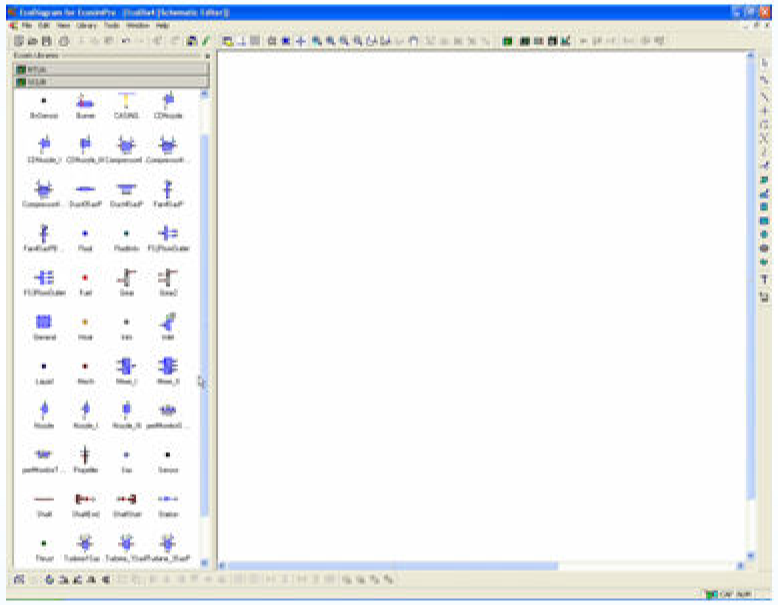
Components are joined together through their ports. Ports define the set of variables to be interchanged between components.

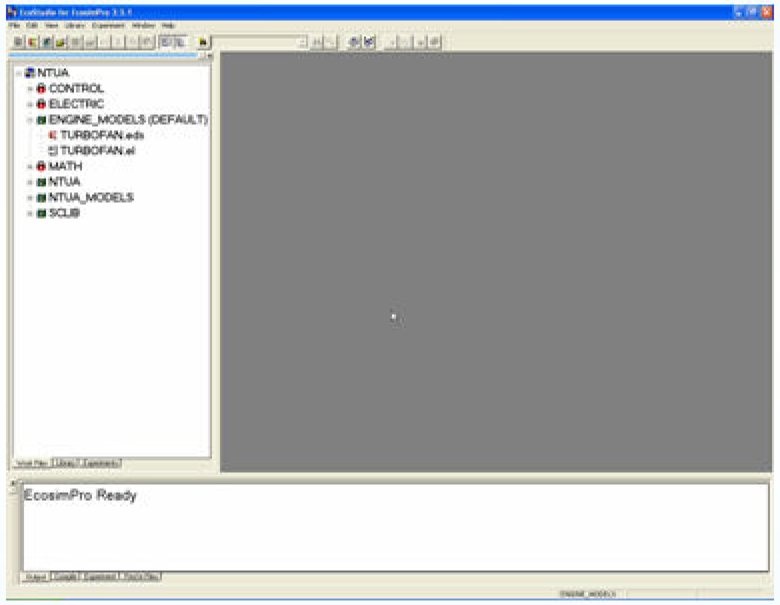
Components & ports are stored in a library.

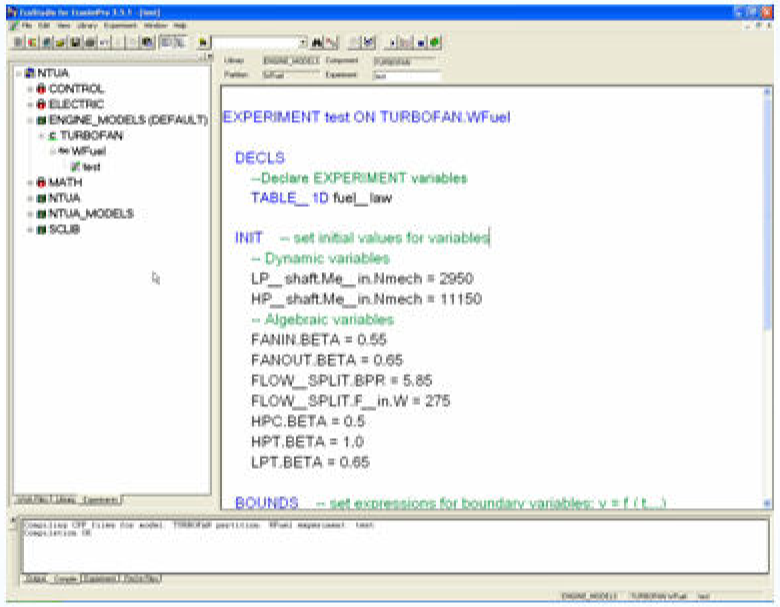
For the purpose of this paper, it is assumed that such a library of basic gas turbine components & ports is available.

Building & Running an Engine Model

Develop & run an engine model in just 3 steps







Step1
Build an engine model graphically

Step 2
Define Partition & Experiment

Step 3
Run simulation & view results

Component Syntax (I)

ABSTRACT COMPONENT absCompressor IS_A gasTurbo

Does NOT represent a physical component and cannot be instantiated.
Defines interface & methods that can be shared by multiple Components

Component Syntax (I)

ABSTRACT COMPONENT absCompressor IS_A gasTurbo

Declares inheritance

Component Syntax (I)

```
ABSTRACT COMPONENT absCompressor IS_A gasTurbo
  PORTS
        IN Fluid F_in
  DATA
        REAL inertia = 0
```

Public Part

Component Syntax (I)

```
ABSTRACT COMPONENT absCompressor IS_A gasTurbo
  PORTS
        IN Fluid F_in
  DATA
        REAL inertia = 0
```

Define direction, type & name of Port

Component Syntax (I)

```
ABSTRACT COMPONENT absCompressor IS_A gasTurbo
  PORTS
        IN Fluid F_in
  DATA
        REAL inertia = 0
```

Define data type & name. Specify default value

Component Syntax (I)

