YCH-60 Airborne Mine Countermeasures Proof of Concept Demonstration

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Abstract—The investigation of transitioning the Airborne Mine Countermeasures (AMCM) mission to the H-60 helicopter platform required the demonstration of the capability to tow water-borne weapon systems from a YCH-60 prototype aircraft. Naval Rotary Wing Aircraft Test Squadron (NRWATS) was tasked to conduct a multi-phased test during the concept demonstration. The purpose of the Phase I and II testing was to investigate the YCH-60 aircraft capability to conduct the AMCM tow mission under dynamic conditions. Specifically, the test was designed to evaluate aircraft performance and handling qualities, to evaluate adequacy of structural towing provisions, to evaluate design tow speeds and tensions, and to collect usage spectrum data. Flight tests were conducted during a joint Navy and Sikorsky Aircraft Corporation flight test from 17 November 1999 to 17 January 2000 at the Sikorsky Aircraft facility, Stratford, CT and at Naval Air Station (NAS) Patuxent River, MD. This paper addresses the results and evaluations of Phases I and II.

TABLE OF CONTENTS

1. INTRODUCTION
2. DESCRIPTION OF TEST AIRCRAFT / EQUIPMENT
3. SCOPE OF TESTS
4. METHOD OF TESTS
5. RESULTS AND EVALUATION
6. CONCLUSIONS

1. INTRODUCTION

Background

The H-60 Airborne Mine Countermeasures (AMCM) effort was initiated by a Joint Assessment letter from the Director, Expeditionary Warfare Division (N85), Deputy Chief of Naval Operations, which directed a study of transitioning MH-53 AMCM capabilities to the H-60 helicopter. The study addressed the feasibility of outfitting the H-60 helicopter with five weapon and sensor systems, including the improved towed sonar system (AQS-20/X), the Airborne Mine Neutralization System (AMNS), the Airborne Laser Mine Detection System (ALMDS), the Organic Airborne and Surface Influence Sweep (OASIS), and the Rapid Airborne Mine Clearance System (RAMICS). Because the AQS-20X and OASIS were designed as towed sensors, the response to the N85 directive was to establish a proof-of-concept demonstration of the H-60 as a tow platform. Due to the Naval helicopter force restructuring plan which called for a neck-down in current type/model aircraft to the H-60 airframe, the focus of the N85 directive was on the usage of the CH-60S platform in the AMCM role. Therefore, Sikorsky Aircraft Corporation was contracted to team with Naval Air Systems Command and Naval Sea Systems Command to provide a multi-phased proof-of-concept tow test and evaluation using the YCH-60 prototype aircraft as the test platform. Phase I included a ground tethered static tow demonstration. Phase II consisted of One Engine Inoperative (OEI) tests and a limited dynamic tow demonstration using the AN/SPU-1/W Magnetic Orange Pipe (MOP) system. Follow-on proof-of-concept testing will be conducted during Phase III. Phase III will include captive carriage, stream, tow, and recover operations of an AQS-20X towed sonar system. The CH-60 AMCM demonstration was conducted by Sikorsky Aircraft and the Navy.

The CH-60 AMCM demonstration was conducted by Sikorsky Aircraft and the Navy. The Naval Rotary Wing Aircraft Test Squadron was tasked to participate with Sikorsky Aircraft Company in a joint test effort to investigate the potential for the YCH-60 aircraft to perform the AMCM mission.

Purpose

The purpose of this test was to investigate the capability of the YCH-60 aircraft to conduct the AMCM tow mission by establishing its ability to tow under dynamic conditions, to evaluate aircraft performance and handling qualities, to evaluate adequacy of structural towing provisions, to evaluate design tow speeds and tensions, and to collect usage spectrum data.

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DESCRIPTION OF TEST AIRCRAFT/EQUIPMENT

Test Aircraft

The YCH-60 aircraft was a twin turbine-engine powered, four-bladed helicopter manufactured by the Sikorsky Aircraft Corporation division of United Technologies. The YCH-60 was a prototype design which melded an UH-60 Blackhawk airframe with a SH-60 Seahawk power and drive train, flight control system, and dynamic components. The aircraft, depicted in figure 1, had an overall length of 64 feet 10 inches and a maximum test operating weight of 22,000 lbs. AMCM modifications to the hybrid aircraft included airframe strengthening for a tow point addition and mission avionics to support the tow mechanisms. The test aircraft, YCH-60 BuNo 966673, was representative of the production AMCM CH-60S for the purposes of this test.

