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NASA Ames Research Center, Dryden Flight Research Facility, Edwards, California

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Summary

The verification and validation process is a critical portion of the development of a flight system. Verification, the steps taken to assure the system meets the design specification, has become a reasonably understood and straightforward process. Validation is the method used to ensure that the system design meets the needs of the project. As systems become more integrated and more critical in their functions, the validation process becomes more complex and important. This paper discusses the tests, tools, and techniques which are being used for the validation of the high alpha research vehicle (HARV) turning vane control system (TVCS) and documents the problems and their solutions. The emphasis of this paper is on the validation of an integrated system.

Nomenclature

A/D	analog to digital converter
Ames-Dryden	Ames Research Center, Dryden Flight Research Facility
DDI	digital display indicator
EMI	electromagnetic interference
FCS	flight control system
FMET	failure mode and effects tests
HARV	high alpha research vehicle
HIL	hardware in the loop
HOL	higher order language
HUD	head-up display
INS	inertial navigation system
I/O	input/output
ITF	Integrated Test Facility
MC	mission computer
N_z	normal acceleration
PCM	pulse code modulation
RAM	random access memory
RAV	remotely augmented vehicle
RFCS	research flight control system
SID	simulation interface device
TVCS	turning vane control system
UMN	universal memory network
V&V	verification and validation

Introduction

The F-18 high alpha research vehicle (HARV) flown at Ames Research Center, Dryden Flight Research Facility (Ames-Dryden) at Edwards, California is a flight-test platform for the High-Angle-of-Attack Technology Program.[1] The two objectives of this program are to provide flight-validated design methodology including experimental and computational methods that accurately predict high-angle-of-attack aerodynamics, flight dynamics, and flying qualities; and improve controllability and agility at high angles of attack and expand the usable high-angle-of-attack envelope. The aircraft provides a system which can allow major modifications while retaining the basic F-18 systems as a backup.

The F-18 HARV was modified to add various research control modes. This modification was done by integrating a research flight control system (RFCS) with the basic F-18 control system. The RFCS can take control of the aircraft while the F-18 control system continues to provide the input, output, redundancy management, and a backup for the RFCS. The basic F-18 flight control system (FCS) was not changed functionally but major modifications were required to provide an interface with the RFCS.

A thrust vectoring control system (TVCS) was also added to the HARV. The TVCS modification includes the addition of thrust vectoring vanes to be used for high-angle-of-attack maneuvering by deflecting the engine exhaust. The avionics system was also modified to provide the appropriate information to the pilot and inputs to the RFCS. This design resulted in the integration of avionics with the control system.

The major modification of the basic F-18 control system, the integration of the avionics into the RFCS, and the structural modifications of the aircraft dictated thorough testing of the F-18 system as well as the research system. Several tools were developed to test the modified HARV flight control and avionic systems adequately. A simulation which could be configured was designed for the development, analysis, and testing of the HARV systems. The unique configuration of the HARV TVCS required special testing capabilities and tests as well as the standard validation techniques. The integration of the basic flight control computers, research flight control computers, mission computer (MC), and inertial navigation system (INS) introduced additional complexity and difficulty into the validation environment. The validation testing of the modified system is considered to be the most important aspect in assuring a system is ready for safe flight test. This paper will describe the modifications incorporated in the HARV, the tests, tools, and techniques used for the validation of the HARV TVCS system.

Aircraft Description

The F-18 HARV aircraft was the sixth full-scale development aircraft. References 2 and 3 provide a general description of the F-18 system. This aircraft was used for handling qualities investigations at high angles of attack, spin testing, and as a test bed for modifications to various systems that would ultimately be included in production aircraft. NASA received the HARV configured as an early roll rate 1 aircraft with a single MC and a single digital display indicator (DDI) in the cockpit. Before the addition of the RFCS, modifications had been made to add production stabilator actuators, redesigned inboard/outboard leading-edge flap transmissions, differential leading-edge flaps, roll rate 2 flight control computers, a second MC, and a second DDI. The MCs had been upgraded with double density memory. A spin chute, emergency hydraulic system, and emergency electrical system had also been added to the aircraft for testing at angles of attack above 55°. The HARV configuration also includes two pulse code modulation (PCM) systems, five video cameras, and one 35-mm wingtip camera.

System Modification Description

The addition of the TVCS and the RFCS to the F-18 HARV aircraft included modifications to the aircraft structure, engines, the cockpit, avionics system, FCS, and hydraulic system (Fig. 1).[4] The system design uses the basic F-18 avionics and FCS as a building block that handles the communications and health monitoring while the RFCS provides an experimental embedded computer that can take control of the aircraft. The aircraft structure was modified by adding three turning vanes to each engine to provide thrust vectoring capability. Engine modifications included the removal of the external nozzle and a bias added to the engine control unit for increased stall margin. The cockpit was modified by the addition of switches for the pilot interface.

Research Flight Control System Integration

The integration of the RFCS into the F-18 system included provisions for flexibility, testability, and safety. The RFCS can perform alternate control law processing for research and turning vane control. The basic F-18 system is used for normal flight, take-off and landing, and if system failures occur.

