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Thermal Control System Automation Project (TCSAP)

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Roger L. Boyer
McDonnell Douglas Space Systems Company
Thermal Systems
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INTRODUCTION

Good morning! My presentation today is on the Thermal Control System Automation Project (TCSAP). Before going into the meat of the project, I would like to take this opportunity to recognize those responsible. This project is managed by Mark Gersh of Space Station Level 1 Engineering. It is monitored locally here at NASA JSC by Nick Mesloh of the Crew and Thermal Systems Division and Bryan Basham of the Automation & Robotics Division. Those responsible for the work performed to date at McDonnell Douglas include Tim Hill, William Morris, Charlie Robertson, and myself.

AGENDA

- External Thermal Control System (ETCS) Background
- Project Objectives and Benefits
- Technical Approach
  - High Fidelity Simulator (HFS)
  - RODB-like Software
  - Knowledge Based System (KBS)
  - Integrated System Scenario
- Baseline Integration and Evolution
- Summary

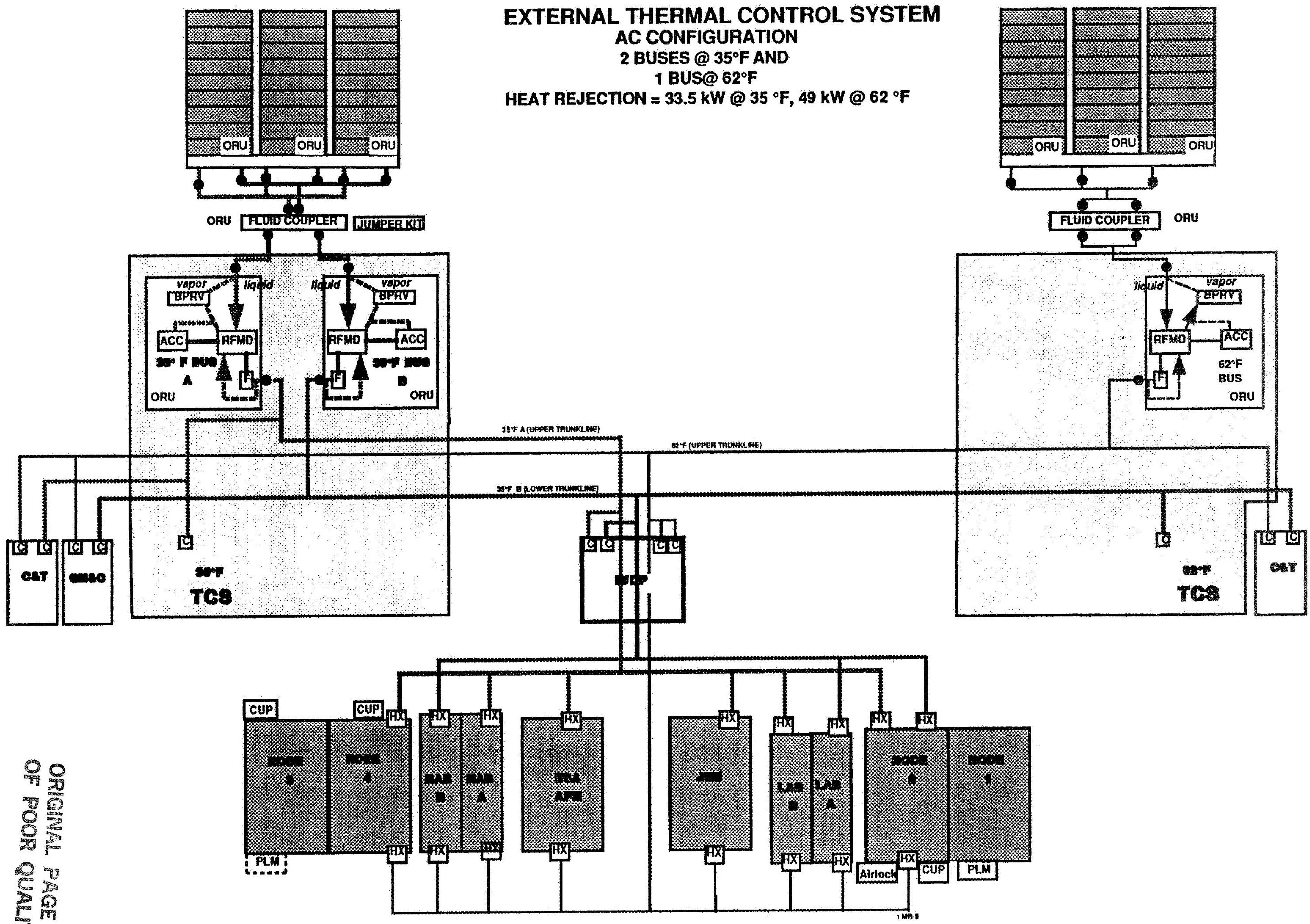
AGENDA

After hearing about the ATCS in the previous presentation, I'll provide only a brief introduction of the ETCS and identify the issues associated with it that drive the need for additional Fault Detection, Isolation, and Recovery (FDIR) capability. That will allow me to lead into what TCSAP is about and the benefits that SSFP can gain from it.

During my presentation, you will see several acronyms specific to TCSAP. The principal ones are: FDIR, High Fidelity Simulator (HFS), Runtime Object Database (RODB), and Knowledge Based System (KBS).

After discussing the technical approach taken by this project, I will walk you through a scenario of the Integrated System, identify how TCSAP's milestones are aligned with those of the TCS / SSF, and present our plans for migrating the system to on-board.

EXTERNAL THERMAL CONTROL SYSTEM
AC CONFIGURATION
2 BUSES @ 35°F AND
1 BUS@ 62°F
HEAT REJECTION = 33.5 kW @ 35 °F, 49 kW @ 62 °F



ETCS ASSEMBLY COMPLETE

- This figure shows the integrated baseline ETCS Assembly Complete (AC) configuration for SSF, as discussed in the preceding presentation. Note that there are three fluid loops (or buses): two at 35 oF and one at 62 oF. Also note that the two 35 oF buses do not share the same heat loads.

