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I am submitting herewith a thesis written by Thomas C. Gurney entitled, "Carrier Suitability Testing of the F/A-18E/F Airplane." I have examined this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

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CARRIER SUITABILITY TESTING
OF THE F/A-18E/F AIRPLANE

A Thesis
Presented for the
Master of Science Degree

The University of Tennessee, Knoxville

Thomas C. Gurney

May 1998

DEDICATION

This thesis is dedicated to the F1 test team with whom it has been my privilege to work.

ACKNOWLEDGMENTS

I would like to thank several of my colleagues who have been instrumental to this work: Mr. Howard Gofus, F1 Test Conductor, who kept me out of trouble in the air, guided the test effort to such a successful result, and pointed me in the right direction for much of the research material; LT Frank Morley, who shared the piloting responsibilities with me and logged the first shipboard trap; Gerard Garay, Charlie Trost, Henry Melton and all the LSOs who manned the test sites through the many hours of traps and cats; Mr. Bill Clements, who set the lens perfectly every time, whenever and wherever; and Mr. T. Jeff Miller who monitored aircraft loads, pored over the data, and sought forgiveness from the powers that be when "pilot technique" resulted in hitting the point "too hard".

I would especially like to thank my wife Anne, and children Philip and Elizabeth, who endured the long hours, days, and weeks of separation resulting from my duties with the F/A-18E/F test team. And who, with patience and understanding, supported me in the further task of completing this thesis.

ABSTRACT

The F/A-18E/F is the result of major upgrades to previous series of F/A-18 aircraft (F/A-18A/B/C/D). These upgrades produced what is essentially a new airplane requiring a complete Engineering and Manufacturing Development (EMD) program. A major phase of the EMD program was Carrier Suitability testing.

The objective of this thesis was to demonstrate that the F/A-18E/F airplane is carrier suitable. The scope of tests was limited to the basic airplane with no wing pylons, referred to as "clean aircraft loading". Tests included Initial Sea Trials onboard USS John C. Stennis (CVN 74) in January, 1997. The final demonstration point for the carrier suitability clean aircraft loading was completed on 9 June, 1997.

Aircraft F/A-18F1, the first two-seat version produced, was assigned as the carrier suitability test airplane. The airplane was heavily instrumented to record loads at the landing gear, arresting hook and critical aircraft backup structure points.

Results show that the F/A-18E/F can operate from the decks of existing U.S. Navy aircraft carriers with acceptable margins of safety in performance and structural loads and that the airplane is compatible with existing government ground support equipment.

The opinions, analysis and conclusions expressed in this thesis are solely those of the author and have not been officially approved by the Naval Air Warfare Center or the United States Navy.

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LIST OF ABBREVIATIONS AND NOMENCLATURE

A/B	Afterburner
AGL	Above Ground Level
AOA	Angle of Attack
APU	Auxiliary Power Unit
ATC	Automatic Throttle Control
Ball	Source light of the FLOLS (also, 'Meatball')
Bolter	landing attempt where the hook fails to engage the arresting cable
Bringback	combination of fuel and stores during carrier landing
Burble	disturbed airflow aft of an aircraft carrier
CAS	Control Augmentation System
CAIS	Common Airborne Instrumentation System
carrier	Aircraft carrier
CATM	Captive Air Training Missile
CDP	Cross-deck Pendant (arresting cable)
CG	Center of Gravity
CQ	Carrier Qualification
CVN	Class designation for nuclear powered aircraft carriers
DAF	Dial-A-Function (Variable flight control software)
DATM	Dummy Air Training Missile
AOA bracket	HUD angle of attack reference cue
EFD	Engine Fuel Display
EMD	Engineering and Manufacturing Development
FADEC	Full Authority Digital Engine Control
FCC	Flight Control Computer
FCLP	Field Carrier Landing Practice

FCS	Flight Control System
FLOLS	Fresnel Lens Optical Landing System
FPA	Flight Path Angle
fps	feet per second
g	Load Factor, as measured by force of gravity
GPS	Global Positioning System
H/E	Airplane Hook-to-Eye measurement
hot-pit	Ground refueling with engines operating
HUD	Head Up Display
INS	Inertial Navigation System
IST	Initial Sea Trials
ITT	Integrated Test Team
JBD	Jet Blast Deflector
kt	knot (1 nautical mile per hour)
KCAS	Knots Calibrated Airspeed
KGS	Knots Groundspeed
lb	pounds
LEF	Leading Edge Flap
LEX	Leading Edge Extension
LSO	Landing Signal Officer
MAC	Mean Aerodynamic Chord
MAX	Maximum engine power with full afterburner
Max trap	Maximum aircraft gross weight allowable for arrested landing
MC	Mission Computer
MDI	Multi-purpose Display Indicator
Meatball	Source light of the FLOLS (also, 'Ball')

MK	Mark (U.S. Navy designation for some equipment)
MIL	Military Rated Power (maximum power without afterburner)
MPCD	Multi-Purpose Color Display
MSL	Altitude referenced to Mean Sea Level
NAS	Naval Air Station
NAVAIR	Naval Air Systems Command
NAWCAD	Naval Air Warfare Center Aircraft Division
nm	nautical mile (6,000 feet)
NWS	Nose Wheel Steering
Nx	Longitudinal acceleration
Nz	Normal acceleration
On-speed	optimum angle of attack for landing approach
PA	Power Approach aircraft configuration
PA1/2	Power Approach, Half Flap aircraft configuration
PMG	Permanent Magnet Generator
Ramp	farthest aft edge of the carrier flight deck
RATS	Reduced Authority Thrust System
RPM	Revolutions Per Minute, (% of maximum)
Round down	curved surface joining the carrier landing area and the ramp
Source	image light of the FLOLS (provides relative glideslope information)
TC	Test Conductor
TEF	Trailing Edge Flap
TM	Telemetry
trap	slang for arrested landing
UFCD	UpFront Control Display
USS	United States Ship

CHAPTER I

INTRODUCTION

Background

The F/A-18 Hornet was designed in the late 1970s as a replacement aircraft for the aging F-4 Phantom II and A-7 Corsair II. The airplane entered service in the early 1980s as a multi-role platform capable of performing air-to-air fighter and air-to-ground strike missions. The initial F/A-18 series were the F/A-18A, single seat strike fighter and the F/A-18B, dual seat trainer. In the late 1980s, the F/A-18C (single seat) and F/A-18D (dual seat) series were introduced and represented major hardware upgrades to the earlier series. These upgrades provided increased capabilities including cockpit compatibility with night vision devices as well as adding a dual seat combat mission capability. Through software and hardware upgrades, the airplane evolved to the point where there was no longer room for growth in the form of additional aircraft systems. All available internal volume was filled with mission systems which utilized all available electrical power and cooling capability. Additionally, the weight of the airplane and its systems increased to the point where mission effectiveness was affected due to restrictions on maximum payload recovery weight (bringback) aboard the carrier. While still highly capable, the airplane had nearly reached its maximum potential for growth. Clearly, a new airframe, with additional room for growth was required. To build on the proven effectiveness of the F/A-18, and to meet the stated requirements, the navy chose the F/A-18E (single seat) and F/A-18F (dual seat) airplanes.

The McDonnell Douglas Aircraft Company (now Boeing) designed and built the F/A-18E/F. To conduct the Engineering and Manufacturing Development (EMD) program an Integrated Test Team (ITT) was formed. The ITT represents a new approach to airplane testing in which contractor and government personnel work as an integrated team to conduct flight test and demonstration of the new system. By combining what were once separate, yet often redundant tests, the ITT concept should reduce the time required from initial aircraft production to initial operational capability. The ITT is composed of approximately 300 contractor and 150 government personnel. Boeing retains overall responsibility for contract delivery, but all other responsibilities, including test planning, support and data analysis, are shared equally between government and contractor personnel.

Ten test articles were produced to support the EMD effort. These include seven airworthy aircraft and three ground test aircraft. Of the seven flying airplanes, five are E series and two are F series. For a more complete description of the test articles, refer to "Developmental Performance Flight Test Planning and Procedures for the F/A-18E/F Super Hornet" (Morley). The EMD program was budgeted at $3.1 billion (FY 90) and is scheduled to be complete in November, 1998.

The objective of this thesis was to demonstrate that the F/A-18E/F airplane is carrier suitable. Figure 1-1 shows a history of naval aircraft conducting initial sea trials. Given the increasing interval between new aircraft procurement, it is hoped that this thesis will provide a useful reference to members of future test teams involved in carrier suitability testing of a new airframe.

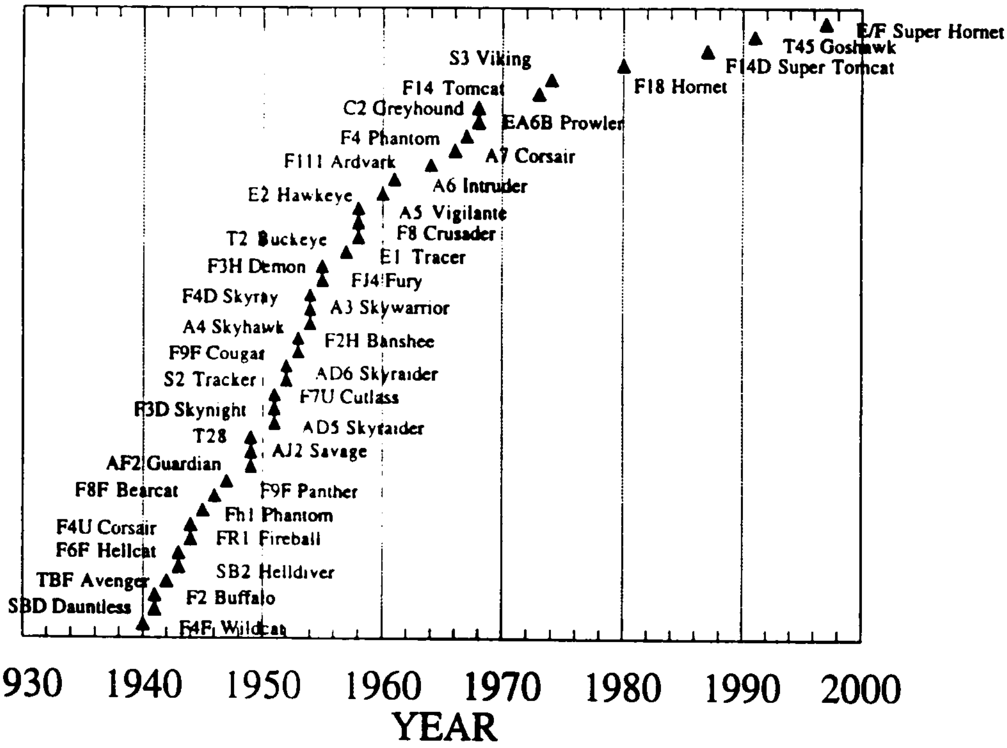


Figure 1-1. Naval Aircraft Initial Sea Trials Dates

Source: Mike Tribino, F/A-18E/F Initial Sea Trials Briefing. Patuxent River, MD, December 1996.

