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An Investigation of the Rotor Tip Path Height of the MH-60S Helicopter in View of Forklift Clearance in Support of the United States Navy Medium Lift Shipboard Logistics Mission

Jonathan Patrick Kline
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Jonathan Patrick Kline entitled "An Investigation of the Rotor Tip Path Height of the MH-60S Helicopter in View of Forklift Clearance in Support of the United States Navy Medium Lift Shipboard Logistics Mission." 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 J. Ranaudo, George W. Masters

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

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

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Anne Mayhew_
Vice Chancellor and Dean of
Graduate Studies

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AN INVESTIGATION OF THE ROTOR TIP PATH HEIGHT OF THE MH-60S HELICOPTER IN VIEW OF FORKLIFT CLEARANCE IN SUPPORT OF THE UNITED STATES NAVY MEDIUM LIFT SHIPBOARD LOGISTICS MISSION

A Thesis

Presented for the

Master of Science Degree

The University of Tennessee, Knoxville

Jonathan Patrick Kline

August 2005

DEDICATION

This thesis is dedicated to my wife, Mary Helen,
my children, Brandon, Stephen, and Elizabeth, and my parents.
The incredible support and selfless sacrifice
of my wife and children throughout the last 4 years
have made it possible for me to pursue my goals.
They have contributed more to my effort
through their time than should be asked of any family.
The unswerving belief of my parents in my abilities
has been a source of strength for me since my earliest
days. Their example and support have been
the keys to my successes throughout my life.

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Throughout my navy career, several officers have been instrumental in my professional development and encouraged me to broaden my horizons. Specifically, CAPT John Hardison, USN, Deputy Commander, Helicopter Sea Combat Wing Pacific, and CDR Shoshana Chatfield, USN, Commanding Officer, HSC-25, encouraged me to pursue a career as a Test Pilot. CDR P. Joseph Twomey, USN, MH-60S Government Flight Test Director was instrumental in providing motivation to further my education through this Master's Degree program. CDR Dale Feddersen, USN, was the epitome of professionalism and helped me walk from the academic world of flight test theory into the practical application of test and evaluation. To all of them, I am grateful for the direction they have given my professional life.

Finally, I would like to thank my family for their extraordinary patience and understanding at the loss of our time together over many days and nights. Their contribution cannot be put into words adequate to express their sacrifice.

ABSTRACT

The purpose of this paper is to summarize Department of the Navy tests performed to measure rotor tip path height of the MH-60S helicopter and present an analysis of collected data to determine if safe cargo loading operations on the MH-60S can be conducted with a forklift while the rotor is engaged. Testing was conducted to measure the dynamic height of the rotor tip path plane during incremental cyclic displacements, rotor response to external disturbances, and pilot tendencies when centering the cyclic control stick. Additional information was gathered on representative forklifts in use on U.S. Navy ships, and shipboard operating procedures for cargo movement. A comparison between the forklift and rotor heights was conducted to evaluate the clearance available for forklifts transiting the rotor arc.

While it cannot be concluded that cargo loading using a forklift with the rotor engaged can be conducted without incident, substantial data were gathered that indicated that current safety precautions coupled with the clearance from the engaged rotor would allow for safe conduct of the evolution.

Specifically, if operations are conducted with low profile forklifts, which have an obstruction height shorter than the average male, rotor clearance is considered sufficient to preclude catastrophic interaction between the rotor and the equipment. Additional research, safety review, and equipment and publication changes are recommended to further increase the safety of conducting these operations.

PREFACE

The ground 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, Maryland. 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 Government, United States Department of Defense, the Naval Air Systems Command, or the Naval Air Warfare Center Aircraft Division, Patuxent River, MD. Technical information contained in this thesis has been reviewed by the Program Executive Officer, Air ASW, Assault, & Special Missions (PEO (A)) and cleared for open publication.

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LIST OF ACRONYMS AND ABBREVIATIONS

AC	alternating current
AFCS	Automatic Flight Control System
AMCM	Airborne Mine Countermeasures
APU	auxiliary power unit
ARG	Amphibious Ready Group
ASVS	airborne separation video system
ATO	air transfer officer
CCO	combat cargo officer
CCU	cockpit control unit
COMNAVCRUITCOMINST	Commander, Naval Recruiting Command Instruction
COMSCINST	Commander, Military Sealift Command Instruction
CRM	Crew Resource Management
CRU	controller recorder unit
CV	aircraft carrier, conventional powered
CVN	aircraft carrier, nuclear powered
DC	direct current
deg	degrees
DTS	data transmission system
FDSO	flight deck safety officer
ft	feet
GIU	ground interface unit
HC	Helicopter Combat Support Squadron
HCO	Helicopter Control Officer
HSC	Helicopter Sea Combat Squadron
HX	Air Test and Evaluation Squadron
hz	hertz
ICS	intercommunication system
IMDS	Integrated Mechanical Diagnostics System
in.	inch
IRIG	Inter Range Instrumentation Group
JPEG	Joint Photographic Experts Group
KIO	knock it off
LCDR	Lieutenant Commander

LHD/LHA	multipurpose amphibious assault ship
LPD	amphibious transport dock ship
LSD	dock landing ship
LSE	landing signalman, enlisted
LTTC	long-term test capability
MHE	mechanical handling equipment
MSC	multi system controller
MSC	Military Sealift Command
NAS	Naval Air Station
NATOPS	Naval Air Training and Operating Procedures Standardization
NAVAIR	Naval Air Systems Command
NAVAIRSYSCOM	Naval Air Systems Command
NM	Nautical Miles
Nr	main rotor speed
NRWATS	Naval Rotary Wing Aircraft Test Squadron
NTAB	NAVAIR Technical Assurance Board
NWP	Naval Warfare Publication
NVG	night vision goggle
OGH	Overhead guard height
ORD	Operational Requirements Document
ORM	Operational Risk Management
PAC	Pilot at the Controls
PEO (A)	Program Executive Officer, Air ASW, Assault, & Special Missions
PMC	Passenger, Mail, Cargo
psi	pounds per square inch
ROTC	Reserve Officer Training Corps
s	second
T-AE	ammunition ship
T-AFS	combat stores ship
T-AO	fleet oiler
T-AOE	fast combat support ship
TPP	tip path plane
TRIM REL	trim release
UHF	ultra high frequency
USDOT	United States Department of Transportation
v	volts

VERTREP	vertical replenishment
VOD	vertical onboard delivery

I. INTRODUCTION

1 BACKGROUND

1.1 Development

In accordance with the U.S. Navy Helicopter Master Plan, the MH-60S Knighthawk Multi-Mission helicopter was procured by the U.S. Navy as a replacement for the Boeing H-46D Sea Knight for the U.S. Navy medium lift logistics mission. United Technologies Sikorsky Aircraft Corporation was awarded the contract to develop the CH-60S in 1997. Delivery of the first production CH-60S for testing occurred in January 2000. Expanded mission requirements resulted in a subsequent re-designation of the aircraft by the Navy as the MH-60S in 2001. Operational Evaluation was completed in May 2002, and the first operational deployment was made in January 2003 aboard the USS ESSEX (LHD 2). (AirForce Technology.com, 2005)

As it replaces the H-46D, the MH-60S must assume the missions performed by the Helicopter Combat Support (HC) community. These missions include Vertical Replenishment (VERTREP), day and night amphibious search and rescue, vertical onboard delivery (VOD), and airhead operations. Additional missions include Combat Search and Rescue, Special Warfare Support, torpedo and drone recovery, noncombatant evacuation operations, aeromedical evacuations, humanitarian assistance, executive transport, and disaster relief. (Hensley, 1997)

VOD operations have historically been a critical part of the logistics mission. From 1990 – 1996, H-46D detachments from Helicopter Combat Support Squadrons FIVE and EIGHT moved over 2,500 tons of internal cargo and another 2,500 tons of internal mail (Hensley, 1997). For ease of loading, unloading, and movement about the ship using shipboard compatible forklifts, internal cargo is packaged in large tri-wall containers banded to wooden pallets. The MH-60S, developed as a form, fit, function replacement for the H-46D, incorporates a reversible cabin floor with rollers fitted to one side which can accommodate up to two standard navy pallets to perform the internal cargo mission (GlobalSecurity.org, 2000).

1.2 Cargo Loading Restriction

During MH-60S Developmental Test and Evaluation, a systems safety evaluation of the cargo handling system was conducted at Naval Rotary Wing Aircraft Test Squadron (NRWATS), now Air Test and Evaluation Squadron TWO ONE (HX-21). The evaluation resulted in publication of a Naval Air Systems Command (NAVAIR) Technical Assurance Board (NTAB) Part II Yellow Sheet deficiency report that cited insufficient clearance from the rotor disk to the Hyster 400 forklift to permit cargo loading operations with a forklift with the rotor head engaged. A Part II deficiency is defined as an "objectionable characteristic that requires significant operator compensation to attain adequate performance, or a routine hazard to weapon system or personnel exists" (NAVAIR, 2002). To document the concerns, measurements to the static rotor were made from the rotor tips to the ground with the blades positioned to 0, 90, 180 and 270 degrees relative, referenced clockwise from the nose of the aircraft. Additional measurements were made to the top of the crew compartment of a Hyster 400 forklift. The distance between the top of the compartment and the rotor tip was determined to be approximately 2.5 feet at the 90 and 270-degree positions. Not expecting the height of the rotor system to be significantly different at 100% rotor speed

(Nr) than in the static condition, the systems safety evaluators judged that the clearance was insufficient to safely conduct forklift operations with the rotor engaged. Pending further investigation, the remedial action during testing was to prohibit VOD operations with a forklift with the rotor engaged. The report recommendation was that the contractor investigate and take corrective action as soon as practicable and that a restriction be placed in the MH-60S Naval Air Training and Operating Procedures Standardization (NATOPS) manual against loading and unloading palletized cargo in the cabin utilizing a forklift with the rotors engaged (NTAB, 2001).

As a result of this restriction, the MH-60S must be shut down to load and unload cargo that is palletized, or break down each pallet of material and hand-load it in the cabin, greatly increasing the time required to conduct internal cargo transfer. Post-cruise reports from the initial MH-60S operational detachments have indicated that the internal cargo system is not being utilized as a direct result of the restriction against loading cargo with a forklift with the rotor engaged.

1.3 Hazards of Military Operations

By their nature, military operations are hazardous and involve accepting risk to provide operational capability. The hazards that are encountered and forecast during planning are managed using Operational Risk Management (ORM) principles to minimize occurrences of the identified hazards and reduce the severity of the consequences. Additionally, Crew Resource Management (CRM) is used during missions to actively manage the risks that occur.

1.4 Tasking

Since completion of the initial airworthiness testing of the helicopter, the issue of adequate clearance had not been revisited. During the MH-60S NTAB Yellow Sheet review in April 2004, HX-21 was tasked to conduct a study of the height of the rotor tip path at the 3 o'clock and 9 o'clock positions at 100% Nr in order to evaluate the safety of conducting forklift operations with the rotor head engaged. Data were gathered for the rotor at 100% Nr, with incremental lateral cyclic deflections. A crew station analysis was conducted to quantify cyclic stick positioning based upon aircrew muscle memory.

2 PURPOSE OF TEST

The purpose of the rotor tip path measurement test was to determine the height of the rotor tip path of the MH-60S helicopter (and by similarity, all H-60 helicopters) while the main rotor head was engaged, and the rotor tip path response to varying cyclic control inputs.

3 AIRCRAFT DESCRIPTION

3.1 General

The MH-60S Knighthawk helicopter, presented in Figure A-1[1] and Figure A-2, is manufactured by Sikorsky Aircraft Corporation, Stratford, Connecticut. The medium lift helicopter is a twin engine, single main rotor helicopter designed primarily for the Navy logistics mission, including Vertical Onboard Delivery (VOD) of internal cargo and passengers and Vertical Replenishment (VERTREP), as well as the Amphibious Search

[1] Figures A-1 through A-27 are located in Appendix A.

and Rescue mission aboard U.S. Navy amphibious assault ships. The aircraft was designed for growth to perform Organic Anti-Mine Countermeasures, Combat Search and Rescue, and Surface Warfare. The aircraft structure is an amalgam of the US Army UH-60L Blackhawk and the US Navy SH-60 Seahawk (Figure A-3). The fuselage and cabin area, including the cargo hook and landing gear, are primarily of the Blackhawk, while the engines and dynamic components, including the transmissions and rotor head, are those of the Seahawk (Table B-1)[2]. The Knighthawk includes several features unique to the airframe, including the Lockheed Martin Common Cockpit, designed for use in both the MH-60S and MH-60R, and an integrated, reversible cargo roller system for loading palletized cargo. The following descriptions are provided for those systems which were integral to the conduct of this test. A complete and detailed description can be found in A1-H60SA-NFM-000, *Naval Air Training and Operating Procedures Satndardization Manual, Navy Model MH-60S.*

3.2 Auxiliary Power Unit

The auxiliary power unit (APU) is a turbine engine that was designed to provide 400 Hz AC/28 vDC electrical power to aircraft systems until the rotor is engaged and the main generators are turned on, and air for the Environmental Control System until the engines are online and can provide bleed air. The APU provides sufficient power to operate all normal aircraft electrical components (A1-H60SA-NFM-000, 2004).

[2] Tables B-1 through B-7 are located in Appendix B.

3.3 Hydraulic System

The hydraulic system consists of 2 separate systems and 3 redundant pumps. Both systems provide hydraulics for redundant primary servos used to transfer flight control inputs to the main rotor system. The #1 system provides hydraulics for the tail rotor system. The #2 system provides hydraulics for the pilot assist servos which reduce cockpit workload by boosting the mechanical flight control inputs. Each of the three pumps is capable of providing hydraulic fluid to the flight control system at up to 3,000 psi. The two primary pumps are driven by an accessory drive off of the main transmission module and operate when the rotor is turning. The #1 pump supplies hydraulic pressure to the #1 hydraulic system while the #2 pump provides pressure to the #2 system. The back-up hydraulic pump is an electrically driven pump that can provide full hydraulic pressure to both main hydraulic systems. With the rotors static, the APU provides 400 Hz AC electrical power to drive the back-up pump, which provides hydraulic pressure to move the flight controls and recharge the APU accumulator (A1-H60SA-NFM-000, 2004).

3.4 Flight Controls

The MH-60S flight control system is a hydraulically boosted, irreversible (aerodynamic loads on the rotor system are isolated from the flight controls), mechanical system that consists of two identical cyclic and collective control sticks, and two sets of anti-torque pedals in the cockpit. The cyclic is used to control pitch and roll, the collective to control power and, consequently, climb and descent rate, and the pedals to control yaw. The controls are mechanically linked between the pilot and copilot stations.

Flight control inputs are transmitted via push-pull rods under the floor boards and in the cabin area to the overhead flight control assemblies. The flight control assemblies are hydraulically boosted in the pitch, yaw and collective channels, then transmitted to the mechanical mixing unit. The mixing unit combines the cyclic, collective, and anti-torque pedal inputs, then transmits them via hydraulic primary servos to the stationary swashplate, and ultimately, to the rotor head. Cyclic inputs alter the tip path plane (TPP) by increasing the pitch (and consequently the lift) of each rotor blade once per revolution such that deflection of the cyclic results in deflection of the TPP by making one side of the rotor system fly higher than the other. Collective inputs increase the pitch of all of the rotor blades equally throughout the revolution of the head, providing an increase in lift generated. Pedal inputs change the pitch of the tail rotor blades to provide anti-torque to counter the torque of the main rotor (A1-H60SA-NFM-000, 2004).

3.5 Automatic Flight Control System (AFCS)

Because the MH-60S flight controls are irreversible, the automatic flight control system (AFCS) includes a trim system to provide artificial control feel. The trim system uses two hydraulic servos for the pitch/roll channels. The parallel trim actuator assemblies provide the flight control force gradients and reference position. Moving the cyclic without depressing the cyclic trim release (TRIM REL) button provides a force gradient that is proportional to the distance the cyclic is moved from the reference position. Pressing the cyclic TRIM REL disengages the trim function and allows control movement with no force gradient. Releasing the TRIM REL re-engages trim with a new reference position (A1-H60SA-NFM-000, 2004).

3.6 Cabin Area

The MH-60S fuselage is that of the US Army UH-60 Blackhawk with dual sliding cargo doors. As such, the cabin area of the MH-60S provides the same amount of cargo space, but is outfitted with a new, integrated cargo handling system that is comprised of reversible floorboards with cargo rollers mounted to one side that can handle up to two standard tri-wall pallets (40"W x 48"L x 40"H). The cabin can also be configured to carry 2 crewmen and up to 13 passengers in crashworthy, stroking seats (Sikorsky, 2001). With the landing gear struts serviced to a nominal level within the normal range, the cabin floor sits approximately 30 inches (2.5 feet) above the ground. The unobstructed height of the cabin door opening is approximately 61inches (5.1 feet), for a total overall height from the ground to the top of the door of approximately 91 inches (7.6 feet).

