Pratt & Whitney

Build-a-Model
Parametric Simulation Environment
User's Manual

V2.0.1
Evaluation Release A

May 16, 2006

This document is the property of Pratt & Whitney, and is delivered on the express condition that it and the information contained in it are not to be used, disclosed, or reproduced in whole or in part, for any purpose without the express written consent of United Technologies Corporation; and that no right is granted to disclose or so use any information contained in said document. These restrictions do not limit the right to use information obtained from another source.

Contact Information:

Steve Sirica
Pratt & Whitney
tel: (860) 557-4781
e-mail: steven.sirica@pw.utc.com

Igor Fuksman
Pratt & Whitney
tel: (860) 565-9612
e-mail: igor.fuksman@pw.utc.com

Table of Contents

1 Introduction 1
2 Program Description 1
3 Program Setup 1
3.1 System Requirements 2
3.2 Installation 2
3.3 Cautions 2
4 Panel Overview 3
4.1 Cycle Model 3
4.1.1 Configuration Panel 3
4.1.2 Customer Interface 3
4.1.3 User Variables 4
4.1.4 Map Selection 4
4.1.5 Bleed Setup 4
4.1.6 Sub-System Schedules 5
4.1.7 Custom Schedules 5
4.1.8 Additional Schedules 6
4.1.9 Calculators 6
4.1.10 Viewer Variable List 7
4.1.11 Additional Balances 7
4.1.12 Design Point 8
4.1.13 Design Sizer 8
4.1.14 Ratings/Limits 9
4.1.15 Off Design 10
4.2 Output Panel 11
4.3 Error Log Panel 11
5 Advanced Features 11
5.1 File Printing 11
5.2 Batch Operation 12
5.3 Subroutine Operation 12

1 Introduction

Pratt & Whitney's (P&W's) Aircraft Build-a-Model parametric environment provides steady-state & transient mathematical modeling of practically any air-breathing gas turbine configuration. This release is targeted specifically for evaluation purposes to solicit customer feedback on the general usage of this revolutionary parametric simulation environment. This tool provides the user with a true parametric environment offering greater flexibility then ever provided to users' outside of P&W.

Three generalized sample models are provided as a means of demonstrating some of the tool's more typical capabilities. These models are generic and do not represent any particular propulsion system. The three example models supplied are:

- High Bypass Ratio Turbofan (turbofan_com.bam)
- Low Bypass Ratio Turbofan (turbofan_mil.bam)
- Turboshaft with Free Power Turbine (turboshaft.bam)

2 Program Description

Build-a-Model provides a generic parametric modeling system with a Graphical User Interface. The GUI dynamically creates the necessary input for the underlying **Numerical Propulsion Simulation System (NPSS)** and controls execution of the simulation. Standard **ARP5571** nomenclature is used to define applicable Input / Output variables. The GUI automatically creates a display of the engine configuration and the respective engine station numbering. Additionally, the GUI provides an interface to a **Model Tree**, which displays a list of common input and output variables, including names and descriptions, as well as switch settings and options. Variables can be "dragged" from the **Model Tree** to any of the editable fields in the GUI panels and will automatically contain the correct scope and case syntax.

3 Program Setup

The simulation can operate as a stand-alone program though use of the GUI, and can also be configured to execute in batch mode or as a subroutine to a main program (only recommended once Design Point has been set). For stand-alone GUI execution, once the program is launched, simply open one of the supplied example files and modify / populate the inputs. The user can also construct any supported configuration through the use of the **Configuration Panel** interface and then populate the required inputs (this will be discussed in the appropriate sections of the manual). Standard text output for detailed thermodynamic performance is provided as well as options for **Column Output** and

Comma Separated Values. Details on customization of installation effects are covered in detail later in this document.

Note that any changes made to inputs are not automatically saved. The example configurations are read-only and are your reference baseline. After making changes to input, simply go to **File Save** and name the session (extension should be .bam).

3.1 System Requirements

This tool is designed to operate on **Windows NT**, **Windows 2000**, and **Windows XP**. Installation of **Java Run Time library 1.4.2** is required for program execution. This run time library is readily available for free download at **www.sun.com**. One additional file is also required for execution, **DFORMD.DLL** – which is the **Visual Fortran** threaded run-time support program. If this file is not on your system, it is available for free download at **www.hp.com**.

3.2 Installation

Copy the entire contents of the CD to a folder of your choice. Once you have copied the contents and verified that the additional required files are installed on your system (**Java Run Time** library and Fortran **DFORMD.DLL**), edit the bam.bat file and modify the following lines as required to match your system details.

```
rem Please set INST_TOP and GUI_JAVA during installation
rem  - INST_TOP is full path to "bam_v2.0.1a" directory
rem  - GUI_JAVA is full path to Java directory
set INST_TOP=K:\devl\share\npss\sim\mda\BAMevaluation\v2.0.1\bam_v2.0.1a
set GUI_JAVA=K:\test\wnt\java\j2sdk1.4.2\bin\java
```

After this is complete, go to the directory of your choice and execute bam.bat from a command prompt. The simulation will operate from the folder it was executed in, including all writing of output files.

3.3 Cautions

This parametric model is executing the underlying simulation system in an interactive mode. As a result, once a variable is set, it does not return to the base value unless it is explicitly reset. For example, consider the situation where the base **Design Point** is set up with zero customer power extraction. If the user extracts power in the off-design mode and then executes the **Design Point** without resetting the power extraction to OFF or 0.0, this value will be retained and used in the subsequent **Design Point** calculations. Note that the simulation can always be reinitialized by opening a saved .bam model.

During rare events where inputs are entered into the simulation that cause execution to hang, it is sometimes necessary to kill the process. This is accomplished by going to **Windows Task Manager** (Ctrl-Alt-Del) and ending the **PEDWizart.nt.exe** process. After this it is safe to restart the model.

4 Panel Overview

The GUI environment consists of many interface panels. Many of these panels will never need to be modified by the user after the initial setup and are used for detailed customization of the underlying simulation. A high level description of each of these panels is provided for reference.

4.1 Cycle Model

This panel contains a series of sub-panels that allow for complete definition and execution of parametric engine model. They are described below.

4.1.1 Configuration Panel

This panel (Figure 1) displays the engine configuration as well as station identification. Upon loading of an existing configuration (.bam), this panel is dynamically redefined. This is also the interface where the user would create any supported configuration from scratch. If you are creating a new configuration and already have an existing session open, it is recommended that you use the **File New** menu before creating the new configuration, otherwise not all of the Panels and Tabs will be reinitialized Next simply use the drop-down menus to select the desired configuration and press **Apply**. This will begin the process on building a new model. In the rare event that a desired configuration is not available through the drop-down list, P&W can supply custom configuration files that can be loaded through the custom configuration section.

4.1.2 Customer Interface

This panel (Figure 2) is generally used as a single point of input for the external customer. In a typical parametric environment, the underlying simulation is more complex than the general user would want to deal with. This interface provides a means to set / modify values for **Design** and **Design Sizing** variables at a single location. These variables can be accessed from anywhere in the model through the use of a **Cint** scope (i.e. Cint.T041des). These variables are typically mapped to the appropriate sections (parm_in = Cint.T041des).

Examples provided in this evaluation version provide complete flexibility with no predefined / hardwired design rules. Typical Build-a-Model Parametric models supplied to external customers will contain P&W specified design rules / criteria built-in and require **Design Sizing** operation through the **Customer Interface** panel.

After entering the inputs in the **Value** column (remember to hit enter after typing / pasting input), press the **Apply** button at the bottom of the panel. This will send the information to the underlying simulation.

This panel also has an **Import** / **Export** type of capability through the use of the **Save** and **Open** buttons. This provides a means to change this setup once it is delivered to external user. The external user will have the ability to load modified inputs (which include new **Variables** and modified **Ranges**).

4.1.3 User Variables

This panel (Figure 3) is for declaration of new variables for further use in the simulation. These include the full complement of variable types in **NPSS** (real, integer, string) as well as Independent and Dependent Balance variables. Declaration of variables in this panel prevents the error of declaring same variable more than once.

When creating ad-hoc variables, it is recommended that this be done through the **Calculators** panel. Additionally, it is recommended that user defined balances be done through the **Additional Balances** panel. These respective panels provide a more user friendly interface with added flexibility.

4.1.4 Map Selection

This panel (Figure 4) is used to select the appropriate component maps through the use of drop-down lists. For this release, the selection is limited to the E3 compressor and turbine maps that are provided in the **NPSS** release as well as generic examples for the remaining components. It is possible to load new maps by typing the name of the map in the appropriate drop-down section. Note that maps must adhere to the supported formats. User supplied maps must end with a .runin extension and be stored in the **\maps** subdirectory.

4.1.5 Bleed Setup

This panel (Figure 5) allows for the definition and configuration of pre-defined bleeds and user defined bleeds. User defined bleeds are generally used for turbine cooling, leakages, and other secondary flows. The user will need to define the appropriate extraction and re-entry locations as well as work fractions and flow levels. Typical **Customer Bleed**(s) and **Stability Bleed**(s) ports are automatically created. Specification of **Customer Bleed**(s) (flow, % flow, or scheduled bleed) is handled through either standard **ARP5571** input or the **Custom Schedules** panel. **Stability Bleed**(s) is typically defined through the appropriate **Sub-Systems Schedules** panel. There is also a FABL sub-tab that allows for secondary flow definition using P&W methodology.

4.1.6 Sub-System Schedules

This panel (Figure 6) and the respective sub-panels are for detailed sub-system definition. These effects typically include the following:

- Shaft Parasitic Losses
- Stability Bleed(s)
- Fan Warpage
- Heat Addition to Fuel
- Variable Exhaust Nozzle Area Scheduling
- Component Calibration

These sub-system effects can be defined either through populating the appropriate tables or set through the use of a function. Note that the population of the independent variables in the tables defaults to preconfigured drop-down lists but these variables can be over-written with any available variable. If the function is defined to use a user supplied table, this user defined table is input in the Data sub-tab and must adhere to **NPSS** table syntax. When setting up these sub-systems, care should be paid to the selection of variables to prevent a use-before-calculate situation.

There are two additional features available in this panel; **Clear** and **Load**. Pressing the **Clear** button erases all inputs from table. The **Load** button allows for import of table data from an external file. Note that the format of this file is very particular (examples are provided on CD). The parser is still under development. Additionally, MS Excel Copy / Paste features with Insert / Delete Row capability is under development and will most likely negate the need for the **Load** feature.

4.1.7 Custom Schedules

This panel (Figure 7) contains the sub-panels that allow the customer to easily specify custom installation effects. These effects include:

- Inlet Recovery
- Exhaust Nozzle Discharge Coefficient
- Exhaust Nozzle Velocity Coefficient
- Customer Bleed Flow
- Customer Power Extraction
- Heat Addition to Duct Flow
- Installation Drag Coefficient

These sub-panels allow the user to set up a multi-variant table to specify the effect as well as an equation (entered under function sub-tab). To specify that the simulation use the table or function effects, set the respective switch (i.e. CpwrH.switchPwr = "CUSTOM";) Note that for single input values, it is not required to use these panels, simply specify the value in the normal input manner (i.e. CpwrH.switchPwr = "INPUT"; CpwrH.Pwr_in = 75.0; specifies to extract 75 horsepower from the high-spool).

