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# Enhancements to the Engine Data Interpretation System (EDIS)


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**Prepared for:**

George C. Marshall Space Flight Center
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16. Abstract

The Engine Data Interpretation System (EDIS) expert system project assists the data review personnel at NASA/MSFC in performing post-test data analysis and engine diagnosis of the Space Shuttle Main Engine (SSME). EDIS uses knowledge of the engine, its components, and simple thermodynamic principles instead of, and in addition to, heuristic rules gathered from the engine experts. EDIS reasons in cooperation with human experts, following roughly the pattern of logic exhibited by human experts. EDIS concentrates on steady-state static faults, such as small leaks, and component degradations, such as pump efficiencies. The objective of this contract was to complete the set of engine component models, integrate heuristic rules into EDIS, integrate the Power Balance Model into EDIS, and investigate modification of the qualitative reasoning mechanisms to allow "fuzzy" value classification. The result of this contract is an operational version of EDIS. EDIS will become a module of the Post-Test Diagnostic System (PTDS) and will, in this context, provide system-level diagnostic capabilities which integrate component-specific findings provided by other modules.

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## 1. Introduction

The Engine Data Interpretation System (EDIS) expert system project was conceived with the goal to assist the data review personnel at NASA/MSFC in performing post-test data analysis and engine diagnosis of liquid propulsion engines exemplified by the Space Shuttle Main Engine (SSME). EDIS was to use knowledge of the engine, its components, and simple thermodynamic principles instead of, or in addition to, heuristic rules gathered from the engine experts. EDIS was to reason in cooperation with human experts, following roughly the pattern of logic exhibited by human experts. EDIS concentrates on steady-state static faults, such as small leaks, and component degradations, such as pump efficiencies, which do not require immediate shutdown or similar drastic actions. EDIS systematically analyzes the behavior of each component of the SSME, searching for a plausible explanation of the observed data anomalies. Triggered by tell-tale anomalies and expert-defined fault expectations EDIS hypothesizes a fault and then attempts to prove that this fault is consistent with the rest of the data.

EDIS is not meant to replace review personnel but to facilitate their work. EDIS is capable of providing a "second opinion" that can be contrasted with human data interpretations. EDIS is methodical and will detect inconsistencies of a fault hypothesis with the data. It can thus also be used to verify hypotheses proposed by review personnel. (The required interface features for this type of behavior have yet to be added though.)

A limited prototype of a knowledge-based post-test data analysis and fault diagnosis system for the space shuttle main engine had been constructed under a previous contract. That system demonstrated the validity of our qualitative model-based reasoning approach to general engine diagnostic applications. Earlier versions of EDIS also performed anomaly detection but the current version expects a set of anomalies as input. An independent module provided by NASA from a different contract, the PTDS (Post-Test Diagnostic System), will provide this data. EDIS will become a module of the PTDS and will, in this context, provide system-level diagnostic capabilities which integrate component-specific findings provided by other modules. EDIS may be used to reconcile hypotheses generated by specialist modules with the behavior of the engine as a whole.

The objective of this contract was to initiate another phase of development of EDIS, to be used to create a complete, useable prototype that will successfully interact with existing numerical models. Four specific tasks were identified as listed below. We have successfully addressed all the tasks of the contract as explained below. The list of tasks and a short statement of the results of each task appear in the next section. The following sections explain the concepts and implementation of our solutions in more detail. We continue with an example, list some known problems, make some suggestions for future work which would enhance the present EDIS system, and give our conclusions. Several appendices contain source code (only available in the master copy) and example data.

## 2. Tasks

**Task 1:** Complete the set of engine component models. Gather NASA MSFC engine systems expertise, and apply to the constraint representation using the NEXPERT software tool.

*Results:* Completed (see Section 3). Refinements may be needed.

**Task 2:** Integrate heuristic rules into EDIS. Subject existing leak rules to critique by NASA engineers. Modify the heuristic evaluation function to apply the heuristics. Incorporate the capability for the user to enter specific information regarding faults and as well as influence the heuristic evaluation function.

*Results:* Mostly completed (see Section 6). Rules were extracted from interview transcripts prepared by engineers from MSFC, LeRC, Aerojet, and Sverdrup. User input must occur through the NEXPERT developer's interface because the Motif-based UIF is not available yet. This is not really practical.

**Task 3:** Integrate the Power Balance Model into EDIS. Manipulate data to be accessible by NEXPERT.

*Results:* Mostly completed (see Section 7). Data has to be transferred and formatted manually.

**Task 4:** Investigate modification of qualitative reasoning mechanisms to allow uncertainty for value classification. Use fuzzy logic to describe uncertainty.

*Results:* A methodology was developed (see Section 8) but no complete diagnostic system has been coded yet.

## 3. Component Models

The EDIS system contains a collection of basic thermodynamic components from which arbitrary systems can be configured. The configuration is read by EDIS at the start of processing from a specified sub-directory.

Each component type is associated with a specific file. The file names for the components are listed with the description of the component models which follows. The SSME configuration is described in detail in section 5

Component models have two major parts; one part, the structural part, describes the interconnections among components, and another part, the behavioral part, specifies the ways in which a component may be behaving. In addition, faults which affect component types are described in terms of deviant behavior and their relative likelihoods are specified. Structural and behavioral model templates are each organized in a class hierarchy. Figures 1 and 2 show the two hierarchies. The behavioral type hierarchy is very shallow because the behavior

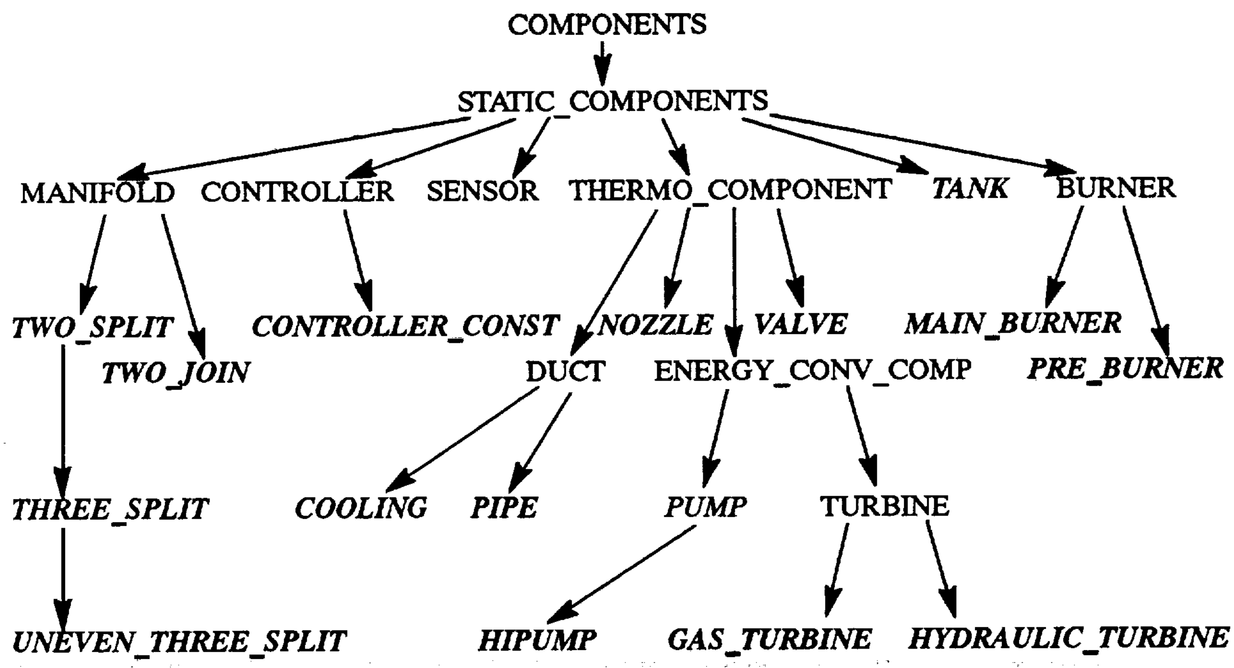
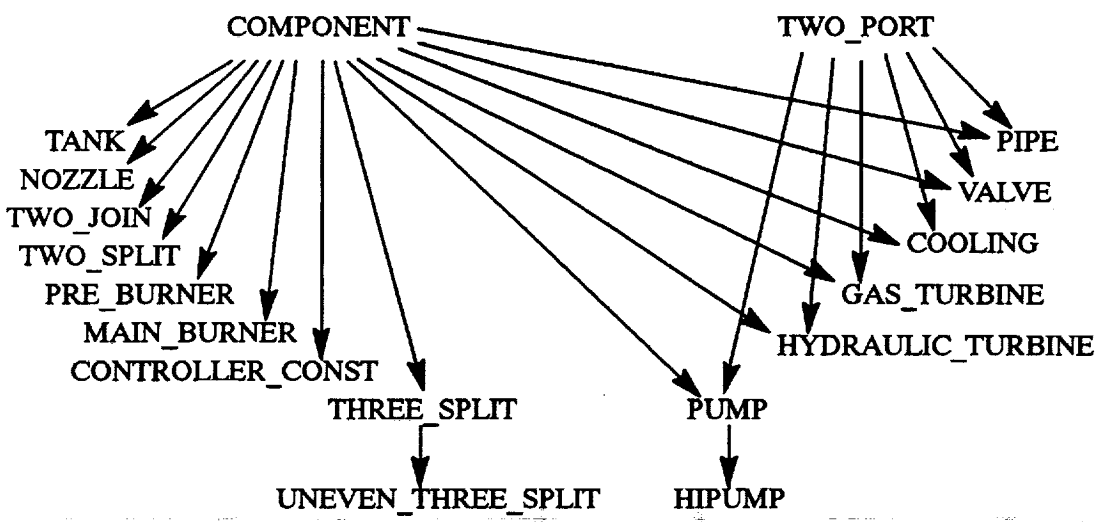



Figure 1: Hierarchy of Structural Component Types. Abstract types are shown in roman font, types for which instances are defined are shown in bold italics.

of each type is represented using type-specific rules and no inheritance mechanism exists among rules. Most behavior rules, however, make use of common building blocks to describe component behavior. These building blocks are derived from the constraint types used in defining component behavior, see below.

The behavioral model associates with each component a set of qualitative-valued parameters whose values represent the momentary behavior of the component. Normal component behavior is characterized by a set of constraints associated with the component. For steady-state analysis these constraints can be derived from conservation laws. For example, a pipe in a thermodynamic system carrying fluid is characterized by the difference of the energies of the fluid entering and leaving the pipe caused by friction, and a pump transforms mechanical energy supplied to its shaft into fluid energy. Commonly, parameters representing energy cannot be measured directly but are derived from constituent parameters. For example, fluid energy depends on pres-




Note: Every class shown by its name "NAME", e.g. PIPE, in this graph is actually called "NAME"_BEHAVIOR, e.g. PIPE_BEHAVIOR, in the program code. The suffix "_BEHAVIOR" is omitted to enhance readability.

Figure 2: Hierarchy of Behavioral Component Types

sure, height, and flow rate. In steady–state, only deviations from normal values are of interest. Therefore, the parameter values may be restricted to the qualitative values **NORMAL, LOW, HIGH,** and the special label **Unknown**. Also, the conservation equations may be simplified, e.g. by linearizing, or may even be transformed into qualitative confluences [1].

Parameters associated with a component fall into one of two categories, measurable and derived. Derived parameters are related to measurable parameters through relations which do not depend on the state of the component, called "mathematical constraints" (M.C.). Relations between parameters representing energies and other conserved quantities are called "fundamental constraints" (F.C.) and characterize component behavior modes. After simplification, linearization, and transformation into the qualitative domain, constraint expressions are called "incremental qualitative constraints" (IQCs).

It has been shown by Kalagnanam et al. [7] that the ordinal properties of the involved quantities do not change even under such strong simplifications as long as the simplifying transformations are monotonic. Our simplifications and transformations from quantitative to qualitative models therefore preserve relative magnitude of parameter values. If, for example, the qualitative model predicts an increase in value then the quantitative model (if it existed) would also predict an increase. Invariance of ordinal properties in essence guarantees that qualitative values are predicted correctly by IQC's.

Five types of IQCs are defined. The two–place relation "proportional" ($\wp$/2), the three–place relations "qualitative–synergy" ($\oplus$/3), "qualitative–antagonism" ($\ominus$/3), and "qualitative–optimum" ($\odot$/3), and the four–place qualitative–synergy ($\oplus$/4), an extension of the three–place synergy. These relations are best defined using relation tables. The four–place qualitative synergy is not listed because it can be derived from its three–place version.

$$\oplus(A,B,C,D) = \left\{(A_i,B_j,C_k,D_l) \mid \exists x : \oplus(x,B_j,C_k) \wedge \oplus(A_i,x,D_l),\ x \in \{LOW, NORMAL, HIGH\}\right\} \quad \text{(eq. 1)}$$

The NEXPERT implementation uses explicit representations for three– and four–place relations; they are stored as sets of tuples in files gtypei.nxp (⊕/3), gtypeii.nxp (⊖/3), gtypeiii.nxp (⊕/4), and gtypeiv.nxp (⊙/3). In these files parameters have generic names A, B, C, and D. Three–place relations are to be read as ○(A,B,C) or equivalently (B ○ C) → A, and four–place relations as ○(A,B,C,D) or (B ○ C ○ D) → A.

**Relation ℘**

| ℘ | |
|---|---|
| LOW | LOW |
| NORMAL | NORMAL |
| HIGH | HIGH |

**Relation ⊕/3**

| B ⊕ C →A | C | | |
|---|---|---|---|
| B | LOW | NORMAL | HIGH |
| LOW | LOW | LOW | LOW, NORMAL, HIGH |
| NORMAL | LOW | NORMAL | HIGH |
| HIGH | LOW, NORMAL, HIGH | HIGH | HIGH |

**Relation ⊖/3**

| B ⊖ C →A | C | | |
|---|---|---|---|
| B | LOW | NORMAL | HIGH |
| LOW | LOW, NORMAL, HIGH | LOW | LOW |
| NORMAL | HIGH | NORMAL | LOW |
| HIGH | HIGH | HIGH | LOW, NORMAL, HIGH |

**Relation ⊙/3**

| B ⊙ C →A | C | | |
|---|---|---|---|
| B | LOW | NORMAL | HIGH |
| LOW | NORMAL | LOW | LOW |
| NORMAL | LOW | NORMAL | LOW |
| HIGH | LOW | LOW | NORMAL |

For example, the pressure difference in a pipe is derived from input and output pressures via a mathematical constraint. Fluid velocity in the pipe determines energy loss due to friction. The energy balance between input and output of the pipe is expressed by a balance between fluid velocity $V$ and pressure difference $p_{diff}$. This balance is captured by the fundamental constraint $V = p_{diff}$. The fact that the pipe does not normally leak (pipe branches are represented separately) is expressed by the F.C. ***Inflow = Outflow***, derived from mass conservation.

Behaviors of connected components are interrelated through the parameters shared at the interface between components. For example, if a pipe is connected to a pump, fluid pressure, temperature, and velocity at the pipe output are identical to fluid pressure, temperature, and velocity at the pump input. Note that although in fluid systems inputs and outputs can be distinguished, the constraint model is non–directional. Connection constraints are simply equality constraints on the qualitative values. In the following sections we will develop models of all the component types implemented in EDIS.

One of the important features of EDIS is that the models can express that certain behaviors are physically impossible under reasonable assumptions. For example, no heat or energy is transferred to the fluid or gas except where explicitly specified. No mass can be introduced into the system except from the tanks. These additional "physical constraints" help in reducing the number of assumptions which may realistically be made about component and system behavior.

The heuristic evaluation function implemented in EDIS matches component behaviors against fault modes specific to each component. If the behavior matches a fault mode, its likelihood is adjusted to reflect the likelihood of the matching fault mode. We have defined a small set of fault modes and we will note in the discussion of each component type what fault modes are currently being tested for.

### 3.1 Component Type PIPE

The behavior of a pipe is characterized by energy conservation, see equations (2) and (3), and a mass conservation equation (4) between the pipe inlet and the pipe outlet. We assume that any possible changes in inlet and outlet temperatures are irrelevant to the diagnosis, see equation (5). A separate model for cooling ducts models temperature changes caused by heat transfer.

$$\frac{V_{in}^2}{2g} + z_{in} + \frac{p_{in}}{\gamma} - E_{Loss} = \frac{V_{out}^2}{2g} + z_{out} + \frac{p_{out}}{\gamma} \qquad \text{(eq. 2)}$$

$$E_{Loss} = f\,\frac{V^2}{2g}\,\frac{L}{D} \qquad \text{(eq. 3)}$$

$$\gamma_{in} A_{in} V_{in} = \gamma_{out} A_{out} V_{out} \qquad \text{(eq. 4)}$$

$$\dot{Q}_{in} = \dot{Q}_{out} \qquad \text{(eq. 5)}$$

$\overline{V}$ = average fluid velocity

$V$ = fluid velocity

$g$ = gravitational constant

$z$ = height

$p$ = pressure

$\gamma$ = density

$L$ = pipe length

$D$ = pipe diameter

$f$ = friction coefficient

$A$ = pipe cross-sectional area

$\dot{Q}$ = heat flow rate

After linearization and simplification equations (2) through (5), reduce to (6) through (8) respectively. The delta operator ($\Delta$) indicates incremental (small signal) change and K is a constant which depends on the operating point, the pipe dimensions, and the friction coefficient.

$$\Delta\left(p_{in} - p_{out}\right) = K \cdot \Delta\overline{V} \qquad \text{(eq. 6)}$$

$$\Delta V_{in} = \Delta V_{out} \qquad \text{(eq. 7)}$$

$$\Delta T_{in} = \Delta T_{out} \qquad \text{(eq. 8)}$$

T = temperature

The essence of these equations, which is captured by IQC's, is that the pressure difference between inlet and outlet is proportional to the velocity, and that the input velocity is proportional to the output velocity as long as the pipe is operating correctly. Also, Temperature changes at the input are passed through the pipe unchanged. Faults which could invalidate the constraints are pipe leaks and obstructions, for example. Finally, we can formulate the IQCs. Note that all parameters in the IQCs represent small changes from an operating point.

**Fundamental Constraints:**

$$p_{diff} \wp \overline{V} \qquad \text{(eq. 9)}$$

$$V_{in} \wp V_{out} \qquad \text{(eq. 10)}$$

**Mathematical Constraints:**

$$p_{in} \ominus p_{out} \rightarrow p_{diff} \qquad \text{(eq. 11)}$$

$$V_{in} \oplus V_{out} \rightarrow \overline{V} \qquad \text{(eq. 12)}$$

**Assumptions:**

In addition, some simplifying assumptions are being made.

$$T_{in} = T_{out} \qquad \text{(eq. 13)}$$

**Physical constraints:**

$$V_{out} \leqq V_{in} \qquad \text{(eq. 14)}$$

**Fault modes:**

| | |
|---|---|
| Leak: | $V_{out} < V_{in}$ |
| Obstruction: | $p_{diff} > \nabla$ |

### 3.2 Component Type COOLING

A cooling duct behaves like a pipe except that heat is transferred into the medium (fuel in our case) from the cooled component. We made a major simplification and assumed that the temperature $T_{source}$ of the cooled component is not changed by changes in the temperature and flow of medium in the cooling duct. Feedback from the cooling duct to the cooled component is not modeled. All constraints, assumptions, and fault modes of component type PIPE apply and the following constraints are added. Changes in temperature increase from cooling duct input to cooling duct output are positive for increases in heat inflow ($\dot{Q}_{in}$) and negative for increases in mass flow rate through the cooling duct ($\overline{V}$) (eq. 15). Heat inflow is determined by the temperature difference between $T_{source}$ and $T_{in}$ (eq. 16).

**Mathematical Constraints:**

$$\dot{Q}_{in} \ominus \nabla \rightarrow T_{diff} \qquad \text{(eq. 15)}$$

$$T_{source} \ominus T_{in} \rightarrow \dot{Q}_{in} \qquad \text{(eq. 16)}$$

$$T_{out} \ominus T_{in} \rightarrow T_{diff} \qquad \text{(eq. 17)}$$

In the implementation we neglect changes in cooling duct input temperature ($T_{in}$) because $T_{source}$ is much larger than $T_{in}$. Then, changes in heat inflow are equivalent to changes in heat source temperature ($T_{source}$) and (eq. 15) and (eq. 16) simplify to (eq. 18).

$$T_{source} \ominus \overline{V} \rightarrow T_{diff} \qquad \text{(eq. 18)}$$

### 3.3 Component Type VALVE

The model for component type VALVE is similar to the PUMP model except that the pressure difference between input and output now also depends on valve position. We assume that temperature does not change between input and output and we do not allow for leaks in a valve, i.e. input and output massflow rate are identical. We model the translation of the valve position command into the actual measured position by (eq. 20). Valve failure can occur if the valve is blocked, for example, and (eq. 19) is violated, or if the valve does not respond correctly to the position command from the controller and (eq. 20) is violated. Next, we list the complete set of constraints for type VALVE.

**Fundamental Constraints:**

$$p_{diff} \wp \nabla \ominus \text{position} \qquad \text{(eq. 19)}$$

$$\text{position} \wp \text{commanded\_position} \qquad \text{(eq. 20)}$$

**Mathematical Constraints:**

$$p_{in} \ominus p_{out} \rightarrow p_{diff} \qquad \text{(eq. 21)}$$

**Assumptions:**

$$T_{in} = T_{out} \qquad \text{(eq. 22)}$$

$$V_{in} = V_{out} = \bar{V} \qquad \text{(eq. 23)}$$

**Physical constraints:**

$$p_{diff} \geqq \bar{V} \ominus \text{position} \qquad \text{(eq. 24)}$$

**Fault modes:**

Blockage: $p_{diff} > \bar{V} \ominus \text{position}$

Servo fault: $\text{position} \neq \text{commanded\_position}$

### 3.4 Component Type PUMP

To analyze a pump we again start with the energy balance equation (eq. 25), i.e. the first law of thermodynamics, this time written as a rate equation for a steady-state, steady-flow process. We neglect potential energy.

$$\dot{W} + \dot{Q} + \dot{m}_{in}\left[p_{in}v + \frac{V_{in}^2}{2}\right] = \dot{m}_{out}\left[p_{out}v + \frac{V_{out}^2}{2}\right] \qquad \text{(eq. 25)}$$

$\dot{Q}$ = heat transfer rate

$\dot{m}$ = mass flow rate

$\dot{W}$ = incoming power

$V$ = fluid velocity

$v$ = specific volume

The mass balance demands

$$\dot{m}_{in} = \dot{m}_{out} = \dot{m} \qquad \text{(eq. 26)}$$

Assuming an adiabatic process where $\dot{Q} = 0$ and letting $V_{in} = V_{out}$ gives

$$\dot{W} = \dot{m}(p_{out} - p_{in})v \qquad \text{(eq. 27)}$$

Next we can replace $\dot{m}v$ by AV, where A is the pipe cross-sectional area and V is fluid velocity, and get

$$\dot{W} = (p_{out} - p_{in})AV \qquad \text{(eq. 28)}$$

We now introduce the qualitative variables MechPWR and PV_Product which stand for the expressions on either side of equation (eq. 28). In addition to equation (eq. 28) we have a relation between input and output mass flow rates from equation (eq. 26) and a relation between the rotational speed of the pump ($\omega$) and the effective velocity of the fluid through the pump ($\bar{V}$) (eq. 29). An analysis of several data sets collected during test firings of the SSME shows, however, that this relation does not hold for the low pressure pumps. We must assume that turbulence and seal leakage have a large effect on this relation. It is therefore ignored for type PUMP but enforced for type HIPUMP which is used to represent the behavior of the high pressure pumps.

$$\nabla = K\omega \quad \text{(eq. 29)}$$

Also, we are not modeling leak faults in a pump. Leaks are only considered in pipes and cooling ducts. Therefore, the mass balance which was a fundamental constraint for type PIPE now becomes an assumption. Again, we ignore changes in temperature within the pump. Nevertheless, it may be advantageous to describe pump inefficiencies by the temperature rise they cause in the fluid being pumped. Pump efficiency faults may be easier to represent and find using such an extended model. We are considering this enhancement for the future.

Mechanical power (MechPWR) can be derived from shaft speed ($\omega$) and torque (Tq) (eq. 32), the pressure difference ($p_{diff}$) as before from $p_{in}$ and $p_{out}$ (eq. 34), and PV_Product from fluid velocity ($\nabla$) and pressure difference ($p_{diff}$) (eq. 33). In a pump, pressure difference is calculated as $p_{out}-p_{in}$, a positive quantity. The behavioral model for a pump can now be formulated.

**Fundamental Constraints:**

$$\text{MechPWR} \wp \text{PV\_Product} \quad \text{(eq. 30)}$$

$$\nabla \wp \omega \quad \text{(eq. 31)}$$

**Mathematical Constraints:**

$$\text{Tq} \oplus \omega \rightarrow \text{MechPWR} \quad \text{(eq. 32)}$$

$$p_{diff} \oplus \nabla \rightarrow \text{PV\_Product} \quad \text{(eq. 33)}$$

$$p_{out} \ominus p_{in} \rightarrow p_{diff} \quad \text{(eq. 34)}$$

$$V_{in} \oplus V_{out} \rightarrow \nabla \quad \text{(eq. 35)}$$

**Assumptions:**

$$V_{in} = V_{out} \quad \text{(eq. 36)}$$

$$T_{in} = T_{out} \quad \text{(eq. 37)}$$

**Physical constraints:**

$$\text{MechPWR} \geqq \text{PV\_Product} \quad \text{(eq. 38)}$$

$$\omega \geqq \nabla \quad \text{(eq. 39)}$$

**Fault modes:**

| | |
|---|---|
| Impeller Problem: | $\omega > \nabla$ |
| Low Efficiency: | MechPWR > PV_Product |

### 3.5 Component Type HIPUMP

The type HIPUMP models the behavior of the high-pressure pumps used in the SSME. The high-pressure pumps produce an extremely large increase in pressure level from input to output. The qualitative model manipulates relative changes in parameter values and therefore has to be careful to interpret deviations with respect to the appropriate steady-state level. Pressure deviations at the input have two different reference levels, the low pressure-level of the upstream components and the high-pressure level of the downstream side. The pressure at the high-pressure pump input therefore may have two possible diverging interpretations, i.e. qualitative values. The parameter associated with the high-pressure pump holds a value which corresponds to the high-pressure level. The output pressure parameter of the upstream component holds the qualitative value with respect to the low-pressure level. In order to maintain these two interpretations the following changes were made to the PUMP model.

- Deviations at $p_{in}$ which were derived on the low pressure (upstream) side are ignored by the high-pressure pump.
- If analysis of the high-pressure pump predicts $p_{in}$ to be NORMAL, this value is not propagated to the upstream low-pressure component because a much finer scale is used there to detect anomalies.
- When analyzing the behavior of a high-pressure pump $p_{in}$ is never assumed to be LOW because such a deviation is either small enough to be neglected or serious enough to interfere with correct functioning of the SSME. EDIS only deals with "small" anomalies.
- If input pressure is measured the measured value is interpreted from the low-pressure side point of view.

In addition, another assumption holds for the high pressure pump type.

**Additional Assumption:**

$$\nabla = \omega \qquad \text{(eq. 40)}$$

### 3.6 Component Type HYDRAULIC_TURBINE

The behavioral model of type HYDRAULIC_TURBINE is identical to the PUMP model except that the pressure difference is taken from input to output. Also, the inequalities which characterize fault modes and physical constraints are inverted because mechanical power now leaves the component.

**Fundamental Constraints:**

$$\text{MechPWR} \ \wp \ \text{PV\_Product} \qquad \text{(eq. 41)}$$

$$\nabla \ \wp \ \omega \qquad \text{(eq. 42)}$$

**Mathematical Constraints:**

$$\text{Tq} \oplus \omega \rightarrow \text{MechPWR} \qquad \text{(eq. 43)}$$

$$p_{diff} \oplus \nabla \rightarrow \text{PV\_Product} \qquad \text{(eq. 44)}$$

$$p_{in} \ominus p_{out} \rightarrow p_{diff} \qquad \text{(eq. 45)}$$

$$V_{in} \oplus V_{out} \rightarrow \nabla \qquad \text{(eq. 46)}$$

**Assumptions:**

$$V_{in} = V_{out} \qquad \text{(eq. 47)}$$

$$T_{in} = T_{out} \qquad \text{(eq. 48)}$$

**Physical constraints:**

$$\text{MechPWR} \leqq \text{PV\_Product} \qquad \text{(eq. 49)}$$

$$\omega \leqq \nabla \qquad \text{(eq. 50)}$$

**Fault modes:**

Impeller Problem: $\omega < \nabla$

Low Efficiency: MechPWR < PV_Product

### 3.7 Component Type GAS_TURBINE

In a gas turbine the first law of thermodynamics equates mechanical power produced (MechPWR) to the difference in enthalpy of the gas entering and leaving the turbine ($h_{diff}$) (eq. 51). We are neglecting differences in gas velocity and assuming an ideal gas.

**Fundamental Constraints:**

$$\text{MechPWR} \;\wp\; h_{diff} \qquad \text{(eq. 51)}$$

$h_{diff}$= difference in enthalpy of entering and exhausted gas

**Mathematical Constraints:**

$$h_{in} \ominus h_{out} \rightarrow \text{MechPWR} \qquad \text{(eq. 52)}$$

$h_{in}$= enthalpy of gas entering the turbine

$h_{out}$= enthalpy of gas leaving the turbine

**Assumptions:**

$$V_{in} = V_{out} = \nabla \qquad \text{(eq. 53)}$$

$$h_{in} = p_{in} = T_{in} \qquad \text{(eq. 54)}$$

$$h_{out} = p_{out} = T_{out} \qquad \text{(eq. 55)}$$

**Physical constraints:**

$$\text{MechPWR} \leqq h_{diff} \qquad \text{(eq. 56)}$$

**Fault modes:**

Low Efficiency: MechPWR < $h_{diff}$

### 3.8 Component Type PRE_BURNER

A pre–burner produces a fuel–rich hot gas through incomplete combustion which drives a high–pressure turbo–pump and which eventually reaches the main combustion chamber where it is burned completely. The equations which govern the combustion process are once again derived from energy balance equations. The enthalpy created in the incomplete combustion process, i.e. the enthalpy of formation of the steam produced, can be simplified to a linear function of the mixture ration (MR). Enthalpy is determined from temperature under ideal gas conditions. The complete enthalpy balance equates enthalpy of the products ($h_{out}$) to the product of mixture ratio (MR) and mean inflow temperature ($\overline{T}$). We linearize and simplify this product relation and rewrite it as an incremental qualitative–synergy of mixture ratio (MR) and mean inflow temperature ($\overline{T}$) (eq. 57). Mass conservation equates input flows ($V_{ox}$, $V_{fuel}$) with output flow ($V_{out}$) (eq. 58).

**Fundamental Constraints:**

$$h_{out} \;\wp\; \text{MR} \oplus \overline{T} \qquad \text{(eq. 57)}$$

$h_{out}$ = output enthalpy of partially burned fuel

MR = mixture ratio (oxygen vs. fuel)

T = mean input temperature of oxygen and fuel

**Mathematical Constraints:**

$$V_{ox} \oplus V_{fuel} \rightarrow V_{out} \qquad \text{(eq. 58)}$$

$$V_{ox} \ominus V_{fuel} \rightarrow MR \qquad \text{(eq. 59)}$$

$V_{ox}$ = oxygen input mass flow rate

$V_{fuel}$ = fuel input mass flow rate

$$T_{ox} \oplus T_{fuel} \rightarrow T \qquad \text{(eq. 60)}$$

$T_{ox}$ = oxygen input temperature

$T_{fuel}$ = fuel input temperature

We observe that the output pressure produced by the preburner back–pressures the fuel input. We assume that changes in $p_{out}$ are translated directly into changes in $p_{in}$ since the pressure produced by the preburner is much higher than the fuel input pressure.

$$p_{out} \wp p_{in} \qquad \text{(eq. 61)}$$

$p_{in}$ = fuel input pressure

In the implementation, we assume that the controller will keep the fuel flow fairly constant and regulate oxygen flow to the preburners via the preburner oxygen valves. Thus the incremental quantity $V_{fuel}$ is zero and MR, i.e. changes in the mixture ratio, can be equated to $V_{ox}$, i.e. changes in oxygen input flow.

Simplification of (eq. 59) $\quad V_{ox} \wp MR \qquad$ (eq. 62)

**Assumptions:**

$$h_{out} = p_{out} = T_{out} \qquad \text{(eq. 63)}$$

**Physical constraints:**

$$h_{out} \leqq MR \oplus T \qquad \text{(eq. 64)}$$

**Fault modes:**

No fault modes are defined yet for the preburner. If lower than anticipated output enthalpy ($h_{out}$) was observed due to some problem with the combustion process itself then this behavior could be defined as a fault mode. Mixture ratio problems, however, are external to the preburner.

### 3.9 Component Type MAIN_BURNER

We modeled the main burner as if it were operating at optimal mixture ratio. Therefore our model predicts that any change to higher or lower mixture ratio will lead to lower engine output. This assumption appears to be wrong since the controller operation indicates that power still increases with oxygen flow and therefore with higher mixture ratios. Power also depends on the total amount of fuel and oxygen supplied to the main burner. Power is equated with output pressure, enthalpy, and temperature. The MAIN_BURNER type also has provisions to attach a cooling component to it.

**Fundamental Constraints:**

$$p_{out} \wp V_{balance} \oplus V_{out} \qquad \text{(eq. 65)}$$

$V_{balance}$=a quantity which represents the optimum mixture ratio

**Mathematical Constraints:**

$$V_{ox} \odot V_{fuel} \rightarrow V_{balance} \qquad \text{(eq. 66)}$$

$$V_{ox} \oplus V_{fuel} \rightarrow V_{out} \qquad \text{(eq. 67)}$$

**Assumptions:**

$$h_{out} = p_{out} = T_{out} \qquad \text{(eq. 68)}$$

**Physical constraints:**

$$p_{out} \leqq V_{balance} \oplus V_{out} \qquad \text{(eq. 69)}$$

**Fault modes:**

No fault modes are defined yet for the main burner. If lower than anticipated output power ($p_{out}$) was observed due to some problem with the combustion process itself then this behavior could be defined as a fault mode.

### 3.10 Component Type CONTROLLER_CONST

Type CONTROLLER_CONST models a controller which is supposed to keep a parameter value at a constant level, i.e. the parameter should have value NORMAL, by setting a control input parameter value appropriately. Such as controller is considered to be operating normally as long as the controlled parameter has value NORMAL. The CONTROLLER_CONST model has been specifically designed to model the fuel flow control system of the SSME. It is the least generic component of the system because input and output parameter names have to be defined in our models. Type CONTROLLER_CONST measures a parameter named $V_{in}$ and controls a component (usually a valve) through a parameter named “commanded_position.”

**Fundamental Constraints:**

$$V_{in} = \text{NORMAL} \qquad \text{(eq. 70)}$$

**Fault modes:**

Controller fault: $V_{in} \neq \text{NORMAL}$

### 3.11 Component Type TWO_SPLIT

Component type TWO_SPLIT models a pipe “T” with one input and two outputs. It does not include any straight pipe sections. We therefore assume that the pressures at all its terminals are equal, that the temperatures are equal and that the sum of outflows is equal to the inflow. No faults are associated with pipe splits and joins. Output ports are distinguished by labels A and B.

**Mathematical Constraints:**

$$V_{out\_A} \oplus V_{out\_B} \rightarrow V_{in} \qquad \text{(eq. 71)}$$

$V_{out\_A}$=output flow rate into port A

$V_{out\_B}$=output flow rate into port B

**Assumptions:**

$$T_{in} = T_{out\_A} = T_{out\_B} \quad \text{(eq. 72)}$$

$$p_{in} = p_{out\_A} = p_{out\_B} \quad \text{(eq. 73)}$$

### 3.12 Component Type THREE_SPLIT

Component type THREE_SPLIT is an extension of type TWO_SPLIT for the case of one input and three outputs. This type is not truly necessary and a component of type THREE_SPLIT could be replaced by a sequence of two components of type TWO_SPLIT. This type has been added for convenience, however. Output ports are distinguished by labels A, B, and C.

**Mathematical Constraints:**

$$V_{out\_A} \oplus V_{out\_B} \oplus V_{out\_C} \rightarrow V_{in} \quad \text{(eq. 74)}$$

**Assumptions:**

$$T_{in} = T_{out\_A} = T_{out\_B} = T_{out\_C} \quad \text{(eq. 75)}$$

$$p_{in} = p_{out\_A} = p_{out\_B} = p_{out\_C} \quad \text{(eq. 76)}$$

### 3.13 Component Type UNEVEN_THREE_SPLIT

The type UNEVEN_THREE_SPLIT was created as modification of THREE_SPLIT to address the case where one branch of the outflow is significantly smaller than the other two. Similar to the problems addressed by component type HIPUMP, the different operating levels make it hard to classify deviations consistently from the points of view of large and small normal flow rate. An example for this situation is found in the DIFFUSER where the amount of fuel flow to the MCC cooling duct is much smaller than both the flow into the nozzle cooling and the CCV valve.

The model basically ignores the small outflow into port C. No value is assigned to the flow parameter $V_{out\_C}$ unless it can be determined from the value set at the MCC cooling duct input.

**Mathematical Constraints:**

$$V_{out\_A} \oplus V_{out\_B} \rightarrow V_{in} \quad \text{(eq. 77)}$$

**Assumptions:**

$$T_{in} = T_{out\_A} = T_{out\_B} = T_{out\_C} \quad \text{(eq. 78)}$$

$$p_{in} = p_{out\_A} = p_{out\_B} = p_{out\_C} \quad \text{(eq. 79)}$$

### 3.14 Component Type TWO_JOIN

Component type TWO_JOIN models the joining of two input flows into a single output flow. Again we assume that the pressures are forced to be equal but we derive the output temperature from the magnitudes and temperatures of the input flows.

**Mathematical Constraints:**

$$V_{in\_A} \oplus V_{in\_B} \rightarrow V_{out} \quad \text{(eq. 80)}$$

$$\dot{Q}_{in\_A} \oplus \dot{Q}_{in\_B} \rightarrow \dot{Q}_{out} \quad \text{(eq. 81)}$$

$$T_{in\_A} \oplus V_{in\_A} \rightarrow \dot{Q}_{in\_A} \quad \text{(eq. 82)}$$

$$T_{in\_B} \oplus V_{in\_B} \rightarrow \dot{Q}_{in\_B} \quad \text{(eq. 83)}$$

**Assumptions:**

$$p_{in\_A} = p_{in\_B} = p_{out} \quad \text{(eq. 84)}$$

### 3.15 Component Type NOZZLE

The type NOZZLE has no behavior constraints associated with it. Output temperature is the only parameter of interest because it has a cooling component associated with it. Deviations in output temperature are assumed to directly follow deviations in input temperature.

**Assumptions:**

$$T_{in} = T_{out} \quad \text{(eq. 85)}$$

### 3.16 Component Type TANK

No constraints are defined for type TANK. It is defined in order to provide boundary components to the SSME model.

### 3.17 Component Type SENSOR

Type SENSOR is neither defined nor used at this time. If defined, sensor faults could be included in the fault diagnosis. Diagnosis becomes less efficient with larger numbers of components, however, and a separate module will address sensor faults.

## 4. Diagnostic Reasoning

Diagnostic reasoning is realized by a heuristic $A^*$ search methodology. Component are analyzed one by one until the behavior of the SSME is completely determined. When a component is analyzed all its possible behaviors are enumerated. Each component behavior is rated according to the estimated likelihood that it represents the actual behavior of the component. Each new behavior is combined with the behaviors already analyzed and global likelihoods for the resulting behavior hypotheses are calculated. A set of component behaviors is called a "scenario." Scenarios created early in the search contain behaviors for only a few components. After the last component has been analyzed, scenarios exist which contain completely specified behaviors for all components of the SSME.

EDIS operates on a single scenario at a time. Whenever a component is analyzed and its behaviors are generated and attached to the current scenario, multiple successor scenarios are generated. The heuristic evaluation function identifies the most likely among them and this most likely scenario is chosen for further processing. Several choices in this process are critical for the performance of EDIS: the order in which components are chosen for analysis, the "local" evaluation of each new component behavior, and the global evaluation of the scenario made up of a number or scenarios.

More formally, we define a behavior of the device $\boldsymbol{D}$ to be diagnosed, which is composed of a set of components ***Comp***, as a set of parameters $\boldsymbol{P}$ and a function $\boldsymbol{Beh} : \boldsymbol{P} \rightarrow \boldsymbol{Val}$ which assigns each parameter in $\boldsymbol{P}$ one of the elements in the set of qualitative values ***Val***. The set ***Val*** is currently defined as ***Val*** = {**NORMAL, HIGH, LOW, Unknown**}. A behavior description is called a *scenario*. In addition, a scenario contains a function

*Mode* : *Comp* → *BM* which maps each constituent component in *Comp* into a behavior mode in *BM* or the special symbol **ToBeAnalyzed** if the behavior mode remains to be determined. One possible behavior mode of each component is the **NonFaulty** mode; fault modes are defined individually for each component type.

A *finished scenario* is a scenario whose **Mode** function maps every component in *Comp* into *BM* – **ToBeAnalyzed** and whose function *Beh* maps every parameter in *P* into a value in *Val* – **Unknown**. A *partial scenario* is a scenario whose *Mode* function maps at least one component in *Comp* into **ToBeAnalyzed**. A finished scenario represents a solution which identifies the faulty component(s), i.e. all those components which are mapped into something other than **NonFaulty**, and explains in detail how the behavior of the device has changed because of the fault(s). By itself, a shift in the values of the parameters associated with a component does not necessarily imply a fault of this component; it can be caused by a shift in operating point due to changed input or output conditions.

Diagnostic search progresses by means of execution of search operators. Search operators expand a partial scenario *S* and generate its successor scenarios. Partial scenarios without successor nodes are *active* or *open*. Operators determine additional parameter values, i.e. they change the image of a subset of device parameters under the mapping function *Beh* from **Unknown** to values in *Val* – **Unknown**. A particular operator must be defined for each component type. However, operators are composed, in part, of generic expansion functions which apply to qualitative confluences, such as "+" and "–" as they appear in the qualitative constraints which define correct component behavior. In our implementation the consistent value assignments for each qualitative confluence are pre-computed and cached as a value tuple list. Thus a form of the arc consistency algorithm [4] is applied to a subset of the nodes in the constraint network, increasing the efficiency of the algorithm. Enumeration is accomplished by selecting only those entries from the value tuple list which conform to the parameter values already chosen.

The set of constraints associated with a component is analyzed in such a way as to minimize guessing. Constraints which operate on larger numbers of parameters and those which define fewer legal value tuples are satisfied first. These strategies conform to the "constraint arity" and "constraint tightness" heuristics in [3].

Fundamental constraints are ignored, i.e. suspended, by expansion operators but mathematical constraints and inviolable physical conservation constraints are enforced. When the behavior of a pipe is expanded, for example, the mathematical constraint $p_{diff} = p_{in} - p_{out}$ is enforced and restricts the value combinations which may be assigned to $p_{diff}$, $p_{in}$, and $p_{out}$. The inviolable constraint $V_{in} \geqq V_{out}$ restricts the possible value assignments to the input and output velocity parameters $V_{in}$ and $V_{out}$. The expansion operation accomplishes what normally constitutes the first step in a qualitative simulation [1]; it determines the possible initial state of the device. Here, no dynamic behaviors are considered and thus no additional qualitative simulation mechanisms are needed.

Successor scenarios enumerate all possible behaviors of the component whose behavior was expanded last, in the context of what was already known about the component behavior from measurements and previously made assumptions. The set of possible behaviors is, in general, much smaller than the unrestricted set of behaviors implicitly implied by straight-forward constraint suspension. The proposed algorithm thus develops a more detailed diagnosis than constraint suspension or Rieger's algorithm but, on the other hand, has to represent behavior explicitly which is less efficient. Operators can exhaustively expand behavior because only a small subset of parameters is assigned values at a time and because parameters associated with a component are tightly coupled by mathematical constraints. The search space is thus hierarchically decomposed even though the device description is not necessarily hierarchical.

Consistency of parameter assignments within one component is guaranteed by the expansion operators. Global consistency of assignments within a scenario is guaranteed because each scenario maps each parameter into a single value. Different components which share one or more parameters must therefore agree on their values. If an operator attempts to change the value of a parameter which is anything other than **Unknown**, then this particular successor scenario being developed becomes invalid and is removed.

Each active partial scenario constitutes a node in the search tree competing to be expanded. A heuristic evaluation function ranks the active partial scenarios and selects the best one for further expansion. The evaluation function judges the parameter assignments already made and estimates the change in cost which is likely to accumulate until the scenario is fully expanded. According to the standard definition of the $A^*$ algorithm [5, page 76], the heuristic evaluation function $f'$ is calculated as $f' = g + h'$ where the quality of the expansion achieved so far corresponds to the cost $g$ of the path from the initial node to the current node, and the expected worsening corresponds to the expected cost $h'$ of the remaining path.

The function $g$ which judges the quality of a particular scenario takes into account the merit of each identified behavior mode and the number of components yet to be analyzed. The cost estimate $h'$ depends on whether a fault has been hypothesized yet and on the results of expanding similar partial scenarios. The cost function $g$ is parameterized by a set of merit figures assigned to each behavior mode by a domain expert, which may be modified for a particular application, if necessary.