3.7 Rotor System

The MH-60S rotor system incorporates the dynamic components of the naval Seahawk helicopter (SH-60B/F, HH-60H). The main rotor head sits atop a modular transmission with a built-in 3 degree forward tilt (Hewlett, 2004). The main rotor is a fully articulated, four-bladed system retained to a one piece titanium hub by elastomeric bearings. Rotor blade angle of attack is controlled by the collective and cyclic, with collective inputs increasing the pitch of the rotor blades uniformly throughout the revolution of the head and cyclic inputs imparting changes once per revolution. Each blade is free to lead, lag, flap, and droop independently. Control inputs are transmitted to the rotor head via pitch change rods attached to the rotating swashplate. The stationary and rotating swashplates are mounted concentrically, with the stationary swashplate inside of the rotating swashplate. The stationary swashplate transmits inputs from the primary hydraulic servos to raise, lower, and tilt the rotating swashplate in response to flight control inputs from the cockpit. Each rotor blade incorporates an anti-flap restraint and droop stop assembly. The anti-flap restraints prevent the blades from flapping excessively at low Nr, and are retracted by centrifugal force at approximately 35% Nr. The droop stops prevent the blades from drooping too low at low Nr, and are retracted by centrifugal force at approximately 55% Nr. Once retracted, the only obstruction to rotor blade flapping and drooping is the spindle which passes through the blade cuff. (A1-H60SA-NFM-000, 2004)

4 FORKLIFT DESCRIPTIONS

Though there are many different manufacturers and models of forklifts, there are common areas of interest when considering a forklift for use in loading cargo in a helicopter, including: the mast assembly; the operator enclosure and guard; and the lift height of the lowered mast. As can be seen in Figure A-4, the carriage assembly (forks that are used to support the palletized load) is attached to the mast assembly. The mast assembly consists of nested beams perpendicular to the forks that extend using a hydraulic piston and provide a mechanism for raising and lowering the carriage assembly. The driver of the forklift sits or stands within the operator enclosure, and the highest point of the enclosure is the overhead guard. The dimensional characteristics of interest on the forklifts include the overhead guard height (OGH), the collapsed/lowered mast height, and the free lift height (Figure A-5). The overhead guard height is measured from the ground to the top of the operators' enclosure. The collapsed/lowered mast height is measured from the ground to the top of the mast assembly when the carriage assembly is on the ground. The free lift height is a measure of how high the carriage assembly can be raised without increasing the height of the mast assembly. A partial list of shipboard approved and flight deck certified forklifts in use with the U.S. Navy and the ships on which they are employed is provided in Table B-2. Data for forklifts in use on Military Sealift Command (MSC) ships were not available for this report; however, the characteristics of those forklifts and dimensional data of interest will include the same parameters. When a comprehensive list of forklifts in use aboard MSC ships is identified, the conclusions and recommendations of this report can be applied to those forklifts as well.

5 FLIGHT DECK CHARACTERISTICS

5.1 Aircraft Carriers

Aircraft carriers include conventional and nuclear powered carriers (CV and CVN). Having the largest flight deck (Figure A-6), the aircraft carrier affords the most flexibility for helicopter operations. The landing spots provide guidance for general location of the aircraft to land, but do not have markings that dictate specific aircraft placement or alignment on the flight deck. In general, landing alignment on the aircraft carrier is with the aircraft aligned longitudinally with the ship's direction of travel. Three landing spots are located on the port side of the ship (angled deck), abeam the island. When utilizing these spots, cargo loading can only be done via the starboard cargo door. Additional spots for helicopter landing located on the bow permit cargo loading from either side of the aircraft. Some carriers have an additional landing spot certified for helicopter operations aft of the island on the starboard side. A landing on that spot permits cargo loading from the port side of the aircraft. During normal operations, the port side spots and the starboard spot aft of the island are the most frequently used. (NAVAIR 00-80T-105, 1999)

5.2 Large Amphibious Assault Ships

The large amphibious assault ships (LHD, LHA) serve as troop transport ships and helicopter carriers, carrying both Navy and Marine Corps aircraft (Figure A-7). The large amphibious assault ships provide specific markings on each spot for aircraft alignment and guidance for positioning the aircraft to ensure sufficient clearance from adjacent landing spots. Each landing spot has an athwart-ship line-up line for fore-aft alignment, and a longitudinal line-up line for lateral alignment. The MH-60S is landed with the longitudinal centerline of the helicopter over the longitudinal line-up line and the nose of the helicopter on the athwart-ship line-up line. The port side spots permit cargo loading only through the starboard cabin door. Though they are rarely used, the starboard side spots permit access for cargo only through the port cabin door. (NAVAIR 00-80T-106, 1998)

5.3 Small Amphibious Assault Ships

The small amphibious assault ships (LPD, LSD) serve as staging platforms for seaborne transport of ground troops and equipment for a rapid-response capability for the U.S. military. The ships have two landing spots with port and starboard landing alignments (Figure A-8). The landing consists of a line-up line and a landing circle. The line-up line is offset 30 – 45 degrees from the ship longitudinal centerline, depending on ship class. Aircraft landing is conducted with the main landing gear in the forward half of the landing circle, and the longitudinal centerline of the helicopter over the line-up line. The decision to conduct a port or starboard landing is based on prevailing winds, and is generally chosen to keep the winds on or near the nose of the aircraft. With the nose aligned from port to starboard (port approach) the port cargo door is used for cargo loading. When landing with the nose aligned from starboard to port (starboard approach), the starboard cargo door is used for cargo loading. (NAVAIR 00-80T-122, 2003)

5.4 Supply Ships

The U.S. Navy uses a multitude of classes of supply ships, including the AOE/T-AOE (fast combat support ship), T-AFS (combat stores ship), T-AO (oiler), and T-AE (ammunition ship). All ships designated with a "T" are civilian-contracted ships operated by the Military Sealift Command (MSC). The supply ships have flight deck markings and alignments that are similar to the small amphibious assault ships, with the difference that the supply ships have only one landing spot (Figure A-9). The line-up lines are offset 30 – 45 degrees from ship centerline depending on ship class. Landing positioning, choice of landing direction, and cargo loading limitations are the same as on the small amphibious assault ships (NAVAIR 00-80T-122, 2003). The supply ships are also marked with VERTREP obstruction lines (T-line, T-ball line) to provide an indication of obstruction clearance during VERTREP operations (NAVAIR, 2003).

6 FLIGHT DECK PERSONNEL

The flight deck is a dynamic and dangerous environment, subject to rapidly changing conditions and a high operational tempo. Prior to serving on the flight deck during flight operations, all personnel involved are trained on flight deck safety. To minimize the potential for injury or mishaps, the flight deck is manned by the minimum number of people required for safe operations. Primary personnel include: a Landing Signalman Enlisted (LSE), responsible for directing the helicopter to the landing spot and controlling access to the helicopter; chock and chain runners, responsible for securing the helicopter to the flight deck during fueling and passenger and cargo loading operations; the Helicopter Control Officer (HCO) or Air Boss, responsible for control of the helicopter to include issuing takeoff and landing clearances, and management of flight operations to ensure required evolutions are completed; and the Flight Deck Safety Officer, responsible for overseeing all flight deck operations from the flight deck level to ensure compliance with applicable safety directives (NWP 4-01.4, 1996). Additional personnel who work on the flight deck on a regular basis include the refueling team, the crash and rescue team, cargo management personnel, and aircraft maintenance personnel. All of these people are required to work together and be cognizant of the safety requirements to work on the flight deck. Communications are maintained by UHF radio communications, walkie-talkies, and standard pre-defined hand and visual signals to ensure coordination of flight deck movement.

II. TEST METHODS AND PROCEDURES

1 GENERAL

The test was divided into three phases to quantify rotor TPP height during normal operations. The first phase was conducted to determine the effects of control positioning. The second phase was conducted to quantify the effects of unstable/gusty wind conditions. The third phase was conducted to determine the possible deviation of the cyclic from the measured center position when the pilot relied on muscle memory to center the cyclic longitudinally and laterally, as well as to determine how far from centered the cyclic could be moved before physical cues indicated an off-center position. During phases I and II, a digital high-speed camera system was used to record tip path behavior for post-test processing. All tests with the rotors turning were conducted with winds of 5 knots or less. During all evaluations, the pilot and copilot stations were occupied by NATOPS qualified helicopter pilots who were United States Naval Test Pilot School graduates.

2 DIGITAL CAMERA SYSTEM

The Airborne Separation Video System (ASVS) is a Tri-Service Program for a fast-frame, electronically shuttered, high-resolution, digital imaging camera system primarily for Aircraft-Store or Ground Launcher-Store compatibility engineering and analysis. The ASVS supports several configurations, including: Cockpit Control Unit (CCU) Configuration with Controller Recorder Unit (CRU) or Multi-System Controller (MSC), MSC Standalone Airborne (unmanned flight system), and the MSC Standalone Ground Configurations (Springer, 2005).

The Long-Term Test Capability (LTTC) camera used in the ASVS allows for the image size to vary dependent on the user's needs. The LTTC camera's ability to vary the image size provides the user with the ability to vary the frame rate and image storage capacity. The image storage capacity is dependent on the vertical and horizontal image size specified. The camera sensor is a Complementary Metal-Oxide Semiconductor (CMOS) with capability for 1,280 x 1,024 pixel resolution. The data rate from the LTTC real time digital data output interface is constant; however, the amount of data transmitted is directly dependent on the vertical image size, and the interval between frames is dependent on the selected frame rate (Springer, 2005).

The MSC with LTTC (Figure A-10) provides the Joint Photographic Experts Group (JPEG) lossless compression and storage of the camera images. The MSC also interfaces with the Ground Interface Unit (GIU) and Data Transmission System (DTS) to provide displays of either live images or the stored images. The MSC replaces either the CRU or both the CRU and CCU (Springer, 2005).

For this test, the ASVS included LTTC cameras, a Local and Wide Area Network (LAN/WAN) bridge, a GIU, and the MSC with the cameras mounted to ground work stands. The system functions were tested and programmed in the mobile processing unit before the test using the GIU. The ASVS mission was then downloaded from a laptop computer to the MSC. During test setup, full control of the ASVS was performed from the laptop. The laptop was used to preview lighting and field of view prior to the test event. During the test, the laptop remained connected to the MSC to maintain control and edit the MSC functions. After each data point, the data were downloaded to the MSC and stored in a digital file format, then transferred to the mobile processing station, allowing the cameras to be reset for the next event (Springer, 2005).

3 DATA COLLECTION

The aircraft was positioned on the HX-21 flight line for the test. Multiple fixed reference points on the aircraft were surveyed and marked with adhesive targets (Figure A-11) to assist with post-test data analysis. Four digital high-speed cameras were positioned as shown in Figure A-12. The side cameras were the primary data collectors, with the forward cameras positioned to serve as backups. All of the cameras were synchronized and time-stamped with Inter Range Instrumentation Group (IRIG) time code. The cameras were set to 1,024 x 1,024 pixel resolution at 1/5000 shutter speed for the test. The side cameras were placed perpendicular to the aircraft, with the rotor hub in the center of the field of view. The height of these cameras corresponded to the nominal height of the rotor tips at 0 pitch as they passed the 90 or 270 degree point, as measured clockwise from the nose of the helicopter. The digital cameras were wired to a mobile processing station (a modified recreational vehicle outfitted with lab and processing equipment) where the data was downloaded and recorded following each event. Initially, all 4 cameras were used to record the events. The mobile processing station was equipped with an anemometer to record and report real-time wind direction and speed. Ultra-high frequency (UHF) radio communications were maintained between the aircraft and the mobile processing station throughout the test event to coordinate data recording with the cyclic inputs.

The location of the rotor blades and the image plane of each camera were surveyed prior to the event. With the aircraft in its surveyed location, and the rotor static, a calibration pole with 6 reference targets at 1-foot vertical increments (Figure A-13) was placed at 10 different pre-surveyed locations, 5 for each side of the aircraft. The pole positions were exactly 1 blade radius from the rotor hub, at 45, 67.5, 90, 112.5 and 135 degrees along the rotor's path. The pole was similarly located between 225 and 315 degrees on the left side. At each of the 10 locations, the blade position was surveyed and an image of the calibration pole was taken. With the known dimensions and location of the calibration pole, the image was used to correlate pixel count with height and angular position. Comparison of the surveyed blade height and angular position with the measurements from the image data demonstrated a maximum azimuth error of ±0.92 degrees and a maximum blade height error of ±0.36 inches.

Data were collected during each event to allow for plotting the angle vs. height from 45 to 135 degrees, and from 225 to 315 degrees along the path of travel of the rotor tip. The frame rate of the cameras was set to 200 frames per second to minimize download and data reduction time while still assuring the accuracy of the measurements. During post-test analysis, the blade location in the images was measured in pixels. The lateral position of the blade tip in the image in pixels was transformed into the blade's angular location, and its vertical position in pixels was transformed into blade height by referring to the calibration data.

4 CYCLIC INSTRUMENTATION

4.1 General

Cloth measuring tapes were installed on the copilot (left seat) cyclic using duct tape and paperclips in accordance with standard installation techniques used by the NAVAIR Shipboard Suitability Branch (Figure A-14). The tape measures were a retractable-type with a release button located on the side that had to be depressed in order to retract. A dime and nickel were taped on the button to keep it depressed throughout the evolution so that the tape measure could extend and retract freely as the cyclic was moved through its range of travel.

4.2 Longitudinal Cyclic Instrumentation

The tape measure for longitudinal position was attached to the base of the cyclic grip so that the tape ran from where the cyclic flares out for a hand rest towards the flight display (Figure A-14 and Figure A-15). A thin welding rod was bent at both ends then affixed to the cockpit instrument panel with duct tape just below the flight display. The welding rod was bent and affixed so that the rod was a uniform 1 inch from the face of the panel (Figure A-16). A paper clip was attached to the end of the tape measure using duct tape, then looped over the welding rod so that it was free to travel laterally while maintaining an accurate perpendicular distance reading longitudinally. A paper clip was also affixed to the side of the tape measure and bent so that it provided an index to which the measurement could be referenced.

4.3 Lateral Cyclic Instrumentation

The tape measure for lateral position was affixed to the sill of the copilot window, just below the vent. The tape measure was installed perpendicular to the window, and was centered 1/2 inch aft of the forward-most jettison latch panel, with the case set so that the tape fed out at the 6 o'clock position. The end of the tape had a paperclip attached to it with duct tape, and was attached to another paperclip at the reference point on the cyclic. The cyclic reference point for lateral measurements was located 3/4 inch below the ICS/radio trigger switch, with a paper clip affixed using duct tape to allow for attachment of the measuring tape. (Figure A-14 and Figure A-17)

5 CYCLIC ENVELOPE

The cyclic envelope was measured to determine the centered cyclic position referenced to the installed tape measures. The cyclic envelope measurements were made with the rotors static, back-up hydraulic pump on, collective full down, and directional pedals centered. The cyclic was displaced full forward, then displaced laterally to the extremes of travel. From the point of maximum lateral displacement, it was moved full travel longitudinally. At each point of maximum displacement, a lateral and longitudinal measurement was recorded.

6 PHASE I: CYCLIC DISPLACEMENT EFFECTS ON TIP PATH HEIGHT

To determine the actual height of the rotor tip path with the rotor engaged, photographic data of the rotor tips were recorded while the cyclic was displaced. While the left seat pilot referenced the tape measure instrumentation on the left cyclic to provide lateral and longitudinal positioning information, the right seat pilot displaced the cyclic laterally while maintaining it centered longitudinally. Cyclic control inputs were made in 1/2 inch increments from 0 to 2 inches of displacement both left and right, then 1/4 inch increments out to the knock-it-off (KIO) point. The KIO point was defined by one of five possibilities: droop stop or spindle contact on the rotor head, identified by a knocking sound from the head; the aircraft becoming “light on the wheels”; exceeding pilot or observer comfort level; cyclic contact with pilot body; or reaching maximum cyclic travel. At each stabilized 1/2 inch increment, camera data were recorded for 5 seconds. After reaching cyclic displacements in either direction of 2 inches, 3 inches, and at the final KIO point, the aircraft was shut down and the rotor head, droop stops, and spindles inspected for any possible damage.

7 PHASE II: ROTOR SYSTEM TRANSIENT RESPONSE

A major concern for shipboard forklift operations is the transient response of the rotor system in gusty wind conditions on the flight deck. Ship superstructure interference and deck edge effects make the airwake profile over the flight deck difficult to predict. In an effort to quantify transient rotor characteristics, lateral cyclic step inputs were made and the rotor response recorded by the digital cameras. A step input is defined as an input of a predetermined magnitude that is completed in less than 0.2 seconds, and then held for the duration of the data collection period (USNTPS FTM 107, 1995). The inputs were made against a control fixture, Figure A-18, in 1/4 inch increments out to a target of 1 inch of displacement both left and right. The inputs were made by the right seat pilot while the left seat pilot held the control fixture in place. After the input was made, the cyclic was held against the control fixture for the duration of data recording to document any transient overshoot response. Data were gathered in each direction at each 1/4 inch increment target.

8 PHASE III: MAN-MACHINE INTERFACE

The final test phase was designed to identify both how far from center the pilot places the cyclic when done without the benefit of control position indications, and how far the cyclic could be displaced without the pilot at the controls (PAC) perceiving it to be out of the centered position. The test was conducted with the rotors static, APU on, back-up hydraulic pump on, and both pilots in full flight gear (flight suit, flight boots, helmet, gloves, and SV-2 survival vest). With the trim system disengaged by depressing the cyclic TRIM REL switch, the pilots were tasked to center the cyclic laterally and longitudinally relying solely on muscle memory. Once the cyclic was trimmed to the perceived centered position, the cyclic position indicated by the measuring tapes was recorded. Subsequently, each pilot was asked to displace the cyclic laterally and report when the cyclic was noticeably out of position based on physical cues. Each task was completed both to the left and right by each pilot, and the cyclic positions indicated on the measuring tapes were recorded.

III. TEST RESULTS

1 GENERAL

Test results for static and dynamic rotor tests are located in the Test and Test Conditions tables, Table B-3 and Table B-4. All test objectives were met and all test points were completed. At no point during the test was any contact of the spindle or droop stops encountered. Post turn inspections of the head revealed no damage to any of the components.

2 CYCLIC ENVELOPE

With the cyclic instrumented with cloth measuring tapes, a cyclic control envelope was determined to establish a centered cyclic position. With the APU and back-up hydraulic pump on, the rotors static, collective full down, and pedals centered, the cyclic was moved throughout its full range of travel, with measurements taken at the end points of travel. The control envelope was rectangular, measuring 7 inches longitudinally and 9 1/2 inches laterally. The cyclic control envelope measurements are presented in Table B-5, with the envelope presented in Figure A-19. Once a control envelope was determined, the cyclic was trimmed to the centered position for the rotors turning tests.