The RFCS control laws and basic F-18 control laws operate in parallel (both computed continuously) throughout the flight envelope to reduce engagement/disengagement transients. The basic F-18 system has been extensively tested in the high-angle-of-attack regime, and has been shown to be robust and controllable.[5,6] Because of the extensive testing, the functionality of the basic F-18 control laws was left unchanged except when it was required to incorporate RFCS input/output (I/O) and maintain control of the forward-loop integral path of the longitudinal control laws. The input and output of this integrator is reduced to zero when RFCS is engaged to prevent integrator windup and hard-over commands when switching from the RFCS to the basic F-18 system. A similar design is used in the RFCS control laws to reduce the integrators to zero when RFCS is not engaged.

Another feature of the RFCS consists of requesting parameters from the basic F-18 control system through dual port random access memory (RAM). The RFCS also controls the parameters available for downlink by way of the 1553 data bus. This process is active whether or not RFCS is engaged. Therefore, data from the memory of either system can easily be made available on the 1553 data bus.

A two-step process is used to engage the RFCS, and both steps are controlled by the basic F-18 system. A discrete from a cockpit switch informs the F-18 system that the pilot wants to arm the RFCS. The F-18 system then checks to assure conditions are proper for arming. No input, output, 1553 bus, actuator, or computer failures can be present. The RFCS does its own checks and sends a "GO" discrete across dual port RAM, which the basic F-18 system monitors. If arm conditions are met, the 701E sends out four discretes, one from each channel, to hold the solenoid-held arm switch. When the RFCS is armed, the basic F-18 system sets the turning vanes to a predetermined position near the boundary of the engine exhaust plume. The 701E control laws continue to control the aircraft. The pilot can then engage the RFCS by using the existing nose wheel steering switch on the stick. Once engaged, the RFCS controls the aircraft and the basic F-18 system commands the actuators to positions provided by the RFCS.

Other capabilities integrated into the RFCS include an RAV interface which allows inputs from a ground computer and a pilot-selectable switch used on a DDI. The pilot can select one of five settings, which the MC then sends to the RFCS. The RFCS only accepts the selection when not armed or engaged. Once engaged, the RFCS can then use the selection as an alternate gain, a flag for a new mode, or any other choice programmed into the RFCS.

Research Flight Control System Control Laws

The RFCS control laws are completely independent of the basic F-18 control laws and can be easily modified without affecting the performance of the basic F-18. The RFCS control laws could be as simple as a "pass through" mode for basic F-18 computed commands, since the basic F-18 surface commands are made available to the RFCS before the end of the computational frame. All nominal selected sensor signals are made available to the RFCS. Unique signals required by the RFCS are currently computed in the MC and passed to the basic F-18 system over the 1553 bus. The additional signals were not added to the basic system input selection management to maintain the original configuration.

The initial RFCS design uses sideslip rate and angle of attack as primary feedback signals in addition to the standard body axis rates and accelerations. The INS derived angle of attack is computed in the MC since the production F/A-18 angle-of-attack vanes are limited to approximately 35° true angle of attack. Sideslip rate is computed from the kinematic equations of motion based on body axis accelerations, body attitudes and rates, and computed angle of attack and true velocity. The INS sideslip rate and angle of attack are single string inputs, since only one MC is being used at a time, and the HARV is equipped with a single INS. Computing additional signals in the MC or in the RFCS eliminates the need for modifications to the basic system, but increases the system integration and the problems associated with a distributed system.

The initial RFCS control laws were designed by McDonnell Douglas Aircraft Company to demonstrate the TVCS system capabilities and to allow expansion of the RFCS flight envelope. The control laws are separated into longitudinal, lateral–directional, thrust vane mixer, and gross thrust estimation sections. Propulsion system integration is localized into the thrust estimation and vane mixer sections. In this way, modifications to the more standard longitudinal/lateral/directional control laws could be made without requiring complete knowledge of the complex interactions and gain scheduling associated with the thrust vanes and engines.

Longitudinal control is an angle-of-attack command system using pilot stick position, angle of attack, pitch rate, and inertial coupling feedback as inputs. Normal acceleration is not used as a feedback. Collective stabilator, pitch thrust vectoring, and leading- and trailing-edge flaps are used for stabilization and maneuvering flight. Trimming is done primarily with stabilators unless pitch thrust vectoring is required because of stabilator saturation. At low angle of attack, when a normal acceleration (N_z) command system is desirable, commanded N_z is converted to an angle of attack command using a simple computed N_z/angle of attack and a 2 g/in. stick gradient. This system will automatically fade to an angle-of-attack command system based on flight condition and stick position.

The lateral–directional system uses roll rate and yaw rate, lateral acceleration, sideslip rate, and inertial coupling as feedback signals. Differential stabilator, aileron, rudder, and yaw vectoring are used for stabilization, coordination, and maneuvering flight. Lateral stick position commands the stability axis roll rate while the rudder pedal position commands sideslip angle. A system design goal is that no rudder pedal input is required for roll coordination. At low angles of attack and higher Mach numbers, the lateral–directional commands from the FCS are used in the RFCS with the addition of some yaw thrust vectoring to augment rudder power.

The performance of the six thrust vectoring vanes is a complex relationship dependent on nozzle exit radius, nozzle pressure ratio, gross thrust, and on the position of the other vanes. To simplify the RFCS control law structure, a vane mixer was developed to coordinate the vane deflections to achieve the commanded pitch and yaw vectoring moments. The control laws command a desired pitch and yaw vectoring moment to the mixer, which then computes the six vane deflections required to achieve the commanded moments. Gross thrust is estimated from engine parameters and used by the mixer to scale the desired pitch and yaw vectoring commands to the thrust available.

