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Single Stage Rocket Technology's Real Time Data System

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ABSTRACT

The Single Stage Rocket Technology (SSRT) Delta Clipper Experimental (DC-X) Program is a United States Air Force Ballistic Missile Defense Organization (BMDO) rapid prototyping initiative that is currently demonstrating technology readiness for reusable suborbital rockets. The McDonnell Douglas DC-X rocket performed technology demonstrations at the U.S Army White Sands Missile Range in New Mexico from April-October in 1993.

The DC-X Flight Operations Control Center (FOCC) contains the ground control system that is used to monitor and control the DC-X vehicle and its' Ground Support Systems (GSS). The FOCC is operated by a flight crew of 3 operators. Two operators manage the DC-X Flight Systems and one operator is the Ground Systems Manager.

A group from McDonnell Douglas Aerospace at KSC developed the DC-X ground control system for the FOCC. This system is known as the Real Time Data System (RTDS).

The RTDS is a distributed real time control and monitoring system that utilizes the latest available COTS computer technology. The RTDS contains front end interfaces for the DC-X RF uplink/downlink and fiber optic interfaces to the GSS equipment. The FOCC operators run applications on the RTDS Unix workstations. Twenty one customized SSRT applications were developed for the FOCC RTDS. The application design was based on the programs "aircraft like" operability requirements.

The paper will contain descriptions of the RTDS architecture and FOCC layout. Detailed information on the 21 DC-X applications will be included. A section will include the DC-X ground operation philosophies and rapid prototyping techniques. The paper will describe the DC-X ground operations performed in the FOCC.

1. SSRT Introduction

McDonnell Douglas Space Systems Company, of Huntington Beach, California, was awarded the $58.9 million Single Stage Rocket Technology Program contract to demonstrate single-stage rocket technology (SSRT) on the Delta Clipper Experimental vehicle, or DC-X, in August 1991. The DC-X is a Ballistic Missile Defense Organization (formerly the Strategic Defense Initiative Organization) rapid prototyping initiative that is demonstrating the technology readiness of SSRT. The DC-X, designed for vertical takeoff and landing, is an operational one-third scale experimental test vehicle of an actual reusable launch system. The reusable vehicle is propelled by liquid oxygen/liquid hydrogen rocket engines. A full-scale Delta Clipper, the DC-Y, will be capable of placing a 20,000-lb payload into low-earth orbit.

2. SSRT Real-Time Data System

The real-time data system (RTDS) was developed by the Kennedy Space Center division of McDonnell Douglas to meet the DC-X requirements for an advanced launch processing system that provided "aircraft-like" capabilities. The RTDS provided the ground monitoring, control, and data archival/reduction capabilities for the DC-X vehicle and its ground support systems (GSS). The RTDS was located at the White Sands Missile Range in the mobile DC-X ground operations base, a 40-foot trailer known as the Flight Operations Control Center (FOCC).

This paper presents a view of the DC-X program, then relates the RTDS to the program, and explains how the DC-X team was able to do its work quickly, cheaply, and successfully.

3. DC-X Program Summary

The DC-X is a rapid prototyping initiative that enabled the vehicle to be designed, built, and flown in two years. A highly motivated team of McDonnell Douglas employees from the company's Huntington Beach, Long Beach, St. Louis, and Kennedy Space Center divisions teamed with subcontractors from across the nation to design, build, and integrate the DC-X vehicle in 18 months. The vehicle was shipped to the NASA White Sands Test Facility in New Mexico in April 1993 for a series of static fire tests. The tests were successfully completed in June and the DC-X vehicle and its entire ground support system were packed and shipped to the flight test site at the U.S. Army White Sands Missile Range.

Two static fire tests were conducted at White Sands to verify system operation after the move from the test facility. These full-system tests were conducted successfully and the vehicle was prepared for flight. The first flight of the DC-X, a 60-second, 150-foot hover test to verify the operation of flight systems, was made August 18, 1993 at the White Sands Delta Clipper site. Two additional test flights, conducted at higher altitudes, with increased pitch and roll maneuvers, were completed successfully on September 11th & September 30th. These tests demonstrated the following DC-X goals:

- Validate vertical takeoff and landing concepts
- Validate "aircraft-like" supportability and maintainability concepts
- Demonstrate rapid prototyping development approach
- Demonstrate rapid turnaround capabilities

Funding for the program was depleted at the end of October 1993, and the DC-X remained mothballed at White Sands awaiting additional funding. This funding was received in early May of 1994. The flight test program has completed two flights on June 20th and 27th of 1994. Additional DC-X flights which continue to expand the DC-X flight envelope and demonstrate the operability characteristics are planned in 1994.

