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An Expert System for Simulating Electric Loads Aboard Space Station Freedom

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Abstract

Space Station Freedom will provide an infrastructure for space experimentation. This environment will feature regulated access to any resources required by an experiment. Automated systems are being developed to manage the electric power so that researchers can have the flexibility to modify their experiment plan for contingencies or for new opportunities.

To define these flexible power management characteristics for Space Station Freedom, a simulation is required that captures the dynamic nature of space experimentation; namely, an investigator is allowed to restructure his experiment and to modify its execution. This changes the energy demands for the investigator's range of options.

We have developed an expert system competent in the domain of cryogenic fluid management experimentation. It will be used to help us design and test automated power scheduling software for Freedom's electric power system. The expert system allows experiment planning and experiment simulation. The former evaluates experimental alternatives and offers advice on the details of the experiment's design. The latter provides a real-time simulation of the experiment replete with appropriate resource consumption.

1 Introduction

The experiment chosen for simulation is Cryogenic Fluid Management (CFM) because we have access to both designs and investigators. The expert system tool chosen for building the simulation hinges on two needs: the simulator must replicate the investigator's ability to alter his experiment, and the simulator must be used to demonstrate automated power management strategies. The experiment flexibility issue requires capturing experiment operating knowledge and providing a human command and control system for selecting the many options. The automated power management demonstration issue requires the full fidelity of a human-interactive experiment without the overhead of a principal investigator to manage its complexities. Expert system development shells provide convenient features for building software to meet these requirements. First, they provide an environment for developing command and control displays. Second, they can capture data-dependent procedural knowledge. And third, they can provide expert consultation for neophyte experimenters.

In our application the experiment's fluid and thermal physics and power system interfaces are written in conventional procedural code using a LISP dialect. The agenda of the command and control activities is maintained and executed by goal-directed search through a set of rules. The rules are written to specify the circumstances under which advice is given, screens are displayed, or simulation code run. Menus are used to prompt for command responses.

2 Meeting the Needs

The purpose of the Cryogenic Fluid Management (CFM) expert system that has been developed is to enable a user, who may not be knowledgeable in cryogenic techniques, to successfully manage a cryogenic fluid system. Through this expert system's direction, the user is able to make logical decisions to efficiently govern the experiment and perform typical transfer and storage operations. The simulation also serves as an interactive electrical load within a computer-based representation of the Space Station Freedom electrical power system. The Space Station Freedom program is actively pursuing research and development in the areas of load scheduling and failure cause diagnosis using this experiment's power consumption model [1]. When using the CFM expert system, the operator will actually be functioning as a Principal Investigator (PI)