ABSTRACT COMPONENT absCompressor IS_A gasTurbo

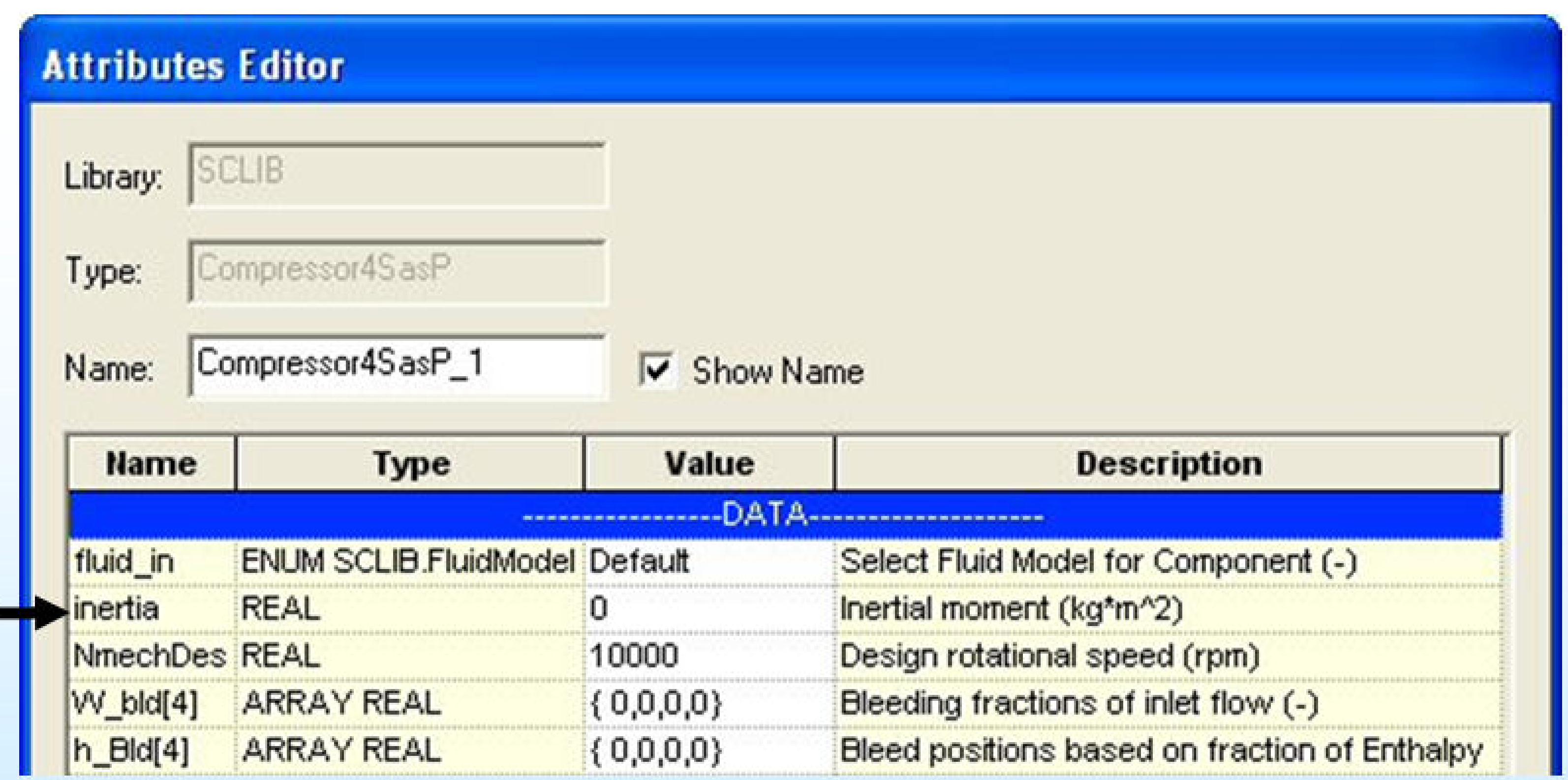
PORTS

IN Fluid F_in

DATA

REAL inertia = 0

This appears & can be edited in the Attributes Editor window



Component Syntax (I)

```
ABSTRACT COMPONENT absCompressor IS_A gasTurbo
  PORTS
        IN Fluid F_in
  DATA
        REAL inertia = 0
  DECLS
        REAL Nc
```

Define local component variables (private)

Component Syntax (I)

```
ABSTRACT COMPONENT absCompressor IS_A gasTurbo
  PORTS
        IN Fluid F_in
  DATA
        REAL inertia = 0
  DECLS
        REAL Nc
  TOPOLOGY
        PATH F_in TO F_out
```

Define sub-components & connection paths

Component Syntax (I)

```
ABSTRACT COMPONENT absCompressor IS_A gasTurbo
  PORTS
        IN Fluid F_in
  DATA
        REAL inertia = 0
  DECLS
        REAL Nc
  TOPOLOGY
        PATH F_in TO F_out
  INIT
        readCompressorMap(WcTab, effTab,PRtab, SMtab)
```

Assign initial values to component variables

Component Syntax (II)

DISCRETE

**ASSERT (SMpct > 5) WARNING "Compressor **
working beyond Surge Line"

Describe the conditions & effects of discrete events

Component Syntax (II)

DISCRETE

**ASSERT (SMpct > 5) WARNING "Compressor \
working beyond Surge Line"**

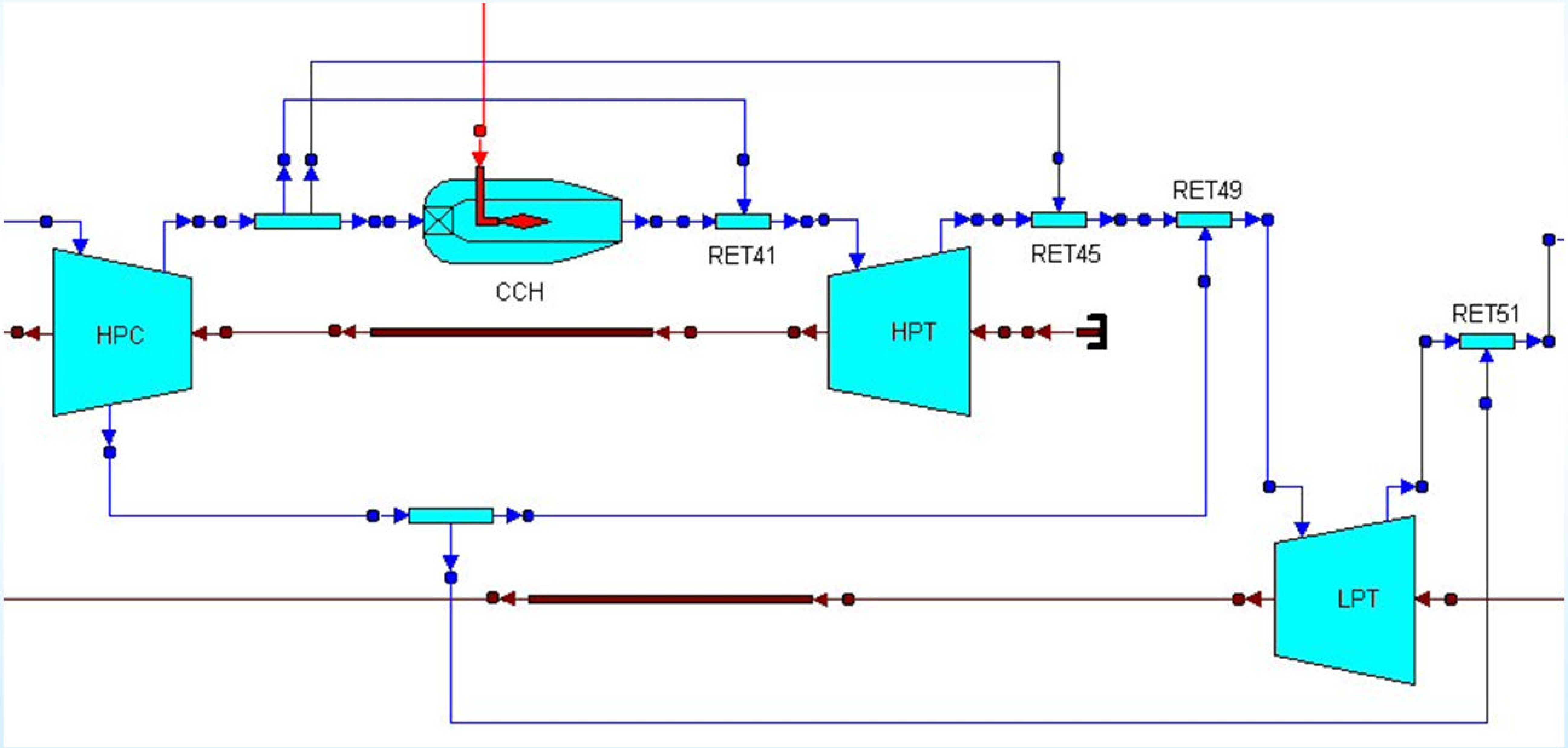
CONTINUOUS

```
--Shaft Dynamics
Dpwr = inertia * (PI/30)**2 * Nmech * Nmech'
--Compressor Power
pwr = - (F_in.W * (ht_out – ht_in)
```

