DEPARTMENT OF THE NAVY
NAVAL AIR TEST CENTER
PATUXENT RIVER, MARYLAND 20670

DEC 1 0 1985

Dear Sir:

Paper No. 100 entitled "Dynamic Interface Flight Test and Simulation Limitations" was not published in time for distribution at the Eleventh European Rotorcraft Forum in London, England. The paper is currently being distributed to forum attendees. I regret any inconvenience this may have caused you.

Please keep in mind that the Dynamic Interface effort is an ongoing program. If any questions arise concerning the paper or the program, please don't hesitate to contact Mr. Jerry Higman, Code RW81H at the Naval Air Test Center. Further, if you are aware of any similar efforts, please contact the same code at AV 356-1336 or commercial (301) 863-1336.

Sincerely,

R. Henry
Director
Rotary Wing Aircraft Test Directorate

Encl:
(1) Paper No. 100, Dynamic Interface Flight Test and Simulation Limitations

ELEVENTH EUROPEAN ROTORCRAFT FORUM

Paper No. 100

DYNAMIC INTERFACE
FLIGHT TEST AND SIMULATION LIMITATIONS

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Naval Air Test Center
Patuxent River, Maryland, USA

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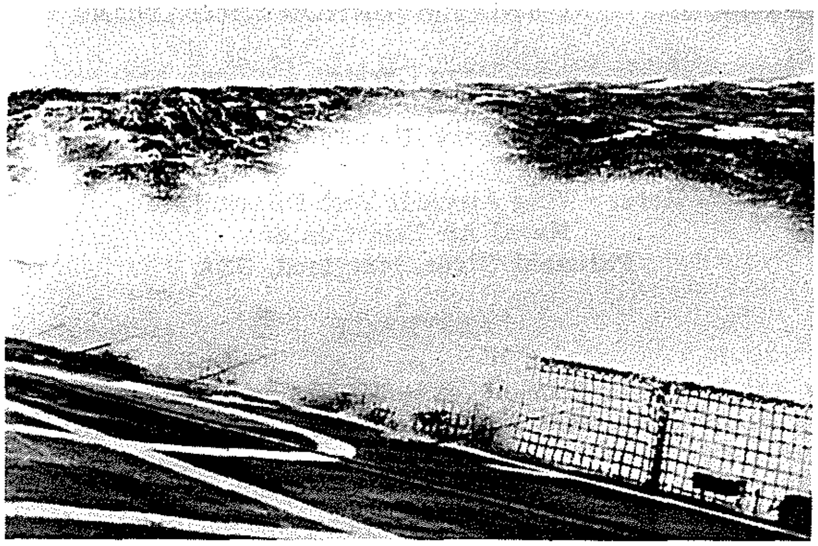
ABSTRACT

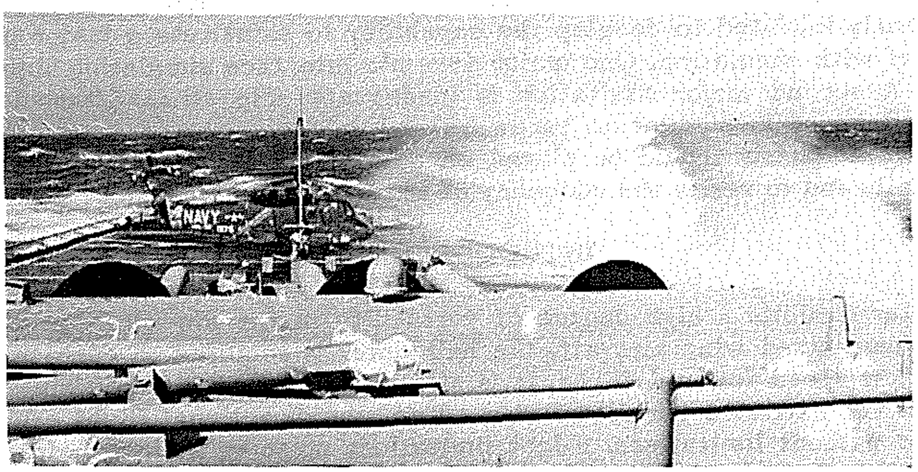
The helicopter shipboard landing or dynamic interface scenario presents a hostile environment where flight limitations are difficult to quantify. Flight test limitations are usually listed under the general categories of helicopter, ship, pilot, and environment. Environmental factors such as ship airwake turbulence, ship motion, and limited visual cues at night all contribute to high pilot workload required to perform a shipboard landing in a confined area. The Naval Air Test Center has an ongoing parallel flight test and analytical effort to define the helicopter shipboard operational envelopes. The flight test effort involves approximately 8-10 at-sea test programs per year, which is not sufficient to eliminate the current large backlog of helicopter/ship test combinations. An analytical effort was recently initiated to develop the capability to substitute a major portion of the flight test effort with simulation. One major dynamic interface simulation limitation is the visual system. A second major limitation is inadequate ship airwake/turbulence models. Current rapid advances in simulation hardware and software should soon eliminate these limitations. More emphasis should be placed on obtaining at-sea quantitative test data to define flight limits and to verify the adequacy of the simulation models.

INTRODUCTION

The helicopter exhibits a high degree of versatility in the low airspeed flight regime. Unlike conventional fixed wing aircraft, the helicopter is required to operate in rearward, sideward, and slow speed forward flight. It is also required to make hovering turns over a spot or to hover for extended periods of time. This omnidirectional flight capability of the helicopter is not without limitations. Flight limitations must be defined before the mission potential of the helicopter can be determined. Fortunately, the helicopter low speed, land-based flight limitations in calm air are well-defined and can be demonstrated by the aircraft manufacturer and/or the aircraft procuring organization as required. As the flight versatility of the helicopter results in its application to more specialized missions, the previously well-defined flight limitations become less valid. These specialized missions also bring along their own set of unique environmental conditions. The helicopter shipboard landing or dynamic interface (DI) scenario presents a hostile environment, as shown in figure 1, where the flight limitations are difficult to quantify, as discussed in reference 1. Factors such as ship airwake turbulence, ship motion, landing spot obstructions, confined landing areas, and limited visual cues at night all contribute to the high pilot workload required to perform the helicopter shipboard landing. As a result of the "can do" attitude resulting from the helicopter flight versatility, a ship may request the pilot to land the helicopter outside its envelope if constraints are placed on ship maneuvering. The maximum safe operating envelopes must be developed to make use of the full potential of the helicopter during the shipboard landing task.



FFG-8 during SH-60B DI Testing



BB-62 during SH-2F DI Testing

Figure 1
ADVERSE DI TEST CONDITIONS

BACKGROUND

The current helicopter/ship symbiosis had its beginning in 1943 when a U.S. Army pilot landed the Sikorsky XR-4 helicopter on the merchant tanker, S.S. BUNKER HILL. Early helicopter pilots were forced to adopt a "can do" attitude to demonstrate and sell the helicopter for shipboard applications. Reference 2 points out that, although the U.S. Navy considered the helicopter to have only minor applications in 1943, 10 years later no one could do without it. The shipboard applications of the early helicopters were limited by inadequate engine power to carry a specific payload or to follow a moving deck. The lack of endurance and controllability for extended hovers also limited its application to the ASW mission.