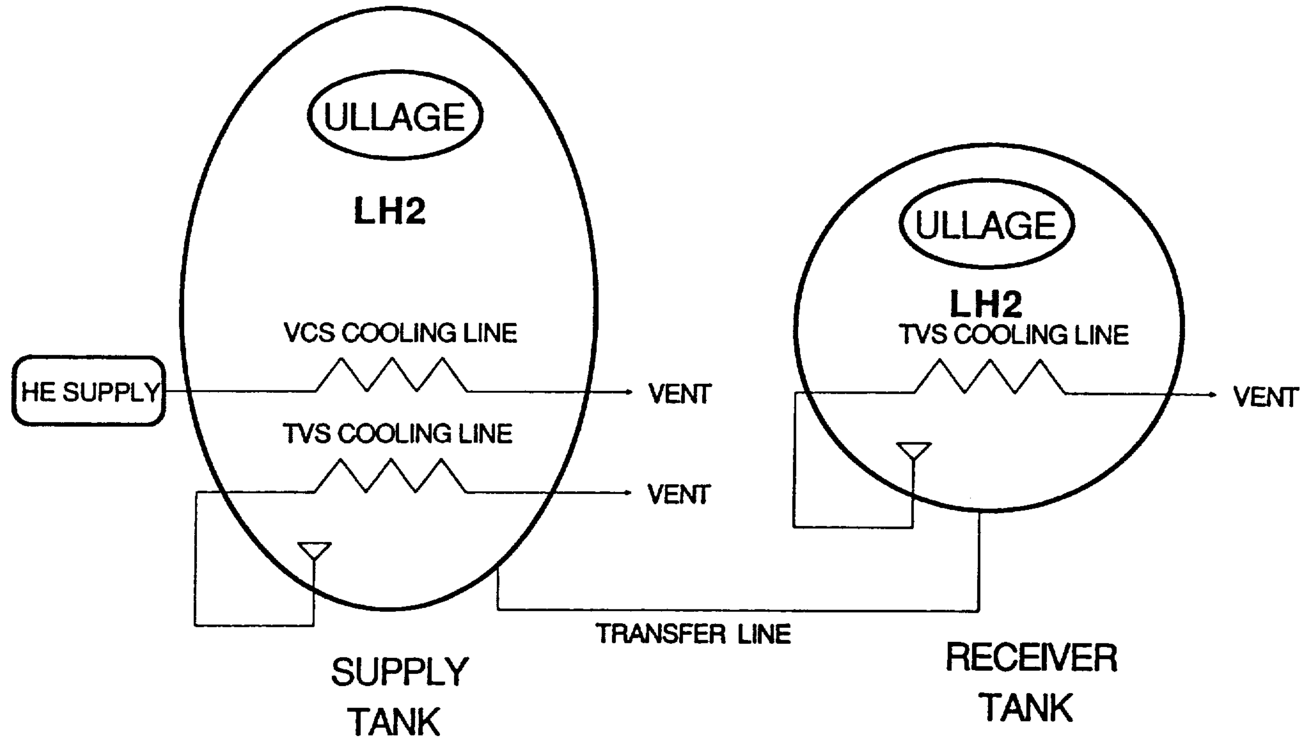

Figure 1: Cryogenic Fluid Management Experiment

on the Space Station Freedom.

The main objective in selecting which experiment to model was to choose a dynamic one that included a number of detailed, interactive processes that would impose significant scheduling constraints upon the automated power system. Cryogenic Fluid Management was an ideal choice due to the importance of monitoring and controlling the critical system states (e.g., tank pressure, temperature, etc.). The proper regulation of these dynamic states is the key issue in investigating transfer of fluids in zero gravity.

An expert system is advantageous when dealing with a system as dynamic as Cryogenic Fluid Management. The expert system's monitoring capabilities can check for extreme conditions and alert the operator to take appropriate action. In addition, the expert system guides the user through the varied experimental procedures of the CFM system by providing instruction and supervisory control. Lastly, the security and interdiction capabilities of the expert system prohibit the user from creating hazardous situations.

3 A CFM Expert System

3.1 The CFM Experiment

The Cryogenic Fluid Management system [2, 3, 4] that has been simulated consists of two tanks, a supply tank and a receiver, connected by a transfer line (Figure 1). The system is used to store and to transfer liquid hydrogen (LH2). Heat experiments are performed to evaluate the characteristics of the tanks. Due to the low boiling point of LH2 (20 deg R) and the resulting tank pressurization, the chief objectives of the system are to prevent LH2 boil-off and to control tank pressure. Two cooling systems are included to assist in overseeing the CFM system. These are the Thermodynamic Vent System (TVS) which pumps LH2 from the supply tank through a heat exchanger in the wall of the tank, and a Vapor-Cooled Shield (VCS) which is a helium-cooled shield surrounding the tank.

3.2 CFM Expert System Features

The features of the CFM expert system include automatic supervisory control, experiment option explanations, human-interactive planning using simulations, and power usage. These characteristics provide the information required for successful management of the CFM system.

Automatic Supervisory Control

Automatic supervisory control was implemented to ensure that necessary events are instantiated. Due to the heat of the environment and the low boiling point of LH2, tank pressure is a critical parameter. Instead of forcing the inexperienced operator to recognize the limits, ventilation of the tank is automatically initiated by the expert system. Supervisory control is also used to override decisions made by the operator that are illogical or possibly dangerous (e.g., using the cooling system to cool an empty tank). If such a condition is chosen, the top-level guidance rules block the action and send a message to the operator explaining the situation.

