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An Integrated Rotorcraft Avionics/ Controls Architecture to Support Advanced Controls and Low-Altitude Guidance Flight Research

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AN INTEGRATED ROTORCRAFT AVIONICS/CONTROLS ARCHITECTURE TO SUPPORT ADVANCED CONTROLS AND LOW-ALTITUDE GUIDANCE FLIGHT RESEARCH

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Abstract

Salient design features of a new NASA/Army research rotorcraft—the Rotorcraft-Aircrew Systems Concepts Airborne Laboratory (RASCAL)—are described. Using a UH-60A Black Hawk helicopter as a baseline vehicle, the RASCAL will be a flying laboratory capable of supporting the research requirements of major NASA and Army guidance, control, and display research programs. The paper describes the research facility requirements of these programs together with other critical constraints on the design of the research system. Research program schedules demand a phased development approach, wherein specific research capability milestones are met and flight research projects are flown throughout the complete development cycle of the RASCAL. This development approach is summarized, and selected features of the research system are described. The research system includes a real-time obstacle detection and avoidance system which will generate low-altitude guidance commands to the pilot on a wide field-of-view, color helmet-mounted display and a full-authority, programmable, fault-tolerant/fail-safe, fly-by-wire flight control system.

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Introduction

The preface to the proceedings from an International Symposium on "In-Flight Simulation for the 90's" held in Braunschweig, Germany, in July 1991 contains the following assessment of flight simulation:

> Within the aerospace community, flight simulation has become virtually synonymous with the reproduction of the cockpit flight environment in a ground-based simulation facility. As this discipline has matured and assimilated the advances in digital processor and electronic imaging technologies, ground-based flight simulation has found its legitimate role in pilot-in-the-loop applications, both as a research and development tool and as a training aid. Nevertheless, ground-based flight simulation does have limitations related to the incomplete – and sometimes conflicting – nature of visual and motion cues which are presented to the pilot. As a result, in-flight simulation has played a unique role in aerospace research, development, and test pilot training by providing the proper environment and immersing the pilot in a real flight situation.

For rotorcraft, in-flight simulation is becoming increasingly important as autonomous systems are developed to relieve pilot workload, particularly during nap-of-the-Earth flight and as fly-by-wire flight control technology is exploited. In addition, the fidelity of aerodynamic modeling for rotorcraft is far from maturity, with the result that important handling and performance phenomena such as rotor wake interactions cannot be adequately simulated on the ground. This paper describes the planned development and preliminary design features of a modern rotorcraft in-flight simulation facility—the Rotorcraft-Aircrew Systems Concepts Airborne Laboratory (RASCAL)—heavily influenced by the requirements of major NASA and Army rotorcraft guidance, control, and display research and development (R&D) programs at the Ames Research Center, Moffett Field, California.

As described in Ref. 1, the Army/Sikorsky UH-60A Black Hawk helicopter (Fig. 1) was determined to be the most appropriate available baseline vehicle for RASCAL development. In October of 1989, a UH-60A, originally used as the Army's Advanced Digital-Optical control System (ADOCS) demonstrator aircraft, was loaned to NASA Ames Research Center by the U.S. Army, and the development of the RASCAL research facility was initiated.

The paper begins with a statement of the objective of the RASCAL development, including an overview of the research programs which will utilize its capabilities. These research requirements and other critical design constraints are summarized. The approach to be taken in the development of the RASCAL, which is also driven by the requirements of the flight research elements of the programs it will support, is then described. Finally, selected design features of the RASCAL Research System are presented.

Project Objective and Research Requirements

The objective of the RASCAL facility development project is the design, development, integration, and testing of an airborne laboratory capable of supporting the flight research requirements of several major NASA and Army guidance, control, and display R&D programs. These programs are described in Ref. 1 and include the following:

1. Automated Nap-of-the-Earth Flight (ANOE): Analysis, ground simulation, and flight research to develop low-altitude guidance algorithms and pilot's display laws for rotorcraft terrain-following/terrain-avoidance and obstacle avoidance

2. Superaugmented Concepts for Agile Maneuvering Performance (SCAMP): Analysis, ground simulation, and flight research to investigate methods for the enhancement of rotorcraft maneuverability and agility through the application of advanced flight-control concepts

3. Rotorcraft Agility and Pilotage Improvement Demonstration (RAPID): In-flight validation and demonstration of ground simulation-derived solutions to selected Army-identified "technology barriers" to the development of next generation/future systems.

Fig. 1 Rotorcraft-Aircrew Systems Concepts Airborne Laboratory (RASCAL).

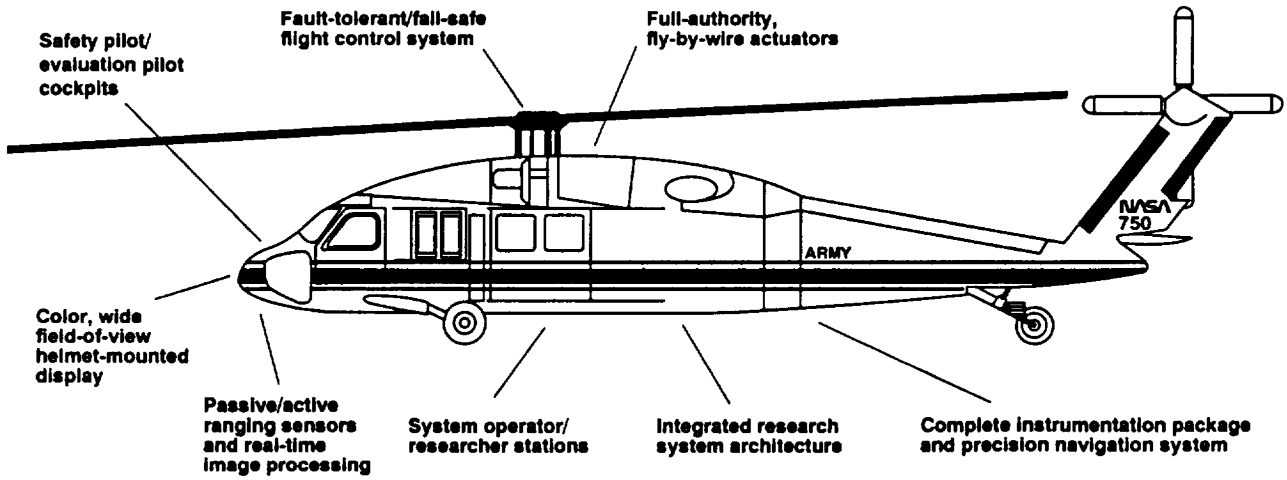

Fig. 2 RASCAL research system components.