AMCM Aircraft Modifications

The AMCM tow modification consisted of an airframe tow fitting, a rigid tow arm, a flexible link, and a tow hook as depicted in figure 2. The tow point location was determined through design optimization of aircraft pitch attitude and main-rotor flapping parameters during tow operations. The tow fitting was located in the transition area aft of the main cabin, in the lower airframe between stations 464 and 485. The tow fitting consisted of structural load bearing members integrated into the aircraft fuselage. The tow boom attached to the tow fitting and was joined to a braided steel flexible cable. The tow hook was fitted to the flexible link and was designed to enclose two Cartridge Actuated Devices (CAD) and guillotine cutter assemblies for emergency cable shear. In addition, an avionics access door was fitted to the lower port side of the transition section. Manually adjustable, aft facing mirrors were installed forward of the lower portion of the pilot and copilot doors.

Test Aircraft Instrumentation

The test aircraft was modified to include a flying qualities, performance, and structural data acquisition and recording system. An airspeed boom was attached to provide instrumented airspeed, angle of attack, and sideslip angle. Data was recorded in high-speed PCM format onto a HEIM digital tape recorder. The system was designed to accommodate an airborne monitor mounted in the cabin to provide real time display of selected parameters. The system was also capable of data telemetry for real-time monitoring at a remote site.

Test Equipment

The AN/SPU-1W Magnetic Orange Pipe (MOP), shown in figure 3, was a surface-running towed device used in anti-magnetic mine warfare. The MOP was fabricated from 30 ft of ten-inch diameter schedule 20 steel pipe (10.75 in. outside diameter). Each MOP weighed 1,000 lbs. and was buoyant in water. MOPs were connected in series using braided nylon line.
3. SCOPE OF TESTS

Test and Test Conditions

The evaluation of the YCH-60 tow capability was conducted jointly by the Naval Air Systems Command, Naval Sea Systems Command, and Sikorsky Aircraft Corporation. The flight test was conducted during daylight visual meteorological conditions (VMC) and consisted of 22 flights totaling 21.5 flight hours. Qualitative and quantitative flight tests were conducted in assessing the aircraft structures, performance, and flying qualities during tow operations. Aircrew human factors were assessed throughout the test. With the exception of six flights, all test flights were conducted with a mixed cockpit crew of a Sikorsky test pilot and a Naval Rotary Wing Aircraft Test Squadron test pilot. Aircraft structures, performance, and flying qualities were tested against the requirements of the AQS-20X sensor tow envelope. Specific performance goals were to tow up to 6,000-lbs. tension and at speeds up to 24 KGS. Human factors were tested against all applicable specifications listed in reference [1] through [5].

Phase I Tests and Test Conditions

The initial testing, Phase I, was conducted at the Sikorsky Heliport in Stratford, CT and consisted of ground-tethered static tow work and forward-flight tow-boom extended envelope development. The ground tether point was fixed to a 20,000-lb. block positioned centrally on the heliport and the tether cable was 450 ft. long. Ground-tethered testing was conducted from 100 ft. AGL and consisted of critical azimuth, tension sweeps, skew angle sweeps, fixed stabilator angle variation, cable tension impulse tests, and four cable jettison tests. Table 1 presents the cable jettison conditions.

<table>
<thead>
<tr>
<th>AIRCRAFT GW/CG (lbs./in.)</th>
<th>CABLE TENSION (lbs.)</th>
<th>SKEW ANGLE</th>
<th>STABILATOR MODE</th>
</tr>
</thead>
<tbody>
<tr>
<td>13,690 / 359.2</td>
<td>3,181</td>
<td>0°</td>
<td>Auto</td>
</tr>
<tr>
<td>13,940 / 360.3</td>
<td>2,546</td>
<td>0°</td>
<td>Fixed - 0°</td>
</tr>
<tr>
<td>17,588 / 351.6</td>
<td>2,534</td>
<td>20° right</td>
<td>Auto</td>
</tr>
<tr>
<td>17,445 / 351.1</td>
<td>6,289</td>
<td>0°</td>
<td>Auto</td>
</tr>
</tbody>
</table>

Notes: (1) Skew angle is defined as tow cable angle relative to the body-fixed X-Z plane.

Phase II Tests and Test Conditions

Phase II was conducted at NAS Patuxent River, MD and consisted of One Engine Inoperative (OEI) height-velocity (H-V) investigation and dynamic tow using from 1 to 5 AN/SPU-1 MOPS. The OEI H-V tests were conducted both un-tethered and ground-tethered. Un-tethered OEI H-V tests were conducted first as a build-up to the more critical tethered conditions. The tethered conditions were used to simulate actual towing conditions. Table 2 details the tethered OEI test configurations. Five dynamic tow flights were flown, two in the test buildup configuration and three at the heavier mission aircraft gross weight. Dynamic tow operations were conducted in Chesapeake Bay from 95-100 ft. AGL and in wind conditions ranging from 8 to 22 knots, with gusts to 25 knots. Dynamic tow testing consisted of critical azimuth, tension sweeps, skew angle sweeps, fixed stabilator angle variation, AMCM turns from various wind azimuths, and a maximum tow tension demonstration. A limited Automatic Flight Control System (AFCS) evaluation of the aircraft Doppler hover coupler feature was conducted under tow conditions.