- Each bus includes both active and passive components. The active components (e.g., the Rotary Fluid Management Device) can fail during operation for a variety of reasons (e.g., loss of power, mechanical failure, and flow blockage). The passive components (e.g., cold plates) can leak or become blocked. As a result, a variety of failure modes can exist for a variety of different components. Overall, the dynamics of the ETCS allows some time for FDIR following most anticipated failure modes. For those events where time is critical, FDIR is performed on-board.

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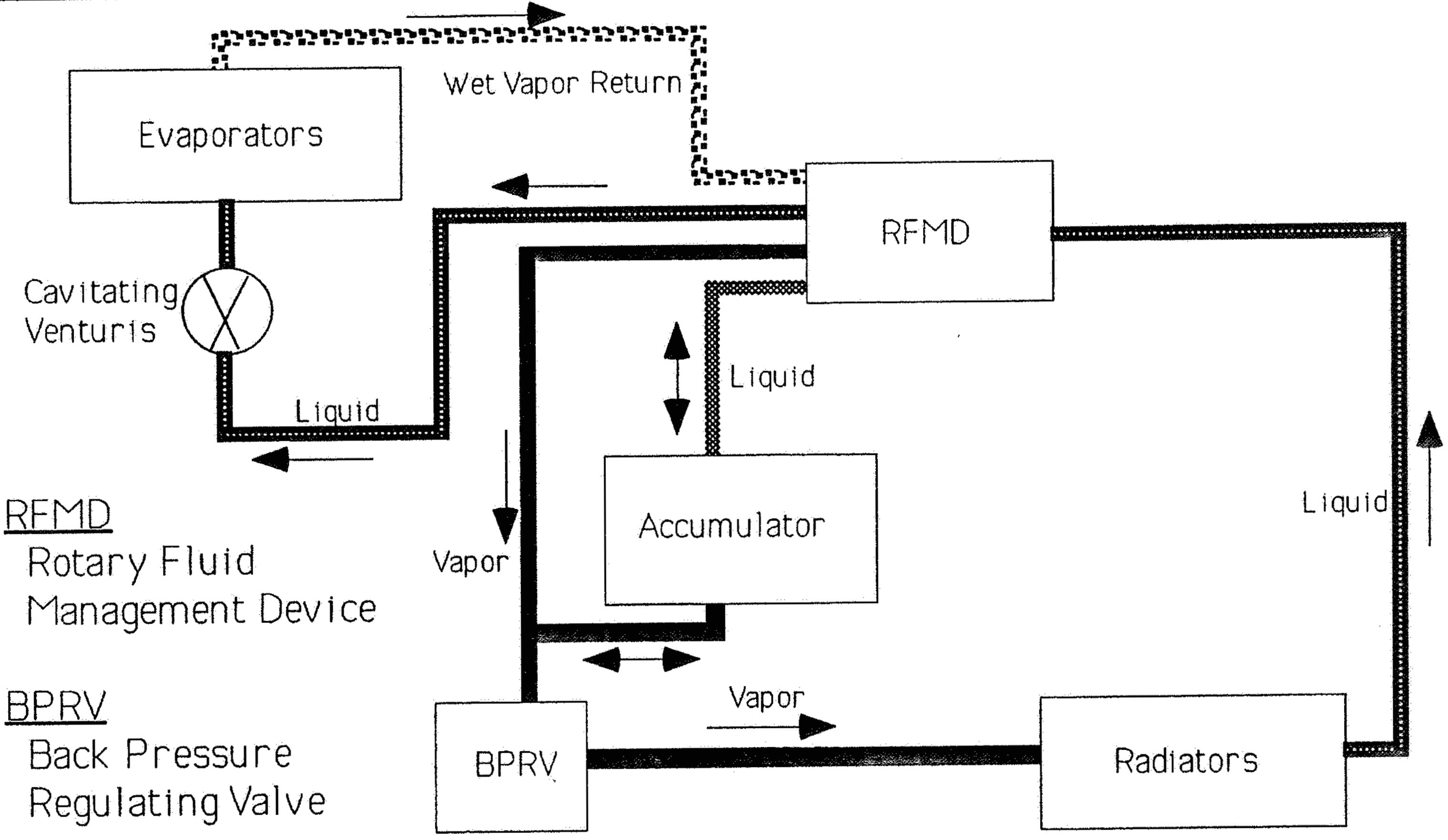
ETCS FUNCTIONAL SCHEMATIC



RFMD
Rotary Fluid
Management Device

BPRV
Back Pressure
Regulating Valve

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ETCS FUNCTIONAL SCHEMATIC

- The ATCS design has evolved from the single-phase fluid system used in the Apollo and Space Shuttle programs to a two-phase system on SSF. For a single-phase system, heat loads are applied in series along the fluid flow path prior to entering the radiators. A centrifugal pump is used to provide the pumping head for the system. However, for SSF, greater heat loads are required and electric power is limited. Therefore, a two-phase fluid system is needed.

- Again this figure was discussed in the preceding presentation. The important points to draw from it are the multi-phase conditions of the ammonia within the ETCS and the variety of equipment utilized. The RFMD pumps liquid ammonia to the evaporators and cold plates, which remove heat from various locations / equipment around the station. The cavitating venturi provide flow control to the evaporators. A two-phase mixture is returned to the RFMD, which separates the vapor from liquid. The RFMD pumps the vapor to the radiators, which condense the fluid to a subcooled state. The RFMD also maintains inventory control along with the accumulator. The BPRV maintains setpoint temperature by controlling system pressure. Not shown are the various sensors or instrumentation on the bus, which can fail in such a way as to provide erroneous or misleading data to the FDIR software and crew.

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BASELINE FDIR

- 2 Standard Data Processors (SDPs) on-board.
- Time and safety critical FDIR will be handled on-board.
- Sensor data downlinked to ground operations (Space Station Control Center and Engineering Support Center).
- Ground operations will be man-tended 24 hours per day for the duration of SSF.

