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A Review and Analysis of Precision Approach and Landing System (PALS) Certification Procedures

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To the Graduate Council:

I am submitting herewith a thesis written by John D. Ellis entitled "A Review and Analysis of Precision Approach and Landing System (PALS) Certification Procedures." I have examined the final electronic copy of 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.

Robert B. Richards, Major Professor

We have read this thesis and recommend its acceptance:

Ralph D. Kimberlin, Charles T. N. Paludan

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Anne Mayhew
Vice Provost and Dean of Graduate Studies

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A REVIEW AND ANALYSIS OF PRECISION APPROACH AND LANDING SYSTEM (PALS) CERTIFICATION PROCEDURES

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

John D. Ellis
August 2003

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ABSTRACT

The Precision Approach and Landing System (PALS) is an Electronic Landing Aid (ELA) installed aboard all operational Naval Aircraft Carriers and is designed to provide an all-weather approach and recovery capability during daylight or darkness with minimum interference from conditions of severe weather and sea state for carrier based aircraft. The PALS consists of the AN/SPN-46 Automatic Carrier Landing System, the AN/SPN-41 Independent Landing Monitor/Instrument Carrier Landing System, and a qualified aircraft. PALS is capable of three modes of operation; fully automatic, pilot manual control based on cockpit displays of glide slope and centerline error data, and pilot manual control based on approach controller talk down.

Whether performing a fully automatic or a manual approach, consistent and reliable operation of the PALS is paramount in instilling aviator confidence in the system. Erroneous or conflicting data between the sub-systems may cause the aviator to abandon the PALS in favor of a higher workload, manual, non-precision approach. Naval Air Systems Command instruction establishes the general criteria by which certification of the PALS is required. This thesis discusses the methodology used to certify PALS for proper and safe operation aboard modern naval aircraft carriers. These discussions also include operational considerations, which must be made relative to operating in the shipboard environment.

PREFACE

The flight test results contained within this thesis were obtained during United States Department of Defense sponsored Naval Air Systems Command projects conducted by the Naval Air Warfare Center Aircraft Division, Patuxent River, MD. The discussion of the data, conclusions and recommendations presented are the opinions of the author and should not be construed as an official position of the United States Department of Defense, the Naval Air Systems Command, or the Naval Air Warfare Center Aircraft Division, Patuxent River, MD.

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GLOSSARY

ACLS	Automatic Carrier Landing System
AFCS	Automatic Flight Control System
AI	Attitude Indicator
AOA	Angle of Attack
APCS	Automatic Power Compensator System
CATCC	Carrier Air Traffic Control Center
DDI	Digital Display Indicator
DMC	Deck Motion Compensation
ELA	Electronic Landing Aid
HUD	Heads Up Display
ICLS	Instrument Carrier Landing System
IFLOLS	Improved Fresnel Lens Optical Landing System
ILM	Independent Landing Monitor
ILS	Instrument Landing System
LRLS	Long Range Line-up System
PALS	Precision Approach and Landing System
PQR	Pilot Quality Rating
SARI	Stand-by Attitude Reference Indicator
UFC	Up Front Controller
VLA	Visual Landing Aid

CHAPTER I

INTRODUCTION

BACKGROUND

The economy and security of the United States of America depends upon protecting overseas interests as well as encouraging peace and stability around the globe. Forward presence by U.S. Navy aircraft carrier battle groups and amphibious ready groups helps accomplish this. At the heart of these battle groups is the aircraft carrier, supporting the naval aviation community. Naval aviation is the very tip of this forward presence providing support, reconnaissance, or force where and when it is needed.

The basics of being able to provide these services through naval aviation is the ability to launch and recover aircraft from the deck of an aircraft carrier under varying conditions. These conditions include, but are not limited to, weather, sea state, visibility, and various aircraft and ship emergencies. Due to the nature of modern naval aviation missions, it is not out of the ordinary for an aircraft carrier to recover an aircraft in the black of the night, during thunderstorms, in 25 foot seas with a fatigued pilot returning from a three hour, heavily tasked mission. It was dangerous missions such as this that led the aviation community to establish the requirement for an automatic carrier landing system. This system had to be capable of providing for the safe and reliable final approach and landing of carrier-based aircraft during daylight or darkness, with minimum interference from conditions of severe weather and sea state and no limitation due to low ceilings and visibility.[1]

In response to this requirement, the U.S. Navy developed the Precision Approach and Landing System (PALS). The PALS consists of the AN/SPN-46 Automatic Carrier Landing System (ACLS), the AN/SPN-41 Independent Landing Monitor (ILM) /Instrument Carrier Landing System (ICLS), and a properly equipped aircraft. The AN/SPN-46 ACLS, referred to as the ACLS, is a radar based system comprised of shipboard and airborne based components developed to provide an automatic or manual touchdown capability for carrier based aircraft. The AN/SPN-41 ICLS, referred to as the ICLS, is a completely independent landing system designed to allow the pilot to monitor the ACLS and to provide the pilot with accurate flight path information for Instrument Landing System (ILS) type approaches in the event the ACLS fails entirely.

In April of 1988, the first AN/SPN-46 based PALS installation was certified aboard the USS John F. Kennedy. The benefits the system provided to naval aviation were immediately recognized. Since that original installation, all other existing and newly constructed aircraft carriers have been equipped with AN/SPN-46 based PALS. PALS is now a vital component to modern naval aircraft recovery.

SCOPE

Whether performing a fully automatic or a manual approach, proper operation of the PALS is of paramount importance to instilling aviator confidence in the system.

Erroneous or conflicting data between the sub-systems may cause the aviator to lose confidence and abandon the PALS in favor of a much higher workload, manual, non-precision approach. The system must have a high rate of operational availability and provide highly accurate and dependably repeatable data to the pilot. This need for accurate, repeatable performance from the system demands vigilant system maintenance and extremely thorough periodic inspections. In order to ensure the system is performing at this demanding level, a periodic certification process is in place. The procedures of the certification process and the responsibilities of the certifying organizations are documented in detail.[2] These details highlight the timeline for the certifications, what organizations are responsible for the various tests involved in the certification process, and how the tests will be accomplished. In addition, several other documents describe the tests in detail.[3,4] These documents are reviewed and updated periodically to ensure the newest and most efficient test methods are utilized during the certification process.

This thesis will discuss the methodology used during the certification process based on certifications conducted since May 1990 and offer alternative methods that may enhance the certification process.

CHAPTER II

SYSTEM DESCRIPTION

SHIPBOARD SYSTEMS

The U.S. Navy's fleet of aircraft carriers operates year-round, in waters spanning the globe. Recovering aircraft aboard these vessels is said by many to be one of the most dangerous jobs in the world. Multiple, highly specialized systems have been developed over the years to aid pilots in landing aboard an aircraft carrier. The specific landing systems that the pilot utilizes and the manner of approach adopted by the pilot is dependent on whether it is day or night and the prevailing weather, ceilings, and visibility around the ship. Although these landing systems operate independently, it is their synergistic effect that provides the most benefit to the pilot during recoveries. A pilot may utilize one particular landing system as primary during the major portion of a recovery but the other systems will, most assuredly, be referenced by the pilot at least to verify the information being received from the primary landing system. It is because of this "cross referencing" of landing aids that all systems must provide the same accurate data to the pilot. Systems displaying erroneous information make it impossible for the pilot to render an informed decision because the pilot is not sure which system is correct. This is an important consideration concerning the implementation of the PALS. Not only must the PALS operate properly and provide accurate information to the pilot, but it must also agree with the other landing aids utilized by the pilot. Since the PALS consists of two independent landing aids, the ACLS and the ICLS, these two systems must provide the same dependable information. In addition, the PALS must also agree with the visual landing aids located on the aircraft carrier, such as flight deck lighting and marking, Improved Fresnel Lens Optical Landing System (IFLOLS), and Long Range Line-Up System (LRLS).

Visual Landing Aids

Shipboard flight deck lighting and marking is necessary to ensure safe takeoff, landing, and flight deck handling operations of aircraft. Figure 1 is a view of the aircraft carrier deck with labeled deck markings and lighting. Deck lighting related to recovering aircraft aboard the aircraft carrier include deck edge lights, centerline and landing area lights, overhead flood lights, vertical drop line lights, and safe parking lights. Major markings consist of landing area ladder, centerline, and foul line.