Option Explanation

Explaining the experiment's options of the CFM system is an integral aspect of the model that describes the terms and processes involved. Aside from listing the available options, the expert system must provide sufficient information to familiarize the operator with the experiment operations. Menus are used to present basic options to the user. After choosing an operation (e.g., tank fill, pressure experiment, etc.), the system guides the operator through each step of the process. On-line text and graphics are displayed to explain the current step while the operator is prompted for the necessary input. If requested at the main menu, the system will also provide advice to help the operator choose the next operation based on the current system conditions.

Experiment Planning and Simulation

The expert system and its thermodynamic simulation can be used in either of two ways: as an experiment planner or as a simulation of a planned experiment. The former defines the particular procedures while the latter simulates actually conducting the experiment. During the planning mode, variable parameters are selected for a particular part of the experiment. This part is simulated using these parameters and the results displayed to the experimenter. This simulation can be repeated any number of times to determine the effects of any independent variables. This feature allows the operator to estimate the results that different inputs (e.g., LH2 flow rate, pressure setting, etc.) will have on the CFM system before actually conducting the experiment. For instance in the planning mode of a transfer line chill-down, the user might discover that doubling the LH2 flow rate would only decrease the cooling time by thirty minutes. The user, benefitting from this knowledge, would be able to choose a lower, more efficient LH2 flow rate.

Once the user is satisfied with the estimates from the planning mode, he may perform the actual experiment. Since we really do not have the actual hardware, the fluid dynamic model is called upon once again—this time with the set of procedures and experimental parameters chosen during the planning phase—to simulate the experiment's execution.

Power Consumption

The CFM expert system, aside from demonstrating the benefits of expert systems, will act as an electrical load within the power system model. When the CFM expert system is initiated, a base amount of power is assumed to operate the system. In performing different CFM operations, other power consuming components are activated or deactivated. The total CFM system load is recorded and stored in the LISP environment. Each time the CFM electrical load changes, the total load is "time-stamped." From this information a power profile can be constructed. This load profile can then be accessed by the power system model, and used during automated load management [5].

3.3 General Operation

Two sections comprise the CFM expert system. The actual simulation of the cryogenic system was designed within a LISP environment while the rule-structure essential to govern the CFM system was developed using PC+, a Texas Instruments expert system software package.

All of the dynamic states needed to identify the CFM system are stored in a LISP environment. LISP routines, which are stored in the same environment, were written for each process that manipulates these system states.

The expert system is made of a number of modules called frames. Control of the program is transferred from frame to frame as certain operations are performed and different inputs are selected. Each frame has a goal associated with it that is the driving mechanism in evaluating the affected if-then rules of the frame. Through backward chaining the rules associated with a certain frame are tested in a sequence governed by an ordering function (utility) and system conditions in order to achieve the goal of the frame. This method permits the firing of specific rules to enable the desired action. The net result is a depth-first search through possible solutions generating a new subgoal at each step and searching for a way to satisfy it. If a subgoal is found, the solution is propagated back to the top goal; otherwise, the search routine backtracks to the last decision fork and begins a subgoal search down one of the other branches.

General operation of the program follows a basic loop (Figure 2). The expert system guides the operator through possible CFM options. Once an action is chosen, its corresponding LISP routine is called and evaluated. The updated system states are imported to the expert system. The operator chooses another expert system option and the process repeats itself.

3.4 Thermodynamic Principle

The basic assumption of the simulation is that a certain amount of heat Q *(BTU)* from the environment is added to the CFM system during each time period Δt (*sec*). The tank states include:

P The pressure within the tank.

m The mass of the H2 vapor.

V The volume of the H2 vapor.

T The temperature within the tank.