The general evaluation algorithm defines the cost function $g$ as

$$g = \prod_{i=1}^{n} \frac{1}{q_i} + \frac{n_y}{n} \qquad \text{(eq. 86)}$$

$$\text{where } q_i = q(Mode(comp_i))$$

and the function $q_i$ maps each behavior mode of component $comp_i$ into a figure of merit supplied by the domain expert, and $q$(**ToBeAnalyzed**) = 1. The product is taken over the behavior modes of all $n = |Comp|$ components of the device. The figure of merit for each behavior mode is $\leqq 1$ so that the combined cost of two or more fault modes is larger, in general, than that of a single fault. The figure of merit of the **NonFaulty** behavior is usually defined as 1. The product rule is motivated by the assumption that faults are independent and the fact that the joint probability of independent events is given by the product of their individual probabilities. A more sophisticated evaluation function could take joint probabilities of interrelated failure modes into account. The ratio $n_y/n$ is the ratio of the number of yet to be analyzed components over the total number of components. It slowly decreases as more components are analyzed. It is included to keep the line of reasoning from skipping between different branches in the search tree, i.e. to favor depth-first processing, which facilitates cooperation with a human user.

Behaviors whose mode is **normal** are subjected to another test in order to identify more and less likely ones among them. The quality of each normal behavior is reduced according to the following procedure. For each behavior the number of parameters is recorded whose values is not **NORMAL**. Behaviors with the lowest number of non-normal parameters are considered best and their quality ratings remain unchanged. The quality of all other behaviors is reduced according to how many more non-normal parameters they include than the best behaviors. The difference in the number of non–normal parameters is multiplied by 0.01 to derive the penalty for each behavior.

The expected cost estimate $h'$ is defined as

$$h' = h_1' + h_2' \qquad \text{(eq. 87)}$$

$$h_1' = \begin{cases} 5 & \text{if no fault has been hypothesized yet} \\ 1 & \text{otherwise} \end{cases}$$

$h_1'$ anticipates that at least one fault will be found and ensures that promising failure modes are considered early on. $h_2'$ is adjusted dynamically as information about global consistency becomes available. If a fault is hypothesized but the scenario has to be abandoned later because its global quality becomes too low, $h_2'$ is set to a value which measures the observed worsening of scenario quality. This value of $h_2'$ is applied to all scenarios derived under this fault hypothesis.

Another use of $h_2'$ would be in the case where a set of parameters at the interface of a component is found to lead only to scenarios with higher cost. Then, all the scenarios with identical value assignments for these interface parameters could have their $h_2'$ cost estimate increased to anticipate the higher cost expected to be incurred during further expansion. This is not currently implemented and would be subsumed to a large extent by a scenario recombination mechanism described in Section 12 on future work.

The dynamic adjustment of the cost estimator is an instance of dependency–directed backtracking because the cause of the low quality scenarios is looked up higher in the search tree, appropriately modified, and inhibits further exploration of the afflicted branch; at least until no better options are left. The same mechanism could be used to eliminate all partial scenarios which share parameter assignments which can be shown to lead to inconsistencies. Inconsistencies are detected in step 4 of the algorithm presented below, when no successor scenarios can be generated. We are now ready to define the diagnostic search algorithm D–Search.

Algorithm **D–Search**:

1. Create an initial active scenario $S_0$. All its parameters map to **Unknown** and all the components map to **ToBeAnalyzed**. Set the set $AS$ of active partial scenarios to $\{S_0\}$.
2. Fill in the known data: classify measurements into qualitative values and set the values of the measured parameters in $S_0$ accordingly. Make the initial scenario $S_0$ the current scenario $S_0$.
3. Choose a component $comp_j$ from the current scenario $S_i$ which is mapped into **ToBeAnalyzed** by function *Mode* of $S_i$ and apply the expansion operator associated with its component type. Remove $S_i$ from $AS$.
4. If no successor scenarios were generated in step 3, i.e. the set of parameter assignments and behavior modes of $S_i$ is inconsistent, then goto 6, else apply the heuristic evaluation function to the successor scenarios.
5. If the successor scenarios $\{S_k\}$, $k = 1,\ldots,m$, where $m$ is the number of successors generated in step 3, are finished, then add them to $FS$, the set of finished scenarios, $FS = FS \cup \{S_k\}$, else add them to $AS$.
6. If $AS$ is empty, then goto 10, else rank the active partial scenarios in $AS$ according to cost $f$.

7. Select the best (lowest cost $f'$) partial scenarios from $AS$ and make it the current scenario $S_i$. Break ties arbitrarily.
8. Global consistency check: Find the component in $S_i$ analyzed last. Check that its interface parameters are assigned one value $v \in Val-$**Unknown** only. If there are conflicting values assigned, then remove $S_i$ from $AS$ and goto 6.
9. Goto 3
10. If $FS$ is empty, then no consistent scenarios could be found and the algorithm failed to generate a diagnosis; otherwise the scenarios in $FS$ enumerate all possible behaviors and thus all possible faults.

It should be noted that the set $FS$ is likely to be very large, especially in the situation of interest where few parameter values are known. The "best" diagnosis is not necessarily minimal, though. The heuristic evaluation function can be tuned to prefer a combination of several faults over some single faults. This feature is useful when secondary faults may be induced by a primary fault.

The set $FS$ is empty only in the exceptional case when the measured values are inconsistent with any possible device behavior. This case may occur when sensors malfunction or measurements are incorrectly interpreted.

The last issue to be addressed concerning the diagnostic search algorithm is step 3, the selection of a component to be analyzed next. Component selection determines the order in which the search space is explored. If the component which is actually faulty is chosen early, then the algorithm will produce the correct diagnosis fast. At this step, additional expertise should and can be brought to bear on the diagnostic search. The diagnostic system which has been developed around the proposed algorithm can execute a set of heuristic rules or request user input to select a component to be analyzed and also a behavior mode to assume. When a user chooses to submit his or her own hypothesis, the system will test whether it is consistent with the available data and evaluate its quality relative to competing hypotheses.

Components are selected based on the number of unknown parameter values associated with each component, reasoning focus and continuity control, and the likelihood that this component is the cause of the anomalies. The number of unknown parameters is used to estimate the number of different allowable value assignments to the remaining parameters. Fewer unassigned values usually imply stronger restrictions on the remaining parameter values and thus a higher likelihood of choosing the correct value. Fox [3] has formalized this heuristic as "variable value goodness texture."

A generic constraint satisfaction algorithm might use a search process with the single goal of optimizing search efficiency. In an interactive system the user who monitors reasoning progress has to be considered. Users more easily follow depth-first search which fully explores a single line of reasoning than an optimized strategy which appears to jump between various lines of reasoning based on different assumptions.

Once a set of components has been analyzed, the algorithm will tend to select a component for analysis which is connected to the component which was analyzed last. The reasoning thus follows the structural interconnectivity of the device as represented by the device schematic, emulates a human expert reasoning strategy, and facilitates explanation of system behavior.

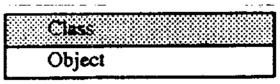
The most effective way to streamline search and constraint satisfaction is to identify the faulty component as early as possible and to guess its fault mode correctly. After that, choices are limited to correct behavior modes for all other components (in the common case of a single fault), of which there exist far fewer than faulty behavior modes. Two somewhat different operating modes of the constraint satisfaction search can thus be discerned. An 'exploring' mode, which is in effect before any fault assumption has been made and the search tries to locate the component which may account for the anomalies ($h_1' = 5$), and a 'verification' mode, which is entered after a component has been incriminated and the constraint satisfaction algorithm tries to show that the assumption is consistent with the data and does not require unlikely assumptions about other component behaviors ($h_1' = 1$).

Guessing the responsible fault behavior, i.e. hypothesizing which component is faulty and is causing the observed anomalies, is supported by any and all of heuristic expertise, component failure rates, and probabilities of specific faults, if available. Heuristic functions are not restricted to investigate only data associated with the component under considerations, but may take overall system behavior into account. In a feedback system, such as the SSME, telltale effects of faults can sometimes be observed at sensors far removed from the original cause.

The algorithm presented above concentrates on a single hypothesis at a time and implements a single line of reasoning. Multiple hypotheses could be explored in parallel either by choosing more than one "best" partial scenario in step 7 or by applying more than one operator in step 3. The algorithm presented appears to be well suited for distributed implementation because such multiple lines of reasoning require very little interaction. Information to be shared only travels up and down the search tree. Only the selection of the best partial scenario is a global operation. Information traveling down the search tree implements the normal line of reasoning. Information travels up the search tree when special conditions, such as inconsistencies, are encountered during expansion which are to be considered in the heuristic evaluation functions of scenarios waiting to be expanded.

## 5. SSME Configuration

Figure 3 shows a top level view of the SSME configuration. Only the "Terminal Components" are shown (defined in file *terminal*) which do not take part in the reasoning process. They provide the linkage to the environment of the SSME. The two pipes F190 and O190 lead to parts of the system which are not modeled. Also not modeled are the controllers for the valves MFV, CCV, MOV, and OPOV. Only the FPOV controller is modeled. The following figures show additional detail of the model. All components are shown in the form




where Object is the name of the component and Class is its class name. Some of the names are standard, others

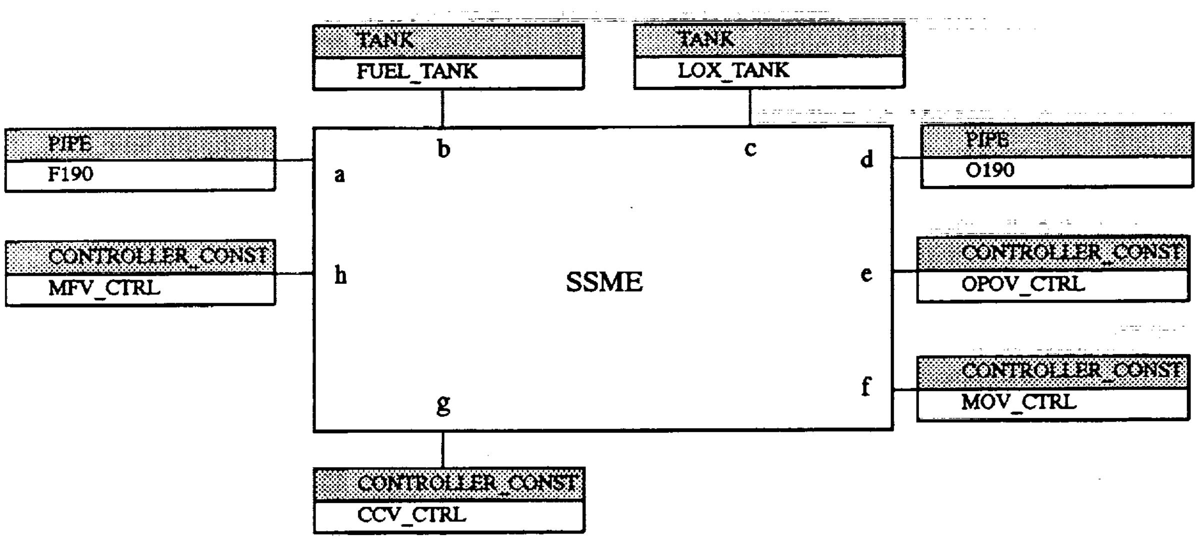



Figure 3: SSME Model – Components and Interconnections, Level 1

were invented for this project (they can easily be changed later). Figure 4 shows the four main blocks of the SSME configuration: fuel and oxygen supplies, the cooling piping, and the MCC and nozzle assembly. The MCC/NOZZLE block is shown in more detail in Figures 5, the COOLING block in Figure 6, the FUEL SUPPLY block in Figure 7, and the LOX SUPPLY block in Figure 8. Appendix A.2 contains the set of configuration files which define the SSME configuration.

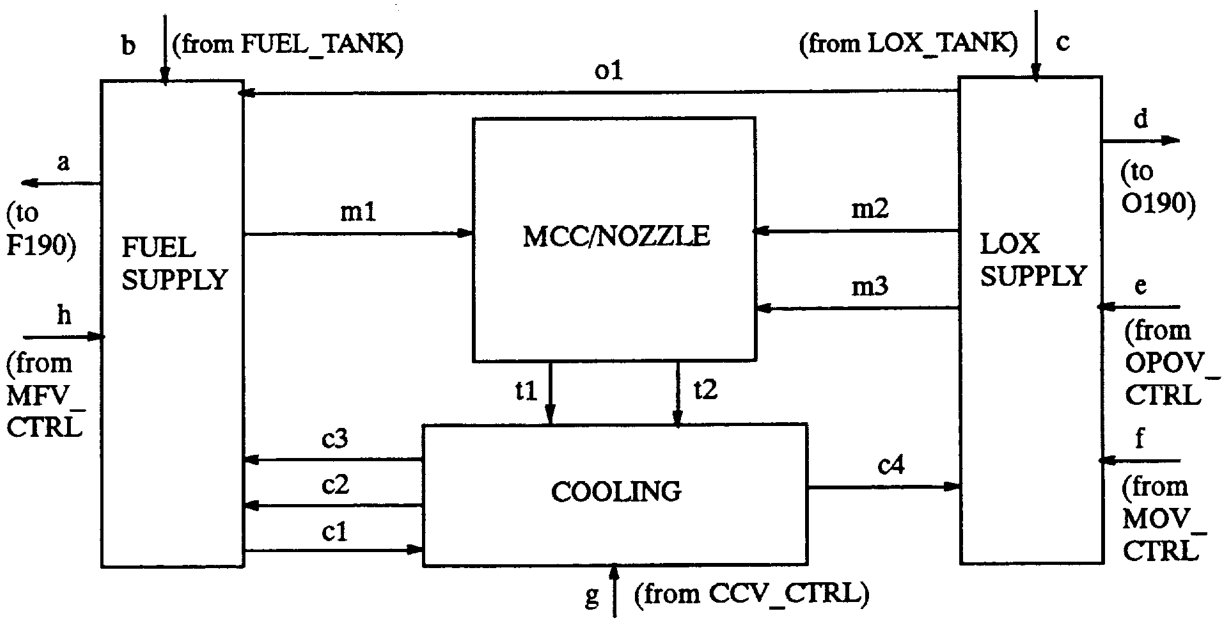



Figure 4: SSME Model – Components and Interconnections: Block Diagram

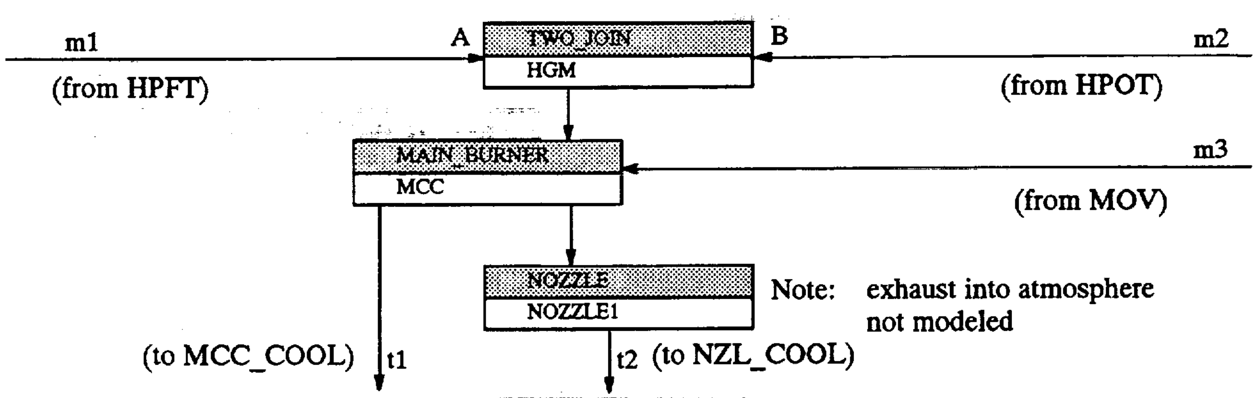



Figure 5: SSME Model – MCC/NOZZLE

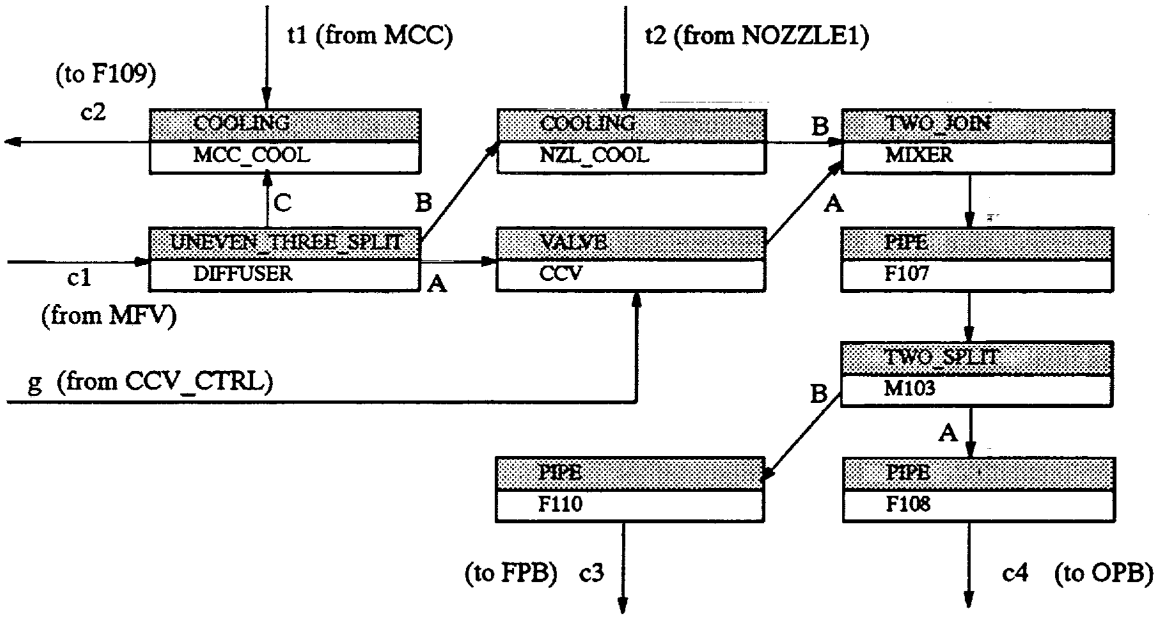



Figure 6: SSME Model – COOLING

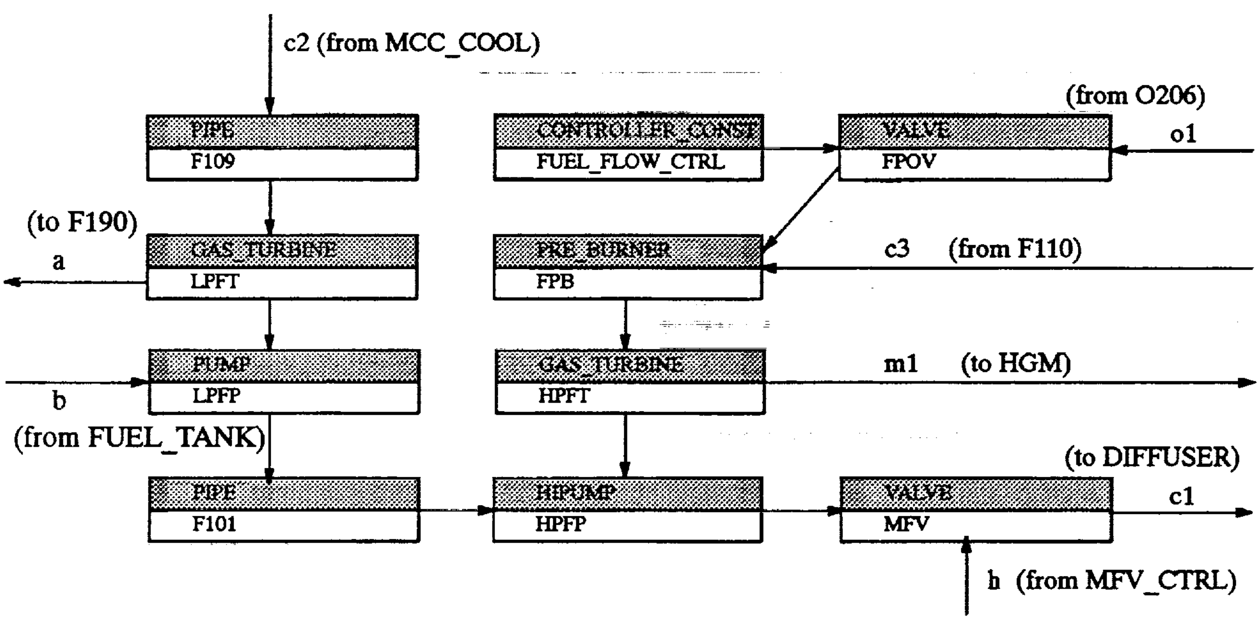



Figure 7: SSME Model – FUEL SUPPLY

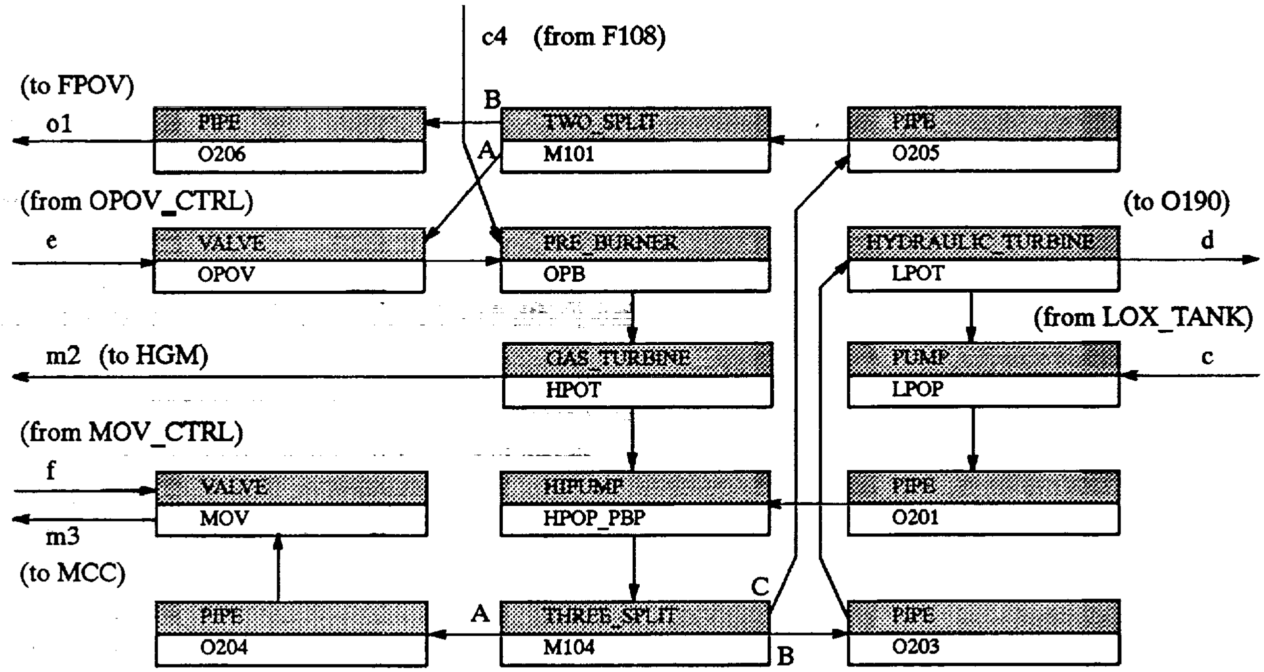



Figure 8: SSME Model – LOX SUPPLY

## 6. Heuristic Rules

Traditional expert systems rely heavily on the ability of heuristic rules to rapidly identify common faults. Finding common faults fast is also a design goal of EDIS but, in addition, broad fault coverage is desired. Common faults can be dealt with by providing heuristic rules which, when successfully executed, predict a likely fault and force EDIS to prefer those assumptions about SSME behavior which are consistent with the fault predicted by the heuristic rules. This feature must be explicitly enabled by setting the slot USE_HEURISTIC_RULES.Value to TRUE. Unlike the rest of EDIS these rules are of necessity specific to the SSME and are therefore stored in a file in the confssme directory with the other SSME specific configuration data. There are also two more files (fuel_side and lox_side) which describe a grouping of components specific to the SSME. These files are read only when slot USE_HEURISTIC_RULES.Value is TRUE.

A small number of heuristic rules are implemented which can identify certain likely faults rapidly. These rules may be run at the start of the reasoning process and fundamentally change the way the search space is explored. Without heuristic suggestions, EDIS tries to determine system behavior and hypothesizes faults only to satisfy specific anomalous parameter values. If a heuristic rule identifies a likely fault, EDIS attempts to find a behavior which is consistent with this fault assumption. Heuristic rules easily combine evidence from different parts of the system. For example, the heuristic rule which identifies a leak in the MCC Cooling duct tests for anomalous values at the LPFP as well as the MCC Cooling duct. In some other cases rules check for effects of fuel side problems at components as remote as the HPOTP. On the other hand, behavior synthesis proceeds component by component and uses only data local to a component to generate fault hypotheses. Given a set of well designed heuristic rules, a hypothesis generated by a heuristic rule will most likely be correct, while hypotheses generated based on local behavior only are more tentative and are likely to be found to be inconsistent with the remaining data.

Unfortunately, it is still not obvious which one of these two methods will arrive at an answer earlier. In the example included, the standard diagnostic process which does not utilize heuristic rules finds the correct answer earlier even though it selects and discards several wrong hypotheses before it generates the correct one. The problem with the heuristic suggestions is that they force EDIS to develop a consistent behavior starting at a component with many unknown parameters. Many unknown parameters will lead to many possible behaviors because the leak hypothesis is not specific enough to effectively limit the number of possible behaviors. The standard reasoning process chooses components for investigation in an order which minimizes guessing and is therefore likely to derive the correct behavior which implicitly contains and ultimately reveals the correct fault hypothesis. The reasoning process which executes heuristic rules has not been refined as much as the standard constraint satisfaction approach. Several modifications are possible which could improve the performance of EDIS when given a heuristic suggestion which could not be implemented yet. Fortunately, most of them also promise to enhance the standard reasoning process.

The shortcomings associated with using heuristic rules can, at least sometimes, be overcome by using data generated by the Power Balance Model (PBM), see below. This is not, however, a guaranteed way of efficiently solving the diagnostic problem, but just another heuristic method which, we hope, will work most of the time.

Below a listing of the implemented heuristic rules can be found, formulated in structured English. File `heuristic-rules.tkb` included in Appendix A.3 contains a listing of the rule code in NEXPERT syntax. EDIS will use the heuristic rules only if the slot USE_HEURISTIC_RULES.Value is set to TRUE before processing starts. Rules may either suggest a specific fault in a specific component, such as LOW EFFICIENCY of the HPFP, or a specific fault in a class of components, such as LEAK in a FUEL–SIDE DUCT, i.e. a pipe or cooling duct.

| | | | |
|---|---|---|---|
| **if** | | | |
| | HPOT discharge temp | is | HIGH |
| and | HPFT discharge temp | is | NORMAL or HIGH |
| and | HPFP discharge pressure | is | LOW |
| and | HPFP speed | is not | LOW |
| and | MCC pressure | is | NORMAL |
| **then suspect a** | | | |
| | LEAK | in a | FUEL–SIDE DUCT |

**Rule 1**

| | | | |
|---|---|---|---|
| **if** | | | |
| | HPOT discharge temp | is | HIGH |
| and | HPFP discharge pressure | is | LOW |
| **then suspect a** | | | |
| | LEAK | in a | FUEL–SIDE DUCT |

**Rule 2**

| | | | |
|---|---|---|---|
| **if** | | | |
| | FPOV position | is | HIGH |
| and | HPFT discharge temp | is | HIGH |
| and | FPB pressure | is | HIGH |
| **then suspect a** | | | |
| | LOW EFFICIENCY | in the | HPFP |

**Rule 3**

| | | | |
|---|---|---|---|
| **if** | | | |
| | LPFP speed | is | LOW |
| and | MCC Cooling disch temp | is | LOW |
| and | MCC Cooling disch press | is | LOW |
| **then suspect a** | | | |
| | LEAK | in the | MCC Cooling duct |

**Rule 4**

| | | | |
|---|---|---|---|
| **if** | | | |
| | HPOT discharge temp | is | HIGH |
| and | MCC Cooling disch temp | is | HIGH |

| | | | |
|---|---|---|---|
| **and** | LPFP speed | is | LOW |
| **then suspect a** | | | |
| | LEAK | in the | NOZZLE Cooling duct |

**Rule 5**

| | | | |
|---|---|---|---|
| If | | | |
| | OPOV position | is | HIGH |
| **and** | HPOTP speed | is | NORMAL |
| **and** | MCC pressure | is | NORMAL |
| **then suspect a** | | | |
| | LOW EFFICIENCY | in the | HPOT |

**Rule 6**

When a specific component is implicated, the search process starts at this component, finds all possible behaviors of the component and identifies those component behaviors which are consistent with the fault hypothesis. One of these behaviors is chosen and EDIS tries to find a consistent behavior of the whole SSME given the fault assumption and the assumptions made when developing the initial component behavior. When a set of components is implicated, EDIS initiates the search in standard order, i.e. with components where few assumptions have to be made. When a component is encountered during search which is in the implicated set and one or more of its behaviors are consistent with the hypothesized fault, the fault is assumed to have occurred at this component. EDIS then continues in its attempt to justify the fault hypothesis by completing the behavior of the SSME. When a set of components are implicated, they are thus tried in the order in which they are encountered during the search, at least until one of them forms the basis of a complete and consistent SSME behavior.

## 7. Power Balance Model

The Power Balance Model performs data reduction after engine tests. A file is produced which contains values for many internal unmeasurable parameters. Some of these parameters are used within the EDIS qualitative model, too. A method was developed through which the results of the PBM-based analysis can guide the heuristic search performed by EDIS. This feature must be explicitly enabled by setting the slot USE_PBM_DATA.Value to TRUE. The file PBM_values.nxp must be created before enabling this feature. It contains definitions of "template" objects whose parameter values have been filled with the available PBM data. EDIS compares the component behaviors it generates against these template objects and rewards those behaviors which have larger numbers of matching parameter values.

Parameter values generated by the PBM do not convey the same level of confidence as measured parameters because the PBM has only limited fault simulation capabilities. EDIS therefore does not add the PBM supplied parameters to the set of measured parameters but only uses them to identify likely SSME behavior. Any component behavior generated by EDIS during the search is compared against the PBM predicted values and the better the match the greater the chance that the proposed behavior represents the actual behavior. The current implementation subtracts 0.02 from the local quality of any behavior for each parameter value which does not agree with the PBM data.

The PBM generates numerical data which are translated into qualitative values via a process described below. Since we did not have any better information we set the limit above which a deviation would be considered anomalous at 2.5%. Performance of EDIS is quite sensitive to this limit. For example, we selected only one of several data for MCC cooling duct flow. One of the values showed a 2.42% increase, another a 2.56% increase (at locations 1103 and 1104 in the A-ARRAY, respectively). Using the larger of the two, EDIS performed as expected since larger than normal flow is consistent with a leak. Using the lower deviation value, EDIS was unable to verify the leak hypothesis in reasonable time. This "brittleness" of performance is typical of "crisp" qualitative classification (and also of traditional heuristic rule-based systems). Preliminary results on our research into the application of fuzzy classification to SSME diagnosis are described in Section 8. Fuzzy classification promises to alleviate the brittleness problem.

The use of PBM data does not significantly change the search process in our example. The PBM predicts most parameter values to be normal and EDIS already favors normal values over deviations for normal component behaviors. The search therefore proceeds exactly as it does without the use of PBM predictions. There are small differences in some of the behaviors but these do not alter EDIS' interpretation of component behavior modes.

A combination of heuristic rules and PBM data proved to be the most effective way of diagnosing the MCC cooling leak fault in the example. The heuristic rules correctly predict the MCC cooling leak and the PBM data correctly predict values for three critical parameters. These predictions combined with some measured values lead EDIS to select the "correct" behavior for the MCC cooling duct and the leak is diagnosed in a single pass through the component network without any backtracking. It is interesting to note that some details, i.e. parameter values, differ in the answers generated by EDIS in its normal qualitative search mode and the heuristic/PBM guided mode. Roughly speaking, the heuristic/PBM solution corresponds to a bigger leak, e.g. the outflow is assumed to be LOW, while the qualitative search predicts a small leak, e.g. the outflow is assumed to be NORMAL. Both solutions comply with the low value of output pressure measured by a sensor. Either assumption is consistent with lower than normal mechanical power generated by the LPFT.

The directory edis3/PBM contains executables and sample files which illustrate the creation of the PBM_values.nxp file. The file PBM_parameters must be available. It contains a subset of the entries of the PBM90A A–ARRAY variable listing from file vardoc (from EPVAX) as of 18-Dec-1992. Lines with parameters which have equivalents in the EDIS qualitative model contain a bracketed term at the end of the line which indicates the corresponding component and the component parameter. For example, the line

```
4     P1FP1  LPFP INLET PRESSURE          [LPFP pin]
```

indicates that PBM parameter P1FP1 at location 4 is equivalent to the input pressure ($p_{in}$) parameter of the LPFP in the qualitative model. The list of equivalences is as yet possibly incomplete.

Next, the files containing the test data and the comparison data must be moved into this directory. They are currently stored on the IBM system. The comparison data file may be off-line and has to be loaded. Now program displaydb can now be executed to prepare the intermediate file PBM_numeric_deviations.

Execute program displaydb using the commandline

displaydb *comparison_data_file test_data_file time_slice* -1 > PBM_numeric_deviations

to create file PBM_numeric_deviations. The sample file was created with displaydb a1613 a1614 29 -1 > PBM_numeric_deviations

Individual values can be displayed using an alternate form of this command.

displaydb *test_data_file time_slice index*

Using time slice1, the test date and test duration and the time slice duration can be displayed at indices 934, 935, and 936, respectively. After selecting a time slice, displaying the datum at index 937 reveals the start time of the chosen time slice.

Finally, program make_PBM_params can be executed. It reads files PBM_parameters and PBM_numeric_deviations and writes file PBM_values.nxp. This file must be moved into the edis3/confssme directory. No parameters are necessary since all files have standard names. All files for the sample case described above are listed in the appendix.

## 8. Fuzzy qualitative system

A mathematical model of a system describes the system in terms of the underlying analytical equations that determine its behavior. It is required to know the exact relations between system variables to develop a mathematical model. A mathematical model is an exact representation of the system and produces exact results. Analytical equations do not represent knowledge about the system explicitly. Commonsense knowledge a person has about the system, cannot be represented in a mathematical model. A mathematical model suffers from the "interpretation problem."

A qualitative model provides an alternative to a mathematical model in a complex and uncertain environment. In the absence of exact analytical equations, an abstract qualitative model can be developed. Given limited numerical information about the system, a qualitative model can produce very useful results. If the problems are difficult to solve numerically and the precision of the results required is not high, it is advisable to resort to qualitative methods. Another advantage of qualitative model, apart from relaxing the requirement of precise numerical information, is the ability to represent the commonsense knowledge explicitly and therefore, yields easier interpretation. But the intentional neglect of the available numerical information may result in over abstraction of the system. The results obtained from an over abstracted model are imprecise. Qualitative systems also suffer from the limitations associated with the inherent ambiguity in qualitative arithmetic. Resolving the ambiguities in qualitative arithmetic increases the precision of results and decreases search complexity. One approach is to explore an unambiguous mathematical formalism for qualitative variables and another is to make use of the available quantitative information to refine the results obtained from qualitative analysis.

Fuzzy qualitative modeling is a combined approach which makes use of all the available quantitative information and is supported by the arithmetic of possibility theory of fuzzy sets. The Fuzzy qualitative modeling paradigm integrates possibility theory of fuzzy sets with qualitative interval calculus for more detailed and accurate modelling of the system. This reduces the ambiguities inherent in the pure qualitative methods and produces more precise results than those obtained by a pure qualitative model. This is a generalization of qualitative modeling and offers an intermediate level of model abstraction.

The fuzzy qualitative models can be categorized as deep causal models which capture underlying causal phenomena and facilitate reasoning from first principles. These models can be used as generic components of a model-based diagnostic system.

### 8.1 Fuzzy qualitative model

A component model describes all the possible behaviors of the component. In a constraint-based model, behavior of a component is described by a set of constraints. In a fuzzy qualitative model, the modeling primitives are fuzzy constraints and fuzzy qualitative states.

#### 8.1.1 Fuzzy qualitative states

Possibility measure is a natural way of representing subjective uncertainty. It is the measure of material difficulty of an event occurring plus the subjective evaluation of the occurrence of the event [8]. To model the uncertain belief, it is required not to rigidify the relationship between the indications one has in favor of an event and those that weigh against it. Unlike probability, possibility of an event is independent of the possibility of the contrary event.

The range of a fuzzy variable is a closed interval bounded by the maximum and minimum possible values, chosen to ensure that the whole range of interesting behaviors is covered. The closed range of the variable is divided into an arbitrary but finite number of fuzzy subsets or fuzzy intervals. Each fuzzy interval represents a fuzzy qualitative value. The set of fuzzy qualitative values covering the whole range of interest allows all numerical values that the variables may take to be mapped onto their associated fuzzy qualitative values. The number of fuzzy intervals chosen depends upon the granularity desired. Since the range is divided into a finite number of fuzzy intervals, a variable takes a finite number of fuzzy qualitative values. There is a direct mapping from numerical range to fuzzy qualitative values. A variable has, associated with it a quantity space Q, with the following properties.

- finiteness: The range is divided into a finite number of fuzzy intervals and therefore a variable can take on a finite number of fuzzy qualitative values.
- Coverage: Fuzzy qualitative values the variable can take on cover all the behaviors of interest.
- Mapping: There is a direct mapping between the numerical range and the fuzzy qualitative values.
- Granularity: The number of fuzzy intervals is arbitrarily chosen depending upon the granularity desired.
- Closed: The range is closed and all the possible numerical values outside the range can be conveniently represented by the fuzzy qualitative values of the intervals at both the ends of the range.
- Overlapping: Fuzzy intervals are overlapping to account for ambiguity in the definition of fuzzy qualitative values.

A fuzzy interval, for example the value "Low", is defined by a fuzzy number which is represented by a 4-tuple (a, b, c, d), where $p(a) = 0$, $p(b) = 1.0$, $p(c) = 1.0$, $p(d) = 0$. $p(x)$ is the possibility of a numerical value x falling in the qualitative value ("Low" in this case). The 4-tuple representation implies a trapezoidal shape for the possibility distributions of fuzzy numbers. In general, any convex function could be chosen.

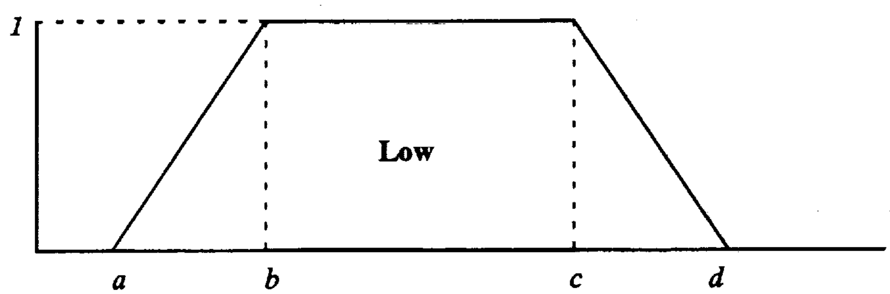



Figure 9: A fuzzy interval

The fuzzy qualitative domain consists of n values if there are n fuzzy intervals in the range. The value of a fuzzy variable is represented by an n-tuple($P_1$, $P_2$, ... $P_n$) where $P_i$ is the measure of possibility in the ith interval.

For simplicity, consider a fuzzy qualitative domain with only three fuzzy intervals, low, normal and high. Heuristic information is required to define the fuzzy intervals. In the present example, the "normal" fuzzy interval is defined symmetric with respect to the origin. The intervals, low and high are defined symmetrical with respect to the normal interval. It is common to select overlapping fuzzy intervals in such a way that the sum of the possibilities of a numerical value falling in any of the fuzzy intervals is always equal to 1.

This mode of representation of the value of a variable enables a convenient mode of switching between the fuzzy qualitative method and the crisp qualitative method. The subjective definition of the fuzzy sets introduces an element of subjectivity.

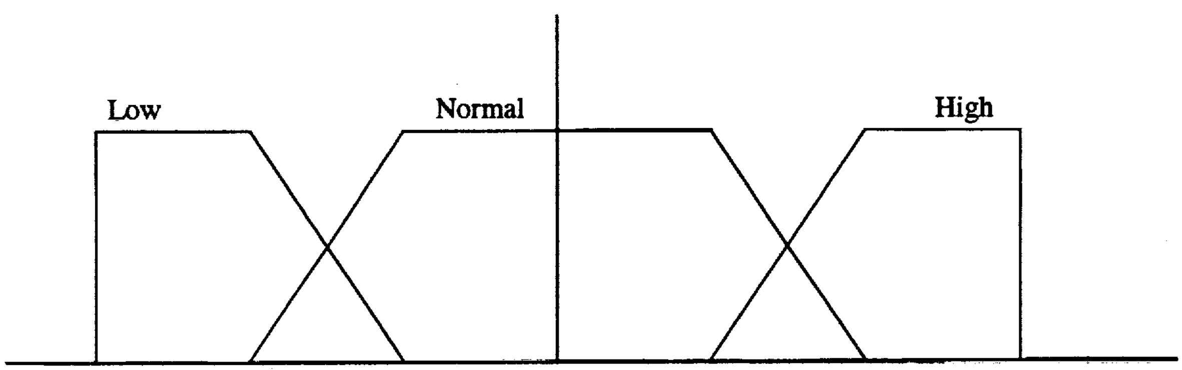
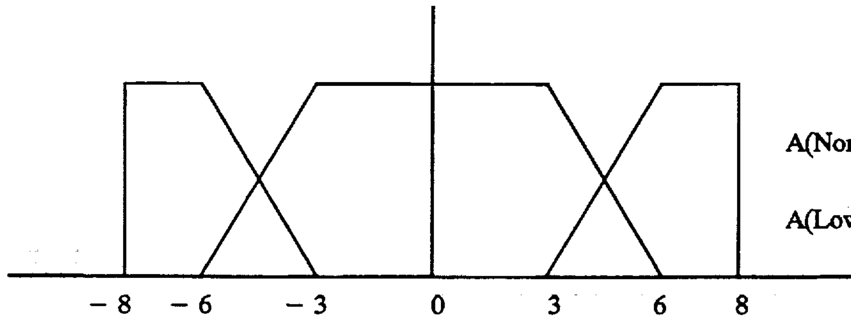



Figure 10: Definition of three overlapping fuzzy intervals

### 8.1.2 Fuzzy interval arithmetic

Fuzzy interval arithmetic is a generalization of interval arithmetic. Fuzzy interval arithmetic operates on the possibility values of the interval and not the intervals directly. From the possibility values of the fuzzy intervals, a corresponding interval on the real number line is computed and the arithmetic is done over these intervals. The possibility values of the resultant interval in all the fuzzy intervals of the domain are computed.

Fuzzy qualitative addition: Consider a simple example of adding two variables with fuzzy qualitative values. Let A, B and C be the variables, whose fuzzy values are defined by the fuzzy intervals as shown in Figure 11 below.

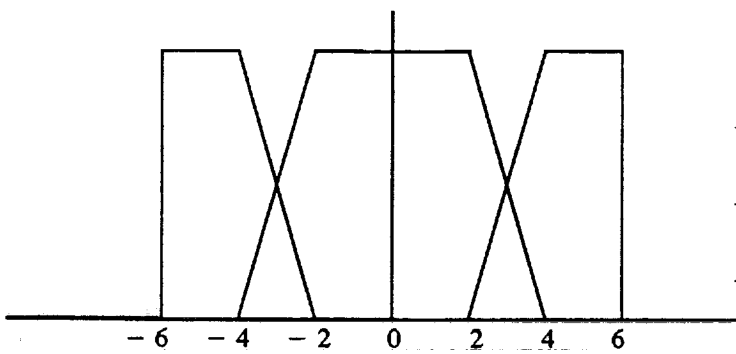



A(High) = (3, 6, 8, 8)

A(Normal) = (− 6, − 3, 3, 6)

A(Low) = (− 8 , − 8, − 6, − 3)

Figure 11a: Fuzzy intervals for variable A

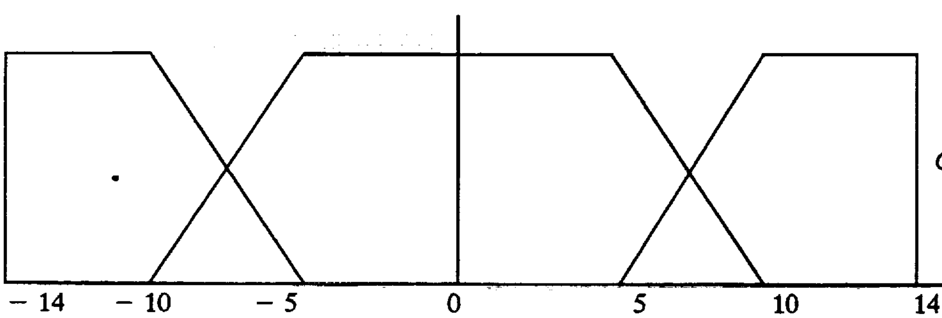



*B(High)* = (2, 4, 6, 6)

*B(Normal)* = (− 4, − 2, 2, 4)

*B(Low)* = (− 6, − 6, − 4, − 2)

Figure 11b: Fuzzy intervals for variable B




*C(H)* = (5, 10, 14, 14)

*C(N)* = (− 10, − 5, 5, 10)

*C(L)* = (− 14, − 14, − 10, − 5)

Figure 11c: Fuzzy intervals for variable C

To find the sum of A(High) and B(Low): C(?) = A(High) + B(Low)

A(High) =(0.0, 0.0, 1.0) ...possibility of falling into interval Low (=0.0), Normal (=0.0), and High (=1.0)
=(3, 6, 8, 8)...fuzzy number representing fuzzy interval High of variable A;

B(Low) = (1.0, 0.0, 0.0) = (–6, –6, –4, –2);
A(High) + B(Low) = (–3, 0, 4, 6)

The resulting sum, which is again represented as a fuzzy number, is now mapped in the quantity space of variable C. Find the area overlapped by the resultant interval onto the three fuzzy sets of C. The ratio of the area overlapped on each fuzzy set to the total area of the fuzzy set corresponds to the possibility of the result lying in that set. The above resultant interval gives the following possibility figures:
C(0.0, 0.43, 0.01) $\approx$ C(0.0, 4.3, 0.0).

