

Real-Time Application of Knowledge-Based Systems

Randal W. Brumbaugh
PRC System Services
Aerospace Technologies Division

Eugene L. Duke
NASA Ames Research Center
Dryden Flight Research Facility
Edwards, California

The Rapid Prototyping Facility (RPF): A Real-Time Application of Knowledge-Based Systems.

At the Dryden Flight Research Facility of the NASA Ames Research Center, the Aircraft Automation Group is engaged in research aimed at applying expert systems technology in a real-time flight test environment. NASA and PRC researchers have developed a facility which allows an expert system prototype to be rapidly and safely demonstrated with a test aircraft. Applications range from monitoring and displays to outer loop aircraft control.

This presentation is intended to document the facility development and architecture, demonstrate its utility by presenting a typical application, and detail recent accomplishments and future goals.

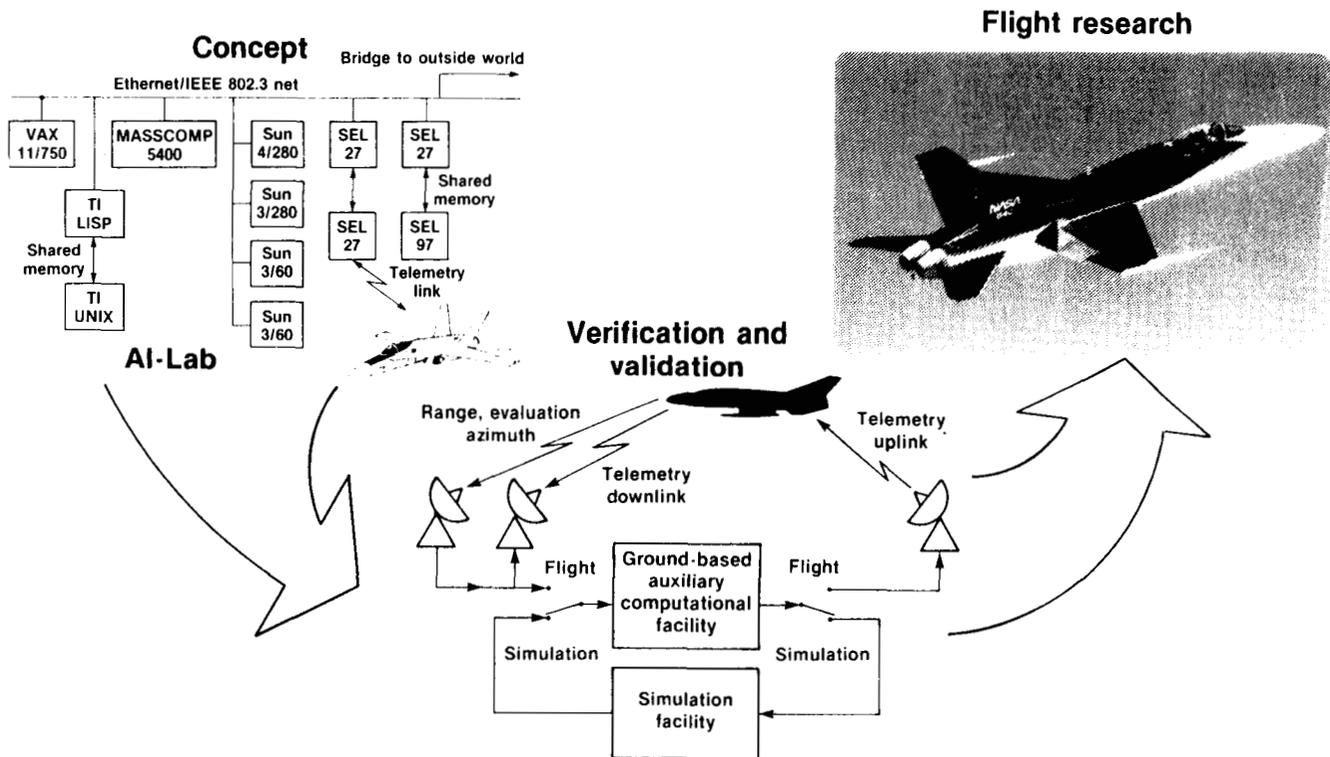
Rapid Prototyping Facility: Concept

The development of a knowledge-based or expert system generally includes an early implementation of a prototype system. This prototype system provides a means of assessing concept feasibility, examining knowledge representation and inference strategies and provides a demonstration to gain support for a larger, more complete program.

The value of prototyping the major components of a knowledge-based system early in the development cycle is that many problems or potential problems can be discovered. Addressing these problems at an early stage is generally less costly and time-consuming than later modification.