<table>
<thead>
<tr>
<th>TARGET CABLE TENSION (lbs.)</th>
<th>CABLE TENSION AT ENGINE CUT (lbs.)</th>
<th>STABILATOR MODE</th>
</tr>
</thead>
<tbody>
<tr>
<td>15,700 / 363.8</td>
<td>3,000</td>
<td>2,100</td>
</tr>
<tr>
<td>18,750 / 355.9</td>
<td>3,000</td>
<td>2,223</td>
</tr>
<tr>
<td>18,958 / 356.6</td>
<td>6,000</td>
<td>6,807</td>
</tr>
<tr>
<td>18,668 / 355.6</td>
<td>6,000</td>
<td>5,765</td>
</tr>
</tbody>
</table>

Notes: (1) All cuts were done at zero skew angle, into the prevailing wind (2) Maximum headwind for tethered OEI cable cuts was 5 KTAS

Test Envelope

Table 1

Static Tow Cable Jettison Conditions

Table 2

Tethered OEI H-V Test Configurations

Figure 3
AN/SPU-1 Magnetic Orange Pipes
The test aircraft was operated within the limits of the H-60F/H NATOPS Flight Manual, reference [6], and the NAVAIRSYSCOM flight clearance. Ground tethered static tow tests were flown at tensions from zero to 6,200 lbs. and skew angles from 20° right to 20° left. Dynamic tow tests were flown at ground speeds from hover to 42 KGS, tensions to 8,915 lbs.

Test Loadings and Configurations

Aircraft test loadings and configurations are presented in Table 3. Aircraft ballasting was accomplished by configuring the aircraft with the External Stores Support System (ESSS) and two 230 gal auxiliary fuel tanks each ballasted with 1,300 pounds of a water/alcohol mixture. External ballasting was required for jettison capability. Gunners windows open. AN/SPU-1 MOP. No submerged AQS shapes were deployed, towed, or retrieved. In addition, because the cockpit was not configured with production representative avionics, tactical navigation handling qualities or precision of the AMCM role were not evaluated. Aircraft tow and OEI performance was evaluated against test day conditions without engineering referral to higher density altitude conditions.

Limitations to Scope

The testing of the AMCM capability of the CH-60 was limited to tethered hover and towing of a surface towed AN/SPU-1 MOP. No submerged AQS shapes were deployed, towed, or retrieved. In addition, because the cockpit was not configured with production representative avionics, tactical navigation handling qualities or precision in the AMCM role were not evaluated. Aircraft tow and OEI performance was evaluated against test day conditions without engineering referral to higher density altitude conditions.

<table>
<thead>
<tr>
<th>CONDITION</th>
<th>TAKEOFF GW/CG (lbs.)/(ins.)</th>
<th>CONFIG</th>
<th>TESTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Build-up Test Weight 15K Clean</td>
<td>15,200/365. 0 long. Neutral lat.</td>
<td>Basic aircraft</td>
<td>Tow boom extended Static tow</td>
</tr>
<tr>
<td>Build-up Test Weight 15K Dirty</td>
<td>15,700/365. 0 long. Neutral lat.</td>
<td>ESSS / no stores</td>
<td>OEI H-V Dynamic tow</td>
</tr>
<tr>
<td>Mission Weight 19K</td>
<td>19,500/357. 0 long. 1.7 left lat.</td>
<td>2 x 230 gal aux. L/R outboard sta.</td>
<td>1,300 lbs./tank</td>
</tr>
</tbody>
</table>

NOTES: (1) Aircraft configured with the cabin doors closed, gunners windows open.

4. Method of Tests

General

The YCH-60 tow testing was conducted in a build-up fashion to establish a dynamic tow envelope based on the requirements of the AQS-20X towed sonar. Specific performance goals were to tow up to 6,000-lbs. tension and at speeds up to 24 KGS. To build-up to attain these performance goals, static testing preceded dynamic testing and un-tethered OEI H-V tests were conducted prior to tethered test events. All testing at the build-up aircraft test weights, configurations 15K clean and 15K dirty in Table 3, were conducted prior to comparative testing at the aircraft mission gross weight, configuration 19K. All test events used on-board data recording, capturing a 10-second minimum data collection for steady test conditions and the full duration of selected transient conditions between steady data points. Real-time data telemetry for the defined critical parameters was also implemented throughout the test with Navy and Sikorsky engineering staff monitoring abort criteria. Human factors data was collected from pilots during a post flight-test interview using a Human Engineering Performance Scale. Assessments were correlated to various flight parameters in each of the 10 rating areas.