4. DC-X - New Ways of Doing Things

The primary goal of the SSRT program is to provide inexpensive access to space into the next century to give this nation a low-cost advantage in space transportation. To meet this goal, the DC-X had to do things better, faster, and cheaper.

Rapid prototyping technologies were used extensively to allow the development team to complete the job on schedule. Automatic code-generating software aided in the rapid development of DC-X flight software, allowing the flight software to be changed and validated in hours instead of many days. Use of off-the-shelf technology with open system architecture was maximized throughout the program. The off-the-shelf products reduced development time while providing many of the necessary capabilities at much lower risk and costs.

The off-the-shelf products used extensively in the development of the RTDS for the FOCC included:

- UNIX system V
- ISO SC16 open systems interconnection protocol
- IEEE 802 network standards (includes Ethernet)
- DARPA TCP/IP networking protocol
- C-ISAM data structure
- ANSI X3.135-1986 SQL database interface
- IEEE 1014 (VME) bus interface
- IEEE 754 floating point number standard

The DC-X also took a new approach to operation of launch vehicles. The entire DC-X system was designed with aircraft-like operability and maintainability concepts. McDonnell Aircraft applied its experience in military aircraft design to develop the avionics systems for the DC-X vehicle, providing easy access to line-replaceable avionics units from access bays, similar to aircraft. The avionics systems were designed with built-in test features and automated modes that allow for rapid checkout of the vehicle subsystems. Douglas Aircraft applied its experience in developing commercial aircraft supportability and maintainability features to help design these critical elements into the DC-X operating procedures. Douglas also contributed expertise from commercial aircraft cockpit controls and displays technology. Several of the commercial aircraft concepts were designed into the RTDS ground control system human-computer interfaces.

The RTDS was designed with many automated features that allowed the DC-X and GSS to be controlled and monitored with a crew of only three. The system was delivered and installed before the vehicle assembly was completed. This allowed the RTDS to be integrated and validated with vehicle subsystems as they were assembled and attached to the core vehicle structure. The parallel checkout of the RTDS interfaces with the actual hardware during assembly allowed for many real-time modifications and enhancements to the RTDS human-computer interfaces before the vehicle assembly was completed. The effective use of off-the-shelf software development packages allowed the RTDS changes to be made rapidly while integrating the vehicle components. This parallel effort allowed the entire vehicle and ground system to be fully integrated and ready for the static fire tests at White Sands on the same day that the vehicle completed final assembly.

The DC-X and GSS components and systems were all checked out with the same RTDS checkout system, which was also used for the integration component tests during vehicle assembly, avionics subsystem verifications, engine static fire tests, and the entire flight test series.

The reusability capabilities of the DC-X vehicle along with the new operability, maintainability, and supportability concepts have allowed the entire DC-X program to be conducted by approximately 35 persons. Thus, the DC-X has proved that low-cost programs are possible – today and for the future.

5. Real-Time Data System Background

The DC-X required a state-of-the-art automated ground control system that could implement customized real-time user monitoring and control interfaces, provide automated sequences and automatic reactive control functions, and contain capabilities for archiving, retrieving, and reducing flight test data. This system would have to be designed, developed, validated, and delivered within 10 months. The Kennedy Space Center division of McDonnell Douglas was asked to develop this ground control system because of its experience in this area. The RTDS was subsequently developed by the division's Automated Checkout Systems department based on a system it designed for space shuttle payload checkout, which is still in use. This baseline system, the partial payload checkout unit (PPCU), has been used in the Operations and Checkout Building at KSC since 1990.

PPCU is a generic, real-time data monitor and control system with front-end and back-end interface extensions and a distributed network of data processing and recording equipment. PPCU utilizes highly modular subsystems, industry standards, and commercial software and hardware, where practical, to provide a reliable, flexible, and continuously upgradable system at minimal cost.

6. Ground Systems Layout

The FOCC primarily consists of the equipment housed in a van and external interfaces to the DC-X vehicle GSS. The boundaries of the FOCC are illustrated in Figure 1.

The RTDS, the primary subsystem of the FOCC, serves as the operator interface for real-time monitor and control of both the DC-X vehicle and the GSS.