3 PHASE I: CYCLIC DISPLACEMENT EFFECTS ON TIP PATH HEIGHT

The photogrammetric data were processed post-test to determine rotor tip path height between 45 and 135 degrees and 225 and 315 degrees, measured clockwise relative to the nose of the aircraft. The data were processed for each 1/2 inch increment of cyclic displacement, and are presented in Table B-6. The data presented include the azimuth and height of the tip path at the low point and high point of the rotor arc for both the port and starboard side of the aircraft, as well as tip path height at the 90 and 270 degree positions, for each displacement. Figure A-20 and Figure A-21 are the data plots for the port and starboard sides of the aircraft for all of the cyclic displacements. The data confirm that the rotor tip follows a path that increases in height as it travels clockwise from the 0 degree position to the 180 degree position, then decreases as it travels from 180 degrees back to 0 degrees because of the 3 degree forward tilt of the transmission. As a result, the lowest point of the rotor on each side of the aircraft was generally located at the forward-most point of camera coverage, and the highest point on each side of the aircraft was generally located at the aft-most point of camera coverage. During the first data run with the cyclic centered, all four cameras were used to record rotor position. Following a review of data from that run, only the two side cameras were used for data collection for the remainder of the testing. Data for cyclic centered and maximum displacements left and right are summarized in Table 1, below.

Table 1:
Cyclic Displacement vs. Rotor Tip Path Height at Selected Azimuth Locations

Cyclic Input (in)	Relative Azimuth (deg)	Tip Path Height		Cyclic Input (in)	Relative Azimuth (deg)	Tip Path Height		Cyclic Input (in)	Relative Azimuth (deg)	Tip Path Height	
		in	ft			in	ft			in	ft
Center	39	114	9.47	4" Lt	37	133	11.07	3-1/4" Rt	50	86	7.18
	90	**131**	**10.9**		**90**	**170**	**14.21**		**90**	**96**	**8.0**
	139	148	12.35		126	178	14.86		141	128	10.70
	218	148	12.35		218	127	10.60		232	175	14.60
	270	**131**	**10.9**		**270**	**91**	**7.59**		**270**	**168**	**14.0**
	319	113	9.45		306	84	7.0		321	131	10.94

Source: Mr. David Springer, Atlantic Test Range Optical Systems, NAS Patuxent River, MD

With the cyclic centered, maximum rotor height was at 139 and 218 degrees and reached 148 inches (12.35 feet). At the 90 and 270 degree positions, the rotor height was 131 inches (10.9 feet). Minimum rotor height was at 39 and 319 degrees and reached 114 and 113 inches (9.47 and 9.45 feet) respectively.

Maximum cyclic displacement tested to the left was 4 inches (84% of full cyclic displacement), resulting in the tip path reaching a low point of 84 inches (7.0 feet) at 306 degrees, and 91 inches (7.59 feet) at 270 degrees. With maximum left cyclic displacement, the high point on the right side of the aircraft was at 126 degrees, with a tip path height of 178 inches (14.86 feet). At the 90 degree position, the tip path height was 170 inches (14.21 feet). KIO to the left was called based on reaching aircrew and observer comfort level.

Maximum cyclic displacement to the right was 3 1/4 inches (68% of full cyclic displacement), resulting in the tip path reaching a low point of 86 inches (7.18 feet) at 50 degrees, and 96 inches (8.0 feet) at 90 degrees. With maximum right cyclic displacement, the high point on the left side of the aircraft was at 232 degrees, with a tip path height of 175 inches (14.58 feet). At the 270 degree position, the tip path height was 168 inches (14.0 feet). KIO to the right was called as a result of the cyclic contacting the leg of the pilot in the left seat.

4 PHASE II: ROTOR SYSTEM TRANSIENT RESPONSE

Data were recorded during lateral cyclic step inputs of up to 1 inch left and 1 1/4 inches right. Real-time monitoring and post-test data analysis revealed no evidence of overshoot of the rotor system following a step input. Additionally, the steady state height of the rotor following the input was consistent with the values obtained during Phase I of the testing. A time history data plot of the tip path response at selected angular positions for a 1 inch left input is presented in Figure A-22.

5 PHASE III: MAN-MACHINE INTERFACE

Evaluation of the magnitude of error of the operator in placing the cyclic in the centered position was consistent between subjects. Without referencing the installed measuring tapes (relying on “muscle memory”), both pilots placed the cyclic within 1/4 inch forward and 1/2 inch right of measured center. When evaluating the possible deviation from center, both pilots noted the cyclic to be off-center at approximately 1/2 inch of left displacement. This was attributed to the physiological cue created by the right arm crossing the body. When displaced right, both pilots noted the cyclic to be off-center at approximately 1 1/2 inches of right displacement, or 1 inch greater than where the cyclic was placed when centering based on muscle memory.

IV. ANALYSIS

1 GENERAL

Logistics helicopter operations encompass a large number of variables to ensure the safe and efficient transfer of cargo and personnel. It turns out that the simple question is, "Is there enough clearance between the rotor arc of the MH-60S and the top of all the forklifts that would transit the arc?" However, developing a complete answer is not quite as simple as the question. An understanding of the flight deck environment, knowledge of the factors that are a part of cargo loading evolutions, and comprehension of the acceptance of risk in light of operational requirements must be established in order to fairly evaluate the concept of using a forklift with the rotor engaged.

2 ROTOR TIP PATH HEIGHT

Helicopter pilots are trained to keep the cyclic in the centered position when the helicopter is on the ground or the deck of a ship. During the test, with the cyclic centered, the tip path height was consistent between the right and left side at 131 inches (10.92 feet) at the 3 and 9 o'clock positions. At the extremes of cyclic travel, the lowest rotor tip path recorded was 91 inches (7.59 feet) at the 9 o'clock position with 4 inches of left cyclic displacement (84% of maximum cyclic travel). The data collected demonstrated near-symmetrical variation on the right and left side of the rotor with cyclic displacement. Therefore, it is assumed that the rotor height would similarly drop to approximately 91 inches (7.59 feet) at the 3 o'clock position with 4 inches of right cyclic displacement.

Testing demonstrated that the physiological cues presented to the pilot at the controls (PAC) will lead to identification of an off-center position prior to reaching 84% of maximum lateral displacement in either direction. More probable is that the cyclic position would be maintained between 1/2 inch left (10% of maximum cyclic travel) and 1 1/2 inches right (32% of maximum cyclic travel) of measured center. With 1/2 inch of left cyclic displacement, the resulting tip path height is no lower than 126 inches (10.52 feet) at the 9 o'clock position. With 1 1/2 inches of right cyclic displacement, the resulting tip path height is no lower than 116 inches (9.64 feet) at the 3 o'clock position. As seen from test results with up to a 1 1/4 inch step input, the dynamic overshoot of the rotor to a sudden disturbance is immeasurably small. As such, wind gusts and flight deck turbulence are neglected as significant factors influencing tip path height during flight deck evolutions.

Additionally, while displacing the cyclic to one side causes the tip path to drop on that side, it also causes the tip path to rise on the opposite side. Therefore, with the cyclic displaced to the right by 1 1/2 inches, the tip path plane at the 9 o'clock position rises to as high as 147 inches (12.25 feet). Similarly, when displaced 1/2 inch to the left, the tip path rises to 134 inches (11.17 feet) at the 3 o'clock position.

While the pilot is able to actively manage the tip path height to provide more or less clearance by displacing the cyclic while visually monitoring the tip path, there is no cockpit indication of what the tip path height is at any given time, or for any specific cyclic position. The only information available to the pilot is visual observation of the tip path and estimation of its height. There is also no cockpit indication of the centered cyclic position, forcing the pilot to rely on muscle memory gained through experience and physiological cues to maintain the cyclic in a centered position. While future growth of the aircraft will include the Integrated Mechanical Diagnostic System (IMDS), which includes control positions among the monitored parameters that can be displayed in the cockpit, the current fleet aircraft provide inadequate feedback to the pilots and aircrew for accurate control positioning.

3 HEIGHT RESTRICTIONS AND ROTOR CLEARANCE

A search of naval regulations and operating procedures, including the CV/N NATOPS manual, Underway Replenishment Manual, Helicopter Operating Procedures for Air Capable Ships NATOPS Manual, and LHA/D NATOPS manual, revealed no data or restrictions that delineated the minimum clearance requirements or maximum personnel or equipment height when transiting the engaged rotor arc of the H-60 helicopter, nor for any other helicopter. While the MH-60S NATOPS contains no specific height restrictions, it does state that rotor tip path can reach as low as 4 feet from the deck off the nose of the helicopter, and further states that entry and exit from the helicopter is to occur at the 3 o'clock or 9 o'clock position. Implicit in that statement and restriction is that the rotor tip path height is considered a hazard in the flight deck environment. However, it also implies that there is sufficient clearance to safely transit the rotor arc at the 3 and 9 o'clock positions.

As there is no further restriction on the height of the personnel that are authorized to enter or exit, it can be further inferred that it is deemed safe for the full spectrum of heights found in the U.S. Navy. According to the FAA Human Factors Design Standard, the 50th percentile height of a male in the United States is 69.1 inches (5.76 feet), while the 99th percentile male is 75.2 inches (6.27 feet) (USDOT, 2003). Within the Navy, COMNAVCRUITCOMINST 1130.8F restricts the maximum height of personnel joining the military to 78 inches (6.50 feet). Neglecting the additional height added by typical flight deck gear (helmets and boots), the assumption is made that personnel or equipment that stand up to 78 inches tall may transit the rotor arc while the rotor is engaged with no restrictions other than entry and exit at the 3 or 9 o'clock position.

Based on an obstruction height of 78 inches, the clearance provided from the rotor at the 3 or 9 o'clock position with the cyclic centered is 53 inches (4.42 feet). While the clearance would decrease by having the cyclic displaced in either direction, the physiological cues present when the cyclic is off-center will limit the magnitude of centering error. Therefore, even with the cyclic displaced 1 1/2 inches right (the extreme of the centering error discussed in chapter III, paragraph 5), there still exists 38 inches (3.17 feet) of clearance at the 3 o'clock position. Additionally, as will be discussed in a later section, purposely displacing the cyclic 1 inch left increases the clearance at the 3 o'clock to 60 inches (5 feet).

While no information could be found that delineated a height restriction or clearance requirements, the precedent exists that cargo loading during VOD operations must be accomplished using a low profile forklift to ensure adequate clearance from the aircraft structure. The H-53, one of the primary VOD platforms in use with the U.S. Navy, is a single main rotor helicopter with a high tail rotor and a rear cargo ramp to allow for passenger and cargo loading (Figure A-23). The Underway Replenishment Manual states specifically that during VOD operations with the H-53 helicopter, a low profile forklift is required to load palletized cargo as a result of the low tailboom clearance (NWP 4-01.4, 1996). The H-53 performs VOD operations from the same ship classes as the MH-60S, which implies that in order to comply with the instruction, those ships have low-profile forklifts stationed on the flight deck to load and unload cargo from the H-53.

4 FORKLIFTS

Certification of U.S. Navy and MSC forklift operators includes ensuring they possess a Mechanical Handling Equipment (MHE) permit issued by the ship, and a valid government or state license to operate self-propelled forklifts. Additional requirements include passing the Forklift and Pallet Truck Operator's Explosive Handling Course and demonstrated proficiency in the handling of the forklift truck for which they are to be licensed. Forklift operator training includes safe operational procedures for operating the forklift. Among the topics covered, operators are trained to drive with the load as close to the deck as practical (normally 4 inches above the deck), and to ensure that the driver's vision remains unobstructed by the load (COMSCINST 5100.17C, 1998; TM-0532-LP-009-8790, 1997).

Operationally, assuming that the majority of palletized loads to be placed in the helicopter are standard tri-wall containers (40 inches high), the maximum height of the load while transiting the arc would be no more than 44 inches (3.67 feet). Even if a package exceeding that height were to be loaded, the maximum height of a load that can be loaded into the MH-60S is limited by the size of the cargo door to 61 inches (5.08 feet); therefore, the maximum height of the load during transit of the rotor arc should be no more than 65 inches (5.42 feet), which is still less than the maximum allowable enlistment height by 13 inches (1.08 feet).

Publications research and conversations with Navy logisticians gave no indication that the shipboard-compatible, flight-deck-certified forklifts in use by the U.S. Navy were procured based on any height restriction specific to a particular helicopter. For the forklifts identified in Table B-2, the height of the tallest point varies from shorter than the average man on the low profile forklift (67.75 inches/5.65 feet) up to 88 inches (7.33 feet). However, ten of the eleven forklifts identified are less than 84 inches (7 feet) to the tallest point. As the cargo compartment of the aircraft is approximately 30 inches from the ground, five of the eleven identified forklifts also have a free lift height that enables them to load cargo from the carriage assembly into the aircraft without raising the mast.

Review of technical and training manuals for several forklifts revealed no failure modes that result in uncommanded extension of the mast or carriage assemblies. By observation, the rate of change of the mast height while raising the carriage assembly is such that if the fork lift operator mistakenly started to raise the mast when attempting to load the helicopter, instead of conducting a free lift of the carriage assembly, the error would be evident before the mast was high enough to contact the rotors.

5 SHIPBOARD CARGO AND PERSONNEL LOADING OPERATIONS

5.1 General Shipboard and H-60 Procedures

Shipboard procedures for personnel and cargo transiting the engaged rotor arc require that all movement be controlled by the LSE, and that no one transit the rotor arc without permission from the LSE. The LSE must also get concurrence from the Pilot-in-

Command prior to giving permission to transit the rotor arc (NAVAIR 00-80T-122, 2003). All personnel entering or exiting the H-60 aircraft with the rotors turning are required to do so at the 3 o'clock or 9 o'clock position (NATOPS, 2004; Hewlett, 2004). In addition to the pilots, logistics helicopters employ aircrew that act in the capacity of a loadmaster to manage onloading and offloading cargo and personnel. The aircrew loadmaster and the pilots are in constant communication throughout cargo evolutions through the use of the helicopter intercommunication system (ICS). While cargo loading operations are being conducted, no other personnel or materials are permitted to transit the rotor arc (i.e. fuel team, aircraft mechanics, flight deck crew, etc.).

While there are slight differences in the handling of cargo and personnel depending on the ship class, all ships have a person designated as responsible for the safe conduct of the cargo operations. Aircraft carriers and large amphibious assault ships have dedicated logistics personnel, the Air Transfer Officer (ATO) or Combat Cargo Officer (CCO), who are responsible for supervising preparation of cargo and personnel for transfer, and escorting them to and from the helicopter. The ATO or CCO, with assistance from the aircrew loadmaster, supervises the loading operation. Smaller amphibious assault ships and Navy-operated supply ships use a Flight Deck Officer (FDO) in a similar capacity (NAVAIR 00-80T-105, 1999; NAVAIR 00-80T-106, 1998). MSC supply ships have a Cargo Mate who is directly responsible for the safe and orderly transfer of materials departing the ship via helicopter. On all ships, while conducting forklift operations to load aircraft, a dedicated safety observer is employed to ensure safe movement of the forklift on the flight deck. During a recent test period aboard USS BATAAN (LHD 5), the author spoke with the Combat Cargo Officer who stated that the only forklift used on that ship for loading any model helicopter is the low profile LiftKing LK6SLP (Figure A-27).

5.2 Specific MH-60S Cargo Procedures

With the current restrictions on loading the MH-60S while the rotor is engaged, the fleet operator is left with three options. First, the aircraft can be shut down while a forklift is used to load and secure the cargo. Second, the cargo can be broken into packages that can be loaded by hand. Third, the cargo can be transferred externally via VERTREP. As discussed below, each option has advantages and disadvantages that, when considered fully, make loading and unloading with a forklift while the rotor is engaged the preferred method.

5.2.1 Rotors Static Loading

Shutting down and restarting the helicopter is a time consuming task that introduces new operational risks into the evolution. In addition to the extra time involved simply with the process of shutting down and starting up the helicopter, the issue of maintenance support is critical during helicopter operations. When the helicopter shuts down to load or unload cargo on the ship on which it is deployed, full maintenance support is available to address any problems encountered during the start. When shut down on another ship, any maintenance problems encountered will interfere with that ship's operations. Through personal experience, the Air Boss of an aircraft carrier is extremely reluctant to have a helicopter that is not an organic part of his airwing shut down on the ship because of the risk that it will not restart and will delay fixed wing launch and recovery operations. Additionally, when the helicopter is shutting down and starting up, the ship has to cease maneuvering to provide steady wind over deck conditions, which delays required ship maneuvers and may delay recovery of other aircraft. Finally, on a single spot ship, shutting down the helicopter renders the flight deck unusable for other operations until it is restarted and launched, at the expense of useful mission time.

5.2.2 Hand Carried Packages

Breaking cargo into hand carried packages is another time consuming process that introduces risk. When cargo needs to be delivered to a location that does not have a forklift available, smaller packaging is required to facilitate moving by hand. Also, because of the ability to piece together the packages during the loading process , more cargo can be moved by the helicopter when it is in smaller packages (Figure A-24). However, hand loading is a time-consuming process because each piece of cargo has to be moved individually from its storage or staging location to the aircraft, then from the aircraft to its delivery location. When transferring between facilities with the capability to use forklifts, if all of the cargo can be put into palletized tri-wall containers, the cargo can be moved in bulk, requiring much less time. After the tri-walls have been loaded, additional smaller packages can be placed in the helicopter around the palletized loads to maximize useful cargo space. Finally, when cargo is broken into hand carried packages, more personnel are required to load and unload the helicopter, resulting in increased manning requirements on the flight deck and an increase in traffic under the rotor arc.