To support the requirements of these R&D programs, the RASCAL research system will include the following (Fig. 2):

1. A high quality instrumentation, signal conditioning, and data acquisition system including rigid body, rotor state, and propulsion system sensors, suitable for both experimental data and flight control applications

2. Appropriate passive (e.g., video or FLIR) and active (e.g., radar or laser) sensors for image-based guidance and navigation including obstacle detection/avoidance

3. An on-board precision navigation system suitable for low-altitude flight

4. A flexible, programmable pilot's display system including a panel-mounted display suitable for a digital map and a color, wide field-of-view, helmet-mounted presentation of flight status and command information and sensor-based imagery

5. Terrain data base storage for low-altitude navigation with no image sensor-aiding

6. On-board computational capability for real-time image processing, vehicle motion estimation, guidance algorithm generation, and pilot's display generation

7. An in-flight researcher interface with the system for monitoring the experiments and for effecting configuration changes to allow productive use of the available flight time

8. A programmable, fly-by-wire research flight control system including high-performance actuators; a flight control computer, programmable in a higher-order language, with a hardware/software architecture necessary for the throughput and speed requirements of the various SCAMP control concepts; and a high-speed data bus with sufficient capacity for the anticipated bus traffic

9. The capability to evaluate both conventional controllers, using an artificial force-feel system, and integrated, multi-axis side-stick controllers

10. A capability for the integration of autonomous guidance commands with the research flight control system

RASCAL Research System Design Requirements

An in-house preliminary design of the RASCAL research system was conducted during the summer and fall of 1991. The efforts of the preliminary design team included the establishment of prioritized design requirements for the research system. The top six of these requirements, in priority order, are:

1. Flight Safety: The RASCAL research system shall not degrade the flight safety reliability of the baseline Black Hawk helicopter.

2. Performance: The RASCAL research system shall have the capability to implement SCAMP high-bandwidth flight control laws, which include the use of rotor state feedback, and a real-time image processing, guidance, and display system suitable for the ANOE

guidance, and display system suitable for the ANOE program. The capability of the research flight control system shall be limited only by the performance of the basic UH-60A flight control system.

3. Research Flight Envelope: The RASCAL allowable research flight envelope shall be the Black Hawk flight envelope. No expansion of that flight envelope is required. Aggressive maneuvering while using the research system shall be conducted at altitude, clear of terrain and obstacles. Aggressiveness may be limited near the terrain and obstacles.

4. Cost Constraints: The RASCAL research system design must be compatible with the available funding from NASA, Army, and Federal Aviation Administration (FAA) sources.

5. Research Productivity: The RASCAL research system shall be designed with a high mission reliability and with the capability of obtaining a maximum number of research data points per flight hour.

6. Schedule Constraints: The RASCAL research system shall be developed in a manner that allows specific SCAMP, ANOE, and RAPID flight research experiments to be flown at intervals throughout the overall facility development period.

The milestones for RASCAL facility capability dictated by the requirements of the SCAMP, ANOE, and RAPID flight research experiments schedule are indicated in Fig. 3. These experiments are summarized as follows:

SCAMP and RAPID

Rigid-Body Modeling. Data acquisition to support the development and validation of rigid-body models suitable for use in SCAMP control law development

Baseline Maneuverability/Agility Measures. Development of relevant measures of rotorcraft maneuverability and agility and measurement of the maneuverability and agility characteristics of the basic Black Hawk

Rotor-state Modeling. Rotor state data acquisition to support the extension of the SCAMP rotorcraft models to include rotor system dynamics

Rigid-Body Flight Control Systems (FCS). Flight implementation and evaluation of SCAMP control laws involving the feedback and control of rigid-body states

Rotor-State Feedback FCS. Flight implementation and evaluation of SCAMP control laws which include the feedback and control of rotor states

ANOE

Passive Ranging Validation. Acquisition of airborne video imagery data from stereo TV cameras for off-line validation of range estimation algorithms

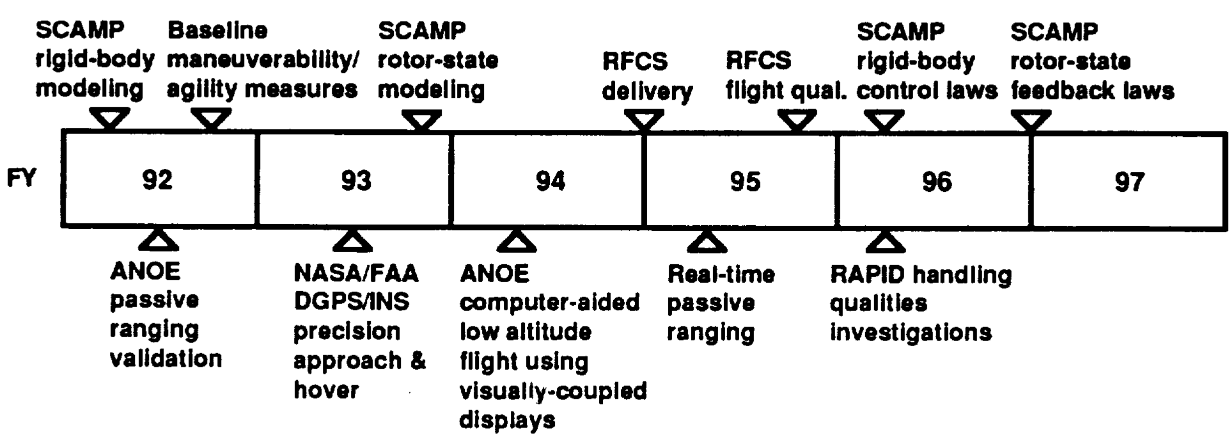

Fig. 3 RASCAL research facility capability milestones.

SCAMP and RAPID

Rigid-Body Modeling. Data acquisition to support the development and validation of rigid-body models suitable for use in SCAMP control law development

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Rotor-State Feedback FCS. Flight implementation and evaluation of SCAMP control laws which include the feedback and control of rotor states

RASCAL Research System Development Program

Research program requirements dictate that RASCAL flight test programs be conducted at several stages throughout the development of the RASCAL as a research facility. The research system that is to be installed on the RASCAL must meet the research objectives of these programs in a timely manner. A phased development program has been defined to provide a system that can support research activities at several stages as the system is developed. The functional capability that is implemented at any phase of the development program to meet the immediate research goals is maintained and adds to the overall facility capability. This additive approach results in a system that, upon completion, will have more integrated capability than any of the individual research programs presently require. Future research programs will have the full integrated capability available for the conduct of flight test programs.

A critical element of this approach to the development of the RASCAL is that the system development risks must be minimized. This constraint requires that the facility be developed using state-of-the-art, but proven, technology. Care will be taken to severely limit technology development requirements in specifying the RASCAL Research System.

The research programmatic milestones identified for the RASCAL and presented in Fig. 3 have been grouped into four development phases as indicated in Fig. 4. Each of these four phases results in the accomplishment of specific, reportable research goals. The system requirements for each of the phases is presented below.

Phase 1. Acquisition of stereo video data for post-flight processing will be accomplished, allowing the validation of passive ranging algorithms. Measurement and documentation of the basic UH-60A dynamics and controls characteristics are to be accomplished, thereby providing a baseline against which future improvements in maneuverability and agility can be judged.