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TCSAP OBJECTIVES

- Develop a Knowledge-Based System (KBS) that utilizes a combination of rule and model-based reasoning to perform Fault Detection, Isolation, and Recovery (FDIR) on the SSF External Thermal Control System (ETCS).

- Develop an ETCS High Fidelity Simulator (HFS) and Runtime Object Database (RODB)-like software for cost effective development & testing of the FDIR software.

- Develop an evolution plan to migrate automated FDIR functionality from ground to on-board.

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BENEFITS

- Improve ETCS FDIR reliability.
- Increase ETCS FDIR functionality.
- Enhance ETCS safety.
- Reduce costs associated with testing the KBS.
- Improve SSF ground support productivity.
- Enhance crew and ground training with both the HFS and KBS.

BENEFITS

There are several benefits associated with using advanced automation on the ETCS and the approach being taken by TCSAP.

- ETCS FDIR reliability can be improved by extensive testing against the HFS and comparing to ETCS thermal testbed results.
- ETCS FDIR functionality can be increased by using model based reasoning to identify novel faults. Novel faults are those faults not identified in the system's Failure Mode and Effects Analysis (FMEA).
- ETCS safety can be enhanced as a result of improving its FDIR reliability and functionality.
- Costs associated with testing the KBS can be minimized by using the HFS instead of the actual ETCS hardware. Furthermore, testing the actual hardware under certain fault scenarios can be dangerous and potentially damaging to the hardware itself.
- SSF ground support productivity can be improved by reassigning manpower from round-the-clock system monitoring to other tasks.
- Both crew and ground training can be enhanced with the HFS and KBS.

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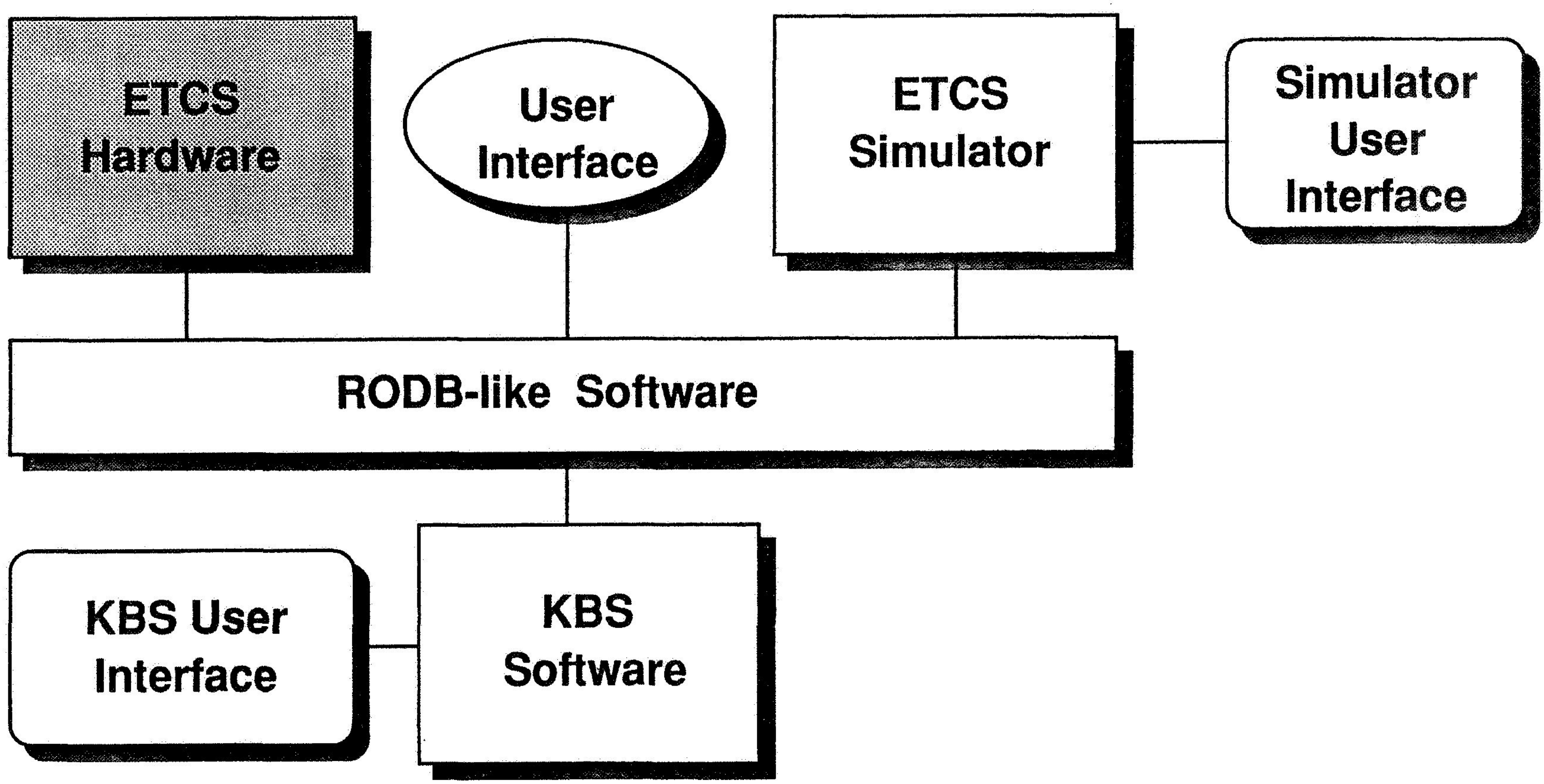
TCSAP SOFTWARE ARCHITECTURE