Write differential-algebraic equations describing component's continuous behaviour

Developing & Using a New Turbine Component (I)

Turbine model ‘inherited’ from original FORTRAN code

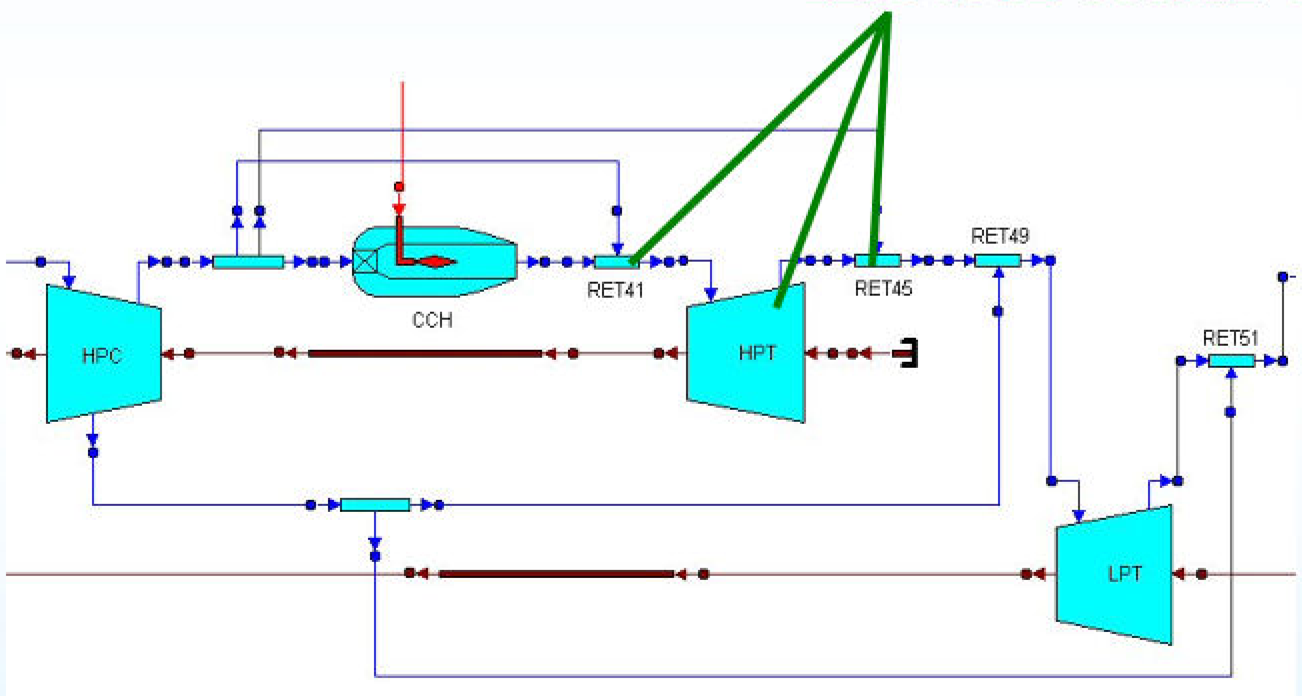


Developing & Using a New Turbine Component (I)

Turbine model 'inherited' from original FORTRAN code

Drawbacks

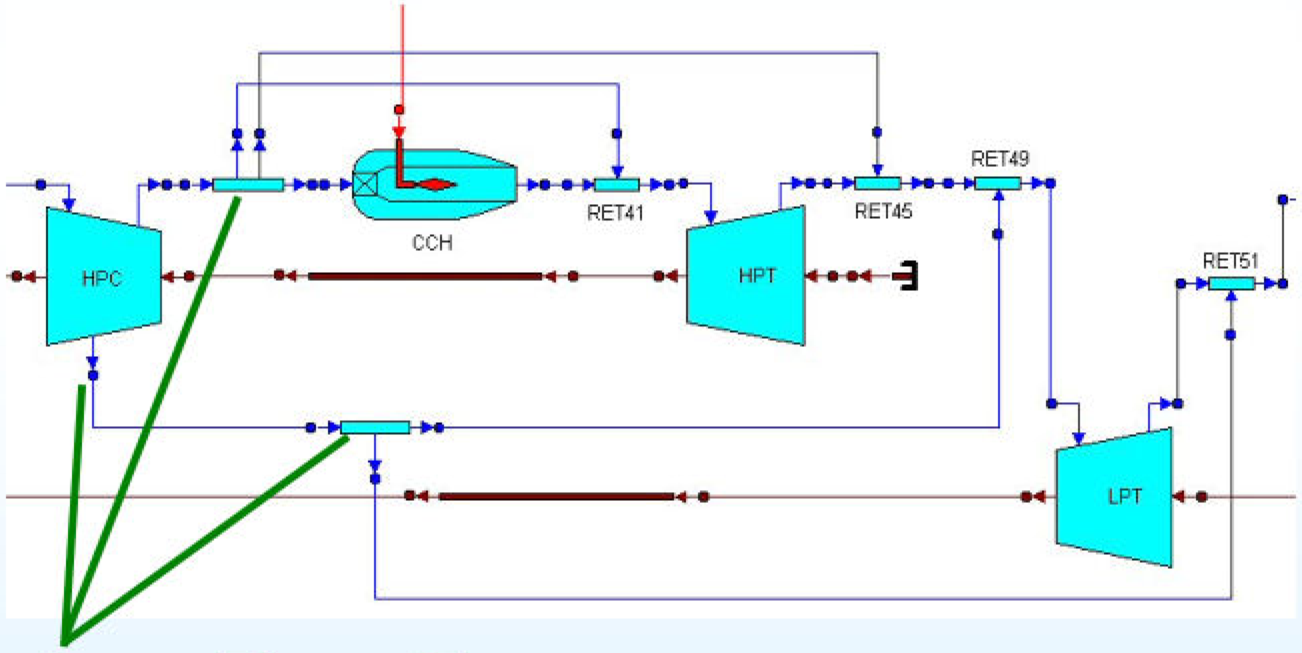
3 components are used to model each cooled turbine



Developing & Using a New Turbine Component (I)