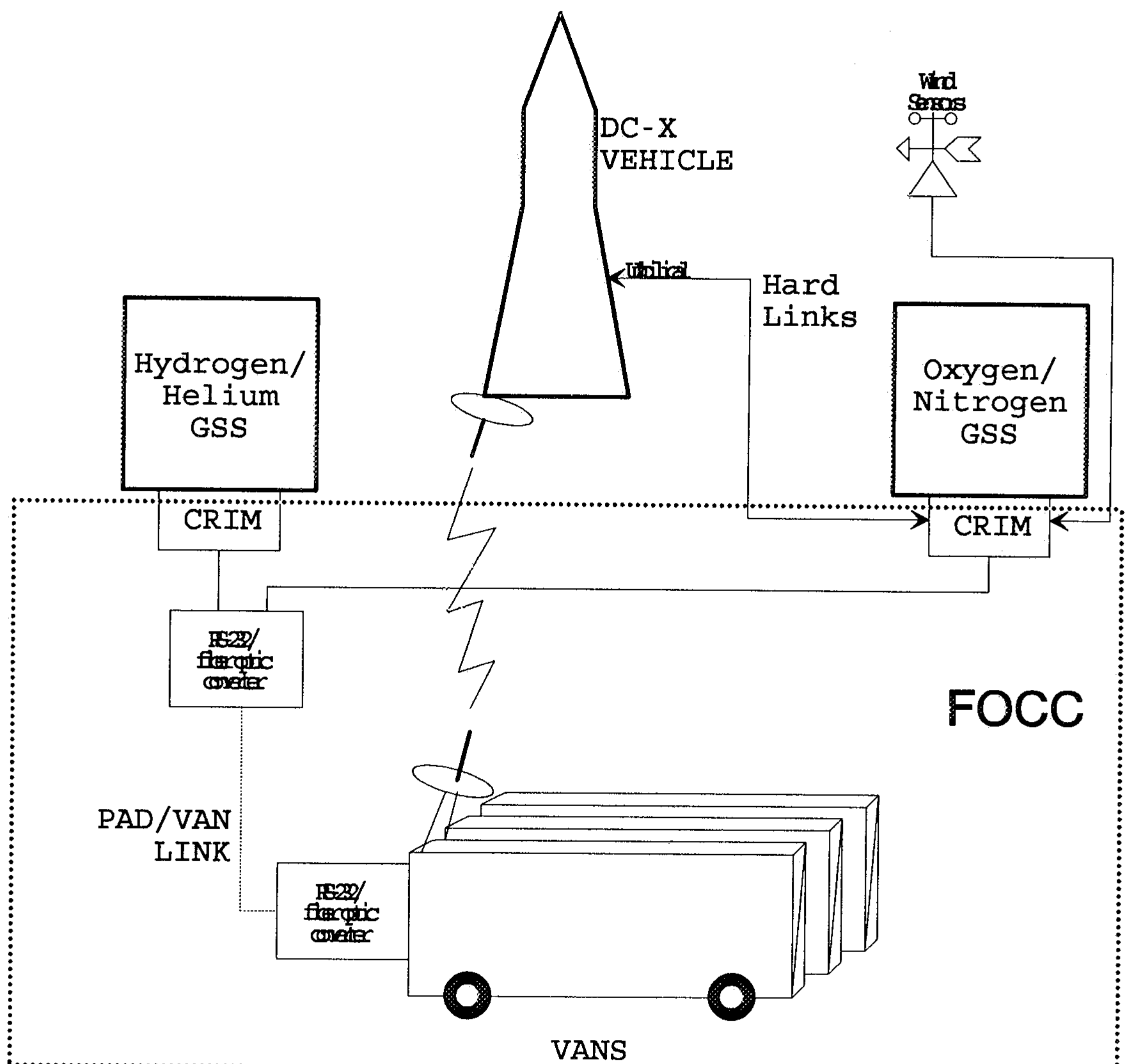

Figure 1. The Flight Operations Control Center

7. RTDS Architecture

The RTDS processing elements provide for monitoring and displaying real-time data. The recording elements provide independent real-time data recording. The architecture is implemented as shown in Figure 2 and consists of five major subsystems connected via Ethernet networks. Each subsystem consists of one or more processors in parallel or in clusters.