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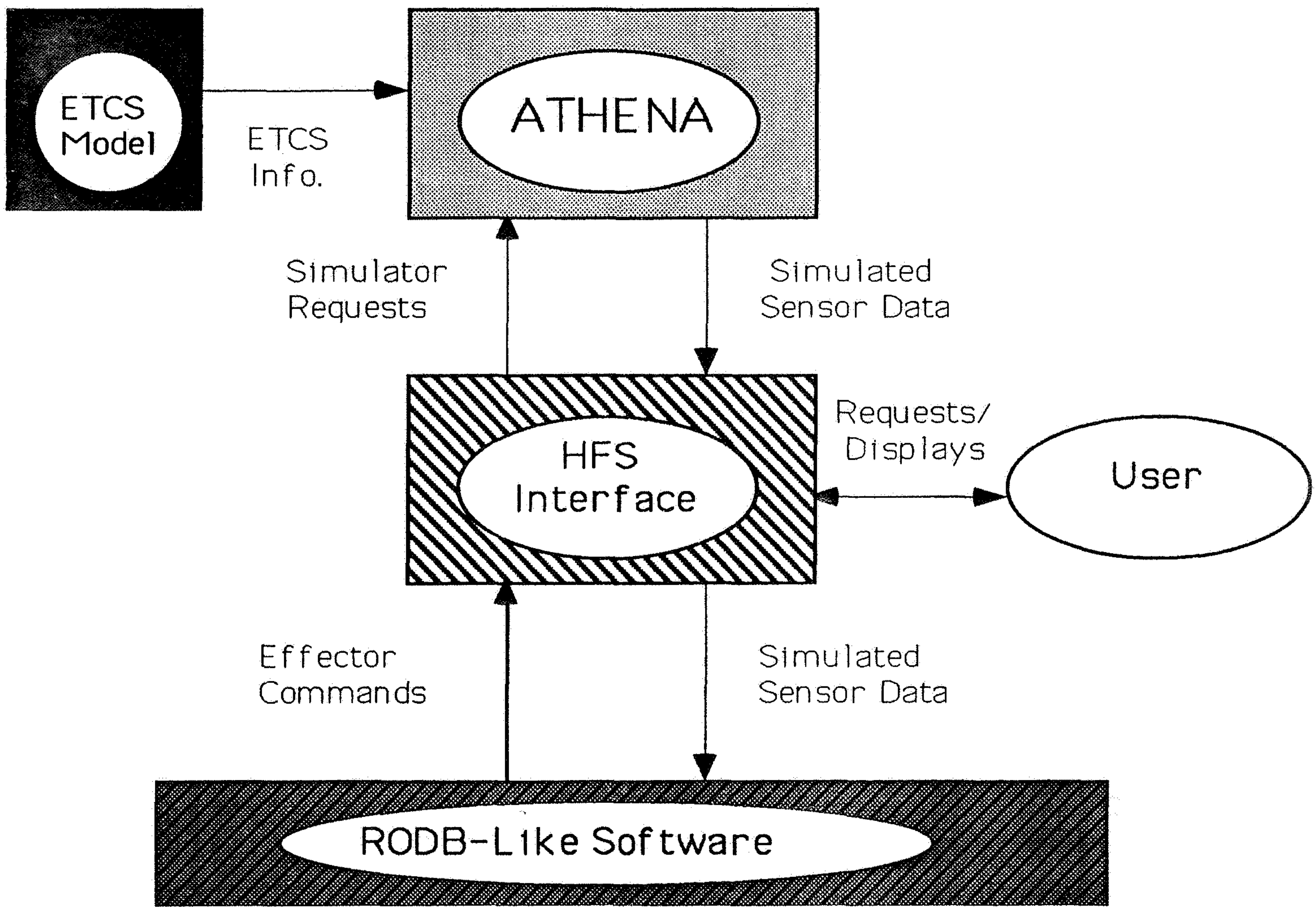
TCSAP SOFTWARE ARCHITECTURE

- This figure identifies the major TCSAP software components and how they are integrated. Note that hardware data can be generated by either the actual hardware or simulator and read by the RODB-like software. The RODB-like software provides the appropriate data to the KBS. Each software component has its own user interface for monitoring and control, if so desired. The simulator user interface is required for fault injection and can be used in a stand-alone mode. The RODB-like user interface is solely for monitoring. The KBS user interface is used for both monitoring and control.

HFS ARCHITECTURE



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HFS ARCHITECTURE

- The HFS is made up of three major components. The Advanced Thermal-Hydraulic Energy Network Analyzer (ATHENA) represents the heart of the HFS with its six equation set of conservation equations, 1-D heat conduction models, and special process correlations (e.g., two-phase pressure drop). ATHENA requires application specific information concerning the physical dimensions, component connectivity, and component functionality. The HFS interface provides sensor data to and receives effector commands from either the user or RODB-like software.

- The HFS must run to as close as real-time as possible and still provide hardware-like sensor data. The HFS must also allow a modular means of updating component models as the ETCS design evolves.

