Helicopter Dynamic Interface Testing Aboard High Speed Catamarans

Abstract—JOINT VENTURE (HSV-X1) is a prototype high-speed catamaran, which was designed to rapidly transport troops and equipment in the littoral environment. One of JOINT VENTURES designed capabilities is helicopter operations. Naval Air Warfare Center Aircraft Division (NAWC-AD) Patuxent River, Maryland conducted Dynamic Interface (DI) flight tests of JOINT VENTURE using H-60 helicopters. The purpose of these tests was to evaluate the aviation facilities of JOINT VENTURE to certify the ship for helicopter operations under daylight Visual Meteorological Conditions (VMC) and develop a safe envelope for conducting helicopter operations. The flight test techniques typically used for DI were developed for helicopter operations aboard mono-hulled ships. They determine the maximum safe relative winds over the flight deck and ship motion (pitch and roll). The ship motion and relative winds generated by ship speed on a high-speed catamaran are vastly different than the motion of a mono-hulled ship. The focus of this paper is the validity of traditional DI test techniques when testing the dynamic interface between helicopters and non-traditional ship types.

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1. INTRODUCTION

Background

Naval Warfare Development Command (NWDC), in conjunction with the U.S. Army, USMC and Coast Guard (NWDC Lead) issued a contract for leasing a catamaran type vehicle as a surrogate High Speed Vessel (HSV) (e.g. 40+ knots) to conduct a series of Joint and Service specific experiments for a 12-18 month period. Part of the experimentation included conducting flight operations in support of the proposed Joint and Service specific missions. The test ship was modified to demonstrate a flight deck capability during the experiment. NWDC tasked Naval Air Systems Command (NAVAIR) to perform Dynamic Interface testing of the H-60 helicopter aboard JOINT VENTURE (HSV-X1) during October 2001.

JOINT VENTURE was modified for the HSV mission, to include installing a flight deck, and had previously never operated helicopters from the flight deck.

Purpose

The primary goal of this evaluation was to validate the general day launch/recovery envelope for medium lift helicopters aboard JOINT VENTURE and expand that envelope for H-60 operations as time permitted. A Secondary goal of this evaluation was a validation of classic Dynamic Interface test technique in this unique environment.

2. DESCRIPTION OF TEST EQUIPMENT

SH-60B Seahawk

The SH-60B is a single main rotor, twin-engine helicopter manufactured by United Technologies Corporation, Sikorsky Aircraft Division. The helicopter is primarily designed for undersea warfare (USW) and surface warfare (SUW) missions from Naval air capable ships. The helicopter is powered by two T700-GE-401C engines, each capable of developing a continuous rating of 1662 SHP and a maximum of 1940 SHP. SH-60B BuNo 162337, originally manufactured as an SH-60B, is an extensively modified flight test aircraft that is being used to simulate the flying qualities and performance of an MH-60R. The aircraft was equipped with onboard Flying Qualities and Performance (FQ&P), and structural/vibration instrumentation packages. A cockpit video camera/recording system is included in the cabin instrumentation system to record pilot Vertical Instrument Display System (VIDS) gage imagery. In addition to BuNo 162337’s instrumentation systems, it also contains an extensive internal ballasting system. Up to 6950 lbs of ballast can be installed in several locations throughout the aircraft, including the tail transition section, six cabin locations, in the forward/ aft datalink antenna housings, in the forward ESM antenna housings, and in the stub wing flotation mounts.

MH-60S Knighthawk

The MH-60S helicopter is a twin-engine, single main rotor, ship-based, utility helicopter. It is constructed primarily of a UH-60L Blackhawk airframe, outfitted with SH-60 Seahawk mechanical flight controls and dynamic components. The aircraft is equipped with fixed main and tail gear, which consists of two single-wheel, main landing gears, and a single-wheel, swivel-type tail wheel. Each main landing gear incorporates a UH-60 oleo strut (modified for higher sink rate landings), and a SH-60 drag beam, axle assembly, tie down ring, brake assembly and tire. The tail gear assembly is of the UH-60, and the strut has been rotated 180°. The aircraft is equipped with 1700-GE-401C engines (with improvements defined in ECP 3930), which provide maximum continuous power of 1662 SHP, intermediate power of 1800 SHP, and contingency power of 1940 SHP. The aircraft is also equipped with the Lockheed Martin Common Cockpit, which is designed for installation in both the MH-60S and the MH-60R. Additional aircraft equipment includes: SH-60 hydraulic rescue hoist, vibration absorbers, anti-ice system, fire-extinguishing system, environmental control system, single-point pressure and HIFR refueling systems; newly designed internal palletized cargo handling system; 9000 lb. cargo hook; and UH-60L wire strikes system, gunner’s windows, external stores structural provisions, dual cabin doors, fuel cells, hover IR suppressers, and airspeed sensing system.