Scope of Thesis

Aircraft F/A-18F1, the first dual seat airplane produced, was designated the primary platform for conducting carrier suitability testing. Testing included demonstrating airplane compatibility with existing shipboard systems and demonstrating structural integrity during catapult assisted launches and arrested landings outlined in government specifications. The scope of this thesis is limited to tests of the basic airplane with no wing pylons or pylon mounted ordnance or stores, referred to as "clean aircraft loading". Tests were conducted between March, 1996 and June, 1997 and included Initial Sea Trials (IST) onboard USS John C. Stennis (CVN 74) in January, 1997.

Quantitative data are presented in terms of flight parameters outlined in the military specifications. Component loads are presented as percentages of maximums, rather than absolute values, in order to comply with releasability of information restrictions.

Test Loading and Configuration

For demonstration points, aircraft loading included wingtip mounted Dummy Air Training Missiles - 9 and fuselage mounted Dummy or Captive Air Training Missiles - 7. As mentioned previously, no pylons were loaded on the test airplane. Airplane configurations for catapult launch and arrested landings are presented in Table 1-1. Figure 1-2 shows the force and moment sign conventions used for data analysis.

Table 1-1. Test Configurations

Configuration	Gross Wt Range	CG Range	Landing Gear	Flap Position
Catapult Takeoff, (CTO)	36,400 to 47,500 lb	23.7% to 28.0% MAC	Down	Full
Power Approach, (PA)	34,000 to 43,900 lb	23.1 to 28.7% MAC	Down	Full
Power Approach 1/2 (PA1/2)	34,000 to 43,900 lb	23.1 to 28.7% MAC	Down	Half

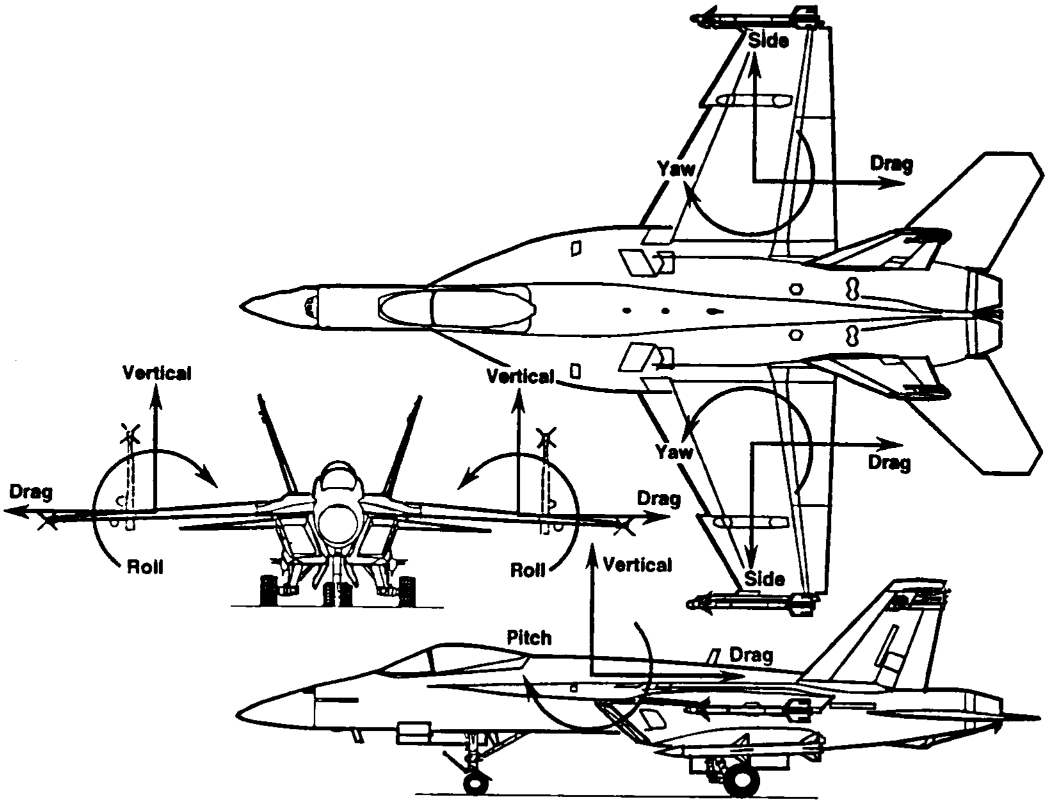


Figure 1-2. Force and Moment Sign Conventions

Source: F/A-18E/F Structural Design Loads Report, Volume V, St. Louis, MO.: McDonnell Douglas Aerospace, June 1995.

Flight Test Interdependencies

With Initial Sea Trials scheduled less than fourteen months after the start of EMD flight test, many interdependent tests were conducted near simultaneously. Aircraft F/A-18E1 cleared the flight envelope in the areas of aeroelastic effects and flying qualities. F/A-18E2 demonstrated the propulsion system envelope and verified engine performance. One of the ground test aircraft, dubbed the "Drop Test Article", demonstrated landing gear integrity during a series of drops from incrementally increasing heights. Such interdependent tests will not be covered in detail in this thesis, but Figure 1-3 outlines some such interdependencies related to Initial Sea Trials.

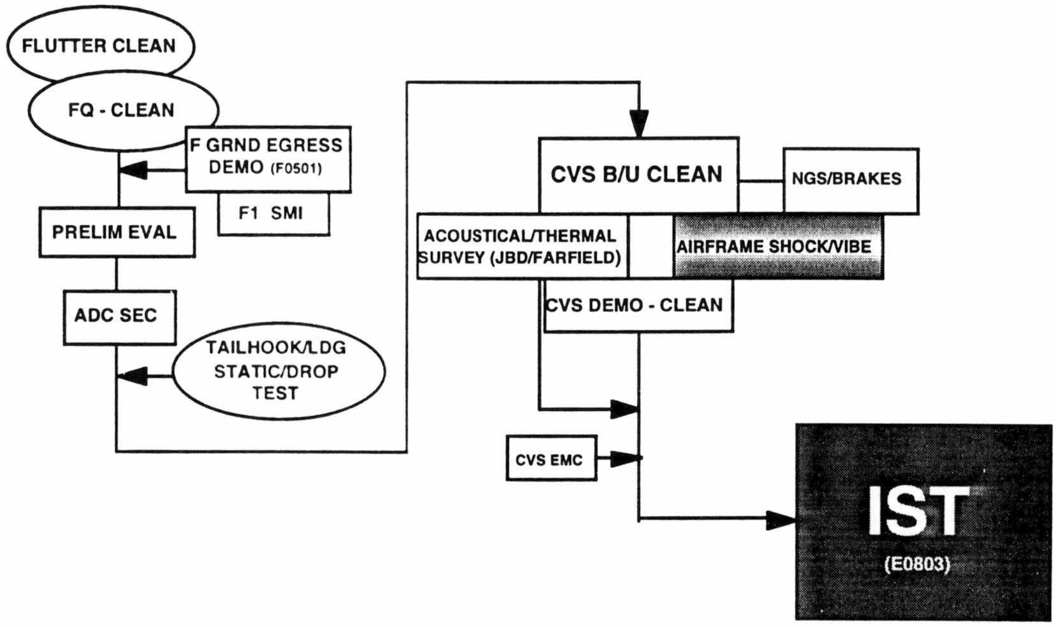


Figure 1-3. Flight Test Interdependencies

Source: Howard Gofus, "Flight Test Update", presentation for the Society of Experimental Test Pilots, March 1997.

Author Participation in Testing

As the lead carrier suitability test pilot assigned to the Integrated Test Team, the author was directly involved in development of test plans, conduct of tests and analysis of results. The author flew as pilot during the majority of carrier suitability test flights.

The opinions, analysis and conclusions expressed in this thesis are solely those of the author and have not been officially approved by the Naval Air Warfare Center or the United States Navy.

CHAPTER II

DESCRIPTION OF F/A-18E/F AIRPLANE

General

As described in the Preliminary Flight Manual, the F/A-18E is a single-place (F/A-18F is a two-place) fighter/attack aircraft built by Boeing (formerly McDonnell Douglas Aerospace). The airframe is a balance of conventional and composite materials and is powered by two General Electric F414-400 turbofan engines with afterburner. The aircraft features a variable camber mid-wing with extended leading edge extensions (LEX) mounted on each side of the fuselage from the wing roots to just forward of the canopy bow. The twin vertical stabilizers are angled outboard 20 degrees from the vertical. The wings have hydraulically actuated leading edge and trailing edge flaps, ailerons and LEX vents. Twin rudders and differential stabilators are also hydraulically actuated. Spoilers are mounted on the top of each LEX. The pressurized cockpit is enclosed by an electrically operated clam shell canopy. An aircraft mounted auxiliary power unit (APU) is used to start the engines. On the ground, the APU may be used to supply air conditioning or electrical and hydraulic power to the aircraft systems. (F/A-18E/F Preliminary Flight Manual, pg I-1-1.)

The airplane is controlled by a four channel digital 'fly-by-wire' Flight Control System (FCS) through hydraulically acuated irreversible flight control surfaces. Lateral control is provided by a combination of ailerons, trailing edge flaps, and asymmetric deflection of the all-moveable horizontal tail. Each engine is controlled by a Full Authority Digital Engine Control (FADEC) mounted on the engine case. Throttle commands are transmitted electrically to the FADECs from two throttle handles located in the cockpit.

The airplane wing span is approximately 44 feet 11 inches; length is 60 feet 2 inches; and height to the top of the vertical stabilizers is 16 feet. (ibid.)

Major changes from previous series F/A-18s include a lengthened fuselage (approximately 4 feet), larger wings, stabilizers and control surfaces. Internal fuel capacity was increased by approximately 3,600 lbs. The hydraulic system was modified to provide dual pressure (3000 and 5000 psi) capability for flight control actuation. The aircraft electrical system consists of an aircraft battery and two engine driven electrical power generation systems. Each power generation system consists of an AC generator and three shaft-mounted Permanent Magnet Generators (PMGs) providing 28 volt DC power for the Flight Control Computers (FCCs) and aircraft DC busses. A total of eleven weapons stations are located on the wings and fuselage.

Crew station upgrades include the addition of a touch-sensitive UpFront Control Display (UFCD) for pilot interface with communication and navigation equipment, and a new Engine Fuel Display for display of fuel quantity and critical engine parameters. Two Multi-purpose Display Indicators (MDIs) are common with F/A-18C/D aircraft. Upgrades have been made to the Multi-Purpose Color Display (MPCD) used for presentation of digital map and compass information or as an additional MDI.

