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Analysis of the Instrument Carrier Landing System Certification Process for Amphibious Assault Ships

Arthur Prickett
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Arthur Prickett entitled "Analysis of the Instrument Carrier Landing System Certification Process for Amphibious Assault Ships." 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:

Richard Ranaudo, Charles 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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Charles T. N. Paludan

Accepted for the Council:

Anne Mayhew

Vice Provost and Dean of Graduate Studies

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ANALYSIS OF THE INSTRUMENT CARRIER LANDING SYSTEM CERTIFICATION PROCESS FOR AMPHIBIOUS ASSAULT SHIPS

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

Arthur Prickett
August 2003

DEDICATION

This thesis is dedicated to my family for their support and encouragement. I further dedicate this work to those who spend months at sea so that we may all spend time at home with our families.

ACKNOWLEDGEMENTS

I wish the thank the officers, engineers, and staff of the Carrier Suitability Department of the Naval Air Warfare Center Aircraft Division for the expertise and dedication that allowed me to safely and effectively conduct this flight test effort. I also wish to thank Dr. Bob Richards for his time and advice in the writing of this thesis.

ABSTRACT

The AN/SPN-41 Instrument Carrier Landing System (ICLS) is a precision electronic approach and landing aid that provides shipboard guidance information to Navy and Marine Corps aircraft. The ICLS emits a microwave beam that is received by the aircraft and presented to the pilot as azimuth and elevation needles. These needles indicate the deviation from the ideal glide path and course line and provide the pilot with direct guidance information. This system has long been in use on aircraft carriers and has recently been adapted for use on other U.S. Navy aviation ships.

The shipboard landing task is a challenging effort that is undertaken daily by naval aviators on amphibious assault class ships. The amphibious assault ship, also known as an L-class ship, is smaller than an aircraft carrier and is designed to host helicopters and Vertical/Short Take Off and Landing (V/STOL) aircraft. Until recently, aviators landing on an L-class ship relied on verbal talk-down from a shipboard controller who was tracking the aircraft with precision approach radar (PAR). This radar had low reliability, especially during poor weather conditions, and did not provide the pilot with any direct guidance information. For these reasons, the AN/SPN-41A ICLS has been adapted for use on L-class ships and is presently being installed on new ships and retrofitted to existing ships of the class.

This thesis will examine the procedures used to certify the AN/SPN-41A ICLS for use aboard the L-class ship and recommend improvements to that process.

PREFACE

The flight test results contained within this thesis were obtained during a United States Department of Defense sponsored Naval Air Systems Command project 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

μs	Microseconds
Ψ_{TAC}	TACAN bearing
AACS	Aircraft Approach Control System
ACLS	Automatic Carrier Landing System
AGL	Above Ground Level
ARI	Attitude Reference Indicator
DEG	Degrees
FAF	Final Approach Fix
ft	Feet
GPS	Global Positioning System
HSI	Horizontal Situation Indicator
HUD	Heads-Up Display
ICLS	Instrument Carrier Landing System
LHA	Amphibious Assault Ship, Aviation
LHD	Amphibious Assault Ship, Dock
MRAALS	Marine Remote Area Approach and Landing System
NATOPS	Naval Air Training and Operations
NAWCAD	Naval Air Warfare Center Aircraft Division
NMI	Nautical Mile
nmi	Nautical Mile
OLS	Optical Landing System
PAR	Precision Approach Radar
PCSB	Pulse Coded Scanning Beam
R_e	Mean radius of the earth
R_{TAC}	TACAN range
SMS	Ship's Motion Sensor
TACAN	Tactical Air Navigation
V/STOL	Vertical/Short Takeoff and Landing
Z_{RADALT}	Radar Altitude
$K_{Z_{TAC-EL}}$	Height of ICLS elevation transmitter below TACAN antenna.
$K_{Z_{SURF-TAC}}$	Height of TACAN antenna above sea surface
$K_{X_{TAC-AZ}}$	Longitudinal distance from TACAN antenna to ICLS azimuth transmitter
$K_{Y_{TAC-AZ}}$	Lateral distance from TACAN antenna to ICLS azimuth transmitter
$K_{X_{TAC-EL}}$	Longitudinal distance from TACAN antenna to ICLS elevation transmitter

CHAPTER 1: INTRODUCTION

BACKGROUND

The amphibious assault ship, also known as an L-class ship, is smaller than an aircraft carrier and is designed to host helicopters and Vertical/Short Take Off and Landing (V/STOL) aircraft, such as the AV-8B Harrier II. The term L-class, as used in this discussion, refers specifically to LHA (Amphibious Assault, General Purpose) and LHD (Amphibious Assault, Multi-Purpose) class ships. These ships are designed to use closely integrated air and sea support to place expeditionary forces onto hostile shores.

Until recently, aviators landing on an L-class ship relied on a verbal talk-down from a shipboard controller who was tracking the aircraft with a precision approach radar (PAR). This radar had low reliability, especially during poor weather conditions, and did not provide the pilot with any direct guidance information. For these reasons, an interim solution was sought to provide the AV-8B pilot with onboard approach path information.

The AN/SPN-41 Instrument Carrier Landing System (ICLS) has been in use on aircraft carriers since the early 1970s. This system provides vertical and lateral guidance information, via onboard instruments, to appropriately equipped Navy and Marine Corps aircraft. The AN/SPN-41 ICLS has been adapted for use on L-class ships and is presently being installed on new ships and retrofitted to existing ships of the class. The L-class version of the ICLS has been designated as the AN/SPN-41A.

The Naval Air Warfare Center Aircraft Division (NAWCAD) was tasked with the initial certification of the AN/SPN-41A aboard an L-class ship. In addition, NAWCAD periodically verifies the operation of the ICLS system for each ship and provides repairs and adjusts the alignment as necessary.

The AN/SPN-41 ICLS aboard aircraft carriers was typically certified during a Precision Approach and Landing Systems (PALS) certification. During these certifications, the ICLS glideslope and lineup guidance was compared directly with similar information that was provided by the AN/SPN-46(V) Automatic Carrier Landing System (ACLS). Since the L-class ship did not have an accurate and independent guidance system for such a comparison, a new certification method was required for certifying ICLS installations aboard L-class ships.

A new certification test plan was developed by NAWCAD to use the existing navigation systems that were available on the L-class ships and in NAWCAD test aircraft[1]. These new methods involved triangulation of the aircraft position relative to the ship to calculate the basic alignment angles of the AN/SPN-41A ICLS. Data were recorded from pilot observations and aircraft onboard instrumentation.

SCOPE OF THESIS

The prototype AN/SPN-41A installation for amphibious assault ships was first evaluated in January 1995 aboard the USS Wasp[2]. The system performance was generally satisfactory, however, guidance signals were partially hindered by structures

adjacent to one of the AN/SPN-41A transmitters. The transmitter was moved to a more favorable location and the system was again evaluated in April 1997[3]. The second evaluation was the source of data for this discussion. In addition, this study is focused on the certification of the ICLS and does not address the evaluation of other systems that were certified concurrently during this effort.

CHAPTER 2: SYSTEM DESCRIPTION

BACKGROUND

The Aircraft Approach Control System (AACS) was developed by Eaton Corporation Power Control Operations of Milwaukee, Wisconsin. The system underwent extensive technical evaluation at the Naval Air Test Center, Patuxent River, Maryland, in 1966 and was operationally evaluated in 1968. The Navy procured the Aircraft Control Approach Transmitting Set portion of this system in 1969 as the AN/SPN-41 Instrument Carrier Landing System (ICLS)[4]. The AN/SPN-41A was later developed for L-class ships.

SHIPBOARD COMPONENTS

GENERAL

The AN/SPN-41A Instrument Carrier Landing System is a pulse coded scanning beam (PCSB) emitter that transmits elevation and azimuth guidance signals to appropriately equipped Navy and Marine Corps aircraft. The AN/SPN-41A radiates two coded microwave beams into the approach volume behind the ship. The signal coverage from each beam is approximately 20-degrees to either side of centerline and 0 to 10-degrees above the horizon for a range of 50 miles. The antennas are stabilized, using inputs from the ship's motion sensors (SMS), to ensure that the scanned beams remain level to the horizon regardless of the attitude of the ship.

The azimuth and elevation transmitting groups are enclosed in two separate radomes. Each transmitting group consists of a transmitter, an antenna, and a stabilization system. The elevation group is located on the aft end of the island structure, approximately 24-feet above the flight deck. The azimuth group is located at the aft end of the ship, slightly below the flight deck and approximately 5-feet starboard of the ship's tramline. The tramline is the center of the takeoff and landing area and is aligned with the centerline of the ICLS. Figure 1 shows the locations of the AN/SPN-41A transmitter groups, auxiliary navigation equipment, and deck markings on an LHD-class ship. The arrangement of the LHA-class ship is very similar to the LHD-class. The TACAN, V/STOL OLS, and tramline are used to provide reference data for this evaluation.

PERFORMANCE

GENERAL

The AN/SPN-41A radiates two pulse-coded microwave scanning beams into the approach volume. Each transmitter group emits a fan-shaped beam that is scanned through the full coverage limits at a rate of 2.5 scans per second. Twenty discrete channels are available using 10 radio frequencies and two sets of intrapair pulse codes. The angular position of the receiving aircraft relative to the desired courseline and glidepath is determined by decoding the pulse timing from the elevation and azimuth beams.

Figure 1
AN/SPN-41A Transmitter Group Locations on LHD-Class Ship

Source: U.S. Navy, Digital Photo Archive, 990218-N-9593R-002

AZIMUTH

The azimuth beam provides lateral guidance information to a minimum of 20-degrees to either side of centerline. The proportional deflection area of the azimuth guidance is 6-degrees to either side of centerline, as shown in Figure 2. The full and proportional azimuth coverage is only required to meet a minimum angle from centerline. Coverage angles that exceed that minimum are acceptable. The proportional deflection area is defined as the coverage area where the error indicator moves linearly from the center position to a full deflection. The indicator remains fully deflected when the aircraft is outside of the proportional region.

The azimuth beamwidth is 10-degrees high in the vertical plane and 2-degrees wide in the horizontal plane. The angular offset of the aircraft from centerline is determined by decoding the time between pulse pairs in the azimuth scanning beam, as shown in Figure 3. A nominal interpair spacing time of 60 μs corresponds to centerline. This spacing increases by 2 μs per degree of angular deviation from centerline. The direction right or left of centerline is defined by the intrapair spacing. The intrapair spacing is constant on either side of centerline and changes instantly from one value to the other as centerline is crossed.

ELEVATION

The elevation beam provides vertical guidance information from 0 to 10-degrees above the horizon. The proportional deflection area of the elevation guidance is

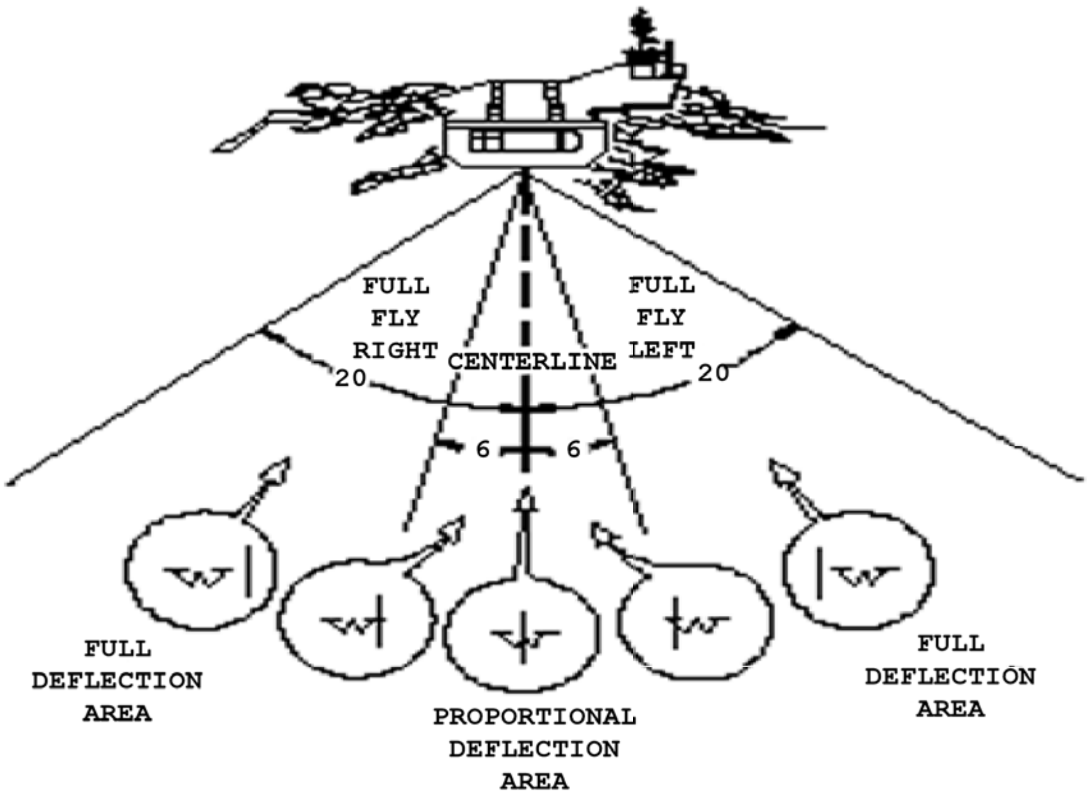

Figure 2
AN/SPN-41A Azimuth Signal Coverage

Source: Users Logistics Support Summary for Transmitting Sets AN/SPN-41 and AN/SPN-41A

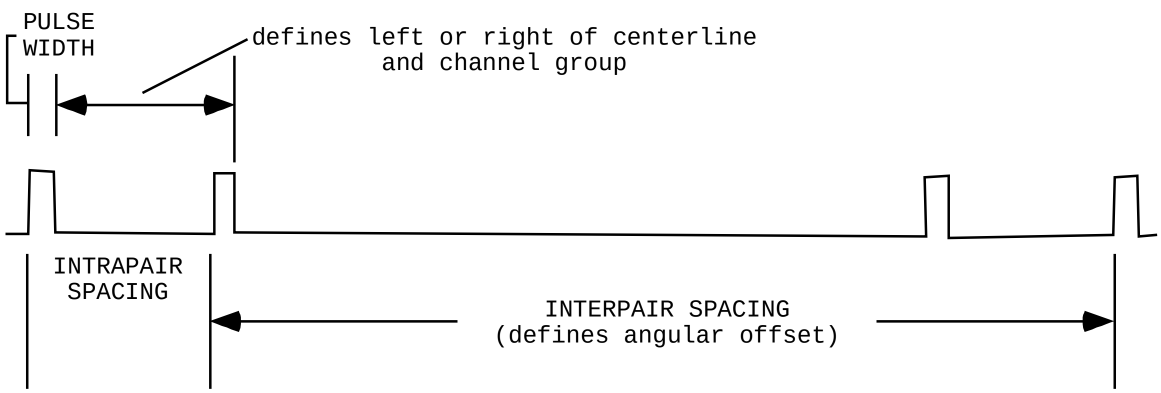

Figure 3
Azimuth Pulse-Pair Spacing

Source: Contract Specification, Ground Subsystem, Marine Remote Area Approach and Landing System

1.4-degrees above and below glideslope, as shown in Figure 4. The glideslope is adjustable from 2.5 to 5.0-degrees in 0.25-degree increments.