The Naval Air Test Center (NAVAIRTESTCEN) conducted a flight evaluation of the Sikorsky XHJS-1 and the Piasecki XHJP-1 (HUP) in 1949. As a result of the evaluation, the Piasecki HUP was selected primarily because of its larger center of gravity range. Flying qualities and performance (FQ&P) testing was also conducted on the model HSS-1 helicopter in 1956 and on the model HSS-1N helicopter in 1958.

Carrier suitability testing of the model HSS-2 helicopter aboard the USS LAKE CHAMPLAIN (CV-39) was conducted in 1961. It was reported that automatic blade folding/spreading reduced the flight deck personnel required to launch and recover the HSS-2 by about 50%. It was also noted that the automatic blade folding/spreading feature on one aircraft malfunctioned on 4 out of 5 flights. Takeoff, hover, landing, and waveoff characteristics of the YHSS-2 were reported as excellent in winds up to 40 kt. Some difficulty was experienced with directional control while landing in a 40 kt wind gusting to 48 kt with a relative bearing of 120 deg port; however, the landing was conducted successfully.

The DI program was established at NAVAIRTESTCEN in 1970 in response to the Light Airborne Multi-Purpose System (LAMPS) MK I program. A standard lighting configuration was developed for H-2/FF-1052 operations. By 1981, the LAMPS MK III SH-60B helicopter was being used to develop Recovery Assist, Secure, and Traverse (RAST) procedures for operations on FFG class ships.

FLIGHT TEST TECHNIQUES

BACKGROUND

The current NAVAIRTESTCEN DI flight test techniques have evolved, for the most part, over the last 15 years. Early test technique development was spurred on by the LAMPS MK I program in 1970, as described in reference 3. Ship landing decks (FF-1052) originally designed for the drone anti-submarine helicopter were used for LAMPS MK I H-2 helicopter operations. The reference 3 article discusses both visual landing aids (VLA's) testing and shipboard flight envelope testing during the initial stage of the DI program. Reference 4 reviews the early Royal Navy flight test techniques for determining the limitations in operating helicopters from small ships.

A review of the SH-2F helicopter DI testing on board the USS BOWEN (FF-1052) and USCG HAMILTON (WHEC) during the mid-1970's is discussed in references 5 and 6. Reference 5 describes the state-of-the-art in air capable ship/helicopter operations in terms of the environment, the ship, and the helicopter. Reference 6 suggests improvements in aircraft flight information presented to the pilot for the shipboard landing task. The 1980 United Kingdom helicopter-ship flight test techniques and resulting test limitations are discussed in reference 7.

The National Aerospace Laboratory of the Netherlands describe their 1979 helicopter-ship qualification test procedures in reference 8. Reference 1 discusses both the current helicopter-ship operating limits and the flight test techniques used to determine the limits at the National Aerospace Laboratory.

The current DI test techniques are outlined in reference 9. Although conventional DI flight testing has changed little over the past 15 years, a new emphasis is being placed on analytically developing the launch/recovery envelopes.

PROGRAM PLANNING

Detailed planning is required for a DI program since safety is paramount and because of the many variables involved in at-sea testing. The program elements include the ships, helicopters, weather/sea state, pilot/engineer test team, test instrumentation, and test location. A ship authorized to conduct independent steaming operations in an area of probable moderate to high winds and sea states is scheduled 3 to 6 months prior to the test. The test aircraft are subsequently identified. Fleet aircraft are normally used because tests are often conducted at a remote location from NAVAIRTESTCEN. A review is conducted of similar previous tests, including documented lessons learned and aircraft low speed FQ&P data. The project test plan and ship operations plan are then written. A presail conference is held on board the ship with key ship personnel to discuss the details of the planned tests. Prior to the at-sea testing, any special aircraft or ship instrumentation is installed and calibrated. During the at-sea testing, two 3-hour test periods (one day and one night) of flight operations are normally conducted each day until the testing is complete.

GENERAL PROCEDURES

During each launch and recovery, the test engineer stationed on the ship's bridge or in the helicopter control station is in direct communication with the pilot and recommends a specific wind-over-deck (WOD) speed. Upon concurrence from the pilot in command, the test engineer requests the Commanding Officer or the Officer of the Deck to maneuver the ship to provide the necessary WOD. All test conditions are recorded by the test engineers. Pilot comments are recorded on kneeboard cards or portable cockpit voice recorders. Selected photographic coverage is made by NAVAIRTESTCEN personnel for documentation.

LAUNCH/RECOVERY

Day, Night, Degraded Modes; Clear Deck

Tests are conducted by a gradual buildup to limit combinations of relative windspeed and direction for given values of ship motion and aircraft gross weight. The increase in pilot workload resulting from degradation of aircraft FQ&P is evaluated. The pilot assigns each takeoff and landing a qualitative rating based on the difficulties encountered while flying the data point. The Pilot Rating Scale (PRS), presented in table 1, is a four point scale where a PRS-1 or PRS-2 is satisfactory and a PRS-3 or PRS-4 is unsatisfactory. The buildup uses the following sequence:

1) The initial WOD required is 10 to 20 kt at 0 deg relative to the bow. Takeoffs and landings are conducted as the WOD is increased in increments of 5 kt to the maximum obtainable with the existing ambient conditions or until an unacceptable pilot rating (PRS-3 or PRS-4) is assigned. If an unsatisfactory rating is assigned, the point is reflown and the reason for the limit documented. The WOD speed is then reduced in 5 kt increments until a satisfactory rating is obtained.

2) The WOD direction relative to the bow is then changed to port or starboard in 15 deg increments while maintaining a constant windspeed or achieving the maximum windspeed available at the azimuth. For example, if a landing is graded satisfactory (PRS-1 or PRS-2) with the wind at 030 deg and 30 kt, as shown in figure 2, the next point would be 045 deg and 30 kt or the maximum velocity that is attainable (if not 30 kt) with existing ambient conditions. A takeoff and landing is then made at this condition. If an unacceptable pilot rating (PRS-3 or PRS-4) is attained, additional landings and takeoffs will be conducted as the WOD speed is reduced in 5 kt increments until an acceptable pilot rating is achieved. This procedure is continued, as illustrated in figure 2, until the maximum safe launch/recovery envelopes are developed for day and night operations. Degraded mode testing is conducted with the aircraft automatic flight control system off during the approach and landing.

Table 1

PILOT RATING SCALES FOR HELICOPTER SHIPBOARD LANDINGS
Dynamic Interface Pilot Rating Scale

PRS No.	Pilot Effort	Description
1	Slight	No problems; minimal pilot effort required.
2	Moderate	Consistently safe launch and recovery operations under these conditions. These points define the fleet limits recommended by NAVAIRTESTCEN.
3	Maximum	Landings and takeoffs successfully conducted through maximum effort of experienced test pilots under controlled conditions. These evolutions could not be consistently repeated by fleet pilots under operational conditions. Loss of aircraft or ship system is likely to raise pilot effort beyond capabilities of average fleet pilot.
4	Unsatisfactory	Pilot effort and/or controllability reach critical levels, and repeated safe landings and takeoffs by experienced test pilots are not probable, even under controlled test conditions.

