

## **Adjustable Autonomy Testbed**

Jane T. Malin and Debra K. Schreckenghost

The Adjustable Autonomy Testbed (AAT) is a simulation-based testbed located in the Intelligent Systems Laboratory in the Automation, Robotics and Simulation Division at NASA Johnson Space Center. The purpose of the testbed is to support evaluation and validation of prototypes of adjustable autonomous agent software for control and fault management for complex systems. The AAT project has developed prototype adjustable autonomous agent software and human interfaces for cooperative fault management. This software builds on current autonomous agent technology by altering the architecture, components and interfaces for effective teamwork between autonomous systems and human experts. Autonomous agents include a planner, flexible executive, low level control and deductive model-based fault isolation. Adjustable autonomy is intended to increase the flexibility and effectiveness of fault management with an autonomous system. The test domain for this work is control of advanced life support systems for habitats for planetary exploration. The CONFIG hybrid discrete event simulation environment provides flexible and dynamically reconfigurable models of the behavior of components and fluids in the life support systems. Both discrete event and continuous (discrete time) simulation are supported, and flows and pressures are computed globally. This provides fast dynamic simulations of interacting hardware systems in closed loops that can be reconfigured during operations scenarios, producing complex cascading effects of operations and failures. Current object-oriented model libraries support modeling of fluid systems, and models have been developed of physico-chemical and biological subsystems for processing advanced life support gases. In FY01, water recovery system models will be developed.

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DRAFT

# Operations Concepts for Life Support

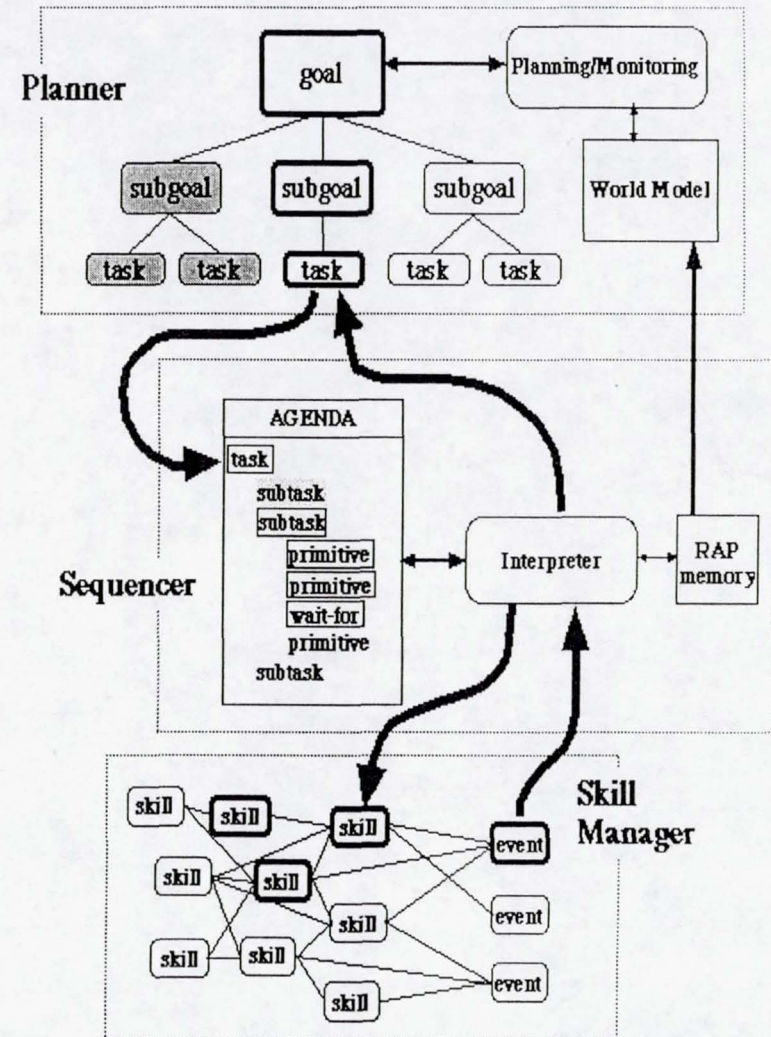
- Autonomous control systems should operate safely without eyes-on, vigilance monitoring
  - Implement safe operations with well-defined protocols at boundary conditions
  - Provide strategies for notifying humans when interesting or unusual events occur or a need for manual action arises
  - Support remote monitoring of systems
  - Generate activity histories and event summaries
- Human support is performed *by exception* – during critical operations, anomalies, or unusual situations
  - Support novel manual operations in response to anomaly or opportunity
  - Permit human override of automation
  - Operate autonomous system continuously, even when human is in control
- Operations results from LMLSTP Phase III Test (Fall, 97)
  - Engineer workload with automated control system
    - 6-8 hrs per week on console, plus 6 hrs every 4 days for incineration and 3 hours every 20 days for planting/harvesting
  - Tasks with human-in-the-loop: incineration, plant/harvest, calibration