The elevation beamwidth is 1.3-degree high in the vertical plane and 40-degrees wide in the horizontal plane. The angular offset of the aircraft from glideslope is determined by decoding the time between pulse pairs in the elevation scanning beam, as shown in Figure 5. A nominal interpair spacing time of 60 μs corresponds to zero glideslope. This spacing increases by 2 μs per degree of angular deviation above zero and decreases by 2 μs per degree of angular deviation below zero.

ADDITIONAL SHIPBOARD SYSTEMS

GENERAL

Additional shipboard navigation systems were used for reference data during this evaluation. These systems are briefly described in the following section. The location of these systems is shown in Figure 1. Deck markings were also used as a visual line-up reference for the pilot.

TACTICAL AIR NAVIGATION (TACAN)

The Tactical Air Navigation (TACAN) system provides precise bearing and slant-range distance information from the TACAN station to appropriately equipped

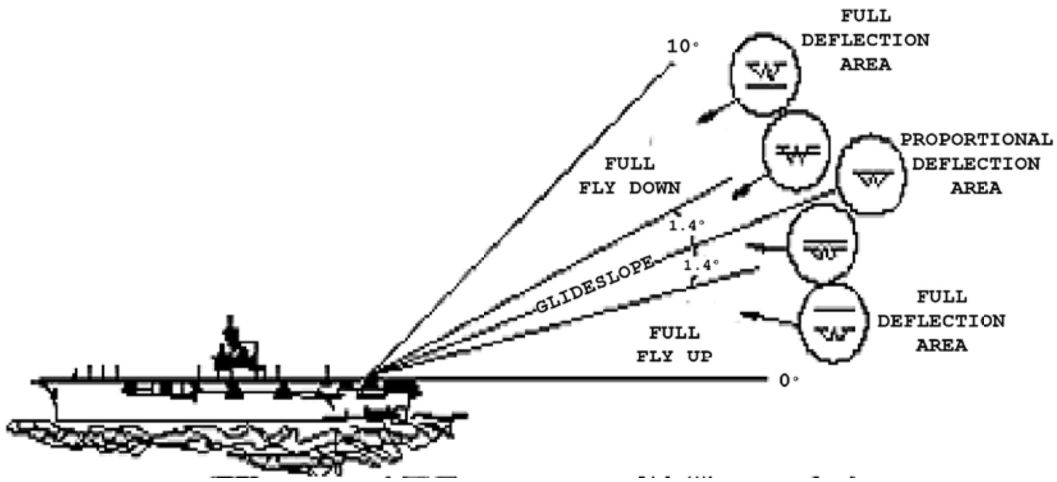

Figure 4
AN/SPN-41A Elevation Signal Coverage

Source: Users Logistics Support Summary For Transmitting Sets AN/SPN-41A and AN/SPN-41A

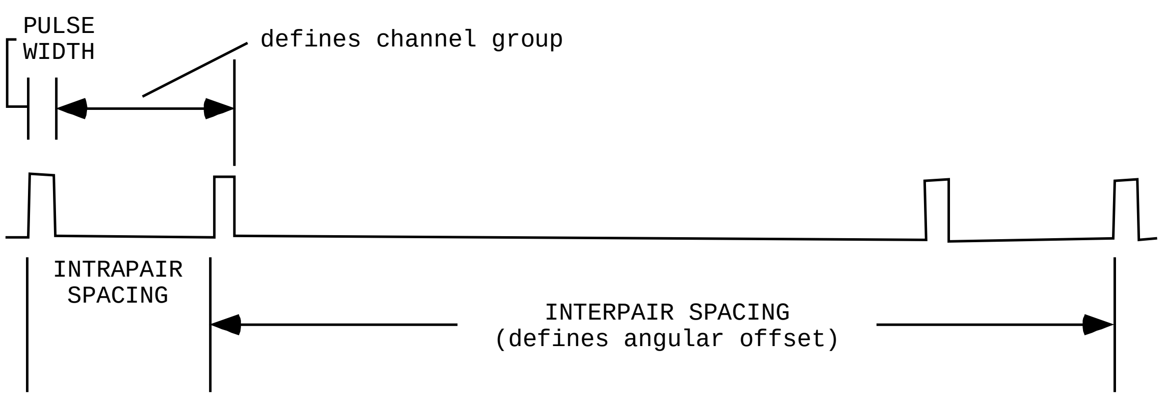

Figure 5
Elevation Pulse-Pair Spacing

Source: Contract Specification, Ground Subsystem, Marine Remote Area Approach and Landing System

aircraft. The TACAN system provides 360 courses radiating from the station. These courses, known as radials, are identified by their magnetic bearing from the station.[6] Magnetic north is the zero-reference for bearing. Figure 6 shows TACAN position determination using aircraft instruments.

The TACAN system provides guidance information via pulse-coded UHF signals. The shipboard equipment consists of a rotating antenna for transmitting bearing information and a receiver-transmitter for transmitting distance information. Bearing to the TACAN station is determined by measuring the phase angle between a main reference pulse and an auxiliary pulse. Distance is determined by measuring the elapsed time between interrogating pulses sent by the aircraft and synchronized reply pulses sent by the TACAN station.

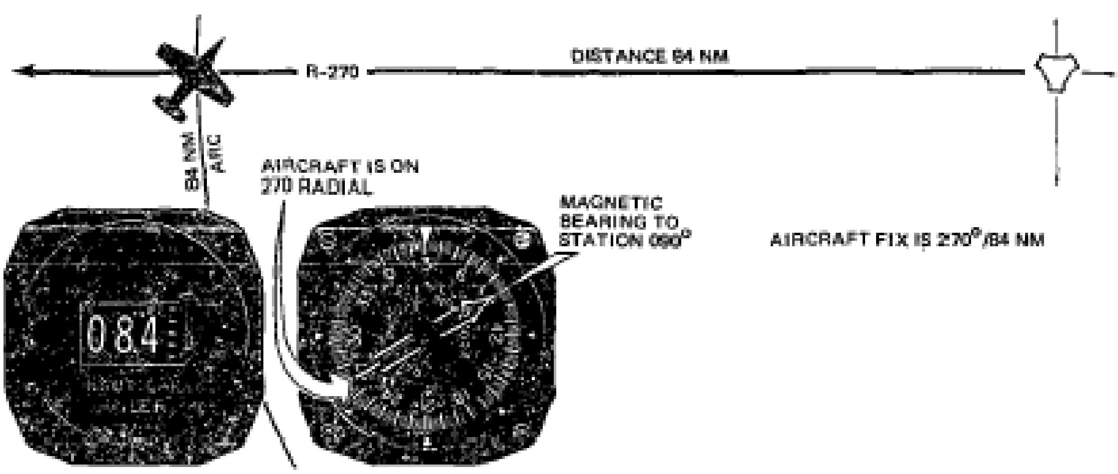

Figure 6
TACAN Position Determination

Source: NATOPS Instrument Flight Manual

VERTICAL/SHORT TAKEOFF AND LANDING OPTICAL LANDING SYSTEM

The Vertical/Short Takeoff And Landing Optical Landing System (V/STOL OLS) provides visual glide slope information to an AV-8B pilot approaching the flight deck of an amphibious assault ship.[7] The pilot typically transitions from ICLS guidance to V/STOL OLS guidance after visually acquiring the OLS around 1-nmi from the ship. The alignment of the AN/SPN-41A to the V/STOL OLS was checked visually by the pilot through a number of approaches during the certification testing.

The system is stabilized for ship's pitch and roll, and the glide slope setting is computer-controlled to a 3.0 degree fixed basic angle. The V/STOL OLS indicator is located on the aft portion of the island structure and attached to a tower, as shown in Figure 1. Two indicator assemblies (source light boxes), each 5 feet high, are vertically stacked on end and mounted to the bulkhead or tower. A horizontal datum arm assembly is mounted on each side of the light boxes at their junction. The datum arms are approximately 36 feet above the flight deck. LHA class ships currently use a five light datum arm configuration and LHD class ships use a four light configuration. The indication that the pilot sees is a virtual image (an amber "ball" of light) on the indicator display face that appears to move up or down with respect to the datum arms, depending on the vertical motion of the aircraft. To achieve and maintain the proper glide slope, the pilot positions the aircraft so that the ball is lined up with the reference datum arms. Figure 7 shows the V/STOL OLS display.

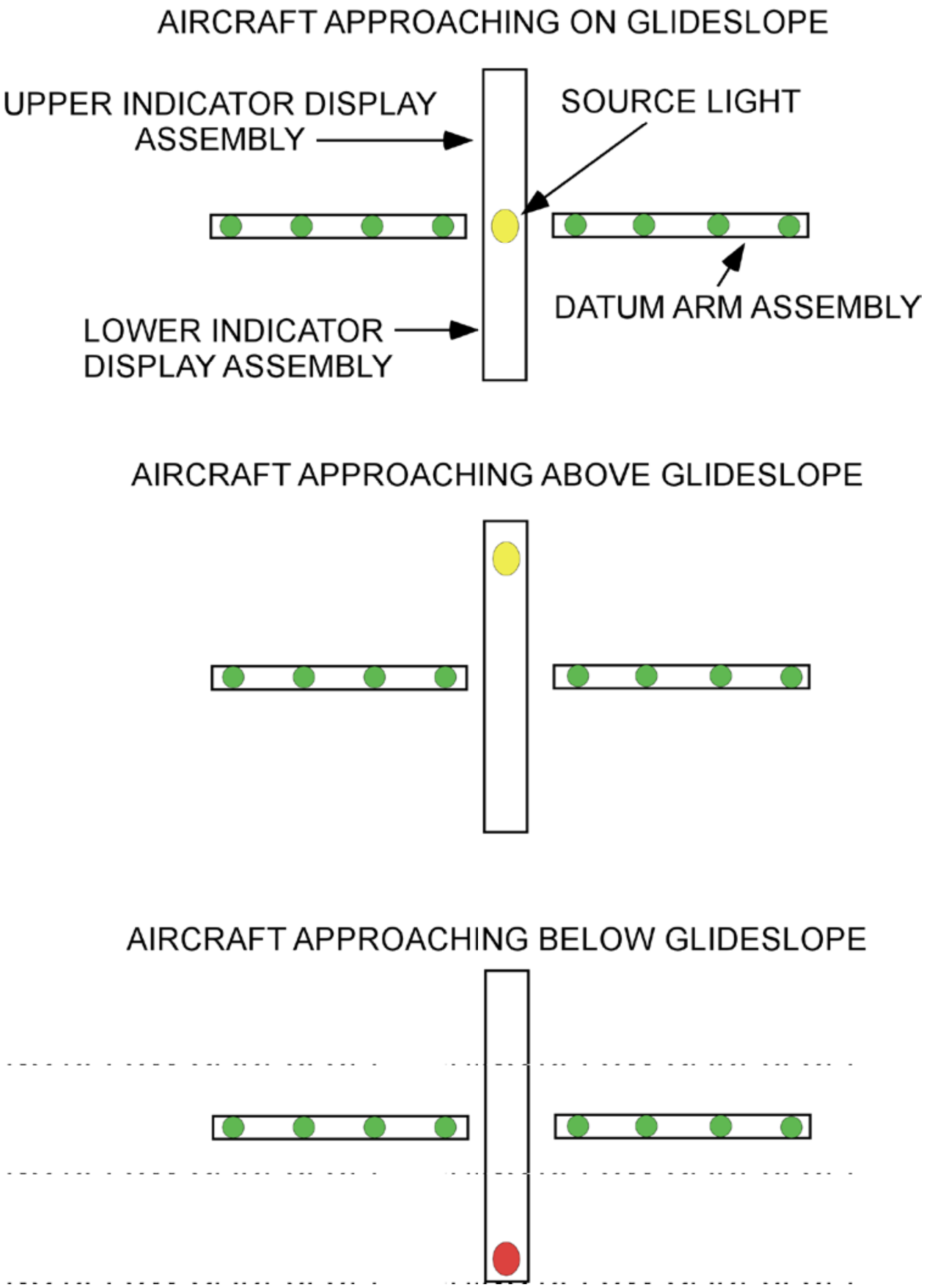

Figure 7
V/STOL OLS Display

Source: V/STOL Shipboard and Landing Signal Officer NATOPS Manual

AIRBORNE SYSTEMS

TEST AIRCRAFT

The AN/SPN-41A system aboard amphibious assault ships is intended for use with the AV-8B Harrier II V/STOL aircraft. This type of aircraft was not available for this evaluation so a NAWCAD F/A-18A Hornet aircraft was used. The F/A-18A was deemed a suitable substitute, since landing on the ship was not a requirement for the tests and the ICLS components in the F/A-18A and AV-8B are identical. The ICLS guidance displays and information presentation in the F/A-18A cockpit are also very similar to the AV-8B. In addition, the NAWCAD F/A-18A was equipped with onboard instrumentation and cockpit video and audio recording capability.

The F/A-18A test aircraft was also equipped with the production ICLS, TACAN, and radar altimeter systems described below.

