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Development and Testing of the Phase 0 Autonomous Formation Flight Research System

Shane Petersen, Jay Fantini, Ken Norlin, and John Theisen
NASA Dryden Flight Research Center
Edwards, California

Steven Krasiewski
Spiral Technology, Inc.
Edwards, California

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National Aeronautics and
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Edwards, California 93523-0273

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Nomenclature

A/C	aircraft
AFF	Autonomous Formation Flight
AIAA	American Institute of Aeronautics and Astronautics
AIMS	Airborne Information Management System
AMUX	analog multiplex
ARI	attitude reference indicator
ARTS	Airborne Research Test System
CG	center of gravity
COTS	commercial off-the-shelf
DDI	digital display indicator
DFRC	Dryden Flight Research Center
FCC	flight control computer
FTE	flight test engineer
GN&C	guidance navigation and control
GPS	global positioning system
HUD	head-up display
INS	inertial navigation system
ILS	instrument landing system
NASA	National Aeronautics and Space Administration
PBD	push-button display
PCM	pulse code modulation
PSFCC	production support flight control computer
RFCS	research flight control system
SID	simulation interface device
TM	telemetry
UAV	unmanned aerial vehicle
V&V	verification and validation
VME	Versa Module Europa
X	forward
Y	lateral
Z	vertical
g	gravity
σ	standard deviation

DFRC Autonomous Formation Flight "The Beginning"

- **NASA Autonomous Formation Flight Project (1995-Initial Requirements)**
  - Targeted three technology areas
    - Relative Navigation, moving GPS base station
    - Formation Control accuracy at < 3 feet
    - Drag reduction
  - Predicted benefits
    - Reliable, safe, autonomous flight control
    - Fuel savings with reduced emissions
    - Characterization of vortex conditions

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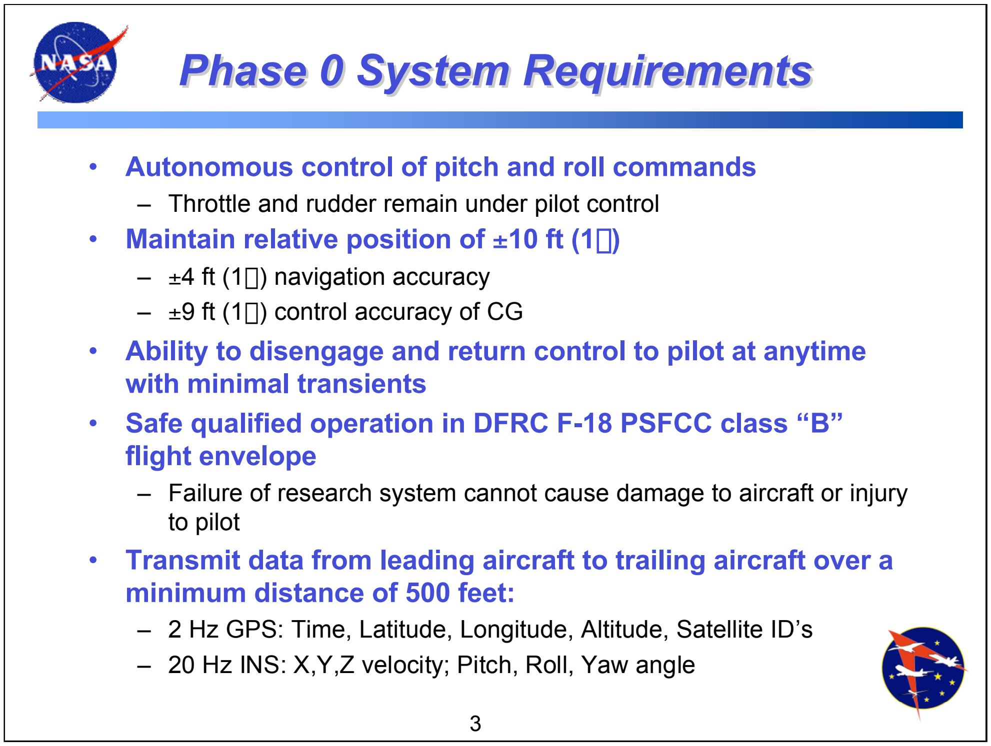
The Autonomous Formation Flight (AFF) project was initiated in 1995 with a goal to demonstrate at least 10-percent drag reduction by positioning a trailing aircraft in the wingtip vortex of a leading aircraft. The first step in accomplishing this feat, Phase 0, was to develop a station-keeping system that enables the trailing aircraft to autonomously maintain formation flight with the leading aircraft. In doing so, two technology areas needed to be investigated. First, a relative navigation system, based on global positioning and capable of accurately tracking both leading and trailing aircraft positional data, was needed. Second, a control system, using positional data of both aircraft was required to be able to command the trailing aircraft to autonomously maintain a position relative to the leading aircraft.

The Phase 0 technology served as a proof of concept for an expanded autonomous system that targets drag reduction benefits by implementing the station-keeping technology to position the trailing aircraft in the wingtip vortex of the leading aircraft.

Predicted benefits from the expanded autonomous system include:

- reliable and safe relative position of leading and trailing aircraft autonomous flight control.
- characterization of leading aircraft wingtip vortex.
- reduced fuel consumption resulting from trailing aircraft drag reduction.

This presentation focuses on the design and testing of the AFF Phase 0 research system.