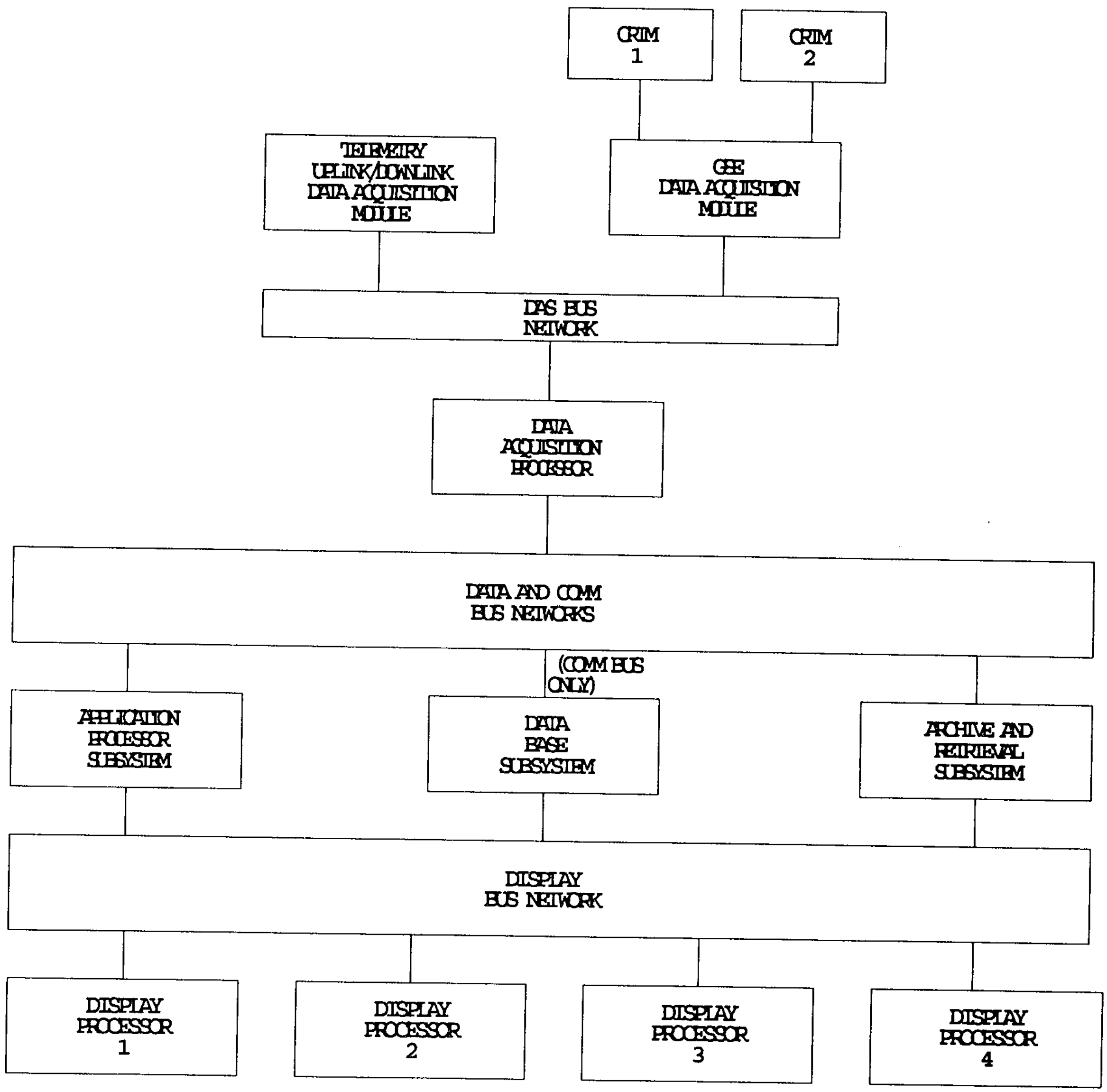

Figure 2. RTDS Architecture

Data Acquisition Modules

The interface from the RTDS to the DC-X vehicle and GSS is composed of a data acquisition subsystem that operates in an autonomous fashion. The subsystem features three data acquisition modules connected to a data acquisition processor for data concentration. Each module is configured with hardware and software to preprocess a dedicated data link. The RTDS contains three data acquisition modules: telemetry downlink, telemetry uplink, and ground support equipment (GSE). For DC-X, these three modules' front-end interfaces are PCM telemetry downlink, RF RS-422 uplink, and GSE RS-232. They interface with fiber optic modems that connect the commercial remote interface modules (CRIMs) at the launchpad to the RTDS GSE data acquisiton modules in the FOCC. This generic RTDS subsystem architecture provides flexibility to incorporate additional interface types in the future by simply adding an additional module to the data acquisition subsystem bus network in the RTDS.

Subsystem preprocessing consists of all the interface and data-dependent operations required to provide normalized, time-tagged data to the RTDS. The raw data from the vehicle and GSS is passed through a data acquisition module data filter. Each sample is compared with the last sample that changed significantly. If a significant change of value has occurred, then the new sample value is processed. Limit-checks are performed on the processed data in order to detect measurements that have violated any upper or lower limiting conditions. After limit-checking, the processed data is distributed throughout the rest of the system.