ICLS RECEIVER-DECODER

Guidance signals from the AN/SPN-41A may be received and decoded by Navy and Marine Corps aircraft equipped with the AN/ARA-63 ICLS Receiver-Decoder group. The airborne components of the AN/ARA-63 consist of the radio receiver, pulse decoder, receiving antenna, and waveguide[8]. The radio receiver mixes, detects, and amplifies the guidance signals to provide a coded pulse train to the pulse decoder. The receiver output signals are received and decoded by the pulse decoder for azimuth and elevation information. The decoder also provides warning signals when azimuth or elevation steering is not valid. Guidance information is provided to the pilot as needles on the

Attitude Reference Indicator (ARI) and as deviation bars on the Heads-Up Display (HUD), as shown in Figure 8. The deviation bars shown on the HUD are also more commonly referred to as needles.

The ICLS needles provide a fly-to reference for the pilot. The velocity vector, as shown in Figure 8, indicates the flight path of the aircraft. The aircraft is on-glideslope and on-course when the ICLS needles are centered within the velocity vector.

RADAR ALTIMETER

The radar altimeter set indicates clearance over land or water. Operation is based on precise measurement of time required for an electromagnetic energy pulse to travel from the aircraft to the surface and return.[6] The set consists of a receiver-transmitter, individual transmitting and receiving antennas, and a height indicator. The receiver-transmitter produces the energy pulses, transmits the energy to the surface, receives the reflected signal, and processes this data for display as altitude by the HUD unit and the height indicator.

TACTICAL AIR NAVIGATION (TACAN)

The Tactical Air Navigation (TACAN) system provides precise bearing and slant-range distance information from the TACAN station to appropriately equipped aircraft. TACAN range and bearing information are presented to the pilot on both the HUD and the Horizontal Situation Indicator (HSI). TACAN symbology consists of a TACAN symbol, TACAN bearing pointer and tail. The TACAN symbol indicates the position of

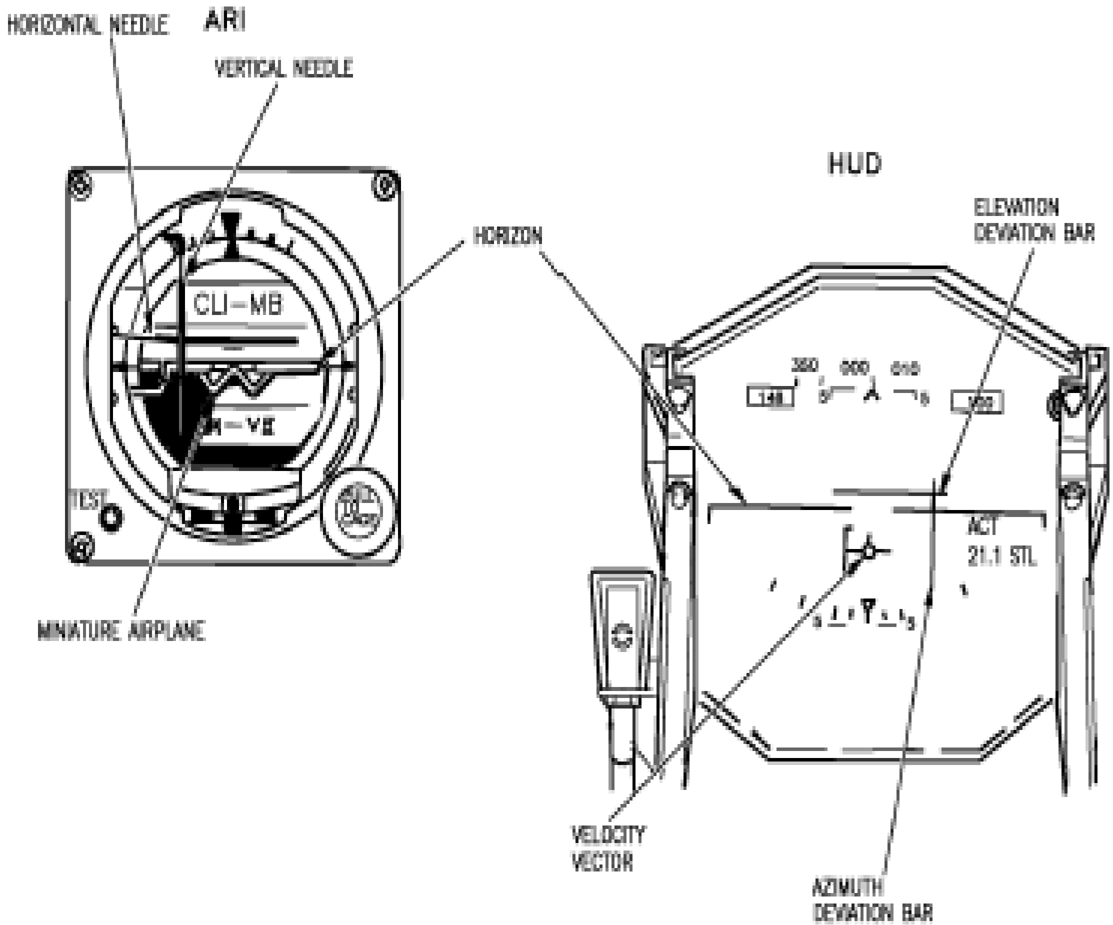

Figure 8
Aircraft ICLS Displays

Source: Organizational Maintenance Principles of Operation, Data Link, Instrument Landing, and Radar Beacon Systems

the TACAN station relative to the aircraft symbol. The TACAN bearing pointer and tail are located outside of the compass rose and indicate bearing to the TACAN station.[6]

CHAPTER 3: SHIPBOARD LANDING TASK

GENERAL

Navy and Marine Corps aircraft operate from amphibious assault ships twenty-four hours a day around the globe. Aircraft launch and recover during day and night operations in adverse environmental conditions such as low visibility, low cloud ceilings, high wind, heavy precipitation, and high sea state. These circumstances dictate the procedures used by the ship and the pilot to safely recover the aircraft.

RECOVERY PROCEDURES

The type or "Case" of recovery procedure is determined by the prevailing visibility conditions and whether it is day or night. Case I recoveries are conducted during the daytime when visibility is 3,000-feet vertically and 5 nautical miles (nmi) horizontally (3000/5) or greater.[10] Daytime Case II recoveries are conducted when visibility is less than Case I conditions, but better than 1000-feet / 5-nmi. Case III recoveries are conducted when the visibility is less than 1,000/5 or during night unaided recoveries. The intent of the Case II and III recovery is to use procedures and/or instruments and radar to guide the aircraft to a point where the pilot is able to assume visual control and complete the approach.

CASE III RECOVERY

Case III operations are conducted at night and during the day with visibility less than 1000/5. The Case III recovery is an instrument approach terminating in a full-stop

landing or a transition to a visual pattern. A standard Case III recovery begins with an approach to the ship using TACAN or radar vectors from the ship's air traffic control center. When the aircraft arrives at the final bearing of the ship and is within the appropriate range, the pilot transitions to an ICLS approach or a talk-down approach from a shipboard controller. The instrument approach may continue to no less than to 400-feet AGL. When the pilot has visually acquired the V/STOL OLS, the visual approach may commence. The pilot uses the V/STOL OLS for glideslope information and the ship's tramline for lateral lineup. A typical Case III recovery for an L-class ship is shown in Figure 9.

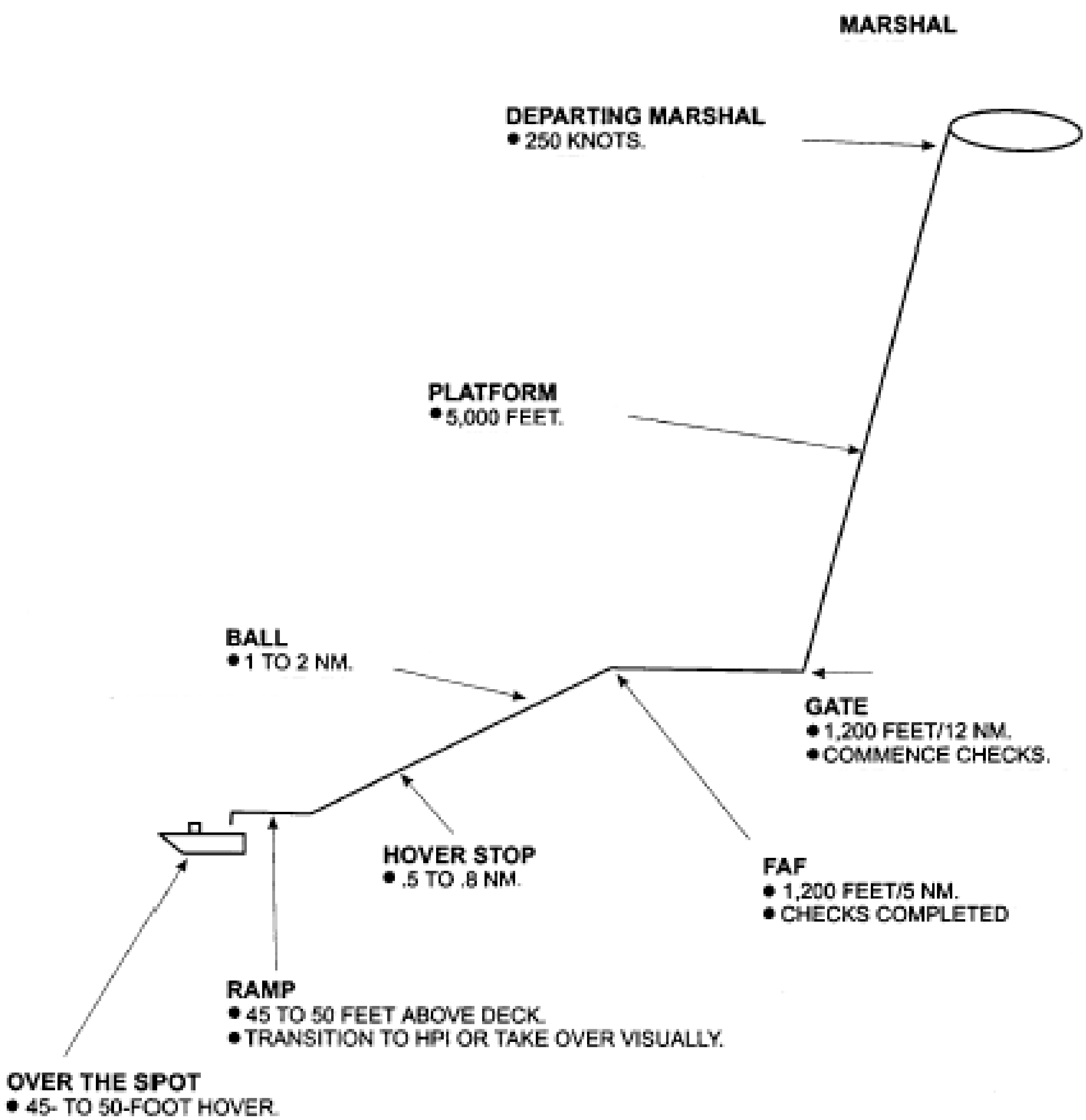

Figure 9
Case III Recovery

Source: V/STOL Shipboard and Landing Signal Officer NATOPS Manual

CHAPTER 4: FLIGHT TEST METHODS

GENERAL

Testing was conducted by NAWCAD engineers and test pilots using a NAWCAD F/A-18A aircraft.[3] Two test flights were conducted during daylight visual meteorological conditions for a total of 3.2 flight hours. The test aircraft was loaded with a single centerline external fuel tank. Aircraft configuration was flaps full down with landing gear extended and speed brake retracted. Sea state during the tests was calm, with negligible ship motion. Tests were performed in accordance with an approved test plan.

AN/SPN-41A AZIMUTH COVERAGE DETERMINATION

The maximum and proportional coverage of the azimuth guidance information was determined using data from a series of constant altitude approaches to the ship. The extended centerline alignment was also verified during these passes. The pilot was given a specific TACAN range and bearing that corresponded to the desired angular offset from the centerline. The aircraft was banked back and forth across this TACAN bearing, as shown in Figure 10, causing the azimuth needle to perform as outlined in Table 1. The position of the needles is also graphically depicted, in Figure 10, at selected points in the aircraft flight path. This test was conducted for the port and starboard proportional and maximum coverage limits and the extended centerline bearing.

Table 1
AN/SPN-41A Azimuth Coverage Offsets

Azimuth Limit	Needle Movement
Full coverage limit	Appear and disappear as the full coverage limit was intercepted.
Proportional limit	Move between full deflection and near full deflection as the proportional coverage limit was intercepted.
Centerline	Move back and forth across center needle position as ship extended centerline was intercepted.

