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NORTH ATLANTIC TREATY ORGANISATION

RESEARCH AND TECHNOLOGY ORGANISATION

BP 25, 7 RUE ANCELLE, F-92201 NEUILLY-SUR-SEINE CEDEX, FRANCE

RTO AGARDograph 300

Flight Test Techniques Series – Volume 22

Helicopter/Ship Qualification Testing

(Les essais de qualification hélicoptère/navire)

This AGARDograph has been sponsored by the SCI-055 Task Group, the Flight Test Technology Team of the Systems Concepts and Integration Panel (SCI) of RTO.

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Edited by
G.D. Carico, R. Fang, R.S. Finch, W.P. Geyer Jr., Cdr. (Ret.) H.W. Krijns and K. Long

This AGARDograph has been sponsored by the SCI-055 Task Group, the Flight Test Technology Team of the Systems Concepts and Integration Panel (SCI) of RTO.

The Research and Technology Organisation (RTO) of NATO

RTO is the single focus in NATO for Defence Research and Technology activities. Its mission is to conduct and promote cooperative research and information exchange. The objective is to support the development and effective use of national defence research and technology and to meet the military needs of the Alliance, to maintain a technological lead, and to provide advice to NATO and national decision makers. The RTO performs its mission with the support of an extensive network of national experts. It also ensures effective coordination with other NATO bodies involved in R&T activities.

RTO reports both to the Military Committee of NATO and to the Conference of National Armament Directors. It comprises a Research and Technology Board (RTB) as the highest level of national representation and the Research and Technology Agency (RTA), a dedicated staff with its headquarters in Neuilly, near Paris, France. In order to facilitate contacts with the military users and other NATO activities, a small part of the RTA staff is located in NATO Headquarters in Brussels. The Brussels staff also coordinates RTO's cooperation with nations in Middle and Eastern Europe, to which RTO attaches particular importance especially as working together in the field of research is one of the more promising areas of initial cooperation.

The total spectrum of R&T activities is covered by the following 7 bodies:

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS Studies, Analysis and Simulation Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These bodies are made up of national representatives as well as generally recognised 'world class' scientists. They also provide a communication link to military users and other NATO bodies. RTO's scientific and technological work is carried out by Technical Teams, created for specific activities and with a specific duration. Such Technical Teams can organise workshops, symposia, field trials, lecture series and training courses. An important function of these Technical Teams is to ensure the continuity of the expert networks.

RTO builds upon earlier cooperation in defence research and technology as set-up under the Advisory Group for Aerospace Research and Development (AGARD) and the Defence Research Group (DRG). AGARD and the DRG share common roots in that they were both established at the initiative of Dr Theodore von Kármán, a leading aerospace scientist, who early on recognised the importance of scientific support for the Allied Armed Forces. RTO is capitalising on these common roots in order to provide the Alliance and the NATO nations with a strong scientific and technological basis that will guarantee a solid base for the future.

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Helicopter/Ship Qualification Testing

(RTO AG-300 Vol. 22 / SCI-038)

Executive Summary

NATO's rotorcraft aviation forces rely heavily on ship-based operations for both military and commercial applications. The requirements to provide surveillance, supplies and force projection options in areas where land-based operations are not available also dictate aircraft/ship operations. These multi-national forces operate from a variety of different aircraft and ships in both weather and visibility extremes.

Basic helicopter flight limitations are usually determined in a land-based environment by the aircraft manufacturer and/or by the procuring activity. The land-based limitations are not valid in the shipboard environment due to the individual factors including ship air wake/turbulence, ship motion, confined landing areas and visual cue limitations and due to the combined effects of these factors. Future NATO operators and force commanders may require the maximum helicopter/ship operational capability that can be accomplished in any environmental condition.

The purpose of this AGARDograph is to document the helicopter/ship qualification test procedures including the preparation, execution and data analysis of helicopter/ship flight testing that should be employed, combined with best safety practices to obtain that maximum operational capability. Attention is focused on helicopter take-off and landing, which constitutes the main part of the test programme.

The following topics are described:

- the factors influencing the helicopter/ship operations;
- how these factors are determined in various qualification programme elements;
- how these factors are used to set up a flight test programme on board the ship;
- how the ship-borne flight tests, within the constraints of safety and efficiency, are carried out;
- in what way, during the tests, repeated use is made of the data obtained in the previous qualification programme elements and of the experience of the test team, resulting in the smallest possible number of flying hours without affecting the quality of the results.

A brief outline of helicopter/ship qualification programmes as carried out by the Netherlands' National Aerospace Laboratory (NLR) at Amsterdam, the United Kingdom's Defence Evaluation & Research Agency (DERA) at Boscombe Down and the United States' Rotorcraft Shipboard Suitability Branch of the Naval Air Systems Command at Patuxent River, Maryland are given. It describes how detailed information of the helicopter capabilities, ship's motion characteristics and the wind-climate above the ship's flight deck is used to set up and to execute a safe and efficient flight test programme. The programme leads to a safe and maximum operational availability of the helicopter on board the ship in terms of take-off and landing capabilities as a function of relative wind and sea-state.

Les essais de qualification hélicoptère/navire

(RTO AG-300 Vol. 22 / SCI-038)

Synthèse

Les flottes d'aéronefs à voilure tournante de l'OTAN sont fortement tributaires des opérations embarquées pour valider leurs applications militaires et commerciales. La mise en œuvre d'aéronefs à partir de navires est également dictée par la nécessité de disposer de capacités de surveillance, d'approvisionnement et de projection de force dans des zones où l'utilisation de bases terrestres est exclue. Ces forces multinationales mettent en œuvre une grande variété d'aéronefs et de plates formes maritimes et ce, dans des conditions météorologiques et de visibilité souvent extrêmes.

D'une façon générale, les limites de vol standard des hélicoptères sont fixées par l'avionneur et/ou par les services des approvisionnements en fonction d'un environnement terrestre. Or, ces limitations ne sont pas adaptées à l'environnement maritime embarqué en raison de facteurs propres tels que les turbulences de sillage et les mouvements des plates formes, l'exiguïté des aires d'atterrissage et les limitations des repères visuels, sans compter les effets combinés de tous ces facteurs. Les futurs équipages et commandants de forces de l'OTAN auront probablement besoin d'une synergie opérationnelle la plus grande possible entre hélicoptères et navires, quel que soit l'environnement.

Cette AGARDographie a pour objet de répertorier en les documentant les procédures pour les essais de qualification des hélicoptères à la mer, et notamment la préparation, l'exécution et l'analyse des données des essais en vol des hélicoptères, ainsi que les meilleures procédures de sécurité, afin de disposer de cette synergie opérationnelle maximale. L'accent est mis sur le décollage et l'atterrissage des hélicoptères car ils constituent l'essentiel du programme d'essais.

Les sujets suivants sont abordés :

- les facteurs ayant une influence sur les opérations des hélicoptères à la mer;
- la prise en compte de ces facteurs dans différents éléments des programmes de qualification;
- l'intégration de ces facteurs dans l'établissement d'un programme d'essais en vol dans le cadre d'un embarquement à la mer;
- l'exécution de ces essais en vol à partir de navires, compte tenu des contraintes de sécurité et d'efficacité associées;
- le recours répété durant les essais aux données obtenues lors de l'exécution des programmes de qualification précédents, ainsi qu'à l'expérience de l'équipe d'essais, de façon à réduire au minimum les heures de vol nécessaires sans nuire à la qualité des résultats.

Un bref aperçu est donné des programmes de qualification des hélicoptères à la mer tels qu'ils sont conduits par le Netherlands National Aerospace Laboratory (NLR) d'Amsterdam, le Defence Evaluation and Research Agency (DERA) de Boscombe Down au Royaume-Uni et par le Rotorcraft Shipboard Suitability Branch du Naval Air Systems Command de Patuxent River aux Etats-Unis. Cet aperçu décrit aussi comment les informations détaillées sur les capacités de l'hélicoptère, les caractéristiques des mouvements du navire et celles du vent sur le pont d'envol sont exploitées en vue de la préparation et l'exécution d'un programme d'essais en vol dans de bonnes conditions de sécurité et d'efficacité. Ce programme permettra d'assurer en toute sécurité une disponibilité opérationnelle maximale de l'hélicoptère embarqué du point de vue de ses capacités de décollage et d'atterrissage en fonction du vent relatif et de l'état de la mer.

Click inside the blue boxes to view the corresponding section

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AGARDograph Series 160 and 300

The Systems Concepts and Integration (SCI) Panel has a mission to distribute knowledge concerning advanced systems, concepts, integration, engineering techniques, and technologies across the spectrum of platforms and operating environments to assure cost-effective mission area capabilities. Integrated defence systems, including air, land, sea, and space systems (manned and unmanned) and associated weapon and countermeasure integration are covered. Panel activities focus on NATO and national mid- to long-term system level operational needs. The scope of the Panel covers a multidisciplinary range of theoretical concepts, design, development, and evaluation methods applied to integrated defence systems.

One of the technical teams formed under the SCI Panel is dedicated to Flight Test Technology. Its mission is to disseminate information through publication of monographs on flight test technology derived from best practices which support the development of concepts and systems critical to maintaining NATO's technological and operational superiority. It also serves as the focal point for flight test subjects and issues within the SCI Panel and ensures continued vitality of the network of flight test experts within NATO.

These tasks were recognized and addressed by the former AGARD organization of NATO in the form of two AGARDograph series. The team continues this important activity by adding to the series described below.

In 1968, as a result of developments in the field of flight test instrumentation, it was decided that monographs should be published to document best practices in the NATO community. The monographs in this series are being published as individually numbered volumes of the AGARDograph 160 Flight Test Instrumentation Series.

In 1981, it was further decided that specialist monographs should be published covering aspects of Volume 1 and 2 of the original Flight Test Manual, including the flight testing of aircraft systems. The monographs in this series (with the exception of AG 237, which was separately numbered) are being published as individually numbered volumes of the AGARDograph 300 Flight Test Techniques Series.

At the end of each AGARDograph 160 Flight Test Instrumentation Series and AGARDograph 300 Flight Test Techniques Series volume is an annex listing all of the monographs published in both series.

Foreword

Introduction to the subject
Ships have been used for commercial and military sea-based applications for many centuries. The airplane has gained fame during the twentieth century for both commercial and military applications. Helicopter/ship operations have been ongoing since the middle of the twentieth century. Many countries and numerous commercial activities use the helicopter to extend the capability of ships. The helicopter is often considered a very versatile aircraft with few flight limitations. Basic helicopter flight limitations are usually determined in a land-based environment by the aircraft manufacturer and/or by the procuring activity. The land-based limitations are not valid in the shipboard environment due to the individual factors listed below and due to the combined effects of the following factors:

- Ship airwake/turbulence
- Ship motion
- Confined landing area
- Visual cue limitations

Operators request the maximum helicopter/ship operational capability that can be exercised in any environmental condition. To obtain the maximum operational capability, combined with best safety practices, helicopter/ship qualification testing is required. Helicopter/ship qualification testing, sometimes referred to as "dynamic interface (DI) testing" or as the "clearing process", is used to develop safe operational envelopes for helicopters operating off ships under a variety of weather conditions. The results of helicopter/ship qualification testing are referred to as the Ship Helicopter Operating Limitations (SHOLs).

Contributions from three countries in two separate parts
Helicopter/ship testing is considered high risk testing that should only be performed by agencies that have specialized flight test and research teams that are knowledgeable of, and have experience in, this type of testing. In NATO these conditions are fulfilled only in a limited number of countries amongst which are The Netherlands, the United Kingdom and the United States of America. Specialists from those countries have contributed to this AGARDograph. All three countries have several similar procedures related to determining SHOLs. At the same time some of the procedures differ, with the NL/UK flight test programs being more similar to each other than to the procedures employed by the US. To accommodate these differences it was decided to split the AGARDograph into two parts, one covering the NL/UK clearance process and the other dealing with the process in the US. Although as a consequence of this approach some overlap will be found comparing the two parts, the big advantage is that the process described in each part is consistent in its nomenclature and its sequence and that each part can be read independently from the other.

The Netherlands National Aerospace Laboratory (NLR) in Amsterdam and the UK Defense Evaluation Research Agency (DERA) at Boscombe Down have conducted numerous helicopter/ship qualification tests on national, as well as foreign, contractor aircraft/ship types to establish the SHOLs.

The Naval Air Warfare Center, Aircraft Division at Patuxent River, MD, in the USA has used Dynamic Interface (DI) testing over the past several years to try to eliminate a large helicopter/ship test backlog.

For some time, prior to the actual helicopter/ship flight testing, the Dutch have successfully used a combination of wind tunnel data (ship model), full-scale airwake data, and land-based helicopter data to predict operating limits. The UK and USA rely primarily on basic helicopter/ship testing.

Future developments
Future developments are expected in the field of increased application of simulation. The ability to predict helicopter/ship operational envelopes analytically represents one of the more difficult challenges associated with flight-testing. Inspired by the cost of testing and the inability to readily control test conditions, both the UK and USA have strong ongoing analytic efforts to help support future helicopter/ship qualification testing. With 3 new ship classes operating with 5 types of aircraft anticipated within the coming decade, the UK has initiated a First of Class Flying Trials program in 1997, which includes developing an advanced simulation capability. In the USA DI testing continues, with more emphasis being placed on simulation and wind tunnel efforts as potential test support tools of the future. The USA initiated an Office of Secretary of Defense (OSD) sponsored Joint Helicopter Ship Integration Program (JHSIP) in 1998. This program focuses on validating and evaluating joint service helicopter/ship operational capabilities, with some work in the area of DI simulation.

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The Netherlands contribution to the AGARDograph was only possible due to the valuable assistance and contribution received from the Royal Netherlands Navy in the course of the years. The author wishes to express his appreciation for the valuable contribution received from the following departments of the Royal Netherlands Navy:

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Part 1

DUTCH / BRITISH CLEARANCE PROCESS

by

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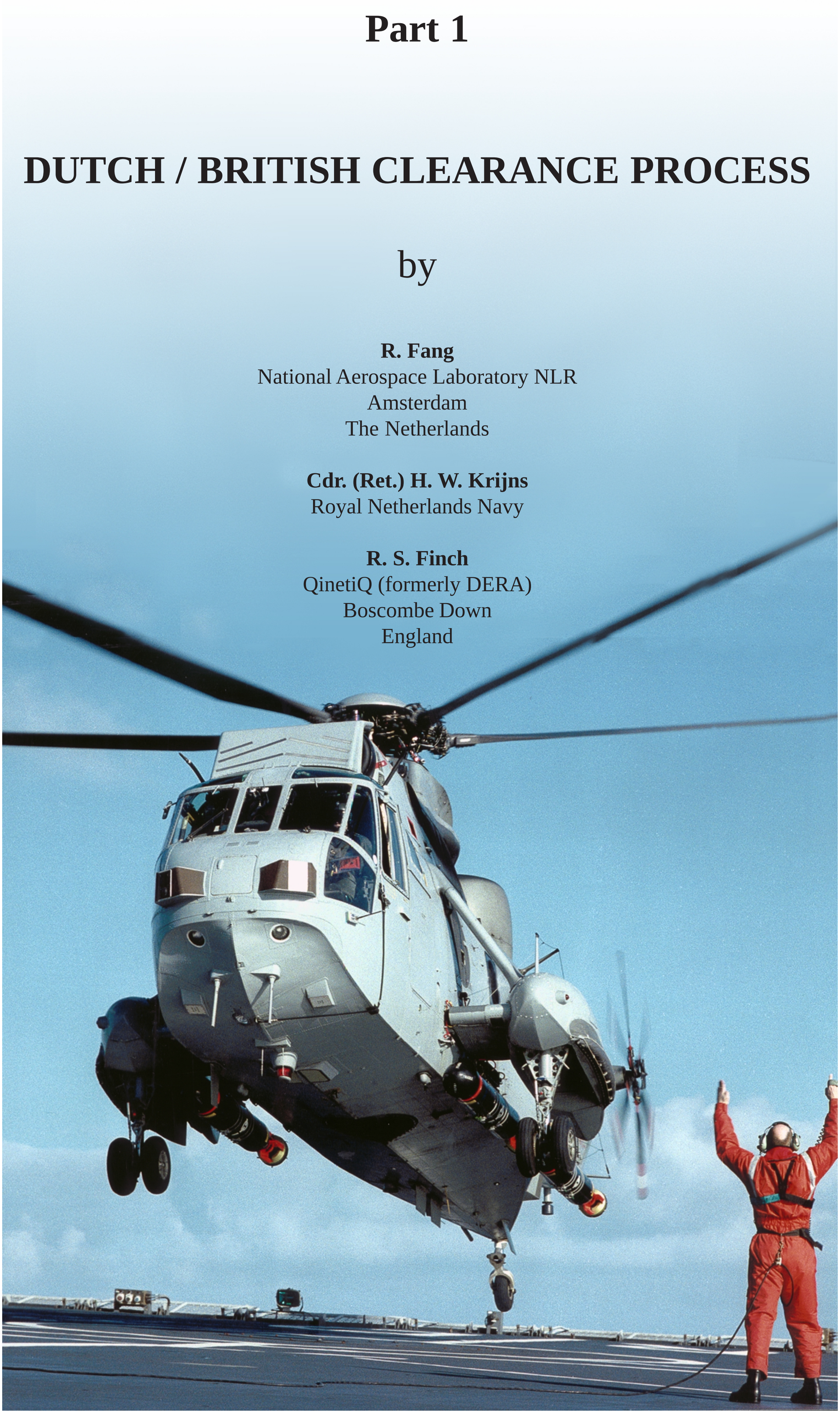

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List of Abbreviations of Part 1

A/F	Aft/Fore
AFS	Advanced Flight Simulator
AGL	Above Ground Level
CC	Command & Control Centre [UK: Opsroom; USA: Combat Information Centre]
CVS(G)	Aircraft Carriers (Guided Missiles)
F/A	Fore/Aft
FDO	Flight Deck Officer
GPI	Glide Path Indicator
GSI	Glide Slope Indicator
HCO	Helicopter Control Officer
HEDAS	Helicopter Data Acquisition System
HIFR	Helicopter In Flight Refuelling
IGE	In Ground Effect (hover)
NAWCAD	Naval Air Warfare Center Aircraft Division
NLR	Nationaal Lucht- en Ruimtevaartlaboratorium (National Aerospace Laboratory NLR - the Netherlands)
OAT	Outside Air Temperature
o/b	on board
OGE	Out of Ground Effect (hover)
PC	Personal Computer
PD	Project Definition
RAF	Royal Air Force
RFA	Royal Fleet Auxiliary
RN	Royal Navy
RNLN	Royal Netherlands Navy
RMDU	Remote Multiplexing/Digitizer Unit
RRR	Rotors Running Refuelling
RW	Relative Wind
SHOLs	Ship Helicopter Operational Limitations
T&E	Test and Evaluation
UVW	Orthogonal velocity components of a local wind velocity vector
Vertrep	Vertical replenishment
WAU	Wind data Acquisition Unit
XD	Cross Deck

1. Introduction

In recent years operations with a large variety of helicopter types from various classes of naval ships have steadily increased world-wide. The improved capabilities of present-generation helicopters offer a wide range of possibilities for ship-helicopter combinations to cope with the growing demand being put on modern maritime forces. Many even relatively small vessels are being equipped with a helicopter flight deck.

Sometimes an almost marginal facility is provided for take-off, landing and deck handling. Yet, helicopter operations may be required in a wide range of operational conditions (day, night, sea-state, wind, visibility etc) with the highest possible payload. Nowadays, in line with the increasing importance of helicopter/ship operations the helicopter manufacturer sometimes additionally provides limitations of a general nature for helicopter-ship operations.

The limitations for land-based operations (determined after extensive factory testing) are based amongst others on a rigid and unobstructed landing site. On the other hand, the limitations for ship-borne operations are to be based on an obstructed landing site (flight deck) which may show random oscillatory movement and where amongst others extremely turbulent wind conditions can prevail.

Because of the unique characteristics of each helicopter-type/class-of-ship combination and the innumerable combinations possible it is understandable that usually no (extensive) testing has been carried out by the helicopter manufacturer for all combinations that may be of interest. It follows that the limitations given, if any, must be considered as general guidelines, with large safety margins with respect to the helicopter capabilities and pilot ability to control the helicopter, and thus do not provide a maximum operational availability of the helicopter on board the ship. It is expected that the actual limitations, i.e. those that allow maximum availability of the helicopter within the constraints of safety, are lying somewhere between the limitations for land-based and those for ship-borne operations as given by the manufacturer. To determine these limitations a dedicated helicopter-ship qualification programme is to be executed. Figure 1 shows an example of helicopter operations in rough weather.

Fig. 1 Helicopter operations on board a ship in a rough environment.

In this AGARDograph an overview is given about the factors influencing helicopter-ship operations, the way they are determined in various qualification programme elements and how they are used to set up a flight test programme on board the ship.
Described is:

- How the execution of the ship-borne tests is within the constraints of safety and efficiency;
- The use made of data obtained in the previous programme elements;
- The use made of the experience of the test team.

The result is the smallest possible number of flying hours that does not affect the quality of the results. The attention is focused on helicopter take-off and landing which in fact constitute the main part of the tests. Finally some results are given.

2. Experience

The Royal Netherlands Navy (RNLN), being one of the first operators of ship-borne helicopters on small ships and operating world-wide, pioneered in concert with the aeronautics home laboratory NLR, the development of helicopter-ship qualification procedures. This collaborative effort has led to a four-step qualification programme described in this volume.

The “Nationaal Lucht- en Ruimtevaartlaboratorium” (NLR) is the Netherlands expert institute on aerospace technology and related subjects. From 1968 to date it actively participated in twenty-one (21) qualification programmes. Six (6) of these programmes were carried out in co-operation with four (4) international operators.

In the period from 1982 up to 2002 dedicated qualification procedures have been applied by NLR for helicopter-ship qualification testing. The applied methodology has been successfully used in eleven qualification programmes for agencies at home and abroad. Four types of helicopters and eight classes of ships were involved. Helicopter maximum take-off mass ranged from 4040 kg (8900 lbs) to 9715 kg (21400 lbs). Ship’s maximum water displacement ranged from 485 tons to 17000 tons. The most extreme helicopter-ship combination worth mentioning was a 4040 kg (8900 lbs) helicopter on a 485-ton ship equipped with a flight deck of 7 by 7.6 m.

In the UK, The Royal Navy (RN) has been operating ship-borne helicopters on small ships world-wide for almost half a century. The UK Aircraft Test & Evaluation Centre at “QinetiQ” Boscombe Down (former Defence Evaluation & Research Agency’s site) is responsible for conducting trials to determine the limitations appropriate to UK Military Ship Helicopter Operations (SHOLs).

Starting in the mid 1950s, Boscombe Down has conducted ship trials using almost every helicopter type that has seen service with the UK Armed Forces, including the Whirlwind, Wasp, Wessex, Sea King, Scout, and Gazelle. The techniques used by the UK have been developed since the late 1960s and although refinements have been made, the same basic techniques have been used successfully and safely for nearly 30 years.

Since 1977, when Boscombe Down conducted the first RN Lynx trial, it has undertaken a total of 19 Lynx Ship Trials, including a trial for the Brazilian Government on their Mk 10 Frigate Class and two further trials for other NATO navies. In addition, starting in 1987, Boscombe Down has undertaken a number of trials to clear RAF Chinook helicopters to operate on both RN and RFA flight decks. In the 1990s Boscombe Down and NLR collaborated successfully to clear RN helicopters onto a number of RNLN ships.

3. Basic Set-up

3.1 General

One of the most important staff requirements for helicopter compatible ships is the helicopter type to be operated from a given class of ship. This requirement implicitly defines the deck sizing, hangar spacing and technical support features for optimal and safe helicopter operations.

A ship can be considered as an isolated island, which is in turn domicile and working area of several disciplines. Each discipline has its own specific requirements.

The designers of a ship attempt to meet all requirements within predefined constraints. The final draft by the design office will therefore be a compromise, within which each discipline must strive to fulfil its tasks.

As the helicopter is one of the many systems of a ship, it is obvious that helicopter operations are to be performed within the constraints of the aforementioned compromise.