Incorporated in the aircraft design are 17 cubic feet of unused volume for future systems upgrades, and excess electrical and cooling capacity to support such systems. Maximum allowable carrier recovery payload has been increased to over 9,000 pounds of fuel and stores.

Main Landing Gear

The main landing gear incorporate a lever design with an air-oil shock absorber. Figure 2-1 summarizes the major components of the main landing gear. The shock absorber is a dual chamber design which provides landing and taxi energy absorption. The low pressure chamber is effective throughout the stroke and the high pressure chamber acts on the last 4 inches of travel.

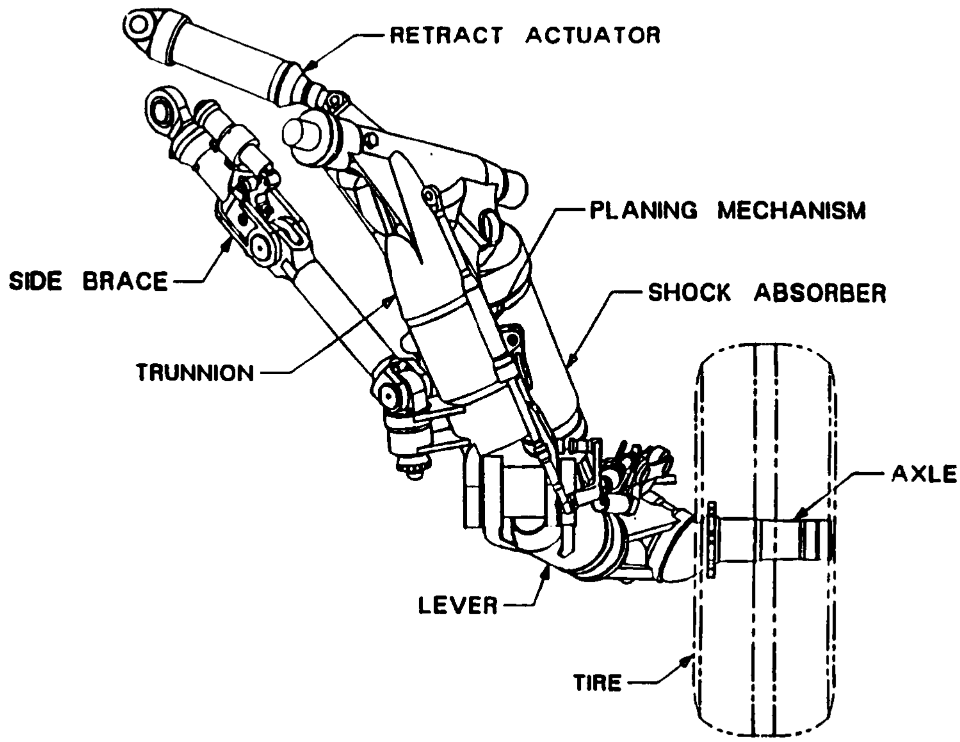


Figure 2-1. Main Landing Gear Components

Source: F/A-18 E/F Structural Design Loads Report, Volume V. Report number MDC 95A0007. St. Louis, Missouri: McDonnell Douglas Aerospace, June 1995.

The main landing gear basic shape is a triangle with the shock absorber forming one side, the trunnion assembly forming another side, and the lever/axle forming the base. The gear strokes in a nearly vertical plane in order to minimize tire scrubbing and associated side loads during compression on landing. A planing mechanism ensures the wheel is oriented in the vertical plane when the gear is extended. The trailing arm gear has proven to function well during obstruction roll-over. (F/A-18E/F Structural Design Loads Report, pg. 2-12.)

Nose Landing Gear

The nose landing gear is a forward retracting gear with a conventional cantilever piston, air-oil shock absorber design which provides landing, taxi, and catapult energy absorption. The dual chamber nose gear strut has high and low pressure pistons. Primary landing energy absorption occurs within the low pressure cavity by metering hydraulic fluid through the entire range of stroke. The high pressure piston provides a firm spring and shock absorber during taxi and carrier operations and serves to position the tow bar uniformly for catapult prelaunch hook-up. For structural efficiency the launch bar and drag brace are kept nearly collinear. A fitting for a repeatable catapult holdback bar is attached to the nose gear scissors apex joint. (F/A-18E/F Structural Design Loads Report, pg. 2-1.) Figure 2-2 summarizes the major components of the nose landing gear. The launch bar serves as the interface between the airplane and the catapult shuttle during catapult assisted launch. The drag brace transmits the load from catapult launch to the airplane back-up structure, while the shock absorber absorbs the compressive load associated with catapult acceleration.

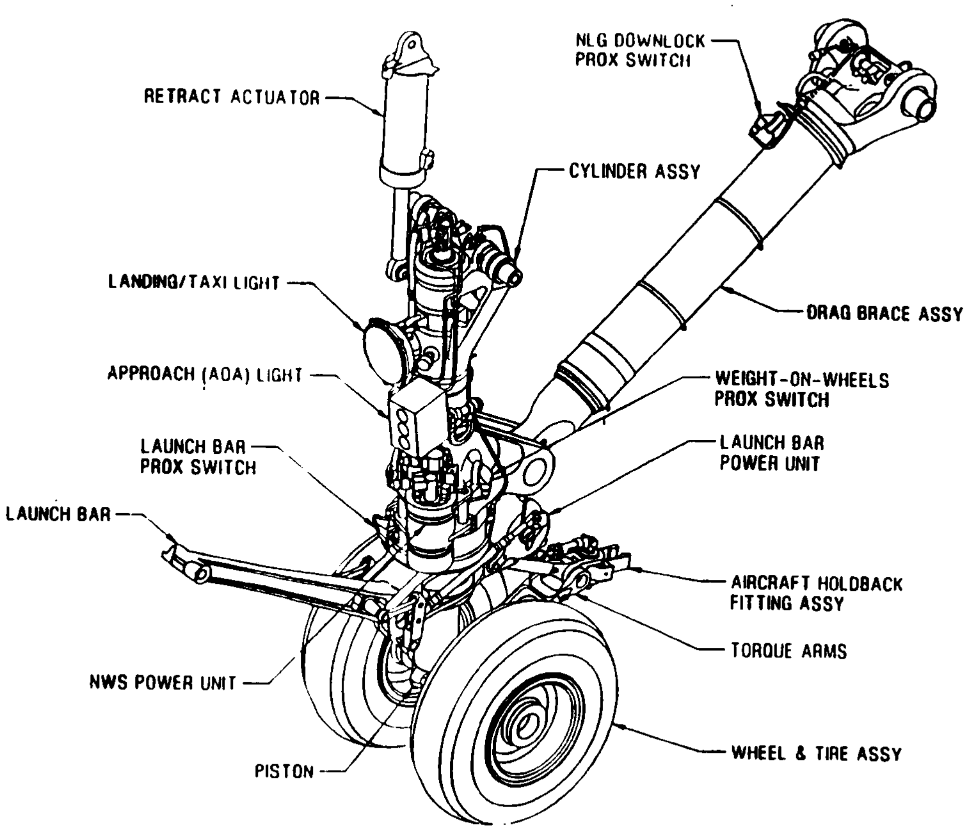


Figure 2-2. Nose Landing Gear Components

Source: F/A-18 E/F Structural Design Loads Report, Volume V. Report number MDC 95A0007. St. Louis, Missouri: McDonnell Douglas Aerospace, June 1995.

Arresting Hook

The arresting hook system is composed of a shank with a replaceable hook point, a vertical holddown/damper and an uplatch. The hook is located far aft on the centerline keel to provide clearance between the arresting cable and the engines and horizontal tails during the dynamic cable motions associated with arrested landing. The vertical damper serves to hold the hook shank in the down position and minimize hook bounce following touchdown. Lateral damping and hook centering are

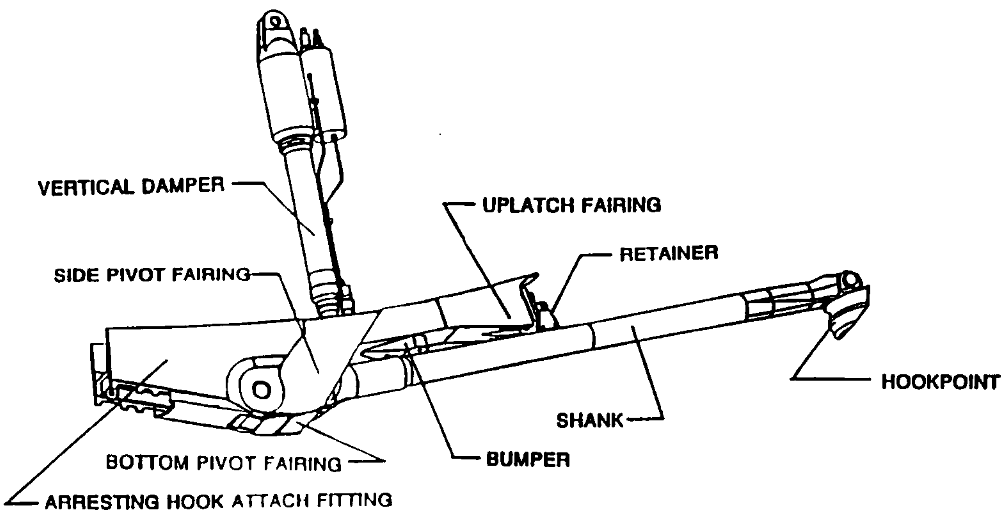


Figure 2-3. Arresting Hook System Components

Source: F/A-18 E/F Structural Design Loads Report, Volume V. Report number MDC 95A0007. St. Louis, Missouri: McDonnell Douglas Aerospace, June 1995.

incorporated in a device located in the hook shank near the pivot point. (ibid., pg. 2-24.) Figure 2-3 summarizes the major components of the arresting gear.

Reduced Authority Thrust System

A Reduced Authority Thrust System (RATS) is incorporated to reduce the wind-over-deck required for carrier landings by limiting thrust during arrestment (pilots select MIL thrust upon landing in order to maintain flyaway thrust in the event of a bolter). The primary airplane mission computer (MC) samples throttle position, landing gear position, arresting hook position, weight-on-wheels, wheel speed and deceleration to determine if a successful arrestment has been made. With arrestment confirmed, the MC sends a RATS command to the FADEC which reduces MIL thrust by approximately 10% and thereby reduces the energy required to be absorbed by the arresting gear. RATS is overridden by selecting MAX afterburner power. (F/A-18E/F Preliminary Flight Manual, pg. I-2-8.)