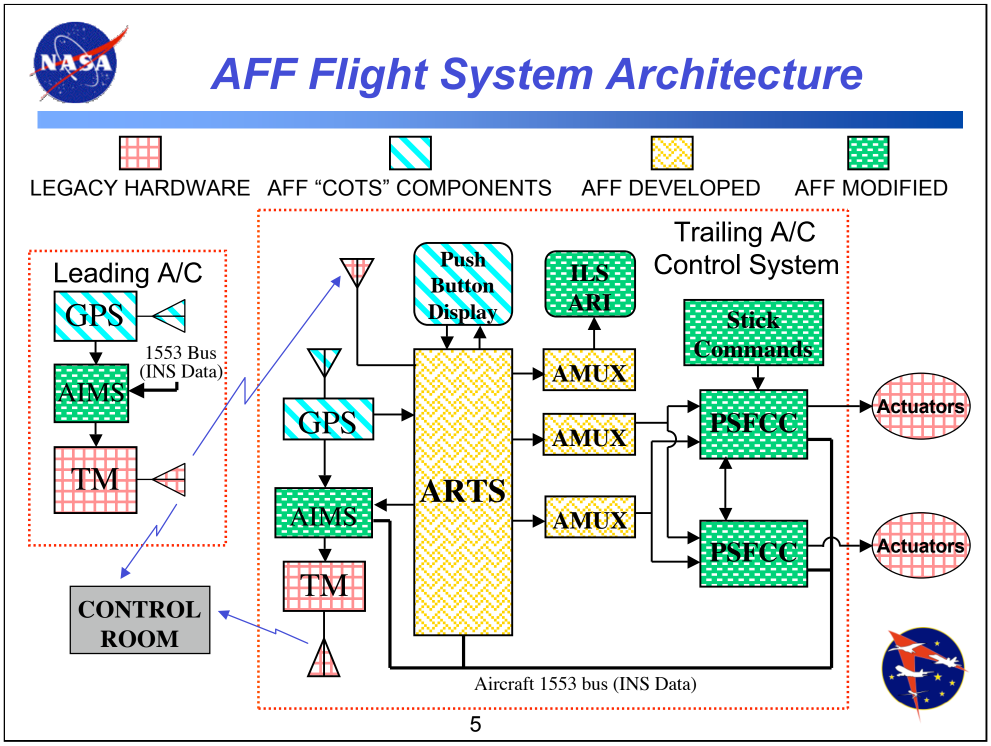


In developing the Phase 0 station-keeping system, five specific requirements were established for performance and control of the autonomous system:

1. The autonomous control shall only extend to pitch and roll commands. This requirement is set forth to simplify the autonomous system for proof of concept. Autonomous control of the throttle command, which has been planned for the next phase, was less important because the control requirements in the pitch and roll axis were an order of magnitude tighter than the separation control requirements.
2. The autonomous station-keeping systems shall maintain a relative position of ±10 ft with a standard deviation of 1σ. Future phases will dictate tighter relative position requirements, but for purposes of technology demonstration, a more modest error margin has been chosen for Phase 0.
3. The autonomous station-keeping systems shall relinquish control to the pilot based upon disengagement criteria from multiple sources. Automatic disengagements occurred after violating a flight condition constraint. Manual disengagements were initiated by the pilot through selection of one to three independent cockpit switches. The transition of pitch and roll control authority from the autonomous system back to the pilot was required to be free of significant pitch and roll transient responses.
4. Qualification efforts shall be made to ensure safe operation in the proposed flight envelope. The class "B" envelope (as defined by the Military Standard) for AFF Phase 0 defines Mach number and altitude flight limitations that will not result in significant damage to aircraft or injury to pilot should a system failure occur.
5. The global positioning system (GPS) and inertial navigation system (INS) communication range between the leading and the trailing aircraft was to extend to a minimum of 500 ft. This requirement was set forth to enable the autonomous system activation through an ample array of positional test points.

The flight test portion of AFF Phase 0 consisted of two F-18 aircraft flying in formation. An F/A-18B airplane, NASA aircraft tail number 846, flew as the leading aircraft. The only research modifications made to aircraft number 846 were the addition of a GPS and an Airborne Information Management System (AIMS). NASA aircraft tail number 845, also an F/A-18B airplane, flew as the trailing aircraft. Research modifications made to the aircraft number 845, include the following:

- GPS
- Airborne Research Test System(ARTS)
- Analog multiplex (AMUX) cards
- Instrumentation and telemetry (TM) modifications
- Instrumentation landing system (ILS) modifications
- Production support flight control computer (PSFCC) with software modifications
- AIMS unit modifications

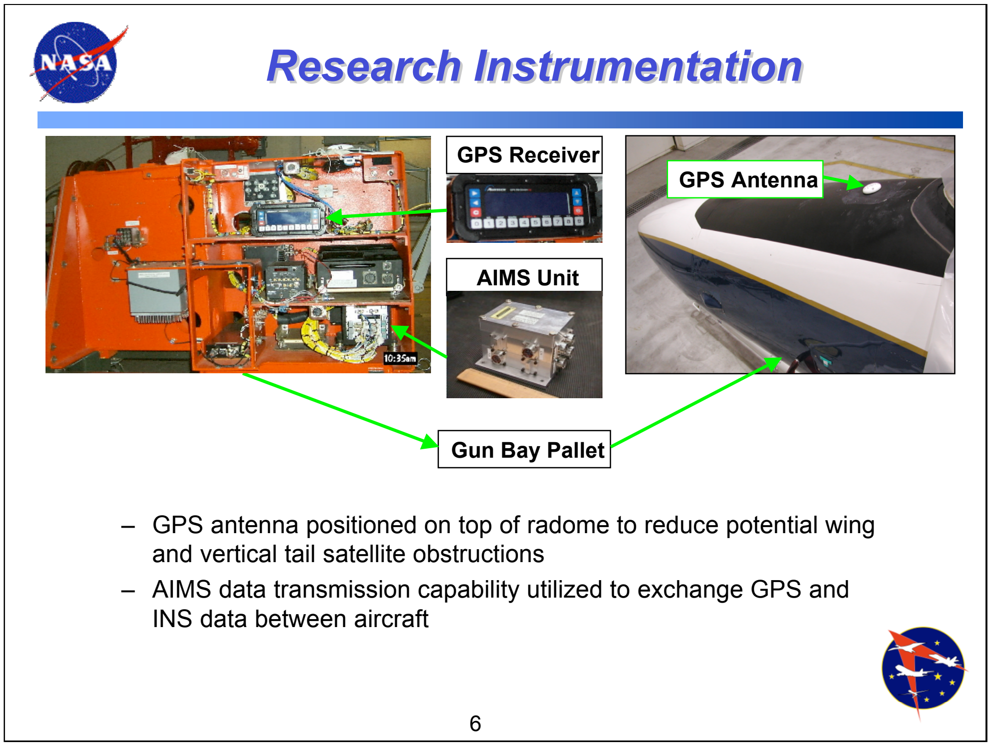


The GPS and INS data from the leading aircraft were packed into telemetry words, with all other pertinent aircraft instrumentation data, using the AIMS unit. These data were then telemetered to the trailing aircraft ARTS and mission control room for monitoring purposes.

The ARTS served as the primary component for the AFF Phase 0 control system. By receiving GPS and INS data from both the leading and trailing aircraft, the ARTS control laws calculated the pitch and roll commands that were sent to the PSFCCs. The AMUX cards interfaced pitch and roll commands between the ARTS and the PSFCCs. Additionally, the AMUX cards received a "heartbeat" signal from the ARTS, which represented the current health status of the ARTS fault detection software. If the ARTS detected an error, the heartbeat signal intentionally failed, and the AMUX card would modify the output pitch command, causing the PSFCCs to return pitch and roll control back to the pilot. The trailing aircraft AIMS unit packed the trailing aircraft instrumentation, GPS, and ARTS data and telemetered them to the mission control room for monitoring purposes.