The IFLOLS, shown in figures 2 and 3, is the primary visual landing aid aboard all U.S. Navy aircraft carriers.[5] It consists of a system of lights located on the port side of the ship, adjacent to the landing area. It is designed to provide the pilot a visual indication relating the position of the approaching aircraft to a prescribed glide slope. The display consists of an amber light, known as the “meatball”, that appears to move up or down the indicator assembly relative to the horizontal row of green datum lights depending on the vertical position of the aircraft relative to the predetermined glide slope. The glide slope is designed to bring the aircraft down to the desired touchdown spot with a safe arresting clearance above the ramp of the aircraft carrier. During a manual approach, it is the pilot’s job to maneuver the aircraft so the meatball lines up with the

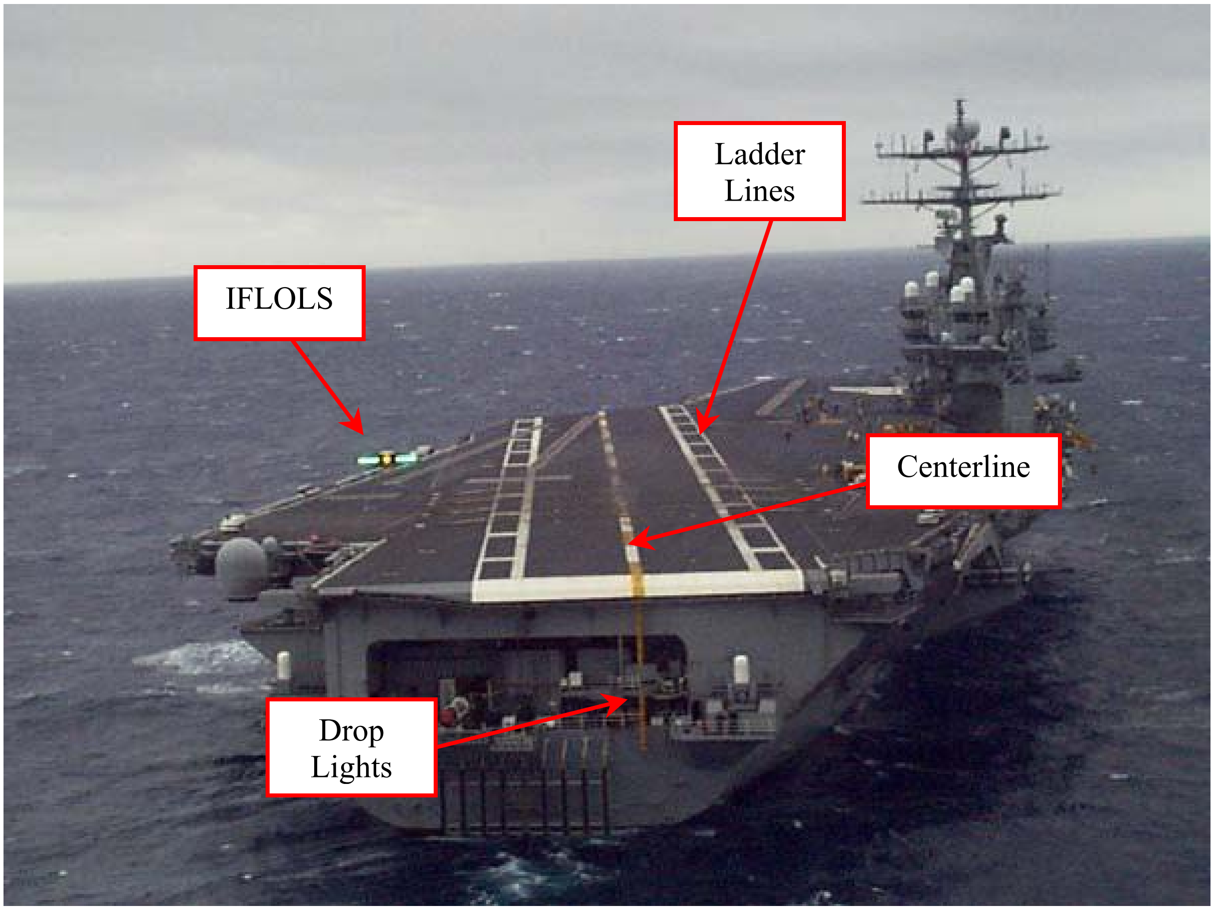


Figure 1
Carrier Deck Lighting and Marking
Source: Naval Air Warfare Center, Patuxent River, Maryland, October 1997

Figure 2
IFLOLS Hardware
Source: Evaluation of the Improved Fresnel Lens Optical Landing System, Naval Air Warfare Center, Patuxent River, Maryland, 01 May 1997 (NAWCADPAX—97-90-RTR)

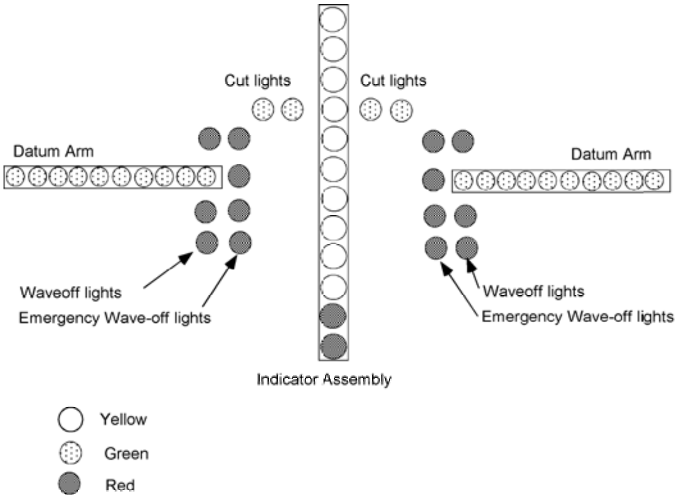


Figure 3
IFLOLS Display Lights
Source: Evaluation of the Improved Fresnel Lens Optical Landing System, Naval Air Warfare Center, Patuxent River, Maryland, 01 May 1997 (NAWCADPAX—97-90-RTR)

datum arms, placing the aircraft on the proper glide slope. When using either the ACLS or the ICLS during an approach, if the glide slope information presented to the pilot differs from that of the IFLOLS then the pilot will discontinue using the PALS and rely on the IFLOLS for the remainder of the approach.

The LRLS is a visual landing aid which uses steady and flashing lasers of different colors to provide centerline line-up information to the pilot on approach to an aircraft carrier. The system is designed to provide precise information at ranges outside the range capability of the centerline drop lights thus enabling the pilot to make earlier corrective actions to line-up deviations and to improve boarding rates and safety by reducing the probability of large line-up corrections in-close. The LRLS inclination is varied with the glide slope to allow the aircraft to fly out the top of the vertical coverage at a designated cut-off range where the pilot will transition to the centerline drop lights and deck marking for line up cues. Figure 4 depicts the LRLS, as installed, on top of the centerline drop lights. Figure 5 is a depiction of the various laser corridors indicating aircraft position relative to centerline.[6]

AN/SPN-41 ICLS

The AN/SPN-41 ICLS, referred to as ICLS, is a shipboard mounted, stabilized ILS similar to commercially used land based ILS units. It employs microwave scanning techniques to provide the pilot a display of glide slope and line up error information similar to the ACLS information display described in the next section. The major shipboard components of the ICLS include two separate, stabilized antennas used for

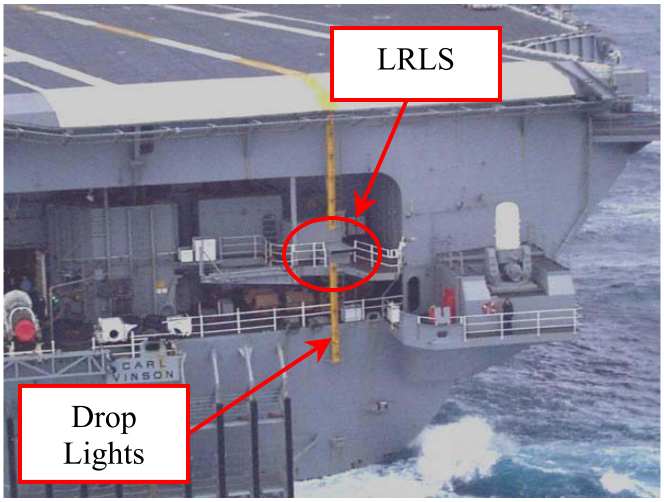


Figure 4
LRLS as Installed
Source: Long Range Line-Up System Developmental Tests, Naval Air Warfare Center, Patuxent River, Maryland, October 1997

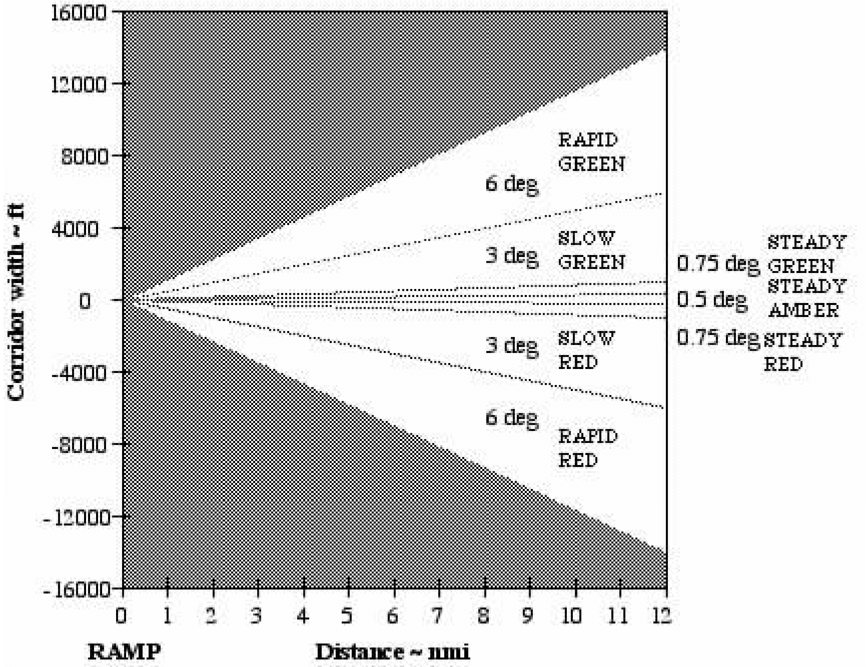


Figure 5
LRLS Corridors
Source: Long Range Line-Up System Developmental Test And Evaluation Test Plan, Naval Air Warfare Center, Patuxent River, Maryland, 02 October 1997 (NSATS Test Plan #2126)