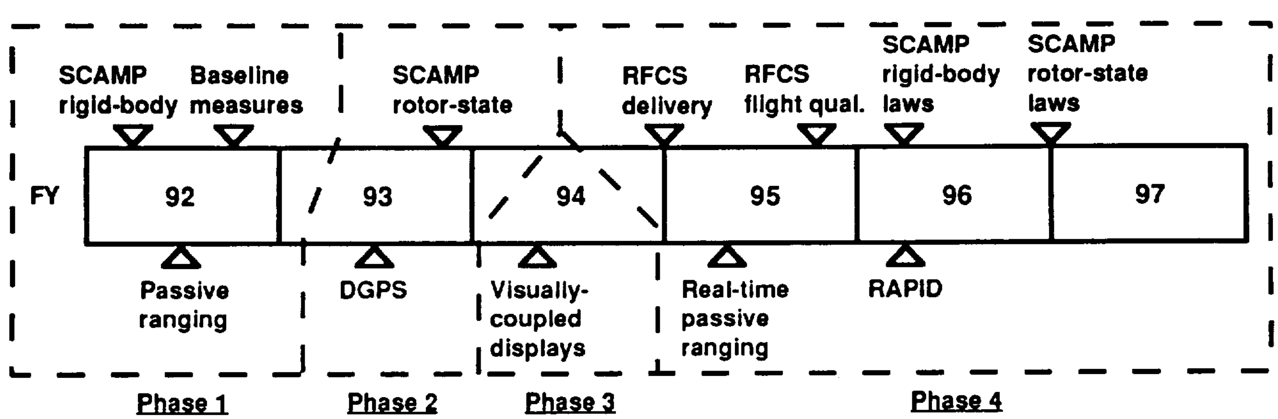

Fig. 4 RASCAL facility development phases.

Phase 2. Differential Global Positioning System (DGPS) position measurement capability will allow the development of guidance/display laws for precision approach and hover. The additional capability of acquiring and documenting rotor state measurements will complete the UH-60A baseline identification.

Phase 3. A wide-field-of-view, color, helmet-mounted display will add the capability to provide enhanced guidance information to the pilot, allowing the development of display laws to assist in the ability to conduct missions in an NOE environment.

Phase 4. Real-time processing of the stereo video data on board the RASCAL will allow the presentation of obstacle ranging information and sensor/computer-aided guidance commands to the pilot. A full-authority, fly-by-wire research flight control system will allow development and demonstration of control laws that more fully utilize the maneuverability and agility capabilities of the UH-60A.

System architectures have been established for each of the phases of the RASCAL development program that allow the additional capabilities to add to the overall system capability. The specific research requirements of each phase are met by this approach while the facility capability is always increased. This approach will be beneficial as new research programs are defined and the full capability of the RASCAL can be utilized.

Phase 1

The architecture for the RASCAL Phase 1 Research System is shown in Fig. 5. The central element of the research system for Phase 1 is the data acquisition computer, which uses an Intel 80486 processor. Analog sensors provide control position and a limited set of body state measurements. A Litton LN-93 Inertial Navigation Unit (INU) is installed to measure body attitudes and angular rates, and linear velocities and accelerations. Communication between the INU and the data acquisition computer is provided by a Mil-Std-1553B bus. A GEC Marconi HADS Air Data Computer that had been installed on the aircraft previously has been incorporated to provide low airspeed and local flow angle information.

A pair of high resolution video cameras is mounted on the nose of the RASCAL to provide data for the post-flight validation of passive ranging algorithms. The video data are time-correlated with the aircraft state data and processed post-flight. Provisions are incorporated to replace the video cameras with a FLIR installation. An experimenter's station is installed in the cabin allowing convenient control of the video and data systems.

Phase 2

Additional components added to the Phase 1 RASCAL system architecture will allow the research goals of Phase 2 to be accomplished. The resulting architecture is shown in Fig. 6. The basic data acquisition capability installed for Phase 1 will remain, with additional sensors installed to provide rotor state information. A guidance/navigation computer will be added to perform the guidance and navigation law computations. To provide guidance information to the pilot, a panel-mounted display will be installed and driven by the guidance/navigation computer. A DGPS that communicates directly with the guidance/navigation computer through a digital bus will be included. An uplink data stream from a ground-based GPS is required to provide the differential corrections to the airborne unit.

A research system operator's station will be implemented in the forward area of the RASCAL cabin for control of the research system. An experiment support/observer's station will be installed in the aft cabin to accommodate a second researcher or to provide for an observer during flight test operations.

Phase 3

The most significant addition to the RASCAL research system architecture to accommodate the low-altitude guidance research goals for Phase 3 will be the addition of a wide-field-of-view, multi-color helmet-mounted display system as shown in Fig. 7. Included will be the helmet, incorporating the display capability, a programmable display generator and a head tracker system. A second Mil-Std-1553B bus is anticipated to provide the data communications required to process guidance and navigation laws and to pass that information to the helmet. Additionally, that information must be recorded by the data acquisition system for post-flight processing.