Although the system was designed so as to prevent a "RATS failed on" condition, testing was required with this failure condition simulated. In order to allow the pilot to rapidly set the throttles to the appropriate RPM for a simulated failure, a spring-loaded throttle block, shown in figure 2-4, was placed on the throttle quadrant to provide a tactile cue to the proper setting, without limiting throttle motion. The RATS block was attached with Velcro during engine run up on deck (or on the catapult) and left in place during waveoff and bolter tests.

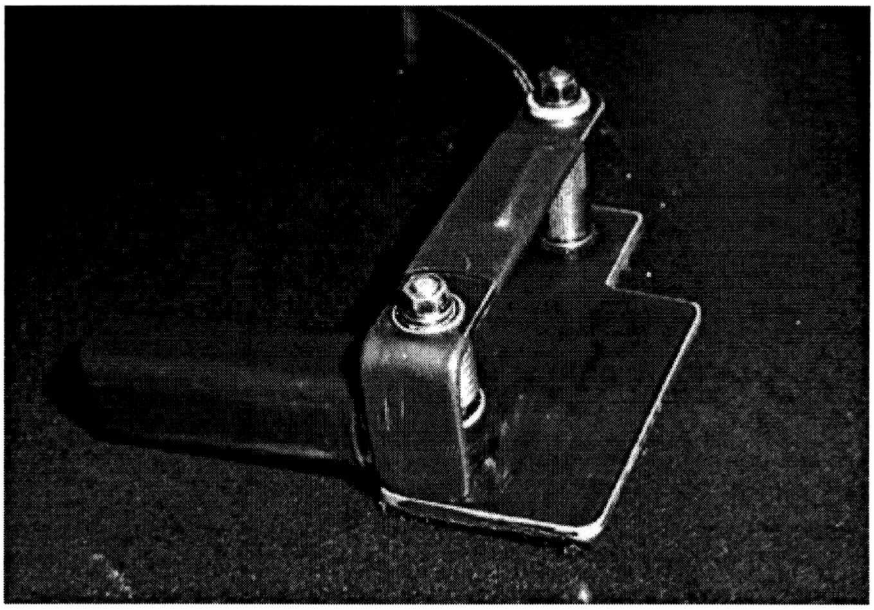


Figure 2-4. Reduced Authority Thrust System Block

Source: Photo by Randy Hepp

Flight Test Features

Several features were incorporated in the aircraft software to facilitate accomplishment of some unique flight test requirements. Using cockpit multi-purpose display indicators (MDIs) and the upfront control display (UFCD) the pilot could modify aircraft equipment operation to meet the requirements for particular tests. These features increased the efficiency of flight testing and are discussed in the following paragraphs.

Dial-A-Function

The feature known as Dial-A-Function (DAF) allowed the pilot to modify the way the flight control computers (FCCs) commanded control surface deflections. In previous test programs, the FCCs would have to be loaded with unique software to accomplish this same effect, and the effect would be permanent until the FCCs were reloaded with 'normal' software. Such modifications would require hours of regression testing to ensure flight safety. By utilizing DAF, the desired modifications were incorporated only when required for specific tests, and a simple press of a button returned the FCS to normal operation. This eliminated the need for full-envelope regression testing of proposed DAF options. Configuration control of approved DAF options was maintained through the flight test program operational limitations database. There was no actual "dial" associated with DAF. Digital entries were made utilizing the UFCD to input desired parameters, and options were selected and activated using pushbuttons on the MDIs and control stick. Up to four options could be programmed, but only one could be active at any given time.

Flight Test Fuel Transfer

Through a special flight test display on a cockpit multi-purpose display Indicator the pilot could command individual fuel valve positions within the fuel transfer system. This special display, shown in Figure 2-5, combined three existing display formats: the fuel format, the fuel quantity format, and the fuel transfer format. During normal operations, fuel transfer valves are positioned automatically

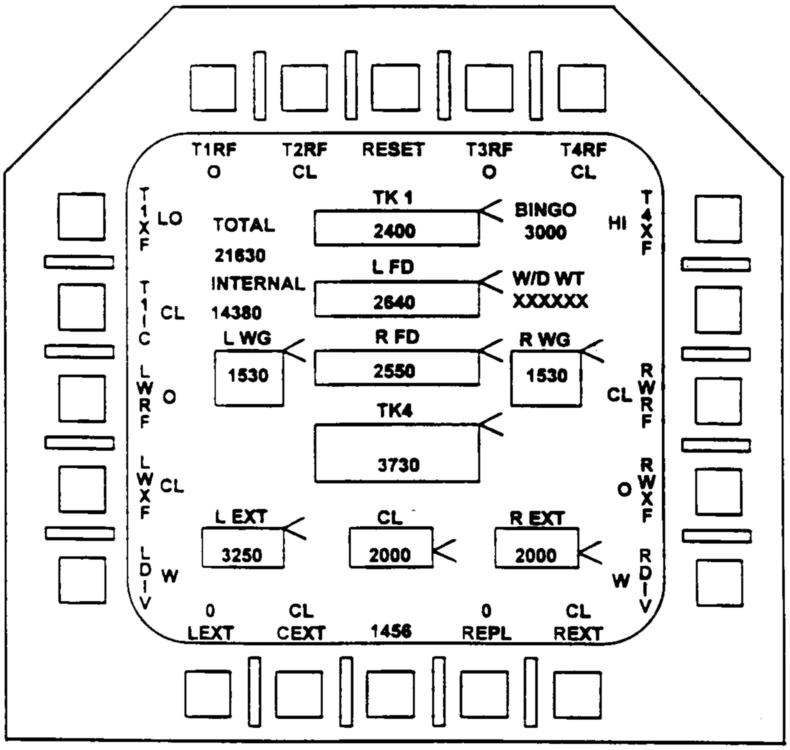


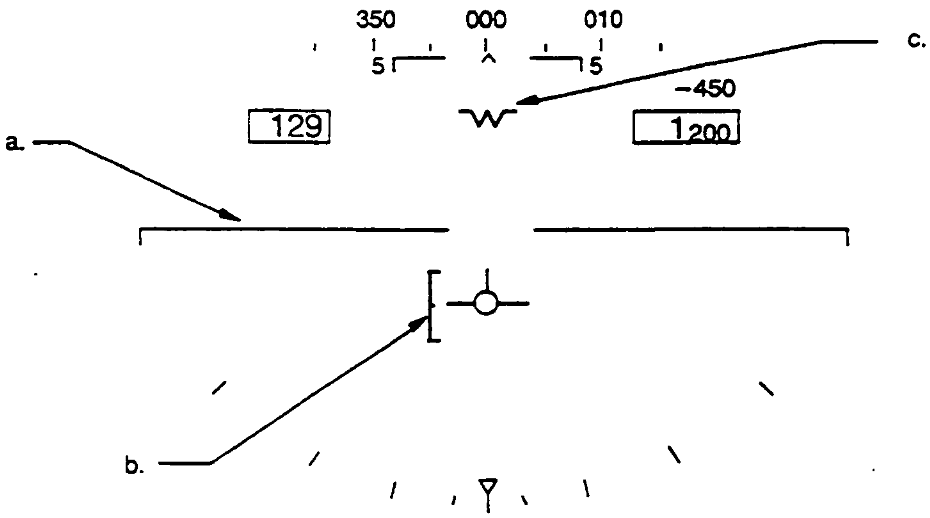
Figure 2-5. Combined Fuel / Fuel Quantity / Fuel Transfer Display

Source: Carrier Suitability Build Up/Demonstration - Clean Loading, Test Work Description, St. Louis, MO.: McDonnell Douglas Aerospace, October 1995 to maintain appropriate fuel levels and temperatures and to control aircraft center or gravity (CG). In order to accomplish testing at the limits of allowable aircraft CG, the flight test fuel transfer function was used to isolate fuel in either the forward or aft-most internal fuel tanks, thereby affecting CG. By incorporating this capability in the mission computer software, the need for special flight test hardware to control fuel transfer was eliminated, again increasing test efficiency.

Adjustable Angle-of-Attack Bracket

During normal operations, carrier based airplanes fly their landing approaches at what is known as "on-speed" angle of attack (AOA). In the case of the F/A-18 on-speed AOA is 8.1°. This AOA provides optimum aircraft touchdown attitude for arrested landing. Angle of attack is displayed digitally on the HUD during most flight phases, but during the landing phase, with landing gear extended, a reference mark on the HUD, known as the AOA bracket, provides a cue to the pilot for flying on-speed. Figure 2-6 shows the F/A-18E/F HUD with the AOA bracket.

During carrier suitability testing many of the landing demonstration test points required specific pitch attitudes at touchdown rather than that pitch attitude corresponding to 8.1° angle of attack. In order to establish the proper pitch attitude, the pilot was required to fly at some AOA other than on-speed. Once again software was incorporated in the airplane's mission computers to allow for modification of the normal display. This software allowed the pilot to 'adjust' the AOA bracket to reference any desired AOA.



a. Extended horizon line
b. Angle of Attack bracket
c. Waterline symbol (pitch attitude reference)

Figure 2-6. F/A-18E/F Head Up Display Landing Format

Source: "Operation of the F/A-18 Avionic Subsystem." St. Louis, MO.: McDonnell Douglas Aerospace, September 1995.

Instrumentation

Data System Description

The instrumentation system installed on aircraft F1 was the Common Airborne Instrumentation System (CAIS). System components included an onboard magnetic tape recorder and telemetry transmitter located in the gun bay in the airplane nose section. Accelerometers, strain gages and position sensors were mounted on critical aircraft components and provided inputs to the CAIS. Additionally, signals from the airplane's MIL-STD 1553 data bus were available for recording and transmission by the CAIS. A detailed description of the CAIS can be found in the Carrier Suitability Build Up/Demonstration Test Work Description.

External Camera System

Two cameras were installed to support carrier suitability tests. A nose landing gear camera was installed in a periscope arrangement on the gun bay door with a field of view for catapult documentation which covered the nose landing gear, both main landing gear and the underside of both wings from the wing root to the wingfold. An arresting hook camera was installed on the left engine bay door with a field of view which covered the arresting hook from the pivot point to the hook point, throughout the entire range of hook travel. The camera installations were capable of accepting 16mm film cameras operating at frame rates from 24 to 400 frames per second. The cameras were activated by a single switch located on the left throttle handle. (Carrier Suitability Build Up, pg. 2-4.)

CHAPTER III

DESCRIPTION OF EQUIPMENT

General

The following paragraphs provide brief descriptions of some of the unique systems which are integral to performing the task of safely launching and recovering airplanes from the decks of aircraft carriers.

