

AEROSPACE INFORMATION REPORT

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Descriptions of Systems Integration Test Rigs (Iron Birds)
for Aerospace Applications

RATIONALE

AIR5992 has been reaffirmed to comply with the SAE Five-Year Review policy.

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1. SCOPE

This Aerospace Information Report (AIR) provides information on systems integration rigs, commonly referred to as “Iron Birds” for aerospace applications.

- a. It includes background historical information including descriptions of Iron Birds produced to date, important component elements and selection rationale, hydraulic system design and operational modes and illustrates the design approaches to be considered.
- b. It provides illustrations of the various systems that should be considered for Iron Bird testing in the development phase and utilization during the production program.
- c. It includes recommendations for simulation, component development tests, system integration and lessons learned.

1.1 Purpose

The information conveyed in this AIR is intended to help aircraft systems designers to design and develop Iron Birds for Aerospace applications. The document describes the design approaches that should be considered and provides descriptions of Iron Birds produced to date on various commercial and military programs.

2. APPLICABLE DOCUMENTS

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1 Applicable Documents

2.1.1 SAE Publications

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Telephone: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

AIR4253	Description of Actuation Systems for Aircraft with Fly-By-Wire Flight Control Systems
ARP603	Impulse Testing of Hydraulic Hose, Tubing and Fitting Assemblies
ARP1383	Impulse Testing of Hydraulic Actuators, Valves, Pressure Containers, and Similar Fluid System Components
ARP4752	Aerospace - Design and Installation of Commercial Transport Aircraft Hydraulic Systems
AS5440	Hydraulic Systems, Aircraft, Design and Installation Requirements For
AS94900	Aerospace - Flight Control Systems - Design, Installation and Test of Piloted Military Aircraft; General Specification For

2.1.2 U.S. Government Publications

Available from the Document Automation and Production Service (DAPS), Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, <http://assist.daps.dla.mil/quicksearch/>.

MIL-STD-810F	Environmental Engineering Considerations and Laboratory Tests
MIL-HDBK-831	Preparation of Test Reports

MIL-HDBK-2165	Testability Handbook for Systems and Equipment
MIL-STD-5522	Test Requirements and Methods for Aircraft Hydraulic and Emergency Pneumatic Systems
MIL-H-8891A	Hydraulic Systems, Manned Flight Vehicles, Type III Design, Installation & Data Requirements for, General Specification for

2.1.3 Other Publications

AMA 525/3	Airworthiness Manual Chapter 525 - Transport Category Aeroplanes
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3. BACKGROUND

It appears that the development of "Systems Integration Test Rigs" occurred simultaneously with the development of hydraulically powered flight controls. Known generically as "Iron Birds", the term adopted through much of the remainder of this document, the rigs have typically been given formal names, specific to each program, usually emphasizing the primary function the program contractor had in mind. Historically Iron Birds were a functional "mockup" of the aircraft mechanical control system and they were used for development and validation testing of both the aircraft control system and the hydraulic system. Several flight control related issues on the Hughes "Spruce Goose" were noted to have been solved on a mock up that included not only the hydraulic and mechanical elements of the flight control system; but also simulated the control surface stiffness, moment of inertia, air loads, and even aerodynamic damping. With the advent of high authority redundant control augmentation systems (CAS), fly-by-wire technology (FBW), and vehicle management systems (VMS) the Iron Bird has evolved into more of a system integration facility. There is no question that the Iron Bird facility has been critical to the development and advancement of flight control systems since the inception of powered systems.

The Iron Bird is considered an aircraft flight control and subsystems mockup because it dynamically duplicates the flight control system and supporting subsystems with preproduction/production components as installed on the aircraft. An extensive array of equipment from each of the major aircraft subsystems is used to build the Iron Bird facility. Typically Iron Birds have included: flight critical aircraft computers; flight control actuators and valves; utility actuators and valves; a limited cockpit/crew station sufficient to assess functional responses and failure transients (stick/pedals/throttle/displays); an electrical system and wiring; a six-degree-of-freedom airframe and engine dynamic simulation; motor driven hydraulic pumps, hydraulic reservoirs, lines and fittings, heat exchangers and filter manifolds; components in spatially correct locations; simulated surface installations; and extensive test instrumentation and data recording capability. Iron Birds can also have other utility systems installed on them, for example; landing gear systems, cargo/bomb door actuation, and hydraulically powered electrical generators.

The major benefit of including an Iron Bird facility in an airplane systems development and validation program is technical and schedule risk reduction. Typically an Iron Bird can be completed and populated with aircraft hardware or aircraft-like hardware as much as one year prior to integration testing on the first aircraft. If a problem is discovered prior to the system installation on the aircraft it will obviously be less costly to correct than if the problem were discovered on the aircraft. There is always more flexibility in the program schedule prior to aircraft roll out than there is afterward.

To assess the benefits of finding problems early, experience is often relied on, but history from previous programs within the company can also be quantified, as can the costs associated with program delays at different points in the system development. New systems or more integrated systems lead to more risk than the testing of mature technologies. It should also be noted that the Iron Bird also has the advantage that the facility itself is much more accessible and easier to work on than an actual aircraft. This accessibility is also important when considering the cost associated with investigating and correcting system problems.

On military programs Iron Bird requirements are defined in government and industry standards (AS94900, AS5440, and MIL-STD-5522). On commercial programs company processes, experience and FAA regulations determine the use of an Iron Bird.

Often the decision to develop an Iron Bird facility is dictated by corporate culture, history, and experience. With the maturing of many flight control technologies and the improvement of many analytical techniques, the traditional uses for an Iron Bird facility are beginning to be reassessed. The cost associated with developing an Iron Bird must be carefully considered in light of the necessity to control the costs associated with new aircraft development. Some contractors

believe that for prototype programs the aircraft can be used as its own Iron Bird, augmented by less sophisticated test benches and hydraulic checkout facilities to fulfill the integration test requirements at a reduced cost.

The use of an Iron Bird is often evolving within a company and different companies tend to use Iron Birds differently. This AIR will attempt to provide the pros and cons of these various approaches so that readers will be able to better determine how they may take advantage of an Iron Bird facility.

3.1 Types of Testing Performed on Systems Integration Test Rigs

Determining the scope of testing that will be accomplished on an Iron Bird is essential in deriving the requirements for the facility. The scope of the testing must be determined using a disciplined systems engineering approach to determine system requirements and to determine how these requirements will be validated. Each individual requirement must be reviewed and a determination made regarding how and where to validate each of these requirements. The Iron Bird test plan should document the required tests and the expected results.

For each requirement that has to be verified by test, the question needs to be considered where the requirement would be validated if not on an Iron Bird. Again, this often means that the test will have to be performed on the aircraft. The risk of performing a particular test on the aircraft has to be considered carefully as there are often constraints on an aircraft that are not a factor on an Iron Bird. The Iron Bird often has more data capturing capability than an aircraft since there are no volume or power constraints on the instrumentation system. The accessibility of an Iron Bird is often a great benefit especially considering the ease in which failures can be inserted and tested without the risk of damaging the aircraft.

A decision to use the Iron Bird facility for certification activities can significantly impact its manufacture.. This has not typically been done in military programs and many commercial aircraft manufacturers also treat the facility as an engineering integration and test facility. However, some commercial companies have recently investigated using the Iron Bird for formal certification. In general, anything that the responsible FAA specialist can be convinced is representative of the airplane can be used for certification. In order to get credit for certification, the test article must have FAA conformity, which requires released drawings, material and configuration control, and an FAA inspector to verify that all the parts are actually built per the drawings. The desire to use the Iron Bird for certification should be carefully considered versus the cost of certifying these items with aircraft testing or other test facilities.