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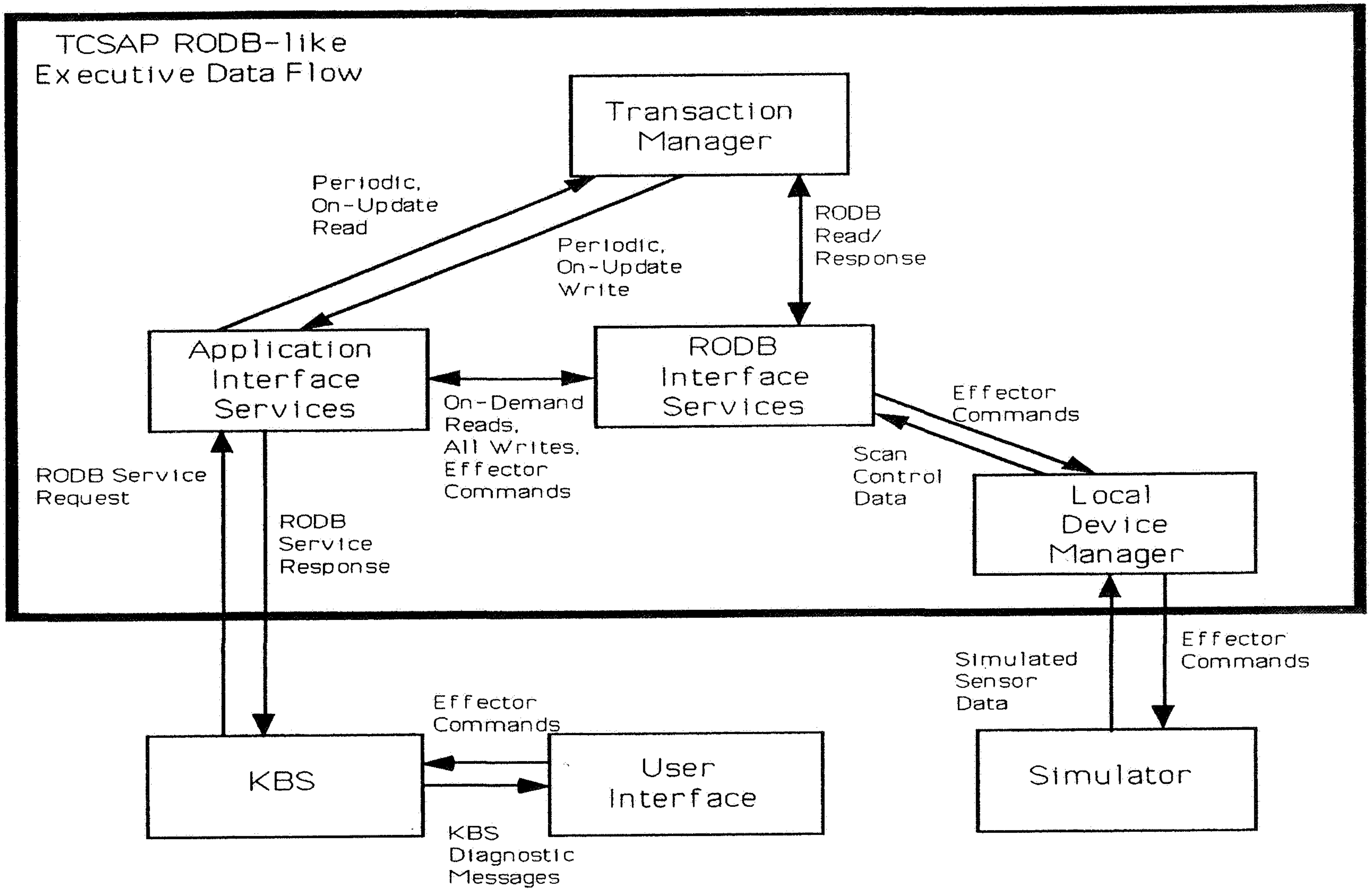
TCSAP RODB DATA FLOW



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TCSAP RODB DATA FLOW

- The RODB-like software developed by TCSAP performs the same functions as the baseline RODB, except only for the ETCS. The ETCS subsystem has essentially four data packages associated with it: the Transaction Manager, The Application Interface Services, the RODB Interface Services, and the Local Device Manager.

- The Local Device Manager reads the sensor values received from the simulator/hardware, performs limit checks, and stores the sensor values into the appropriate sensor object.

- The Application Interface Services allow external applications to tie into the RODB-like software.

- The Transaction Manager tracks the on-update and cyclic data requests received from the Application Interface Services.

- The RODB Interface Services act as the interface to the sensor objects. The Application Interface Services can ask the Interface Services for an on-demand data request, which is a one-shot data request. This service allows external programs to request certain sensors one time and not see them again. Note that the Interface Services can access sensor data from any other subsystem and can be portrayed in a three-dimensional schematic coming out of the page and connecting to the other subsystem's Local Device Mgr.

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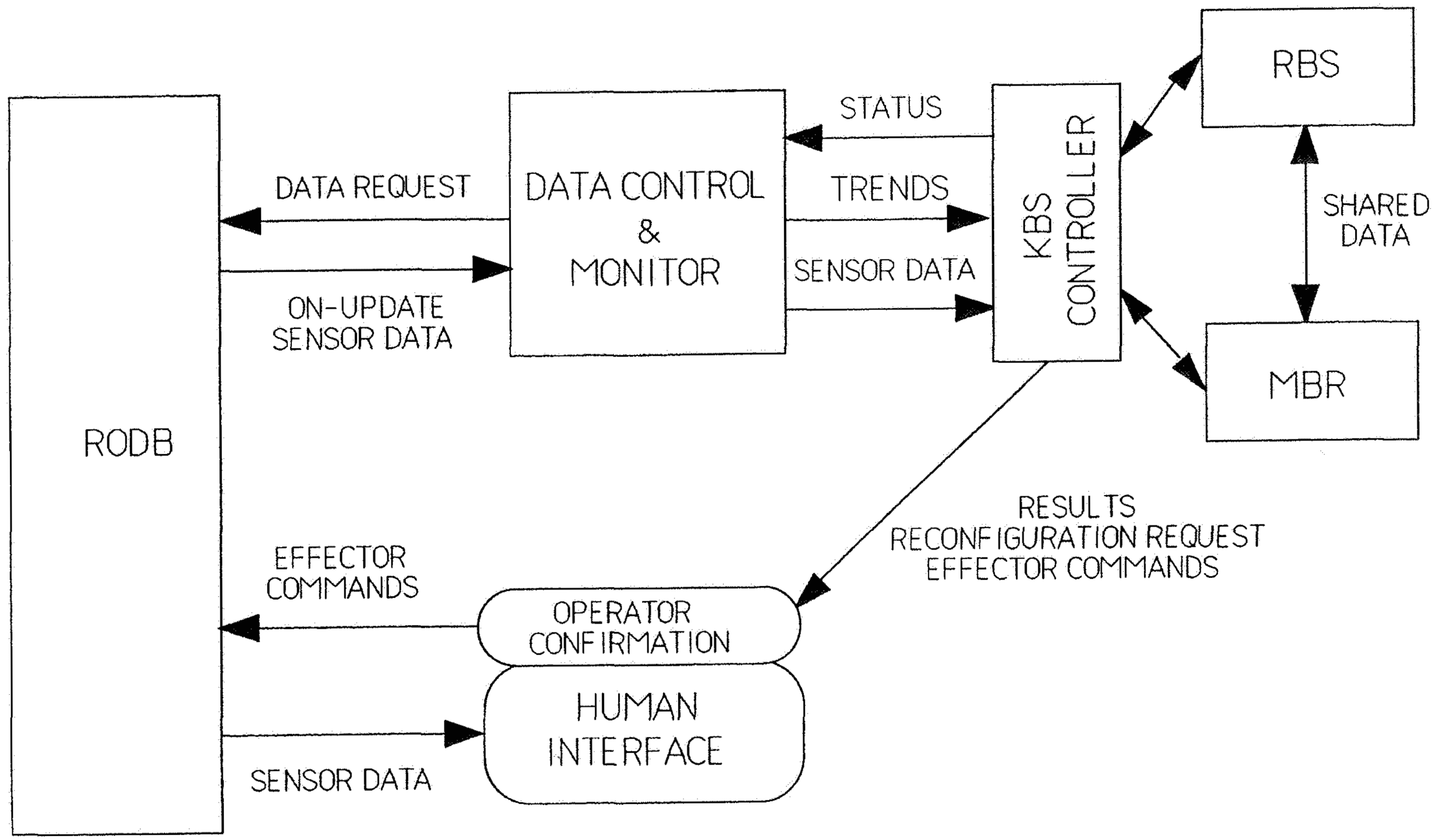
KBS FUNCTIONAL ARCHITECTURE