As with the **Sub-System Schedules** panel, there are two additional features available in this panel; **Clear** and **Load**. Pressing the **Clear** button erases all inputs from table. The **Load** button allows for import of table data from an external file. Note that the format of this file is very particular (examples are provided on CD). The parser is still under development. Additionally, MS Excel Copy / Paste features with Insert / Delete Row capability is under development and will most likely negate the need for the **Load** feature.

Similar to Sub-Systems Schedules, Custom Schedules can also be defined as a function instead of a predefined table. Additionally, the function definition must be used if there is a requirement to define 3D (and larger) tables as these are not currently supported via the GUI table definition.

4.1.8 Additional Schedules

This panel (Figure 8) is a placeholder for anything that is not covered in the normal panels and is entered in a free form input that adheres to **NPSS** syntax. Note that due to the interactive parsing of the input, the /* … */ syntax for skipping blocks of input does not work. The // prefix is required on every line that is to be skipped (no occurrence of the /* format is allowed – even in a line that starts with //). It is possible to load and parse a complete file through the use of the #include <yourfilename.ext> capability but this is discouraged as the intention is for the .bam file to be fully self contained. Note that this information applies to **all** free form input windows in Build-a-Model.

4.1.9 Calculators

This panel (Figure 9) allows for the creation of ad-hoc variables that are based on the results of the simulation. These calculated parameters show up on the output under the custom section when Custom Output option is turned on. There are four categories available:

- **Corrected Parameter** – allows for automatic calculation of corrected values using theta and delta parameters
- **Compressor Efficiency** – allows for combining compressors to calculate an overall compressor efficiency
- **Turbine Efficiency** – allows for combining of turbines to calculate an overall turbine efficiency
- **Generic** – allows for custom calculations

These variables can be accessed from anywhere in the simulation through the use of a **Cycle** scope (i.e. Cycle.OPR).

4.1.10 Viewer Variable List

This panel (Figure 10) provides the user with the interface to define what variables are output to **Columns** and **Comma Separated Values**. Initial list are dynamically created based on selected configuration but can be modified. CSV output list is limited to 256 variables (MS Excel limitation). There is also an aliasing option to provide a customized naming to the output (see example below). Aliasing is not required for every variable in the list; they can be mixed and matched.

Name list without Alias (will show up in output as CmpH.WcIn)
"CmpH.WcIn",

Name list with Alias (will show up in output as W25R)
"CmpH.WcIn = W25R",

When a warning or limit is encountered during the execution of the simulation, the default behavior for Column and CSV output is to mark the limited point with a + or *. This automatic marking can be disabled with the following switch settings:

Disable Markings
ColumnOutput.showMark = FALSE;
CsvOutput.showMark = FALSE;

Enable Markings
ColumnOutput.showMark = TRUE;
CsvOutput.showMark = TRUE;

4.1.11 Additional Balances

This panel (Figure 11) is where user defined balances are defined. Note that when defining a balance with this panel, it is not necessary to define the Independent and Dependent in the **User Variables** panel. Balances can be defined as Always Active, Active in Design Point, and Active Off-Design. Clicking the Check Box for the balance will toggle the balance as active / deactive (you must press Apply after setting balance up). Note that if a balance is active in the Design Point, it will also be active in the Design Point defined through the Design Sizer.

When using a user defined balance that is active Off-Design, it is recommended that the user provide guesses which are defined in functions. This is recommended to set consistent guesses for every point and keep ensure simulation repeatability. This is typically not required for balances that are active only in Design Point as these are generally being set in the Design Point panel. Contact P&W if you have any questions regarding this feature.

4.1.12 Design Point

This panel (Figure 12) establishes necessary information required to process design point. Minimum required input is highlighted in green. The GUI Help menu contains a section on Design Point inputs. Please review this section for more information regarding required and optional design inputs.

Note that the settings for controlling the output can be specified on the **Design Point** panel. These output options are either "OFF" or "ON". The following outputs can be set by user (these are located at the top of the panel).

- viewer.switchSolverOutput — Controls Solver Output
- viewer.switchBasicOutput — Controls Typical Cycle Output
- viewer.switchReferenceOutput — Controls Detailed Reference Output
- viewer.switchBleedOutput — Controls Detailed Bleed Output
- viewer.switchCustomOutput — Controls Custom Output (Calculators Panel)
- viewer.switchColumnOutput — Controls Column Output
- viewer.switchCsvOutput — Controls CSV Output
- viewer.switchUbinOutput — Controls Binary Output (binary file intended for use with P&W internal tools)

Nested sweeping of variables is also set up on the **Design Point** panel in the **Design Matrix** section. Typical use of this would be sweeping T4 and cycle pressure ratio during **Design Point**. For an external release, **Customer Interface** variables are mapped to this section and other appropriate balance settings. In this evaluation release, the user would sweep Design Point input variables to accomplish this (i.e. Pset.parm_in, CmpH.PRdes). This sweeping of variables can either be Inactive, Active in Design Point, or Active with the Design Sizer.

4.1.13 Design Sizer

This panel (Figure 13) establishes the setup required for design and sizing of an engine (Design and Off-Design) through the use of the Nested Solver. Examples of the use of this panel are provided in the supplied models.

The user would define the settings for the specific points to be executed in this panel. Additionally, there are Pre and Post Execute sections for further definition and control of settings (these are optional and are not normally required). Pressing the up-arrow above the Definition sub-tab reveals a free-form text input section. This allows for advanced settings / input to the **NPSS** simulation. Pressing the down-arrow collapses this window.

This panel has a separate limit section that allows definition of constraints / limits as applicable to the Nested Solver Sizing matrix.

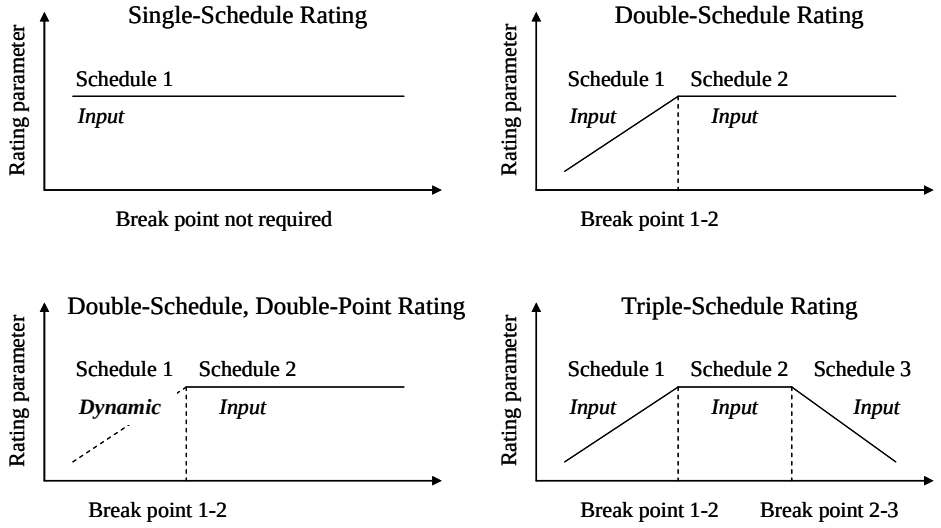
It is recommended that the user set all inputs consistently in Off-Design sizer points due to the interactive nature of this tool. For example, if an Off-Design sizing point has

power extraction and the Design Point does not, you must reset power extraction to "OFF" for the Design Point.

There are two additional features on this panel; **Save** and **Open**. **Save** will write the contents and settings of this panel to a file with a .bamsz extension. This file can then be brought into another simulation with the **Open** feature. This can be very useful since setting up the Sizing with the Nested Solver can be somewhat complex. A note of caution on this usage is that one should limit the Importing of Sizing files to ones that were created by an identical configuration. For example, if you Open / Load a Sizing file that was created from a simulation that was a different configuration (Saved in 2-Spool Turbofan, Opened in 1-Spool Turboshaft), since the module and station names for each configuration are dynamically created, there is a high probability that the setup will be incompatible between the two simulations.

4.1.14 Ratings/Limits

This panel (Figure 14) controls the automatic rating definition and limit setup. The following rating structures are available:



The rating schedule inputs can be cross-referenced to the results of the **Design Point** and the **Design Sizer**. In addition to running ratings, the program also allows the user to specify percent rating. Normally, percent rating parameter should not be specified for various IDLE ratings and for MINAB rating. Additionally, the percent rating parameter should not be specified for MAXAB rating as well (in this case percent rating input is used to specify augmentation level and is setup automatically).

Limits are not active during the dynamic rating creation and are applied off-design only. There is a separate limit section available in the **Design Sizer** panel for constraining the Nested Solver. Engineering Status Indicators (ESIs) are reported when a limit is

encountered. Generic Max Limit ESI is 70022503. Generic Min Limit ESI is 70012503. Table Extrapolation Limit ESI is 71005101. Up to 10 ESIs can be added to Column and CSV output using the following names (ESI0, ESI1, ESI2, ESI3, ESI4, ESI5, ESI6, ESI7, ESI8, ESI9).

As with the **Design Sizing** panel, this panel has two additional features; **Save** and **Open**. Save will write the contents and settings of this panel to a file with a .bamrl extension. This file can then be brought into another simulation with the **Open** feature. This can be very useful since setting up the Ratings and Limit structure can be somewhat complex. One note of caution on this usage is that you should limit the Importing of Ratings / Limits files to ones that were created by an identical configuration. For example, if you Open / Load a Sizing file that was created from a simulation that was a different configuration (Saved in 2-Spool Turbofan, Opened in 1-Spool Turboshaft), since the module and station names for each configuration are dynamically created, there is a high probability that the setup will be incompatible between the two simulations.

4.1.15 Off Design

This panel (Figure 15) is where the user specifies all of the off-design input. This input adheres to **ARP5571** structure and utilizes NPSS syntax. Note that it is possible to specify the input in an external file and read that file in through this interface with the following syntax:
#include <yourfilename.ext>

There are two additional sub-tabs available on this panel; **For Loop** and **If Else**. These provide an interface for the user to populate ranges and by pressing the upper Apply button this will write the required **NPSS** syntax to the free form text section at the cursor location.

Users are encouraged to utilize the Model Tree drag-and-drop feature to avoid typographical errors. All statements should be terminated with a semicolon (;) or the program may crash (interactive mode waiting for end of input).

Occasionally some points may have difficulty converging. This difficulty can often be overcome by running a successful point and stepping towards the desired target value with small +/- increment (as applicable) after disabling the internal solver guesses (this will effectively set the guess to "last point" values). This is accomplished with the following settings:

Disables internal guess logic and uses last converged point as guess
Gcrv.switchGuess = "OFF";

After successful execution of point, remember to turn internal guess logic back on.

Enables internal guess logic
Gcrv.switchGuess = "ON";

4.2 Output Panel

This panel (Figure 16) contains the text output that is specified at execution (Basic, Reference, Bleed, and Custom). It does not include the **Comma Separated Values** and **Column Output**. CSV output gets written to separate .csv file (after Reset is pressed). Column Output gets concatenated with output from the main Output Panel display to .bamout file after Reset is pressed.

4.3 Error Log Panel

This panel (Figure 17) contains a running list of program errors, warnings, and limits encountered during execution. It is only cleared upon re-opening of .bam simulation or program restart.

5 Advanced Features

This section describes some of the advanced features available. These will not typically be used by the general user.

5.1 File Printing

This feature is available through the Menu Print to File. Individual files or complete simulation files can be printed. The individual file printing is useful when trying to debug setup errors. Additionally, this feature can be used to capture the settings of a particular functionality (i.e. bleed sub-system setup) and can be then brought into a full NPSS external session. The Print All Files feature will write out complete contents of simulation. This is required prior to batch and subroutine execution.