It can easily be argued that the greatest benefit of an Iron Bird facility is derived while preparing the test facility to begin the formal testing. This will be where many integration problems will be discovered. Experience shows that although some problems are discovered once formal testing has started; the majority of the problems will be discovered by accident. Test plans are written based on past experience and knowledge of the most likely “unknowns”. These are often referred to as the “known unknowns” and are items that are usually accommodated in the design to begin with. Of greater concern is what is referred to as “unknown unknowns”. These are often discovered during functional check out and preparation for tests that will be performed during the course of the formal testing. These types of problems underscore the necessity of having a test team familiar with the system being tested. There must be a disciplined process for verifying expected results and documenting unexpected results or an “anomaly”. It is often the test team’s investigation of an unanticipated characteristic or an anomaly that leads to discovering problems with the system – often the characteristic was not related to the system being tested. It is therefore essential that the test team is very familiar with the system and that adequate time be provided for investigation of anomalies, suspected problems, and regression testing. Also, the test plan should include a period of time for “stress testing” which consists of unstructured tests intended to assess the robustness of system design.

The scope of testing which must be performed on an Iron Bird will be uniquely tailored for each aircraft program. The required testing will be dependent on many factors, such as:

- The aircraft and systems design
- The aircraft development schedule
- Experience with similar certified systems
- Testing that can be or has been adequately performed in lower cost facilities, etc.

The emphasis of the next sections is on providing examples of testing that has typically been performed in the Iron Bird facility

3.1.1 Hydraulic System Integration

The Iron Bird allows the testing of complex aircraft hydraulic systems that have only relatively recently been successfully modeled. The bulk of the hydraulic system testing is accomplished in conjunction with the flight control integration testing described in the following sections. Many of these tests are described in more detail in the specifications listed in Section 3.2. The types of testing considered for Hydraulic Integration are summarized below.

3.1.1.1 Hydraulic System Functional Testing

Initial testing on an Iron Bird typically consists of system functional testing. The emphasis of this testing is functional checkout of the system and ensuring that all the components in the system will work together. The testing also consists of assessing the system and confirming that it is performing per the analytical predictions. Once the system appears to be operating correctly, additional testing is performed to further quantify system performance.

3.1.1.2 Hydraulic System Demand

Hydraulic demand and pump sizing are often assessed on the Iron Bird. In order to perform this testing a closed loop simulation is desired and is used to provide realistic aircraft component usage. This could be approximated open loop, but is much more representative of what will be observed in flight if an aerodynamic model is available. The flight controls and flying qualities teams need to consult with the hydraulic system designers to determine where in the flight envelope the power requirements of the control surfaces coupled with other utilities most challenge the hydraulic power available. Typically this will be a slow speed regime where power settings are low and control activity is high. For some aircraft this could be the approach phase when flaps are being extended and the gear are being lowered, coupled with high control surface usage. For tactical aircraft, a spin or departure is often the cause of the highest control surface usage but it could also be a carrier landing or aggressive maneuvering while using a high flow utility such as a gun.

3.1.1.3 Hydraulic System Pressure Drop

Pressure drop testing is often used to verify that the pressure drops throughout the system meet the predictions of the modeling techniques used in recent years to design hydraulic systems. Pressure drop data is essential to ensure that actuators will achieve their specified loaded rate performance and that pumps will not cavitate.

3.1.1.4 Hydraulic Water Hammer

Water hammer or pressure surge testing is often performed on an Iron Bird; however, the desire to accomplish this testing will require that the Iron Bird accurately represent the aircraft hydraulic system. Flight hardware or a very close facsimile is necessary as this phenomenon is very dependent on the actual layout of the hydraulic system.

3.1.1.5 Hydraulic Pump Ripple

Hydraulic pump ripple testing is also conveniently accomplished on an Iron Bird. The plumbing and support brackets around the hydraulic pump must be accurately represented to determine the pump ripple on the actual aircraft.

3.1.1.6 Hydraulic System Vibration Surveys

Visual and instrument data can easily be collected on line and component installations to ascertain the levels of acceleration forces induced in the hydraulic system by the different modes of operation. The validity of this information will be dependent by how well the Iron Bird represents the actual aircraft. Specifically the system support brackets and backup structure stiffness must be accurately reproduced.

3.1.1.7 Hydraulic System Temperature Surveys

System temperature tests may be performed to compare operational temperatures with analytically predicted temperatures. All mission profiles shall be performed and monitored including maneuvers and testing representative of the anticipated flight test program.

3.1.2 Electrical System Integration

Electrical systems have not traditionally been represented on an Iron Bird. However, with the criticality of the modern redundant electrical power and distribution systems and due to the multiple controllers and other components making up the modern aircraft electrical system, it is becoming beneficial to have as much of the aircraft electrical system represented as possible. This is especially true with the “more electric” aircraft that are being developed.

3.1.2.1 Electrical System Functional Testing

Similar to the hydraulic system testing, the initial electrical system testing consists of functional testing. The emphasis of this testing is functional checkout of the electrical system and ensuring that all the components in the system will work together. The testing assesses the compatibility of the electrical components with other aircraft hardware and confirms that the system is performing per the analytical predictions. Once the system appears to be operating correctly, additional testing is performed to further quantify system performance.

3.1.2.2 Electrical System Power Generation Testing

Testing to ensure that adequate electrical power is available for all flight modes including degraded states. This testing is best completed with a closed loop simulation representing the aerodynamics of the aircraft.

3.1.2.3 Electrical System Switching Transients

This testing is intended to assess the effects of power switching that occur in the electrical system when systems are being powered up or down. The testing quantifies the effects of power or bus interrupts and transients. The testing is concerned with transitioning between ground and aircraft power and between the various nominal and backup electrical buses.

3.1.2.4 Electrical System Regenerative Effects Testing

Regenerative effects' testing is concerned with quantifying the response of the electrical system when electrical components regenerate electrical power back into the aircraft electrical system. An electro-mechanical actuator being backdriven by airloads or by another component could cause this.

3.1.2.5 Electrical System Battery Life Testing

An Iron Bird facility is an excellent location to assess battery life for emergency applications. This testing is especially representative when the Iron Bird is operated with a pilot in the loop or in a closed loop sense.

3.1.3 Open Loop Flight Control Integration

Open loop flight control system testing refers to testing that can be performed without a closed loop aerodynamic simulation being present. Types of open loop testing that are considered for an Iron Bird facility are listed below.

3.1.3.1 Open Loop Flight Control System Characterization

System characterization tests are intended to determine the relationship between the control input and the control surface output at various flight conditions. While this relationship can often be determined analytically, this type of testing remains valuable to qualify the test facility and to validate that the expected values are indeed achieved.

3.1.3.2 Open Loop Flight Control Uncommanded Motion Testing

Uncommanded motion testing refers the determination of uncommanded motion at the flight control surfaces. This is often influenced by nonlinearities such as deadband and friction within the system and is therefore difficult to predict analytically.

3.1.3.3 Open Loop Flight Control System Threshold and Hysteresis Testing

Similarly, system threshold is often difficult to assess analytically due to the nonlinearities associated with real hardware. Hysteresis is another characteristic that is difficult to assess until all the flight control hardware is integrated together. The determination of system threshold and hysteresis can lead to insight into closed loop phenomena such as residual oscillations.

3.1.3.4 Open Loop Flight Control System Rate Testing

Rate testing is intended to quantify the rates associated with various components such as flight control actuators and landing gear. Integrated system testing is necessary because of the complex relationships between individual components and the power distribution system.

3.1.3.5 Open Loop Flight Control System Configuration and Mode Switching

Configuration and Mode switching testing is the testing of the transients associated with configuration or flight mode changes such as a change of flap settings. In the open loop sense these transients can only be assessed as a surface motion. A closed loop simulation or additional aerodynamic modeling would be necessary to determine the resulting vehicle motion.