Unlike qualitative addition, fuzzy qualitative addition is well defined and does not give ambiguous results. If the result has non-zero possibility values in more than one fuzzy set, either only one fuzzy set with maximum possibility value can be considered or all the fuzzy sets with possibility greater than a preset limit. The symmetric definition of the fuzzy sets guarantees the existence of the additive inverse.

Fuzzy constraints are bi-directional. To check for the consistency of the solution in the previous example, find the value of A, given C and B. Use the fuzzy sets and the possibility values of the previous example.
A(?, ?, ?) = C(0.0, 0.43, 0.0) – B(1.0, 0.0, 0.0)
= (–10, –7.15, 7.15, 10) – (–6, –6, –4, –2)
=(–4, –1.15, 11.15, 12) = (–4, –1.15, 8, 8)
This results in A(0.0, 0.81, 1.0). Note that A(0.0, 0.0, 1.0) is one of the solutions. It can be seen from the non-zero value of the possibility for the value of A falling into fuzzy interval "Normal," that fuzzy calculus introduces some ambiguity, but not as much as crisp qualitative calculus.

### 8.1.3 Fuzzy Constraints

Fuzzy constraints are abstractions of the algebraic constraints that determine component behavior. Fuzzy constraints are relations between fuzzy qualitative variables. The factor of satisfaction of a fuzzy constraint can be graded. Testing for a fundamental fuzzy constraint is essentially comparing two fuzzy numbers corresponding to the left hand side and the right hand side of the constraint.

Measuring equality between two fuzzy numbers:
The difference between two fuzzy sets can be found by summing the squared differences between them. Normalizing this result by dividing by the support value ( the maximum support minus the minimum support) results in a grade. This grade reflects how different the two fuzzy sets are. Negating this grade results in a grade for how equal the sets are. If the result is 0.0 then the sets share no members (to any degree). If the grade is 1.0 the two sets are identical. This grade of equality can be taken as degree of satisfaction of the fuzzy constraint.

The grade of equality between two fuzzy numbers $A(a_1, a_2, a_3, a_4)$ and $B(b_1, b_2, b_3, b_4)$ \
$$= (b_1 - a_1)^2 + (b_2 - a_2)^2 + (b_3 - a_3)^2 + (b_4 - a_4)^2 \;/\; (\text{max\_diff} - \text{min\_diff})$$
where
$$\text{max\_diff} = \max(\;(b_1 - a_1), \;(b_2 - a_2), \;(b_3 - a_3), \;(b_4 - a_4)\;)$$
$$\text{min\_diff} = \min(\;(b_1 - a_1), \;(b_2 - a_2), \;(b_3 - a_3), \;(b_4 - a_4)\;)$$

Quality of a component behavior:
The quality of the behaviors can be computed using the degree of satisfaction of the constraints. A component behavior is normal if the degree of satisfaction of all the fundamental constraints is 1.0. The quality helps in ranking the behaviors and selecting the behavior with best quality for further expansion.

## 8.2 Implementation

The fuzzy qualitative diagnostic system for fault diagnosis of SSME is being implemented in C++ in the HP-UX environment. An object diagram of the diagnostic system for SSME is shown in Figure 12 below.

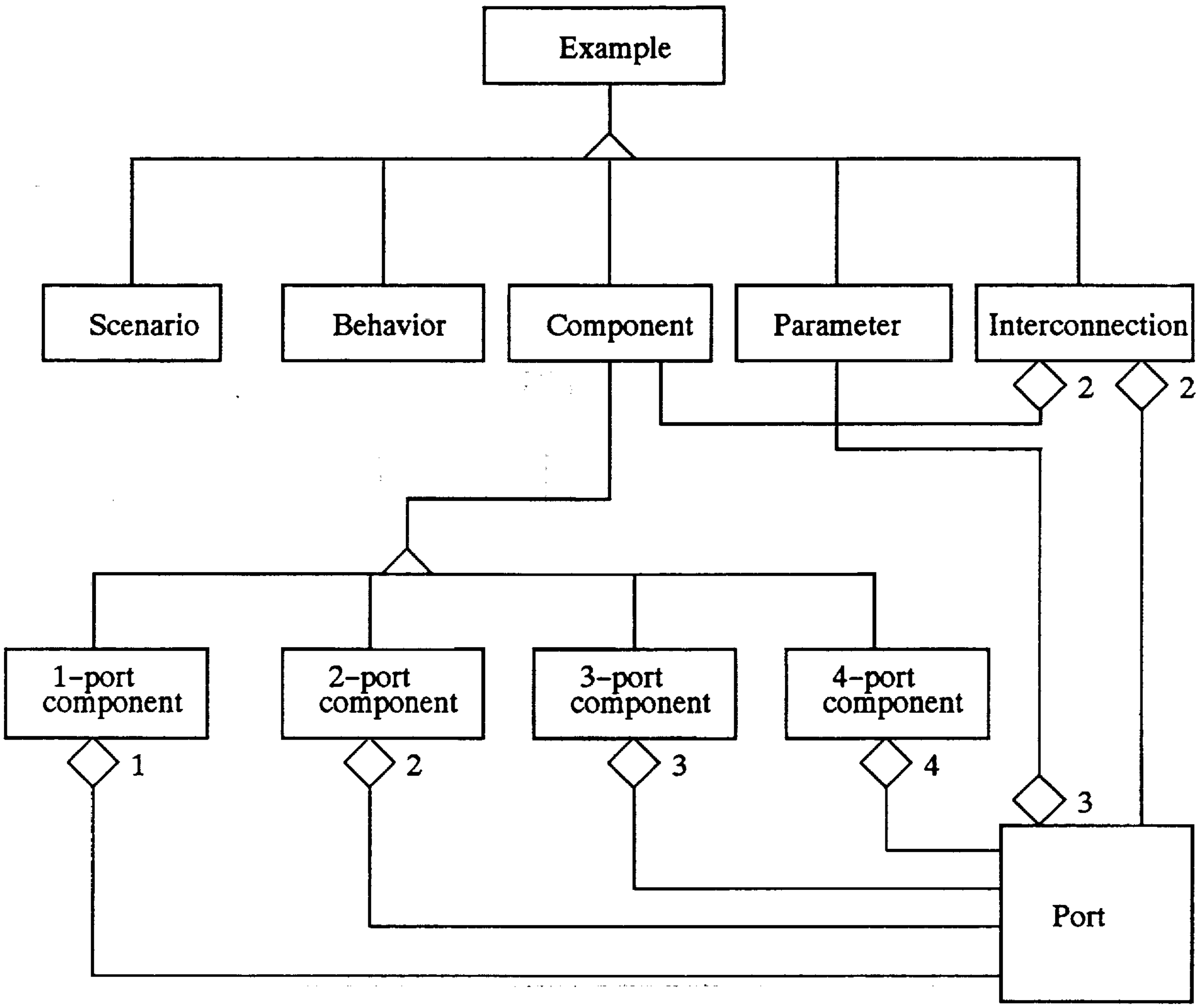



Figure 12a: Object Diagram

The fuzzy qualitative space for all the parameters is implemented as object class "Fuzzy_Value." The class Fuzzy_Value has the following features:

- it defines the three fuzzy sets, low, normal and high using three fuzzy numbers,
- it stores the fuzzy values which represents the possibility values in the three fuzzy sets,
- it stores the numerical range of the variable, a 4-tuple number,
- it defines the mathematical operations addition, subtraction, multiplication, and average,
- it defines an equality relation for objects of class Fuzzy_Value.

All the parameters in the SSME are abstracted under a common class, Parameter. A parameter has an associated name if it is measured. A parameter maybe either measured or derived. The value of a parameter is compared against a comparison value and the deviation is mapped to its fuzzy qualitative space. The values of interface parameters are common to the neighboring components and are propagated between the neighbors.

Class Port:
A thermodynamic component has one or more ports. A port has three parameters, pressure, flow rate and temperature. A port is shared between two neighboring components.

Component interconnections are implemented as objects of class "Interconnections" which consists of the names to the two neighboring components, A and B, and their corresponding ports, port_A and port_B. The set_port_A function propagates interface parameters from the port_B of component B. The set_port_B function propagates interface parameters from the port_A of component A.

A component is an aggregate of the constituent ports, interconnections, derived parameters and the corresponding list of behaviors created. Each component xxx has a class xxx_behavior defined for it.

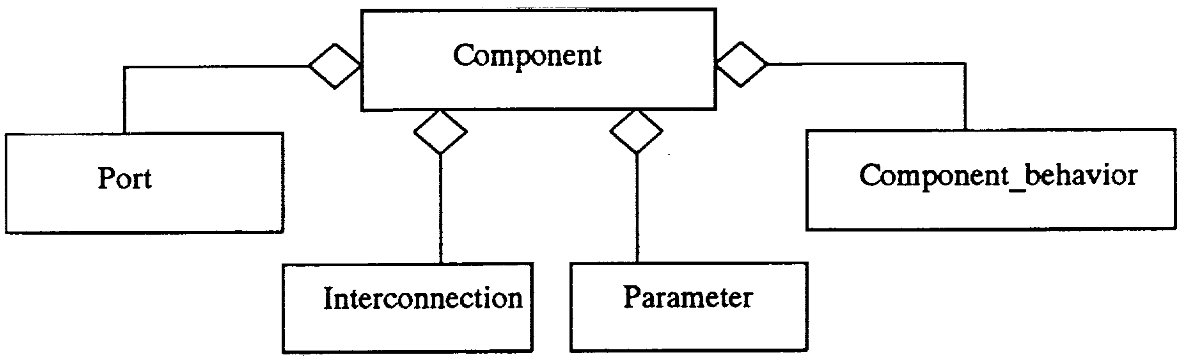



Figure 12b: Component object class

Class "Behavior" is an abstract class for all the component behaviors so that they can be grouped together in one collection. A component_behavior has a mode and a list of assumptions. The mode of the component behavior may be either normal, or any of the fault modes. A mode is characterized by quality which is a measure of the satisfaction of the fundamental constraints.

Class "Scenario": A scenario is a collection of the behaviors of the analyzed components. It stores the name of the last analyzed component. Class Scenario has a cost attribute. Each scenario is ranked based on the cost function. A scenario is chosen for expansion when it has the lowest cost function value.

Class "Example" is an abstract class that acts as superclass to the subclasses - Scenario, Behavior, Component, Interconnection and parameter classes. It consists of all the methods of Scenario, Behavior, Component, Interconnection, Parameter classes.

The functional diagram of the diagnostic system for the SSME is shown below:

1. Scenario consists of all components, which are yet to be analyzed. Read in the configuration files, one for each component to initialize the structure of SSME. Read in the fault modes of each thermodynamic component.

2. Read in the measured data and the comparison data. Find the possibility value of the parameters in all the three fuzzy sets.

3. Choose a component $comp_j$ from all the components with maximum ratio of number of known parameters to unknown parameters to analyze its behavior.

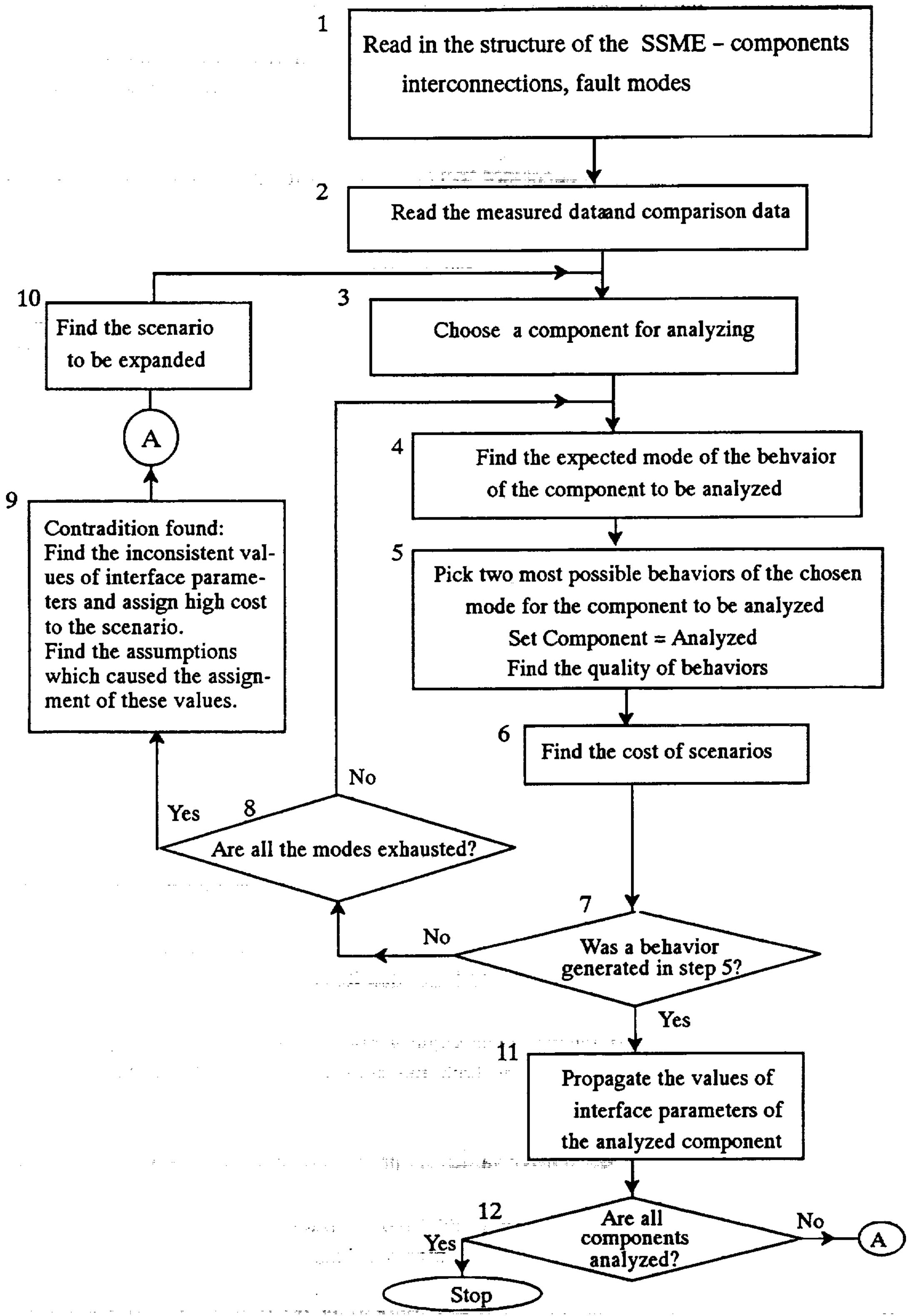



Figure 13: Data flow diagram

4. Find the expected mode of the behavior for the component chosen for analyzing.

5. Pick the **two most possible behaviors** of the chosen mode for the component to be analyzed. Set the analyzed flag of the component. Find the degree of satisfaction of the fundamental constraints and compute the quality of behavior.

6. Find the heuristic evaluation function of successor scenarios. If the successor scenarios finished, set the finished flag, else add them to the set of active scenarios.

7. If no behavior was generated in the step 5, Go to step 8. Otherwise go to step 11.

8. If behaviors of all modes of the component have been tried, there exists no physically possible behavior for the component. There exists a contradiction. These particular set of parameter values do not define any component behavior. Go to step 9. If behaviors of all modes of the component have not been tried, go to step 4 to pick up the next expected behavioral mode.

9. Contradiction is found. Find the inconsistent values of parameters which resulted in contradiction and assign high cost to the scenarios with this particular assignment of values to parameters. Find the assumptions which caused the assignment of these values and mark them bad.

10. Rank the active partial scenarios in AS according to heuristic evaluation function value. Select the partial scenario with least cost for expansion from the set of active scenarios.

11. Global consistency check: The interface parameters of the last analyzed component are propagated to the neighboring components.

12. If all the components are analyzed, stop. Else go to step 10.

### 8.3 Comparison against crisp qualitative method

A fuzzy diagnostic system offers better solutions compared to the crisp qualitative system.

1. In a pure qualitative system, the deviation of the parameter values can be either low, normal and high which indicate only the sign of the deviation of the parameter value and not the magnitude of the deviation. Any numerical information, such as the upper and lower bounds of the deviation of a measured parameter, are not made use of and therefore it is vaguely represented. In a fuzzy qualitative system, the deviation of parameter value is represented by the possibility values in the three fuzzy intervals. The range between maximum positive and maximum negative deviations of the parameter value is divided into three fuzzy intervals, low, normal and high. This mode of representation takes both the sign and magnitude of the deviation into consideration.

2. In a pure qualitative system, only the qualitative values are propagated between the interface parameters. The numerical information associated with the parameter deviation value is neither explicitly represented nor propagated. The unmeasured parameters can only have qualitative values with no corresponding numerical values and the degree of possibility is restricted to only binary values.

In a fuzzy qualitative system, the numerical range corresponding to the possibility value is also propagated. This results in estimating the partial numerical ranges of the unmeasured parameters, when their values are propagated from the neighboring component through interface parameter.

3. Qualitative calculus is inherently ambiguous and lacks additive inverses and multiplicative inverse. The direction of solving the qualitative constraints is fixed. Given the values of constraining variables, it is possible to find the value of the constrained variable. In general, it is not possible to find the unknown value of the constraining variable, given the value of constrained variable.

In the fuzzy qualitative calculus, by defining the fuzzy sets to be symmetrical with respect to the normal set about the origin, it is possible to find the additive inverse of a fuzzy interval. The closed intervals enable solving the constraints in both the directions and the consistency of the sets of possible solutions can be proved.

4. In a pure qualitative system, there is no concept of partial fulfillment of the constraint. As a result, a large number of behaviors may belong to a single behavioral mode. Using fuzzy constraints it is possible to find the degree of satisfaction of the fundamental fuzzy constraints which can be used to compute the quality of the behavior. Behaviors are ranked using quality factor. Using two–place fundamental constraints, finding the degree of satisfaction is equivalent to measuring the grade of equality of two fuzzy numbers. Quality of a behavior is equal to 1 if all the fundamental constraints are completely satisfied.

### 8.4 Limitations of fuzzy qualitative model

Fuzzy qualitative system requires that more numerical information be given, like the absolute value ranges, the maximum and minimum deviations of the parameter values and all the numerical information required to solve algebraic equations. In the absence of the numerical information, it reduces to a simple qualitative system.

Heuristic knowledge is required to properly define the fuzzy sets, which guarantees that the additive inverse of a fuzzy interval can be found.

### 8.5 Management of complexity by selective expansion

In the current implementation, the search space is exhausted completely i.e. all the successor scenarios of a scenario are generated. All the possible behaviors of component are created. In a fuzzy qualitative diagnostic system, either only the most possible behavior of the chosen mode or a set of behaviors of the chosen mode with quality greater than a preset limit can be created. Mode of the behavior to be created is chosen depending upon the heuristic information or the global quality of the scenario. A selective expansion of the search space is done rather than an exhaustive one. This selective expansion avoids the search space getting unmanageably large.

## 9. Running EDIS

EDIS requires a set of configuration and support files located in a configuration directory. An example of configuration files which define the current model of the SSME can be found in Appendix A.2. If heuristic rules and PBM data are to be used, the corresponding knowledge base and data files must be placed in the configuration directory, too. The sequence of operations to run EDIS is listed next.

1. Log in on “bahama” and go to the directory which contains the EDIS knowledge bases. Only bahama has a valid NEXPERT license at this time.
2. Run NEXPERT using the “nexpert &” command.
3. Load the four EDIS knowledge bases kb111b.tkb, kb111c.tkb, planner.tkb, and qualitac.tkb in this order.

4. "Volunteer" the value TRUE for data object USE_HEURISTIC_RULES.Value only if you want to run heuristic rules.
5. "Volunteer" the value TRUE for data object USE_PBM_DATA.Value only if you have and want to use PBM data.
6. "Suggest" hypothesis LOAD_SAFE.
7. Start NEXPERT knowledge processing with "Knowcess".
8. When prompted enter the configuration directory. This may be absolute or relative to the current directory. Always end with a '/'.
9. You may want to watch progress in the Transcript window. Finally, the Session Control window will report that NEXPERT is done. Check out the object BEST_SCENARIO which contains information about the best diagnosis EDIS could find.

## 10. Example

In this section we will demonstrate the performance of EDIS with an example. The example case is test A1614 where a MCC Cooling leak was diagnosed by the SSME experts. Test A1613 was chosen as comparison test and the following anomalies were reported.

- LPFP_DS_PR LOW
- MCC_CLNT_DS_PR LOW
- MCC_CLNT_DS_TMP LOW
- LPFT_INLET_PR LOW
- LPFP_SPEED LOW

Appendix A.5.1 contains a list of all measured parameter values in qualitative form. The anomalies listed above can be found there and all other parameter values are shown to be normal. EDIS expects such a set of qualitative parameter values as input. EDIS, however, assigns values to only those parameters which are listed as "ASSOCIATE_PARAMETERS" (strange wording due to foreign graduate student) in the configuration file of any of the component types. In this set of files, parameters are identified by their standard names as recorded in the configuration files, such as LPFP_DS_PR.

Appendix A.5.2 lists the larger set of numerical PBM data from both tests for a time slice of 10 seconds starting at 395 seconds into the test. These data are transformed into qualitative form and are read when PBM predictions are used to guide EDIS. They are identified by their location number in the A–ARRAY file. The original anomalies can be found there, too. For example, the lower than expected LPFP discharge pressure (LPFP_DS_PR) can be found at location 485 in file PBM_numeric_deviations, which indicates a 4.73% drop in pressure.

### 10.1 Standard Operating Mode

In standard operating mode EDIS iterates over the components in a manner which minimizes guessing. The fuel low controller is analyzed first because all its parameters are known. Thereafter, EDIS follows the network of component interconnections, analyzing one component at a time. Pipe splits and joins are avoided because they introduce a large degree of ambiguity. In the example, the next component analyzed is F101, the pipe/duct from LPFP to HPFP, which contains the fuel flow meter. Then the HPFP is analyzed, etc. Appendix A.5.3 lists the transcript of the NEXPERT session. The following faults are hypothesized in order.

| | | |
|---|---|---|
| 1. | HPFP | low efficiency |
| 2. | HPOP | low efficiency |
| 3. | LPOP | low efficiency |
| 4. | LPFP | low efficiency |
| 5. | LPFP | low efficiency (same fault mode as 4., but slightly different component behavior) |
| 6. | MCC Cooling | leak |

Whether a fault is hypothesized at a component depends on whether one or more fault modes are consistent with the measured and previously assumed parameter values and how likely the matching fault modes are. Appendix A.2.2 contains a listing of file faults which associates likelihoods with specific faults. A value of above 0.2 will normally direct EDIS into attempting to hypothesize the given fault mode. A value less than that indicates that the fault mode should only be considered after all "better" fault modes have proven unlikely or inconsistent.

Behavior hypotheses with the smallest number of anomalous parameter values are preferred among competing behavior hypotheses in the no-fault, i.e. normal, behavior mode. Fault modes are not differentiated in this manner.

### 10.2 Using PBM Data

In this mode of operation, EDIS prefers component behaviors whose parameter values agree with the values predicted by the PBM. A transcript of EDIS executing with this option enabled is shown in Appendix A.5.5. EDIS does not operate significantly different from the standard case. The reason for the similarity is that the PBM predicts most parameter values to be normal and normal values are preferred by EDIS in its normal search mode. This, in fact, verifies the validity of the heuristics from which the heuristic evaluation function of EDIS was derived.

### 10.3 Using Heuristic Rules

EDIS does not readily find a solution when heuristic rules are used at the beginning of the session even though the rules correctly identify the MCC Cooling leak as the cause of the observed anomalies. Too few parameters are known (only 3 out of 10) for the MCC Cooling duct, too many behaviors are possible (40 in this case), and too many of these behaviors (25) are instantiations of the LEAK fault mode. EDIS has no facilities to make an informed choice between these behaviors and tries them in arbitrary order.

### 10.4 Using Heuristic Rules and PBM Data

Executing heuristic rules *and* using PBM data proved to be the most efficient way to solve the given diagnostic problem. EDIS identifies the correct fault hypothesis (MCC Cooling leak) at the start using its heuristic rules, then it identifies the correct MCC Cooling behavior by matching the 25 competing behaviors (see above) against the PBM predictions, and then EDIS analyzes the remaining components to make sure that the proposed hypothesis is consistent with the data and the behavior constraints of all components. The heuristic which selects the most normal behavior for all the remaining components makes it possible for EDIS to select the "right" behavior for all remaining components on its first try. No backtracking at all needs to be performed. This is definitely an ideal and unexpected situation. The transcript of this session is shown in Appendix A.5.6.

The leak behaviors hypothesized by the standard method and this method differ slightly. The former suggests a smaller leak than the latter, i.e. the standard method guesses $V_{out}$ to be NORMAL, while here $V_{out}$ is supposed to be LOW. Both have to assume that $V_{in}$ is HIGH. Since output pressure $p_{out}$ is LOW in both cases the fact that the LPFT produces lower than expected power (MechPWR = LOW) does not resolve the ambiguity either. The ambiguity illustrated by this example is inherent in EDIS because there are too few measurements available to uniquely identify the behavior of each component. Future versions of EDIS might be able to analyze and present equivalent cases such as these together.

## 11. Known Limitations

1. OPOV control to maintain power level is not modeled yet.
2. The main combustion chamber (MCC) model assumes combustion at the optimal mixture ratio where any decrease or increase in LOX flow reduces combustion efficiency and output pressure. After studying the controller behavior in more detail we discovered that LOX flow is still used to control and maintain power, i.e. MCC pressure. Therefore we conclude that the MCC must be operating on the slope instead of the plateau of the pressure curve and the implemented model is wrong.
3. The interface to the anomaly detection system could not be implemented because of the immature developmental status of the specification of the record formats for the anomalies and uncertainty about the interaction protocols between the anomaly detection modules and EDIS.
4. Power balance data have to be transferred to the correct EDIS directory by hand.
5. Anomalies cannot be distinguished by size. Only three qualitative values are available.

## 12. Future Work

1. Integrate EDIS with the PTDS and the Motif user interface. Use data classified by PTDS.
2. Verify and refine the component models. Some of the models make assumptions which may not always be true or may be oversimplified. For example, the pump models do not take the temperature increase of the pumped fuel or LOX into account. Larger than usual temperature increases may, however, indicate pump efficiency problems.
3. Test EDIS on more real cases. If necessary, add and/or modify component models.
4. Improve the search process. A large amount of search can be avoided if scenarios are allowed to reconverge after being split. In the current version, separate scenarios are maintained as long as scenarios differ in at least one parameter value. Scenarios are, however, equivalent if they predict the same fault (possibly none) and the parameter values at the "boundary" of the analyzed components have the same values. Thus some parameter values "inside" the analyzed components, i.e. within a component or at the interface between two analyzed components, may differ but the remaining search is identical for such a set of scenarios. They could be recombined into a single "aggregate-scenario." Savings of search time and storage space appear likely to be achievable by this approach.

5. Design a general solution to the problem of differing classification scales. Currently, special methods are used to deal with the classification of parameter values at interfaces between components which operate at widely diverging operating points. For example, pressure deviations at the HPFP input can be analyzed with respect to either the input (low) pressure level or the output (high) pressure level. This is discussed in detail in the section on HIPUMP behavior. Again at the DIFFUSER, fuel flow is distributed unevenly and flow rate deviations may be categorized against differing scales. The UNEVEN_THREE_SPLIT component model was developed to manage this case. It would be much better and lead to a more maintainable system if a general solution to this problem was implemented.
6. Improve the heuristic evaluation function. For example, small failure effects which do not result in *prima facie* anomalies could be used to strengthen or weaken confidence in fault hypotheses. A small fuel leak, for example, most of the time causes a small increase in LOX flow and OPOV position as the controller is trying to maintain the requested power level. Both effects may be small enough not to be considered anomalies by themselves. When the diagnostic system is evaluating competing hypotheses and a fuel leak is proposed based on obvious anomalies, presence of such small scale effects could lead to increased confidence in a hypothesis.
7. Investigate whether pre–start analysis results would facilitate diagnosis. The interview transcripts frequently mention expectations for engine behavior and measurement values based on information gained from analysis of engine pre–start behavior. It is not clear whether this information impacts only anomaly detection or could also assist in fault diagnosis performed by EDIS.
8. Enlarge the knowledge base of heuristic rules used to identify likely faults and guide the qualitative reasoning system.
9. Re–implement the diagnostic system in CLIPS in order to make it easier to incorporate it into the complete diagnostic systems.
10. Complete the proof–of–concept fuzzy system and evaluate its performance relative to the purely qualitative system.

## 13. Conclusions

The current version of EDIS contains models for all major engine components, has a fully functional diagnostic reasoning module, and accepts suggestions generated by heuristic rules and by PBM data reduction. EDIS has not been extensively tested. All tests were done using a single MCC Cooling leak fault that occurred at test number A1614. During these tests we discovered a few small problems with our models which were due to the simplifications applied. It is to be expected that other cases will uncover additional modification requirements. We recommend a series of tests on a larger number of cases.

EDIS is able to find common faults with current resource limitations and management but more difficult faults, i.e. unexpected and multiple faults, may exhaust the available time and memory resources, see below. Additional refinements to the search process described in Section 12 above and enhancements to the resource management are necessary before EDIS is deployed and used on a day–to–day basis.

The anomaly detection process is not necessarily exact because it depends on human judgement in a variety of ways. The current version of EDIS is not forgiving at all when confronted with a set of anomalies which is not consistent with expected component behavior modes. In some cases this problem may lead to the discarding of the correct solution. Crisp qualitative models can not efficiently deal with classification inconsistencies.

We hope that the version of EDIS discussed in Section 8, enhanced with fuzzy classification and logic, will provide an effective and efficient remedy.

**CAVEAT EMPTOR:** The implemented diagnostic system explores the space of all possible solutions, i.e. all possible behaviors of the SSME. It enumerates behaviors with and without faults; but with the currently supplied heuristic bias it prefers behaviors with a single fault. Note that the size of the search space grows exponentially with the number of parameters and thus with the number of components. It is therefore possible that the program will run out of memory or fail to give an answer within a reasonable time. Only the use of heuristics makes it possible to diagnose realistic anomalies. Without heuristics there would be no hope of finding a good solution. However, heuristics may fail and the system may propose a "wrong" diagnosis or none at all. Even if the system works correctly, its diagnosis may not identify the actual fault. From the system's point of view a diagnosis is correct if it identifies the most likely fault given the available measurements and the supplied heuristics. Unfortunately this fault may yet be different from the actual fault. Note that bias due to knowledge limitations is a problem inherent to all machine and human reasoning.

The algorithm implemented is a version of $A^*$ search. This type of search algorithm is guaranteed to find the best solution and to find it first but only if the heuristic evaluation function consistently underestimates the actual cost (or badness) of each evolving solution. We tried to use such a function at the beginning of the project and quickly discovered that the algorithm lacked focus on likely faults expected of an expert system. It tended to explore low likelihood areas of the search space because the evaluation function did not penalize these unlikely solutions enough, while making sure that even an unlikely solution would be found. The final version of the heuristic evaluation function is not guaranteed to underestimate the cost of evolving solutions and therefore might pass up the best solution in the first attempt. No possible solutions are totally disregarded, however, they are just considered later in the search. The new algorithm draws broader conclusions from instances when an assumption cannot be justified , i.e. explained by a complete high quality scenario representing engine behavior. It will assume that the given assumption is bad and retract it after the first justification attempt has failed, even if some other means of justifying it might actually succeed. The rational for this behavior is derived from the fact that the algorithm always attempts to complete the most likely justification first. The implemented algorithm therefore does not guarantee that that solution proposed first is the best one, but with reasonable heuristic information the most likely solutions will be generated before the less likely ones. As always, the meaning of "likely" depends on the heuristics, i.e. if the system is told that pumps fail more frequently than pipes it will prefer solutions that imply pump problems over those that imply pipe problems.

Pure qualitative models do not adequately model a system such as the SSME. The problem is that the same parameter value is interpreted differently depending on which component is analyzed. For example, the output pressure of the LPFP is actually identical to the input pressure of the HPFP (neglecting the duct between them for this example). A change in this pressure may, however, be considered significant, i.e. anomalous, when viewed in the context of the LPFP, and negligible when viewed in the context of the HPFP. The vastly different absolute values of pressure at the outputs of the LPFP and HPFP cause this discrepancy. The same size change will appear significant relative to the absolute pressure value at the LPFP and insignificant at the HPFP. A possible solution to this problem is to neglect changes in the HPFP input pressure values. We defined a separate "High-Pressure Pump" model in our system which implements this behavior. It appears reasonable to assume that components which have much larger operating values at their output compared to their input would tend to "hide" deviations which are passed unchanged in size from input to output. Relative to the operating point the same size change will, of course, appear much smaller at the output.

Another example is the confluence of flows of different magnitudes. The resultant flow may not be affected at all by a change in magnitude of a few percent of the smaller contributor. Rather than using specialized models for all these special cases, we conclude that it would be better if the model was aware of the difference in absolute magnitude. The purely qualitative model must then be extended with quantitative information. The fuzzy set theory-based system and the Order-of-Magnitude based system represent two attempts at coping with large variations in operating values.

The computational complexity of the search for a consistent parameter value assignment, i.e. a scenario which explains the observer data and anomalies, is exponential. Memory requirements and computation time may grow excessively. In our implementation memory resource limits are the critical bound and it is entirely possible that process memory limits are reached.

## 14. References

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# APPENDIX

## A.2 SSME Configuration Files

### A.2.1Component Files

Type PIPE (File pipe)

\F101.NAME\="F101"
\F101.MEDIUM_INPUT\="LPFP"
\F101.parameter_coupled_to_pin\="pout"
\F101.parameter_coupled_to_Vin\="Vout"
\F101.parameter_coupled_to_Tin\="Tout"
\F101.MEDIUM_OUTPUT\="HPFP"
\F101.parameter_coupled_to_pout\="pin"
\F101.parameter_coupled_to_Vout\="Vin"
\F101.parameter_coupled_to_Tout\="Tin"
\F101.ASSOCIATE_PARAMETERS\="LPFP_DS_PR,LPFP_DS_TMP,FUEL_FLOW"
\F101.GENERIC_PARAMETERS\="pin,Tin,Vout"
\F108.NAME\="F108"
\F108.MEDIUM_INPUT\="M103"
\F108.parameter_coupled_to_pin\="pin"
\F108.parameter_coupled_to_Vin\="VoutB"
\F108.parameter_coupled_to_Tin\="Tin"
\F108.MEDIUM_OUTPUT\="OPB"
\F108.parameter_coupled_to_pout\="pin"
\F108.parameter_coupled_to_Vout\="Vin"
\F108.parameter_coupled_to_Tout\="Tin"
\F108.ASSOCIATE_PARAMETERS\="Notknown"
\F108.GENERIC_PARAMETERS\="Notknown"
\F110.NAME\="F110"
\F110.MEDIUM_INPUT\="M103"
\F110.parameter_coupled_to_pin\="pin"
\F110.parameter_coupled_to_Vin\="VoutC"
\F110.parameter_coupled_to_Tin\="Tin"
\F110.MEDIUM_OUTPUT\="FPB"
\F110.parameter_coupled_to_pout\="pin"
\F110.parameter_coupled_to_Vout\="Vin"
\F110.parameter_coupled_to_Tout\="Tin"
\F110.ASSOCIATE_PARAMETERS\="Notknown"
\F110.GENERIC_PARAMETERS\="Notknown"
\F109.NAME\="F109"
\F109.MEDIUM_INPUT\="MCC_COOL"
\F109.parameter_coupled_to_pin\="pout"
\F109.parameter_coupled_to_Vin\="Vout"
\F109.parameter_coupled_to_Tin\="Tout"
\F109.MEDIUM_OUTPUT\="LPFT"
\F109.parameter_coupled_to_pout\="pin"
\F109.parameter_coupled_to_Vout\="Vin"
\F109.parameter_coupled_to_Tout\="Tin"
\F109.ASSOCIATE_PARAMETERS\="MCC_CLNT_DS_PR,MCC_CLNT_DS_TMP,LPFT_INLET_PR"
\F109.GENERIC_PARAMETERS\="pin,Tin,pout"
\F190.NAME\="F190"
\F190.MEDIUM_INPUT\="LPFT"
\F190.parameter_coupled_to_pin\="pout"
\F190.parameter_coupled_to_Vin\="Vout"
\F190.parameter_coupled_to_Tin\="Tout"

\F190.MEDIUM_OUTPUT\="Notknown"
\F190.parameter_coupled_to_pout\="Notknown"
\F190.parameter_coupled_to_Vout\="Notknown"
\F190.parameter_coupled_to_Tout\="Notknown"
\F190.ASSOCIATE_PARAMETERS\="Notknown"
\F190.GENERIC_PARAMETERS\="Notknown"
\O204.NAME\="O204"
\O204.MEDIUM_INPUT\="M104"
\O204.parameter_coupled_to_pin\="pin"
\O204.parameter_coupled_to_Vin\="Vout"
\O204.parameter_coupled_to_Tin\="Tin"
\O204.MEDIUM_OUTPUT\="MOV"
\O204.parameter_coupled_to_pout\="pin"
\O204.parameter_coupled_to_Vout\="Vin"
\O204.parameter_coupled_to_Tout\="Tin"
\O204.ASSOCIATE_PARAMETERS\="Notknown"
\O204.GENERIC_PARAMETERS\="Notknown"
\O203.NAME\="O203"
\O203.MEDIUM_INPUT\="M104"
\O203.parameter_coupled_to_pin\="pin"
\O203.parameter_coupled_to_Vin\="VoutB"
\O203.parameter_coupled_to_Tin\="Tin"
\O203.MEDIUM_OUTPUT\="LPOT"
\O203.parameter_coupled_to_pout\="pin"
\O203.parameter_coupled_to_Vout\="Vin"
\O203.parameter_coupled_to_Tout\="Tin"
\O203.ASSOCIATE_PARAMETERS\="Notknown"
\O203.GENERIC_PARAMETERS\="Notknown"
\O205.NAME\="O205"
\O205.MEDIUM_INPUT\="M104"
\O205.parameter_coupled_to_pin\="pin"
\O205.parameter_coupled_to_Vin\="VoutC"
\O205.parameter_coupled_to_Tin\="Tin"
\O205.MEDIUM_OUTPUT\="M101"
\O205.parameter_coupled_to_pout\="pin"
\O205.parameter_coupled_to_Vout\="Vin"
\O205.parameter_coupled_to_Tout\="Tin"
\O205.ASSOCIATE_PARAMETERS\="Notknown"
\O205.GENERIC_PARAMETERS\="Notknown"
\O206.NAME\="O206"
\O206.MEDIUM_INPUT\="M101"
\O206.parameter_coupled_to_pin\="pin"
\O206.parameter_coupled_to_Vin\="VoutC"
\O206.parameter_coupled_to_Tin\="Tin"
\O206.MEDIUM_OUTPUT\="FPOV"
\O206.parameter_coupled_to_pout\="pin"
\O206.parameter_coupled_to_Vout\="Vin"
\O206.parameter_coupled_to_Tout\="Tin"
\O206.ASSOCIATE_PARAMETERS\="Notknown"
\O206.GENERIC_PARAMETERS\="Notknown"
\O201.NAME\="O201"
\O201.MEDIUM_INPUT\="LPOP"
\O201.parameter_coupled_to_pin\="pout"
\O201.parameter_coupled_to_Vin\="Vout"

```
\O201.parameter_coupled_to_Tin\="Tout"
\O201.MEDIUM_OUTPUT\="HPOP_PBP"
\O201.parameter_coupled_to_pout\="pin"
\O201.parameter_coupled_to_Vout\="Vin"
\O201.parameter_coupled_to_Tout\="Tin"
\O201.ASSOCIATE_PARAMETERS\="LPOP_DS_PR"
\O201.GENERIC_PARAMETERS\="pin"
\O190.NAME\="O190"
\O190.MEDIUM_INPUT\="LPOT"
\O190.parameter_coupled_to_pin\="pout"
\O190.parameter_coupled_to_Vin\="Vout"
\O190.parameter_coupled_to_Tin\="Tout"
\O190.MEDIUM_OUTPUT\="Notknown"
\O190.parameter_coupled_to_pout\="Notknown"
\O190.parameter_coupled_to_Vout\="Notknown"
\O190.parameter_coupled_to_Tout\="Notknown"
\O190.ASSOCIATE_PARAMETERS\="Notknown"
\O190.GENERIC_PARAMETERS\="Notknown"
\F107.NAME\="F107"
\F107.MEDIUM_INPUT\="MIXER"
\F107.parameter_coupled_to_pin\="pin"
\F107.parameter_coupled_to_Vin\="Vout"
\F107.parameter_coupled_to_Tin\="Tout"
\F107.MEDIUM_OUTPUT\="M103"
\F107.parameter_coupled_to_pout\="pin"
\F107.parameter_coupled_to_Vout\="Vin"
\F107.parameter_coupled_to_Tout\="Tin"
\F107.ASSOCIATE_PARAMETERS\="Notknown"
\F107.GENERIC_PARAMETERS\="Notknown"
**********
```

## Type COOLING (File cooling)

```
\MCC_COOL.NAME\="MCC_COOL"
\MCC_COOL.MEDIUM_INPUT\="DIFFUSER"
\MCC_COOL.parameter_coupled_to_pin\="pin"
\MCC_COOL.parameter_coupled_to_Vin\="VoutC"
\MCC_COOL.parameter_coupled_to_Tin\="Tin"
\MCC_COOL.MEDIUM_OUTPUT\="F109"
\MCC_COOL.parameter_coupled_to_pout\="pin"
\MCC_COOL.parameter_coupled_to_Vout\="Vin"
\MCC_COOL.parameter_coupled_to_Tout\="Tin"
\MCC_COOL.COOLS\="MCC"
\MCC_COOL.parameter_coupled_to_Tsource\="Tout"
\MCC_COOL.ASSOCIATE_PARAMETERS\="MCC_CLNT_DS_PR,MCC_CLNT_DS_TMP"
\MCC_COOL.GENERIC_PARAMETERS\="pout,Tout"
\NZL_COOL.NAME\="NZL_COOL"
\NZL_COOL.MEDIUM_INPUT\="DIFFUSER"
\NZL_COOL.parameter_coupled_to_pin\="pin"
\NZL_COOL.parameter_coupled_to_Vin\="VoutB"
\NZL_COOL.parameter_coupled_to_Tin\="Tin"
\NZL_COOL.MEDIUM_OUTPUT\="MIXER"
\NZL_COOL.parameter_coupled_to_pout\="pin"
\NZL_COOL.parameter_coupled_to_Vout\="VinB"
\NZL_COOL.parameter_coupled_to_Tout\="TinB"
\NZL_COOL.COOLS\="NOZZLE1"
\NZL_COOL.parameter_coupled_to_Tsource\="Tout"
\NZL_COOL.ASSOCIATE_PARAMETERS\="Notknown"
\NZL_COOL.GENERIC_PARAMETERS\="Notknown"
**********
```