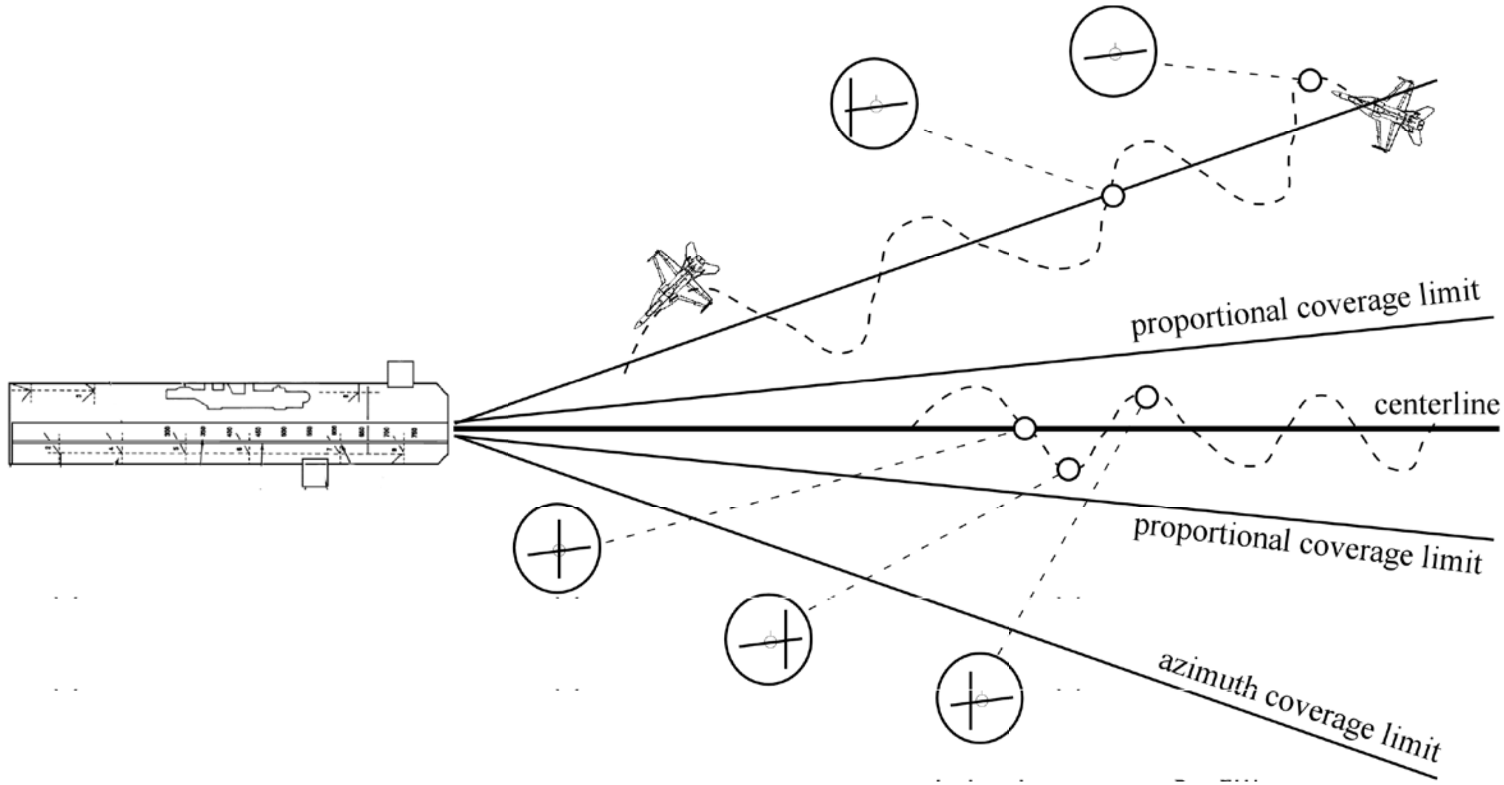

Figure 10
Azimuth Coverage Flight Profile

Source: Author

AN/SPN-41A ELEVATION COVERAGE DETERMINATION

Approaches were flown on the centerline TACAN final bearing at constant altitudes to determine elevation coverage limits, as depicted in Figure 11. The test altitudes were 500-ft, 1,000-ft, and 2,000-ft AGL. The pilot noted the TACAN range and radar altitude values that corresponded to the upper and lower elevation proportional coverage limits, centered elevation needle, and upper coverage limit. The position of the needles is also graphically depicted, in Figure 11, at selected points in the aircraft flight path.

The test team had considered another method for collecting elevation coverage data that was similar to the azimuth data collection profile. The pilot could have alternately climbed above the desired glidepath and descended below the glidepath in a sinusoidal manner. This would have collected several more data points per coverage angle. The test team decided that this method could have led to large deviations from glidepath at low altitudes. This was concluded to be an unacceptable risk for a fast-moving fixed-wing aircraft and this method was not pursued.

ICLS / OLS ALIGNMENT

The final phase of an instrumented approach is generally a transition to the V/STOL OLS for the last mile of the approach. During the ICLS certification process, the ICLS basic glideslope alignment was checked against the glideslope of the OLS. These systems must be in agreement in order for the pilot to make a seamless transition from ICLS needle guidance to OLS visual guidance.

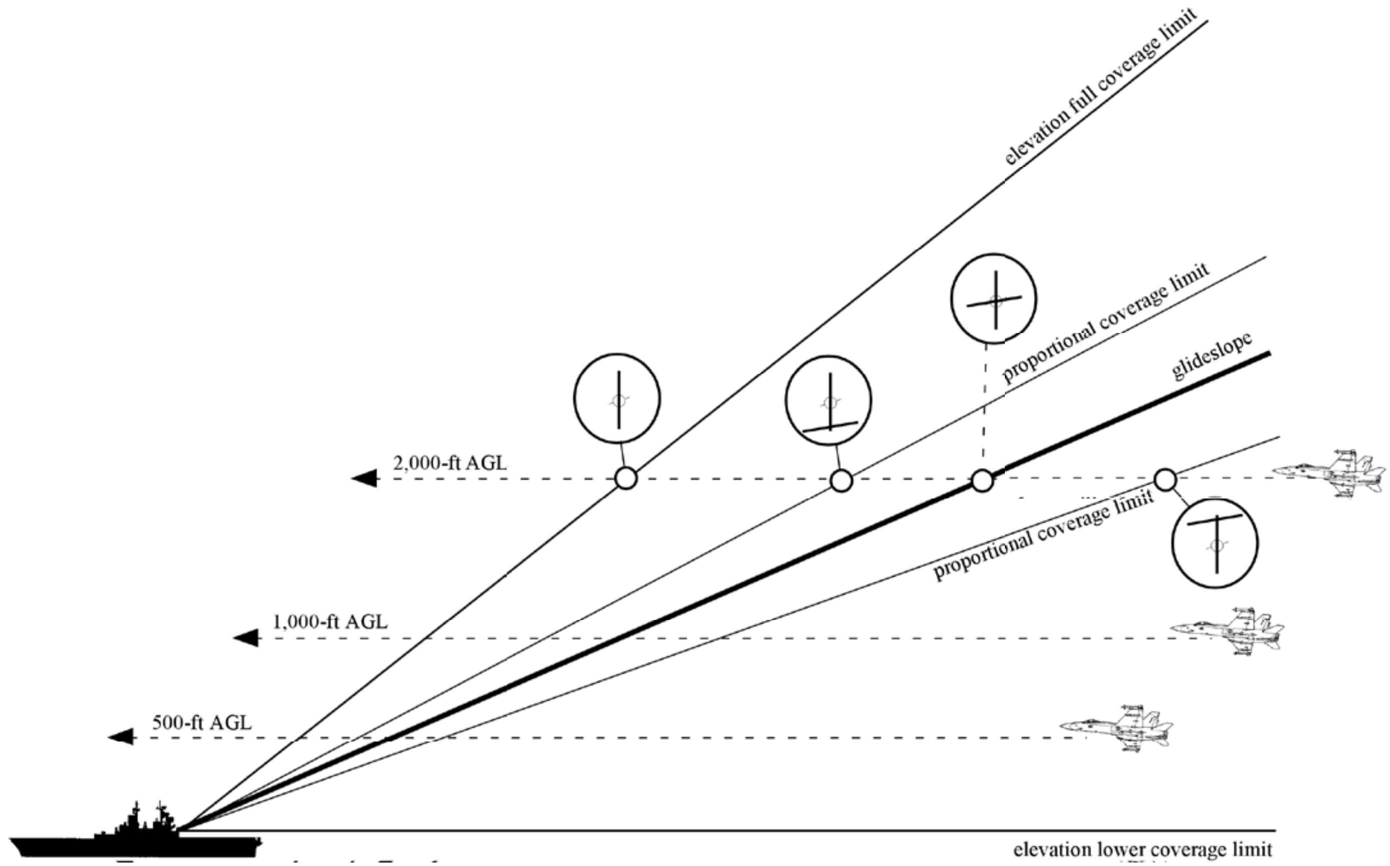

Figure 11
Elevation Coverage Flight Profile

Source: Author

A number of simulated Case III approaches were conducted from the final approach fix to approximately 0.5-nmi from touchdown. The pilot reported radar altimeter and TACAN range and bearing information at 0.2-nmi increments after visually acquiring the OLS. The pilot maintained a centered OLS “ball” during these approaches and also reported the position of the ICLS elevation needle with respect to the centered position. The systems were deemed as aligned when the ICLS elevation needle was within 0.15-degrees of the centered position. The basic alignment of the OLS is also independently verified by another certification agency.

CHAPTER 5: RESULTS AND ANALYSIS

GENERAL

The focus of the ICLS certification is to determine the angles of alignment and coverage for the azimuth and elevation transmitters. The most basic way to accomplish this is to determine the position of the test aircraft relative to the transmitters during a given test point. These test points would include the moment that an ICLS guidance needle crosses the centered position, reaches full deflection, or the instant when a needle disappears at a coverage limit. Aircraft position data is recorded at these desired moments.

DATA RECORDING

Data were recorded by engineers aboard the ship and by the pilot aboard the aircraft. The pilot recorded aircraft data, observed from cockpit instruments, onto paper flight cards and relayed that information to engineers by radio. In addition, the aircraft was equipped with a digital instrumentation system that recorded aircraft onboard sensor data onto a magnetic tape. Video images of cockpit instruments and audio of pilot comments and radio transmissions were recorded by an onboard videocassette recorder. Engineers aboard ship recorded ship magnetic heading data onto paper data cards.
Table 2 shows the data parameters that were recorded and their respective accuracies.

Pilot-reported data and ship heading data were entered into a spreadsheet, during

Table 2
Data Parameters

Parameter	Units	Resolution	
		Observed	Instrumentation
TACAN Range	Nautical miles	0.1	0.05
TACAN Bearing	Degrees	0.5	0.5
Aircraft Radar Altitude	Feet	10	2
ICLS Lateral Deviation	Degrees	0.15	0.15
ICLS Vertical Deviation	Degrees	0.06	0.06
Ship Magnetic Heading	Degrees	0.5	N/A

the testing, for basic calculations. Digital instrumentation data was processed after the completion of testing. Data was extracted from the aircraft onboard tape and recorded to a compact disk for use in a desktop computer. The observed and instrumentation data were independently analyzed, using the same equations, to calculate the final coverage angles from each set of data. The results are presented and compared later in this chapter.

DATA ANALYSIS

The data analysis methods and equations used during the flight test effort were reviewed and determined to be inadequate for the purposes of this discussion. These equations did not take into account corrections factors such as earth curvature and transmitter location offsets from the TACAN antenna. In addition, these equations did

not consider the altitude of the aircraft when using the TACAN slant-range to determine the actual range of the aircraft from the ship. New equations were developed by the author to account for all of these offsets and corrections. The new equations were used for all calculations in this thesis.

POSITION EQUATIONS

The position of the aircraft was calculated relative to the position of the azimuth and elevation transmitters. A Cartesian coordinate system was developed for elevation and azimuth calculations, with the respective transmitter as the origin of those coordinates. The coordinate systems are shown in Figure 12 and Figure 13.

The position of the aircraft was determined by three onboard parameters: radar altitude (Z_{RADALT}), TACAN range (R_{TAC}), and TACAN bearing (Ψ_{TAC}). Radar altitude is a direct measurement of the distance between the bottom of the aircraft and the surface beneath the aircraft. TACAN range is the line-of-sight (slant range) distance from the aircraft to the ship's TACAN antenna. TACAN bearing is the relative magnetic bearing from the aircraft to the TACAN antenna. In addition, the distance from the aircraft to the transmitters must be adjusted by applying corrections to the aircraft position. These factors include the height, range, and lateral offset of the transmitters from the ship's TACAN antenna and the surface of the sea.

$K_{Z_{TAC-EL}}$:   Height of ICLS elevation transmitter below TACAN antenna.

$K_{Z_{SURF-TAC}}$: Height of TACAN antenna above sea surface

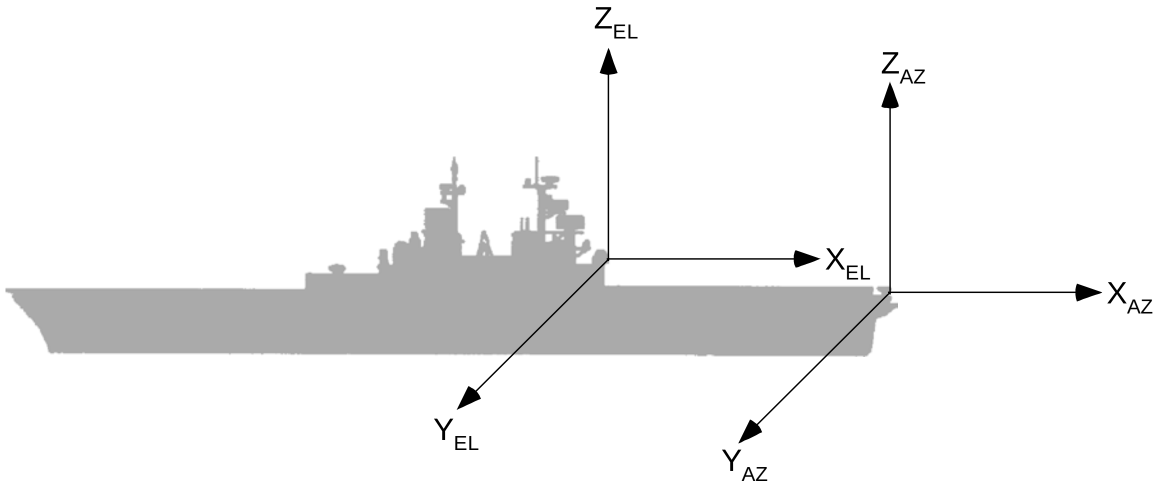

Figure 12
Transmitter Coordinate System

Source: Author

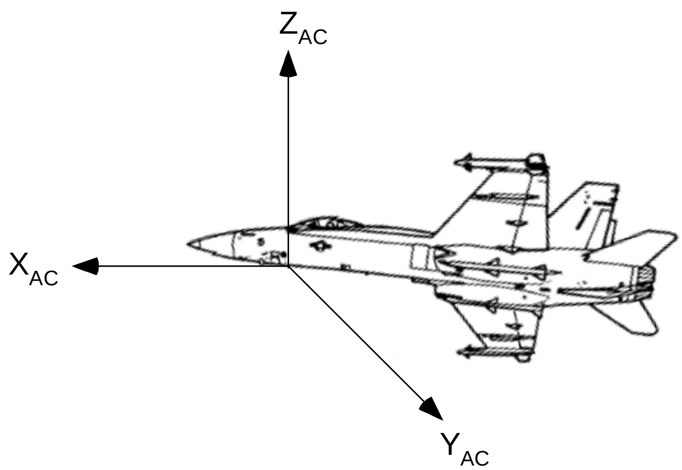

Figure 13
Aircraft Coordinate System

Source: Author

$K_{X_{TAC-AZ}}$: Longitudinal distance from TACAN antenna to ICLS azimuth transmitter

$K_{Y_{TAC-AZ}}$: Lateral distance from TACAN antenna to ICLS azimuth transmitter

$K_{X_{TAC-EL}}$: Longitudinal distance from TACAN antenna to ICLS elevation transmitter

R_e: Mean radius of the earth

$$R_e = 6378.1(\text{km}) \bullet \frac{3{,}281(\text{ft})}{(\text{km})} = 20{,}926{,}546.1(\text{ft})$$

The height of the aircraft above the TACAN (Z_{AC}) must be calculated from the aircraft-to-TACAN slant range (R_{TAC}) and the height of the aircraft above the surface of the earth (Z_{RADALT}). Figure 14 depicts the terms used in the following equations.