Due to the fact that some panels are dynamically populated (in particular Ratings / Limits panel), the simulation must be executed once through the GUI prior to printing all files. If this is not done, the contents of the dynamically populated panel files will not be correct.

Design Point and / or **Design Sizer** files will be commented out in *printed* model (.mdl) file if "**Execute on Open**" option is not selected on the **Design Point** / **Design Sizer** panels. The user should either check the **Execute on Open** option on the respective panel prior to printing or uncomment the files (remove //) in the model (.mdl) file.

Once the entire simulation is printed out for batch / subroutine mode execution, there is no mechanism in place that prevents the user from modifying the resulting **NPSS** simulation files. However, users are **discouraged** from updating the simulation in this manner. The **recommended procedure** is to update the simulation through the GUI,

save the updated .bam file, and then re-print the entire simulation again. This way, the .bam file contains the master copy and all generated results can be traced back to it.

5.2 Batch Operation

After writing all of the required simulation files out with the Print to File feature, you can now execute the simulation from the command prompt in a batch mode without the GUI active. One file that is created when you Print to File is called example.run. This file contains the necessary instructions to operate in batch mode. Prior to program execution, the proper environment variables will need to be set.

To set the proper environment variables, type the following command:
..... full path .....\bam.bat setenv

To launch the program in batch mode, type the following command:
PEDwizard.nt.exe example.run

Note that example.run contains the necessary inputs to run off-design. To change the off-design inputs, either modify the off-design runin file or bring another file in by modifying example.run contents.

5.3 Subroutine Operation

After writing all of the required simulation files out with the Print to File feature, you can now link the simulation to another C++ or Fortran program and execute it in subroutine mode. Examples of C++ (runcd1.c) and Fortran (runcd2.f) driver programs are supplied. Instructions on subroutine mode are supplied in the subroutine_mode_readme.txt file, as well as a Makefile which contains the appropriate compiler settings. As with operation in batch mode, the proper environment variables will need to be set prior to program execution.

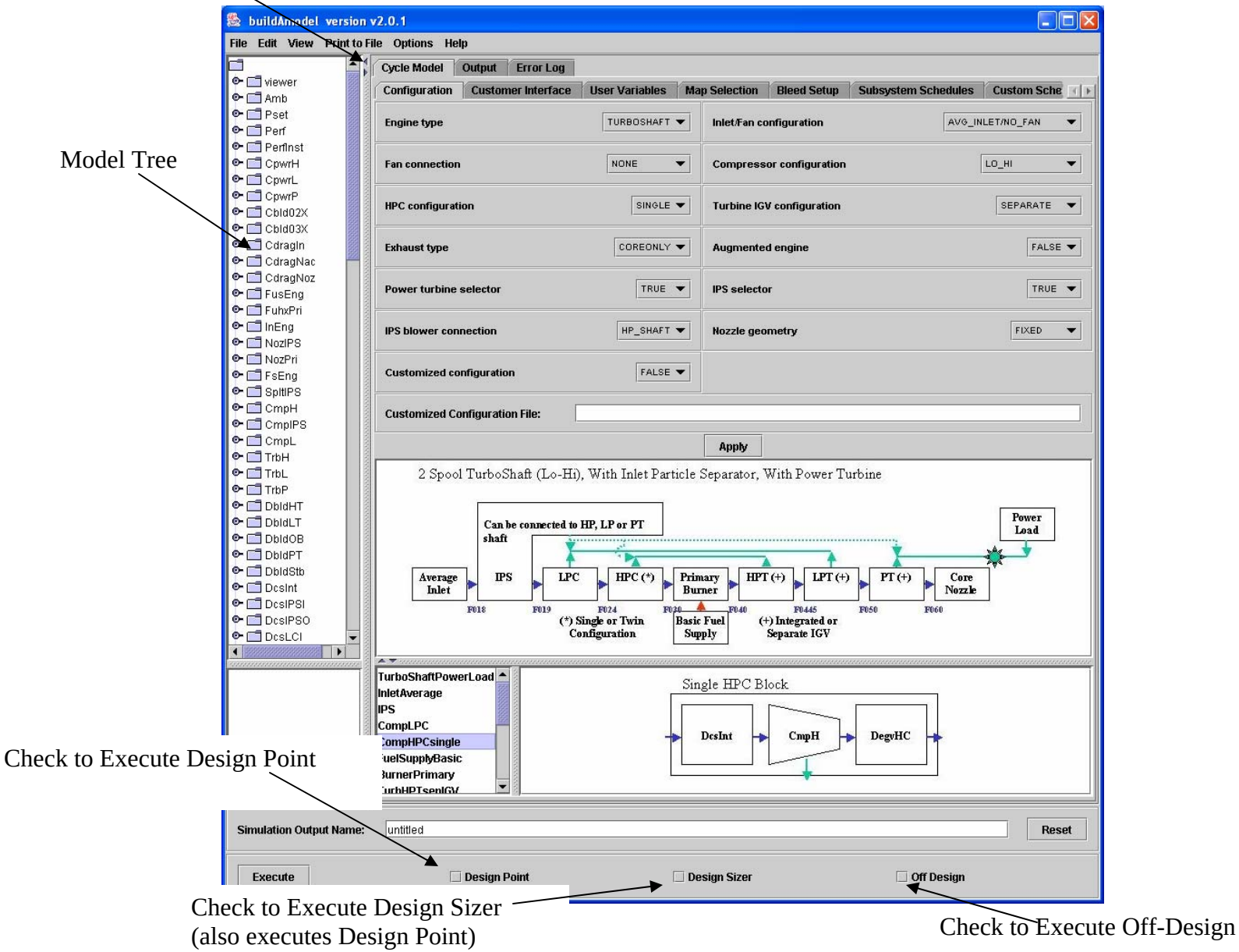
To compile and link with a C++ program, use the following command (Makefile sets appropriate compiler switches):
nmake /f Makefile.win32 runcd1

To compile and link with a FORTRAN program, use the following command (Makefile sets appropriate compiler switches):
nmake /f Makefile.win32 runcd2

To set the proper environment variables prior to execution, type the following command:
..... full path .....\bam.bat setenv

Appendix A – Overview of Panels

Figure 1: Configuration Panel Overview



Variable Name **Figure 2: Customer Interface Panel Overview** Variable Description