# Type VALVE (File valve)

```
\FPOV.NAME\="FPOV"
\FPOV.MEDIUM_INPUT\="O206"
\FPOV.parameter_coupled_to_pin\="pout"
\FPOV.parameter_coupled_to_Vin\="Vout"
\FPOV.parameter_coupled_to_Tin\="Tout"
\FPOV.MEDIUM_OUTPUT\="FPB"
\FPOV.parameter_coupled_to_pout\="pin_OX"
\FPOV.parameter_coupled_to_Vout\="Vin_OX"
\FPOV.parameter_coupled_to_Tout\="Tin_OX"
\FPOV.CONTROLLED_BY\="FUEL_FLOW_CTRL"
\FPOV.parameter_coupled_to_commanded_position\="commanded_position"
\FPOV.ASSOCIATE_PARAMETERS\="FPOV_POSITION,FPOV_POSITION"
\FPOV.GENERIC_PARAMETERS\="position,commanded_position"
\MFV.NAME\="MFV"
\MFV.MEDIUM_INPUT\="HPFP"
\MFV.parameter_coupled_to_pin\="pout"
\MFV.parameter_coupled_to_Vin\="Vout"
\MFV.parameter_coupled_to_Tin\="Tout"
\MFV.MEDIUM_OUTPUT\="DIFFUSER"
\MFV.parameter_coupled_to_pout\="pin"
\MFV.parameter_coupled_to_Vout\="Vin"
\MFV.parameter_coupled_to_Tout\="Tin"
\MFV.CONTROLLED_BY\="MFV_CTRL"
\MFV.parameter_coupled_to_commanded_position\="commanded_position"
\MFV.ASSOCIATE_PARAMETERS\="HPFP_DS_PR,HPFP_DS_TMP,position,commanded_position"
\MFV.GENERIC_PARAMETERS\="pin,Tin,MFV_POSITION,MFV_POSITION"
\CCV.NAME\="CCV"
\CCV.MEDIUM_INPUT\="DIFFUSER"
\CCV.parameter_coupled_to_pin\="pin"
\CCV.parameter_coupled_to_Vin\="Vout"
\CCV.parameter_coupled_to_Tin\="Tin"
\CCV.MEDIUM_OUTPUT\="MIXER"
\CCV.parameter_coupled_to_pout\="pin"
\CCV.parameter_coupled_to_Vout\="Vin"
\CCV.parameter_coupled_to_Tout\="Tin"
\CCV.CONTROLLED_BY\="CCV_CTRL"
\CCV.parameter_coupled_to_commanded_position\="commanded_position"
\CCV.ASSOCIATE_PARAMETERS\="CCV_POSITION,CCV_POSITION"
\CCV.GENERIC_PARAMETERS\="position,commanded_position"
\MOV.NAME\="MOV"
\MOV.MEDIUM_INPUT\="O204"
\MOV.parameter_coupled_to_pin\="pout"
\MOV.parameter_coupled_to_Vin\="Vout"
\MOV.parameter_coupled_to_Tin\="Tout"
\MOV.MEDIUM_OUTPUT\="MCC"
\MOV.parameter_coupled_to_pout\="pin_OX"
\MOV.parameter_coupled_to_Vout\="Vin_OX"
\MOV.parameter_coupled_to_Tout\="Tin_OX"
\MOV.CONTROLLED_BY\="MOV_CTRL"
\MOV.parameter_coupled_to_commanded_position\="commanded_position"
\MOV.ASSOCIATE_PARAMETERS\="MOV_POSITION,MOV_POSITION"
\MOV.GENERIC_PARAMETERS\="position,commanded_position"
```

```
\OPOV.NAME\="OPOV"
\OPOV.MEDIUM_INPUT\="M101"
\OPOV.parameter_coupled_to_pin\="pin"
\OPOV.parameter_coupled_to_Vin\="VoutB"
\OPOV.parameter_coupled_to_Tin\="Tin"
\OPOV.MEDIUM_OUTPUT\="OPB"
\OPOV.parameter_coupled_to_pout\="pin_OX"
\OPOV.parameter_coupled_to_Vout\="Vin_OX"
\OPOV.parameter_coupled_to_Tout\="Tin_OX"
\OPOV.CONTROLLED_BY\="OPOV_CTRL"
\OPOV.parameter_coupled_to_commanded_position\="commanded_position"
\OPOV.ASSOCIATE_PARAMETERS\="OPOV_POSITION,OPOV_POSITION"
\OPOV.GENERIC_PARAMETERS\="position,commanded_position"
**********
```

## Type PUMP (File pump)

\LPFP.NAME\="LPFP"
\LPFP.MEDIUM_INPUT\="FUEL_TANK"
\LPFP.parameter_coupled_to_pin\="pout"
\LPFP.parameter_coupled_to_Vin\="Vout"
\LPFP.parameter_coupled_to_Tin\="Tout"
\LPFP.MEDIUM_OUTPUT\="F101"
\LPFP.parameter_coupled_to_pout\="pin"
\LPFP.parameter_coupled_to_Vout\="Vin"
\LPFP.parameter_coupled_to_Tout\="Tin"
\LPFP.COUPLED_TO\="LPFT"
\LPFP.parameter_coupled_to_omega\="omega"
\LPFP.parameter_coupled_to_MechPWR\="MechPWR"
\LPFP.parameter_coupled_to_Tq\="Tq"
\LPFP.ASSOCIATE_PARAMETERS\="ENG_FUEL_INLET_PR,ENG_FUEL_IN-LET_TMP,LPFP_DS_PR,LPFP_DS_TMP,LPFP_SPEED1"
\LPFP.GENERIC_PARAMETERS\="pin,Tin,pout,Tout,omega"
\LPOP.NAME\="LPOP"
\LPOP.MEDIUM_INPUT\="LOX_TANK"
\LPOP.parameter_coupled_to_pin\="pout"
\LPOP.parameter_coupled_to_Vin\="Vout"
\LPOP.parameter_coupled_to_Tin\="Tout"
\LPOP.MEDIUM_OUTPUT\="O201"
\LPOP.parameter_coupled_to_pout\="pin"
\LPOP.parameter_coupled_to_Vout\="Vin"
\LPOP.parameter_coupled_to_Tout\="Tin"
\LPOP.COUPLED_TO\="LPOT"
\LPOP.parameter_coupled_to_omega\="omega"
\LPOP.parameter_coupled_to_MechPWR\="MechPWR"
\LPOP.parameter_coupled_to_Tq\="Tq"
\LPOP.ASSOCIATE_PARAMETERS\="ENG_OX_INLET_PR,ENG_OX_IN-LET_TMP,LPOP_DS_PR,LPOP_SPEED1"
\LPOP.GENERIC_PARAMETERS\="pin,Tin,pout,omega"
**********

## Type HIPUMP (File hipump)

```
\HPFP.NAME\="HPFP"
\HPFP.MEDIUM_INPUT\="F101"
\HPFP.parameter_coupled_to_pin\="pout"
\HPFP.parameter_coupled_to_Vin\="Vout"
\HPFP.parameter_coupled_to_Tin\="Tout"
\HPFP.MEDIUM_OUTPUT\="MFV"
\HPFP.parameter_coupled_to_pout\="pin"
\HPFP.parameter_coupled_to_Vout\="Vin"
\HPFP.parameter_coupled_to_Tout\="Tin"
\HPFP.COUPLED_TO\="HPFT"
\HPFP.parameter_coupled_to_omega\="omega"
\HPFP.parameter_coupled_to_MechPWR\="MechPWR"
\HPFP.parameter_coupled_to_Tq\="Tq"
\HPFP.ASSOCIATE_PARAMETERS\="FUEL_FLOW,HPFP_DS_PR,HPFP_DS_TMP,HPFP_SPEED1"
\HPFP.GENERIC_PARAMETERS\="Vin,pout,Tout,omega"
\HPOP_PBP.NAME\="HPOP/PBP"
\HPOP_PBP.MEDIUM_INPUT\="O201"
\HPOP_PBP.parameter_coupled_to_pin\="pout"
\HPOP_PBP.parameter_coupled_to_Vin\="Vout"
\HPOP_PBP.parameter_coupled_to_Tin\="Tout"
\HPOP_PBP.MEDIUM_OUTPUT\="M104"
\HPOP_PBP.parameter_coupled_to_pout\="pin"
\HPOP_PBP.parameter_coupled_to_Vout\="Vin"
\HPOP_PBP.parameter_coupled_to_Tout\="Tin"
\HPOP_PBP.COUPLED_TO\="HPOT"
\HPOP_PBP.parameter_coupled_to_omega\="omega"
\HPOP_PBP.parameter_coupled_to_MechPWR\="MechPWR"
\HPOP_PBP.parameter_coupled_to_Tq\="Tq"
\HPOP_PBP.ASSOCIATE_PARAMETERS\="HPOP_DS_PR,HPOP_DS_TMP,HPOP_SPEED"
\HPOP_PBP.GENERIC_PARAMETERS\="pout,Tout,omega"
```

## Type HYDRAULIC_TURBINE (File hturbine)

\LPOT.NAME\="LPOT"
\LPOT.MEDIUM_INPUT\="O203"
\LPOT.parameter_coupled_to_pin\="pout"
\LPOT.parameter_coupled_to_Vin\="Vout"
\LPOT.parameter_coupled_to_Tin\="Tout"
\LPOT.MEDIUM_OUTPUT\="O190"
\LPOT.parameter_coupled_to_pout\="pin"
\LPOT.parameter_coupled_to_Vout\="Vin"
\LPOT.parameter_coupled_to_Tout\="Tin"
\LPOT.COUPLED_TO\="LPOP"
\LPOT.parameter_coupled_to_omega\="omega"
\LPOT.parameter_coupled_to_MechPWR\="MechPWR"
\LPOT.parameter_coupled_to_Tq\="Tq"
\LPOT.ASSOCIATE_PARAMETERS\="LPOP_SPEED1"
\LPOT.GENERIC_PARAMETERS\="omega"
**********

## Type GAS_TURBINE (File gturbine)

```
\LPFT.NAME\="LPFT"
\LPFT.MEDIUM_INPUT\="F109"
\LPFT.parameter_coupled_to_pin\="pout"
\LPFT.parameter_coupled_to_Vin\="Vout"
\LPFT.parameter_coupled_to_Tin\="Tout"
\LPFT.MEDIUM_OUTPUT\="F190"
\LPFT.parameter_coupled_to_pout\="pin"
\LPFT.parameter_coupled_to_Vout\="Vin"
\LPFT.parameter_coupled_to_Tout\="Tin"
\LPFT.COUPLED_TO\="LPFP"
\LPFT.parameter_coupled_to_omega\="omega"
\LPFT.parameter_coupled_to_MechPWR\="MechPWR"
\LPFT.parameter_coupled_to_Tq\="Tq"
\LPFT.ASSOCIATE_PARAMETERS\="LPFT_INLET_PR,LPFP_SPEED1"
\LPFT.GENERIC_PARAMETERS\="pin,omega"
\HPFT.NAME\="HPFT"
\HPFT.MEDIUM_INPUT\="FPB"
\HPFT.parameter_coupled_to_pin\="pout"
\HPFT.parameter_coupled_to_Vin\="Vout"
\HPFT.parameter_coupled_to_Tin\="Tout"
\HPFT.MEDIUM_OUTPUT\="HGM"
\HPFT.parameter_coupled_to_pout\="pin"
\HPFT.parameter_coupled_to_Vout\="Vin"
\HPFT.parameter_coupled_to_Tout\="Tin"
\HPFT.COUPLED_TO\="HPFP"
\HPFT.parameter_coupled_to_omega\="omega"
\HPFT.parameter_coupled_to_MechPWR\="MechPWR"
\HPFT.parameter_coupled_to_Tq\="Tq"
\HPFT.ASSOCIATE_PARAMETERS\="FPB_PC,HPFT_DS_TMP1,HPFP_SPEED1"
\HPFT.GENERIC_PARAMETERS\="pin,Tout,omega"
\HPOT.NAME\="HPOT"
\HPOT.MEDIUM_INPUT\="OPB"
\HPOT.parameter_coupled_to_pin\="pout"
\HPOT.parameter_coupled_to_Vin\="Vout"
\HPOT.parameter_coupled_to_Tin\="Tout"
\HPOT.MEDIUM_OUTPUT\="HGM"
\HPOT.parameter_coupled_to_pout\="pin"
\HPOT.parameter_coupled_to_Vout\="VinB"
\HPOT.parameter_coupled_to_Tout\="TinB"
\HPOT.COUPLED_TO\="HPOP_PBP"
\HPOT.parameter_coupled_to_omega\="omega"
\HPOT.parameter_coupled_to_MechPWR\="MechPWR"
\HPOT.parameter_coupled_to_Tq\="Tq"
\HPOT.ASSOCIATE_PARAMETERS\="OPB_PC,HPOT_DS_TMP1,HPOP_SPEED"
\HPOT.GENERIC_PARAMETERS\="pin,Tout,omega"
**********
```

# Type PRE_BURNER (File pburner)

```
\FPB.NAME\="FPB"
\FPB.FUEL_IN\="F110"
\FPB.parameter_coupled_to_pin\="pout"
\FPB.parameter_coupled_to_Vin\="Vout"
\FPB.parameter_coupled_to_Tin\="Tout"
\FPB.GAS_OUT\="HPFT"
\FPB.parameter_coupled_to_pout\="pin"
\FPB.parameter_coupled_to_Vout\="Vin"
\FPB.parameter_coupled_to_Tout\="Tin"
\FPB.OX_IN\="FPOV"
\FPB.parameter_coupled_to_pin_OX\="pout"
\FPB.parameter_coupled_to_Vin_OX\="Vout"
\FPB.parameter_coupled_to_Tin_OX\="Tout"
\FPB.ASSOCIATE_PARAMETERS\="FPB_PC"
\FPB.GENERIC_PARAMETERS\="pout"
\OPB.NAME\="OPB"
\OPB.FUEL_IN\="F108"
\OPB.parameter_coupled_to_pin\="pout"
\OPB.parameter_coupled_to_Vin\="Vout"
\OPB.parameter_coupled_to_Tin\="Tout"
\OPB.GAS_OUT\="HPOT"
\OPB.parameter_coupled_to_pout\="pin"
\OPB.parameter_coupled_to_Vout\="Vin"
\OPB.parameter_coupled_to_Tout\="Tin"
\OPB.OX_IN\="OPOV"
\OPB.parameter_coupled_to_pin_OX\="pout"
\OPB.parameter_coupled_to_Vin_OX\="Vout"
\OPB.parameter_coupled_to_Tin_OX\="Tout"
\OPB.ASSOCIATE_PARAMETERS\="OPB_PC"
\OPB.GENERIC_PARAMETERS\="pout"
**********
```

## Type MAIN_BURNER (File mburner)

\MCC.NAME\="MCC"
\MCC.FUEL_IN\="HGM"
\MCC.parameter_coupled_to_pin\="pin"
\MCC.parameter_coupled_to_Vin\="Vout"
\MCC.parameter_coupled_to_Tin\="Tout"
\MCC.GAS_OUT\="NOZZLE1"
\MCC.parameter_coupled_to_pout\="pin"
\MCC.parameter_coupled_to_Vout\="Vin"
\MCC.parameter_coupled_to_ToutB\="Tin"
\MCC.COOLED_BY\="MCC_COOL"
\MCC.parameter_coupled_to_Tout\="Tsource"
\MCC.OX_IN\="MOV"
\MCC.parameter_coupled_to_pin_OX\="pout"
\MCC.parameter_coupled_to_Vin_OX\="Vout"
\MCC.parameter_coupled_to_Tin_OX\="Tout"
\MCC.ASSOCIATE_PARAMETERS\="MCC_PC"
\MCC.GENERIC_PARAMETERS\="pout"
**********

## Type CONTROLLER_CONST (File ctrlfuel)

\FUEL_FLOW_CTRL.NAME\="FUEL_FLOW_CTRL"
\FUEL_FLOW_CTRL.MEASURES_AT\="F101"
\FUEL_FLOW_CTRL.parameter_coupled_to_Vin\="Vout"
\FUEL_FLOW_CTRL.CONTROLS\="FPOV"
\FUEL_FLOW_CTRL.parameter_coupled_to_commanded_position\="commanded_position"
\FUEL_FLOW_CTRL.ASSOCIATE_PARAMETERS\="FUEL_FLOW,FPOV_POSITION"
\FUEL_FLOW_CTRL.GENERIC_PARAMETERS\="Vin,commanded_position"
\MFV_CTRL.NAME\="MFV_CTRL"
\MFV_CTRL.MEASURES_AT\="Notknown"
\MFV_CTRL.parameter_coupled_to_Vin\="Notknown"
\MFV_CTRL.CONTROLS\="MFV"
\MFV_CTRL.parameter_coupled_to_commanded_position\="commanded_position"
\MFV_CTRL.ASSOCIATE_PARAMETERS\="Notknown"
\MFV_CTRL.GENERIC_PARAMETERS\="Notknown"
\CCV_CTRL.NAME\="CCV_CTRL"
\CCV_CTRL.MEASURES_AT\="Notknown"
\CCV_CTRL.parameter_coupled_to_Vin\="Notknown"
\CCV_CTRL.CONTROLS\="CCV"
\CCV_CTRL.parameter_coupled_to_commanded_position\="commanded_position"
\CCV_CTRL.ASSOCIATE_PARAMETERS\="Notknown"
\CCV_CTRL.GENERIC_PARAMETERS\="Notknown"
\MOV_CTRL.NAME\="MOV_CTRL"
\MOV_CTRL.MEASURES_AT\="Notknown"
\MOV_CTRL.parameter_coupled_to_Vin\="Notknown"
\MOV_CTRL.CONTROLS\="MOV"
\MOV_CTRL.parameter_coupled_to_commanded_position\="commanded_position"
\MOV_CTRL.ASSOCIATE_PARAMETERS\="Notknown"
\MOV_CTRL.GENERIC_PARAMETERS\="Notknown"
\OPOV_CTRL.NAME\="OPOV_CTRL"
\OPOV_CTRL.MEASURES_AT\="Notknown"
\OPOV_CTRL.parameter_coupled_to_Vin\="Notknown"
\OPOV_CTRL.CONTROLS\="OPOV"
\OPOV_CTRL.parameter_coupled_to_commanded_position\="commanded_position"
\OPOV_CTRL.ASSOCIATE_PARAMETERS\="Notknown"
\OPOV_CTRL.GENERIC_PARAMETERS\="Notknown"
**********

## Type TWO_SPLIT (File twosplit)

\M103.NAME\="M103"
\M103.MEDIUM_IN\="F107"
\M103.parameter_coupled_to_pin\="pout"
\M103.parameter_coupled_to_Vin\="Vout"
\M103.parameter_coupled_to_Tin\="Tout"
\M103.MEDIUM_OUTA\="F108"
\M103.parameter_coupled_to_poutA\="pin"
\M103.parameter_coupled_to_VoutA\="Vin"
\M103.parameter_coupled_to_ToutA\="Tin"
\M103.MEDIUM_OUTB\="F110"
\M103.parameter_coupled_to_poutB\="pin"
\M103.parameter_coupled_to_VoutB\="Vin"
\M103.parameter_coupled_to_ToutB\="Tin"
\M103.ASSOCIATE_PARAMETERS\="Notknown"
\M103.GENERIC_PARAMETERS\="Notknown"
\M101.NAME\="M101"
\M101.MEDIUM_IN\="O205"
\M101.parameter_coupled_to_pin\="pout"
\M101.parameter_coupled_to_Vin\="Vout"
\M101.parameter_coupled_to_Tin\="Tout"
\M101.MEDIUM_OUTA\="OPOV"
\M101.parameter_coupled_to_poutA\="pin"
\M101.parameter_coupled_to_VoutA\="Vin"
\M101.parameter_coupled_to_ToutA\="Tin"
\M101.MEDIUM_OUTB\="O206"
\M101.parameter_coupled_to_poutB\="pin"
\M101.parameter_coupled_to_VoutB\="Vin"
\M101.parameter_coupled_to_ToutB\="Tin"
\M101.ASSOCIATE_PARAMETERS\="Notknown"
\M101.GENERIC_PARAMETERS\="Notknown"
**********

## Type THREE_SPLIT (File trisplit)

\M104.NAME\="M104"
\M104.MEDIUM_IN\="HPOP_PBP"
\M104.parameter_coupled_to_pin\="pout"
\M104.parameter_coupled_to_Vin\="Vout"
\M104.parameter_coupled_to_Tin\="Tout"
\M104.MEDIUM_OUTA\="O204"
\M104.parameter_coupled_to_poutA\="pin"
\M104.parameter_coupled_to_VoutA\="Vin"
\M104.parameter_coupled_to_ToutA\="Tin"
\M104.MEDIUM_OUTB\="O203"
\M104.parameter_coupled_to_poutB\="pin"
\M104.parameter_coupled_to_VoutB\="Vin"
\M104.parameter_coupled_to_ToutB\="Tin"
\M104.MEDIUM_OUTC\="O205"
\M104.parameter_coupled_to_poutC\="pin"
\M104.parameter_coupled_to_VoutC\="Vin"
\M104.parameter_coupled_to_ToutC\="Tin"
\M104.ASSOCIATE_PARAMETERS\="HPOP_DS_PR,HPOP_DS_TMP"
\M104.GENERIC_PARAMETERS\="pin,Tin"
**********

## Type UNEVEN_THREE_SPLIT (File utrisplit)

\DIFFUSER.NAME\="DIFFUSER"
\DIFFUSER.MEDIUM_IN\="MFV"
\DIFFUSER.parameter_coupled_to_pin\="pout"
\DIFFUSER.parameter_coupled_to_Vin\="Vout"
\DIFFUSER.parameter_coupled_to_Tin\="Tout"
\DIFFUSER.MEDIUM_OUTA\="CCV"
\DIFFUSER.parameter_coupled_to_poutA\="pin"
\DIFFUSER.parameter_coupled_to_VoutA\="Vin"
\DIFFUSER.parameter_coupled_to_ToutA\="Tin"
\DIFFUSER.MEDIUM_OUTB\="NZL_COOL"
\DIFFUSER.parameter_coupled_to_poutB\="pin"
\DIFFUSER.parameter_coupled_to_VoutB\="Vin"
\DIFFUSER.parameter_coupled_to_ToutB\="Tin"
\DIFFUSER.MEDIUM_OUTC\="MCC_COOL"
\DIFFUSER.parameter_coupled_to_poutC\="pin"
\DIFFUSER.parameter_coupled_to_VoutC\="Vin"
\DIFFUSER.parameter_coupled_to_ToutC\="Tin"
\DIFFUSER.ASSOCIATE_PARAMETERS\="Notknown"
\DIFFUSER.GENERIC_PARAMETERS\="Notknown"
**********

## Type TWO_JOIN (File twojoin)

\MIXER.NAME\="MIXER"
\MIXER.MEDIUM_INA\="CCV"
\MIXER.parameter_coupled_to_pinA\="pout"
\MIXER.parameter_coupled_to_VinA\="Vout"
\MIXER.parameter_coupled_to_TinA\="Tout"
\MIXER.MEDIUM_OUT\="F107"
\MIXER.parameter_coupled_to_poutA\="pin"
\MIXER.parameter_coupled_to_Vout\="Vin"
\MIXER.parameter_coupled_to_Tout\="Tin"
\MIXER.MEDIUM_INB\="NZL_COOL"
\MIXER.parameter_coupled_to_pinB\="pout"
\MIXER.parameter_coupled_to_VinB\="Vout"
\MIXER.parameter_coupled_to_TinB\="Tout"
\MIXER.ASSOCIATE_PARAMETERS\="Notknown"
\MIXER.GENERIC_PARAMETERS\="Notknown"
\HGM.NAME\="HGM"
\HGM.MEDIUM_INA\="HPFT"
\HGM.parameter_coupled_to_pinA\="pout"
\HGM.parameter_coupled_to_VinA\="Vout"
\HGM.parameter_coupled_to_TinA\="Tout"
\HGM.MEDIUM_OUT\="MCC"
\HGM.parameter_coupled_to_poutA\="pin"
\HGM.parameter_coupled_to_Vout\="Vin"
\HGM.parameter_coupled_to_Tout\="Tin"
\HGM.MEDIUM_INB\="HPOT"
\HGM.parameter_coupled_to_pinB\="pout"
\HGM.parameter_coupled_to_VinB\="Vout"
\HGM.parameter_coupled_to_TinB\="Tout"
\HGM.ASSOCIATE_PARAMETERS\="HPFT_DS_TMP1,HPOT_DS_TMP1"
\HGM.GENERIC_PARAMETERS\="Tin,TinB"
**********

## Type NOZZLE (File nozzle)

\NOZZLE1.NAME\="NOZZLE1"
\NOZZLE1.MEDIUM_INPUT\="MCC"
\NOZZLE1.parameter_coupled_to_pin\="pout"
\NOZZLE1.parameter_coupled_to_Vin\="Vout"
\NOZZLE1.parameter_coupled_to_Tin\="Tout"
\NOZZLE1.COOLED_BY\="NZL_COOL"
\NOZZLE1.parameter_coupled_to_Tout\="Tsource"
\NOZZLE1.ASSOCIATE_PARAMETERS\="MCC_PC"
\NOZZLE1.GENERIC_PARAMETERS\="pin"
**********

## Type TANK (File tank)

```
\FUEL_TANK.NAME\="FUEL_TANK"
\FUEL_TANK.MEDIUM_OUTPUT\="LPFP"
\FUEL_TANK.parameter_coupled_to_pout\="pin"
\FUEL_TANK.parameter_coupled_to_Vout\="Vin"
\FUEL_TANK.parameter_coupled_to_Tout\="Tin"
\FUEL_TANK.ASSOCIATE_PARAMETERS\="ENG_FUEL_INLET_PR,ENG_FUEL_INLET_TMP"
\FUEL_TANK.GENERIC_PARAMETERS\="pout,Tout"
\LOX_TANK.NAME\="LOX_TANK"
\LOX_TANK.MEDIUM_OUTPUT\="LPOP"
\LOX_TANK.parameter_coupled_to_pout\="pin"
\LOX_TANK.parameter_coupled_to_Vout\="Vin"
\LOX_TANK.parameter_coupled_to_Tout\="Tin"
\LOX_TANK.ASSOCIATE_PARAMETERS\="ENG_OX_INLET_PR,ENG_OX_INLET_TMP"
\LOX_TANK.GENERIC_PARAMETERS\="pout,Tout"
**********
```

## Class TERMINAL (File terminal)

\FUEL_TANK.NAME\="FUEL_TANK"
\F190.NAME\="F190"
\LOX_TANK.NAME\="LOX_TANK"
\O190.NAME\="O190"
\MFV_CTRL.NAME\="MFV_CTRL"
\CCV_CTRL.NAME\="CCV_CTRL"
\MOV_CTRL.NAME\="MOV_CTRL"
\OPOV_CTRL.NAME\="OPOV_CTRL"
**********

### A.2.2Fault Mode Likelihoods

Fault Mode Likelihoods

```
\pipe_leak.component\="PIPE"
\pipe_leak.fault\="LEAK"
\pipe_leak.probability\="0.1"
\pipe_obstruction.component\="PIPE"
\pipe_obstruction.fault\="OBSTRUCTION"
\pipe_obstruction.probability\="0.12"
\cooling_leak.component\="COOLING"
\cooling_leak.fault\="LEAK"
\cooling_leak.probability\="0.2"
\cooling_obstruction.component\="COOLING"
\cooling_obstruction.fault\="OBSTRUCTION"
\cooling_obstruction.probability\="0.1"
\pump_impeller_problem.component\="PUMP"
\pump_impeller_problem.fault\="IMPELLER_PROBLEM"
\pump_impeller_problem.probability\="0.15"
\pump_low_efficiency.component\="PUMP"
\pump_low_efficiency.fault\="LOW_EFFICIENCY"
\pump_low_efficiency.probability\="0.3"
\hipump_impeller_problem.component\="HIPUMP"
\hipump_impeller_problem.fault\="IMPELLER_PROBLEM"
\hipump_impeller_problem.probability\="0.25"
\hipump_low_efficiency.component\="HIPUMP"
\hipump_low_efficiency.fault\="LOW_EFFICIENCY"
\hipump_low_efficiency.probability\="0.4"
\valve_blockage.component\="VALVE"
\valve_blockage.fault\="VALVE_BLOCKAGE"
\valve_blockage.probability\="0.1"
\valve_servo_fault.component\="VALVE"
\valve_servo_fault.fault\="VALVE_SERVO_FAULT"
\valve_servo_fault.probability\="0.08"
\gas_turbine_low_efficiency.component\="GAS_TURBINE"
\gas_turbine_low_efficiency.fault\="LOW_EFFICIENCY"
\gas_turbine_low_efficiency.probability\="0.25"
\hydraulic_turbine_impeller_problem.component\="HYDRAULIC_TURBINE"
\hydraulic_turbine_impeller_problem.fault\="IMPELLER_PROBLEM"
\hydraulic_turbine_impeller_problem.probability\="0.12"
\controller_fault.component\="CONTROLLER_CONST"
\controller_fault.fault\="CONTROLLER_FAULT"
\controller_fault.probability\="0.08"
**********
```

## A.3 Heuristic Rules File

heuristic-rules.tkb

```
(@VERSION=      020)
(@PROPERTY=     component_classes       @TYPE=String;)

(@CLASS=  SSME_CONFIGURATION
        (@SUBCLASSES=
                FUEL_SIDE
                LOX_SIDE
        )
)

(@CLASS=  FUEL_SIDE
)

(@CLASS=  LOX_SIDE
)

(@OBJECT= CONTROL_HEURISTICS
        (@PROPERTIES=
                current_behavior
                component_classes
                bool_temp
                temporary
        )
)

(@OBJECT= FUEL_SIDE_FILE
        (@CLASSES=
                LOAD_CONTROL
        )
        (@PROPERTIES=
                class_name
                file_exists
                file_name
                NAME
                retrieve
        )
)

(@OBJECT= LOX_SIDE_FILE
        (@CLASSES=
                LOAD_CONTROL
        )
        (@PROPERTIES=
                class_name
                file_exists
                file_name
                NAME
                retrieve
        )
)

(@OBJECT= Abernethy_101_108_Fuel_Leak
)

(@OBJECT= Randy_Hurt_Fuel_leak
)

(@OBJECT= Randy_Hurt_HPFP_efficiency_low
)

(@OBJECT= Randy_Hurt_MCC_Cooling_leak
)

(@OBJECT= Randy_Hurt_NZL_Cooling_leak
)

(@OBJECT= Randy_Hurt_HPOT_efficiency_low
)

(@OBJECT= SUGGESTION_TYPES
        (@PROPERTIES=
                Value @TYPE=Boolean;
        )
)

(@SLOT=   FUEL_SIDE_FILE.class_name
        (@SOURCES=
                (RunTimeValue       ("FUEL_SIDE"))
        )
)

(@SLOT=   FUEL_SIDE_FILE.NAME
        (@SOURCES=
                (RunTimeValue       ("fuel_side"))
```

```
	)
)

(@SLOT=	LOX_SIDE_FILE.class_name
	(@SOURCES=
		(RunTimeValue	("LOX_SIDE"))
	)
)

(@SLOT=	LOX_SIDE_FILE.NAME
	(@SOURCES=
		(RunTimeValue	("lox_side"))
	)
)

(@RULE=	fuel_line_leak
	@INFCAT=1;
	@COMMENTS="component_name can also hold a pair (system section class,component class), see below for an example.\
Another set of files must be read to assign components to each system section";
	(@LHS=
		(Is	(<|SCENARIO_BEHAVIORS|>.comp_name)	("HPOT"))
		(Is	(<|SCENARIO_BEHAVIORS|>.Tout)	("HIGH"))
		(Is	(<<|SCENARIO_BEHAVIORS|>>.comp_name)	("HPFT"))
		(Is	(<<|SCENARIO_BEHAVIORS|>>.Tout)	("NORMAL","HIGH"))
		(Is	(<<<|SCENARIO_BEHAVIORS|>>>.comp_name)	("HPFP"))
		(Is	(<<<|SCENARIO_BEHAVIORS|>>>.pout)	("LOW"))
		(IsNot (<<<|SCENARIO_BEHAVIORS|>>>.omega)	("LOW"))
		(Is	(<<<<|SCENARIO_BEHAVIORS|>>>>.comp_name)	("MCC"))
		(Is	(<<<<|SCENARIO_BEHAVIORS|>>>>.pout)	("NORMAL"))
	)
	(@HYPO=	EXPERT_HEURISTIC_RULE)
	(@RHS=
		(CreateObject	(Abernethy_101_108_Fuel_Leak)	(|EXPERT_RULE_SUGGESTIONS|,\
|HEURISTIC_SUGGESTIONS|))
		(Let	(Abernethy_101_108_Fuel_Leak.component_name)	("FUEL_SIDE,DUCT"))
		(Let	(Abernethy_101_108_Fuel_Leak.suggested_fault)	("LEAK"))
		(Let	(Abernethy_101_108_Fuel_Leak.suggestion_type)	("component_and_fault_type"))
	)
)

(@RULE=	fuel_line_leak2
	@INFCAT=0;
	@COMMENTS="Small-scale effects: OPOV position H, LPOP Vin H";
	(@LHS=
		(Is	(<|SCENARIO_BEHAVIORS|>.comp_name)	("HPFP"))
		(Is	(<|SCENARIO_BEHAVIORS|>.pout)	("LOW"))
		(Is	(<<|SCENARIO_BEHAVIORS|>>.comp_name)	("HPOT"))
		(Is	(<<|SCENARIO_BEHAVIORS|>>.Tout)	("HIGH"))
	)
	(@HYPO=	EXPERT_HEURISTIC_RULE)
	(@RHS=
		(CreateObject	(Randy_Hurt_Fuel_leak)	(|EXPERT_RULE_SUGGESTIONS|,\
|HEURISTIC_SUGGESTIONS|))
		(Let	(Randy_Hurt_Fuel_leak.component_name)	("FUEL_SIDE,DUCT"))
		(Let	(Randy_Hurt_Fuel_leak.suggested_fault)	("LEAK"))
		(Let	(Randy_Hurt_Fuel_leak.suggestion_type)	("component_and_fault_type"))
	)
)

(@RULE=	HPFP_efficiency_low
	@INFCAT=0;
	@COMMENTS="Small-scale effects: HPFP pout H, HPOT Tout H";
	(@LHS=
		(Is	(<|SCENARIO_BEHAVIORS|>.comp_name)	("FPOV"))
		(Is	(<|SCENARIO_BEHAVIORS|>.position) ("HIGH"))
		(Is	(<<|SCENARIO_BEHAVIORS|>>.comp_name)	("HPFT"))
		(Is	(<<|SCENARIO_BEHAVIORS|>>.Tout)	("HIGH"))
		(Is	(<<<|SCENARIO_BEHAVIORS|>>>.comp_name)	("FPB"))
		(Is	(<<<|SCENARIO_BEHAVIORS|>>>.pout)	("HIGH"))
	)
	(@HYPO=	EXPERT_HEURISTIC_RULE)
	(@RHS=
		(CreateObject	(Randy_Hurt_HPFP_efficiency_low)	(|EXPERT_RULE_SUGGESTIONS|,\
|HEURISTIC_SUGGESTIONS|))
		(Let	(Randy_Hurt_HPFP_efficiency_low.component_name)	("HPFP"))
		(Let	(Randy_Hurt_HPFP_efficiency_low.suggested_fault) ("LOW_EFFICIENCY"))
		(Let	(Randy_Hurt_HPFP_efficiency_low.suggestion_type) ("specific_component"))
	)
)

(@RULE=	MCC_Cooling_leak
	@INFCAT=0;
	@COMMENTS="Small-scale effects: LPOP Vin H, MOV position H, OPOV position H, HPFP pout L";
	(@LHS=
		(Is	(<|SCENARIO_BEHAVIORS|>.comp_name)	("LPFP"))
		(Is	(<|SCENARIO_BEHAVIORS|>.omega)	("LOW"))
		(Is	(<<|SCENARIO_BEHAVIORS|>>.comp_name)	("MCC_COOL"))
		(Is	(<<|SCENARIO_BEHAVIORS|>>.Tout)	("LOW"))
		(Is	(<<|SCENARIO_BEHAVIORS|>>.pout)	("LOW"))
	)
	(@HYPO=	EXPERT_HEURISTIC_RULE)
	(@RHS=
		(CreateObject	(Randy_Hurt_MCC_Cooling_leak)	(|EXPERT_RULE_SUGGESTIONS|,\
|HEURISTIC_SUGGESTIONS|))
		(Let	(Randy_Hurt_MCC_Cooling_leak.component_name) ("MCC_COOL"))
```

```
            (Let    (Randy_Hurt_MCC_Cooling_leak.suggested_fault)    ("LEAK"))
            (Let    (Randy_Hurt_MCC_Cooling_leak.suggestion_type)    ("specific_component"))
      )
)

(@RULE=    Nozzle_Cooling_leak
      @INFCAT=0;
      @COMMENTS="Small-scale effects: HPFT Tout H, OPOV position H, NZL_COOL Vin H, MCC_COOL Vin L";
      (@LHS=
            (Is     (<|SCENARIO_BEHAVIORS|>.comp_name)    ("HPOT"))
            (Is     (<|SCENARIO_BEHAVIORS|>.Tout)    ("HIGH"))
            (Is     (<<|SCENARIO_BEHAVIORS|>>.comp_name)        ("MCC_COOL"))
            (Is     (<<|SCENARIO_BEHAVIORS|>>.Tout)  ("HIGH"))
            (Is     (<<<|SCENARIO_BEHAVIORS|>>>.comp_name)     ("LPFP"))
            (Is     (<<<|SCENARIO_BEHAVIORS|>>>.omega)    ("LOW"))
      )
      (@HYPO=    EXPERT_HEURISTIC_RULE)
      (@RHS=
            (CreateObject        (Randy_Hurt_NZL_Cooling_leak) (|EXPERT_RULE_SUGGESTIONS|,\
|HEURISTIC_SUGGESTIONS|))
            (Let    (Randy_Hurt_NZL_Cooling_leak.component_name)    ("NZL_COOL"))
            (Let    (Randy_Hurt_NZL_Cooling_leak.suggested_fault)     ("LEAK"))
            (Let    (Randy_Hurt_NZL_Cooling_leak.suggestion_type)    ("specific_component"))
      )
)

(@RULE=    HPOT_efficiency_low
      @INFCAT=0;
      @COMMENTS="Would also expect to see HPOT Tout H, and maybe OPB pout H";
      (@LHS=
            (Is     (<|SCENARIO_BEHAVIORS|>.comp_name)    ("OPOV"))
            (Is     (<|SCENARIO_BEHAVIORS|>.position) ("HIGH"))
            (Is     (<<|SCENARIO_BEHAVIORS|>>.comp_name)        ("HPOP_PBP"))
            (Is     (<<|SCENARIO_BEHAVIORS|>>.omega)        ("NORMAL"))
            (Is     (<<<|SCENARIO_BEHAVIORS|>>>.comp_name)     ("MCC"))
            (Is     (<<<|SCENARIO_BEHAVIORS|>>>.pout)        ("NORMAL"))
      )
      (@HYPO=    EXPERT_HEURISTIC_RULE)
      (@RHS=
            (CreateObject        (Randy_Hurt_HPOT_efficiency_low)      (|EXPERT_RULE_SUGGESTIONS|,\
|HEURISTIC_SUGGESTIONS|))
            (Let    (Randy_Hurt_HPOT_efficiency_low.component_name)        ("HPOT"))
            (Let    (Randy_Hurt_HPOT_efficiency_low.suggested_fault) ("LOW_EFFICIENCY"))
            (Let    (Randy_Hurt_HPOT_efficiency_low.suggestion_type)("specific_component"))
      )
)

(@RULE=    match_found_2
      @INFCAT=-15001;
      @COMMENTS="Suggested fault: For now, no more than one suggestion is generated in MADE_FIRST_SCENARIO!";
      (@LHS=
            (IsNot (CONTROL_OBJECT.matching_fault)    (NOTKNOWN))
            (Yes   (USE_HEURISTIC_RULES))
            (=      (LENGTH(<|HEURISTIC_SUGGESTIONS|>))  (1))
            (=      (COMPARE(<|HEURISTIC_SUGGESTIONS|>.suggested_fault,CONTROL_OBJECT.current_fault))   (0))
            (Reset(SUGGESTION_TYPES))
            (Yes   (SUGGESTION_TYPES))
      )
      (@HYPO=    MATCH_FOUND)
      (@RHS=
            (Strategy      (@EXHBWRD=TRUE;))
      )
)

(@RULE=    use_heuristics1
      @INFCAT=-15000;
      (@LHS=
            (Is     (<|HEURISTIC_SUGGESTIONS|>.suggestion_type)  ("specific_component"))
            (Name         (<|TEMP_BEHAVIOR|>.comp_name)     (CONTROL_HEURISTICS.temporary))
            (=      (COMPARE(<|HEURISTIC_SUGGESTIONS|>.component_name,CONTROL_HEURISTICS.temporary))      (0))
      )
      (@HYPO=    SUGGESTION_TYPES)
      (@RHS=
            (Do     (1.5)   (CONTROL_OBJECT.current_prob))
      )
)

(@RULE=    use_heuristics2
      @INFCAT=-15000;
      @COMMENTS="We are less convinced (prob=1.0) in this case. TEST: Both comp type and config type must be in the parent classes";
      (@LHS=
            (Is     (<|HEURISTIC_SUGGESTIONS|>.suggestion_type)  ("component_and_fault_type"))
            (Execute       ("AtomNameValue") (@ATOMID=<|TEMP_BEHAVIOR|>;@STRING="@RETURN=CONTROL_HEURISTICS.current_behavior,\
@NAMES";))
            (Execute       ("GetRelatives")      (@ATOMID=\CONTROL_HEURISTICS.current_behavior\;\
@STRING="@CLASSES,@PARENTS,@EVERYLEVEL,@RETURN=CONTROL_HEURISTICS.component_classes";\
))
            (Execute       ("TestMultiValue")    (@ATOMID=<|HEURISTIC_SUGGESTIONS|>.component_name;\
@STRING="@SUBSET,@TEST=@v(CONTROL_HEURISTICS.component_classes),\
@RETURN=CONTROL_HEURISTICS.bool_temp,@COMP=STRING";))
            (Yes   (CONTROL_HEURISTICS.bool_temp))
      )
      (@HYPO=    SUGGESTION_TYPES)
      (@RHS=
            (Do     (1.0)   (CONTROL_OBJECT.current_prob))
```

## Class FUEL_SIDE (File fuel_side)

\MCC_COOL.NAME\="MCC_COOL"
\NZL_COOL.NAME\="NZL_COOL"
\FPB.NAME\="FPB"
\DIFFUSER.NAME\="DIFFUSER"
\FUEL_FLOW_CTRL.NAME\="FUEL_FLOW_CTRL"
\MFV_CTRL.NAME\="MFV_CTRL"
\CCV_CTRL.NAME\="CCV_CTRL"
\LPFT.NAME\="LPFT"
\HPFT.NAME\="HPFT"
\F101.NAME\="F101"
\F108.NAME\="F108"
\F110.NAME\="F110"
\F109.NAME\="F109"
\F190.NAME\="F190"
\F107.NAME\="F107"
\HPFP.NAME\="HPFP"
\LPFP.NAME\="LPFP"
\FUEL_TANK.NAME\="FUEL_TANK"
\MIXER.NAME\="MIXER"
\M103.NAME\="M103"
\FPOV.NAME\="FPOV"
\MFV.NAME\="MFV"
\CCV.NAME\="CCV"
**********

## Class LOX_SIDE (File lox_side)

\MOV_CTRL.NAME\="MOV_CTRL"
\OPOV_CTRL.NAME\="OPOV_CTRL"
\HPOT.NAME\="HPOT"
\HPOP_PBP.NAME\="HPOP/PBP"
\LPOT.NAME\="LPOT"
\OPB.NAME\="OPB"
\O201.MEDIUM_INPUT\="LPOP"
\O203.NAME\="O203"
\O204.NAME\="O204"
\O205.NAME\="O205"
\O206.NAME\="O206"
\O190.NAME\="O190"
\LPOP.NAME\="LPOP"
\LOX_TANK.NAME\="LOX_TANK"
\M104.NAME\="M104"
\M101.NAME\="M101"
\MOV.NAME\="MOV"
\OPOV.NAME\="OPOV"
**********