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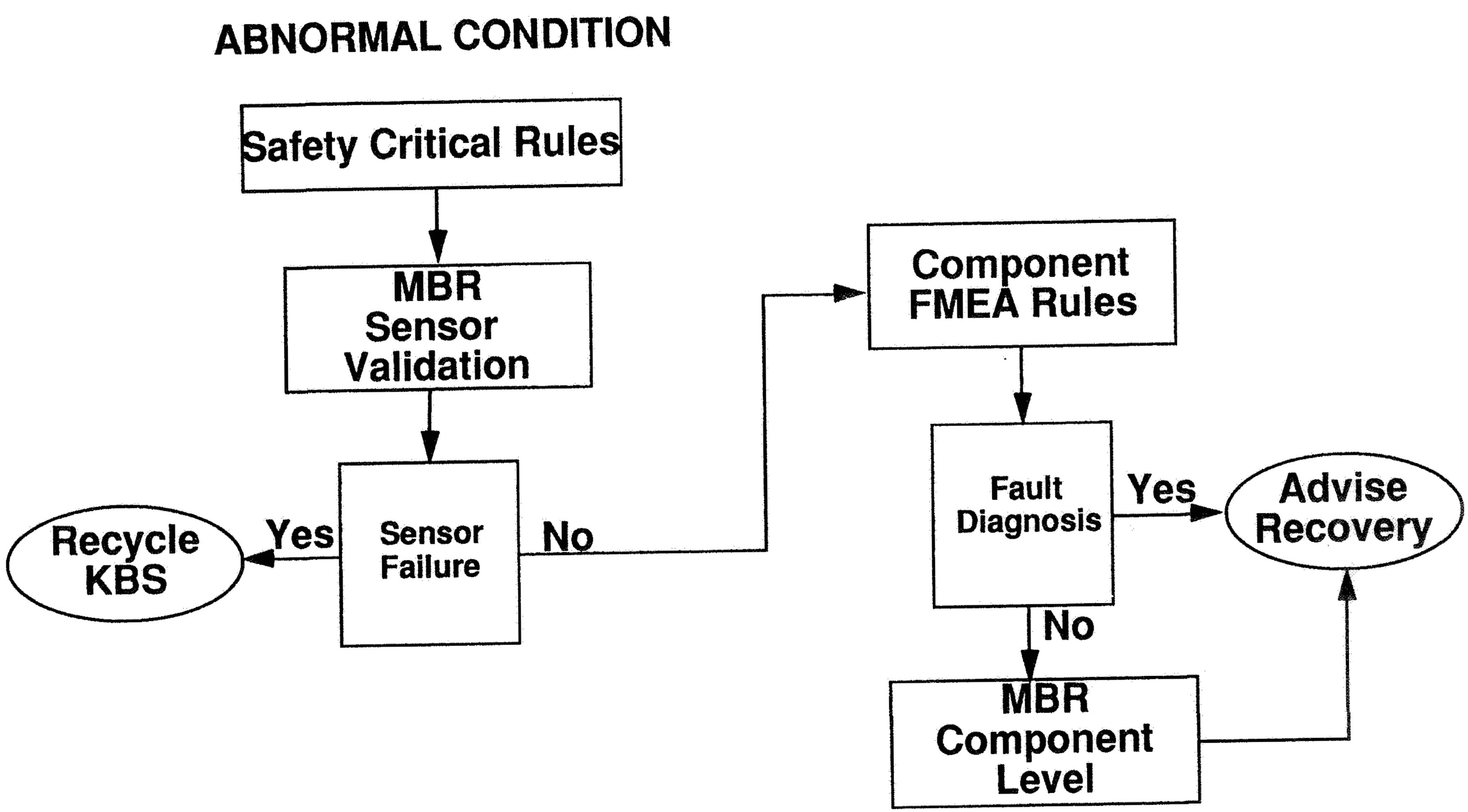
KBS FUNCTIONAL ARCHITECTURE

- The KBS receives sensor data from the RODB-like software, performs a trending analysis on selected sensors, and sends the data (both quantitative and qualitative data) to the KBS controller. The controller manages the order in which data is provided to the various sets of rules and model based reasoning applications, which are discussed further on the following slide. Once a fault has been detected and isolated, a message is sent to the human interface for confirmation of the recommended recovery action.