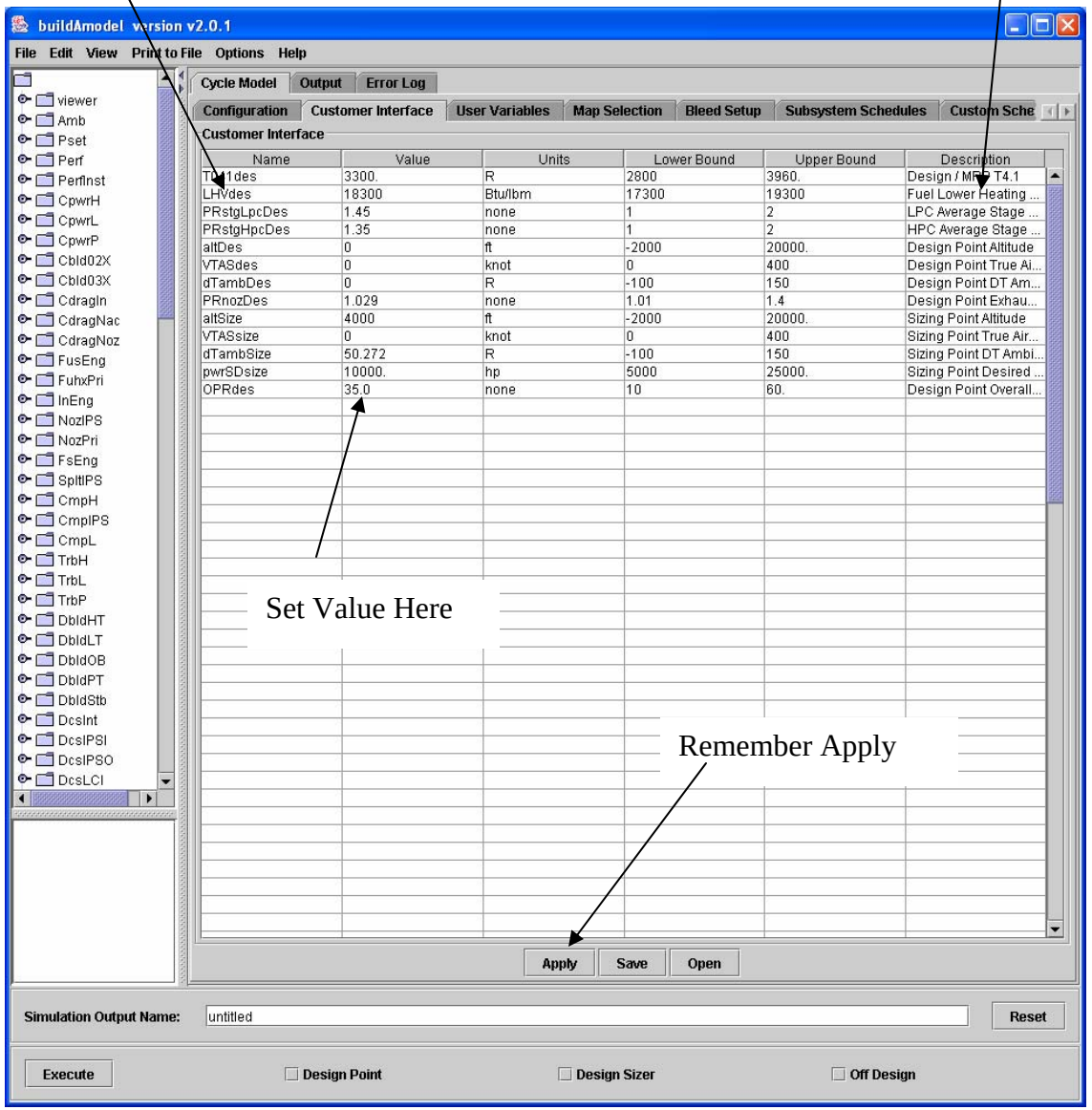


Figure 3: User Variables Panel Overview

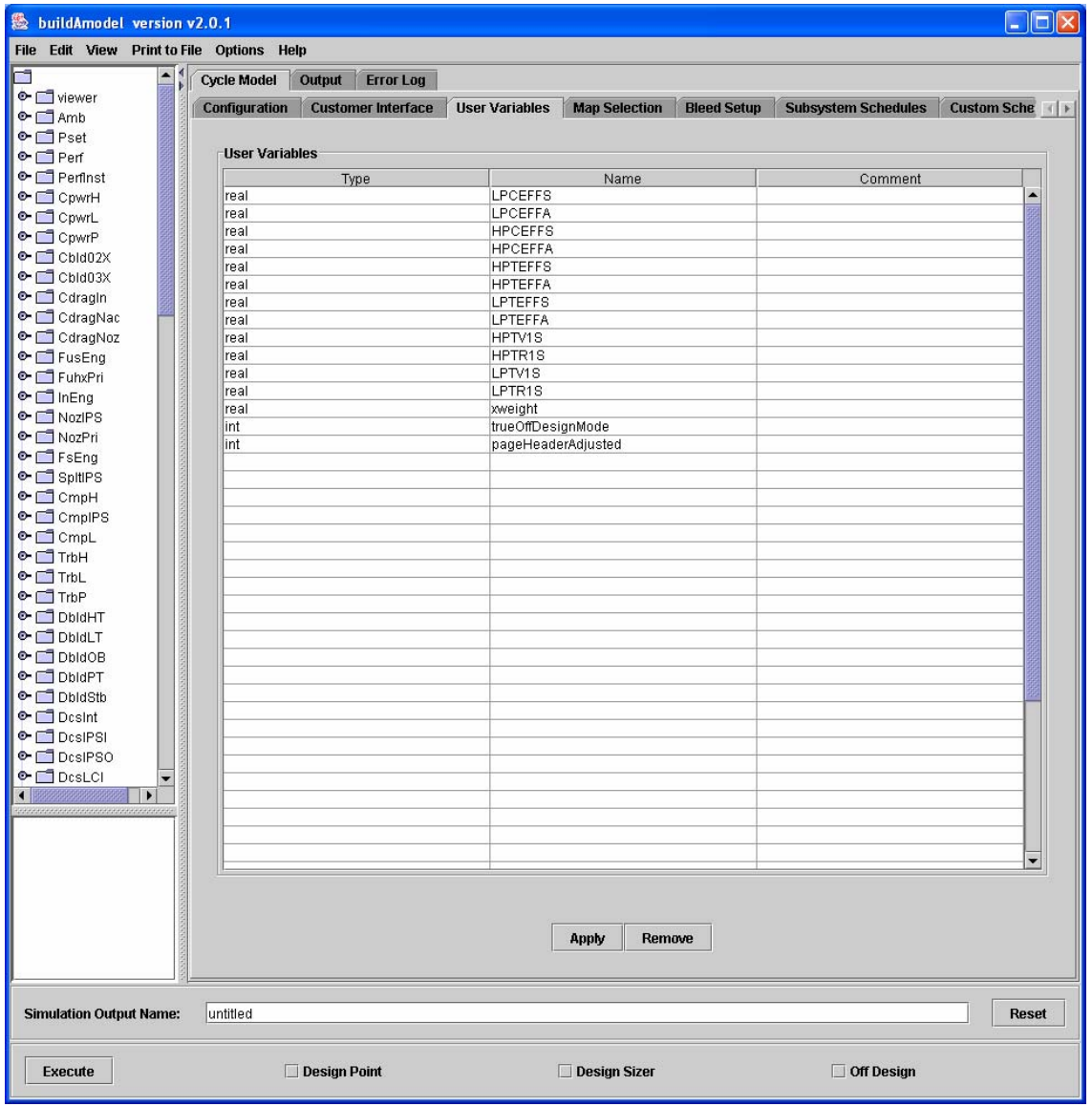


Figure 4: Map Selection Panel Overview

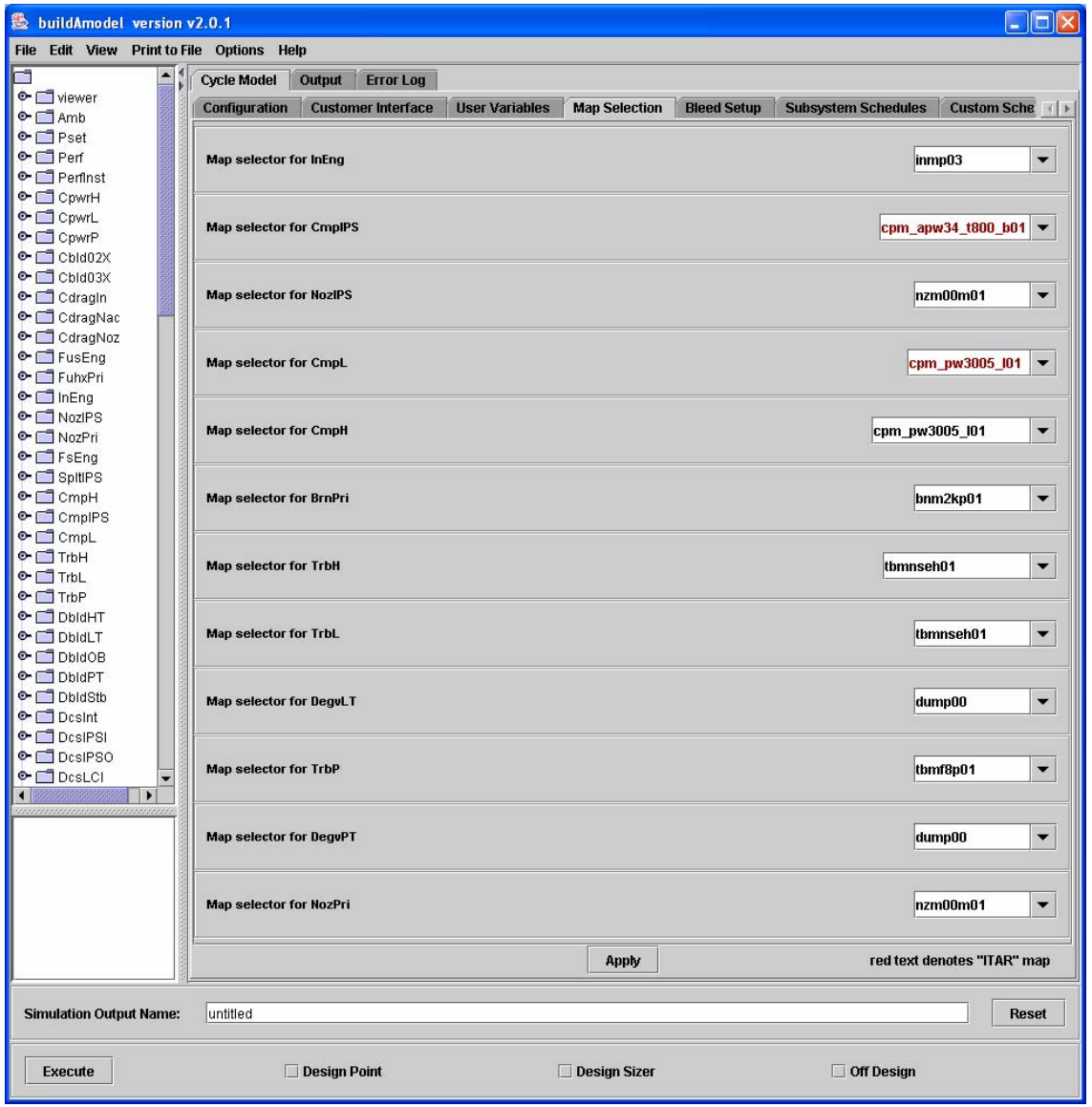


Figure 5: Bleed Setup Panel Overview

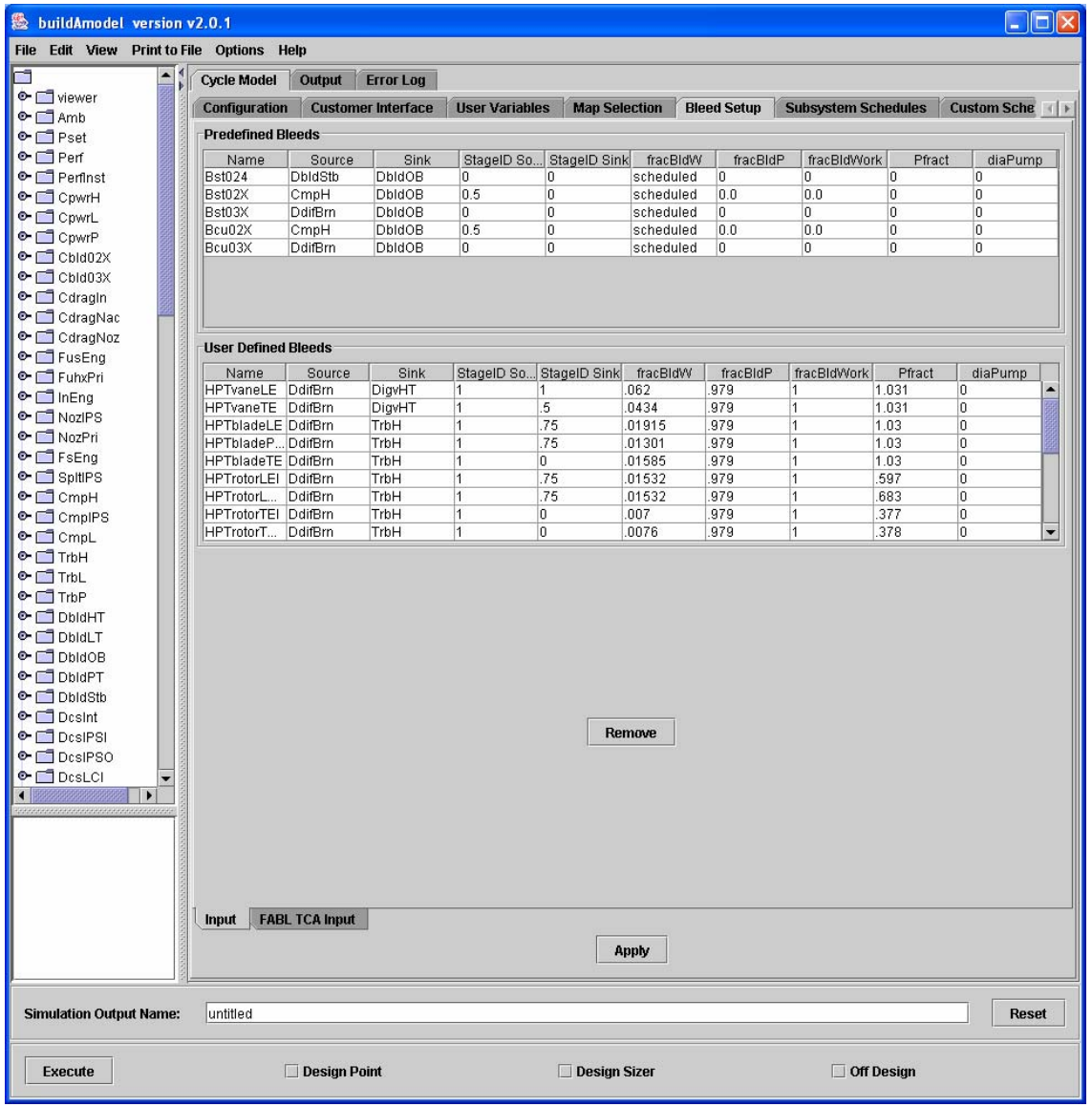
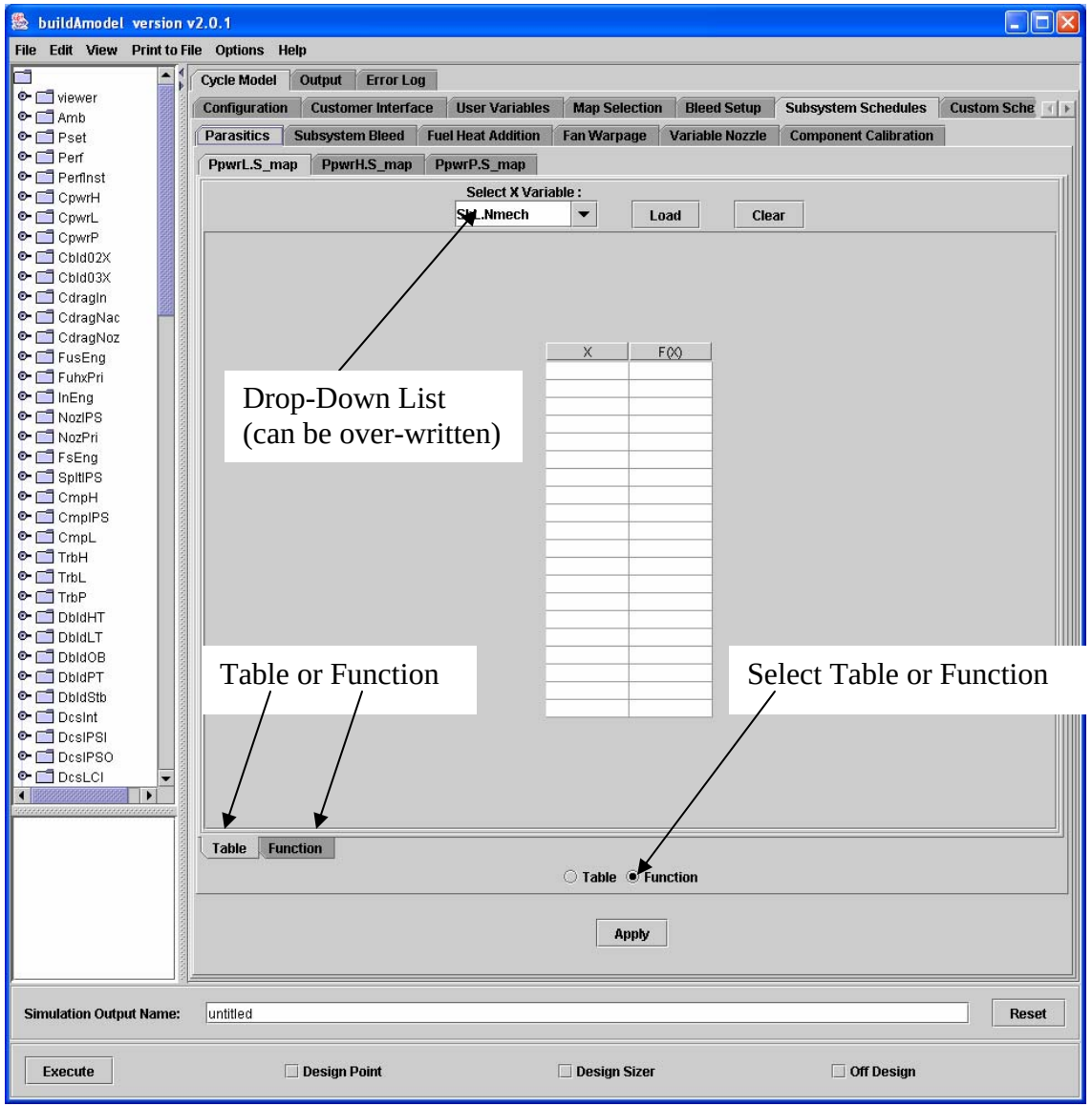