For a better understanding of the methodology as applied in the Netherlands and the United Kingdom, the factors/subjects in connection with helicopter ship operations, as described in the following paragraphs, are of importance.

3.2 Starting point in the Netherlands & UK

Both nations have dedicated Flight Operational and Technical procedures laid down in national regulations which are applied to ensure safe and optimal usage of the helicopter/ship combination.

3.2.1 Procedures

Flight procedures

- The standard Dutch flight operations are carried out according to the "single pilot concept". This implies the following Dutch crew composition:
  - one pilot (right-hand cockpit seat);
  - one tactical co-ordinator (left-hand cockpit seat);
  - one sensor operator (at the sensor console in the cabin).

- The standard UK military flight procedures call for the Pilot in the right-hand seat to conduct take offs and landings at sea. Indeed for the Lynx and Merlin helicopters the “right-hand seat - single pilot concept,” (as per the Dutch) is standard. For the Sea King, two pilots are used and depending on the type of landing being flown, either pilot may “be in control”.

- During standard recovery / flight operations, ship controlled approaches are carried out up to ¼ mile from the ship, using a nominal 3-deg glide slope.

- During the recovery from ¼ mile up to land-on (touch down) and during launch up to transition to forward flight, the Flight Deck Officer (FDO) directs the pilot by marshalling signals and by radio communication.

- During standard flight (launch & recovery) operations the ship's Command & Control Centre (CC), the helicopter and the FDO are always on one dedicated communication frequency.

Technical procedures

- Before flight operations are permitted o/b a "NEW" or "CONVERTED" class of ship, the following activities are mandatory:
  - Harbour flight acceptance trials. Confirmation that all required technical and logistic features for helicopter operations are available and operational. Operator's responsibility, NLR or QinetiQ input only on request.
  - Flight acceptance trials at sea. Confirmation that all systems (ship and helicopter) are operating according to standard. Operator's responsibility with NLR or QinetiQ input.
  - Execution of helicopter flight trials o/b the ship in relation to standard operational procedures. Determination of Ship Helicopter Operational Limitations (SHOLs) for a "NEW"-class of ship and if applicable updating of the SHOLs for a "CONVERTED" class of ship. Joint programme between operator and NLR or QinetiQ.

4. Helicopter Ship-borne Operational Procedures

4.1 Helicopter sortie o/b a ship

A helicopter sortie o/b a ship (day and night) can be divided into the following phases:

Stowed (Fig.2)

Helicopter stowed and secured in hangar. Generally the main rotor and tail are folded.

Fig. 2 Helicopter stowed and secured in hangar

Traversing (=Ranging) (Figs. 3A & 3B)

Folded helicopter is moved from hangar to the landing spot on the flight deck using a suitable traversing system.

Fig. 3A Ranging (manoeuvring) the helicopter to the flight deck

Fig. 3B Positioning the helicopter for a relative wind (into-wind) take-off

Secured (=Lashed/Tie Down) (Fig. 4)
The folded helicopter is secured to the deck using lashings and / or a deck locking system.

Fig. 4 Helicopter secured on deck preparing for engine start and blade unfolding

Unfolding (=Spreading) (Figs. 5A & 5B)
Helicopter blades and tail are unfolded automatically or manually. When automatic blade unfolding is applied, engine start up is performed first.

Fig. 5A Helicopter blades are unfolded automatically.
To avoid blade damage, manual support is deemed essential

Fig. 5B Manual unfolding of the helicopter blades

Engine Start/Rotor Engagement
Engine or engines are started and rotors are coupled.

Take-off
When conditions are inside the SHOLs and Command has issued take-off permission, deck crew removes nylon lashings, whereupon the pilot, when applicable, disengages the deck lock system.
Helicopter lifts off into a hover over the deck and moves clear of the ship.

Departure
Once the helicopter is clear of the ship's superstructure it transits to forward flight and departs from the ship.

Mission
The helicopter crew carry out their mission.

Approach
After the helicopter mission is completed, a specific pattern is followed to set-up for a landing. The approach phase ends as the helicopter is hovering in a waiting position in the vicinity of the ship.

Landing
The helicopter moves from the waiting position to the flight deck and lands. On touch down the pilot immediately engages the deck lock system. Lashings can be employed for further securing. Some operators also employ a haul down system to recover the helicopter.

Engine Shut Down/Rotor Disengagement
Engines are shut down. The rotors are disengaged and stopped, normally using a rotor brake.

Folding
The helicopter blades and tail are folded.

Traversing (=Ranging)
The folded helicopter is moved from the flight deck to the hangar using a traversing system.

Stowed
The helicopter is secured in the hangar using tie down chains.

During a mission, the helicopter can return to the ship for example for refuelling or to pick up or release external cargo. Picking-up or releasing external cargo is called vertical replenishment (“VERTREP”).

Apart from VERTREP it is for most types of helicopters possible to transfer persons and (small) loads by means of a winch (“winching”).

Refuelling can be done on deck with engines and rotors running (hot refuelling - “RRR”) (Fig.6) or hovering close to the ship (helicopter in flight refuelling - “HIFR”).

For safe operations and optimal operational use of the helicopter, it is of essential importance to determine the limitations for each of the afore-mentioned phases.

Fig. 6   Rotor Running Refuelling (Hot refuelling)

The significant result of shipboard helicopter compatibility testing is at least one or all of the following envelopes: engage/disengage, Vertical Replenishment, Helicopter In-Flight Refuelling, and launch/ recovery. Once developed, these envelopes largely establish the allowable range of wind/ship motions conditions that safely permit routine shipboard helicopter operations. Conversely, for any given ambient wind condition, the envelopes permit a ship operator to safely operate helicopters from a wider variety of ship course/speed combinations, optimizing his tactical and operational flexibility.

An example of a secured and lashed helicopter on deck in rough weather between two sorties is shown in figure 7.

Fig. 7 Helicopter secured and lashed on deck in rough weather

The following subsections discuss the various procedures for the take-off, departure, approach and landing phases.

4.2 Navy procedures

4.2.1 Take-off and landing

In general take-off and landing with a helicopter are easiest into the wind. However, on small ships this procedure is not always possible and furthermore it does not always provide optimal results because of the presence of obstacles. Therefore different take-off and landing procedures are applied to increase the operational availability of the helicopter on board the ship. To the authors' knowledge there are six different procedures which are being applied worldwide. The three most common procedures applied in the Netherlands and in the UK are visualized and compared below. The other three procedures will be briefly highlighted.

1) Fore/aft or forward facing procedure (F/A)(Fig. 8)

A fore/aft take-off is performed as follows:

- align the helicopter with the ship's centre-line, with its nose in the sailing direction;
- hover above the flight deck with initial ship's heading;
- fly sidewards to hover position alongside the ship either to port or starboard (windward side);
- turn away 30° from ship's heading;
- climb out.

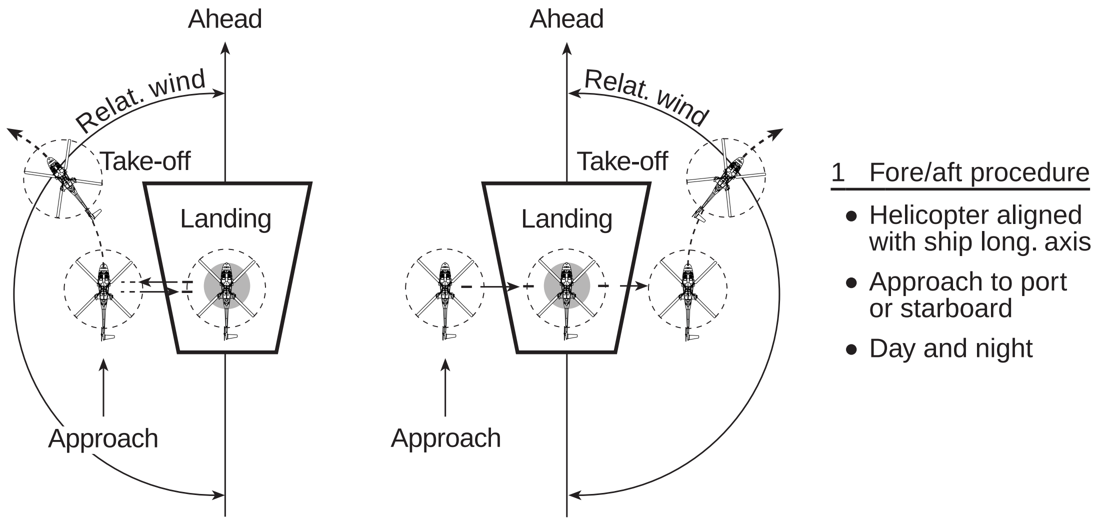


Fig. 8A Example of fore/aft take-off and landing paths

A fore/aft landing is performed as follows:

- approach the ship to a hover wait position alongside the ship (preferably to port because of pilot's view over the flight deck). The helicopter's longitudinal axis is parallel to the ship's centre-line;
- fly sidewards to the hover position over the landing spot;
- land

Fig. 8B Fore/aft take-off to port

2) Relative-wind or into wind procedure (RW)(Fig. 9)
The relative-wind take-off is performed as follows:
• swivel (if possible) the helicopter with its nose into the relative wind direction;
• hover with this heading above the flight deck;
• if necessary to avoid obstacles (e.g. the hangar), fly sidewards to a hover position alongside the ship;
• climb out.

The relative-wind landing is performed as follows:
- approach the ship from the leeward side;
- continue flight up to the hover position above the landing spot (helicopter nose into the relative wind);
- land.

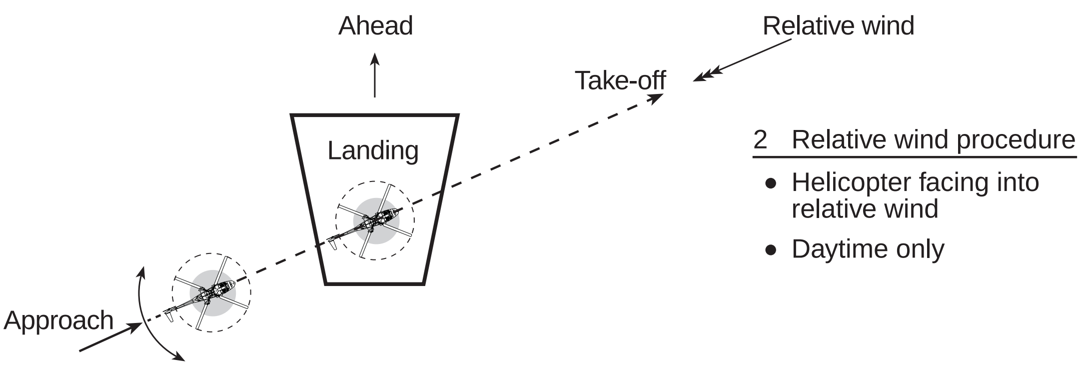


Fig. 9A Relative or into wind take-off and landing flight paths. Approach either from port or starboard.

Fig. 9B Relative wind (into-wind) procedure facing starboard

3) Cross-deck procedure (XD)(Fig. 10)
This procedure is not common to the Royal Navy.
The cross-deck take-off is performed as follows:
- swivel (if possible) the helicopter until its longitudinal axis is perpendicular to the ship's centre-line;
- lift off and climb out at this heading.

The cross-deck landing is performed as follows:
- approach the ship from abeam either from port or starboard (leeward side);
- continue flight up to the hover position above the landing spot;
- land.

Note:

XD is not RW at 90°. The XD-procedures are related to (and executed perpendicular to) the ship's longitudinal axis. The relative wind (speed and direction) can vary independently with respect to the helicopter longitudinal axis.

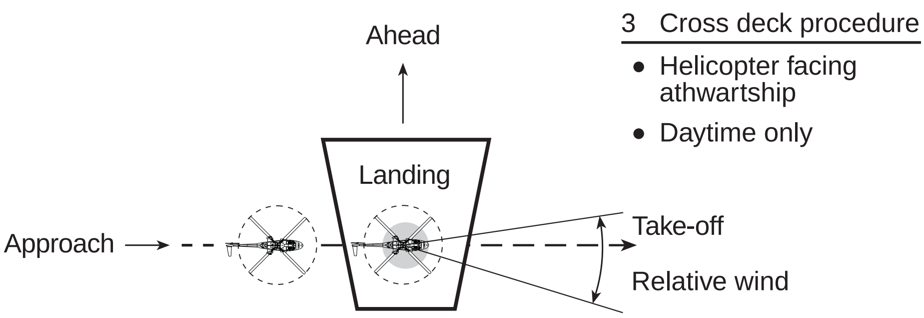


Fig. 10A Cross-deck take-off and landing flight paths. Approach either from port or starboard

Comparing the various take-off and landing procedures, the following remarks can be made:
- <u>The F/A procedure</u> has the advantage that the pilot's view over the flight deck is rather good, especially during the approach (to the port side of the ship) and sidewards flight before landing. For that reason, the procedure can also be carried out at night . However, this procedure is only applicable if the cross-wind component with respect to the helicopter (and thus also to the ship) does not exceed the helicopter limitations. More details on this subject are given in chapter 5.

Fig. 10B Cross-deck facing port procedure

- During the <u>RW procedure</u> where no or only small cross-wind components are present, yaw control is not a limiting factor. However, during this procedure the pilot's view over the flight deck is rather poor especially during the approach from port. In spite of the fact that wind is from ahead it is expected that a lower wind speed limit will apply compared to the F/A procedure. The same holds for ship’s motion. The RW procedure is only carried out by day.

- During the <u>XD procedure</u> cross-wind components can be encountered. Therefore yaw control has to be watched very carefully. Besides, the pilot's view over the flight deck is, compared to that during the RW procedure, rather restricted, especially during the approach from port. Because of this, the wind speed- and ships' motion limits are expected to be even lower than those for the RW procedure. The XD procedure is only carried out by day.

The following three less common procedures are briefly discussed.

4) Aft/Fore or facing astern procedure (A/F)(Fig. 11)
An aft/fore take-off is performed as follows:
- the helicopter is aligned with the ship's centre-line, with its nose facing the stern of the ship;
- lift off and climb out at this heading.

An aft/fore landing is performed as follows:
- approach the ship under approximate 45° from ahead, to a hover wait position alongside the ship (preferably to starboard because of pilot's view over the flight deck);
- align the helicopter's longitudinal axis parallel to the ship's centre-line (helicopter still facing the stern of the ship);
- fly sidewards to the hover position over the landing spot;
- land.

NOTE:
This procedure has been applied on ships with a relative large flight deck in comparison to the helicopter. The pilot’s visual orientation and reference is difficult when carrying out the Aft/Fore procedures.

5) Astern procedure.

The astern take-off is performed as follows:

- align the helicopter with the ship's centre-line, with its nose in the sailing direction;
- hover above the flight deck with initial heading;
- fly backwards relative to ship's heading to hover wait position aft of the ship;
- turn away approximately 30° from ship's heading;
- climb out.

The astern landing is performed as follows:

- approach the ship from astern. The approach path is along the ship's centre-line;
- continue flight up to the hover position over the landing spot;
- land.

NOTE:

In the Netherlands the astern landing is only used for precautionary or emergency landing. The ship speed is then increased to maximum obtainable and a "Semi-running" landing is carried out.
In the UK the astern procedure (take-off or landing) is not commonly used.

Fig. 11 Positioning the helicopter for a stern take-off following the aft/fore procedures

6) Oblique procedures

The oblique procedures are carried out either over port or starboard. The helicopter longitudinal-axis is under an angle of either 30° or 45°, with respect to the ship's centre-line.

The oblique take-off and landing are carried out in the same manner as the relative wind procedures, however with the restriction that the helicopter heading is predetermined and fixed.

4.2.2 Role of Flight Deck Officer (FDO)

The FDO in the RNLN & RN has several tasks during helicopter operations. His tasks are:

- controlling all activities on the flight deck;
- being interlocutor between ship's command and flight deck personnel;
- acting as safety officer during standard helicopter operations and emergencies;
- marshalling the helicopter during take-off and landing (Fig. 12)

During helicopter operations the FDO is assisted by the flight deck chief.
The FDO has repeater indicators (Fig. 13) on ship data.

Fig. 12 Marshalling the helicopter during dual spot operations

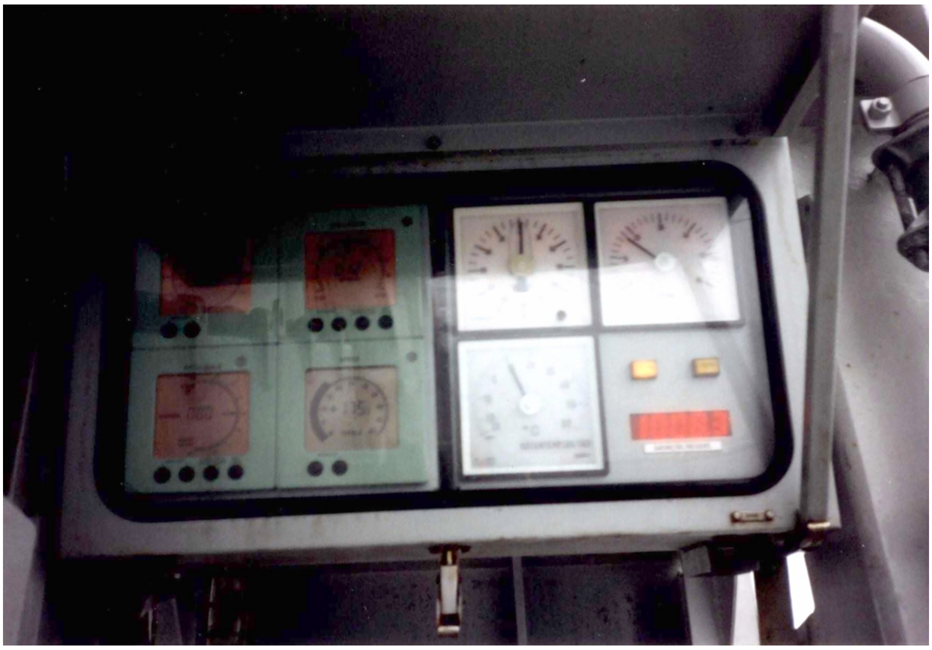


Fig. 13 Information presented to the FDO by means of repeater instruments

5. Qualification Programme

5.1 Objectives

The main objectives of a qualification programme are:

- the determination of operational limitations, regarding flight as well as deck handling etc., for a specific helicopter-ship combination;
- the adjustment of standard operations;
- the establishment of additional rules and procedures if applicable;
- the establishment of a data base for future flight activities.

The determined SHOLs contain in general the following information:

- helicopter type / day or night / flight condition (launch/recovery or traversing/ranging the helicopter from hangar to flight deck and vice versa, etc.).
- applied flight procedures during launch/recovery;
- allowable maximum all-up masses of the helicopter;
- wind limitations. The data are presented as a polar diagramme, the radius representing the wind speed and the azimuth the wind direction as measured by the ships' systems;
- allowable ship motions.

The execution of a qualification programme as described in this part of the AGARDograph may seem to be rather expensive at first instant. However the advantages that are gained in the long run are enormous. Once a ship and a helicopter have been qualified for ship-borne operations, updating the SHOLs after modifications on the helicopter or on the ship is relatively easy as only the relevant parts of the qualification programme have to be carried out. The same holds for the determination of SHOLs for a new helicopter type or a new class of ship put into service with the operator. In this respect the reader should be aware of the following:

1. The life cycle of a helicopter was at least 15 to 20 years, and nowadays 30 to 35 years.
2. The lead-time for the design and building of a ship is approximately 8 years.
3. The life cycle of a ship is at least 25 to 35 years.

5.2 Activities

Helicopter

- Land-based flight testing to obtain relevant information on helicopter performance, control margins and handling qualities in addition to the data provided by manufacturer.

Ship

Project definition phase (PD) of the ship

- Determination of required flight deck dimensions based amongst others on estimated air-borne scatter and landing scatter.
- Wind tunnel testing on a scale model of the ship to determine optimal exhaust stack and funnel design (location, shape and sizing) with respect to exhaust gas nuisance (smoke and temperature) over the flight deck and at the air intakes of various ship systems.

Design and Development phase of the ship

- Wind tunnel testing on a scale model (as established in the PD phase) of the ship to determine:
  - Optimal anemometer positions.
  - Air flow deviations at various predefined positions above and around the ship.
  - Air wake characteristics above the flight deck and behind the ship.
  - Temperature increment above flight deck (as a result of the ship's exhaust gasses).

- Technical assistance (on request) in the evaluation of deck handling systems.

Operational phase of the ship

- Full-scale air flow pattern and ship motion testing.
- Calibration of ship's wind measuring systems.
- Correlation of the full-scale air flow data with the data obtained in the wind tunnel.

Mid-life modernisation of the ship

- Wind tunnel testing on the modified scale model of the ship if applicable.
- Updating of SHOLs based on these wind tunnel data.

Helicopter-Ship

Operational state

- Determination of SHOLs for specific helicopter types on board specific classes of ships.
- Determination of "Cross-ops". These are limited SHOLs for non-organic helicopters o/b a specific class of ship for "foreign" helicopter operators.

6. Scope of Test Programme

6.1 General

An important aspect of helicopter-ship qualification testing is safety. The problem is to define this in quantitative terms, taking into account the limitations imposed by the environment, the capabilities of the helicopter and the capabilities of the pilot. In order to obtain the required data in a safe and efficient way, a programme of preparatory measurements, analysis and flight testing is executed. The scheme presently in use is depicted in figure 14.

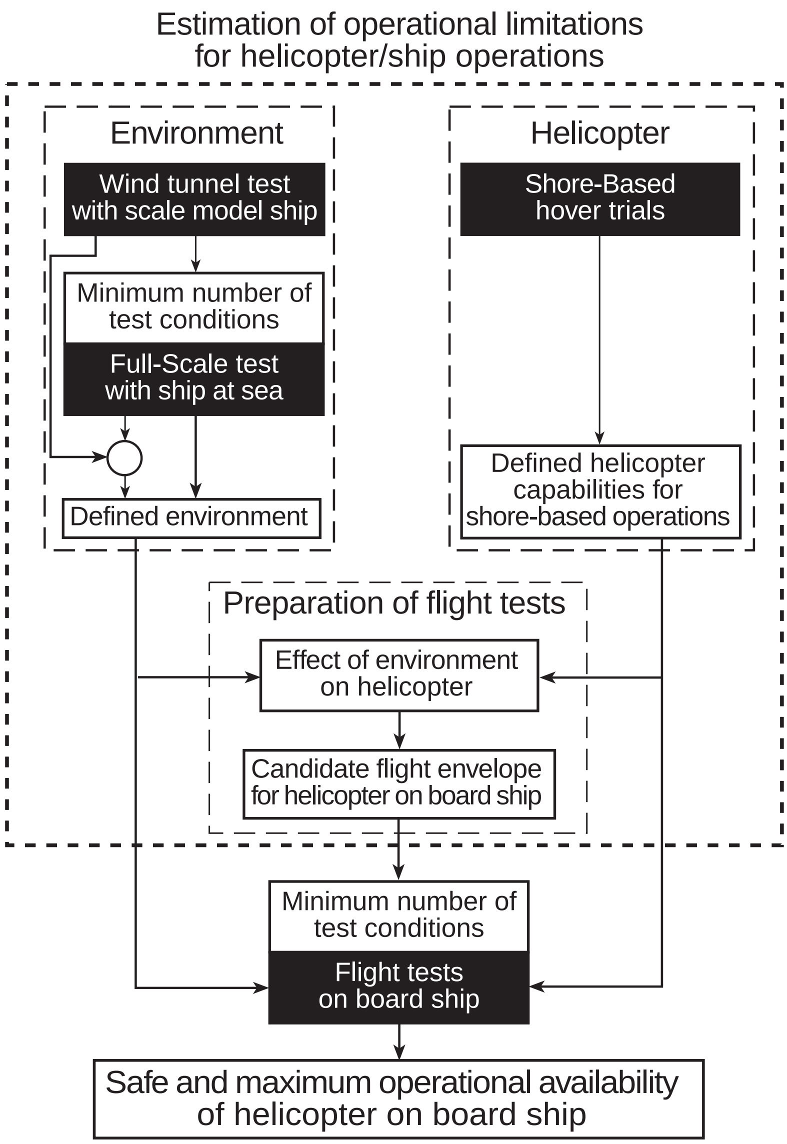


Fig. 14 Set-up of helicopter/ship qualification programme as carried out by NLR

QinetiQ also essentially follows the NLR scheme shown in figure 14. Apart from the shore-based hover tests conducted by Boscombe Down prior to tests with an aircraft and a ship, other trials are conducted by other UK Agencies, which provide data to assist in pre-trial planning. The requirements for these tests vary depending upon the type of ship being considered and some or all of the following may be available prior to helicopter tests.

