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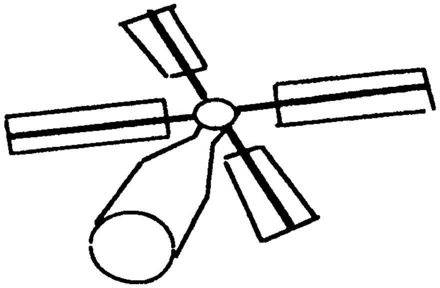
The Environmental Control and Life Support System Advanced Automation Project

Brandon S. Dewberry
NASA / George C. Marshall Space Flight Center
System Software Branch / EB42
Marshall Space Flight Center, AL 35812
(205) 544-4247
NASAMail : BDEWBERRY
email : brandon@deputy.msfc.nasa.gov

Environmental Control System History



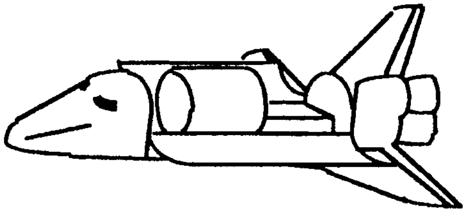
SkyLab

Systems:

- air conditioning
- trace contaminant control
- carbon dioxide removal
- long duration consumables supported by ground resupply

Controls:

- embedded analog circuitry with ground supervision
- open-loop (scheduled) control



Shuttle / SpaceLab

Systems:

- air conditioning
- trace contaminant control
- carbon dioxide removal
- some oxygen generation
- short duration consumables

Controls:

- embedded analog circuitry with some flight software supervision
- firmware controllers introduced into subsystems
- scheduled control

Space Station Freedom ECLSS Description

The Space Station Freedom ECLSS can be divided into 2 parts: Environmental Control, which is the air conditioning part, and Life Support, which is the regenerative part that supplies air and water to the crew.

Environmental Control contains trace contaminant control, the temperature and humidity control, and atmospheric pressure control subsystems.

Life Support contains air revitalization which is carbon dioxide removal, carbon dioxide reduction, and oxygen generation, as well as water recovery management which recycles waste water after use.

The interaction of these reclamation subsystems (air and water) is minimized by gas and water tankage in between the subsystems. This minimizes the control complexity similiar to using a large amount of fuel in the carberator to minimize dependency on fine tuned parameters.

Hardly any controls are RLC (Analog circuits). Embedded firmware (software which has been made permanent in controller) is extensively allocated to each subsystem, with some flight software supervision on-board to manage system change-over and interaction.

The system is still controlled basically open-loop, meaning that chemical and gaseous constituents are not used overall to change system setpoints - but mostly checked occasionally to verify the health of the system.

The system is heavily monitored and timed, scheduled control is used.

Space Station Freedom ECLSS

FREEDOM

Systems:

- air conditioning (environmental control)
- trace contaminant control
- air revitalization also includes carbon dioxide removal, carbon dioxide reduction, and oxygen generation
- waste water is recycled after use
- reclamation subsystem interaction minimized by tankage
- long duration resupply minimized by recycling air and water

Controls:

- embedded firmware with some flight software supervision
- still basically open-loop, heavily monitored, scheduled control

Restructured Regenerative ECLSS Description

This is a picture of the regenerative ECLSS subsystems after restructure removed the separate hygiene recovery loop. Air Revitalization (AR) subsystems are lightly shaded, Water Reclamation (WR) subsystems have dark waves, and the Temperature and Humidity Control (THC) subsystem is shaded with alternating dashes.

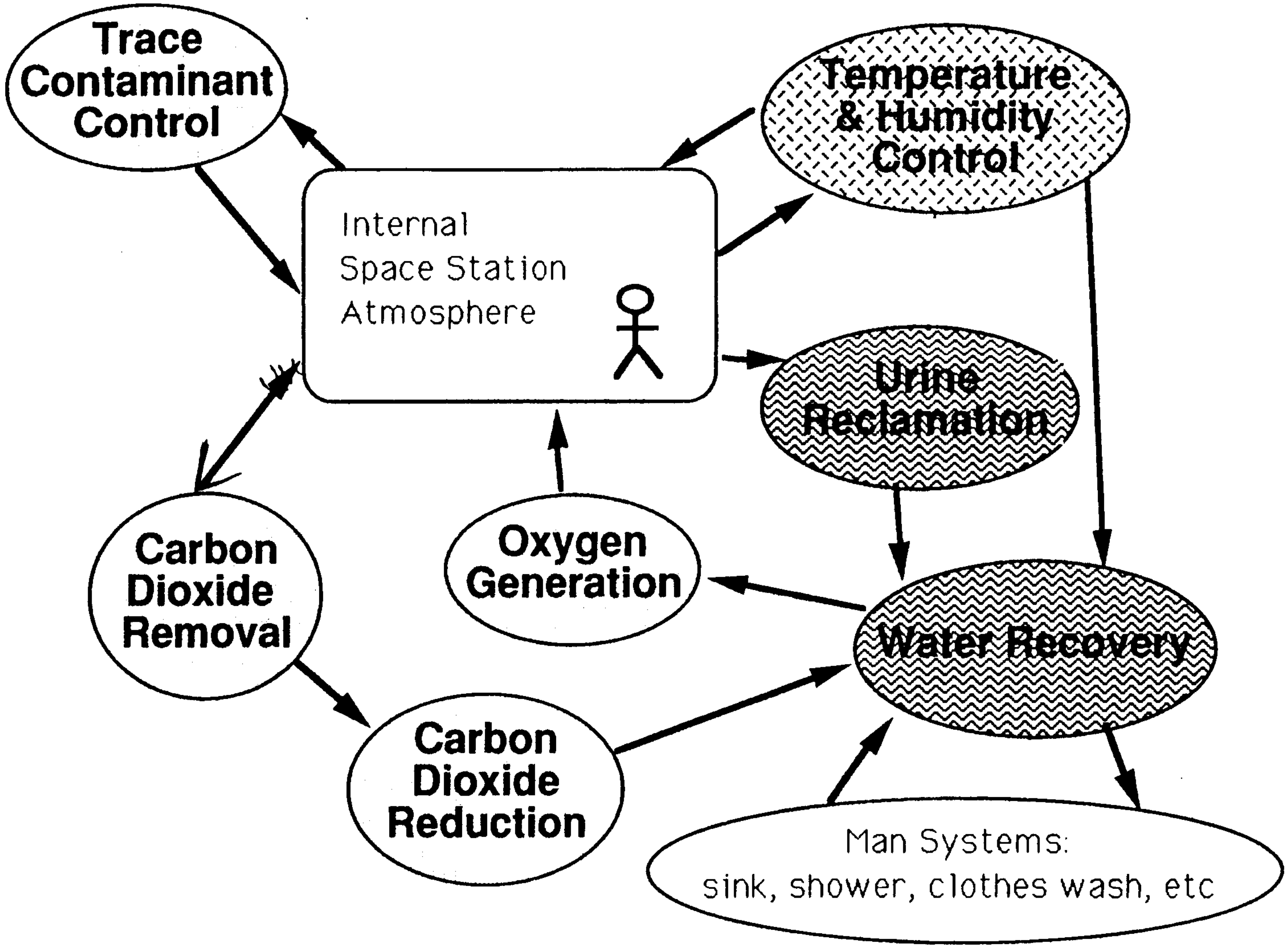
The Space Station Freedom ECLSS supplies air and water to the crew by regenerating oxygen from the overabundance of water, and reclaiming waste water and condensate.