Flight Control Modifications

The basic F-18 FCS was extensively modified for the incorporation of another computer to provide research capabilities. The flight control computers were upgraded to the latest production hardware and software configurations. This upgrading generated spare card slots in the flight control computer chassis. An additional computer, a 1750A programmable in Ada, was added to the system in three spare card slots (Fig. 2). Ada is a programming language based on PASCAL, originally developed on behalf of the U.S. Department of Defense for use in embedded computer systems. Additional analog I/O cards were developed to drive the TVCS actuators. Modifications were also made to the mother board to accommodate the additional boards.

The 701E computer and the 1750A communicate through dual port RAM. The pitch rate and yaw rate gyro signals were run through additional analog to digital converters (A/Ds) to provide 100 deg/sec rates to the RFCS without affecting the normal 60 deg/sec rates used by the basic F-18 system.

Extensive software modifications were made to allow the basic F-18 control system and the RFCS to work together. Modifications were made in the executive, input selection monitoring, actuator signal management, built-in test, and data management.

The basic F-18 system was programmed to transfer data to the RFCS by way of dual port RAM twice in each frame; once after it has completed its input selection and monitoring and once after it has finished its control law computations. After the first data transfer, the basic F-18 system waits up to 2.2 msec for data from the RFCS before it processes the actuator signal management (Fig. 3). Software was added to the basic F-18 system to control and monitor the turning vane actuators and to monitor the additional high rate gyro signals.

The 701E 1553 bus data management was also heavily modified. An additional message was input to the basic F-18 system with information from the MC for use in the RFCS. Two flight control output messages were modified to be data programmable from the RFCS and output at 80 Hz. One of these messages can output data from the basic F-18 system or RFCS while the other is strictly data from the RFCS. These messages were added to provide real-time data monitoring during flight test.

Avionics Modifications

Major modifications for the avionic systems were required to provide additional information to the FCS, obtain additional information from the FCS, to add and modify pilot displays, and add a remotely augmented vehicle (RAV) interface. These modifications required software changes in the MC.

Modifications were made to the MC executive, input, and output modules. Routines were also added to the MC to provide to the RFCS angle-of-attack and angle-of-sideslip rate calculated from inertial navigation system (INS) data. In addition, engine parameters were sent to the RFCS for gain scheduling. The flight control needed these parameters computed at 80 Hz, therefore, the MC executive was modified to increase the maximum rate from 20 to 80 Hz.

Remote terminals not on the HARV 1553 bus were removed from the processing loop in the MC to allow time to complete the added 80-Hz loops. Existing lower rate remote terminals were transferred from bus 1 to bus 2 to allow room for the 80-Hz messages on the bus. The bus 1 utilization is now at approximately 85 percent and bus 2 is now at approximately 50 percent.

The modifications to the MC and FCS changed the way the MC was used. The HARV MC now provides inner loop feedback data to the RFCS and has no weapon systems tasks. To provide a backup capability, the two MCs were given identical loads. To prevent bus contention on the two main buses, only one MC is powered at a time. If an MC fails, the pilot switches power to the other MC through an existing cockpit switch.

Modifications were made to existing display pages on the DDIs to add information about the RFCS. Additional RFCS information is presented to the pilot on the head-up display (HUD) (Fig. 4). An additional remote terminal was added to the 1553 bus to allow the MC to accept data from ground based computers through the use of the RAV system. The RAV can be used to generate displays to aid the pilot in reaching precise flight conditions and to provide inputs directly to the RFCS from a ground computer. The RAV system contains one message of 16 words at 80 Hz.

Hydraulic System Modifications

The addition of the turning vanes and actuators required modification to the hydraulic system. The turning vane actuators only use one of the hydraulic systems, unlike the other surfaces on the F-18 aircraft which are powered by both systems to allow surface control with one hydraulic system failed. The turning vane actuators are deactivated with the loss of a single hydraulic supply.

The turning vanes use aileron actuators which were modified to reduce the damping time after an actuator failure. The hardware design of the turning vane mechanical system allows actuator extension of 3.1 in. before there is structural interference, but the full stroke of the actuators is 4.38 in. Therefore, the actuators are being modified to include a mechanical stop at 3 in. of stroke.

Validation Approach

The main thrust in validation testing is to identify areas where the system functions differently than expected and measure the difference. A detailed knowledge of how the system is expected to perform is required to identify these areas. In addition, the system must be thoroughly exercised in as close to the actual system environment as possible. This approach required the development of a high fidelity six-degree-of-freedom simulation that could easily be configured to use various pieces of flight hardware.

The design philosophy emphasized that the basic F-18 system would always be available as a backup to the research system. This allowed the research system to be treated as a noncritical element of the control system. The amount of validation testing required for the basic F-18 system was not reduced since it had to be heavily modified to incorporate the RFCS. The MC became critical to the operation of the RFCS because of the integration of sideslip rate and angle of attack calculated from INS parameters into the inner loop of the control system, the use of engine parameters as gain schedule inputs, and the addition of the capability to modify RFCS surface commands with external RAV inputs.

The RFCS control laws are written in Ada and cross-compiled to the flight central processing unit (CPU). The use of a higher order language (HOL) reduced the development time and simulation integration,[7] but had no effect on the scope of verification testing required.