Commercial Remote Interface Module

The RTDS has a CRIM located on each side of the DC-X flight stand. The CRIM is a VME chassis that contains a microcontroller card and several discrete and analog input/output cards. The CRIM continuously monitors the analog and discrete status of the GSS equipment and sends the status back to the RTDS GSE data acquisition module. Commands from the RTDS GSE modules are received over the RS-232 communication lines and the appropriate analog and discrete channels are activated upon their receipt. Vehicle electrical power is also controlled through the CRIM.

Data Acquisition Processor

The concentrator in the data acquisition processor combines the data outputs from the modules into an integrated data stream broadcast to the other RTDS subsystems. The processor also receives system commands and end-item commands and routes them to the appropriate modules. Once loaded and initialized, the subsystem broadcasts data to the data acquisition processor for use by the application processor and the archive and retrieval subsystem.

Application Processor

The application processor is the RTDS real-time data processing element and provides for execution of the customized DC-X user application programs. It broadcasts measurement data to the display processors and processes commands from the users originating at the display processor. Commands issued from user applications are routed through a command distribution manager on the application processor which verifies user permissions prior to issuing and routing commands to their proper destinations. All commands are recorded for posttest retrieval.

Archival and Retrieval Subsystem

The archival and retrieval subsystem contains the recording elements within the RTDS system. This subsystem records the digitized raw telemetry stream, as well as the processed telemetry and GSE data. Data are recorded to hard disk to support near-real-time retrieval of the vehicle and GSS information. Data can be retrieved and plotted in minutes using the hard disk-archived information. The data are also recorded on 4mm tape for the historical posttest retrieval archives. RTDS subsystem health, end-item commands, user "mouse" selections, and system messages are also recorded by the archival and retrieval subsystem.

Display Processors

Four color graphics workstations called display processors provide the user interface to control and monitor the DC-X vehicle and GSS. Operators send commands by a mouse and use the display processor multiwindow graphics capability to configure the system to their specific needs. The windows environment is an X-Windows-based system; that is, it is implemented with off-the-shelf software tools to allow a continual upgrade path to future releases of hardware and software. The user interface is capable of being logically configured, based upon the user permission level, to support a range of capability from system configuration and monitor-only permissions to total control and monitoring permissions.

Database Subsystem

The database subsystem contains the RTDS data retrieval processing, configuration management utilities, and the RTDS generic measurement and command database. RTDS front-end interfaces and command data formats are defined in this generic database. The RTDS operator updates the telemetry uplink, and downlink, and GSE measurement and command information in the generic database using customized database forms. The subsystem then builds generic real-time tables for each of the RTDS subsystems. This generic database structure allowed for near-real-time modifications to the DC-X measurement and command information. This feature was critical in meeting the rapid pace of the DC-X program, where sensors were being added and modified continually.

The generic format of the RTDS allows the system to contain multiple formats and provides the flexibility to easily support new systems in the future. New launch systems could be supported simply by defining the front-end telemetry and GSE information in the database and developing the customized user interface applications.

8. RTDS Human-Computer Interface

The DC-X ground operations procedures were developed using "aircraft-like" concepts to reduce ground operator workload. The RTDS was designed to allow a crew of only three operators to perform all the activities required for the DC-X preflight, flight, and postflight operations. Two operators, the flight manager and deputy flight manager, are assigned DC-X vehicle monitoring and control functions similar to pilot and co-pilot functions, while the third operator performs the duties of the ground systems manager.

Twenty-one customized applications were developed for the DC-X and its GSS as listed below:

Ground Support Systems (7)
- GSS propellant safing and master controls
- Liquid hydrogen
- Liquid oxygen
- Gaseous hydrogen
- Gaseous oxygen
- Gaseous nitrogen
- Gaseous helium

Vehicle Subsystems (9)
- Flight sequencer controls
- Vehicle hydraulics
- Vehicle main engines
- Vehicle reaction control system
- Vehicle propulsion system
- Vehicle avionics
- Vehicle rate/accelerometer sensors and radar altimeter
- Vehicle electrical system
- Flight constants

Flight Displays (2)
- Flight profile
- Flight subsystem monitoring

RTDS Administration
- Pseudo measurement initialization
- Data acquisition module controls
- GSE-CRIM automated checkout

The RTDS applications were designed with many automated sequences and graphical monitoring features. The user interfaces maximize the DC-X operability features and keep the operator workload to a minimum. Electronic checklists record preflight steps to allow the operator to avoid use of paper manuals. Application displays are schematics of the actual GSS and DC-X vehicle subsystems to allow for rapid assessment of subsystem status and configuration. The displays rely heavily on the effective use of color coding, alarms, and positional dynamics to give the user both graphical and numerical representations of the vehicle and GSS information.