The value for Z_{AC} may be determined by calculation of the look-up angle (γ) from the XY-plane to the aircraft, for a given value of R_{TAC}. The angle γ is included in a triangle formed by [R_{TAC}], [Z_{RADALT} + R_e], and [$K_{SURF\text{-}TAC}$ + R_e]. The law of cosines may be used to find γ. For this situation, the law of cosines shows:

$$(\text{Z}_{\text{RADALT}} + \text{R}_{\text{e}})^2 = (R_{TAC})^2 + (\text{K}_{\text{SURF-TAC}} + \text{R}_{\text{e}})^2 - 2(R_{TAC})(\text{K}_{\text{SURF-TAC}} + \text{R}_{\text{e}})\cos(\gamma + \pi/2)$$

Part of the previous equation may be simplified by trigonometric addition formulas.

$$\cos(\gamma + \pi/2) = \cos(\gamma)\cos(\pi/2) - \sin(\gamma)\sin(\pi/2) = -\sin(\gamma)$$

$$(\text{Z}_{\text{RADALT}} + \text{R}_{\text{e}})^2 = (R_{TAC})^2 + (\text{K}_{\text{SURF-TAC}} + \text{R}_{\text{e}})^2 + 2(R_{TAC})(\text{K}_{\text{SURF-TAC}} + \text{R}_{\text{e}})\sin(\gamma)$$

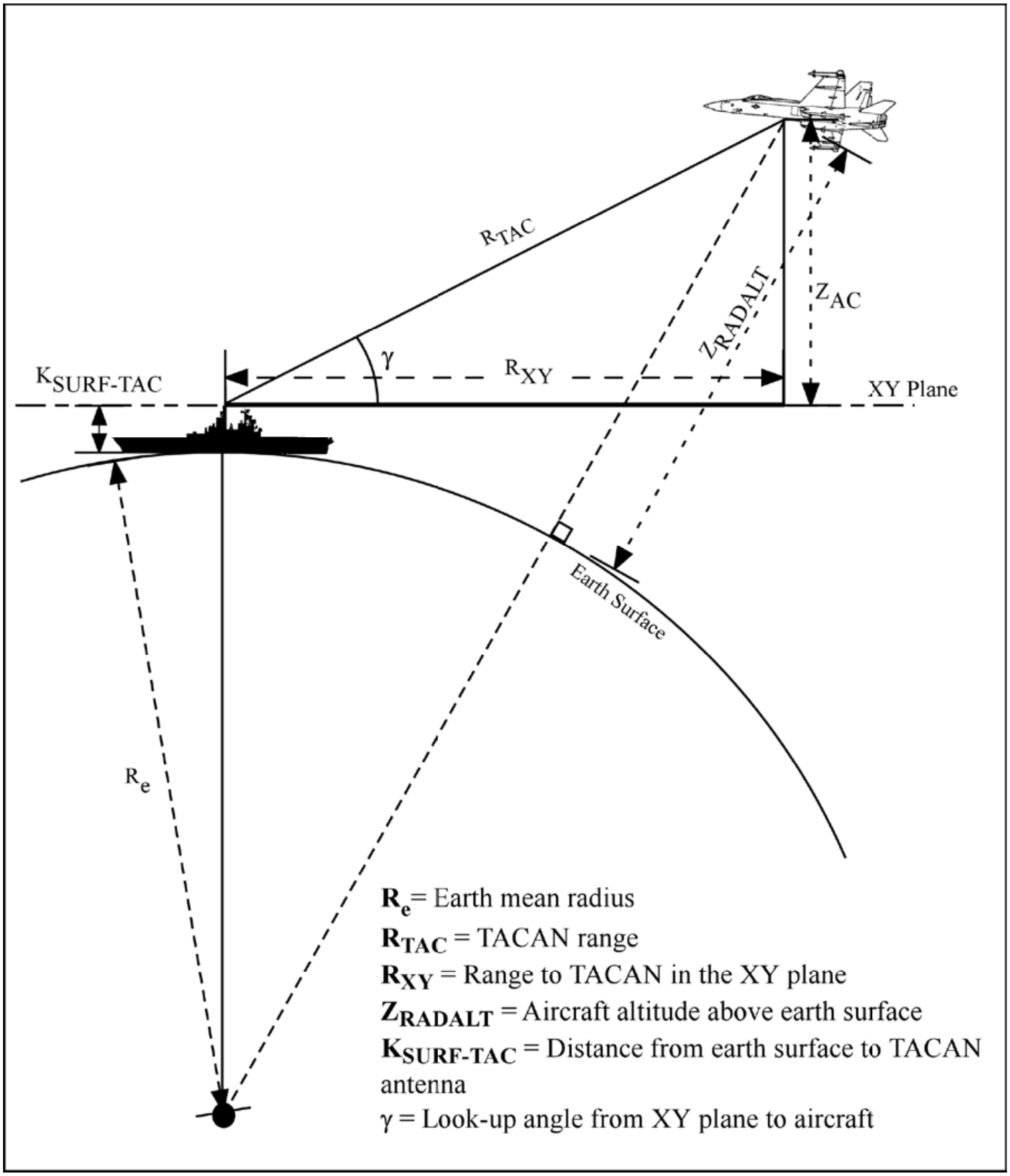

Figure 14
Calculation of XY Range

Source: Author

Solving for sin(γ) yields:

$$\sin(\gamma) = \left(\frac{(\mathrm{Z}_{\mathrm{RADALT}} + \mathrm{R}_{\mathrm{e}})^2 - (R_{TAC})^2 - (\mathrm{K}_{\mathrm{SURF\text{-}TAC}} + \mathrm{R}_{\mathrm{e}})^2}{2(R_{TAC})(\mathrm{K}_{\mathrm{SURF\text{-}TAC}} + \mathrm{R}_{\mathrm{e}})} \right)$$

R_{XY} may now be solved by simple trigonometry using R_{TAC} and γ.

$$Z_{AC} = R_{TAC} \sin(\gamma)$$

$$Z_{AC} = R_{TAC} \left(\frac{(\mathrm{Z}_{\mathrm{RADALT}} + \mathrm{R}_{\mathrm{e}})^2 - (R_{TAC})^2 - (\mathrm{K}_{\mathrm{SURF\text{-}TAC}} + \mathrm{R}_{\mathrm{e}})^2}{2(R_{TAC})(\mathrm{K}_{\mathrm{SURF\text{-}TAC}} + \mathrm{R}_{\mathrm{e}})} \right)$$

The height of the aircraft above the TACAN (Z_{AC}) is defined below.

$$Z_{AC} = \left(\frac{(\mathrm{Z}_{\mathrm{RADALT}} + \mathrm{R}_{\mathrm{e}})^2 - (R_{TAC})^2 - (\mathrm{K}_{\mathrm{SURF\text{-}TAC}} + \mathrm{R}_{\mathrm{e}})^2}{2(\mathrm{K}_{\mathrm{SURF\text{-}TAC}} + \mathrm{R}_{\mathrm{e}})} \right)$$

The range of the aircraft from the TACAN in the XY plane (R_{XY}) is defined below.

$$R_{XY} = \sqrt{R_{TAC}^{\ 2} - Z_{AC}^{\ 2}}$$

$$R_{XY} = \sqrt{R_{TAC}^{\ 2} - \left(\frac{(\mathrm{Z}_{\mathrm{RADALT}} + \mathrm{R}_{\mathrm{e}})^2 - (R_{TAC})^2 - (\mathrm{K}_{\mathrm{SURF\text{-}TAC}} + \mathrm{R}_{\mathrm{e}})^2}{2(\mathrm{K}_{\mathrm{SURF\text{-}TAC}} + \mathrm{R}_{\mathrm{e}})} \right)^2}$$

The aircraft X_{AC} and Y_{AC} position must be calculated from R_{XY} and the relative angle between the aircraft and the centerline of the ship. This angle (ΔΨ) is the difference between the ship's magnetic heading (Ψ_{SHIP}) and the TACAN bearing of the aircraft (Ψ_{TACAN}).

$$\Delta\Psi = \left(\Psi_{SHIP} - \Psi_{TACAN}\right)$$

The XY position of the aircraft relative to the TACAN antenna is given below.

$$X_{AC} = R_{XY}\cos(\Delta\Psi)$$

$$Y_{AC} = R_{XY}\sin(\Delta\Psi)$$

The XY coordinates of the aircraft relative to the azimuth transmitter may be determined by adding corrections for the distance between the azimuth transmitter and the TACAN antenna.

$$X_{AC_{AZ}} = X_{AC} + K_{X_{TAC-AZ}}$$

$$Y_{AC_{AZ}} = Y_{AC} + K_{Y_{TAC-AZ}}$$

Substituting values from previous equations yields the position of the aircraft in reference to the azimuth transmitter.

$$X_{AC_{AZ}} = R_{XY}\cos(\Delta\Psi) + K_{X_{TAC-AZ}}$$

$$Y_{AC_{AZ}} = R_{XY}\sin(\Delta\Psi) + K_{Y_{TAC-AZ}}$$

Similarly, the XZ coordinates of the aircraft relative to the elevation transmitter may be calculated by applying the appropriate corrections.

$$X_{AC_{EL}} = X_{AC} + K_{X_{TAC-EL}}$$

$$Z_{AC_{EL}} = Z_{AC} + K_{Z_{TAC-EL}}$$

Substituting values from previous equations yields the position of the aircraft in reference to the elevation transmitter.

$$X_{AC_{EL}} = R_{XY} \cos(\Delta\Psi) + K_{X_{TAC-EL}}$$

$$Z_{AC_{EL}} = \left(\frac{(\mathrm{Z}_{\mathrm{RADALT}} + \mathrm{R_e})^2 - (R_{TAC})^2 - (\mathrm{K}_{\mathrm{SURF\text{-}TAC}} + \mathrm{R_e})^2}{2(\mathrm{K}_{\mathrm{SURF\text{-}TAC}} + \mathrm{R_e})} \right) + K_{Z_{TAC-EL}}$$

The desired angles for azimuth and elevation may be determined by geometry.

$$\theta_{AZ} = \tan^{-1}\left(\frac{Y_{AC_{AZ}}}{X_{AC_{AZ}}} \right) \qquad \theta_{EL} = \tan^{-1}\left(\frac{Z_{AC_{EL}}}{X_{AC_{EL}}} \right)$$

Substituting values from previous equations yields the final equations for the azimuth and elevation coverage angles.

$$\theta_{AZ} = \tan^{-1}\left(\frac{R_{XY} \sin(\Delta\Psi) + K_{Y_{TAC-AZ}}}{R_{XY} \cos(\Delta\Psi) + K_{X_{TAC-AZ}}} \right)$$

$$\theta_{EL} = \tan^{-1}\left(\frac{\sqrt{R_{TAC}{}^2 - R_{XY}{}^2} + K_{Z_{TAC-EL}}}{R_{XY} \cos(\Delta\Psi) + K_{X_{TAC-EL}}} \right)$$

DATA ACCURACY

The accuracy of the final angular calculations is dependent on the accuracy of the data used in those calculations. The rules of significant figures state that the result of an arithmetic operation may not be any more accurate than the least accurate measurement.

The calculation of the basic glideslope of the AN/SPN-41A is required to be within 0.1-degrees of the ideal value of 3.0-degrees. This calculation requires at least two significant figures for all of the measurements that are used in that calculation. Table 3 shows the number of significant figures available in each measured parameter. The number of significant figures varies between certain ranges of values for each parameter. For example, the value of observed R_{TAC} at 1.5 miles contains two significant figures, while the value at 10.5 miles contains three significant figures. The value of the instrumented parameter may also have an additional significant figure due to increased resolution of that parameter from the instrumentation system. The data was read only to within the known uncertainty of each parameter. Any additional resolution was discarded prior to calculations.

The tabular data from pilot observations and instrumentation records was reviewed to determine the number of significant figures that were available for final calculations. For the ranges of values in the data, three significant figures were available from instrumentation records and two were available from pilot observations.

AZIMUTH COVERAGE

Azimuth coverage was determined from five constant-altitude passes. The coverage limit was determined by noting aircraft position when the ICLS azimuth needle disappeared and reappeared on the onboard display. The proportional azimuth coverage was determined by noting aircraft position when the ICLS azimuth needle encountered full deflection and also when it moved off of the fully deflected position. The centerline position was determined by noting aircraft position when the ICLS azimuth needle

Table 3
Significant Figures in Measurements

Measure	Number of Significant Figures		Range of Values
	Observed	Instrumentation	
TACAN Range (R_{TAC})	1	2	$0.1 \leq R_{TAC} < 1.0$
	2	3	$1.0 \leq R_{TAC} < 10.0$
	3	4	$R_{TAC} \geq 10$
TACAN Bearing (Ψ_{TAC})	1	1	$\Psi_{TAC} < 1$
	2	2	$1 \leq \Psi_{TAC} < 10$
	3	3	$\Psi_{TAC} \geq 10$
Aircraft Radar Altitude (Z_{RADALT})	0	1	$Z_{RADALT} < 10$
	1	2	$10 \leq Z_{RADALT} < 100$
	2	3	$100 \leq Z_{RADALT} < 1000$
	3	4	$Z_{RADALT} \geq 1000$
Ship Magnetic Heading (Ψ_{SHIP})	1	1[†]	$\Psi_{SHIP} < 1$
	2	2[†]	$1.0 \leq \Psi_{SHIP} < 10.0$
	3	3[†]	$\Psi_{SHIP} \geq 10$

[†]Note: Ship magnetic heading was not available from the aircraft onboard instrumentation; therefore the observed value was used for all calculations.

crossed the centered-needle position. Time histories of the aircraft data for azimuth coverage passes are shown in Figures A-1 through A-5. The results of the azimuth calculations are presented in Table 4.