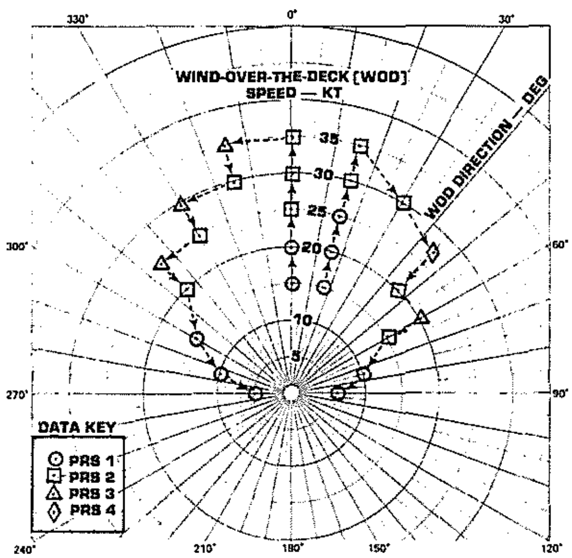


Figure 2A
TYPICAL LAUNCH/RECOVERY
ENVELOPE DEVELOPMENT

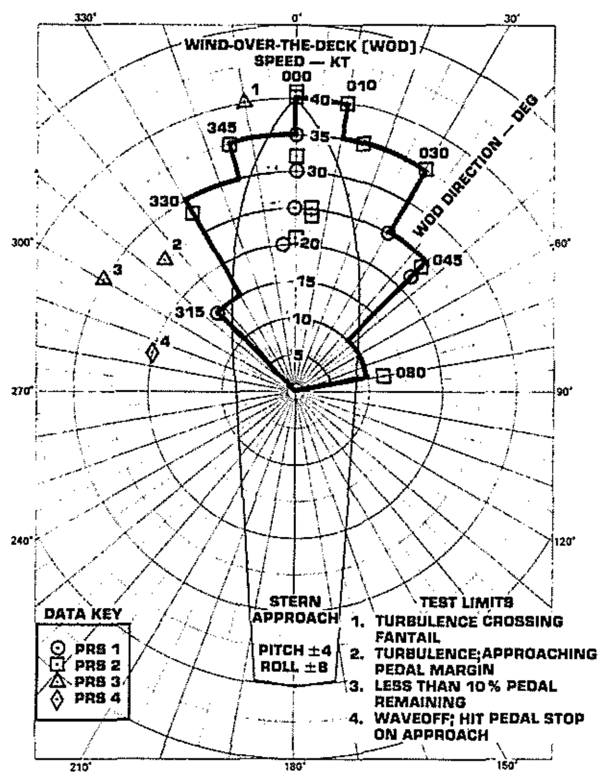


Figure 2B
SH-2F/CG-47 NIGHT
LAUNCH/RECOVERY DATA FAIRING
FORE-AND-AFT LANDING
ASE/BOOST ON

Recovery Assist, Secure, and Traverse

RAST systems are used to extend the helicopter/ship operational capability by enabling the aircraft to operate during sea state conditions resulting in ship motion too great for normal clear deck landings. The RAST system provides automatic hauldown/securing, powered traversing between the flight deck and hangar, and mechanical positioning for takeoffs. Free deck landings (without the RAST cable) can also be made into the rapid securing device.

Initial shore-based flight tests are conducted to evaluate the aircraft flying qualities, RAST system performance, and piloting techniques associated with each phase of the RAST recovery, secure, and deck handling operation. Hover trim control positions are determined for varying cable tension and hover height. The effect of cable release on the aircraft's flying qualities under different tensions and offsets is evaluated. Step inputs in cable tension are made from the minimum to the maximum selectable tension for both center and offset conditions. The aircraft response to step control inputs in each flight control axis is evaluated for a selected cable tension. Tethered landings are evaluated for both centered and offset cable conditions by increasing the cable tension in steps. Landings are then accomplished by selecting constant cable tensions. Finally, the effects of VLA's and selected degraded modes (aircraft flight control systems, etc.) are evaluated. The same tests are conducted at sea, plus additional tests to determine operational problems.

ROTOR ENGAGE/DISENGAGE

The helicopter rotor engage and disengage envelopes are determined by a minimum rotor blade-to-airframe clearance or by qualitative evaluation factors. The rotor blade-to-airframe clearance is currently determined by the use of a series of frangible styrofoam pegs of various lengths mounted in the blade tip arc. If, during a critical engage/disengage condition, the rotor blade contacts one or more of the pegs, the remaining pegs will indicate the blade-to-airframe clearance. The rotor engage and disengage envelopes are developed in the same manner as the launch/recovery envelopes, based on a blade clearance scale (BCS) instead of the PRS. A photograph of the frangible styrofoam pegs installation, including a protective board to deflect the rotor blade, is shown in figure 3. The BCS is presented in table 2.

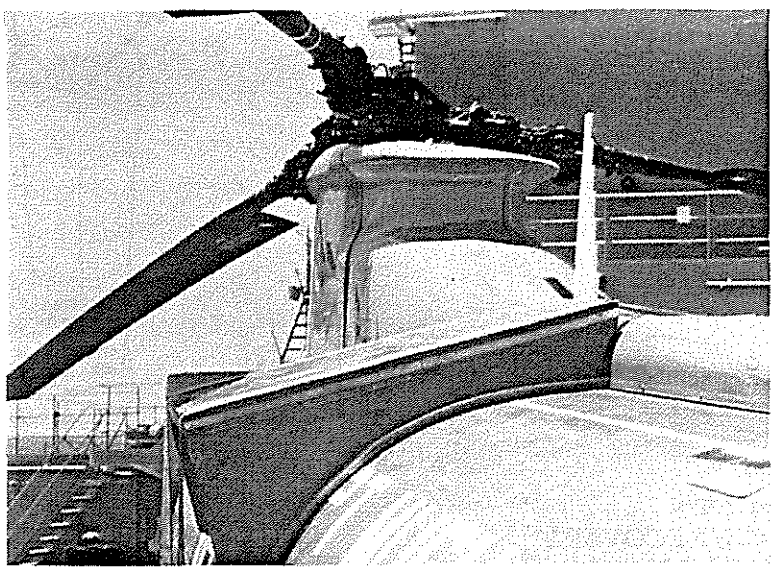


Figure 3
"GREASY BOARD" PROTECTIVE DEVICE WITH STYROFOAM PEGS

Table 2

BLADE CLEARANCE SCALE

BCS No.	Pegs Remaining	Blade Clearance	Data Symbol
1	7	23 in.	⊙
2	2-6	8-23 in.	⊡
3	1	5-8 in.	◬
4	0	0-5 in.	◈