The facility discussed here provides a flexible, general-purpose capability for prototyping flight systems which contain a combination of knowledge-based and algorithmic components. The user has a wide choice of processors, tools and resources, including the Ames-Dryden real-time simulation facility and research aircraft, through the Remotely Augmented Vehicle (RAV) system.

A developer with a concept for a knowledge-based flight system may select resources and distribute applications to rapidly develop a prototype system. The facility then allows easy transition to simulation verification and validation, and possible flight test of the concept.



ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

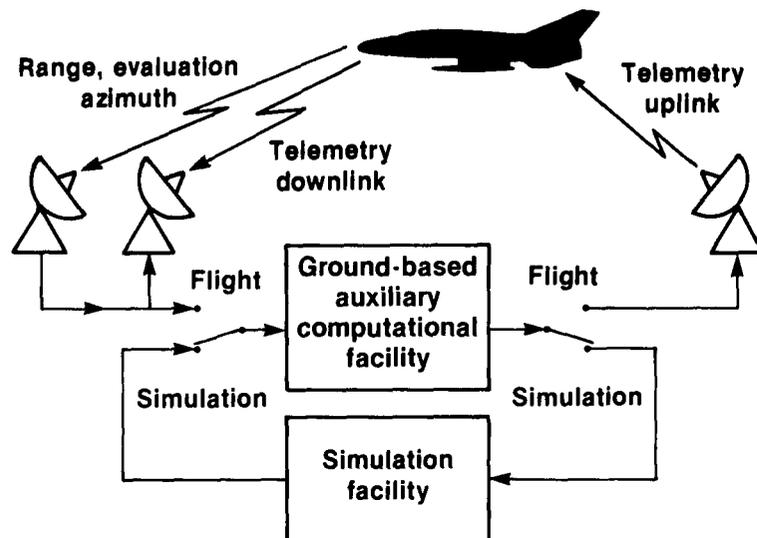
Components: The Remotely Augmented Vehicle (RAV) System

The rapid prototyping facility is an extension of the Ames-Dryden RAV system capability. The main elements of this facility, shown in the figure, are

1. A specially modified aircraft
2. An auxiliary computational facility
3. A high fidelity simulator

Each element serves a unique function in providing a path for rapid system transition from simulation to flight. It is this transition capability that provides the power of the facility to a prototype system developer.

The aircraft used requires two main modifications. The first is the addition of sensors and a high quality instrumentation and telemetry downlink system. The second is the integration of a telemetry uplink system into the onboard systems. Uplinked data may be routed to the flight control system for closed loop control, or to an onboard display system if displays are desired. Once so configured, the aircraft requires no further modifications; changes are performed by altering the auxiliary computational facility.



- Specially modified aircraft
- Simulation facility
- Auxiliary computational facility
 - Numeric and symbolic processors
 - Duplication of flight systems in simulation facility

Components: The Remotely Augmented Vehicle (RAV) System

When the telemetry links are operating, the aircraft systems essentially become a node in a distributed processing system which includes a suite of ground based computational facilities. These may include systems for handling TM links, for displaying, recording, or processing data in real-time, or for performing specialized tasks such as knowledge-based control or monitoring. This allows processors which cannot be physically located onboard the vehicle due to limitations in space, ruggedization or cooling, to act nearly identically to an onboard computer.

As an alternative to the flight system, the aircraft may be replaced by the simulation system. The simulation facility provides modelling of the aircraft so that systems may be verified prior to flight operation. It is a key feature, and a requirement for safety, that the interface between the simulation and the actual aircraft TM links be identical. In this way, a concept tested in the simulator is provided a path to flight test experience (see previous figure).

How Fast is "Real Time" ?

Any system which must provide a response in a given time interval can be said to be a "real-time" system. The length of the time interval varies greatly, depending on the system and application. It may even differ between components of a single system. A display processor will typically have a slower response criterion than an aircraft flight control system, although both are parts of a larger system. Some systems also have requirements such as a constant frame time, or connection to a regular clock interrupt.

The rapid prototyping facility provides for real-time response at several levels. Interactive systems must provide response at human speeds. Typically this applies to editors, compilers, and display systems. Outer-loop systems provide control of system state trajectory, and inner-loop systems are required for system stability. A trajectory guidance controller is an example of outer-loop control; a flight control system provides inner-loop functions.

The final measure of a real-time system is that it respond "in-time." The developer using the RPF chooses from computing resources and tools with different capabilities. Efficient distribution of processing is key to meeting response time specifications, but redistribution of processes is not difficult.