The azimuth full and proportional coverage limits were actually wider than values set forth in the test standards. This is acceptable as the standard only specifies a minimum coverage angle. Analysis of the aircraft instrumentation data shows the centered needle position to be aligned slightly port and the pilot-observed data showed the centered position to be slightly starboard. There was some noticeable oscillation in the azimuth needle during some passes. A problem was found in a faulty Control Signal Converter (CSC) in the aircraft, causing intermittent downgrades in the azimuth needle presentation in the aircraft. This was believed to be the cause of the azimuth needle oscillation. Overall, the pilot found the azimuth coverage and needle stability to be satisfactory.

The difference between pilot observed data and instrumentation data for azimuth coverage limits shows a difference in angular coverage that ranged from 0.10-degree to 1.04-degree. As previously stated, these angles are only required to meet a minimum value, therefore the relatively larger deviation is permissible between the two data sets. The observed and instrumented data for the extended centerline differed by 0.53-degrees, however, both values fell within the required 0.3-degrees of zero.

Table 4
AN/SPN-41A Azimuth Coverage Angles

Limit	Data Source	Expected Angle (deg)	Measured Angle (deg)	Standard Deviation (deg)	No. of Samples
Coverage Limit (Port)	Observed	-20	-22	1.0	11
	Instrumentation	-20	-21.5	1.21	23
	Difference		0.50	0.21	
Coverage Limit (Starboard)	Observed	20	22	0.86	11
	Instrumentation	20	22.1	0.854	26
	Difference		0.10	0.01	
Proportional Limit (Port)	Observed	-6	-8.2	0.37	12
	Instrumentation	-6	-9.24	0.927	8
	Difference		1.04	0.55	
Proportional Limit (Starboard)	Observed	6	6.5	0.71	10
	Instrumentation	6	7.05	0.900	6
	Difference		0.55	0.19	
Coverage Limit	Observed	0	0.28	1.1	8
	Instrumentation	0	-0.250	0.642	17
	Difference		0.53	0.45	

ELEVATION COVERAGE

Elevation coverage was determined from three constant-altitude passes. The coverage limit was determined by noting aircraft position when the ICLS azimuth needle disappeared and reappeared on the onboard display. The proportional azimuth coverage was determined by noting aircraft position when the ICLS azimuth needle encountered full deflection and also when it moved off of the fully deflected position. The centerline position was determined by noting aircraft position when the ICLS azimuth needle crossed the centered-needle position. Time histories of the aircraft data for elevation coverage passes are shown in Figures A-6 to A-8. The results of the elevation calculations are presented in Table 5.

The proportional elevation coverage was very precise. The glide slope value fell well within the required tolerance of 0.1-degrees. The upper coverage limit was slightly above the minimum required limit of 10-degrees. The proportional limits were within the specified tolerance of 0.1-degrees. The elevation guidance presented a constant oscillation in the aircraft ICLS elevation needle. Records from the previous AN/SPN-41A installation aboard this ship also show this oscillation in the elevation needle. This problem appeared to be worse when the aircraft was at range or at the edges of the lateral coverage. This may be due to multipath from the large amount of deck area aft of the elevation antenna. This oscillation did not exceed ±0.15-degrees and was not objectionable to the pilot. Elevation needle coverage and stability were satisfactory.

Table 5
AN/SPN-41A Elevation Coverage Angles

Limit	Data Source	Expected Angle (deg)	Measured Angle (deg)	Standard Deviation (deg)	No. of Samples
Lower Proportional	Observed	1.6	1.6	0.048	3
	Instrumentation	1.6	1.52	0.0156	3
	Difference		0.08	0.03	
Glide slope	Observed	3.0	3.0	0.043	3
	Instrumentation	3.0	2.95	0.0462	3
	Difference		0.05	0.00	
Upper Proportional	Observed	4.4	4.5	0.014	3
	Instrumentation	4.4	4.39	0.0681	3
	Difference		0.11	0.05	
Upper Coverage Limit	Observed	10	11	0.20	3
	Instrumentation	10	10.6	0.164	3
	Difference		0.40	0.04	

The difference between pilot-observed data and instrumentation data showed a difference in centerline coverage of 0.05-degrees. The proportional coverage difference ranged from 0.08-degrees to 0.11-degrees. Although 0.11-degrees was slightly above the required tolerance, the individual values were within the 0.1-degree tolerance and these values were considered acceptable.

ICLS / OLS ALIGNMENT

The alignment of the ICLS basic glideslope and the OLS glideslope was confirmed during three simulated Case III recoveries. The OLS glideslope was slightly higher than the ICLS glideslope, however, the alignment was within the required 0.15-degree tolerance at 1-nmi. This slight difference is due to the location of the OLS, which is approximately 20-feet higher than the AN/SPN-41 elevation transmitter.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

GENERAL

Overall, the methods developed to test and evaluate the alignment of the AN/SPN-41A ICLS installations aboard L-class ships were judged to be satisfactory. It has also been proven, however, that the increased precision provided by instrumentation in these tests does not present a significant improvement in the accuracy of the final calculation of basic ICLS coverage angles. Observations recorded by pilots from production aircraft instruments proved to be sufficiently accurate to meet the required tolerances for the ICLS coverage angles. The flight test methods discussed herein are recommended for continued certification of the AN/SPN-41A aboard L-class ships. The data collection methods examined in this work are also recommended for continued use. The improved data analysis equations developed in this thesis should be used for greater accuracy in future efforts. In addition, the implementation of the cost-saving measures outlined below should be considered.

COST-SAVING MEASURES

The rising expenses related to flight test and the continuous pressure to decrease budgets necessitate a constant search for ways to reduce costs. The single-most expensive factor in ship certification effort budgets is almost always the aircraft flight-hour costs. The flight-hour rate for most of the NAWCAD-owned fixed-wing aircraft has exceeded $10,000 per hour and continues to rise. The total cost of a certification effort

often reaches the six-figure mark. A number of cost-saving alternatives for flight-test support have been investigated in recent years.

HELICOPTERS

The flight-hour rates for test helicopters are often a fraction of the rate for fixed-wing aircraft. An additional benefit is that a helicopter can complete an approach to a full-stop landing aboard the L-class ship. This provides the opportunity for face-to-face debriefs with aircrew and review of the pilot data cards. The ability to land and refuel aboard ship also increases the time that the aircraft is available on station for testing. The major drawback of using a helicopter is that these aircraft do not contain production ICLS systems. A simple solution was developed by NAWCAD technicians to resolve this issue. A special pallet was constructed that contains a complete ICLS airborne receiver-decoder system and display unit. This allows the helicopter pilot to receive the same information that an AV-8B or F/A-18A pilot would. The pallet may be easily installed and removed from the helicopter as needed for test periods. The helicopter is equipped with a production TACAN receiver and radar-altimeter. The helicopter method for L-class ICLS certification is recommended for efforts when instrumentation is not available or is not required for concurrent testing efforts.

LIGHT CIVIL AIRCRAFT

Several recent shorebased test efforts have turned to light civil aircraft for flight-test support. A number of private aviation firms have provided aircraft that are equipped with the necessary equipment and instruments to conduct programs similar to ICLS

certification. Presently, a Piper Cheyenne aircraft is being equipped with a flight test pallet that contains an AN/ARA-63 ICLS receiver, an ACLS radar beacon, Global Positioning System (GPS) receivers with data recording, TACAN, and a radar altimeter.[11] The flight hour rate for this aircraft is projected to be less than five-percent of the cost of using a NAWCAD fixed wing jet aircraft. This aircraft is intended for use in an upcoming radar certification program aboard an L-class ship. The availability of GPS in the aircraft and on the ship will allow for precise differential GPS calculations to determine the position of the aircraft with respect to the ship. The precision of GPS measurements far exceeds the accuracy available with the instruments that are currently used for L-class ICLS certifications. The use of a light civil aircraft is highly recommended for the significant cost-savings and increased accuracy associated with that solution.

REFERENCES

1. *Installation Certification of AN/SPN-41 Aboard USS Wasp (LHD-1), Test Plan 1605*, Naval Air Warfare Center Aircraft Division, 2 May 1994.

2. *USS WASP AN/SPN-41 CERTIFICATION, FINAL SITREP*, Naval Air Warfare Center Aircraft Division, 13 Jan 1995.

3. Prickett, A. *USS WASP (LHD-1) AN/SPN-41A Instrument Carrier Landing System Certification, NAWCADPAX--99-131-RTR*, 5 August 1999.

4. *Users Logistics Support Summary (ULSS) For Transmitting Sets AN/SPN-41A and AN/SPN-41A, ULSS-ATC-015*, Naval Air Systems Command, 2 May 1994.

5. *Contract Specification, Ground Subsystem, Marine Remote Area Approach and Landing System (MRAALS), ELEX-L-118A*, Naval Electronic Systems Command, 13 November 1974.

6. *NATOPS FLIGHT MANUAL, NAVY MODEL, F/A-18A/B/C/D, A1-F18AC-NFM-000*, Naval Air Systems Command, 1 July 2002.

7. *L-Class Ship AN/SPN-41A, AN/SPN-35, and VSTOL/OLS Flight Certification, Test Plan 2217*, Naval Air Systems Team, 15 June 1998.

8. *Organizational Maintenance Principles of Operation, Data Link, Instrument Landing, and Radar Beacon Systems, A1-F18AE-630-100*, Naval Air Systems Command, 1 June 1998.

9. *NATOPS Instrument Flight Manual, NAVAIR 00-80T-112*, Naval Air Systems Command, 1 April 1986.

10. *V/STOL Shipboard and Landing Signal Officer NATOPS Manual, NAVAIR 00-80T-111*, Naval Air Systems Command, 30 November 1999.

11. *AN/SPN-35C System DT-IIB/C Flight Test Plan, Test Plan 2573*, Naval Air Systems Command, 21 April 2003.

APPENDICES

APPENDIX A
FIGURES

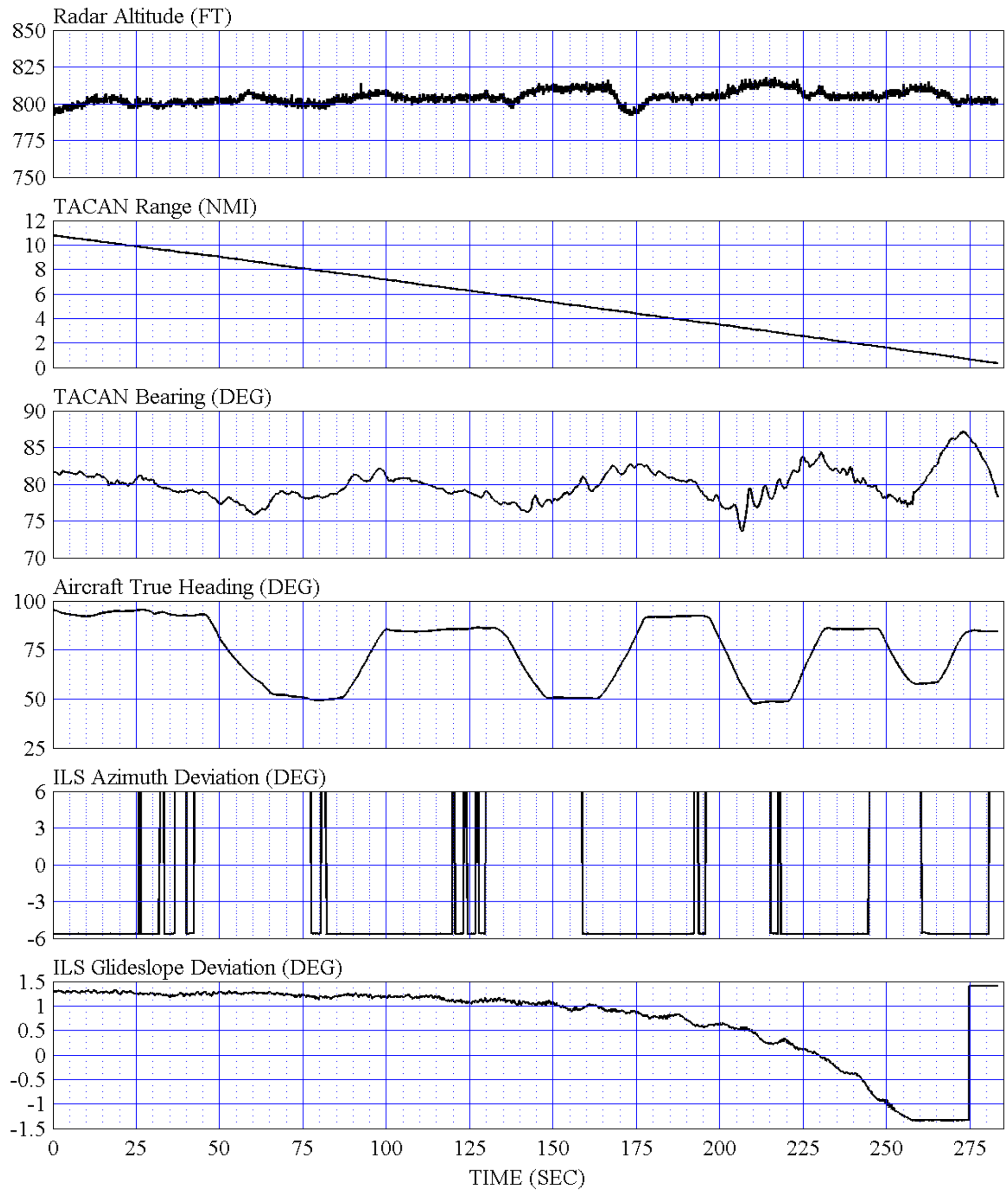

Figure A-1
Full Port Azimuth Coverage Pass Time History

Source: USS WASP (LHD-1) AN/SPN-41A Instrument Carrier Landing System Certification