SHIPBOARD CLEARANCE REQUIREMENTS

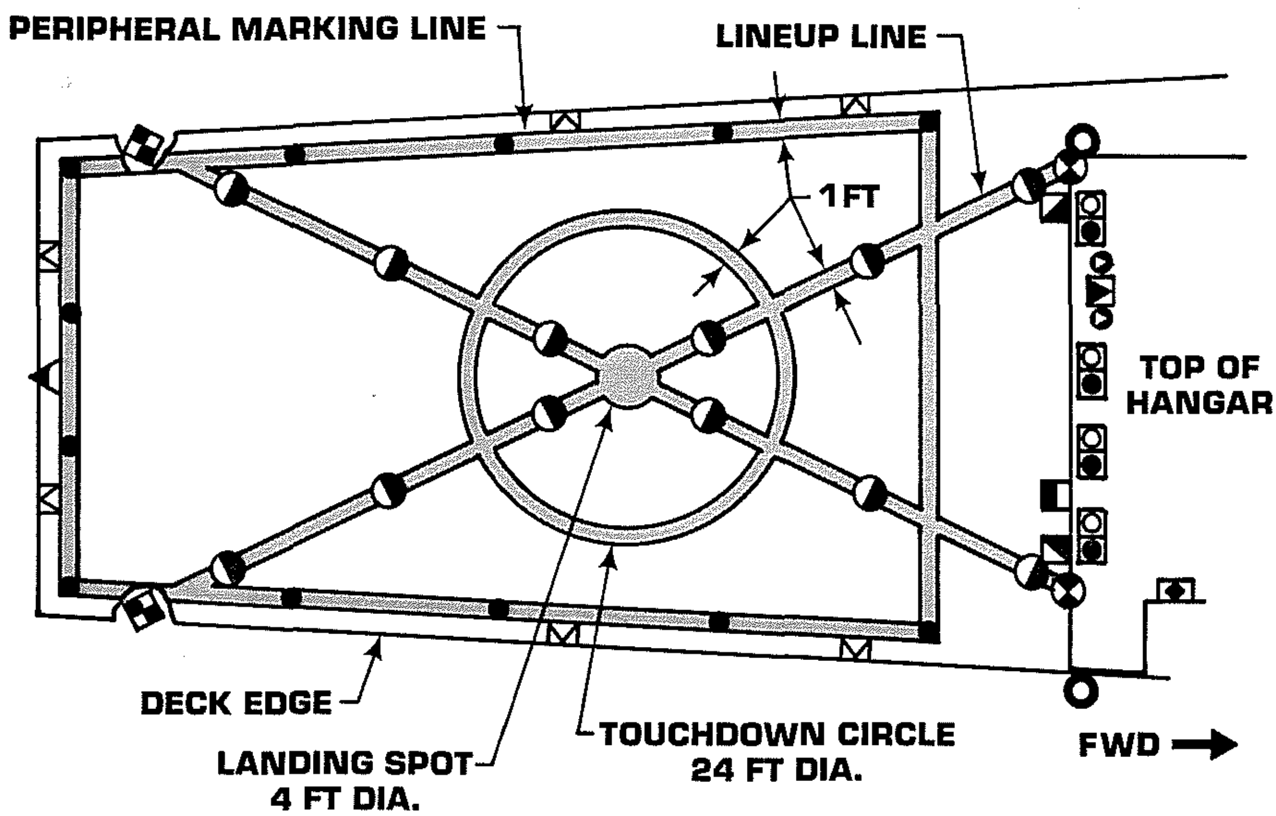
Adequate clearance between helicopter rotor, fuselage, and landing gear and shipboard obstructions is required for the aircraft to safely land on and operate from air capable ships. Clearance restrictions imposed beyond those actually required may be detrimental to other ship operational requirements. Inadequate clearances may unnecessarily jeopardize personnel, aircraft, and ship. Confirmation of existing criteria or establishment of new criteria may impact existing and future ship designs and operational procedures. Clearances are qualitatively evaluated by the pilots and engineers throughout the DI evaluation and recorded by video and movie cameras.

VISUAL LANDING AIDS

VLA's are required to minimize the helicopter/ship operating limitations resulting from night or low visibility conditions. Reference 3 points out that VLA's on aviation capable ships must contribute visual cues to the solution of the following problem areas:

1) Ship identification and orientation.
2) Ship speed and direction.
3) Aircraft approach course and glidepath.
4) Ship landing area and obstruction identification.
5) Aircraft lineup and closure rate.
6) Ship motion and relative wind.
7) Aircraft hover position and landing rate-of-descent.
8) Ship signals for emergency conditions (waveoff, etc.).

VLA testing varies from evaluating effects of different color filters (red, white, and yellow) for specific lights to evaluating complete lighting configurations. Initial mission-related shore-based tests are conducted to optimize the light color, number of lights, location of lights, light intensity, etc. This minimizes the variables required for follow-on at-sea testing. Qualitative comments, pilot ratings, and, when possible, movie coverage from cockpit cameras are used in the evaluation. The standard lighting configuration developed for the LAMPS MK I program is shown in figure 4.



SYMBOL	NOMENCLATURE
	EDGE LIGHTS (RED)
	LINEUP LIGHTS (WHITE), DECK INSTALLED, UNIDIRECTIONAL
	FORWARD EXTENDED LINEUP LIGHTS (WHITE)
	AFT EXTENDED LINEUP LIGHTS (RED)
	FLASH SEQUENCER
	OBSTRUCTION LIGHTS (BLUE)
	OVERHEAD FLOODLIGHTS (YELLOW)
	OVERHEAD FLOODLIGHTS (WHITE)
	DECK SURFACE FLOODLIGHTS (RED OR WHITE)
	HANGAR WASH FLOODLIGHTS (RED OR WHITE)
	MAINTENANCE FLOODLIGHT (YELLOW)
	CLEAR/FOUL DECK INDICATOR (RED, AMBER, GREEN)
	STABILIZED GLIDESLOPE INDICATOR (RED, AMBER, GREEN)
	WAVEOFF LIGHTS (RED)

Figure 4
VLA DIAGRAM

VERTICAL REPLENISHMENT

Vertical replenishment (VERTREP) consists of using the helicopter to transfer various stores and commodities from one ship to another, from shore to ship, or from ship to shore. An initial study of the load and a review of previous reports will give the test team a good idea of what to expect during flight. The size, shape, weight, type of hookup, and flight conditions will influence the load dynamics. The natural frequencies of the sling load should also be analyzed prior to flight.

Initial shore-based tests of the external loads are required. A buildup approach to the flight limits and a chase helicopter are required for all external load testing. After shore-based testing is completed, the recommended envelopes are then evaluated in the at-sea environment for the VERTREP mission.

HELICOPTER IN-FLIGHT REFUELING

Helicopter in-flight refueling (HIFR) is accomplished with the aircraft hovering 10 to 15 ft above the flight deck spot designated by an "H" (port aft corner of flight deck). Test procedures for establishing the HIFR envelope are similar to those used to develop a launch/recovery envelope, except the scope of the testing is less. Emphasis is placed on determining the optimum aircraft position (approach, hover, and departure) to accomplish the HIFR. HIFR limitations may result from ship airwake turbulence or obstructions as reflected in pilot workload/performance.

FLIGHT TEST LIMITATIONS

GENERAL

DI flight test limitations fall under four general categories as discussed in references 1, 8, and 9. These categories include:

1) Aircraft.
2) Ship.
3) Environment.
4) Pilot.

Since 1950, NAVAIRTESTCEN has published approximately 100 reports on DI testing. A program is currently underway to implement the flight test helicopter/shipboard limitations listed in these reports as part of a computerized data base. This section of the paper presents the preliminary results of that study.