3.1.3.6 Open Loop Flight Control System Redundancy Management Testing

Testing of failures and resets to assess Flight Control Redundancy Management is becoming a significant portion of the testing that occurs on an Iron Bird. Because of the accessibility of the Iron Bird components, failures can be inserted relatively easily and accommodation of transients associated with these failures can be assessed. Again, in the open loop sense these transients can only be assessed as a surface motion and additional analysis would be necessary to determine the resulting vehicle motion.

Failure testing can include the failure of individual channels in individual components and can also be used to assess the effect of opens and shorts of aircraft wiring. Of significant interest are the effects of electrical and hydraulic failures.

3.1.3.7 Open Loop Flight Control Built In Test (BIT) Development

With the advent of digital flight controls, a significant need for the Iron Bird facility has evolved with the need to develop Built In Test (BIT) capabilities. Having a mature BIT developed has big dividends associated with it when the flight control system is installed in the aircraft. Many aircraft programs are delayed by the qualification of new BIT software. The ease with which failures can be inserted in the Iron Bird speeds the determination of the system's ability to detect failures. Much knowledge of the systems performance in the presence of failures can really be a benefit in developing maintenance procedures for the aircraft.

3.1.3.8 Open Loop Flight Control Model verification

While the sophisticated analytical capabilities available today are sometimes used as an argument for eliminating Iron Bird testing, it should be noted that often the Iron Bird is the perfect facility to validate the models being used for analysis. Without the Iron Bird these models may not be adequately verified prior to flight testing.

3.1.3.9 Open Loop Flight Control Surface Frequency Response

Iron Birds sometimes incorporate load inertias and structural compliances which simulate those predicted for the production hardware to allow the servoelastic behaviour of the surface actuation systems to be tested. However, simulating the aircraft actuation installations with accuracy is difficult so this type of testing is often allocated to specialized, single-surface test rigs, sometimes called "Short Jigs" or "Partial Benches". See Section 3.4.3 for more discussion.

3.1.4 Closed Loop Flight Control Integration (Pilot-in-the-Loop)

The term closed loop, or pilot in the loop, refers to testing where an aerodynamic loop is closed around the Iron Bird using a mathematical simulation of the aerodynamics of the airframe. The simulation uses the surface positions that are measured on the actual Iron Bird hardware to drive the aerodynamic model. The aerodynamic model is then used to supply rates and accelerations back into the flight control system and to provide some type of visual feedback to the pilot.

In years past there was often significant debate associated with the necessity for a closed loop simulation capability at the Iron Bird. Even if a closed loop simulation was developed it was often used to drive “steam” gauges in the cockpit due to the expense of a visual “out the window” reference system. With the advent of today’s low cost computers and displays, however, a good “out the window display” can be provided for a relatively minor increase in cost and greatly increase the usefulness of the Iron Bird facility. While the pilot displays may not be developed to the fidelity necessary for a flying qualities facility, the advantages that this capability provides are significant.

Several programs, such as the B2 and F-15, have interfaced existing simulation facilities with the Iron Bird thus providing a high fidelity flying qualities simulation with the actual aircraft hardware. Having this capability also allows one to use the Iron Bird for avionics integration testing where interaction of avionics with the actual flight control system, actuators, hydraulics, etc., may be crucial (i.e., terrain following or some autopilot modes) With the elimination of mechanical control systems, interfacing two different facilities has become easier to achieve.

Integration testing that may be performed with a closed loop facility is listed below.

3.1.4.1 Closed Loop Flight Control System Characterization

Similar to the open loop testing described in the preceding section, system characterization tests are intended to determine the relationship between the control input and the control surface output at various flight conditions – this time in a closed loop system. While this relationship can often be determined analytically, this type of testing remains valuable to qualify the test facility and the closed loop simulation and to validate that the expected values are indeed achieved.

3.1.4.2 Closed Loop Flight Control Residual Oscillation Testing

Residual oscillations are the result of nonlinearities such as thresholds and hysteresis on the closed loop aircraft. Due to the difficulty predicting this phenomena reliably, the Iron Bird will often be the only avenue to assess this phenomena prior to flight.

3.1.4.3 Closed Loop Flight Control Effects of Rate Limiting

Similar to the open loop rate testing, this is a closed loop test to assess the characteristics of control saturation. Depending on the fidelity of the closed loop simulation and the pilot displays available, the testing can be set up to drive the pilot into a high gain task so the susceptibility to Pilot Induced Oscillations may be assessed. It should be noted that a high fidelity simulation is necessary for flying qualities analysis. The fidelity of the Iron Bird displays must be carefully considered when trying to interpret pilot comments or piloted data collected during Iron Bird testing.

3.1.4.4 Closed Loop Flight Control Failures and resets

Failure transients and reset transients are best analyzed in a closed loop test environment because of the immediate feedback relative to aircraft transients. Most specifications for failure transients are written based on aircraft motion as a result of the transient. In addition to the tests described in the previous section there are several tests that can be achieved in a closed loop sense that could not be achieved open loop. This could easily be expanded to investigate reduced hydraulic pressure situations such as that which occurs while attempting to perform a windmill airstart.

3.1.4.5 Closed Loop Flight Control Mission Profiles

This type of testing generally refers to recreating specific mission profiles that have been envisioned for the aircraft. These are often used to develop and refine vehicle procedures. It cannot be overemphasized how important it is to consider inputs and maneuvers that will be addressed during the flight-testing of the vehicle.

3.1.5 Utility System Testing

Utility systems functions like landing gear, door actuation, gun drive motors, etc can have a large system impact which must be assessed, for example, by using the gun drive motor while aggressively maneuvering. However, these systems may often be represented with similarly sized industrial actuators or appropriately sized orifices rather than flight hardware. Again, the system requirements and a knowledge of the system must be used when developing requirements for the Iron Bird facility.

3.1.6 Crew Training

Many Iron Birds are used for various training exercises in addition to the training inherent in the testing described above. The Iron Bird facility may be the best facility to train the pilot with various emergency features associated with the aircraft hardware. Because failures are easily inserted and because the Iron Bird has much of the real hardware, there is often a benefit to practicing procedures in this facility.

On a different level the flight crew training may also be a beneficial time to train a test team in the response to various failures and to illustrate what certain failures may look like on strip charts and other test instrumentation.

Training on an Iron Bird facility must be closely coordinated ahead of time to ensure that the fidelity of the simulation and the hardware present is sufficient to provide a beneficial learning experience. If the simulation is not correct the training may impart negative learning, resulting in the crew learning to look for inappropriate cues. Again, the fidelity of the Iron Bird displays must be evaluated with the anticipated capture of pilot comments or piloted data collected during Iron Bird testing.

3.1.7 Maintenance Training

In addition to flight crew training, Iron Bird facilities are sometimes used to train maintenance crews. There are some advantages to this since most of the system components are visible and provide the maintainers insight into the general system layout. However, because of the visibility and easy access, the training benefit may be limited when applied to the real aircraft.

3.1.8 Engineering Investigations

Many companies keep their Iron Birds maintained well past first flight. The facility is often very valuable to support engineering investigations, check for additional functionality that has been provided, software updates, prove out modifications, etc. Aircraft testing tends to be very expensive and once operational an aircraft may not be available with the instrumentation necessary to support an investigation. In addition, testing can be performed on the Iron Bird that would not be prudent to be performing on an actual aircraft or during a flight test program. Suspect aircraft hardware and "can not duplicates" can be assessed at the Iron Bird in conditions that are in many ways similar to the actual aircraft environment.