5.2.3 External Load Transfer

External transfer of cargo, or VERTREP (Figure A-25), is an expeditious means of moving cargo from one ship to another. The evolution is conducted by the helicopter making an approach to the delivery ship that terminates in a hover over the flight deck at 5 – 10 feet. Ship personnel then attach a sling over the aircraft cargo hook, and the load is lifted clear of the flight deck and delivered to the receiving ship or installation. VERTREP is the preferred method for transferring large quantities of supplies between ships at sea because of the rapid transfer rate and the maneuvering flexibility provided to the ships. However, VERTREP is not the ideal solution for all cargo transfers. During VERTREP, the cargo is staged on the flight deck, which subjects it to the prevailing weather. Additionally, the Underway Replenishment Manual states that it is preferred to transfer high value cargo and mail internally to reduce the risk of an inadvertent loss of the load. The standard VERTREP transfer is conducted between ships 700 – 1000 yards apart. The recommended maximum VERTREP transfer radius of 25 – 35 NM is reserved for high value cargo and is not to be used routinely (NWP 4-01.4, 1996). As a result, while palletized loads can be moved via VERTREP, the distance limitations and risk of loss or damage to the load make it undesirable for transferring high value cargo and mail. While no data was found on high value cargo, Hensley, et al, found that 2,500 tons of mail were moved internally between 1990 and 1996.

6 AIRCRAFT CHARACTERISTICS

The distance from the ground to the MH-60S cabin cargo loading deck is approximately 30 inches. The standard tri-wall pallet container in use by the U.S. Navy is 40 inches high. The physical size of the main cabin door restricts the maximum height of a palletized load that can be placed into the aircraft to 61 inches. The rotor system is higher at the center of the rotor hub than at the blade tips due to the physical connection at the blade root and the smaller bending moment as the blade radius approaches the hub, resulting in greater height of the rotor plane as the center of the helicopter is approached.

Despite the multi-mission nature of the aircraft, the MH-60S does not change configurations easily. Transitioning from a passenger configuration to a palletized cargo configuration requires removing the seats, installing physical barriers on the aircraft to prevent damage while loading, and reconfiguring the cabin floor to the cargo roller configuration (NATOPS, 2004). As the task is time-consuming and conspicuous, the aircraft is likely to be launched in the proper configuration and dedicated to internal cargo movement in order to minimize the time lost in configuration changes. Additionally, because the seats that are removed require storage in the aircraft, a crew is unlikely to transition to carrying palletized cargo in the middle of a logistics mission. The extensive compensation and reconfiguration required to transition from passengers to cargo minimizes the chance that unbriefed palletized cargo loading situations will arise.

7 AIRCREW TRAINING

In the naval aviation world, aircrew training is a long, meticulous, and repetitive process to ensure safety and standardization. Throughout the aviation training program, safe operation of the aircraft is constantly emphasized. In an effort to reduce human error mishaps and incidents, the U.S. Navy instituted programs emphasizing Operational Risk Management (ORM) and Crew Resource Management (CRM). ORM focuses on applying the principles of risk analysis to identify potential hazards with proposed operations prior to conducting the operation, then enacting controls to mitigate the risk of those hazards occurring or the consequences of their occurrence. ORM principles can be used for any activity, from riding a bike to launching aircraft from an aircraft carrier. CRM is specific to the interaction of flight crews, dealing with the ideals of maintaining good situational awareness, ensuring effective communication, and understanding the mission that is being conducted. The Naval Aviation Training and Operating Procedures Standardization (NATOPS) program was implemented to ensure standard practices within each aircraft series. Included among the items in the NATOPS program are restrictions to aircraft operations in the form of notes, cautions, and warnings located in the aircraft operating manual. These serve to emphasize items to the aircrew that require special attention during aircraft operation. The NATOPS manual also requires that a mission brief be conducted prior to each flight. The brief includes the flight profile, mission requirements, crew assignments and responsibilities, and a review of ORM and CRM issues that are specific to the mission being flown (A1-H60SA-NFM-000, 2004).

During the NATOPS brief, a crew performing a logistics mission will brief the conduct of onloading and offloading passengers and cargo, including responsibilities for passenger briefs and monitoring and securing internal cargo. Because of the dynamic nature of the rotor system and the direct control of tip path provided by the flight controls, one pilot is always physically manipulating the controls, whether in flight or on the ground. As mentioned, the NATOPS manual contains a specific warning to the aircrew that an untended cyclic can lead to the tip path reaching as low as 4 feet at the nose of the aircraft. As a result, aircrew are trained to pay particular attention to the tip path and cyclic position when on deck, especially during shipboard operations.

8 RISK ANALYSIS

As stated previously, flight operations present many hazards to personnel in the aircraft and on the ground. Military flying, by its very nature, is high risk. Some of the routine operations that are conducted include shipboard take-offs and landings, external load transfers (Figure A-25), over-water search and rescue (Figure A-26), night vision goggle (NVG) operations, catapult launches, and weapons employment. All of these operations carry with them a risk of injury, aircraft damage, or catastrophic loss of life, but the requirements to perform these missions necessitate accepting the inherent risk. The risks, however, are not accepted and the missions are not performed without acknowledgement of the hazards and the implementation of controls to mitigate them.

In identifying risks that are acceptable, the most important factor considered are the consequences versus the operational advantage gained. For shipboard operations, it is obvious that the mission of the Navy would not be met without the capability to operate aircraft from ships for logistics support, organic defense, and power projection. Therefore, the risk of shipboard operations is outweighed by the benefits gained. A similar case could be made for the other high risk operations previously mentioned, such as rapid re-supply via VERTREP or rescuing a downed airman. The consequences of the identified hazards, should they occur, are outweighed by the benefit of performing the mission. Therefore, one must consider whether the benefits of being able to load palletized cargo without shutting down the helicopter or breaking the pallets into individual packages outweigh the hazards associated with transiting the engaged rotor with a forklift.

The greatest risk to an operation is the hazard that is not anticipated. While unplanned and unbriefed situations can arise during any mission, a deliberate risk analysis of the operation facilitates the identification of a majority of the hazards likely to be encountered. When done properly, specific mitigation procedures can be implemented to reduce the risk of the hazard occurring and the severity of the consequences if it does occur. Risk management has always been a part of military operations. With the cost of assets increasing, the process has become even more ingrained in the culture of the navy, leading to more thorough briefings of missions and safer conduct of high risk operations.

The obvious greatest risk to forklift operations with the rotor engaged is the possibility of contact of the rotor system and the forklift. The consequences of such an occurrence are unarguably severe, with severe equipment damage and severe injury and death very real possibilities. The risk of this occurrence is mitigated significantly when one considers the clearance available with a low profile forklift, the current restrictions and safety procedures in place on the flight deck for entry and exit from the rotor arc, and aircrew training that emphasizes the hazards of the rotor system. Implementation of additional controls is also available to further mitigate the risk.

9 FORKLIFT TO ROTOR CLEARANCE

Testing demonstrated that with the cyclic displaced to the extremes of pilot comfort, the rotor tip path could come as low as 91 inches (7.58 feet) from the deck at the 3 o’clock and 9 o’clock positions. At that height, the rotor comes within 2 inches of two of the eleven identified shipboard forklifts (18%). Of note, however, is that at that height, there still remains 22 inches (1.83 feet) of clearance from the low profile forklift. Just as important, testing also indicated that based on muscle memory, the operator is not likely to displace the cyclic beyond 1 1/2 inches right or 1/2 inch left. As a result, the rotor is not likely to dip below 116 inches (9.67 feet) at the 3 o'clock and 126 inches (10.50 feet) at the 9 o'clock position. This provides a minimum of 28 inches (2.33 feet) of clearance from the tallest forklifts, and 48 inches (4 feet) of clearance from the low profile forklift at the 3 o'clock position. With the cyclic centered, clearance increases to 43 inches (3.58 feet) from the tallest forklift, and 63 inches (5.25 feet) from the low profile. Rotor to forklift clearance is increased even further with intentional displacement of the cyclic in the direction opposite the forklift. Table 2, below, provides a summary of the effects of cyclic positioning when transiting the rotor arc from the starboard side at the 3 o'clock position for the two extremes of forklifts. Low profile forklift height and the maximum recommended obstruction height are shown versus demonstrated muscle memory error to the right of 1 1/2 inches, cyclic centered, demonstrated muscle memory error left of 1/2 inch, and an intentional displacement of 1 inch to the left in Figure A-29.

On each of the ships large enough to carry forklifts, the helicopter can be landed to permit cargo loading through either cabin door, based on landing direction on the oblique line-up, or landing spot on the large amphibious ships or aircraft carrier. However, except for the little used bow spots on the aircraft carrier, none of the flight deck spots are arranged to allow cargo to be loaded through both cabin doors simultaneously. As a result, rotor-to-forklift clearance concerns are isolated to one side

Table 2:
Forklift to Rotor Clearance of Selected Forklifts at the 3 O'clock Position with Varying Cyclic Displacements

Cyclic Position	Forklift	Forklift Height		Rotor Height		Clearance		Comments
		in	ft	in	ft	in	ft	
Centered	E40B/XM	88	8.33	131	10.92	43	3.58	
	LK6SLP	68	5.67			63	5.25	
1/2" left	E40B/XM	88	8.33	134	11.17	46	3.83	Muscle memory error, left displacement
	LK6SLP	68	5.67			66	5.50	
1" left	E40B/XM	88	8.33	138	11.50	50	4.17	Possible intentional displacement to increase clearance
	LK6SLP	68	5.67			70	5.83	
4" left	E40B/XM	88	8.33	170	14.17	82	6.83	KIO point
	LK6SLP	68	5.67			102	8.50	
1 ½" right	E40B/XM	88	8.33	116	9.67	28	2.33	Muscle memory error, right displacement
	LK6SLP	68	5.67			48	4.00	
3 1/4" right	E40B/XM	88	8.33	96	8.00	8	0.67	KIO point
	LK6SLP	68	5.67			28	2.33	

of the aircraft during any single cargo loading evolution (generally the side that is towards the ship superstructure on supply ships and small amphibious assault ships).

10 EXISTING OPERATIONS WITH ROTOR INTERFERENCE POTENTIAL

Many routine helicopter flight operations bring with them an inherent danger of undesired interaction with the rotor system. However, with appropriate risk mitigation procedures in place, these operations are performed on a regular, sometimes daily, basis.

To perform the range support mission, the MH-60S employs the Aegis telescoping snare pole for recovery of target drones and torpedoes. In the fully collapsed position, the pole is 8 feet long. In the fully telescoped position, the pole is 20 feet long.

The method of employment has the user is stationed in the cargo door, hooking the pole onto the target while the helicopter maintains a low, over-water hover. In order to accomplish this, the pole is held vertically outside the aircraft then extended to its full length. As the pole is raised and lowered in an attempt to capture the target, there is potential for it to be raised into the rotor system. The aircrew procedures for target recovery address this risk with a warning in the manual to avoid raising the pole into the rotor system. Additionally, the risk is mitigated by highlighting the hazard during aircrew training and providing instruction on proper technique (Phillips, et al., 2004).

The flight deck area of the smaller navy ship classes provides minimal clearance for the rotor system during VERTREP. Current flight deck certification for the H-60 requires clearance of only 13 feet 5 inches horizontally from the rotor to the nearest obstruction during VERTREP operations. This is applicable for both day and night operations. As opposed to cargo loading, where the aircraft is chained to the flight deck, VERTREP approaches are dynamic maneuvers that involve the aircraft approaching the ship superstructure, then stopping to end up in a 5 to 10 foot hover suitable for an external load pick-up or delivery. To mitigate the risk of rotor collision with the ship superstructure, a limit line (T-line) is painted on the flight deck. During the VERTREP approach, adequate clearance is ensured if the center of the rotor is maintained aft of the T-line (NAVAIR-ACS-1J, 2003). The meaning of flight deck markings and required aircraft positioning during VERTREP are taught during initial aircrew shipboard training.

V. CONCLUSIONS

1 GENERAL

It is the opinion of the author that adequate rotor tip path to forklift clearance exists and that sufficient risk mitigation procedures can be enacted to reduce the risk of catastrophic rotor-to-forklift interaction to an acceptable level. However, because flight deck forklifts that exceed the height of the engaged rotor exist, and no amount of warnings or training can eliminate inattention to detail or willful disregard of safety procedures, the risk of catastrophic interaction cannot be eliminated.

2 SPECIFIC

2.1 Forklifts

According to the data presented in Table B-2, the forklifts in use by the U.S. Navy that are certified for flight deck use range in height from 67.75 inches (5.67 feet) to 88 inches (7.33 feet). Of the forklifts identified, one was shorter than the permissible enlistment height of 78 inches (6.50 feet), eight were taller by 6 inches or less, and only two were more than 6 inches taller. While the two that were more than 6 inches taller can be found on all ship classes that are large enough to load cargo using a forklift, these ships are also outfitted with other forklifts that afford more clearance, specifically the Liftking LK6SLP.

Technical manual review revealed no forklift failure modes that lead to an uncommanded extension of the mast assembly that would raise the mast to a position to interfere with the rotor system. Additionally, with the exception of the LKUSN4S on the

LPD class ship, the free lift height of the available forklifts was sufficient to load cargo into the cabin of the helicopter without raising the mast assembly.

The Liftking LK6SLP and similar low profile forklifts are the recommended forklifts for conducting cargo loading operations with the MH-60S with the rotors engaged. Figure A-27 and Figure A-28 demonstrate the clearance available with the LK6SLP forklift. The low profile results in the greatest amount of clearance from the rotor system, the forklifts are available on the ship classes that can load palletized cargo, and the Underway Replenishment Manual already maintains a requirement for low profile forklifts to be used with other U.S. Navy logistics aircraft. Transitioning to a low profile forklift as the sole forklift for loading cargo on the flight deck will also simplify the logistics footprint of the forklifts aboard ship.

2.2 Cargo Loading Evolution

While cargo loading on the flight deck is a dynamic evolution in a demanding environment, multiple layers of safety controls are in place to ensure a safe evolution, including: specifically designated personnel in charge of cargo loading; redundant safety oversight (Air Boss, HCO, LSE, FDO, aircrew); flight deck personnel and fork lift operator training programs; aircrew training and briefing; and standardized rotor transit procedures with the rotors engaged. Additionally, the combination of forklift driver training to minimize the height of the load, standard load size, maximum allowable load height in the aircraft cabin, and unlikelihood of an unbriefed internal cargo transfer provides further safety margin to load palletized cargo. With cargo transfer being one of the primary missions of the MH-60S helicopter, aircrew training can be tailored to address safety issues, crew coordination, and clearance requirements while conducting cargo transfers using a forklift with the rotor engaged.

2.3 Maximum Obstruction Height

While no information could be located that specified a maximum height for transiting the rotor arc, it is the opinion of the author that the maximum obstruction height that should be permitted to transit the engaged rotor arc is 84 inches (7 feet). At that height, there remains 7 inches (0.58 feet) of clearance from the rotor to the forklift at the 9 o'clock position even with the cyclic at the maximum displacement evaluated. On the large deck ships for which forklift information was available (CV/N, LHD/A), the probable side for loading cargo is the right side of the helicopter. With that in mind, even at the maximum right cyclic displacement evaluated (3 1/4 inches), clearance at the 3 o'clock position is still 12 inches (1 foot). Keeping the cyclic within the bounds of the demonstrated muscle memory error of 1/2 inch left to 1 1/2 inches right, the minimum clearance is 38 inches (3.17 feet) at the 3 o'clock position. Allowing that pilot training can address the need to monitor tip path height during cargo loading, a deliberate 1 inch displacement of the cyclic in the direction opposite the forklift will increase clearance to 54 inches (4.50 feet). Displacing the cyclic by 1 inch provides an extra 7 to 10 inches of clearance from the rotor. Given that the recommended maximum equipment height is 6 inches greater than the allowable enlistment height, an intentional displacement of the cyclic will result in greater clearance than that afforded to personnel transiting the rotor arc with the cyclic centered.

2.4 Safety

It is the opinion of the author that it is highly unlikely that the extremes of cyclic reached during testing would be encountered during normal aircraft operations with a properly trained and qualified crew. The physiological cues and exceedance of crew comfort level discussed in chapter III will alert the crew before the extremes are approached. When adhered to, the current shipboard and aircraft safety procedures discussed in chapter IV are adequate for loading cargo on the MH-60S using a forklift while the rotor is engaged. While there is potential for interference between the tip path of the MH-60S helicopter and some of the shipboard-compatible, flight-deck-certified forklifts in use by the U.S. Navy, significant mitigation measures can be put into place to reduce the risk of contact. Of the forklifts identified, the Hyster E40XM and E40B have a static height that the author feels are incompatible with dynamic rotor forklift operations. Additionally, the LKUSN4S does not have appropriate free lift height characteristics and should not be used with the rotor engaged.

2.5 Risk

The varied missions of the military require accepting risk for the purposes of operational mission accomplishment. The proven and widely used risk management tools of ORM and CRM are available to identify the risks associated with the cargo loading operation. They can be used effectively to reduce the risk of occurrence of undesired rotor to forklift interaction. When compared to the risks encountered by military aircraft during routine operations, the risk of using a forklift to load cargo with the rotor engaged is outweighed by the operational advantage gained in reducing cargo transfer time and increase the utility of the primary logistics helicopter in use by the U.S. Navy.

VI. RECOMMENDATIONS

1 MAXIMUM EQUIPMENT HEIGHT

Based on the height of the rotor tip path with the cyclic centered, the physiological cues to an off-center cyclic position, the allowable height for personnel in the military, the absence of measurable transient overshoot in the rotor system, and the benefits gained by intentional cyclic displacement opposite the forklift, the author recommends that the maximum height of personnel and equipment transiting the rotor arc of the MH-60S be established at 84 inches (7 feet). This height provides up to 4 feet of clearance with the cyclic centered, allows for almost 3 feet of clearance during normal operations when centering errors occur, and still provides for clearance from the rotor arc at the extremes of cyclic displacement. Clearances are presented graphically in Figure A-29. This also permits maximum operational flexibility with multiple forklift models that are currently employed for moving cargo on U.S. Navy ships.