Airflow trials are conducted on every ship prior to helicopter tests. The aim of this test is to establish the magnitude of errors in the ship's anemometer system. Such information is vital since, unless the system is to a required accuracy, helicopter operations from that ship will not be recommended.

Air pattern trials are normally only conducted on multi-spot ships, i.e. those with more than one landing spot such as an aircraft carrier {CVS(G)}. These trials, which would be conducted at the same time as Airflow tests, map the variation in wind speed and direction compared to free stream, along and across the flight deck at the various landing points. This can give an indication of areas where there may be difficulty in operating but more importantly it can show the variation between landing spots and thus determine the degree of read-across between spots. This would reduce the amount of separate testing required on each landing spot during subsequent tests with a helicopter.

Wind tunnel test results of ship models can be used in a similar way to air pattern results. Flow visualisation across the flight deck can show areas of turbulence and down draughting air, which may create problems for an aircraft. Such results are useful but are treated with caution by Boscombe Down, as evidence to show a correlation with the real ship is not usually available. Consequently any areas or conditions of likely turbulence would not be excluded from testing but these test points would be approached in an extremely cautious and progressive way. The tunnel test results may also explain unusual results obtained with the aircraft during trials at sea.

The nature of the problems that may be encountered are discussed in this chapter. The preparatory measurements and analyses that can be carried out to estimate the preliminary operational envelope for helicopter/ship operations are discussed in the following sections.

6.2 Land-based vs. ship-borne helicopter operations

As a result of the take-off and landing environment characteristics, land-based helicopter operations generally differ from ship-borne operations. A survey of the main differences is shown in table 1.

Note that unlike land-based take-offs and landings, ship-borne take-offs and landings occur in winds from any direction relative to the helicopter. The freedom of naval ships to manoeuvre is normally often limited by operational constraints, thus creating relative winds in which the helicopter is forced to take off or land in non-ideal conditions.

Figure 15 is a picture of a launch/recovery platform "flight deck" aboard a ship of the Royal Netherlands Navy. Typical land-based helicopter platforms are normally large, flat, open spaces which are conducive to low atmospheric wind turbulence. Conversely, a ship's superstructure always creates air-wake turbulence over the flight deck and the platform attitude is never stationary. In addition, the interaction of the ambient environment (true winds and sea motion) with the ship, which creates the operational environment for the helicopter, is not the same for every class of ship.

For land-based helicopter operations, the manufacturer provides the operational limitations and procedures. These are laid down in the manuals.

As the oscillations of the landing platform on a moving vessel are strongly dependent on the ships' characteristics and the operational environment, the helicopter manufacturer can only provide some general guidance for ship-borne helicopter operations. Dedicated operational limitations for ship-borne operations are therefore the responsibility of the operator.

Table 1: Comparison of take-off & landing area characteristics

	Ashore	o/b Ships
Take-off, approach and landing procedure	Into wind	Varying relative wind w.r.t. Helicopter
Air flow	Smooth	Turbulent & Gusty
	Clear	Polluted Smoke & Spray
Landing site Characteristics	Open & Spacious	Confined area & Obstacles
	Fixed slopes	Varying pitch, roll & Vertical motion (heave)
Operational limitations	Helicopter & Terrain	Helicopter/class of ship & Operational environment
Aircrew manual	Operational Limitations	In some cases only rough guidelines

Fig. 15 Flight deck and hangar lay-out o/b a Royal Netherlands Navy ship (forced roll situation)

6.3 Factors affecting ship-borne helicopter operations

In general the factors affecting ship-borne helicopter operations can be placed into one of the following categories: the helicopter, the class of ship, the operational environment, the crew and the operator. Each category may contain various groups, while the groups contain several factors. An example is presented in table 2.

Table 2: Factors affecting ship-borne helicopter operations

Category	Group	Factor
HELICOPTER	Configuration	Rotor systems Air flow Landing gear Pilot's view
	Performance & control	Mass Environment Control characteristics Engine performance
	Mechanical	Transmission Structural design loads
SHIP	Flight deck	Dynamic motions Obstacles Dimensions Smoke & spray Distorted airflow Deck markings and friction
	Equipment	Deck handling systems Communication facilities Landing aids
ENVIRONMENTAL	Weather	Natural turbulence Visibility Spray Atm. temperature & press. True wind
	Geographical location	Local or area Sea motion characteristics
CREW	Capabilities	Training Experience & skill
	Human factors	Crew co-ordination Motivation Physical ability
OPERATOR	Procedures	Standard
	Requirements	National & International Commitments and tasks

6.4 Main elements determining the scope of qualification programmes

The scope of a qualification programme is defined by the following elements:

- Operator's requirements
- Operator's standard operating procedures for helicopter & ship
- Operational environment (geographic region & class of ship)
- Helicopter capabilities & performance
- Efficiency
- Safety

Taking these elements into account a qualification programme as described in the following chapters can be executed.

7. Factors Affecting Ship-borne Helicopter Control and Handling

7.1 General

A helicopter operating on board a ship is subjected to a very adverse and turbulent environment. A comparison between land-based and ship-borne platforms was made and a brief overview of the ship environment in which a helicopter operates has been given in previous chapters.

The problem is to define the limitations imposed by the environment in quantitative terms. In order to obtain the required data, wind-tunnel and full-scale measurements are carried out to determine the environment above the flight deck.

7.2 The effect of the ship on the environment for helicopter operations

The major factor limiting the helicopter operations on ships compared to land-based operations is the small flight deck for take-off and landing, which is:

- moving (pitch, roll & heave)
- obstructed by obstacles (mainly the hangar in front of the flight deck) which, apart from collision risk, generate:
  - distorted air flow
  - a complicated turbulence field (in addition to natural turbulence)
  - influence of spray, causing a reduced view over the flight deck and possibly resulting in engine surging or even engine flame out
- and where stacks and funnels are in the near vicinity generating:
  - exhaust gas, which may cause:
    - ∗ additional turbulence
    - ∗ an increase of the ambient air temperature above the flight deck (increase of density altitude)
    - ∗ reduced view over the flight deck

Although the ship's course and speed as such do not constitute limiting factors for helicopter operations, they may create, in combination with sea-state, wave/swell direction and true wind a limiting condition.

Since the ship’s environment is much more complex than the environment ashore, it should be determined in what way the take-off and landing envelope as provided in the flight manual for land-based operations (Fig. 16) is affected. To evaluate the effect of the ship environment on the helicopter performance, detailed data of the helicopter capabilities are needed. If not available in advance, these are obtained during land-based hover tests. These tests are used to evaluate yaw control performance in cross wind conditions and also at high torque values needed in the low-speed region. Furthermore helicopter pitch and bank angles needed for hover at high wind speeds from all directions relative to the helicopter are determined. Finally tests are carried out in those wind conditions where main-/ tail-rotor interference might exist, causing helicopter oscillations. It is understood that these tests are executed within the limitations for land-based operations as given by the helicopter manufacturer (Fig. 16). The data obtained should indicate where, within the land-based envelope, regions exist where the margin between available and required helicopter performance is small. An example of torque and yaw control performance obtained from such tests is given in figure 17.

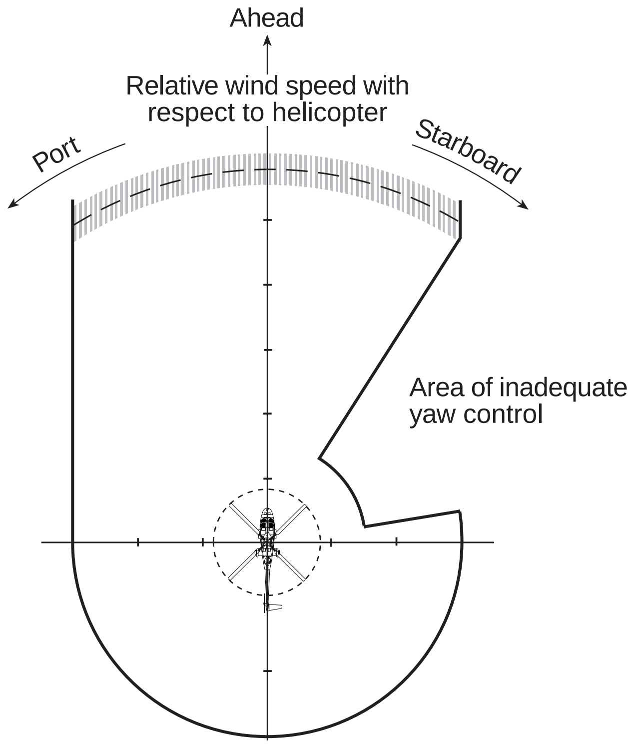


Fig.16 Typical relative low wind speed envelope as provided by the manufacturer

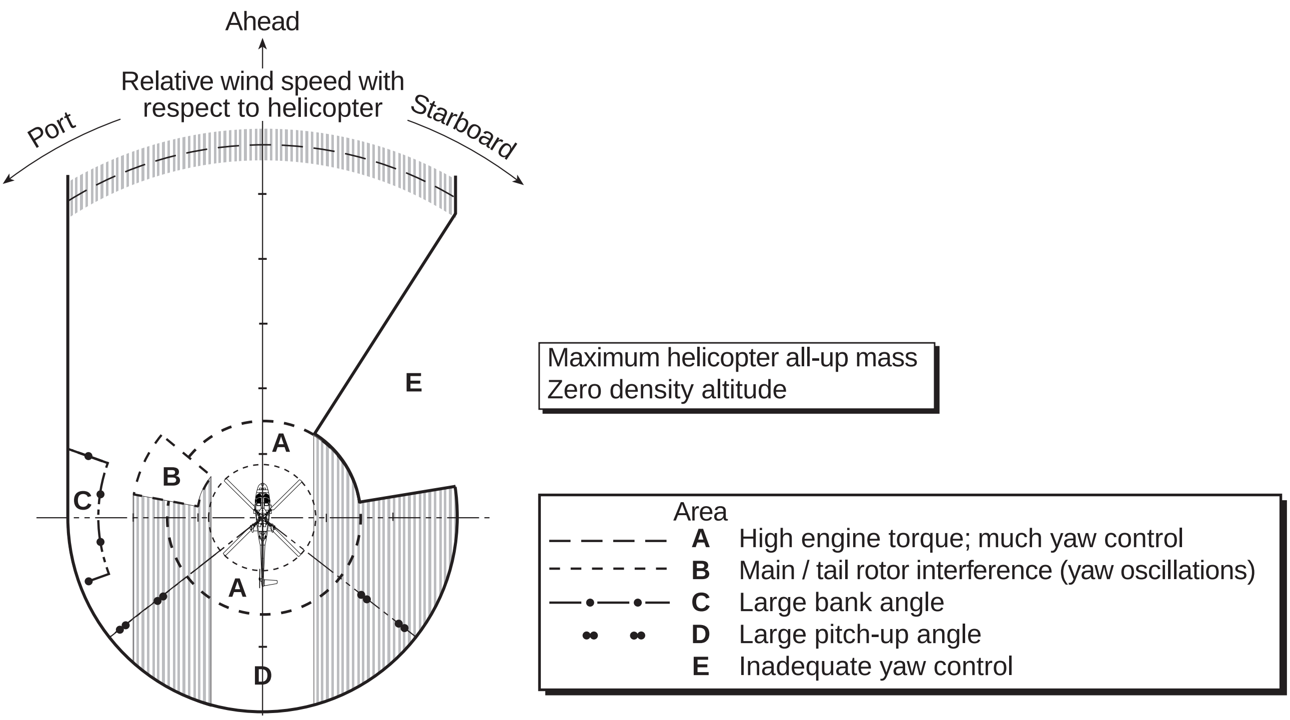


Fig. 17 Detailed results from land-based hover tests

Fig. 18 General set-up during land-based flight trials

Knowing the ship environment and the relevant performance of the helicopter, the effects on helicopter operations can be estimated, if not quantitatively, then at least qualitatively. Such effects can be grouped into two classes:

- effects that may result in hazardous flight conditions, which will have to be avoided;
- effects which will create a difficult and demanding situation for the pilot.

These effects should be evaluated carefully and the operational applicability should be evaluated by means of flight testing.

7.3 Hover performance

The purpose of the so called “hover ladder” flight test (Fig.18) is to compare the torque required to hover at various gross weights with those predicted by the helicopter operator’s manual both in ground effect (IGE) and out of ground effect (OGE). Manuals in general do not provide adequate detailed information to derive optimum limitations for combinations of specific helicopter types on board a specific class of ship.

The test is performed at altitudes of 5, 15, and 50 to 60 feet above ground level (AGL), yawing the helicopter relative to the ambient wind in 45 degree increments, starting at the nose of the helicopter and working around from 0° to 405° (360 + 45 degrees). When a stable hover condition is reached, engine torque, rotor rpm, helicopter attitudes, and flight control positions are recorded in addition to ambient conditions (pressure altitude, OAT, ambient winds etc., etc.). The result of this test provides a good baseline to work from to predict helicopter power and control performance requirements out at sea.

7.4 Yaw control

Similar to helicopter performance, good handling qualities and control are necessary to counteract turbulence and ship's motions adequately. During transitions to and from forward flight, take-off and landing, a control margin is required to maintain controllability during any unexpected situation (gusts, turbulence,...). In most cases, control margin limitations occur for pedal controls. For helicopters that employ tail rotors, yaw control is an area of concern. Conditions where inadequate yaw control exists (area E in Figure 17) must be avoided. Therefore a decelerating flight from approach speed to hover, while the relative wind above the flight deck is situated in the shaded area under area E (Fig. 17), must be avoided as the relative wind condition of the area E will be traversed. Such an approach to an obstructed flight deck with inadequate yaw control is hazardous.

Wind conditions close to those areas where inadequate yaw control exists must be approached very carefully because of yaw control variations needed to counteract turbulence and ship motions adequately.

7.5 Landings on an oscillating deck

Most helicopter manufacturers provide sloped landing limitations for take-off and landing operations outside unprepared helicopter landing sites. In most land-based operations, pilots can adjust the helicopter heading to land either up-slope, down-slope, or cross-slope depending on the safest option. Similarly, limitations may restrict helicopter ship-borne operations due to the relative geometric attitude of the helicopter to the ship.

In the Netherlands the Flight Deck Officer will launch & recover the helicopter during a quiescent motion period of the ship, with the deck in an almost horizontal position. It must be remarked that before take-off and directly after the land-on the helicopter is secured to the flight deck by means of a harpoon-grid system (in some navies known as "Talon"-system). The system greatly increases the allowable ship motions. For those operators where the helicopter crew lacks the assistance of a Flight Deck Officer to launch and land the helicopter, the deck slope aspect is of great importance in order to avoid dynamic roll over.

7.6 High wind speed from ahead

Another factor that will affect helicopter handling qualities and control is air-wake turbulence due to high wind speeds from the forward sector. In this case, the turbulence caused by the ship superstructure affects the helicopter such that the pilot cannot maintain sufficient control for safe take-off or landing.
Relative wind conditions where very heavy turbulence exists (Fig. 19; high wind speed from ahead), in combination with spray nuisance (Fig. 20; reducing pilot's view over the flight deck) and rather large ship amplitudes, especially in pitch (Fig. 21; inherent to the accompanying high sea-state), have to be avoided. In such cases the control inputs required to counteract the helicopter response to turbulence in combination with manoeuvring, necessary to avoid collision with parts of the oscillating ship may be too large (overtorqueing, maximum control margin), and create a hazardous condition.

7.7 Low relative wind speed

High engine power is needed at low relative wind speed and at high helicopter mass (area A in Figure 17). The power and yaw control margins in that condition might be too small to counteract adequately a certain amount of ship's motions. Therefore helicopter mass and density altitude should be watched very carefully during helicopter ship operations. Furthermore, at low relative wind speed the down-wash of the rotor generates spray, which is most bothersome when the helicopter hovers alongside the flight deck (Fig.22).

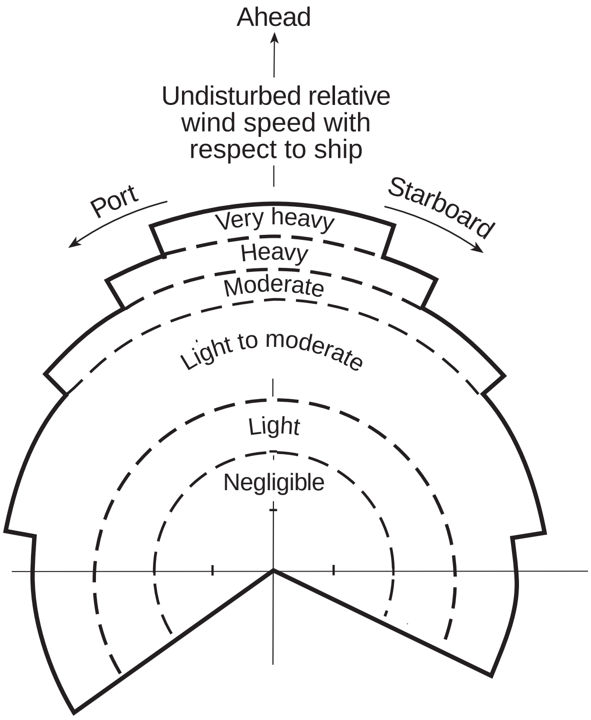


Fig. 19 Turbulence level above the deck as a function of relative wind

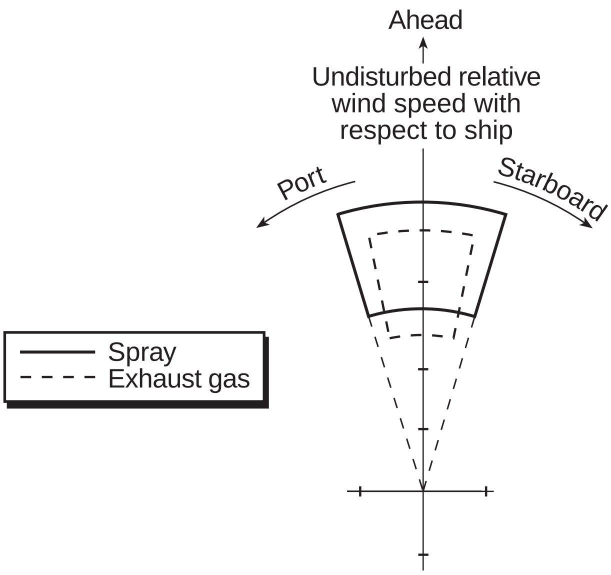


Fig. 20 Relative wind conditions during which spray and exhaust gas may be bothersome

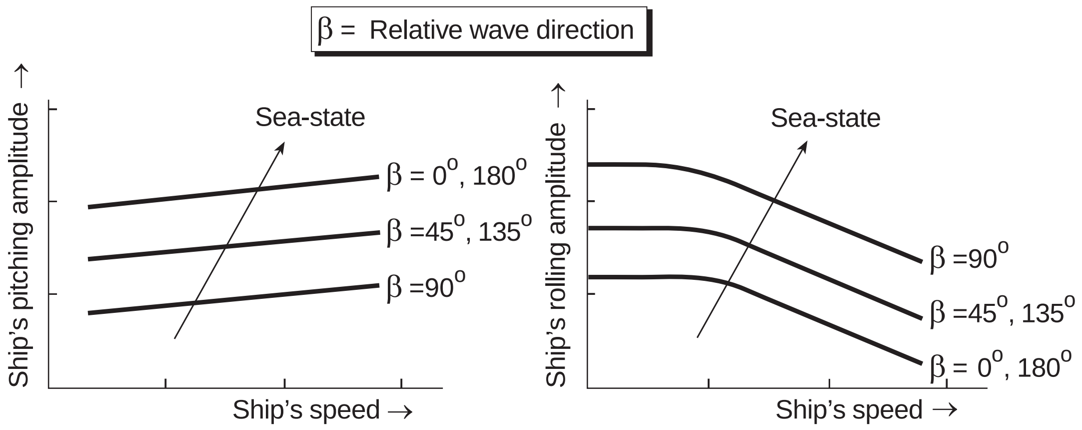


Fig. 21. Example of ship's pitch and roll amplitudes as a function of ship's speed and course

7.8 Strong tail wind

Taking into consideration the presence of obstacles near the flight deck, strong tail-wind conditions (area D in Figure 17) can create a hazardous situation. Moreover, such wind conditions result in large helicopter pitch-up angles reducing pilots view over the flight deck. For these reasons strong tail-winds (above 10 kts) should be tested with extreme caution. When areas of the land-based relative-wind diagram in which either of the hazardous conditions may occur are left out, a candidate ship-operation-relative-wind diagram results of which an example is shown in figure 23. It should be noted that such a diagram results from measurement of the ship's environment, helicopter performance measurements and analyses. Whether or not the diagram can be used operationally has to be determined by means of dedicated flight tests. To determine those areas in which testing has to be carried out an evaluation (also based on the measurements and analysis mentioned above) of the following conditions, where difficult and demanding situations will occur for the pilot, has to be made.

Fig. 22 Spray resulting from downwash and recirculating airflow

7.9 Blade sailing

Especially helicopters with a fully articulated main rotor system are subjected to blade sailing during rotor start up and/or shut down in a turbulent/gusty wind environment. The problems associated with blade sailing are: tunnel and/or forward cockpit strike and the risk of decapitation of deck personnel.

There are no specific test procedures for this subject in the Dutch & British procedures. The only precautions which are taken during flight testing are:

- never exceed manufacturer's limitations and
- start up and shut down main rotor in optimal obtainable wind and ship motion conditions during flight testing.

In practice, this problem has not been met in the Dutch nor in the British experience.

7.10 Hot exhaust gas ingestion

Another factor that affects helicopter performance is hot exhaust gas ingestion. There are two types of shipboard problems associated with hot exhaust gas.

The first is the helicopter ingesting hot gases from the ship propulsion or energy generating systems. During wind-tunnel testing on a ship's model and during full-scale wind climate testing (Chaps. 6.2 and 6.3) close attention is paid to this subject.

The second is the helicopter re-ingesting its gas turbine exhaust due to recirculation.
Helicopter problems may be a result of a combination of the two. Hot exhaust gas ingestion decreases the helicopter’s available power.

7.11 Pilot field of view and visual orientation

Field of view analysis in preparation for a shipboard flight test is usually not a critical issue unless the test helicopter is a prototype or the purpose of the test is to evaluate a new deck marking configuration for ship-borne operations.

Visual cues provide the pilot with situational awareness and the ability to manoeuvre the helicopter over the landing spot. The situational awareness can be degraded by several factors.

At high cross-winds from port, during fore and aft landing from port, the helicopter will bank to the left (port). On the other hand the ship's list will be over right (starboard). This results in a deteriorated pilot's view over the flight deck (Fig.17 Area C).

When operating in high tail winds the increased nose-up attitude of the helicopter will also result in a deterioration of pilot's view.

Other factors that will degrade the pilot's view of the flight deck during approach and hover are the salt spray generated by the ship's hull (Sect. 5.7) and by the recirculation of the downwash of the rotor in low relative wind speeds.

Degradation of pilot's view and visual cues will result in a high to unacceptable pilot's workload and is a limiting factor for helicopter ship-borne operations.

7.12 Approach aids

Shipboard lighting, if not properly managed, can pose a significant problem at night to a pilot approaching the ship in darkness. Normally for night flying operations a "darkened ship" routine is maintained, which implies that all exteriour lighting is switched off, ship's navigation lights are dimmed if necessary and only flight essential lighting is on. In the Royal Netherlands Navy and Royal Navy this consists of:

- A glide slope/path indicator (GSI or GPI). The GSI is a semistabilized indicator showing vertically a green sector with an inclination between 2 deg. and 4 deg. for the correct 3 deg. glide path. Above 4 deg. it shows amber and below 2 deg. it shows red. The horizontal sector is 15 deg. centred around the (predetermined) approach line to the ship.
- A fixed horizon bar consisting of fixed dimmable white bulb lights which are mounted above the hangar door.