Figure 6: Sub-System Schedules Panel Overview



Select Installation Effect Panel

Figure 7: Custom Schedules Panel Overview

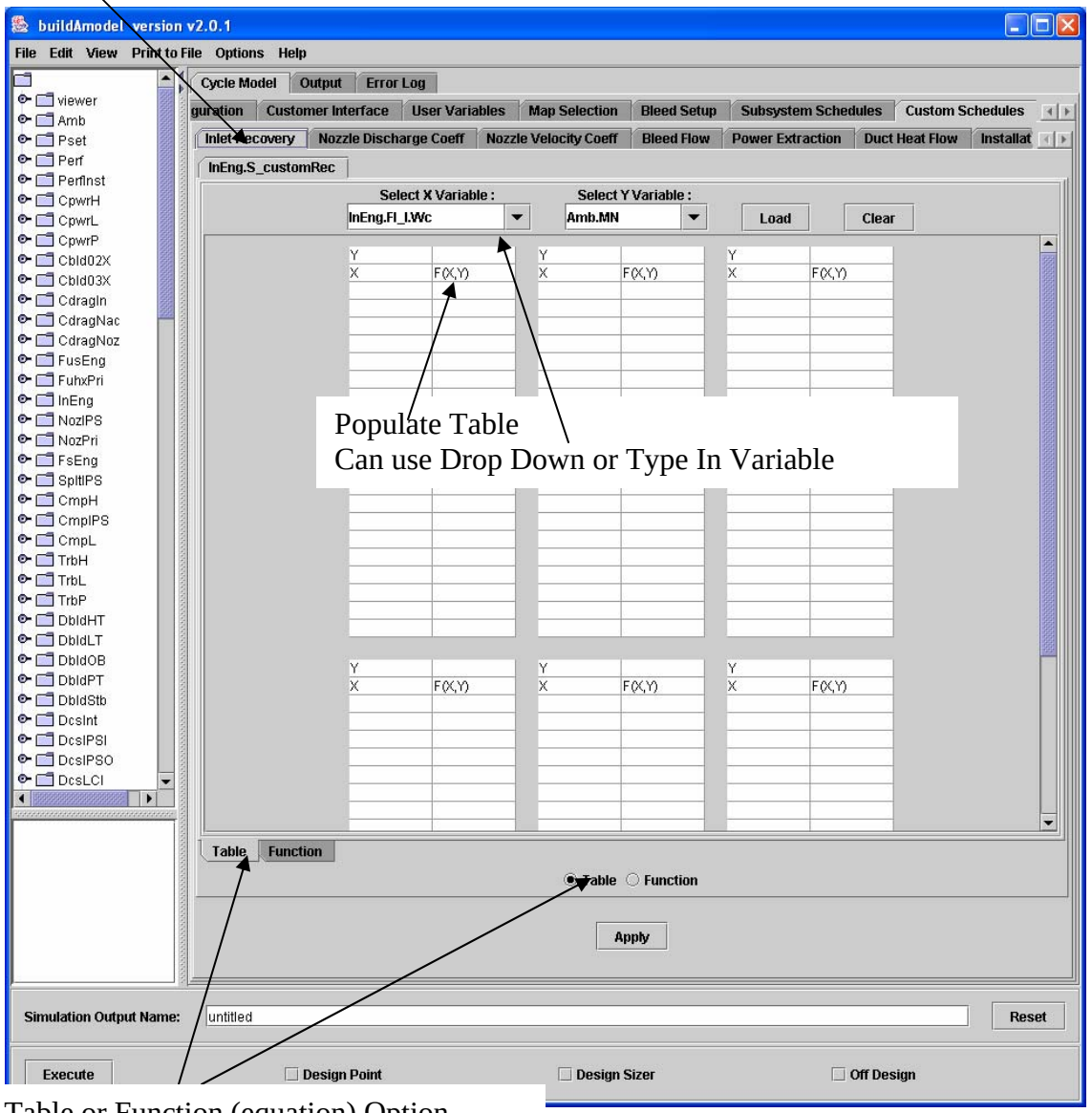


Figure 8: Additional Schedules Panel Overview

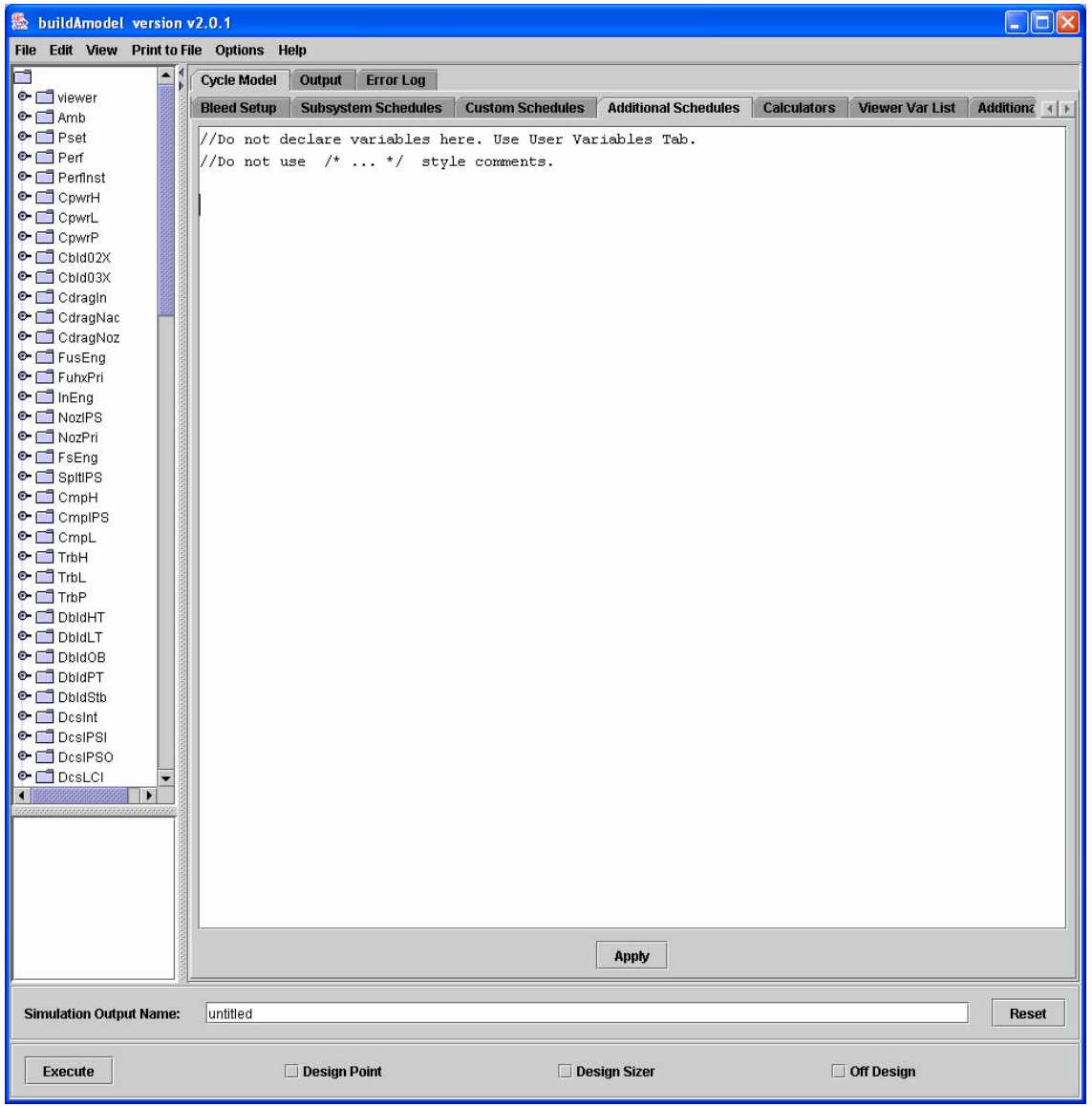