The production FCS control laws were designed to function with a wide range of external stores that change the mass, inertia, and aerodynamic properties of the aircraft. The addition of the TVCS, however, increased the pitch inertia significantly more than any existing stores configuration. Piloted simulation was used to verify that the increased weight and pitch inertia did not adversely affect the basic HARV handling qualities or spin recovery. Existing structural notch filters in the longitudinal axis may not adequately match the structural modes of the modified aircraft, which creates a potential problem. Any modifications required will be determined after ground vibration tests.

As with any control system design, linear analysis was used to verify classical stability, linear performance, and stability margins specified in MIL SPEC 8785 for the RFCS control laws. Approximately 150 flight conditions were used, varying Mach, altitude, angle of attack, and gross weight. A linear structural bending model was used in addition to the rigid body aerodynamic model to evaluate structural mode interaction and notch filter performance. The linear analysis was rerun with each update of the aerodynamic or thrust vectoring models to assure adequate stability margins. Parametric variations in vectoring performance were used to indicate system sensitivity to inaccuracies in the simulation models. Time history and frequency response comparisons between the linear analysis and the nonlinear simulation were used to validate the linear model results.

Sine sweep inputs to the nonlinear simulation were used to generate closed-loop and open-loop frequency responses. Evaluation of open-loop stability from closed-loop frequency sweeps is possible because of the availability of inner loop control system parameters in the dual port RAM.

Validation Tests

Many types of tests are required for the system validation. Each test is designed to ensure certain aspects of the system are performing as expected. These tests rely upon the accuracy of results from the various simulations. Ultimately a subset of the total tests is run on an aircraft-in-the-loop simulation to verify that the other simulations accurately model the aircraft systems.

Control system tests address two areas. The first area includes the modified F-18 systems. Tests on these systems are performed to verify that the basic F-18 control system performance was not modified. This was done by comparing time history responses and frequency responses of the original F-18 system with the modified basic F-18 system. The second area includes the RFCS and the interface between the RFCS and the basic F-18 control system. The RFCS was tested to verify the system implementation was as expected and that it also provided desirable flying qualities. The interface is tested to ensure that information is passed between the two systems properly and any errors will be recognized. These tests include time history responses to steps or pulses, frequency responses, and system reaction to inputs beyond the expected signal range.

Failure mode and effects tests (FMET) consist of inserting failures at various flight conditions, which verify that the FCS detects the failures, reacts properly to the failure, and that the effect of the failure is acceptable. Specific tests were included to prove the RFCS could not affect the basic F-18 control system when the RFCS is not engaged. Failures which occur when the RFCS has control of the aircraft result in downmoding the basic F-18 system. Therefore, tests were performed to determine the ability of the basic F-18 to recover from any condition the RFCS could generate. The F-18 system was also tested to assess the effects of added inertias in the pitch axis on transients resulting from failures.

Piloted evaluation is used to determine that the basic F-18 system still provides acceptable flying qualities and could recover from any situation the RFCS generates. This evaluation was made by having pilots perform normal and aggressive tasks with a properly functioning system. Failures were inserted to determine how the pilot dealt with transients generated by system reconfiguration and to exercise emergency procedures. The flying qualities of the RFCS were also evaluated.

The majority of the validation testing is performed with a hardware-in-the-loop (HIL) simulation. An extensive series of on-aircraft tests is necessary to complete the validation of the flight system. These tests cover the aspects which involve the integration of the system into the aircraft systems and structure.

Proof load tests are performed to show that the structure will withstand 110 percent of the predicted load. Ground vibration tests are performed to verify the structural modes match predictions. Ground resonance tests are performed to ensure there are no interactions between the structure and the control system. This test increases the flight sensor feedback gains to show that the system is free of structural resonance at twice the maximum system gain that will be met in flight. Limit cycle tests are performed to verify the control system rigid body gain and phase margins are as predicted. This test increases the simulated feedback sensor gains until an instability is met or to show the measured closed-loop gain and phase margins change accordingly. Aircraft systems tests verify that the aircraft systems function properly and do not adversely affect each other. Hydraulic capacity tests are run to verify the aircraft could operate all systems sufficiently. Electromagnetic interference (EMI) tests verify systems do not react to interference generated by sources that will be met by the aircraft during its operation.

Flight test is also included in the validation of the RFCS. The basic F-18 system will be evaluated in flight for its ability to recover from possible transients before engaging the RFCS. The RFCS can also be monitored while the aircraft is controlled by the basic F-18 control system. Thus the feedback parameters generated from INS data can easily be validated in flight before being used.

Tools

As in all system validation tasks, the development of tools and facilities was a large effort. Several of the test system developments that were underway for the Integrated Test Facility (ITF)[8] were mature enough for the HARV test team to include in the validation plans. The ITF systems included a time history data recording system, a universal memory network (UMN), a simulation interface device (SID), and an auto test system. Figure 5 shows the relationship between the components.

The time history data recording system can capture all the parameters available in the simulation and both 1553 buses. This capability was useful for looking at additional information about a test when unexpected results were obtained. The UMN distributes real-time data to many computers. This capability gave the history data recording access to all the simulation parameters and allowed the development of real-time displays for a small number of parameters. These parameters may reside in any of the computers in the test system including the F-18 computers and the RFCS. The SID is the interface between the simulation and the flight control computers. It is capable of signal conversion, isolation, protection and modifying signals for structural resonance tests, or failure mode and effects tests.