KBS LOGIC FLOW



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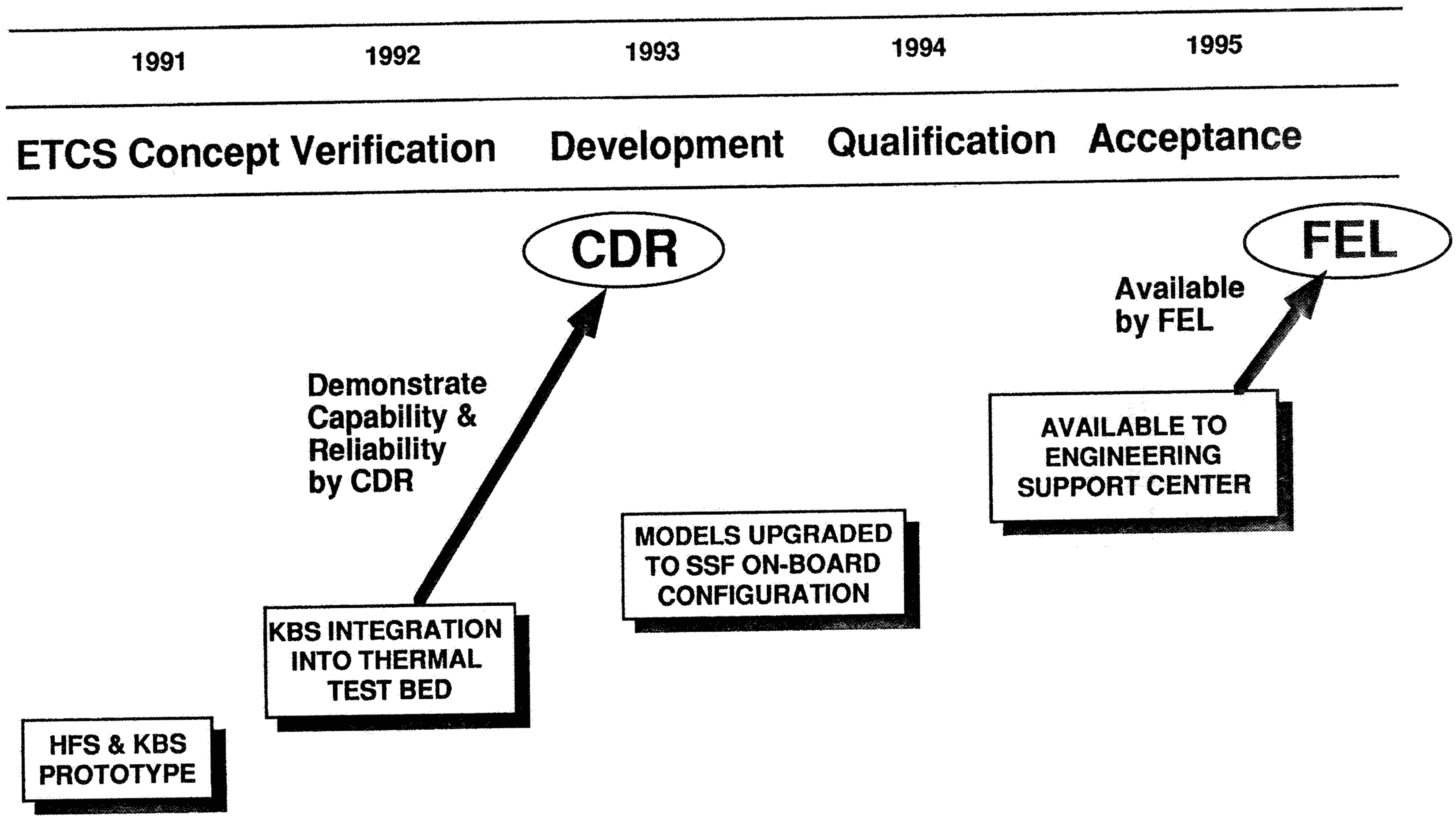
KBS LOGIC FLOW

- Incoming ETCS sensor data is compared to an expected range of values. If the range is exceeded for any sensor, the complete set of sensor values are sent to the KBS controller. The KBS controller manages the evaluation of incoming sensor data. The safety critical rules are checked first along with sensor validation. If the sensor is determined to be invalid, then it is flagged as such and the KBS continues its monitoring. However, if the sensor is determined to be valid and not indicative of a safety critical fault, then the Failure Mode & Effects Analysis (FMEA) rules are checked. If the event is not determined to be of those identified in the ETCS FMEA, then it is considered to be a novel fault and must be evaluated by the component model based reasoner of the KBS. When either a safety critical event, FMEA fault, or a novel fault is identified, a message identifying the fault is sent to the human interface along with the recommended recovery action.

TCSAP INTEGRATION INTO BASELINE



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TCSAP INTEGRATION INTO BASELINE

- This slide shows a comparison between the major phases of the ETCS Verification program and the TCS Automation Project milestones. The top bar gives a general idea of the time frame in fiscal years. The ETCS design is currently in the concept verification phase until the end of FY92. The TCS Critical Design Review (CDR) is scheduled for January 1993 and First Element Launch (FEL) is scheduled for December 1995.

- During 1991, a prototype HFS and KBS was developed. During 1992, TCSAP will integrate the KBS into the ETCS test bed to demonstrate its capability and reliability prior to CDR. The next step is to modify the models to represent the on-board configuration, enhance the model based reasoning capability, and make both the HFS and KBS available for the ESC by FEL. Note that the ETCS will not be activated until MB-5.

- The point of this slide is to show that TCSAP is in sync with the ETCS baseline schedule, thus allowing the SSF program the opportunity to use the KBS in the ESC by the time the ETCS is activated.