Figure 9: Calculators Panel Overview

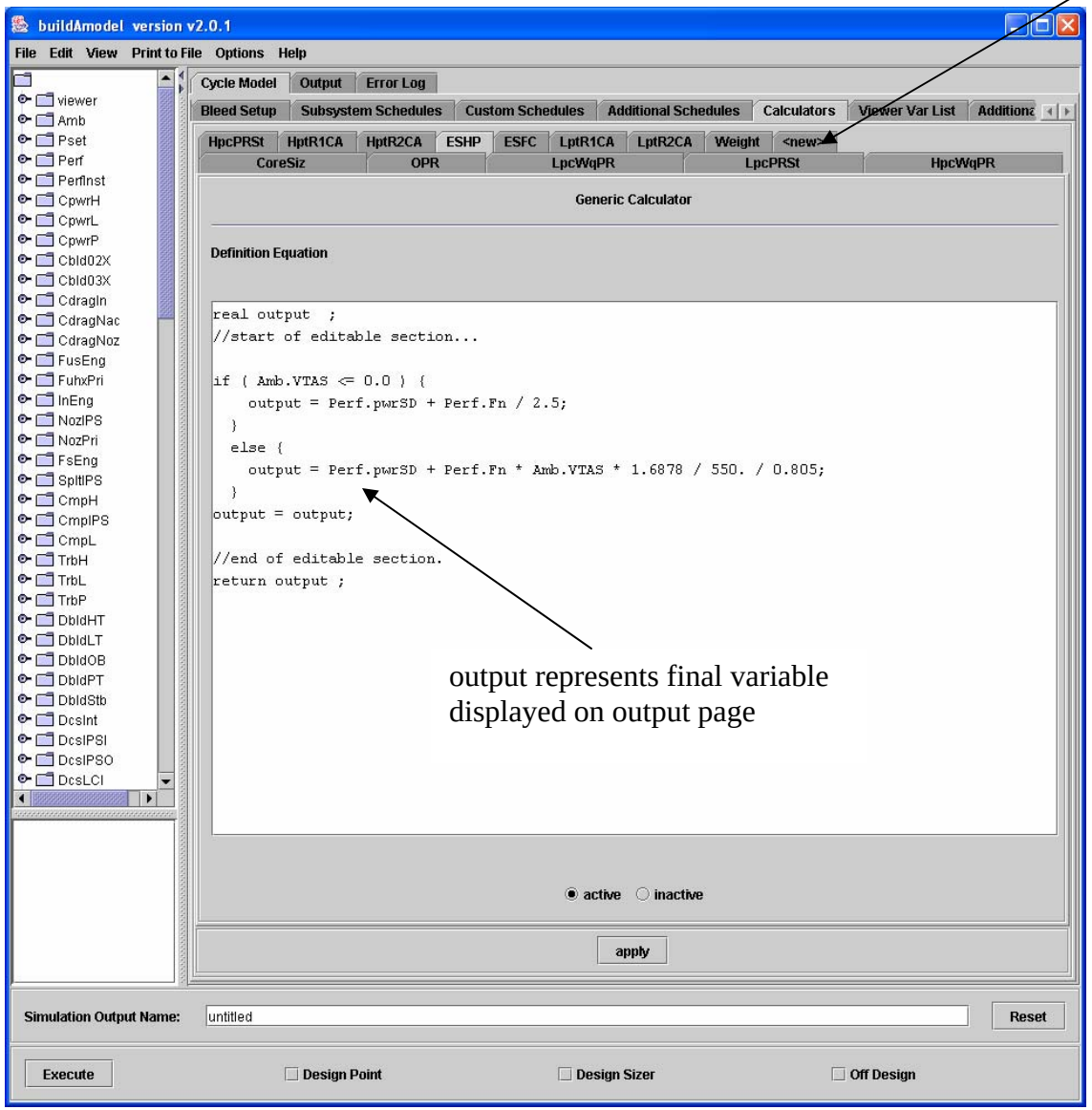


Figure 10: Viewer Variable List Panel

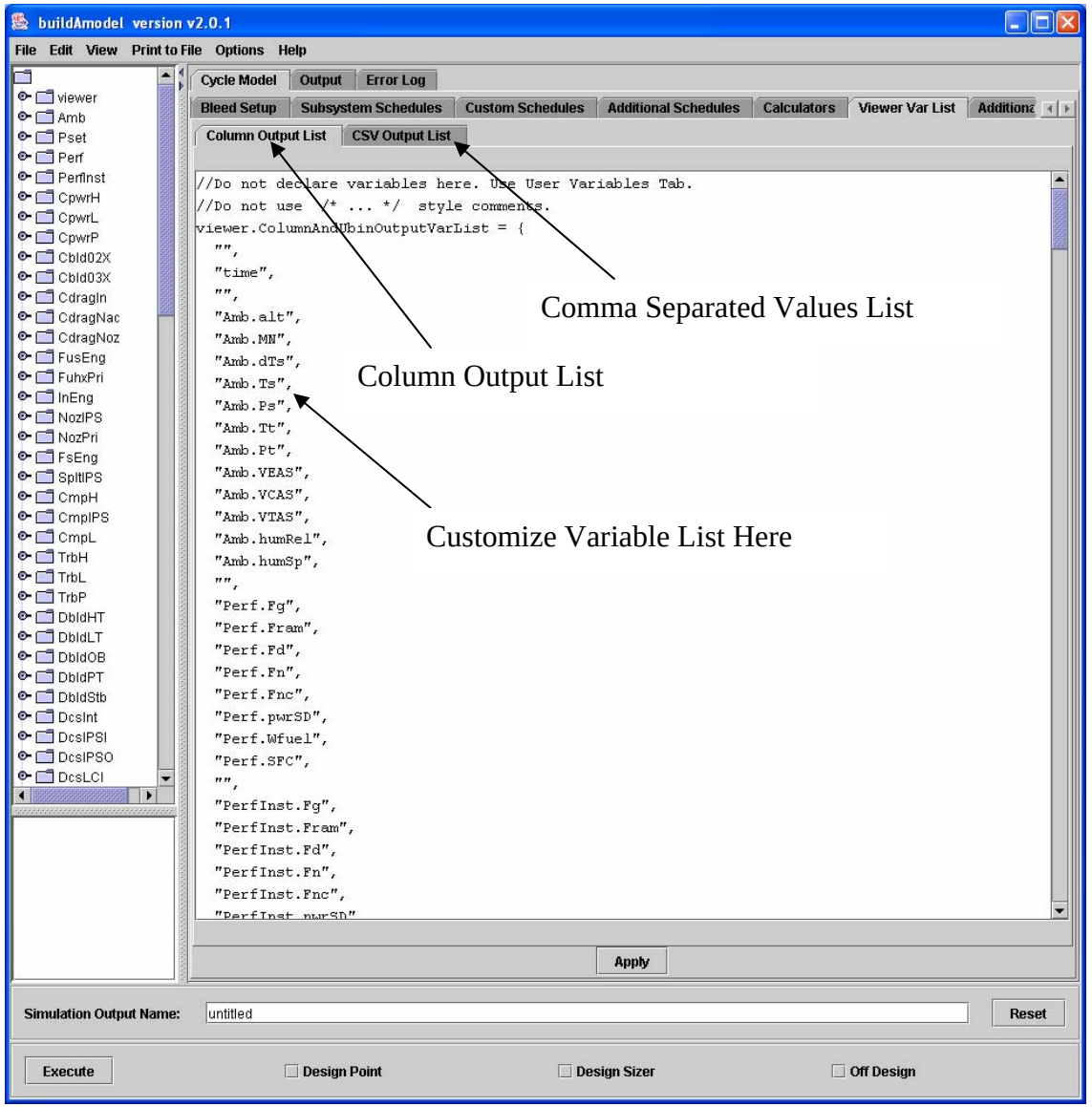


Figure 11: Additional Balances Panel Overview

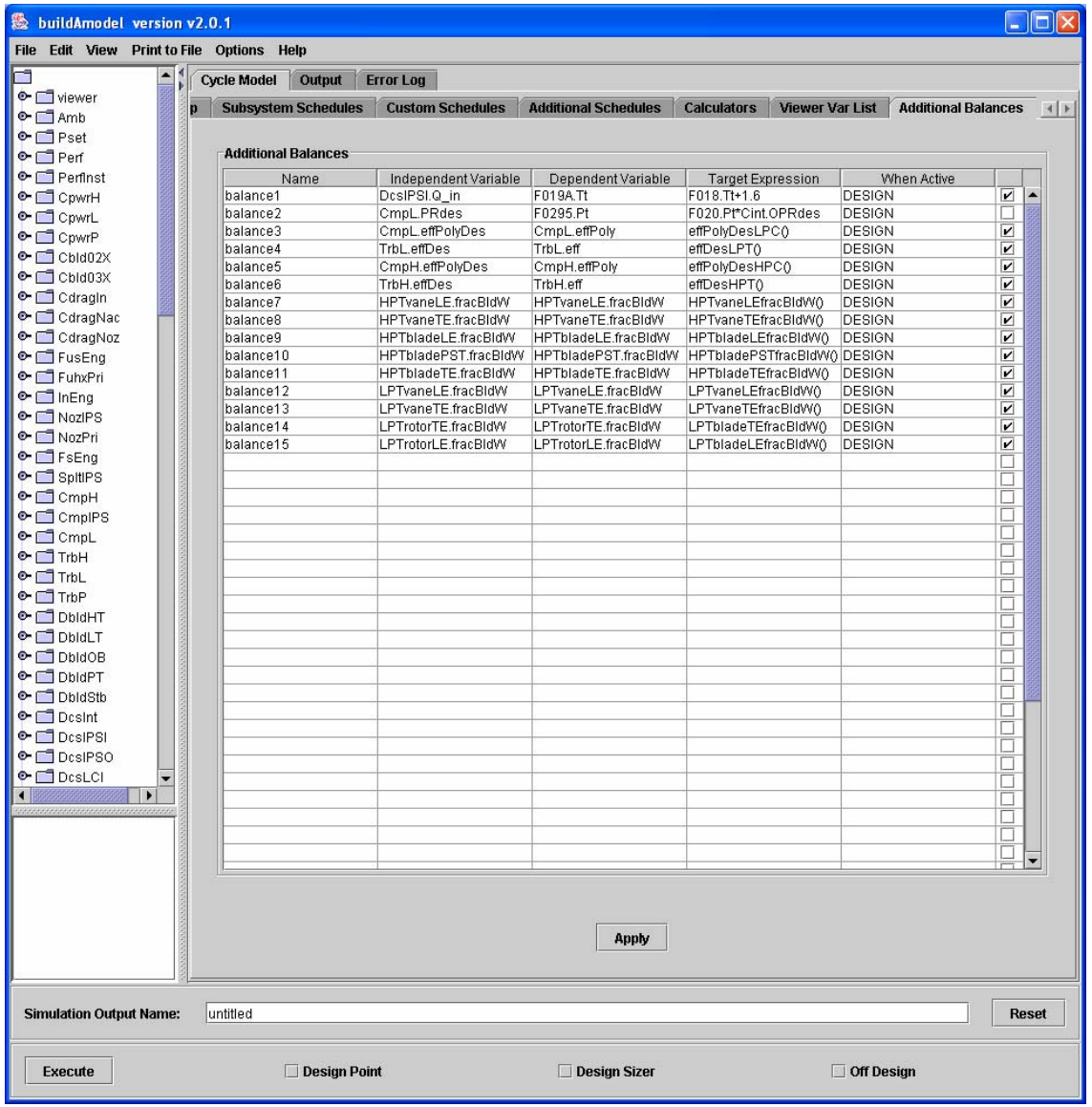
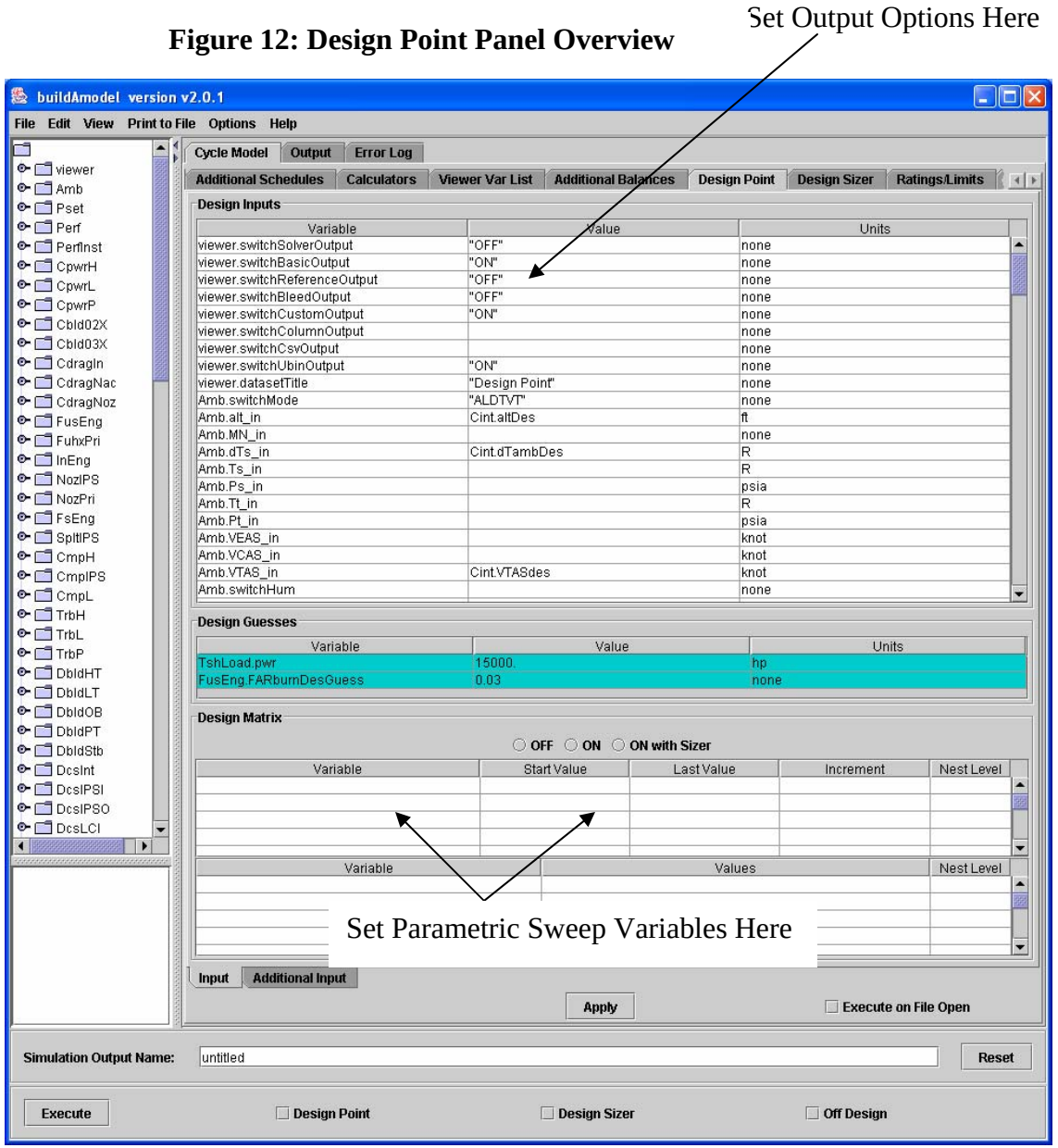