7.13 Piloting skills

Controlling the helicopter in the conditions encountered during ship-board operations is a demanding job. The workload depends both on the helicopter flight characteristics and on the amount of ship (flight deck) motion, the turbulence level encountered, the view over the flight deck, visibility and lighting conditions (day or night). In this highly dynamic environment the workload of the pilot may become too high, and conflict with the flight safety. Excessive workload situations may result in further or additional operational limitations. To evaluate the dynamic behaviour of the helicopter/pilot combination in the complex turbulent environment of the moving flight deck of a ship, the execution of actual flight tests is the only means available at present. To establish optimal and safe limitations it is crucial that the tests are carried out by pilots with maximum experience in ship-borne helicopter operations. Apart from that the "test" pilot has to take into account the capabilities and skill of the "average' pilot who has to operate up to the limitations which are produced.

Although during the qualification flight tests the pilot is backed up by recordings of the helicopter performance and behaviour, his opinion remains one of the most important contributions to the process of determining operational limitations due to high workload and dynamic response effects.

Furthermore the safety of the flight testing ultimately rests on his ability to properly judge the severity of the actual conditions in which the testing takes place.

7.14 Candidate flight envelope

The relative wind envelope in which the "difficult" areas are indicated, is the basis for the flight test programme to be carried out on board the ship. It is shown in figure 23.

At high relative wind speed from ahead, the accompanying turbulence (moderate to heavy; area B) and especially the large pitch amplitudes of the ship need much control effort of the pilot which might result in such large power variations that the maximum allowable continuous torque is often exceeded. Besides, the presence of spray and exhaust gas (areas C, D), reducing the pilot's view over the flight deck, increases his workload even more. Hot exhaust gasses above the flight deck and along the helicopter flight path close to the ship, have a similar effect on the helicopter rotor and engine performances as increased density altitude.

At low relative wind speeds, high power and large control inputs are required to precisely control the helicopter, while the ship's stabilization system being generally less effective causes additional control inputs (areas A, C & E) to correct for ship motions.

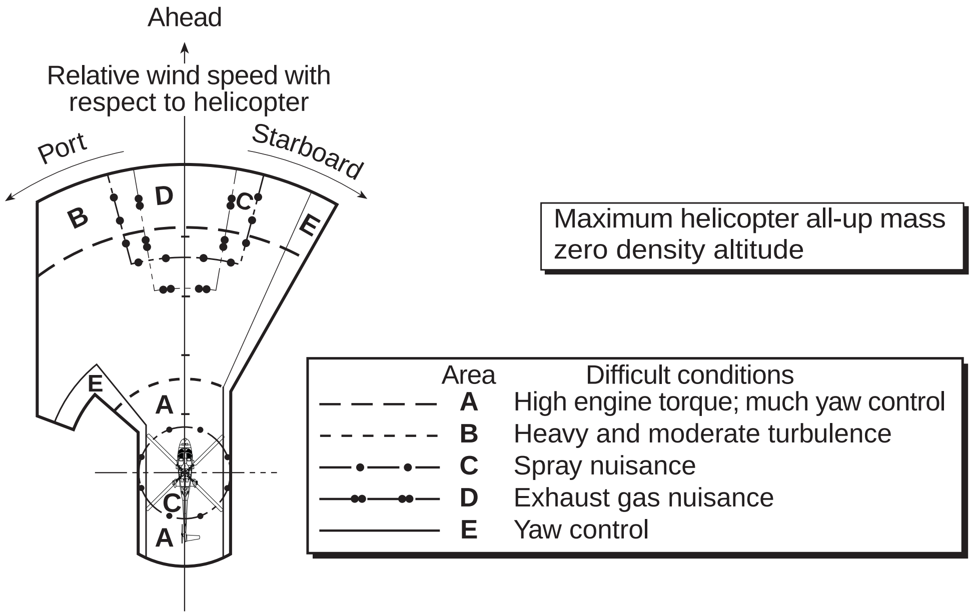


Fig. 23 Candidate flight envelope to be tested o/b a ship

The candidate relative wind envelopes for ship-borne testing, based on the manufacturer's low speed flight envelope (Fig. 16), are divided into various aircraft mass bands for each type of landing to be evaluated (Sect 4.2.1). Generally speaking, an aircraft will have a wider (larger) operating envelope at light all up mass (AUM) than at heavy AUM due to reduced control and power margins as the helicopter mass increases. The aircraft mass bands are decided upon before any trials take place and depend upon the particular aircraft. The aim is to produce 4 to 5 bands covering the range of masses at which the aircraft will be required to operate. This range normally extends some way beyond the maximum permitted AUM of the aircraft to account for non-standard atmospheric conditions. The test mass, calculated in terms of $M/(\sigma\omega^2)$ (mass divided by relative density and rotor speed ratio squared) is referred to as CORRECTED MASS. The trials are conducted at various values of $M/(\sigma\omega^2)$ and used to produce the "corrected envelopes" which are issued by the operators.

8. Testing

8.1 General

This section gives a brief description of the tests to be carried out in a qualification programme.

8.2 Wind tunnel tests on a scale model of the ship

Wind tunnel tests on ship models are carried out to determine the airflow characteristics (airflow deviations with respect to the undisturbed oncoming relative wind, turbulence) above the flight deck and in the possible approach paths of the helicopter to the ship as function of the relative wind. The relative wind is the wind vector resulting from the true wind and ship's course and speed. Furthermore the ship's exhaust plume paths and prediction of plume temperature (by plume dispersion measurement) as a function of ship's power settings and relative wind conditions are determined. Finally the position error of the ship's anemometer is determined which is, apart from the instrumentation error of the anemometer, needed to establish the relation between the undisturbed relative wind conditions and those prevailing above the flight deck and at the helicopter approach paths.

An example of a wind tunnel investigation on stack and funnel design in relation to smoke nuisance, is presented in figure 24. The figure shows the original design (bottom part) and the proposed design determined from the wind tunnel investigation. Both situations presented are for identical head wind and exhaust gas dispersion.

Note:

By carrying out these tests in the design stage of the ship it is often possible to determine that, by a small change to the superstructure the airflow patterns above the flight deck can be improved and the exhaust gas nuisance can be decreased, so that costly modifications of the existing ship may be prevented. The same holds for the position of the ship's anemometers on a yard of a mast and in relation to other sensors.
Furthermore one must keep in mind that an optimum stack/funnel design for flight operations does not automatically include an optimum for Infra Red Signature and/or Radar Reflection Cross-Section, so often compromises have to be made.

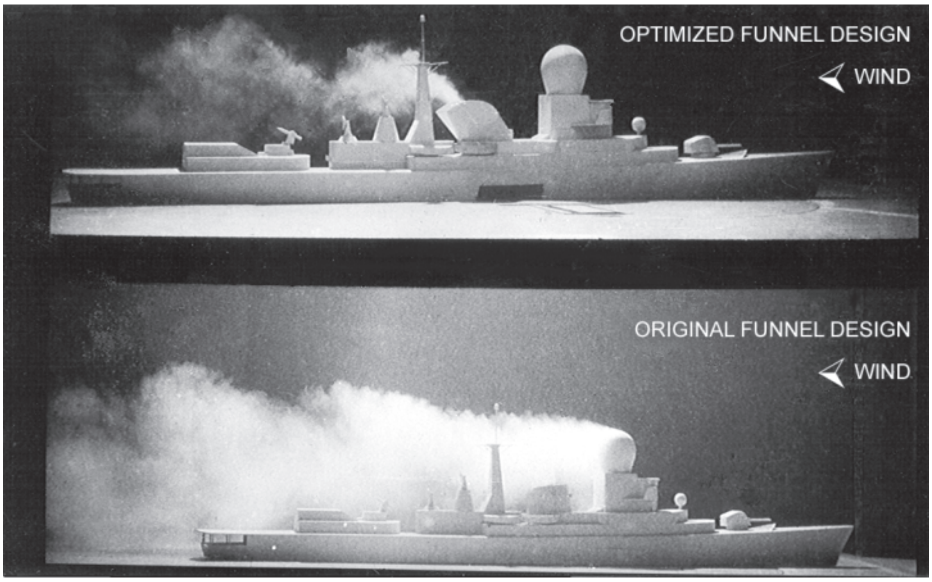


Fig. 24 Stack & exhaust gas nuisance investigation on a wind tunnel model

8.3 Full-scale ship's wind climate and motion tests

Wind climate tests on board the ship are carried out to verify the wind-tunnel test results concerning the air flow characteristics above the flight deck. For these tests two movable masts with wind measuring systems including temperature probes and data acquisition units are used. One mast contains one measuring and acquisition system at 3m height above the flight deck. The second mast contains two systems at heights of 5 m and 10 m above the flight deck (Fig. 25). With the established relation between the wind tunnel test results and full-scale ship test results, the real wind climate in the various helicopter approach paths and over the flight deck is predicted.

The instrumentation error of the ship's anemometer is determined and the position error, as established during the wind tunnel tests, is verified. With the information obtained, an unambiguous relation between the anemometer readings, the air flow conditions above the flight deck and in the helicopter approach paths and the undisturbed relative wind condition is determined.

Ship motion characteristics (pitching, rolling and heaving motions) are determined as a function of sea state, wave/swell direction and ship's speed. Examples of results concerning ship motion, turbulence, exhaust gas and spray above the flight deck have been discussed and presented in chapter 5 (Figs. 19-21).

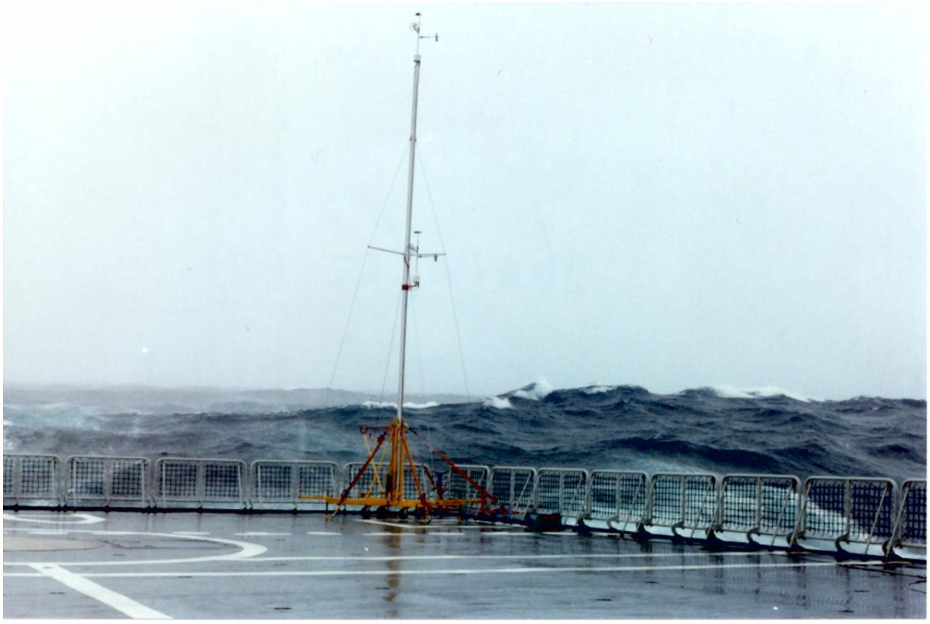


Fig. 25 NLR moveable mast as used during ship airwake measurements

8.4 Helicopter

From the analyses described in the previous chapters a number of take-off and landing procedures result, with for each of these a candidate relative wind diagram (see example in Fig. 26).

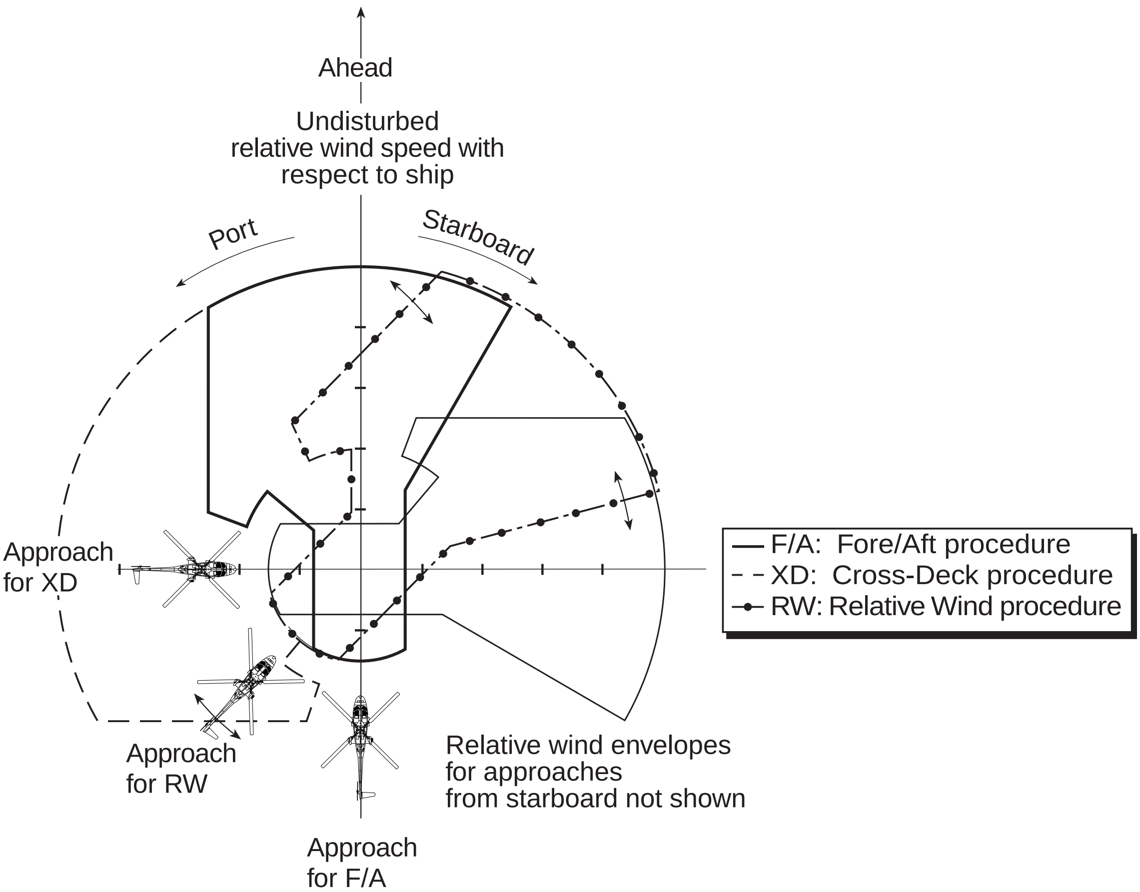


Fig. 26 Composition of possible wind envelopes for various helicopter approach headings with respect to the ship

These diagrams then are combined to form a candidate helicopter-ship operations envelope. Since overlaps of the relative-wind diagrams for the various procedures will occur, a choice is made, taking into account the relative size of each of the overlapping sectors (maximizing the ship-borne operations envelope) and the expected ease of operating the helicopter. The trade-off is made, using operator requirements, engineering and pilot judgement. An example of a typical Dutch candidate helicopter-ship operations diagram is shown in figure 27.

Using ship anemometer calibration data, obtained during wind climate measurements, this operational envelope is related to relative wind indications available on the ship in relation to actual wind conditions above the flight deck. An example of such an envelope (valid for the fore/aft procedure Fig. 23) is shown in figure 28.

This candidate operational envelope will contain a number of areas for which the analyses indicate a requirement for testing. The problems that may occur are identified and the test procedure and instrumentation, required to investigate these areas safely, are determined.

These areas result in a total number of conditions, which all are preferably to be tested.

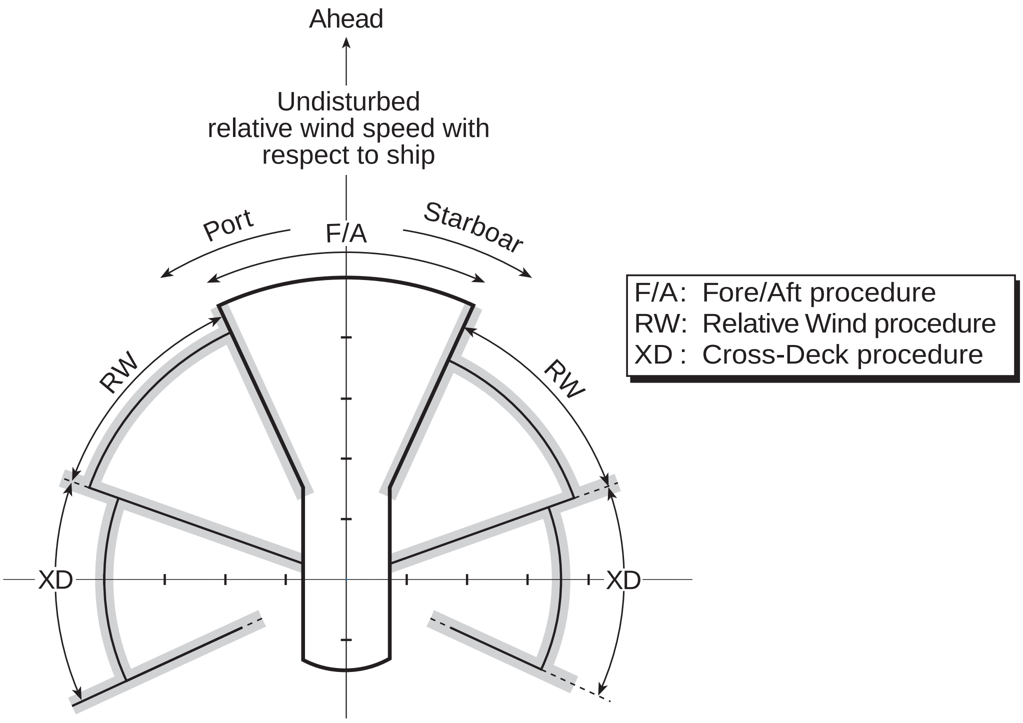


Fig. 27 Resultant candidate relative wind envelope to be tested during helicopter flight testing on board the ship.

Since the flight-testing is to be carried out on board a ship in a limited period of time, the exact conditions at which tests can take place cannot be determined beforehand. Conditions that will be tested depend on the sea-state and wind conditions that are present in the area where the tests are taking place. Of course, the area and time of the year are selected to maximize the probable occurrence of the desired test conditions. However, this still usually does not provide the experimenter with a free hand to vary his test conditions at will.

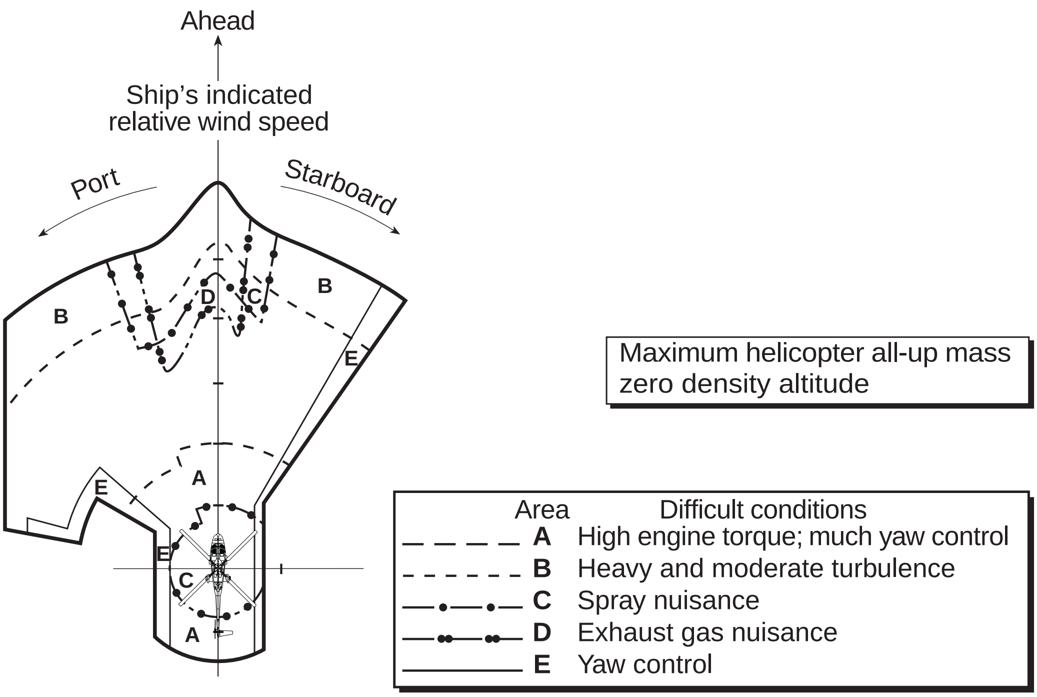


Fig. 28 Relative wind envelope for fore/aft take-off and landing to be tested o/b the ship, corrected for ship anemometer system

8.5 Flight testing

As evident from the previous paragraph, the flight-test programme has to be defined in an interactive way during the testing period. The actual execution of the flight-test programme is governed by two main aspects:
- safety
- efficiency.

Safety is principally obtained by starting the flight tests in conditions easy for aircraft and ship personnel, leading to test team familiarization:
- low helicopter mass
- relative-wind conditions well inside the boundaries of the candidate relative-wind envelope (no "tough" conditions; e.g. Fig. 28)
- fore/aft procedure (the easiest)
- fair weather
- first by day, later on by night.

After a thorough familiarization, efficiency is obtained by making adequate use of the information that becomes available during the flight tests and by analyzing, on board the ship, that information in conjunction with the data base obtained prior to the flight tests. Thus maximum use is made of the information obtained from the tests, and the number of test flights required can be minimized.

During the test period the selection of test conditions is a major task. Based on the analyzed results of the tests that have already been carried out, a number of alternatives for the next test condition are defined. This exercise is carried out in parallel for test conditions related to each of the potential problem areas of the candidate operational envelope, thus yielding a large selection of usable test conditions. The choice of the next test condition then depends on the available forecast wind/sea state conditions in the area within reach of the ship. Problems like judging the reliability of weather forecast versus time of the ship to travel to the area of interest are to be solved.

Given certain environmental conditions (wind, sea state, temperature) a number of conditions can be created by changing ship speed and heading relative to the wind (relative wind conditions) and waves (flight deck motion), although these cannot always be changed independently. The only parameter that can be changed independently appears to be helicopter mass.

Clever use of information obtained on board, in conjunction with thorough knowledge of the factors that limit operations, is used to minimize the problems created by the difficulty to establish the most desirable test conditions. Often it is not a matter of demonstrating the capability to operate the helicopter at the condition specified, but to obtain data at differing conditions and interpolating or extrapolating the results to the conditions required.

The following data are normally acquired during the tests:
- actual data of helicopter parameters:
  - engine torques
  - control deflections
  - pitch and bank angles
  - heading
  - radar altimeter
  - doppler velocities
  - engine inlet temperature
  - type-dependent additional parameters

- actual data of ship parameters such as:
  - speed
  - heading
  - wave/swell direction (estimation)
  - pitching and rolling angles
  - anemometer readings (relative wind condition)
  - stabilization data
  - propulsion mode
  - vertical and lateral acceleration at the flight deck

- pilot's comment on workload, influenced by:
  - take-off and landing procedure
  - ship's motions
  - turbulence
  - view over the flight deck
  - spray and exhaust gas nuisance.

Pilot's workload is expressed in the following adjectival rating scale:
- low
- high
- just unacceptable
- beyond unacceptable

Note that two types of data become available: quantitative data on helicopter performance and ship behaviour, and qualitative data on pilot workload and helicopter controllability. The latter should be referenced to the average pilot skill level.

Within the constraints imposed by the environment in which the tests have to be carried out, all effort is made to carry out the testing as efficient as possible. To this end the nominal procedure as depicted in figure 29 is used. For each condition tested, the results are evaluated and subsequently the required increase in severity of the conditions of the next test condition is determined. Of course in this process both engineering insight and flight technical skill (of the pilot) is involved.