Turbine model 'inherited' from original FORTRAN code

Drawbacks



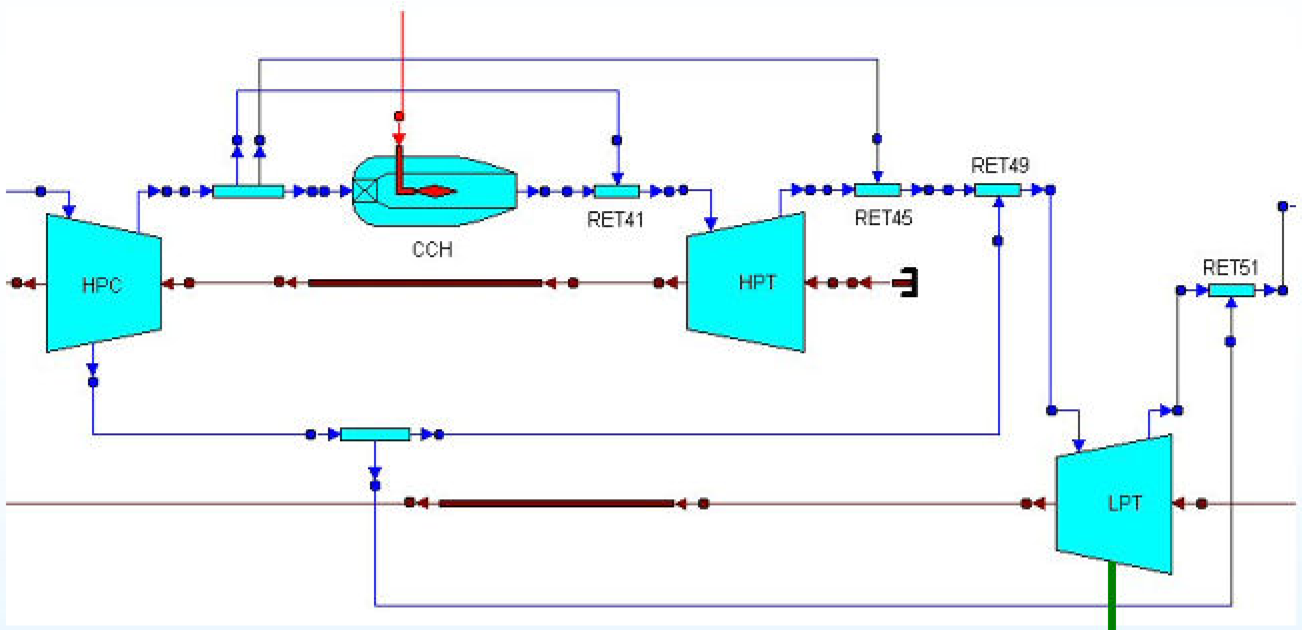
Work potential of cooling flows
defined at bleed location

1 bleed port /return component

Developing & Using a New Turbine Component (I)

Turbine model 'inherited' from original FORTRAN code

Drawbacks



Can NOT calculate SOT or Thermodynamic efficiency

Developing & Using a New Turbine Component (II)

Create new component by modifying existing one

```
PORTS
  IN Sas SasP[nSasP] "Secondary Air System Flows“

DATA
  ENUM switchEffType effType = EqSS
         "Select efficiency type definition (-)“
  REAL Wtw_q_Wc[1] = {0}
         "Fraction of each Sas flow doing work in the equivalent turbine rotor (-)"
  REAL WNGV_q_Wc[1] = {0}
         "Fraction of each Sas flow used for NGV cooling (-)"
  REAL Wpump_q_Wc[1] = {0}
         "Fraction of each Sas flow pumped up through rotor blades (-)"
  REAL Rdia[1] = {0.6}
         "Rotor Mean Blade Diameter used in Pumping Power Calculation (m)"
```

Developing & Using a New Turbine Component (II)

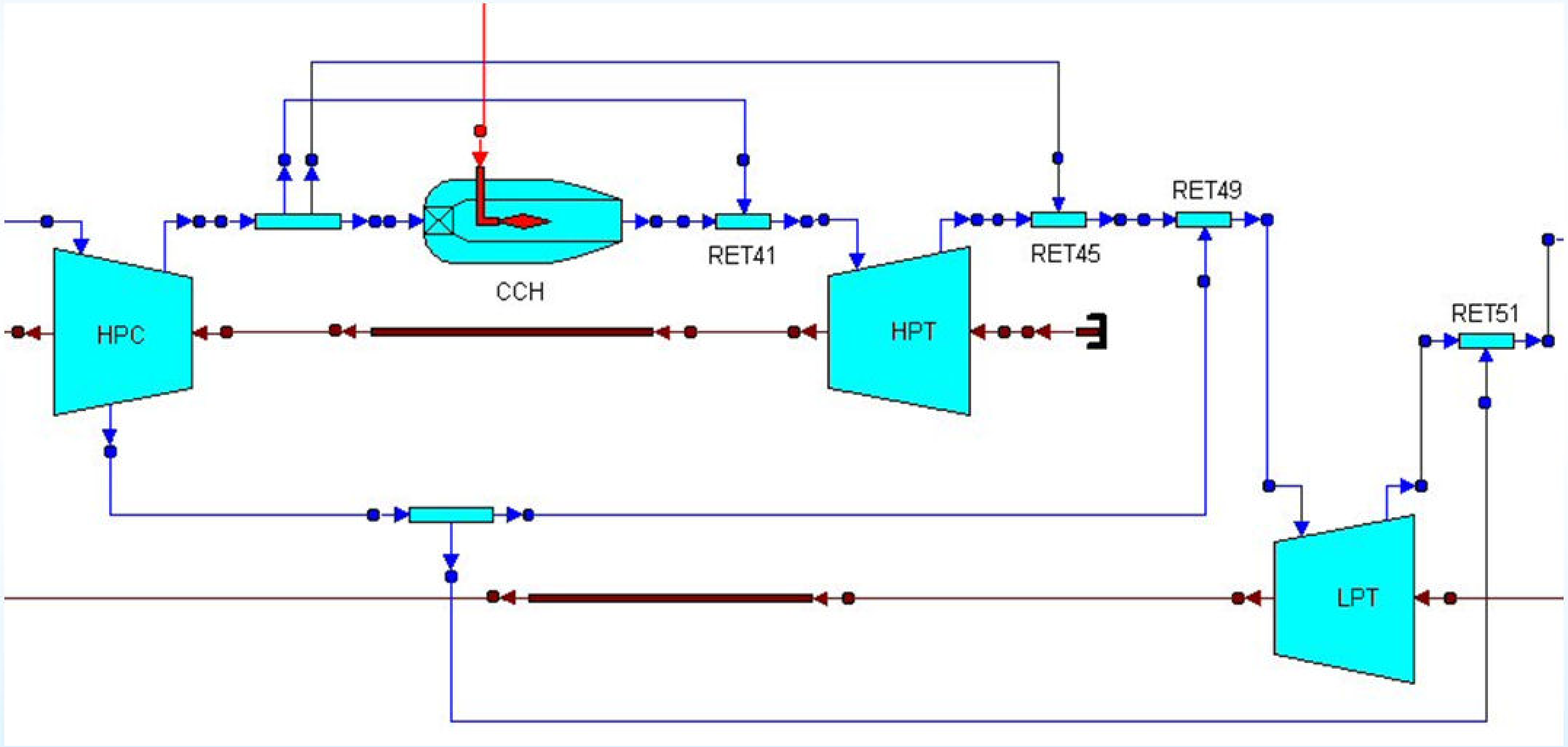
Create new component by modifying existing one

In CONTINUOUS calculate:

- **the stator exit conditions from mixing the inlet main flow and the NGV cooling flows**
- **the equivalent rotor inlet conditions from mixing the main inlet flow with the appropriate fraction of each cooling flow according to its work potential**
- **the power required to pump the rotor blade cooling flow according to the rotor mean blade diameter and the rotor blade cooling mass flows**
- **the turbine power and exit flow conditions according to the user selected efficiency definition**
- **the other efficiency definition**