Ground Support Systems

The GSS contains seven applications for loading propellants and gases in the vehicle. The four gases have automatic topping modes that key off temperatures and pressures to control their flow. The liquid propellants have automated purging and loading sequences. The loading procedures monitor tank-level sensors to control the flow of the liquid oxygen and hydrogen. Automatic and manual safing features ensure that the vehicle can be quickly safed in the event of fires or leaks.

Vehicle Systems

The flight sequencer application contains the electronic checklist and controls to sequence through the 18 automated vehicle modes. The flight manager used this application to monitor events as the automated vehicle modes were commanded. The application has several screens that change as the flight manager commands the vehicle through its preflight built-in-tests and simulated flight modes. The deputy flight manager used the various subsystem screens to monitor the status of the built-in test equipment and subsystems throughout the preflight sequence.

Flight Screens

Two screens were developed to monitor the DC-X flight. The flight profile monitors the vehicle profile, latitude/longitude positions, altitude, and the pitch, roll, yaw information. The vehicle subsystem monitor displays engine performance graphs, propulsion, hydraulic, landing gear, flap, and engine gimballing status.

Figures 1-4 contain black and white copies of four actual DC-X RTDS displays.

9. Conclusions

The DC-X program has proven that things can be accomplished quickly and cost-effectively by following a "build a little, test a little" rapid prototyping philosophy. The rapid prototyping technology was effective on this program, and could be used in the future as a means of achieving better, faster, and cheaper development.

The next step is to continue our "build a little, test a little" philosophy and move onto the two-third scale prototype known as the SX-2. This vehicle will be capable of higher altitude flight, higher velocities, and have greater maneuverability. The SX-2 will start to prototype and test lightweight material technology that will be required for the ultimate success of the full-scale single-stage-to-orbit vehicle known as the DC-Y.