With the knowledge available in advance and the data obtained during the previous test flight, the influence of a given test condition on the helicopter limitations can be predicted rather well.

A prediction of the increase in pilot workload is only possible to a certain extent. If, for example, the workload in a certain condition is "low", the permitted increase in difficulty of the next test condition will be greater than in the case for "high" workload. The same rule is applied (in reverse) in the case a condition is considered "unacceptable". If it is "beyond unacceptable" (occurring sporadically), a large decrease in difficulty is applied whereas if the condition is considered "just unacceptable" a small decrease in difficulty is applied. With the application of these prediction methods, good engineering judgement and the experience of pilot and test team, the number of flying hours can be reduced to a minimum, and a maximum of results will be obtained in the shortest possible time.

Typical rating scales for a specific helicopter type, as used in the UK are shown in tables 3 and 4. Each take-off and landing is assessed for control and power margins as well as pilot handling qualities.

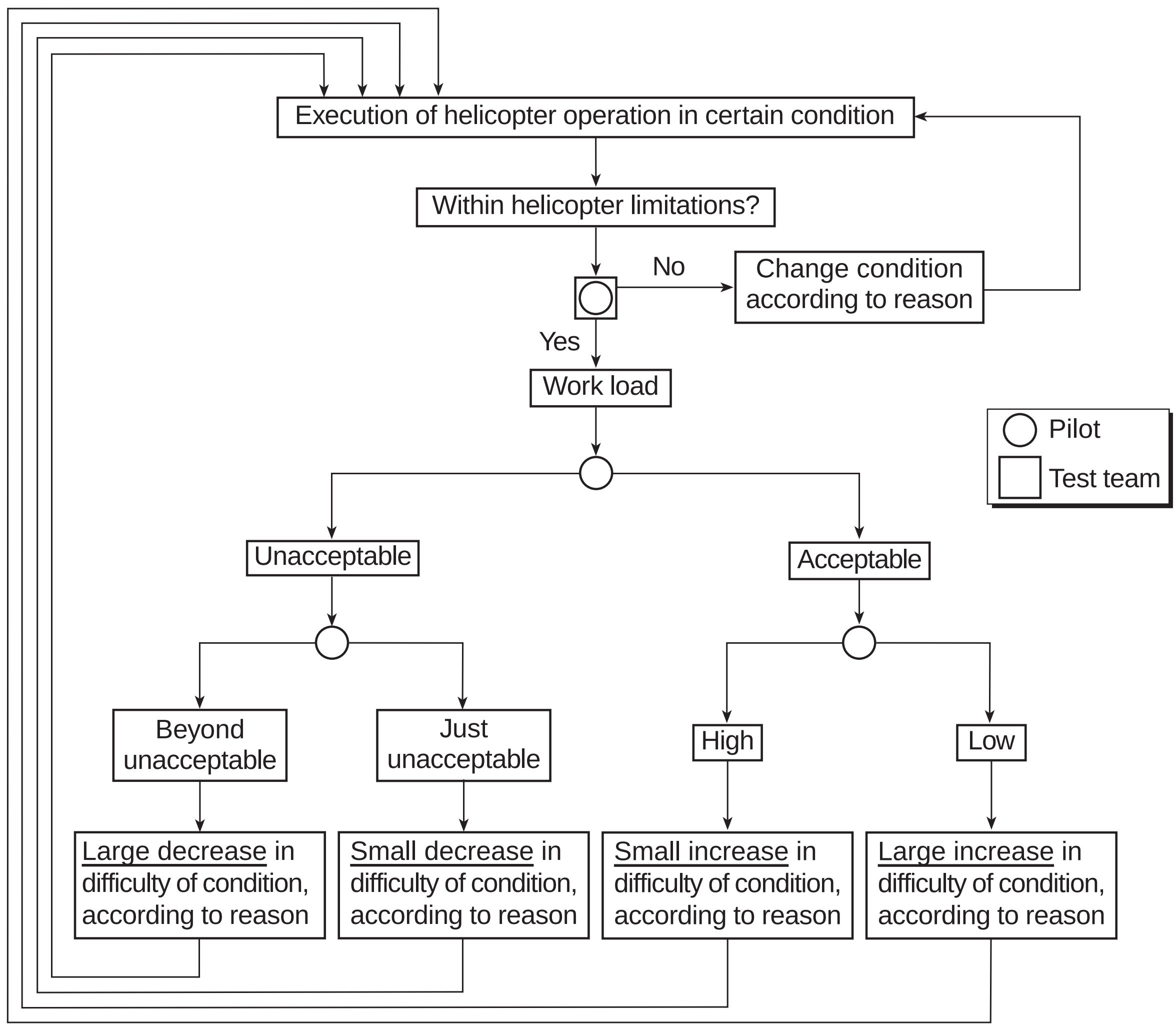


Fig. 29 Flight test procedure o/b the ship

The assessment of control generally means the evaluation of tail rotor pitch or rudder pedal margins where it has been determined that cyclic and collective margins are adequate. Power is evaluated using torque values, thus the rating scale is based on indicated torque values in relation to transmission or engine limits.

In table 3, it can be seen that five-point scales are used. It can also be seen that both mean and maximum torque, pedal and cyclic values are rated. The more limiting value is used to assess the take-off or landing.

Torque and tail rotor considerations on their own are not adequate to cover all eventualities, and it is necessary for the pilots to assess the handling difficulty or workload associated with a take-off and landing.

For pilot handling a six-point scale, as given in table 4, is used.

To attempt to assess all wind conditions at all masses would be a very large if not untenable task. The philosophy therefore allows for this by permitting landings at different masses to be read across (extrapolated) to other procedures. However, there are rules for this and not all take-offs or landings can be read across.

In essence take-offs or landings which are rated as unacceptable at low mass (>4 on the rating scale) are also read up to higher masses as unacceptable. Take-offs or landings which are rated as acceptable at high mass (3 or less on the rating scale) are read down to lower masses. The reasoning behind this is perhaps obvious; an easy landing at high mass is also likely to be easy (if not easier) at a lower mass. Equally a landing which is rated as unacceptable at low mass because of lack of power or control margins will not be any better at a higher mass and the same is considered to be true of handling issues. This provides a rational basis for expanding the evidence available at any one mass without conducting a particular test point at that mass.

Table 3: Torque, Pedal & Cyclic Rating Scales

RATING	MEAN %	PEAK %
TORQUE		
1/2 3 4 5	< 95 95-98 89-100 > 100	< 105 105-110 110-115 > 115
PEDAL	POSITION	
1/2 3 4 5	> 12 12-10 10-5 < 5	> 10 10-5 5-0 0
F/A CYCLIC	POSITION	
1/2 3 4 5	> 20 20-16 16-14 < 14	> 10 10-15 5-2 < 2

NOTE:

Ratings of 1 to 4 are acceptable; rating 5 is unacceptable.

Table 4: QinetiQ Pilot Rating Scale

Rating	Description	Explication
1 2	NO PROBLEM SATISFACTORY	Minimal pilot effort required resulting in an easy task. Landing carried out with low pilot workload.
3 4	LIMIT(S) APPROACHED OR REACHED	Safe landings can be carried out, but limits of power etc approached or reached; pilot workload moderate. Situation becoming difficult due to one or more factors. These points define the fleet limits recommended by QinetiQ.
5	UNACCEPTABLE	Test pilot able to land helicopter under controlled conditions, but limits of power etc are exceeded. High pilot workload.
6	DANGEROUS	Test pilot attempting the landing causes aircraft limitations to be exceeded. Excessive pilot workload.

8.6 Drafting SHOLs/Constructing Wind Envelopes

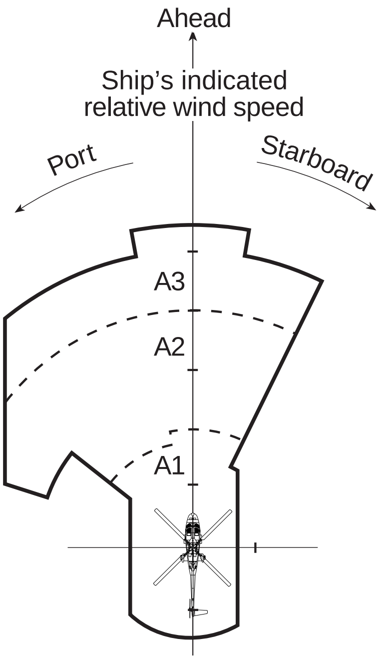
The operational wind envelopes are drawn up around the acceptable test points attained during the trials. When constructing the wind envelopes, ratings of 1-3 are included, ratings 5/6 are excluded. Rating 4 denotes the limit of acceptability in each case. Where necessary the envelopes are rationalised in the interests of simplicity. The complete SHOL comprises both the wind envelopes and the ship motion limitations.

Different envelopes are produced for use by day and by night. The main difficulty with landing at night is due to the scotopic vision of the human eye in these conditions. At low light levels the visual acuity of the eye is degraded so that distance and hence speed/closure rate are difficult to judge. For this reason winds from astern are not cleared for night operations, because Boscombe Down experience has shown that there are too many errors of judgement leading to overtorqueing and/or overshooting the approach. In general this is the only difference between day and night wind envelopes, but during tests at sea it is assessed, to ensure that other areas can be included at night. The deck motion limits applied at night might also be somewhat lower than those permitted by day.

9. Establishment of Helicopter Operational Envelopes for Ship-borne Operations

At the completion of the flight tests on board the ship, a fair idea about the operational limitations has usually been obtained. For final results, measured data (of helicopter and ship) together with pilot's comment are analysed in detail. The operational limitations are presented in the form of graphs. Examples of these graphs are given in the figures 30 and 31.

In figure 30, limitations are given for the fore/aft take-off and landing procedure while in figure 31 the result is shown for the total relative wind envelope optimized within the constraints of safety and maximum operational usability of the helicopter.

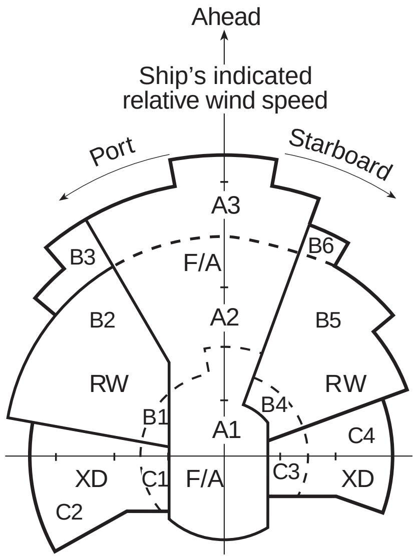


Allowable helicopter mass and ship's oscillations			
Area	Percentage of max. Helicopter all-up mass	Amplitudes of ship's oscillations	
		Pitching (deg)	Rolling (deg)
A1	94	3.0	9.0
	97	1.0	1.5
A2	100	5.0	9.0
A3	100	5.0	7.0

Zero density altitude

Fig. 30 Take-off and landing limitations for fore/aft procedure (NL-presentation)

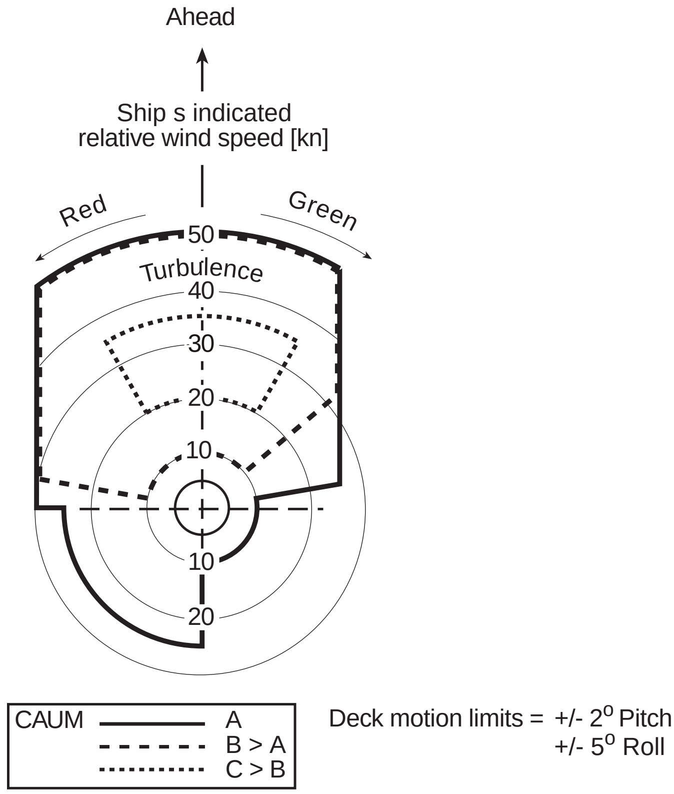
Following the determination of acceptable wind envelopes and ship motion limits, the SHOLs for a range of aircraft Corrected All Up Mass (CAUM) are issued to the operators, together with advice concerning modifications to the ship such as improved deck markings or lighting and any warnings about turbulence. Should any helicopter deficiencies have come to light during the trials then these would also be brought to the attention of the appropriate authority. An example of an operational SHOL diagram is shown in Figure 32.



Allowable helicopter mass and ship's oscillations			
Area	Percentage of max. Helicopter all-up mass	Amplitudes of ship's oscillations	
		Pitching (deg)	Rolling (deg)
A1	94	3.0	9.0
	97	1.0	1.5
A2	100	5.0	9.0
A3	100	5.0	7.0
B1	94	2.0	8.0
	97	1.0	1.5
B2	100	5.0	9.0
B3	100	4.0	9.0
B4	94	1.5	6.0
	97	1.0	1.5
B5	100	3.5	8.0
B6	100	3.0	6.0
C1	94	2.0	7.0
	97	1.0	1.5
C2	100	5.0	8.0
C3	94	1.5	5.0
	97	1.0	1.5
C4	100	3.0	6.0

Zero density altitude

Fig. 31 Limitations for daytime operations (NL-presentation)



Aircraft type 2BC - Ship class F

Day forward facing
Port & Starboard approach

Fig. 32 Limitations for daytime operations (UK-presentation)

10. Simulating the Helicopter/Ship Interface

10.1 International research activity

So far this AGARDograph has described the process of determining SHOLs using a combination of wind tunnel, land-based and ship-based testing. Neither the Dutch nor the UK Test Agencies currently make use of any related simulation capability. With the increasing defence budget constraints now facing many countries, it is appropriate to undertake a review of simulation approaches to the determination of SHOLs to see if there is a more cost-effective way of achieving the same end result.

The defence research community, both in the UK and abroad has, for some years, been actively pursuing a programme of work aimed at developing helicopter/ship dynamic interface simulation. The results of this work, once it is seen to be sufficiently mature, could be of great benefit to the Test and Evaluation (T&E) community. In the UK, QinetiQ has played a leading part in this international collaborative effort, whose aims are to:
- improve existing helicopter and ship models
- develop common data formats
- share trials data and research findings
- develop and promote common pilot rating scales
- invest in model fidelity and validation issues
- encourage an exchange programme of both test pilots and engineers for both simulator and flight trials

Over the past few years research conducted at QinetiQ’s Bedford site, utilising the Advanced Flight Simulator (AFS), has been directed at improving ship motion models, ship air-wake and turbulence modelling, visual scene content and development of improved helicopter mathematical models. The research activity is aimed, at some future date, at being able to carry out some ship/helicopter compatibility testing using simulation. For example, simulation could be used to indicate potential 'hot spots' in the ship/helicopter operating envelope. Subsequent flight tests could then be concentrated in and around such areas, thereby reducing flight test time, easing the difficulties of ship availability and the vagaries of the weather and increasing the effectiveness of sea trials.

In a SHOL these ‘hot spots’ are identified on the basis of helicopter power performance and controllability as a function of mass and density altitude and wind relative to the helicopter. The determination of the wind relative to the helicopter is obtained by using the air flow data from the wind tunnel testing on a ship’s model and/or full scale wind flow measurements on board the trials ship. An outcome of this research could, in the future, bring significant benefit to the Royal Navy, in terms of the cost of the helicopter/ship flight test clearance activity and in providing dedicated ships for trials.

10.2 Modelling ship motion

The application of improved ship motion modelling could provide T&E with an important tool in the determination of future ship motion limits for SHOLs. Although ship designers are carrying out research programmes to improve the ship stabilisation systems in order to decrease the severity of ship motions, such motion is and will continue to be an important feature of helicopter deck operations. Pilots must take off and land inside limits promulgated by the helicopter Design Authority to ensure that structural, and other limits are not exceeded. In a simulator this means that a realistic presentation of ship motion is very important. The wind direction and speed, the direction that the sea is running and the ship's speed are all important parameters. To date this area has received little specific attention, primarily because deck landing was not part of the usual suite of tasks for naval helicopter training simulators. Most current simulators either provide simple harmonic motion driven models or crude models using a small number of superimposed sine waves. A 'real wave' environment can be complex because it can consist of a long wavelength swell, induced by a wind that has been blowing, perhaps a few hundred miles away, in combination with a locally generated wave system induced by the local wind. Although a given wave environment may have been generated by a complex set of events, waves at a given time and point can appear to be like a series of superimposed sine waves.

Experience has shown that ship motion time histories often show the appearance of lulls when the ship experiences a period of low motion activity. It is these lulls, or quiescent periods, that pilots take advantage of to launch or recover the helicopter. Clearly it is important that any simulation of ship motion should include such quiescent periods as well as the characteristic amplitudes of movement and the associated frequency.

UK ship motion modelling has concentrated on employing time history data, produced using a non real time computer model, replayed in real time for simulation trials. Typically the data used in the QinetiQ AFS covers 20 minutes of motion in pitch, roll, yaw, heave and sway. To date this simulation has been adequate for the tasks being performed.

It would also be possible to use real ship motion data in simulators such as the AFS. In the Netherlands ship motion data are collected during full-scale wind climate measurements. These data are stored in digital form. For a given sea state and wind condition various runs are made for two to three ship speeds and different headings. In a joint international exchange and research programme these data could provide a significant input to improving current ship motion modelling.

In the UK real ship motion data is only currently available in limited quantities for a few conditions, although data collected over the last ten years during Boscombe Down SHOL trials may be of the right quality to add to this database. The same problems apply with using real data as with computer generated data in terms of flexibility, data storage space and the limited number of available conditions.

10.3 Ship air wake modelling

Operations of helicopters from ships present a demanding task for both pilot and aircraft. Simulation of helicopters, particularly in the low speed regime is also exacting. Understanding and being able to accurately model the airflow patterns above and around a ship, in conjunction with a ship model and then introducing a piloted simulation of a helicopter at the ship interface, remains one of the major challenges facing the defence research community.

In any such helicopter/ship simulation, ship air wake and turbulence modelling plays a major role in performing deck operations. Until recently the simulation community had given little attention to generating realistic air wake and turbulence models. This was because other deficiencies, such as the visual system, meant that deck operations could not be conducted effectively in a simulator. The position of the flight deck at the rear of a small ship and the close proximity of superstructure results in a turbulent environment with many updraughts, downdraughts and vortices. These all impact with the helicopter causing both low and high frequency effects for which the pilot has to compensate, so increasing workload and influencing pilot control strategy. The relative wind speed and direction around the flight deck and superstructure dictates the degrees of disturbance. An additional consideration can be the effect of hot exhaust gases from ships' funnels.

Over the past few years in both the UK and the Netherlands, work has been undertaken to improve the measurement and prediction of the airflow around ships, particularly around the area of the flight deck. Wind tunnel models, mathematical modelling and simulation techniques can all be used to predict the airflow pattern around the ship. It is hoped that the eventual outcome of this work will be improvements in the prediction of airflow patterns, thus allowing ship designers to tailor the airflow in the flight deck area, in order to maximise the operational capability of ship based helicopters. In order to provide feedback so as to improve the airflow prediction techniques it is necessary to measure the airflow both on the flight deck and on the final approach flight paths. Measurement of the airflow over the flight deck is fairly straightforward, and is achieved with the use of a number of anemometers placed at selected positions over the deck. Measuring the airflow further away from the ship is more difficult and is best achieved with some form of remote sensing system. Laser anemometry is one such system.

In the Netherlands, ship airflow wind tunnel data has been validated on board all the ships tested in the wind tunnel. NLR have 100% confidence in the wind tunnel data as the correlation between full-scale air flow test and wind tunnel is higher than 95% (measuring positions over the flight deck). NLR also considers that the data obtained in the wind tunnel for the various approach paths close to and far behind the ship would have the same reliability.

In the Netherlands the results of wind tunnel testing are used by various organisations. The ships' designers use the data to tailor the ship's structure in order to maximise helicopter operations in terms of airflow disturbances and hot exhaust gas nuisance generated by the ship. Furthermore they use the data for proper positioning of air intakes. NLR flight test engineers apply these data to draw-up test programmes and to provide the operator with preliminary SHOLs for first training and acquaintance with a new ship. As with the ship motion data, the ship airflow data are stored in digital form. In a joint international exchange and research programme this data could provide a significant input to improving current ship air wake modelling. The Dutch methodology could well be used in the current US laser anemometry research programme and could also contribute in the simulation investigation.

10.4 Helicopter simulation

Helicopter simulation has been the subject of significant effort over the past 20 to 30 years. In common with fixed wing simulation great advances have been made with regard to the use of motion and visual cueing. The task of the helicopter simulator designer is, however, not an easy one. Helicopters are inherently less stable than their fixed wing equivalents. This along with dynamic coupling of all axes makes for a more complex model than is required for most fixed wing applications. Additional technical challenges arise from the fact that helicopter pilots have a significantly greater field of view, and require greater visual detail (e.g. low level texture of trees and grass) than fixed wing pilots in order to obtain representative visual cues.

In order to reduce the number of calculations, and thereby increase the speed of the simulation, designers have, in the past, been forced to cut corners and make compromises. For example instead of modelling the airflow of each rotor blade some simulators use blade element modelling for one blade and assume symmetry for all the others. Compromises such as this can cause the simulator to behave differently in different flight regimes; in these cases it is common for the designer to build in 'fixes' for specific areas of the flight envelope and in some cases individual manoeuvres. Whereas this is adequate for training purposes; it is currently considered insufficiently accurate for test and evaluation.

Further advances in helicopter simulation may reduce the time and effort currently required for SHOL trials by allowing the characteristics of the ship/helicopter interface to be examined prior to the flight trials. Any simulation used must be accurate in terms of flying characteristics, motion and visual cueing. In addition a means must be found to incorporate modelling of the airflow pattern (previously discussed) so that both ship and helicopter characteristics are represented correctly. It will be necessary for the ship and helicopter airflow modelling to be combined as the total airflow about the deck is significantly altered by the presence of the helicopter when it is close to the ship.

Improvements in the visual modelling of ships is also required before meaningful simulator T&E studies can take place. In the UK (at QinetiQ Bedford) the only ships currently modelled in the AFS are the Royal Navy's Carrier Class (CVS), the Type 23 Frigate and HMS Ocean, the Royal Navy's new Helicopter Carrier. Recent enhancements to the AFS's visual system have increased the pilot's field of view to 210 degrees (from 120 degrees) and the elevation field of view to the right to 210 degrees (from 48 degrees). These improvements have greatly improved the level of visual cueing available on the AFS.

10.5 Summary

In today's austere financial climate the test and evaluation community is under increasing pressure to reduce flight clearance costs, whilst continuing to provide the high standard of product that the customer has learnt to expect. Simulation techniques as outlined above, could be considered as one tool that has potential to support future SHOL flight testing. However, before simulation and modelling can be used by the T&E community to generate the evidence to underpin SHOL clearances, certain advances are required:

a) The scope of the air flow models must be extended to cover all areas now explored by flight testing. These must include the approach, landing, take-off and overshoot. Each air flow model must be validated to ensure the accuracy of the prediction throughout the required range.
b) The simulation must reflect the changes in airflow close to the deck caused by the interaction of the helicopter, ship's structure and the airflow.
c) Helicopter simulation must be improved to adequately represent the helicopter.
d) The helicopter model must be configured to react to the input from the air pattern model correctly. An independent validation must be made to ensure that the helicopter/ship simulation adequately replicate the characteristics of the helicopter in the ship environment.