3.2 Systems Represented on Test Rigs

Due to the complexity of the modern integrated flight control system, many recent aircraft manufacturers are acknowledging that there are distinct advantages to having as much of the real aircraft represented at the Iron Bird facility as possible. The decision regarding how much of the aircraft to model, and how much aircraft hardware to include, are dependent on the test plan negotiated for the program. All requirements have to be validated in the most efficient manner possible. For flight controls applications, the Iron Bird facility is often the best place for this type of testing.

Often the decision on what to represent on an Iron Bird depends on a specific company's experience with Iron Birds. It can also depend on the infrastructure that may be in place to support the Iron Bird. Many companies have taken advantage of a common location for all Iron Birds and there are definite advantages to being able to share common assets such as a data collection system.

Table 1 represents the results of an industry survey showing the types of systems that have been represented on Iron Birds by various programs. It will be noted that all programs that have invested in an Iron Bird have used it for hydraulic and flight controls testing. All the facilities have also had some degree of closed loop or pilot in the loop capability. Electrical system testing is becoming more common.

TABLE 1 SYSTEMS REPRESENTED ON IRON BIRDS

Aircraft	Duration - yrs	Configuration		Utilization									
		Prototype	Production	Primary Flight Controls	Secondary Flight Controls	Landing Gear Systems	Electrical System	Hydraulic Systems	Other	Flight Simulator	Surface Inertias	Passive Loading	Active Loading
Boeing/North American Rockwell B-1			X	X	X	X		X		X	X	X	
Northrop Grumman B-2			X	X		X		X		X	X	X	
Grumman E-2A			X	X	X			X		X			
BAE Systems Nimrod MRA.4	5		X	X	X	X			X	X	X		X
McDonnell Douglas F-4			X	X	X			X	X	X			
McDonnell Douglas F-4 SFCs			X	X	X			X	X	X			
Grumman F-14			X	X	X	X		X	X	X			
McDonnell Douglas F-15A	18		X	X	X			X	X	X	X	X	
Boeing/McDonnell Douglas F-15E	20+		X	X	X			X	X	X	X		
McDonnell Douglas F-15 S/MTD	17	X		X	X			X	X	X	X		
McDonnell Douglas F/A-18A/B			X	X	X		X	X	X	X	X		
Boeing F/A-18E/F	2		X	X	X		X	X	X	X	X		
Panavia Tornado	30+	X	X	X	X	X		X	X	X			
Eurofighter Typhoon	13+	X	X	X	X	X		X	X	X			
Grumman X-29		X		X	X	X		X		X			
Boeing/North American Rockwell X-31*				X	X	X	X	X		X	X		
McDonnell Douglas X-36*	1+	X		X		X	X	X	X	X	X		
Boeing X-50*	1+	X		X		X	X	X	X	X	X		
Northrop/McDonnell Douglas YF-23A		X		X	X		X	X		X	X		X
Airbus A300 / A310	32+	X	X	X	X	X	X	X	X	X	X		L
Airbus A320 / A318 / A319 / A321	26+	X	X	X	X	X	X	X	X	X	X		L
Airbus A330 / A340	12+	X	X	X	X	X	X	X	X	X	X		L
Boeing 737		X	X	X	X	X		X		X			
Boeing 747		X	X	X	X	X		X		X			
Boeing 757		X	X	X	X	X		X		X			
Boeing 767		X	X	X	X	X		X		X			
Boeing 777		X	X	X	X	X	X	X		X	X	X	
Sud Aviation Caravelle		X	X	X	X	X		X	X	X			
Aerospatiale-BAC Concorde		X	X	X	X	X		X	X	X			
Saab 2000			X	X							X	X	
Bell-Agusta BA609	4+		X	X	X				X	X			
Boeing-Sikorsky RAH66	10+	X	X	X	X		X	X		X	X		X
Bell-Boeing V-22	17+	X	X	X	X	X	X	X	X	X	X		X

Notes: (*) Testing performed on aircraft, (L) – Limited capability

3.2.1 Hydraulic Systems

In determining the hydraulic testing requirements on the Iron Bird, the fidelity necessary for the aircraft hydraulic system must be determined. There are many trades that need to be considered. If it is determined that the actual flight worthy components and tubes are necessary, then the Iron Bird may not be completed as early as it could if non-flight worthy tubes and components are used. Of course, the use of components or tubes that are only similar to the actual aircraft hardware poses a risk that needs to be considered. The use of pre-production or aircraft similar hardware influences the usefulness of vibration and pressure drop testing. Vibration testing will also be dependent on how well the tubing supports represent those found on the aircraft. The central hydraulic system should duplicate the aircraft system if any kind of pump ripple (pulsation) testing is being considered.

Often these trades will be based on the experience of the test team and will depend heavily on what has been successful on past programs. The facility often plays a role in determining if the aircraft hydraulic system will be simulated exactly. Often there are limitations on floor space or possible height restrictions that have to be considered. The C-17 had to remove some building rafters to achieve the desired height for the horizontal tail and large coiled tubes were utilized to achieve the proper tubing length for the fuselage. The F-15 S/MTD Iron Bird was actually a second configuration to the F-15E Iron Bird where the flight control fixtures were located on the floor below the F-15E structure. The Boeing 777 Iron Bird has one wing in the correct location relative to the fuselage but the second wing is turned to run along the fuselage for space considerations. Many of the Airbus Iron Birds have the wings turned slightly to run along the length of the fuselage.

Hydraulic pumps are very noisy when running in the open and it is generally good practice to include some type of sound insulation around the pumps to try to reduce the decibel level. Often the hydraulic pumps are placed in a separate sound insulated room. An electrical variable drive motor typically drives the hydraulic pumps. These motors may be set to specific speeds or may have the speed dependent on flight condition and throttle setting. This capability is especially important for pilot in the loop or closed loop testing.

A difficult trade to make is how much of the secondary hydraulic components need to be included. This would include items like the landing gear. The landing gear is an expensive component to include in an Iron Bird and is often simulated with a beam mass simulation using industrial actuators. On several programs, the landing gear has been simulated with an orifice sized to simulate the hydraulic flow associated with the use of the landing gear.

3.2.2 Electrical Systems

How much of an electrical system to include again requires an assessment of the risks involved with not having it. Often the electrical system has not been included but with the advent of more electric aircraft, such as the F-35, the capabilities of the electrical system are becoming a bigger player in the operation of the aircraft flight controls. Because many of the more electric systems are in the initial stages of development it is increasingly beneficial to have these new systems tested prior to getting to flight testing.

3.2.3 Mechanical Systems

Mechanical items that should be considered for inclusion in an Iron Bird include any mechanical items that are a part of the flight control system. More difficult decisions are those that are concerned with other elements not directly connected to the flight controls or hydraulic systems.

3.2.4 Flight Control Systems

In the days of the mechanical control systems it was more important to have the physical layout of the Iron Bird representative of the aircraft. Now that many aircraft are fly-by-wire, the actual layout is less important and is more determined by the requirements necessary to simulate the hydraulic system. However, for fly-by-wire aircraft it is important to use the same or similar wire harnesses that are going to be used on the real aircraft. This may restrict the layout. The wiring is important since the Iron Bird is also used to evaluate voltage losses due to line lengths, and the inductive/captive loading induced by the wiring. Also some limited Electromagnetic Compatibility testing may be performed.

When planning the Iron Bird it is beneficial to separate the electrical wiring from the hydraulic plumbing. Placing the electrical wiring high in overhead racks and keeping the hydraulic plumbing low and close to the floor helps to keep the hydraulic fluid out of the wiring should a hydraulic leak occur.

Most Iron Birds will include the control mechanisms used by the flight crew. This could be control yokes or sticks, pedals and throttles. A simulation of the actual cockpit is often desired but must be approached with caution. If the cockpit is not simulated exactly or is only partially functional there is the possibility of negative training should the aircrew use the facility.