Figure 12: Design Point Panel Overview



Select Points to Set Titles

Figure 13: Design Sizer Panel Overview

Set Title Here

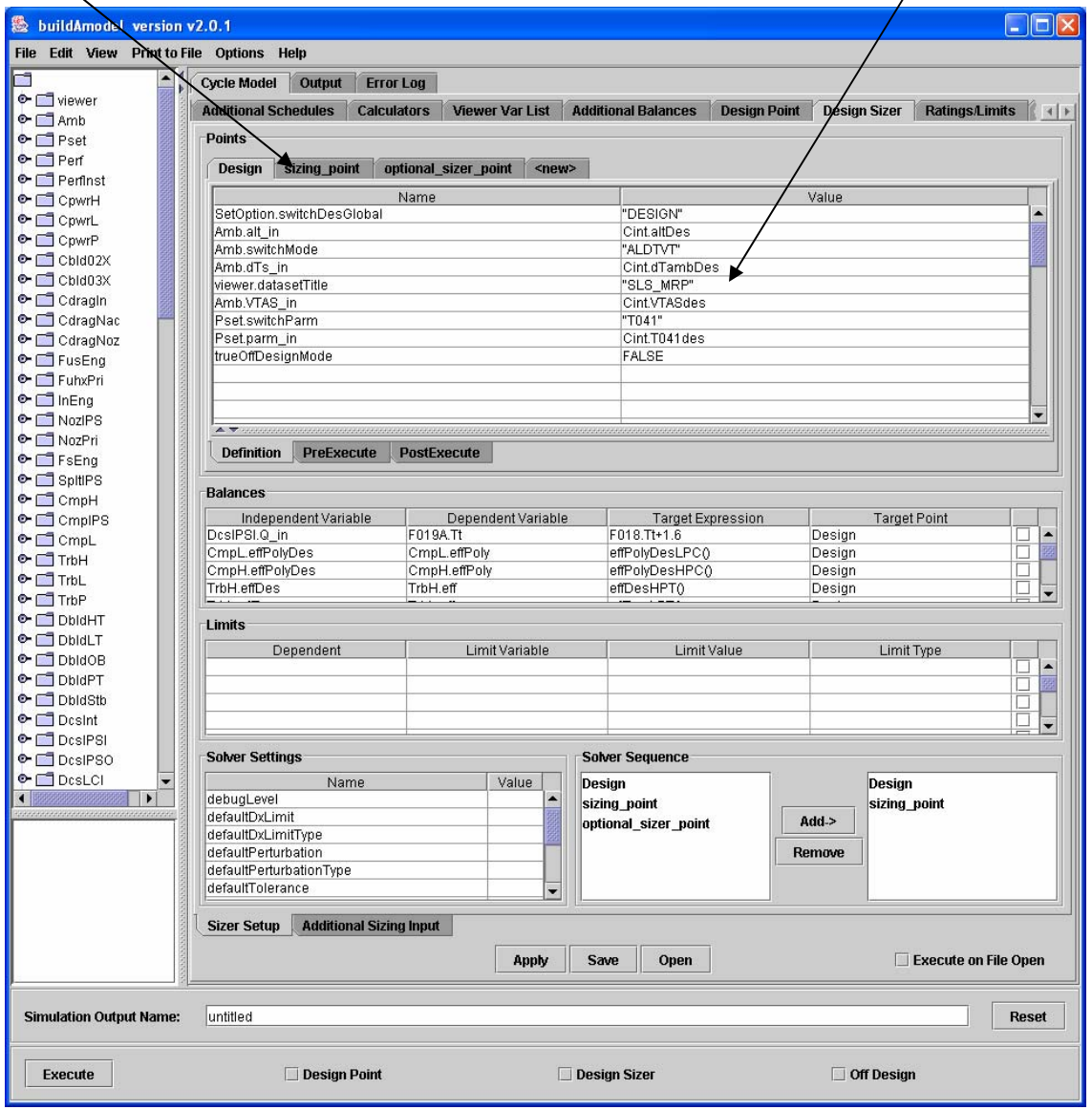


Figure 14: Ratings and Limits Panel Overview

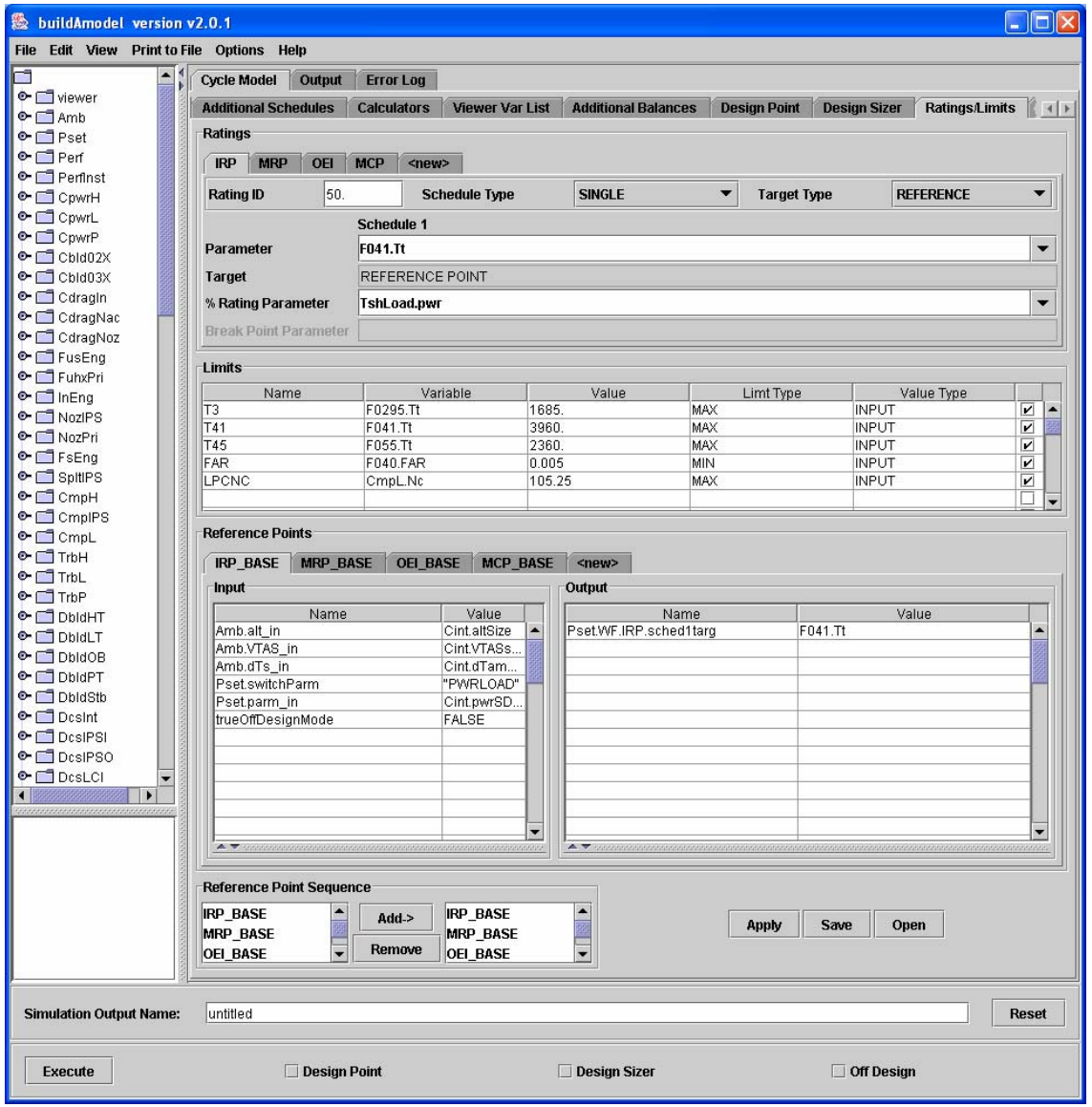