11. Concluding Remarks

A description of the four step approach as applied by NLR in the Netherlands is given together with an outline of the aspects to be tested and the influences of various factors on each aspect. The programme build up is such that an operator can decide on the issues to comply with his requirements.

In the period from 1982 to 2002 the four-step approach has been systematically and successfully applied for eleven qualification programmes for agencies at home and abroad. Four types of helicopter and eight classes of ship were involved. Helicopter maximum take-off mass ranged from 4040 kg (8900 lbs) to 9715 kg (21400 lbs). Ship's maximum water displacement ranged from 485 tons to 17000 tons.

For three classes of ship the operational envelopes had to be adjusted due to mid-life modifications to the ship's superstructure. It was deemed necessary to perform some additional wind tunnel testing. Thereafter it was possible to estimate new operational envelopes, which were finally validated by means of flight testing on board. It showed that the applied methodology has led to the desired results.

In conclusion it may be stated that the qualification of helicopters for use on board ships can be carried out safely and efficiently when applying the methodology as described in this volume. The effort to be invested in the helicopter flight programme on board the ship is minimized by a thorough preparation, which consists of obtaining detailed information about the helicopter capabilities including experimental flight tests, ship's motion characteristics and the wind-climate above the ship's flight deck.

In the UK, The Royal Navy (RN) has been operating ship-borne helicopters on small ships world-wide for almost half a century. Starting in the mid 1950s, Boscombe Down has conducted ship trials using almost every helicopter type that has seen service with the UK Armed Forces, including the Whirlwind, Wasp, Wessex, Sea King, Scout, Gazelle, Lynx, Chinook and, most recently, the Merlin. The techniques used by the UK and described in this volume have been developed since the late 1960s and although refinements have been made, the same basic techniques have been used successfully and safely for nearly 30 years.

Annex A: Instrumentation as Applied by NLR

A1 Wind climate and ship motion full scale tests

During the wind climate and ship motion measurements NLR installs a data-acquisition and processing system on board the ship.

On-line processing is carried out to monitor the various parameters and to adapt the test programme if required.

A block diagram of the instrumentation set-up is given in figure A1. The list of parameters, as recorded during these tests is given in table A1.

In the following sections a brief description of the data acquisition and processing systems is given.

A1.1 NLR wind data acquisition system

The wind measurements are performed with low-inertia Gill-Young anemometer units. These units consist of three orthogonal propellers (UVW) and are used to measure the local wind velocities in three perpendicular directions. The units are sealed and incorporate internal blowers to maintain positive pressure within the unit to limit environmental contamination of the bearings.

In the base of each anemometer unit a temperature sensor is installed to measure the local air temperature.

A small, ruggedized and salt spray resistant Wind data Acquisition Unit (WAU) is developed by NLR. In this unit the analogue signals of the wind- and temperature sensors are multiplexed and converted into a digital form. Depending on the application, the digitizing process may include conversion to engineering units. Hereafter, the data is serially put out through a serial communication interface, following the RS-422 protocol, to the host processor system for logging of the data and further processing.

Although the wind sensor assemblies require 115 VAC power, for safety reasons the supply voltage to the data acquisition unit has been kept below 42 VAC. Therefore the required 115 VAC is derived from the input voltage using a step up transformer in the data acquisition unit.

A1.2 Wind measurements above the flight deck

The wind measurements above the flight deck are performed by means of a movable mast fitted with low-inertia Gill-Young anemometers at two heights (5 m and 10 m) above the flight deck and a WAU at the base.

The general procedure for collecting data is as follows. For a particular true wind the moveable mast is placed on a predefined position on the flight deck. This position is similar to a position as measured in the wind tunnel. Depedent on sea state a ship speed is defined and ship's heading is into the wind. Data are collected during a 5-minute period. After this period only the ship's heading is changed and again data are collected. After several changes in heading (approximately 210°) a new ship speed and heading is selected and data collection continues as described. The mast is then placed on a new position and the process is repeated.

A1.3 Reference system at the bow of the ship

As a reference position, for the calculation of the undisturbed relative wind the top of the jack staff at the bow is chosen.

A third set of Gill-Young low-inertia anemometers fitted with a WAU is used to measure the air flow at this position.

This reference position is chosen for the following reasons:
- Correction factors to be applied are known, as a calibrated system and position is used.
- Information is acquired to determine the atmospheric boundary layer correction coefficient.
- The air flow deviations, due to the presence of the ship are minimal over a wide range of azimuth angles.

A1.4 Information from ship system

The following parameters acquired from the ships's systems are (Tab. A1 & Fig. A1):
- Port indicated wind direction.
- Port indicated wind speed.
- Starboard indicated wind direction.
- Starboard indicated wind speed.
- The wind sensor selector switch position.

- Heading.
- Speed.
- Pitch angle.
- Roll angle.

NOTE:

Generally a ship is equiped with two anemometer systems providing redundancy and avoiding erroneous readings.

The afore-mentioned nine signals are fed into a computerized acquisition unit. The output of this unit to the NLR data processing system follows the RS-422 protocol.

A1.5 NLR data processing system

The NLR data processing system consists of two ruggedized personal computer systems. One system is used for data logging and storage and real time monitoring of various relevant parameters. The raw data are calibrated and are stored as engineering units on magnetic media (floppy disk) for post processing. The second system, which also provides quick look results, is used for on-line processing.

Table A1 Ship parameters recorded during wind climate & ship motions measurements

Parameter	Location	Range	
Velocity components UVW	Bow & Flight deck	0/50	m/s
Local temperature	Bow & Flight deck	-30/70	ºC
Indicated wind speed	Port & Starboard	0/60	m/s
Indicated wind direction	Port & Starboard	0/360	deg
Selected wind sensor	Port or Starboard	- - - -	
Atmospheric pressure	- - - -	900/1100	hPa
Ship speed	- - - -	0/50	m/s
Ship heading	- - - -	0/360	deg
Ship pitch angle	- - - -	+/-20	deg
Ship roll angle	- - - -	+/-30	deg

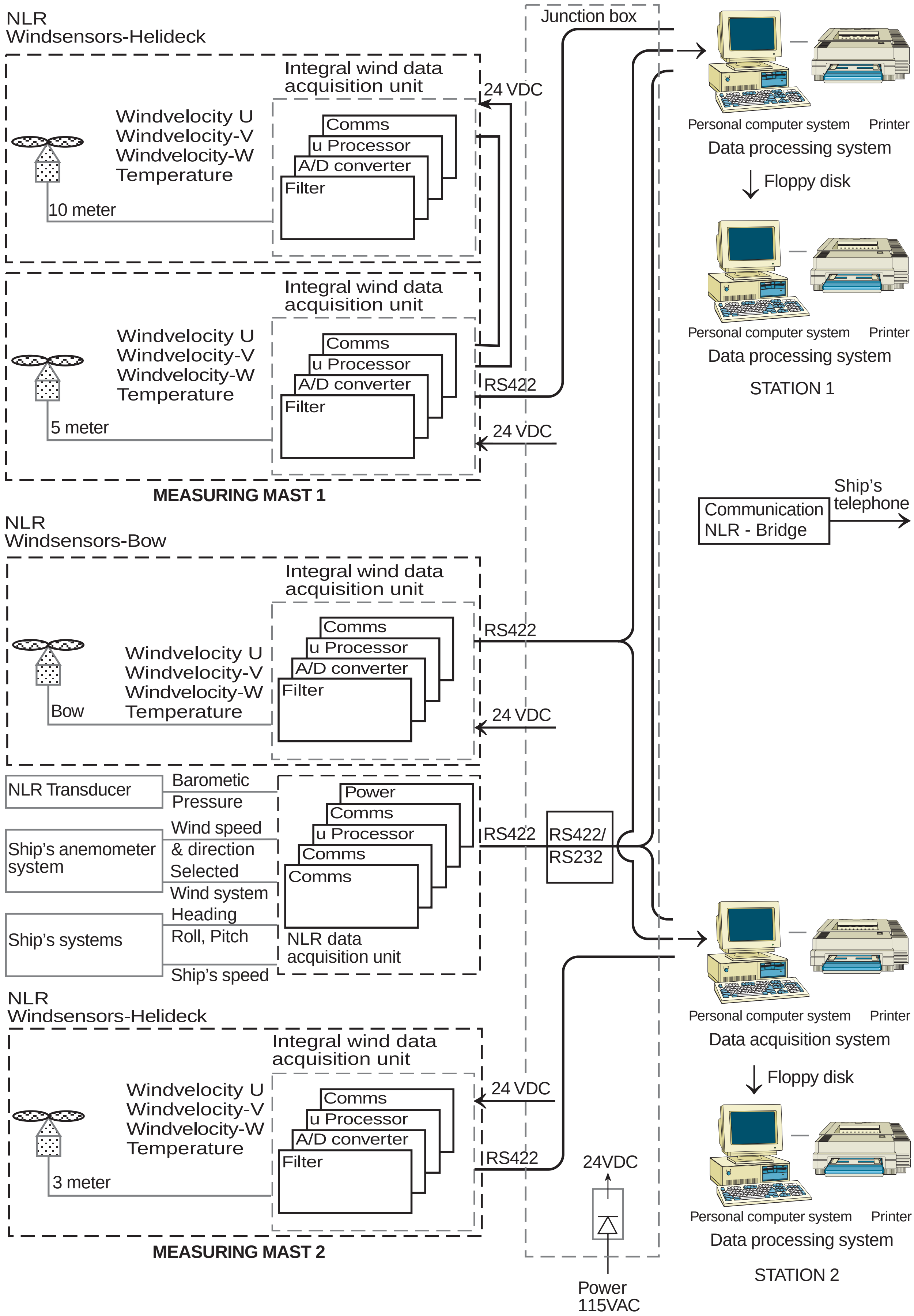


Fig. A1 Block diagram of wind climate and ship motion data acquisition and processing system

A2 Instrumentation in flight trials

In helicopter/ship qualification testing NLR instrumentation is used on board the ship and in the helicopter in order to record the required parameters. Simultaneously, quick look processing (Fig A2.1) is carried out to monitor the various parameters and to adapt the test programme if required.
The parameters as recorded in the helicopter are presented in table A2.

In the following sections a brief description is given of the instrumentation systems on board both the ship and the helicopter.

A2.1 Ship instrumentation

During the helicopter/ship flight trials, the NLR-data acquisition and processing system used, is based on the system used during the wind climate measurements (Annex A1). However, the movable mast is omitted. A block diagram of the instrumentation set up during the helicopter-ship qualification programme is given in figure A2.2.

Fig. A2.1 NLR o/b data acquisition and processing system

Table A2 Helicopter parameters recorded during flight testing

Parameter	Range	
Pedal position	+/- 100	%
Collective position	0/100	%
Cyclic Fore/Aft position	+/-100	%
Cyclic lateral position	+/-100	%
Heading	0/360	deg
Roll attitude	+/-360	deg
Pitch attitude	+/-360	deg
Doppler velocities:		
longitudinal (Vx)	-30/120	kts
lateral (Vy)	+/-40	kts
Engine torque Port & Starboard	0/180	%
Engine inlet temperature	-30/100	ºC
Radio altimeter	0/1000	ft

A telemetry system with a receiving antenna is added to receive real-time helicopter data transmitted by the instrumentation system in the airborne helicopter.

As back-up for the telemetry system, the helicopter data are also recorded on tape in the helicopter.

A2.2 Helicopter instrumentation

The instrumentation package installed on board the helicopter (upper left Fig. A2.2) is based on a standard instrumentation system as developed for flight testing with various helicopters. The major component in the system is the Remote Multiplexer/Digitizer Unit (RMDU). This RMDU scans all input channels, digitizes the analog channels and outputs them on one serial digital data-stream. In the RMDU a time code generator has been installed to maintain synchronization with the data recording on board the ship.

The data acquisition system in the helicopter acquires the parameters as listed in table A2.

To avoid signal reconstruction errors due to the sampling process it is necessary to remove unwanted dynamic components from the input signal by filtering. Also, some signal levels are too low for direct digitization by the RMDU and have to be amplified. Pre-sample filter cards as installed in the Pre-Sample Filter Unit (PSFU) provide these two functions. Next to the filter cards the PSFU can accommodate AC filter boards and/or frequency to DC voltage converter cards. These cards convert a frequency modulated square wave input signal into a DC voltage. The various signals, coming from the sensors in the helicopter have been applied to these two systems by means of a series of input connector panels.

The digital data-stream from the RMDU is transmitted to both a small data cartridge recorder for data storage and to a telemetry transmitter, transmitting the helicopter data to the ship's host processing system.

The instrumentation can be controlled by means of a knee-mounted remote control panel .

Potentiometers are mechanically linked to the collective and pedal levers to gather the movement of these controls. A pedal deflection display is installed in the cockpit. To measure the engine inlet temperature, a temperature probe is mounted on the helicopter cabin roof just forward of the starboard engine.

For the engine torque signals, split cables between the torque indicators and the torque comparator are installed. The other helicopter parameters are directly hooked up to the helicopter systems using terminal connections.

In order to connect helicopter systems, additional sensors and remote controls to the NLR instrumentation system, an additional wiring harness is temporally installed in the helicopter.

A2.3 Communication

Two-way voice communication between NLR and the airborne helicopter is provided by means of a VHF (130.1) air-band transceiver. Communication between the ship and helicopter on deck by means of a closed loop telephone system (“telebrief”) is monitored by NLR. Two-way communication between NLR - bridge and NLR -Opsroom is generally realized by telephone (ship's system). During the tests, use is made of the following communication links between the NLR observers/bridge/helicopter/FDO:

telebrief	: bridge - FDO - Helicopter;
VHF (130.1)	: helicopter - NLR;
UHF	: helicopter - ship;
Telephone	: NLR - bridge.

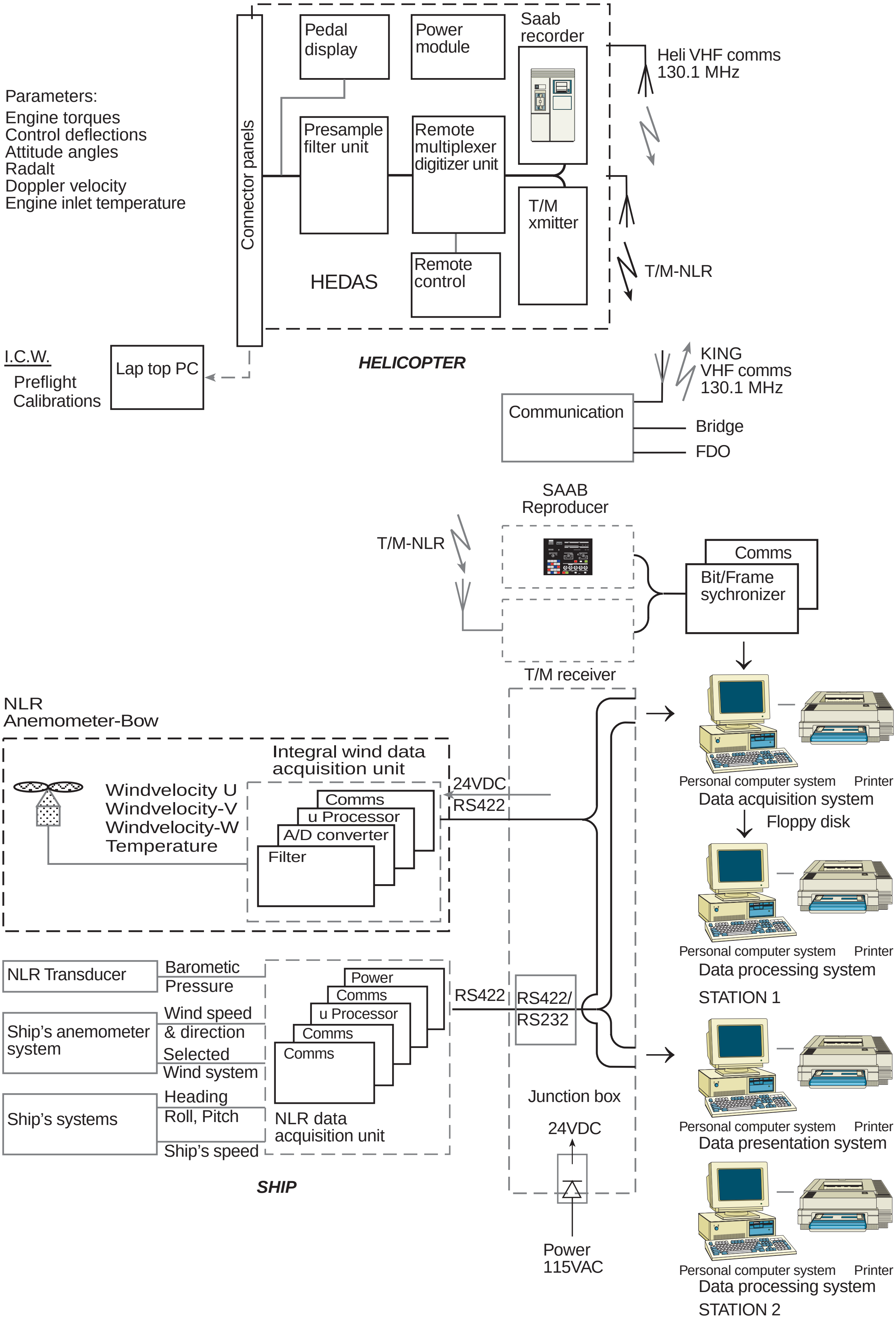


Fig. A2.2 Block diagram of data acquisition and processing system as used during helicopter/ship testing

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Part 2

AMERICAN CLEARANCE PROCESS

by

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Naval Air Systems Command
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List of Abbreviations of Part 2

AGL	Above Ground Level
ANVIS	Aviators Night Vision Imaging Systems
CAD	Cartridge Actuated Device
CG	Center of Gravity
DI	Dynamic Interface
EFP	Elevated Fixed Platform
FA	Fore Aft
FFG	Guided Missile Fast Frigate
FOV	Field Of View
GW	Gross Weight
HCO	Helicopter Control Officer
IGE	In Ground Effect (hover)
LHA	Amphibious Assault ship
L/R	Launch / Recovery
LSE	Landing Signalman Enlisted
LSO	Landing Safety Officer
NAVAIR	Naval Air Systems Command
NAWCAD	Naval Air Warfare Center Aircraft Division
NVD	Night Vision Device
NVG	Night Vision Goggles
OAT	Outside Air Temperature
OGE	Out of Ground Effect (hover)
PC	Personal Computer
PRS	Pilot Rating Scale
RAST	Recovery Assist, Secure Traverse
RW	Relative Wind
SAMS	Ship Airwake Measurement System
SMP	Ship Motion instrumentation Package
TFCP	Trimmed Flight Control Position
VLA	Visual Landing Aids
WOD	Wind Over Deck

1. Introduction

1.1 Background

U.S. rotorcraft/ship operations started in May 1943 when an Army pilot landed a Sikorsky XR-4 aboard the converted tanker SS BUNKER HILL [1]. Early helicopters were under powered and difficult to control and no ship wanted one at this time. Rotorcraft technology improved rapidly and 20 years later, it seemed like no ship could do without a helicopter. U.S. Navy helicopter/ship operations increased during the 1950's due to the Korean War and in the late 1960's and in the 1970's as a result of the Vietnam War. Helicopter/ship operations were also spurred on by the advent of the SH-2F Light Airborne Multi-Purpose System (LAMPS MK1) program in the 1970's, and by the SH-60B LAMPS MK3 helicopter program during the 1980's. Considerable visual landing aids and launch/recovery helicopter/ship testing were conducted by the Naval Air Test Center at Patuxent River, MD during the 1970's. A separate Dynamic Interface Section was established in 1982 to speed up the conventional helicopter/ship testing and to start developing an analytic capability to support helicopter/ship testing. The U.S. Navy and Marine Corps operates a large variety of helicopters from the relatively light Super Cobra (AH-1W) to the giant Sea Dragon (MH-53E) with a maximum gross weight of 73,500 lbs. These helicopters must routinely operate aboard ships ranging from small surface combatants to aircraft carriers to meet the operational needs of the U.S. Navy. Figure 1 shows typical shipboard operations aboard an U.S. amphibious class ship.

Fig. 1 CH-53E, CH-46E and AH-1W aboard LHD 1, USS WASP

The large number of helicopter/ship combinations presents the U.S. Navy with a unique challenge to ensure all helicopter/ship combinations required to operate have the operational flexibility necessary to complete their mission in the most adverse weather conditions. Throughout the years, the development of test and evaluation methods have changed and grown to meet this challenge. Carico and Madey [2] and Long and Williams [3] discuss helicopter/ship compatibility testing, analytic options, and the evolvement of the Pilot Rating Scale (PRS) upon which the development of a helicopter/ship operational capability is based. The helicopter/ship compatibility test methods and tools discussed in this paper are a result of over 50 years of shipboard flight test experience and are proven safe and reliable.

This paper is the second part of an AGARDograph on helicopter/ship qualification programs. It is a collaborative effort by the Dutch, UK and Americans to establish the operational philosophies and test methodologies for each country's helicopter/ship qualification program. All three countries have several similar procedures related to determining Ship Helicopter Operating Limits (SHOLs). At the same time some of the procedures differ, with the NL/UK flight test programs being more similar to each other than to the procedures employed by the U.S. Some of the helicopter/ship qualification test program differences of the individual countries include:

- The use of wind tunnel, full scale airwake data, and land-based test data to develop ship-based flight envelopes
- The use of operational pilots versus test pilots
- Functions of the Landing Signal Enlisted (LSE) versus Flight Deck Officer (FDO)
- The use of a general launch recovery envelope
- The use of a standard landing touchdown circle
- The use of referred aircraft gross weight versus actual test weight
- The use of different pilot rating scales
- Test philosophies including test time, test location, and test instrumentation

The purpose of this paper is to describe U.S. shipboard helicopter procedures and discuss U.S. shipboard compatibility test and evaluation methods for single spot ships. Initially the overall shipboard helicopter integration process is described in order to establish the number of organizations involved. In addition, this gives the reader an understanding of where ship/helicopter compatibility test enters into the process. Chapter 2 describes the initial helicopter/ship test conditions. Chapter 3 reviews helicopter shipboard operational procedures. Chapter 4 reviews helicopter flight test procedures. Chapter 5 discusses DI test factors and Chapter 6 focuses on developing launch/recovery envelopes. Chapter 7, the final chapter, reviews DI modeling and simulation.

1.2 U.S. Navy Acquisition

The U.S. Navy weapon acquisition process is very complex and involves many organizations in the Navy community. The two largest activities in the Navy's acquisition process are the Naval Sea Systems Command (NAVSEA) and the Naval Air Systems Command (NAVAIR). Program managers within NAVAIR and NAVSEA manage weapon systems (aircraft, ships, missiles, etc.) from cradle to grave. The Aircraft Launch and Recovery Equipment (ALRE) program manager (PMA 251) under NAVAIR is responsible for the product focused life cycle management of ALRE systems, including shipboard aviation facilities certification and requirements, aircraft support equipment, and helicopter/ship compatibility testing. The primary RDT&E organizations that support NAVAIR and NAVSEA are the Naval Surface Warfare Center (NSWC), Naval Air Warfare Center Aircraft Division (NAWCAD), and the Naval Research Laboratory (NRL). The NAVAIR Dynamic Interface (DI) Team relies on the Naval Rotary Wing Aircraft Test Squadron of NAWCAD for test pilot and aircraft (when available) support. Rotary Wing Ship Suitability (AIR 4.11.3.2) provides engineering support and conducts all test and evaluation for helicopter/ship compatibility.