FIGURE 3 - LIQUID HYDROGEN GROUND SUPPORT EQUIPMENT

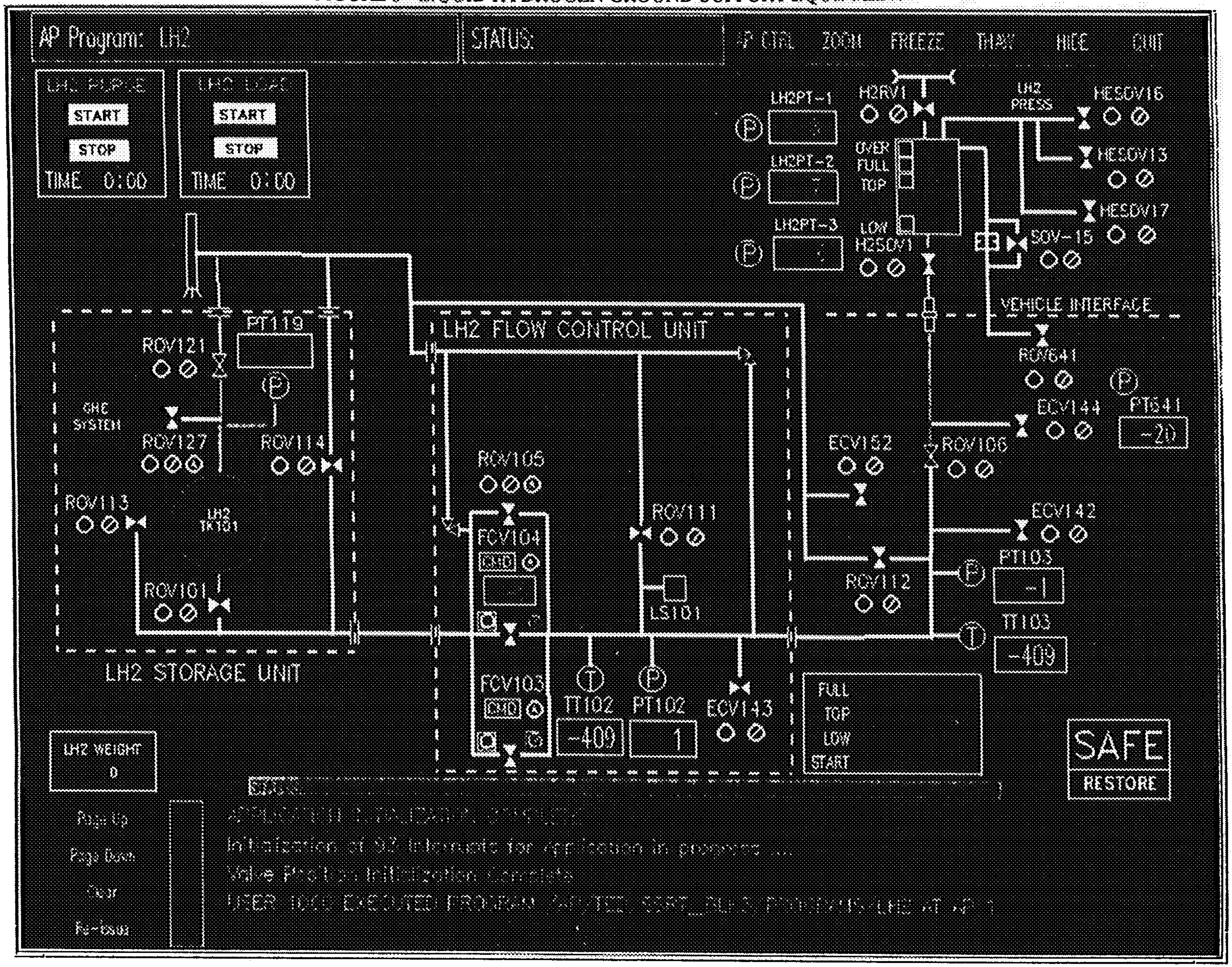

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FIGURE 4 - DC-X VEHICLE SUBSYSTEM FLIGHT MONITORING