These complex interacting subsystems will be developed and integrated in parts - the temperature and humidity control, trace contaminant control, and carbon dioxide removal subsystems will be the extent of the initial ECLSS subsystems during Man-Tended Operations. Water Recovery will be gradually integrated and operational at the Permanently Manned Configuration (PMC). The oxygen used by four crew members in 90 days does not present a logistics barrier, so Air Revitalization Components CO2 Reduction and Oxygen Generation, do not come online until Eight Man Crew Operations.

Notice that the Water Recovery System is the end of the line for contaminants in the air and water - where the buck stops - and chemical and microbial faults would propagate to this reservoir.

The ECLSS Advanced Automation Project

Restructured Regenerative ECLSS



Software Architecture

This is a cartoon of the ECLSS software architecture. Flight software is shown on the left inside node and lab module boxes. Ground software is shown at right in the ECLSS sustaining engineering facility.

During scrub activity in FY90 and restructure activity in FY91 all sensors and software which were not required for "real-time" control and fault detection was moved to the ground.

On board the software can be divided into hard real-time and soft real-time. Hard real-time is control code in which a delay in response can cause a failure. Soft real-time is supervisory code in which a delay in response will cause a degradation of performance, but not a failure.

On-board fault detection of realtime processes is contained in both hard real-time and soft-realtime software.

All ground software is a combination of soft real-time or non-real-time software.

Fault detection is finding that a fault has occurred. Fault diagnosis is discovering which component of the subsystem caused the fault and how it occurred.

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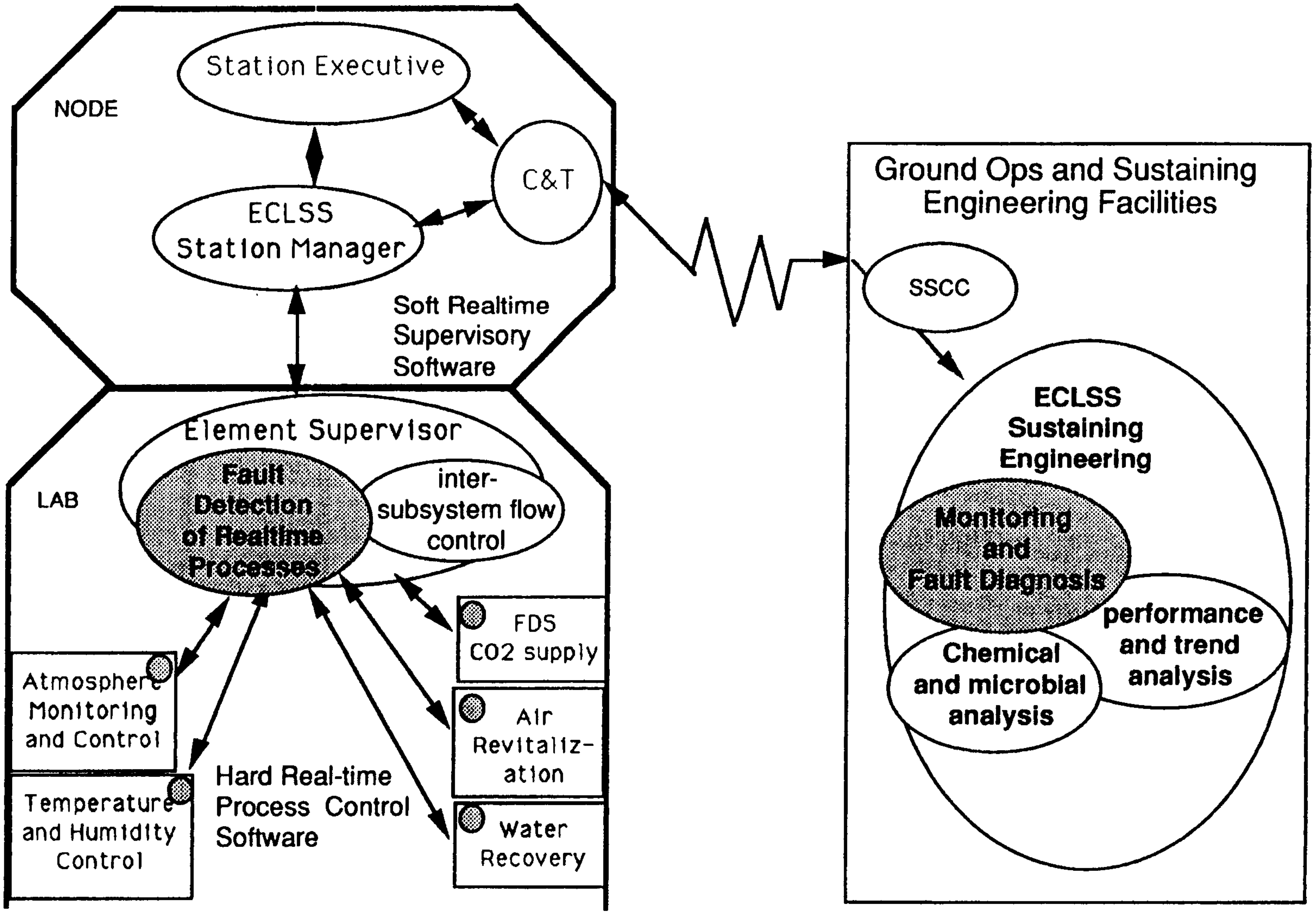
Software Architecture



The ECLSS Advanced Automation Project

Objectives Description

The objectives of the ECLSS Advanced Automation project include reduction of the risk of associated with the integration of new, beneficial software techniques. Our prime contractor has a certain conservative attitude toward advanced software - or non-advanced software for that matter.