Ground and Preflight Checklists/Tests

A proof load test of the aircraft and the tow point was conducted prior to flight test. In addition, a dynamic cable-cut test was conducted in a test fixture to assess tow boom and cable response to Cartridge Actuated Device (CAD) actuation. The proof load and cable cut results were published in a Sikorsky Engineering Report. A full Electromagnetic Compatibility Safety of Flight Test (EMC SOFT) was successfully conducted during the first ground turn.

Static Tow

The initial ground-tethered static-tow tests were conducted heading into the true wind while tension was increased incrementally from approximately 1,000 lbs. to 6,000 lbs. in approximately 1,000 lb. increments. Critical azimuth tests were conducted from a 2,000-lb. target tension to 6,000 lbs. in 2,000 lb. increments. Azimuths were sampled in 15° increments, starting oriented into the prevailing wind to 180° left and right. All azimuths were sampled prior to increases in tension. Static critical azimuth was also conducted in 90° increments to evaluate transients during a steady tension turn. All static tow turns were flown targeting constant tension, centered skew. Skew angle variations were investigated into the wind at 2,000, 4,000, and 6,000-lbs. tension from centered skew to 20° left and right in 5° increments. Stabilator angle variations were investigated at constant tensions and wind azimuths. Stabilator variation effectiveness was compared by flying all test points with the stabilator in the AUTO mode and then by manually fixing the stabilator angle at angles from full trailing edge down to full trailing edge up (in 10° increments) at the same tension/skew/wind conditions. Towed body surge effects were simulated from an initial
tension of 4,000 lbs., using up to 1 inch cyclic and collective pulses building up in amplitude and rate. Static tow cable cuts were conducted with the aircraft aligned into the wind. Table 1 is the matrix of static cable cut parameters.

One Engine Inoperative Height-Velocity Investigation

One Engine Inoperative (OEI) Height-Velocity (HV) build-up consisted of run-on landings, power recovery autorotations, and un-tethered simulated single engine failures. Un-tethered OEI was conducted by simulating engine failures in forward flight at conditions emulating those found during worst case static tow testing. Airspeed for initiation of the un-tethered OEI events was reduced from 30 KTAS to hover in two 10 KT and then two 5 KT increments at a test altitude of 500 ft AGL. From the hover condition at 300-ft AGL, the test condition was lowered in altitude to 300 ft AGL in 100-ft increments. Each un-tethered OEI event was initiated by first setting the number one engine torque to a 102% target by retarding the number two engine Power Control Lever (PCL) from the FLY detent, or normal flight position, until the target torque was set on the number one engine. The engine torque of 102% was determined from the dual engine power required during static tow at 6,000 lb. tension in the 19K configuration. When the engine and flight condition was set, flight controls were fixed open loop. Following a test event countdown, the number two engine was then retarded its remaining travel into the IDLE throttle stop. To characterize rotor system response initially, the PCL failure rate was increased, starting with a 3 second PCL reduction and building down to an instantaneous reduction. All subsequent test points used this instantaneous PCL reduction. Following the simulated engine failure, a 1.3-second delay, simulating AMCM pilot recognition and reaction time, was induced prior to pilot-in-the-loop response. Following the 1.3 second delay, cable shear and tow coupler departure was simulated by depressing the cyclic emergency shear and cyclic coupler depart pushbuttons, and the fly away was performed. The single engine fly-away was flown minimizing altitude loss less than 100 ft., maintaining Nₙ ≥ 90% and establishing a positive rate of climb without exceeding single engine torque and temperature limits. Criteria for aborting the data point included Nₙ less than 85% or altitude loss exceeding 100 ft. The event was complete upon attaining a positive rate of climb under single engine conditions.

Tethered simulated OEI tests were conducted in a manner similar to that used during the un-tethered build-up. Events were flown in the order presented in Table 2 for build-up. With the aircraft stable at the target tension, the number two engine was retarded to the IDLE throttle stop and the fly-away was executed using the procedure described above, with the cyclic emergency release actuation commanding the tow cable shear circuit. In addition, the fly-aways were flown using the repeatable technique determined during the un-tethered build-up. Following event completion, the tow boom was recovered from a hover by setting the tow hook on the ground and sliding laterally and descending to complete setting the tow hook and flexible link on the ground. The tow hook shear circuit and cable cutters were then inspected and de-armed prior to the next event.