JOINT VENTURE (HSV-X1)

JOINT VENTURE is a high-speed wave piercing sealift catamaran. Incat Tasmania, Pty Ltd built the ship. This hull (050) was originally launched November 1998 as the high-speed ferry TOP CAT, which made the 102 nm trip across the Cook Straight, New Zealand three times a day for two years. This ferry route was upgraded to a larger vessel, and the TOP CAT underwent a major refit for the U.S. Military charter. The ship is 96 meters long, and 26 meters wide with a full time crew of 29. The ship has a maximum operating deadweight of 770 metric tons (849 short tons), with a corresponding draft of 3.7 meters (12 feet).
JOINT VENTURE is powered by four Alstom/Rustom 20RK270 marine diesel engines, producing 9,390 horsepower each. The engines drive four Lips-15OD water jets through four Reintjes-VIJ683 gearboxes. The ship’s maximum (light weight) range is in excess of 4,500 nm (without refueling), with a maximum speed of 48+ knots, and a fully loaded speed in excess of 38 knots. The flight deck measures 50’ wide by 80’ long, and was designed to handle all legacy Naval Helicopters up to H-46 size. No visual or electronic navigational aids are provided. For the purposes of the experiment, JOINT VENTURE was instrumented to measure 3-component accelerations at various locations on the ship, stresses in the hull, relative wind speed and various ship performance data. The modifications to the ship will allow it to accomplish the following tasks:

- Capable of maintaining a service speed of 35 knots with more than 545 short tons of military vehicles, troops and equipment over a distance of 1,110 nautical miles in sea state 3.
- Able to deploy distances over 4,500 nautical miles without refueling with 250 metric tons of cargo onboard, within 9 days at an average speed over 22 knots.
- Crew accommodation and facilities capable of sustaining 40 personnel for extended operating periods, 15 days and over, without replenishment.
- Seating capacity for 325 battle ready troops and their equipment plus additional transient berthing facilities for 60 personnel.
- Vehicle deck area and deadweight will allow the carriage of over 17 LAV-III or 14 M2A3 fighting vehicles plus troops, equipment and other vehicles.
- A quarter ramp capable of loading/unloading military armored wheeled and tracked vehicles to almost any wharf height and Seafit pontoon.
- Able to launch and recover fast military support RHIBs (Rigid Hull Inflatable Boats) up to 11 meters length in sea state 3.
- A helicopter deck capable of landing rotary wing aircraft up to and including the H-60 Seahawk, H-46 Sea Knight and MH-60S Knighthawk during daylight operations.

3. SCOPE OF TEST

The NAVAIR test team conducted this evaluation during 3 flights encompassing 12.9 flight test hours, and 52 total launch/recoveries (40 in 162337 and 12 in 165742). The testing was conducted in daylight visual meteorological conditions. The aircraft were crewed with two pilots and one naval aircrewnen. Maximum sustained winds during the evaluation were 23 knots and maximum sea state was 3.

4. METHOD OF TEST

Mono-Hulled (normal) ship motion

The motion of ships is usually described using 3 measures of angular and 3 measures of linear motion. The angular measures of motion are pitch, roll, and yaw. The linear measures of motion are heave, sway and surge, which correspond to the vertical, lateral, and longitudinal axes of the ship. The measures of ship motion used in dynamic interface testing to define a safe landing environment versus a dangerous landing environment are pitch and roll. The magnitude of a ship’s Pitch and Roll increase with increasing wave motion and vary depending on the ships angle to the waves. A ship traveling perpendicular to waves tends to pitch more than roll and a ship traveling parallel to the swell tends to roll more than pitch. As the wave motion increases so does the amplitude of the ships motion, however the period of the ships motion does not. Figure 2 shows the motion of a frigate in moderate seas. The roll of the ship has increases from 3 to 8 degrees but the period of
the motion remains the same. Assuming that the ships pitch and roll motion can be considered simple periodic motion the maximum acceleration and minimum velocity occur at the maximum displacement amplitude and the minimum acceleration and maximum velocity occur at the minimum amplitude, or when ships flight deck is parallel to the horizon or flat.