## A.4 PBM Data Support Files

PBM_data.tkb

```
(@VERSION=      020)

(@PROPERTY=     setup @TYPE=Boolean;)

(@CLASS=  PBM_TEMPLATES
      (@PROPERTIES=
            commanded_position
            comp_name
            h_diff
            MechPWR
            MR
            omega
            p_diff
            pin
            pin_OX
            position
            pout
            PV_Product
            q_dot_in
            q_dot_inB
            T_diff
            setup
            Tbar
            Tin
            Tin_OX
            TinB
            Tout
            Tq
            Tsource
            Vbalance
            Vbar
            Vin
            Vin_OX
            VinB
            Vout
            VoutB
            VoutC
      )
)

(@OBJECT= PBM_TEMPLATES_FILE
      (@CLASSES=
            LOAD_CONTROL
      )
      (@PROPERTIES=
            class_name
            file_exists
            file_name
            NAME
            retrieve
      )
)

(@SLOT=   PBM_TEMPLATES_FILE.class_name
      (@SOURCES=
            (RunTimeValue     ("PBM_TEMPLATES"))
      )
)

(@SLOT=   PBM_TEMPLATES_FILE.NAME
      (@SOURCES=
            (RunTimeValue     ("PBM_values.nxp"))
      )
)

(@SLOT=   PBM_TEMPLATES.setup
      (@SOURCES=
            (Execute     ("AtomNameValue") (@ATOMID=SELF;@STRING="@RETURN=CONTROL_OBJECT4.temporary,\
@NAMES";))
            (Do    (SUBSTRING(CONTROL_OBJECT4.temporary,0,(STRLEN(CONTROL_OBJECT4.temporary) - STRLEN("_PBM_template"))))\
      (SELF.comp_name))
            (Do    (CONTROL_OBJECT4.temporary)       (\SELF.comp_name\.PBM_template_behavior))
            (RunTimeValue     (TRUE))
      )
)

(@RULE=   set_up_PBM
      (@LHS=
            (Name       (<|PBM_TEMPLATES|>.setup)   (<|PBM_TEMPLATES|>.setup))
      )
      (@HYPO=   SET_UP_PBM)
)

(@RULE=   count_PBM_matches_commanded_position
      (@LHS=
            (Is     (\CONTROL_OBJECT4.temporary\.commanded_position)   (KNOWN))
            (Equal (<|CURRENT_BEHAVIOR|>.commanded_position)   (\CONTROL_OBJECT4.temporary\.commanded_position))
```

```
    )
    (@HYPO=  COUNT_PBM_MATCHES)
    (@RHS=
        (Do  (<|CURRENT_BEHAVIOR|>.temp_int + 1)    (<|CURRENT_BEHAVIOR|>.temp_int))
    )
)

(@RULE=  count_PBM_matches_h_diff
    (@LHS=
        (Is  (\CONTROL_OBJECT4.temporary\.h_diff)    (KNOWN))
        (Equal(<|CURRENT_BEHAVIOR|>.h_diff)    (\CONTROL_OBJECT4.temporary\.h_diff))
    )
    (@HYPO=  COUNT_PBM_MATCHES)
    (@RHS=
        (Do  (<|CURRENT_BEHAVIOR|>.temp_int + 1)    (<|CURRENT_BEHAVIOR|>.temp_int))
    )
)

(@RULE=  count_PBM_matches_MechPWR
    (@LHS=
        (Is  (\CONTROL_OBJECT4.temporary\.MechPWR)    (KNOWN))
        (Equal(<|CURRENT_BEHAVIOR|>.MechPWR)    (\CONTROL_OBJECT4.temporary\.MechPWR))
    )
    (@HYPO=  COUNT_PBM_MATCHES)
    (@RHS=
        (Do  (<|CURRENT_BEHAVIOR|>.temp_int + 1)    (<|CURRENT_BEHAVIOR|>.temp_int))
    )
)

(@RULE=  count_PBM_matches_MR
    (@LHS=
        (Is  (\CONTROL_OBJECT4.temporary\.MR) (KNOWN))
        (Equal(<|CURRENT_BEHAVIOR|>.MR) (\CONTROL_OBJECT4.temporary\.MR))
    )
    (@HYPO=  COUNT_PBM_MATCHES)
    (@RHS=
        (Do  (<|CURRENT_BEHAVIOR|>.temp_int + 1)    (<|CURRENT_BEHAVIOR|>.temp_int))
    )
)

(@RULE=  count_PBM_matches_omega
    (@LHS=
        (Is  (\CONTROL_OBJECT4.temporary\.omega)    (KNOWN))
        (Equal(<|CURRENT_BEHAVIOR|>.omega)    (\CONTROL_OBJECT4.temporary\.omega))
    )
    (@HYPO=  COUNT_PBM_MATCHES)
    (@RHS=
        (Do  (<|CURRENT_BEHAVIOR|>.temp_int + 1)    (<|CURRENT_BEHAVIOR|>.temp_int))
    )
)

(@RULE=  count_PBM_matches_p_diff
    (@LHS=
        (Is  (\CONTROL_OBJECT4.temporary\.p_diff)    (KNOWN))
        (Equal(<|CURRENT_BEHAVIOR|>.p_diff)    (\CONTROL_OBJECT4.temporary\.p_diff))
    )
    (@HYPO=  COUNT_PBM_MATCHES)
    (@RHS=
        (Do  (<|CURRENT_BEHAVIOR|>.temp_int + 1)    (<|CURRENT_BEHAVIOR|>.temp_int))
    )
)

(@RULE=  count_PBM_matches_pin
    (@LHS=
        (Is  (\CONTROL_OBJECT4.temporary\.pin) (KNOWN))
        (Equal(<|CURRENT_BEHAVIOR|>.pin) (\CONTROL_OBJECT4.temporary\.pin))
    )
    (@HYPO=  COUNT_PBM_MATCHES)
    (@RHS=
        (Do  (<|CURRENT_BEHAVIOR|>.temp_int + 1)    (<|CURRENT_BEHAVIOR|>.temp_int))
    )
)

(@RULE=  count_PBM_matches_pin_OX
    (@LHS=
        (Is  (\CONTROL_OBJECT4.temporary\.pin_OX)    (KNOWN))
        (Equal(<|CURRENT_BEHAVIOR|>.pin_OX)    (\CONTROL_OBJECT4.temporary\.pin_OX))
    )
    (@HYPO=  COUNT_PBM_MATCHES)
    (@RHS=
        (Do  (<|CURRENT_BEHAVIOR|>.temp_int + 1)    (<|CURRENT_BEHAVIOR|>.temp_int))
    )
)

(@RULE=  count_PBM_matches_position
    (@LHS=
        (Is  (\CONTROL_OBJECT4.temporary\.position)    (KNOWN))
        (Equal(<|CURRENT_BEHAVIOR|>.position)    (\CONTROL_OBJECT4.temporary\.position))
    )
    (@HYPO=  COUNT_PBM_MATCHES)
    (@RHS=
        (Do  (<|CURRENT_BEHAVIOR|>.temp_int + 1)    (<|CURRENT_BEHAVIOR|>.temp_int))
    )
)
```

```
(@RULE=   count_PBM_matches_pout
    (@LHS=
        (Is    (\CONTROL_OBJECT4.temporary\pout)      (KNOWN))
        (Equal(<|CURRENT_BEHAVIOR|>.pout)      (\CONTROL_OBJECT4.temporary\pout))
    )
    (@HYPO=   COUNT_PBM_MATCHES)
    (@RHS=
        (Do   (<|CURRENT_BEHAVIOR|>.temp_int + 1)      (<|CURRENT_BEHAVIOR|>.temp_int))
    )
)

(@RULE=   count_PBM_matches_PV_Product
    (@LHS=
        (Is    (\CONTROL_OBJECT4.temporary\PV_Product)      (KNOWN))
        (Equal(<|CURRENT_BEHAVIOR|>.PV_Product)      (\CONTROL_OBJECT4.temporary\PV_Product))
    )
    (@HYPO=   COUNT_PBM_MATCHES)
    (@RHS=
        (Do   (<|CURRENT_BEHAVIOR|>.temp_int + 1)      (<|CURRENT_BEHAVIOR|>.temp_int))
    )
)

(@RULE=   count_PBM_matches_q_dot_in
    (@LHS=
        (Is    (\CONTROL_OBJECT4.temporary\q_dot_in)   (KNOWN))
        (Equal(<|CURRENT_BEHAVIOR|>.q_dot_in)  (\CONTROL_OBJECT4.temporary\q_dot_in))
    )
    (@HYPO=   COUNT_PBM_MATCHES)
    (@RHS=
        (Do   (<|CURRENT_BEHAVIOR|>.temp_int + 1)      (<|CURRENT_BEHAVIOR|>.temp_int))
    )
)

(@RULE=   count_PBM_matches_q_dot_inB
    (@LHS=
        (Is    (\CONTROL_OBJECT4.temporary\q_dot_inB) (KNOWN))
        (Equal(<|CURRENT_BEHAVIOR|>.q_dot_inB) (\CONTROL_OBJECT4.temporary\q_dot_inB))
    )
    (@HYPO=   COUNT_PBM_MATCHES)
    (@RHS=
        (Do   (<|CURRENT_BEHAVIOR|>.temp_int + 1)      (<|CURRENT_BEHAVIOR|>.temp_int))
    )
)

(@RULE=   count_PBM_matches_T_diff
    (@LHS=
        (Is    (\CONTROL_OBJECT4.temporary\T_diff)      (KNOWN))
        (Equal(<|CURRENT_BEHAVIOR|>.T_diff)      (\CONTROL_OBJECT4.temporary\T_diff))
    )
    (@HYPO=   COUNT_PBM_MATCHES)
    (@RHS=
        (Do   (<|CURRENT_BEHAVIOR|>.temp_int + 1)      (<|CURRENT_BEHAVIOR|>.temp_int))
    )
)

(@RULE=   count_PBM_matches_Tbar
    (@LHS=
        (Is    (\CONTROL_OBJECT4.temporary\Tbar)      (KNOWN))
        (Equal(<|CURRENT_BEHAVIOR|>.Tbar)      (\CONTROL_OBJECT4.temporary\Tbar))
    )
    (@HYPO=   COUNT_PBM_MATCHES)
    (@RHS=
        (Do   (<|CURRENT_BEHAVIOR|>.temp_int + 1)      (<|CURRENT_BEHAVIOR|>.temp_int))
    )
)

(@RULE=   count_PBM_matches_Tin
    (@LHS=
        (Is    (\CONTROL_OBJECT4.temporary\Tin) (KNOWN))
        (Equal(<|CURRENT_BEHAVIOR|>.Tin) (\CONTROL_OBJECT4.temporary\Tin))
    )
    (@HYPO=   COUNT_PBM_MATCHES)
    (@RHS=
        (Do   (<|CURRENT_BEHAVIOR|>.temp_int + 1)      (<|CURRENT_BEHAVIOR|>.temp_int))
    )
)

(@RULE=   count_PBM_matches_Tin_OX
    (@LHS=
        (Is    (\CONTROL_OBJECT4.temporary\Tin_OX)      (KNOWN))
        (Equal(<|CURRENT_BEHAVIOR|>.Tin_OX)      (\CONTROL_OBJECT4.temporary\Tin_OX))
    )
    (@HYPO=   COUNT_PBM_MATCHES)
    (@RHS=
        (Do   (<|CURRENT_BEHAVIOR|>.temp_int + 1)      (<|CURRENT_BEHAVIOR|>.temp_int))
    )
)

(@RULE=   count_PBM_matches_TinB
    (@LHS=
        (Is    (\CONTROL_OBJECT4.temporary\TinB)      (KNOWN))
        (Equal(<|CURRENT_BEHAVIOR|>.TinB)      (\CONTROL_OBJECT4.temporary\TinB))
    )
    (@HYPO=   COUNT_PBM_MATCHES)
```

```
        (@RHS=
                (Do     (<|CURRENT_BEHAVIOR|>.temp_int + 1)      (<|CURRENT_BEHAVIOR|>.temp_int))
        )
)

(@RULE=   count_PBM_matches_Tout
        (@LHS=
                (Is     (\CONTROL_OBJECT4.temporary\Tout)        (KNOWN))
                (Equal(<|CURRENT_BEHAVIOR|>.Tout)        (\CONTROL_OBJECT4.temporary\Tout))
        )
        (@HYPO=   COUNT_PBM_MATCHES)
        (@RHS=
                (Do     (<|CURRENT_BEHAVIOR|>.temp_int + 1)      (<|CURRENT_BEHAVIOR|>.temp_int))
        )
)

(@RULE=   count_PBM_matches_Tq
        (@LHS=
                (Is     (\CONTROL_OBJECT4.temporary\Tq)  (KNOWN))
                (Equal(<|CURRENT_BEHAVIOR|>.Tq)  (\CONTROL_OBJECT4.temporary\Tq))
        )
        (@HYPO=   COUNT_PBM_MATCHES)
        (@RHS=
                (Do     (<|CURRENT_BEHAVIOR|>.temp_int + 1)      (<|CURRENT_BEHAVIOR|>.temp_int))
        )
)

(@RULE=   count_PBM_matches_Tsource
        (@LHS=
                (Is     (\CONTROL_OBJECT4.temporary\Tsource)     (KNOWN))
                (Equal(<|CURRENT_BEHAVIOR|>.Tsource)     (\CONTROL_OBJECT4.temporary\Tsource))
        )
        (@HYPO=   COUNT_PBM_MATCHES)
        (@RHS=
                (Do     (<|CURRENT_BEHAVIOR|>.temp_int + 1)      (<|CURRENT_BEHAVIOR|>.temp_int))
        )
)

(@RULE=   count_PBM_matches_Vbalance
        (@LHS=
                (Is     (\CONTROL_OBJECT4.temporary\Vbalance)  (KNOWN))
                (Equal(<|CURRENT_BEHAVIOR|>.Vbalance)  (\CONTROL_OBJECT4.temporary\Vbalance))
        )
        (@HYPO=   COUNT_PBM_MATCHES)
        (@RHS=
                (Do     (<|CURRENT_BEHAVIOR|>.temp_int + 1)      (<|CURRENT_BEHAVIOR|>.temp_int))
        )
)

(@RULE=   count_PBM_matches_Vbar
        (@LHS=
                (Is     (\CONTROL_OBJECT4.temporary\Vbar)        (KNOWN))
                (Equal(<|CURRENT_BEHAVIOR|>.Vbar)        (\CONTROL_OBJECT4.temporary\Vbar))
        )
        (@HYPO=   COUNT_PBM_MATCHES)
        (@RHS=
                (Do     (<|CURRENT_BEHAVIOR|>.temp_int + 1)      (<|CURRENT_BEHAVIOR|>.temp_int))
        )
)

(@RULE=   count_PBM_matches_Vin
        (@LHS=
                (Is     (\CONTROL_OBJECT4.temporary\Vin) (KNOWN))
                (Equal(<|CURRENT_BEHAVIOR|>.Vin) (\CONTROL_OBJECT4.temporary\Vin))
        )
        (@HYPO=   COUNT_PBM_MATCHES)
        (@RHS=
                (Do     (<|CURRENT_BEHAVIOR|>.temp_int + 1)      (<|CURRENT_BEHAVIOR|>.temp_int))
        )
)

(@RULE=   count_PBM_matches_Vin_OX
        (@LHS=
                (Is     (\CONTROL_OBJECT4.temporary\Vin_OX)     (KNOWN))
                (Equal(<|CURRENT_BEHAVIOR|>.Vin_OX)     (\CONTROL_OBJECT4.temporary\Vin_OX))
        )
        (@HYPO=   COUNT_PBM_MATCHES)
        (@RHS=
                (Do     (<|CURRENT_BEHAVIOR|>.temp_int + 1)      (<|CURRENT_BEHAVIOR|>.temp_int))
        )
)

(@RULE=   count_PBM_matches_VinB
        (@LHS=
                (Is     (\CONTROL_OBJECT4.temporary\VinB)        (KNOWN))
                (Equal(<|CURRENT_BEHAVIOR|>.VinB)        (\CONTROL_OBJECT4.temporary\VinB))
        )
        (@HYPO=   COUNT_PBM_MATCHES)
        (@RHS=
                (Do     (<|CURRENT_BEHAVIOR|>.temp_int + 1)      (<|CURRENT_BEHAVIOR|>.temp_int))
        )
)
```

```
(@RULE=   count_PBM_matches_Vout
      (@LHS=
            (Is     (\CONTROL_OBJECT4.temporary\.Vout)       (KNOWN))
            (Equal(<|CURRENT_BEHAVIOR|>.Vout)        (\CONTROL_OBJECT4.temporary\.Vout))
      )
      (@HYPO=   COUNT_PBM_MATCHES)
      (@RHS=
            (Do    (<|CURRENT_BEHAVIOR|>.temp_int + 1)       (<|CURRENT_BEHAVIOR|>.temp_int))
      )
)

(@RULE=   count_PBM_matches_VoutB
      (@LHS=
            (Is     (\CONTROL_OBJECT4.temporary\.VoutB)      (KNOWN))
            (Equal(<|CURRENT_BEHAVIOR|>.VoutB)       (\CONTROL_OBJECT4.temporary\.VoutB))
      )
      (@HYPO=   COUNT_PBM_MATCHES)
      (@RHS=
            (Do    (<|CURRENT_BEHAVIOR|>.temp_int + 1)       (<|CURRENT_BEHAVIOR|>.temp_int))
      )
)

(@RULE=   count_PBM_matches_VoutC
      (@LHS=
            (Is     (\CONTROL_OBJECT4.temporary\.VoutC)      (KNOWN))
            (Equal(<|CURRENT_BEHAVIOR|>.VoutC)       (\CONTROL_OBJECT4.temporary\.VoutC))
      )
      (@HYPO=   COUNT_PBM_MATCHES)
      (@RHS=
            (Do    (<|CURRENT_BEHAVIOR|>.temp_int + 1)       (<|CURRENT_BEHAVIOR|>.temp_int))
      )
)
```

# PBM Parameters

| | | | |
|---|---|---|---|
| 2 | RMEP | ENGINE MIXTURE RATIO | [MCC MR] |
| 4 | P1FP1 | LPFP INLET PRESSURE | [LPFP pin] |
| 5 | P1OP1 | LPOP INLET PRESSURE | [LPOP pin] |
| 6 | T1FP1 | LPFP TEMPERATURE | [LPFP Tin] |
| 7 | T1OP1 | LPOP INLET TEMPERATURE | [LPOP Tin] |
| 10 | PCCOM | CHAMBER PRESSURE COMMAND | |
| 227 | DP210 | MOV INLET PRESSURE DROP | [MOV p_diff] |
| 243 | DPOCO | LPOP DISCHARGE DUCT PRESSURE DROP | [O201 p_diff] |
| 246 | DPOT1 | LPOT PRESSURE DROP | [LPOT p_diff] |
| 254 | DP(1) | HPFP DISCHARGE DUCT PRESSURE DROP | |
| 255 | DP(2) | PBP INLET DUCT PRESSURE DROP | |
| 256 | DP(3) | MFV PRESSURE DROP | [MFV p_diff] |
| 257 | DP(4) | PBP DISCHARGE DUCT PRESSURE DROP | |
| 258 | DP(5) | NOZZLE JACKET DISCHARGE MANIFOLD & MIXER PRESSURE DROP | |
| 259 | DP(6) | MOV PRESSURE DROP | [MOV p_diff] |
| 262 | DP(9) | CCV INLET DUCT PRESSURE DROP | |
| 263 | DP(10) | HPOP DISCHARGE DUCT PRESSURE DROP - SECTION 1 | |
| 265 | DP(12) | OPB OXIDIZER INLET DUCT PRESSURE DROP | |
| 266 | DP(13) | OPB FUEL INLET MANIFOLD PRESSURE DROP | |
| 267 | DP(14) | OPOV PRESSURE DROP | [OPOV p_diff] |
| 270 | DP(17) | FPB FUEL MANIFOLD PRESSURE DROP | |
| 271 | DP(18) | FPOV PRESSURE DROP | [FPOV p_diff] |
| 274 | DP(21) | HPOT INLET DUCT PRESSURE DROP | |
| 275 | DP(22) | LPFT DISCHARGE DUCT PRESSURE DROP | |
| 277 | DP(24) | HPFT INLET DUCT PRESSURE DROP | |
| 278 | DP(25) | LPFT INLET DUCT PRESSURE DROP | |
| 279 | DP(26) | HPFT COOLING CIRCUIT PRESSURE DROP | |
| 281 | DP(28) | MCC COOLING JACKET DISCHARGE MANIFOLD PRESSURE DROP | |
| 282 | DP(29) | LPOT INLET DUCT PRESSURE DROP - SECTION 2 | |
| 283 | DP(30) | MFV DISCHARGE DUCT PRESSURE DROP | |
| 285 | DP(32) | FPB FUEL INLET DUCT PRESSURE DROP | [F110 p_diff] |
| 286 | DP(33) | MCC COOLING JACKET INLET DUCT PRESSURE DROP | |
| 288 | DP(35) | NOZZLE COOLING JACKET INLET DUCT PRESSURE DROP | |
| 290 | DP(37) | CCV PRESSURE DROP | [CCV p_diff] |
| 291 | DP(38) | CCV DISCHARGE DUCT PRESSURE DROP | |
| 292 | DP(39) | FPB FUEL INLET DUCT PRESSURE DROP | |
| 294 | DP(41) | OPB FUEL INLET DUCT PRESSURE DROP | |
| 305 | DP(52) | NOZZLE COOLING JACKET DISCHARGE DUCT PRESSSURE DROP | |
| 313 | HINJGF | HGM HOT GAS ENTHALPY - FUEL SIDE | |
| 314 | HINJGO | HGM HOT GAS ENTHALPY - OXIDIZER SIDE | |
| 315 | DTBYO | OPB COOLING CIRCUIT TEMPERATURE RISE | |
| 316 | DTMFV | MFV TEMPERATURE RISE | |
| 317 | DTFP1 | LPFP TEMPERATURE RISE | |
| 318 | DTFP2 | HPFP TEMPERATURE RISE | |
| 319 | DTFT1 | LPFT TEMPERATURE RISE | |
| 320 | DP59 | CCV DISCHARGE DUCT & MIXER PRESSURE DROP | |
| 322 | DTFT2 | HPFT TEMPERATURE DROP | |
| 323 | DTOT2 | HPOT TEMPERATURE DROP | |
| 324 | H1OT1 | LPOT INLET ENTHALPY | |
| 325 | H2OT1 | LPOT DISCHARGE ENTHALPY | |
| 328 | H2OT2 | HPOT DISCHARGE ENTHALPY | |
| 334 | DTJ | MCC NOZZLE JACKET TEMPERATURE RISE | [NZL_COOL T_diff] |
| 335 | DTJ2 | MCC JACKET TEMPERATURE RISE | [MCC_COOL T_diff] |
| 336 | DTOP2 | HPOP TEMPERATURE RISE | |
| 337 | DTOP3 | PBP TEMPERATURE RISE | |
| 359 | ENFT1 | LPFT SPEED | |
| 360 | ENFT2 | HPFT SPEED | |
| 361 | FECOM | ENGINE THRUST (COMMANDED) | |
| 362 | FSL | ENGINE THRUST (SEA LEVEL) | |
| 364 | ENOT1 | LPOT SPEED | |
| 365 | ENOT2 | HPOT SPEED | |
| 369 | H1CCV | CCV INLET ENTHALPY | |
| 370 | H38 | CCV DISCHARGE ENTHALPY | |
| 371 | H2J1 | MIXER HOT HYDROGEN INLET ENTHALPY | |
| 372 | H1 | NOZZLE COOLING JACKET INLET ENTHALPY | |
| 373 | H2 | NOZZLE COOLING JACKET DISCHARGE ENTHALPY | |
| 374 | H3 | MCC COOLING JACKET INLET ENTHALPY | |
| 375 | H4 | MCC COOLING JACKET ENTHALPY AT BOUNDARY LAYER ATTACH POINT | |
| 378 | HFP1 | LPFP HEAD RISE | [LPFP p_diff] |
| 379 | HFP2 | HPFP HEAD RISE | [HPFP p_diff] |
| 380 | H2FT2M | HPFT DISCHARGE ENTHALPY (AFTER MIX) | |
| 381 | HINJ | MAIN INJECTOR HOT GAS ORIFICE INLET ENTHALPY | |
| 382 | HINPB1 | NOZZLE COOL JACKET DISCHARGE ENTHALPY (AFTER MIX) | |
| 383 | HINPB2 | PREBURNER INLET FUEL EFFECTIVE ENTHALPY | |
| 384 | HOP1 | LPOP HEAD RISE | [LPOP p_diff] |
| 385 | HOP2 | HPOP HEAD RISE | [HPOP_PBP p_diff] |
| 386 | HOP3 | PBP HEAD RISE | |
| 387 | HPFP1 | LPFP POWER | [LPFP MechPWR] |
| 388 | HPFP2 | HPFP POWER | [HPFP MechPWR] |
| 389 | HPFT1 | LPFT POWER | [LPFT MechPWR] |
| 390 | HPFT2 | HPFT POWER | [HPFT MechPWR] |
| 391 | HPOP1 | LPOP POWER | [LPOP MechPWR] |
| 392 | HPOP2 | HPOP POWER | [HPOP_PBP MechPWR] |
| 393 | HPOP3 | PBP POWER | |
| 394 | HPOT1 | LPOT POWER | [LPOT MechPWR] |
| 395 | HPOT2 | HPOT POWER | [HPOT MechPWR] |
| 396 | HCT | HPFT COOLING CIRCUIT DISCHARGE ENTHALPY | |
| 397 | H2OT2M | HPOT DISCHARGE ENTHALPY (AFTER MIX) | |
| 398 | H1MFV | MFV INLET ENTHALPY | |
| 399 | HTBYO | OPB COOLING CIRCUIT DISCHARGE ENTHALPY | |
| 400 | H1FP1 | LPFP INLET ENTHALPY | |
| 401 | H1FP2 | HPFP INLET ENTHALPY | |
| 402 | H1FT1 | LPFT INLET ENTHALPY | |
| 403 | H1FT2 | HPFT INLET ENTHALPY | |
| 404 | H1OT2 | HPOT INLET ENTHALPY | |

| | | | |
|---|---|---|---|
| 405 | H2FP1 | LPFP DISCHARGE ENTHALPY | |
| 406 | H2FP2 | HPFP DISCHARGE ENTHALPY | |
| 408 | H2FT1 | LPFT DISCHARGE ENTHALPY | |
| 409 | H2FT2 | HPFT DISCHARGE ENTHALPY | |
| 412 | H2OP3 | PBP DISCHARGE ENTHALPY | |
| 413 | H2OP2 | HPOP DISCHARGE ENTHALPY | |
| 414 | PEXC | HGM DISCHARGE PRESSURE - FUEL SIDE | |
| 415 | PEXCO | HGM DISCHARGE PRESSURE - OXIDIZER SIDE | |
| 417 | PEXTCJ | PREBURNER FUEL SUPPLY DUCT INLET PRESSURE (MIXER DISCHARGE) | [MIXER pin F107 pin] |
| 420 | PFPB | FPB CHAMBER PRESSURE | [FPB pout HPFT pin] |
| 421 | H2OP1 | LPOP DISCHARGE ENTHALPY | |
| 422 | H1OP1 | LPOP INLET ENTHALPY | |
| 423 | H1OP2 | HPOP INLET ENTHALPY | |
| 424 | H1OP3 | PBP INLET ENTHALPY | |
| 433 | PINFM | HGM INLET PRESSURE - FUEL SIDE | [HGM pin] |
| 442 | POMC | HGM COOLING CIRCUIT INLET PRESSURE - OXIDIZER SIDE | |
| 443 | POPB | OPB CHAMBER PRESSURE | [OPB pout] |
| 458 | P1MFV | MFV INLET TOTAL PRESSURE | [MFV pin] |
| 460 | P1FP2 | HPFP INLET PRESSURE | [F101 pout] |
| 461 | P1FT1 | LPFT INLET PRESSURE | [LPFT pin] |
| 462 | P1FT2 | HPFT INLET PRESSURE | [HPFT pin] |
| 463 | P1OP3 | PBP INLET PRESSURE | |
| 464 | P1OP2 | HPOP INLET PRESSURE | [HPOP_PBP pin O201 pout] |
| 465 | P1OT1 | LPOT INLET PRESSURE | [LPOT pin M104 pin] |
| 466 | P1OT2 | HPOT INLET PRESSURE | [HPOT pin] |
| 469 | P10 | HPOP DISCHARGE DUCT DISCHARGE PRESSURE | |
| 476 | P12 | OPOV INLET PRESSURE | [OPOV pin M101 pin] |
| 477 | P13 | OPB FUEL INJECTOR INLET PRESSURE | |
| 478 | P14 | OPB OXIDIZER INJECTOR INLET PRESSURE | [OPB pin_OX] |
| 481 | P17 | FPB FUEL INJECTOR INLET PRESSURE | |
| 482 | P18 | FPB OXIDIZER INJECTOR INLET PRESSURE | [FPB pin_OX] |
| 485 | P2FP1 | LPFP DISCHARGE PRESSURE | [LPFP pout F101 pin] |
| 486 | P2FP2 | HPFP DISCHARGE PRESSURE | [HPFP pout] |
| 487 | P2OP1 | LPOP DISCHARGE PRESSURE | [LPOP pout O201 pin] |
| 488 | P2OP2 | HPOP DISCHARGE PRESSURE | [HPOP_PBP pout] |
| 489 | P2OP3 | PBP DISCHARGE PRESSURE | |
| 493 | P210 | MOV INLET PRESSURE | [MOV pin O204 pout] |
| 496 | P3P | MFV DISCHARGE PRESSURE | [MFV pout DIFFUSER pin] |
| 501 | P2TFT1 | LPFT DISCHARGE PRESSURE | [LPFT pout] |
| 502 | P2TFT2 | HPFT DISCHARGE PRESSURE | [HPFT pout] |
| 504 | P2TOT2 | HPOT DISCHARGE PRESSURE | [HPOT pout] |
| 505 | P20 | CCV INLET PRESSURE | [CCV pin] |
| 515 | P2MFV | MFV DISCHARGE PRESSURE | |
| 519 | P33 | MCC COOLING JACKET INLET PRESSURE | [MCC_COOL pin] |
| 520 | P34 | OPOV DISCHARGE PRESSURE | [OPOV pout] |
| 521 | P35 | NOZZLE COOLING JACKET INLET PRESSURE | [NZL_COOL pin] |
| 522 | P36 | FPOV DISCHARGE PRESSURE | [FPOV pout] |
| 523 | P37 | CCV DISCHARGE PRESSURE | [CCV pout] |
| 525 | P39 | FPB FUEL MANIFOLD INLET PRESSURE | [FPB pin F110 pout] |
| 526 | P4 | PBP DISCHARGE DUCT DISCHARGE PRESSURE | |
| 528 | P41 | OPB FUEL MANIFOLD INLET PRESSURE | [OPB pin F108 pout] |
| 529 | P42 | OPB IGNITER OXIDIZER INLET PRESSURE | |
| 535 | P6 | MOV DISCHARGE PRESSURE | [MOV pout MCC pin_OX] |
| 537 | P7 | MFV DISCHARGE DUCT DISCHARGE PRESSURE | |
| 539 | P9 | PREBURNER FUEL SUPPLY DUCT DISCHARGE PRESSURE (FINAL) | |
| 558 | RMG | FPB MIXTURE RATIO | [FPB MR] |
| 559 | RMGO | OPB MIXTURE RATIO | [OPB MR] |
| 583 | TCT | HPFT COOLING DISCHARGE TEMPERATURE | |
| 585 | TEXTCJ | MIXER DISCHARGE TEMPERATURE | [MIXER Tout F107 Tin] |
| 586 | T2CCV | CCV DISCHARGE TEMPERATURE | [CCV Tout MIXER Tin] |
| 594 | TJ1 | NOZZLE COOLING JACKET DISCHARGE TEMPERATURE | [NZL_COOL Tout MIXER TinB] |
| 596 | T1OP2 | HPOP INLET TEMPERATURE | [HPOP_PBP Tin O201 Tout] |
| 604 | TORFT1 | LPFT TORQUE | |
| 605 | TORFT2 | HPFT TORQUE | |
| 606 | TOROT1 | LPOT TORQUE | [LPOT Tq LPOP Tq] |
| 607 | TOROT2 | HPOT TORQUE | |
| 608 | TPB | FPB TEMPERATURE | [FPB Tout HPFT Tin] |
| 609 | TPBO | OPB TEMPERATURE | [OPB Tout HPOT Tin] |
| 613 | TTBYO | OPB COOLING CIRCUIT DISCHARGE TEMPERATURE | |
| 615 | T1FP2 | HPFP INLET TEMPERATURE | [HPFP Tin F101 Tout] |
| 616 | T1FT1 | LPFT INLET TEMPERATURE | [LPFT Tin] |
| 621 | T2FP1 | LPFP DISCHARGE TEMPERATURE | [LPFP Tout F101 Tin] |
| 626 | T2FP2 | HPFP DISCHARGE TEMPERATURE | [HPFP Tout MFV Tin] |
| 627 | T2FT1 | LPFT DISCHARGE TEMPERATURE | [LPFT Tout] |
| 628 | T2FT2 | HPFT DISCHARGE TEMPERATURE | [HPFT Tout HGM Tin] |
| 629 | T2FT2A | HPFT DISCHARGE TEMPERATURE (MIXED) | |
| 633 | T2OP1 | LPOP DISCHARGE TEMPERATURE | [LPOP Tout O201 Tin] |
| 634 | T2OP2 | HPOP DISCHARGE TEMPERATURE | [HPOP_PBP Tout M104 Tin] |
| 635 | T2OP3 | PBP DISCHARGE TEMPERATURE | |
| 636 | T2OT1 | LPOT DISCHARGE TEMPERATURE | [LPOT Tout] |
| 637 | T2OT2 | HPOT DISCHARGE TEMPERATURE | [HPOT Tout HGM TinB] |
| 639 | T2MFV | MFV DISCHARGE TEMPERATURE | [MFV Tout DIFFUSER Tin] |
| 649 | T2FCV | FPOV DISCHARGE TEMPERATURE | [FPOV Tout FPB Tin_OX] |
| 650 | T2OCV | OPOV DISCHARGE TEMPERATURE | [OPOV Tout OPB Tin_OX] |
| 661 | WFE | ENGINE FUEL FLOWRATE | |
| 663 | WFJ2 | MCC JACKET FLOWRATE | |
| 665 | WMFV | MFV FLOWRATE | [MFV Vbar DIFFUSER Vin] |
| 674 | WFPBIF | FPB IGNITER FUEL FLOWRATE | |
| 675 | WFPBIO | FPB IGNITER OXIDIZER FLOWRATE | |
| 677 | WFPBF | FPB FUEL FLOWRATE | [FPB Vin F110 Vout] |
| 678 | H1J2 | MCC COOLANT INLET ENTHALPY | |
| 679 | WFPBO | FPB OXIDIZER FLOWRATE | [FPB Vin_OX FPOV Vout] |
| 680 | WFP1 | LPFP FLOWRATE | [LPFP Vbar] |
| 681 | WFP2 | HPFP FLOWRATE | [HPFP Vbar] |
| 682 | H2J2 | MCC COOLANT DISCHARGE ENTHALPY | |
| 684 | WFTEX | HGM MANIFOLD FLOWRATE - FUEL SIDE | [HGM Vin HPFT Vout] |
| 686 | WFT1 | LPFT FLOWRATE | [LPFT Vin F109 Vout] |
| 687 | WFT2 | HPFT FLOWRATE | [HPFT Vin FPB Vout] |

| | | | |
|---|---|---|---|
| 689 | WINMC | LPFT DISCHARGE DUCT FLOWRATE | |
| 692 | WMOV | MOV FLOWRATE | [MOV Vbar O204 Vout MCC Vin_OX] |
| 701 | WOE | ENGINE OXIDIZER FLOWRATE | |
| 707 | WOPBF | OPB FUEL FLOWRATE | [OPB Vin F108 Vout] |
| 708 | WOPBFI | OPB FUEL INLET DUCT FLOWRATE | |
| 709 | WOPBO | OPB OXIDIZER FLOWRATE | [OPB Vin_OX OPOV Vout] |
| 711 | WOP1 | LPOP FLOWRATE | [LPOP Vbar O201 Vin] |
| 712 | WOP1EX | LPOP DISCHARGE DUCT FLOWRATE | [O201 Vbar] |
| 713 | WOP2 | HPOP INLET FLOWRATE (NOT INCLUDING WBYOP3 OR WOTEB) | [HPOP_PBP Vbar O201 Vout M104 Vin] |
| 714 | WOP2EX | HPOP DISCHARGE FLOWRATE | |
| 715 | WOP3 | PBP FLOWRATE (INCLUDES BYPASS FLOW & BEARING COOLANT FLOW) | |
| 720 | WOT1 | LPOT FLOWRATE | [LPOT Vbar O203 Vout] |
| 723 | W1OP3 | PBP INLET DUCT FLOWRATE - SECTION 1 | |
| 724 | W210 | HPOP DISCHARGE DUCT FLOWRATE - SECTION 2 | |
| 725 | WOP3P | PBP FLOWRATE (INCLUDES BYPASS FLOW & BEARING COOLANT FLOW) | |
| 729 | WOT2 | HPOT FLOWRATE | [HPOT Vin OPB Vout] |
| 731 | WPBO | PREBURNER OXIDIZER FLOWRATE | |
| 739 | WTCJBY | NOZZLE JACKET BYPASS FLOWRATE | |
| 740 | WTCJ1 | NOZZLE JACKET FLOWRATE | [NZL_COOL Vbar] |
| 747 | W22 | LPFT DISCHARGE DUCT FLOWRATE | |
| 766 | W13 | OPB FUEL INLET MANIFOLD FLOWRATE | |
| 767 | W17 | FPB FUEL INLET MANIFOLD FLOWRATE | |
| 768 | W514 | OPOV FLOWRATE | [OPOV Vbar M101 Vout] |
| 769 | W518 | FPOV FLOWRATE | [FPOV Vbar O206 Vout] |
| 772 | W30 | MFV DISCHARGE DUCT FLOWRATE | |
| 795 | POSMFV | MFV POSITION | |
| 796 | POSMOV | MOV POSITION | |
| 797 | POSCCV | CCV POSITION | |
| 798 | POSOPB | OPOV POSITION | |
| 799 | POSFPB | FPOV POSITION | |
| 807 | WMIX2 | MIXER FLOWRATE (NOZZLE) | [MIXER VinB NZL_COOL Vout] |
| 808 | WPBFU | MIXER DISCHARGE FLOWRATE | [MIXER Vout F107 Vin] |
| 813 | WOPBHG | OPB HOT GAS FLOWRATE | [OPB Vout HPOT Vin] |
| 908 | D(8) | LPFT SPEED | |
| 909 | D(9) | HPFT SPEED | |
| 910 | D(10) | HPFT DISCHARGE TEMPERATURE AVERAGE | |
| 911 | D(11) | FPB CHAMBER PRESSURE | |
| 913 | D(13) | LPOT SPEED | |
| 914 | D(14) | HPOP DISCHARGE TEMPERATURE | |
| 916 | D(16) | HPOT SPEED | |
| 917 | D(17) | HPOT DISCHARGE TEMPERATURE AVERAGE | |
| 918 | D(18) | OPB CHAMBER PRESSURE | |
| 920 | D(20) | LPFT INLET TEMPERATURE | |
| 989 | D(89) | HPFP DISCHARGE TEMPERATURE | |
| 990 | D(90) | NOZZLE COOLING JACKET DISCHARGE TEMPERATURE | |
| 991 | D(91) | HPOP INLET TEMPERATURE | |
| 992 | D(92) | PBP DISCHARGE TEMPERATURE | |
| 993 | D(93) | MIXER DISCHARGE TEMERATURE | |
| 994 | D(94) | LPFP DISCHARGE TEMPERATURE | |
| 995 | D(95) | LPFT DISCHARGE TEMPERATURE | |
| 997 | D(97) | OPOV DISCHARGE TEMPERATURE | |
| 998 | D(98) | FPOV DISCHARGE TEMPERATURE | |
| 1104 | WFT1C | MCC COOLANT FLOWRATE | [MCC_COOL Vbar] |

# displaydb.c

```
#define SUN /* this may also work on HP9k */

#include <stdio.h>
#include "dbaccess.h"

#define MAXINDEX 1349
#define FSIZE sizeof(float)

FILE *fp, *fp2;
char *datafilename, *datafilename2;
int slice, index;

int print_item(index, value)
    int index;
    float value;
{
 char mystr[80];
 switch (index) {
/* case 933:
   strcpy(mystr, (char)value);
   printf("Test number: %s", mystr);
   break; */
 case 934:
   printf("Test date: %6.0f\n", value);
   break;
 case 935:
   printf("Test duration %3.0f\n", value);
   break;
 case 936:
   printf("Slice duration %3.0f\n", value);
   break;
 case 937:
   printf("Slice start time %3.0f\n", value);
   break;

 default:
   printf("Index %d Value %f\n", index, value);
   break;
 }
}

int print_item2(index, value1, value2)
    int index;
    float value1, value2;
{
 char mystr[80];
 switch (index) {
/* case 933:
   strcpy(mystr, (char)value1);
   printf("Test number: %s", mystr);
   break; */
 case 934:
   printf("Test date: %6.0f\n", value1);
   break;
 case 935:
   printf("Test duration %3.0f\n", value1);
   break;
 case 936:
   printf("Slice duration %3.0f\n", value1);
   break;
 case 937:
   printf("Slice start time %3.0f\n", value1);
   break;

 default:
   if ((value1 > 0.0000001)||(value1 < -0.0000001)) {
     printf("Index %5d  Value1 %10f  Value2 %10f  Diff %12f  %%  %5.2f\n",
          index, value1, value2, value2-value1, (value2-value1)/value1*100.0);
   }
   else {
     printf("Index %5d  Value1 %10f  Value2 %10f  Diff %12f\n",
          index, value1, value2, value1-value2);
   }
   break;
 }
}

main(argc,argv)
int argc;
char *argv[];
{
float a_array[1350];
float a_array2[1350];
int i;

if (argc <= 3) {printf("Usage: displaydb <data_file_name> <slice #> <index>\n");
             printf("  or: displaydb <data_file_1> <data_file_2> <slice #> <index>\n");
             printf("      If index < 0: lists all values in slice\n");
             printf("      If 2 file names are given (second form): Values from both are printed\n");
```

```
            printf("     and their absolute difference and percent change are shown.\n");
            exit(1);}

datafilename = argv[1];
if (argc == 5) {              /* two files given */
  datafilename2 = argv[2];
  slice = atoi(argv[3]);
  index = atoi(argv[4]);
}
else
  {
   slice = atoi(argv[2]);
   index = atoi(argv[3]);
  }


/*
datafilename = "a1613";
*/


if (argc == 5) {
printf("\n============================================================================\n");
printf("Slice %5d  File1 %11s  File2 %11s  %17s  %8s\n", slice, datafilename, datafilename2, "Diff 2-1", "%");
printf("--------------------------------------------------------------------------\n\n");
}
else {
printf("\n==================================================\n");
printf("File %s Slice %d Index %d\n", datafilename, slice, index);
printf("------------------------------------------------\n\n");
}


if ((fp = fopen(datafilename, "r")) == NULL) {
  fprintf(stderr, "%s: Cannot open %s\n", *argv, datafilename);
  exit(1);
}


if (argc == 5) {
  if ((fp2 = fopen(datafilename2, "r")) == NULL) {
   fprintf(stderr, "%s: Cannot open %s\n", *argv, datafilename2);
   exit(1);
  }
}


if (fseek(fp, (slice-1)*FSIZE*(MAXINDEX +1), SEEK_SET) != 0) {
  printf("Error seeking time slice in file %s\n", datafilename);
  exit(1);
}
if (argc == 5) {
  if (fseek(fp2, (slice-1)*FSIZE*(MAXINDEX +1), SEEK_SET) != 0) {
   printf("Error seeking time slice in file %s\n", datafilename2);
   exit(1);
  }
}


fread(a_array, FSIZE, MAXINDEX + 1, fp);
for (i = 0; i <= MAXINDEX; i++) {
  a_array[i] = xflt(a_array+i);
}


if (argc == 5) {
  fread(a_array2, FSIZE, MAXINDEX + 1, fp2);
  for (i = 0; i <= MAXINDEX; i++) {
   a_array2[i] = xflt(a_array2+i);
  }
}


if (argc == 5) {
  if (index < 0) {
   for (i = 0; i <= MAXINDEX; i++) {
    if ((a_array[i] > 0.0000001)||(a_array[i] < -0.0000001)) {
        printf("%10d : %17f %18f %18f %9.2f\n",
              i+1, a_array[i], a_array2[i], a_array2[i]-a_array[i],
              (a_array2[i]-a_array[i])/a_array[i]*100.0);
    }
    else {
        printf("%10d : %17f %18f %18f\n",
              i+1, a_array[i], a_array2[i], a_array[i]-a_array2[i]);
    }
   }
  }
  else {
   print_item2(index, a_array[index-1], a_array2[index-1]);
  }
}
else
  {
   if (index < 0) {
    for (i = 0; i <= MAXINDEX; i++) {
        printf("%i  :  %f\n", i+1, a_array[i]);
    }
   }
   else {
    print_item(index, a_array[index-1]);
```

```
    }
}

fclose(fp);

if (argc == 5) {
  fclose(fp2);
}

printf("\n\n");

}
```

# make_PBM_params.c

```
#include <stdio.h>

char *get_qual_value(FILE *dev_file, int loc);
int write_to_file(FILE *nexp_file, char *comp, char *param, char *q_val);

const char * low="LOW";
const char * normal="NORMAL";
const char * high="HIGH";

int write_to_file(FILE *nexp_file, char *comp, char *param, char *q_val)
{
/* printf("\\%s_PBM_template.%s\\=\"%s\"\n",comp,param,q_val); */
 fprintf(nexp_file, "\\%s_PBM_template.%s\\=\"%s\"\n",comp,param,q_val);
}

char *get_qual_value(FILE *dev_file, int loc)
{
 extern const char * low;
 extern const char * normal;
 extern const char * high;
 int loc2;
 char dev_line[256], *result;
 float percent_change, valid, limit=2.5;

 do {
  fgets(dev_line, 256, dev_file);
  sscanf(dev_line," %d ", &loc2);
 }
 while (loc2 != loc);
 sscanf(dev_line," %*d : %f %*f %*f %f ", &valid, &percent_change);
/* printf("%f\n", percent_change); */
 if (valid != 0.0) {
  if (percent_change > limit) result = high;
  else if (percent_change <  (0 - limit)) result = low;
  else result = normal;
  return(result);}
 else return(NULL);
}

int main(int argc,char **argv)
{
/* const char * low="LOW";
const char * normal="NORMAL";
const char * high="HIGH"; */

int i, location;
FILE *deviation_file, *parameter_file, *nexpert_file;
char dev_line[256], par_line[256], comp[80], param[80];
char *bracket, *q_value;

if (! (deviation_file = fopen("PBM_numeric_deviations", "r")))
 {
  printf("Cannot open input file PBM_numeric_deviations!\n");
  exit(1);
 };
if (! (parameter_file = fopen("PBM_parameters", "r")))
 {
  printf("Cannot open input file PBM_parameters!\n");
  fclose(deviation_file);
  exit(1);
 };
if (! (nexpert_file = fopen("PBM_values.nxp", "w")))
 {
  printf("Cannot open output file PBM_values.nxp!\n");
  fclose(deviation_file);
  fclose(parameter_file);
  exit(1);
 };

for (i=1; i <= 5; i++) fgets(dev_line, 256, deviation_file);

while (fgets(par_line, 256, parameter_file))
 {
  if (bracket = (char *)strchr(par_line,'['))
   {
     sscanf(par_line,"%d ", &location);
     q_value = get_qual_value(deviation_file,location);
     if (q_value) {
      bracket++;
      sscanf(bracket,"%s",comp);
      bracket += strlen(comp) + 1;
      sscanf(bracket,"%s",param);
      bracket += strlen(param);
      while (*(bracket-1) != ']') {
       /*    printf("LOCATION %d %s %s\n", location,comp,param); */
       write_to_file(nexpert_file,comp,param,q_value);
       bracket++;
       sscanf(bracket,"%s",comp);
       bracket += strlen(comp) + 1;
```

```
            sscanf(bracket,"%s",param);
            bracket += strlen(param);
          }
          *(param+strlen(param)-1) = '\0';
          /*     printf("LOCATION %d %s %s\n", location,comp,param); */
          write_to_file(nexpert_file,comp,param,q_value);
        }
      }
   }

fprintf(nexpert_file,"**********\n");

   fclose(deviation_file);
   fclose(parameter_file);
   fclose(nexpert_file);

exit(0);
}
```