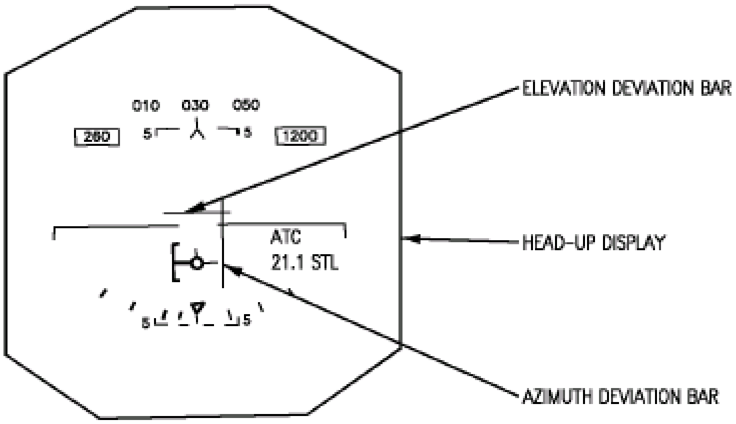


Figure 6
AN/SPN-41 ICLS Cockpit Display
Source: NATOPS Flight Manual Navy Model F/A-18A/B/C/D, Naval Air Technical Data and Engineering Service Command, Naval Air Station North Island, California, 15 July 2001

azimuth and elevation and two transmitting units. These transmitting units send coded microwave signals to all aircraft within a volume approximately 7 nautical miles wide, 3 ½ nautical miles high, and 20 nautical miles astern of the aircraft carrier. The receiver/decoder in the aircraft receives the signals, decodes the data, and presents the data in a cockpit display for the pilot to interpret. This display shows the desired flight path to the aircraft carrier with respect to the position of the aircraft. It is referred to as a "fly to" display because the position indicators show the pilot where to fly the aircraft. It is the pilot's responsibility to interpret the flight path information and line up the aircraft manually for a proper approach. Figure 6 is an example of the ICLS cockpit display.[4] Figure 7 is an example of typical deviations from glide slope and centerline that the pilot would view at various locations.

During conditions of optimum weather, sea state, and visibility the ICLS is used

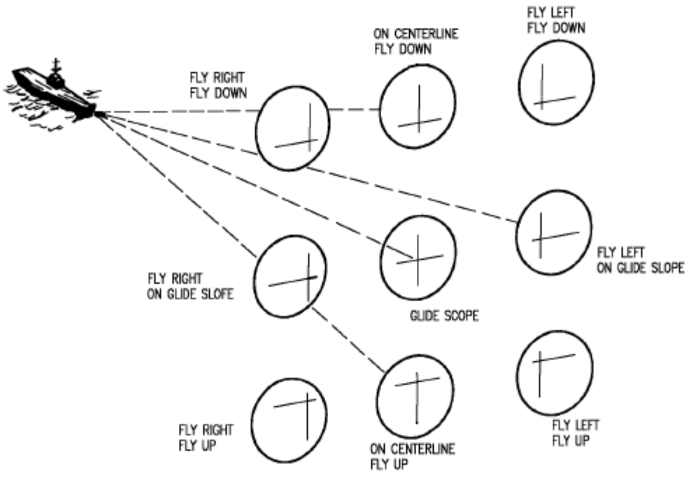


Figure 7
AN/SPN-41 ICLS Display Deviations
Source: NATOPS Flight Manual Navy Model F/A-18A/B/C/D, Naval Air Technical Data and Engineering Service Command, Naval Air Station North Island, California, 15 July 2001

at the beginning of a visual approach to aid the pilot in aligning the aircraft to the desired flight path so the pilot may transition in close to the IFLOLS and deck lighting and marking for visual landing cues. Under less than desirable conditions, the ICLS is used to aid the pilot in positioning the aircraft for AN/SPN-46 ACLS acquisition. When the pilot has properly positioned the aircraft and it has been acquired by the ACLS, the pilot will have the option of flying a manual approach based on ACLS flight path cues or a “hands off”, automatic approach controlled by the ACLS. In either case, the ICLS will be used as an independent monitor of glide slope and lineup performance to the ACLS during the approach. The use of the ICLS as an independent landing monitor to the ACLS is a crucial feature of the PALS. Without this capability, the pilot would be unable to judge the accuracy of the ACLS commands and error signals. Inaccurate ACLS information is a safety of flight issue during low visibility conditions when the pilot is unable to reference visual cues on the aircraft carrier to judge performance. The ICLS eliminates this problem by providing the pilot with a totally independent source of glide slope and line up information to directly compare with the information from the ACLS.[7]

AN/SPN-46 ACLS

The AN/SPN-46 ACLS is a stabilized, radar based landing system designed to provide a safe and reliable final approach and landing of carrier-based aircraft during daylight or darkness, with minimum interference from conditions of severe weather and sea state and no limitation due to low ceilings and visibility. Although the system was designed as an automatic landing system, it also provides a manual control capability.

The ACLS consists of two precision tracking radars, computers, a data link transmitter, ship motion sensors, and control consoles. The two precision tracking radars enable it to track two aircraft simultaneously. They provide unrestricted coverage in azimuth throughout an angular sector between 150 and 225 degrees relative to the ship's heading, in elevation between plus 30 and minus 15 degrees, and are capable of acquiring aircraft at a range of up to 10 nautical miles. This theoretical envelope is referred to as the acquisition window. Figure 8 shows the standard instrument pattern flown with respect to the ACLS acquisition window.

System operation is similar to a voice controlled aircraft approach and landing. The controller positions the acquisition window at the pattern altitude and the extended centerline of the aircraft carrier. The system locks onto the aircraft when it penetrates the acquisition window. The radar tracks a beacon on the aircraft, the aircraft's airframe, or

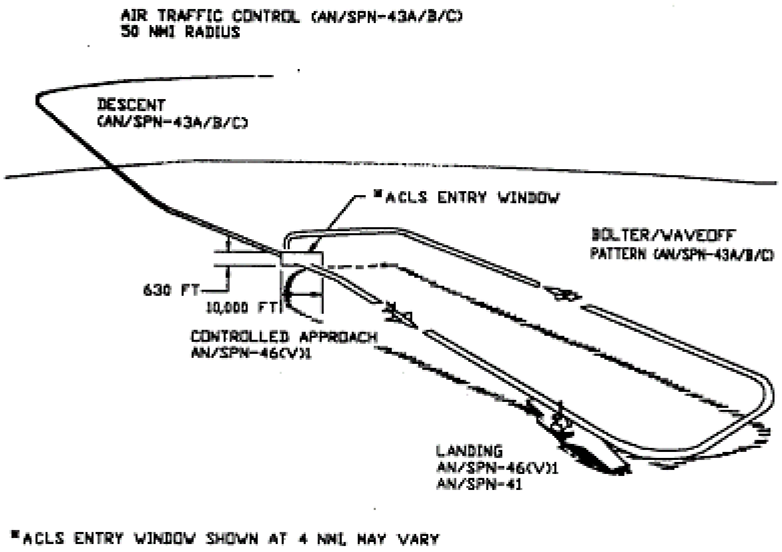


Figure 8
ACLS Flight Pattern
Source: AN/SPN-46(V)1 Automatic Carrier Landing System (ACLS) Console Operating Procedures, Naval Air Warfare Center, St Inigoes, Maryland, 31 March 1998

both to determine the aircraft's spatial position with respect to the radar antenna. The data for slant range and angular position are then converted by the computer into lateral, longitudinal, and vertical position coordinates relative to the desired touchdown point on the deck. The ship motion sensors provide data to the computer to correct for ship's rotational motion and heave. The corrected data are entered into a flight computational routine for comparison with a stored flight path for the particular type of aircraft being tracked. Deviations from the desired flight path are then converted by the computer into pitch or vertical rate commands and bank commands, taking into account the response characteristics of the controlled aircraft type. These commands are then transmitted to the aircraft through the data link or verbally from the console operator depending on the mode of control desired.[7]

If the pilot chooses to make an automatic approach then the transmitted commands are coupled into the Automatic Flight Control System (AFCS) in the aircraft and to the pilot's cockpit displays to allow the pilot to monitor the approach. The AFCS, controlled by the ACLS, keeps the aircraft on the designated flight path and glide slope. The Approach Power Compensator System (APCS) maintains the approach angle of attack by automatically controlling the throttle setting. Approximately 12 seconds prior to touchdown, the ACLS introduces Deck Motion Compensation (DMC), based on touchdown point heave, into the aircraft control algorithm so the aircraft will be in phase with the ship's moving flight deck at touchdown.

If the pilot chooses to make a manual approach then the pilot either maneuvers the aircraft based on the ACLS information presented on the cockpit displays or follows the voice commands of the controller. In either case, automatic or manual, the pilot relies on all other sources of information available to aid in the approach. The ICLS is relied upon to position the aircraft for the ACLS acquisition window and as a second, independent source to monitor the approach. When the aircraft reaches ¾ nautical mile from the ship and the weather permits a visual approach, the pilot transitions to the visual landing aids to support the approach. If continuing an automatic approach then the IFLOLS will be used to monitor the approach, but if it is a manual approach then the pilot will use the IFLOLS as the primary source for glide slope control taking into account the great benefit of precise lineup the ACLS provided to that point in the approach.

AIRCRAFT SYSTEMS

In order for the PALS to work effectively, a host of components must be installed and operating properly on the aircraft. Some of these components are used in conjunction with the ICLS and some with the ACLS. Major ACLS aircraft components include a data link, an AFCS, a coupler to join the AFCS with the data link receiver, an APCS, beacon, beacon antenna, and cockpit displays. Major ICLS aircraft components include a dual mode receiver/decoder, antenna and wave guide assembly, and cockpit displays.

The cockpit displays provide visual situational awareness to the pilot at all times. In an F/A-18, the pilot uses the Up Front Controller (UFC) to input data relating to the PALS such as frequencies and channels. The pilot has the option of viewing the PALS visual cues on any of four devices; the Heads Up Display (HUD), the Standby Attitude Reference Indicator (SARI), the Multi-Purpose Color Display (MPCD), and two Digital Display Indicators (DDI). The SARI only has the capability of displaying the ICLS commands. Figure 9 shows each of the cockpit displays available for PALS in the F/A-18 aircraft.