Jet Blast Deflector

A jet blast deflector (JBD) is a set of panels, hinged on one side, which are raised from the carrier deck behind an airplane positioned for catapult launch. The JBD deflects jet exhaust upward, preventing the high velocity jet plume from impinging on other aircraft, equipment or personnel on the carrier deck. The MK7 Mod 0 JBD consists of six panels, each 6 feet wide with a slant height of 14 feet. When installed on an aircraft carrier, the panels are internally cooled by sea water. (Carrier Suitability Testing, pg. 5-20.) The Naval Air Warfare Center Aircraft Division facility at Lakehurst, NJ is equipped with a MK7 Mod 0 JBD located adjacent to the test runway. Due to its landlocked installation, this JBD utilizes fresh water recirculated through an underground storage tank for cooling. Otherwise, the JBD is identical to shipboard systems.

Catapult Launch Equipment

A shipboard catapult is steam powered and consists of a slotted twin cylinder launching engine, hydraulic retraction engine, and control system as illustrated in the general arrangement drawing of Figure 3-1. The Naval Air Warfare Center Aircraft Division, facility at Patuxent River, MD is equipped with one shipboard type steam catapult installation, designated the TC-7 catapult. The TC-7 is the equivalent of a navy C13-1 catapult and is located adjacent to runway 32. Steam is supplied to the catapult from boilers and is delivered to the two catapult cylinders through launch valves. The launch valves are hydraulically operated and control the amount of steam entering the cylinders. A Capacity Selector Valve (CSV) is used to control the opening rate of the launch valves to provide the appropriate force for a given aircraft gross weight and desired flyaway speed. At the end of the catapult stroke, tapered spears mounted in front of each piston engage a water brake which dissipates the piston energy. (Carrier Suitability Testing, pg. 2-6.)

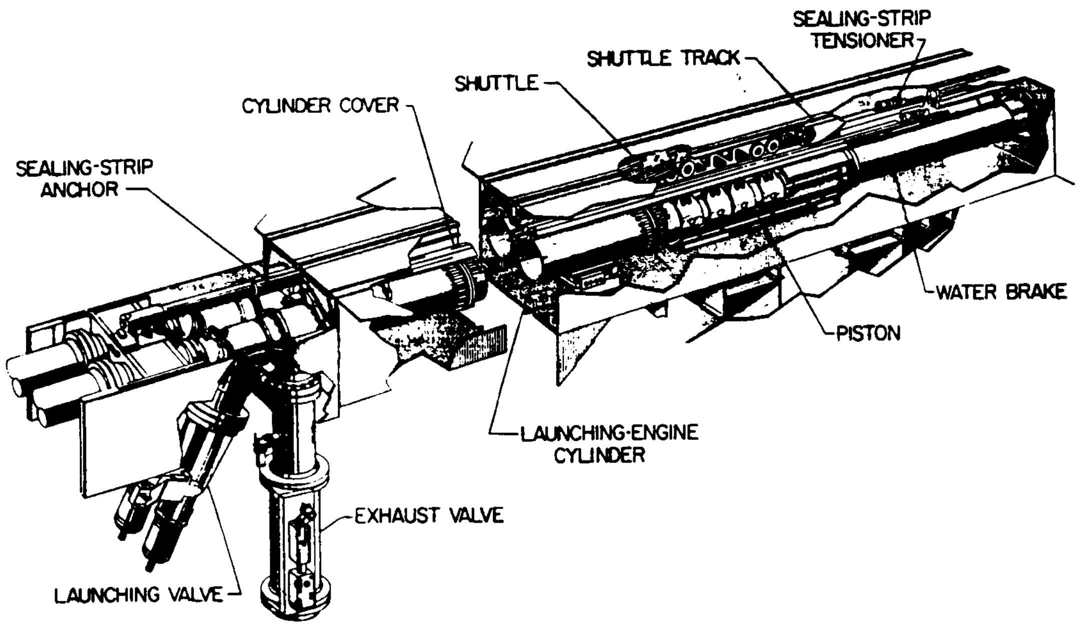


Figure 3-1. General Arrangement Drawing of Shipboard Catapult

Source: Zirkel, John, et.al., "Aircraft Carrier Reference Data Manual." Naval Air Warfare Center Aircraft Division, Lakehurst, NJ., January 1994.

Catapult systems vary slightly by operating steam pressure, cylinder diameter and length of power stroke. The Naval Air Warfare Center Aircraft Division facility at Lakehurst, NJ is equipped with a navy C13-2 catapult installed on the test runway.

Arresting Equipment

The MK7 Mod 3 Constant Runout Arresting Gear installed on runway 32 at Naval Air Warfare Center Aircraft Division , Patuxent River, MD is essentially identical to the arresting equipment used aboard fleet carriers. The cable which aircraft engage, called the cross deck pendant (CDP), is 1-3/8 inches in diameter and spans the width of the landing area. The CDP attaches at each end to a 1-7/16 inch diameter purchase cable which runs through deck edge sheaves to the arresting gear equipment below the landing area. Minor differences in sheave arrangement and length of purchase cable exist from ship to ship. A general arrangement drawing shipboard arresting gear is presented in Figure 3-2.

When an aircraft engages the CDP, the forces are transferred to the purchase cables which are each reeved to a set of moveable and a set of fixed sheaves on the arresting engine. The fixed sheaves are attached to a cylinder filled with fluid and the moveable sheaves are attached to a ram. A constant runout control valve controls the rate at which hydraulic fluid is forced out of the cylinder by the ram. The control valve must be set for the gross weight of the aircraft being arrested. Fleet practice is to use a constant weight setting (corresponding to the maximum allowable recovery weight) for recovery of specific model airplanes regardless of the actual landing gross weight. (Carrier Suitability Testing, pg. 3-21.)

The Naval Air Warfare Center Aircraft Division facility at Lakehurst, NJ also has a MK7 Mod 3 arresting gear system installed on the test runway.

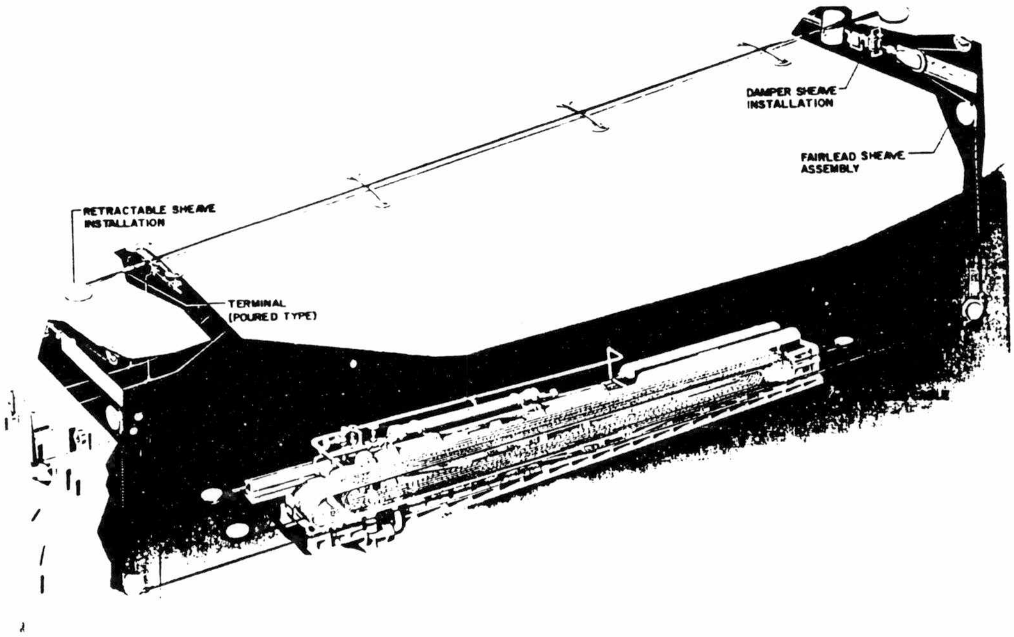


Figure 3-2. General Arrangement Drawing of Shipboard Arresting Gear

Source: Zirkel, John, et.al., "Aircraft Carrier Reference Data Manual." Naval Air Warfare Center Aircraft Division, Lakehurst, NJ., January 1994.

Fresnel Lens Optical Landing System (FLOLS)

The Fresnel Lens Optical Landing System (FLOLS) provides a pilot with a visual indication relating the position of his approaching aircraft to a prescribed glideslope. A FLOLS is located on the port side of the flight deck on all U.S. Navy aircraft carriers and on the left side of most runways at Naval Air Stations. The FLOLS consists of a source light assembly, horizontal row of green datum lights at the mid-point of the source assembly, vertical rows of red lights, called "wave-off" lights, and another small horizontal row of green lights, called "cut" lights, above the source assembly. The FLOLS arrangement is shown in Figure 2-6.

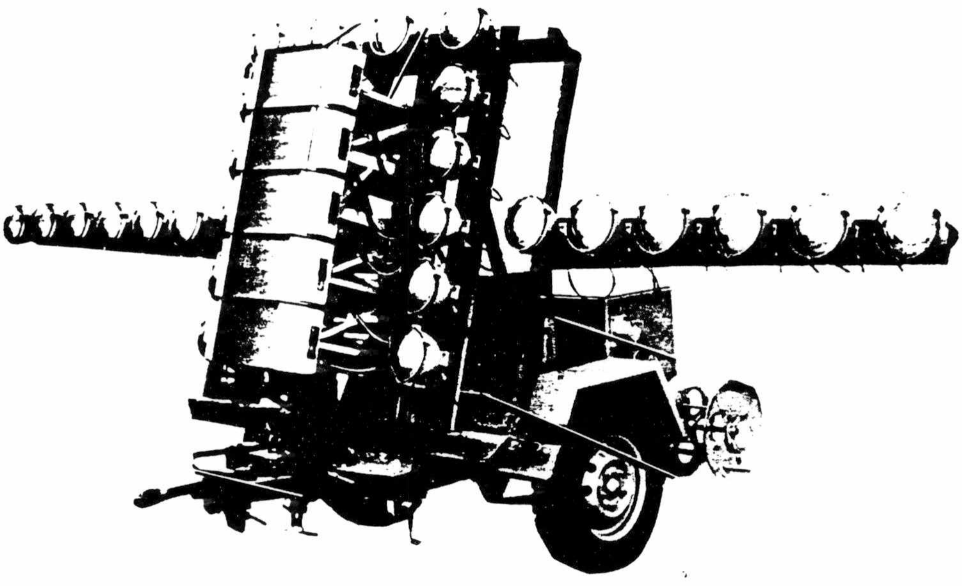


Figure 3-3. Fresnel Lens Optical Landing System

Source: Technical Manual, "Portable Shore-Based Fresnel Lens Optical Landing System, MK 8 MOD 1." Washington, D.C.: Department of the Navy, Naval Air Systems Command, January 1982.