While in flight, the ILS attitude reference indicator (ARI) vertical and lateral needles guided the pilot to the desired station-keeping position before autonomous control was engaged. These needle commands were calculated in the ARTS and sent to the ILS subsystem by an AMUX interface.

Activating the autonomous station-keeping system required an armed and engaged ARTS as well as an armed and engaged PSFCC. This activation requirement was put in place to minimize any possibility of the autonomous system erroneously activating. Arming and engaging the ARTS was accomplished by the flight test engineer (FTE) in the aircraft through the push-button display (PBD) interface. The PBD was also used to select user-defined control gain sets, heading information, and separation distances for the autonomous system. The pilot armed the PSFCCs by means of the digital display indicator (DDI) and engaged the PSFCCs through the nosewheel steering button on the stick.

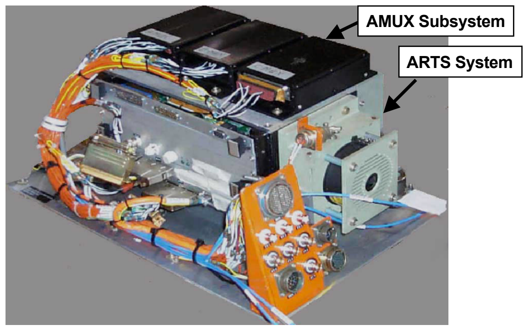


The research instrumentation system on each aircraft was responsible for sending associated GPS and INS data to the ARTS subsystem. The INS data from each aircraft were available on the Military Standard 1553 bus. Each aircraft had a GPS receiver installed. The antenna for the leading aircraft GPS subsystem was positioned on top of the radome to reduce potential wing and vertical tail satellite obstructions. For the trailing aircraft, the GPS antenna was positioned on top of the turtleback (just aft of the canopy).

The leading aircraft used the AIMS interface to encapsulate the GPS and INS data and transmit the data to both the trailing aircraft ARTS and to the control room for monitoring purposes. The trailing aircraft GPS data were sent directly into the ARTS subsystem, and the INS data were extracted from the 1553 bus by the ARTS.

The trailing aircraft AIMS unit was responsible for packing ARTS messages, GPS data, and 1553 instrumentation data onto a telemetry stream. The telemetry stream was then transmitted to the control room for monitoring.

Airborne Research Test Subsystem



- Host guidance and autonomous control code
- Compute Pitch and roll commands for the PSFCCs
- Interface to Mil-Std 1553 bus
- Interface to TM subsystems and data collection subsystem
- Direct GPS interface
- Located in Gun Bay Pallet
- COTS 6U VME Hardware

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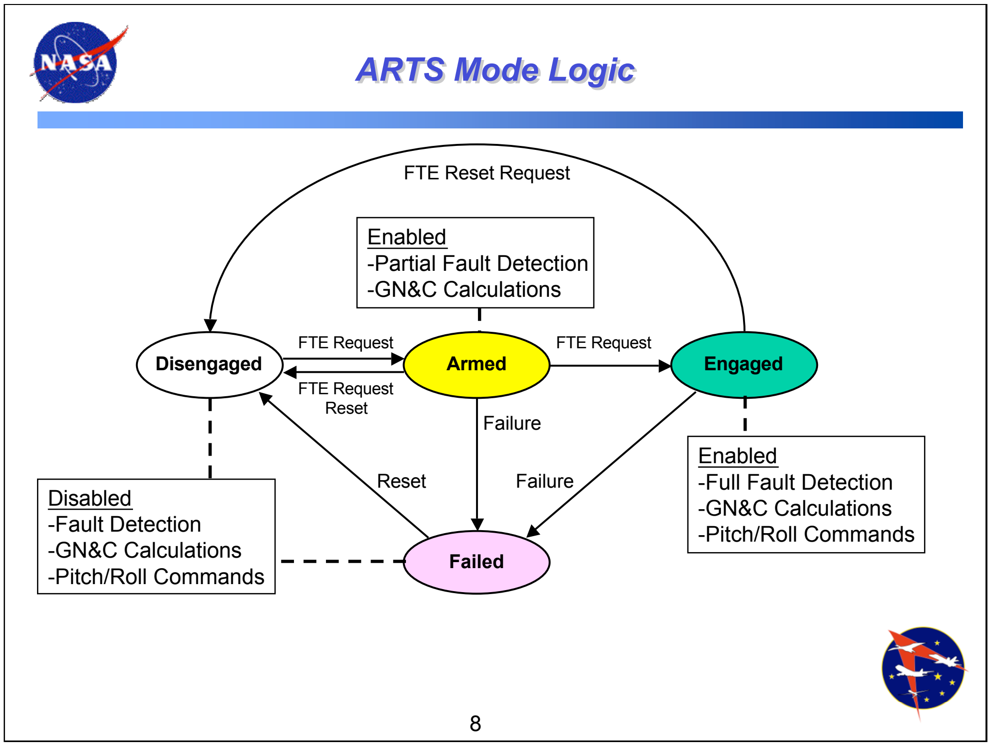
As previously mentioned, the ARTS was the primary component of the Phase 0 flight system architecture. The ARTS is a 6U Versa Module Europa (VME) chassis composed of four VME boards, power board, CPU board, Military Standard 1553 board, and a TM decommutation board. All boards except the power board were commercial off the shelf (COTS) equipment. The chief responsibilities of the ARTS subsystem include:

- Host guidance and autonomous control software
- Generation of pitch and roll commands
- Generation of heartbeat command for autonomous system disengagement purposes
- Interface with the aircraft 1553 bus
- Interface with TM subsystems
- GPS interface



ARTS mode logic dictated the armed, engaged, and disengaged states of the ARTS. Arming the ARTS required having the FTE initialize the controller performance gain set and the commanded relative position and heading information using the PBD. Once the ARTS was armed, entering an engaged state required a full set of aircraft flight parameters to be satisfied. These control parameter faults included:

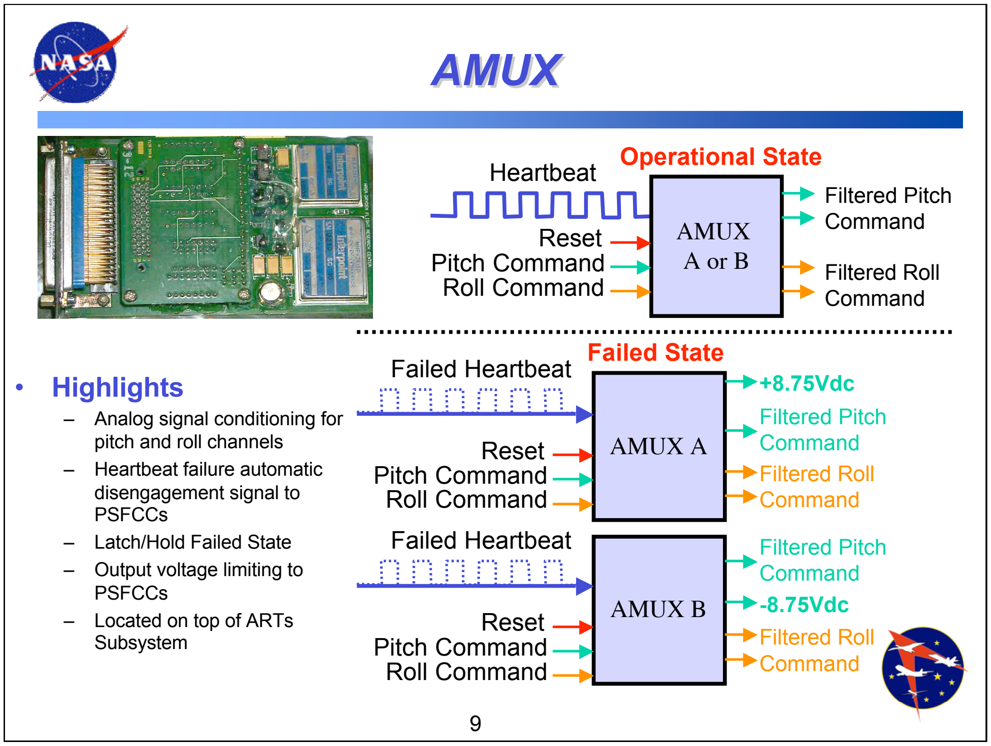
Input data: Pitch and roll angles and angle rates, normal acceleration, angle of attack, and leading and trailing wander angle limits

Controller: Nose-to-tail spacing limits, positional errors, and velocity errors

Output data: Pitch and roll command magnitude limits

Loss of data: Leading and trailing aircraft inertial data loss, GPS data loss, and common satellite loss

A detected failure from any one of these parameters would transition the ARTS to a failed state, in which case the ARTS would need a FTE-commanded reset to reenter the disengaged state. The return to the disengaged state is necessary to repeat the arm-engage cycle.



Three AMUX units were integrated into the AFF system. The two AMUX units shown in the above slide receive pitch and roll analog commands, as well as digital heartbeat and reset commands, from the ARTS computer. The AMUX, in turn, relays the analog commands to the PSFCCs.

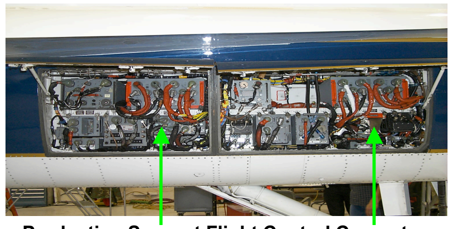
Within the AMUX subsystem, the pitch and roll commands were signal conditioned with the following:

- Buffered input/output (I/O)
- Three-pole low-pass filter
- Voltage limiting on signal output to within ±8.75 Vdc
- Duplexed pitch and roll outputs

The heartbeat command is a discrete pulse that controls a multiplexing mechanism associated with the pitch command. Given a healthy heartbeat signal sourced from the ARTS, the AMUX will output the conditioned pitch and roll commands. After receiving a failed heartbeat signal, the AMUX responds by replacing two of the pitch outputs with 8.75 and –8.75 Vdc, respectively. The roll command is unaffected. This condition is held until the heartbeat is restored to a healthy status and a subsequent reset pulse is received from the ARTS, at which time the AMUX would resume outputting the conditioned pitch and roll commands.

The other AMUX system (not shown) receives the vertical and lateral commands from the ARTS and passes them to the ILS system. These commands are conditioned with buffered I/O, a three-pole low-pass filter, and output voltage limiting.

Production Support Flight Control Computer



Production Support Flight Control Computers

- **PSFCC General Functionality**
  - Basic F/A-18 Flight Control Computer (FCC)
  - Additional processor for research control laws
    - Allows for quick evaluation in controlled tests
    - Using basic flight control system for take-off, landing and recovery from undesirable dynamics
- **Software Modifications**
  - Pitch and Roll stick inputs replaced by ARTS Pitch and Roll inputs while autonomous system is armed and engaged.
  - Piloted Pitch and Roll stick commands reinstated at any time

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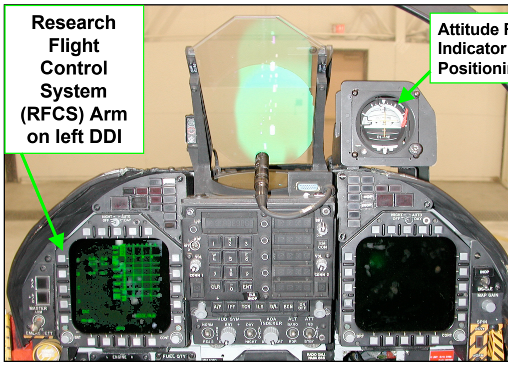
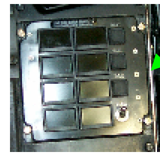
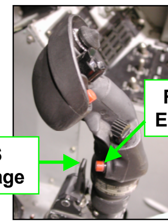
For AFF, the PSFCCs allow automated control to be evaluated at desired flight conditions, and the basic F-18 flight control system is used for takeoff, landing, and recovery from undesirable dynamics.

The PSFCCs are comprised of basic F/A-18B flight control computers and F/A-18B flight control computers, modified to include a research flight control system (RFCS). This architecture was developed to allow alternate control algorithms to be flight-tested while retaining the basic F/A-18 flight control system intact as a backup. The AFF used this capability to eliminate the stick dead band and provide comparatively greater linear control authority. Additionally, the PSFCCs have a separate input to allow for external command sources. This separate path is used to bring in the pitch and roll commands generated in the ARTS computer.