Landing Aboard a Pitching and Rolling Deck

When landing a helicopter aboard a ship, the pilots try to maintain the helicopter in a level attitude and touchdown with little or no longitudinal or lateral drift. The landing evolution can be broken down into several sub-tasks including lateral and longitudinal position maintenance, vertical descent rate maintenance, heading maintenance, and roll and pitch attitude maintenance. Minimizing the drift requires the aircrew to anticipate the deck motion because helicopter response characteristics are not quick enough to follow the ship’s motion. Maximum pitch and roll become excellent predictors of the workload associated with predicting the deck motion because they directly correlate with how quickly the ship will be accelerating at maximum pitch or roll and how fast the deck will be moving when the ship passes through the flat position.

JOINT VENTURE motion

Testing aboard JOINT VENTURE presented a new challenge to the classic techniques of Dynamic Interface testing because the motion of this type of ship didn’t adhere to the same ship motion models as a mono-hulled ship. Figures 3 and 4 show the pitch and roll motion of JOINT VENTURE in Port Bow and Beam Seas. The period of motion changed in varying seas and was not periodic in the same sea conditions. To verify that pitch and roll could be used to predict the limits of acceptable workload, the team conducted testing to workload end points using classic DI techniques.
periods, which investigated the effects of ship motion, ship relative wind speed, and ship relative wind direction on helicopter flying qualities. During shipboard flight tests, one NAVAIR Patuxent River engineer had direct radio communication capability with the test aircraft. The Shipboard Test Coordinator (STC) requested that the Officer-of-the-Deck (OOD) provide the Wind-Over-Deck (WOD), or other appropriate conditions required for each test sequence. These conditions were relayed to the helicopter by the Helicopter Control Officer who also cleared the helicopter to land aboard the ship.

**Deck Landing Qualification**

Prior to expanding the launch and recovery envelope, each pilot completed 6-day Deck Landing Qualification landings. All DLQ launches and recoveries were conducted at wind and ship motions conditions located within the general envelope presented in Figure 5. The general envelope is designed to allow helicopter operations on an untested flight deck with minimal risk by limiting WOD and ship motion conditions to the historically most favorable for helicopter operations.

![Diagram of General Launch and Recovery Envelope](image)

**Figure 5**

General Launch and Recovery Envelope

**Launch/Recovery Test Progression**

The initial WOD condition for each flight-test period was located within the boundaries of L/R envelopes previously tested as safe and/or within the general envelope. After the ship attained the desired WOD conditions, one or more L/R evolutions was conducted. After a L/R sequence followed by an "ops normal" call to the tower, pilots assigned a rating of 1 through 5 from the Deck Interface Pilot Effort Scale (DIPES), figure A-5, to each of the L/R sequences and radioed them back (with other applicable data and comments) to engineers aboard ship. If a pilot assigned a DIPES 1, 2, or 3 to any L/R sequence, the sequence could be repeated for verification. If a pilot assigned a DIPES 4, the sequence could also be repeated for verification, but only with pilot and test coordinator's concurrence. If a pilot assigned a DIPES 5 to any L/R sequence, the combination of relative WOD speed, WOD direction, approach type, and/or ship motion would not be repeated; the WOD speed and direction would be changed to conditions corresponding to a previous DIPES 1, 2, or 3. Pilots could also elect to relay approach/recovery DIPES ratings while the aircraft was on deck, prior to launch. In the event that a approach/recovery had received a DIPES 4, pilots and engineers would verbally confirm/establish the desired launch/department WOD and/or resultant ship motion before launch. In the event that the approach/recovery was assigned a DIPES 5, the WOD conditions would be changed prior to the subsequent launch. After the test aircraft completed the desired L/R sequences for a given set of wind conditions, the ship was maneuvered to produce new relative WOD conditions for the next L/R sequence. To ensure a safe incremental buildup, each new relative WOD condition was located within 5 knots or 15 degrees from established safe conditions. This basic envelope development test sequence (L/R evolution - verbal report - ship maneuver) was repeated during the underway test to develop launch/recovery envelopes.

