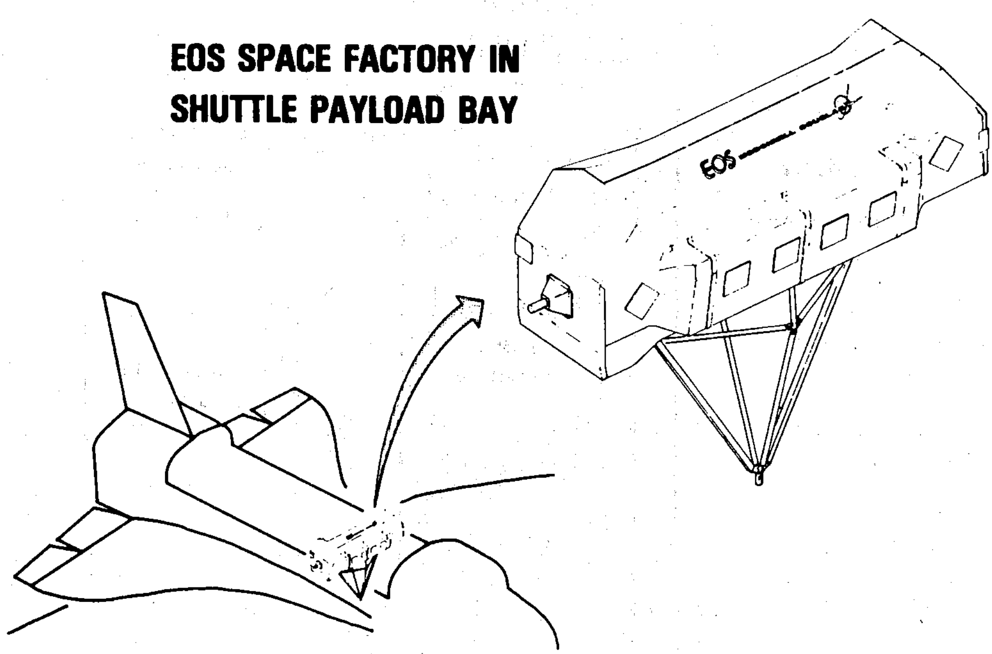
DEVELOPING REAL TIME PROCESS CONTROL IN SPACE

R. J. Wood
Payload Specialist
McDonnell Douglas Astronautics Company
St. Louis, Missouri

Since 1982, McDonnell Douglas Corporation has been purifying new pharmaceutical materials on the space shuttle. As demonstrated using a continuous flow electrophoresis system mounted in the crew comparment, McDonnell Douglas can process over 700 times more material and achieve purity levels four times higher than those possible in similar operations on the ground.

As a first step toward commercial space processing, a prototype production plant has been developed to fly in the shuttle's cargo bay. This fully automated factory has been designed to operate continuously and autonomously during its missions. Critical to this goal is a new closed loop control system, employing digital cameras to monitor the purification process.

Previous flight experience has shown that ground calibration is not adequate for predicting optimum zero gravity operating conditions. Therefore, process fine tuning will be required on initial flights. To expedite these adjustments and maximize product return on these first flights, a process control engineer will fly with the factory, operating it from the crew compartment. This will increase the command and data rates at least 20 fold.