1.3 U.S. Rotorcraft/Ship Integration Process

1.3.1 New Ship

The Chief of Naval Operations (CNO) establishes aircraft requirements for each new ship class. Depending on the mission of the ship, the aviation facilities requirements will be tailored to specific aircraft types. For example, a new class of ship with a mission which only specifies the employment of an H-60 for Anti Submarine Warfare (ASW) will be capable of supporting an H-60 detachment for a six month deployment, but it may not have a hangar large enough to fit an H-3. PMA-251 provides guidance to NAVSEA on the aviation facilities and deck sizing with support from the In-Service Engineering Department of NAWC. Deck strength issues are handled by Surface Ship Structural Integrity Department (NAVSEA 05P1). NRL investigates the hazard of the ship exhaust plume on flight deck personnel using computational fluid dynamics (CFD). However the ship airwake effects on helicopter operations are not investigated during the design phase of the new ship. Historical data of helicopter operations on similar ship classes are used in seakeeping studies conducted by the Hydrodynamics Group (NAVSEA 05H) with assistance from Naval Surface Warfare Center Carderock Division Code 55 to estimate the helicopter operability. Lastly all aircraft certified to operate on the new ship class are tested by the DI Team to evaluate compatibility of the aviation facilities and develop launch/recovery envelopes for specific ship classes.

1.3.2 New Aircraft

A new aircraft must go through extensive prerequisite testing and certification before it is authorized to operate aboard any ship class. During the acquisition phase, the Electromagnetic Environmental Effects Division of NAWCAD conducts landbased tests to ensure the aircraft can operate in the harsh shipboard electromagnetic environment. The In-Service Engineering Department of NAWC investigates clearance issues and facility requirements for certification aboard all qualified ships classes. NAVSEA 05P1 certifies the aircraft aboard all ship classes capable of handling the aircraft's weight. In addition, the Aeromechanics and Flight Controls competency of NAVAIR determines the performance and low airspeed handling qualities of the aircraft. Lastly the DI Team conducts DI tests to determine the aircraft's shipboard compatibility and develop launch/recovery envelopes for specific ship classes.

1.3.3 Modified Aircraft/Ship 3

The ship/aircraft integration process for a modified aircraft or ship depends on the suspected impact of the modification on ship/helicopter operations. At the very least, aircraft/ship modifications may require DI testing to determine the impact of the change on current launch/recovery envelopes.

1.3.4 Current Fleet Operability Enhancements/Joint Operations

The US Navy and Marine Corps operates 8 helicopter types and the Navy operates 37 ship classes [3]. Therefore the number of aircraft/ship combinations is too large to develop operating envelopes for all combinations. Only a prioritized list of aircraft/ship combinations required to operate together (as determined by the CNO) is tested to expand launch/recovery envelopes. All other helicopters certified for operations aboard a ship class, including joint operations between other U.S. armed services helicopters and U.S. Navy ships, are typically allowed to operate in a conservative launch/recovery envelope, termed the "general envelope" as shown in figure 2.

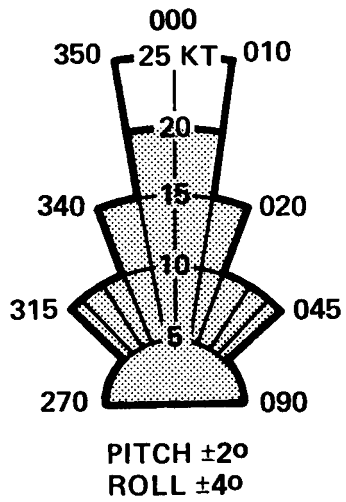

Fig. 2 DI General Envelope

1.4 Dynamic Interface Test Objectives

A helicopter ship qualification program, which the U.S. defines as a Dynamic Interface test, evaluates, improves, and/or develops all aspects of shipboard helicopter compatibility. Preparations for a shipboard helicopter compatibility test may include model-scale and full-scale ship airwake and exhaust plume surveys, flight simulation, and helicopter performance testing. Issues addressed during a test may include the adequacy, effectiveness, and safety of shipboard aviation support facilities and/or procedures for all potential ship-based helicopter types. Typical examples of support facilities evaluated are the flight deck, deck fittings, deck safety nets, aircraft hangars, and maintenance work spaces, as well as, refueling, firefighting, and helicopter control stations. Procedures that are qualitatively evaluated include those related to deck handling, repositioning, tiedown, refueling, and maintenance tasks. Additionally, shipboard helicopter tests may include evaluations of ship airwake, exhaust gas, and electromagnetic interference effects on shipboard helicopter operations. Investigations of shipboard visual cues such as flight deck markings and visual landing aid (VLA) lighting packages are also essential parts of shipboard helicopter test efforts. The testing of VLA lighting packages typically includes the evaluation, development, and optimization of existing lighting schemes and/or procedures for both Night Vision Goggle (NVG) and non-NVG operations.

The significant result of shipboard helicopter compatibility testing could be an engage/disengage or launch/recovery envelope. Optimal Helicopter In Flight Refueling (HIFR) and Vertical Replenishment (VERTREP) wind conditions have been established and are universal. Typically initial DI tests of a new ship/aircraft combination will include HIFR and VERTREP evaluations but are not required. Once developed, these envelopes greatly increase the allowable range of wind/ship motion conditions that safely permit routine shipboard helicopter operations. Similarly, for any given ambient wind conditions, the envelopes permit a ship operator to safely operate helicopters from a wider variety of ship course/speed combinations, greatly increasing the tactical and operational flexibility.

The U.S. take-off and landing wind diagrams are termed launch/recovery wind envelopes. A sample wind envelope is shown in Figure 3. Note that the relative Wind Over Deck (WOD) direction is defined by the dotted radial lines relative to the ship's bow and the wind over deck speed is defined by the dotted concentric circles. The approach line graphically illustrates the type of approach to be executed for this particular launch/recovery envelope. The shaded region indicates the wind over deck conditions for safe night helicopter/ship operations. All envelopes are valid for all gross weights and center of gravity unless otherwise noted. In some cases the aircraft may require more torque to operate shipboard than what is indicated by the landbased torque requirements in the aircraft operating handbook. These cases are noted on the envelope so that the pilot can account for the difference in performance for shipboard operations. The launch/recovery envelope also lists the maximum ship roll and pitch limits for safe helicopter/ship operations. Launch/recovery envelopes are published for day and night operations and each approach type (stern, port-to-starboard, or starboard-to-port). In the case of a Recovery Assist Secure and Transverse (RAST) capable aircraft and ship combination, separate envelopes are published for recovery assist (haul down and deck lock) and free deck (deck lock only) operations.

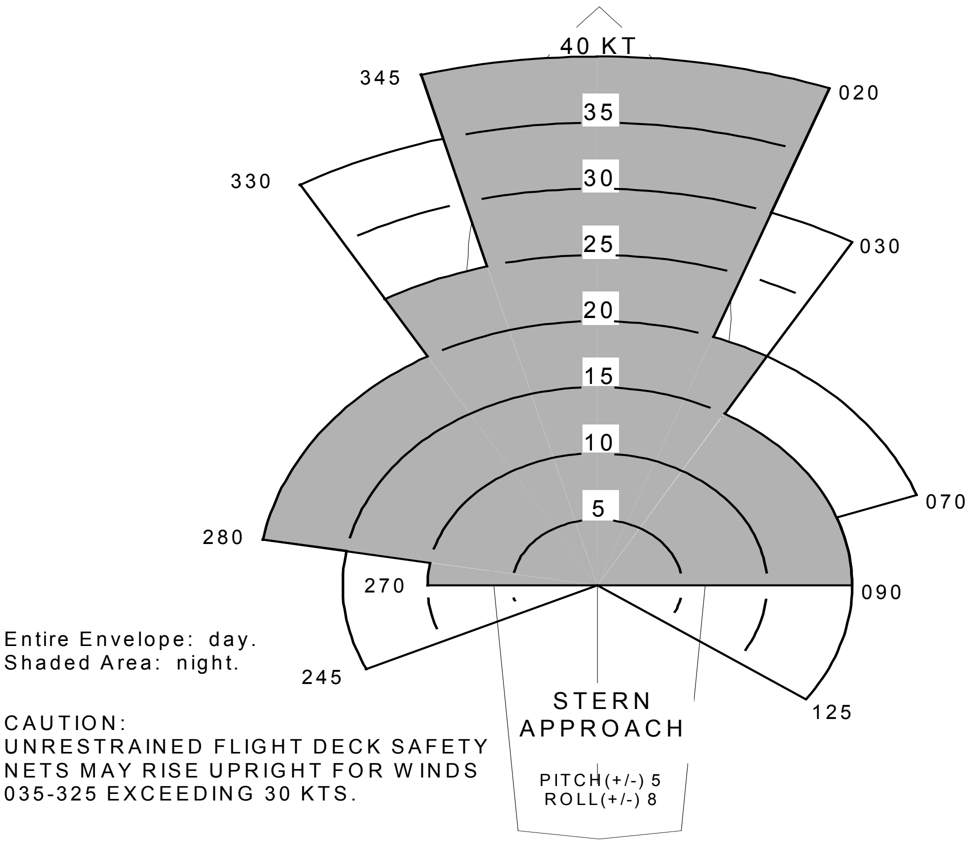

Fig. 3 DI Launch/Recovery Operational Envelope

1.5 Scope of a Typical DI Test Program

In the U.S. test programs, the typical scope for a new aircraft/ship combination includes: an evaluation of the shipboard aviation facilities and procedures; an evaluation of the ship airwake, exhaust gas, and electromagnetic interference effects on shipboard helicopter operations; and most importantly, the development of launch/recovery envelopes. An overview of a typical DI process in terms of test program components is presented in figure 4.

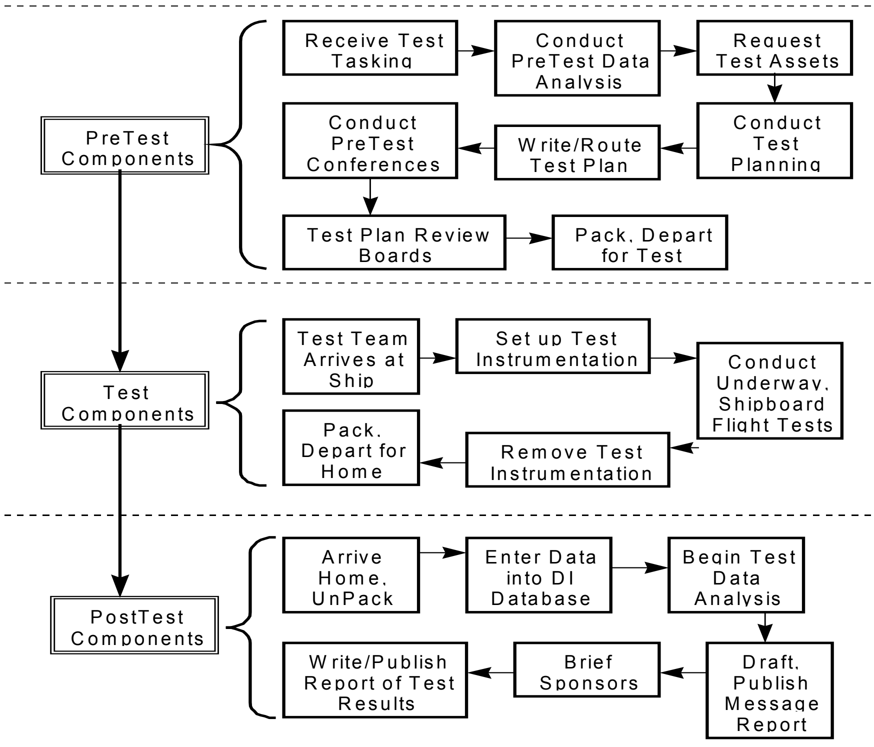

Fig. 4 Typical DI Test Program Components

1.6 DI's Experience

NAWCAD Pax River has conducted over 170 test programs in the past 45 years for the U.S. Navy and Marine Corps as well as the Army and Coast Guard which encompassed 39 classes of ships and 17 types of helicopters.

2. Initial Test Considerations

2.1 General

When operating aboard ship, one must know what phenomenon and hazards are associated with the ship environment and factors affecting the helicopters operation in this adverse environment. This chapter is intended to give the reader a basic knowledge of the shipboard environment. Next the factors affecting helicopter operation in the shipboard environment are divided into categories and described. In reality, these factors affecting the aircraft combine to create a very complex flying environment. The test pilot must evaluate the factors affecting the aircraft in all of these categories and rate the difficulty of the launch and recovery. Lastly, several on-deck issues are discussed.

2.2 The Ship Environment

During shipboard operations, a helicopter is subjected to a very adverse and turbulent environment with many constraints. In comparison with land-based take-offs and landings, ship-based take-offs and landings occur in winds from any direction relative to the helicopter. Relative Wind-Over-Deck conditions may be constrained by ship operational requirements forcing the aircraft to land in non-ideal wind conditions. Typically land-based helicopter platforms are large, flat, open spaces which are conducive to low atmospheric wind turbulence. Figure 5 is a picture of flight deck aboard an USS SPRUANCE class destroyer that is on average 69 feet long and 41 feet wide. At a minimum, the SH-60B rotor tips may be approximately 4 feet from the nearest obstruction or the tail wheel may be 2.5 feet from the aft deck edge. Also note that the ship superstructure is not conducive to low airwake turbulence levels and the platform attitude is never fixed. In addition, the interaction of the ambient environment (true winds and sea state) with the ship which creates the operational environment for the helicopter is not the same for every ship class.

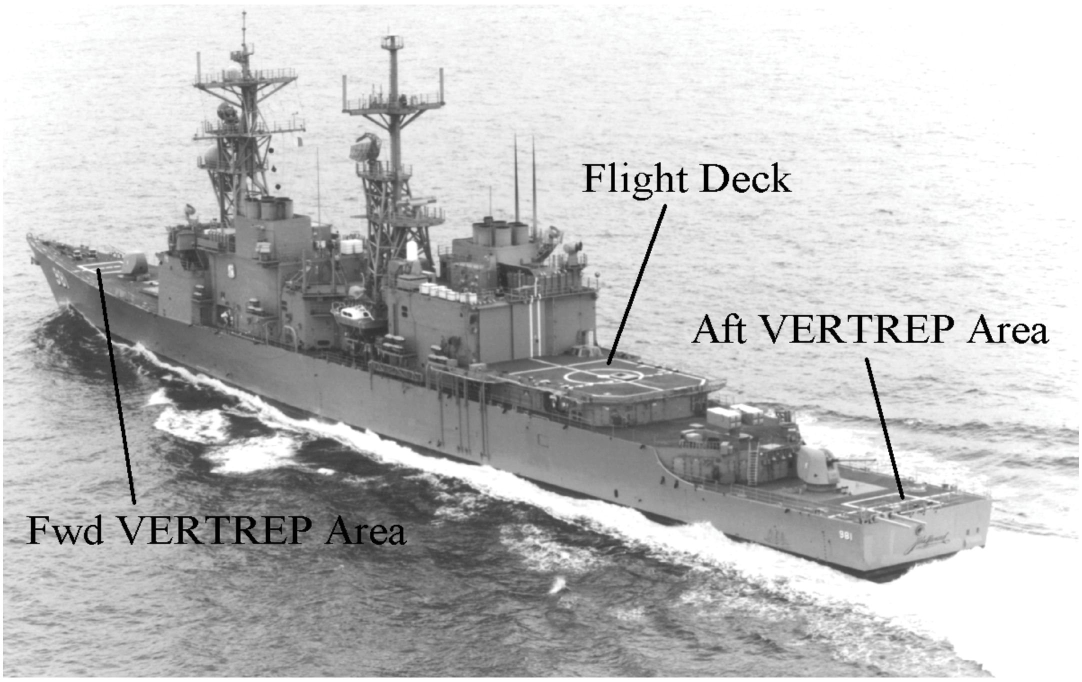

Fig. 5 Location of Flight Deck and VERTREP Areas on a Typical Surface Combatant

Ship motion characteristics for ships depend on ship hull geometry, loading and ambient conditions and are fairly similar for air capable ships. The maximum amplitudes and periods for pitch and roll for sea state 5 are given in Table 1. The pitch and roll characteristics of an aircraft carrier are also given to provide a comparison between different sizes of ships. The sea state scale with values ranging from 1 to 8 was developed by the World Meteorological Organization to characterize sea conditions. In sea state 5, the seas are very rough with average wave heights of approximately 12 feet and winds are moderate to almost gale force ranging from 27 to 40 knots.

Table 1: Ship Motion Characteristics for Sea State 5

			Pitch		Roll	
Class	Length (feet)	Displacement (tons)	Max Amp. (deg.)	Period (secs)	Max Amp. (deg.)	Period (secs)
FFG 7	445	4100	2.4	5	17.6	13
DD 963	563	8040	2.0	7	20.5	17
CG 47	567	9466	1.9	7	19.1	17
CVN 68	1092	91487	0.8	10	5.0	21

Note: The maximum amplitudes and periods for ship pitch and roll were calculated using U.S. Ship Motion Program 95

For most air capable ships, several distinct features remain consistent and play a significant role in ship airwake characteristics. Wind anemometers located on the ship's mast measure the relative winds used to define safe helicopter/ship operations. Even though the anemometers are typically 60 feet above the flight deck, they are still contained within the ship airwake; therefore not measuring the true relative freestream wind velocity. In addition, the relative wind-over-deck conditions do not reflect the local wind characteristics over the flight deck. In most cases, a flat faced, sharp cornered hangar is placed immediately forward of the flight deck. A typical hangar height is approximately 15 feet. The vertical face of the hangar causes large flow recirculation zones over the flight deck. In addition, the sharp corners, railings, and masts create a highly turbulent airwake. Ship's exhaust stacks are placed amidships which for some WOD conditions is upstream of the aircraft approach or departure path. In some cases, ship's service gas turbine generator stacks are placed immediately forward or aft of the flight deck that may raise the local air temperature over the flight deck or along the approach path. Separately, the elements of the ship environment are complex and difficult to predict; however, the environment is even more complex due to the interaction of these elements. For example, airwake due to the ship motion was seen in the mast mounted anemometer measurements and most likely will be seen in the ship airwake environment over the flight deck.

2.3 Helicopter Performance

A helicopter operating landbased requires the most power hovering in still or low speed winds and experiences a reduction in power required hovering in ground effect. When operating shipboard, an aircraft hovering in still or low speed relative winds may require more power than the predicted out of ground effect hover power. In order to gain the power savings due to ground effect, aircraft must be hovering in low relative winds within one rotor diameter of an infinite, smooth ground surface. Therefore, one of the factors affecting a helicopter's power requirements is the lack of the necessary conditions to obtain power savings due to ground effect. In addition, higher torque requirements may be needed when hovering or transitioning to or from forward flight in low relative wind speeds or turbulence. Higher power requirements reduces power margins that may be needed to counteract adequately a certain amount of ship's oscillation to avoid collision with the obstacles.

Another factor that affects aircraft performance is hot exhaust ingestion. There are two types of shipboard problems associated with hot exhaust. The first is the aircraft ingesting hot gases from the ship gas turbine generator or exhaust stacks. The second is the aircraft re-ingesting its gas turbine exhaust. Aircraft problems may be a result of a combination of the two. Unlike the affects of low relative wind speed and lack of ground effect which increase power required, hot exhaust ingestion limits the aircraft power available.

2.4 Helicopter Handling Qualities and Control

Adequate handling qualities are imperative in the shipboard environment due to the confined landing area. In order to maintain safe distances from obstacles, the aircraft's forward landing gear must be placed in a standard 24 foot diameter touchdown circle with the aircraft aligned with the lineup line. (The 24 foot touchdown circle is based on qualitative engineering assessments made during the late 1960's.) For H-60 recoveries into the Rapid Securing Device (RSD), the RAST probe must be placed in the RSD trap that is 3 foot wide and 3 foot long. In most cases handling quality limitations are caused by ship airwake turbulence. Adequate control margins are also required to counteract unanticipated situations such as gusts or turbulence. Similar to the Dutch, the U.S. requires a 10% control margin during any shipboard operations. In most cases control limitations are caused by pedal limits.

2.5 Visual Cues

Visual cues provide the pilot with situational awareness and the ability to accurately position the aircraft over the landing spot. Lack of or degraded visual cues is dangerous in the shipboard environment due to the small landing area and small clearances with the ship's superstructure. When approaching the ship in tailwinds, it is common for the pilots to feel as though they are being pushed into the ship. In addition, larger aft stick inputs are required throughout the approach and hover phase that causes a higher nose up attitude. The higher nose up attitude limits the pilot's downward field of view that also may affect the visual cues. Factors that may degrade the pilot's view of the flight deck during approach and hover are the salt spray generated by the downwash of the rotor in low relative wind speeds and smoke generated by the ship's exhaust stacks. Lastly the pilot's ability to maintain a steady hover behind the ship depends largely upon the view of a distinct horizon. Lack of a distinct horizon may be caused by fog, precipitation, haze or nighttime operations.

2.6 Helicopter/Ship Geometric Interface Limitations

Most helicopter manufacturers provide sloped landing limitations for take-off and landing operations out of unprepared helicopter landing sites. In most land-based operations, pilots can adjust the aircraft heading to land up-slope, down-slope, or cross-slope depending on the safest option. Similarly, limitations must be determined for the relative geometric attitude of the aircraft to the ship. However, ship-based operations may be more restrictive depending on aircraft trim hover attitude, ship maximum pitch and roll, and aircraft lineup. For example, an aircraft ship-based sloped landing limit for a fore/aft lineup may be a pitch of 5 degrees and a roll limits of 15 degrees. However, the aircraft sloped landing limit for an oblique lineup may be decreased due to the ship pitch and roll combining to create a larger slope along the lineup line.

2.7 The Pilot

The most important factor that affects helicopter operations in the shipboard environment is the pilot because ultimately he/she is the one that must process the information given and manipulate the controls to launch and recover safely. Therefore the envelopes must consider pilots with various levels of experience and skill. A qualitative parameter used to evaluate the difficulty of a shipboard task is pilot workload. Typically high pilot workload results from handling qualities and visual cues and can include effects of the environment like ship motion. Pilot comfort level may also play a role in determining safe shipboard operating conditions. For example, an AH-1W test pilot was conducting a recovery to an LHA spot under high winds and rated the landing as unsatisfactory due to the uncomfortable attitude of the aircraft upon touchdown. Although rating the human ability is subjective, using trained test pilots provides the objectivity to consistently judge the skill level of the average fleet pilot.

All U.S. test pilots are required to attend an accredited Test Pilot School before participating in any Navy flight testing. The United States Naval Test Pilot School (USNTPS), located at Naval Air Station, Patuxent River, MD, is an intense ten month flight test and evaluation course that trains experienced fleet pilots and flight test engineers how to be better and more effective testers. The pilots are taught specific thought process and incremental/build up techniques that can be applied when evaluating any given aircraft. They fly many different aircraft to provide a breadth of experience in aircraft with various flight characteristics, which provides a baseline for comparison with other aircraft. Throughout the course they learn an awareness of the control inputs and aircraft response and how it relates to the aircraft flying characteristics. Pilots are taught about the various rating scales and how to apply them in a consistent manner and the importance of mission relation. This rigorous training provides the pilots the necessary tools for flight testing but most importantly teaches them how to objectively rate mission tasks, such as shipboard launch/recovery operations, keeping in mind the experience and ability of the average fleet pilot.

2.8 On Deck Issues

There are two helicopters in the US military that are tandem rotor and operate from ships. These are the US Navy H-46 Sea Knight and the US Army H-47 Chinook. The H-46 helicopter is currently detached aboard ships throughout the Navy. The main problem associated with H-46 helicopters in a shipboard environment is tunnel strikes. A “tunnel strike” occurs when flight deck turbulence drives the aft rotor blades to flap to the point of striking the synch shaft connecting the aft and forward transmissions on the aircraft. Tunnel strikes commonly occur upon startup (rotor engagement) or shutdown (rotor disengagement). Testing can be performed to identify wind over deck conditions that exacerbate rotor flapping. The procedure involves spotting an H-46 on the flight deck, chocked and chained, and engaging the rotors. The aircraft is fitted with a wood and Teflon “greasy board”, which is fitted to the forward portion of the synch shaft and protects the shaft from the blade flapping to an extreme. Various length styrofoam “frangible” pegs are set up in a vertical fashion on the synch shaft to determine the minimum distance of the blades to the shaft. The aircraft rotors are engaged and disengaged under one wind condition with a blade clearance scale applied to reflect the maximum blade deflections over the synch shaft. The wind condition is then systematically varied to develop an engage/disengage envelope.

3. Helicopter Shipboard Operational Procedures

3.1 General

It is important to understand the many phases of shipboard helicopter operations for a typical mission. Although they do not involve helicopter flight, they can have a large impact on helicopter operability and helicopter/ship compatibility. The typical phases of any USN helicopter mission are shown below and are very similar to the Dutch phases.