The source assembly is composed of five Fresnel lens boxes stacked vertically. The central idea behind the design was to provide a "light image", called the "source" or "ball", which appears to move depending on the viewer's position. (Nielsen, pg. 105.) To maintain desired glideslope, a pilot flies his airplane so as to keep the source light aligned between the horizontal datum lights. If the aircraft is too high, the pilot will see the source light appear above the datums. Conversely, if the aircraft is below thereference glideslope the pilot will see the source light below the datum lights. (Carrier Suitability Testing, pg. 3-8.) Though beyond the scope of this thesis, a detailed description of the lens optics can be found in Nielsen. What is important for the purposes of this paper is that the reference glideslope presented by the FLOLS can be adjusted by simply tilting the source light assembly. This is the method by which aircraft sink speed was controlled during landing structural tests.

CHAPTER IV

CARRIER SUITABILITY TEST PROGRAM

Introduction

The objective of the Initial Sea Trials (IST) phase of F/A-18E/F Engineering and Manufacturing Development (EMD) was to provide an early assessment of the airplane in the aircraft carrier environment. The objective of the carrier suitability demonstration tests was to show that the airplane, including all onboard equipment, met the structural, functional and performance requirements of the Detail Specification for Model F/A-18E/F Aircraft Weapon System. The combined military specification (Demonstration Requirements for F/A-18E/F Aircraft) outlined the shorebased and shipboard tests required for completion of IST and carrier suitability demonstration. Table 4-1 outlines these requirements and the locations at which testing occurred. Shorebased testing comprised the majority of work and included evaluation of flying qualities, high angle of attack characteristics, field of view and hook to eye measurements, suitability of recommended approach angle of attack and associated airspeeds, approach, bolter and waveoff performance characteristics, trim transients with configuration changes, single engine and degraded engine handling qualities and performance, catapult launch and arrested landing characteristics and loads, and ground handling qualities. Shipboard testing included evaluation of catapult launch flyaway characteristics at various center of gravity (CG) locations and trim conditions, flying qualities and performance characteristics during approach at different wind over deck conditions and various CG locations, and flight deck and hangar deck handling and support equipment compatibility. Aircraft F/A-18F1, the

Table 4-1. Carrier Suitability Test Summary

Test Requirement	Location of Tests
Approach Flying Qualities and Performance	Patuxent River, MD
Field of View / Hook to Eye Measurements	Patuxent River, MD
Jet Blast Deflector Compatibility	Lakehurst, NJ
Catapult Loads and Launch Controllability	Patuxent River, MD Lakehurst, NJ
Catapult Steam Ingestion / Catapult Spotting	Patuxent River, MD
Roll-in Arrestments	Lakehurst, NJ
Airframe Drop Tests	St. Louis, MO
Arrested Landing Loads / Hook Dynamics	Patuxent River, MD
Degraded Modes (simulated: RATS fail, Single Engine)	Patuxent River, MD
Initial Sea Trials	USS John C. Stennis
Support Equipment Compatibility	Patuxent River, MD USS John C. Stennis

first two-seater produced, was assigned as the carrier suitability test airplane. Shipboard testing was conducted aboard USS John C. Stennis (CVN 74) from 18 to 23 January, 1997. The final demonstration point for the carrier suitability clean aircraft loading was completed on 9 June 1997.

Demonstration Requirements

Catapult requirements included demonstrating longitudinal accelerations to 5.5 gs with the airplane aligned on catapult centerline and with the airplane angled to catapult centerline such that the main landing gear tires were offset 24 inches from their centerline position. The engines were required to demonstrate tolerance to steam ingestion during launches with the TC-7 catapult intentionally degraded to increase steam leakage during the power stroke. The specification also called for excess airspeeds greater than 40 knots above normal and demonstration of hands-off flyaway characteristics. Arrested landing demonstration requirements are outlined in Table 4-2. For the high sink rate landings, 21.1 feet per second sink rate corresponds to 80 percent of maximum design sink rate at the carrier landing design gross weight. The 'obstruction rollover' referred to in two of the demonstration

Table 4-2. Arrested Landing Demonstration Requirements

Test Point	Sink Rate (fps)	Pitch	Roll	Yaw	Hook Load lbs	Notes
Mean Pitch Attitude High Sink Rate	≥ 21.1	3.1° - 6.1°	-	-	-	Three points. One with obstruction rollover.
Nose Down Pitch Attitude High Sink	≥ 21.1	≤ 0.1°	-	-	-	Three points. One with obstruction rollover.
Tail Down Pitch Attitude High Sink	≥ 21.1	≥ 9.1°	-	-	-	
Rolled / Yawed Opposite	≥ 16.9	-	≤ -5°	≥ 5°	-	
Rolled / Yawed Same direction	≥ 16.9	-	≥ 5°	≥ 5°	-	
Free Flight*	≤ 9.4	≥ 12.2°	-	-	≥ 170,850	Three points. *Cable engagement prior to main tire touch down.
Maximum Hook Load	≥ 16.9	-	-	-	≥ 201,000	
Maximum Hook Load, Off Center	≥16.9	-	-	-	≥ 201,000	20 feet off center cable engagement.
Rolled	≥ 16.9	3.6° - 5.6°	> 6°	-	-	

Source: Adapted from Demonstration Requirements for F/A-18E/F Aircraft, Combined Addendum 131 and Basic MIL-D-8708B, Washington, D.C.: Department of the Navy, Naval Air Systems Command, February 1992.

conditions required that the nose tire rollover the arresting cable such that "the vertical nose gear load just prior to tire contact with the obstruction shall be not less than 75 percent of the load attained without the superposition of the deck obstruction load". (Demonstration Requirements for F/A-18E/F Aircraft, pg. 83.) A free flight arrestment is defined as one during which the tailhook engages the arresting cable prior to main tire touchdown with the aircraft in a rate of descent. The distinction between this type arrestment and an 'inflight' arrestment is that an inflight occurs with the airplane established in a climb and will normally result in extensive damage to the aircraft.

Airplane Flying Qualities and Performance

Prior to commencing catapult and arrested landing tests, evaluations of airplane flying qualities and performance were conducted. Flying qualities tests included evaluation of aircraft handling in both full and half flap landing configurations at angles of attack up to 20 degrees. Landing approaches were conducted with intentional deviations in glideslope and lineup in order to assess aircraft response to aggressive control inputs. Waveoff and simulated bolter tests were conducted to confirm engine performance predictions. Flying qualities and engine response were excellent. The airplane appeared to be more stable in response to gusts and disturbances than previous series F/A-18s, while retaining the superb handling qualities demonstrated in the F/A-18A/B/C/D.

Lakehurst Testing

In October 1996 the F1 team deployed to the Naval Air Warfare Center Aircraft Division test facility at Lakehurst, NJ for jet blast deflector (JBD) compatibility, arresting gear roll-in, and C13 MOD2 catapult testing.

Jet Blast Deflector Tests

Jet Blast Deflector (JBD) tests included demonstrating the ability of the MK7 MOD0 JBD to dissipate the heat encountered with the F/A-18F in full afterburner and positioned at normal catapult hook up distances both on and angled slightly off centerline. Additionally, engine tolerance to exhaust gasses deflected from the JBD and reingested through the engine intakes was demonstrated. Figure 4-1 shows the test positions for JBD compatibility tests. During these tests acoustic and vibration data were also recorded.

It was discovered during JBD tests that the concentration of heat from the dual afterburner plumes caused cooling water temperatures within a portion of the JBD panels to exceed limits. This required a reworking of the plumbing inside the JBD, increasing the diameter of orifices within the JBD panels in order to increase water flow rate. Re-testing proved the modification was successful in eliminating the temperature exceedance. The modification was conducted on the JBDs onboard USS John C. Stennis in order to support sea trials.

Engine tolerance to high inlet temperatures was demonstrated by spotting F/A-18F1 behind the JBD with an F-14 in full afterburner forward of the JBD as shown in Figure 4-2. A second position was tested with F/A-18F1 angled 45 degrees to the JBD such that the left engine intake was exposed to the jetwash directly behind the left outboard panel of the JBD. Engine parameters remained within limits throughout the demonstrations.

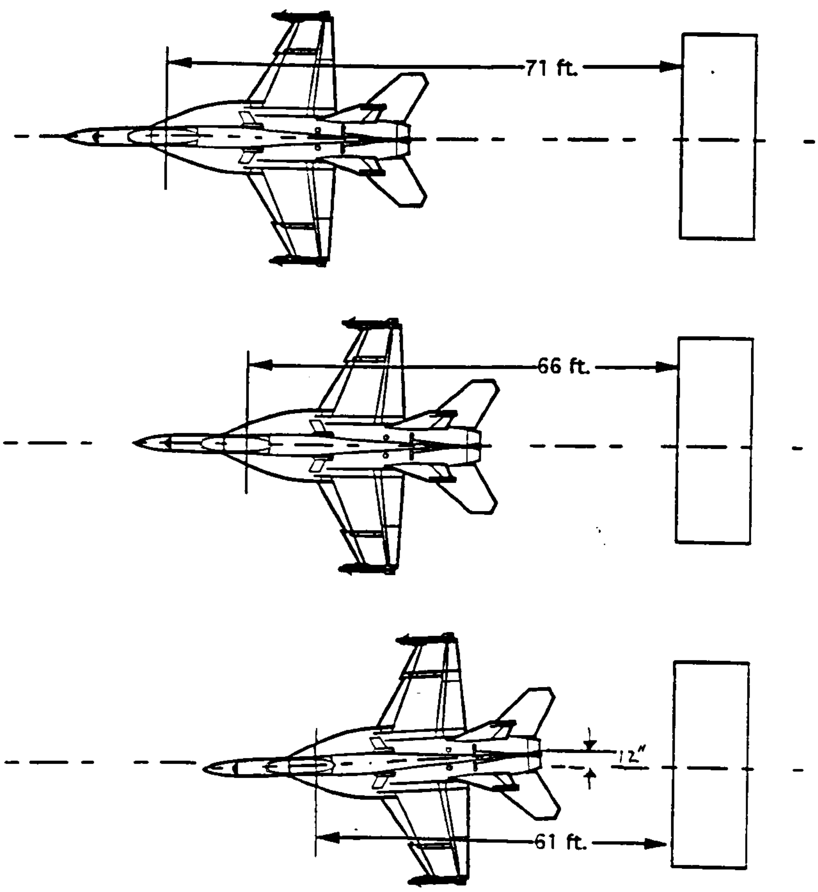


Figure 4-1. F/A-18F Positions Forward of JBD

Source: F/A-18E/F Acoustic/Thermal Environment Survey - JBD Compatibility Test Work Description, St. Louis, MO.: McDonnell Douglas Aerospace, September 1996.