Real-Time Applications Within Rapid-Prototyping Facility

What does real-time mean?

- **Interactive**
 - Response at human speeds (1.0–0.1Hz)
- **Outer-loop systems**
 - Response required to control system trajectory (25–1Hz for aerospace systems)
- **Inner-loop systems**
 - Response required to stabilize dynamic system (1000–25Hz for aerospace systems)
- **In-time**
 - Response provided in time required

Goals for rapid-prototyping facility

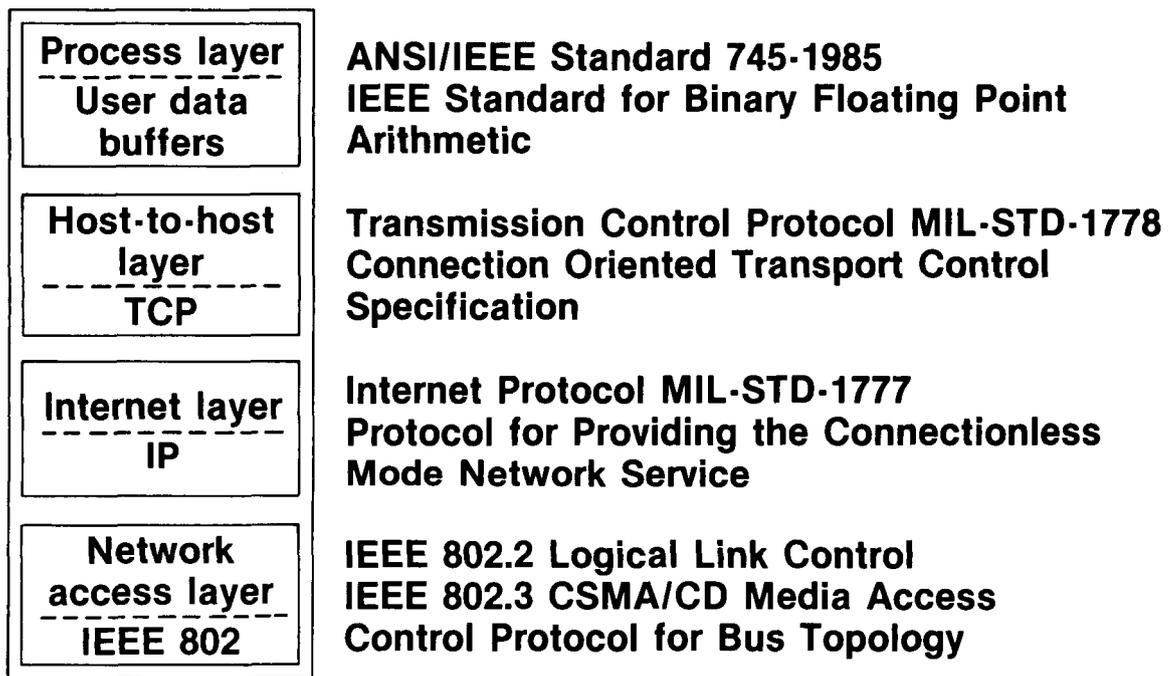
- **In-time responses for tasks up to 25Hz**

Flexibility through Standardization

The wide selection and flexibility of the resources available in the RPF is a result of the use of standard interfaces which are widely recognized and supported by nearly all manufacturers. Expanding or altering the network of computers is a quick and simple procedure. The use of standards also provides access to the resources available to users of the central facility computers, which contain a variety of printers, plotters and disk storage devices.

The computers are linked through a network based on a thick Ethernet/IEEE 802.3 cable. The DOD standard TCP/IP protocol is used throughout for communication. Standard utilities for virtual terminal emulation (telnet) and file transfer (ftp) are available to users during development. Executing processes transfer data in single precision IEEE 754 floating point format. Many processors support this format directly; others require a simple conversion routine to change the data to their local floating point format.