Pilot/System Interface Components







- **Description**
  - Standard F-18 cockpit, except addition of PBD and relocation of the ARI
  - FTE (backseat) arms/engages ARTS computer via PBD interface
  - Pilot flies to position using Positioning Needles on ARI
  - Pilot arms RFCS via DDI and engages via nose wheel steering button
  - Pilot disengages RFCS system via RFCS disengagement paddle switch

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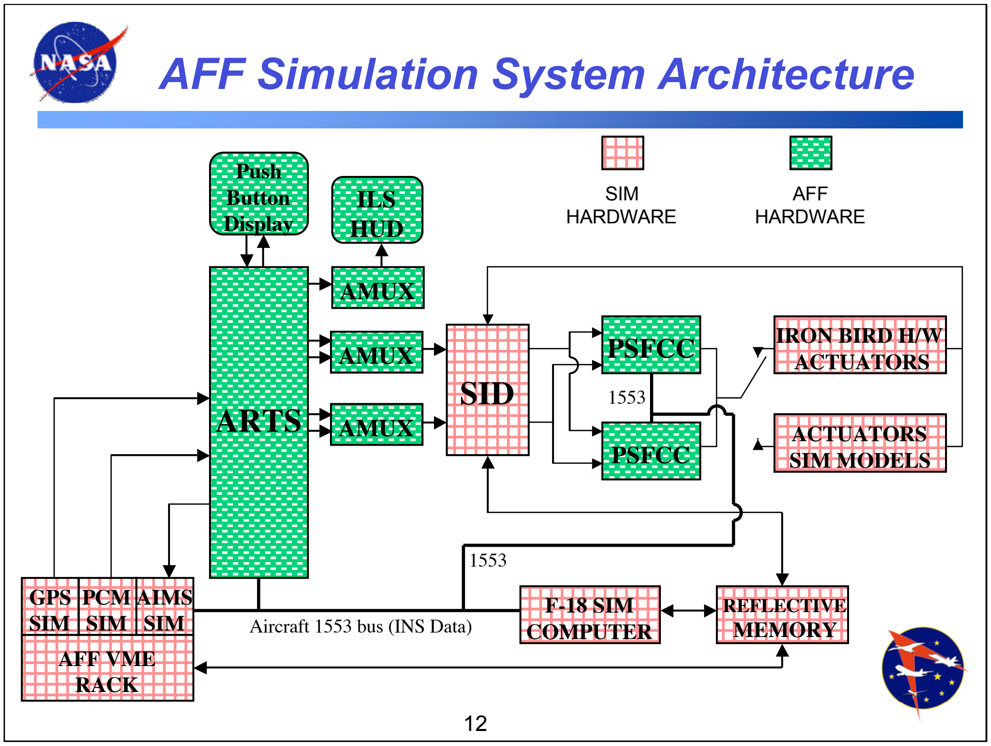
The pilot interfaces shown consist of an ARI, PBD located in the aft seat front panel, nosewheel steering, paddle switches located on the pilot stick, and DDI located on the pilot front panel. The ILS needles are located on the ARI and were used to provide the pilot with an indication of vertical and lateral position errors relative to the commanded position within formation. By centering the needles (zeroing the errors), the pilot was able to guide the aircraft to the desired position before engaging the system. Movement of the needles during a test point gave the pilot an indication of the control law accuracy. The FTE in the cockpit used the PBD to select the desired control gain set, select test point conditions, arm the ARTS, and engage the ARTS. The pilot used a tile button on the DDI to arm the PSFCC. To engage the PSFCC, the pilot depressed the nosewheel steering switch located on the stick. The pilot could disengage the AFF system by toggling the paddle switch on the F/A-18B stick, positioning the flap switch (not shown) to anything other than “auto,” or activating the spin-recovery switch (not shown).



The existing NASA Dryden F-18 simulation facilities were modified to accurately model the AFF Phase 0 flight system architecture for testing. Additional flight hardware (not shown in the above slide) are the mission computer, control converter, DDI, and the F -18 cockpit.

The primary differences between the flight system and simulation system architectures are the simulation of both leading and trailing aircraft GPS and INS data and the use of the simulation interface device (SID) to conduct specialized testing. The SID provides the interface between the simulation computer and flight hardware. The aircraft tail numbers 845 and 846 GPS and INS data were simulated in the AFF VME rack. The SID monitored and controlled various signal I/Os during testing and induced hardware failures during simulation.

Simulation Description

F-18B Sim Lab

- **Description**
  - F-18 Simulation Lab allows pilot input, automated testing, data collection, emulation of flight conditions and required aircraft systems/subsystems
  - High fidelity simulation models
  - Simulator graphics seen from trailing aircraft perspective

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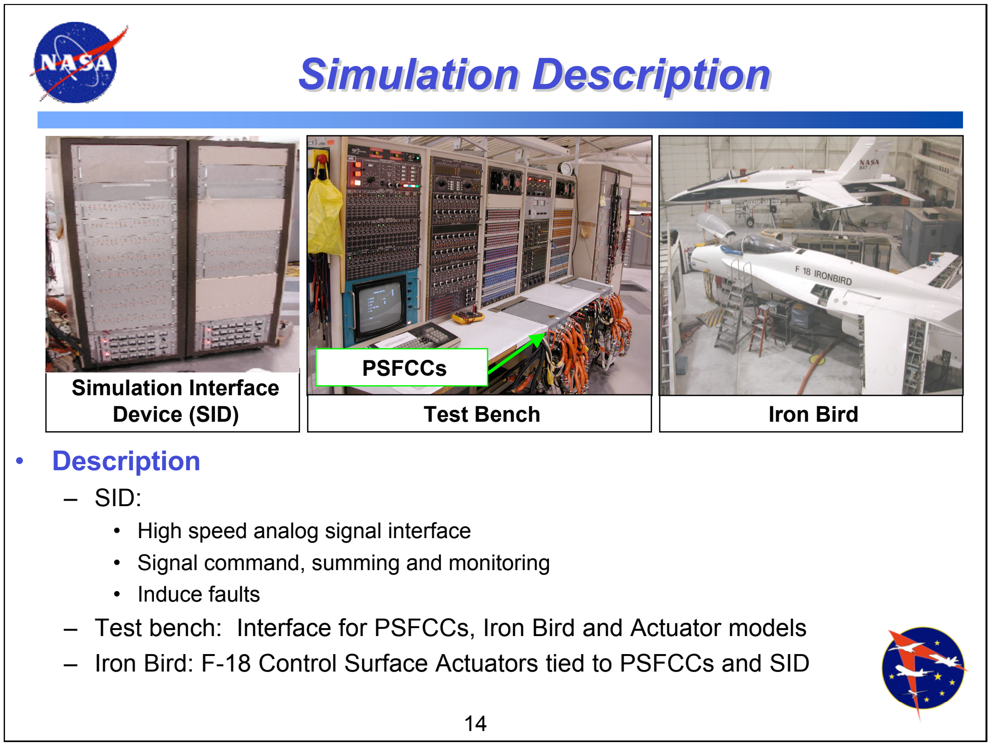
The F/A-18 six-degree-of-freedom simulation contains high-fidelity models; including aerodynamic, control law, aircraft sensor, engine, actuator, and atmospheric models; and flat-Earth equations of motion. Atmospheric models include a discrete gust and the NASA Dryden turbulence model. The leading aircraft trajectory data was recorded during flight and played back while the trailing aircraft simulation was executed. The projected aircraft images were three-dimensional solid models and included realistic movement of flight control surfaces on both aircraft. Model response to piloted input, which was recorded and analyzed, proved to be an important trouble-shooting tool during the test.