# Adjustable Autonomy Testbed

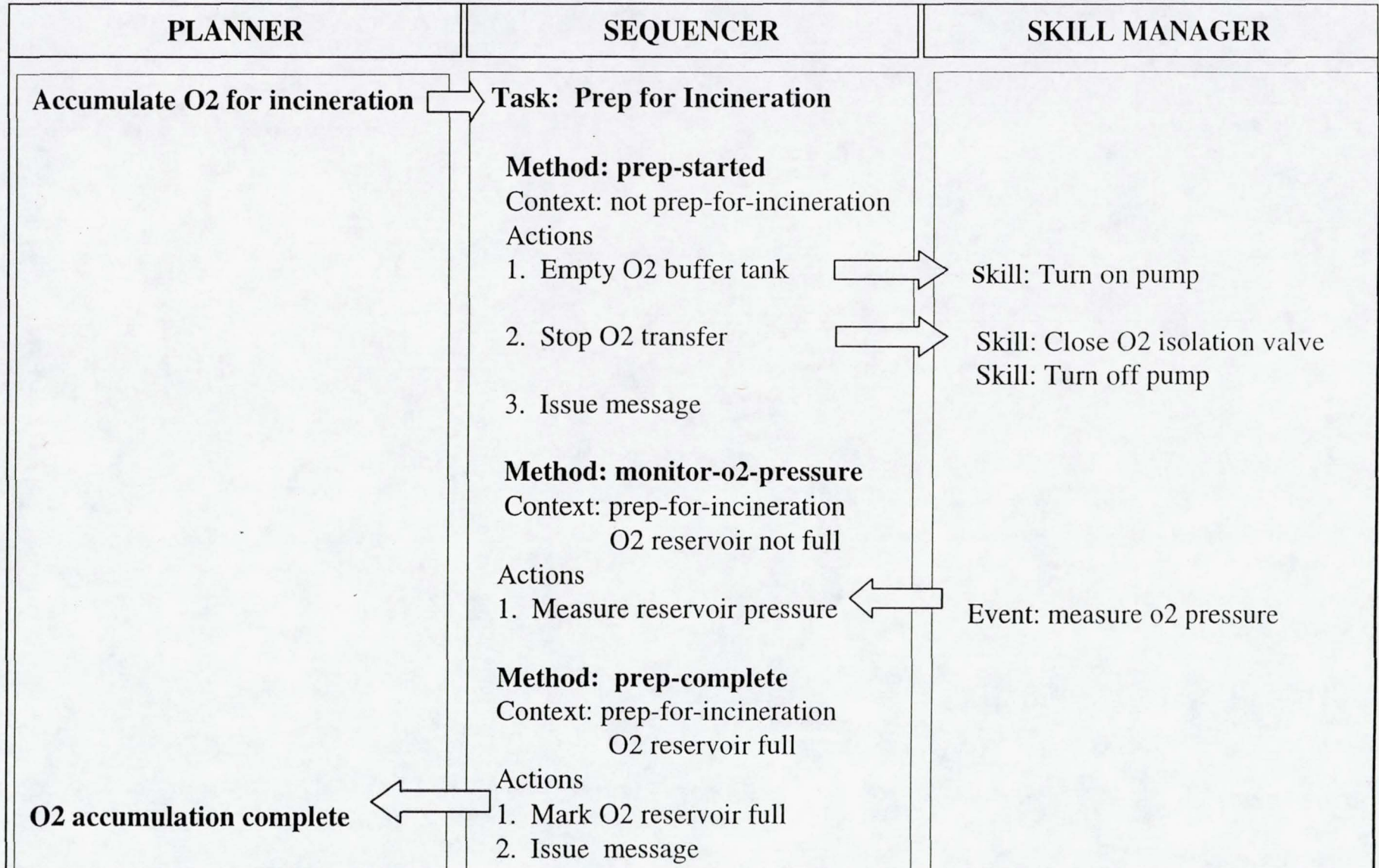
- Purpose
  - Develop automated control software that supports human-in-the-loop operations
  - Provide a simulated life support environment to develop and test this control software
- Approach
  - Add improved capability for user to monitor and command control processes in 3T
    - Displays that provide an overview of system operations (e.g., ARS) and summarize control activity history
    - Notification of faults and automated actions in response to them
    - Electronic procedures for manual commands
  - Provide new fault detection capability that complements anomaly handling in 3T
    - Integrate with model-based fault diagnosis software from Ames (Livingstone)