AIRCRAFT

The U.S. Navy/Marine Corps rotorcraft and ships involved in current or projected DI testing are listed in table 3. The diversity of the helicopter configurations is summarized below:

Helicopter Characteristic	Variation		
Maximum Takeoff Weight:	2,900 lb	→	70,000 lb
Rotor System:	Teetering	→	Multibladed, articulated
Rotor Diameter:	33 ft 4 in.	→	79 ft
Landing Gear:	Skid	→	Wheel
Control System:	Mechanical bar	→	Multimode digital system

Table 3

SCOPE OF THE DI TEST REQUIREMENTS

Aircraft	Ships
CH-46	LPH
UH-1N	LHA
AH-1T(TOW)	DD-963
AH-1J	DDG-993
H-2	FFG-7
H-3	CG-47
SH-60B	CGN-38
CH-53D	LPD
CH-53E	CG-21
TH-57	BB-61
JVX	DDG-37
	CGN-25
	CGN-9
	LSD
	AFS-1
	AE-26
	AOE-1
	AOR
	AST
	CV

These aircraft must demonstrate satisfactory flying qualities and performance (FQ&P) characteristics, including low speed ground based, FQ&P in calm air to sideward flight limits of 30-35 kt, and to rearward flight limits of 25-30 kt. The sideward flight limit airspeeds are rarely attained in defining the launch/recovery envelope of the helicopter in the turbulent environment of a small ship. Specific helicopter limitations may include basic design configuration parameters (size, landing gear design, field-of-view (FOV), blade/fuselage clearance, turnover roll angle, etc.) or the resulting FQ&P limitations (inadequate control remaining, insufficient power available, excessive pilot workload, excessive vibration, etc.). A sample of the helicopter-related limitations found during the DI data base review are summarized in table 5.

SHIP

Helicopter DI operating envelopes are required for CV/CVN aviation ships, LPH/LHA amphibious aviation ships, and all other air capable ships that maintain aviation facilities (DD, FF, etc.). Static interface paper studies are first conducted to ensure the helicopter will safely fit on the ship landing deck. For each aircraft, the ships are certified to a level indicative of the meteorological conditions under which the aircraft must operate (day, night, VMC, IMC, etc.). The ships are also certified to a class indicative of the aircraft support facilities provided by the ships. The level and class of helicopter/ship operations are defined in reference 10 and summarized in table 4. Helicopter/ship clearance criteria is specified in reference 11 and summarized in figure 5. The ship DI limitations are primarily a function of their landing deck size, deck clearance, deck markings, VLA, ship motion, ship turbulence, and the aircraft support facilities available. A sample of the ship-related limitations found during the DI data base review are summarized in table 6.

Table 4

ENVIRONMENTAL CONDITIONS FOR SPECIFIC LEVELS OF OPERATION

Level I	-	Instrument Meteorological Conditions Day/Night
Level II	-	Visual Meteorological Conditions Day/Night
Level III	-	Visual Meteorological Conditions Day Only

BASIC TYPES OF SHIPBOARD AIRCRAFT FACILITIES

Class 1	-	Land, Service, Maintains
Class 2	-	Land and Service
Class 3	-	Land Only
Class 4	-	Vertical Replenishment (VERTREP)/Hover Area
Class 5	-	VERTREP/High Hover Area
Class 6	-	Helicopter In-Flight Refueling (HIFR)

SYMBOL	OBSTRUCTION CRITERIA
A	6 FT MAXIMUM
B	26 IN. MAXIMUM (18 IN. FOR NEW SHIPS)
C	2 FT 6 IN. TO 5 FT MAXIMUM (DEPENDS ON HELICOPTER)
D	6 IN. MAXIMUM AT PERIPHERAL MARKING
E	4.5 IN. MAXIMUM PERMITTED (NOT DESIRABLE)
F	CLEAR DECK
G	VARIES WITH ROTOR DIAMETER H-2: 33 FT
H	1.5 ROTOR DIAMETERS
I	3 ROTOR DIAMETERS

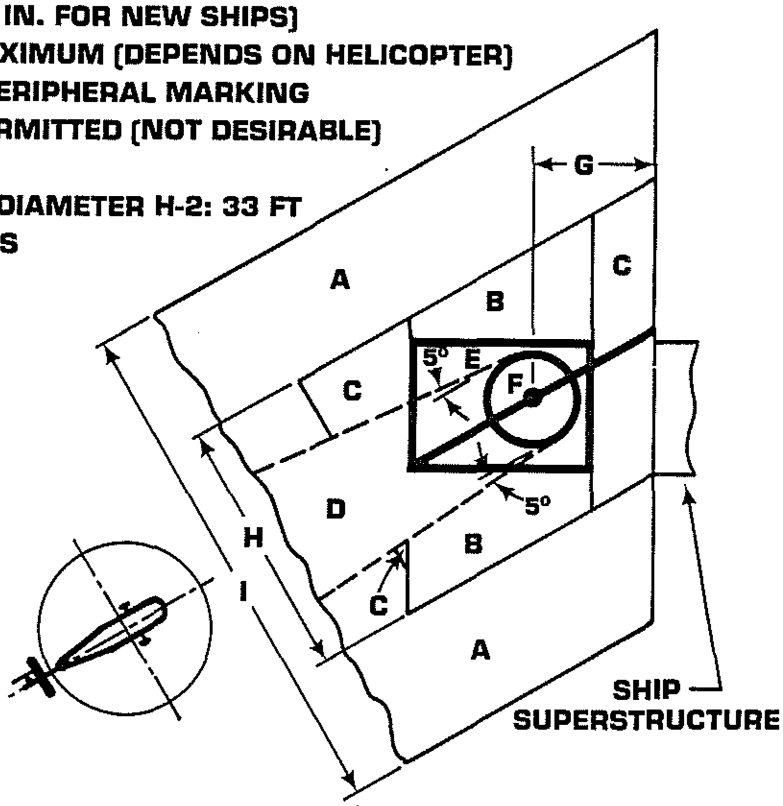


Figure 5
CLEARANCE CRITERIA

Table 5

SAMPLE HELICOPTER DI LIMITATIONS

A. Aircraft Configuration

Year/Helo	Ship	Limitation or Enhancing Characteristic
1961/YHSS-2	CVS-39	Unsatisfactory method of tail pylon fold. Malfunction of automatic rotor blade folding/spreading function.
1964/UH-46A	AFS-1 AKS-32	Cargo hook not satisfactory for multiple loads.
1966/CH-53A	LPH-7 LPD-4	FOV inadequate during shipboard approach. Noseup hover attitude (8 deg) for aft CG.
1968/RH-3A (VERTREP Evaluation)	AE-23 AE-58	Inadequate provision for emergency external load release. Poor cockpit FOV. Unreliable radar altimeter operation while carrying external load, same problem UH-2C, no problem with CH-46D.
1974/SH-2F	DE-1052	Inability to vertically adjust left cockpit seat restricts copilot's FOV. Moving tailwheel forward 6 ft was an enhancing characteristic.

B. Stability and Control

Year/Helo	Ship	Limitation or Enhancing Characteristic
1970/BHT-211	AFS-4	Inadequate roll and yaw rate damping in hover. Unsatisfactory directional controllability in sideward flight. Excellent performance characteristic.
1973/SH-2F	DLG-34	Directional control response characteristics and longitudinal bobweight cutout (<40 kt) was enhancing.
1968/UH-2C (VERTREP Evaluation)	AE-23 AF-58	Lack of adequate left directional control power and control effectiveness. Poor IGE flying qualities. Inadequate right directional control effectiveness.
1968/CH-46D (VERTREP Evaluation)	AE-23 AF-58	Excellent external load capability. Excellent flight control margins.
1968/RH-3A	AE-23 AF-58	Inadequate directional control power.
1975/SH-3H	CG-11	Insufficient directional control margin in right crosswinds for aircraft not having improved tail pylon and drive shaft group.
1979/SH-3H	CV-43	Remove tail rotor buzz warning for aircraft having improved tail pylon and drive shaft group.