The auto test system was particularly useful. It automatically ran predefined tests on the various simulations by the use of test scripts. The test scripts could set up the simulation, define the test type, define the test conditions, manipulate inputs to the system under test, and record test results with the time history data recording system. Once a test script was written and worked properly, it could be run whenever necessary. This capability allows many tests to be repeated in less time than it took to perform manually.

Another tool used during verification and validation (V&V) was the capability incorporated in the RFCS to make available any memory location in the basic F-18 system or in the RFCS computer on the 1553 bus. This allowed internal FCS parameters to be reviewed as part of the validation testing and during system troubleshooting.

Simulations

Simulations were major tools in the testing of the HARV systems. A simulation which could be configured was developed to provide the flexibility to include the flight hardware necessary (Fig. 5). An all-software simulation consisted of two simulation computers, a cockpit with two flight DDIs, a HUD, and flight MCs. One of the simulation computers contains the aerodynamic model, basic F-18 control laws, actuator models, and interfaces to run the cockpit and strip charts, while the other simulation computer contains the RFCS control laws in Ada. The HIL simulation consisted of all of the previously mentioned systems plus actual flight control computers and analog actuator models. The ironbird simulation included aircraft actuators instead of analog actuator models for all surfaces except the leading- and trailing-edge flaps. The flaps are not used for dynamic maneuvering and were not required for testing. The simulation can also be interfaced to the HARV aircraft. The majority of the V&V testing was done on the HIL, with a subset completed on the ironbird and the aircraft. Figure 6 lists the types of tests each simulation could support.

Problems Encountered During Validation

During the testing of the HARV systems, problems have been met in the interfaces between the control and the avionics systems. These problems involved the activation of pilot displays, the resetting of discretes to engage the RAV, and the effects of angle of attack sent to the MC going beyond the expected range. These problems were easily resolved and corrected. Other problems were also encountered which were not specifically part of the HARV system.

The documentation on the F-18 systems describes the system in varying degrees of detail. Finding the one piece of information that was needed was a recurring problem because it required searching through several of the volumes of information. Progress was hampered during the integration of the flight hardware into the simulation because of the inability to sort quickly through the information. Creating and maintaining communication paths between knowledgeable people located across the country was difficult. The individual with the proper knowledge about the system was not always available to answer questions. These problems will become much harder to deal with in a larger, more complex system. The development of systems[9] that can quickly sort through information which is easily maintained and controlled could save many months of searching for accurate answers. These information systems could be made available to locations in different geographical areas. This would allow questions to be answered even when the most knowledgeable individuals are no longer available.

The ability to collect the data that the F-18 system generated was a very useful asset. However, the large amounts of data generated made it difficult to quickly review even a small set of parameters. This problem is being addressed by adding the ability to capture and display on a Unix® workstation a small set of real-time parameters from all sources.

Concluding Remarks

The high alpha research vehicle (HARV) system modification to add a research flight control system (RFCS) and turning vane control system (TVCS) included the integration of avionics, engine parameters, and external inputs into the flight control system. This integration introduced flexible experimental components into the system. The validation of the HARV system modification included many aspects. The system design included the capability to extract internal parameters from the control systems. The interface between the RFCS and the basic F-18 system contained checks and balances to ensure the safety of the total system was not compromised by unforeseen circumstances. The testing addressed critical issues to ensure the backup system was not compromised by the addition of the experimental systems. The Integrated Test Facility (ITF) systems were used to automate repetitive tests, collect large amounts of data, and allow the test team to concentrate on interpreting test results rather than the test system. The test team not only encountered problems with the system under test but also with the inability to sort through the information in an efficient manner, maintaining communication over large distances, and obtaining desired results in a timely manner.

In conclusion, the validation of an integrated system must begin with system design. The testability, ability to respond

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to unexpected circumstances, and the ability to quickly obtain accurate answers about correct system behavior must all be considered as important aspects of system design to allow efficient validation.