## A.5 MCC Leak Example Case Data

### A.5.1MCC Leak Example: Qualitative values of measured parameters

Qualitative Parmeter Values

\MCC_PC_REFERENCE.QUALITATIVE_VALUE\="NORMAL"
\MCC_PC.QUALITATIVE_VALUE\="NORMAL"
\LPFP_DS_PR.QUALITATIVE_VALUE\="LOW"
\LPFP_DS_TMP.QUALITATIVE_VALUE\="NORMAL"
\HPFP_DS_PR.QUALITATIVE_VALUE\="NORMAL"
\MCC_CLNT_DS_PR.QUALITATIVE_VALUE\="LOW"
\MCC_CLNT_DS_TMP.QUALITATIVE_VALUE\="LOW"
\FPB_PC.QUALITATIVE_VALUE\="NORMAL"
\HPFP_CLNT_LNR_PR.QUALITATIVE_VALUE\="NORMAL"
\MCC_FUEL_INJECTOR_PR.QUALITATIVE_VALUE\="NORMAL"
\LPOP_DS_PR.QUALITATIVE_VALUE\="NORMAL"
\HPOP_DS_PR.QUALITATIVE_VALUE\="NORMAL"
\LOX_DOME_TMP.QUALITATIVE_VALUE\="NORMAL"
\PBP_DS_PR.QUALITATIVE_VALUE\="NORMAL"
\PBP_DS_TMP.QUALITATIVE_VALUE\="NORMAL"
\HPOP_DS_TMP.QUALITATIVE_VALUE\="NORMAL"
\ENG_FUEL_INLET_TMP.QUALITATIVE_VALUE\="NORMAL"
\ENG_FUEL_INLET_PR.QUALITATIVE_VALUE\="NORMAL"
\ENG_OX_INLET_TMP.QUALITATIVE_VALUE\="NORMAL"
\ENG_OX_INLET_PR.QUALITATIVE_VALUE\="NORMAL"
\FUEL_FLOW.QUALITATIVE_VALUE\="NORMAL"
\HPFP_DS_TMP.QUALITATIVE_VALUE\="NORMAL"
\HPFP_BAL_CAV_PR.QUALITATIVE_VALUE\="NORMAL"
\HPFP_COOLANT_LINER_TMP.QUALITATIVE_VALUE\="NORMAL"
\HPFP_DRAIN_PR.QUALITATIVE_VALUE\="NORMAL"
\HPFP_DRAIN_TMP.QUALITATIVE_VALUE\="NORMAL"
\LPFT_INLET_PR.QUALITATIVE_VALUE\="LOW"
\FUEL_PRESSURANT_INTERFACE_PR.QUALITATIVE_VALUE\="NORMAL"
\FUEL_PRESSURANT_INTERFACE_TMP.QUALITATIVE_VALUE\="NORMAL"
\OPB_PC.QUALITATIVE_VALUE\="NORMAL"
\FPOV_POSITION.QUALITATIVE_VALUE\="NORMAL"
\MCC_LOX_INJECTOR_TMP.QUALITATIVE_VALUE\="NORMAL"
\MCC_LOX_INJECTOR_PR.QUALITATIVE_VALUE\="NORMAL"
\POGO_PRE_CHARGE_PR.QUALITATIVE_VALUE\="NORMAL"
\HEAT_EXCHANGER_DS_PR.QUALITATIVE_VALUE\="NORMAL"
\HEAT_EXCHANGER_INTERFACE_PR.QUALITATIVE_VALUE\="NORMAL"
\HEAT_EXCHANGER_INTERFACE_TMP.QUALITATIVE_VALUE\="NORMAL"
\OPOV_POSITION.QUALITATIVE_VALUE\="NORMAL"
\HPOP_SPEED.QUALITATIVE_VALUE\="NORMAL"
\LPOP_SPEED1.QUALITATIVE_VALUE\="NORMAL"
\HPOP_BAL_CAV_PR1.QUALITATIVE_VALUE\="NORMAL"
\LPFP_SPEED1.QUALITATIVE_VALUE\="LOW"
\HPOT_DS_TMP1.QUALITATIVE_VALUE\="NORMAL"
\HPFT_DS_TMP1.QUALITATIVE_VALUE\="NORMAL"
\HPFP_SPEED1.QUALITATIVE_VALUE\="NORMAL"
\MFV_POSITION.QUALITATIVE_VALUE\="NORMAL"
\MOV_POSITION.QUALITATIVE_VALUE\="NORMAL"
\CCV_POSITION.QUALITATIVE_VALUE\="NORMAL"
**********

## A.5.2MCC Leak Example: Comparison of numerical data

PBM_numeric_deviations

| Slice 29 | File1 a1613 | File2 a1614 | Diff 2-1 | % |
|---|---|---|---|---|
| 1 : | 1.039888 | 1.040192 | 0.000303 | 0.03 |
| 2 : | 6.008003 | 5.996758 | -0.011246 | -0.19 |
| 3 : | 14.668247 | 14.651808 | -0.016439 | -0.11 |
| 4 : | 24.534515 | 24.639374 | 0.104858 | 0.43 |
| 5 : | 98.367554 | 98.842560 | 0.475006 | 0.48 |
| 6 : | 37.747559 | 37.457550 | -0.290009 | -0.77 |
| 7 : | 165.911163 | 166.015625 | 0.104462 | 0.06 |
| 8 : | 0.229589 | 0.231791 | 0.002202 | 0.96 |
| 9 : | 1.690277 | 1.879307 | 0.189030 | 11.18 |
| 10 : | 3125.905273 | 3126.816895 | 0.911621 | 0.03 |
| 11 : | 0.000000 | 0.000000 | 0.000000 | |
| 12 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 13 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 14 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 15 : | 26.500000 | 26.500000 | 0.000000 | 0.00 |
| 16 : | 15.299999 | 15.299999 | 0.000000 | 0.00 |
| 17 : | 0.013001 | 0.013203 | 0.000202 | 1.56 |
| 18 : | 0.013330 | 0.013330 | 0.000000 | 0.00 |
| 19 : | 7500.000000 | 7500.000000 | 0.000000 | 0.00 |
| 20 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 21 : | 0.000000 | 0.000000 | 0.000000 | |
| 22 : | 498.055176 | 523.206543 | 25.151367 | 5.05 |
| 23 : | 10.283998 | 10.283998 | 0.000000 | 0.00 |
| 24 : | 90.295990 | 90.295990 | 0.000000 | 0.00 |
| 25 : | 390254.125000 | 390454.875000 | 200.750000 | 0.05 |
| 26 : | 14.668247 | 14.651808 | -0.016439 | -0.11 |
| 27 : | 33.000000 | 33.000000 | 0.000000 | 0.00 |
| 28 : | 19.619995 | 19.619995 | 0.000000 | 0.00 |
| 29 : | 3.971998 | 3.971998 | 0.000000 | 0.00 |
| 30 : | 83.064148 | 83.064148 | 0.000000 | 0.00 |
| 31 : | 1.092199 | 1.092199 | 0.000000 | 0.00 |
| 32 : | 10.799999 | 10.799999 | 0.000000 | 0.00 |
| 33 : | 1.386000 | 1.386000 | 0.000000 | 0.00 |
| 34 : | 2.896000 | 2.896000 | 0.000000 | 0.00 |
| 35 : | 1.011114 | 1.010729 | -0.000385 | -0.04 |
| 36 : | 12.000000 | 12.000000 | 0.000000 | 0.00 |
| 37 : | 12.000000 | 12.000000 | 0.000000 | 0.00 |
| 38 : | 7.400000 | 7.400000 | 0.000000 | 0.00 |
| 39 : | 10.189999 | 10.189999 | 0.000000 | 0.00 |
| 40 : | 11.724998 | 11.724998 | 0.000000 | 0.00 |
| 41 : | 6.849998 | 6.849998 | 0.000000 | 0.00 |
| 42 : | 5.000000 | 5.000000 | 0.000000 | 0.00 |
| 43 : | 6.000000 | 6.000000 | 0.000000 | 0.00 |
| 44 : | 10.089998 | 10.089998 | 0.000000 | 0.00 |
| 45 : | 14.919998 | 14.919998 | 0.000000 | 0.00 |
| 46 : | 16.919983 | 16.919983 | 0.000000 | 0.00 |
| 47 : | 0.500000 | 0.500000 | 0.000000 | 0.00 |
| 48 : | 0.000000 | 0.000000 | 0.000000 | |
| 49 : | 0.060000 | 0.060000 | 0.000000 | 0.00 |
| 50 : | 96.038086 | 96.511475 | 0.473389 | 0.49 |
| 51 : | -0.109161 | 0.289368 | 0.398529 | -365.08 |
| 52 : | 0.215000 | 0.215000 | 0.000000 | 0.00 |
| 53 : | 0.383000 | 0.383000 | 0.000000 | 0.00 |
| 54 : | 12.019999 | 12.019999 | 0.000000 | 0.00 |
| 55 : | 5.199999 | 5.199999 | 0.000000 | 0.00 |
| 56 : | 5.199999 | 5.199999 | 0.000000 | 0.00 |
| 57 : | 2.900000 | 2.900000 | 0.000000 | 0.00 |
| 58 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 59 : | 0.990341 | 0.995184 | 0.004842 | 0.49 |
| 60 : | 0.972574 | 0.980250 | 0.007676 | 0.79 |
| 61 : | 1.023678 | 1.013735 | -0.009943 | -0.97 |
| 62 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 63 : | 0.985196 | 0.974770 | -0.010426 | -1.06 |
| 64 : | 1.062466 | 1.077913 | 0.015448 | 1.45 |
| 65 : | 1.016024 | 1.012693 | -0.003330 | -0.33 |
| 66 : | 0.968910 | 0.944607 | -0.024303 | -2.51 |
| 67 : | 38000.000000 | 38000.000000 | 0.000000 | 0.00 |
| 68 : | 76.906433 | 76.906464 | 0.000031 | 0.00 |
| 69 : | 470000.000000 | 470000.000000 | 0.000000 | 0.00 |
| 70 : | 6388.164062 | 6388.164062 | 0.000000 | 0.00 |
| 71 : | 2002.959961 | 2002.959961 | 0.000000 | 0.00 |
| 72 : | 6388.164062 | 6388.164062 | 0.000000 | 0.00 |
| 73 : | 0.996604 | 0.996605 | 0.000000 | 0.00 |
| 74 : | 0.978000 | 0.978000 | 0.000000 | 0.00 |
| 75 : | 82.500000 | 82.500000 | 0.000000 | 0.00 |
| 76 : | 82.500000 | 82.500000 | 0.000000 | 0.00 |
| 77 : | 2.549999 | 2.549999 | 0.000000 | 0.00 |
| 78 : | 25.799988 | 25.799988 | 0.000000 | 0.00 |
| 79 : | 3125.905273 | 3126.816895 | 0.911621 | 0.03 |
| 80 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 81 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 82 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 83 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 84 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 85 : | 412.000000 | 412.000000 | 0.000000 | 0.00 |
| 86 : | 0.000000 | 0.000000 | 0.000000 | |
| 87 : | 1.015055 | 1.014589 | -0.000465 | -0.05 |

| | | | | |
|---|---|---|---|---|
| 88 : | 1.034258 | 1.036100 | 0.001842 | 0.18 |
| 89 : | 0.996876 | 0.994775 | -0.002101 | -0.21 |
| 90 : | 0.962178 | 0.960224 | -0.001954 | -0.20 |
| 91 : | 0.989823 | 1.003180 | 0.013357 | 1.35 |
| 92 : | 190.919983 | 190.919983 | 0.000000 | 0.00 |
| 93 : | 12500.000000 | 12500.000000 | 0.000000 | 0.00 |
| 94 : | 0.041826 | 0.042803 | 0.000977 | 2.34 |
| 95 : | 5087.000000 | 5087.000000 | 0.000000 | 0.00 |
| 96 : | 0.187000 | 0.187000 | 0.000000 | 0.00 |
| 97 : | 1631.000000 | 1631.000000 | 0.000000 | 0.00 |
| 98 : | 0.002151 | 0.002151 | 0.000000 | 0.00 |
| 99 : | 0.259972 | 0.260048 | 0.000076 | 0.03 |
| 100 : | 0.250000 | 0.250000 | 0.000000 | 0.00 |
| 101 : | 4010.000000 | 4010.000000 | 0.000000 | 0.00 |
| 102 : | 0.001337 | 0.001337 | 0.000000 | 0.00 |
| 103 : | 11.781599 | 11.781599 | 0.000000 | 0.00 |
| 104 : | 0.002201 | 0.002201 | 0.000000 | 0.00 |
| 105 : | 0.010520 | 0.010520 | 0.000000 | 0.00 |
| 106 : | 0.003247 | 0.003247 | 0.000000 | 0.00 |
| 107 : | 0.006517 | 0.006517 | 0.000000 | 0.00 |
| 108 : | 16000.000000 | 16000.000000 | 0.000000 | 0.00 |
| 109 : | 0.054520 | 0.054520 | 0.000000 | 0.00 |
| 110 : | 0.000690 | 0.000690 | 0.000000 | 0.00 |
| 111 : | 0.001946 | 0.001946 | 0.000000 | 0.00 |
| 112 : | 0.027540 | 0.027540 | 0.000000 | 0.00 |
| 113 : | 0.002632 | 0.002632 | 0.000000 | 0.00 |
| 114 : | 0.104100 | 0.104100 | 0.000000 | 0.00 |
| 115 : | 0.002100 | 0.002100 | 0.000000 | 0.00 |
| 116 : | 98558.000000 | 98558.000000 | 0.000000 | 0.00 |
| 117 : | 1390.000000 | 1390.000000 | 0.000000 | 0.00 |
| 118 : | 0.050000 | 0.050000 | 0.000000 | 0.00 |
| 119 : | 11.320000 | 11.320000 | 0.000000 | 0.00 |
| 120 : | 4881.000000 | 4881.000000 | 0.000000 | 0.00 |
| 121 : | 0.008000 | 0.008000 | 0.000000 | 0.00 |
| 122 : | 0.999158 | 0.998992 | -0.000167 | -0.02 |
| 123 : | 0.000000 | 0.000000 | 0.000000 | |
| 124 : | 0.000000 | 0.000000 | 0.000000 | |
| 125 : | 0.000000 | 0.000000 | 0.000000 | |
| 126 : | 4.059999 | 4.059999 | 0.000000 | 0.00 |
| 127 : | 30668.437500 | 29211.523438 | -1456.914062 | -4.75 |
| 128 : | 6000.000000 | 6000.000000 | 0.000000 | 0.00 |
| 129 : | 0.020760 | 0.020760 | 0.000000 | 0.00 |
| 130 : | 0.091000 | 0.091000 | 0.000000 | 0.00 |
| 131 : | 0.010043 | 0.010475 | 0.000433 | 4.31 |
| 132 : | 0.057900 | 0.057900 | 0.000000 | 0.00 |
| 133 : | 0.076200 | 0.076200 | 0.000000 | 0.00 |
| 134 : | 0.009725 | 0.009510 | -0.000215 | -2.21 |
| 135 : | 0.974578 | 0.974743 | 0.000165 | 0.02 |
| 136 : | 0.059080 | 0.059080 | 0.000000 | 0.00 |
| 137 : | 0.481500 | 0.481500 | 0.000000 | 0.00 |
| 138 : | 0.005700 | 0.005700 | 0.000000 | 0.00 |
| 139 : | 0.997976 | 1.076662 | 0.078686 | 7.88 |
| 140 : | 1.199999 | 1.199999 | 0.000000 | 0.00 |
| 141 : | 0.047300 | 0.047300 | 0.000000 | 0.00 |
| 142 : | 1.879000 | 1.879000 | 0.000000 | 0.00 |
| 143 : | 0.577500 | 0.577500 | 0.000000 | 0.00 |
| 144 : | 166.000000 | 166.000000 | 0.000000 | 0.00 |
| 145 : | 0.038400 | 0.038400 | 0.000000 | 0.00 |
| 146 : | 1.860998 | 1.860998 | 0.000000 | 0.00 |
| 147 : | 0.169000 | 0.169000 | 0.000000 | 0.00 |
| 148 : | 30.000000 | 30.000000 | 0.000000 | 0.00 |
| 149 : | 0.005687 | 0.005687 | 0.000000 | 0.00 |
| 150 : | 0.052300 | 0.052300 | 0.000000 | 0.00 |
| 151 : | 174600.000000 | 174600.000000 | 0.000000 | 0.00 |
| 152 : | 0.000686 | 0.000686 | 0.000000 | 0.00 |
| 153 : | 0.352800 | 0.352800 | 0.000000 | 0.00 |
| 154 : | 766.000000 | 766.000000 | 0.000000 | 0.00 |
| 155 : | 0.134000 | 0.134000 | 0.000000 | 0.00 |
| 156 : | 0.112500 | 0.112500 | 0.000000 | 0.00 |
| 157 : | 0.192000 | 0.192000 | 0.000000 | 0.00 |
| 158 : | 0.012600 | 0.012600 | 0.000000 | 0.00 |
| 159 : | 0.005000 | 0.005000 | 0.000000 | 0.00 |
| 160 : | 0.300000 | 0.300000 | 0.000000 | 0.00 |
| 161 : | 0.618500 | 0.618500 | 0.000000 | 0.00 |
| 162 : | 1.199999 | 1.199999 | 0.000000 | 0.00 |
| 163 : | 0.173400 | 0.173400 | 0.000000 | 0.00 |
| 164 : | 0.529000 | 0.529000 | 0.000000 | 0.00 |
| 165 : | 0.060347 | 0.059739 | -0.000608 | -1.01 |
| 166 : | 0.020810 | 0.020810 | 0.000000 | 0.00 |
| 167 : | 0.011800 | 0.011800 | 0.000000 | 0.00 |
| 168 : | 1.556257 | 1.687683 | 0.131426 | 8.44 |
| 169 : | 0.153000 | 0.153000 | 0.000000 | 0.00 |
| 170 : | 138850.000000 | 138850.000000 | 0.000000 | 0.00 |
| 171 : | 74568.000000 | 74568.000000 | 0.000000 | 0.00 |
| 172 : | 339270.000000 | 339270.000000 | 0.000000 | 0.00 |
| 173 : | 89965.000000 | 89965.000000 | 0.000000 | 0.00 |
| 174 : | 45138.000000 | 45138.000000 | 0.000000 | 0.00 |
| 175 : | 535500.000000 | 535500.000000 | 0.000000 | 0.00 |
| 176 : | 30.000000 | 30.000000 | 0.000000 | 0.00 |
| 177 : | 130.000000 | 130.000000 | 0.000000 | 0.00 |
| 178 : | 245000.000000 | 245000.000000 | 0.000000 | 0.00 |
| 179 : | 194000.000000 | 194000.000000 | 0.000000 | 0.00 |
| 180 : | 0.007120 | 0.007120 | 0.000000 | 0.00 |
| 181 : | 0.535802 | 0.535314 | -0.000489 | -0.09 |
| 182 : | 1.500000 | 1.500000 | 0.000000 | 0.00 |
| 183 : | 0.168000 | 0.168000 | 0.000000 | 0.00 |
| 184 : | 0.000000 | 0.000000 | 0.000000 | |
| 185 : | 65000.000000 | 65000.000000 | 0.000000 | 0.00 |

| | | | | |
|---|---|---|---|---|
| 186 : | 1.013733 | 1.013346 | -0.000387 | -0.04 |
| 187 : | 0.012500 | 0.012500 | 0.000000 | 0.00 |
| 188 : | 0.026500 | 0.026500 | 0.000000 | 0.00 |
| 189 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 190 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 191 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 192 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 193 : | 0.891073 | 0.900923 | 0.009850 | 1.11 |
| 194 : | 0.807200 | 0.807200 | 0.000000 | 0.00 |
| 195 : | 1.033400 | 1.033400 | 0.000000 | 0.00 |
| 196 : | 1.196472 | 1.250399 | 0.053926 | 4.51 |
| 197 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 198 : | 20900.000000 | 20900.000000 | 0.000000 | 0.00 |
| 199 : | 29.000000 | 29.000000 | 0.000000 | 0.00 |
| 200 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 201 : | 82.240143 | 82.240143 | 0.000000 | 0.00 |
| 202 : | 1.504730 | 1.505049 | 0.000319 | 0.02 |
| 203 : | 0.951398 | 0.951558 | 0.000160 | 0.02 |
| 204 : | 1.961967 | 1.961432 | -0.000536 | -0.03 |
| 205 : | 2882.286621 | 2804.322266 | -77.964355 | -2.70 |
| 206 : | 4325.671875 | 4332.679688 | 7.007812 | 0.16 |
| 207 : | 287.210449 | 287.554688 | 0.344238 | 0.12 |
| 208 : | 4205.500000 | 4208.031250 | 2.531250 | 0.06 |
| 209 : | 1.866611 | 1.866415 | -0.000196 | -0.01 |
| 210 : | 52000.000000 | 52000.000000 | 0.000000 | 0.00 |
| 211 : | 1570.885254 | 1528.712891 | -42.172363 | -2.68 |
| 212 : | 1570.979980 | 1528.801758 | -42.178223 | -2.68 |
| 213 : | 7775.234375 | 7775.156250 | -0.078125 | 0.00 |
| 214 : | 7689.757812 | 7692.625000 | 2.867188 | 0.04 |
| 215 : | 1884.011230 | 1897.846680 | 13.835449 | 0.73 |
| 216 : | 1684.228027 | 1639.615234 | -44.612793 | -2.65 |
| 217 : | 1684.228027 | 1639.615234 | -44.612793 | -2.65 |
| 218 : | -811.693848 | -809.597656 | 2.096191 | -0.26 |
| 219 : | -822.295410 | -811.830566 | 10.464844 | -1.27 |
| 220 : | 0.000000 | 0.000000 | 0.000000 | |
| 221 : | 0.000000 | 0.000000 | 0.000000 | |
| 222 : | -823.186035 | -820.675781 | 2.510254 | -0.30 |
| 223 : | -840.590820 | -828.914551 | 11.676270 | -1.39 |
| 224 : | 4001.000000 | 4001.000000 | 0.000000 | 0.00 |
| 225 : | 6001.000000 | 6001.000000 | 0.000000 | 0.00 |
| 226 : | 1684.228027 | 1639.615234 | -44.612793 | -2.65 |
| 227 : | 47.846252 | 47.629211 | -0.217041 | -0.45 |
| 228 : | 21.433075 | 21.282898 | -0.150177 | -0.70 |
| 229 : | 0.824784 | 0.824721 | -0.000062 | -0.01 |
| 230 : | 401.263184 | 407.114258 | 5.851074 | 1.46 |
| 231 : | 48.910950 | 49.184845 | 0.273895 | 0.56 |
| 232 : | 73.433044 | 79.667969 | 6.234924 | 8.49 |
| 233 : | 36.060303 | 36.121460 | 0.061157 | 0.17 |
| 234 : | 24.890167 | 25.028778 | 0.138611 | 0.56 |
| 235 : | 2980.142090 | 2966.480469 | -13.661621 | -0.46 |
| 236 : | 0.921638 | 0.929231 | 0.007593 | 0.82 |
| 237 : | 49.548981 | 58.451569 | 8.902588 | 17.97 |
| 238 : | 5.763311 | 5.504456 | -0.258856 | -4.49 |
| 239 : | 173.086273 | 184.453278 | 11.367004 | 6.57 |
| 240 : | 11.612564 | 11.090994 | -0.521570 | -4.49 |
| 241 : | 185.549164 | 168.618042 | -16.931122 | -9.12 |
| 242 : | 1095.488281 | 1141.797363 | 46.309082 | 4.23 |
| 243 : | 36.402039 | 36.422180 | 0.020142 | 0.06 |
| 244 : | 13.305758 | 14.411146 | 1.105389 | 8.31 |
| 245 : | 43.699738 | 52.865021 | 9.165283 | 20.97 |
| 246 : | 3736.286133 | 3741.070312 | 4.784180 | 0.13 |
| 247 : | 87.075806 | 87.200745 | 0.124939 | 0.14 |
| 248 : | 9.349928 | 9.655035 | 0.305107 | 3.26 |
| 249 : | 2175.591309 | 2156.150391 | -19.440918 | -0.89 |
| 250 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 251 : | 78.837372 | 79.275269 | 0.437897 | 0.56 |
| 252 : | 0.000000 | 0.000000 | 0.000000 | |
| 253 : | 22.119446 | 23.950073 | 1.830627 | 8.28 |
| 254 : | 94.923065 | 95.041077 | 0.118011 | 0.12 |
| 255 : | 14.023527 | 13.872250 | -0.151278 | -1.08 |
| 256 : | 46.359161 | 48.412476 | 2.053314 | 4.43 |
| 257 : | 8.487036 | 8.881512 | 0.394476 | 4.65 |
| 258 : | 164.326233 | 167.903473 | 3.577240 | 2.18 |
| 259 : | 91.522461 | 90.676697 | -0.845764 | -0.92 |
| 260 : | 952.055664 | 930.703125 | -21.352539 | -2.24 |
| 261 : | 598.803223 | 598.086914 | -0.716309 | -0.12 |
| 262 : | 391.079102 | 391.999512 | 0.920410 | 0.24 |
| 263 : | 69.289520 | 69.397858 | 0.108337 | 0.16 |
| 264 : | 1002.171387 | 969.575195 | -32.596191 | -3.25 |
| 265 : | 13.633186 | 15.300093 | 1.666906 | 12.23 |
| 266 : | -6.989126 | 16.691650 | 23.680777 | -338.82 |
| 267 : | 937.333008 | 796.952637 | -140.380371 | -14.98 |
| 268 : | 429.449707 | 422.855957 | -6.593750 | -1.54 |
| 269 : | 1037.450684 | 1032.199219 | -5.251465 | -0.51 |
| 270 : | 12.724550 | 28.465485 | 15.740934 | 123.71 |
| 271 : | 917.976074 | 893.815918 | -24.160156 | -2.63 |
| 272 : | 476.230957 | 458.404785 | -17.826172 | -3.74 |
| 273 : | 1193.688477 | 1176.644531 | -17.043945 | -1.43 |
| 274 : | 27.726288 | 30.050476 | 2.324188 | 8.38 |
| 275 : | 32.499420 | 31.051636 | -1.447784 | -4.45 |
| 276 : | 715.341797 | 718.124023 | 2.782227 | 0.39 |
| 277 : | 17.146332 | 17.225677 | 0.079346 | 0.46 |
| 278 : | 184.957184 | 178.494598 | -6.462585 | -3.49 |
| 279 : | 2818.295410 | 2794.435059 | -23.860352 | -0.85 |
| 280 : | 223.852417 | 214.844696 | -9.007721 | -4.02 |
| 281 : | 57.177246 | 55.225739 | -1.951508 | -3.41 |
| 282 : | 89.404022 | 89.532318 | 0.128296 | 0.14 |
| 283 : | 22.595673 | 22.443237 | -0.152435 | -0.67 |

| | | | | | |
|---|---|---|---|---|---|
| 284 | : | 85000.000000 | 85000.000000 | 0.000000 | 0.00 |
| 285 | : | 22.900360 | 23.249603 | 0.349243 | 1.53 |
| 286 | : | 100.064026 | 97.522186 | -2.541840 | -2.54 |
| 287 | : | 232.590607 | 382.661621 | 150.071014 | 64.52 |
| 288 | : | 115.906189 | 117.559448 | 1.653259 | 1.43 |
| 289 | : | 136.557861 | 172.275635 | 35.717773 | 26.16 |
| 290 | : | 49.014557 | 48.634979 | -0.379578 | -0.77 |
| 291 | : | 0.000000 | 0.000000 | 0.000000 | |
| 292 | : | 26.439606 | 26.339050 | -0.100555 | -0.38 |
| 293 | : | 50.766113 | 30.391418 | -20.374695 | -40.13 |
| 294 | : | 98.607452 | 102.419006 | 3.811554 | 3.87 |
| 295 | : | -29.285614 | -7.330830 | 21.954784 | -74.97 |
| 296 | : | 436.204102 | 387.557129 | -48.646973 | -11.15 |
| 297 | : | 1302.503418 | 1425.779785 | 123.276367 | 9.46 |
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| 299 | : | 359.540039 | 353.966309 | -5.573730 | -1.55 |
| 300 | : | 1429.694824 | 1441.861816 | 12.166992 | 0.85 |
| 301 | : | 13.305758 | 14.411146 | 1.105389 | 8.31 |
| 302 | : | 54.147552 | 69.767334 | 15.619781 | 28.85 |
| 303 | : | 126.626099 | 126.671204 | 0.045105 | 0.04 |
| 304 | : | 330.485840 | 332.415527 | 1.929688 | 0.58 |
| 305 | : | 15.696051 | -9.086666 | -24.782717 | -157.89 |
| 306 | : | 645.154785 | 755.785645 | 110.630859 | 17.15 |
| 307 | : | 16.421692 | 18.499146 | 2.077454 | 12.65 |
| 308 | : | 12.676003 | 12.870478 | 0.194475 | 1.53 |
| 309 | : | 276.560059 | 267.552734 | -9.007324 | -3.26 |
| 310 | : | 3844.421875 | 3849.672363 | 5.250488 | 0.14 |
| 311 | : | 6998.023438 | 7013.085938 | 15.062500 | 0.22 |
| 312 | : | 5.715288 | 5.701145 | -0.014143 | -0.25 |
| 313 | : | -822.190430 | -820.067383 | 2.123047 | -0.26 |
| 314 | : | -840.696289 | -830.068848 | 10.627441 | -1.26 |
| 315 | : | 0.000000 | 0.000000 | 0.000000 | |
| 316 | : | 0.488801 | 0.488801 | 0.000000 | 0.00 |
| 317 | : | 5.342014 | 5.157238 | -0.184776 | -3.46 |
| 318 | : | 54.164490 | 53.446075 | -0.718414 | -1.33 |
| 319 | : | 17.381287 | 16.578461 | -0.802826 | -4.62 |
| 320 | : | 3.092218 | -8.996962 | -12.089180 | -390.95 |
| 321 | : | 7.261265 | 9.262882 | 2.001617 | 27.57 |
| 322 | : | 150.469818 | 149.748535 | -0.721283 | -0.48 |
| 323 | : | 112.326050 | 111.126038 | -1.200012 | -1.07 |
| 324 | : | -37.959106 | -37.727905 | 0.231201 | -0.61 |
| 325 | : | -44.444550 | -44.207581 | 0.236969 | -0.53 |
| 326 | : | -909.123535 | -908.835938 | 0.287598 | -0.03 |
| 327 | : | -48.000000 | -47.794037 | 0.205963 | -0.43 |
| 328 | : | -846.071289 | -834.468750 | 11.602539 | -1.37 |
| 329 | : | 0.000000 | 0.000000 | 0.000000 | |
| 330 | : | 1448.466797 | 1405.748535 | -42.718262 | -2.95 |
| 331 | : | 234954.000000 | 233472.625000 | -1481.375000 | -0.63 |
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| 334 | : | 356.607422 | 357.732910 | 1.125488 | 0.32 |
| 335 | : | 381.881836 | 371.177246 | -10.704590 | -2.80 |
| 336 | : | 24.035126 | 24.049927 | 0.014801 | 0.06 |
| 337 | : | 11.282290 | 11.287514 | 0.005224 | 0.05 |
| 338 | : | 2.179998 | 2.179998 | 0.000000 | 0.00 |
| 339 | : | 0.280000 | 0.280000 | 0.000000 | 0.00 |
| 340 | : | 0.708144 | 0.709683 | 0.001539 | 0.22 |
| 341 | : | 0.753538 | 0.757118 | 0.003580 | 0.48 |
| 342 | : | 0.526800 | 0.532320 | 0.005521 | 1.05 |
| 343 | : | 0.819946 | 0.811429 | -0.008517 | -1.04 |
| 344 | : | 0.689397 | 0.689415 | 0.000019 | 0.00 |
| 345 | : | 0.663454 | 0.656520 | -0.006933 | -1.05 |
| 346 | : | 0.254709 | 0.254729 | 0.000020 | 0.01 |
| 347 | : | 136.755310 | -5.811361 | -142.566671 | -104.25 |
| 348 | : | 7364.046875 | 6951.328125 | -412.718750 | -5.60 |
| 349 | : | 5565.273438 | 5801.593750 | 236.320312 | 4.25 |
| 350 | : | 1.034258 | 1.036100 | 0.001842 | 0.18 |
| 351 | : | 37.837921 | 35.632721 | -2.205200 | -5.83 |
| 352 | : | 0.838997 | 0.852369 | 0.013372 | 1.59 |
| 353 | : | 0.645903 | 0.643710 | -0.002193 | -0.34 |
| 354 | : | 0.743599 | 0.725165 | -0.018434 | -2.48 |
| 355 | : | 363.520996 | 363.593750 | 0.072754 | 0.02 |
| 356 | : | 363.636719 | 363.709473 | 0.072754 | 0.02 |
| 357 | : | 451.089355 | 451.037109 | -0.052246 | -0.01 |
| 358 | : | 484108.500000 | 484204.125000 | 95.625000 | 0.02 |
| 359 | : | 15866.257812 | 15499.335938 | -366.921875 | -2.31 |
| 360 | : | 34826.398438 | 34778.031250 | -48.367188 | -0.14 |
| 361 | : | 488801.500000 | 488801.500000 | 0.000000 | 0.00 |
| 362 | : | 390076.625000 | 390172.125000 | 95.500000 | 0.02 |
| 363 | : | 0.000000 | 0.000000 | 0.000000 | |
| 364 | : | 5222.015625 | 5224.867188 | 2.851562 | 0.05 |
| 365 | : | 28395.640625 | 28431.828125 | 36.187500 | 0.13 |
| 366 | : | 390254.125000 | 390454.875000 | 200.750000 | 0.05 |
| 367 | : | 17.659180 | 17.555420 | -0.103760 | -0.59 |
| 368 | : | 484108.500000 | 484204.125000 | 95.625000 | 0.02 |
| 369 | : | 199.025238 | 195.438293 | -3.586945 | -1.80 |
| 370 | : | 0.000000 | 0.000000 | 0.000000 | |
| 371 | : | 1582.302734 | 1582.088379 | -0.214355 | -0.01 |
| 372 | : | 206.733154 | 203.145294 | -3.587860 | -1.74 |
| 373 | : | 1584.300293 | 1584.086426 | -0.213867 | -0.01 |
| 374 | : | 206.557373 | 203.082489 | -3.474884 | -1.68 |
| 375 | : | 1888.576660 | 1897.614746 | 9.038086 | 0.48 |
| 376 | : | -1.329216 | -1.329277 | -0.000061 | 0.00 |
| 377 | : | -1.056177 | -1.056089 | 0.000088 | -0.01 |
| 378 | : | 8780.390625 | 8306.250000 | -474.140625 | -5.40 |
| 379 | : | 177046.750000 | 176766.250000 | -280.500000 | -0.16 |
| 380 | : | -810.960449 | -808.801758 | 2.158691 | -0.27 |
| 381 | : | -785.354492 | -790.323730 | -4.969238 | 0.63 |

| | | | | | |
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| 382 | : | 846.370605 | 846.716797 | 0.346191 | 0.04 |
| 383 | : | 871.657227 | 872.535645 | 0.878418 | 0.10 |
| 384 | : | 681.120117 | 680.488281 | -0.631836 | -0.09 |
| 385 | : | 8013.757812 | 8025.851562 | 12.093750 | 0.15 |
| 386 | : | 6419.710938 | 6446.195312 | 26.484375 | 0.41 |
| 387 | : | 3459.628418 | 3272.562500 | -187.065918 | -5.41 |
| 388 | : | 65750.250000 | 65477.937500 | -272.312500 | -0.41 |
| 389 | : | 3459.629395 | 3272.563965 | -187.065430 | -5.41 |
| 390 | : | 65750.250000 | 65477.937500 | -272.312500 | -0.41 |
| 391 | : | 1656.234375 | 1655.021973 | -1.212402 | -0.07 |
| 392 | : | 24214.796875 | 24512.671875 | 297.875000 | 1.23 |
| 393 | : | 1531.616699 | 1545.909668 | 14.292969 | 0.93 |
| 394 | : | 1656.234375 | 1655.021973 | -1.212402 | -0.07 |
| 395 | : | 25746.414062 | 26058.578125 | 312.164062 | 1.21 |
| 396 | : | 141.935944 | 138.685883 | -3.250061 | -2.29 |
| 397 | : | -822.038574 | -811.555664 | 10.482910 | -1.28 |
| 398 | : | 0.000000 | 0.000000 | 0.000000 | |
| 399 | : | 822.769531 | 823.019043 | 0.249512 | 0.03 |
| 400 | : | -106.967682 | -107.662598 | -0.694916 | 0.65 |
| 401 | : | -86.957184 | -88.561920 | -1.604736 | 1.85 |
| 402 | : | 1658.905762 | 1612.898438 | -46.007324 | -2.77 |
| 403 | : | -535.488281 | -533.989258 | 1.499023 | -0.28 |
| 404 | : | -583.459473 | -578.058105 | 5.401367 | -0.93 |
| 405 | : | -91.035767 | -92.623718 | -1.587952 | 1.74 |
| 406 | : | 214.939392 | 211.431244 | -3.508148 | -1.63 |
| 407 | : | 1493.018066 | 1455.863281 | -37.154785 | -2.49 |
| 408 | : | 1571.516113 | 1529.305176 | -42.210938 | -2.69 |
| 409 | : | -841.849121 | -838.150391 | 3.698730 | -0.44 |
| 410 | : | -95.685577 | -96.989746 | -1.304169 | 1.36 |
| 411 | : | 131.542969 | 129.597870 | -1.945099 | -1.48 |
| 412 | : | -28.012848 | -27.895447 | 0.117401 | -0.42 |
| 413 | : | -37.676910 | -37.445801 | 0.231110 | -0.61 |
| 414 | : | 3358.910645 | 3371.488770 | 12.578125 | 0.37 |
| 415 | : | 3383.432617 | 3401.971680 | 18.539062 | 0.55 |
| 416 | : | 4258.562500 | 4263.554688 | 4.992188 | 0.12 |
| 417 | : | 5673.867188 | 5672.687500 | -1.179688 | -0.02 |
| 418 | : | 3442.862305 | 3442.001953 | -0.860352 | -0.02 |
| 419 | : | 3410.314941 | 3411.146973 | 0.832031 | 0.02 |
| 420 | : | 5114.882812 | 5134.750000 | 19.867188 | 0.39 |
| 421 | : | -54.758698 | -54.716400 | 0.042297 | -0.08 |
| 422 | : | -56.028168 | -55.984680 | 0.043488 | -0.08 |
| 423 | : | -53.197266 | -53.153717 | 0.043549 | -0.08 |
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| 425 | : | -936.622559 | -931.647949 | 4.974609 | -0.53 |
| 426 | : | 3360.766113 | 3352.695312 | -8.070801 | -0.24 |
| 427 | : | 0.229586 | 0.234845 | 0.005258 | 2.29 |
| 428 | : | 0.185572 | 0.185726 | 0.000154 | 0.08 |
| 429 | : | 0.213036 | 0.213020 | -0.000015 | -0.01 |
| 430 | : | 0.136324 | 0.136216 | -0.000108 | -0.08 |
| 431 | : | 0.085357 | 0.087292 | 0.001935 | 2.27 |
| 432 | : | 3136.913574 | 3137.850586 | 0.937012 | 0.03 |
| 433 | : | 3383.800781 | 3396.517578 | 12.716797 | 0.38 |
| 434 | : | 4200.765625 | 4190.304688 | -10.460938 | -0.25 |
| 435 | : | 3310.000000 | 3322.303711 | 12.303711 | 0.37 |
| 436 | : | 3416.078125 | 3416.651367 | 0.573242 | 0.02 |
| 437 | : | 3396.738770 | 3416.382812 | 19.644043 | 0.58 |
| 438 | : | 5838.195312 | 5840.593750 | 2.398438 | 0.04 |
| 439 | : | 4921.500000 | 4865.007812 | -56.492188 | -1.15 |
| 440 | : | 3153.584473 | 3154.542480 | 0.958008 | 0.03 |
| 441 | : | 3555.613281 | 3434.521484 | -121.091797 | -3.41 |
| 442 | : | 3404.465820 | 3405.560059 | 1.094238 | 0.03 |
| 443 | : | 5165.000000 | 5173.625000 | 8.625000 | 0.17 |
| 444 | : | 1.358866 | 1.345037 | -0.013828 | -1.02 |
| 445 | : | 1.472212 | 1.472334 | 0.000122 | 0.01 |
| 446 | : | 3548.352051 | 3425.258789 | -123.093262 | -3.47 |
| 447 | : | 5659.937500 | 5646.625000 | -13.312500 | -0.24 |
| 448 | : | 5705.492188 | 5705.609375 | 0.117188 | 0.00 |
| 449 | : | 41623.546875 | 41633.492188 | 9.945312 | 0.02 |
| 450 | : | 0.001470 | 0.001470 | 0.000000 | 0.00 |
| 451 | : | 1.502628 | 1.495081 | -0.007547 | -0.50 |
| 452 | : | 3084.205566 | 3085.142090 | 0.936523 | 0.03 |
| 453 | : | 0.409330 | 0.405777 | -0.003553 | -0.87 |
| 454 | : | 1.713087 | 1.715132 | 0.002045 | 0.12 |
| 455 | : | 0.307038 | 0.306419 | -0.000620 | -0.20 |
| 456 | : | 0.357950 | 0.357579 | -0.000372 | -0.10 |
| 457 | : | 0.538200 | 0.539045 | 0.000846 | 0.16 |
| 458 | : | 6186.007812 | 6175.179688 | -10.828125 | -0.18 |
| 459 | : | 0.000000 | 0.000000 | 0.000000 | |
| 460 | : | 256.779297 | 242.852478 | -13.926819 | -5.42 |
| 461 | : | 4679.367188 | 4631.289062 | -48.078125 | -1.03 |
| 462 | : | 5097.734375 | 5117.523438 | 19.789062 | 0.39 |
| 463 | : | 4240.890625 | 4246.195312 | 5.304688 | 0.13 |
| 464 | : | 396.470215 | 396.530273 | 0.060059 | 0.02 |
| 465 | : | 4169.156250 | 4174.015625 | 4.859375 | 0.12 |
| 466 | : | 5137.273438 | 5143.570312 | 6.296875 | 0.12 |
| 467 | : | 23.598419 | 23.701996 | 0.103577 | 0.44 |
| 468 | : | 229.530762 | 215.567596 | -13.963165 | -6.08 |
| 469 | : | 4276.343750 | 4281.351562 | 5.007812 | 0.12 |
| 470 | : | 1383.277344 | 1386.649902 | 3.372559 | 0.24 |
| 471 | : | -55.152985 | -55.110321 | 0.042664 | -0.08 |
| 472 | : | -42.900238 | -42.841156 | 0.059082 | -0.14 |
| 473 | : | -29.595795 | -29.330048 | 0.265747 | -0.90 |
| 474 | : | 5949.226562 | 5938.125000 | -11.101562 | -0.19 |
| 475 | : | 3978.882324 | 3982.648926 | 3.766602 | 0.09 |
| 476 | : | 7372.367188 | 7385.437500 | 13.070312 | 0.18 |
| 477 | : | 5594.445312 | 5596.476562 | 2.031250 | 0.04 |
| 478 | : | 6202.445312 | 6205.820312 | 3.375000 | 0.05 |
| 479 | : | 6903.703125 | 6986.960938 | 83.257812 | 1.21 |