As system modeling has improved, the use of the Iron Bird is changing somewhat. Many tests that used to be very important are now achieved accurately using analysis. However, due to the advent of fly-by-wire systems, other tests such as Built in Test assessment have become a major portion of the Iron Bird testing.

Most avionics functions are represented in part by test benches. These benches generally will include patch panels or break out panels so that failures may be inserted. This failure testing is a vital element that can be easily achieved on an Iron Bird but would be relatively difficult on an aircraft.

One important design consideration to make when developing an Iron Bird is to decide whether to use manual knobs and switches or virtual instrument inputs through a computer monitor or soft keys. The advantage with manual knobs and switches is that they are always available and they give the user a good feel of the system response. However, the disadvantage is that they take up more space and are more costly. The virtual instrument method would take up less space. However, the inputs may be difficult to access. For smaller applications, the manual knob and switch method is recommended, for larger applications the virtual instrument method is recommended to minimize console space. The trend is that virtual instruments are getting better especially when using touch screens.

Likewise, there is the similar design consideration for displays. Fixed analog displays give the user a better feel for the response than a digital display system. However, they may take up more space. Multi-functional displays such as a computer monitor may not give the user the same feel, but they can be re-configured and require less space than dedicated displays.

3.3 Systems Integration Test Rig Structure

The structure of the Iron Bird is often determined by available space. If a new facility is being built then there is more flexibility. Often the structure is a "blue steel" representation of the aircraft. Because of the desire to bring an Iron Bird up as soon as possible, the Iron Bird structure may lead the design of the aircraft. The "blue steel" therefore is modeled around major spars and bulkheads that are identified for mounting of flight control and hydraulic components. Often the structure that supports the "aircraft blue steel" has to be modified as the facility comes together and the actual aircraft orientation is defined.

It must be appreciated that testing such as frequency response testing can be very violent, especially if surface inertias are represented. Testing should be identified as early as possible, at least broadly defined, so the facility can be designed to accommodate the desired testing. Frequency response testing of the actuators has caused damage to Iron Bird facilities in the past and the design of the surface structure must be designed with this in mind. This testing may also determine how well the structure has to be isolated and anchored. It is suggested when running frequency response testing to use small amplitudes generally less than 5% full stroke to prevent damage to the rigs and actuators.

Providing power to the Iron Bird is also an important consideration as there is generally a significant power requirement between the power required by the aircraft systems and that required by the data systems and simulated components and computers. Safety cut offs should also be provided throughout the facility in case of a hazardous situation. Also when running the Iron Bird with hydraulic operation, it is important to have at least two operators. If one person becomes incapacitated, the other person will be able to assist. In addition, there should be provisions for one or more open shower heads within the Iron Bird facility to provide emergency treatment of test personnel, in the event of a rupture of a hydraulic line.

Adequate housing must be provided for the test team and this should allow adequate visibility of the Iron Bird facility either directly or via video. It is often useful to have remotely controlled or mobile cameras that can be positioned to observe particular tests. Due to the positions that test team members are required to monitor during testing, an intercom system is often necessary for test efficiency and safety reasons.

A new trend in Iron Bird design is becoming more popular. This is the use of component or system suppliers to also provide complete fixtures for use with the Iron Bird. This could be a system built on a set of short jigs that are provided to the airframe manufacturer for inclusion on their Iron Bird or it could be left to the supplier to have an Iron Bird at their facility. A suppliers Iron Bird is dependent on their systems being independent of those systems provided by other suppliers.

3.4 Test Rig Control Surface Representation

In the discussion of Iron Birds one of the most contentious issues is often whether to include a simulated surface and whether to try to simulate the airloads that the aircraft experiences while flying. There is no denying that an active load system is a very expensive feature to provide on an Iron Bird. The program must consider the necessity of this expense and must carefully weigh the decision against using a less expensive passive load system or possibly no load system at all.

3.4.1 Surface Inertia

Iron Bird facilities have been built with everything from actual aircraft control surfaces to no surface representation at all. Again, the system test validation requirements have to be carefully considered. The cost of including a surface simulation can vary significantly depending on the fidelity desired. If servoelastic interactions are to be tested it is preferable to try to utilize an actual aircraft control surface. This type of testing also requires an accurate simulation of the control surface backup structure. It is important to get the inertia as close to possible as the real aircraft since this will establish the resonant frequency of the actuators. It is important to test the actuator resonance to verify it will not cause a problem with the design.

For BIT testing it is generally a good idea to have the correct moment about the surface hinge line represented. If the BIT test turns off a control surface that fails to a damped trail mode, then the rate at which the surface droops may be an important item to simulate, if the BIT test is monitoring that rate. On the other hand, having a surface inertia represented can have significant impact to the design of the Iron Bird especially if frequency response testing is anticipated.

3.4.2 Airloads

The use of airloads has been hotly debated in many venues. However, airloads can be simulated simply or quite complexly and their use again is dependent on test verification requirements. The addition of a fully active airload system to an Iron Bird will approximately double its cost. Developing an active load system is similar to designing an aircraft flight control system. Obviously the decision to pursue this option is often dependent on a company's experience designing this type of system.

Many facilities have taken the less expensive approach of using a passive load system using some form of torsion bar or spring arrangement to load the surface. These are obviously limited to representing a particular flight condition and are typically not utilized in a closed loop simulation. Another variation of the passive load system is to statically simulate the surface load using hydraulic and/or pneumatic pressure.

If the aircraft has a manual reversion mode then the use of some form of simulated airload may be important to adequately assess failure transients in the event of a failure.

Testing without simulated airloads is perfectly acceptable in many situations. It is realized that the hydraulic system usage, while not exactly aircraft representative, is probably conservative.

3.4.3 Stiffness

If the Iron Bird includes representation of the surface inertia then the stiffness of the representation needs to be the same or much higher than that of the aircraft. If the servoelastic stability of the control surface actuation system is to be assessed the aircraft stiffness must be represented but if not, the stiffness must be increased significantly, and carefully assessed, to ensure there are no servoelastic instabilities on the Iron Bird that do not exist on the aircraft. To expand on the information in 3.4.1, if servoelastic interactions are to be tested it is preferable to use aircraft surfaces and backup structure, or accurate representations of the aircraft inertias and compliances, in order to reproduce the installed resonant frequencies and confirm that performance problems, including control stability, will not arise. This is difficult to do with accuracy and, for installations such as all-moving surfaces, with both torsional and bending modes of significance, next to

impossible. For this reason, servoelastic response testing is often relegated to specialized, single-surface Short Rigs, associated with or independent from the Iron Bird. These rigs feature extremely heavy and stiff primary structure to ensure that no misleading rig response modes distort the actuator-installed response. The structural compliance and surface inertias are simulated with single elements readily tested and adjusted. See Section 4.2.1.1.2 for illustrations of the F-15 S/MTD Short Jigs, which, in this particular case, were associated with an adjacent comprehensive Iron Bird.

4. DESCRIPTIONS OF MILITARY SYSTEMS INTEGRATION RIGS

The following sections detail Iron Birds used on several contemporary aircraft programs. These Iron Birds represent different types of aircraft and different testing philosophies.

4.1 Bombers

4.1.1 Northrop Grumman B-2 Flight Control and Hydraulic Integration Laboratory (FCHIL)

Northrop's approach for system integration of the B-2 Flight Control System is classical in nature with added emphasis on modeling. Several facilities are utilized including; an Iron Bird, component test benches, a motion base simulator, hardware in the loop simulator, and the air vehicle. In addition, analysis and modeling plays an equally important role and provides significant checks and balances on the test facilities.