In order to alleviate MSFC and Prime Contractors' concerns over development of diagnostic and control systems which maximize ECLSS operational functionality while meeting development constraints.

Demonstrations of this software to baseline engineering and test personell will show the benefits of these techniques. The advanced software will be integrated into ground testing and ground support facilities, familiarizing its usage by key personell.

The ECLSS Advanced Automation Project

Objectives

Reduce the risk of integration of new, beneficial software techniques.

Develop diagnostic and control systems which maximize ECLSS operational functionality while meeting development constraints.

Demonstrate to baseline engineering the benefits of these techniques by integrating them into ground testing and ground support.

Benefits Description

Reduced Instrumentation without decreasing functionality can be achieved by using models of the system to diagnose faults rather than dedicate sensors for fault diagnosis.

Reduced Crew IVA to trace and fix faults in the system is achieved by isolating the fault to a component which can be replaced. Testing for isolation should be minimized.

Currently, large Orbital Replaceable Units (ORU's) are being designed, for instance, the Condensing Heat Exchanger, the main component of the Temperature and Humidity Control subsystem, is approximately a 3x3x3 box which is an ORU. The consequences are that faults are isolated only to this large black box and a spare box this large must be available to fix a fault in this system.

Inhanced Safety by persistent, consistent monitoring. The software proposed is not artificially intelligent. It simply automatically monitors the subsystems for faults and reports it, then helps the operator to isolate that fault to a component. It performs the monitoring day and night, presenting the operator with consistent results of its analysis.

Increased Productivity by presenting information rather than data. The operators first job looking at the sensor values of a system being monitored is to form a mental model of the system. This software will assist the operator to perform this function.

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Benefits

Reduced Instrumentation without decreasing functionality.

Reduced Crew IVA to trace and fix faults in the system.

Inhanced Safety by persistent, consistent monitoring.

Increased Productivity by presenting information rather than data.

Technical Approach Description

This is basically an outline of the Technical Approach section which is the main portion of this presentation. This section is divided into:

Model-Based Fault Detection and Diagnosis - a brief overview and example of the technology,

Graphical User Interfaces which we've developed to increase operator productivity while showing the performance of the system,

Predictive Monitoring of Complex Systems will be discussed somewhat by Dr. Richard Doyle of JPL, and will not be addressed in this presentation. It will be mentioned on the distributed computing environment slide.

Distributed Computing Environment overhead will show in general how these tools fit together into a concise whole.

Specific Implementation outlines the hardware and software tools for development and delivery of this software.

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Technical Approach

Model-Based Fault Detection and Diagnosis

Innovative Graphical User Interfaces

Predictive Monitoring of Complex Systems

Distributed Computing Environments

Specific Implementation

Model-Based Diagnosis Description

Model Based Fault Detection and Diagnosis are two processes which rely on the same structural and behavioral model of the system.

Nominal behavior - defined by the computer model - is compared with the behavior of the system. The computer has access to command changes and resulting sensor value changes.

Fault detection is reporting to the operator when a descrepancy exists between nominal and system behavior. The model is run in parallel with the system and modeled sensor values are compared with system sensor values.

Fault detection is the act of finding out which specific component caused the failure. This is achieved by comparing sibling sensor values of the faulty sensor and by inverting the component transfer functions to determine the possibility of the upstream component causing the fault.

Two things separate this technique from traditional associational approaches:

1) sensors are part of the component model, and diagnosis of sensor faults is as easy as diagnosis of other component faults (not so in associational fault diagnosis).

2)any off nominal behavior is considered a fault, an exhaustive list of all fault possibilities is not required (as in associational fault diagnosis).

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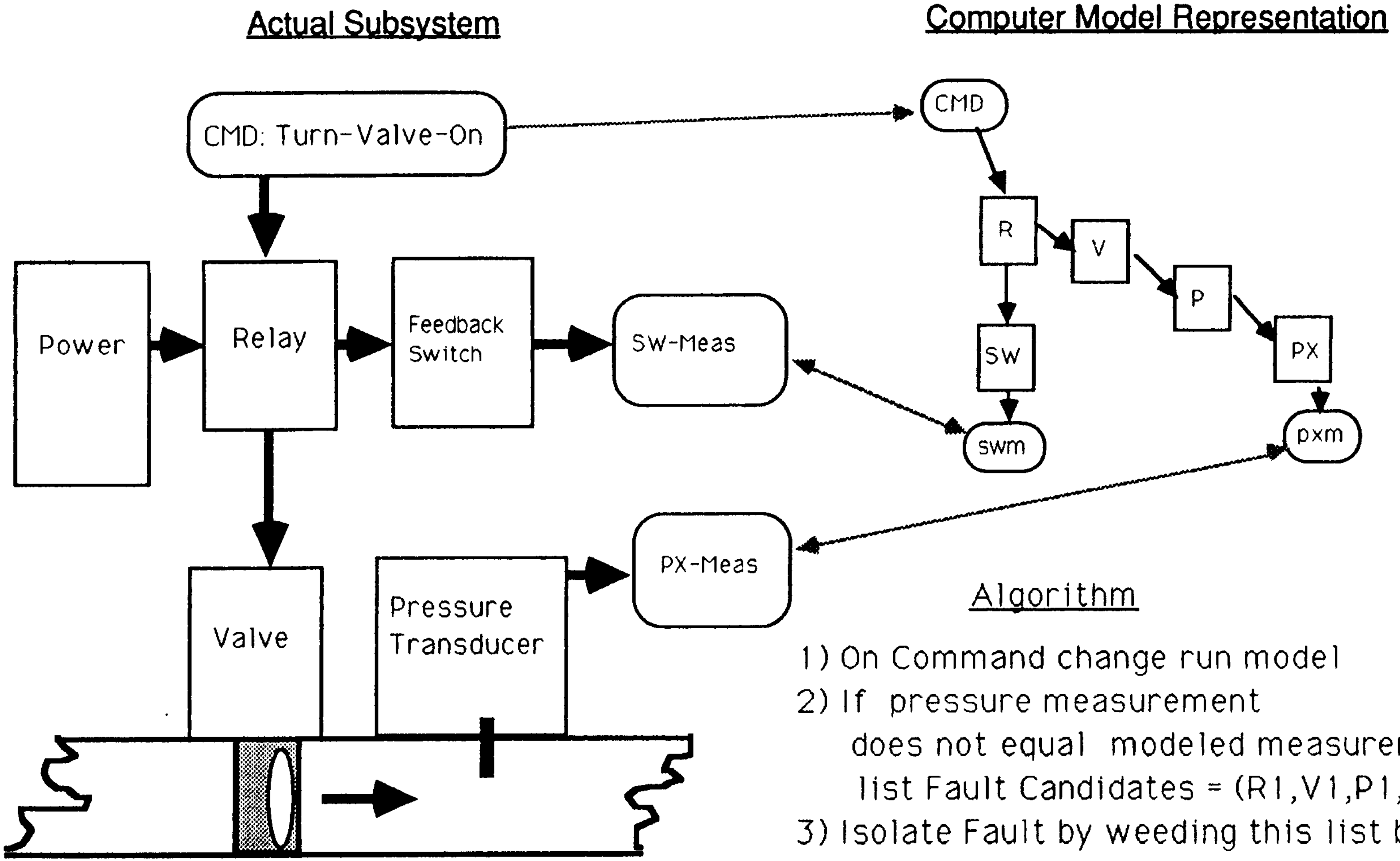
Model-Based Diagnosis