Communication Standards in AI-Lab



Current Architecture

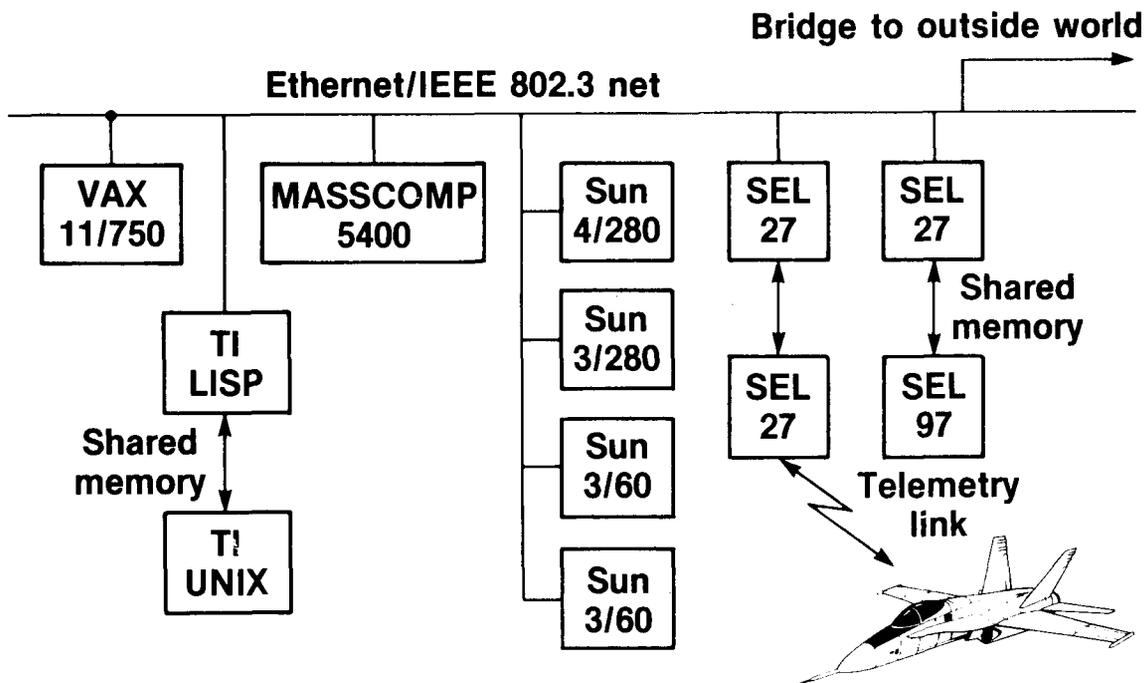
The computer systems in the RPF are divided into two groups. The first is the computer systems of the Aircraft Automation group; the other is the systems of the Ames-Dryden Simulation/ RAV facility.

The simulation/RAV computers are shown on the right side of the figure. These are very high speed FORTRAN processors. The systems shown are typical. The facility contains several systems used for development, simulation and RAV. Each system contains two computers connected by a high-speed shared memory link. These systems provide simulation, cockpit interfaces and displays, connection to hardware-in-the-loop simulation components and RAV linkage.

The majority of the remaining computers are general purpose UNIX-based workstations with high resolution graphics interfaces. These provide general purpose computing and development resources. Several languages and tools are available to users including C, FORTRAN and CLIPS.

The VAX 11/750 is used primarily for its disk storage and tape facilities. It also hosts several tools for expert system development including C, FORTRAN, Common LISP, OPS5 and CLIPS.

The TI Explorer LX is a multi-processor system designed for applications requiring close integration of symbolic and numeric computing. The primary processor is a symbolic processing architecture with LISP, ART and a graphics interface. It communicates through shared memory or data streams with a conventional processor running applications under the UNIX operating system.



An Application: The Automated Flight Test Management System (ATMS)

The ATMS system, developed by Sparta, Inc., is designed as the premier application for the rapid prototyping facility. This system demonstrates many of the capabilities of the RPF for use in planning, monitoring and control tasks involving several cooperating resources. It includes expert systems, numerical algorithms, graphics, simulation, control, monitoring and use of RAV capability.

The ATMS aids engineers in a flight test environment by using expert system technology to optimize flight maneuver lists to fit time and range constraints. It is designed to aid both in pre-flight planning and in in-flight execution and monitoring. It is designed to benefit flight test engineers, researchers and pilots so that the best data possible is obtained at minimum cost and time.

- **Flight test planning**
 - Program planning
 - Block planning
 - Preflight planning