Dynamic Tow

Dynamic tow of the AN/SPU-1 MOP was conducted by targeting desired steady state tensions of 2,000, 4,000 and 6,000 lbs. and towing at the resulting ground speed. Data was measured in 45° increments around the azimuth. The MOPs were towed using two 4-sided turn techniques, one oriented to the true wind azimuth and one oriented 45° from this, and one eight-sided turn technique. All dynamic tow turns were flown targeting constant tension, centered skew and were made in both the clockwise and counter-clockwise direction. Data was taken during the stable portion of each leg and during the turns. Skew angle variations were investigated into the wind at 2,000, 4,000, and 6,000-lbs. tension from centered skew to 20° left and right in 5° increments. Stabilator angle variations were investigated at constant tensions and wind azimuths. Stabilator variation effectiveness was compared by flying all test points with the stabilator in the AUTO mode and then by manually fixing the stabilator at incidence angles from full trailing edge down to full trailing edge up in 10° increments up at the same tension/skew/wind conditions. The number of MOPs connected serially was incrementally increased by flight to achieve higher tow tensions at lower groundspeeds. At the 15K dirty configuration, 1 and 2 MOPs were towed. At the 19K configuration 3, 4, and 5 MOPs were towed. Maximum steady state tow tension was demonstrated heading into the wind by building up in 1,000-lb. tension increments from 2,000 lbs. to 8,915 lbs. During each test event, data was collected on-board, via telemetry, and pilot workload assessments were made on keyboard data cards. A limited Automatic Flight Control System (AFCS) coupler evaluation was conducted by capturing a tension where pilot workload was moderate (3,000 to 4,000 lbs.), noting the groundspeed (27-30 KGS), setting that groundspeed in the AFCS speed potentiometer, and engaging the hanger coupler.

Chronology

The YCH-60 AMCM tow demonstration tasking was received on 18 March 1999. Test planning was conducted up until flight clearance approval on 17 November 1999. Phase I flight test was flown from 2 to 17 December 1999. Phase II flight test was flown from 21 December 1999 to 19 January 2000. A message report, was released on 25 February 2000. Final data reduction was completed 15 April 2000.

5. RESULTS AND EVALUATION

Aircraft Performance
Tow Power Required—The YCH-60 tow power required was evaluated throughout dynamic tow test. Power required for three aircraft weight configurations during steady tow upwind indicated that power requirements were non-linear with cable tension and with aircraft weight. The average dual-engine power required for towing at 6,000-lbs. tension and an aircraft gross weight of 18,775 lbs. was 97%. A maximum continuous torque limit of 120% torque was used for all tests.

Power Margin During AMCM Tow Operations—The YCH-60 power margins were evaluated at the aircraft mission gross weight at tow speeds up to 40 KGS and at tow tensions up to 6,000 lbs. during straight and turning towed flight under test day conditions. A minimum 20% dual-engine power margin for all tensions and flight conditions was demonstrated. Under the conditions tested, the YCH-60 demonstrated the capability to perform the AMCM tow mission with sufficient power margin to perform tow operations in more adverse (hotter and higher) ambient conditions and at increased operational aircraft gross weight. Within the scope of this test, the 20% power margin available at tow tensions up to 6,000 lbs. is satisfactory.

Safe Height for Recovery from Single Engine Failure under Tow—The safe height for recovery from single engine failure under tow was evaluated during build-up to and during four ground-tethered simulated single engine failures from 300 feet AGL, one at the 15K dirty configuration and three at the 19K configuration. Tow tensions at engine cut initiation ranged from 2,223 to 6,807 lbs. with skew centered. Due to the limitations of the simulation, the engine-out audio warning was not activated. The OEI HV testing showed repeatable recoveries from engine failure under tow were possible with less than 85-100 feet of altitude loss at tensions less than 6,000 lbs. and at power required conditions less than 110% dual-engine torque. Consistent \( N_R \) decay rates of 1-2% per second were found and single engine torque during the recovery phases ranged from 135 - 147 %. Recovery from the simulated engine failure followed the set time delay and subsequent actuation of the emergency release switch on the cyclic. The recovery required an initial pitch over from the tow attitude to 16°-18° nose-down while maintaining collective position. At approximately 50 feet of altitude loss, the aircraft nose was pitched smoothly back to the horizon while collective was adjusted to maintain \( N_R \) between 94-96 %. The final OEI event demonstrated a successful recovery with 85 feet altitude loss from a simulated engine failure under tow at 19,000 lbs. ACGW / 5,765 lbs. of tension.