Figure 15: Off-Design Panel Overview

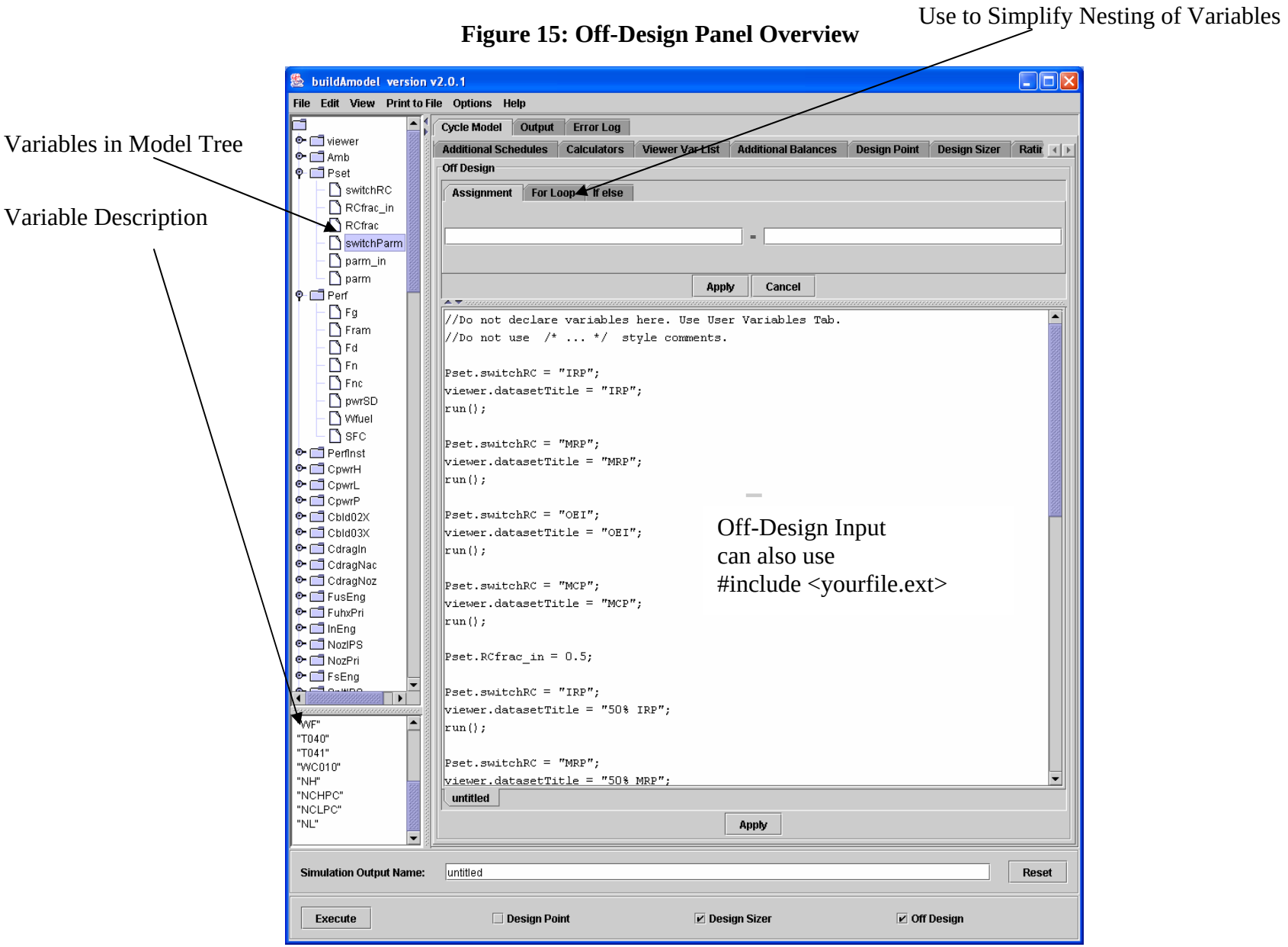


Figure 16: Output Panel Overview

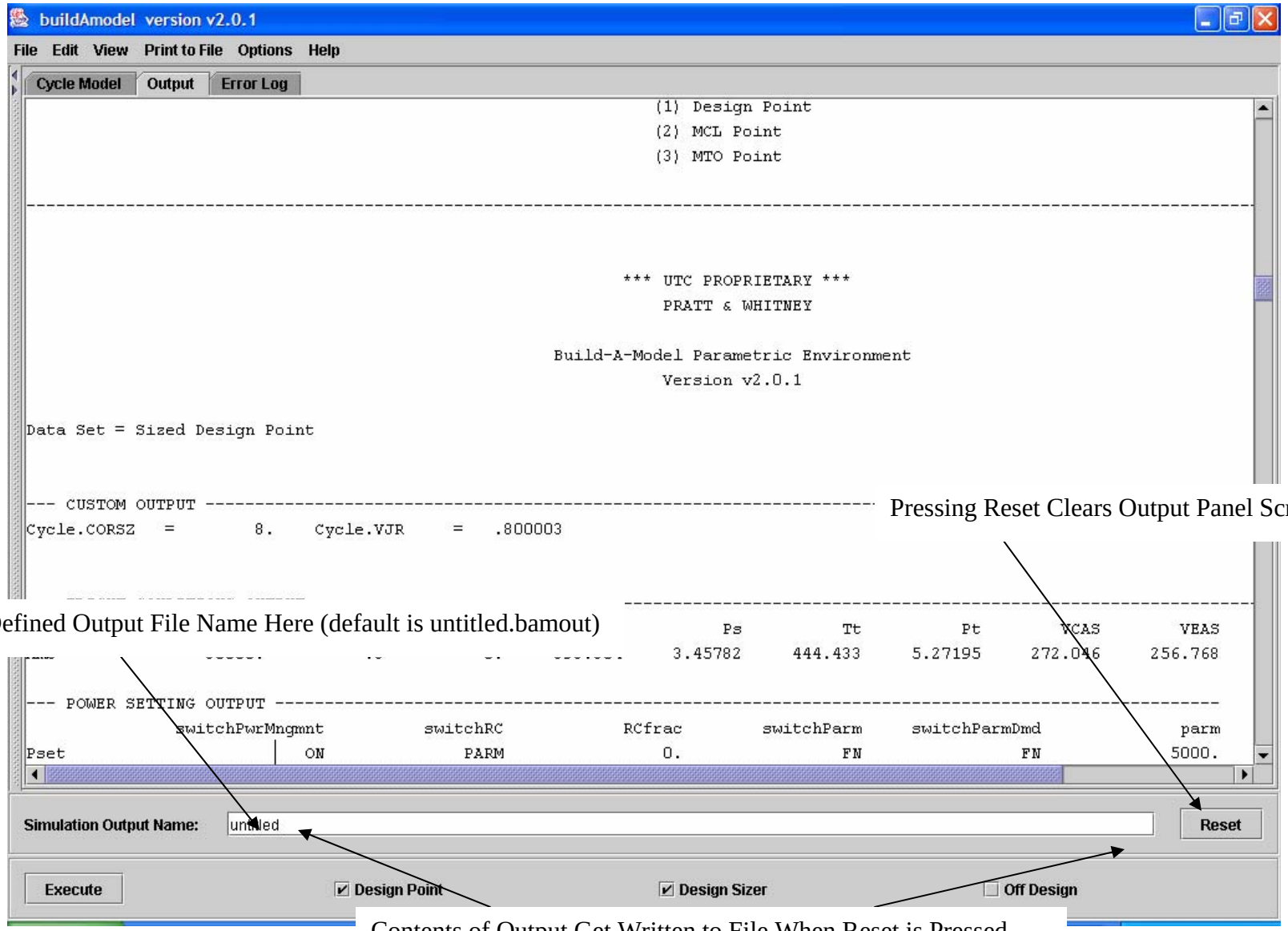
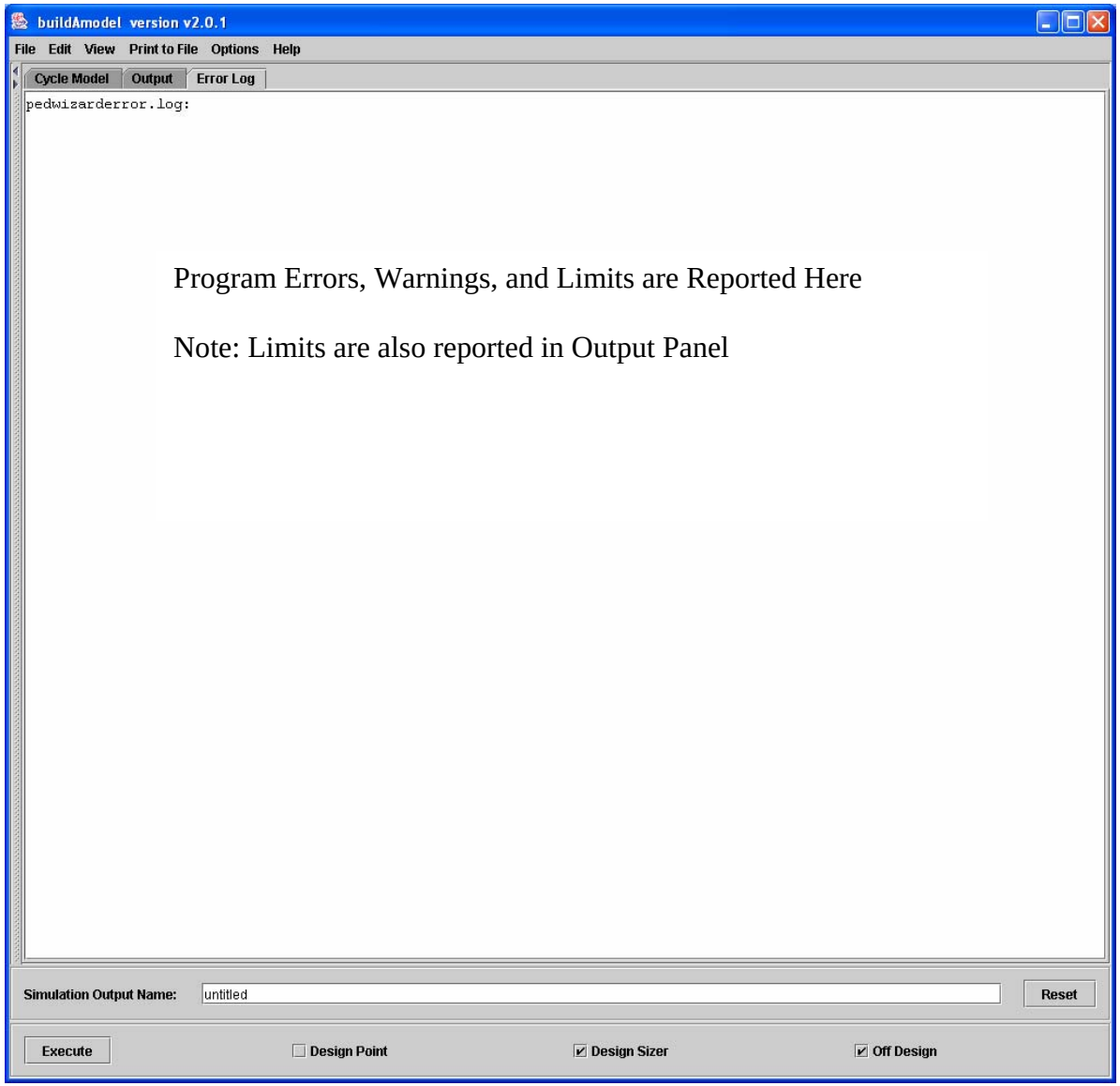


Figure 17: Error Log Panel Overview



Intentionally Left Blank