- **Flight test trajectory control**

- **Flight test maneuver monitor**

- **In-flight re-planner**

C-5

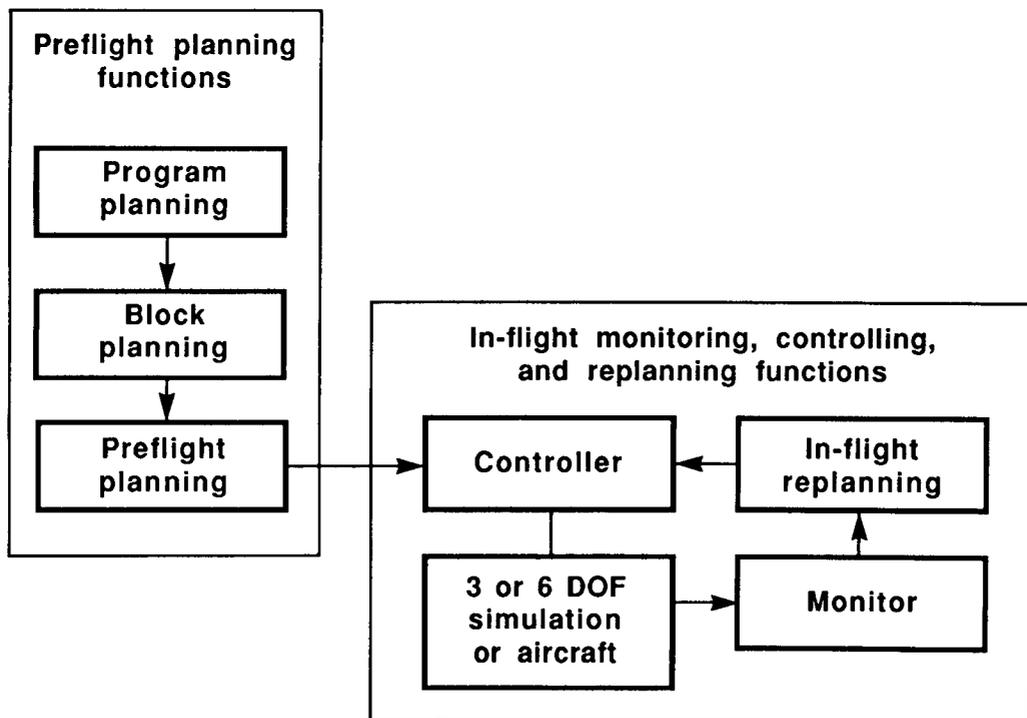
ATMS: Final System

The final ATMS system implementation will provide full flight planning, monitoring and control capabilities. The system uses knowledge of a flight project's goals, priorities and needs to formulate a plan for blocks of flights, individual flights, and finally chooses lists of maneuvers for each flight. The maneuvers for a specific flight are ordered to optimize use of available time, range, space and fuel.

After the FTE and system have defined a flight card containing an ordered list of maneuvers to be performed during the flight, the flight can be simulated either with a 3 degree-of-freedom simulation, or a more correct 6 degree-of-freedom simulation.

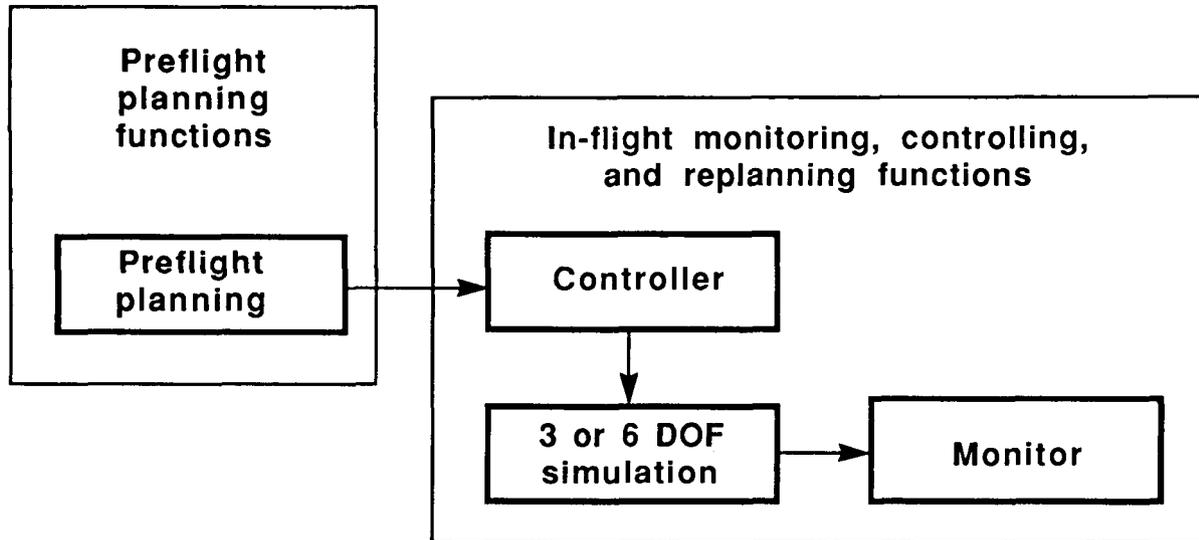
During the flight, the selected maneuvers can be flown by a research pilot or by a flight test trajectory controller through the RAV link. As each maneuver is performed, the monitor function checks data to be sure that it is of acceptable quality for research requirements. It also monitors constraints such as range boundaries and restrictions and aircraft structural limits to be sure they are not violated.