PALS OPERATIONAL MODES

The ACLS is capable of four methods of aircraft control; Mode I, II, IID, and III. These four methods differ by the type of control, automatic or manual, and the source of the information, display or voice. Mode I is an automatically controlled approach. Mode II is a manually controlled approach in which ACLS information is provided to the pilot

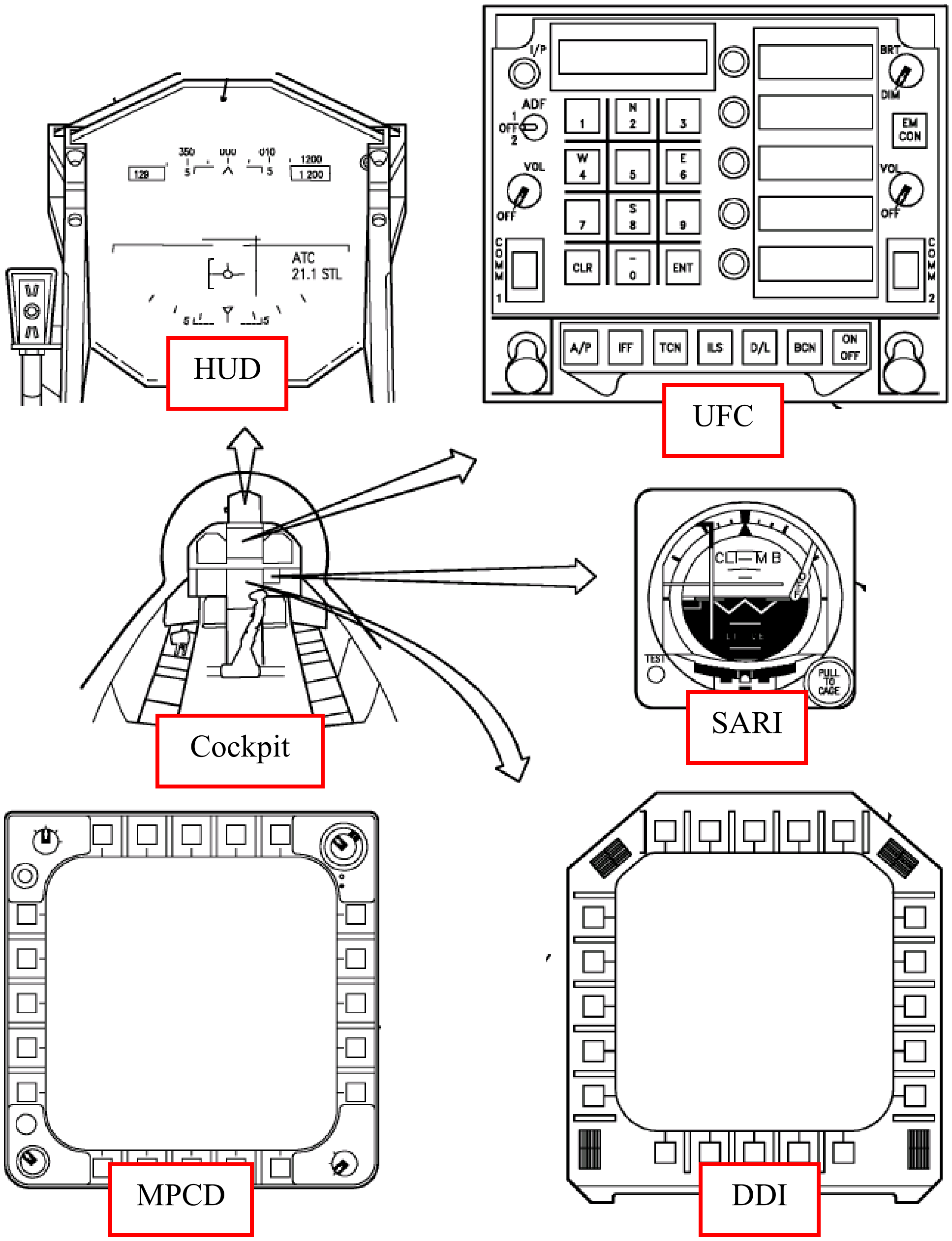


Figure 9
PALS Cockpit Displays and Controls
Source: NATOPS Flight Manual Navy Model F/A-18A/B/C/D, Naval Air Technical Data and Engineering Service Command, Naval Air Station North Island, California, 15 July 2001

on a cockpit display. Mode III is a manually controlled approach in which information is provided by voice communications. Mode IID, also referred to as the flight director mode, is a manually controlled approach, designed specifically for the F-14D aircraft, that provides guidance based on Mode I calculations.

During Mode I approaches, the ACLS controls the aircraft from acquisition to touchdown. During all other modes of operation, the ACLS provides information to the pilot during the entire approach, however, at ¾ nautical mile from touchdown, weather permitting, the pilot uses the VLAs as the primary source of control information. In all cases the ICLS is used as an independent landing monitor.

When the aircraft is acquired, the pilot requests one of the four ACLS approach modes from the air traffic control personnel. The available approach modes will be determined by the aircraft type and what ACLS components are installed and operating properly on the aircraft. The ACLS approach sequence begins with establishing data link communications approximately 6 nautical miles from the aircraft carrier. This communication is established when the ACLS controller enters the aircraft's data link address into the console. The pilot receives confirmation of this through a LANDING CHECK light in the cockpit. The pilot continues the approach manually until the aircraft enters the ACLS acquisition window. When the ACLS has acquired the aircraft, the pilot will observe an ACLS LOCKON light in the cockpit and ACLS error signals for glide slope and lineup are displayed. After receiving error signals, the COUPLER AVAILABLE light illuminates indicating to the pilot that commands are available for automatic control. It is then the job of the pilot to ensure the aircraft is configured for landing, near the final approach speed, and in level flight with the APCS engaged if Mode I is chosen. If the pilot desires a Mode I then the pilot must engage the AFCS and report coupled to the controller. The controller then initiates the transmission of pitch and bank commands. When these commands are received by the aircraft the COMMAND CONTROL light is illuminated in the cockpit to inform the pilot. The approach will continue to be controlled automatically until touchdown. At 12 seconds from touchdown, the DMC is added to the commands to get the landing aircraft in phase with the deck motion of the aircraft carrier and a 10-SECOND light illuminates to indicate to the pilot that DMC commands are being received. During the approach, the controller monitors the sequence of events on the control console by means of a display that graphically depicts the messages being transmitted to the aircraft and the position of the aircraft relative to centerline and glide slope.[7]

CHAPTER III

CERTIFICATION METHODOLOGY

OPERATIONAL CONSIDERATIONS

When conducting flight tests on an aircraft carrier there are several operational and environmental factors that must be taken into consideration. Although one would like to have complete control of the testing scenario, many variables are simply out of the hands of the test conductors. Some of these variables have a pronounced affect on the performance of the aircraft, particularly when the aircraft is under automatic control.

In addition to free air turbulence, the test conductor must also consider the turbulence that is a direct result of the aircraft carrier. This trailing airflow as the aircraft carrier progresses forward is known as the burble. The characteristics of the burble are influenced by many factors such as the magnitude and direction of the wind over the deck of the aircraft carrier, the ship's rotational and translational motion, the ship's trim condition, and the current flight deck configuration and operations. The characteristics of the burble have a direct impact on the ability of the ACLS to maintain the aircraft flight path within acceptable tolerances.

Because of the degrading effects of burble on the performance of the ACLS, it is important for the test conductor to understand the level or severity of the burble. However, the burble is a very intangible factor and quantifying it is not an easy task.

Numerous wind tunnel studies have been conducted to analyze the many factors influencing the burble, including island design and aircraft configuration on deck resulting in changes in the wind over deck magnitude and direction. These studies have yielded theories explaining the general affects and trends of varying the wind over deck magnitude and direction but have provided no solid quantifiable data to improve flight testing in a real world environment. The current methods used to define the level of turbulence are pilot qualitative opinion and aircraft instrumentation. The pilot will draw opinions on the burble based on aircraft motion such as normal accelerations and attitude accelerations, APCS throttle activity, and angle of attack (AOA) excursions. In addition, the flight test engineers also draw qualitative opinions on the burble based on aircraft instrumentation parameters such as AOA, airspeed, and attitude. To date, there are no better methods to quantify the severity of the burble while flight testing.

The aircraft carrier's motion and trim conditions are also important considerations when flight testing. Flight tests of the PALS should be conducted with the ship's pitch and roll trim in a condition that is representative of the ship's normal operating condition. As the pitch trim is increased, bow up, the burble effect is increased and a large loss in head wind magnitude is observed. However, as the pitch trim is decreased, bow down, the aircraft tend to land forward of the desired touchdown point. In an attempt to minimize the burble effect and the loss of head wind magnitude without sacrificing touchdown performance, the ideal trim condition of the ship for flight operations is slightly bow up in pitch and level in roll. The loading of the aircraft carrier determines the ship's trim condition. The location of fuel, provisions, armament, and aircraft onboard affects the trim. An adjustment such as transferring fuel from one holding tank in the bow of the aircraft carrier to another in the stern can change the pitch trim of the ship by several degrees.