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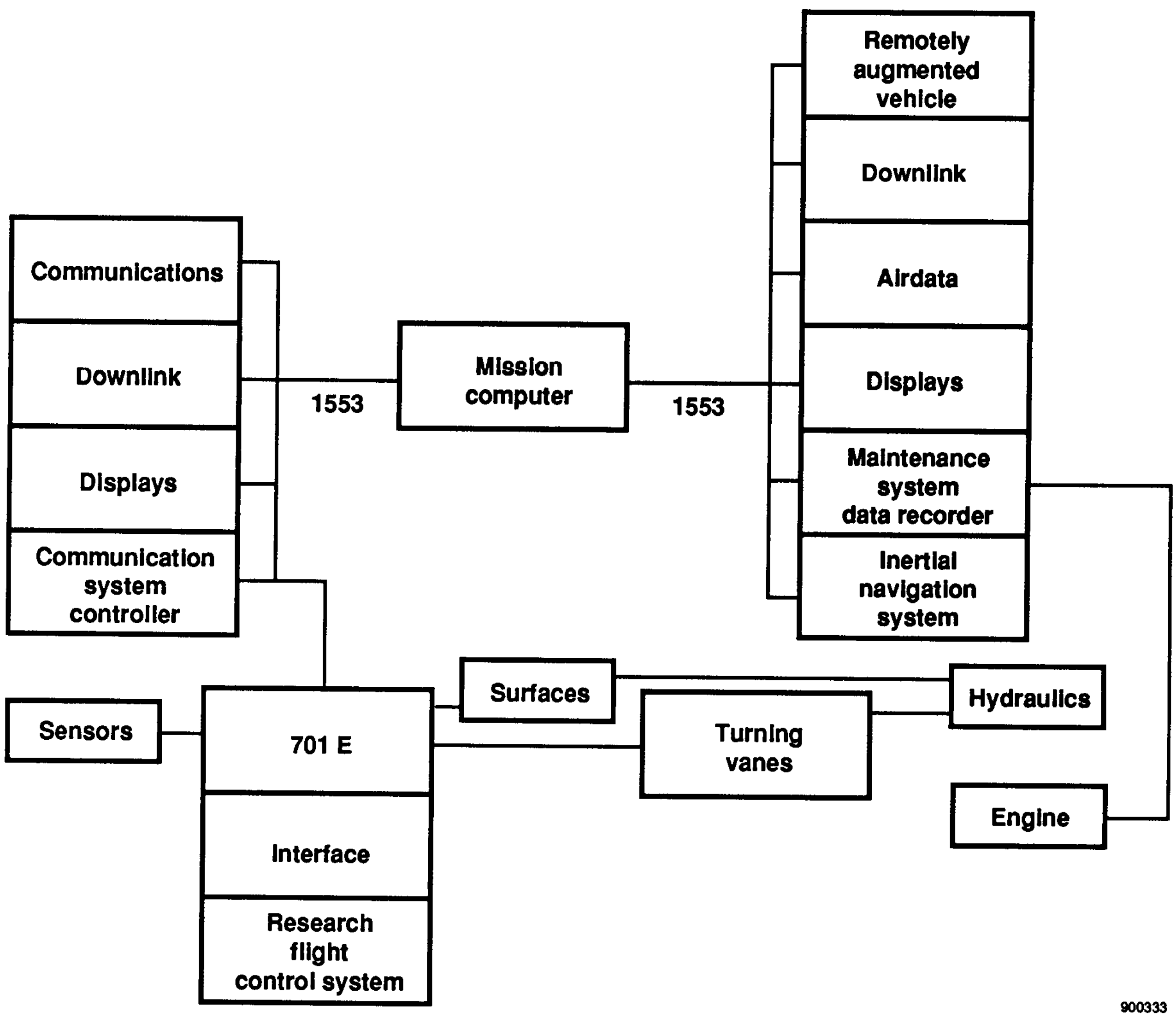

Fig. 1 HARV system components.