Algorithm

1) On Command change run model
2) If pressure measurement
   does not equal modeled measurement
   list Fault Candidates = (R1,V1,P1,PX)
3) Isolate Fault by weeding this list by
   checking sibling sensors and
   back propogation of the discrepancy

Results from Reverse Osmosis Analysis Description

We have developed Model Based Fault Detection of the Reverse Osmosis Hygiene Water Recovery Subsystem. Reverse Osmosis was a competing technology for water recovery. Its complexity provided a good proof of concept at the time.

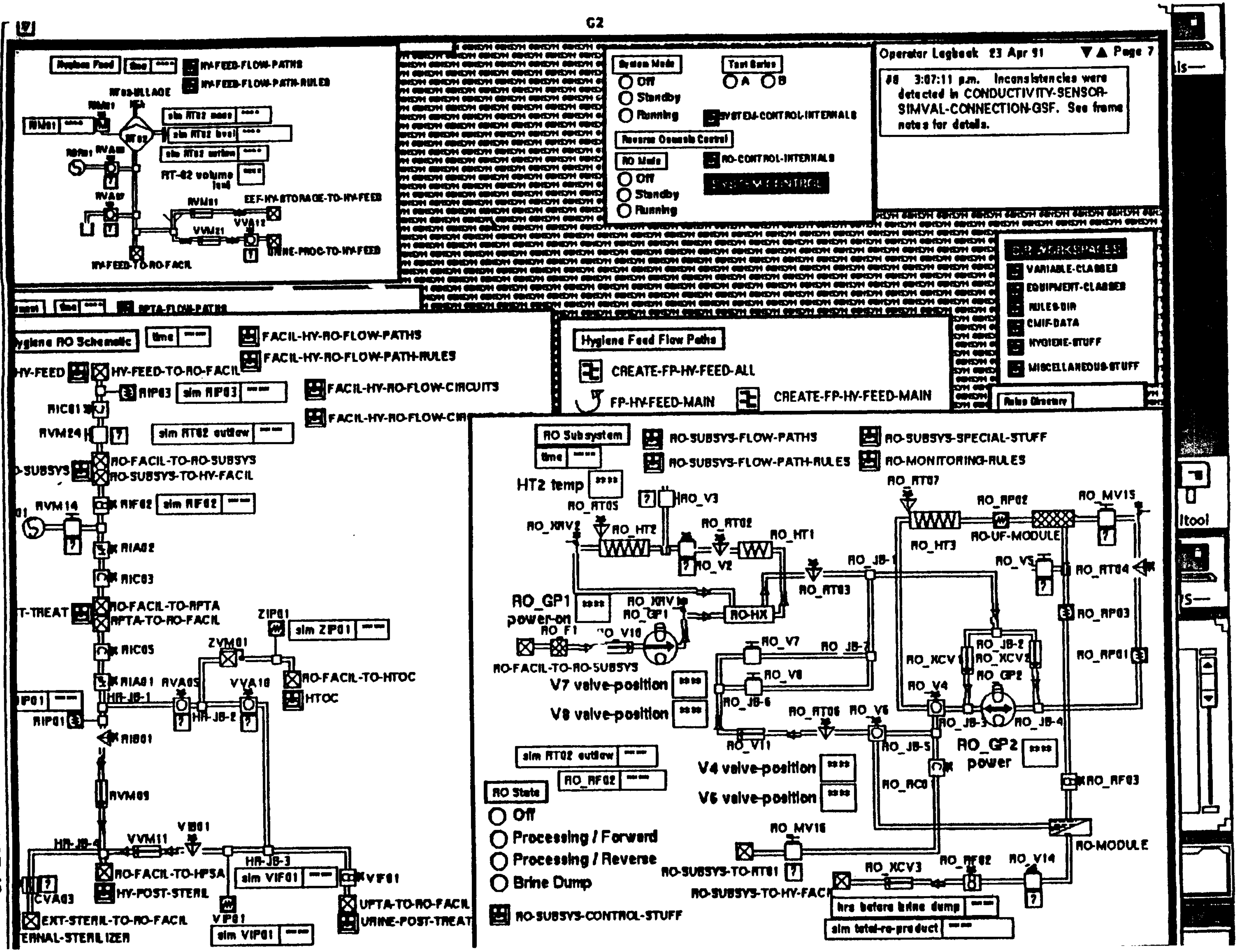
Subsequently, this subsystem was pulled from the baseline in favor of Multifiltration (MF). Apparently, the complexity of the system was more detrimental than the MF's resupply of unibed penalty.

Even though we lost some work in that we possibly could have had the prototype developed and integrated this year, 3 things were learned from this study:

1) component models are still valid - pumps, valves, and tanks have very similar models in any system,

2) a multiaspect equation solver is needed to model these complex flow systems,

3) the commercial tool, G2, is a fine tool for model-based fault detection, but not suited for Model-Based Diagnosis. The reason is the difficulty in answering questions about the model in software - reasoning about the model components themselves.