During failure modes and effects tests (FMETs), an Iron Bird with flight actuators, rather than software actuator models, was controlled by the trailing aircraft simulation to provide a hydraulic actuator response.



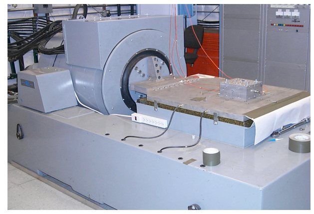
The SID, test bench, and Iron Bird provide interfaces for the PSFCCs, flight actuators, and F-18 simulation laboratory.

The SID is a high-speed analog interface between the F-18 simulation laboratory and the test bench. The AFF Phase 0 primarily used the SID capabilities when performing verification and validation (V&V) testing with the ARTS, AMUX, and PSFCC subsystems. Using the SID, the test conductor was able to monitor all commands to and from these subsystems. In addition, the SID provided the capability of monitoring and recording system response to induced hardware faults on these commands.

The test bench is composed of the PSFCCs, hardware actuator models, and SID–Iron Bird interface. At the test bench, a switch is used to determine whether to incorporate F-18 actuator models or physical F-18 actuators (Iron Bird) in the hardware-in-the-loop simulation (HILS) testing.

Component Level Tests

- **Software Testing:**
  - ARTS
  - PSFCC
- **Hardware Functional Testing:**
  - ARTS
  - AMUX
  - PBD
- **Hardware Environmental Testing:**
  - AFF Developed Hardware
    - ARTS
    - AMUX



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Subsystem level tests verified that all AFF Phase 0 hardware to be incorporated in the HILS testing functioned as designed and would not adversely affect each other or the simulation hardware. These tests began with a functional checkout of the ARTS and AMUX hardware and the ARTS–PSFCC RFCS software. Other AFF subsystems were not subjected to the same level of testing because of previous flight qualifications.

The ARTS hardware functional checkout was performed with test software to verify data I/O. The AMUX was tested using a function generator to replicate pitch and roll, heartbeat, and reset command inputs. When satisfactory results were obtained for both subsystems, environmental tests were conducted to ensure proper operation in the expected environment.

The class “B” envelope allowed for reduced testing of the ARTS and PSFCC software using module rather than unit testing. Module testing allowed for quicker regression testing as software problems arose.

Subsystem Level

- **Subsystem Interfaces**
- **ARTS Mode Logic Tests:**
  - Armed State
    - Arming via PBD interface
    - Mode logic arm checks
  - Engaged State
    - Engaging via PBD interface
    - Mode logic engage checks
  - Failed State
    - Mode logic fail checks
  - Disengaged State
    - Disengaging via PBD interface
    - Mode logic disengage checks

- **PSFCC Arm/Engage/Disengage Tests:**
  - Arming check via DDI interface
  - Engagement check via nose wheel steering interface
  - Pilot disengagement checks
    - Pilot initiated: Paddle switch, Spin Switch and Flap Switch
    - Software initiated: RFCS software/ARTS software

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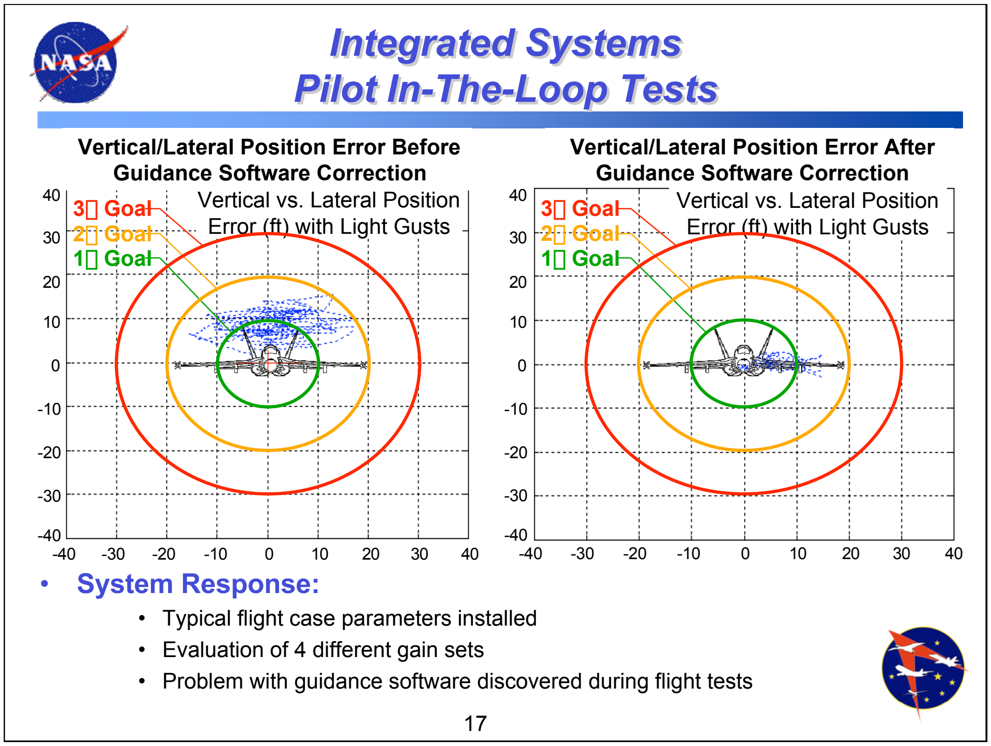
The purpose of verification testing was to verify the performance requirements of each AFF subsystem. The selection of V & V tests were influenced by AFF system flight criticality. By restricting the flight envelope to conditions that allow any combination of control inputs without resulting in structural damage, the AFF system was not required to be tested to flight critical standards.