Flight deck operations can have an effect on PALS certification efforts in several ways. The higher the number of aircraft on the flight deck, the more pronounced the burble. Also, conducting simultaneous launch and recovery operations results in aircraft engines operating at high thrust settings, jet blast deflectors being raised which interrupts airflow, and elevators being lowered causing additional turbulence, all of which affect the burble. In addition, some events conducted on the ship are not compatible with PALS certifications and are counter productive for both operations. For example, taxi drills or emergency barricade rigging on the flight deck make it impossible for the aircraft to come to touchdown and therefore preclude PALS flight tests. Also, fleet operations in which multiple aircraft are conducting arrested landings from the visual flight pattern do not mesh well with the longer instrumented pattern approaches common to a PALS certification.

Some factors such as the aircraft carrier's loading and its effect on the ship's trim condition or the type of flight deck operations planned can be discussed with ship personnel ahead of time and controlled to some extent to ease their impact on the flight tests. However, other factors such as high sea states that may influence the ship's motion, or undesirable wind conditions that may increase the burble effect, are out of the hands of the test conductors and the ship's operators. Although little can be done to alter some of these factors, the test team must be aware of their positive and negative effects on the test results and take them into consideration.

TEST OVERVIEW[2]

A PALS certification is defined as a comprehensive check of the PALS for all of the designated modes of operation. A PALS certification is required after an initial PALS installation, after modifications which affect aircraft control such as major ship or aircraft structural changes, for qualification of aircraft model and series not included in previous certifications, when flight verification tests confirm unsafe or improper aircraft control not attributed to improper function of shipboard hardware or electrical systems, for a major control program modification to improve aircraft control during the last half mile of the approach, for certification of a basic glide slope setting not previously certified, or after a ship's PALS capability has been downgraded not as a result of improper function of shipboard hardware or electrical systems. When an aircraft carrier is certified for a particular PALS mode of operation, all PALS modes with a numerically greater designation are included in that certification. For example, a Mode I PALS certification includes certification to operate using Mode II and Mode III as well. However, the ICLS clearances are not included in that certification. The ICLS certification is performed concurrently with the PALS certification, but the clearances are separate.

PALS certification tests consist of three categories; Category I, Category II, and Category III testing. Category I tests consist of functional non-flight tests of the shipboard components, such as electrical and mechanical tests, that ensure proper installation, interconnection, interface, alignment, and performance of the PALS. These tests are performed by a group of technicians, engineers, and software programmers with an in-depth knowledge of the PALS components and operation. This team provides thorough functional testing of the hardware and software components of the PALS before any flight test is allowed to commence. These tests also provide an initial, rough alignment prior to the flight tests by locking the unstabilized ACLS coordinate system to the aircraft carrier's flight deck. Category II tests include low approaches to the aircraft carrier while pierside that are concluded one quarter nautical mile aft of the aircraft carrier. These tests are designed to evaluate basic radar tracking, system operation, and alignment between ACLS, ICLS, and IFLOLS in the absence of ship's motion prior to the aircraft carrier leaving port and conducting at-sea tests. Because these tests are performed in port, they are a cost effective way to ensure no major problems exist within the PALS components and provide the team with some level of confidence in the PALS before the aircraft carrier goes to sea to perform the Category III tests.

Category III tests are at-sea flight tests and are the main focus of discussion for this thesis. The Category III tests consist of three phases. Phase I of the at-sea flight testing focuses on the basic alignment of the PALS and tracking and control of the ACLS. Once Phase I is completed and the test team is confident that the PALS is performing properly, Phase II concentrates on manipulating the control program parameters of the ACLS to improve the control characteristics for those aircraft exhibiting less than desirable control. The third and final phase, Phase III, of the at-sea flight tests is conducted to develop statistical confidence in the final control program configuration. While operating with the final control program parameters in place, longitudinal and lateral aircraft touchdown dispersion data are collected for analysis to gain statistical confidence in the operation of the PALS. Also, a sufficient number of approaches under varying wind over deck conditions are needed to develop statistical confidence in the control program for off nominal conditions. This phase of testing is also used to develop limitations in the aircraft carrier's trim conditions of pitch, roll, and heave during flight operations. These limitations are then posted as caveats along with other clearances given to the aircraft carrier once the certification is complete.

PHASE I

Phase I of the PALS certification begins with level altitude approaches, referred to as level legs, that are used to verify the level alignment of the ACLS stabilized coordinate system under ship motion conditions. To accomplish this, the radar is locked onto an aircraft as it flies a constant 900 foot approach to the ship using its radar altimeter. Throughout this approach, the pilot makes radio calls of the slight altitude deviations from 900 feet. These altitude deviations are recorded on the altitude time history trace from the output of the ACLS. This time history is then analyzed to determine if the ACLS coordinate system is level based on the level aircraft approach. For this test, a correction for the earth's curvature has to be made since the altitude data from the aircraft sensors are referenced to the earth's surface below the aircraft and the ACLS derived aircraft altitude is referenced to a coordinate system parallel to the earth's surface at the ideal touchdown point on the ship. This causes the altitude of the aircraft above the earth’s surface to be significantly greater than the derived aircraft altitude from the ACLS, specifically at longer ranges from touchdown.

After the radars have been leveled, the majority of the approaches conducted for the remainder of the certification are Mode I. The Mode I approaches conducted during Phase I are designed to evaluate the basic alignment of the ACLS and ICLS, to evaluate correlation with the IFLOLS, and to verify the tracking and control of the ACLS in nominal wind over deck conditions. These Mode I approaches are flown with the aircraft carrier’s trim condition in its normal operating range and while attempting to hold the wind over deck within ± 2 knots of the nominal wind over deck magnitude and ± 3 degrees of the nominal wind over deck direction. The nominal wind over deck, determined by historical data, is considered to be 25 knots of wind directly down the angle deck centerline which is approximately 9 degrees port of the axis of the aircraft carrier or 351 degrees relative to the axis of the ship. Therefore, the nominal wind over deck envelope is defined as 23 to 27 knots of wind at 348 to 354 degrees relative to the axis of the ship.

Several criteria are used to evaluate the PALS during these Mode I approaches in Phase I of the certification. These criteria include standards for the radar and stabilization sensor quality and accuracy, alignment standards for the landing systems, and pilot quality rating standards for the quality of the automatic control. The standards for the radar and stabilization sensor quality and accuracy are implemented by evaluating the time history traces of several key ACLS parameters. The time history traces of these parameters are evaluated by the test team to judge the quality of the tracking during the approaches. Specifically, the traces used to evaluate radar tracking quality are inspected for indications of excess friction in the radar pedestals, indicated by stepping in the traces, and for indications of sloppy tracking, indicated by flat spots on the traces whenever the antennas reverse direction while tracking the aircraft.

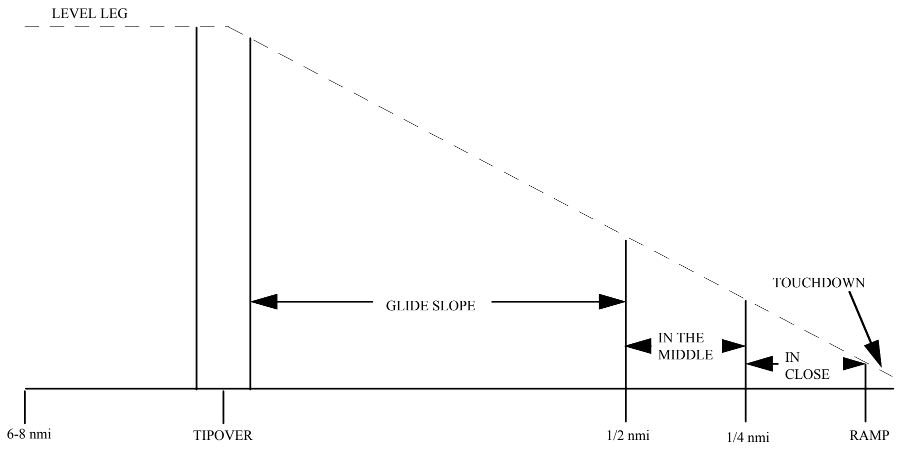
The alignment of the landing systems are also evaluated during the Mode I approaches. The pilot couples the aircraft to the ACLS and flies an automatic controlled approach. As the aircraft is progressing down the glide slope the pilot will make radio calls to the test conductors correlating the ICLS indications with respect to the ACLS indications. When the IFLOLS and deck markings and lighting become visible to the pilot, correlation calls between those and the ACLS will also be made. These calls will be manually recorded on the strip chart traces of glide slope and line up error and used to determine if the ACLS, ICLS, and visual landing aids are providing consistent, accurate data to the pilot. In some instances, differences in ship motion sensors or stabilization algorithms may have some effect on the correlation between the systems. If it is determined that the glide slope or line up information of the systems do not show satisfactory correlation then an engineering judgment may be made to change the alignment or stabilization sensor input of one of the systems to match the other system. This consistency between systems is important if the pilot is to have confidence in the PALS.

Pilot quality ratings are used to measure the quality of the automatic control from the pilot's perspective. The PALS approach is divided into several phases. During every approach, the pilot evaluates the control during each of these phases and assigns a rating based on the PALS Quality Rating Scale. The ratings for all approaches performed in the final program configuration are then averaged. An average rating of 2.5 or less is required for all phases of the approach for certification. Figures 10 and 11 are the various phases of the approach and the PALS Quality Rating Scale, respectively.

PHASE II

Once the basic control characteristics have been determined in Phase I for each aircraft type, the ACLS control program is modified for those aircraft exhibiting undesirable control characteristics to compensate for poor automatic control during the last 20 seconds of the approach. Although the ACLS control equations generate commands to keep the aircraft on the glide slope, the aircraft is occasionally forced off glide slope by disturbances in the burble. The worst case scenario resulting from this is when the aircraft is low as it crosses the ramp of the aircraft carrier or tends to land considerably short of the touchdown point.