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Environmental Control System History Description

SkyLab

The Skylab system was mostly an elaborate air conditioning system. It was not called a life support system but simply an environmental control system. Resupply from the ground, in general, implies the system is an environmental control system and not a life support system.

This basic air conditioning system is augmented by Trace contaminant control (TCC) and CO2 removal capabilities. TCC filters the air of small (trace) amounts of unwanted constituents, usually by activated carbon beds. Carbon dioxide removal lowers the amount of CO2 in the air.

Long duration consumables supported by ground resupply, no recycling of crew wastes to minimize resupply. At this time NASA knew recycling the wastes was the way to go for a permanent space station, but at the time the process and computer technology could not support it.

The skylab subsystems were controlled with embedded analog circuitry, (RLC circuits), with ground supervision. Subsystems, such as heat exchangers, operated continuously based on a built-in setpoint, or had scheduled mode changes.

Shuttle / SpaceLab

Similar to skylab, the Space Shuttle and Spacelab systems were basically elaborate, augmented air conditioning systems. TCCS and CO2 removal were improved over Skylab, while some oxygen generation by electrolysis of water has been experimented with in preparation for a long duration space station.

The controls used are mostly embedded analog circuitry with some flight software supervision. For instance the partial pressures of oxygen and nitrogen are controlled by a ppO2 sensor tied to an O2/N2 flapper valve. This method would not work in a large area with pockets of air. Complete, instantaneous mixing is assumed.

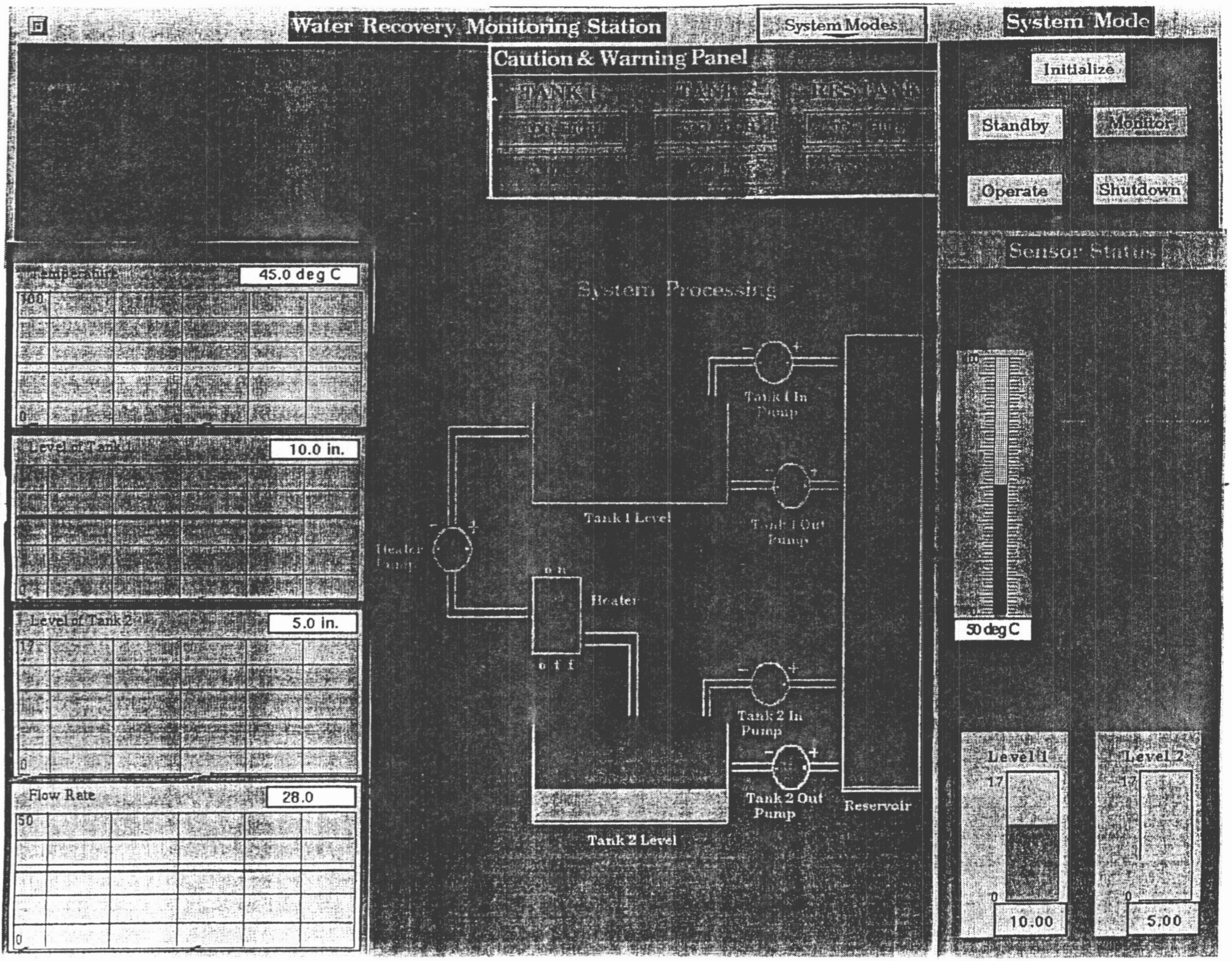
The control software contains firmware controllers (eg. GCMS control), and scheduled, open-loop, test-it-on-the-ground-and-hardwire-the-parameters is still the norm.

Graphical User Interface Description

This is a screen dump of a graphical user interface for a prototype water recovery subsystem.

Extraneous devices, such as multiple input tanks, are not shown on the interface so that it may have more room to deliver the information which the operator needs. Strip charts are included because the operators interviewed insisted that this would be the most valuable feature.

This is a first cut - duplication of sensor data has been avoided in the next version and the central drawing made bigger.



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Distributed Computing Environment Description

This is a cartoon of the overall architecture of the system. The integrated system is fed by a model of the structure and behavior of the system, as well as time-tagged data of system operation in the testbed.

The processing is divided into 3 separate processes:

1) KATE, the Kennedy Automated Test Engineer process, is our development system for Model-Based Fault Detection and Diagnosis.

2) TAE+, which uses the X Windowing System, is a software tool from GSFC which allows easy prototyping of graphical user interfaces. It is being used to display the system state as well as the performance of the KATE system.