# Three Tier (3T) Control Architecture

- **Planner (AP):** predicts activities to achieve control objectives
  - Represents and assigns tasks to multiple agents
  - Monitors plan execution, detects plan execution failure, and replans at failure.
- **Sequencer (RAPs):** selects and orders procedures to implement planned activities
  - Chooses procedures reactively, based on current state of environment.
  - Allocates procedure steps to specific skill managers
- **Skill Manager:** implements procedure steps as closed loop control
  - Skills are activated to issue commands to control instrumentation
  - Events are activated to monitor sensor readings in response to control



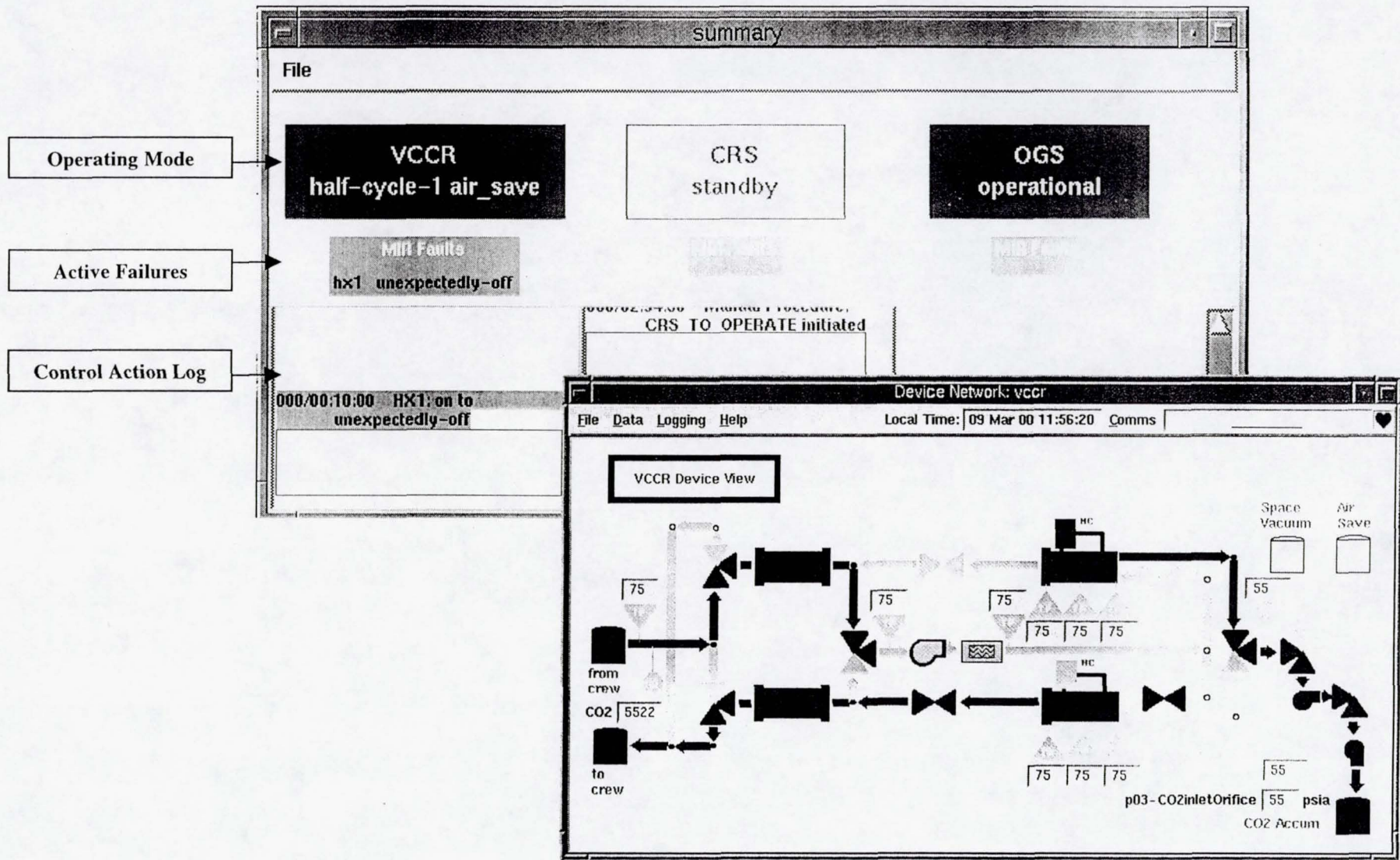
# 3T Example: Prepare for Incineration



# Enhancing 3T for Improved User Interaction

- Monitoring system operation
  - Displays providing an operational overview
  - Histories of control activities and their consequences
  - Notification of faults and automated actions in response to them
- Commanding 3T control system
  - Electronic procedures for manual commands
- Potential for reuse
  - Electronic procedures and displays for new subsystem with creation of new configuration files
  - Remote access to new displays with 3T modification to export raps data
  - Centralized data logs with modification to jForwarder

# Monitoring ARS Operation





# Reviewing Histories of Control Activities

summary

**VCCR**  
 half-cycle-2 accum

CRS

OGS

MIR Mirrors

MIR Faults

```

000/00:37:01 half-cycle-1 accum
000/00:00:00 PU01: on to
on_flow_blocked
000/00:58:48
HANDLE-MIR-FAULTS is
complete with status
GOAL-SUCCEEDED
000/00:00:18 PU01: on_flow_blocked
to on_flow_blocked
000/00:00:18 PU01: on_flow_blocked
to on_flow_blocked
            
```