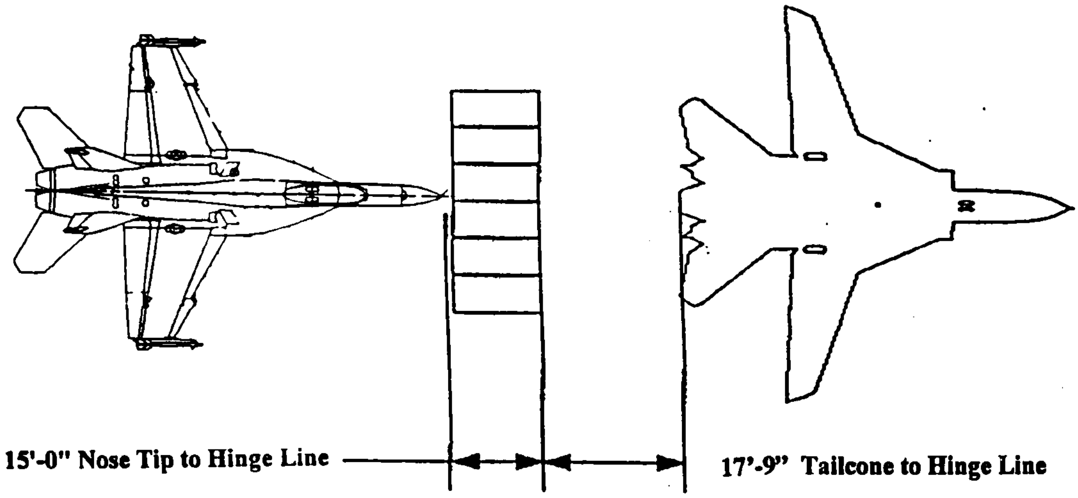


Figure 4-2. F/A-18F Positions Aft of JBD

Source: F/A-18E/F Acoustic/Thermal Environment Survey - JBD Compatibility Test Work Description, St. Louis, MO.: McDonnell Douglas Aerospace, September 1996 (FMV08.02-001)

Roll-In Arrestments

In order to precisely control airplane engaging speed during arresting gear compatibility tests, a technique known as "roll-in" arrestment was employed. The airplane was positioned on the runway at a computed distance from the arresting gear, engines were set to the appropriate power setting for the test point, and brakes released. Just prior to reaching the arresting gear, the airplane hook was lowered (this avoided dragging the hook hundreds, or thousands of feet down the runway). Once the data were evaluated, the starting distance was increased to incrementally increase the groundspeed at which arrestment occurred. The process was repeated until the demonstration requirement was achieved. Eighty three roll in arrestments were conducted to the MOD3 Plus arresting gear at Lakehurst. These allowed demonstration of maximum hook load and hook dynamics during cable engagements up to 20 feet off centerline and cleared the way for further arrested landing work.

Shorebased Catapults

General

Most catapult testing was conducted at the TC-7 catapult site at the Naval Air Warfare Center Aircraft Division, Patuxent River, MD. The airplane demonstrated all required points over the course of 85 launches. Endspeeds as high as 172 KGS and longitudinal accelerations (Nx) up to 5.5 gs were achieved during both military rated thrust and maximum afterburner launches. Forty launches were conducted to evaluate engine steam ingestion with the catapult intentionally degraded to increase steam leakage. In general, the 'ride' quality down the catapult track in the F/A-18F was less bouncy than earlier series Hornets, and flyaway was characterized by smooth rotation to the flight control computer commanded target angle of attack.

Catapult Induced Loads

All loads transmitted to the aircraft during catapult launch were within design limits, but the onboard instrumentation data recorder proved to be very sensitive to some of the abrupt loads. Although the recorder was shock mounted, portions of data were lost on several of the early launch attempts. The recording system operated by filling a 'buffer' with approximately 15 seconds of data, then writing that data onto the magnetic tape in bursts. It was discovered that if the recorder happened to be 'writing' during the catapult holdback release (beginning of the power stroke) or shuttle release (end of the stroke), the shock loads would jolt the recording heads off of the tape, and that portion of the data would be lost. Reinforcing the recording heads with what amounted to internal shock mounts and increasing the 'buffer' size resolved the problem.

Future test programs should include dedicated instrumentation system checkout events in order to ensure system functionality throughout the range of aircraft loads to be tested.

Afterburner Lockout System

Another discovery during catapult testing was that the afterburner (AB) lockout system of the throttle quadrant was not functioning. The AB lockout was designed to prevent inadvertent selection of afterburner during the dynamic regimes of catapult launch and arrested landing. With weight on wheels and either the launch bar or hook extended, a solenoid in the throttle quadrant was designed to place an additional obstruction in the throttle path, increasing the resistance of the afterburner detent. Poor reliability of the solenoid caused the failure of the AB lockout. A new solenoid design should be incorporated in the throttle quadrant.

Steam Ingestion

During steam ingestion tests, the left engine experienced apparent afterburner blowouts on 6 of the 20 afterburner launch points. There was a slight right to left crosswind during the 'blowout' launches which resulted in the majority of steam being ingested through the left intake. All the blowouts were self-recovering and, in fact, were commanded by the full authority digital engine control (FADEC). The FADEC sensed the large temperature spike associated with the ingestion of steam and ceased afterburner operation until the ‘gulp’ of moisture passed through the engine. In the cockpit, the pilot perceived up to 2 degrees of yaw associated with the 1 to 2 second interruption of afterburner, but the flyaway characteristics, hands off the controls, remained satisfactory. Similar self-recovering blowouts were encountered during F/A-18C enhanced performance engine testing in the early 1990s.

MK-7 Arrested Landings

General

All of the shorebased arrested landing tests were conducted at the MK-7 arresting gear site which is located on runway 32 at Patuxent River Naval Air Station. The arresting gear system is the same as that used aboard the aircraft carriers. A total of 271 landing approaches were flown in order to complete all arrested landing demonstration requirements. Of these, 157 were arrested landings, 23 were bolters where hook engagement of the cross deck pendant (CDP) did not occur, and 91 were hook up touch and go landings used as build-up points to incrementally increase sink rate.

Test Technique

The arrested landing loads demonstration points were perhaps the most difficult carrier suitability test points to achieve. Due to the combined requirements for specific pitch attitudes, sink speeds and engaging speeds, these tests were highly dependent on ambient conditions. In accordance with carrier suitability test procedures the standard Fresnel Lens Optical Landing System (FLOLS) was incrementally adjusted to increase or decrease commanded glideslope in order to achieve the desired sink rates (Table 4-2). Glideslope settings as high a 6.5 degrees were commanded. It is undesirable to target glideslopes above this value, since the change in sink rate becomes very sensitive to even minor changes in glideslope above this value and there is greater likelihood of grossly exceeding target sink. If the specification required sink rate could not be achieved with a 6.5 degree lens, the only course was to wait for a day with less headwind (or more tail wind) in order to increase sink rate for a given lens setting.

The demonstration points most difficult to achieve, due to requirement for ideal conditions, were the nose down and tail down points. The problem with the nose down attitude was that the approach airspeed associated with a touchdown at zero degrees pitch was above the maximum arresting gear engine engaging speed. A minimum 15 knots headwind was required in order to reduce aircraft groundspeed and avoid arresting gear overstress. By far the trickiest points, however, were the free flight demonstrations. The apparent incompatibility between required parameters led to some creative use of Dial A Function (DAF). The specification called for at least 12.2 degrees pitch attitude at touchdown with a hook load associated with a high speed landing. Increasing pitch attitude, of course, decreases airspeed, and vice versa. In order to achieve the required groundspeed for cable engagement along with the nose high pitch attitude, the team would have to wait for a day with twenty knots of tailwind, or find a way to increase approach speed at a given pitch attitude. The DAF mode of the flight control system allowed a reconfiguration of the flaps in the Power Approach 1/2 (PA1/2) configuration. The trailing edge flaps were deflected only five degrees instead of the normal 30. The ailerons remained drooped to 30 degrees. Following a flying qualities evaluation, the configuration was deemed suitable for attempting the free flight points and the change in approach speed provided an additional tailwind 'window' for attempting the free flight points.

The approach technique for the pilot during the tail down demonstrations was unique. The angle of attack (AOA) during approach was 14 to 15 degrees, an attitude which caused the nose of the airplane to obscure the landing area. In order to maintain visual contact with the FLOLS the pilot was required to raise the seat to the full up position and lean forward and to the side of the cockpit. Line up was maintained by scanning to the far end of the runway and the Head Up Display (HUD) format was selected on a cockpit multi-purpose display indicator (MDI) in order to reference angle of attack. The head position required to maintain visual contact with the runway precluded viewing the actual HUD. The airplane departure warning tone, which activates at 15 degrees AOA in the landing configuration, provided an aural cue to the pilot to avoid exceeding desired AOA. The flight test adjustable AOA bracket provided rapidly interpretable visual reference for target AOA. The AOA bracket was set to 14 degrees and the HUD attitude source was selected to the "standby" mode which removed the velocity vector (or flight path marker) from the HUD display and caused the AOA bracket to be displayed relative to the aircraft "waterline" symbol (Figure 2-6). During these nose high approaches the velocity vector was display limited (off the bottom of the HUD) and, therefore, provided no useful information to the pilot. Maintaining the proper rate of descent by scanning the FLOLS, and lineup by scanning the end of the runway consumed most of the pilot's effort. As a final check of proper pitch attitude, the Test Conductor would transmit exact pitch attitude (from telemetry) as the airplane descended through 200 feet. This provided a final opportunity for the pilot to adjust pitch attitude in order to achieve target parameters. Persistence was key as many points achieved some, but not all, required conditions--often missing pitch or sink rate by only tenths of a unit.

Drop Test Results

Arrested landing tests were slightly delayed due to results from the drop test article. Those results led to a redesign of some landing gear components which were incorporated on the test airplane prior to commencement of flight testing. This event provided another example of the benefit of having non-flying test articles--a weak link in the landing gear was discovered without jeopardizing a flightworthy asset. Arrested landing tests were interrupted at other times throughout the program when loads exceeded predictions. On these occasions, data were reviewed to ensure adequate strucural integrity margins existed with the encountered loads. If so, the operational limits were adjusted to reflect the new values. If not, component redesign was required.

Hookpoint Loads

Following a build up to high sink rate, half flap arrestments the inspection crew noticed a crack in the hookpoint. When the attachment bolt was removed, the hookpoint was found to have broken into two pieces. Hairline cracks were subsequently found on two other hookpoints which had been used during earlier arrested landing tests. Reworking the hookpoint design to change the radius of curvature between the cable groove and the lug support, shown in Figure 4-3, seemed to resolve the load transmission problem. The aircraft hookpoint was changed following every fifth arrestment and a non-destructive inspection conducted on the used hookpoints to ensure no recurrence of cracks. Once the new hookpoint design demonstrates structural integrity through 100 arrestments, this flight test restriction should be removed and hookpoints should have no more stringent inspection requirements than other carrier airplane hookpoints.