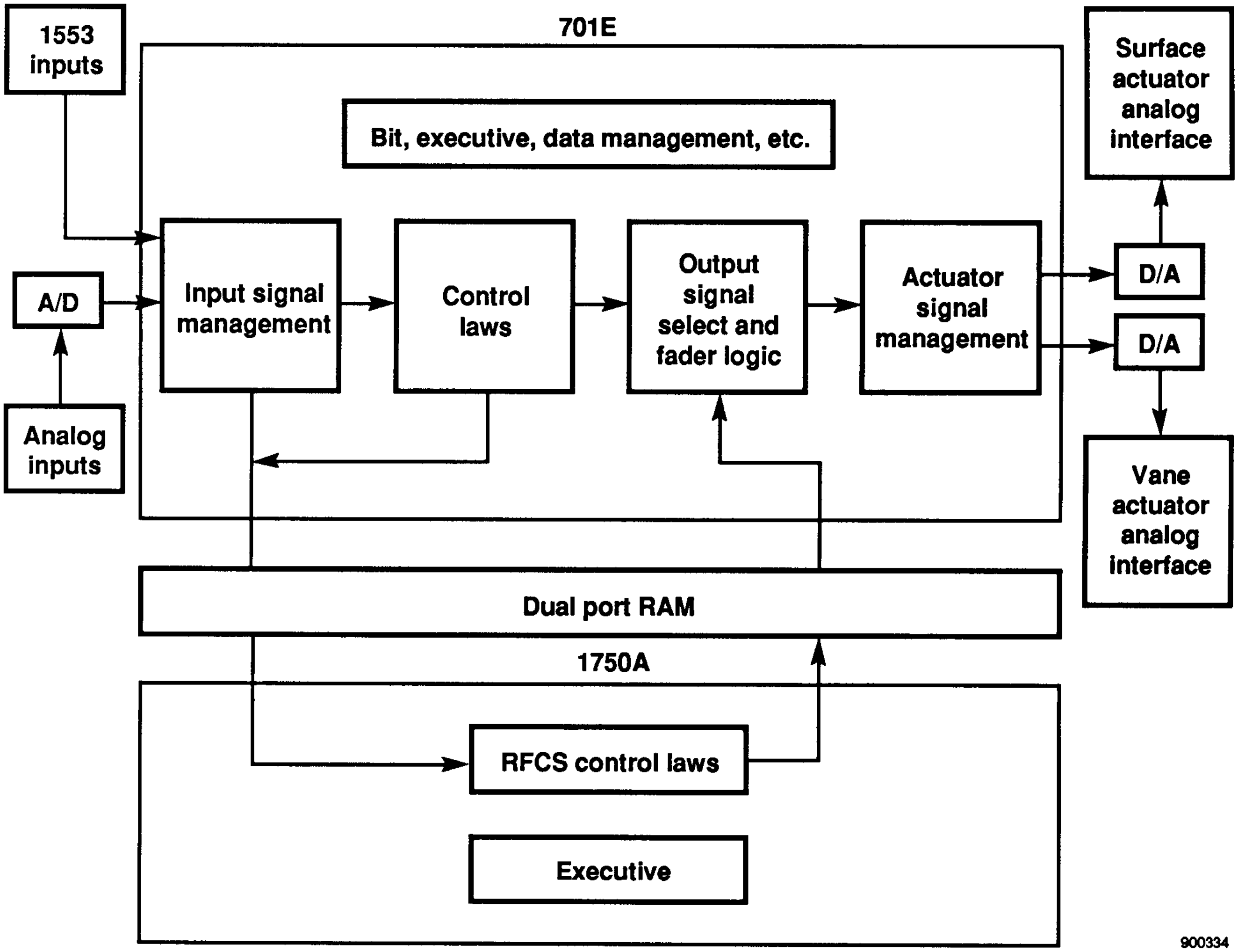

Fig. 2 701 E/RFCS integration.

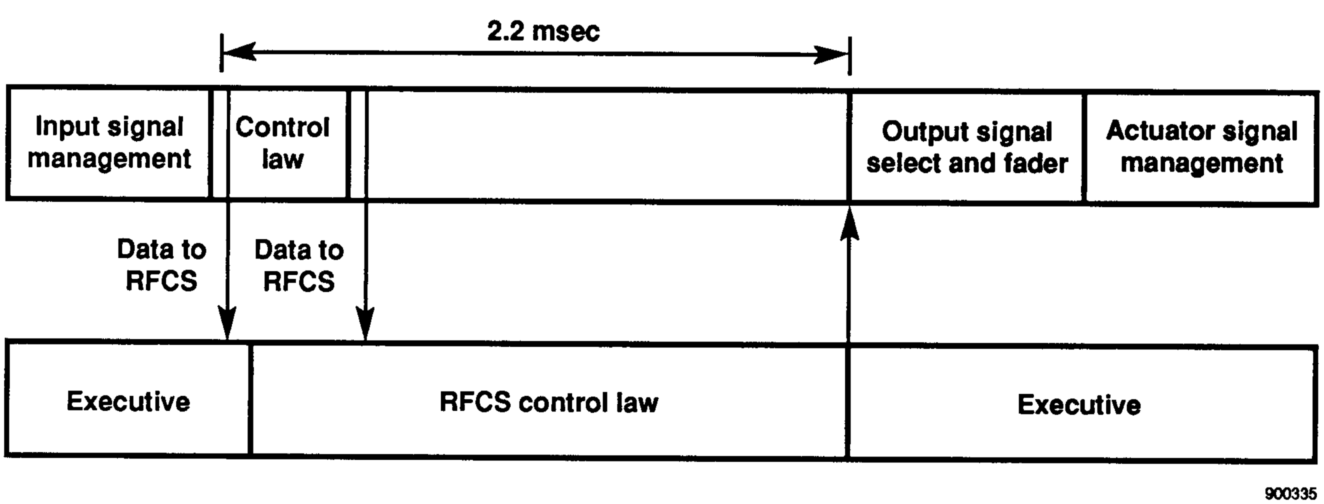

Fig. 3 701 E/RFCS timing diagram.

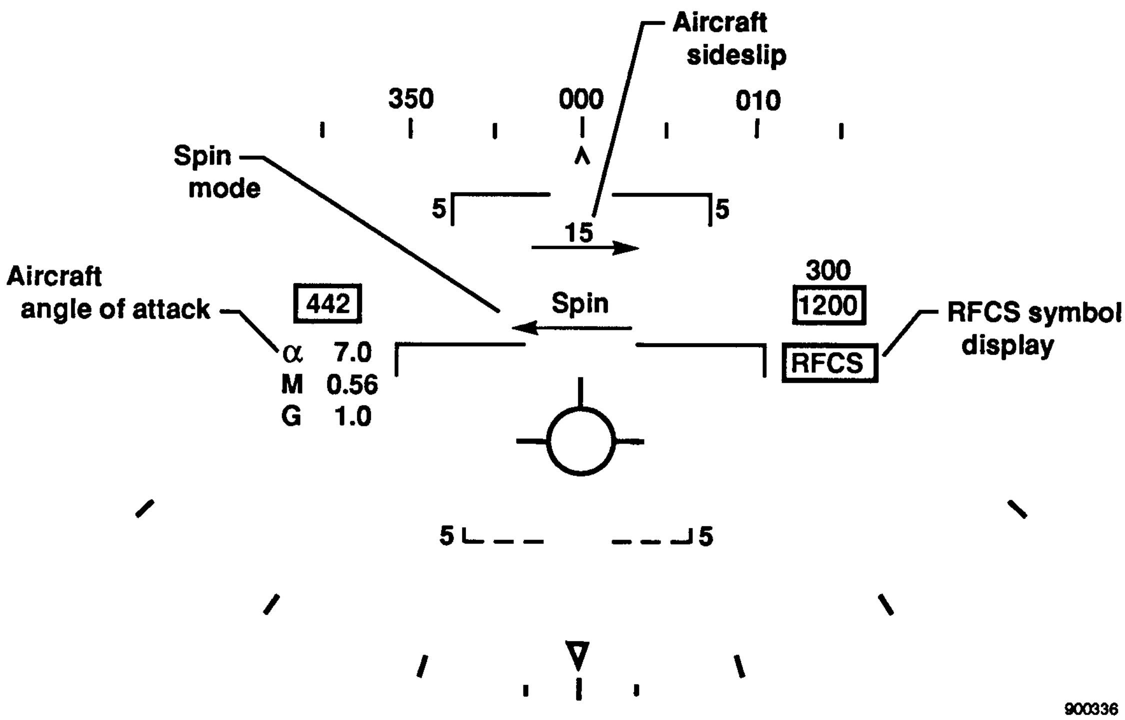

Fig. 4 HUD maneuver display.