C. Helicopter Performance

Year/Helo	Ship	Limitation or Enhancing Characteristic
1968/UH-2C (VERTREP Evaluation)	AE-23 AE-58	Had to tradeoff fuel to increase load capability.

Table 6

SAMPLE DI DATA BASE SHIP LIMITATIONS

A. Ship Configuration

Year/Helo	Ship	Limitation or Enhancing Characteristic
1964/UH-46A	AFS-1 AKS-32	Small size of elevators. Deficiencies in ship helicopter support equipment.
1966/RH-3A	MCS-2	Marginal clearance provided with helicopter on elevator. Deficiencies in helicopter support requirements.
1976/SH-2F	SSP	Limited size of deck restricted operations.

B. Ship Clearance

Year/Helo	Ship	Limitation or Enhancing Characteristic
1971/HH-2D	DE-1059	Deck obstructions in approach path. Inadequate landing area clearance. Undesirable proximity of aft HF antenna on hangar to the takeoff and waveoff flightpaths.

C. Ship Motion

Year/Helo	Ship	Limitation or Enhancing Characteristic
1966/CH-53A	LPH-7	VERTREP operations should not be conducted when sea states create a pitching deck.
1971/SH-2D	DLG-28	With ship roll greater than 13 deg the landing time nearly doubled.
1972/SH-2D	DE-1078 DE-1066	Roll period of the DE-1052 class destroyer escort was about 2/3 that of the DLG-26 in the same sea state and resulted in an increased pilot workload.

D. Ship VLA

Year/Helo	Ship	Limitation or Enhancing Characteristic
1973/HH-2D	DLG(N)-35	White lighting produced significantly larger DI envelopes than red lighting. GSI significantly increased the DI envelopes.
1973/SH-2D	DE-1066	Both red and white water illumination lights induced pilot vertigo. The all-white lighting system provided more effective deck and obstruction definition and less degradation of night vision than red lighting.
1974/H-53 H-46 H-1	LPH-7	Night DI test pointed out increased difficulty in night operations aboard LPH class ship compared to similar operations aboard LAMPS type ships.
1975/HH-3F	WHEC-715	Inadequate flight deck lighting prohibited night operations.

ENVIRONMENT

One of the most serious limitations of DI at-sea testing is the environment, specifically the lack of adequate ambient wind to establish flight limits. Sea state and resulting ship motion, ship airwake/turbulence, and other adverse weather conditions, as shown in figure 1, can produce launch/recovery limitations. Visibility restrictions can preclude the routine use of the ship's VLA's. A sample of environment-related limitations found during the DI data base review are summarized in table 7.

Table 7

SAMPLE DI DATA BASE ENVIRONMENT LIMITATIONS

A. Ship Airwake Environment

Year/Helo	Ship	Limitation or Enhancing Characteristic
1968/CH-46D	AE-23 AE-58	Power requirements occasionally increased by a factor of 15-20% during operating in the environment of the superstructure turbulence and stack gas.
1971/HH-2D	DE-1041	Excessive pilot effort required to hover in turbulent air over confined area of landing platform.
1984/HH-46A	CV-64	Data obtained during rotor engage/disengage testing limited due to unknown flight deck airwake variables.

PILOT

The DI pilots have extensive operational background in specific helicopter/ship combinations. The operational training is supplemented by comprehensive flight test and evaluation training at the U.S. Navy Test Pilot School. As a result of DI test constraints, each qualitative data point can usually be evaluated by only one pilot. Consistent use of a rating scale reflecting the workload of the "average fleet pilot" is essential. The test pilots are thoroughly trained in the use of the Cooper-Harper Handling Qualities Rating (HQR) scale. The DI PRS is a condensation of the HQR scale. The recommended DI launch/recovery envelope limits are based on a PRS-1 or PRS-2. Flight limits are based by a PRS-3 or PRS-4. A similar pilot rating scale used by the Royal Navy is presented in reference 7. Reference 8 shows a nonadjective 10 point scale that has been used to evaluate shipboard landings. Pilot limitations depend on skill level, experience level, aircraft flight characteristics, ship landing deck, and environmental conditions. Helicopter, ship, and environmental factors can combine to produce pilot workload/performance limitations.

ANALYTICAL APPROACH

The NAVAIRTESTCEN program involves defining the operating limitations of approximately one dozen types of U.S. Navy/Marine Corps rotorcraft operating from approximately two dozen different classes of ships. U.S. Army, Air Force, or Coast Guard requirements add to this large test matrix. A Memorandum-of-Agreement (MOA) assigned NAVAIRTESTCEN as the lead Naval Air Systems Command field activity for DI testing in September 1983. The MOA transferred the authority for the planning, coordination, and execution of DI efforts to NAVAIRTESTCEN. A new approach to DI testing was formulated to help eliminate the large test backlog. This approach consisted of a parallel flight test and analytical effort emphasizing flight testing in the near term and emphasizing analytical studies and simulation in the long term.

A record number of 13 at-sea tests were conducted in 1983. The long term effort of acquiring mathematical simulation models and obtaining verification flight test data has just begun. The rapidly improving state-of-the-art in helicopter simulator visual systems, environmental models, and verification techniques will soon permit a portion of the helicopter/ship DI testing to be conducted by simulation.

STATUS OF SHIPBOARD LANDING SIMULATION

BACKGROUND

The first helicopter flight training simulator to be evaluated and documented by a test pilot/flight test engineer team was the SH-2F Weapons Systems Trainer (WST) (Device 2F106). The fidelity of the WST was very good in most areas, as documented in reference 12 in 1975, but shipboard landing training was not recommended. The primary problems were associated with the visual system and the helicopter/ship environmental models as discussed in reference 13.

In 1981, an effort was initiated under the Navy Vertical Takeoff and Landing (NAVTOLAND) program to develop prototype manual shipboard approach and landing flight control systems and display concepts for the H-2 helicopter. The NASA Ames Vertical Motion Simulator (VMS), equipped with a four-window computer-generated image (CGI) visual system, was used in 1982 to simulate the SH-2F landing on a DD-963 class destroyer (reference 14). The test variables included the helicopter flight control system mode, the display mode (heads up display (HUD) or helmet mounted display (HMD)), and windspeed/ship speed. Pilots commented that, in the simulator, the lookdown angle through the forward window was less than in the SH-2F with the seat raised. The reduced lookdown angle did not permit the pilot to see the forward edge of the landing circle on the ship deck. Lack of texture on the ship deck, hangar wall, and sea surface forced the pilots to rely heavily on the HUD/HMD information. In fact, one test pilot commented that the information presented on the HUD was "worth about 2 HQR points" improvement for the shipboard landing tasks evaluated. The ship airwake/turbulence model was graded by the pilots to be excessive in both magnitude and frequency. Reference 14 recommended further improvement and validation of the ship airwake model.