The primary facility for Flight Control System testing is the Flight Control and Hydraulic Integration Laboratory (FCHIL) which includes the Iron Bird. A fixed based cockpit, with an out-the-window display provides for piloted inputs to the Flight Control Computers which are located in the laboratory test console. Air Data and Attitude Motion Sensor Sets provide the feedback for the vehicle in the laboratory. All of these subsystem consoles contain special test equipment that allow for ease of test input, failure insertion, and troubleshooting capabilities. A picture of this facility is shown in Figure 1.

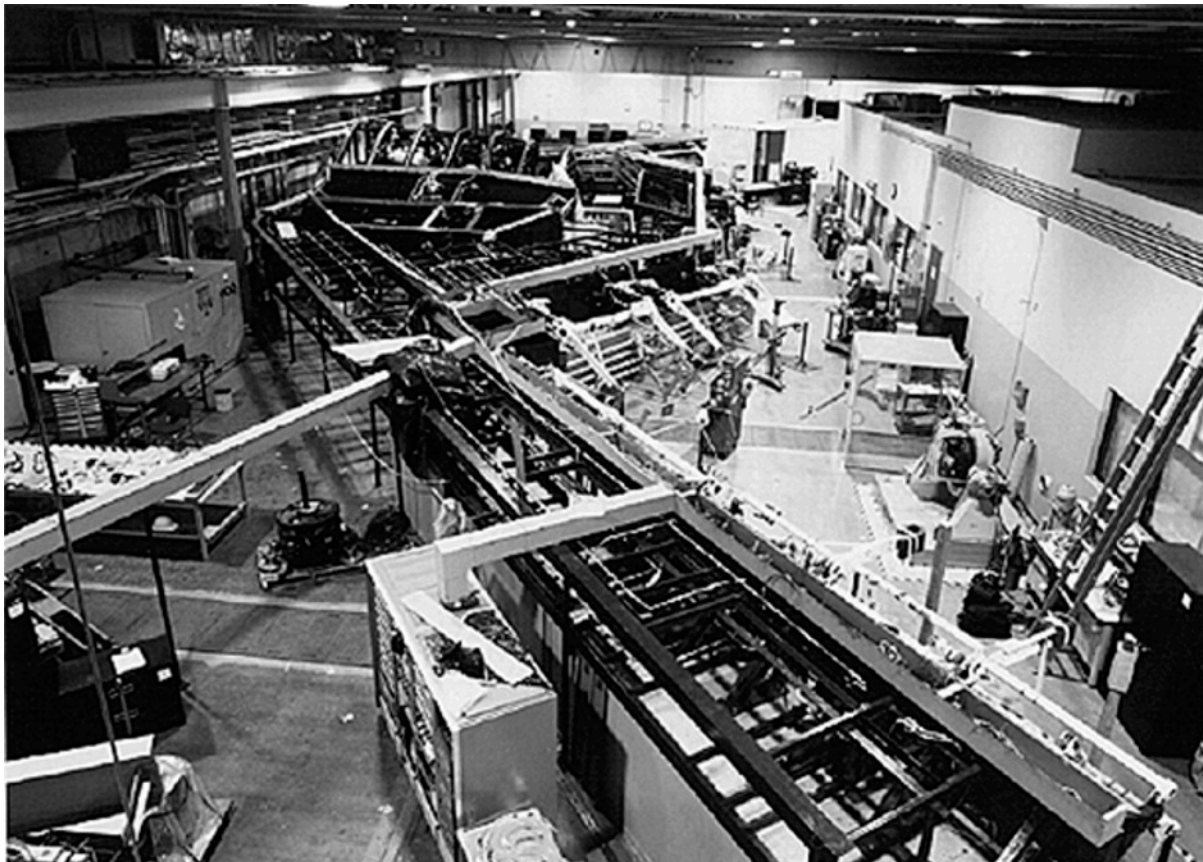


FIGURE 1 B-2 FLIGHT CONTROL AND HYDRAULIC INTEGRATION LABORATORY (FCHIL)

The FCHIL has a real time simulation which ties the laboratory together and is the heart of this facility. The simulation models many things including avionics and aerodynamics. The simulation also provides for a switching capability between the actual subsystems and modeled subsystems. An example is the replacement of the actual air data system with an air data model for some testing.

The Flight Control System is modeled using SIM2, a non-real time 6 degree of freedom, FORTRAN simulation. A real time version of SIM2 is operational in the motion base simulator and is also the basis for the real time FCHIL simulation. SIM2 is updated as flight test information is gathered and this process helps to validate the flight control system.

Son-of-FCHIL is a duplicate of SIM2 but adds laboratory unique characteristics such as time delays and interface requirements. Thus Son-of-FCHIL is the analysis tool that models the real time, closed loop, operation of the laboratory. Data collected from FCHIL is compared to data generated by Son-of-FCHIL. This data comparison validates the FCHIL, as a vehicle for test. Since FCHIL contains real hardware it also supports validating the Flight Control System.

4.1.1.1 FCHIL Testing

The FCHIL provides the tools to complete many different levels of testing. The basic form is development testing. This type of testing includes troubleshooting of anomalies, development of system requirements, development and integration of subsystems and LRU's as well as the entire Flight Control System.

Flight Justification Testing (FJT) is witnessed by Quality Assurance for test execution and validates "Flight Critical" requirements changes. Flight Justification testing is usually a subset of development testing.

System Integration Testing provides for the full up system level testing by tying the avionics and flight controls laboratories together. Data from this laboratory configuration are used as part of requirements and specification verification.

Several types of tests are complete in the FCHIL. One type is manual and automatic flight control system closed loop response verification. Here the dynamic response of the FCHIL is validated by comparison to the Son-of-FCHIL.

Failure Modes and Effects is where fault isolation and vehicle transients are observed. Input signal management and status processing requirements are also tested.

Functionality of Initiated Built-in-Test (IBIT) is verified through FCHIL and SIL. These tests include maintenance level testing such as Standard Built-in-Test (SBIT) and Diagnostic Built-in-Test (DGBIT). Preflight BIT is also verified for functionality in the laboratories.

Manufacturing also needs tools to checkout the vehicles as they come off the assembly lines. Methods and procedures to checkout the vehicles are developed and validated in the FCHIL or SIL. They include testability and Manual Initiated Procedures (MIP).

Testing also verifies correct implementation of software and hardware requirements. For example, a new software requirement defining how the Attitude Motion Sensor Sets transition from align to flight mode would be tested. Use of FCHIL ensures a thorough checkout of these types of system requirements changes, prior to installation on the air vehicle and final delivery to the customer.

Specification validation will use as much of the existing data as possible, minimizing the amount of additional testing required.

The Flight Control and Hydraulic Integration laboratory, which includes the Iron Bird, also played a significant role by providing a tool to develop and dry run tests that eventually have to be run on the air vehicles. These include hydraulic resonance surveys, ground resonance and vibration testing and initial air vehicle checkout by manufacturing.

Capabilities of the air vehicle designed hydraulic system and limitations of an Emergency Hydraulic System were also verified on the Iron Bird. The Emergency Power System is a hydraulic pump configuration, with reduced pressure and flow, for use in flight test.

The Iron Bird actuator installation included the backup structure, surface horn, primary and alternate hydraulic system coil tubing. A surface position sensor is also included that was laboratory unique. This sensor closed the loop with the Flight Simulation Computer. Ground cart plumbing, was used prior to build up of the entire hydraulic distribution system on the Iron Bird.

The FCHIL, with the Iron Bird, has been utilized very heavily by the FCAS. This heavy use occurred in all phases of the actuation systems. It began with early development, progressed to integration, and continued through validation of the Actuation System. All the B-2 Flight Control surfaces have two or three actuators per surface and the Iron Bird is the only test stand that provides for interaction between these actuators. The torsional stiffness of the vehicle surfaces is simulated by a torque tube between actuator attach points. Simulated aerodynamic loading can also be used.