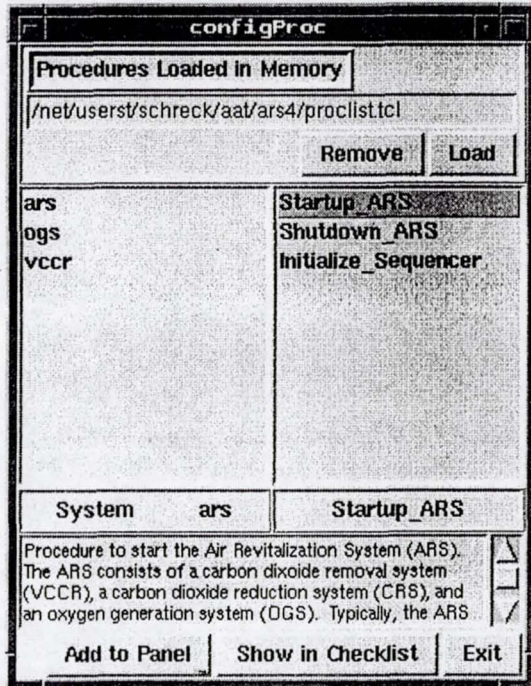
Task Agenda

File
000/07:17:39
ACTIVE
MONITOR-VCCR

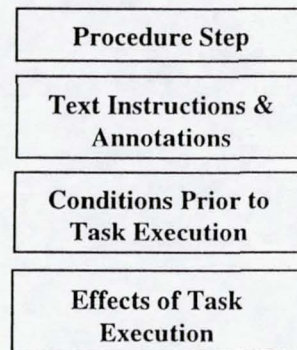
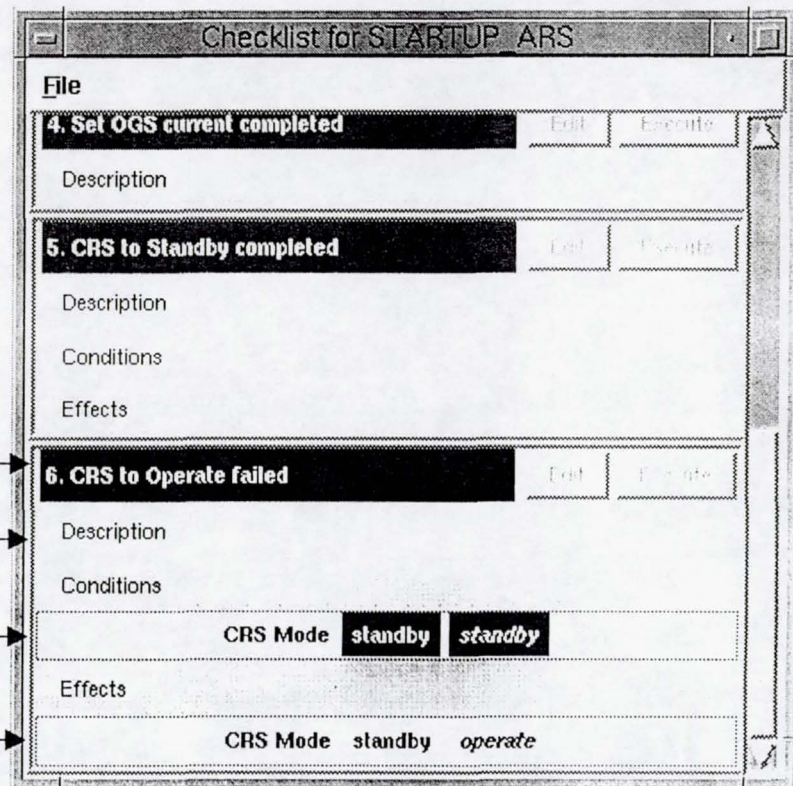
|              |         |   |
|--------------|---------|---|
| 000/08:31:24 | SUCCEED | HANDLE-VCCR-ALERTS  |
| 000/08:31:24 | SUCCEED | put-out-warning vccrskm (even low low even low low even even low) |
| 000/08:31:24 | SUCCEED | handle-mir-faults #<resource: nil>                                |
| 000/08:31:24 | SUCCEED | turn-pump-p vccrskm blower off 120                                |
| 000/08:31:24 | SUCCEED | no-op mir-blower-problem  |
| 000/08:31:24 | SUCCEED | turn-pump-p vccrskm blower on 120                                 |
| 000/08:31:24 | SUCCEED | RESTORE-CONFIGURATIONS  |
| 000/08:31:24 | SUCCEED | no-op nothing-to-restore  |
| 000/08:31:24 | SUCCEED | CHECK-VCCR-CONFIG   |
| 000/08:31:24 | SUCCEED | configure-vccr hc1 air_save                                       |