Recently, a joint Army/Navy program to update the helicopter flying qualities specification, MIL-H-8501A, has generated a renewed interest in helicopter research. This effort is essential to buildup the data base required for the specification revision. One area benefiting from the research has been the helicopter shipboard landing simulation. Under the primary sponsorship of the Naval Air Development Center, helicopter shipboard landing simulations were conducted with the NASA Ames VMS during 1984 and 1985. The simulation setup was similar to the previous NAVTOLAND program except an SH-60B helicopter model, vice the SH-2F helicopter model, was used to study optimum control laws for shipboard landings. The initial pilot comments indicate that the major limitation in the simulation was the poor visual cues, especially when trying to determine closure rate and position information close-in and over the ship's flight deck. If the simulation had concentrated on determining launch/recovery envelopes, another major problem would have been the ship airwake model. At first glance, it would appear that no progress has been made in the helicopter shipboard landing simulation since 1975. A closer examination reveals significant progress in all aspects of helicopter simulation; however, more emphasis should be placed on visual system and environmental model development for the helicopter shipboard landing task.

SHIPBOARD LANDING SIMULATION LIMITATIONS

The U.S. Navy/Marine Corps currently has operational flight trainers (OFT's) to simulate shipboard landing procedures for the CH-46E, CH-53D, CH-53E, and SH-60B helicopters. In addition, shipboard landing research studies are conducted on the NASA Ames VMS and the Naval Training Equipment Center Vertical Takeoff and Landing (VTOL) Simulator. Information is needed on how effective the OFT's are in preparing pilots to perform the actual shipboard landing task and how effective both the OFT's and research simulators would be in developing helicopter launch/recovery envelopes. Questionnaires are used to get fleet feedback on how effective the OFT's are in preparing pilots to perform the shipboard landing task. Test pilots and engineers are used to determine the potential of OFT's and research simulators for use in developing helicopter launch recovery envelopes.

The simulator limitations are usually listed in terms of the visual system, math model, environmental models, motion system, aural system, and cockpit layout. The following discussion of limitations is based on the initial fleet response to questionnaires on Device 2F121 (CH-53D) and Device 2F135 (SH-60B) and qualitative test pilots evaluation comment on the VMS, the VTOL Simulator, and Device 2F135. Simulator configurations are summarized in reference 15.

VISUAL SYSTEMS

The visual system was consistently listed as the biggest limitation for the helicopter shipboard landing task. The problems included lack of scene detail, inadequate FOV, and excessive delays in visual system response. The shape of the simulated ships were reported as accurate and, at a distance, representative of the actual ship. The ship size increased as the aircraft approached, but the scene detail did not improve.

The ocean had the appearance of being absolutely smooth, providing no texture or color tone variations. Most visual presentations had additional ocean surface detail in the form of "ice floes" or cloud shadows. This additional detail provided cues of the ship's translational motion, but did not provide cues for anticipating ship motion from wave action. Although the ship motion was fairly realistic, it was difficult to analyze from the visual scene.

As the aircraft approached the simulated ship, the speed of the aircraft relative to the ship was difficult to determine. Many items on real ships such as light fixtures, pipes, storage cabinets, welds, rivets, padeyes, etc., were not present in the simulation. The fleet pilots evaluating the visual system of Device 2F120 (CH-53D) consistently complained about the lack of depth perception in performing an approach to the ship.

The lack of detail and texture caused problems while hovering over the landing spot and when landing. Ship pitch, roll, and heave rates became more difficult to determine as the aircraft moved closer to the hangar face because of fewer visual cues. As the grey hangar face completely filled the simulator FOV, all rate of closure cues were eliminated.

The FOV available in multiple window simulators falls short of providing the pilot with the visual information available in the real helicopter for critical helicopter flight tasks (reference 16). For the shipboard landing task, the lookdown capability on the pilot quarter and side window areas is usually resticted. When hovering the helicopter over the landing spot with the VMS (SH-60B/DD-963), the only visual cues available were one edge of the hangar, a small portion of the horizon to the left, and the foward part of the lineup line. A landing spot along the approach path, but short of the landing area, was chosen to make hovering and landing predictable and repeatable for purposes of evaluating each landing. This provided more visual cues, such as part of the landing circle, the other lineup line, more deck edge, and more horizon reference to the left and some to the right.

The FOV for the shipboard landing task should also include the rotor tip path plane to evaluate clearance criteria and provide additional information to the pilot when hovering close to the ship, hovering over the landing spot, and landing.

For closed-looped tasks such as shipboard landings, the visual system must not introduce response lags that are perceptible to the pilot. The visual system lag in early operational flight trainers was listed as a major problem as discussed in reference 12. Recent test pilot qualitative evaluations of SH-60B shipboard landings on the VMS and Device 2F135 point out perceptible visual lags in Device 2F135 when compared to the VMS. The VMS Singer-Link CGI visual system has a visual system lag (host computer to visual response) of only approximately 100 msec (reference 17).

In addition, cue synchronization of the visual system, flight instruments, and motion system is required as discussed in reference 15. The lack of cue synchronization is suspected as being a possible reason for simulator sickness experienced by high flight time pilots.

MATH MODELS

The DI test helicopters must be modeled so that at-sea limitations such as inadequate pedal or lateral cyclic margin, excessive pilot workload, excessive vibrations, inadequate power, and excessive attitudes can be duplicated in simulators. These limitations must be duplicated for the basic helicopter and for the automatic flight control system and/or hydraulic boost system off (degraded mode). The fidelity of the simulator math models must be verified periodically with flight test data during the techniques described in reference 18.

Limited fleet feedback on the RH-53D OFT indicated most pilots felt the math model was too sensitive at low airspeeds. From the questionnaire, it was not possible to determine whether the complaints were caused by sensitivity/damping problems or system lags.

ENVIRONMENTAL MODELS

DI at-sea test limitations are influenced heavily by the environment. This includes the WOD speed, direction, turbulence, ship motion, and visibility. Ship airwake/turbulence modeling has received little support in the past compared to the effort focused on modeling the aircraft. As a result the current models are all limited and none have been systematically verified by test data. These models, often based on early wind tunnel data and pilot qualitative comments, may be adequate for pilot familiarization training or generic studies requiring data on a relative scale. Determination of DI launch/recovery envelope requires high fidelity airwake data/models for each class of ships. Additional emphasis must be placed on acquisition of test data and verification of ship airwake turbulence models used in helicopter DI simulation.

Ship motion models usually consist of a series of summed sine waves. The pilot's perception of improved ship motion models may require improved visual systems that show the sea state which is responsible for the ship motion.

MOTION SYSTEMS

SH-60B shipboard landings were accomplished with simulators with motion systems ranging from the large travel of the NASA Ames VMS to the NTEC fixed-based VTOL simulator (g-seat) and the standard motion platform of Device 2F135. The VMS received the highest ratings for the shipboard landing task, most notably in the simulation of vertical acceleration and sideslip. The VMS motion onset cues, steady cues, motion washout, and vibration, including translational lift, were rated as good.

After flying the VMS, one test pilot felt that the maximum vertical movement of the Device 2F135 standard platform was insufficient to provide adequate motion or "g" cues. The pilot tended to compensate for the insufficient vertical cues by introducing larger than necessary collective inputs which produced a tendency for pilot induced oscillations (PIO's) during the approach and hover. The PIO tendency could be prevented during the approach if the pilot used small collective inputs and cross-checked the vertical speed indicator. During the hover, the pilot could prevent the PIO by initially selecting a large collective input to initiate vertical movement, then removing most of the collective input. The math model heave axis sensitivity/damping and visual system lags of each simulator were not compared quantitatively.