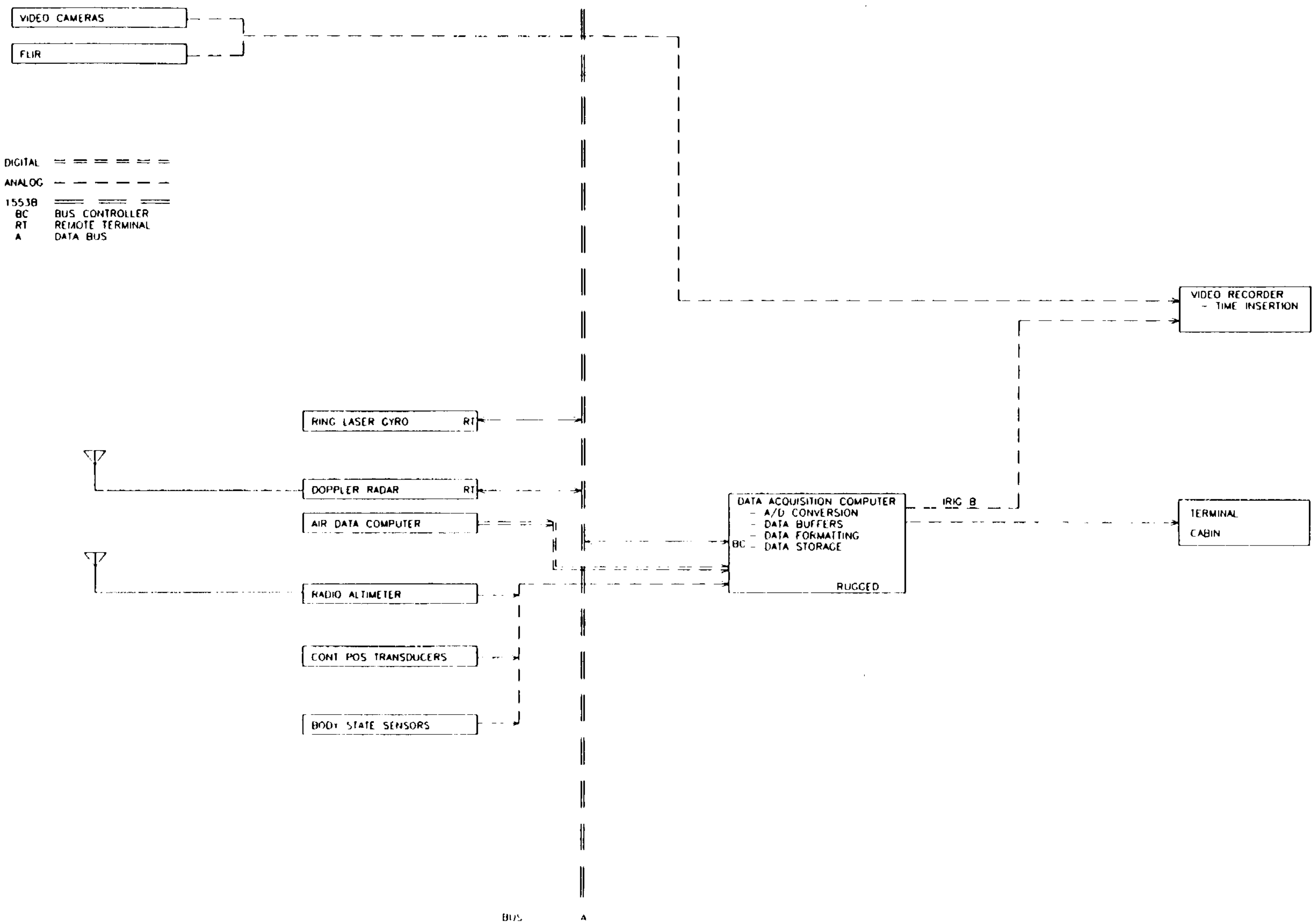

Fig. 5 RASCAL Phase 1 architecture.

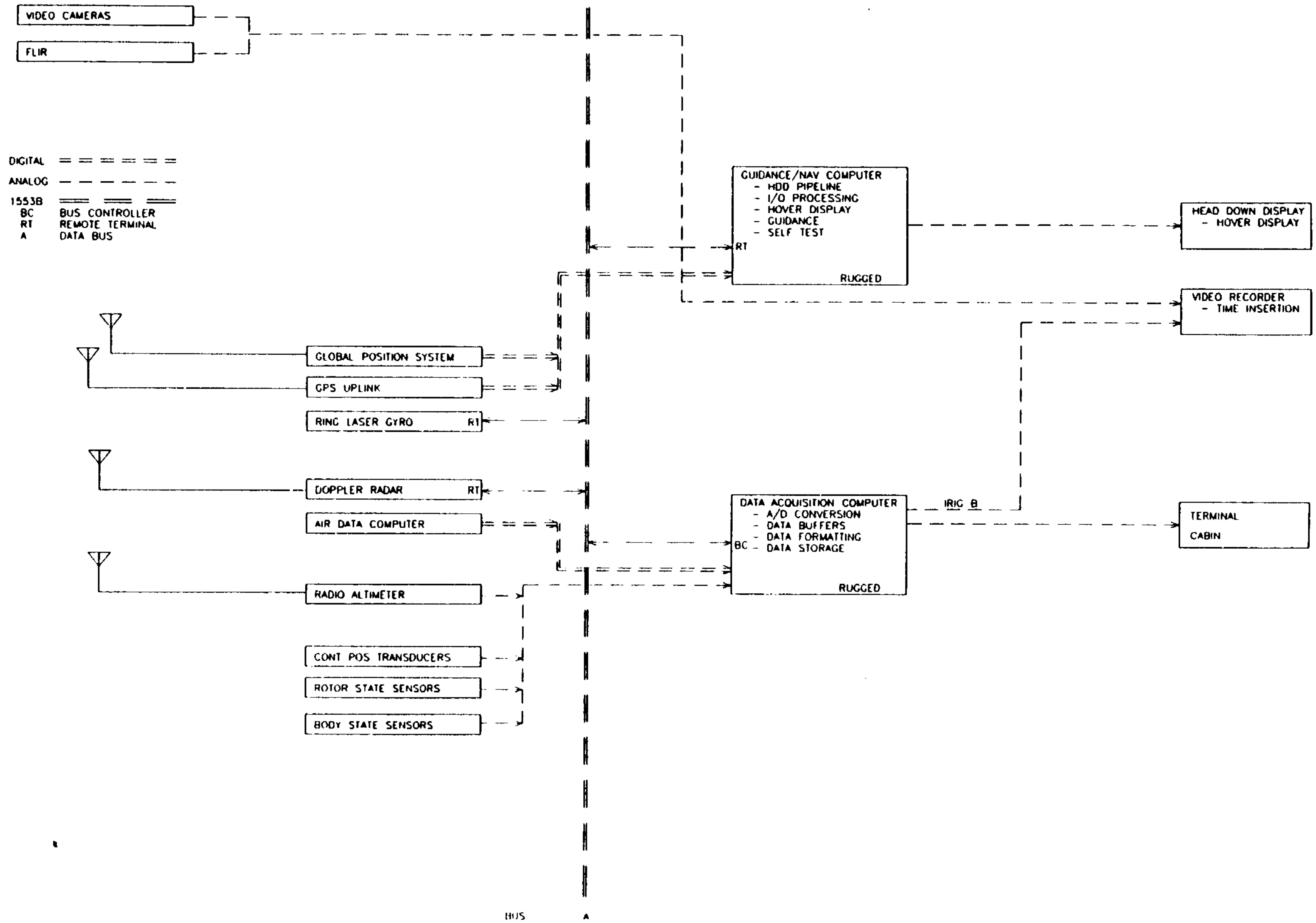

Fig. 6 RASCAL Phase 2 architecture.