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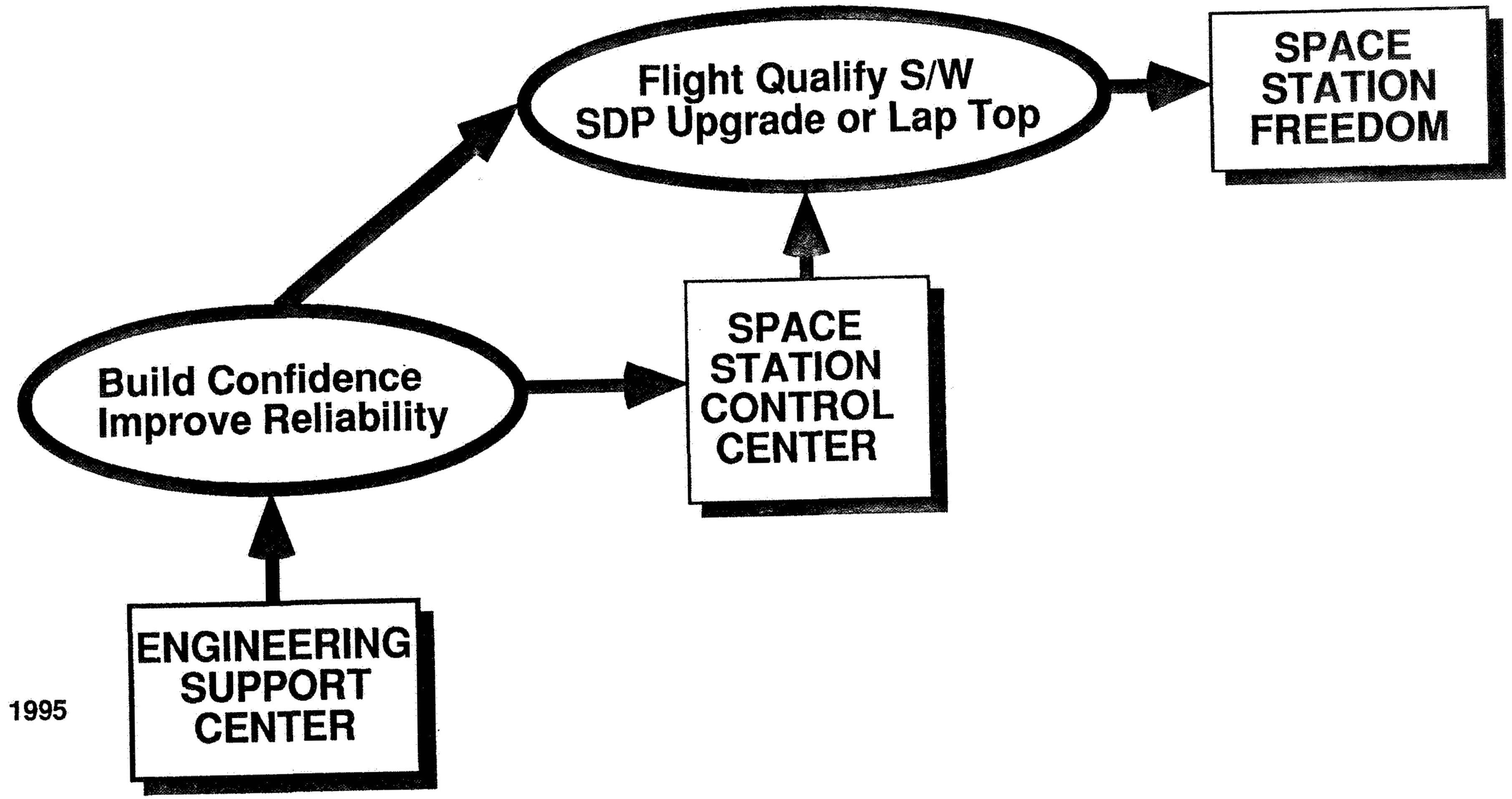
TCSAP GROWTH & EVOLUTION



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TCSAP GROWTH & EVOLUTION

- This slide provides two possible approaches for placing the TCSAP software on-board SSF. The first approach is to migrate it directly to the station from the ESC. The second approach is to migrate it from the ESC to the control center, then to on-board.

- Given that its in the ESC by FEL and it still hasn't proven itself to the SSF program, man tended FDIR would be used to build its confidence. As the operating experience database of the on-board ETCS grows, so will the reliability of the KBS to perform FDIR. Selected portions (e.g., FMEA rules) or all of the KBS may be loaded onto lap top computers that can be carried up and plugged into the space station. Another alternative is to upgrade the SDPs as time, money, and incentive lends itself.

- The point of this slide is to show that TCSAP's KBS can be migrated to on-board.

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TCSAP RELATIONSHIPS

- CREW AND GROUND TRAINING
- ETCS PROCEDURES DEVELOPMENT
- FAILURE ENVIRONMENT ANALYSIS TOOL (FEAT)
- GROUND TEST RESULTS ANALYSIS

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TCSAP RELATIONSHIPS

- The TCSAP HFS can be used for a variety of other uses within the SSF program. For example, crew and ground training can be enhanced with a HFS of the ETCS. The HFS can provide sensor data representing the ETCS under both normal and abnormal conditions. During the development of the ETCS operating procedures, the HFS can be used to evaluate alternative operator actions or procedure steps. The Failure Environment Analysis Tool (FEAT) will be using the ETCS as the prototype system. Due to the closeness of the HFS to the ETCS testbed, it can also be used to assist in ground test results analyses.

- The KBS can serve as a knowledge database for thermal applications and can enhance ETCS training. It can be expanded to include such features as predictive maintenance.

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SUMMARY

- ETCS ISSUES
- FDIR CONFIDENCE
- BENEFITS OF TCS ADVANCED AUTOMATION
- DESCRIBED THE TECHNICAL APPROACH
- DEMONSTRATE THE INTEGRATION OF THE KBS INTO THE ETCS THERMAL TESTBED
- BE THERE FOR FIRST ELEMENT LAUNCH!

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SUMMARY

- In summary, I've identified some of the issues associated with the ETCS and discussed the confidence in the ETCS FDIR. The benefits of the TCSAP software include using the HFS for enhancing training and the KBS for FDIR.

- The technical approach taken by this project was to use a high fidelity simulator of the ETCS and a RODB-like software to test the KBS software. This approach provides a cost effective method for testing the KBS and knowledge acquisition of the ETCS.

- By CDR, TCSAP will have demonstrated its capability and reliability to the SSF program through the integration of the KBS into the ETCS thermal testbed. By FEL, the TCSAP KBS will be available to the ESC for ground operations.

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