| | | | | |
|---|---|---|---|---|
| 480 : | 6904.117188 | 6930.578125 | 26.460938 | 0.38 |
| 481 : | 5591.109375 | 5593.156250 | 2.046875 | 0.04 |
| 482 : | 6308.570312 | 6311.398438 | 2.828125 | 0.04 |
| 483 : | 4182.734375 | 4188.382812 | 5.648438 | 0.14 |
| 484 : | 4254.914062 | 4260.070312 | 5.156250 | 0.12 |
| 485 : | 292.839355 | 278.973633 | -13.865723 | -4.73 |
| 486 : | 6280.929688 | 6270.226562 | -10.703125 | -0.17 |
| 487 : | 432.872070 | 432.952637 | 0.080566 | 0.02 |
| 488 : | 4345.632812 | 4350.750000 | 5.117188 | 0.12 |
| 489 : | 7394.492188 | 7409.617188 | 15.125000 | 0.20 |
| 490 : | 265.698242 | 251.788696 | -13.909546 | -5.24 |
| 491 : | 6044.148438 | 6033.164062 | -10.984375 | -0.18 |
| 492 : | 3546.263184 | 3424.866699 | -121.396484 | -3.42 |
| 493 : | 4228.500000 | 4233.726562 | 5.226562 | 0.12 |
| 494 : | 6438.210938 | 6592.070312 | 153.859375 | 2.39 |
| 495 : | 6417.531250 | 6455.671875 | 38.140625 | 0.59 |
| 496 : | 0.000000 | 0.000000 | 0.000000 | |
| 497 : | 4071.387207 | 4076.073730 | 4.686523 | 0.12 |
| 498 : | 5805.945312 | 5792.664062 | -13.281250 | -0.23 |
| 499 : | 0.000000 | 0.000000 | 0.000000 | |
| 500 : | 0.000000 | 0.000000 | 0.000000 | |
| 501 : | 3448.577637 | 3447.702637 | -0.875000 | -0.03 |
| 502 : | 3462.638184 | 3475.792480 | 13.154297 | 0.38 |
| 503 : | 356.441406 | 356.473633 | 0.032227 | 0.01 |
| 504 : | 3418.857910 | 3440.333008 | 21.475098 | 0.63 |
| 505 : | 5725.976562 | 5712.328125 | -13.648438 | -0.24 |
| 506 : | 4099.335938 | 4104.078125 | 4.742188 | 0.12 |
| 507 : | 7361.257812 | 7374.835938 | 13.578125 | 0.18 |
| 508 : | 3852.255371 | 3855.974609 | 3.719238 | 0.10 |
| 509 : | 4001.099609 | 4001.099609 | 0.000000 | 0.00 |
| 510 : | 12008.195312 | 707.099609 | -11301.095703 | -94.11 |
| 511 : | 90503.000000 | 90503.000000 | 0.000000 | 0.00 |
| 512 : | 2417.099609 | 2417.099609 | 0.000000 | 0.00 |
| 513 : | 4864.320312 | 4809.781250 | -54.539062 | -1.12 |
| 514 : | 1.554476 | 1.573479 | 0.019003 | 1.22 |
| 515 : | 6139.648438 | 6126.773438 | -12.875000 | -0.21 |
| 516 : | 4.683475 | 4.708469 | 0.024994 | 0.53 |
| 517 : | 4.695236 | 4.717484 | 0.022247 | 0.47 |
| 518 : | 7363.101562 | 7377.492188 | 14.390625 | 0.20 |
| 519 : | 6016.984375 | 6006.804688 | -10.179688 | -0.17 |
| 520 : | 6435.039062 | 6588.484375 | 153.445312 | 2.38 |
| 521 : | 6023.742188 | 6009.210938 | -14.531250 | -0.24 |
| 522 : | 6445.125000 | 6483.671875 | 38.546875 | 0.60 |
| 523 : | 5676.960938 | 5663.695312 | -13.265625 | -0.23 |
| 524 : | 3526.417969 | 3514.186035 | -12.231934 | -0.35 |
| 525 : | 5603.835938 | 5621.625000 | 17.789062 | 0.32 |
| 526 : | 7386.007812 | 7400.734375 | 14.726562 | 0.20 |
| 527 : | 1.139999 | 1.139999 | 0.000000 | 0.00 |
| 528 : | 5587.453125 | 5613.171875 | 25.718750 | 0.46 |
| 529 : | 6467.500000 | 6599.406250 | 131.906250 | 2.04 |
| 530 : | 2.506416 | 2.512877 | 0.006460 | 0.26 |
| 531 : | 2.522751 | 2.525522 | 0.002771 | 0.11 |
| 532 : | 6544.578125 | 6576.617188 | 32.039062 | 0.49 |
| 533 : | 68.597870 | 68.594818 | -0.003052 | 0.00 |
| 534 : | 68.654388 | 68.698822 | 0.044434 | 0.06 |
| 535 : | 4136.976562 | 4143.046875 | 6.070312 | 0.15 |
| 536 : | 3735.716797 | 3735.937500 | 0.220703 | 0.01 |
| 537 : | 6117.054688 | 6104.328125 | -12.726562 | -0.21 |
| 538 : | 0.000000 | 0.000000 | 0.000000 | |
| 539 : | 5630.273438 | 5647.960938 | 17.687500 | 0.31 |
| 540 : | 5686.062500 | 5715.593750 | 29.531250 | 0.52 |
| 541 : | 5658.171875 | 5681.773438 | 23.601562 | 0.42 |
| 542 : | 15753.796875 | 15741.945312 | -11.851562 | -0.08 |
| 543 : | 16137.304688 | 16128.265625 | -9.039062 | -0.06 |
| 544 : | 5854.031250 | 5856.804688 | 2.773438 | 0.05 |
| 545 : | 7075.421875 | 7078.796875 | 3.375000 | 0.05 |
| 546 : | 69.766113 | 69.778046 | 0.011932 | 0.02 |
| 547 : | 69.788757 | 69.951843 | 0.163086 | 0.23 |
| 548 : | 70.401031 | 70.472748 | 0.071716 | 0.10 |
| 549 : | 6.008545 | 6.014065 | 0.005520 | 0.09 |
| 550 : | 0.000000 | 0.000000 | 0.000000 | |
| 551 : | 0.763860 | 0.782395 | 0.018535 | 2.43 |
| 552 : | 0.896606 | 0.904724 | 0.008117 | 0.91 |
| 553 : | 0.798541 | 0.816353 | 0.017812 | 2.23 |
| 554 : | 0.000000 | 0.000000 | 0.000000 | |
| 555 : | 654.646484 | 670.342773 | 15.696289 | 2.40 |
| 556 : | 6.009394 | 5.996889 | -0.012505 | -0.21 |
| 557 : | 6.008003 | 5.996758 | -0.011246 | -0.19 |
| 558 : | 0.943377 | 0.951450 | 0.008074 | 0.86 |
| 559 : | 0.673226 | 0.699126 | 0.025900 | 3.85 |
| 560 : | 0.658929 | 0.684588 | 0.025659 | 3.89 |
| 561 : | 4.372171 | 4.384647 | 0.012476 | 0.29 |
| 562 : | 70.689941 | 70.672211 | -0.017731 | -0.03 |
| 563 : | 4.372171 | 4.384647 | 0.012476 | 0.29 |
| 564 : | 4.281281 | 4.292648 | 0.011368 | 0.27 |
| 565 : | 69.943634 | 69.925110 | -0.018524 | -0.03 |
| 566 : | 4.305275 | 4.316406 | 0.011131 | 0.26 |
| 567 : | 4.873102 | 4.889681 | 0.016579 | 0.34 |
| 568 : | 4.873102 | 4.889681 | 0.016579 | 0.34 |
| 569 : | 69.949493 | 69.871460 | -0.078033 | -0.11 |
| 570 : | 70.389709 | 70.385864 | -0.003845 | -0.01 |
| 571 : | 0.642401 | 0.642843 | 0.000443 | 0.07 |
| 572 : | 0.524147 | 0.537056 | 0.012909 | 2.46 |
| 573 : | 0.636804 | 0.675765 | 0.038961 | 6.12 |
| 574 : | 1.824329 | 1.824579 | 0.000250 | 0.01 |
| 575 : | 2.700668 | 2.701349 | 0.000681 | 0.03 |
| 576 : | 71.013275 | 70.993683 | -0.019592 | -0.03 |
| 577 : | 4.836267 | 4.852570 | 0.016302 | 0.34 |

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|---|---|---|---|---|
| 578 : | 97.309540 | 91.888000 | -5.421539 | -5.57 |
| 579 : | 12.124474 | 12.073769 | -0.050705 | -0.42 |
| 580 : | 0.000000 | 0.000000 | 0.000000 | |
| 581 : | 681.960449 | 664.615234 | -17.345215 | -2.54 |
| 582 : | 4.801439 | 4.817924 | 0.016485 | 0.34 |
| 583 : | 97.254059 | 96.060883 | -1.193176 | -1.23 |
| 584 : | 0.000000 | 0.000000 | 0.000000 | |
| 585 : | 277.473145 | 277.477539 | 0.004395 | 0.00 |
| 586 : | 98.215729 | 97.020081 | -1.195648 | -1.22 |
| 587 : | 492.625000 | 480.726562 | -11.898438 | -2.42 |
| 588 : | 492.624512 | 480.726562 | -11.897949 | -2.42 |
| 589 : | 0.000000 | 0.000000 | 0.000000 | |
| 590 : | 1708.430176 | 1721.697754 | 13.267578 | 0.78 |
| 591 : | 1577.485840 | 1602.368652 | 24.882812 | 1.58 |
| 592 : | 1334.388672 | 1379.204102 | 44.815430 | 3.36 |
| 593 : | 0.000000 | 0.000000 | 0.000000 | |
| 594 : | 454.350098 | 454.282715 | -0.067383 | -0.01 |
| 595 : | 846.847656 | 846.457520 | -0.390137 | -0.05 |
| 596 : | 171.714905 | 171.821136 | 0.106232 | 0.06 |
| 597 : | 1732.790527 | 1744.819336 | 12.028809 | 0.69 |
| 598 : | 184.205322 | 184.700958 | 0.495636 | 0.27 |
| 599 : | 1313.631348 | 1354.135742 | 40.504395 | 3.08 |
| 600 : | 0.000000 | 0.000000 | 0.000000 | |
| 601 : | 363.355469 | 363.330566 | -0.024902 | -0.01 |
| 602 : | 363.471191 | 363.446289 | -0.024902 | -0.01 |
| 603 : | 492.625000 | 480.726562 | -11.898438 | -2.42 |
| 604 : | 1145.219238 | 1108.941895 | -36.277344 | -3.17 |
| 605 : | 9915.687500 | 9888.343750 | -27.343750 | -0.28 |
| 606 : | 1665.778809 | 1663.651367 | -2.127441 | -0.13 |
| 607 : | 4762.101562 | 4813.703125 | 51.601562 | 1.08 |
| 608 : | 1918.015625 | 1931.161621 | 13.145996 | 0.69 |
| 609 : | 1465.938477 | 1510.327148 | 44.388672 | 3.03 |
| 610 : | 734.142578 | 725.390137 | -8.752441 | -1.19 |
| 611 : | 547.169922 | 550.911621 | 3.741699 | 0.68 |
| 612 : | 0.000000 | 0.000000 | 0.000000 | |
| 613 : | 277.473145 | 277.477539 | 0.004395 | 0.00 |
| 614 : | 0.000000 | 0.000000 | 0.000000 | |
| 615 : | 43.089569 | 42.614777 | -0.474792 | -1.10 |
| 616 : | 479.625000 | 467.726562 | -11.898438 | -2.48 |
| 617 : | 0.475666 | 0.477139 | 0.001473 | 0.31 |
| 618 : | 0.578000 | 0.578000 | 0.000000 | 0.00 |
| 619 : | 0.156009 | 0.155901 | -0.000108 | -0.07 |
| 620 : | 0.000000 | 0.000000 | 0.000000 | |
| 621 : | 41.626526 | 41.138184 | -0.488342 | -1.17 |
| 622 : | 166.781250 | 166.885895 | 0.104645 | 0.06 |
| 623 : | 181.745239 | 181.876404 | 0.131165 | 0.07 |
| 624 : | 203.345856 | 203.989136 | 0.643280 | 0.32 |
| 625 : | 0.000000 | 0.000000 | 0.000000 | |
| 626 : | 97.254059 | 96.060883 | -1.193176 | -1.23 |
| 627 : | 462.243652 | 451.148438 | -11.095215 | -2.40 |
| 628 : | 1767.545898 | 1781.413086 | 13.867188 | 0.78 |
| 629 : | 1729.335938 | 1742.803711 | 13.467773 | 0.78 |
| 630 : | 39.232086 | 38.839783 | -0.392303 | -1.00 |
| 631 : | 67.356079 | 66.629120 | -0.726959 | -1.08 |
| 632 : | 1259.465332 | 1300.248047 | 40.782715 | 3.24 |
| 633 : | 167.752167 | 167.855713 | 0.103546 | 0.06 |
| 634 : | 195.293732 | 195.871735 | 0.578003 | 0.30 |
| 635 : | 207.586731 | 207.833557 | 0.246826 | 0.12 |
| 636 : | 192.206604 | 192.328003 | 0.121399 | 0.06 |
| 637 : | 1353.612305 | 1399.201172 | 45.588867 | 3.37 |
| 638 : | 1342.388672 | 1387.204102 | 44.815430 | 3.34 |
| 639 : | 97.742859 | 96.549683 | -1.193176 | -1.22 |
| 640 : | 0.177740 | 0.178457 | 0.000717 | 0.40 |
| 641 : | 0.357969 | 0.356894 | -0.001075 | -0.30 |
| 642 : | 0.475998 | 0.475688 | -0.000310 | -0.07 |
| 643 : | 0.297264 | 0.297463 | 0.000199 | 0.07 |
| 644 : | 830.754395 | 811.542480 | -19.211914 | -2.31 |
| 645 : | 1823.504395 | 1820.972168 | -2.532227 | -0.14 |
| 646 : | 0.132820 | 0.104495 | -0.028325 | -21.33 |
| 647 : | 0.670025 | 0.698373 | 0.028348 | 4.23 |
| 648 : | 0.041146 | 0.041231 | 0.000085 | 0.21 |
| 649 : | 211.297852 | 211.459167 | 0.161316 | 0.08 |
| 650 : | 211.234375 | 210.968689 | -0.265686 | -0.13 |
| 651 : | 512.298340 | 500.451172 | -11.847168 | -2.31 |
| 652 : | 1548.458984 | 1546.308594 | -2.150391 | -0.14 |
| 653 : | 267.157715 | 267.303711 | 0.145996 | 0.05 |
| 654 : | 848.709961 | 849.791504 | 1.081543 | 0.13 |
| 655 : | 619.496094 | 620.285645 | 0.789551 | 0.13 |
| 656 : | 136.711914 | 136.786591 | 0.074677 | 0.05 |
| 657 : | 1250.143555 | 1251.736328 | 1.592773 | 0.13 |
| 658 : | 450.945801 | 450.893555 | -0.052246 | -0.01 |
| 659 : | 18.288666 | 18.834991 | 0.546326 | 2.99 |
| 660 : | 3.928347 | 3.921061 | -0.007286 | -0.19 |
| 661 : | 153.461548 | 153.783661 | 0.322113 | 0.21 |
| 662 : | 0.833337 | 0.833916 | 0.000579 | 0.07 |
| 663 : | 27.977386 | 27.666656 | -0.310730 | -1.11 |
| 664 : | 0.000000 | 0.000000 | 0.000000 | |
| 665 : | 149.985504 | 150.327637 | 0.342133 | 0.23 |
| 666 : | 1.123104 | 1.111996 | -0.011108 | -0.99 |
| 667 : | 1076.307129 | 1076.619141 | 0.312012 | 0.03 |
| 668 : | 1.919867 | 2.111099 | 0.191233 | 9.96 |
| 669 : | 0.134956 | 0.134993 | 0.000037 | 0.03 |
| 670 : | 72.821747 | 72.856537 | 0.034790 | 0.05 |
| 671 : | 180.628387 | 180.868530 | 0.240143 | 0.13 |
| 672 : | 65.853943 | 67.376312 | 1.522369 | 2.31 |
| 673 : | 0.000000 | 0.000000 | 0.000000 | |
| 674 : | 0.827072 | 0.810597 | -0.016475 | -1.99 |
| 675 : | 0.433507 | 0.435336 | 0.001829 | 0.42 |

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|---|---|---|---|---|
| 676 : | 15.776806 | 15.588564 | -0.188242 | -1.19 |
| 677 : | 78.045044 | 77.959869 | -0.085175 | -0.11 |
| 678 : | 0.000000 | 0.000000 | 0.000000 | |
| 679 : | 73.625885 | 74.174957 | 0.549072 | 0.75 |
| 680 : | 153.461548 | 153.783661 | 0.322113 | 0.21 |
| 681 : | 153.913849 | 154.248718 | 0.334869 | 0.22 |
| 682 : | 1663.406250 | 1617.179688 | -46.226562 | -2.78 |
| 683 : | 153.108459 | 153.430237 | 0.321777 | 0.21 |
| 684 : | 155.599304 | 156.055878 | 0.456573 | 0.29 |
| 685 : | 0.123504 | 0.121655 | -0.001849 | -1.50 |
| 686 : | 27.977386 | 27.666656 | -0.310730 | -1.11 |
| 687 : | 151.670959 | 152.134827 | 0.463867 | 0.31 |
| 688 : | 230.525421 | 232.698730 | 2.173309 | 0.94 |
| 689 : | 27.295502 | 26.969818 | -0.325684 | -1.19 |
| 690 : | 3.826061 | 3.841618 | 0.015556 | 0.41 |
| 691 : | 3.346209 | 3.397953 | 0.051744 | 1.55 |
| 692 : | 818.146484 | 815.833984 | -2.312500 | -0.28 |
| 693 : | 3.917152 | 3.933422 | 0.016270 | 0.42 |
| 694 : | 3.359634 | 3.410852 | 0.051218 | 1.52 |
| 695 : | 3.614697 | 3.650373 | 0.035677 | 0.99 |
| 696 : | 1.063646 | 1.139660 | 0.076014 | 7.15 |
| 697 : | 0.626629 | 0.739648 | 0.113019 | 18.04 |
| 698 : | 0.190139 | 0.190067 | -0.000072 | -0.04 |
| 699 : | 0.345198 | 0.346011 | 0.000813 | 0.24 |
| 700 : | 1.950249 | 2.139357 | 0.189108 | 9.70 |
| 701 : | 921.997559 | 922.203125 | 0.205566 | 0.02 |
| 702 : | 0.535337 | 0.536077 | 0.000741 | 0.14 |
| 703 : | 817.611328 | 815.297852 | -2.313477 | -0.28 |
| 704 : | 0.134956 | 0.134993 | 0.000037 | 0.03 |
| 705 : | 11.518705 | 11.381269 | -0.137436 | -1.19 |
| 706 : | 0.000000 | 0.000000 | 0.000000 | |
| 707 : | 42.190735 | 43.033905 | 0.843170 | 2.00 |
| 708 : | 42.190735 | 43.033905 | 0.843170 | 2.00 |
| 709 : | 28.403870 | 30.086121 | 1.682251 | 5.92 |
| 710 : | 4.083572 | 4.110640 | 0.027067 | 0.66 |
| 711 : | 922.257324 | 922.463379 | 0.206055 | 0.02 |
| 712 : | 1102.733887 | 1102.968262 | 0.234375 | 0.02 |
| 713 : | 1102.598633 | 1102.833496 | 0.234863 | 0.02 |
| 714 : | 1110.665527 | 1110.905273 | 0.239746 | 0.02 |
| 715 : | 110.092377 | 112.426971 | 2.334595 | 2.12 |
| 716 : | 0.000000 | 0.000000 | 0.000000 | |
| 717 : | 920.088867 | 920.104004 | 0.015137 | 0.00 |
| 718 : | 71.300720 | 73.824615 | 2.523895 | 3.54 |
| 719 : | 0.083146 | 0.085052 | 0.001906 | 2.29 |
| 720 : | 180.476318 | 180.505005 | 0.028687 | 0.02 |
| 721 : | 0.816395 | 0.805320 | -0.011075 | -1.36 |
| 722 : | 0.519884 | 0.544207 | 0.024323 | 4.68 |
| 723 : | 112.042633 | 114.566345 | 2.523712 | 2.25 |
| 724 : | 818.146484 | 815.833984 | -2.312500 | -0.28 |
| 725 : | 0.000000 | 0.000000 | 0.000000 | |
| 726 : | 4386.523438 | 4352.312500 | -34.210938 | -0.78 |
| 727 : | 6.130547 | 6.134830 | 0.004284 | 0.07 |
| 728 : | 1.936363 | 1.936960 | 0.000597 | 0.03 |
| 729 : | 69.285187 | 71.821167 | 2.535980 | 3.66 |
| 730 : | 0.452308 | 0.465040 | 0.012732 | 2.81 |
| 731 : | 102.025452 | 104.355194 | 2.329742 | 2.28 |
| 732 : | 4.258339 | 4.204613 | -0.053726 | -1.26 |
| 733 : | 3.625399 | 2.818214 | -0.807184 | -22.26 |
| 734 : | 0.373050 | 0.377779 | 0.004729 | 1.27 |
| 735 : | 0.617861 | 0.614347 | -0.003513 | -0.57 |
| 736 : | 0.912729 | 0.911265 | -0.001464 | -0.16 |
| 737 : | 1073.197754 | 1073.534180 | 0.336426 | 0.03 |
| 738 : | 119.531281 | 120.211151 | 0.679871 | 0.57 |
| 739 : | 62.674286 | 62.853668 | 0.179382 | 0.29 |
| 740 : | 56.856995 | 57.357483 | 0.500488 | 0.88 |
| 741 : | 1075.458984 | 1075.986816 | 0.527832 | 0.05 |
| 742 : | 1.368673 | 1.369993 | 0.001320 | 0.10 |
| 743 : | 0.206650 | 0.206707 | 0.000057 | 0.03 |
| 744 : | 930.189453 | 930.399902 | 0.210449 | 0.02 |
| 745 : | 27.884003 | 29.541901 | 1.657898 | 5.95 |
| 746 : | 73.192383 | 73.739624 | 0.547241 | 0.75 |
| 747 : | 0.000000 | 0.000000 | 0.000000 | |
| 748 : | 27.762146 | 29.480896 | 1.718750 | 6.19 |
| 749 : | 72.877106 | 73.432007 | 0.554901 | 0.76 |
| 750 : | -0.121855 | -0.060998 | 0.060857 | -49.94 |
| 751 : | 0.641739 | 0.605205 | -0.036534 | -5.69 |
| 752 : | -0.315278 | -0.307602 | 0.007676 | -2.43 |
| 753 : | 0.748785 | 0.742938 | -0.005847 | -0.78 |
| 754 : | 0.445283 | 0.443784 | -0.001500 | -0.34 |
| 755 : | 0.501109 | 0.484511 | -0.016598 | -3.31 |
| 756 : | 1.224766 | 1.227062 | 0.002296 | 0.19 |
| 757 : | 1.057533 | 1.057219 | -0.000315 | -0.03 |
| 758 : | 1.082760 | 1.079916 | -0.002844 | -0.26 |
| 759 : | 0.718942 | 0.719197 | 0.000255 | 0.04 |
| 760 : | 0.731064 | 0.731316 | 0.000253 | 0.03 |
| 761 : | 0.759342 | 0.760455 | 0.001113 | 0.15 |
| 762 : | 7.497343 | 7.478819 | -0.018524 | -0.25 |
| 763 : | 24.559753 | 24.694458 | 0.134705 | 0.55 |
| 764 : | 8.061710 | 8.006901 | -0.054810 | -0.68 |
| 765 : | 8.066910 | 8.071793 | 0.004883 | 0.06 |
| 766 : | 42.287079 | 43.139862 | 0.852783 | 2.02 |
| 767 : | 77.217987 | 77.149261 | -0.068726 | -0.09 |
| 768 : | 25.763000 | 27.443329 | 1.680328 | 6.52 |
| 769 : | 70.232605 | 70.778931 | 0.546326 | 0.78 |
| 770 : | 41.374329 | 42.228607 | 0.854279 | 2.06 |
| 771 : | 77.217987 | 77.149261 | -0.068726 | -0.09 |
| 772 : | 93.128479 | 92.970154 | -0.158325 | -0.17 |
| 773 : | 765.688965 | 765.738770 | 0.049805 | 0.01 |

| | | | | |
|---|---|---|---|---|
| 774 : | 11603.078125 | 11620.078125 | 17.000000 | 0.15 |
| 775 : | 0.998785 | 0.998579 | -0.000206 | -0.02 |
| 776 : | 193.631470 | 191.544281 | -2.087189 | -1.08 |
| 777 : | 4.065384 | 4.018787 | -0.046597 | -1.15 |
| 778 : | 407.959473 | 406.846191 | -1.113281 | -0.27 |
| 779 : | 0.000000 | 0.000000 | 0.000000 | |
| 780 : | 349.586914 | 347.508301 | -2.078613 | -0.59 |
| 781 : | 4.132656 | 4.298428 | 0.165771 | 4.01 |
| 782 : | 9.308701 | 9.223932 | -0.084768 | -0.91 |
| 783 : | 441.669922 | 432.037109 | -9.632812 | -2.18 |
| 784 : | -1.056177 | -1.056089 | 0.000088 | -0.01 |
| 785 : | -1.056177 | -1.056089 | 0.000088 | -0.01 |
| 786 : | 80.359070 | 80.729492 | 0.370422 | 0.46 |
| 787 : | 6.554482 | 7.454908 | 0.900427 | 13.74 |
| 788 : | 371.910156 | 371.835938 | -0.074219 | -0.02 |
| 789 : | 218.941498 | 207.219727 | -11.721771 | -5.35 |
| 790 : | 44.541626 | 44.508118 | -0.033508 | -0.08 |
| 791 : | 243.789093 | 243.652557 | -0.136536 | -0.06 |
| 792 : | 670.997070 | 670.247559 | -0.749512 | -0.11 |
| 793 : | 10.000000 | 10.000000 | 0.000000 | 0.00 |
| 794 : | 0.000000 | 0.000000 | 0.000000 | |
| 795 : | 0.997315 | 0.995551 | -0.001763 | -0.18 |
| 796 : | 1.003361 | 1.004101 | 0.000740 | 0.07 |
| 797 : | 0.995481 | 0.996269 | 0.000787 | 0.08 |
| 798 : | 0.674211 | 0.680128 | 0.005917 | 0.88 |
| 799 : | 0.790184 | 0.790598 | 0.000414 | 0.05 |
| 800 : | -583.140625 | -577.716309 | 5.424316 | -0.93 |
| 801 : | 195.293732 | 195.871735 | 0.578003 | 0.30 |
| 802 : | 0.111000 | 0.111000 | 0.000000 | 0.00 |
| 803 : | 0.012140 | 0.012140 | 0.000000 | 0.00 |
| 804 : | 0.012140 | 0.012140 | 0.000000 | 0.00 |
| 805 : | 2.000000 | 2.000000 | 0.000000 | 0.00 |
| 806 : | 2.000000 | 2.000000 | 0.000000 | 0.00 |
| 807 : | 56.856995 | 57.357483 | 0.500488 | 0.88 |
| 808 : | 119.531281 | 120.211151 | 0.679871 | 0.57 |
| 809 : | 0.036645 | 0.036531 | -0.000114 | -0.31 |
| 810 : | 1.856365 | 1.857166 | 0.000801 | 0.04 |
| 811 : | 154.374847 | 154.833710 | 0.458862 | 0.30 |
| 812 : | 1713.430176 | 1726.697754 | 13.267578 | 0.77 |
| 813 : | 70.594635 | 73.120056 | 2.525421 | 3.58 |
| 814 : | 1746.141602 | 1733.294434 | -12.847168 | -0.74 |
| 815 : | 875.000000 | 875.000000 | 0.000000 | 0.00 |
| 816 : | 1.309431 | 1.298895 | -0.010536 | -0.80 |
| 817 : | 0.657000 | 0.657000 | 0.000000 | 0.00 |
| 818 : | 0.910189 | 0.918422 | 0.008234 | 0.90 |
| 819 : | 2818.295410 | 2794.435059 | -23.860352 | -0.85 |
| 820 : | 2897.132812 | 2873.709961 | -23.422852 | -0.81 |
| 821 : | 1630.719727 | 1630.719727 | 0.000000 | 0.00 |
| 822 : | 7952.054688 | 7952.054688 | 0.000000 | 0.00 |
| 823 : | 2.703897 | 2.698883 | -0.005014 | -0.19 |
| 824 : | 1.224447 | 1.222176 | -0.002272 | -0.19 |
| 825 : | 0.000000 | 0.000000 | 0.000000 | |
| 826 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 827 : | -819.878906 | -817.603027 | 2.275879 | -0.28 |
| 828 : | 3.853502 | 3.869274 | 0.015772 | 0.41 |
| 829 : | 523.574707 | 527.900879 | 4.326172 | 0.83 |
| 830 : | 0.000000 | 0.000000 | 0.000000 | |
| 831 : | 275.510742 | 275.036133 | -0.474609 | -0.17 |
| 832 : | 6.157999 | 6.157999 | 0.000000 | 0.00 |
| 833 : | 69.395416 | 69.318451 | -0.076965 | -0.11 |
| 834 : | 3576.249512 | 3584.871094 | 8.621582 | 0.24 |
| 835 : | 0.000000 | 0.000000 | 0.000000 | |
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| 840 : | 0.000000 | 0.000000 | 0.000000 | |
| 841 : | 1200.000000 | 1200.000000 | 0.000000 | 0.00 |
| 842 : | 0.000000 | 0.000000 | 0.000000 | |
| 843 : | 365.000000 | 365.000000 | 0.000000 | 0.00 |
| 844 : | 385.000000 | 385.000000 | 0.000000 | 0.00 |
| 845 : | 330.000000 | 330.000000 | 0.000000 | 0.00 |
| 846 : | 0.350000 | 0.350000 | 0.000000 | 0.00 |
| 847 : | 630.000000 | 630.000000 | 0.000000 | 0.00 |
| 848 : | 0.000000 | 0.000000 | 0.000000 | |
| 849 : | 922.736328 | 923.124512 | 0.388184 | 0.04 |
| 850 : | 153.570709 | 153.494293 | -0.076416 | -0.05 |
| 851 : | 0.000000 | 0.000000 | 0.000000 | |
| 852 : | 0.000000 | 0.000000 | 0.000000 | |
| 853 : | 0.000000 | 0.000000 | 0.000000 | |
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| 863 : | 0.000000 | 0.000000 | 0.000000 | |
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| 868 : | 2034.550293 | 1895.018066 | -139.532227 | -6.86 |
| 869 : | 1.146242 | 1.142563 | -0.003679 | -0.32 |
| 870 : | 27.977386 | 27.666656 | -0.310730 | -1.11 |
| 871 : | 1.371799 | 1.369883 | -0.001917 | -0.14 |

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| 872 : | 5551.804688 | 5527.062500 | -24.742188 | -0.45 |
| 873 : | 1.510134 | 1.502941 | -0.007193 | -0.48 |
| 874 : | 0.857139 | 0.854705 | -0.002434 | -0.28 |
| 875 : | 26.159821 | 26.461853 | 0.302032 | 1.15 |
| 876 : | 1.350374 | 1.349695 | -0.000679 | -0.05 |
| 877 : | 6525.734375 | 6509.585938 | -16.148438 | -0.25 |
| 878 : | 1.484552 | 1.484858 | 0.000305 | 0.02 |
| 879 : | 2.381550 | 2.382854 | 0.001305 | 0.05 |
| 880 : | 28.481201 | 28.543182 | 0.061981 | 0.22 |
| 881 : | 0.794742 | 0.827302 | 0.032560 | 4.10 |
| 882 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 883 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 884 : | 0.992441 | 0.992410 | -0.000031 | 0.00 |
| 885 : | 1.060556 | 1.064121 | 0.003565 | 0.34 |
| 886 : | 1.030588 | 0.817559 | -0.213029 | -20.67 |
| 887 : | 1.090010 | 1.049099 | -0.040911 | -3.75 |
| 888 : | 0.994714 | 0.994709 | -0.000005 | 0.00 |
| 889 : | 0.991223 | 0.991211 | -0.000012 | 0.00 |
| 890 : | 3006.000000 | 3006.000000 | 0.000000 | 0.00 |
| 891 : | 0.000000 | 0.000000 | 0.000000 | |
| 892 : | 283.290527 | 285.570312 | 2.279785 | 0.80 |
| 893 : | 18.008453 | 18.113037 | 0.104584 | 0.58 |
| 894 : | 163.696625 | 164.492493 | 0.795868 | 0.49 |
| 895 : | 8730.429688 | 8705.546875 | -24.882812 | -0.29 |
| 896 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 897 : | 17.980042 | 17.184479 | -0.795563 | -4.42 |
| 898 : | 215.875580 | 244.833008 | 28.957428 | 13.41 |
| 899 : | 35360.187500 | 31418.812500 | -3941.375000 | -11.15 |
| 900 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 901 : | 3125.905273 | 3126.816895 | 0.911621 | 0.03 |
| 902 : | 5949.226562 | 5938.125000 | -11.101562 | -0.19 |
| 903 : | 4071.387207 | 4076.073730 | 4.686523 | 0.12 |
| 904 : | 153.461548 | 153.783661 | 0.322113 | 0.21 |
| 905 : | 921.997559 | 922.203125 | 0.205566 | 0.02 |
| 906 : | 237.616943 | 223.666229 | -13.950714 | -5.87 |
| 907 : | 43.089569 | 42.614777 | -0.474792 | -1.10 |
| 908 : | 15866.257812 | 15499.335938 | -366.921875 | -2.31 |
| 909 : | 34826.398438 | 34778.031250 | -48.367188 | -0.14 |
| 910 : | 1729.335938 | 1742.803711 | 13.467773 | 0.78 |
| 911 : | 5114.882812 | 5134.750000 | 19.867188 | 0.39 |
| 912 : | 356.441406 | 356.473633 | 0.032227 | 0.01 |
| 913 : | 5222.015625 | 5224.867188 | 2.851562 | 0.05 |
| 914 : | 195.293732 | 195.871735 | 0.578003 | 0.30 |
| 915 : | 7361.257812 | 7374.835938 | 13.578125 | 0.18 |
| 916 : | 28395.640625 | 28431.828125 | 36.187500 | 0.13 |
| 917 : | 1342.388672 | 1387.204102 | 44.815430 | 3.34 |
| 918 : | 5165.000000 | 5173.625000 | 8.625000 | 0.17 |
| 919 : | 3310.000000 | 3322.303711 | 12.303711 | 0.37 |
| 920 : | 479.625000 | 467.726562 | -11.898438 | -2.48 |
| 921 : | 0.000000 | 0.000000 | 0.000000 | |
| 922 : | 4626.335938 | 4589.796875 | -36.539062 | -0.79 |
| 923 : | 922.736328 | 923.124512 | 0.388184 | 0.04 |
| 924 : | 153.570709 | 153.494293 | -0.076416 | -0.05 |
| 925 : | 390254.125000 | 390454.875000 | 200.750000 | 0.05 |
| 926 : | 6.008545 | 6.014065 | 0.005520 | 0.09 |
| 927 : | 1.040003 | 1.040003 | 0.000000 | 0.00 |
| 928 : | 0.997315 | 0.995551 | -0.001763 | -0.18 |
| 929 : | 1.003361 | 1.004101 | 0.000740 | 0.07 |
| 930 : | 0.995481 | 0.996269 | 0.000787 | 0.08 |
| 931 : | 0.674211 | 0.680128 | 0.005917 | 0.88 |
| 932 : | 0.790184 | 0.790598 | 0.000414 | 0.05 |
| 933 : | 9010612.000000 | 9010614.000000 | 2.000000 | 0.00 |
| 934 : | 120889.000000 | 121589.000000 | 700.000000 | 0.58 |
| 935 : | 520.000000 | 520.000000 | 0.000000 | 0.00 |
| 936 : | 10.000000 | 10.000000 | 0.000000 | 0.00 |
| 937 : | 395.000000 | 395.000000 | 0.000000 | 0.00 |
| 938 : | 0.000000 | 0.000000 | 0.000000 | |
| 939 : | 14.668247 | 14.651808 | -0.016439 | -0.11 |
| 940 : | 498.055176 | 523.206543 | 25.151367 | 5.05 |
| 941 : | 0.000000 | 0.000000 | 0.000000 | |
| 942 : | 10.283998 | 10.283998 | 0.000000 | 0.00 |
| 943 : | 90.295990 | 90.295990 | 0.000000 | 0.00 |
| 944 : | 47.500000 | 47.500000 | 0.000000 | 0.00 |
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| 950 : | 0.000000 | 0.000000 | 0.000000 | |
| 951 : | 0.000000 | 0.000000 | 0.000000 | |
| 952 : | 0.876453 | 0.876453 | 0.000000 | 0.00 |
| 953 : | 0.000000 | 0.000000 | 0.000000 | |
| 954 : | 0.000000 | 0.000000 | 0.000000 | |
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| 960 : | 23.598419 | 23.701996 | 0.103577 | 0.44 |
| 961 : | 37.747559 | 37.457550 | -0.290009 | -0.77 |
| 962 : | 96.039429 | 96.512787 | 0.473358 | 0.49 |
| 963 : | 165.911163 | 166.015625 | 0.104462 | 0.06 |
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| 966 : | 6202.445312 | 6205.820312 | 3.375000 | 0.05 |
| 967 : | 6308.570312 | 6311.398438 | 2.828125 | 0.04 |
| 968 : | 7345.796875 | 7359.914062 | 14.117188 | 0.19 |
| 969 : | 5594.445312 | 5596.476562 | 2.031250 | 0.04 |

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| 970 : | 5591.109375 | 5593.156250 | 2.046875 | 0.04 |
| 971 : | 4557.953125 | 4514.187500 | -43.765625 | -0.96 |
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| 974 : | 6087.726562 | 6074.789062 | -12.937500 | -0.21 |
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| 981 : | 5562.179688 | 5559.757812 | -2.421875 | -0.04 |
| 982 : | 273.306641 | 259.376465 | -13.930176 | -5.10 |
| 983 : | 3403.514160 | 3404.597168 | 1.083008 | 0.03 |
| 984 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
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| 989 : | 97.254059 | 96.060883 | -1.193176 | -1.23 |
| 990 : | 453.313965 | 453.246582 | -0.067383 | -0.01 |
| 991 : | 171.714905 | 171.821136 | 0.106232 | 0.06 |
| 992 : | 207.586731 | 207.833557 | 0.246826 | 0.12 |
| 993 : | 277.473145 | 277.477539 | 0.004395 | 0.00 |
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| 996 : | 0.229589 | 0.231791 | 0.002202 | 0.96 |
| 997 : | 0.000000 | 0.000000 | 0.000000 | |
| 998 : | 0.000000 | 0.000000 | 0.000000 | |
| 999 : | 1.690277 | 1.879307 | 0.189030 | 11.18 |
| 1000 : | 0.000000 | 0.000000 | 0.000000 | |
| 1001 : | 0.000000 | 0.000000 | 0.000000 | |
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| 1004 : | 0.000000 | 0.000000 | 0.000000 | |
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| 1008 : | 0.000000 | 0.000000 | 0.000000 | |
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| 1010 : | 0.000000 | 0.000000 | 0.000000 | |
| 1011 : | 0.000000 | 0.000000 | 0.000000 | |
| 1012 : | 0.000000 | 0.000000 | 0.000000 | |
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| 1014 : | 0.000000 | 0.000000 | 0.000000 | |
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| 1016 : | 0.000000 | 0.000000 | 0.000000 | |
| 1017 : | 211.113312 | 236.889771 | 25.776459 | 12.21 |
| 1018 : | 785.164062 | 799.503906 | 14.339844 | 1.83 |
| 1019 : | 88.783844 | 99.807678 | 11.023834 | 12.42 |
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| 1024 : | 0.000000 | 0.000000 | 0.000000 | |
| 1025 : | 0.000000 | 0.000000 | 0.000000 | |
| 1026 : | 3395.500977 | 3396.104004 | 0.603027 | 0.02 |
| 1027 : | 462.711914 | 452.439453 | -10.272461 | -2.22 |
| 1028 : | 79.743622 | 79.680115 | -0.063507 | -0.08 |
| 1029 : | 474.878418 | 464.601074 | -10.277344 | -2.16 |
| 1030 : | 16094.046875 | 16038.218750 | -55.828125 | -0.35 |
| 1031 : | 0.000000 | 0.000000 | 0.000000 | |
| 1032 : | 131146.500000 | 131863.750000 | 717.250000 | 0.55 |
| 1033 : | 130100.125000 | 130755.500000 | 655.375000 | 0.50 |
| 1034 : | 132725.375000 | 132462.875000 | -262.500000 | -0.20 |
| 1035 : | 0.000000 | 0.000000 | 0.000000 | |
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| 1038 : | -197.427338 | -236.117035 | -38.689697 | 19.60 |
| 1039 : | 988.427246 | 928.875977 | -59.551270 | -6.02 |
| 1040 : | 0.000000 | 0.000000 | 0.000000 | |
| 1041 : | 1730.941895 | 1729.177734 | -1.764160 | -0.10 |
| 1042 : | 1727.729980 | 1756.429688 | 28.699707 | 1.66 |
| 1043 : | 1335.730957 | 1373.146973 | 37.416016 | 2.80 |
| 1044 : | 1349.046875 | 1401.261230 | 52.214355 | 3.87 |
| 1045 : | 0.000000 | 0.000000 | 0.000000 | |
| 1046 : | 95.691711 | 95.923187 | 0.231476 | 0.24 |
| 1047 : | 27.304840 | 27.388367 | 0.083527 | 0.31 |
| 1048 : | 165.844391 | 165.928253 | 0.083862 | 0.05 |
| 1049 : | 37.747559 | 37.457550 | -0.290009 | -0.77 |
| 1050 : | 28.894775 | 28.839233 | -0.055542 | -0.19 |
| 1051 : | 129382.375000 | 129921.375000 | 539.000000 | 0.42 |
| 1052 : | 128859.625000 | 129207.125000 | 347.500000 | 0.27 |
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| 1056 : | 0.000000 | 0.000000 | 0.000000 | |
| 1057 : | 0.000000 | 0.000000 | 0.000000 | |
| 1058 : | 0.000000 | 0.000000 | 0.000000 | |
| 1059 : | 0.000000 | 0.000000 | 0.000000 | |
| 1060 : | 0.000000 | 0.000000 | 0.000000 | |
| 1061 : | 0.000000 | 0.000000 | 0.000000 | |
| 1062 : | 0.000000 | 0.000000 | 0.000000 | |
| 1063 : | 51.000000 | 51.000000 | 0.000000 | 0.00 |
| 1064 : | 51.000000 | 51.000000 | 0.000000 | 0.00 |
| 1065 : | 51.000000 | 51.000000 | 0.000000 | 0.00 |
| 1066 : | 15.000000 | 15.000000 | 0.000000 | 0.00 |
| 1067 : | 45.000000 | 45.000000 | 0.000000 | 0.00 |