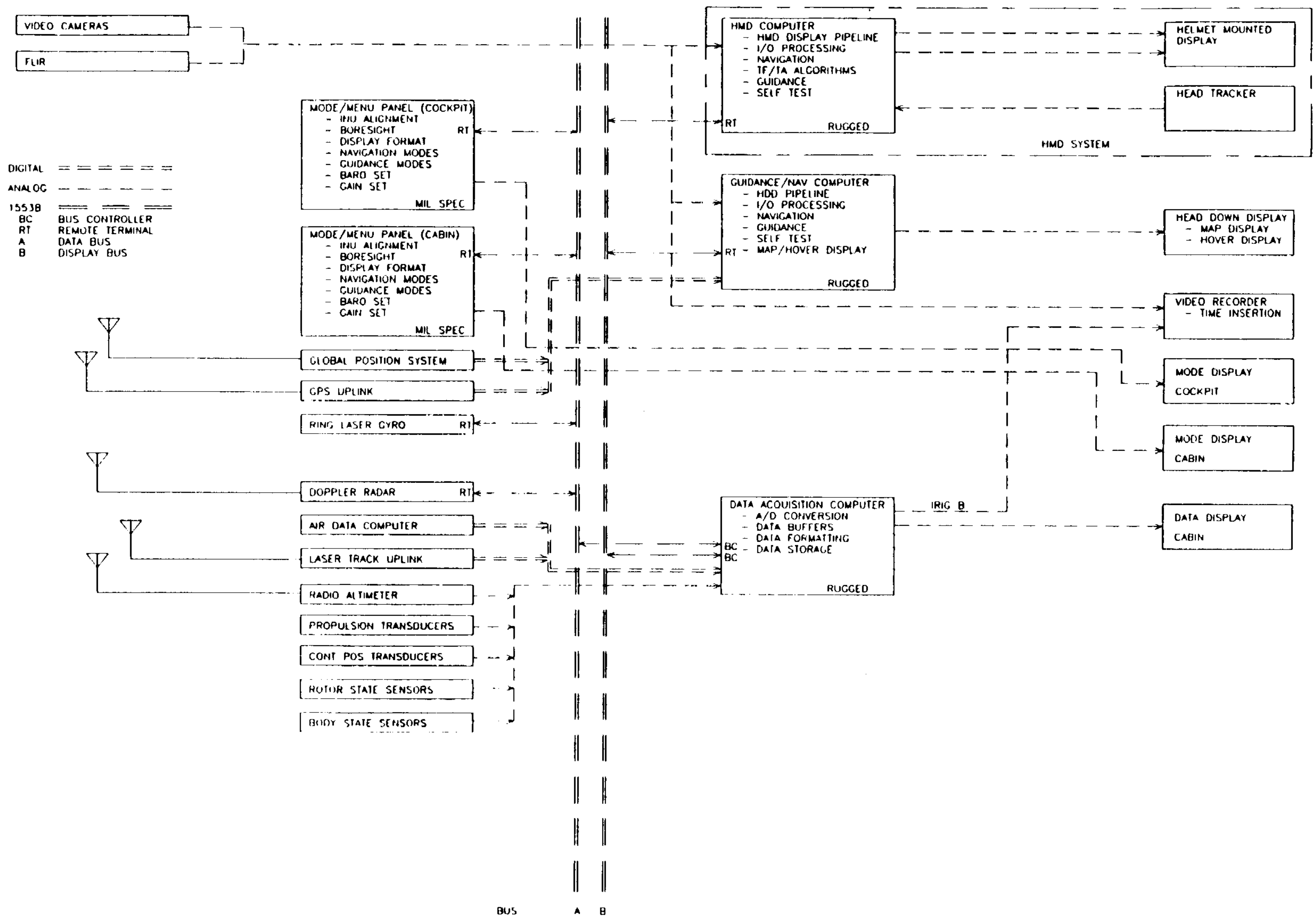

Fig. 7 RASCAL Phase 3 architecture.

Provisions for the acquisition of additional data regarding propulsion system performance will be added during this phase. Truth data for evaluation of the guidance system performance will be provided by uplinking data from the laser tracking system that Ames operates at its Crows Landing flight test facility.

The research system will be, by this phase of development, sufficiently complex to require the incorporation of mode control capability. The mode-menu panels will be used by the evaluation pilot to select guidance and display modes and by the researcher/system operator to centrally control and monitor the research system components and to vary experiment parameters during the flight test. Control/display units will be installed in the cockpit and at the research operator's station to provide this interaction with the research system, which will be accomplished using the Mil-Std-1553B bus.

Phase 4

Two major system installations will be added to the research system to accomplish the research goals for Phase 4. The completion of this phase defines the final system architecture as shown in Fig. 8.

The first of these major installations is a real-time image processor for the passive video ranging system. This unit will process the video signals to extract ranging information and provide it to the guidance/navigation computer. Obstacle avoidance information generated by the guidance/navigation computer will be displayed to the pilot. A high-speed digital bus will be used to communicate the information among the image processor, the guidance/navigation computer, and the helmet-mounted display system.

The second major addition to the RASCAL research system in Phase 4 is the fly-by-wire research flight control system (RFCS). This installation provides the RASCAL with its full in-flight simulator capability. An "evaluation pilot's" station will be implemented by mechanically disconnecting the controls at the right crew station and installing new controls that electrically signal the RFCS. The RFCS will be a full-authority flight control system incorporating the functional components shown in the lower right section of Fig. 8; it is described in the next section.

On-board data analysis capability will be provided by the data analysis computer, which will be capable of real-time data display and post-run data analysis for use by the on-board researcher. A rearrangement of the Mil-Std-1553B buses may be required to accommodate the increased data flow requirements. Telemetry capability will be provided to allow the acquired data to be displayed and recorded on the ground at Ames' flight test facilities.

During Phases 3 and 4, a ground development facility will be built up to support the on-board systems development. A combination of actual and emulated flight hardware will be employed to support hardware flight qualification and subsystems integration and software validation and verification. Inclusion of a simplified fixed-base simulation capability will allow pilot-in-the-loop testing and will support experiment development and pre-flight training activities.