| 000/08:31:24 | SUCCEED | configure-hc-adsorb hc1   |
| 000/08:31:24 | SUCCEED | configure-hc-adsorb-p vccrskm hc1 120                             |
| 000/08:31:24 | SUCCEED | turn-heater-p vccrskm hc2 off 120                                 |
| 000/08:31:24 | SUCCEED | turn-heater-p vccrskm hc1 off 120                                 |
| 000/08:31:24 | SUCCEED | configure-desorb-state-p vccrskm hc1 air_save 120                 |
| 000/08:31:24 | SUCCEED | GCOLLECT  |

# Commanding the ARS Control System

## Select a Procedure

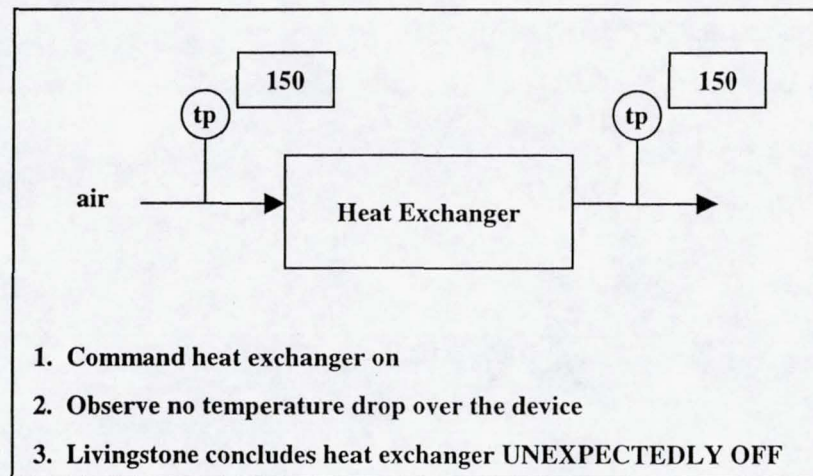


## Execute a Procedure



# Enhancing 3T with Model-based FDIR

- NASA Ames has developed a model-based state assessment tool called Livingstone
  - System Model
    - Components connected by data paths
    - Each component model includes nominal and fault states with transition conditions
  - Use of this model
    - Assess the most likely state by reasoning about the expected and observed consequences of commands