2 SAFETY REVIEW

The author recommends the U.S. Navy conduct a formal safety review of the supplied rotor tip path data to develop a probability and severity risk assessment matrix for catastrophic interaction with the rotor system. This review should be directed towards defining the clearance requirement for personnel and equipment transiting the engaged rotor of the H-60 aircraft based on the likelihood of a catastrophic event occurring.

3 CARGO LOADING

The author recommends that changes be submitted to the A1-0H60SA-NFM-000, MH-60S NATOPS manual, removing the blanket restriction on loading the MH-60S with a forklift while the rotors are engaged. A new restriction should be placed in the MH-60S NATOPS, the Underway Replenishment Manual (NWP 4-01.4), the CV/N NATOPS (NAVAIR 00-80T-105), the LHA/D NATOPS (NAVAIR 00-80T-106), and the Helicopter Operating Procedures from Air Capable Ships NATOPS Manual (NAVAIR 00-80T-122) that restricts loading cargo on the MH-60S with the rotors engaged to forklifts less than 84 inches tall at the point of the highest fixed obstruction. Consideration should be given to adding a statement that a low profile forklift is preferred for cargo loading operations with all helicopters due to increased clearance provided by the lower obstruction heights.

4 AIRCREW PROCEDURES

The author recommends that changes be submitted to the MH-60S NATOPS manual as follows:

"Note – When using a forklift to load cargo with the rotor engaged, the pilot on the side closest to the forklift should monitor the controls. The cyclic can be displaced up to 1" (as measured from the cyclic TRIM REL button) in the direction opposite the forklift to increase rotor to forklift clearance."

Additionally, cargo loading operations with a forklift should be added as a specific briefing item in the cargo section of the pre-flight brief checklist, to include pilot and aircrew responsibilities while a forklift is transiting or operating under the engaged rotor. Pilot and aircrew training manuals should be changed to specifically address the hazards of cargo loading with the rotors engaged and the restrictions governing that operation.

5 AIRCRAFT EQUIPMENT

Consideration should be given to modifying the MH-60S aircraft to allow the pilots to positively identify the centered cyclic position. Control position monitoring is a growth capability for the IMDS system, and expediting the installation of that monitoring system will provide positive indication to the aircrew of cyclic position to ensure the cyclic remains centered during VOD operations. Additional mechanical methods should be investigated to provide an interim solution.

6 FORKLIFT RESTRICTIONS

The author recommends that the following warning be added to the MH-60S NATOPS (A1-H60SA-NFM-000), the Underway Replenishment Manual (NWP 4-01.4), the CV/N NATOPS (NAVAIR 00-80T-105), the LHA/D NATOPS (NAVAIR 00-80T-106), and the Helicopter Operating Procedures from Air Capable Ships NATOPS Manual (NAVAIR 00-80T-122):

"Warning – Due to inadequate rotor tip clearance, the Hyster E40XM and E40B forklifts, and the Liftking LKUSN4S forklift are not authorized for use in loading palletized cargo on H-60 series aircraft with the rotors engaged. Additionally, the height of equipment transiting the engaged rotor arc of the H-60 is limited to 84 inches. Failure to ensure adequate clearance could result in rotor to equipment contact, damage to the aircraft and equipment, and severe injury to personnel."

7 FORKLIFT CONTRACTING

With data on tip path height available, U. S. Navy support equipment managers should investigate contracting to outfit all large deck ships with low profile forklifts for use on the flight deck for the specific purpose of supporting cargo loading and unloading with the H-60 helicopter. This will allow the MH-60S to load and unload cargo with the rotor engaged without restriction and ensure adequate clearance of the forklift and operator from the rotor tip path, maximizing the utility of the U.S. Navy's primary logistics helicopter. Future contracts for flight deck forklifts should specify a maximum height for the highest static component of the forklift to ensure continued compatibility with the logistics helicopter in use.

8 SUPPORT EQUIPMENT REVIEW AND MODIFICATIONS

A comprehensive review of the forklifts and support equipment available for flight deck use should be conducted by the U. S. Navy to ensure that all flight deck equipment has been surveyed. Any support equipment that exceeds the authorized height for transiting the rotor arc should be marked for easy identification of an exceedance of the limit (i.e., orange stripes on static parts greater than 84 inches high).

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APPENDICES

APPENDIX A: FIGURES

Figure A-1: MH-60S Knighthawk helicopter

Source: Global Security.org website <http://www.globalsecurity.org/military/systems/aircraft/images/ch-60_bataan16.jpg>

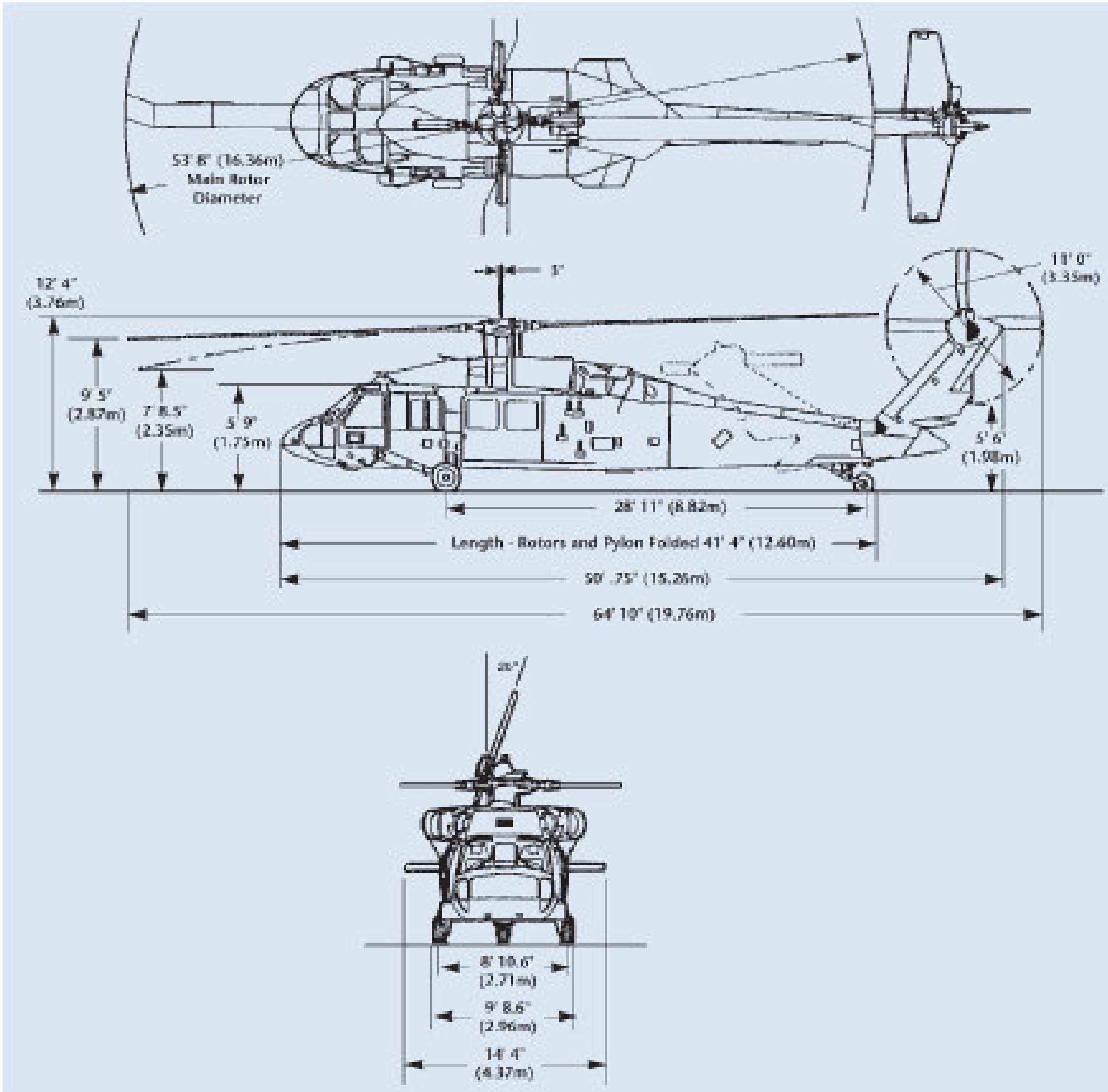

Figure A-2: MH-60S Knighthawk dimensional drawings

Source: United Technologies Sikorsky Aircraft Corporation Website
<http://www.sikorsky.com/file/popup/1,,165,00.pdf>

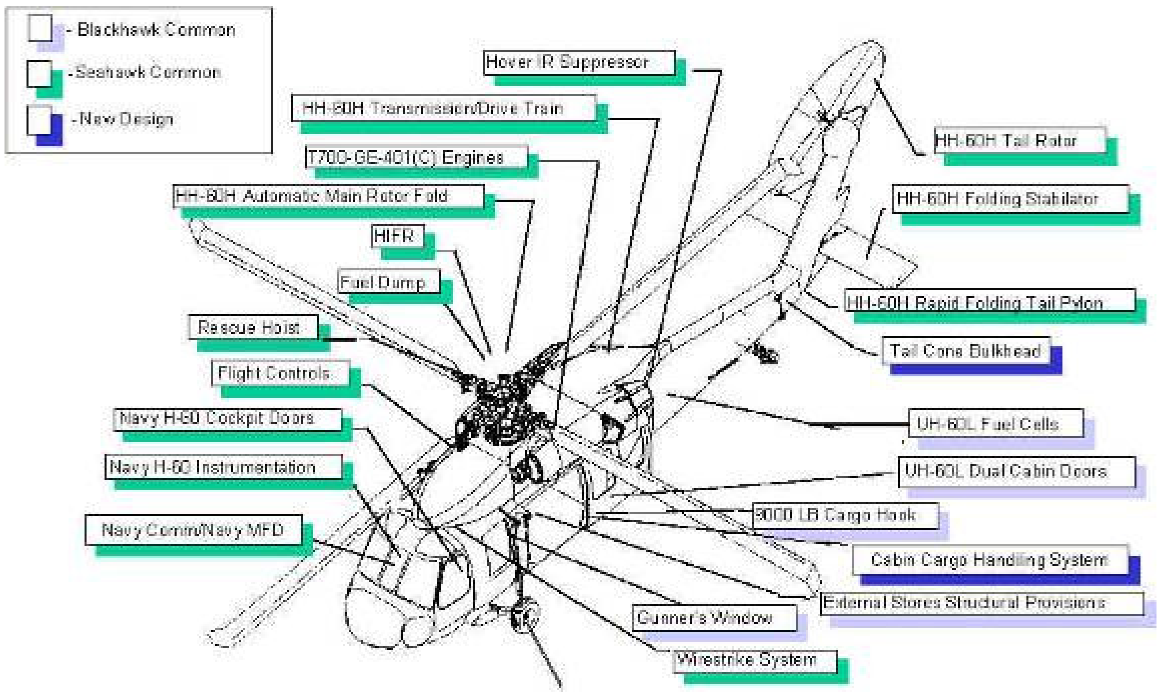

Figure A-3: MH-60S integration of legacy and new structures

Source: Global Security.org website <http://www.globalsecurity.org/military/systems/aircraft/images/ch-60s_config.jpg>

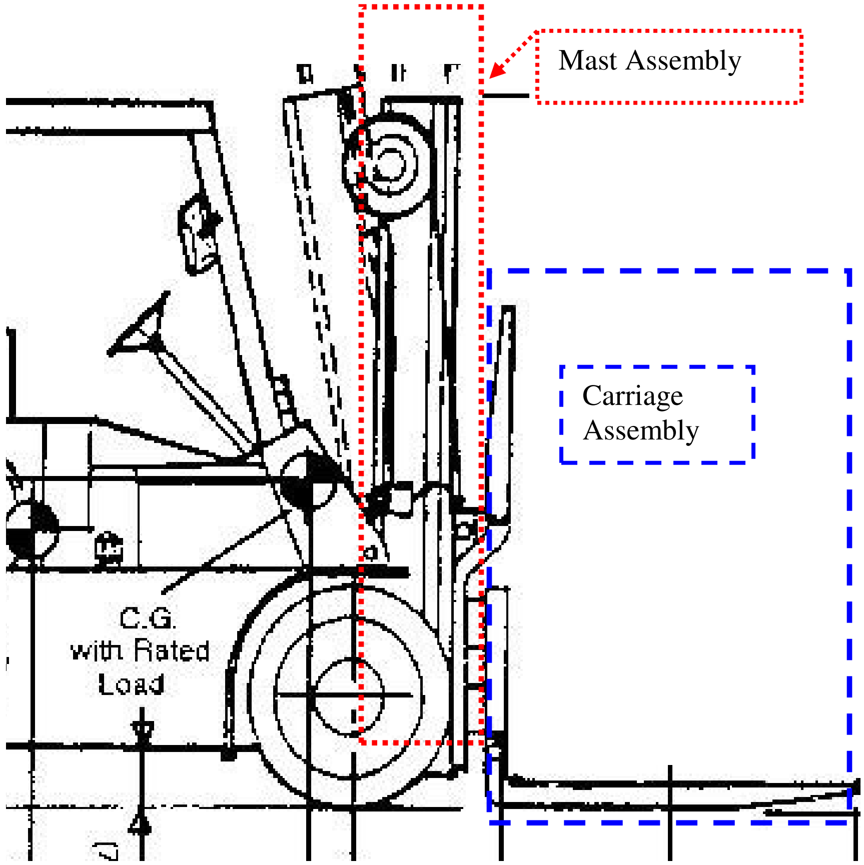

Figure A-4: Typical forklift carriage and mast assembly

Source: Liftking LK6SLP technical manual, TM-0532-LP-009-9790

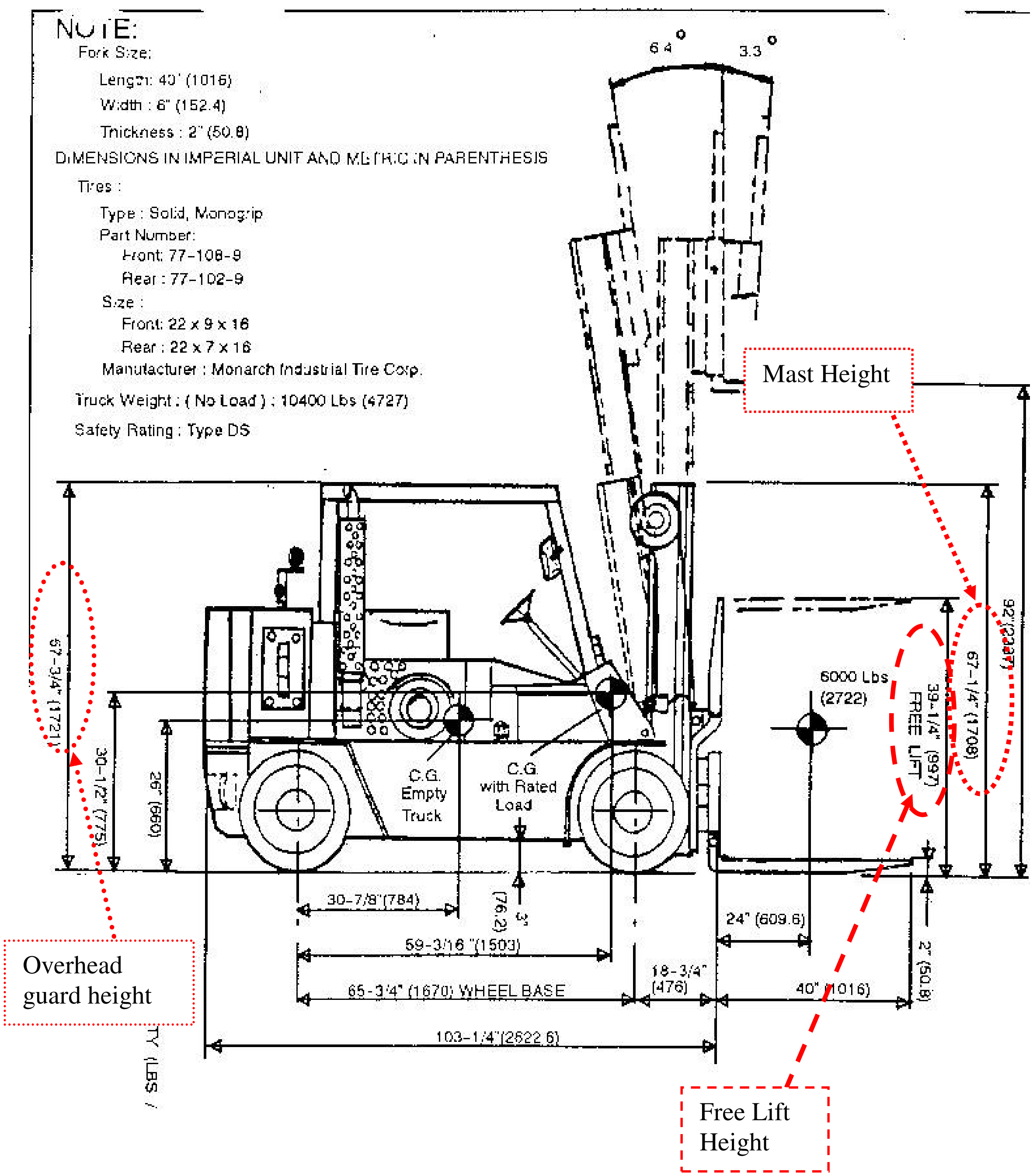

Figure A-5: Liftking forklift truck, model LK6SLP

Source: Ibid.