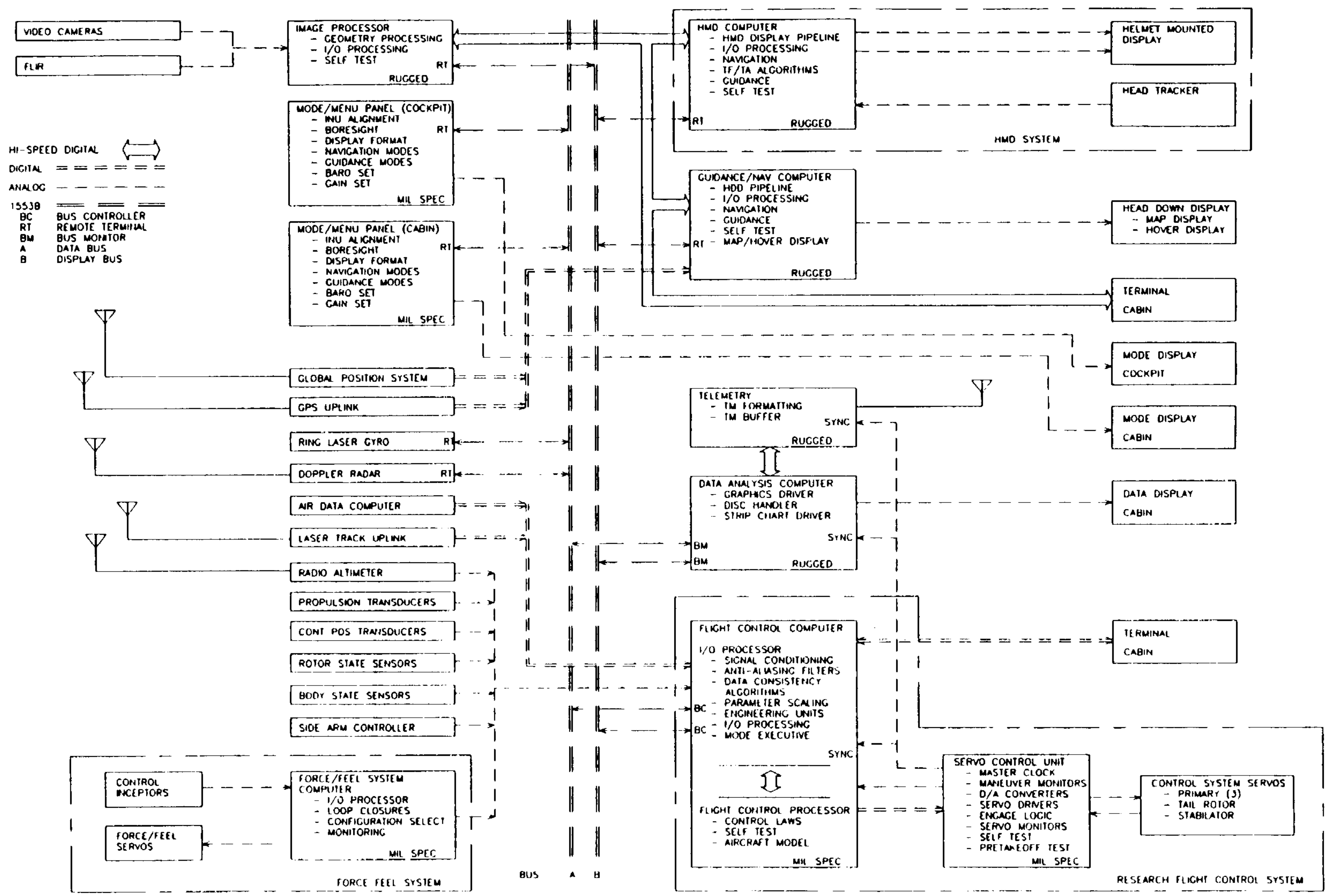

Fig. 8 RASCAL Phase 4 architecture.

Research Flight Control System Requirements and Design Features

The RASCAL RFCS comprises those elements of the research system necessary to achieve full-authority, fly-by-wire flight control by the evaluation pilot. The elements include control inceptors, sensors, a flight control computer, a servo control unit, and research servo-actuators, as illustrated in Fig. 9. The RFCS design requirements were established by consideration of the criteria defined in Refs. 2 through 8. Those considerations and functional requirements are briefly described below. A more complete discussion of the RFCS design features for the RASCAL is presented in Ref. 9.

Safety and Reliability Requirements

The basic design philosophy of the RFCS is fail-safe. On detection of a system fault, the RFCS reverts to a disengaged condition allowing the safety pilot to resume control of the aircraft using the existing mechanical flight control system of the UH-60A. Preferably, the fault is recognized and the RFCS disengaged without any significant control transient, characteristics that are often described as fail-soft or fail-passive. The research flight envelope, especially the allowable aggressiveness near the ground or obstacles, is directly impacted by the expected magnitude of these fault recognition and system disengagement transients.

Most system faults that do not pose an immediate or severe threat to the aircraft can be recognized and acted upon by the safety pilot who is directly and continuously monitoring the action of the basic UH-60A pilot controls. However, the faults that would result in a hardover control transient must be detected very quickly by automatic monitors. Furthermore, control transients associated with detection and isolation of these faults must be small enough to permit the safety pilot to safely regain control even when operating near the ground or among obstacles. Consequently, the most stringent requirement for RFCS system flight-safety reliability is focused on two essential functions:

1. The ability to disengage when required, whether initiated by the automatic safety monitoring system, the safety pilot, or the evaluation pilot

2. The immediate detection, typically within 100 msec, of component failures or software errors that would otherwise lead to unacceptably large and rapid control transients

The performance and response time requirements for these automatic monitors have been established in piloted simulations. The reliability of these safety-critical functions must be such that the probability that they will fail to operate as designed is extremely remote, less than one in 10^7 flight hours. The quantitative basis of this requirement lies in an assumed 1000 flight-hour operating life of RASCAL, to which standard protection from potentially catastrophic failures has been applied.

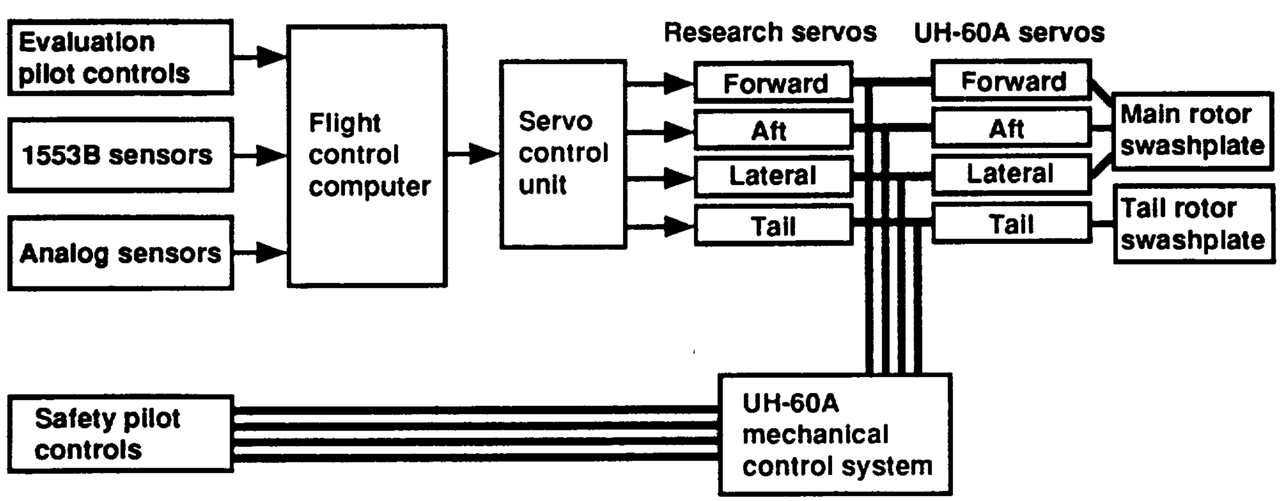

Fig. 9 RFCS components and aircraft interface.

Component Functional and Performance Requirements

This section describes the requirements of the components of the RFCS (Fig. 9) that derive from the safety and performance considerations just described. Depending on the design selected to meet the fail/safe requirements and associated reliability goals, the system architecture may incorporate redundancy of some or all components. However, because the redundancy and redundancy management features are not yet well defined for the RFCS, they are not addressed in this paper.