# Caution and Warning with Livingstone

## Mode Diagram for VCCR Blower Pump

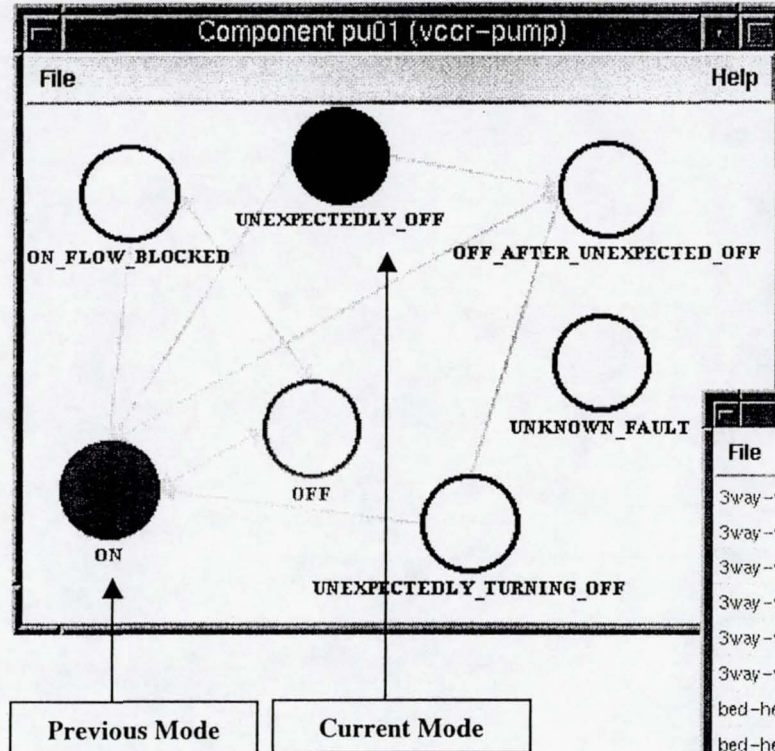
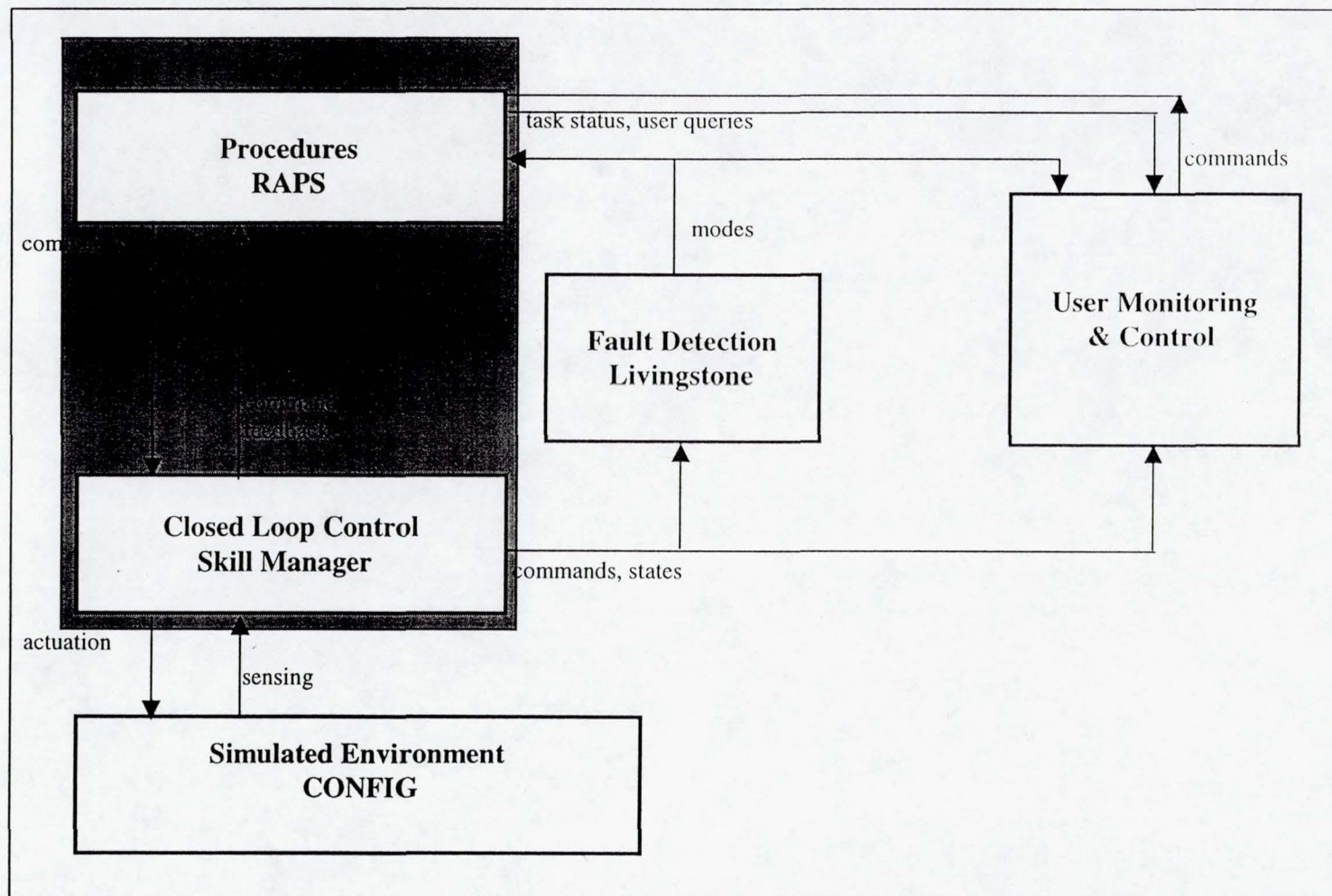