If a maneuver is stopped or unacceptable, the ATMS recommends a course of action: drop the maneuver, repeat it, or reschedule during a subsequent flight. Based on interaction with the FTE, a new plan can then be formulated in-flight.



ATMS: Current Functions

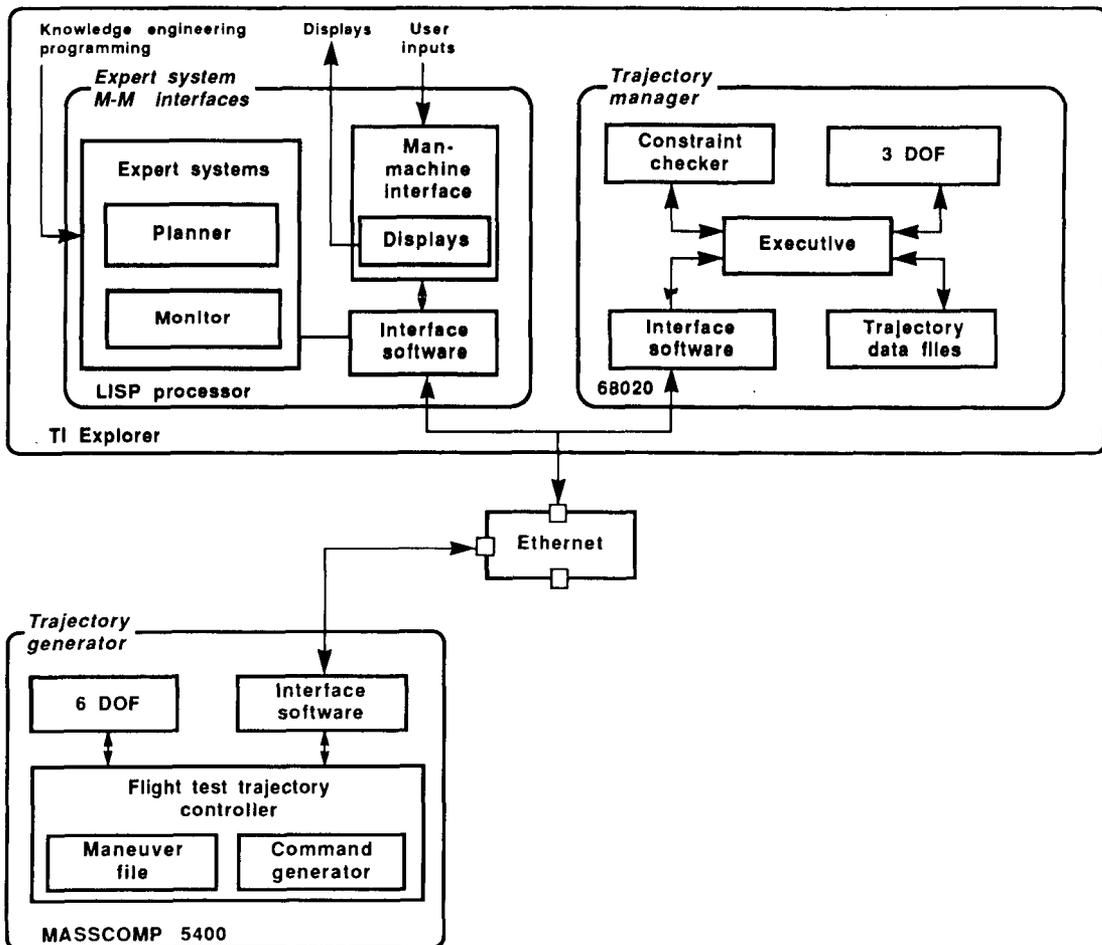
The current ATMS system (Phase I) implements a carefully selected subset of the final system design. The parts selected for implementation are designed to demonstrate distribution of processing, real-time control in a simulation environment, and limited planning and monitoring capability. This system was presented in a demonstration in June, 1988.