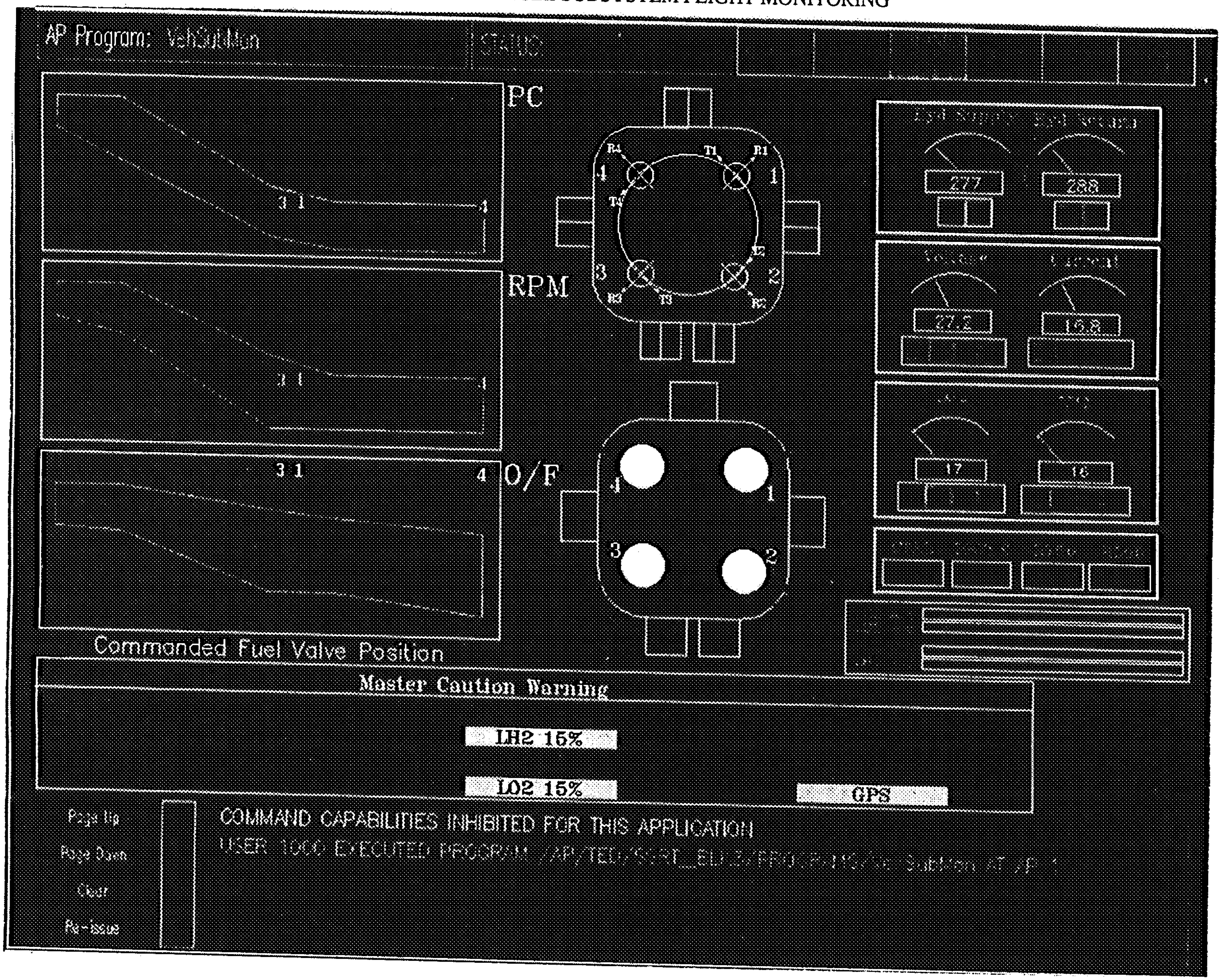

FIGURE 5 - DC-X FLIGHT PROFILE MONITORING

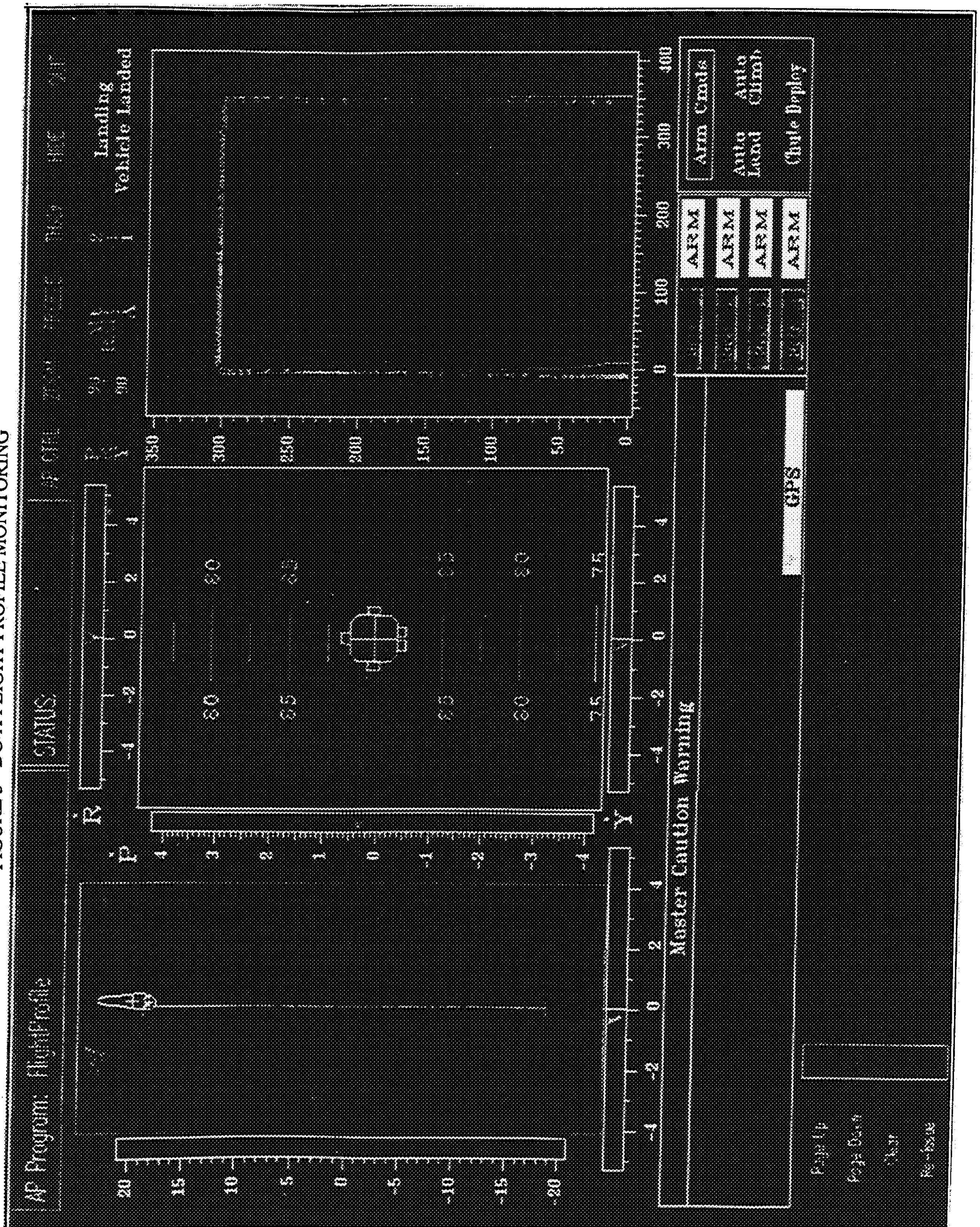

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FIGURE 6 - DC-X PREFLIGHT MODE SEQUENCER