3) Predictive Monitoring is a place-holder for the system from JPL which will allow us to determine dynamic sensor, component, and window prioritization for complex system monitoring.

KATE and the TAE+ system run on separate computers.

The common model is the glue which is the basis for each process and allows separate development and delivery with integrated performance.

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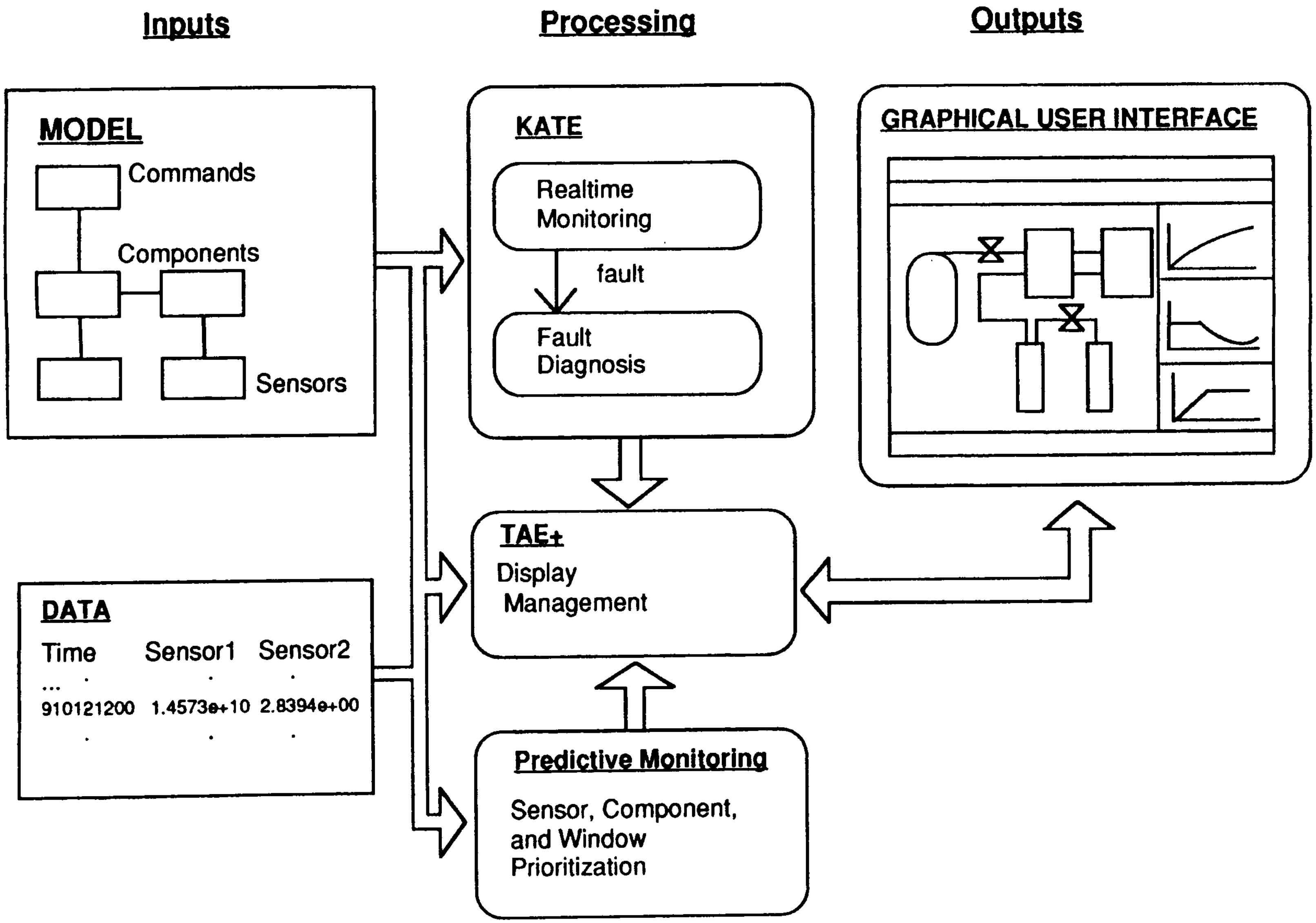
Distributed Computing Environment



Inputs

MODEL

Commands

Components

Sensors

DATA

Time	Sensor1	Sensor2
... .	.	.
910121200	1.4573e+10	2.8394e+00
.	.	.

Processing

KATE

Realtime Monitoring

fault

Fault Diagnosis

TAE+

Display Management

Predictive Monitoring

Sensor, Component, and Window Prioritization

Outputs

GRAPHICAL USER INTERFACE

Implementation and Tools Description

Model Based Diagnosis currently being developed using KATE on a Symbolics. This is an antiquated environment, but suitable for functional proof of concept.

Future plans are to port this functionality to a UNIX environment. Sun Sparcstations are being used, but any high-performance UNIX-based workstation should work for delivery.

Graphical User Interface development uses the X Window System with TAE+. This supports a portable GUI, which is one of the holdups of the KATE system.

ECLSS Predictive Monitoring development is compatible. Although Dr. Doyle's presentation which follows concerns selective rather than predictive monitoring, the basics are the same and software from the effort is compatible.

Implementation and Tools

Model Based Diagnosis currently being developed using KATE on a Symbolics.

Future plans are to port this functionality to a UNIX environment.

Graphical User Interface development uses the X Window System with TAE+.

ECLSS Predictive Monitoring development is compatible.

Baseline Integration Description

After RO was dropped from the baseline we had to go looking for another subsystem to begin with, proving out concept. The CDRA was picked for 2 reasons:

1) the complexity of the component interaction was viewed as an asset, as the test engineers stated, "if you can automatically diagnose this system, I'll be convinced that you can automatically diagnose any in Water Recovery."

2)the testing of this system in 92 supported our demonstration schedule.

A viewgraph of this subsystem and how we fit into the test schedule is coming up.

The Boeing AI Center is involved with ECLSS testing by developing Oracle database interfacing software. This is another foot in the testbed door which doesn't hurt.

Direct interface for monitoring the prototype CDRA subsystem (four bed molecular sieve) has been agreed upon. An RS232 line directly from the subsystem will be used to start with, bypassing the main data aquisistion computer. As the Fault Diagnosis system gains more subsystem functionality, the data aquisition computer will be used.