The overall results of the build-up and subsequent tests underscored the criticality of a repeatable pilot technique and a minimum delay in releasing the tow cable. OEI flyaway performance was shown to be highly dependent on pilot technique and power required and less dependent on tow tension. The AMCM pilot will be able to recover from a single engine failure under zero relative wind conditions with approximately 100-ft. altitude loss.

Recommend increasing minimum tow altitude to 125 ft. AGL. Additionally, recommend investigating automatic tow cable jettison logic and circuitry for single engine failure instances to minimize the time delay between engine failure and pilot response. Further, recommend investigating current engine failure warnings to optimize AMCM tow pilot cueing to engine failure.

Flying Qualities

Pilot Workload—Pilot workload maintaining centered skew and constant tow tension was evaluated throughout dynamic tow testing. The testing included tow at constant heading upwind, downwind, crosswind, and in constant rate turns from 2°-4° per second. Workload was assessed with the hover coupler/Doppler velocity hold feature of the AFCS OFF. Skew stability in all regimes tested was positive in that it tended to return toward center when a left or right skew condition was encountered. Maintaining centered skew during upwind and downwind tow required small, occasional pedal inputs. Maintaining centered skew in turns and crosswind required small, continuous pedal inputs and resulted in moderate pilot workload. Lateral control at all tensions was precise and predictable. However, tension control at low tensions (500 to 2,500 lbs.) was difficult. Maintaining tension within 300 lbs. was difficult requiring small, continuous longitudinal control inputs, resulting in considerable pilot workload. At mid-tensions (2,500 to 5,000 lbs.), the aircraft could be easily trimmed to constant tension within 300 lbs. or constant ground speed within 2 KGS. The subsequent pilot workload was moderate. At high tensions (5,000 to 6,000 lbs.), the aircraft needed to be constantly re-trimmed. Maintaining tension within 300 lbs. at high tensions required maximum tolerable pilot workload, particularly during AMCM turns.

The AMCM pilot will be required to devote full attention to tension and skew control during tow at low and high tensions, and will be unable to navigate the tow track. The high pilot workload at low and high tensions is a deficiency, which should be corrected prior to operational evaluation.

Recommend incorporating a tow coupler in the production aircraft to include, but not limited to, velocity, tension, skew, and track hold features.

Altitude Control—Altitude control was evaluated throughout dynamic tow testing at 100 ft AGL upwind, downwind, crosswind, in turns from 2°-4°/sec, and with the radar-altitude hold feature of the AFCS both ON and OFF. The radar-altimeter system in the Seahawk series aircraft is configured with non-redundant receiver /transmitter components. With RADALT hold engaged, altitude control throughout the tension envelope required the pilot to simply monitor collective position. Conversely, a one minute long
tow with RADALT hold disengaged required full pilot
attention to altitude maintenance and RADALT hold was
subsequently re-engaged.

Within the scope of this test, altitude control with RADALT
hold engaged is satisfactory for the AMCM tow mission.
However, following a radar altimeter system failure, the
AMCM pilot will not be able to navigate the tow-track while
maintaining safe-altitude separation from the water. The
poor altitude control following a radar-altimeter system
failure is a deficiency that should be corrected prior to
operational evaluation.

Recommend incorporating increased redundancy in the
radar-altimeter system.

Control Margins— Aircraft control margins were evaluated
under static and dynamic tow and during tethered dual-
engine cable cuts simulating un-commanded cable
separation. Static and dynamic tow conditions included
upwind, downwind, and crosswind tow as well as turning
from upwind, downwind, and crosswind tow at tow tensions
up to 6,000 lbs. and tow speeds of 40 KGS (dynamic tow).
Dual engine cable cuts were performed at tensions up to
6,000 lbs. (Table 1). The aircraft demonstrated the
capability to tow up to 6,000 lbs. of tension and 40 KGS
with greater than 10% control margin remaining in all axes
during straight and level tow operations. However, during
left turns from downwind conditions (winds 15-22 KTS),
increased left pedal requirements were experienced resulting
in transient excursions within 6% left tail rotor impressed
pitch remaining.

Within the scope of this test, the greater than 10% cyclic and
tail rotor control remaining during straight and level tow
operations to 6,000 lbs. tension was satisfactory. However,
during AMCM turns from downwind conditions, the
AMCM pilot will have insufficient left tail rotor control
margin to counter higher wind conditions resulting in
reduced AMCM track navigation precision.

Recommend increasing the current tail rotor bias from 2.3°
to 3° to allow for greater tail rotor impressed pitch margin
during turns from downwind conditions. Additionally,
recommend operationally reducing tow tension to less than
5,000 lbs. when executing AMCM turns.