Sensors. The primary sensors for the RFCS are indicated in Fig. 8. Of particular interest is that, as part of the SCAMP program, a major effort will be undertaken to measure rotor states. Current plans call for use of rotary variable differential transformers (RVDTs) at the blade roots to sense blade flap, lag, and pitch. Optical methods of sensing these angles are also being investigated. In addition, it is planned to mount pairs of linear accelerometers on each blade to obtain duplicate measures of flap, lag, and pitch and possibly their rates using the state estimation methods described in Ref. 7. These signals will be transmitted or routed through slip rings for processing in the on-board computers.

Controls. The first set of pilot controllers will likely consist of a multi-axis sidestick controller on the evaluation pilot's right with a collective lever on the left. Optional spring-loaded pedals will likely be included. Ultimately, it is planned to have in addition a conventional centerstick, pedals, and collective driven by a fully programmable force-feel system.

Flight Control Computer. The flight control computer (FCC) will contain signal conditioning, bus control, signal processing, and control laws. The internal architecture of the FCC has not yet been determined, especially with regard to the number of processors required. However, it is a requirement that the FCC as a whole be able to perform extensive analog and digital signal processing.

The FCC will communicate with the other subsystems via Mil-Std-1553B data buses (Fig. 8). Those systems include the 1553B-based sensors, the cockpit and cabin mode-menu computers, the guidance and navigation system, and the data acquisition and analysis system. The number and arrangement of buses required for these interactions are being determined based on estimates of projected loading, traded off against hardware and software requirements and compatibility with the phased research system development.

Servo Control Unit. The servo control unit (SCU) will receive, process, and monitor control commands from the FCC. It will contain servo loop closure electronics, control engagement and disengagement of the RFCS, and provide fault detection and isolation logic. These SCU functions are considered flight-safety critical and must meet the 10^{-7} failures/flight hour reliability requirement mentioned above.

Research Servos. The research servos will be mounted at the inputs to each of the UH-60A primary swashplate and tail rotor servos and will provide full-authority control of those servos. The servos will be electrically signaled hydraulic actuators mounted in parallel with the UH-60A mechanical flight control system so that their motions are reflected, via movement of the mechanical linkages, back to the safety pilot's cockpit controls. The detail designs of the research servos' hydraulic and mechanical interfaces to the UH-60A will be modeled on those used successfully for ADOCS.[10] At the same time, lessons learned in the ADOCS program will be used to improve the design for RASCAL.

Low Altitude Guidance System Requirements and Design Features

The RASCAL will be used as a facility for developing and validating intelligent systems for improved helicopter low-altitude, near-terrain flight path control. This requires the ability to conduct research associated with the integration of advanced guidance/navigation systems, knowledge-based guidance/trajectory planning algorithms, obstacle detection sensor systems, sensor information processing systems, and pilot displays to provide visual coupling with the flight control system previously described. The sensor and sensor processing, navigation, and display system elements planned to be developed and installed on the RASCAL are described in this section.

Range Information Derived from a Stereo Video Camera Pair

The first guidance information research system in the RASCAL, installed during Phase 1, is an in-flight video imagery data collection system as shown in Fig. 5. This system uses a stereo pair of monochrome video cameras. These forward-looking cameras are mounted on the nose of the RASCAL ahead of the avionics bay, with a nominal separation of 1 meter. Provision is made to allow some adjustment of the baseline separation. The video imagery is recorded on a pair of commercial quality video cassette recorders for post flight data reduction. Time information is inserted on each video frame from a source synchronized to a master time standard at NASA Ames' ground tracking facility.

The video imagery from each camera is digitized during post-flight processing using an image processor and then stored onto an optical WORM drive. The video frames are then accessible for further processing to determine range information to objects identified in the video frame.

The range determination processing of the video image is based on stereoscopic techniques combined with optical flow, which is the apparent motion of objects at the image plane in a sequence of images taken with a moving camera. It has been shown in Ref. 11 that if the focal length of the video camera and lens, the optical flow components, and the video camera motion are all known, then the slant range to the physical object identified in the video frame can be calculated. This range calculation technique also applies directly to FLIR sensor imagery and a later phase of the RASCAL research project will investigate the use of FLIR sensors for range determination.

The stereo video camera installation will be integrated with research systems planned for installation as part of the later phases of the RASCAL project. They will become part of the basic sensor compliment necessary to support the investigations of computer and sensor aiding for enhanced piloted low-altitude/NOE flight. It is planned that an advanced application of this passive ranging technique will be developed during Phase 4 of the RASCAL project. This advanced passive ranging system involves processing video imagery in real-time on sequences of video images as they are received from the video cameras in flight. The details of the video processing requirements necessary to support real-time ranging computations will not be discussed in this paper. The results of the real-time calculation of range to selected objects will be displayed to the research pilot in a suitable color-coded format to aid in the NOE pilotage task. The real-time range information will be presented to the pilot on systems described as part of the Phase 3 installation on the RASCAL.

Low-Altitude Helicopter Flight Navigation System

A computer-aided low-altitude helicopter guidance system will be installed as part of the RASCAL Phase 2 system as shown in Fig. 6. The guidance system includes an optimal control trajectory generation algorithm based on dynamic programming, a visually-coupled helmet-mounted display (HMD) presentation of pathway-in-the-sky, a displayed phantom aircraft, and a flight-path vector/predictor symbol superimposed over an external video image. Three major computer-based functional elements that form this system are described in Ref. 12: the trajectory generation algorithm; the trajectory coupler, and; the information displayed to the pilot.

The primary guidance is provided by a valley-seeking, trajectory generating algorithm based on a forward-chaining dynamic-programming technique originally developed for the U.S. Air Force.[13] The version to be implemented on RASCAL has been modified for rotorcraft use as reported in Ref. 14. The trajectory generation algorithm uses knowledge of the planned nominal flight route, a digital terrain map, aircraft performance capabilities, and precise navigation information to calculate a trajectory between preselected waypoints using a valley-seeking technique.

The optimal trajectory is then passed as a series of discrete helicopter inertially-referenced states to the trajectory coupler along with commanded bank angles, headings, and vertical flight-path angles. The trajectory-coupler converts this information into a trajectory command that is synchronized to the pilot's display by interpolating within the optimal trajectory points to minimize time delay and provide a continuous display presentation to the pilot.

The information displayed to the pilot consists of a pathway-in-the-sky, as shown in Fig. 10, which represents a three-dimensional perspective of the commanded inertial position and heading of the helicopter states, a phantom aircraft symbol which is maneuvering along the generated optimal trajectory at a position three seconds ahead of the present position of the helicopter, and a flight-path vector/predictor symbol which the pilot superimposes onto the displayed phantom aircraft using the helicopter controls. Supplemental information will be available to the pilot on a color head-down map display showing a plan view of the actual horizontal flight path along with the preplanned flight route and the selected waypoints.