| | | | | |
|---|---|---|---|---|
| 1068 : | 15.000000 | 15.000000 | 0.000000 | 0.00 |
| 1069 : | 15.000000 | 15.000000 | 0.000000 | 0.00 |
| 1070 : | 45.000000 | 45.000000 | 0.000000 | 0.00 |
| 1071 : | 15.000000 | 15.000000 | 0.000000 | 0.00 |
| 1072 : | 30.500000 | 30.500000 | 0.000000 | 0.00 |
| 1073 : | 36.000000 | 36.000000 | 0.000000 | 0.00 |
| 1074 : | 25.000000 | 25.000000 | 0.000000 | 0.00 |
| 1075 : | 25.000000 | 25.000000 | 0.000000 | 0.00 |
| 1076 : | 33.513794 | 33.513794 | 0.000000 | 0.00 |
| 1077 : | 33.513794 | 33.513794 | 0.000000 | 0.00 |
| 1078 : | 0.000000 | 0.000000 | 0.000000 | |
| 1079 : | 0.000000 | 0.000000 | 0.000000 | |
| 1080 : | 0.000000 | 0.000000 | 0.000000 | |
| 1081 : | 0.000000 | 0.000000 | 0.000000 | |
| 1082 : | 0.000000 | 0.000000 | 0.000000 | |
| 1083 : | 0.000000 | 0.000000 | 0.000000 | |
| 1084 : | 0.000000 | 0.000000 | 0.000000 | |
| 1085 : | 0.000000 | 0.000000 | 0.000000 | |
| 1086 : | 0.000000 | 0.000000 | 0.000000 | |
| 1087 : | 0.000000 | 0.000000 | 0.000000 | |
| 1088 : | 0.000000 | 0.000000 | 0.000000 | |
| 1089 : | 0.000000 | 0.000000 | 0.000000 | |
| 1090 : | 0.000000 | 0.000000 | 0.000000 | |
| 1091 : | 0.000000 | 0.000000 | 0.000000 | |
| 1092 : | 0.000000 | 0.000000 | 0.000000 | |
| 1093 : | 0.000000 | 0.000000 | 0.000000 | |
| 1094 : | 0.000000 | 0.000000 | 0.000000 | |
| 1095 : | 0.000000 | 0.000000 | 0.000000 | |
| 1096 : | 0.000000 | 0.000000 | 0.000000 | |
| 1097 : | 0.000000 | 0.000000 | 0.000000 | |
| 1098 : | 0.000000 | 0.000000 | 0.000000 | |
| 1099 : | 0.000000 | 0.000000 | 0.000000 | |
| 1100 : | 0.000000 | 0.000000 | 0.000000 | |
| 1101 : | 395.000000 | 395.000000 | 0.000000 | 0.00 |
| 1102 : | 30.356171 | 29.773682 | -0.582489 | -1.92 |
| 1103 : | 27.270630 | 27.931366 | 0.660736 | 2.42 |
| 1104 : | 23.849548 | 24.461273 | 0.611725 | 2.56 |
| 1105 : | 27.682709 | 27.383484 | -0.299225 | -1.08 |
| 1106 : | 27.026703 | 27.531891 | 0.505188 | 1.87 |
| 1107 : | 1.202293 | 1.250208 | 0.047915 | 3.99 |
| 1108 : | 0.981451 | 0.982236 | 0.000785 | 0.08 |
| 1109 : | 1.154089 | 1.155670 | 0.001581 | 0.14 |
| 1110 : | 1.137697 | 1.159491 | 0.021793 | 1.92 |
| 1111 : | 1.133795 | 1.155737 | 0.021942 | 1.94 |
| 1112 : | 1.040773 | 1.032728 | -0.008045 | -0.77 |
| 1113 : | 0.929834 | 0.903496 | -0.026338 | -2.83 |
| 1114 : | 0.933034 | 0.906430 | -0.026604 | -2.85 |
| 1115 : | 1.016426 | 1.014395 | -0.002031 | -0.20 |
| 1116 : | 0.962189 | 0.938432 | -0.023757 | -2.47 |
| 1117 : | 1.181183 | 1.202496 | 0.021313 | 1.80 |
| 1118 : | 1.004492 | 1.022034 | 0.017542 | 1.75 |
| 1119 : | 922.400391 | 922.549805 | 0.149414 | 0.02 |
| 1120 : | 5853.007812 | 5855.554688 | 2.546875 | 0.04 |
| 1121 : | 921.980957 | 922.193359 | 0.212402 | 0.02 |
| 1122 : | 7707.125000 | 7707.125000 | 0.000000 | 0.00 |
| 1123 : | 1.250298 | 1.250298 | 0.000000 | 0.00 |
| 1124 : | 153.033630 | 153.397064 | 0.363434 | 0.24 |
| 1125 : | 15744.898438 | 15733.726562 | -11.171875 | -0.07 |
| 1126 : | 153.457642 | 153.784271 | 0.326630 | 0.21 |
| 1127 : | 31888.382812 | 31888.382812 | 0.000000 | 0.00 |
| 1128 : | 1.204300 | 1.204300 | 0.000000 | 0.00 |
| 1129 : | 0.000000 | 0.000000 | 0.000000 | |
| 1130 : | 0.372473 | 0.372921 | 0.000447 | 0.12 |
| 1131 : | 0.673990 | 0.674193 | 0.000202 | 0.03 |
| 1132 : | 0.961010 | 0.958860 | -0.002150 | -0.22 |
| 1133 : | 0.984367 | 0.973787 | -0.010580 | -1.07 |
| 1134 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 1135 : | 0.876453 | 0.876453 | 0.000000 | 0.00 |
| 1136 : | 0.877076 | 0.874804 | -0.002273 | -0.26 |
| 1137 : | 2.917759 | 2.917759 | 0.000000 | 0.00 |
| 1138 : | 2.920059 | 2.919474 | -0.000586 | -0.02 |
| 1139 : | 0.000000 | 0.000000 | 0.000000 | |
| 1140 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 1141 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 1142 : | 0.000000 | 0.000000 | 0.000000 | |
| 1143 : | 75.010498 | 131.967773 | 56.957275 | 75.93 |
| 1144 : | 84.308472 | 97.011780 | 12.703308 | 15.07 |
| 1145 : | 1.494102 | 2.326550 | 0.832447 | 55.72 |
| 1146 : | -0.334679 | -0.521147 | -0.186468 | 55.72 |
| 1147 : | 265.512695 | 286.891602 | 21.378906 | 8.05 |
| 1148 : | 208.515900 | 233.599915 | 25.084015 | 12.03 |
| 1149 : | -14.747295 | -21.245453 | -6.498158 | 44.06 |
| 1150 : | -11.091982 | -15.979502 | -4.887520 | 44.06 |
| 1151 : | 1.242491 | 1.453331 | 0.210840 | 16.97 |
| 1152 : | -0.264773 | -0.309703 | -0.044930 | 16.97 |
| 1153 : | 1552.496582 | 1568.353516 | 15.856934 | 1.02 |
| 1154 : | 1754.432129 | 1752.087891 | -2.344238 | -0.13 |
| 1155 : | -538.620117 | -582.543457 | -43.923340 | 8.15 |
| 1156 : | -322.135254 | -339.190918 | -17.055664 | 5.29 |
| 1157 : | 66.000000 | 66.000000 | 0.000000 | 0.00 |
| 1158 : | 30.399994 | 30.399994 | 0.000000 | 0.00 |
| 1159 : | 0.000000 | 0.000000 | 0.000000 | |
| 1160 : | 0.000000 | 0.000000 | 0.000000 | |
| 1161 : | 0.000000 | 0.000000 | 0.000000 | |
| 1162 : | 0.000000 | 0.000000 | 0.000000 | |
| 1163 : | 0.000000 | 0.000000 | 0.000000 | |
| 1164 : | 0.000000 | 0.000000 | 0.000000 | |
| 1165 : | 0.000000 | 0.000000 | 0.000000 | |

| | | | | |
|---|---|---|---|---|
| 1166 : | 0.000000 | 0.000000 | 0.000000 | |
| 1167 : | 32.417328 | 34.355530 | 1.938202 | 5.98 |
| 1168 : | -1764.123047 | -1942.351074 | -178.228027 | 10.10 |
| 1169 : | -1240.480957 | -1548.384766 | -307.903809 | 24.82 |
| 1170 : | -713.485840 | -1136.531738 | -423.045898 | 59.29 |
| 1171 : | 0.000000 | 0.000000 | 0.000000 | |
| 1172 : | 27.403717 | 27.555206 | 0.151489 | 0.55 |
| 1173 : | 541.725098 | 566.392578 | 24.667480 | 4.55 |
| 1174 : | 23.792389 | 25.756317 | 1.963928 | 8.25 |
| 1175 : | 492.237793 | 493.498535 | 1.260742 | 0.26 |
| 1176 : | 18.034485 | 18.133728 | 0.099243 | 0.55 |
| 1177 : | 447.876953 | 468.583496 | 20.706543 | 4.62 |
| 1178 : | 16.324646 | 17.683960 | 1.359314 | 8.33 |
| 1179 : | 0.000000 | 0.000000 | 0.000000 | |
| 1180 : | 33.235779 | 34.780548 | 1.544769 | 4.65 |
| 1181 : | 14513.359375 | 14511.671875 | -1.687500 | -0.01 |
| 1182 : | 12774624.000000 | 12775666.000000 | 1042.000000 | 0.01 |
| 1183 : | 566197.250000 | 571219.875000 | 5022.625000 | 0.89 |
| 1184 : | 201090.125000 | 215010.625000 | 13920.500000 | 6.92 |
| 1185 : | 236.782410 | 237.057434 | 0.275024 | 0.12 |
| 1186 : | 246.296967 | 246.676880 | 0.379913 | 0.15 |
| 1187 : | 379.218750 | 377.831055 | -1.387695 | -0.37 |
| 1188 : | 38.898804 | 38.714111 | -0.184692 | -0.47 |
| 1189 : | 450.126465 | 458.618652 | 8.492188 | 1.89 |
| 1190 : | 55.162903 | 57.326813 | 2.163910 | 3.92 |
| 1191 : | 607.890625 | 609.462891 | 1.572266 | 0.26 |
| 1192 : | 0.000000 | 0.000000 | 0.000000 | |
| 1193 : | 0.000000 | 0.000000 | 0.000000 | |
| 1194 : | 0.000000 | 0.000000 | 0.000000 | |
| 1195 : | 0.000000 | 0.000000 | 0.000000 | |
| 1196 : | 0.000000 | 0.000000 | 0.000000 | |
| 1197 : | 0.000000 | 0.000000 | 0.000000 | |
| 1198 : | 0.000000 | 0.000000 | 0.000000 | |
| 1199 : | -1.054302 | -1.053318 | 0.000984 | -0.09 |
| 1200 : | 0.000000 | 0.000000 | 0.000000 | |
| 1201 : | 0.000000 | 0.000000 | 0.000000 | |
| 1202 : | 0.000000 | 0.000000 | 0.000000 | |
| 1203 : | 0.000000 | 0.000000 | 0.000000 | |
| 1204 : | 0.000000 | 0.000000 | 0.000000 | |
| 1205 : | 0.000000 | 0.000000 | 0.000000 | |
| 1206 : | 0.000000 | 0.000000 | 0.000000 | |
| 1207 : | 0.000000 | 0.000000 | 0.000000 | |
| 1208 : | 0.000000 | 0.000000 | 0.000000 | |
| 1209 : | 0.000000 | 0.000000 | 0.000000 | |
| 1210 : | 0.000000 | 0.000000 | 0.000000 | |
| 1211 : | 0.000000 | 0.000000 | 0.000000 | |
| 1212 : | 0.000000 | 0.000000 | 0.000000 | |
| 1213 : | 0.000000 | 0.000000 | 0.000000 | |
| 1214 : | 0.000000 | 0.000000 | 0.000000 | |
| 1215 : | 0.000000 | 0.000000 | 0.000000 | |
| 1216 : | 0.000000 | 0.000000 | 0.000000 | |
| 1217 : | 0.000000 | 0.000000 | 0.000000 | |
| 1218 : | 0.000000 | 0.000000 | 0.000000 | |
| 1219 : | 0.000000 | 0.000000 | 0.000000 | |
| 1220 : | 0.000000 | 0.000000 | 0.000000 | |
| 1221 : | 0.000000 | 0.000000 | 0.000000 | |
| 1222 : | 0.000000 | 0.000000 | 0.000000 | |
| 1223 : | 0.000000 | 0.000000 | 0.000000 | |
| 1224 : | 0.000000 | 0.000000 | 0.000000 | |
| 1225 : | 0.000000 | 0.000000 | 0.000000 | |
| 1226 : | 0.000000 | 0.000000 | 0.000000 | |
| 1227 : | 0.000000 | 0.000000 | 0.000000 | |
| 1228 : | 0.000000 | 0.000000 | 0.000000 | |
| 1229 : | 0.000000 | 0.000000 | 0.000000 | |
| 1230 : | 0.000000 | 0.000000 | 0.000000 | |
| 1231 : | 0.000000 | 0.000000 | 0.000000 | |
| 1232 : | 0.000000 | 0.000000 | 0.000000 | |
| 1233 : | 0.000000 | 0.000000 | 0.000000 | |
| 1234 : | 0.000000 | 0.000000 | 0.000000 | |
| 1235 : | 0.000000 | 0.000000 | 0.000000 | |
| 1236 : | 0.000000 | 0.000000 | 0.000000 | |
| 1237 : | 0.000000 | 0.000000 | 0.000000 | |
| 1238 : | 0.000000 | 0.000000 | 0.000000 | |
| 1239 : | 0.000000 | 0.000000 | 0.000000 | |
| 1240 : | 0.000000 | 0.000000 | 0.000000 | |
| 1241 : | 0.000000 | 0.000000 | 0.000000 | |
| 1242 : | 0.000000 | 0.000000 | 0.000000 | |
| 1243 : | 0.000000 | 0.000000 | 0.000000 | |
| 1244 : | 0.000000 | 0.000000 | 0.000000 | |
| 1245 : | 0.000000 | 0.000000 | 0.000000 | |
| 1246 : | 0.000000 | 0.000000 | 0.000000 | |
| 1247 : | 0.000000 | 0.000000 | 0.000000 | |
| 1248 : | 0.000000 | 0.000000 | 0.000000 | |
| 1249 : | 0.000000 | 0.000000 | 0.000000 | |
| 1250 : | 0.697200 | 0.697200 | 0.000000 | 0.00 |
| 1251 : | -1.181999 | -1.181999 | 0.000000 | -0.00 |
| 1252 : | 0.520800 | 0.520800 | 0.000000 | 0.00 |
| 1253 : | 0.000000 | 0.000000 | 0.000000 | |
| 1254 : | 0.050000 | 0.050000 | 0.000000 | 0.00 |
| 1255 : | 0.000000 | 0.000000 | 0.000000 | |
| 1256 : | 0.000000 | 0.000000 | 0.000000 | |
| 1257 : | 0.000000 | 0.000000 | 0.000000 | |
| 1258 : | 0.000000 | 0.000000 | 0.000000 | |
| 1259 : | 0.000000 | 0.000000 | 0.000000 | |
| 1260 : | 0.000000 | 0.000000 | 0.000000 | |
| 1261 : | 0.000000 | 0.000000 | 0.000000 | |
| 1262 : | 0.000000 | 0.000000 | 0.000000 | |
| 1263 : | 0.000000 | 0.000000 | 0.000000 | |

| | | | | |
|---|---|---|---|---|
| 1264 : | 0.000000 | 0.000000 | 0.000000 | |
| 1265 : | 0.000000 | 0.000000 | 0.000000 | |
| 1266 : | 0.000000 | 0.000000 | 0.000000 | |
| 1267 : | 0.000000 | 0.000000 | 0.000000 | |
| 1268 : | 0.000000 | 0.000000 | 0.000000 | |
| 1269 : | 0.000000 | 0.000000 | 0.000000 | |
| 1270 : | 0.000000 | 0.000000 | 0.000000 | |
| 1271 : | 0.000000 | 0.000000 | 0.000000 | |
| 1272 : | 0.000000 | 0.000000 | 0.000000 | |
| 1273 : | 0.000000 | 0.000000 | 0.000000 | |
| 1274 : | 0.000000 | 0.000000 | 0.000000 | |
| 1275 : | 0.000000 | 0.000000 | 0.000000 | |
| 1276 : | 0.000000 | 0.000000 | 0.000000 | |
| 1277 : | 0.000000 | 0.000000 | 0.000000 | |
| 1278 : | 0.000000 | 0.000000 | 0.000000 | |
| 1279 : | 0.000000 | 0.000000 | 0.000000 | |
| 1280 : | 0.000000 | 0.000000 | 0.000000 | |
| 1281 : | 0.000000 | 0.000000 | 0.000000 | |
| 1282 : | 0.000000 | 0.000000 | 0.000000 | |
| 1283 : | 0.000000 | 0.000000 | 0.000000 | |
| 1284 : | 0.000000 | 0.000000 | 0.000000 | |
| 1285 : | 0.000000 | 0.000000 | 0.000000 | |
| 1286 : | 0.000000 | 0.000000 | 0.000000 | |
| 1287 : | 0.000000 | 0.000000 | 0.000000 | |
| 1288 : | 0.000000 | 0.000000 | 0.000000 | |
| 1289 : | 0.000000 | 0.000000 | 0.000000 | |
| 1290 : | 0.000000 | 0.000000 | 0.000000 | |
| 1291 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 1292 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 1293 : | 1.007999 | 1.007999 | 0.000000 | 0.00 |
| 1294 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 1295 : | 1.002886 | 1.002886 | 0.000000 | 0.00 |
| 1296 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 1297 : | 0.000000 | 0.000000 | 0.000000 | |
| 1298 : | 0.000000 | 0.000000 | 0.000000 | |
| 1299 : | 0.000000 | 0.000000 | 0.000000 | |
| 1300 : | 0.000000 | 0.000000 | 0.000000 | |
| 1301 : | 0.000000 | 0.000000 | 0.000000 | |
| 1302 : | 0.016555 | 0.016555 | 0.000000 | 0.00 |
| 1303 : | -0.030621 | -0.030621 | 0.000000 | -0.00 |
| 1304 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 1305 : | 1.246698 | 1.246698 | 0.000000 | 0.00 |
| 1306 : | 1.204300 | 1.204300 | 0.000000 | 0.00 |
| 1307 : | 0.000000 | 0.000000 | 0.000000 | |
| 1308 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 1309 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 1310 : | 0.000000 | 0.000000 | 0.000000 | |
| 1311 : | 0.000000 | 0.000000 | 0.000000 | |
| 1312 : | 0.000000 | 0.000000 | 0.000000 | |
| 1313 : | 0.000000 | 0.000000 | 0.000000 | |
| 1314 : | 0.000000 | 0.000000 | 0.000000 | |
| 1315 : | 0.000000 | 0.000000 | 0.000000 | |
| 1316 : | 0.000000 | 0.000000 | 0.000000 | |
| 1317 : | 0.000000 | 0.000000 | 0.000000 | |
| 1318 : | 1.000000 | 1.000000 | 0.000000 | 0.00 |
| 1319 : | 0.000000 | 0.000000 | 0.000000 | |
| 1320 : | 0.000000 | 0.000000 | 0.000000 | |
| 1321 : | 0.000000 | 0.000000 | 0.000000 | |
| 1322 : | 0.000000 | 0.000000 | 0.000000 | |
| 1323 : | 0.000000 | 0.000000 | 0.000000 | |
| 1324 : | 778.259766 | 778.259766 | 0.000000 | 0.00 |
| 1325 : | 32.173981 | 32.173981 | 0.000000 | 0.00 |
| 1326 : | 3.141588 | 3.141588 | 0.000000 | 0.00 |
| 1327 : | 2.015999 | 2.015999 | 0.000000 | 0.00 |
| 1328 : | 1545.429688 | 1545.429688 | 0.000000 | 0.00 |
| 1329 : | 144.000000 | 144.000000 | 0.000000 | 0.00 |
| 1330 : | 0.000000 | 0.000000 | 0.000000 | |
| 1331 : | 0.000000 | 0.000000 | 0.000000 | |
| 1332 : | 0.000000 | 0.000000 | 0.000000 | |
| 1333 : | 0.000000 | 0.000000 | 0.000000 | |
| 1334 : | 0.000000 | 0.000000 | 0.000000 | |
| 1335 : | 0.000000 | 0.000000 | 0.000000 | |
| 1336 : | 0.000000 | 0.000000 | 0.000000 | |
| 1337 : | 0.000000 | 0.000000 | 0.000000 | |
| 1338 : | 0.000000 | 0.000000 | 0.000000 | |
| 1339 : | 0.000000 | 0.000000 | 0.000000 | |
| 1340 : | 0.000000 | 0.000000 | 0.000000 | |
| 1341 : | 0.000000 | 0.000000 | 0.000000 | |
| 1342 : | 0.000000 | 0.000000 | 0.000000 | |
| 1343 : | 0.000000 | 0.000000 | 0.000000 | |
| 1344 : | 0.000000 | 0.000000 | 0.000000 | |
| 1345 : | 0.000000 | 0.000000 | 0.000000 | |
| 1346 : | 0.000000 | 0.000000 | 0.000000 | |
| 1347 : | 0.000000 | 0.000000 | 0.000000 | |
| 1348 : | 0.000000 | 0.000000 | 0.000000 | |
| 1349 : | 0.000000 | 0.000000 | 0.000000 | |
| 1350 : | 10402.500000 | 10402.500000 | 0.000000 | 0.00 |

### A.5.3MCC Leak Example: Standard EDIS execution transcript

Standard EDIS Execution Transcript

NEXPERT Serial Number 1-2.0B-S4X1-051091-1458
Copy for Client of Neuron Data, Inc.

# Next behavior to expand
# CONTROL_OBJECT2.is_now = FUEL_FLOW_CTRL_2
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_2
# Next behavior to expand
# CONTROL_OBJECT2.is_now = F101_4
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_12
# Ignoring pin deviation at HIPUMP
# Next behavior to expand
# CONTROL_OBJECT2.is_now = HPFP_3
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_13
# One fault in behavior
# CONTROL_OBJECT3.best_faulty_behavior = HPFP_7
# Fault type
# CONTROL_OBJECT3.best_current_fault = LOW_EFFICIENCY
# Next behavior to expand
# CONTROL_OBJECT2.is_now = HPFT_6
# No viable expansion!
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_14
# Next behavior to expand
# CONTROL_OBJECT2.is_now = NOZZLE1_5
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_15
# No fault!
# Next behavior to expand
# CONTROL_OBJECT2.is_now = MCC_7
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_20
# Next behavior to expand
# CONTROL_OBJECT2.is_now = MOV_7
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_28
# Next behavior to expand
# CONTROL_OBJECT2.is_now = O204_5
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_30
# Next behavior to expand
# CONTROL_OBJECT2.is_now = M104_7
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_43
# Next behavior to expand
# CONTROL_OBJECT2.is_now = O205_5

# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_49
# Next behavior to expand
# CONTROL_OBJECT2.is_now = M101_8
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_52
# Next behavior to expand
# CONTROL_OBJECT2.is_now = OPOV_6
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_54
# Next behavior to expand
# CONTROL_OBJECT2.is_now = OPB_7
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_60
# Next behavior to expand
# CONTROL_OBJECT2.is_now = HPOT_9
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_61
# Next behavior to expand
# CONTROL_OBJECT2.is_now = HPOP_PBP_8
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_63
# One fault in behavior
# CONTROL_OBJECT3.best_faulty_behavior = HPOP_PBP_14
# Fault type
# CONTROL_OBJECT3.best_current_fault = LOW_EFFICIENCY
# Next behavior to expand
# CONTROL_OBJECT2.is_now = O201_4
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_64
# No fault!
# Next behavior to expand
# CONTROL_OBJECT2.is_now = O201_10
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_72
# Next behavior to expand
# CONTROL_OBJECT2.is_now = LPOP_6
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_73
# One fault in behavior
# CONTROL_OBJECT3.best_faulty_behavior = LPOP_10
# Fault type
# CONTROL_OBJECT3.best_current_fault = LOW_EFFICIENCY
# Next behavior to expand
# CONTROL_OBJECT2.is_now = LPOT_5
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_87
# Next behavior to expand
# CONTROL_OBJECT2.is_now = O203_7
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_89
# Next behavior to expand
# CONTROL_OBJECT2.is_now = O203_10
# New best scenario

```
# CONTROL_OBJECT.current_scenario = SCENARIO_94
# Next behavior to expand
# CONTROL_OBJECT2.is_now = HPFT_10
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_95
# Next behavior to expand
# CONTROL_OBJECT2.is_now = HGM_9
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_110
# Next behavior to expand
# CONTROL_OBJECT2.is_now = DIFFUSER_7
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_117
# Next behavior to expand
# CONTROL_OBJECT2.is_now = CCV_6
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_121
# Next behavior to expand
# CONTROL_OBJECT2.is_now = MIXER_10
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_134
# Next behavior to expand
# CONTROL_OBJECT2.is_now = NZL_COOL_10
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_135
# Next behavior to expand
# CONTROL_OBJECT2.is_now = MFV_7
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_136
# Next behavior to expand
# CONTROL_OBJECT2.is_now = LPFP_3
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_147
# Next behavior to expand
# CONTROL_OBJECT2.is_now = LPFT_3
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_156
# Next behavior to expand
# CONTROL_OBJECT2.is_now = F109_6
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_170
# Next behavior to expand
# CONTROL_OBJECT2.is_now = MCC_COOL_9
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_150
# Fault assumption looks wrong: increase estimated cost
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_74
# Next behavior to expand
# CONTROL_OBJECT2.is_now = LPOT_78
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_198
# No fault!
# Next behavior to expand
```

# CONTROL_OBJECT2.is_now = O203_13
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_199
# Next behavior to expand
# CONTROL_OBJECT2.is_now = HPFT_10
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_200
# Next behavior to expand
# CONTROL_OBJECT2.is_now = HGM_23
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_215
# Next behavior to expand
# CONTROL_OBJECT2.is_now = DIFFUSER_7
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_222
# Next behavior to expand
# CONTROL_OBJECT2.is_now = CCV_11
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_226
# Next behavior to expand
# CONTROL_OBJECT2.is_now = MIXER_44
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_239
# Next behavior to expand
# CONTROL_OBJECT2.is_now = NZL_COOL_17
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_240
# Next behavior to expand
# CONTROL_OBJECT2.is_now = MFV_21
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_241
# Next behavior to expand
# CONTROL_OBJECT2.is_now = LPFP_3
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_254
# One fault in behavior
# CONTROL_OBJECT3.best_faulty_behavior = LPFP_17
# Fault type
# CONTROL_OBJECT3.best_current_fault = LOW_EFFICIENCY
# Next behavior to expand
# CONTROL_OBJECT2.is_now = LPFT_24
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_258
# Next behavior to expand
# CONTROL_OBJECT2.is_now = F109_17
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_266
# Next behavior to expand
# CONTROL_OBJECT2.is_now = MCC_COOL_19
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_253
# One fault in behavior
# CONTROL_OBJECT3.best_faulty_behavior = LPFP_16
# Fault type

# CONTROL_OBJECT3.best_current_fault = LOW_EFFICIENCY
# Fault assumption looks wrong: increase estimated cost
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_253
# Next behavior to expand
# CONTROL_OBJECT2.is_now = LPFT_36
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_269
# Next behavior to expand
# CONTROL_OBJECT2.is_now = F109_27
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_277
# Next behavior to expand
# CONTROL_OBJECT2.is_now = MCC_COOL_28
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_270
# Fault assumption looks wrong: increase estimated cost
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_252
# Next behavior to expand
# CONTROL_OBJECT2.is_now = LPFT_45
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_286
# No fault!
# Next behavior to expand
# CONTROL_OBJECT2.is_now = F109_37
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_300
# Next behavior to expand
# CONTROL_OBJECT2.is_now = MCC_COOL_37
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_301
# One fault in behavior
# CONTROL_OBJECT3.best_faulty_behavior = MCC_COOL_43
# Fault type
# CONTROL_OBJECT3.best_current_fault = LEAK
# Next behavior to expand
# CONTROL_OBJECT2.is_now = FPB_6
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_310
# Next behavior to expand
# CONTROL_OBJECT2.is_now = FPOV_11
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_318
# Next behavior to expand
# CONTROL_OBJECT2.is_now = O206_7
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_319
# Next behavior to expand
# CONTROL_OBJECT2.is_now = F107_10
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_325
# Next behavior to expand
# CONTROL_OBJECT2.is_now = M103_14

# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_328
# Next behavior to expand
# CONTROL_OBJECT2.is_now = F110_9
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_329
# Next behavior to expand
# CONTROL_OBJECT2.is_now = F108_8
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_330

### A.5.4MCC Leak Example: PBM qualitative data file

PBM Qualitative Parameter Values

\MCC_PBM_template.MR\="NORMAL"
\LPFP_PBM_template.pin\="NORMAL"
\LPOP_PBM_template.pin\="NORMAL"
\LPFP_PBM_template.Tin\="NORMAL"
\LPOP_PBM_template.Tin\="NORMAL"
\MOV_PBM_template.p_diff\="NORMAL"
\O201_PBM_template.p_diff\="NORMAL"
\LPOT_PBM_template.p_diff\="NORMAL"
\MFV_PBM_template.p_diff\="HIGH"
\MOV_PBM_template.p_diff\="NORMAL"
\OPOV_PBM_template.p_diff\="LOW"
\FPOV_PBM_template.p_diff\="LOW"
\F110_PBM_template.p_diff\="NORMAL"
\CCV_PBM_template.p_diff\="NORMAL"
\NZL_COOL_PBM_template.T_diff\="NORMAL"
\MCC_COOL_PBM_template.T_diff\="LOW"
\LPFP_PBM_template.p_diff\="LOW"
\HPFP_PBM_template.p_diff\="NORMAL"
\LPOP_PBM_template.p_diff\="NORMAL"
\HPOP_PBP_PBM_template.p_diff\="NORMAL"
\LPFP_PBM_template.MechPWR\="LOW"
\HPFP_PBM_template.MechPWR\="NORMAL"
\LPFT_PBM_template.MechPWR\="LOW"
\HPFT_PBM_template.MechPWR\="NORMAL"
\LPOP_PBM_template.MechPWR\="NORMAL"
\HPOP_PBP_PBM_template.MechPWR\="NORMAL"
\LPOT_PBM_template.MechPWR\="NORMAL"
\HPOT_PBM_template.MechPWR\="NORMAL"
\MIXER_PBM_template.pin\="NORMAL"
\F107_PBM_template.pin\="NORMAL"
\FPB_PBM_template.pout\="NORMAL"
\HPFT_PBM_template.pin\="NORMAL"
\HGM_PBM_template.pin\="NORMAL"
\OPB_PBM_template.pout\="NORMAL"
\MFV_PBM_template.pin\="NORMAL"
\F101_PBM_template.pout\="LOW"
\LPFT_PBM_template.pin\="NORMAL"
\HPFT_PBM_template.pin\="NORMAL"
\HPOP_PBP_PBM_template.pin\="NORMAL"
\O201_PBM_template.pout\="NORMAL"
\LPOT_PBM_template.pin\="NORMAL"
\M104_PBM_template.pin\="NORMAL"
\HPOT_PBM_template.pin\="NORMAL"
\OPOV_PBM_template.pin\="NORMAL"
\M101_PBM_template.pin\="NORMAL"
\OPB_PBM_template.pin_OX\="NORMAL"
\FPB_PBM_template.pin_OX\="NORMAL"
\LPFP_PBM_template.pout\="LOW"
\F101_PBM_template.pin\="LOW"
\HPFP_PBM_template.pout\="NORMAL"
\LPOP_PBM_template.pout\="NORMAL"

\O201_PBM_template.pin\="NORMAL"
\HPOP_PBP_PBM_template.pout\="NORMAL"
\MOV_PBM_template.pin\="NORMAL"
\O204_PBM_template.pout\="NORMAL"
\LPFT_PBM_template.pout\="NORMAL"
\HPFT_PBM_template.pout\="NORMAL"
\HPOT_PBM_template.pout\="NORMAL"
\CCV_PBM_template.pin\="NORMAL"
\MCC_COOL_PBM_template.pin\="NORMAL"
\OPOV_PBM_template.pout\="NORMAL"
\NZL_COOL_PBM_template.pin\="NORMAL"
\FPOV_PBM_template.pout\="NORMAL"
\CCV_PBM_template.pout\="NORMAL"
\FPB_PBM_template.pin\="NORMAL"
\F110_PBM_template.pout\="NORMAL"
\OPB_PBM_template.pin\="NORMAL"
\F108_PBM_template.pout\="NORMAL"
\MOV_PBM_template.pout\="NORMAL"
\MCC_PBM_template.pin_OX\="NORMAL"
\FPB_PBM_template.MR\="NORMAL"
\OPB_PBM_template.MR\="HIGH"
\MIXER_PBM_template.Tout\="NORMAL"
\F107_PBM_template.Tin\="NORMAL"
\CCV_PBM_template.Tout\="NORMAL"
\MIXER_PBM_template.Tin\="NORMAL"
\NZL_COOL_PBM_template.Tout\="NORMAL"
\MIXER_PBM_template.TinB\="NORMAL"
\HPOP_PBP_PBM_template.Tin\="NORMAL"
\O201_PBM_template.Tout\="NORMAL"
\LPOT_PBM_template.Tq\="NORMAL"
\LPOP_PBM_template.Tq\="NORMAL"
\FPB_PBM_template.Tout\="NORMAL"
\HPFT_PBM_template.Tin\="NORMAL"
\OPB_PBM_template.Tout\="HIGH"
\HPOT_PBM_template.Tin\="HIGH"
\HPFP_PBM_template.Tin\="NORMAL"
\F101_PBM_template.Tout\="NORMAL"
\LPFT_PBM_template.Tin\="NORMAL"
\LPFP_PBM_template.Tout\="NORMAL"
\F101_PBM_template.Tin\="NORMAL"
\HPFP_PBM_template.Tout\="NORMAL"
\MFV_PBM_template.Tin\="NORMAL"
\LPFT_PBM_template.Tout\="NORMAL"
\HPFT_PBM_template.Tout\="NORMAL"
\HGM_PBM_template.Tin\="NORMAL"
\LPOP_PBM_template.Tout\="NORMAL"
\O201_PBM_template.Tin\="NORMAL"
\HPOP_PBP_PBM_template.Tout\="NORMAL"
\M104_PBM_template.Tin\="NORMAL"
\LPOT_PBM_template.Tout\="NORMAL"
\HPOT_PBM_template.Tout\="HIGH"
\HGM_PBM_template.TinB\="HIGH"
\MFV_PBM_template.Tout\="NORMAL"
\DIFFUSER_PBM_template.Tin\="NORMAL"

\FPOV_PBM_template.Tout\="NORMAL"
\FPB_PBM_template.Tin_OX\="NORMAL"
\OPOV_PBM_template.Tout\="NORMAL"
\OPB_PBM_template.Tin_OX\="NORMAL"
\MFV_PBM_template.Vbar\="NORMAL"
\DIFFUSER_PBM_template.Vin\="NORMAL"
\FPB_PBM_template.Vin\="NORMAL"
\F110_PBM_template.Vout\="NORMAL"
\FPB_PBM_template.Vin_OX\="NORMAL"
\FPOV_PBM_template.Vout\="NORMAL"
\LPFP_PBM_template.Vbar\="NORMAL"
\HPFP_PBM_template.Vbar\="NORMAL"
\HGM_PBM_template.Vin\="NORMAL"
\HPFT_PBM_template.Vout\="NORMAL"
\LPFT_PBM_template.Vin\="NORMAL"
\F109_PBM_template.Vout\="NORMAL"
\HPFT_PBM_template.Vin\="NORMAL"
\FPB_PBM_template.Vout\="NORMAL"
\MOV_PBM_template.Vbar\="NORMAL"
\O204_PBM_template.Vout\="NORMAL"
\MCC_PBM_template.Vin_OX\="NORMAL"
\OPB_PBM_template.Vin\="NORMAL"
\F108_PBM_template.Vout\="NORMAL"
\OPB_PBM_template.Vin_OX\="HIGH"
\OPOV_PBM_template.Vout\="HIGH"
\LPOP_PBM_template.Vbar\="NORMAL"
\O201_PBM_template.Vin\="NORMAL"
\O201_PBM_template.Vbar\="NORMAL"
\HPOP_PBP_PBM_template.Vbar\="NORMAL"
\O201_PBM_template.Vout\="NORMAL"
\M104_PBM_template.Vin\="NORMAL"
\LPOT_PBM_template.Vbar\="NORMAL"
\O203_PBM_template.Vout\="NORMAL"
\HPOT_PBM_template.Vin\="HIGH"
\OPB_PBM_template.Vout\="HIGH"
\NZL_COOL_PBM_template.Vbar\="NORMAL"
\OPOV_PBM_template.Vbar\="HIGH"
\M101_PBM_template.Vout\="HIGH"
\FPOV_PBM_template.Vbar\="NORMAL"
\O206_PBM_template.Vout\="NORMAL"
\MIXER_PBM_template.VinB\="NORMAL"
\NZL_COOL_PBM_template.Vout\="NORMAL"
\MIXER_PBM_template.Vout\="NORMAL"
\F107_PBM_template.Vin\="NORMAL"
\OPB_PBM_template.Vout\="HIGH"
\HPOT_PBM_template.Vin\="HIGH"
\MCC_COOL_PBM_template.Vbar\="HIGH"
**********

### A.5.5MCC Leak Example: Execution transcript using PBM

Execution Transcript: Using PBM

NEXPERT Serial Number 1-2.0B-S4X1-051091-1458
Copy for Client of Neuron Data, Inc.

# Next behavior to expand
# CONTROL_OBJECT2.is_now = FUEL_FLOW_CTRL_2
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_2
# Next behavior to expand
# CONTROL_OBJECT2.is_now = F101_4
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_12
# Ignoring pin deviation at HIPUMP
# Next behavior to expand
# CONTROL_OBJECT2.is_now = HPFP_3
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_13
# One fault in behavior
# CONTROL_OBJECT3.best_faulty_behavior = HPFP_7
# Fault type
# CONTROL_OBJECT3.best_current_fault = LOW_EFFICIENCY
# Next behavior to expand
# CONTROL_OBJECT2.is_now = HPFT_6
# No viable expansion!
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_14
# Next behavior to expand
# CONTROL_OBJECT2.is_now = NOZZLE1_5
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_15
# No fault!
# Next behavior to expand
# CONTROL_OBJECT2.is_now = MCC_7
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_20
# Next behavior to expand
# CONTROL_OBJECT2.is_now = MOV_7
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_28
# Next behavior to expand
# CONTROL_OBJECT2.is_now = O204_5
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_30
# Next behavior to expand
# CONTROL_OBJECT2.is_now = M104_7
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_43
# Next behavior to expand
# CONTROL_OBJECT2.is_now = O205_5

# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_49
# Next behavior to expand
# CONTROL_OBJECT2.is_now = M101_8
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_52
# Next behavior to expand
# CONTROL_OBJECT2.is_now = OPOV_6
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_54
# Next behavior to expand
# CONTROL_OBJECT2.is_now = OPB_7
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_60
# Next behavior to expand
# CONTROL_OBJECT2.is_now = HPOT_9
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_61
# Next behavior to expand
# CONTROL_OBJECT2.is_now = HPOP_PBP_8
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_63
# One fault in behavior
# CONTROL_OBJECT3.best_faulty_behavior = HPOP_PBP_14
# Fault type
# CONTROL_OBJECT3.best_current_fault = LOW_EFFICIENCY
# Next behavior to expand
# CONTROL_OBJECT2.is_now = O201_4
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_64
# No fault!
# Next behavior to expand
# CONTROL_OBJECT2.is_now = O201_10
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_72
# Next behavior to expand
# CONTROL_OBJECT2.is_now = LPOP_6
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_73
# One fault in behavior
# CONTROL_OBJECT3.best_faulty_behavior = LPOP_10
# Fault type
# CONTROL_OBJECT3.best_current_fault = LOW_EFFICIENCY
# Next behavior to expand
# CONTROL_OBJECT2.is_now = LPOT_5
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_89
# Next behavior to expand
# CONTROL_OBJECT2.is_now = O203_7
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_93
# Next behavior to expand
# CONTROL_OBJECT2.is_now = HPFT_11
# New best scenario

# CONTROL_OBJECT.current_scenario = SCENARIO_94
# Next behavior to expand
# CONTROL_OBJECT2.is_now = HGM_9
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_109
# Next behavior to expand
# CONTROL_OBJECT2.is_now = DIFFUSER_7
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_116
# Next behavior to expand
# CONTROL_OBJECT2.is_now = CCV_6
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_120
# Next behavior to expand
# CONTROL_OBJECT2.is_now = MIXER_10
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_133
# Next behavior to expand
# CONTROL_OBJECT2.is_now = NZL_COOL_10
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_134
# Next behavior to expand
# CONTROL_OBJECT2.is_now = MFV_7
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_135
# Next behavior to expand
# CONTROL_OBJECT2.is_now = LPFP_3
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_146
# Next behavior to expand
# CONTROL_OBJECT2.is_now = LPFT_3
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_155
# Next behavior to expand
# CONTROL_OBJECT2.is_now = F109_6
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_169
# Next behavior to expand
# CONTROL_OBJECT2.is_now = MCC_COOL_9
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_144
# Fault assumption looks wrong: increase estimated cost
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_74
# Next behavior to expand
# CONTROL_OBJECT2.is_now = LPOT_78
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_197
# No fault!
# Next behavior to expand
# CONTROL_OBJECT2.is_now = O203_10
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_198
# Next behavior to expand

# CONTROL_OBJECT2.is_now = HPFT_11
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_199
# Next behavior to expand
# CONTROL_OBJECT2.is_now = HGM_23
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_214
# Next behavior to expand
# CONTROL_OBJECT2.is_now = DIFFUSER_7
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_221
# Next behavior to expand
# CONTROL_OBJECT2.is_now = CCV_11
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_225
# Next behavior to expand
# CONTROL_OBJECT2.is_now = MIXER_44
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_238
# Next behavior to expand
# CONTROL_OBJECT2.is_now = NZL_COOL_17
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_239
# Next behavior to expand
# CONTROL_OBJECT2.is_now = MFV_21
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_240
# Next behavior to expand
# CONTROL_OBJECT2.is_now = LPFP_3
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_253
# One fault in behavior
# CONTROL_OBJECT3.best_faulty_behavior = LPFP_17
# Fault type
# CONTROL_OBJECT3.best_current_fault = LOW_EFFICIENCY
# Next behavior to expand
# CONTROL_OBJECT2.is_now = LPFT_24
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_257
# Next behavior to expand
# CONTROL_OBJECT2.is_now = F109_17
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_265
# Next behavior to expand
# CONTROL_OBJECT2.is_now = MCC_COOL_19
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_252
# One fault in behavior
# CONTROL_OBJECT3.best_faulty_behavior = LPFP_16
# Fault type
# CONTROL_OBJECT3.best_current_fault = LOW_EFFICIENCY
# Fault assumption looks wrong: increase estimated cost
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_252

# Next behavior to expand
# CONTROL_OBJECT2.is_now = LPFT_36
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_268
# Next behavior to expand
# CONTROL_OBJECT2.is_now = F109_27
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_276
# Next behavior to expand
# CONTROL_OBJECT2.is_now = MCC_COOL_28
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_269
# Fault assumption looks wrong: increase estimated cost
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_251
# Next behavior to expand
# CONTROL_OBJECT2.is_now = LPFT_45
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_285
# No fault!
# Next behavior to expand
# CONTROL_OBJECT2.is_now = F109_37
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_299
# Next behavior to expand
# CONTROL_OBJECT2.is_now = MCC_COOL_37
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_300
# One fault in behavior
# CONTROL_OBJECT3.best_faulty_behavior = MCC_COOL_43
# Fault type
# CONTROL_OBJECT3.best_current_fault = LEAK
# Next behavior to expand
# CONTROL_OBJECT2.is_now = FPB_6
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_309
# Next behavior to expand
# CONTROL_OBJECT2.is_now = FPOV_11
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_317
# Next behavior to expand
# CONTROL_OBJECT2.is_now = O206_7
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_318
# Next behavior to expand
# CONTROL_OBJECT2.is_now = F107_10
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_324
# Next behavior to expand
# CONTROL_OBJECT2.is_now = M103_14
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_327
# Next behavior to expand
# CONTROL_OBJECT2.is_now = F110_9

```
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_328
# Next behavior to expand
# CONTROL_OBJECT2.is_now = F108_8
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_329
```

## A.5.6MCC Leak Example: Execution transcript using PBM and heuristic rules

Execution Transcript: Using PBM and Heuristic Rules

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# Next behavior to expand
# CONTROL_OBJECT2.is_now = MCC_COOL_4
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_20
# One fault in behavior
# CONTROL_OBJECT3.best_faulty_behavior = MCC_COOL_76
# Fault type
# CONTROL_OBJECT3.best_current_fault = LEAK
# Next behavior to expand
# CONTROL_OBJECT2.is_now = DIFFUSER_11
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_44
# Next behavior to expand
# CONTROL_OBJECT2.is_now = CCV_6
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_46
# Next behavior to expand
# CONTROL_OBJECT2.is_now = FUEL_FLOW_CTRL_2
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_47
# Next behavior to expand
# CONTROL_OBJECT2.is_now = F101_4
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_57
# Ignoring pin deviation at HIPUMP
# Next behavior to expand
# CONTROL_OBJECT2.is_now = HPFP_4
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_59
# Next behavior to expand
# CONTROL_OBJECT2.is_now = HPFT_6
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_60
# Next behavior to expand
# CONTROL_OBJECT2.is_now = HGM_5
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_101
# Next behavior to expand
# CONTROL_OBJECT2.is_now = HPOT_6
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_102
# Next behavior to expand
# CONTROL_OBJECT2.is_now = HPOP_PBP_6
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_107

# Next behavior to expand
# CONTROL_OBJECT2.is_now = M104_5
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_120
# Next behavior to expand
# CONTROL_OBJECT2.is_now = O205_5
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_126
# Next behavior to expand
# CONTROL_OBJECT2.is_now = M101_8
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_129
# Next behavior to expand
# CONTROL_OBJECT2.is_now = OPOV_7
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_131
# Next behavior to expand
# CONTROL_OBJECT2.is_now = OPB_9
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_137
# Next behavior to expand
# CONTROL_OBJECT2.is_now = F108_7
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_143
# Next behavior to expand
# CONTROL_OBJECT2.is_now = M103_9
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_146
# Next behavior to expand
# CONTROL_OBJECT2.is_now = F110_8
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_148
# Next behavior to expand
# CONTROL_OBJECT2.is_now = FPB_7
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_150
# Next behavior to expand
# CONTROL_OBJECT2.is_now = FPOV_11
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_158
# Next behavior to expand
# CONTROL_OBJECT2.is_now = O206_7
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_159
# Next behavior to expand
# CONTROL_OBJECT2.is_now = NOZZLE1_9
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_160
# Next behavior to expand
# CONTROL_OBJECT2.is_now = MCC_10
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_163
# Next behavior to expand
# CONTROL_OBJECT2.is_now = MOV_9

# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_171
# Next behavior to expand
# CONTROL_OBJECT2.is_now = O204_7
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_172
# Next behavior to expand
# CONTROL_OBJECT2.is_now = F107_9
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_174
# Next behavior to expand
# CONTROL_OBJECT2.is_now = MIXER_14
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_177
# Next behavior to expand
# CONTROL_OBJECT2.is_now = NZL_COOL_12
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_178
# Next behavior to expand
# CONTROL_OBJECT2.is_now = MFV_7
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_179
# Next behavior to expand
# CONTROL_OBJECT2.is_now = F109_5
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_188
# Next behavior to expand
# CONTROL_OBJECT2.is_now = LPFT_4
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_193
# Next behavior to expand
# CONTROL_OBJECT2.is_now = LPFP_5
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_201
# Next behavior to expand
# CONTROL_OBJECT2.is_now = O203_6
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_207
# Next behavior to expand
# CONTROL_OBJECT2.is_now = LPOT_4
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_213
# Next behavior to expand
# CONTROL_OBJECT2.is_now = LPOP_7
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_215
# Next behavior to expand
# CONTROL_OBJECT2.is_now = O201_3
# New best scenario
# CONTROL_OBJECT.current_scenario = SCENARIO_218