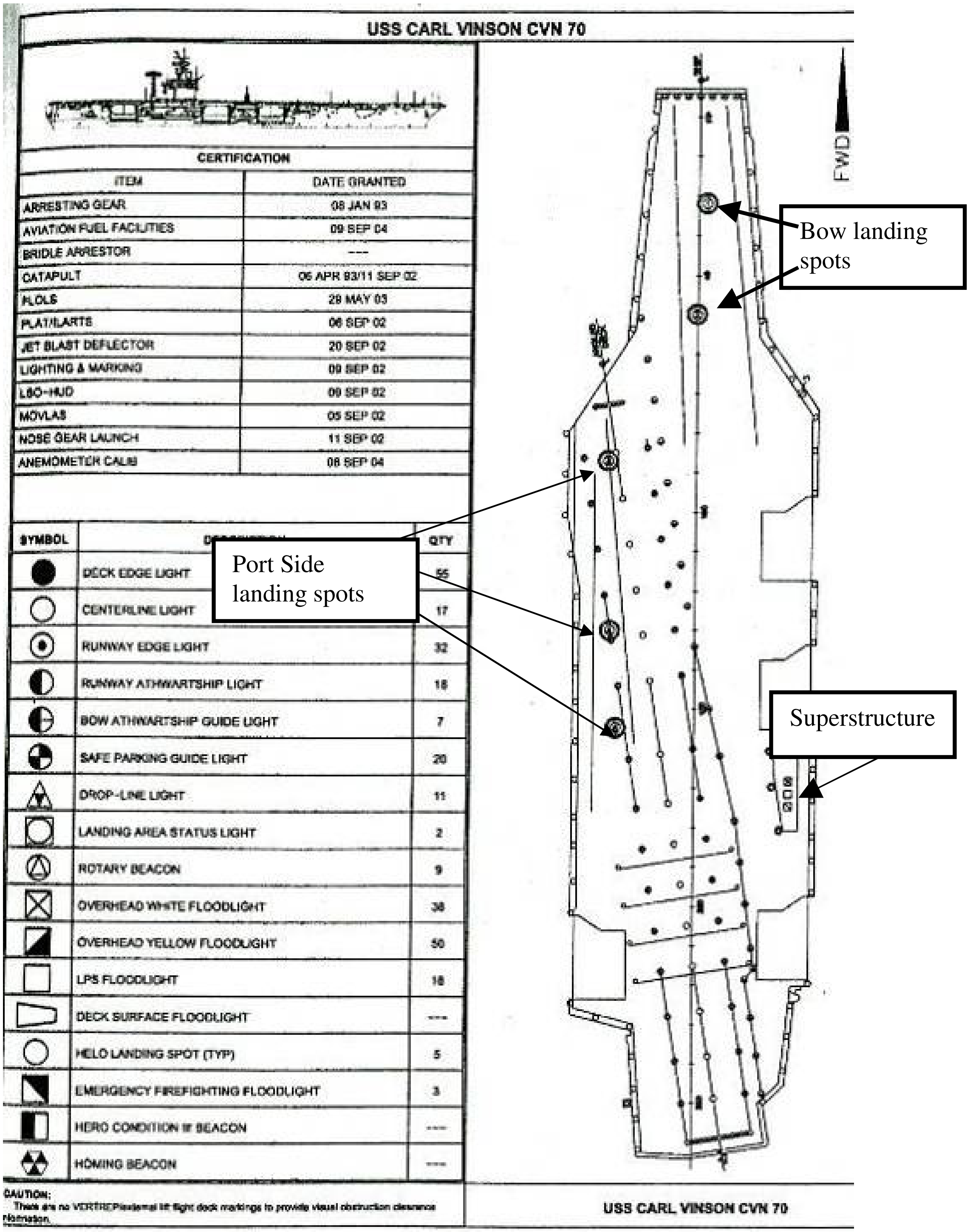

Figure A-6: United States Ship CARL VINSON (CVN 70)

Source: NAEC-ENG-7576. Shipboard Aviation Facilities Resume, Revision AY. Washington: Chief of Naval Operations, 2005.

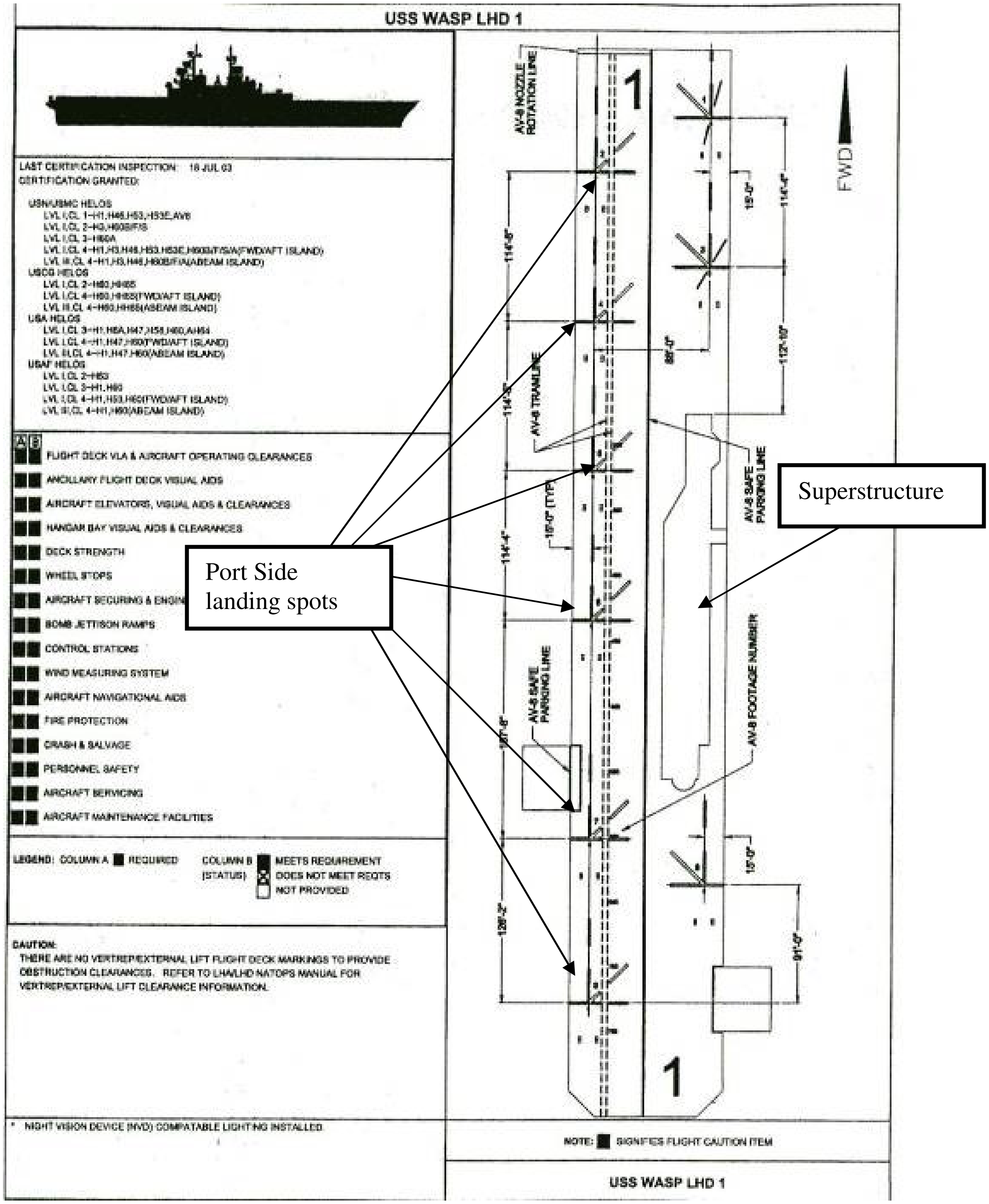

Figure A-7: United States Ship WASP (LHD 1)

Source: Ibid.

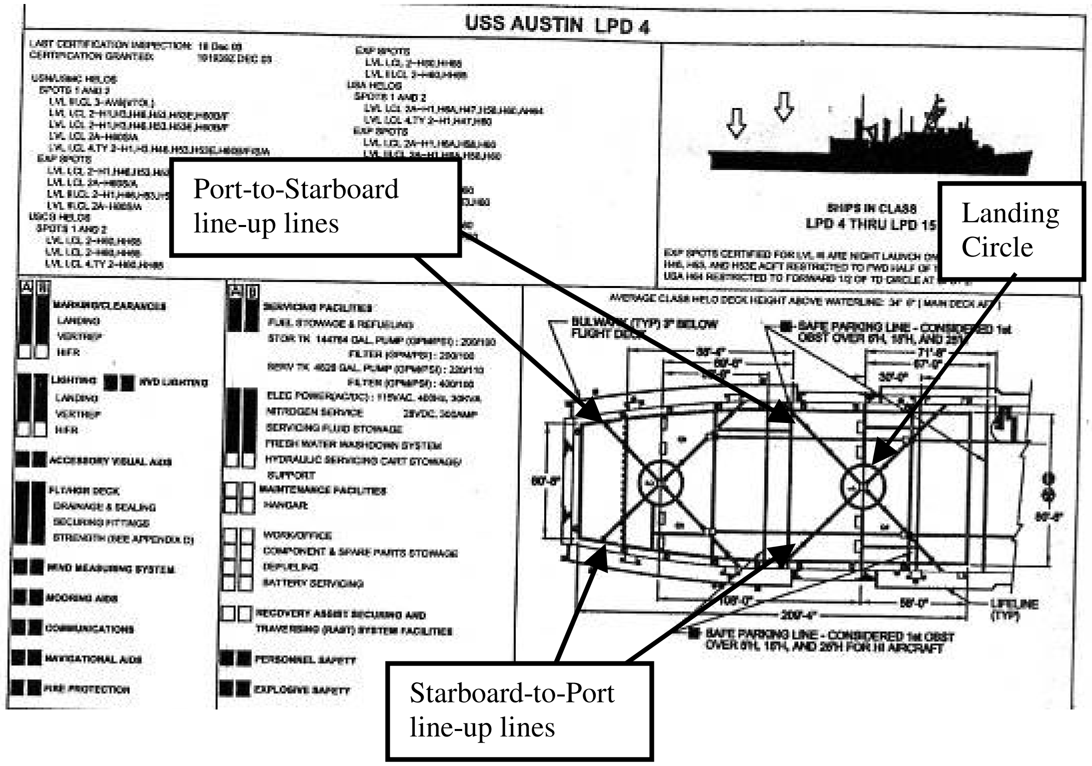

Figure A-8: United States Ship AUSTIN (LPD 4) **-** typical small deck amphibious assault ship flight deck layout

Source: Ibid.

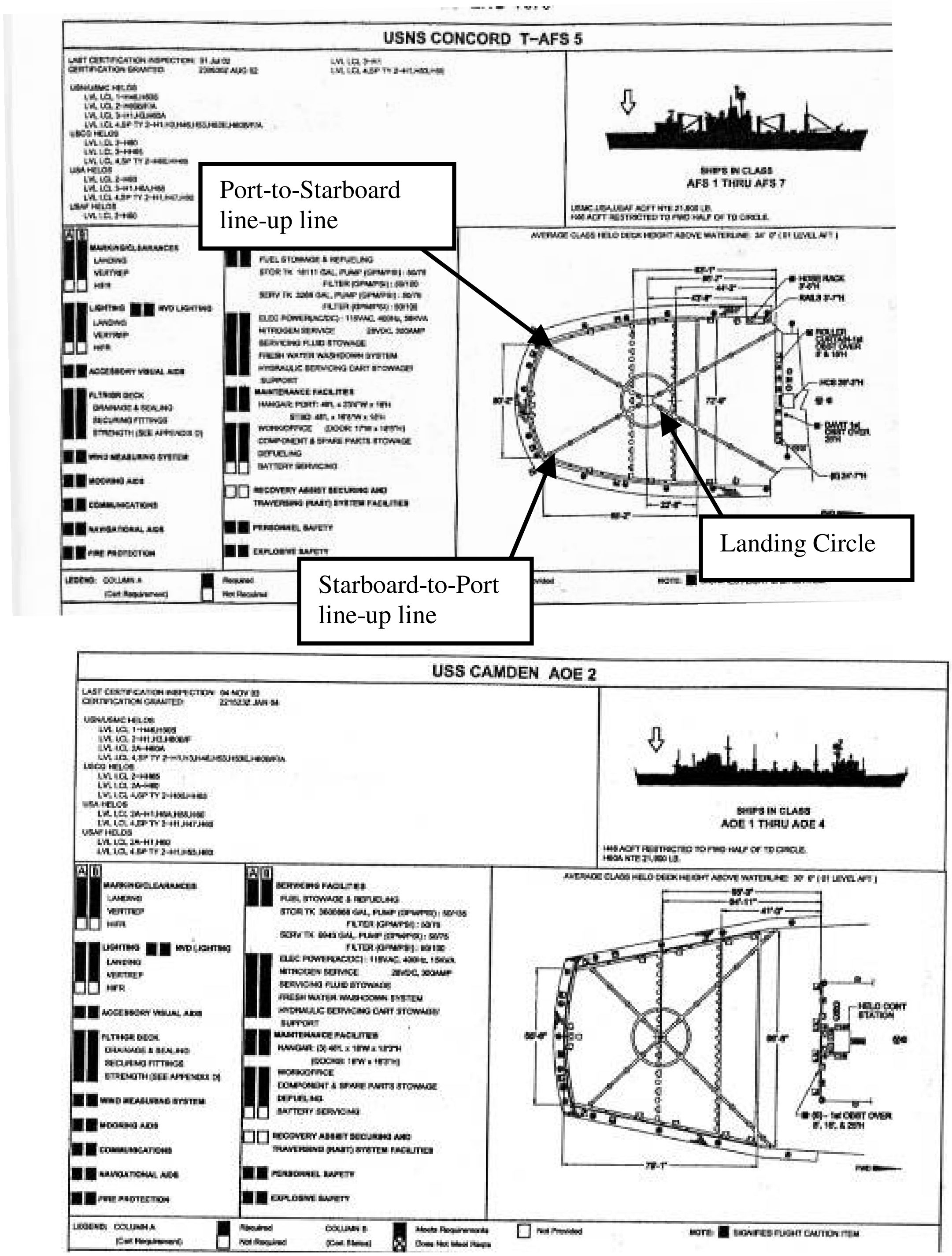

Figure A-9: United States Naval Ship CONCORD (T-AFS 5) and United States Ship CAMDEN (AOE 2) – typical Supply ship flight deck layout

Source: Ibid.

Figure A-10: Multi-System Controller with Long-Term Test Capability Camera

Source: Mr. David Springer, Atlantic Test Range Optical Systems, NAVAIR Patuxent River, MD. 2004.

Figure A-11: Two of the surveyed aircraft reference points – copilot doorframe

Source: LCDR Jonathan Kline, Air Test and Evaluation Squadron TWO ONE, Naval Air Warfare Center, Aircraft Division, Patuxent River, Maryland, 2004.

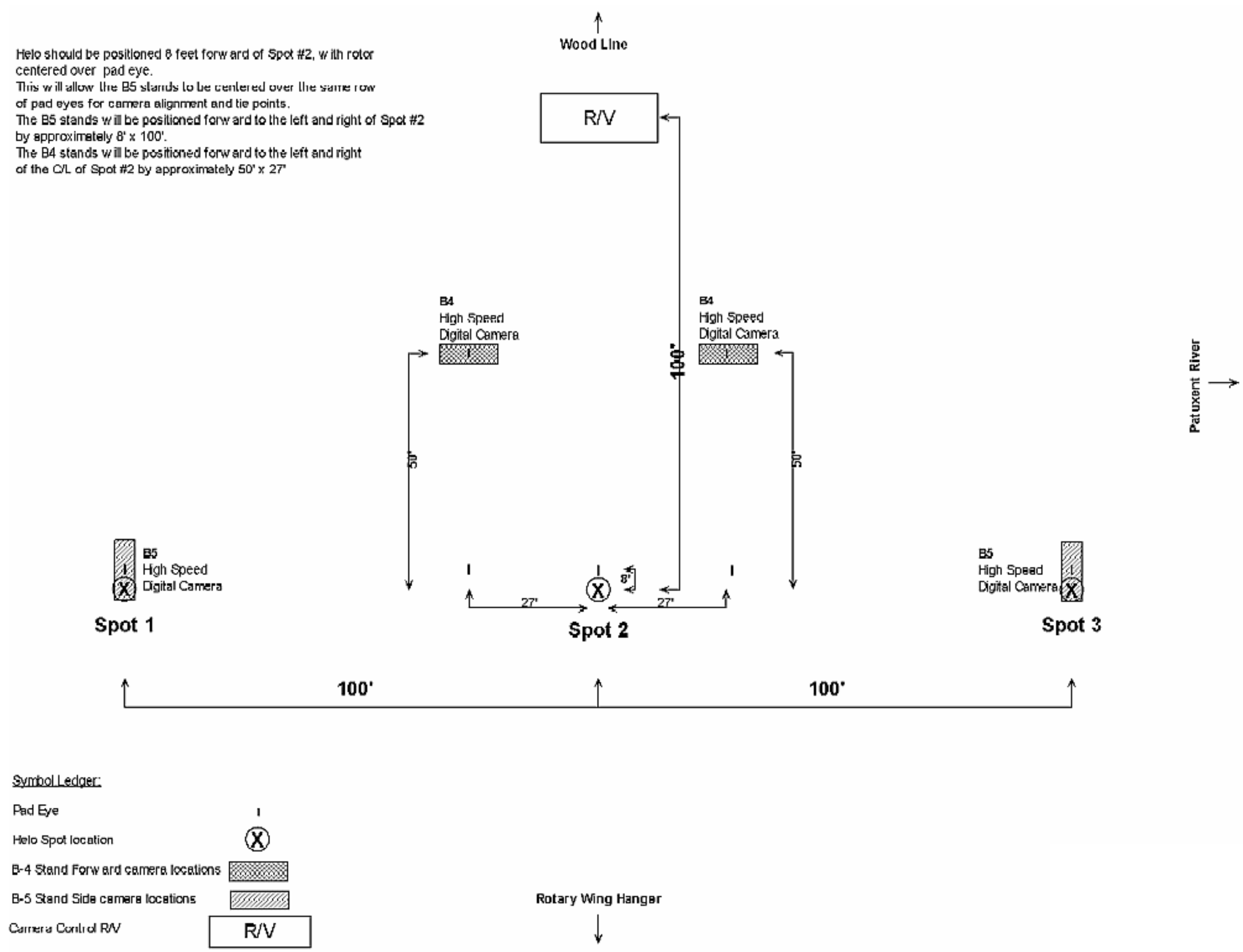

Figure A-12: Flight line camera set-up for rotor tip path survey

Figure A-13: Vertical calibration pole in position @ 1 blade radius from the rotor hub, rotors static

Source: Mr. David Springer, Atlantic Test Range Optical Systems, NAVAIR Patuxent River, Maryland, 2004.