If an aircraft consistently shows unacceptable glide slope deviations during nominal wind over deck conditions then open loop pitch command "ramps" may be added to the commands generated by the control equations to counteract the effects of the burble. The timing and magnitude of the pitch command ramps are based on quantitative assessments of the average vertical error time history of the last 20 seconds of the approach. The



Level Leg	The portion of the approach from after couple but before tipover.
Glide Slope	The portion of the approach from after the tipover transients have damped out until approximately 1/2 nmi or 16 sec from touchdown.
In the Middle	The approach from approximately 1/2 nmi or 16 sec from touchdown to approximately 1/4 nmi or 8 sec from touchdown.
In Close	The approach from approximately 1/4 nmi or 8 sec from touchdown to the ramp
Touchdown	The approach from the ramp to aircraft touchdown.

Figure 10
PALS Approach Phases
Source: Precision Approach Landing System (PALS) Standard Operating Procedures (SOP), Naval Air Warfare Center, Patuxent River, Maryland, 07 October 1994 (SAINST 3710.1)

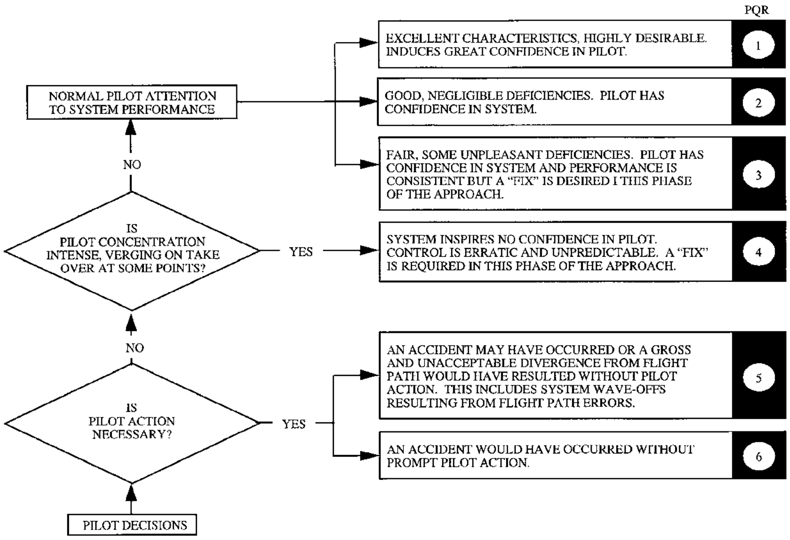


Figure 11
PALS Quality Rating Scale
Source: Precision Approach Landing System (PALS) Standard Operating Procedures (SOP), Naval Air Warfare Center, Patuxent River, Maryland, 07 October 1994 (SAINST 3710.1)

initiation times of the ramps are determined from the time history plots of when the vertical error deviates from the glide slope and is a fairly accurate estimation of where the burble is encountered. The magnitudes of these ramps are calculated for each aircraft based on the gains of the aircraft control program and the vertical error time history. The ramp is an estimation of the command that would be sent to the aircraft from the control program if it had received that particular vertical error. These ramps are then tested and adjusted for each aircraft type until satisfactory glide slope control is achieved.

The creation of the pitch command ramps are the most difficult and time consuming phase of the certification. Pitch command ramps may vary from aircraft to aircraft and ship to ship based on slight changes in the burble due to variations in the deck configuration or island structure on the aircraft carrier. Fortunately, pitch command ramps are more commonly needed in aircraft utilizing pitch attitude command AFCS and most modern naval aircraft capable of automatic control have an AFCS based on vertical rate command. Vertical rate command AFCS are much better at counteracting the effects of the burble than pitch command AFCS.

The burble may not only cause unexpected glide slope deviations, but may also cause the aircraft to touchdown at an unexpected point on the deck. This means the aircraft may land longer or shorter than anticipated. To fix this problem the test team may adjust the radar augmenter height in the ACLS software. The radar augmenter height is the vertical height from the beacon to the arresting hook on the aircraft when the aircraft is in the approach configuration. The radar augmenter height is shown in figure 12. The ACLS attempts to fly the aircraft beacon down the glide slope to a position above the desired touchdown point such that the arresting hook will impact the deck on the desired touchdown point. To correct this, the ACLS moves its beacon glide slope up the exact distance of the radar augmenter height to ensure the arresting hook engages the touchdown point properly. When the aircraft is not landing on the intended touchdown point due to the effects of the burble, the magnitude of the radar augmenter height is modified to guide the arresting hook to a more desirable point on the flight deck.

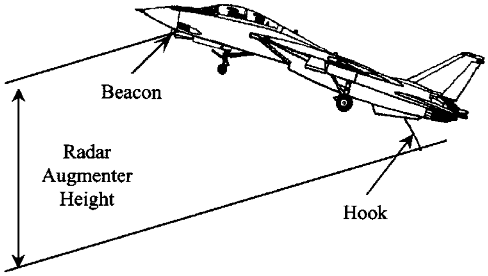
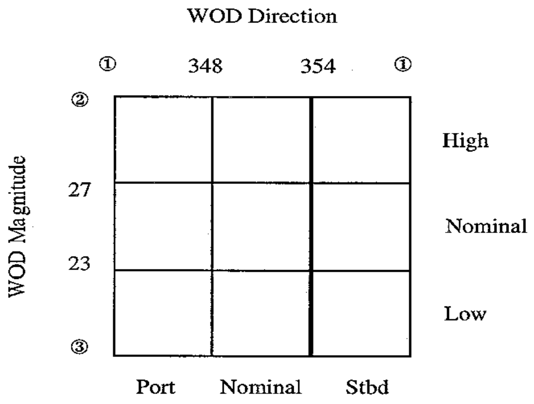


Figure 12
Radar Augmenter Height
Source: Carrier Suitability Testing Manual, Naval Air Warfare Center, Patuxent River, Maryland, 03 April 1991 (SA FTM-01)

PHASE III

Phase III of the at sea flight tests is designed to collect approach and touchdown data under various wind over deck conditions with the final program configuration determined from Phase II. Approaches are first flown with the wind over deck within ± 3 knots of the nominal wind over deck magnitude and ± 5 degrees of the nominal wind over deck direction until the test team is confident that the overall certification criteria can be met. Once the certification criteria discussed in Phases I and II are met, approaches are then flown with predetermined wind over deck variations, referred to as wind cells, to evaluate the quality of the automatic control in off nominal wind over deck conditions. These wind cells are designed to be approximately ± 2 knots in wind over deck magnitude and ± 3 degrees in wind over deck direction because of the significant variations observed in the burble which occur with larger wind over deck changes. Figure 13 is an example of a wind over deck chart and the different wind cells of which it is composed.



1. Wind direction out to 340 (port) and 005 (stbd), not to exceed 7 kt crosswind limit.
2. Up to 35 kt with 3.5 degree glideslope.*
   Up to 40 kt with 4.0 degree glideslope.*
3. Down to minimum recovery WOD.

Figure 13
Typical ACLS Wind Over Deck Chart
Source: Carrier Suitability Testing Manual, Naval Air Warfare Center, Patuxent River, Maryland, 03 April 1991 (SA FTM-01)

In addition to the certification criteria discussed in Phase I, several other criteria are considered in Phase III. Completion rate, aircraft touchdown sink speed, and longitudinal and lateral touchdown dispersion are four factors that are evaluated. However, approaches during which the following conditions existed are not included in the data sample because these conditions result in unrepresentative PALS performance:

a. Known system problems in the shipboard equipment that are corrected prior to the end of the certification.

b. Known system problems in the airborne equipment.

c. Traffic or foul deck wave offs.

d. Operator error.

e. Deck motion and wind over deck outside the certified limits.

The standard for completion rate success is exceeding 65 percent. The mean aircraft touchdown sink speed must be less than 3 feet per second from the ideal sink speed which varies depending on the aircraft glide path and approach speed. The mean lateral touchdown dispersion must be less than 4 feet from the centerline and standard deviation must be less than 5 feet. The mean and standard deviation standards for the longitudinal touchdown dispersion are 24 feet and 60 feet, respectively. The confidence level in the mean longitudinal touchdown dispersion is 95 percent and is illustrated in figure 14. The mean ± 15 ft curve is used if data are available to support all cells. If data to support some of the outer cells can not be collected then the ± 10 ft curve is used. This graph enables the test conductor to determine how many samples will be required to achieve a given touchdown point average with a calculated standard deviation at a 95 percent level of confidence.

