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## **Use of an Expert System Data Analysis Manager for Space Shuttle Main Engine Test Evaluation**

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### **Abstract**

The ability to articulate, collect, and automate the application of the expertise needed for the analysis of space shuttle main engine (SSME) test data would be of great benefit to NASA liquid rocket engine experts. This paper describes a project whose goal is to build a rule-based expert system which incorporates such expertise. Experiential expertise, collected directly from the experts currently involved in SSME data analysis, is used to build a rule base to identify engine anomalies similar to those analyzed previously. Additionally, an alternate method of expertise capture is being explored. This method would generate rules inductively based on calculations made using a theoretical model of the SSME's operation. The latter rules would be capable of diagnosing anomalies which may not have appeared before, but whose effects can be predicted by the theoretical model.

### **Introduction**

The analysis and interpretation of SSME test data presents some significant challenges. A single SSME test can produce in excess of 50 megabytes of data, with current test schedules calling for more than 10 tests per month. In addition, the complexity of the SSME reduces the possibility of such data analysis becoming routine and creates a requirement for high levels of data analysis expertise. As a consequence of these factors, there are rarely enough experts or time for a completely optimal SSME test data analysis.

A large portion of the expertise being used in such analysis is in the form of experiential knowledge gathered and possessed by engineers with years of experience in the task of analyzing SSME test data. Much of this expertise is unavailable to novice engineers, because it has not been articulated and recorded in accessible forms. Thus the possibility of losing significant expertise and analysis capability through the loss of personnel is even higher than in many other expert dependent problem domains. Further, it would be advantageous for NASA to increase the use of its most experienced liquid rocket engine experts in high-level planning and design activities. For this to become possible, some of the burden of SSME data analysis and interpretation must be passed to junior engineers and/or automated.

For the reasons outlined above, engineers in the Propulsion Systems Division at Marshall Space Flight Center recognize that it is highly desirable to articulate and capture SSME data analysis expertise and to automate, or at least reduce the level of expertise required for, some components of the analysis of SSME test data. The

project described in this paper is an attempt to move toward these goals through the construction of an SSME expert system data analysis manager:

An effort has been underway for the past several years at Rocketdyne (NASA's primary contractor for the SSME) to incorporate expert system technology into SSME test data analysis, c.f. [2], [3], [4], and [6]. The approach taken in that effort has been to use a selected database of SSME test results as source information for the inductive generation of expert system rules. The inductive-based expert system building tool ExTran7 has been the primary tool used.

The current effort at Marshall Space Flight Center adopts an approach different from that taken at Rocketdyne. The expert system envisioned has as its primary source of rules the direct articulation of the current methods and expertise being used by NASA engineers. This articulation is being accomplished using an expert interview technique, with interviews being focused on the investigation of past SSME test data reviews. In addition, a potential second source of expertise is being explored. This expertise would be in the form of rules generated by an inductive approach based on calculations produced by a theoretical model of the SSME. Rules induced from such a model would be used to supplement the human-derived expertise component of the system.

The expert system shell package Insight2+ was selected for the initial effort in this project. It was felt that Insight2+ provided enough capability to build a usable system. Furthermore, the simplicity and ease of use of Insight2+ has allowed an increased focus on the process of collecting and organizing the needed expertise, as compared to the use of a more complex tool, which would have required that more time be spent in the process of modelling and encoding the expertise. Evaluations will be performed later to see if there are needs which can not be satisfied by Insight2+, and if this is the case, the expert system will be translated to a more flexible and powerful expert system shell tool.

### Articulating Experiential Expertise

An important consideration in attempting to capture the experiential expertise being applied to SSME data analysis is that the persons possessing the highest level of such expertise are also the persons who are busiest in current SSME data analysis. Thus methods for such expertise capture had to be designed to be efficient and streamlined, because the needed experts' time is in short supply.