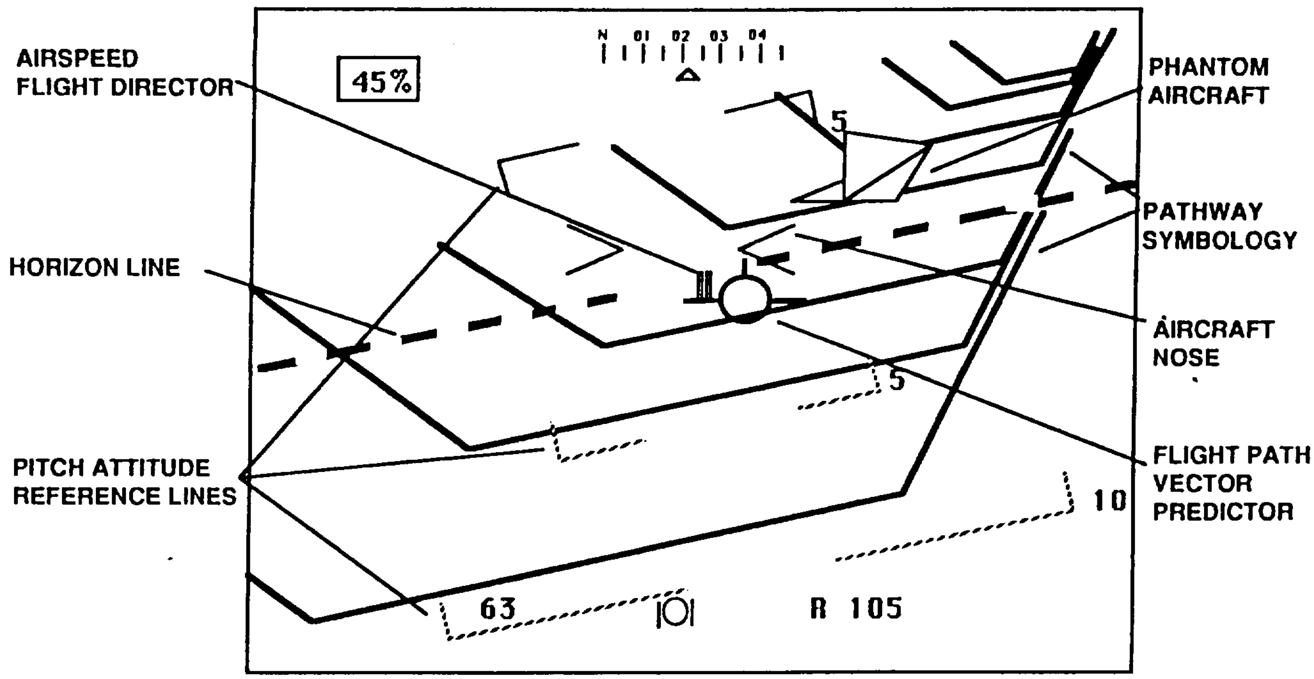

Fig. 10 Helmet-mounted display guidance format.

The major focus of the RASCAL implementation is to investigate the coupling of the video/FLIR information described earlier with the HMD guidance display. A further extension of the research will investigate the presentation of real-time ranging information on the display provided to the pilot through the HMD.

Navigation Sensor System Requirements

The passive ranging system described earlier requires the knowledge of video sensor motions with accuracy sufficient to provide a reliable range calculation. The early development of the technology will be performed in a postflight processing mode which will verify the accuracy of range solutions by comparison with vehicle position truth data provided from a ground-based laser tracking installation. The initial goal is to achieve range accuracies on the order of one meter. Once the reliability of the range calculation technique has been verified it will be extended for in-flight computation to provide real-time ranging for the pilot. This requires that precise position information be available at a sample rate of at least 60 Hz.

The guidance system described earlier requires that vehicle position be known with an accuracy better than 10 meters for the trajectory computation and corresponding pilot guidance cues to be effective. This on-board inertial position information must be provided at a sample rate of at least 20 Hz for effective trajectory computation and to minimize discrete jumps in commands presented in the pilot's display.

To satisfy these position sensing requirements a ring laser gyro Inertial Navigation System (INS) and a differential CA-code Global Positioning System (GPS) are installed in the RASCAL. The integration of the positions and velocities from both systems will be performed in the navigation processor using appropriate Kalman filtering to provide an inertially aided GPS position solution. Techniques used by McNally[15] in providing inertially-aided GPS guidance for fixed-wing aircraft will be extended to rotorcraft in the RASCAL. It is anticipated that position accuracy on the order of 3 meters will be achievable.

Helmet-Mounted Display System

The principal pilot display for these experiments will be a multi-color HMD. A multi-color system is necessary to provide the pilot flight direction and obstacle range cues. The HMD system shown in Fig. 7 consists of two major functional elements; a programmable display generator and the helmet-mounted display and optics unit.

The programmable display generator will be compatible with the graphics library used in laboratory research at NASA Ames to support the software developed as part of the navigation system described earlier. The HMD optics unit will provide a biocular display with a field-of-view of 40 degrees vertically by 60 degrees horizontally. This system will be a flightworthy design compatible with UH-60 flight requirements at NASA Ames.

The HMD system will also accept, as input, the unprocessed video imagery from one of the forward-looking video cameras to couple the pilot to the sensor system. During a later experiment the HMD system will accept, as input, the real-time range information for presentation to the pilot in the form of a mapped, color-coded overlay on the unprocessed video imagery provided by the video/FLIR sensor system. The range information will aid the pilot in avoiding obstacles during NOE flight activities.

Concluding Remarks

Since the first in-flight simulator was developed in 1947 at what was to become NASA Ames Research Center, they have been successfully applied to all aspects of the aircraft development process. The RASCAL represents the latest in a series of helicopter in-flight simulators. The RASCAL is being developed as much more than a handling qualities research tool and will be capable of supporting major NASA, Army, and FAA research programs in integrated guidance, control, and display systems for rotorcraft. A fundamental requirement for these programs is that both ground- and in-flight simulation be applied in a complementary fashion to ensure the completeness and accuracy of the results.

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Salient design features of a new NASA/Army research rotorcraft—the Rotorcraft-Aircrew Systems Concepts Airborne Laboratory (RASCAL)—are described. Using a UH-60A Black Hawk helicopter as a baseline vehicle, the RASCAL will be a flying laboratory capable of supporting the research requirements of major NASA and Army guidance, control, and display research programs. The paper describes the research facility requirements of these programs together with other critical constraints on the design of the research system. Research program schedules demand a phased development approach, wherein specific research capability milestones are met and flight research projects are flown throughout the complete development cycle of the RASCAL. This development approach is summarized, and selected features of the research system are described. The research system includes a real-time obstacle detection and avoidance system which will generate low-altitude guidance commands to the pilot on a wide field-of-view, color helmet-mounted display and a full-authority, programmable, fault-tolerant/fail-safe, fly-by-wire flight control system.

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