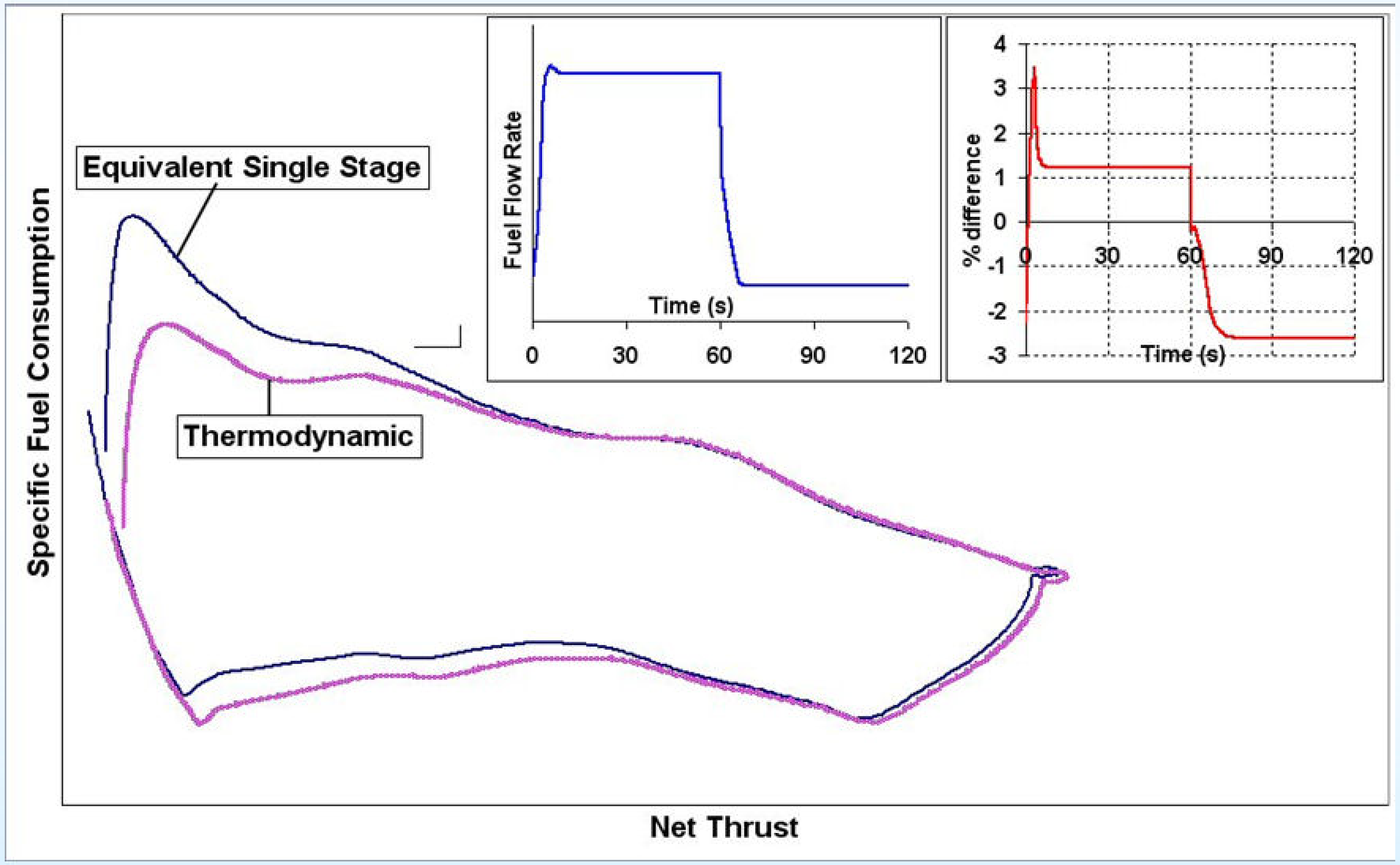
Developing & Using a New Turbine Component (II)

Create new component by modifying existing one

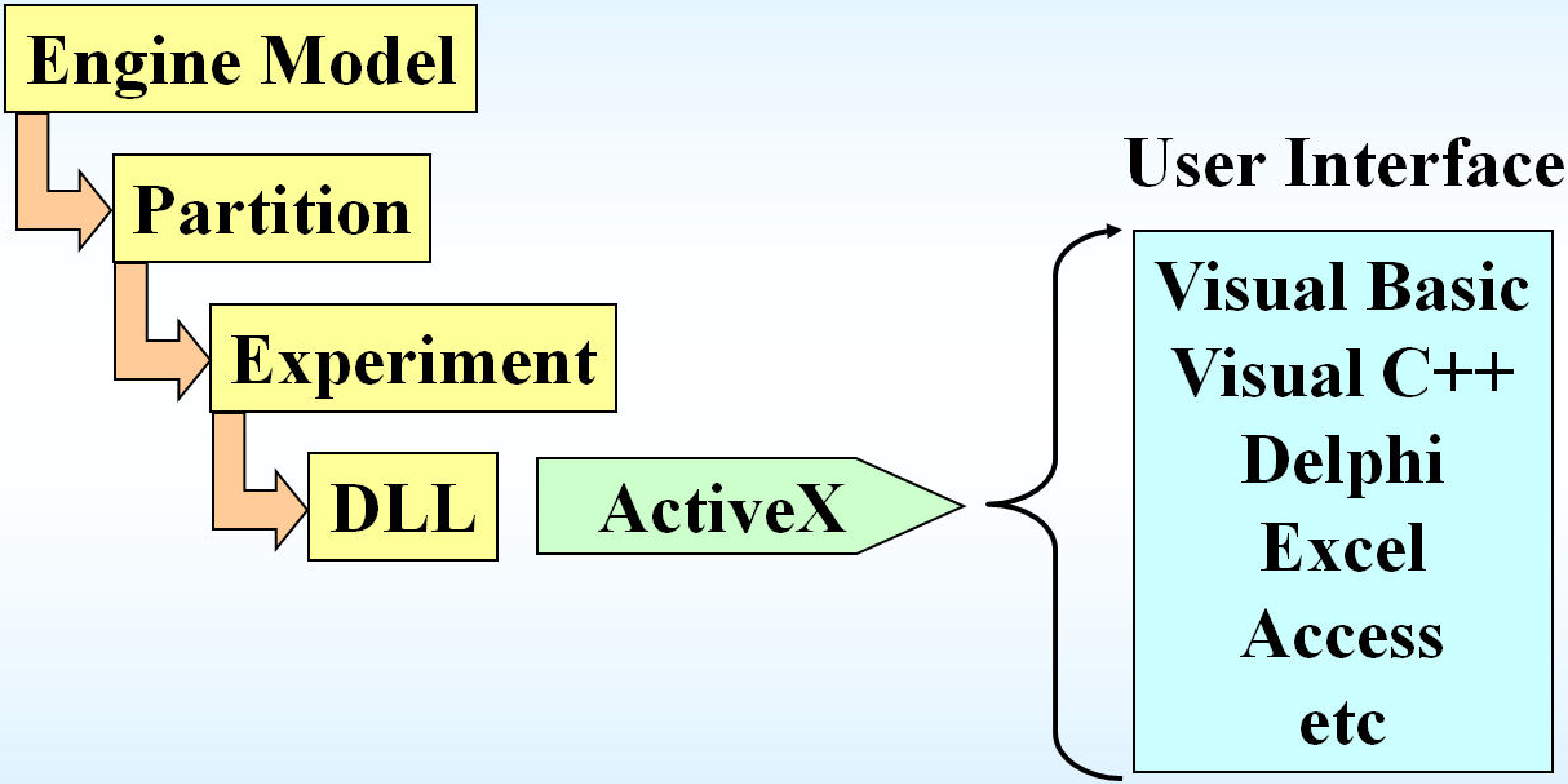


Developing & Using a New Turbine Component (II)