Figure A-14: Copilot cyclic control stick, cloth measuring tape configuration

Source: LCDR Jonathan Kline, Air Test and Evaluation Squadron TWO ONE, Naval Air Warfare Center, Aircraft Division, Patuxent River, MD. 2004.

Figure A-15: Longitudinal cyclic displacement measurement installation

Source: Ibid.

Figure A-16: Welding rod installation

Source: Ibid.

Figure A-17: Lateral cyclic displacement door-mounted measuring tape installation

Source: Ibid.

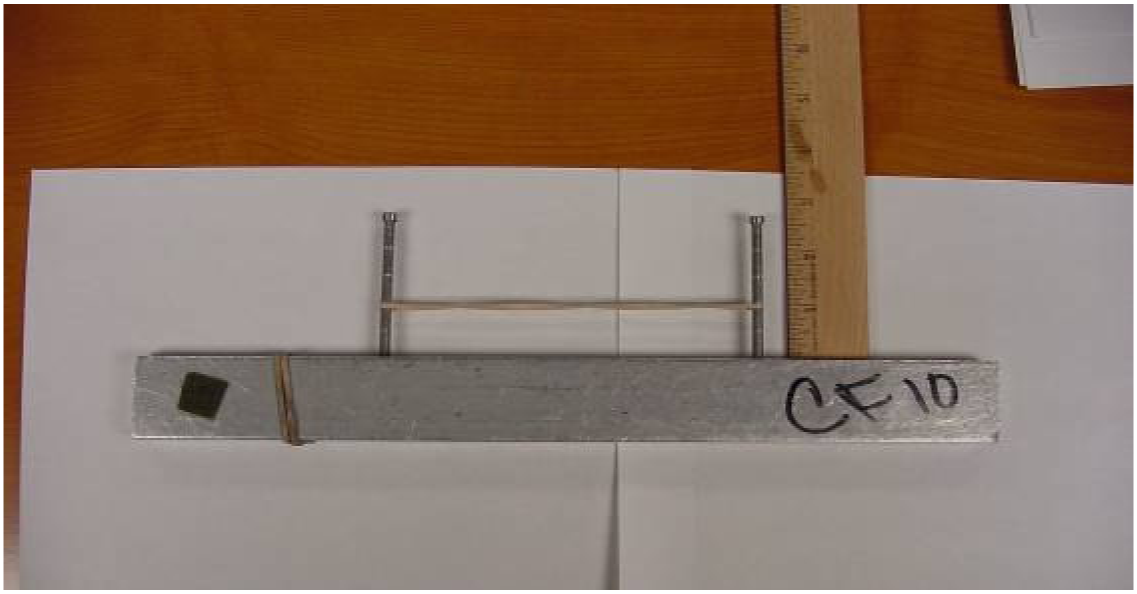

Figure A-18: Cyclic control fixture

Source: Ibid.

MH-60S Helicopter
Bureau Number 166304

Rotors: Static
Collective: Full Down
Pedals: Centered
Method: Cloth Tape Measures

SAS 1/2: On
Boost: On
Trim: On
Winds: <5 knots

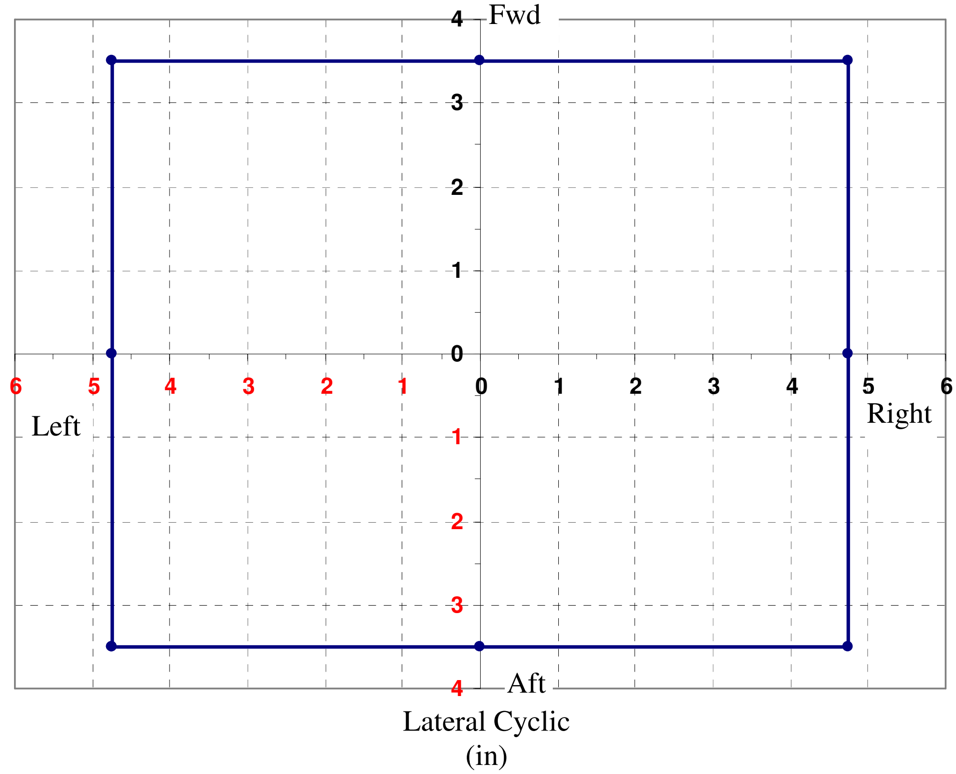

Figure A-19: MH-60S Cyclic Displacement Envelope based on test day measurements using installed cloth tape measures

Figure A-20: MH-60S port side rotor tip path height vs. angular position for cyclic displacements from 4 inches left to 3 1/4 inches right in 1/2 inch increments.

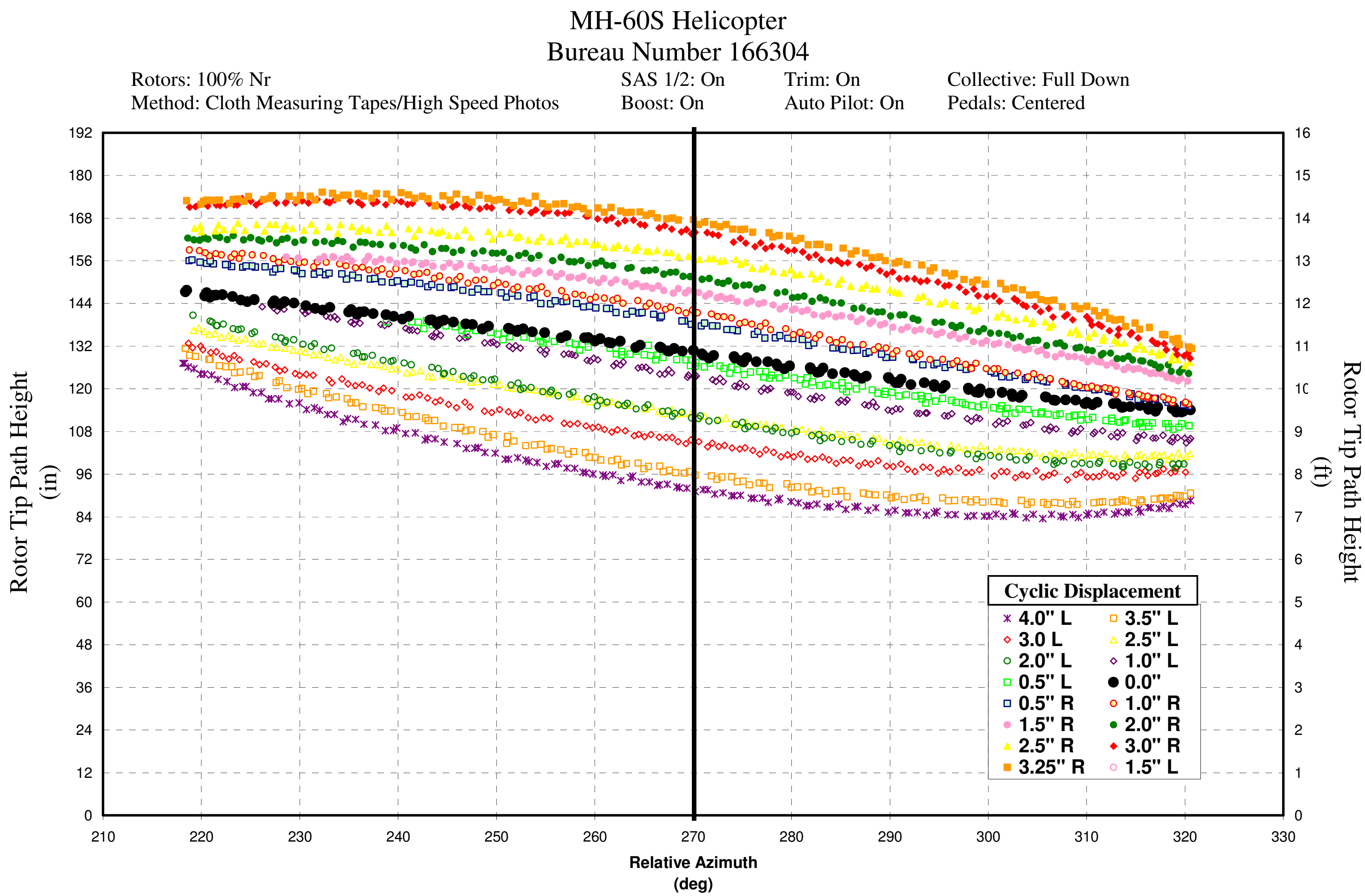
MH-60S Helicopter
Bureau Number 166304
Rotors: 100% Nr
Method: Cloth Measuring Tapes/High Speed Photos
SAS 1/2: On
Boost: On
Trim: On
Auto Pilot: On
Collective: Full Down
Pedals: Centered
Rotor Tip Path Height (in)
Rotor Tip Path Height (ft)
Relative Azimuth (deg)
Cyclic Displacement
4.0" L
3.5" L
3.0 L
2.5" L
2.0" L
1.0" L
0.5" L
0.0"
0.5" R
1.0" R
1.5" R
2.0" R
2.5" R
3.0" R
3.25" R
1.5" L

Figure A-21: MH-60S **s**tarboard side rotor tip path height vs. angular position for cyclic displacements from 4 inches left to 3 1/4 inches right in 1/2 inch increments.

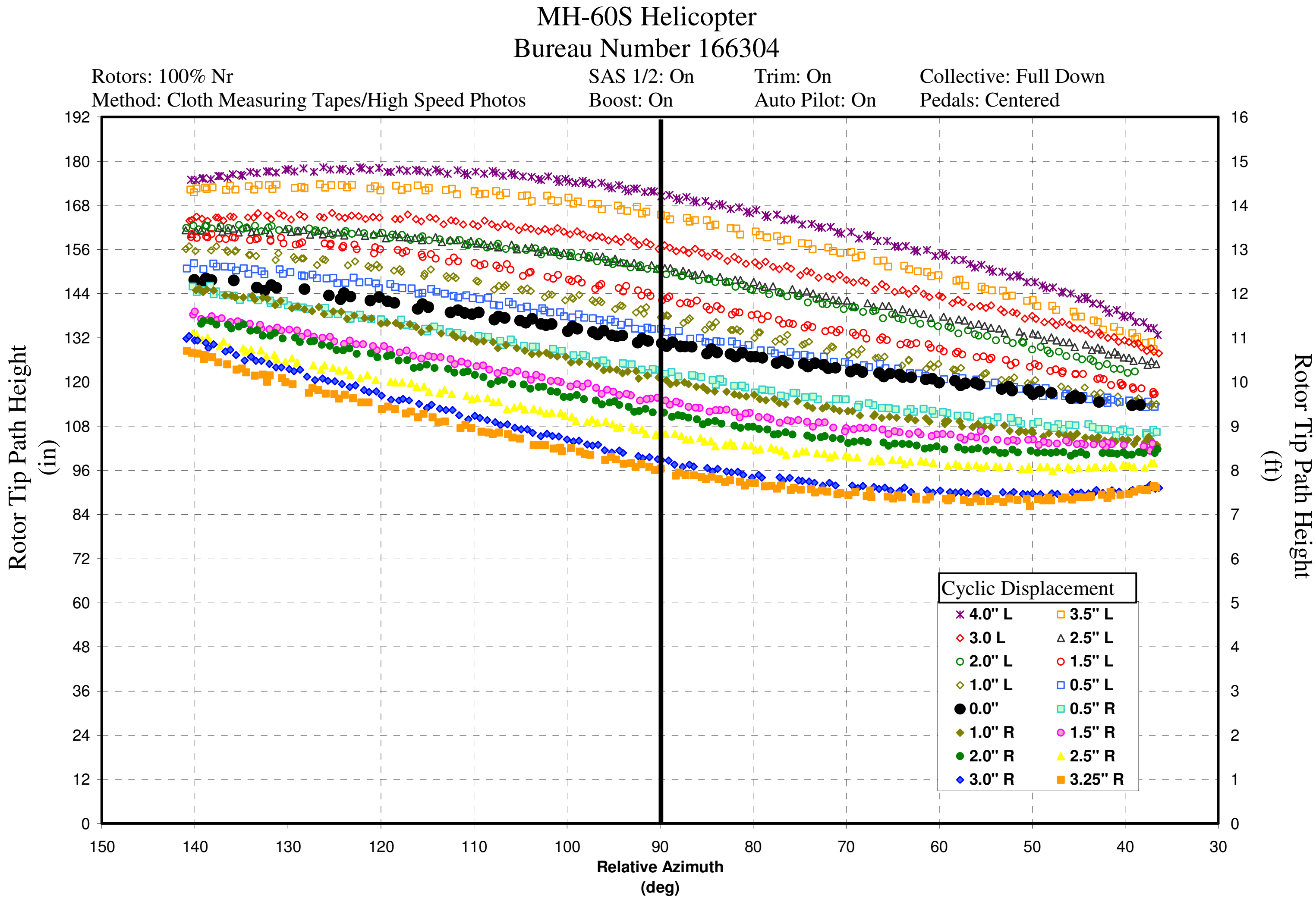
MH-60S Helicopter
Bureau Number 166304
Rotors: 100% Nr
Method: Cloth Measuring Tapes/High Speed Photos
SAS 1/2: On
Boost: On
Trim: On
Auto Pilot: On
Collective: Full Down
Pedals: Centered
Rotor Tip Path Height (in)
Rotor Tip Path Height (ft)
Relative Azimuth (deg)
Cyclic Displacement
4.0" L
3.5" L
3.0 L
2.5" L
2.0" L
1.5" L
1.0" L
0.5" L
0.0"
0.5" R
1.0" R
1.5" R
2.0" R
2.5" R
3.0" R
3.25" R

Figure A-22: MH-60S rotor tip path height vs. time on the port side of the helicopter for selected azimuths following a 1 inch, left, cyclic control step input

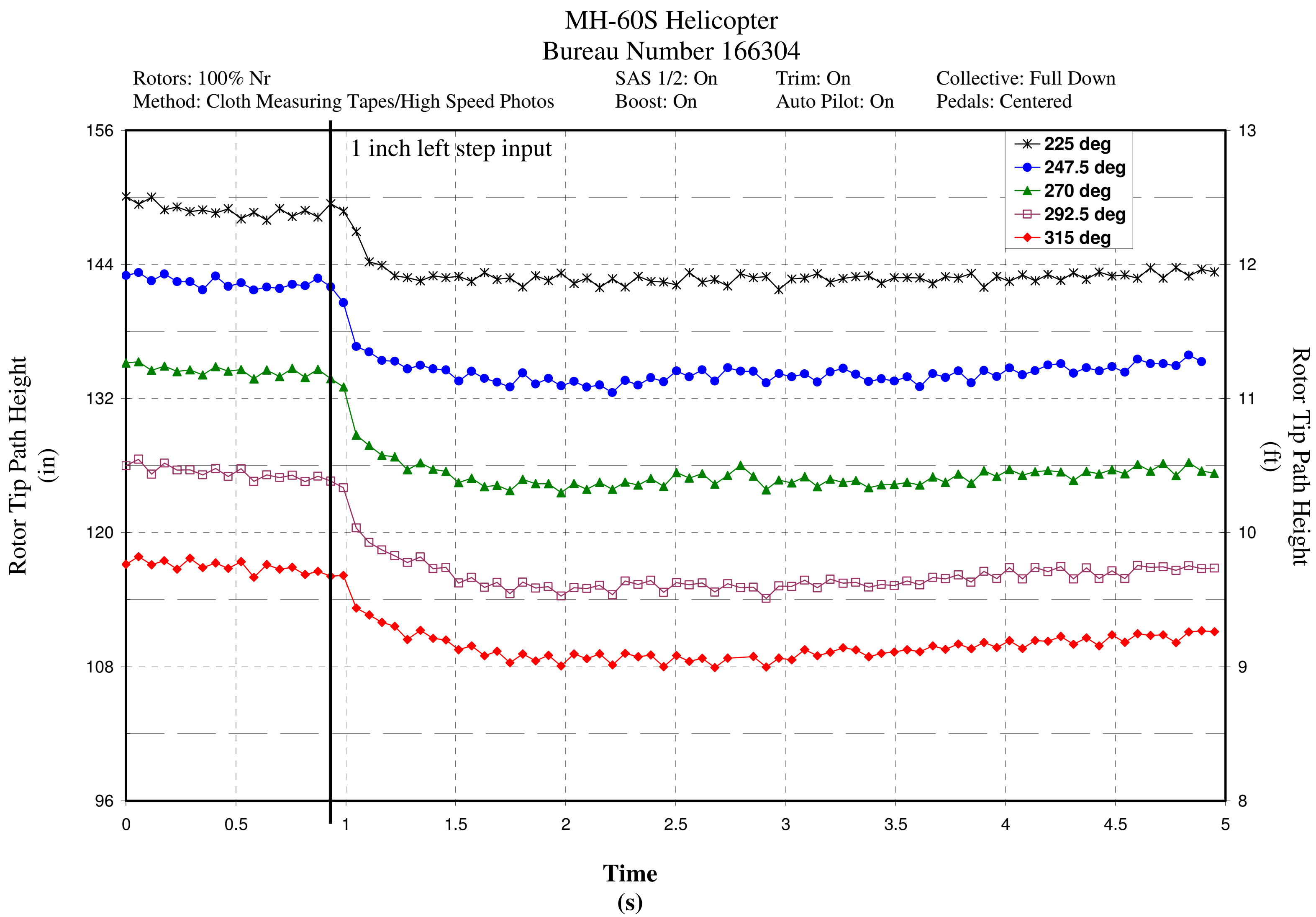
MH-60S Helicopter
Bureau Number 166304
Rotors: 100% Nr
Method: Cloth Measuring Tapes/High Speed Photos
SAS 1/2: On
Boost: On
Trim: On
Auto Pilot: On
Collective: Full Down
Pedals: Centered
1 inch left step input
225 deg
247.5 deg
270 deg
292.5 deg
315 deg
Rotor Tip Path Height (in)
Rotor Tip Path Height (ft)
Time (s)
156
144
132
120
108
96
13
12
11
10
9
8
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

Figure A-23: CH-53D helicopter

Source: GlobalSecurity.org photo archives. Retrieved 1 June 2005.