Given:

Q and the tank states at time = k: $P(k)$, $m(k)$, $V(k)$, and $T(k)$

The updated tank states $P(k+\Delta t)$, $m(k+\Delta t)$, $V(k+\Delta t)$, and $T(k+\Delta t)$ can be found using the following four equations:

$$Q = H_v \Delta m + C_v m(k) \Delta T$$

where H_v equals the heat of vaporization and C_v equals the specific heat.

$$144PV = mRT$$

the ideal gas law.

$$\Delta m = 4.2 \Delta V$$

where LH2 density equals 4.2 lbm/ft^3

$$\Delta P = 7.554 \Delta T$$

an estimate of the P-T equilibrium line, which is the line where both liquid and vapor states exist.

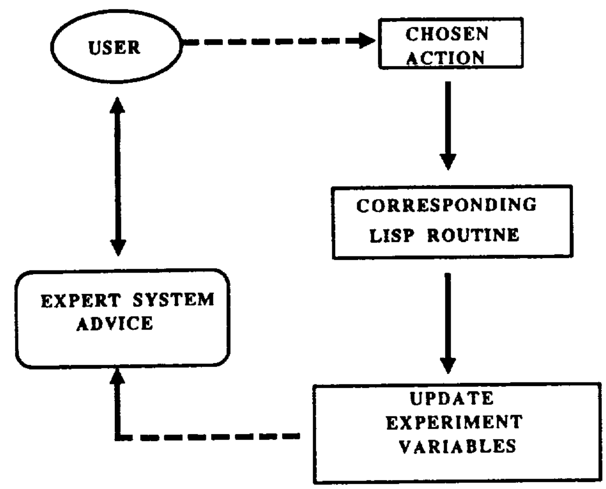

Figure 2: General Operation

Solving the above equations for delta T results in a quadratic equation whose solution in the affected range has one positive and one negative root. The positive root is the desired solution and is used to directly solve for $T(k+\Delta t)$. Through substitution the other system states are then found.

4 Conclusion

Based on the above thermodynamic principles, a viable LISP simulation of a cryogenic fluid system has been constructed. The expert system developed using PC+ software permits a person unfamiliar with Cryogenic Fluid Management to manage this simulation and effectively demonstrates the advantages of an expert system for providing advice and control.

Using an expert system tool greatly simplifies the management of the CFM simulation code. Without the aid of the backward-chaining rule structure, procedural code would have to be written that accounts for every possible situation. The rule structure combines user input and current system conditions to efficiently recognize the appropriate simulation code. Therefore the expert system enables a designer to develop a more straightforward and organized simulation in a shorter amount of time.

The software can be used either to plan experiments or to simulate automated execution of experiments. Power versus time profiles are generated for each activity. These power profiles will be used with automated resource managing systems to plan electric power utilization. The expert system environment has allowed us to rapidly construct a human-interactive, system

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References

[1] J. L. Dolce, P. A. Mellor, and J. A. Kish, "Automated electric power management and control for Space Station Freedom," in *Proc. 25th Intersociety Energy Conversion Engineering Conference*, AIChE (1990).

[2] *Cryogenic On-Orbit Liquid Depot Storage, Acquisition and Transfer Satellite (Cold-Sat) Feasibility Studies,* Martin Marietta, 2(Design Concept), MCR–88–1397/DID C-1/NAS3-25063 (Aug. 24, 1988).

[3] *Cold-Sat Concept Review,* Ball Aerospace Systems Group, Task II/DID C-1/NAS3-25064 (Aug. 23, 1988).

[4] *Feasibility Studies of Cryogenic On-Orbit Liquid Depot Storage, Acquisition, and Transfer Satellite,* General Dynamics Space Systems Division, Technical Presentation/NAS3-25062 (Aug. 25, 1988).

[5] P. A. Mellor, J. L. Dolce, and J. C. Krupp, "Electric power scheduling: a distributed problem-solving approach for Space Station Freedom," in *Proc. 25th Intersociety Energy Conversion Engineering Conference,* AIChE (1990).