4.1.1.2 Specification Compliance

As an overview, the air vehicle provides the most convincing data for specification compliance. No question about the validity of the data exists since no models or laboratories were used. However, one problem with vehicle data, is that it is expensive and time consuming. Another problem is that some tests just can not be run safely on the vehicle, such as some failure modes and effects testing. It is also difficult to control the test conditions during flight test, such as the amount of turbulence. Specification compliance can be achieved through the use of actual air vehicle data from flight and ground test. Also available for specification compliance is FCHIL data from development, Flight Justification and other integration testing. The motion base simulator is another option. Analysis and other simulations provide yet another capability for specification compliance. Together all of these options provide a choice for specification compliance, with all options producing good quality data.

The FCHIL provides a high fidelity test vehicle that contains real hardware. The benefits of using a hardware integration laboratory include safe failure modes and effects testing, ease of model verification, and controlling of test conditions. Some of the problems of using an integration laboratory for specification compliance is the cost of building the laboratory, cost of maintaining the laboratory, and potential scheduling conflicts. Northrop has found the laboratory to be heavily scheduled, requiring setting of priorities.

The facilities, simulation and models discussed here can not model structural resonance issues found during flight test or air vehicle ground resonance testing. Other models exist for these structural effects and are used in control law development and validation by comparison to flight and ground test data.

Finally, laboratory time delays can affect the data. For example, time delays make the FCHIL more susceptible to oscillation due to reduced phase and gain margins. This is sometimes a benefit though, because if the FCHIL does not oscillate with the additional phase loss, the vehicle probably won't either.

Analysis is another method available to meet specification compliance. A benefit of analysis is that it may be the only method available or most cost effective method for validation of certain specification requirements. The flight control concept on the B-2 program is to improve and validate the modeling through comparison to actual hardware. By validating the models, specification compliance can be accomplished, with confidence, through the use of analysis as well as flight test or integration laboratory test data.

Specification compliance of the Flight Control Actuation System has several options available. Test data is available from several facilities for compliance activities. The FCAS supplier, Moog, has a "spec" test fixture. Their test fixture matches the inertia and stiffness characteristics of the procurement specification. The B-2 Iron Bird is not a perfect match. However, the test fixture is limited to single actuator operation.

The electronic supplier, Lear Astronics, has electronically modeled actuators that are used in development of requirements and software qualification. However, this test set up is limited to single side operation.

The Actuation system specification compliance also uses Iron Bird test data due to the actuator interaction. Remember that the Iron Bird is the only test vehicle that has multiple actuators per surface capability. The FCHIL is also used for multi-surface, single side evaluations, such as built-in-tests. Built-in-tests and left to right hand side coordination is verified through the use of the Iron Bird in the FCHIL.

Actuation System specification compliance is available from hardware qualification data and through analysis or simulation. In almost all of these cases models are compared to the test data which provided a good level of confidence in the actuation system, especially for those cases when analysis is the only available option for specification compliance.

In describing how Northrop integrates the Flight Control system on the B-2, we discussed specification compliance for the actuation system and Flight Control System. We have described how the FCHIL and how the laboratory is validated, testing concepts and types of tests, and then some of the uses of the Iron Bird. A trade off exists on whether to have an integration laboratory or not. With an integration laboratory future costs are reduced by finding problems early in the program. An integration laboratory also reduces risks normally associated with a development and flight test program. But, an integration laboratory obviously has cost associated with it.

Not using an integration laboratory leads to finding and resolving problems late in the program and could drive high cost and schedule fixes. Risk of finding anomalies on the air vehicle is increased. However, laboratory costs are reduced. On one side you have higher laboratory costs. On the other side is a risk of higher production costs.

4.1.1.3 Lesson Learned

The use and investment in the FCHIL and SIL have been extremely beneficial to the B-2 by saving valuable air vehicle time during ground and flight test. In addition, the FCHIL and SIL provide a facility to develop requirements and troubleshoot problems off of the air vehicle. Numerous system level anomalies have been identified and resolved quickly. "Numerous" can not be emphasized enough. Many of the anomalies found were considered safety of flight issues.

FCHIL provided for early detection of Hydraulic Pump anomalies that led to design changes. For example, Hydraulic Pump instability at zero flow was observed early in the FCHIL. This anomaly was resolved prior to any air vehicle installations.

Actuation system anomalies were also observed and corrected early in the program. Early observation of several other anomalies provided the data for effective analysis and closure. Pressure transients produced by the actuation system were higher than expected but were not an issue. Cavitation in the distribution system was observed early but again determined to be a non-issue. Also the Iron Bird provided a tool to evaluate line losses and the effect of return line diameter reduction – a weight savings proposal.

Most of these issues were observed and addressed early, prior to vehicle ground and flight testing. This limited the cost of addressing such issues during the ground and flight test portions of the B-2 program.

The FCHIL was also used to dry run manufacturing checkout procedures. Processes required for air vehicle testing have been developed in the FCHIL, such as ground vibration and resonance testing, and hydraulic resonance surveys – like pump ripple. Extensive dry running and process development was completed prior to performing air vehicle tests. Instrumentation methods were also developed.

As discussed previously. FCHIL provides a tool for comparing models to actual hardware. Building confidence in the model is one of the keys to the checks and balance system in place on the B-2 Flight Control System

The FCHIL provides a high fidelity test vehicle that frees up the flight test vehicles.

The integration laboratory is a value added approach that provides for early discovery of anomalies. One example was a hydraulic line motion issue that was discovered during FCHIL testing. The excessive line motion, a sliding through clamps, was resolved by adding bulkhead connections within the long hydraulic runs of the outboard wing sections. This prevented the large motion of the hydraulic lines.

The FCHIL also supports analysis through failure transient evaluations. Many anomalies, whether they be; hardware, subsystem, or system were discovered prior to the production phase of the B-2. Early detection in the FCHIL prevented many expensive retrofits on the aircraft.

In conclusion, the FCHIL reduced the overall cost of the B-2 program. This was done by providing a relatively inexpensive test system to develop and verify system level requirements. FCHIL allows the use of a laboratory rather than the expensive Air Vehicles. The FCHIL also accomplishes tests that can't be done safely in flight test.

Northrop chose a classical approach, with added emphasis on modeling, for the B-2 program because it eliminates most risks associated with a typical aircraft development and test program. This approach provided a quality end product. Flight Controls has set up a system that provides good checks and balances between the air vehicle, FCHIL, other

facilities, and models. These checks and balances provide a high level of confidence in the B-2 hydraulic and Flight Control System.

4.2 Fighters

4.2.1 McDonnell Douglas F-15E / SMTD Integration Test Rig Description

A full scale hydraulic and flight control system integration test rig (Iron Bird) provides an engineering tool for evaluating and verifying interactions between the components of the various subsystems. The F-15 Iron Bird built during 1971 for integration testing of the F-15A/B aircraft was required for integration testing of both the F-15E and F-15 STOL Maneuvering Technology Demonstrator (S/MTD) during the same calendar period.

Several options were discussed in determining the best and most cost effective way to use one iron bird to conduct both the F-15E and S/MTD integration tests. It was decided to use the F-15 A/B Iron Bird to support both the F-15E and S/MTD, and to be able to conduct tests on both aircraft configurations the same day. Both aircraft configurations used the basic same hydraulic system, but different flight control systems and servo cylinders.

The F-15E Automatic Flight Control System (AFCS) was a mechanical system with a Control Augmentation System (CAS) with a triplex digital flight control computer. The S/MTD Integrated Flight and Propulsion Control (IFPC) System was a fly-by-wire system with a quadruplex digital flight control computer and a dual digital nozzle computer for controlling the 2D engine nozzles.