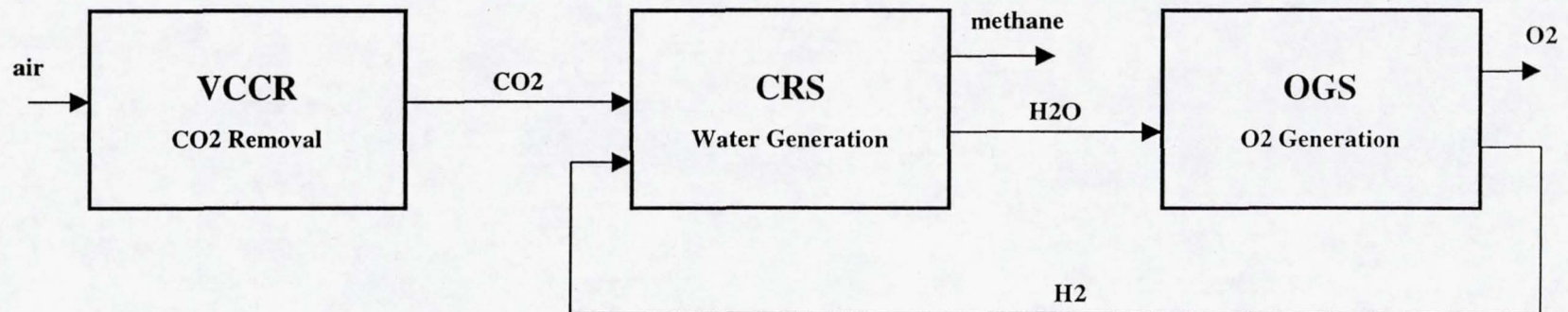
Table of VCCR Livingstone Modes

| VCCR Livingstone - Monitor change |         |  |         |
|-----------------------------------|---------|--|---------|
| File                              |         |  | Help    |
| 3way-valve v01                    | 2_3     |  | Details |
| 3way-valve v02                    | 1_3     |  | Details |
| 3way-valve v03                    | 1_3     |  | Details |
| 3way-valve v08                    | 2_3     |  | Details |
| 3way-valve v09                    | 2_3     |  | Details |
| 3way-valve v10                    | 1_3     |  | Details |
| bed-heater h01                    | off     |  | Details |
| bed-heater h02                    | heated  |  | Details |
| bed-thermocouple tc04             | nominal |  | Details |
| bed-thermocouple tc05             | nominal |  | Details |
| bed-thermocouple tc06             | nominal |  | Details |
| bed-thermocouple tc07             | nominal |  | Details |
| bed-thermocouple tc08             | nominal |  | Details |
| bed-thermocouple tc09             | nominal |  | Details |
| co2-accumulator accum             | nominal |  | Details |