<u>Verification tests</u>

The V & V tests began with the verification of proper functionality between the following subsystems:

- ARTS and PBD (PBD page selection and page updates)
- ARTS and AMUX (heartbeat and watchdog, reset, and pitch and roll command interface)
- AMUX and ILS ARI (needle command deflection)
- AMUX and PSFCC (pitch and roll command voltage limiting to PSFCCs)

Next, ARTS mode logic was verified to ensure commanded relative positions, formation heading, and control law gain sets were initiated before ARTS arming; positional control system fault detection criteria was met before engagement; a failure occurred if any arm or engage criteria was violated; and a disengagement mode was entered if a failed state existed. Finally, the PSFCC arm, engage, and disengage verification checks were made. The ARTS was engaged before PSFCC tests. The PSFCC state parameters include arming the PSFCC RFCS by selecting the appropriate tile button on the left DDI; engaging the PSFCC RFCS by selecting the nosewheel steering button; and disengaging the PSCFF RFCS when an ARTS failed condition exists, the pilot initiates disengagement, or an RFCS software disengagement occurs.

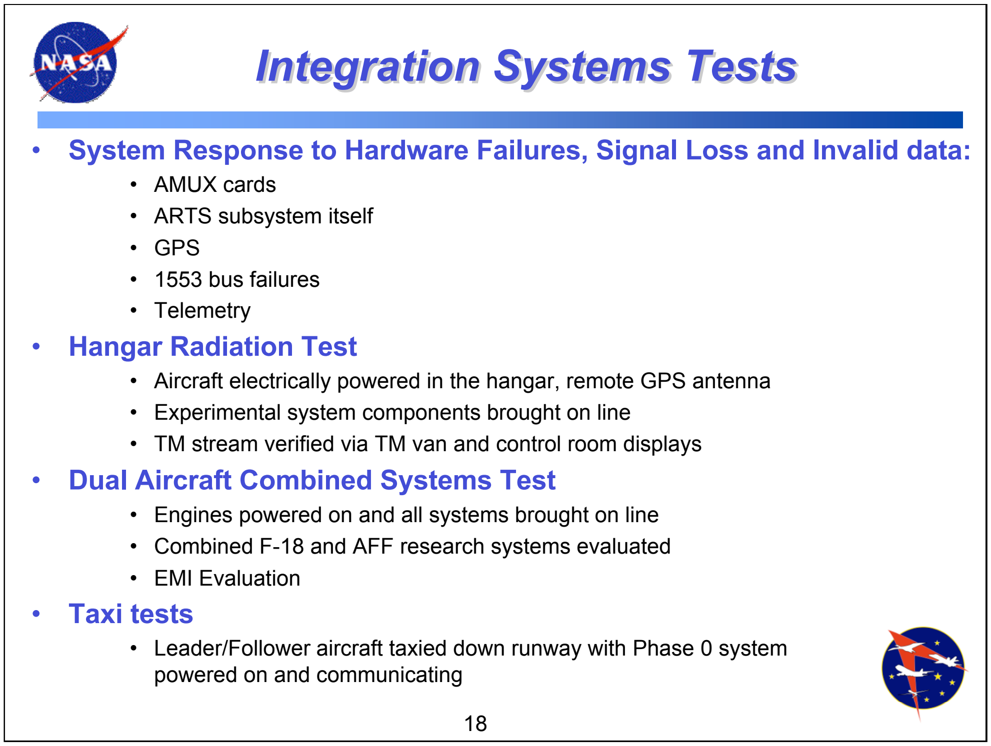


Validation Tests

The final phase of V&V testing was the validation of a typical flight case during HILS. Input parameters of the typical flight scenario include the following:

- Induced gusts
- Altitude
- Velocity
- GPS with observed satellite constellation comparisons
- TM with minimal drop-out
- Separation distance
- Fuel load
- Gain set

The initial pilot in-the-loop test revealed errors very close to the desired ±10 ft 1σ. Results, however, were not as good as expected. At the time, the error was attributed to the GPS simulation methods used, and the control system was expected to respond more favorably during actual flight tests. During flight tests, however, the control system response yielded results notably similar to what was seen in the simulation case. Upon further review, a problem was found in the guidance software. The required correction was made; and regression testing, implementing simulation testing results, yielded a significantly improved control system well within the ±10-ft 1-σ requirement.



Failure Modes and Effects Tests

The failure modes and effects tests (FMETs) were initiated upon completion of the subsystem level test data review. The F/A-18B aircraft is a fly-by-wire aircraft with a backup mechanical linkage to the stabilators for pitch and roll control. The mechanical linkage mode is termed "MECH" mode. Although the F/A-18B aircraft is controllable in MECH mode, the aircraft may become uncontrollable when combined with a hardover surface failure. The objective of this testing was to analyze the AFF system response to induced system failures, including step actuator commands that could lead to MECH reversion.

Transient pitch and roll tests involved step pitch and roll inputs to the PSFCCs. These transients were applied to the trailing aircraft during a simulated station-keeping run under calm air conditions. Tests were then repeated, inducing gusty conditions. No resultant conditions were found to induce MECH reversion.

The ARTS and AMUX cards were individually powered off during testing. Loss of power to the ARTS resulted in PSFCC RFCS disengagement with minor transients. Loss of power to the AMUX cards resulted in the pitch and roll commands floating at the PSFCC inputs. Usually, differences in the floating voltage values caused a PSFCC cross-channel–miscompare disengagement; sometimes they required control-room monitoring to identify the problem.

Ground Tests

Grounds tests were composed of hangar radiation, dual aircraft, and aircraft taxi tests. The hangar radiation test evaluated the TM streams on both aircraft. This evaluation was accomplished by electrically powering each aircraft and AFF research system inside of the hangar, while a transmitted TM signal was received by a mobile TM receiver outside of the hangar. The TM information was recorded, demodulated, and played back at mission control to verify all control-room instrumentation and research displays.

The dual aircraft functional tests evaluated the combined aircraft systems under engine power. During these tests, both aircraft were brought outside of the hangar and placed in a position relative to planned flight formation, while TM information was transmitted to, and monitored in, the control room. Additionally, this test checked for electromagnetic interference (EMI) between F-18 and research hardware.

The taxi test involved taxiing both aircraft in formation down the runway. Both aircraft TM streams were sent to the control room to verify that control-room displays correctly interpreted the aircraft instrumentation and separation distances under dynamic conditions.