Tow Boom Deployed Envelope— Sikorsky Aircraft
evaluated the forward-flight tow-boom-deployed envelope
for the test tow boom configuration. Maximum airspeed with
the tow-boom deployed was established as 90 KTS indicated
airspeed in straight and level, balanced flight. Maneuvering
flight was limited to 30° angle-of-bank, left and right.
Maximum balanced flight climb rate was established as
3,000 fpm and the maximum rate-of-descent in balanced
flight was determined to be 1,500 fpm. Within the scope of
this test, the tow-boom-deployed envelope is satisfactory.

Aircraft Attitudes

Aircraft Pitch Attitude during Tow Operations— The pitch
attitude of the YCH-60 was evaluated throughout the test in
tensions up to 6,000 lbs. for straight and maneuvering towed
flight and with the stabilator in AUTO as well as at fixed
angles. Average pitch attitudes for AMCM operations
varied from level at 1,500 lbs. tension, to 5° nose down
(ND) at 3,000 lbs. tension, to 8° ND at 4,000 lbs. tension, to
10° ND at 5,000 lbs. tension, to 13° ND at 6,000 lbs.
tension. For pitch attitudes down to 10° ND, the pilot felt
no discomfort and the attitude was not noticeable. For nose
attitudes greater than 10° ND there was notable pilot
discomfort associated with the pilot leaning forward in the
seat, the pilot weight being transferred to the shoulder
straps, and the sensation of heavy foot pressure on the
pedals. Aircraft attitudes encountered during dual-centered
AMCM turns at higher tensions often exceeded 10° ND with
bank angles greater than 15°. These high-tension turn
attitudes proved disorienting and induced mild vertigo.
Fixing the stabilator at selected angles of incidence did not
provide sufficient attitude relief, either quantitatively or
qualitatively, to noticeably improve crew comfort.

The notable aircrew discomfort at nose attitudes greater than
10° ND will increase pilot fatigue and decrease crew
effectiveness while performing the AMCM mission at high
tow tensions. The uncomfortable seated position at nose
attitudes greater than 10° ND should be corrected before
operational evaluation of the AMCM system.

Recommend investigation of seat and seat cushion
modifications to relieve the pitched-forward seated position
at nose down attitudes greater than 10°. Further,
recommend a maximum tow tension of 5,000 lbs. for
AMCM turns greater than 30° of heading change.

Pitch and Roll Attitude Envelope— The steady-state pitch
and roll attitude envelope of the CH-60 was evaluated
throughout the demonstration under static and dynamic tow.
The CH-60 attitude envelope is limited by lubrication
requirements of the tail and intermediate gearboxes.
Sustained steady-state attitudes outside the envelope limits
can result in the tail and intermediate gearbox overheating
due to insufficient lubrication. Throughout the test, gearbox
temperatures were also monitored for indications of
lubrication failure. For all conditions tested in steady
and maneuvering tow, the aircraft pitch and roll remained
within the limits of the attitude envelope with the exception of
occasional transient excursions during constant high tension,
turning tow. The transient attitude envelope excursions were
not accompanied by any observable increase in gearbox
temperatures. Within the scope of these tests, the CH-60
steady state pitch and roll attitude envelope is satisfactory
for the AMCM tow mission.

5-2645
Human Factors: Situational Awareness/Crew Coordination

Situational awareness and aircrew coordination were evaluated throughout the dynamic tow test. Throughout the majority of the dynamic tow tests, the pilot at the controls was fully occupied performing flying duties and monitoring tow-parameters. The complete task saturation by basic flight tasks significantly reduced pilot situational awareness and crew coordination. When the pilot-at-the-controls attempted to communicate on the radios or aid in navigation, tow performance (cable skew and tension control) degraded. Crew coordination between the tow pilots was further degraded as the non-flying pilot was required to direct the test, communicate on two radios, maintain the primary outside lookout scan, and direct tow navigation. As a result, crew coordination was rated unacceptable. The AMCM tow pilot-at-the-controls will not be able to contribute to the interpretation of the tactical picture and aircraft systems decision-making during tow operations.

Experience from other platforms indicates that dividing tasks uniquely by crewstation or overloading one of the pilots to the point of task saturation will result in rapid performance break-down and degraded reaction time to tactical and/or aircraft emergency situations. The reduced crew coordination and situational awareness resulting from high pilot workload is a deficiency that should be corrected prior to operational evaluation.

Recommend investigating the incorporation of a tow coupler to decrease the task loading of the AMCM tow pilot-at-the-controls.