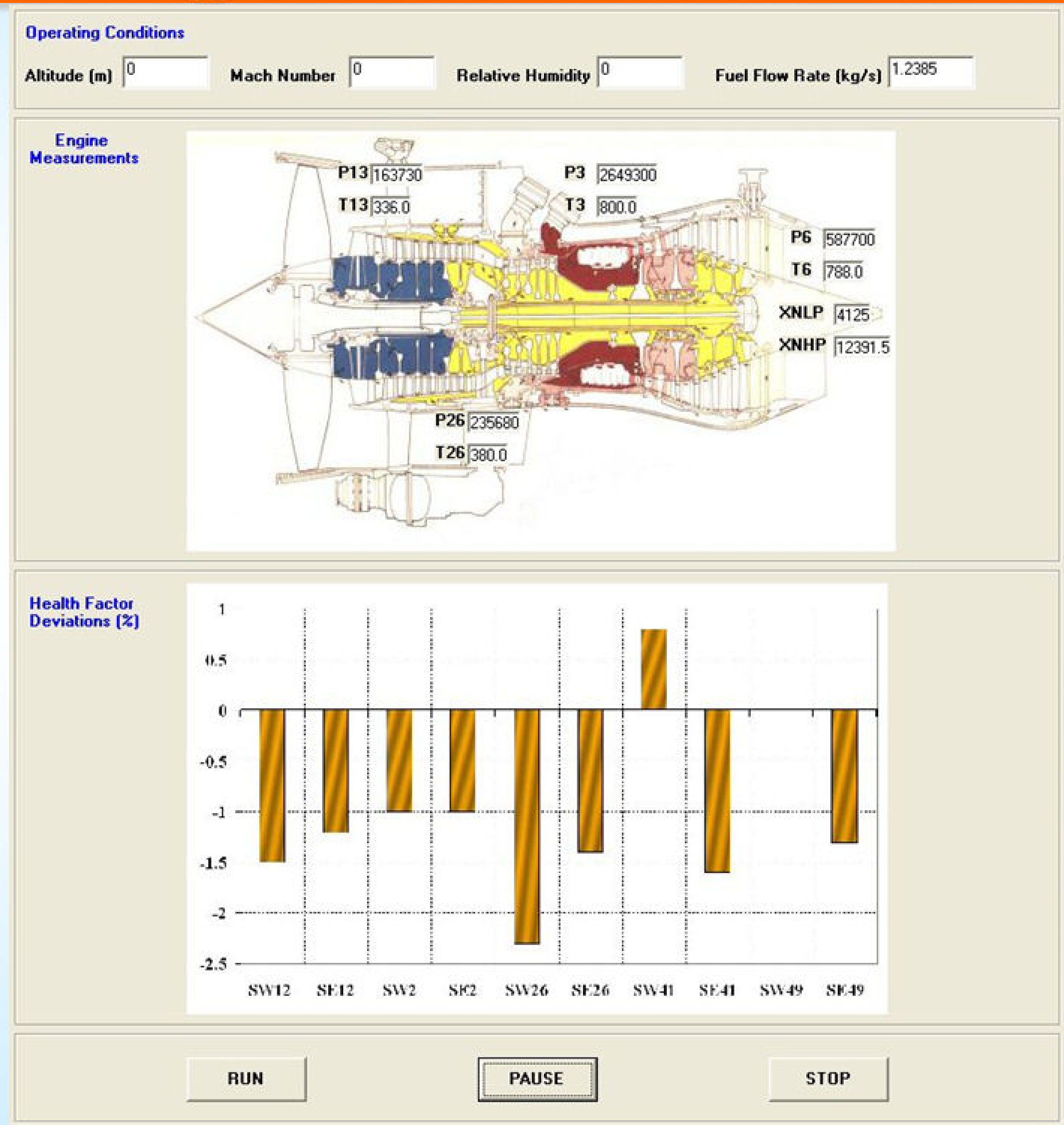
Cooled Turbine Isentropic Efficiency Definition Effect on Performance Parameters



Accessing a Model from an External Application (I)



Accessing a Model from an External Application (II)



Visual Basic GUI for engine condition monitoring

Accessing a Model from an External Application (III)

MS Excel toolbar

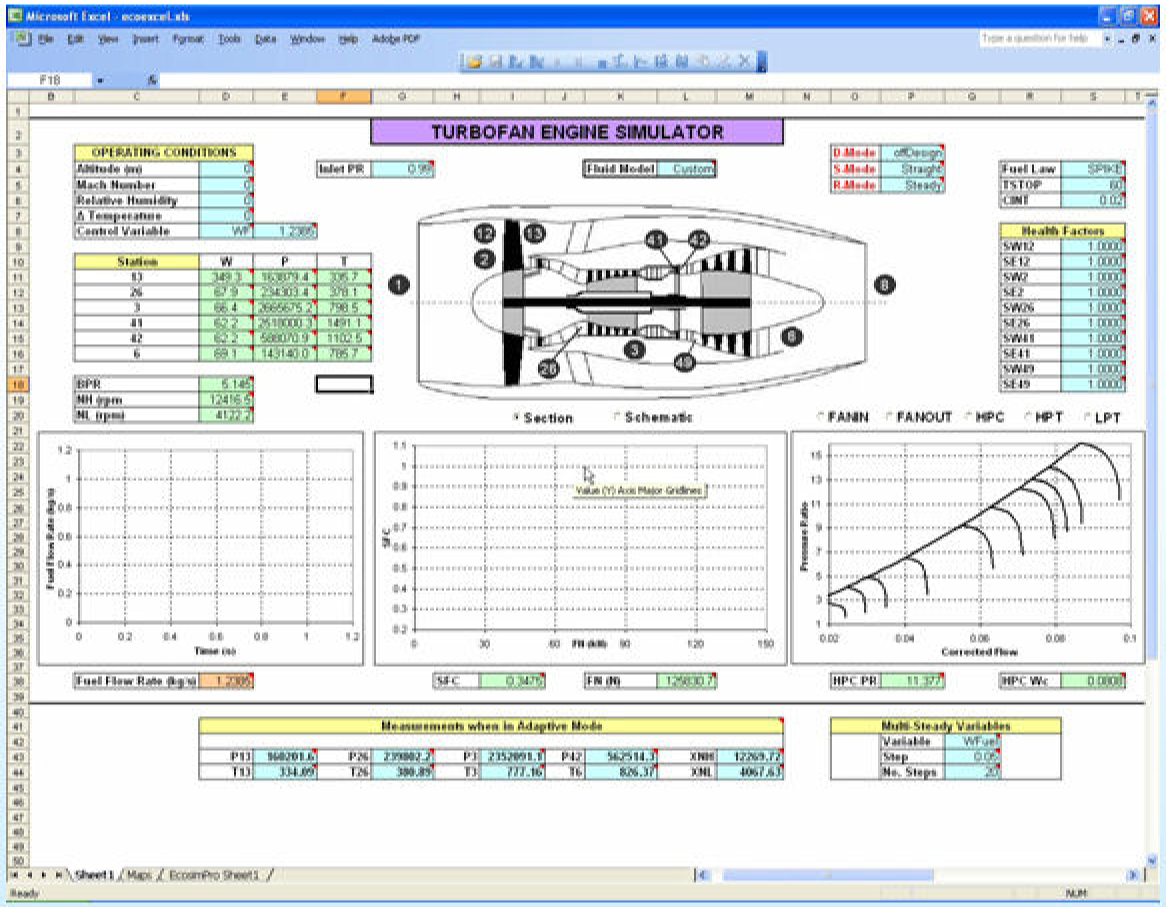
Open Experiment

Accessing a Model from an External Application (III)