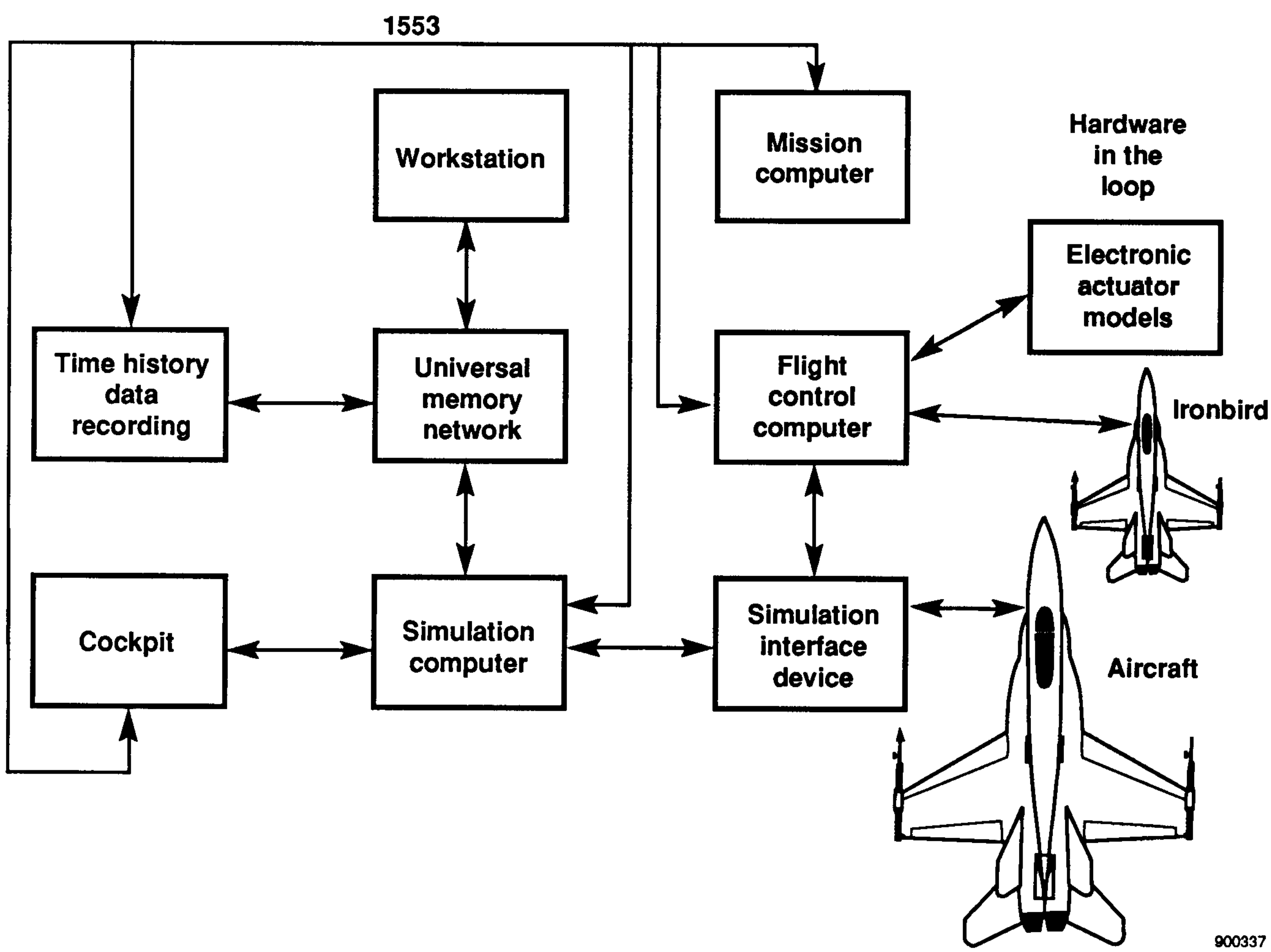

Fig. 5 HARV configurable simulation.

HARV test requirements

	Simulation			
	Software	Hardware	Ironbird	Aircraft
Flight control system	•	•	•	•
Piloted evaluation	•	•	•	•
Failure modes and effects tests		•	•	•
Functional			•	•
Integrated system			•	•
Hydraulic system			•	•
Limit cycle			•	•
Resonance				•

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Fig. 6 Simulation test capability.

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16. Abstract

The verification and validation process is a critical portion of the development of a flight system. Verification, the steps taken to assure the system meets the design specification, has become a reasonably understood and straightforward process. Validation is the method used to ensure that the system design meets the needs of the project. As systems become more integrated and more critical in their functions, the validation process becomes more complex and important. This paper discusses the tests, tools, and techniques which are being used for the validation of the high alpha research vehicle (HARV) turning vane control system (TVCS) and documents the problems and their solutions. The emphasis of this paper is on the validation of an integrated system.

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