ATMS: Workstation Configuration

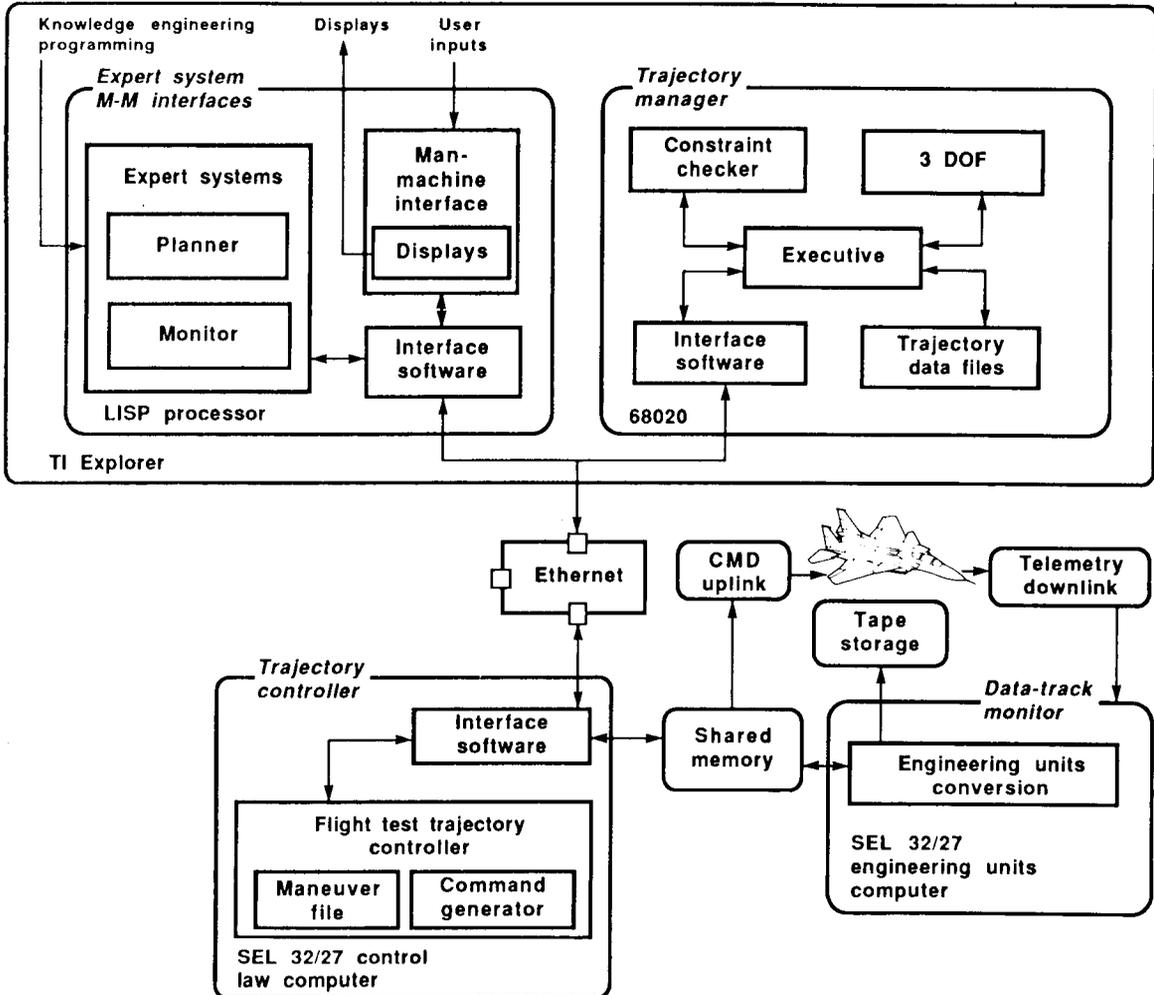
The following three figures depict three different configurations of the ATMS, showing how tasks are distributed among the processors. The configurations progress from planning to validation to flight test.

The first shows how tasks are partitioned for the flight test engineer workstation. This system allows the FTE to enter maneuvers, simulate maneuvers to estimate time, space and fuel used, and suggests an order for flight. The simulations are performed in a local workstation rather than the simulation facility to avoid scheduling time on the simulation computers until a more refined flight plan has been constructed.