**Approach/Departure Technique**

Approaches to the ship were made in accordance with the recommended approach technique listed either in the aircraft NATOPS/pilots flight manual or in accordance with NWP 3-04.1 dated February 1998, reference [4]. After a transition to a 10-foot hover over the ship deck the pilot positioned the aircraft over the intended landing spot, followed by a landing with the main mounts within the marked landing circle. After takeoff into a 10-foot hover over the ship deck, the aircraft used one of two techniques to depart depending on wind conditions. During larger bow winds the aircraft slid laterally clear of the flight deck and transitioned to forward flight. When the winds were positioned abeam or aft of abeam the helicopter was turned 90 degrees over the flight deck and launched into the wind.

**5. RESULTS AND EVALUATION**

**Test Technique Validation**

The ship motion encountered during the HSV evaluation would be considered extremely benign in a mono-hulled evaluation. The maximum pitch and roll motion encountered was 2 and 4 degrees respectively. Under these conditions fleet pilots on a normal ship would consider forgoing chaining the aircraft to the deck for a short deck evolution such as loading passengers. On JOINT VENTURE, however, these conditions produced a DIPES rating of 3 for lateral position maintenance. The normally benign roll motion of 4 degrees produced deck motion that consistently received DIPES three from two different evaluation pilots. When the wind over deck conditions were repeated with less deck motion and the launch and recovery sequence received a DIPES rating of 1. When the roll
motion was less than 2 degrees all of the DIPES ratings were 1 and overall the deck was satisfactory for daytime helicopter operations. It was only when the deck motion exceeded 3 degrees in roll that higher DIPES ratings were assigned and they were consistently assigned for lateral position maintenance. From these data points the test team concluded that pitch and roll could still be used in conjunction with wind over deck to bracket the launch and recovery envelope and realized that the acceptable ship motion limits would be very small for this type of vessel.

General Launch and Recovery Envelope Verification

General L/R envelope verification tests were conducted for stern approaches using a NSH-60B and MH-60S test aircraft. True winds ranged from 9 to 23 knots and maximum ship pitch and roll was 2 and 4 degrees respectively. Pilot ratings of all attempted launches and recoveries were acceptable for fleet operations. The MH-60S conducted 12 launches and recoveries within the general envelope. Within the scope of this test, the day General launch and recovery envelope as shown in figure 5 is safe for operational use.

H-60 B/F/H/J Expanded Launch and Recovery Envelope

H-60 B/F/H/J launch and recovery envelope expansion tests were conducted aboard JOINT VENTURE for stern approaches using an NSH-60B. True wind ranged from 9 to 23 knots, and maximum pitch and roll was 2 and 4 degrees respectively. A total of 41 recoveries were accomplished over a period of 7 flight test hours. Including both launches and recoveries, there were 57 unique relative wind over deck conditions evaluated. Pilots rated all attempted launches and recoveries as acceptable for fleet operations. A plot of test points flown is presented in figure A-2. Within the scope of this test, the H-60 B/F/H/J expanded day launch and recovery envelopes shown in figure A-2 is safe for operational use.