The NTEC VTOL simulator gravity seat did provide motion cues, but they were not representative of the SH-60B helicopter motion. The gravity seat gave indications to the pilot that the "g" force on the helicopter had changed. Its best cues were during rapid "g" changes such as turbulence.

AURAL SYSTEMS

Sound systems present important piloting cues for helicopter mission tasks that involve large power or flightpath changes especially when the pilot is flying with his "head-out-of-the cockpit." All simulators evaluated had some type of noise which was typical of the helicopter in steady flight. Pilot comments differed on the effects of the simulated noise. Variation in engine noise and RPM are perceptible in the SH-60B, particularly with power changes greater than 20% torque. Fuselage wind noise above 50 kt airspeed is also apparent in the SH-60B helicopter. An accurate noise simulation is required for the shipboard landing task since the pilot is required to fly with his "head-out-of-the-cockpit" on the final approach and may make large power changes during the hover and landing.

COCKPIT LAYOUT

The cockpit layout for the OFT's are usually an exact duplicate of the aircraft cockpit and can be used for engine/rotor turnup and shutdown and other procedures type training. Research cockpits tend to be more generic and can be used, with small adjustments, for various type programs. The cockpit layout becomes important when the FOV is a factor or when cross cockpit flying is required.

The cockpit flight control system mechanical characteristics must be verified on a regular basis to avoid pilot perceived simulator flying qualities limitations. It is also important that the correct control functions be available in cockpits used for flying qualities and performance-related experiments. In the reference 14 NAVTOLAND experiment, the pilots objected to the opposite polarity of the simulated HUD roll index compared to the real aircraft. The VMS/SH-60 cockpit layout during the shipboard landing simulation represented the V-22 rotorcraft. This was judged to have little effect on the shipboard landing experiment because the task did not require the pilot to refer to cockpit instrumentation.

FUTURE SIMULATION REQUIREMENTS

Helicopter launch/recovery limitation definition involves high risk at-sea DI flight testing. The ambient environment test conditions such as wind and sea state are difficult to control. Test assets including ships and aircraft are also difficult to schedule. It is not possible to eliminate the current large helicopter/ship test backlog in the foreseeable future by only conducting at-sea testing.

Simulation promises to be good supplement to the flight test effort. It will conveniently permit pilot familiarization training and ground based low speed buildup testing. It will permit the safe development of test techniques for most aspects of DI testing, including VLA evaluations. A specific parameter effect, such as ship motion, could also be isolated and evaluated. However, the current state-of-the-art of helicopter simulation will not permit the analytical development of launch/recovery envelopes. Visual systems with texture and a wide FOV are required. More emphasis must be placed on acquiring at-sea test data and developing a DI data base. A Manned Flight Simulation Facility with a platform motion base and a state-of-the-art visual system is currently being constructed at NAVAIRTESTCEN. The DI Section at NAVAIRTESTCEN is developing the flight test data base and acquiring/verifying the mathematical models needed to define the DI limitations by simulation.

SUMMARY

The NAVAIRTESTCEN DI Section has established the operating limitations for many helicopter/ship combinations based on flight testing. These limitations have been defined in terms of the aircraft, the ship, the environment, and the pilot. The backlog of helicopter/ship combinations requiring testing is large. An analytical program has been established to supplement the flight test effort with a simulation capability. A review of the state-of-the-art of helicopter shipboard landing simulation reveals that inadequate visual systems and ship airwake turbulence models are the major problems. Visual system technology is improving rapidly. Ship airwake/turbulence model studies have commenced, but quantitative at-sea data are needed for model verification. The DI Section is currently building a helicopter shipboard landing data base to be incorporated on a proposed Manned Flight Simulator at NAVAIRTESTCEN.

REFERENCES

1. Hofman, C.F.G.M, and Fang, R.: Determination of Limitation for Helicopter Ship-Born Operations, Tenth European Rotorcraft Forum, The Hague, Netherlands, August 1984.

2. Thomason, Tommy: The History of Helicopter in the U.S. Navy, American Helicopter Society, VERTIFLITE, May/June 1984.

3. Lineback, H.W., LCDR, USN, and Parkinson, R., LT, USN: Helicopter/Ship Interface Testing, 28th Annual National Forum of the American Helicopter Society, Washington, D.C., May 1972.

4. Johnston, J.B.B.: The Operation of Helicopters from Small Ships, Royal Aircraft Establishment Technical Memorandum Aero 1348, August 1971.

5. Kolwey, H.G., and Coumatos, M.J., LT, USN: State-of-the-Art in Non-Aviation Ship Helicopter Operations, Naval Engineers Journal, April 1975.

6. Kolwey, H.G.: Summary of Helicopter Airframe Testing in the Shipboard Environment, 33rd Annual National Forum of the American Helicopter Society, Washington, D.C., May 1977.

7. Finch, R.S.: Notes on UK Helicopter/Ship Trials Conducted by AAEE, ADF 26/05, 24 April 1980.

8. Renirie, L.T., and Hockstra, T.: Helicopter-Ship Qualification Testing, Journal of the American Helicopter Society, January 1981.

9. Carico, Dean, and Madey, S.L., Jr., CDR, USN: DYNAMIC INTERFACE: Conventional Flight Testing Plus a New Analytical Approach, AHS, National Specialist's Meeting on Helicopter Testing Technology, Williamsburg, Virginia, 29 October - 1 November 1984.

10. Shipboard Aviation Facilities Resume, NAEC-ENG-7576, Revision AA, July 1985.

11. Air Capable Ship Aviation Facilities Bulletin No. 1F, NAEC 91122, 17 May 1985.

12. Woomer, C., LT, USN, and Carico, D.: Flight Fidelity Evaluation of the SH-2F Weapons Systems Trainer (Device 2F106), Final Report, Naval Air Test Center Technical Report RW-11R-77, 31 March 1978.

13. Woomer, C.W., LT, USN, and Williams, R.L.: Environmental Requirements for Simulated Helicopter/VTOL Operations from Small Ships and Carriers, Conference Proceedings No. 249, Piloted Aircraft Environment Simulation Techniques, AGARD, NATO, Brussels, Belgium, 24-27 April 1978.

14. Paulk, C.H., Jr., Donley, S., and Hollis, M., CDR, USN: Evaluation of Control and Display Configurations for Helicopter Shipboard Operations, AIAA Paper Preprint #83-2486, Aircraft Design, Systems and Operations Meeting, Fort Worth, Texas, 17-19 October 1983.

15. Galloway, R.T.: Helicopter Training Research at the Visual Technology Research Simulator, FAA Conference on Helicopter Simulation, Proceedings, Atlanta, Georgia, 17-19 April 1984.

16. Bray, R.S.: Experience with Visual and Motion Cueing in Helicopter Simulation, FAA Conference on Helicopter Simulation, Proceedings, Atlanta, Georgia, 17-18 April 1984.

17. Crane, D.F.: The Effects of Time Delay in Man-Machine Control Systems: Implications for Design of Flight Simulator Visual-Display-Delay Compensation, IMAGE III Conference, Phoenix, Arizona, 1984.

18. Ferguson, S.W., et al.: Assessment of Simulation Fidelity Using Measurements of Piloting Technique in Flight, 38th AGARD GCP Symposium, Monterey, California, May 1984.