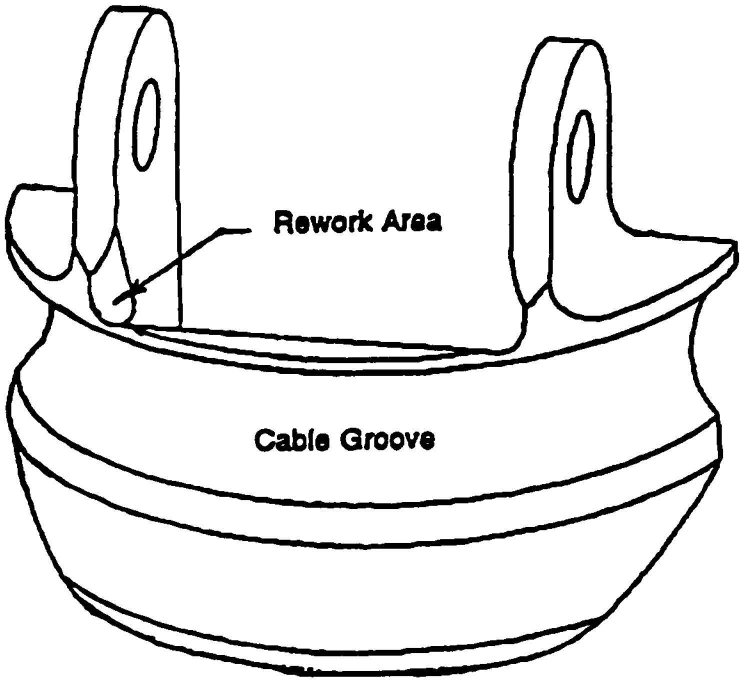


Figure 4-3. Hookpoint Rework

Source: Maintenance Memorandum, Inspection of Reworked Hookpoints, McDonnell Douglas Aerospace, November 1996.

Hook Shank Loads

During the build up to tail down arrestments, testing was halted when the arresting hook shank compression load exceeded the limit for the aft fuselage back-up structure (the aircraft keel). These loads were dubbed 'pogo' loads since the hook shank was acting as a large pogostick with a 42,000 pound rider. Once again a hookpoint modification was ordered--this time the machining change was conducted to reshape the 'heel' of the hookpoint to reduce the shank compression loads at deck impact. The modification was successful in reducing the loads by approximately 15%. (Demonstration Data Report, pg. 15-3.)

Nose Down Pitch Attitude Landing Gear Loads

Following build up arrested landings, the first nose down pitch attitude, high sink rate demonstration point was achieved. Data indicated that all load parameters were within acceptable limits except the nose landing gear axle total vertical/drag combined load which reached 109% of the predicted maximum. Post-flight inspections revealed no damage to the landing gear or aircraft structure and subsequent analysis of the data allowed for expansion of the nose landing gear vertical/drag combined load envelope. The final two nose down pitch attitude demonstration points were successfully completed with loads remaining within the redefined envelope. (Demonstration Data Report, pg. 15-2.)

Reduced Authority Thrust System

Testing was conducted with simulated reduced authority thrust system (RATS) failures in order to evaluate performance in the event of a reduced thrust situation. The RATS block described in Chapter 2 was attached to the throttle quadrant during engine run up on deck (or on the catapult) and left in place during the waveoff and bolter tests. Performance with the simulated RATS failure was adequate to provide satisfactory waveoff capability and comfortable bolter flyaway.

Initial Sea Trials

General

As previously noted, Initial Sea Trials (IST) were conducted aboard USS John C. Stennis (CVN 74) in January, 1997. The fly-on on 18 January was jeopardized by weather, however, as the ship encountered high winds and blowing snow 100 miles off the North Carolina coast. The ship steamed (mostly) clear of the

Figure 4-4. Initial Sea Trials.

Source: Photo by Randy Hepp from airplane piloted by author.

snow, but the 40-45 knot winds caused the first arrested landing to be conducted in the half flap configuration. Figure 4-4 shows F/A-18F1 during its approach turn for the first shipboard arrested landing. After the first day's work, the ship steamed south off the Florida coast where ideal conditions prevailed for the remainder of sea trials. A total of 64 arrested landings and catapult launches were performed during the six days of tests. Two pilots split the 14.2 flight hours accumulated during 13 flights.

Catapult Launches

Catapult launches were conducted at military and maximum afterburner power from each of the four catapults. Center of gravity (CG) was varied using the flight test fuel transfer function, with all CG locations remaining within operating limits. Longitudinal trim was varied to identify possible hazardous effects. In all cases catapult flyaway was comfortable, displaying smooth rotation to target angle of attack with no pilot control input. CG and trim variations had minor effects on rotation rate, but there was no aircraft settling nor did the pilots feel the need to make flight control inputs prior to the completion of the automatic rotation to the flyaway pitch attitude. Effects of crosswinds up to the carrier standard operating limit of 10 knots direct crosswind component were also negligible.

Catapult Hook-Up

During catapult hook-up it was discovered that the launch bar (or tow link) was becoming jammed on the catapult shuttle as the airplane was taxied forward in preparation for launch. Under normal operation, the launch bar should transition smoothly from the deck level guide track to the ramp on the catapult shuttle. Investigation ashore determined that the launch bar had not been machined in accordance with the blue print -- a bevel had been omitted -- and this was the cause of the interference. The launch bar was structurally sound, and a minor modification to catapult hook-up procedures allowed continued testing. Launch bars should be reworked to specification.

Landing Approaches

Approaches were flown in both full and half flap configurations, and with simulated single engine failures and simulated RATS-on failures. "Off nominal" approaches were flown to evaluate flying qualities and engine performance during excessive approach deviations. Effects of crosswinds up to the carrier standard operating limit of 7 knots direct crosswind component were minimal. Flying qualities and engine response were excellent in all configurations tested.

The most significant observation to come from the 172 approaches flown was from the perspective of the carrier flight deck -- at ranges greater than approximately a quarter of a mile the F/A-18F was visually indistinguishable from F/A-18A/B/C/Ds. Earlier series F/A-18s from the two Fleet Replacement Squadrons were conducting carrier qualifications concurrently with F/A-18F1 IST. Those features which would appear to clearly identify the E/F, were masked throughout most of the landing pattern. The inlet shape was shadowed by the wing LEX when the airplane was on final straight-away. The profile of the airplane, both head-on and abeam, was too similar to earlier models to provide accurate distinction, and relative size was not useful since relative range was unknown. Ascertaining which type Hornet is recovering is extremely important to the carrier, since the weight setting for the arresting gear differs by 9,000 pounds between the two aircraft series. Landing an F/A-18E or F at the weight setting for an F/A-18A/B/C/D could severely damage the ship's arresting gear, while landing an F/A-18A/B/C/D at the weight setting for an F/A-18E/F would damage the airplane. Some means must be incorporated to allow unambiguous distinction between the different series F/A-18s in the daytime carrier landing pattern.

A contrast paint scheme applied to the left side, upper portion of the aircraft radome is recommended. A large area of darker color in this region would provide visual distinction at both the abeam position and final straight-away position of the carrier landing pattern. Such a paint scheme should avoid the underside of the airplane which is masked by the aircraft shadow.

CHAPTER V

CONCLUSIONS

General

Within the scope of this thesis, results show that the F/A-18E/F can operate from the decks of existing U.S. Navy aircraft carriers with acceptable margins of safety in performance and structural loads. Successful completion of the clean configuration, carrier suitability demonstration represents a major milestone in the F/A-18E/F development program. Initial Sea Trials were arguably the most successful in Naval Aviation history.

Specific

1. Afterburner lockout system reliability was poor. The system did not provide adequate protection against inadvertent selection of afterburner during catapult launch and arrested landing.

2. The launch bar, as installed on F/A-18F1, was deficient in that the launch bar would hang-up on the catapult shuttle during catapult hook-up, rather than guiding smoothly up the shuttle.

3. The F/A-18E/F was visually indistinguishable from F/A-18A/B/C/Ds throughout the majority of the carrier landing pattern. Ensuring accurate aircraft identification in order to set the appropriate weight setting for shipboard arresting gear will be difficult.

4. The flight test features incorporated in the F/A-18F greatly enhanced test efficiency.

CHAPTER VI

RECOMMENDATIONS

1. The F/A-18E/F should be cleared for carrier operations in the clean aircraft loading.

2. Afterburner lockout solenoid reliability should be improved.

3. Changes to the aircraft launch bar should be incorporated to avoid catapult hook-up delays due to the launch bar hanging up on the catapult shuttle.

4. Measures should be incorporated to increase the visual distinction between the F/A-18E/F and earlier series F/A-18s. Such measures could include modifying the paint scheme so that the two aircraft series are clearly distinguishable. A contrast paint scheme applied to the left side, upper portion of the aircraft radome is recommended.

5. Hookpoints should have no more stringent inspection requirements than other carrier airplane hookpoints.

6. Future aircraft test programs should include dedicated instrumentation system checkout events in order to ensure system functionality throughout the range of aircraft loads to be tested.

7. Future aircraft test programs should examine and incorporate flight test features such as pilot-programmable flight controls, fuel transfer, and selectable display modifications in order to increase test efficiency.

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VITA

Tom Gurney was born in Bethesda, Maryland on December 20, 1958. He was raised in a navy family and attended schools in California, Hawaii, and Virginia, graduating from W. T. Woodson High School, Fairfax, VA, in 1977. He entered the U.S. Naval Academy in July of 1977 where, in May, 1981 he received a Bachelor of Science degree in Aerospace Engineering. He earned his Naval Aviator wings in December of 1982 in Kingsville, Texas, and served as a flight instructor in the T-2C Buckeye airplane until November, 1984. Following a tour with Strike Fighter Squadron 25, flying F/A-18s out of Lemoore, California, he attended the U.S. Naval Test Pilot School, graduating with Class 95 in June, 1989. He served with Strike Aircraft Test Squadron in Patuxent River, Maryland as a test pilot and landing signal officer until 1991. He then returned to the Naval Test Pilot School to serve as an instructor until July, 1992. He served as a department head with Strike Fighter Squadron 151, again flying F/A-18Cs out of Lemoore, from 1993 to 1995. During his tours flying the F/A-18 in operational squadrons he completed two extended deployments to the Western Pacific, Indian Ocean, and Arabian Gulf. He has accumulated over 3800 flight hours in tactical jet aircraft and logged over 450 carrier arrested landings.

At the time of submission of this thesis, he held the rank of Commander, USN, and was assigned as the lead carrier suitability test pilot on the F/A-18E/F Integrated Test Team, Patuxent River, Maryland.