Ship Airwake Environment Over the Flight Deck

The airwake environment over the flight deck of JOINT VENTURE was evaluated for safe helicopter operations during numerous helicopter launch and recovery evolutions. Relative wind speeds ranged from a minimum of 0 knots to a maximum of 56 knots. Relative wind azimuths virtually 360 degrees with a maximum gap of 40 degrees between data points during light port quartering winds were tested. The high relative wind speed points were primarily within 20 degrees of the ship's bow. During these approaches, the aircraft flew through undisturbed air until the aircraft was descending through a 5 foot hover over the flight deck. At that point, the airwake caused some light chop and turbulence that required some flight control movement to maintain position over the landing spot, but the pilot at the controls did not consider it a problem. The minimal ship superstructure forward of the flight deck allowed for an undisturbed air wake over the flight deck during much of the aircraft approach and departure. Aircraft power requirements were easily controlled with an adequate margin of reserve during all the test conditions. No downdrafts or excessively turbulent wind conditions were present to cause any high power demands during any phase of approach or departure. In addition, no tendency to be "sucked in" toward the ship superstructure while over the flight deck was noted during any of the flight evolutions. The higher relative wind over deck (RWOD) conditions created by the high ship speeds provided some real benefits. Crossing the deck edge during approaches with RWOD above 45 knots, average torques ranged from 45 to 55%, which is less than half of the torque that the engines are capable of producing in sea level conditions. In addition the high RWOD resulted in a level aircraft attitude during the final phase of the approach which improved the pilots field of view. The smooth clean airwake experienced by the aircraft during approaches at high RWOD will reduce pilot workload, decrease power required and improve pilot field of view. It is considered an enhancing characteristic and should be incorporated in future designs.

REFERENCES


Lieutenant Commander Andy Lynch, U. S. Navy is a test pilot assigned to Air Test and Evaluation Squadron TWO ONE (HX-21), based at Naval Air Station Patuxent River, MD. He graduated from the U.S. Naval Academy in 1992 with a BSAE. He was designated a Naval Aviator in October, 1994. After completing his initial operational tour with Helicopter Combat Support Squadron ELEVEN (HC-11) in San Diego, CA flying the H-46D Sea Knight he was assigned to Helicopter Combat Support Squadron THREE (HC-3) as an H-46D instructor pilot. During his tour at HC-3 he was accepted to the U.S. Naval Test Pilot School. He graduated from Test Pilot School with class 118 in December 2000. He is currently the MH-60S Platform Coordinator at HX-21.
Mr. Andrew Baker is currently the DI Team Lead and Senior Flight Test Engineer at the NAVAIR Rotary Wing Ship Suitability branch, also known as Dynamic Interface at Patuxent River, MD. Since he started there in 1997, he has either conducted or supported many shipboard helicopter sea trials, including V-22, MH-60S, JSHIP, Commercial VERTREP, MH-68A and many others. Mr. Baker is a Graduate of the United States Naval Test Pilot School, Rotary Wing Curriculum (Class 114). He received his BS degree in Aerospace Engineering from University of Maryland at College Park in 1993, and his MS (Aerospace Engineering) degree from the same institution in 1995. His graduate work centered on helicopter aerodynamics, culminating in his Master’s thesis titled “Three-Component Laser Doppler Velocimeter Measurements of a One-Bladed Rotor”.
### APPENDIX A

#### DECK INTERFACE PILOT EFFORT SCALE (DIPES)

<table>
<thead>
<tr>
<th>EFFORT</th>
<th>GUIDANCE</th>
<th>DIPES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slight to Moderate</td>
<td>Reasonable compensation required. Tracking and positioning accuracy is consistently maintained throughout the operation. Fleet pilots will have enough spare capacity to conduct ancillary tasks.</td>
<td>1</td>
</tr>
<tr>
<td>Considerable</td>
<td>Significant compensation required. Tracking and positioning accuracy occasionally degrades during peaks in ship motion, sea spray or turbulence. Fleet pilots will have difficulty conducting ancillary tasks.</td>
<td>2</td>
</tr>
<tr>
<td>Highest tolerable</td>
<td>Highest tolerable compensation required. Tracking and positioning accuracy degrades regularly during peaks in ship motion, sea spray or turbulence. Fleet pilots will be able to keep up with task requirements but no more. Degraded operations (ship or aircraft) will probably require an abort. Repeated safe operations are achievable. This point defines the recommended limit.</td>
<td>3</td>
</tr>
</tbody>
</table>

**Note:** Each DIPES rating may be given one or more suffixes to describe the cause(s) of the increased workload:
- Pitch control: P
- Height control: H
- Turbulence: T
- Spray: S
- AC/Attitude: A
- Roll control: R
- F/A positioning: F
- Deck motion: D
- Torque control: Q
- Yaw control: Y
- Lateral positioning: L
- Visual cues: V
- Funnel exhaust: E

**Figure A-1**

DECK INTERFACE PILOT EFFORT SCALE
Figure A-2
NSH-60B DATA WITH RECOMMENDED ENVELOPE