Figure A-24: Hand loading cargo in the MH-60S helicopter

Source: Photo by PH2 Elizabeth A. Edwards retrieved from www.news.navy.mil photo archives on 1 June 2005.

Figure A-25: Vertical Replenishment with the MH-60S

Source: Photo by PH1 Robert R. McRill retrieved from www.news.navy.mil photo archives on 1 June 2005.

Figure A-26: MH-60S search and rescue swimmer deployment from a 15 foot hover

Source: Photo by PHAN Sarah E. Ard retrieved from www.news.navy.mil photo archives on 1 June 2005.

Figure A-27: Liftking LK6SLP low profile forklift next to a 6 foot 1 inch person

Source: LT George Austin, Air Test and Evaluation Squadron TWO ONE, Naval Air Warfare Center, Aircraft Division, Patuxent River, MD. 2004.

Figure A-28: Liftking LK6SLP low profile forklift under a static H-60 rotor blade at the 3 o'clock position, next to a 6 foot 1 inch person

Source: LT George Austin, Air Test and Evaluation Squadron TWO ONE, Naval Air Warfare Center, Aircraft Division, Patuxent River, MD. 2004.

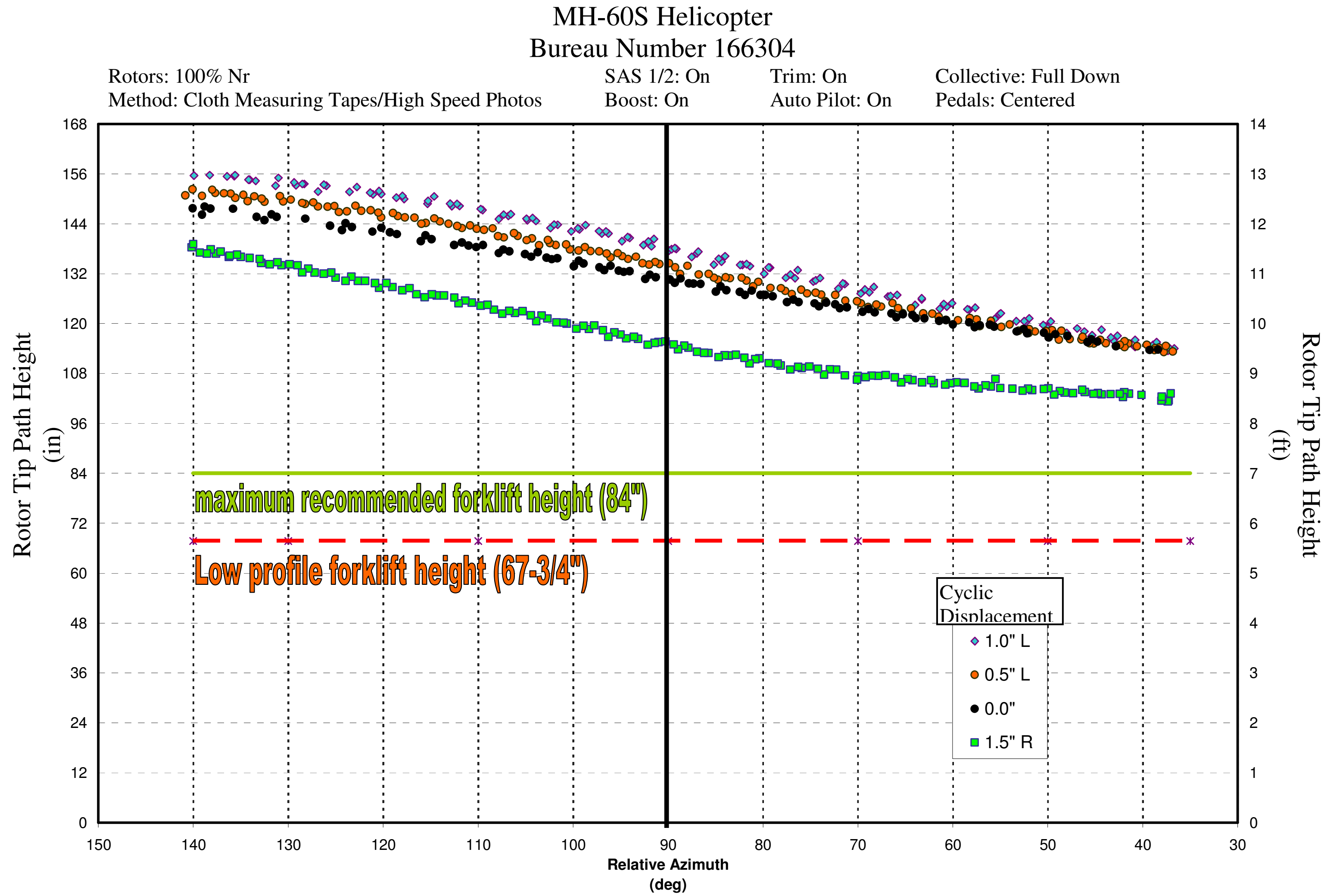

Figure A-29: Rotor tip path height compared to forklift height for selected cyclic displacements

APPENDIX B: TABLES

Table B-1:
MH-60S Design Attribute Lineage

MH-60S Design Attributes	Lineage			
	UH-60L	SH/HH-60	VH-60	Other
Airframe	☑		☑	
Landing Gear	☑		☑	
Fuel Cells	☑		☑	
Hover IR Suppressor	☑	☑	☑	
200 V/M EMI	☑	☑	☑	
Marinized Materials		☑		
Automatic Main Rotor Fold		☑		
Transmission/Drive Train		☑		
T-700-GE-401(C) Engines		☑	☑	
Flight Controls		☑	☑	
Rotor Brake		☑	☑	
AFCS		☑	☑	
Rapid Folding Tail Pylon		☑		
Folding Stabilator		☑	☑	MH-60K
Rescue Hoist		☑		MH-60K
HIFR		☑	☑	
Fuel Dump		☑	☑	
Wire Strike	☑			
Main Wheel Tie-downs		☑		MH-60K
Windshield Washer		☑		
Cockpit Crew Doors		☑		

Source: United Technologies Sikorsky Aircraft Corporation website
<http://www.sikorsky.com/details/1,,CLI1_DIV69_ETI854,00.html>

Table B-2:
U.S. Navy Shipboard Compatible, Flight Deck Certified Forklifts

Manufacturer	Model	OGH[1] (in)	Mast Ht (in)	Free Lift Ht (in)	Ship Class[3]
Case	M4K	80.00	78.00	NA	LPD
	M4KN	80.00	78.00	NA	LHA, LHD, LPD, LSD
Hyster	E40B	88.00	68.00	NA	LPD
	E40XL	83.75	68.00	NA	LHA
	E40XL-MIL	84.00	84.00	NA	LHA, LHD,LPD
	E40XM	85.93	88.30	43.50	LHA, LHD, LSD
	S60XL	81.45	70.10	43.40	CVN, LHA, LHD, LPD, LSD, CV
	S60XM	84.00	70.20	45.50	CV, CVN, LPD, LSD
Liftking	LK6SLP	67.75	67.25	39.25	CV, CVN, LHD, LPD, LSD
	LKUSN4S	80.00	80.00	(2)	LPD
Entwistle	MHE-270	78.00	78.00	48.00	LHA, LHD, LPD, LSD

Notes: (1) OGH – Overhead Guard Height
(2) Mast raises 1/2 distance of the carriage assembly
(3) Ship class and dimensional data provided by Mr. Richard Sova, NAVAIR Lakehurst Support Equipment Division.

Table B-3:
Cyclic Envelope Test and Test Conditions Table

Event	Cyclic Position	Lateral Measurement	Longitudinal Measurement
M1	Full Left, Full Forward	11 ¼”	1 ¾”
M2	Full Right, Full Forward	20 ¾”	1 ¾”
M3	Full Right, Full Aft	20 ¾”	8 ¾”
M4	Full Left, Full Aft	11 ¼”	8 ¾”

Notes: (1) Back-up pump, SAS 1, SAS 2, Trim, Autopilot -On
(2) Rotors – static
(3) Measuring tapes installed on left seat controls

Table B-4:
Dynamic Rotor Tip Path Evaluation Test and Test Conditions Table

Event	Cyclic Position	IRIG Tine	Winds	Comments
1	Centered	150820		
2	½" Left	152130		Noticeable displacement based on muscle memory.
3	1" Left	152640		Noticeable displacement based on muscle memory.
4	1 ½" Left	153150		Noticeable displacement based on muscle memory.
5	2" Left	153720	087/3.7	Noticeable displacement based on muscle memory. Notable increase in vibrations.
6	½" right	154215	090/3.0	
7	1" right	154700	090/3.0	Increase in vibes.
8	1 ½" right	155145	090/3.0	2^0 right roll. Increased vibes. Noticeable displacement based on muscle memory.
9	2" right	155625	140/4.0	2^0 right roll.
Shutdown to inspect head. No indication of droop or spindle contact.				
10	2 ¼" right			
11	2 ½" right	163335	140/4.1	
Shutdown to inspect head. No indication of droop or spindle contact.				
12	2 ¾" right			
13	3" right	164538	090/5.6	
Shutdown to inspect head. No indication of droop or spindle contact.				
14	3 ¼" right	165925	130/3.1	KIO for contact with copilot right leg
Shutdown to inspect head. No indication of droop or spindle contact.				
22	2 ¼" left			
23	2 ½" left	173350	140/4.6	
24	2 ¾" left			
25	3" left	173920	170/3.3	
Shutdown to inspect head. No indication of droop or spindle contact.				
26	3 ¼" left			
27	3 ½' left	175250	170/4.6	
28	3 ¾" left			
29	4" left	175845	130/4.1	KIO for crew comfort
Shutdown to inspect head. No indication of droop or spindle contact.				
34	¼" left Step	181232	110/4.4	No transient response visible. Tip path movement imperceptible
35	½" left Step	181752	120/4.6	
36	¾" left Step	182223	180/3.1	
37	1" left Step	182644	140/4.8	
38	¼" right Step	183135	110/3.9	
39	½" right Step	183615	120/5.0	
40	¾" right Step	184048	030/2.0	
41	1 ¼" right Step	184520	160/4.0	

Source: Test data. LCDR Jonathan Kline Daily Flight Report. July 28, 2004.

Table B-5:
Cyclic Control Envelope Measurements Referenced to Installed Tape Measures

Cyclic Position		Measurement (in)	Envelope (in)	Center Reference (in)
Lateral	Full Left	11-1/4	9-1/2	16
	Full Right	20-3/4		
Longitudinal	Full Forward	1-3/4	7	5-1/4
	Full Aft	8-3/4		

Source: Test data. LCDR Jonathan Kline Daily Flight Report. July 28, 2004.

Table B-6:

Tip Path Height at Selected Azimuth Positions Based on Cyclic Deflection

Cyclic Input (in)	Relative Azimuth (deg)	Tip Path Height		Cyclic Input (in)	Relative Azimuth (deg)	Tip Path Height		Cyclic Input (in)	Relative Azimuth (deg)	Tip Path Height	
		in	ft			in	ft			in	ft
Center	39	114	9.47	1/2" Rt	41	105	8.79	1" Rt	37	103	8.57
	90	**131**	**10.9**		**91**	**123**	**10.27**		**90**	**121**	**10.10**
	139	148	12.35		138	146	12.18		140	145	12.12
	218	148	12.35		219	156	13.02		219	159	13.25
	270	**131**	**10.9**		**271**	**138**	**11.47**		**270**	**141**	**11.78**
	319	113	9.45		320	115	9.59		320	116	9.64
1 1/2" Rt	37	101	8.44	2" Rt	40	100	8.35	2 1/2" Rt	48	96	7.99
	90	**116**	**9.64**		**91**	**112**	**9.31**		**90**	**106**	**8.86**
	140	139	11.59		139	137	11.38		140	133	11.10
	219	159	13.27		223	163	13.59		224	167	13.88
	271	**147**	**12.25**		**271**	**151**	**12.56**		**271**	**156**	**13.03**
	320	122	10.18		320	124	10.35		320	127	10.54
3" Rt	48	89	7.39	3 1/4" Rt	50	86	7.18	1/2" Lt	38	113	9.43
	90	**99**	**8.25**		**90**	**96**	**8.0**		**90**	**134**	**11.20**
	141	132	11.04		141	128	10.70		140	152	12.69
	224	173	14.46		232	175	14.60		218	149	12.41
	270	**164**	**13.67**		**270**	**168**	**13.96**		**270**	**126**	**10.52**
	321	129	10.71		321	131	10.94		319	109	9.04
1" Lt	37	113	9.45	1 1/2" Lt	37	117	9.71	2" Lt	40	122	10.21
	89	**138**	**11.51**		**90**	**142**	**11.85**		**90**	**151**	**12.57**
	141	157	13.07		138	160	13.35		135	163	13.55
	219	148	12.32		218	143	11.94		219	141	11.72
	270	**123**	**10.28**		**270**	**119**	**9.89**		**271**	**112**	**9.36**
	320	105	8.73		317	103	8.55		319	98	8.14
2 1/2" Lt	38	125	10.39	3" Lt	36	128	10.65	3 1/2" Lt	37	129	10.74
	91	**152**	**12.65**		**90**	**156**	**13.01**		**90**	**165**	**13.78**
	134	162	13.50		125	166	13.83		127	174	14.47
	219	137	11.46		219	133	11.07		218	131	10.95
	270	**112**	**9.33**		**271**	**104**	**8.64**		**270**	**96**	**7.97**
	318	100	8.34		308	94	7.86		308	87	7.28
4" Lt	37	133	11.07								
	90	**170**	**14.21**								
	126	178	14.86								
	218	127	10.60								
	270	**91**	**7.59**								
	306	84	6.96								

Notes: (1) **Bold** indicates position closest to 3 o'clock and 9 o'clock position.
(2) All angular positions are referenced clockwise from the nose of the helicopter.
(3) Data provided for low point and high point on each side of the aircraft, plus the 3 and 9 o'clock for each cyclic displacement.

Source: Mr. David Springer, Atlantic Test Range Optical Systems, NAVAIR Patuxent River, MD. 2004.

VITA

Lieutenant Commander (LCDR) Jonathan Kline, United States Navy, was born in Washington, Pennsylvania, on 10 March 1972. He grew up in southwestern Pennsylvania, graduating from Canon McMillan High School in May 1990. In August 1990, he entered Carnegie Mellon University in Pittsburgh, Pennsylvania, as a Naval Reserve Officer Training Corps (ROTC) midshipman. Upon graduating with a degree in Mechanical Engineering in May 1994, he was commissioned an Ensign in the U.S. Navy. After a temporary assignment at the Carnegie Mellon ROTC unit, he began flight training at Naval Air Station (NAS) Pensacola, Florida, in April 1995. After receiving his wings in April 1997, he was assigned to Helicopter Combat Support Squadron THREE (HC-3), NAS North Island, San Diego, California, for training in the H-46D helicopter. Upon completion of his training in December 1997, he transferred to HC-11, also located in San Diego, where he made two deployments to the Pacific Rim and Persian Gulf, providing search and rescue and logistics support for the USS ESSEX (LHD 2) Amphibious Ready Group and USS JOHN C. STENNIS (CVN 74) carrier battle group. In February 2001, LCDR Kline transferred to HC-3 to serve as one of the last instructor pilots in the H-46D. In August 2001, LCDR Kline was selected for training at the United States Naval Test Pilot School, NAS Patuxent River, Maryland. After completion of his training, he transferred to Air Test and Evaluation Squadron TWO ONE, flying the MH-60S, MH-60R, and SH-60F, where he is currently serving. After completion of his tour, he will be returning to the operational navy as a department head at Helicopter Sea Combat Squadron TWO FIVE (HSC 25), Andersen Air Force Base, Guam.