Already allocated a spot in the testbed area to develop software and unobtrusively monitor tests. This was a harder problem than it seems. Each square foot of space in the testbed area is allocated. It is proof of Test Lab support that we have a spot.

"Testing support Equipment is Ground Support Equipment" is a quote from restructure. This implies that since we are helping to develop test equipment, then by default, we are developing ground support equipment because the same equipment is designated to migrate to the ground support facility.

Baseline Integration

We began development and integration of the Carbon Dioxide Removal Assembly (CDRA) Advanced Monitoring application for the ECLSS Preliminary Operational Systems Testbed (POST).

Our group is already configuring the sensor database for baseline testing, and will be involved in other ECLSS testbed software development activities.

Direct interface for monitoring the prototype CDRA subsystem (four bed molecular sieve).

Already allocated a spot in the testbed area to develop software and unobtrusively monitor tests.

"Testing support Equipment is Ground Support Equipment"

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CDRA Viewgraph Description

This is the Carbon Dioxide Removal Assembly. This is the system we plan to develop prototype model-based detection and diagnosis software for.

It uses the Molecular Sieve Technology to remove CO2 from the air.

It operates using scheduled control, air blows one way for a while removing CO2, then the oposite way to push the CO2 absorbed out of the system for venting or reduction.

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ECLSS Testbed Description

This is the outside of the ECLSS Core Module Simulator Testbed.

BLDG 4755 MSFC

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Control Room Viewgraph Description

This is the control room for the core module simulator testbed.

The main displays have operators watching text numbers on VT240 terminals.

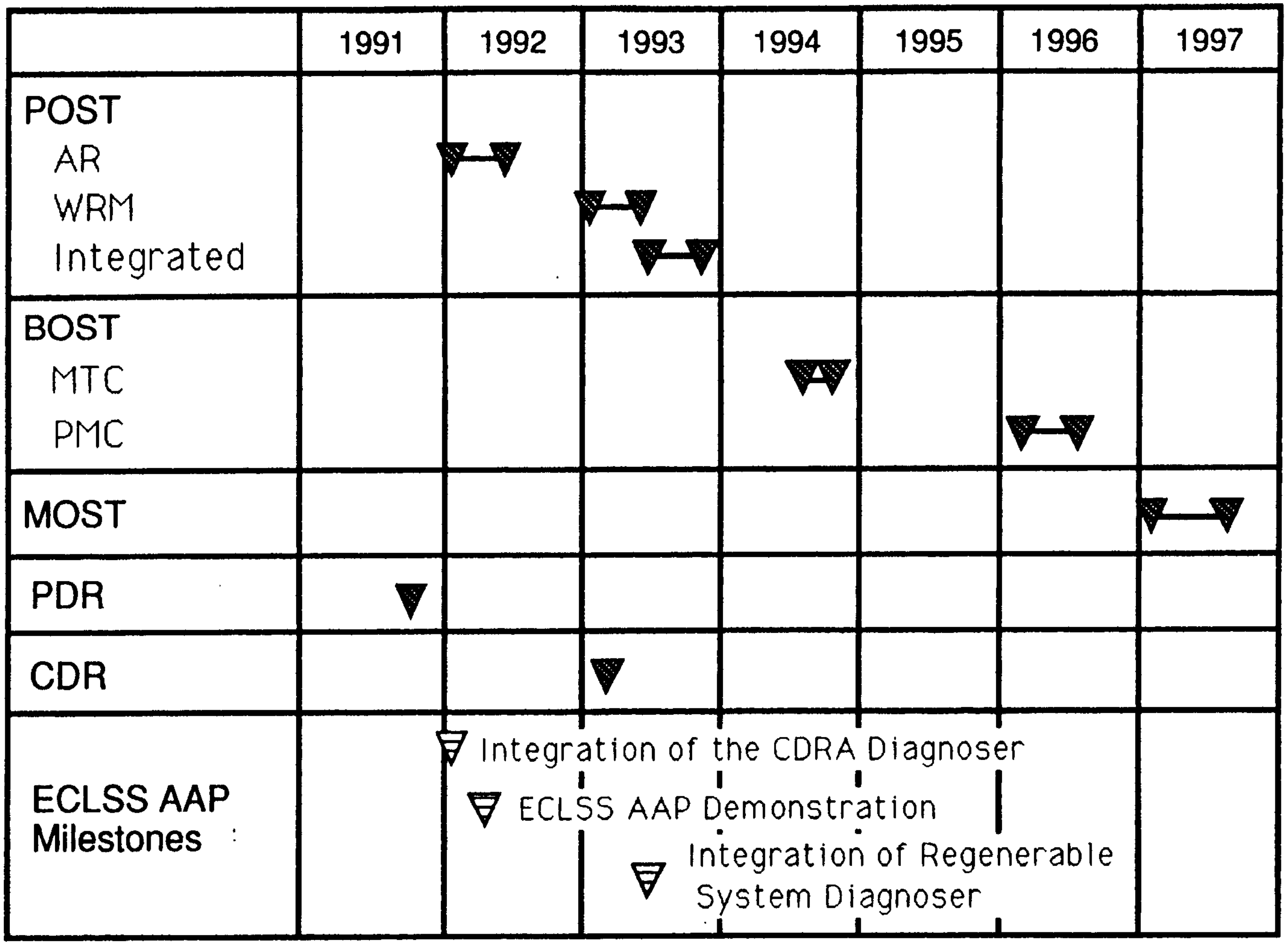
There are plans to use more advanced monitoring techniques in the POST, BOST and MOST ECLSS Testbeds, but not much more advanced.

Integrated Schedule Description

As this schedule indicates, our first big demonstration will be before the ECLSS CDR.

Follow-on work will include more systems in the integrated tests.

Integrated Schedule



Growth and Evolution Options Description

Flight option on portable computer which plugs into front of ECLSS racks. The design has a data interface plug on the front of each double rack. This plug can be used when the subsystem inside is broken for bringing a more cabable diagnostic machine online to concentrate on diagnosing the system failure.

New modules (beyond EMCC) with new Standard Data Processor loads could carry this type of fault detection and diagnosis, the computers used should have more capability and the fault detection algorithm could be model based rather than associational.

Inclusion of chemical and biological in the fault detection and diagnosis system. The overall goal of the ECLSS, for practical and political reasons, is to keep itself operating nominally. Any instrumentation in the ECLSS (eg GCMS) is there to check that the system outputs meet required specifications - not to make sure the crew is safe.