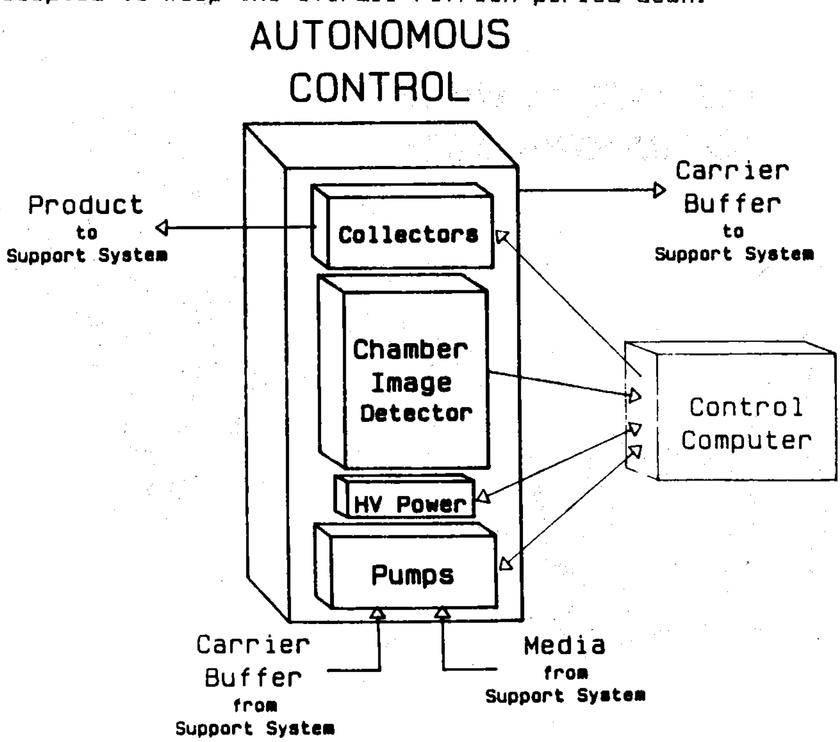


Continuous flow electrophoresis is performed in a rectangular chamber. A solution of the mixture to be separated is injected into a steady, laminar flow of carrier buffer. An electric field is applied across the flow, and differences in the molecular ionization of each component cause the mixture stream to fan out into pure component streams. For research applications, an array of collection tubes is used to collect all separated fractions at the end of the chamber.

For space production, movable collectors are used to extract only the product stream from the separated fractions. To consistently collect pure product as the process fluctuates slightly, an ultraviolet imaging system is used to monitor product stream position. The control computer closes the process loop by locating the product stream in the digitized image, and then adjusts the collectors accordingly.

The factory module consists of four separation chambers supplied by two support systems. This provides dual redundancy for all functions, and four fold redundancy for the critical chambers. Approximately 200 sense points and 100 control points are integrated with 28 microprocessors for factory control and monitoring.

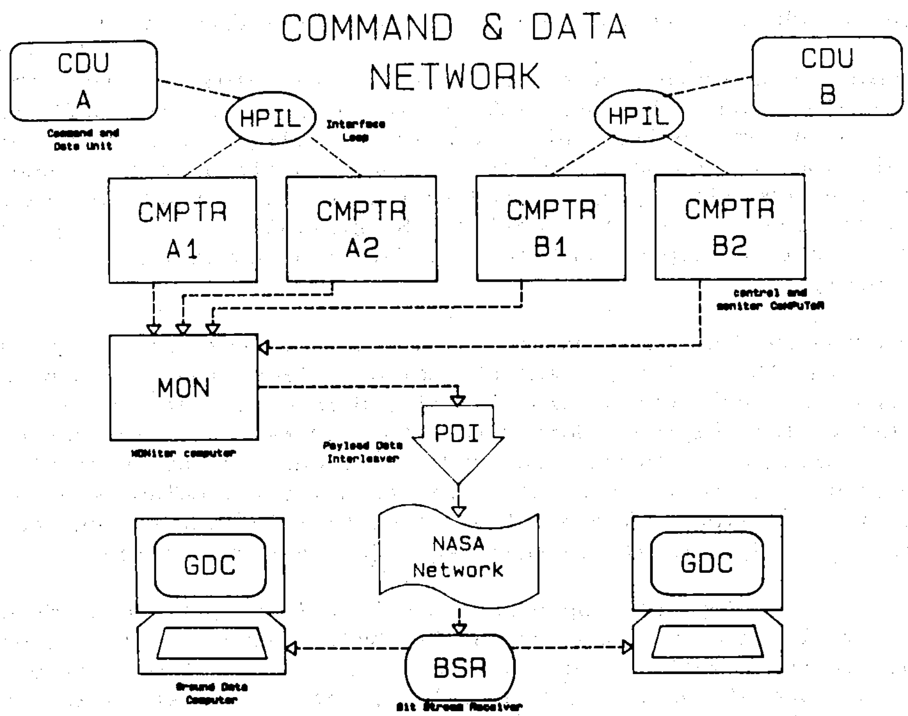
As a standard service to each space shuttle customer, NASA will downlink 1000 bits of data per second from the payload, and allows the definition of no more than 64 distinct commands for uplink to the payload. This ground command capability is inadequate for factory operation, so all commanding will be performed by the flight crew. By reducing the data resolution of chamber images 256 times, all factory data can be refreshed to the ground in 16 seconds. This reduced resolution is sufficient for qualitative monitoring of the process, and was accepted to keep the overall refresh period down.