MS Excel toolbar

MS Excel sheet for turbofan engine calculations

- Design / off design
- Straight / Adaptive
- Steady / Multi-steady / Transient



Using External Code in an Engine Model (I)

To use existing FORTRAN, C or C++ code

1. Declare Interface

```
"FORTRAN" FUNCTION NO_TYPE NewtonRaphson
        (
        FUNC_PTR funct,         -- Function Pointer
        IN INTEGER n,           -- Number of Independent Variables
        IN INTEGER itermax,-- Max No of Iterations
        IN REAL tol,            -- Required Tolerance
        IN REAL eps,            -- Machine EPS
        OUT REAL x[],           -- Array of Independent Variables
        OUT INTEGER ierror-- Flag
        )
```

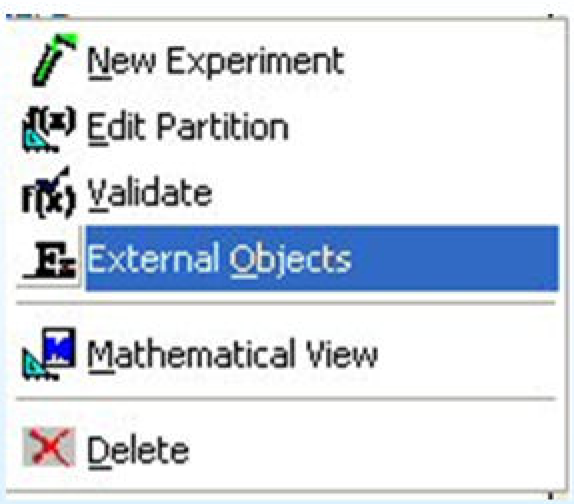
Using External Code in an Engine Model (I)

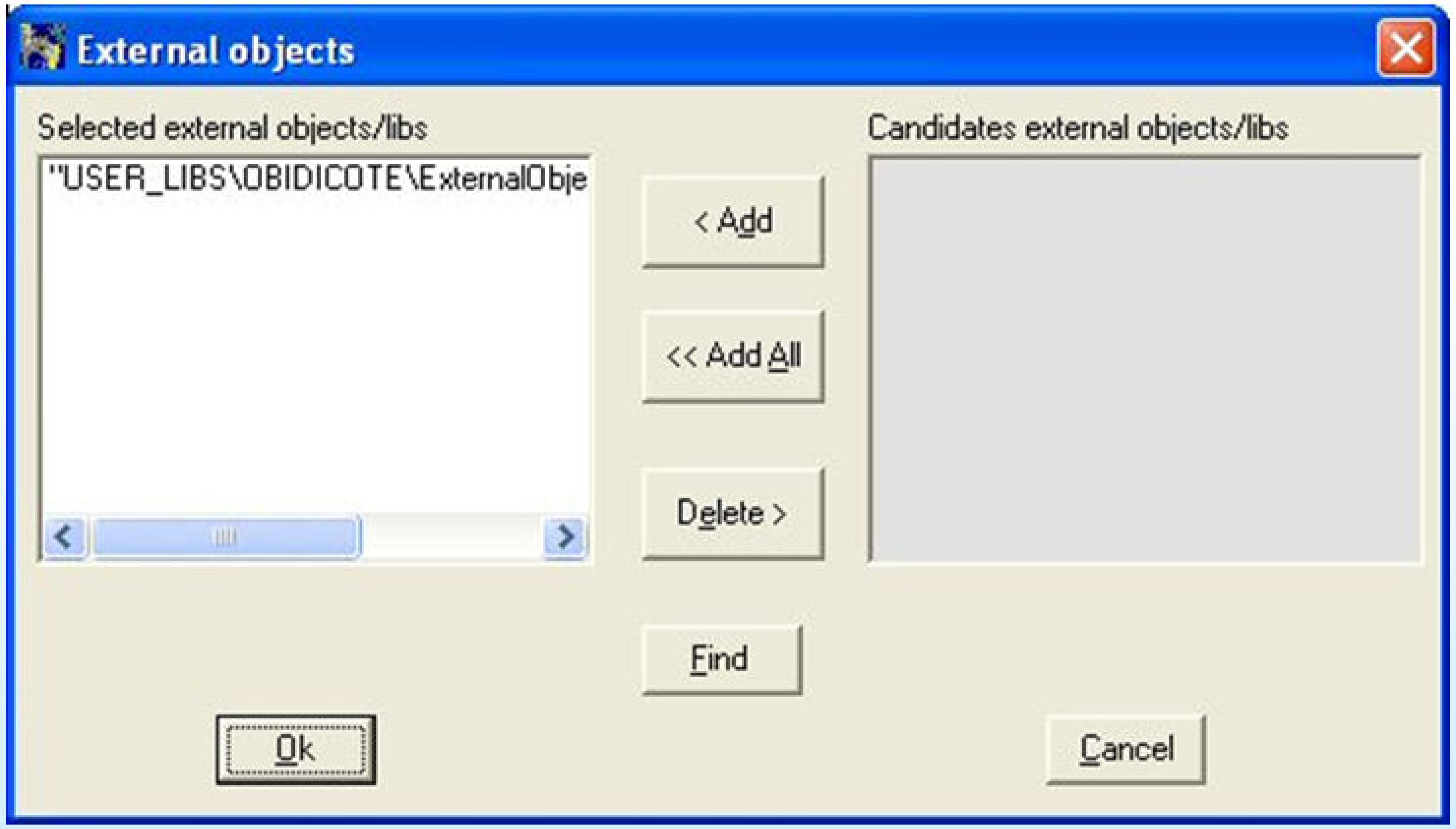
To use existing FORTRAN, C or C++ code

1. Declare Interface

2. Specify location of object or library

IN "USER_LIBS\NTUA\ExternalObjects\NewtonRaphson.obj"





Using External Code in an Engine Model (I)

To use existing FORTRAN, C or C++ code

1. **Declare Interface**
2. **Specify location of object or library**
3. **Use in Components and/or Experiments like normal EL functions**

```
NewtonRaphson(fcn, 10, itermax, tol, eps, x, ierror)
```

Conclusions

Object-Oriented simulation environments offer great advantages for developing different engine performance modelling applications:

- ✓ **Powerful object-oriented language for creating components & setting up simulations**
- ✓ **Advanced graphical user interface for creating engine models**
- ✓ **Mathematical model wizards**
- ✓ **Post-processing capabilities for viewing results**
- ✓ **Connectivity with other applications**
- ✓ **Compatibility with other programming languages**
- × **Changing users' programming philosophy & modelling approach could be an issue**

PRopulsion Object-Oriented SImulation Software (PROOSIS)