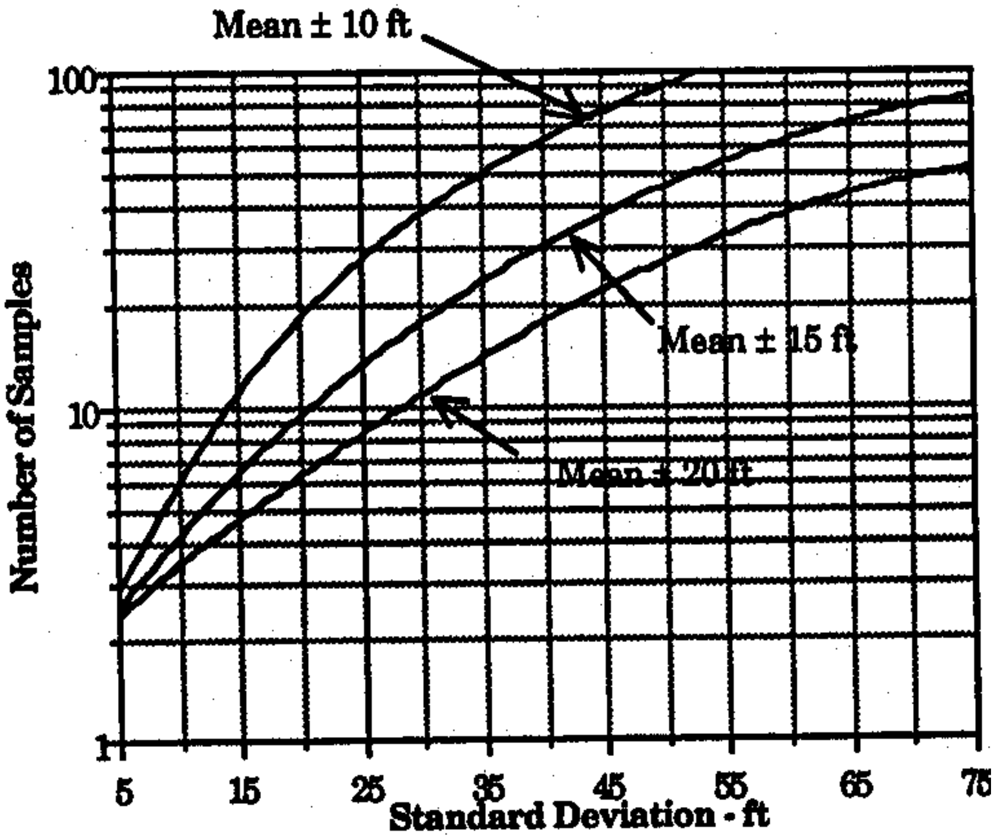


Figure 14
95 Percent Confidence Chart
Source: Carrier Suitability Testing Manual, Naval Air Warfare Center, Patuxent River, Maryland, 03 April 1991 (SA FTM-01)

CHAPTER IV

ANALYSIS OF CERTIFICATION PROCEDURES

GENERAL

Periodic certifications of the PALS, in the current operational configuration, have been ongoing since 1988. The test methods and operational procedures used for the first certification have since been verified through dozens of other PALS certification efforts. These methods and procedures have been documented in test plans and flight test manuals and have been proven effective through the years by positive certification results and, more importantly, PALS employed by the fleet have had an exceptional operational track record.

As can be expected with repetitive testing of this manner, methods and procedures have evolved through the years in an attempt to improve the cost, schedule, and performance of the certification efforts. Some changes have been the result of lessons learned during the flight test. Other changes have been brought about by improvements in technology or new operational procedures within the naval aviation environment. Periodic, mandatory reviews of operational procedures and test methods provide opportunities for discussion within the test team regarding recommended changes. These changes are discussed thoroughly and, if implemented, validated by test results and the improvements are documented and utilized in future tests. This incremental improvement process in conducting the PALS certifications has managed to optimize the certification efforts in many regards. However, there are always areas in which discussion may provide some additional improvements. This chapter discusses several areas of concern within PALS certifications and provides some alternative choices to current test methods and procedures.

CERTIFICATION WITH VARIOUS AIRCRAFT TYPES

All current U.S. Navy and Marine Corps carrier based aircraft are capable of performing Mode III approaches. This merely requires the aircraft to be tracked by the ACLS and the controller to transmit glide slope and line up calls to the pilot via the radio. Mode II and ICLS approaches require the aircraft to be equipped with a data link receiver and cockpit displays for the pilot to interpret the approach information. Most current U.S. Navy and Marine Corps carrier based aircraft are capable of performing Mode II and ICLS approaches. Mode I approaches additionally require the aircraft to be equipped with an ACLS beacon and are only flown by F/A-18 and F-14 variants.

A complete PALS certification authorizes the use of the system for each of these modes of operation with the aircraft that are qualified to perform that particular mode. However, as explained in Chapter III, the procedures used to certify the PALS do not include flying each mode of operation with every aircraft capable of performing that mode. Performing the certification in that manner would certainly demonstrate proper operation of the PALS, but would not be very efficient or necessary because the same software algorithm is used by the ACLS for Mode III and Mode II approaches regardless of the aircraft type. The only difference in the software for various aircraft types is a change in radar augmenter height so the aircraft will land at the correct touchdown point on the deck. In addition, the only difference with a Mode I approach is that the ACLS generates and transmits commands to the aircraft. Therefore, flying a Mode I approach with an F/A-18 aircraft can verify proper operation of Mode III and Mode II approaches for all aircraft types as well as Mode I operation for the F/A-18. Because there is no difference in flying different aircraft types during Mode II and Mode III approaches, it is convenient to use one aircraft type to demonstrate this capability incidentally during Mode I approaches. Planning the certification in this manner allows for the F/A-18 to demonstrate a majority of the system operation and an F-14 to complete the certification by demonstrating only the Mode I capability for it's particular aircraft type.

Completing the certification using only F/A-18 and F-14 aircraft saves money in several ways. As previously explained, reducing the number of aircraft required reduces the number of approaches performed which means less flight hours. Also, it eliminates the need for logistical and maintenance support at sea for the additional aircraft types. However, at approximately $12,000 per flight hour for the F/A-18, the cost of a PALS certification can still exceed $600,000.

These expensive flight hour rates are encouraging the PALS team to explore new options to reduce the costs of a certification. One such option is the use of less expensive commercial aircraft with PALS equipment installed to complete a portion of the certification. For example, a similar ELA test is planning to use a Piper Cheyenne with a specially designed PALS instrumentation package. The PALS instrumentation package presents the ACLS or ICLS display on the Attitude Indicator (AI) to the pilot or copilot. With this package installed, the aircraft is capable of performing ICLS, Mode III, or Mode II approaches. The aircraft would not be able to perform fully automatic Mode I approaches, but it could be used in Phase I of the certification to perform the level leg approaches, to demonstrate basic alignment of the ACLS, ICLS, and IFLOLS, and to verify the tracking of the ACLS. Commercial aircraft, such as the Piper Cheyenne, could be used to complete much of the early work in the certification leaving the Mode I approaches to the F/A-18 and F-14 aircraft to demonstrate ACLS control and touchdown dispersion.

On average, a PALS certification requires 40 flight hours with the F/A-18. If the Piper Cheyenne could be used for the first 10 of those hours at a rate of $600 per flight hour then the overall flight hour rate could be reduced by nearly 25%. That equates to a saving of approximately $120,000 per PALS Certification. Savings of this magnitude would have a profound impact on the testing.

TOUCHDOWN DISPERSION TECHNIQUES[8]

Knowing the exact spot on the flight deck where the ACLS will land the aircraft is very important when flying a Mode I approach. That is why the touchdown dispersion criteria discussed in Phase III was developed. Typically, touchdown dispersion data are collected with high speed cameras. To acquire accurate touchdown data from these cameras, a team of technicians is required to accurately survey and mark the landing area of the flight deck and mount the cameras on the island of the aircraft carrier. High speed snapshots of the aircraft touching down on the flight deck are taken and from these snapshots the data are reduced. Knowing the approach speed, attitude, rate, and geometry of the aircraft as well as the surveyed points on the flight deck, the team is able to post process the camera data using multivariable equations and provide the exact hook touchdown point for each pass.

This method of collecting touchdown dispersion data is highly accurate but very expensive. In the past, high speed 35 mm cameras were used. However, because of the high processing costs of the film, acquiring the data for an entire certification would average $165,000. Recently, high speed digital motion picture cameras have taken the place of the 35 mm cameras. However, the price of acquiring the data digitally would still cost approximately $110,000 for a certification effort. These huge costs led the PALS team to question how the accuracy of camera touchdown data would compare to that obtained visually using an observer.

During a recent certification effort, the flight deck of the aircraft carrier was surveyed and the high speed digital motion picture cameras were installed on the island. In addition, an observer was positioned on the island with a clear view of the landing area. The observer was instructed to relay the mainwheel touchdown point of each aircraft's approach to the test team. The mainwheel touchdown point was chosen over the hook touchdown point because of the difficulty in spotting the arresting hook. In addition, the smoke from the wheels contacting the deck provided a better indicator of mainwheel touchdown. However, the data indicated that there was an additional bias involved in spotting the mainwheel touchdown. Due to the speed of the aircraft, the perceived touchdown to the human eye was actually a slight distance further down the landing area than in reality. After examining the data, an observer bias of 9 feet was determined to be appropriate. Using digital camera data from previous certifications, it was also determined that the arresting hook on the F/A-18C touched down approximately 31 feet behind the mainwheels. After applying the observer bias of 9 feet and the mainwheel to hook correction of 31 feet to the observer calls, and comparing that to the digital camera data for the same passes, the results were very similar. Table 1 presents these results referenced to the ideal touchdown point (i.e. mean of 0 feet). Positive values indicate past the ideal touchdown point and negative values indicate prior to the ideal touchdown point.

Table 1

F/A-18C Hook Touchdown Statistics

Hook Touchdown (ft)	Observed	Camera
Number of Samples	31	31
Mean Touchdown Point	5.4	5.2
Standard Deviation	29.7	31.7
Minimum	-45.3	-65.7
Maximum	81.1	72.0

Source: Calculation of Tailhook Touchdown Dispersion for Shipboard Precision Approach and Landing Systems (PALS) Certifications/Verifications, Naval Air Warfare Center, Patuxent River, Maryland, 24 September 2002 (Memorandum)

In this test, the camera data are considered to be the truth data because of its high degree of accuracy. The average hook touchdown position for 31 passes for the camera and the observer calls, respectively, was 5.2 feet and 5.4 feet past the ideal touchdown point. The standard deviations for each was 31.7 feet and 29.7 feet. The disparities between the minimum and maximum values observed can be explained by a lack of reference point for the observer. There are four arresting wires on the deck that are forty feet apart. The ideal touchdown point is half way between the two and three wire. This means that from the ideal touchdown point the one wire is –60 feet, the two wire is –20 feet, the three wire is 20 feet, and the four wire is 60 feet. When the observer views the mainwheels touching down, an estimation of location between the wires is given as the touchdown point. Therefore, if the aircraft touches down greater than ±60 feet from the ideal touchdown point then it is more difficult to give an estimation because there are no additional wires to use as a visual reference point. However, most of the approaches touch down within ±10 feet of the ideal touchdown point, so it should not be a significant factor.