AFF Phase 0 Testing Strengths, Weaknesses

- **Strengths**
  - Successfully achieved trailing aircraft autonomous station keeping design goals
  - Simulation capabilities provided rapid testing of research modifications made between flights
  - Bulk of design made use of existing hardware and COTS items minimizing new design research and development
  - The majority of the system design flaws were uncovered during subsystem and integration tests.
- **Weaknesses**
  - 3g Maneuver Environmental limitation
  - Bulky hardware system developed specifically for NASA 845
  - No autonomous control for rudder/throttle commands
  - V&V testing confidence weakened due to GPS simulation method inadequacies

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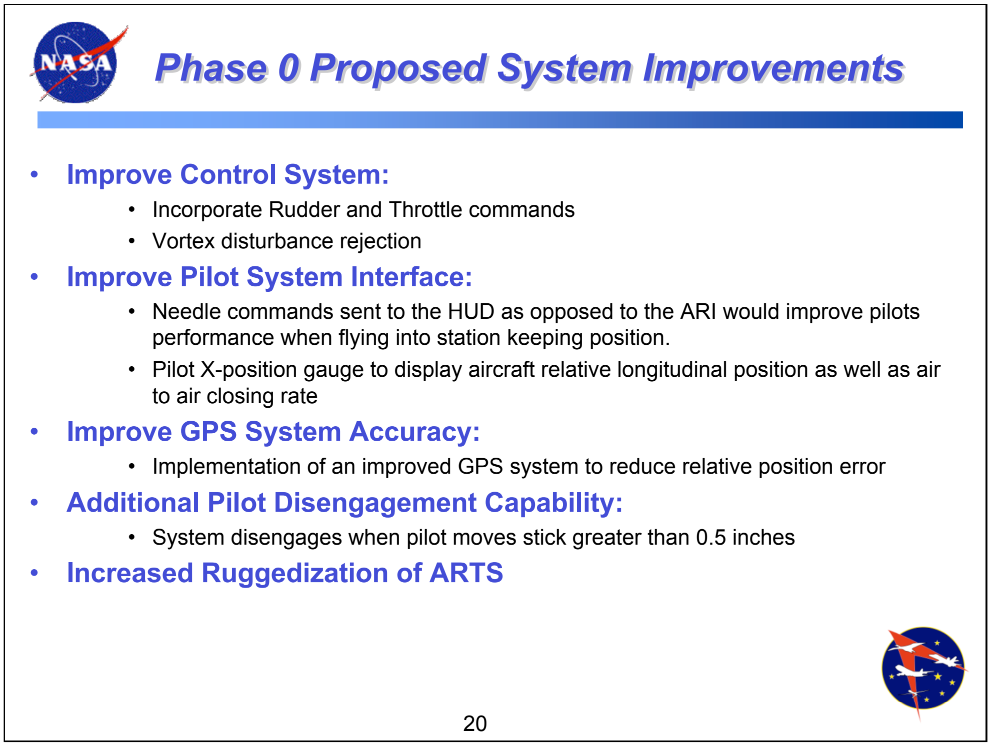
The AFF strengths are as follows:

- The pilot-in-the-loop–simulated flight cases yielded results well within the ±10-ft 1-σ goal.
- The Dryden simulation capabilities were essential for rapid and efficient regression testing when problems were encountered during flight. Although the initial V&V took approximately three weeks for completion, the regression simulation tests were completed within four days when the guidance software problem was exposed during flight tests.
- The AFF system hardware incorporated two NASA Dryden designs. The rest of the AFF system was composed of inherited or modified F-18 hardware and COTS items. Only the ARTS software had to be completely developed by the AFF team. The PSFCC software was received from a previous project with minor AFF modifications incorporated.
- During testing (including subsystem, integration, V & V, and FMETs), system anomalies, including 4 found during flight, were documented in 51 Discrepancy Reports (DRs). Each DR was resolved with a Configuration Change Request (CCR) and satisfactory results from a subsequent Systems Test Report.

The AFF weaknesses are as follows:

- Environmental limitations, resulting from some COTS equipment specifications within the ARTS, led to a 3-*g* maneuverable limitation during flight.
- The AFF Phase 0 system was specifically constructed as a station-keeping technology demonstration using two F-18 aircraft. Consequently, AFF design guidelines did not necessitate that the system be compact and highly portable.
- The station-keeping system did not have control of rudder or throttle commands, which limited the autonomous control.



Recommended improvements to the AFF system are as follows:

- The most significant improvement recommended for the station-keeping control systems is the implementation of autonomous throttle and rudder commands. The throttle command would be instrumental in maintaining nose-to-tail separation. The rudder command would have a profound influence on improving the station-keeping performance. Another control system improvement is the implementation of vortex-disturbance rejection capabilities within the control laws.
- Pilot-system interfaces can be improved by moving the positioning needles to the head-up display (HUD) from the ARI. This move would enable the pilot to fly to the commanded needle position while maintaining line of sight.
- Improving the GPS accuracy has a direct effect on the overall performance of the station-keeping system in reducing relative positional errors.
- For safer flights, an additional disengagement mechanism should be implemented that allows the pilot to disengage the system by simply commanding more than 0.5 in. of stick in any direction. Should the pilot be faced with a situation that might lead to a midair collision, this feature would allow the pilot to instinctively fly avoidance maneuvers and automatically disengage the AFF system without taking any additional action.
- The ARTS should be further ruggedized to eliminate the 3-*g* maneuverable limitation.

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Shane Petersen, Steven Krasiewski, Jay Fantini, Ken Norlin, John Theisen

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Dryden Flight Research Center
P.O. Box 273
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13. ABSTRACT (Maximum 200 words)

The Autonomous Formation Flight (AFF) project was initiated in 1995 to demonstrate at least 10-percent drag reduction by positioning a trailing aircraft in the wingtip vortex of a leading aircraft. If successful, this technology would provide increased fuel savings, reduced emissions, and extended flight duration for fleet aircraft flying in formation. To demonstrate this technology, the AFF project at NASA Dryden Flight Research Center developed a system architecture incorporating two F-18 aircraft flying in leading-trailing formation. The system architecture has been designed to allow the trailing aircraft to maintain station-keeping position relative to the leading aircraft within +/-10 ft. Development of this architecture would be directed at the design and development of a computing system to feed surface position commands into the flight control computers, thereby controlling the longitudinal and lateral position of the trailing aircraft. In addition, modification to the instrumentation systems of both aircraft, pilot displays, and a means of broadcasting the leading aircraft inertial and global positioning system-based positional data to the trailing aircraft would be needed. This presentation focuses on the design and testing of the AFF Phase 0 research system.

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