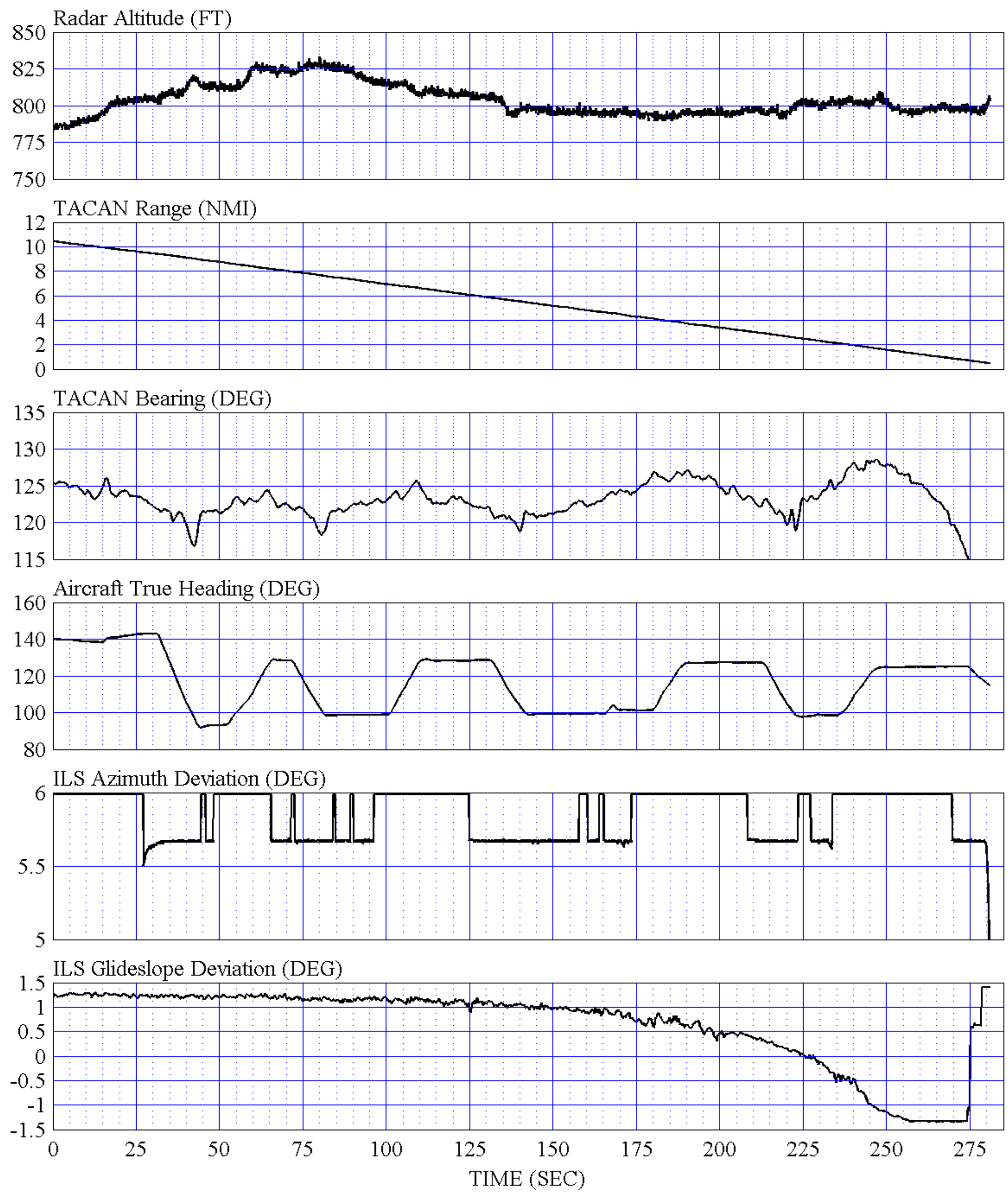

Figure A-2
Full Starboard Azimuth Coverage Pass Time History

Source: USS WASP (LHD-1) AN/SPN-41A Instrument Carrier Landing System Certification

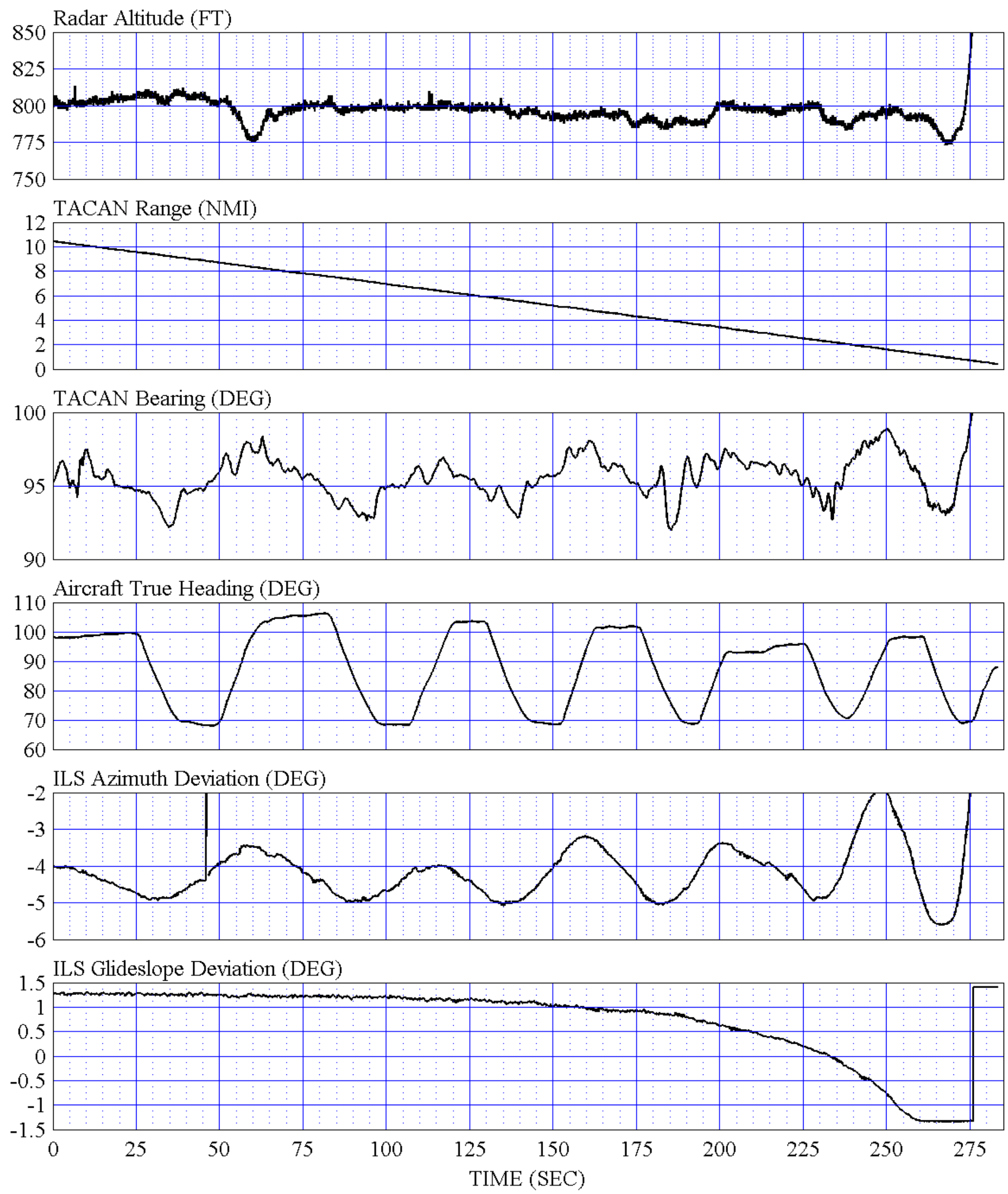

Figure A-3
Proportional Port Azimuth Coverage Pass Time History

Source: USS WASP (LHD-1) AN/SPN-41A Instrument Carrier Landing System Certification

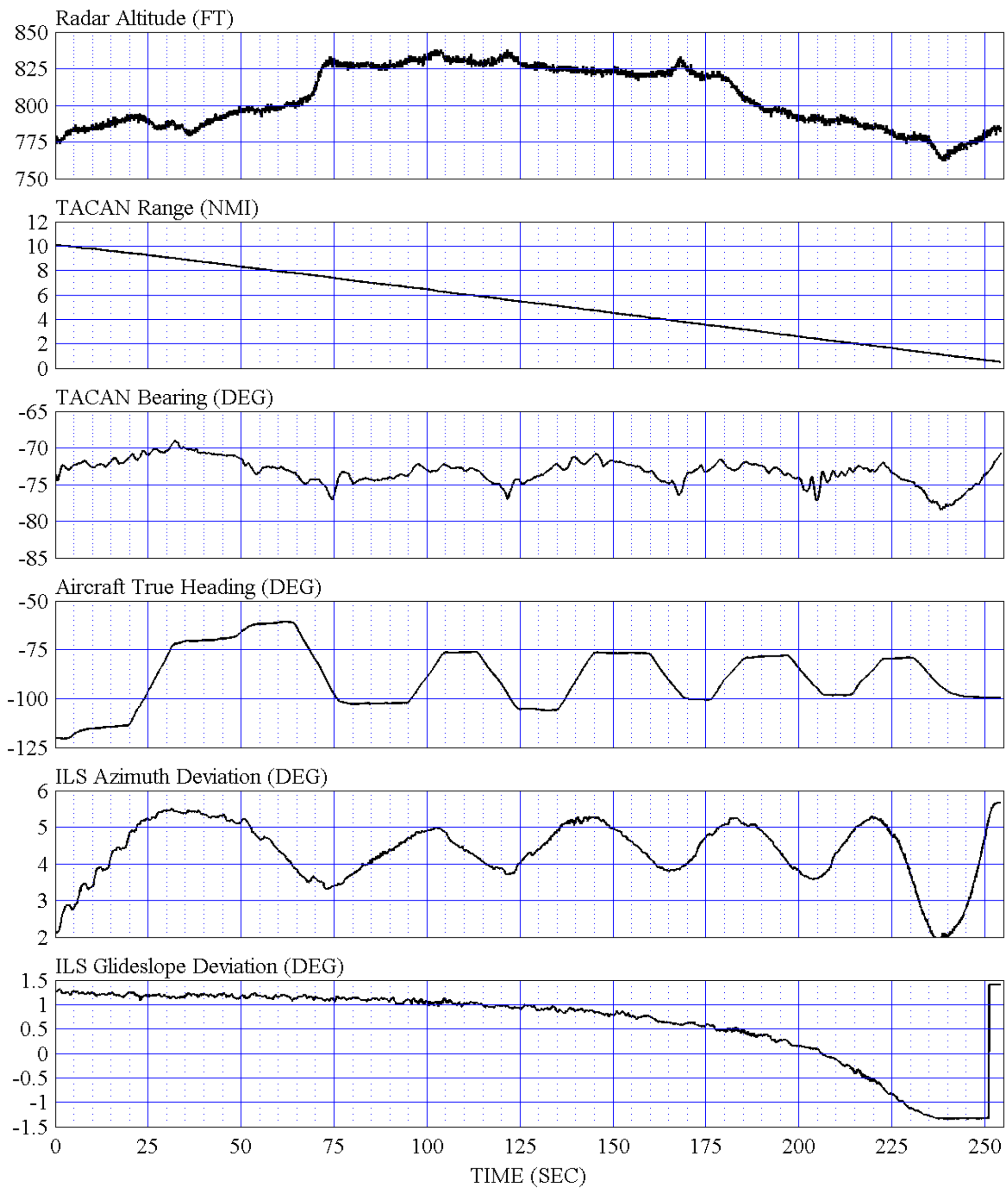

Figure A-4
Proportional Starboard Azimuth Coverage Pass Time History

Source: USS WASP (LHD-1) AN/SPN-41A Instrument Carrier Landing System Certification

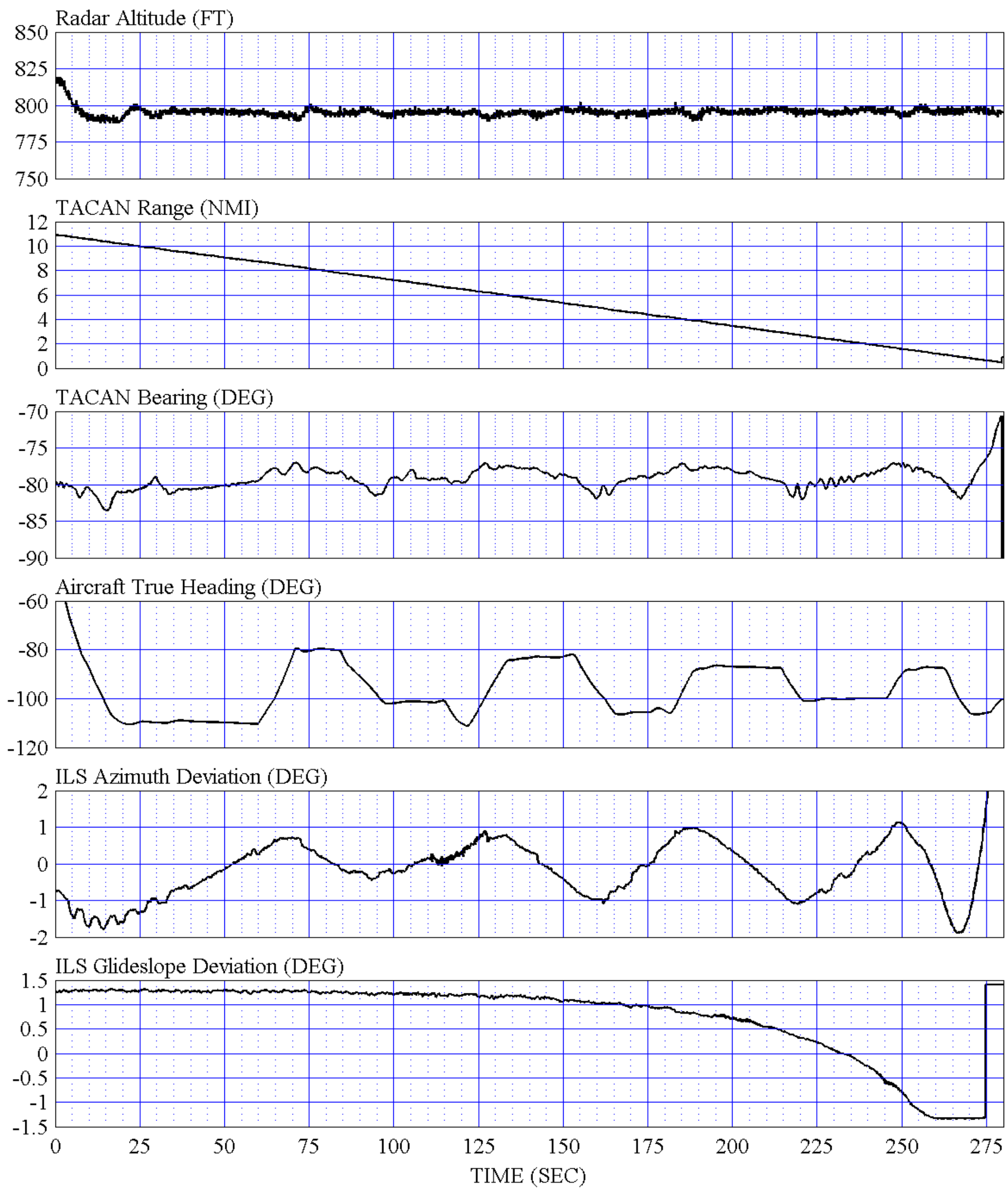

Figure A-5
Centerline Azimuth Coverage Pass Time History

Source: USS WASP (LHD-1) AN/SPN-41A Instrument Carrier Landing System Certification