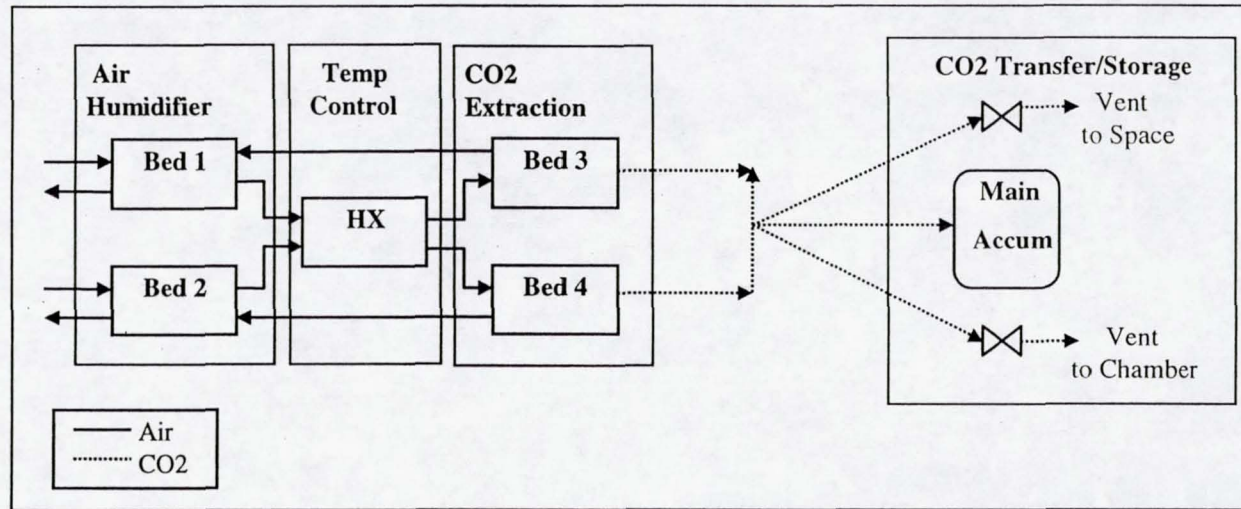
# AAT Demonstration: Architecture



# Operation of Air Revitalization System (ARS)

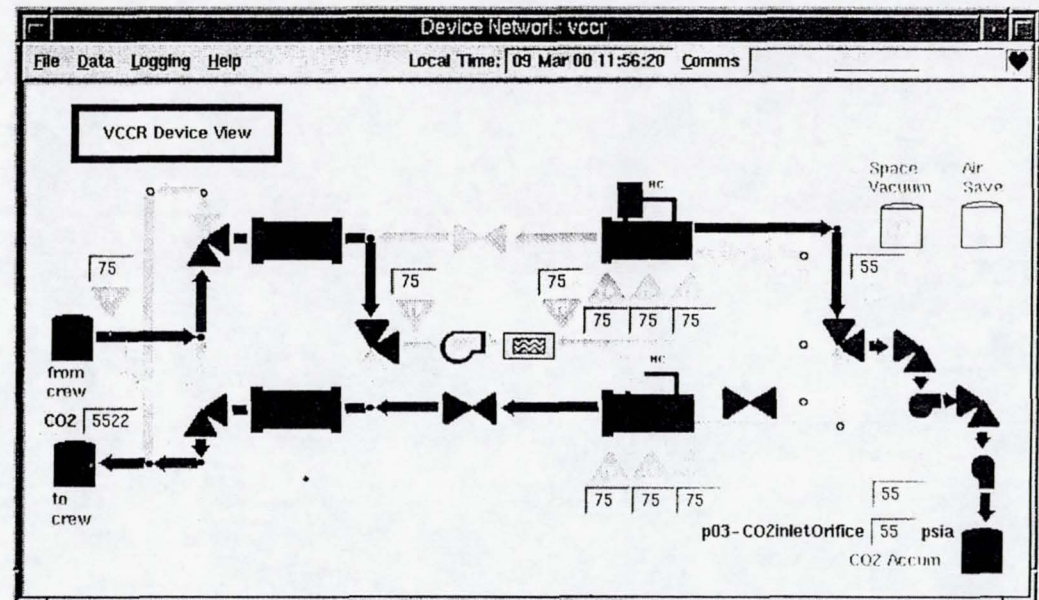


# Operation of the VCCR



VCCR normally operates autonomously

- Human operations
  - Startup and shutdown system
  - Inform system of HX state
- Livingstone identifies nominal and failure states



# Demonstration Scenario

- Nominal Case: Startup the 3 systems of the air system
  - VCCR: removes CO<sub>2</sub> and stores it in a tank
  - CRS: converts CO<sub>2</sub> and H<sub>2</sub> to H<sub>2</sub>O and methane
  - OGS: convert H<sub>2</sub>O to O<sub>2</sub> and H<sub>2</sub>
- Failure Cases: Air blower or heat exchanger turn off unexpectedly
  - Livingstone detects the failure based on temperatures from skill manager and notifies the sequencer
  - Sequencer selects and executes recovery procedures in response to the failure notification
    - Blower: sequencer automatically turns the blower back on
    - Heat Exchanger: sequencer asks human to turn the heat exchanger back on
  - Skill manager issues procedure commands to the sim and receives data from sim indicating commands have taken effect
  - Livingstone notifies sequencer when the fault has been corrected and nominal control resumes
  - Throughout, human can monitor the activity as it occurs or after the fact