The expertise collection method used in this project is a modification of the traditional expert/knowledge engineer interview, with each interview being limited in scope to discussions and explanations of some significant past SSME anomaly analysis. It was decided that these interviews would be conducted in two segments, each segment typically lasting an hour or so. This two phase interview structure has some important advantages. After the initial interview segment, the knowledge engineer can formulate some tentative rules and in this process collect further questions and inquiries which must be answered before full-fledged rule construction can be completed. During the second interview segment (separated ideally by no more than one or two days from the first segment), a more complete articulation of the expertise to be modelled can be accomplished and the communication that occurred during the first interview segment can be checked and, if necessary, corrected.

To illustrate the pace and scope of such interviews, it is instructive to consider an example from the project. An expert interview focusing on two SSME tests focusing on two SSME tests involving fuel leak anomalies was conducted in two segments. The fault tree derived from this interview has a maximum depth of nine, with a three level goal/subgoal structure. One of the three main branches of the fault tree is shown in Figure 1.

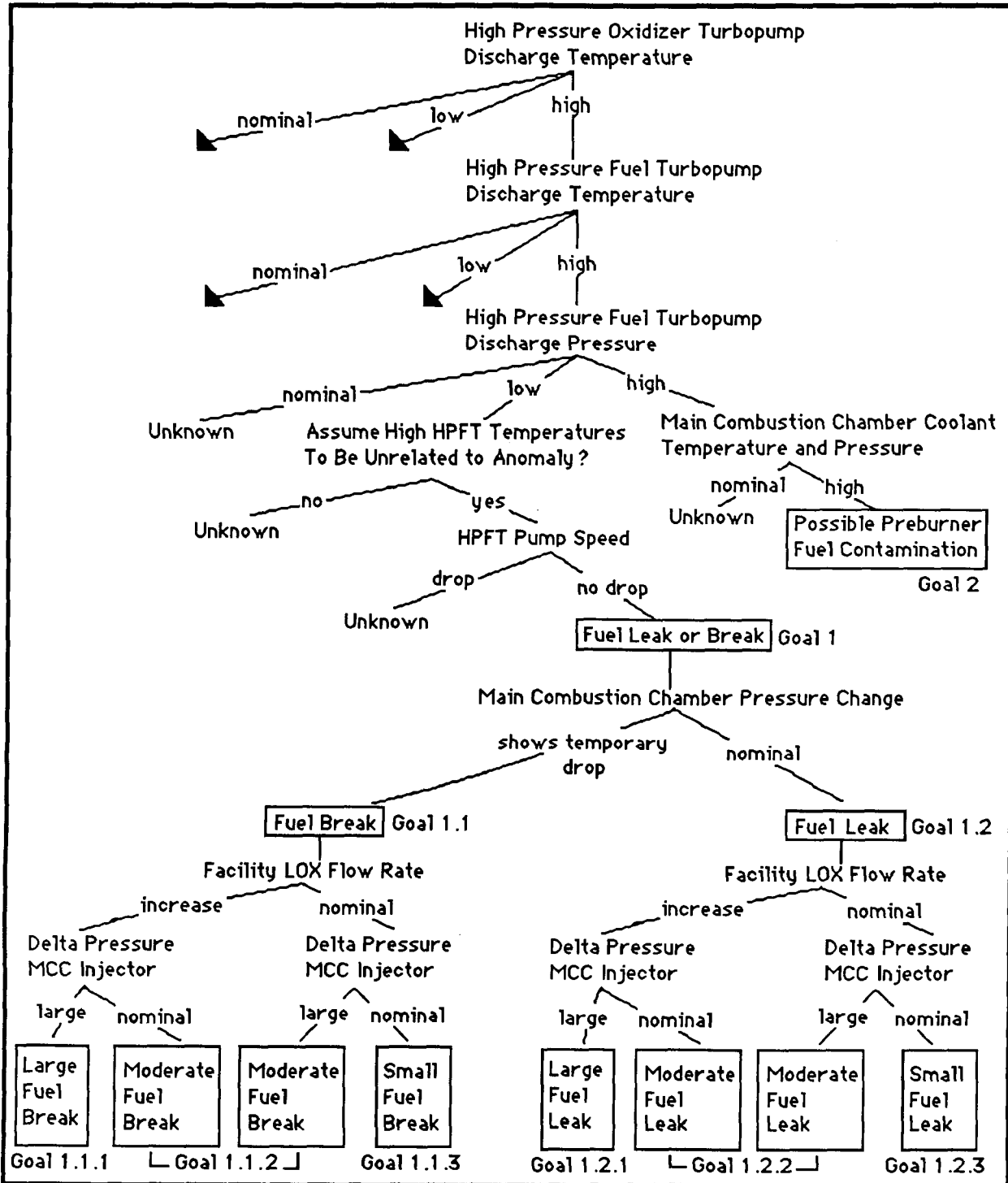


Figure 1: A Portion of the Example Fault Tree.

From the above interview, 19 rules were formulated and incorporated into the expert system rule base. Sixteen of these rules concluded some category of fuel leak, but three rules were derived for other anomalies. These other anomalies had been considered during the initial SSME data analysis for the tests under consideration and then dismissed. However, the hypothetical cases that were constructed for them before their dismissal provided the basis for the rules constructed.

In the tree in Figure 1, note the inclusion of the *Unknown* branches. These represent stubbed reasoning paths in the tree, and suggest possible directions for future expert interviews. Note also how the goal/subgoal structure is incorporated. When a goal at any level is reached, an appropriate report is given to the session user, and the user is invited to use the expert system's "explain" facility to further examine the reasoning applied to reach this goal or subgoal. This hierarchical structure has been designed explicitly to enhance the use of the resultant expert system as a training tool for novice engineers and to aid senior engineers in debugging and refining the expert system.