Both aircraft configurations used the same basic hydraulic system. Therefore, a decision was made to install the F-15E Flight Control Mechanical System and Actuators on the Iron Bird and to build short-jigs and crew station for installing the S/MTD Actuators, Nozzle Control Valves and Actuators, and Cockpit Controls. Ball valves were installed in the plumbing to allow switching the hydraulic system from one configuration to another. A picture of the F-15E / S/MTD Iron Bird is shown in Figure 2 from the aft end looking forward.

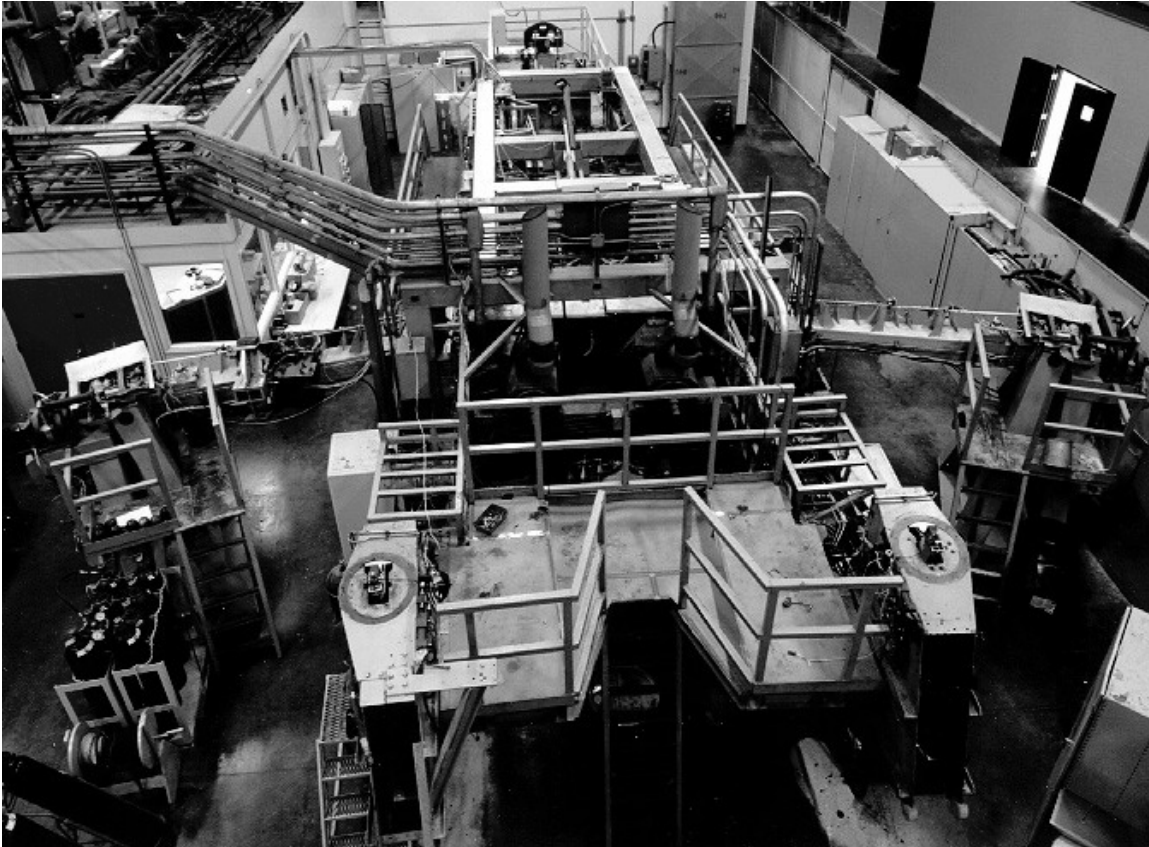


FIGURE 2 F-15 IRON BIRD

4.2.1.1 Iron Bird Description

The F-15 Iron Bird fixture was rigidly constructed using box beams and angle stock. The fixture provided structural attach points to mount the F-15 Hydraulic, Flight Control, and Air Inlet Control Systems in spatial orientation equivalent to the actual aircraft. Backup structures and simulated surfaces with airframe spring rates and inertial loads were provided for the flight control servocylinders. A passive load system with variable surface zero point was installed on the fixture to simulate airloads on the stabilator, rudder, and aileron flight control surfaces.

The hydraulic system installed on the fixture duplicated the preproduction aircraft. The hydraulic components, pumps, reservoirs, accumulators, valves, lines, etc were located as on the aircraft. The hydraulic system consisted of two Primary Control (PC1 and PC2) systems and one Utility (UT) system with two hydraulic pumps. Two 200-hp variable speed DC drives were used to provide power to the hydraulic pumps in the same manner as provided by the aircraft engines.

The mechanical control systems, which included the stick and pedal assemblies, feel and trim actuators, bell cranks, push rods, cables, and Control Stick Boost Pitch Compensator (CSBPC), was installed on the fixture to match aircraft installation. Backup structure for the installed mechanical control system did not duplicate aircraft stiffness. The cockpit also included a seat, throttle, and display panel. An Attitude Direction Indicator (ADI) and laboratory instruments that displayed airspeed and altitude for pilot were installed in the cockpit display panel.

The F-15A/B Flight Control System was a mechanical flight control system with a dual CAS. The dual analog flight control computers consisted of one Pitch and one Roll/Yaw computer. The computers were mounted in an instrumentation rack at the nose of the Iron Bird. The flight control system interconnecting cables were designed and built to duplicate aircraft wiring and lengths with the exception of the bulkhead disconnects. The bulkhead connectors were not included in the wire bundles.

The flight control surfaces were simulated with the proper inertia about the hinge line and the backup structure spring rates were simulated at the actuator / airframe attach points. A passive load system provided aerodynamic loading of the simulated surfaces for the ailerons, rudders, and stabilators. The passive load system provided zero load point and load stroke curve adjustments for each surface.

4.2.1.1.1 F-15E Iron Bird Description

The F-15E Hydraulic System was the same configuration as the F-15A/B Aircraft. The F-15A/B flight control surfaces, backup structures, airframe spring rates and inertial loads were equivalent to those in the F-15E. Therefore, the F-15E Flight Control Actuators were installed in place of the F-15A/B Actuators on the fixture without modifications.

Other changes to the fixture for the F-15E Flight Control System included the feel trim actuators, stick force sensors, stick grips, and CSBPC. An aft stick was added to the cockpit to duplicate F-15E cockpit configuration to get the correct stick dynamics. The cockpit display configuration was the same as for the F-15A/B Iron Bird. The mechanical linkages from the stick and pedal assemblies to the flight control actuators were the same as the F-15A/B.

New AFCS interconnecting cables were designed and fabricated to match aircraft wiring and lengths. The AFCS computer was installed into a Flight Control System Test Bench (FCSLTB) located in the F-15 Control Room. The test bench incorporated interface electronics for cockpit control and displays, sensors, and other subsystem functions external to the AFCS. An Engaging Controller was installed in the Master Control Console to facilitate CAS engagement and disengagement.

The F-15E Iron Bird could be operated in either the stand-alone or linker configuration. In the stand-alone configuration, the Iron Bird tests were conducted using only the Iron Bird Facility. In the linker configuration, the Manned Flight Hardware Simulator (MFHS) was linked to the Iron Bird Facility. Additional discussion of these test configurations has been included in Section 4.2.1.2.

4.2.1.1.2 F-15 S/MTD Iron Bird Description

The short jigs were used for the S/MTD in conjunction with the F-15 Iron Bird in order to facilitate both F-15E and F-15 S/MTD test programs. The short-jigs were fixtures, which were used to support a hydraulic actuator in such a manner that under dynamics conditions the actuator, would respond with the same performance as if it were located within the