The command and data network provides all factory control, operator command and ground monitoring capabilities. Each control and monitor computer (CMPTR), a smaller network of seven microprocessors, controls one separation chamber and shares control of one support system, using thirty four asynchronous tasks. The monitor computer (MON) is a low power consumer used to downlink essential data during launch and entry, and serves as the downlink arbiter throughout the mission.

The command and data units (CDU) are the operator interface. Each is a portable computer with an 25 line by 80 column LCD display (480 by 200 graphics resolution). The two units and interface cable stow in less than one cubic foot, and may be set up anywhere in the crew compartment. The display is divided into two windows, with sixteen different screens selectable on each. The screens include sensor and control tables, flow schematics, full resolution images, and software logic tables. The tables include a full screen editor, which allows new control set points or logic adjustments to be entered by the operator.

Flight support is facilitated with ground data computers (GDC). The capabilities of these desk top computers include real time data and image display, and data archive and recall. An adjustable data filter detects sensor and control redlines, as well as logic transitions, then alerts the support engineer. Data for the entire mission is archived as it arrives, and a snapshot of any mission moment may be recalled even as the mission progresses. Trends may also be analyzed using data history plots.



Ultimately, the electrophoresis factory module will require very little crew interaction during nominal missions. After a short start up procedure, the crew may perform status checks at their option as the mission progresses, until shutdown shortly before entry. All the while, the flight support team will monitor the process, and any adjustments will be voiced to the crew. Such autonomous operation allows this factory to be categorized as a "payload of opportunity", easily added to the flight manifest up to six months prior to flight, with little or no impact on the primary mission objectives. "Payload of opportunity" status is extremely important if regular access to space for production is to be maintained.

Flight experience with the crew compartment electrophoresis experiment indicates that many process adjustments will be needed initially, however, as the new separation chambers are operated in zero gravity for the first time. These adjustments must be made with the actual product media, to insure that the purity required for pharmaceutical application is achieved. To maximize product return and flight results, a McDonnell Douglas engineer will fly as a Payload Specialist on initial factory flights, serving as factory operator and process control engineer.

The Payload Specialist and flight support engineers will share responsibility for factory operation. While the support team monitors the overall operation of the factory, the Payload Specialist will perform checkout and calibration procedures on specific systems. If off-nominal conditions are detected on the ground, the support team will direct the Payload Specialist to appropriate diagnostics.

The data transmission rate to the crew compartment is more than ten times faster than the downlink to the ground, and the CDU polls for only a selected portion of the data, yielding an effective 100 fold data throughput increase in most cases. While only raw, compressed images are rountinely transmitted to the ground, the CDU displays full resolution images for the Payload Specialist, at all stages of the product location algorithm, so that detection parameters may be tuned very rapidly.

All processors in the command and data network are programmed in FORTH. In the unlikely event of serious malfunction, or zero gravity operating characteristics significantly different than expected, FORTH will allow the Payload Specialist to modify or extend the process control software. Diagnostic and transient detection routines, or asynchronous tasks to control dynamics not anticipated, may be added during the mission. The problem can be fully diagnosed, and possible solutions tested, without having to wait for another mission.

Using this development approach on initial factory flights, McDonnell Douglas will checkout and calibrate the autonomous real time process control system, while returning large quantities of product as well. For a commercial manufacturing venture, optimizing each space shuttle flight in this way is a critical part of establishing a regular space production capability.