### Expertise Inductively Generated from a Model

One of the limitations of the rule articulation methodology described above is that it focuses primarily on building rules to recognize anomalies similar to those that have already been observed and analyzed. Of course, it is desirable to have rules that can also recognize and categorize anomalous engine behavior of a type that is being observed for the first time. One possible way of capturing such expertise, which would complement the human-derived expertise described above, involves generating rules indirectly from a theoretical model of the SSME. A model called the *power balance model*, developed jointly by NASA and Rocketdyne, would appear to provide this capability. This model is already being used for direct validation of suspected anomalies. The proposed indirect use of the model for inductive expert rule generation is described below.

The power balance model takes values for some chosen parameters as input and computes changes in predicted values for other related engine performance parameters. By modelling how a hypothetical anomaly will directly affect the values of some input parameters, the power balance model can be used to calculate the predicted effect the anomaly will have on other parameters. Using the model in this way, changes (or deltas) in critical performance parameters can be calculated for a range of anomaly conditions.

For example, nozzle fuel leaks of various magnitudes could be translated into the appropriate input parameter values to produce a calculated matrix of predicted deltas for the chosen performance parameters. The calculated deltas could then be categorized, and from the matrix of categorized deltas, diagnostic rules could be formulated.

A set of rules generated using the methods described above forms a flat (or nonstructured) rule base. Existing methods and programs, [1] and [5], can then be applied to convert this rule base to structured form and to produce a goal/subgoal hierarchy. A simplified hypothetical example situation is illustrated in Figure 2. The most difficult part of this complete methodology is representing the anomalies as model input. This activity often requires some adjustments to the model itself and requires an expert.

It should be possible to write programs to automate the entire process of categorizing the deltas, generating a rule set from the categorized delta matrix, and then converting this rule set to structured form for inclusion in the expert system rule base. Once this automation is accomplished, the calculation of the delta matrices and the definitions of the various delta categories could be changed when desired and the structured rule set automatically regenerated. It is anticipated that the current expert system will be expanded using this methodology in the future.