With regeneration of air and water, the crew and bacteria are integrated parts of the overall system. The next viewgraph shows how MBD can be used to integrate the diagnosis job.

Growth and Evolution Options

Flight option on portable computer which plugs into front of ECLSS racks.

New modules (beyond EMCC) with new SDP loads could carry this type of fault detection and diagnosis.

Inclusion of chemical and biological Models in the fault detection and diagnosis system. The purpose of a life support system, after all, is to keep the crew healthy, not just to keep itself healthy.

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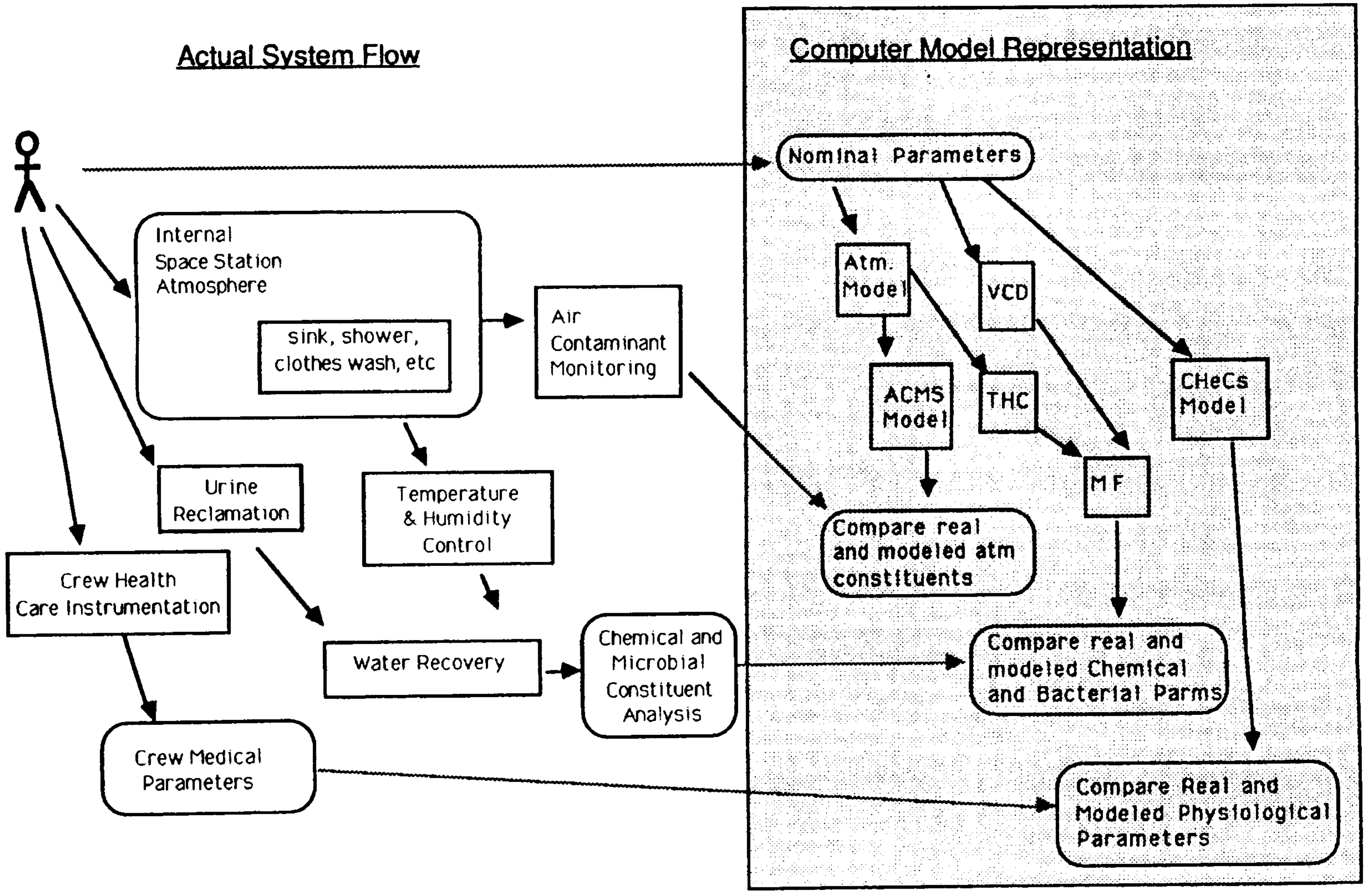
Chemical and Biological Model-Based Fault Detection and Diagnosis



Actual System Flow

Internal Space Station Atmosphere

sink, shower, clothes wash, etc

Air Contaminant Monitoring

Urine Reclamation

Temperature & Humidity Control

Crew Health Care Instrumentation

Water Recovery

Chemical and Microbial Constituent Analysis

Crew Medical Parameters

Computer Model Representation

Nominal Parameters

Atm. Model

VCD

ACMS Model

THC

CHeCs Model

M F

Compare real and modeled atm constituents

Compare real and modeled Chemical and Bacterial Parms

Compare Real and Modeled Physiological Parameters

Chemical and Biological Model-Based Fault Detection and Diagnosis Description

In a manner similar to the model based diagnosis of the valve system shown previously, chemical, physiological, and bacterial faults can be diagnosed using models of the system and instrumentations' structure and behavior.

The CHeCS monitors the medical aspects - blood, detailed urine, etc - while the Life Support system can pick up alternate fault causes.

Long duration trend analysis of chemical and microbial faults in the lines, filters, and crew members may be isolated in this manner.

Related Work

Dr. Richard Doyle / JPL is applying their sensor placement and analysis algorithm to the ECLSS.

In-house work concentrates on Automatic Generation of real-time software from control block diagrams, and Graphical User Interfaces for Payload Monitoring.

Small Business Inovative Research Project applying Neural Networks to the ECLSS Trace Contaminant Analysis and Fire Detection Systems.

The ECLSS Advanced Automation Project

Summary

ECLSS is a complex system which can be automated using advanced software technology.

The subsystem we began with was restructured out of the program, but all was not lost.

Although we originally planned on integrating advanced algorithms in the flight system, we now are refocused on ground test and support.

In the testing and ground support areas, we can make the most immediate beneficial impact, while positioning for flight integration.

Future implementations of life support systems will be more autonomous due to this project.