Structures

Aircraft structural parameters were evaluated throughout the demonstration. Critical parameters identified prior to test were monitored via telemetry. All other structural data were recorded on-board. Tensions to 6,000 lbs., skew from 20° left to 20° right, and stabilator angle were varied at all tested azimuths and relative winds, statically and dynamically. The aircraft was subjected to longitudinal impulse inputs during static testing to produce tension surges plus/minus 1,000 lbs. to a maximum of 5,300 lbs. An up-wind tow to a maximum tension of 8,915 lbs. was demonstrated while towing five MOPs. Surge data was also collected dynamically during the maximum tension demonstration when a MOP connection line inadvertently parted between the first and second MOP resulting in tension surges from zero to 4,500 lbs. and zero to 2,500 lbs. caused by the broaching action of the remaining MOP. No working endurance or do-not-exceed (DNE) limits were reached based on the critical structural parameters that were monitored via real-time telemetry. Final conclusions on the structure of the aircraft will be reported upon the completion of the Sikorsky Aircraft data analysis.

Within the scope of this test and based on the analysis of telemetered data, the AMCM tow mission will have no adverse impact on the replacement times of the CH-60 dynamic components.

Recommend a maximum tow tension of 6,000 lbs. for straight and level tow operations at all wind azimuths. Recommend investigating automatic tow cable jettison logic and circuitry for the instance of a cable snag, which would induce greater tension surges than aircraft design limit loads.

6. CONCLUSIONS

Within the scope of this test, the CH-60 demonstrated excellent potential for the AMCM mission by successfully towing dynamically at continuous tensions up to 6000 lbs. and ground speeds of up to 40 knots.

The capability of the YCH-60 helicopter to conduct the AMCM mission with the AQS-20X towed body was evaluated throughout the test. The expansive tow envelope defined by the aircraft structure of 6,000-lbs. tension at skew angles from 20° left to 20° right in winds from all azimuths will allow the aircraft to tow the AQS-20X to its deepest operational depth and to its maximum operational submerged speed. The generous tail rotor and cyclic control margins coupled with a 20% power margin will allow tow operations throughout the structural envelope at ground-speeds to 40 KTS. The stout capability to recover from single engine failure at aircraft weights up to 19,000-lbs. and tensions up to 6,000-lbs. in zero relative wind conditions when operating at a minimum tow altitude of 125 ft. will minimize tow operations in the single engine height-velocity diagram avoid region. The precise aircraft lateral response and positive skew stability will reduce pilot workload during manual tow operations. However, the high pilot workload maintaining constant tension at high and low tow tensions coupled with the uncomfortable seated position observed during high tension turns require the incorporation of a tow coupler to conduct routine AMCM operations. With the incorporation of a tow coupler, the YCH-60 will make a precise and lethal mine countermeasure weapon system.

REFERENCES

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BIOGRAPHIES

Lieutenant Wade McConvey, U. S. Navy is a test pilot assigned to the Naval Rotary Wing Aircraft Test Squadron (NRWATS), based at Naval Air Station Patuxent River, MD. He graduated from the U. S. Naval Academy in 1991 with a BSME. He was designated a Naval Aviator in the fall of 1993. After completing his initial operational tour with Helicopter Antisubmarine Squadron ELEVEN (HS-11) in Jacksonville, Fl. flying the SH-60F Seahawk helicopter, he was accepted into the Naval Postgraduate School - Test Pilot School (TPS) Cooperative program. He graduated from TPS with Class 116 in December 1999, earning a MSAE for completion of the Co-Op program. LT McConvey is currently the SH-60F Seahawk Platform Coordinator at NRWATS and is a developmental test pilot for a number of ongoing projects, including the SH-60R and CH-60S Seahawk programs.

Lieutenant Clay Michaels, U. S. Navy is a test pilot assigned to the Naval Rotary Wing Aircraft Test Squadron (NRWATS), based at Naval Air Station Patuxent River, MD. He graduated from Vanderbilt University in 1990 with a BEME. He received his commission through the Aviation Officer Candidate School in 1992 and was designated a Naval Aviator in 1993. After completing his initial operational tour with Helicopter Antisubmarine Squadron Light FIFTY-ONE (HSL-51) in Atsugi, Japan flying the SH-60B Seahawk helicopter, he was accepted into the Naval Postgraduate School - Test Pilot School (TPS) Cooperative program. He graduated from TPS with Class 114 in December 1998, earning a MSAE for completion of the Co-Op program. LT Michaels is currently the SH-60B Seahawk Platform Coordinator at NRWATS and is a developmental test pilot for a number of ongoing projects, including the SH-60R and CH-60S Seahawk programs.