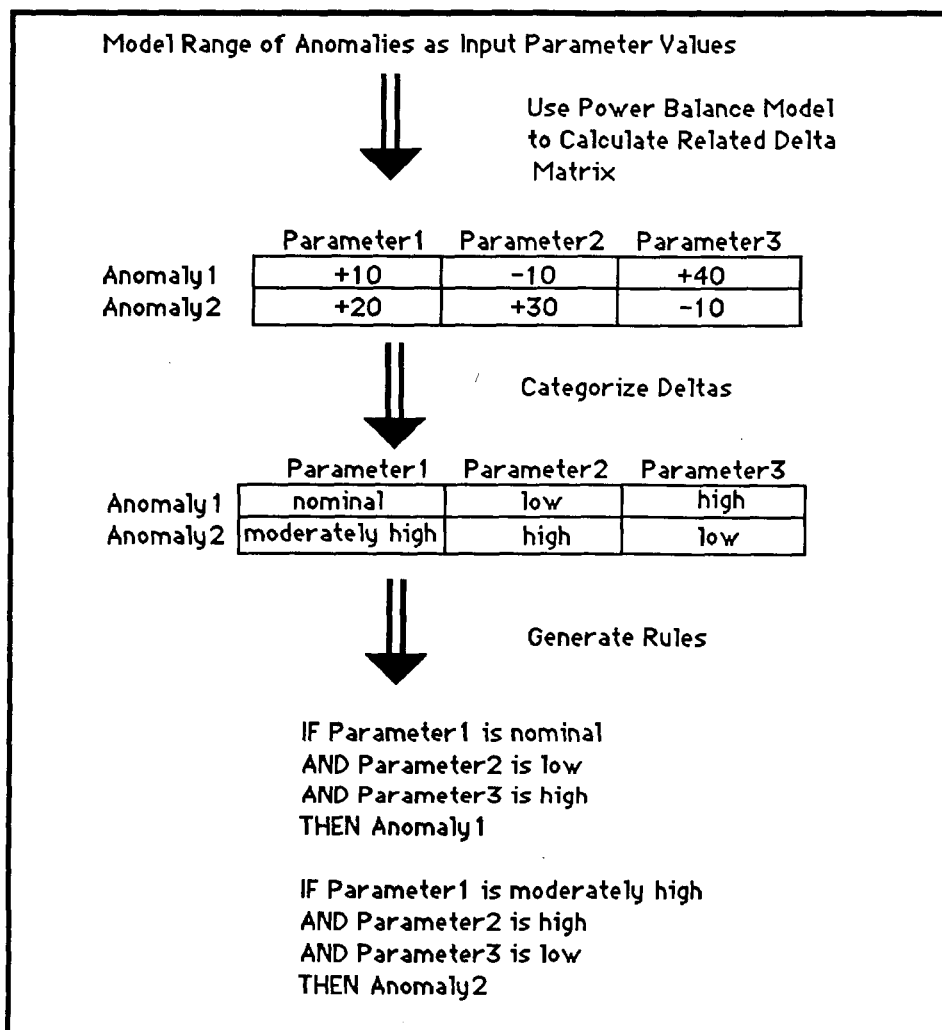


Figure 2: Using the Power Balance Model to Generate Rules.

### Conclusion

An SSME expert system data analysis manager containing directly collected human experiential expertise is being constructed. A methodology has been established for the collection of the expertise, and a significant amount of such expertise has been organized into the current version of the expert system. Particular attention is being paid to incorporating a goal/subgoal hierarchical

structure within the rule base, with appropriate reports given to the system user when goals or subgoals are reached. This structure will optimize the system's usefulness for the novice engineer and allow senior engineers more easily to refine and debug the system.

Expansion of the current expert system is planned through the inclusion of rules derived inductively from calculations made using a theoretical model of the SSME's operation. The goal is to automate the generation of such an inductively derived rule set, so that the model assumptions and the definitions of the parameter categories used in the rules can be easily changed. Such rules will complement the existing expert system's human-derived rules, and the combination of rules from both these sources will provide a rule base with expanded capabilities for identifying a wide variety of engine anomalies.

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