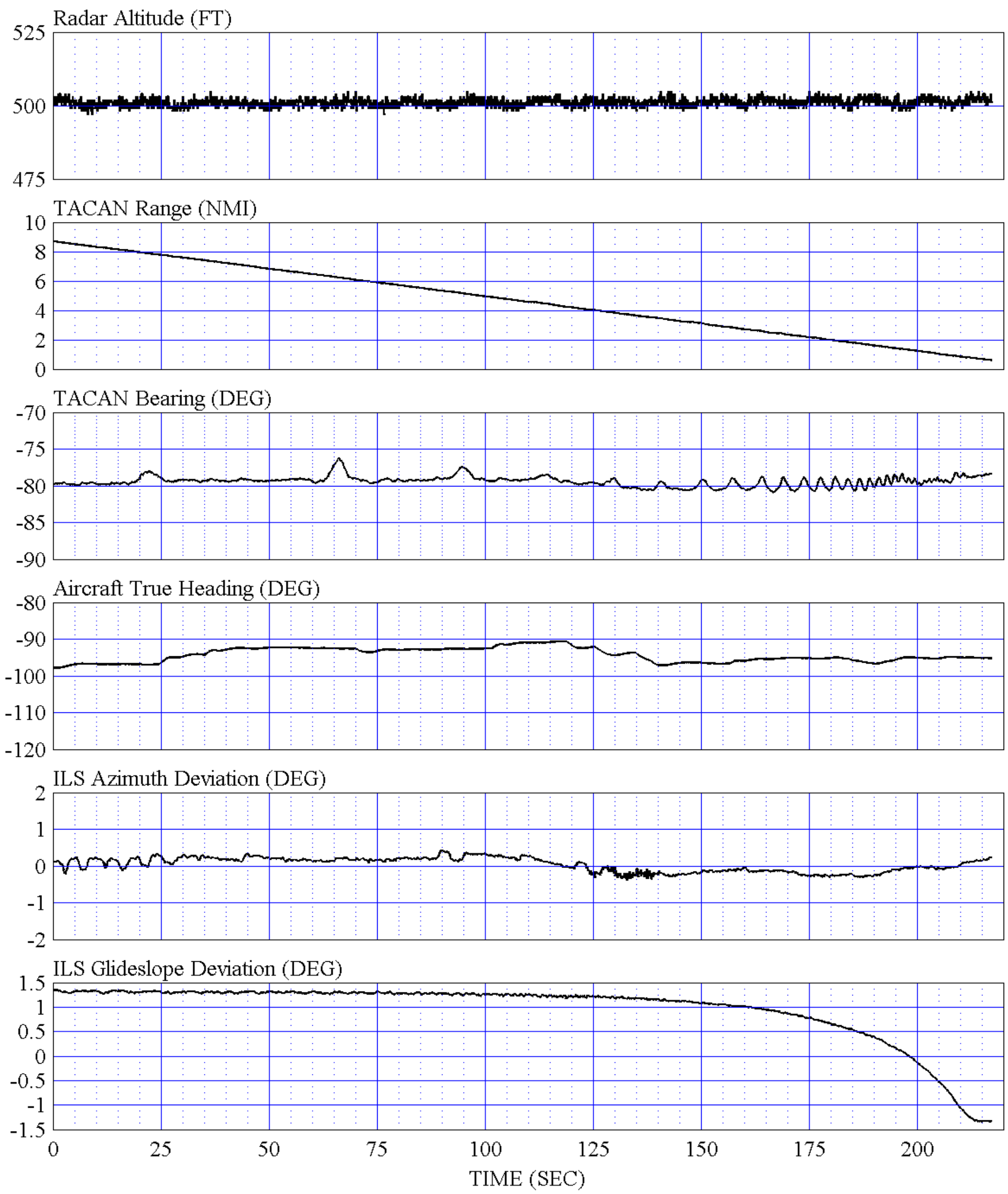

Figure A-6
500-FT Elevation Coverage Pass Time History

Source: USS WASP (LHD-1) AN/SPN-41A Instrument Carrier Landing System Certification

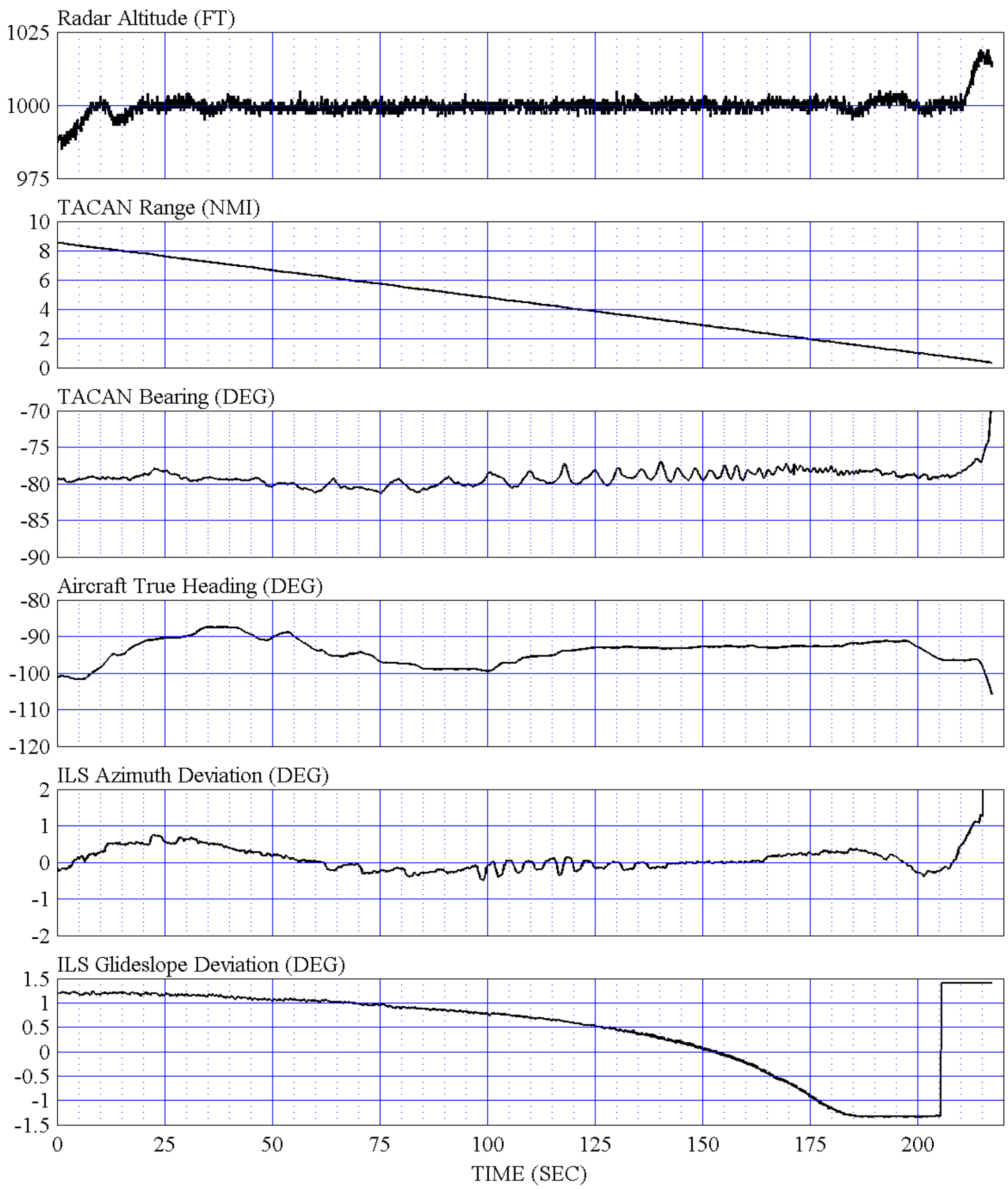

Figure A-7
1,000-FT Elevation Coverage Pass Time History

Source: USS WASP (LHD-1) AN/SPN-41A Instrument Carrier Landing System Certification

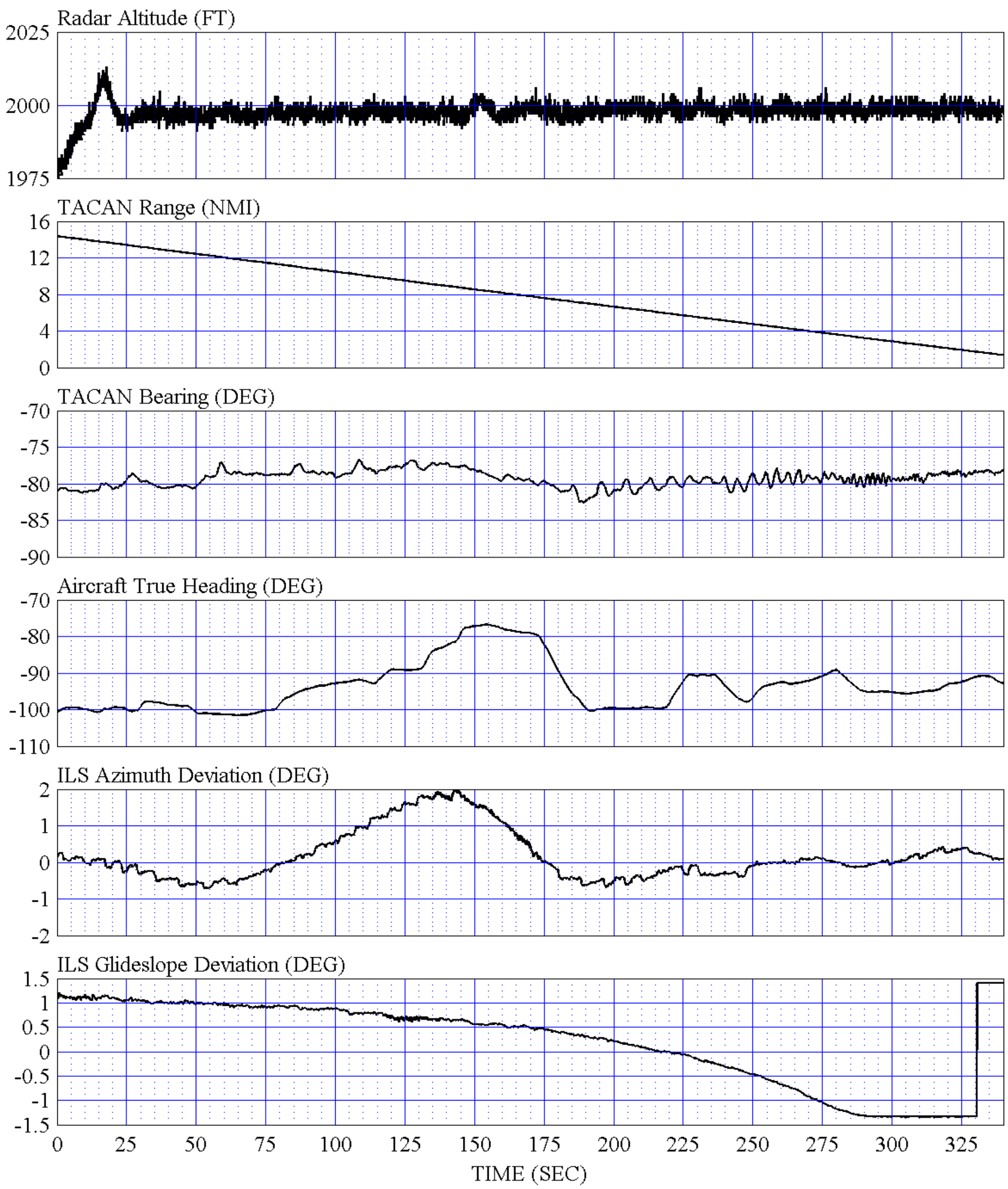

Figure A-8
2,000-FT Elevation Coverage Pass Time History

Source: USS WASP (LHD-1) AN/SPN-41A Instrument Carrier Landing System Certification

VITA

Arthur Prickett received a Bachelor of Science degree in Mechanical Engineering from the University of Maryland. He has worked for the Carrier Suitability Department at Naval Air Warfare Center, Patuxent River, MD., since 1990. Mr. Prickett is a 1998 graduate of the U.S. Naval Test Pilot School, Class 114. Mr. Prickett was the lead Navy engineer for landing systems development on the F/A-18E/F. He has also been involved with landing systems and aircraft compatibility testing aboard several aircraft carriers and amphibious assault ships. Mr. Prickett currently serves as a flight test engineer for landing systems testing for the F/A-18A-D and F/A-18E/F.