If a consensus can be reached that the accuracy of the observer calls is high enough to provide the proper level of confidence in the touchdown dispersion to complete a PALS certification then the cameras can be eliminated in favor of observers. Including an observer as part of the certification team vice setting up high speed cameras can achieve a cost savings of approximately $110,000 per certification.

WIND OVER DECK CONSIDERATIONS

As discussed in Chapter III, the nominal wind over deck envelope to conduct ACLS approaches is 23 to 27 knots of wind at 348 to 354 degrees relative to the axis of the ship. These are ideal wind conditions for Mode I approaches. However, through wind envelope expansion testing, the PALS flight test team has been able to certify a larger wind over deck envelope for different aircraft types. For example, the F/A-18A-D Mode I wind over deck envelope is 15 to 35 knots of wind at 340 to 005 degrees relative to the axis of the ship with a 3.5 degree glide slope setting, and 35 to 40 knots of wind at 340 to 000 degrees relative to the axis of the ship with a 4.0 degree glide slope setting. The F/A-18A-D have the most expansive wind over deck operating envelope because of the wealth of historical data that have been collected on this aircraft throughout the years.

Expanding the wind over deck envelope for ACLS is a very challenging endeavor from several perspectives. Generally, the first problem encountered is generating the winds desired to allow for testing opportunities. Maneuvering a four acre flight deck so that the wind passes over it in a precise direction is a very difficult task to ask of even the best navigator. However, if the ship is able to provide the winds needed for testing then the pilot must have enough confidence in the PALS to conduct an approach that may be on the outer edge of the approach envelope. This requires intense concentration from the pilot, a very experienced landing signal officer on the deck, and experienced PALS engineers monitoring safety of flight parameters. In addition to the PALS wind over deck operational envelope, the test team must also respect an aircraft carrier operationally imposed 7 knot crosswind component limit for all aircraft. This limit can not be broken and becomes a concern during envelope expansion testing when the wind becomes very port or starboard of the ship's landing area.

To conduct wind over deck envelope expansion approaches, highly accurate monitoring devices are required to reduce risks to an acceptable level. It is of the utmost importance that the wind magnitude and direction be as accurate as possible. The aircraft carrier has three wind anemometer devices for collecting wind information. One is located on the bow of the ship and the second and third are located on the port and starboard side on the top of the island structure. The ship has the capability of selecting any of these anemometers as its source of wind data. These anemometers provide data to repeater units which display the wind direction and magnitude. These repeaters are located in several operational spaces throughout the ship where knowledge of the wind conditions would be pertinent.

In theory, all of these repeater displays should provide the same accurate wind information. However, experience has shown that this is not the case. It is common for the repeater on the bridge, where the captain is navigating the ship, to be quite different from the repeater in the Carrier Air Traffic Control Center (CATCC), where the aircraft are being controlled. The obvious problem is which repeater is correct. If the ship is being navigated by the repeater in the bridge and the wind over deck expansion testing is being monitored by the repeater in CATCC and they are 5 degrees apart then which repeater should be used as a truth source.

In addition to discrepant information between repeaters, the varying flow of the wind over the deck of the aircraft carrier presents another problem when attempting to expand the wind over deck operating envelope. As discussed in Chapter III, flight deck configuration, the island of the aircraft carrier, and a host of other factors have a large impact on the burble. Wind direction and magnitude can vary greatly at different locations on the flight deck because of the interruptions in the airflow. The anemometers provide accurate wind direction and magnitude at their location but the real concern for expanding the operating envelope is the wind direction and magnitude in the landing area. Unfortunately, there are no anemometers located in the landing area for safety reasons, so the test team is forced to rely on the wind information from the anemometers located at other places on the aircraft carrier.

During two recent PALS certifications, wind magnitude and direction data were collected from the forward and port anemometers over several flight periods. Analyzing the data determined that the difference in wind magnitude readings from the two anemometers averaged ±1.3 knots from one another and the wind direction averaged ±5.7 degrees on the first ship and ±4.2 degrees from one another on the second ship. The difference in magnitudes was acceptable given the accuracy of reading the repeaters, however, the accuracy in the direction was too large to be considered acceptable. This example of the differences between wind readings at two different anemometers on the ship is intended to illustrate how different the wind conditions at the landing area could be compared to wind conditions at the anemometer.

The worst case scenario is the situation where the wind over deck envelope is being expanded to include more starboard winds. In this case, winds will typically range from 25 to 30 knots at 000 to 005 degrees relative to the axis of the ship. The maximum wind magnitude that can be tolerated at 005 degrees while abiding by the 7 knot crosswind limit is 28 knots. If the test team is receiving information from the anemometer that the wind is 28 knots at 005 degrees and the wind in the landing area is actually 5 degrees more starboard, then the approach may be attempted with a 28 knot wind at 010 degrees yielding a crosswind of greater than 9 knots. This is in violation of the crosswind limit set by the ship and becomes a safety of flight issue. In addition, this creates an air of uncertainty regarding what winds have been tested and what the expanded wind over deck envelope should be since the wind information at the landing area is not known.

These repeater unit discrepancies and the varying wind flow over the deck have prompted the PALS team to search for an alternate source for wind information. Recently, a team was contracted to setup a stand-alone ultrasonic anemometer on the ship to verify the ship's wind anemometers. The ultrasonic anemometer had a resolution of 0.1 degree and an accuracy of ±2 degrees in direction for winds ranging from 58 to 78 knots. This level of precision was accurate enough to compare the ship's anemometers, however, the setup of the ultrasonic anemometer was a problem. To achieve this level of accuracy in measurements the flight deck of the aircraft carrier should have been surveyed to ensure that the position of the ultrasonic anemometer was known to a high degree of accuracy. Instead, the ultrasonic anemometer was setup using "eyeball" methods and the quality of the data was compromised. Plans are being initiated to setup the ultrasonic anemometer again using the flight deck survey technique and properly verify the ship's wind anemometers.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

The AN/SPN-46 based PALS have been operating on U.S. Navy aircraft carriers for over 20 years now. Certification testing to ensure proper and safe operation of the PALS has been performed on these systems throughout those 20 years. This thesis presented the methodology used during the certification process of the PALS. The methodology and procedures used are reviewed and updated periodically to ensure the most recent and efficient test methods are utilized during the certification process. Similar to any test program, the PALS certification process is under constant review to minimize costs and maximize efficiency. This pressure has prompted many changes in the certification process. The discussions in this thesis take this concern into account. In a world where defense expenditures are monitored closely, it remains to be the goal of the PALS certification process to provide a high quality product to the fleet while remaining cost effective. The following recommendations may help to decrease the cost of PALS certifications as well as increase the accuracy and efficiency.

1. Conduct a thorough debrief with the test team utilizing the Piper Cheyenne as an ELA test asset at the conclusion of their testing. Using information gathered in the debrief, conduct a feasibility study on utilizing the Piper Cheyenne as a PALS certification test asset. If the study indicates favorable results then write a test plan to incorporate the Piper Cheyenne into a PALS certification. At the conclusion of the certification, debrief the certification team regarding the impact

of using the new asset, analyze the results to determine the accuracy of the data, and determine the overall cost savings to the project. If the Piper Cheyenne is determined to be a beneficial addition then incorporate it as a permanent test asset in Phase I of PALS certifications.

2. Incorporate the use of touchdown observers instead of high speed digital motion picture cameras to obtain touchdown dispersion data on the USS Ronald Reagan PALS certification in 2003. Conduct a post certification analysis of the data collected to determine accuracy. If the accuracy of the data is acceptable then incorporate touchdown observers on future certifications.
3. Encourage aircraft carriers to submit hazard reports on discrepant wind anemometer repeater units when discovered during PALS certifications. Investigate which agency would conduct operational testing of repeater units and encourage periodic certifications if they are not already being implemented.
4. Write a test plan to conduct wind over deck measurements in the landing area while aboard the USS Ronald Reagan during the PALS certification in 2003. Conduct a survey of the deck and during periods of no flight operations setup the ultrasonic anemometer at several surveyed locations in the landing area to collect time correlated wind data along with the ship's anemometers data. Analyze the data for trends in wind over deck behavior. Consider pursuing funding for more detailed wind over deck evaluations aboard other aircraft carriers.

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VITA

John Ellis was born on 11 May 1972 in Lanham, MD. He graduated from Northern High School, in Owings, MD in 1990. In the fall of 1990 he received the United States Naval Pax Tenn scholarship for engineering and enrolled at the University of Maryland. His summers, winters and cooperative education semesters were spent working as a Junior Professional at the Naval Strike Aircraft Test Squadron (NSATS), Naval Air Warfare Center Aircraft Division, Patuxent River, MD. In May 1996 he received a Bachelor of Science Degree in Mechanical Engineering from the University of Maryland, and began working full time as a flight test engineer at NSATS. In December of 1999, Mr. Ellis graduated from the U.S. Naval Test Pilot School as a member of Class 116. During his tenure as a flight test engineer, Mr. Ellis has been involved with the developmental test and evaluation of various air traffic control and landing systems aboard U.S. Navy aircraft carriers and amphibious assault ships. Mr. Ellis is currently serving as a Precision Approach Landing System flight test engineer for the Ship Suitability Division.