Work Package 2.4 of

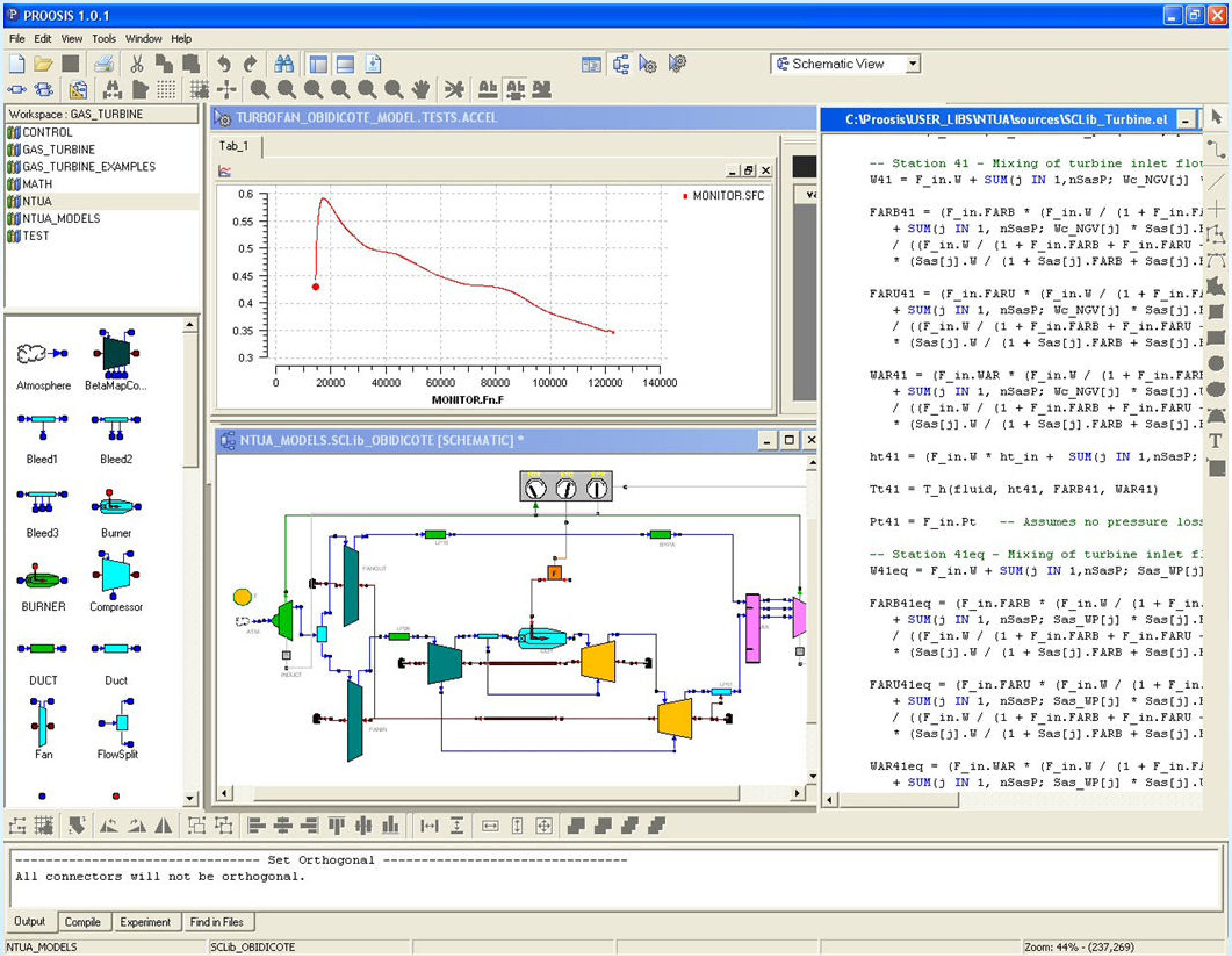
Integrated Project VIVACE

http://www.vivaceproject.com

Funded by the European Union Commission

PARTNERS

AIF, AVIO, CENAERO, CU, EA, ITP MTU, NLR, NTUA, Snecma, Techspace Aero, Turbomeca, USTUTT, Volvo Aero, IberEspacio


PROOSIS 1.0.1
File Edit View Tools Window Help
Schematic View
Workspace : GAS_TURBINE
CONTROL
GAS_TURBINE
GAS_TURBINE_EXAMPLES
MATH
NTUA
NTUA_MODELS
TEST
Atmosphere
BetaMapCo...
Bleed1
Bleed2
Bleed3
Burner
BURNER
Compressor
DUCT
Duct
Fan
FlowSplit
TURBOFAN_OBIDICOTE_MODEL.TESTS.ACCEL
Tab_1
MONITOR.SFC
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0
20000
40000
60000
80000
100000
120000
140000
MONITOR.Fn.F
NTUA_MODELS.SCLib_OBIDICOTE [SCHEMATIC] *
C:\Proosis\USER_LIBS\NTUA\sources\SCLib_Turbine.el
-- Station 41 - Mixing of turbine inlet flow
W41 = F_in.W + SUM(j IN 1,nSasP; Wc_NGV[j]
FARB41 = (F_in.FARB * (F_in.W / (1 + F_in.F
+ SUM(j IN 1, nSasP; Wc_NGV[j] * Sas[j].
/ ((F_in.W / (1 + F_in.FARB + F_in.FARU -
* (Sas[j].W / (1 + Sas[j].FARB + Sas[j].
FARU41 = (F_in.FARU * (F_in.W / (1 + F_in.F
+ SUM(j IN 1, nSasP; Wc_NGV[j] * Sas[j].
/ ((F_in.W / (1 + F_in.FARB + F_in.FARU -
* (Sas[j].W / (1 + Sas[j].FARB + Sas[j].
WAR41 = (F_in.WAR * (F_in.W / (1 + F_in.FAR
+ SUM(j IN 1, nSasP; Wc_NGV[j] * Sas[j].
/ ((F_in.W / (1 + F_in.FARB + F_in.FARU -
* (Sas[j].W / (1 + Sas[j].FARB + Sas[j].
ht41 = (F_in.W * ht_in + SUM(j IN 1,nSasP;
Tt41 = T_h(fluid, ht41, FARB41, WAR41)
Pt41 = F_in.Pt -- Assumes no pressure loss
-- Station 41eq - Mixing of turbine inlet f
W41eq = F_in.W + SUM(j IN 1,nSasP; Sas_WP[j]
FARB41eq = (F_in.FARB * (F_in.W / (1 + F_in.
+ SUM(j IN 1, nSasP; Sas_WP[j] * Sas[j].
/ ((F_in.W / (1 + F_in.FARB + F_in.FARU -
* (Sas[j].W / (1 + Sas[j].FARB + Sas[j].
FARU41eq = (F_in.FARU * (F_in.W / (1 + F_in.
+ SUM(j IN 1, nSasP; Sas_WP[j] * Sas[j].
/ ((F_in.W / (1 + F_in.FARB + F_in.FARU -
* (Sas[j].W / (1 + Sas[j].FARB + Sas[j].
WAR41eq = (F_in.WAR * (F_in.W / (1 + F_in.F
+ SUM(j IN 1, nSasP; Sas_WP[j] * Sas[j].
-------------------------------- Set Orthogonal --------------------------------
All connectors will not be orthogonal.
Output
Compile
Experiment
Find in Files
NTUA_MODELS
SCLib_OBIDICOTE
Zoom: 44% - (237,269)