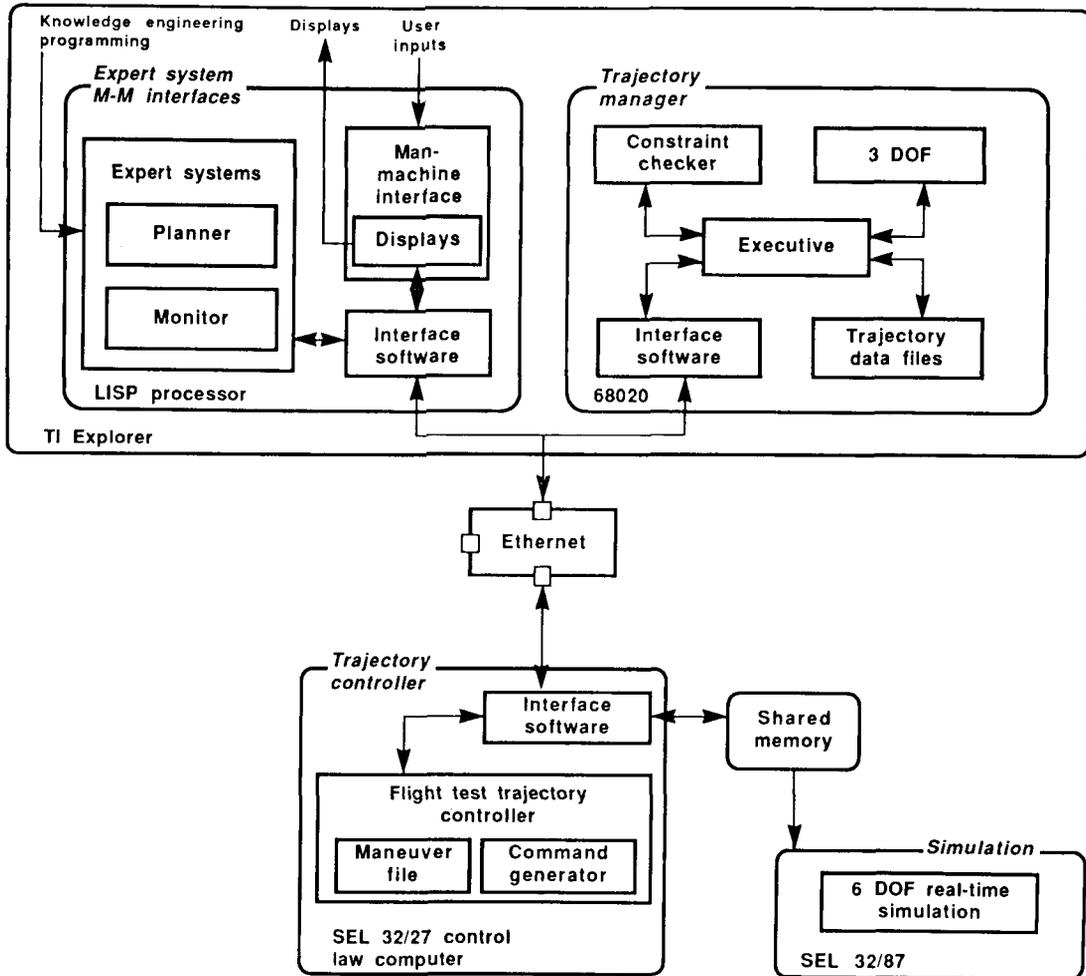
ATMS: Flight Configuration

Once satisfied that the flight card is acceptable, the flight is conducted. The system can monitor data and range constraints, perform maneuvers, or both. The aircraft with RAV links is inserted in place of the simulation computers.



ATMS: Validation Configuration

The simulation validation system adds the Ames-Dryden real-time simulation facility computers and cockpits in place of the workstation. In this mode, the FTE can preview the flight with a research pilot, or obtain very accurate information about the fuel and range requirements.



Status of the Rapid Prototyping Facility

The Rapid Prototyping Facility was developed to meet a need for a facility which allows flight systems concepts to be prototyped in a manner which allows for real-time flight test experience with a prototype system. This need was focused during the development and demonstration of the expert system flight status monitor (ESFSM). The ESFSM was a prototype system developed on a LISP machine, but lack of a method for progressive testing and problem identification led to an impractical system.

The RPF concept was developed, and the ATMS designed to exercise its capabilities. The ATMS Phase I demonstration provided a practical vehicle for testing the RPF, as well as a useful tool. ATMS Phase II development continues.

A dedicated F-18 is expected to be assigned for facility use in late 1988, with RAV modifications.

A knowledge-based autopilot is being developed using the RPF. This is a system which provides elementary autopilot functions and is intended as a vehicle for testing expert system verification and validation methods.

An expert system propulsion monitor is being prototyped. This system provides real-time assistance to an engineer monitoring a propulsion system during a flight.

- **Demonstration of expert system flight status monitor (10/86)**
- **Demonstration of Phase I ATMS (6/88)**
- **F-18 identified for facility (expected by 10/88)**
- **KBS autopilot**
- **Engine monitor**