TRAVERSE
Aircraft with blades and tail folded is moved from the hangar to the launch/recovery spot using the Recovery Assist, Secure Traverse (RAST) system, a winch system, or manual push method depending on the aircraft. Aircraft is secured to the deck using the Rapid Securing Device (RSD) and/or tie down chains.

UNFOLD
Aircraft rotor blades and tail are automatically or manually unfolded into a flight-ready configuration.

ENGINE START/ROTOR ENGAGEMENT
Engines are started and rotors are engaged.

LAUNCH
RSD beams are opened and/or tie down chains are removed. Aircraft lifts off into a hover over the deck.

DEPARTURE
Aircraft transitions into forward flight and flies away from ship.

MISSION
Typical maritime missions include airborne mine countermeasures, antiship surveillance and targeting, antisubmarine warfare, reconnaissance, vertical replenishment and search and rescue.

APPROACH
Once aircraft mission is complete, aircraft follows a specified path to prepare for a landing. The approach phase ends once the aircraft is in a hover over the landing spot.

RECOVERY
The aircraft lands and the RSD beams close and/or tie down chains are employed. In adverse weather and sea states, a RAST system may also be employed to recover the aircraft.

ENGINE SHUTDOWN/ROTOR DISENGAGEMENT
Engines are shutdown. The rotors are disengaged and a rotor brake is used to quickly slow the rotors to a stop.

FOLD
Aircraft blades and tail are automatically or manually folded.

TRAVERSE
Aircraft with blades and tail folded is moved from the launch/recovery spot to the hangar using the RAST system, a winch system, or manual push method depending on the aircraft. Aircraft is secured to the hangar deck using tie down chains.

Aside from shipboard approach, recovery, launch, and departure (launch/recovery) operations, shipboard vertical replenishment (VERTREP) operations and shipboard Helicopter In Flight Refueling (HIFR) operations also require dynamic and complicated ship/helicopter interaction. The U.S. Navy and Marine Corp operate both single and dual piloted aircraft. Generally the U.S. Navy conducts two types of launch/recovery operations aboard air-capable ships: RAST and Non-RAST. RAST is the Recovery Assist, Secure Traverse system employed by surface combatants to recover U.S. Navy H-60 helicopters and move them to and from the hangar. The launch and recovery phases of the typical mission described above are conducted differently depending on RAST or Non-RAST launch/recovery operations. This section describes the approach, recovery, launch, and departure operations, RAST launch/recovery operations, and LSE's role in launch/recovery operations.

3.2 Launch & Recovery Operations

The two typical rotorcraft approach orientations to US Navy air capable ships are oblique and stern. Ship visual landing aids (VLA) are arranged based on approach orientation. Figure 6 shows the typical deck markings for RAST capable DD 963 class ships. The line-up lights and approach line deck markings on a ship designed for a stern approach are offset to the right of the ship centerline, usually supplemented with extended drop-line lights mounted vertically on the fantail below the flight deck. A stern launch/recovery sequence would proceed as follows: The right or left seat pilot would lift off, directed by the LSE, and establish a steady hover 10-15 ft above the flight deck. If a starboard WOD is present, the pilot would then pedal turn to starboard, establish steady rate of ascent and forward airspeed, and enter a starboard racetrack (clockwise oval) flight pattern. Once on final in the pattern, the pilot would establish a 3 deg glide slope and 80 kts ground speed 1.2 NM directly aft of the ship. Arresting the rate of closure and crossing the fantail, the pilot would establish a 10-15 ft hover and position the aircraft over the recovery circle with the aid of the LSE on the flight deck. He would then descend vertically and land with the forward landing gear or forward skid cross-tube within the recovery circle, and with the aircraft centerline parallel to the ship line-up line. The restriction of landing within the recovery circle guarantees the proper aircraft/rotor clearances to the nearest ship obstruction. The glide slope and airspeed conditions used for an oblique launch/recovery sequence are identical to the stern approach. However, in this case, the pilot would approach the ship 33-45 degrees offset to port or starboard of the ship centerline, depending on the orientation of the landing line-up line of the particular ship class. A limited number of ship classes employ an extreme case of an oblique approach where the line-up line is 90 degrees relative to the ship centerline.

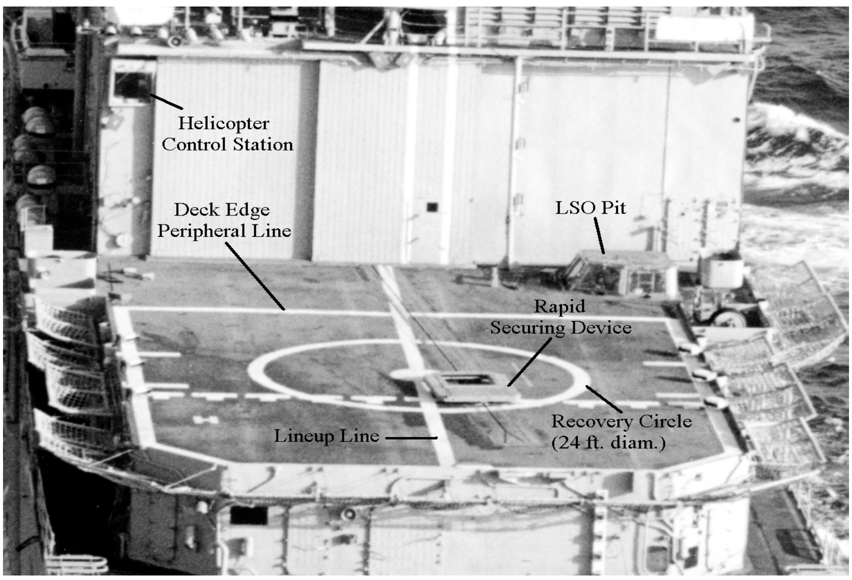

Fig. 6 Typical RAST Capable DD 963 Class Flight Deck

Another more uncommon approach is the ordnance angled offset approach. Pilots are required to perform this approach when they are carrying hung or misfired forward firing ordnance. Hung ordnance is a missile that ignites and expends its propellant but never leaves the rail. Misfired forward firing ordnance is a missile that fails to ignite when initiated by the pilot. For ship classes incorporating both the stern approach and the oblique approach, the pilot is required to maintain a gradually increasing sideslip relative to the line-up line to avoid aiming the weapon at any portion of the ship in the event of an inadvertent launch. If properly executed for a typical stern approach flight deck, the aircraft's ground track remains exactly "up the stern" (identical to that used during non-ordnance evolutions) throughout the ordnance angled offset approach. However, the aircraft nose will always be aligned at some minimum yaw angle relative to the deck lineup line, increasing as the aircraft approaches the ship. No launch/recovery envelopes are developed for such an uncommon occurrence as misfired forward firing ordnance.

3.3 RAST Launch/Recovery Operations

The approach and departure phases of RAST launch/recovery operations are the same as Non-RAST operations. The main differences are in the recovery and launch phases. The two types of RAST recoveries are Recovery Assist (RA) and Free Deck (FD). For an RA landing, the aircraft must hover over the deck while two enlistedmen ground the aircraft’s messenger cable and hook it to the ship’s hauldown cable. The Landing Safety Officer (LSO), the operator of the ship’s RAST system, instructs the pilot’s to reel in and lock the hauldown cable. The RAST cable provides a stabilizing moment for the hovering helicopter. As the pilot holds a steady hover over the RSD, the LSO select the preset hauldown tension and the helicopter comes down into the RSD, and the trap beams close. Lastly the hauldown cable is released in preparation for lift-off. Figure 7 shows an SH-60B performing RA landing.

Fig. 7 SH-60B Performing an RA Landing on a DD 963 Class Ship

For a FD landing, the pilot establishes a high hover, approximately 10-15 ft, over the flight deck. Once ready to land, the pilot lowers his hover height to 3-5 ft and positions the aircraft over the RSD. The LSO provides conning calls to position the aircraft probe over the RSD, instructs the pilot when to land and closes the RSD beams to hold the helicopter on the deck. If the aircraft probe does not enter the RSD, the LSO instructs the pilot to lift into a low hover and attempts to guide the pilot into the RSD again.

There is only one way to launch for RAST launch/recovery operations. Once the pilot is ready to lift, the LSO opens the RSD beams and instructs the pilot to lift. The pilot lifts into a hover and the departure phase is the same as a Non-RAST departure.

3.4 Role of LSE

In the US Navy, the LSE has two primary duties. The first is to ensure the general safety conditions of the flight deck, to include control of the flight deck crew. The second is to communicate to the pilot at the controls, through various hand signals, directions to the proper aircraft placement on the flight deck, fuelling, and deck handling. The signals the LSE provides to the pilot for proper placement on the flight deck are advisory in nature. The only LSE signals which the pilot is required to heed are waveoff and hold. The LSE does not have direct verbal communication to the pilot in the aircraft, but can communicate to the HCO or LSO via the "phonetalker." The phonetalker is an enlisted man equipped with a sound-powered phone. For RAST launch/recovery operations, the LSE is present on the deck for all operations while the H-60 is trapped in the RSD. However, the LSE is not required for the approach, recovery, launch, and departure phases of RAST helicopter operations.

4. Helicopter Shipboard Flight Test Procedures

4.1 Preparations

4.1.1 Historical Data

The DI database was developed in 1988 as an efficient means to store, access, manipulate, and analyze large amounts of DI shipboard helicopter flight test data. The database holds both general and specific information from over 180 DI tests. Currently, 120 parameters are listed for every launch/recovery event. This information is valuable for many purposes. In preparation for a flight test with a CH-46E helicopter aboard an LHA 1 class ship, an engineer could query the database to produce a list of any H-46 variant aboard an LHA. From there he could ferret out all the limiting pilot ratings to evaluate possible trouble spots for the test aircraft. One could find the pedal and lateral cyclic input requirements for every CH-46E DI test recovery conducted to LHA 2 class ships since 1985 in which the aircraft's gross weight exceeded 19,500 lb, the ship roll was greater than 9 deg, and the relative winds exceeded 30 kt. In addition to using the database as a tool for flight test preparation, the flight test engineer can also use it for data presentation. Once all of the shipboard test information is entered into the database, it can automatically develop a data fairing of PRS ratings. It can also automatically calculate necessary pieces of data based on other inputs, such as density altitude given OAT and pressure altitude, and aircraft gross weight and CG location given fuel weight. Based on pilot comments and supporting engineering data, an envelope will be produced and printed out through the database.

4.1.2 Pilot Field of View

Field of view analysis in preparation for a shipboard flight test is usually not a critical issue unless the test aircraft is a prototype or the purpose of the test is to evaluate a new marking configuration aboard the test ship. Simulation is one useful way to evaluate prototype VLA configurations, saving the cost of paint, flight time, travel, labor, per diem, etc. Some simulators have a limited field of view compared to the aircraft to be tested and therefore do not adequately predict the field of regard of a hovering pilot. Field of view is fixed for a given aircraft model. It is based on the relation of the design eye point of the pilot with respect to the edges of the cockpit windows, door windows, or chin bubbles or anything inside the cockpit that may obstruct the pilots view outside the cockpit such as the glare shield. Field of regard is what the pilot sees based on the aircraft’s field of view and attitude. A simpler and less expensive PC-based analysis technique involves knowledge of the specific geometric field of view of the aircraft. Projecting lines from the aircraft design eye point along the periphery of the cockpit windscreen, chin bubble, and windows to the flight deck below provides a "snapshot" of what the pilot can and cannot see on and around the flight deck. All of this information is then input into a program containing the FOV data of various airframes and flight deck lay-outs of major ship classes. Program inputs allow the engineer to adjust the helicopter height above deck, aircraft pitch, roll, and yaw angles as well as longitudinal and lateral position of the aircraft relative to the flight deck recovery spot. Figure 8 depicts the field of view of an SH-60B aboard an FFG 7 class ship in a 15 ft hover, 5 ft aft of the touchdown circle. The dark area represents the portion of the flight deck obstructed to the right seat pilot. Unlike the program with a fixed design eye point, a human pilot can crane his neck, sit up straight, and rotate his head to see around aircraft obstructions. The program provides a good initial analysis of field of view and field of regard of a hovering pilot over a flight deck.

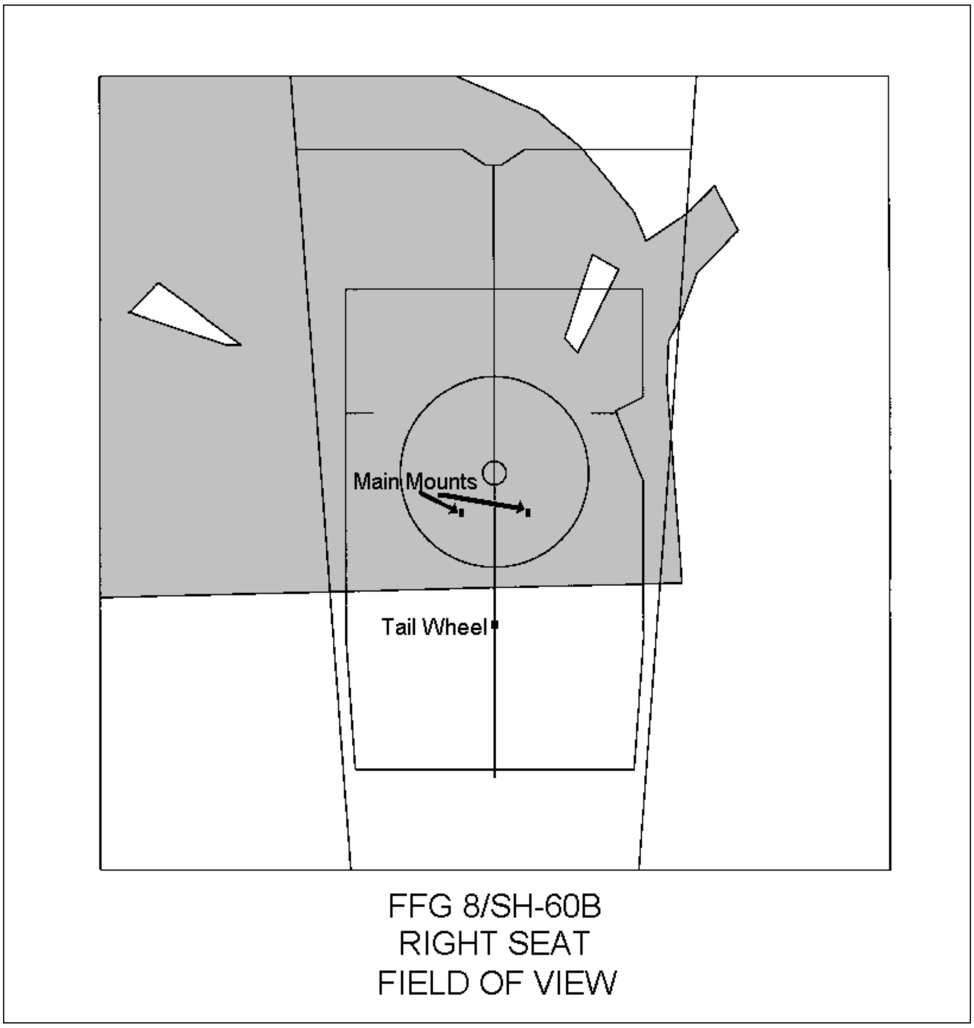

Fig. 8 2-D Field of View Diagram for the SH-60B on a RAST Capable FFG 7 Class Ship

4.1.3 Land-Based Build-up Test

Elevated Fixed Platform

In preparation for flight tests aboard FFG 7 class ships, an elevated fixed platform is used as a practice deck for pilot familiarity flights before the at-sea flight test. This platform is a full scale, land based FFG flight deck with a hangar face and complete VLA. The EFP maintains an operable landing safety officer (LSO) station (moved laterally outboard from its actual shipboard location for safety reasons), and fully functional recovery, assist, secure and traverse (RAST) equipment, thereby producing a realistic land-based RAST system virtually identical to that of a RAST equipped ship. The platform does not allow engineers to control certain variables present in the shipboard environment such as ship motion and limited spatial cueing with the sea. It is especially valuable for pilot/LSO training, proficiency, or in preparation for NVD operations where pattern work and crew coordination is crucial. Practicing on the platform enables the pilots to have a better idea of ship motion limitations before going out to sea. Figure 9 illustrates the EFP.

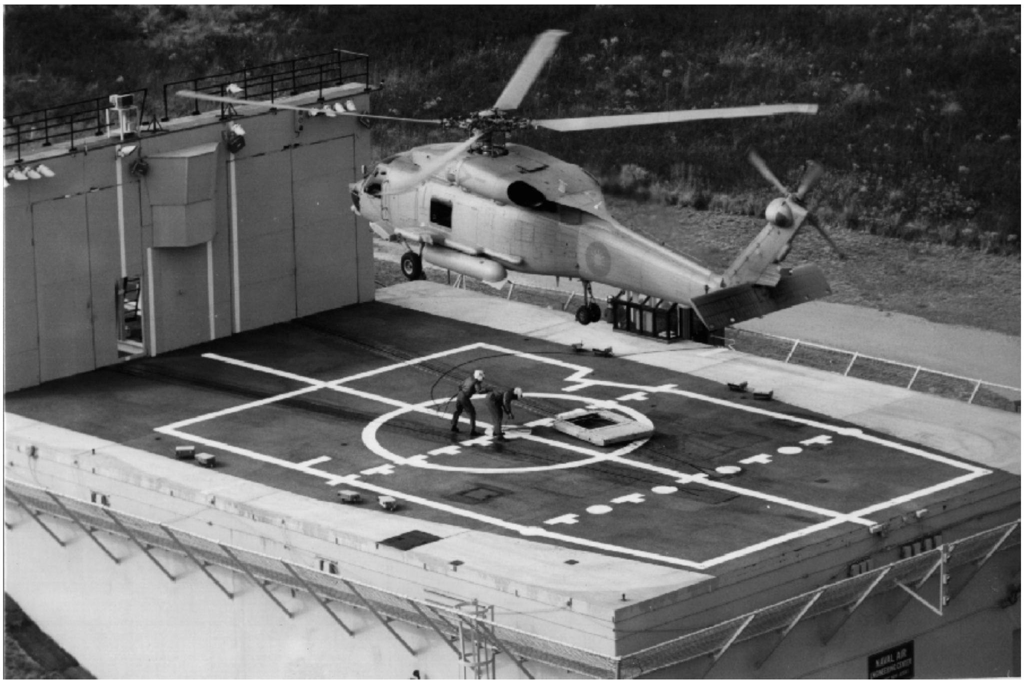

Fig. 9 SH-60B Performing a RA Landing at the EFP

Critical Azimuth Testing

Land-based critical azimuth flight tests are conducted prior to shipboard test operations. It is an evaluation of control margins and pilot workload with variation in airspeed and relative wind azimuth. The qualitative evaluation of trim changes and pilot workload is an integral part of the test. Data are collected simultaneously with trimmed flight control positions (TFCP) in low airspeed flight. Of specific interest are the control margins and pilot workload to accomplish the task of hovering the helicopter within predetermined tolerances at various speeds and directions relative to the airframe. Areas of limited control margin or high pilot workload are noted in preparation for shipboard flight test operations. The test is performed in ambient winds of 4 kts or less. Commonly, the aircraft is flown behind a pace truck, which is instrumented to measure ground speed, with the airframe flown at various azimuths relative to the direction of flight to simulate hovering in different wind conditions. True winds are measured at an onsite measuring device, usually the control tower. Variables adjusted during the test include aircraft height

AGL, airspeed, and azimuth. Flight control positions, aircraft attitudes, engine torque, airframe azimuth and airspeed, height AGL and ambient conditions are recorded.

Hover Performance

The purpose of the hover ladder flight test is to compare in ground effect (IGE) and out of ground effect (OGE) torque required to hover at various gross weights with those predicted by the aircraft operator's manual. Typically, the test is performed at altitudes of approximately 5, 15, and 50 to 60 feet above ground level (AGL), yawing the aircraft relative to the ambient wind in 45 degree increments, starting at the nose of the aircraft and working around to +/- 90 degrees. When a stable hover condition is reached, engine torque, rotor rpm, aircraft attitudes, and flight control positions are recorded in addition to ambient conditions (pressure altitude, OAT, ambient winds.

4.2 Launch/Recovery Envelope Development

4.2.1 General

Launch/recovery envelope development tests consist of data collection at various relative wind and ship motion conditions. Each test event normally consists of an approach and recovery followed immediately by a launch and departure, all conducted by the same pilot at the controls with the same WOD conditions. Parameters of concern for each event include a variety of qualitative and quantitative factors, including but not limited to pilot visual cues, pilot workload, flight control activity, flight control margins, aircraft attitude, aircraft power requirements, landing dispersion, ship airwake turbulence intensity, ship motion and aircraft landing loads. Because each of these and other parameters cannot be isolated and evaluated individually during full-scale flight test, a comprehensive rating is assigned by the aircrew after each event which rates the overall difficulty of the combined set of conditions for that sequence. The pilot rating scale, shown in Table 2, has four difficulty levels. A rating of PRS-2 or less indicates safe events. For any event rated higher than PRS-1, the aircrew is required to provide supplemental comments to indicate which parameters contributed to the elevated difficulty of that event. A review of the development and application of the Dynamic Interface Pilot Rating Scale is presented in reference 3. As a result on ongoing The Technical Cooperation Program (TTCP) work a revised pilot rating scale for DI testing was developed to enhance sharing DI test results by different countries. The new scale is known as the Deck Interface Pilot Effort Scale (DIPES), and is a 5 point scale where ratings 1-3 are acceptable pilot ratings and 4-5 are unacceptable. The Deck Interface Pilot Effort Scale (Table 3) was accepted by NAVAIRSYSCOM in 2001, and is being used on new start programs. Additional scales used in DI testing include a vibration scale, turbulence scale, and visual landing aids scale, as presented in Tables 4-6.

Table 2: Dynamic Interface Pilot Rating Scale

PRS Number	Pilot Effort	Rating Description
1	Slight	No problems; minimal pilot effort required to conduct consistently safe shipboard evolutions under these conditions
2	Moderate	Consistently safe shipboard evolutions are possible under these conditions. These points define the fleet limits recommended by the NAVAIRWARCENACDIV Patuxent River.
3	Maximum	Evolutions are successfully conducted only through maximum effort of experienced test pilots using proven test methods under controlled test conditions. Successful evolutions could not be consistently repeated by fleet pilots under typical operational conditions. Loss of aircraft system or ship system is likely to raise pilot effort beyond capabilities of average pilot.
4	Unsatisfactory	Pilot effort and/or controllability reach critical levels; repeated safe evolutions by experienced test pilots are not probable, even under controlled test conditions.

Table 3: Deck Interface Pilot Effort Scale (DIPES)

EFFORT	GUIDANCE	DIPES
Slight to Moderate	Reasonable compensation required. Tracking and positioning accuracy is consistently maintained throughout the operation. Fleet pilots will have enough spare capacity to conduct ancillary tasks.	**1**
Considerable	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.	**2**
Highest Tolerable	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.	**3**
Excessive	Excessive compensation required. Accuracy is poor in one or more axes. Fleet Pilots will be purely reacting to external influences rather than anticipating them. A safe abort may not be possible if an aircraft or ship system is lost during a critical phase of the evolution. Fleet pilots under operational conditions could not consistently repeat these evolutions safely.	**4**
Dangerous	Extreme compensation required. Repeated safe evolutions are not possible even under controlled test conditions with fully proficient crews.	**5**

Acceptable (DIPES 1-3)   Unacceptable (DIPES 4-5)

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
Roll control:	R	F/Aft positioning:	F
Deck Motion:	D	Torque Control:	Q
Yaw control:	Y	Lateral positioning:	L
Visual Cues:	V	Funnel Exhaust:	E
A/C Attitude:	A		

Table 4: Turbulence Scale

Intensity	Aircraft Reaction	Reaction Inside Aircraft
Light	TURBULENCE: The aircraft momentarily experiences slight, erratic changes in altitude or attitude. CHOP: The aircraft experiences slight, rapid, and somewhat rhythmic bumpiness without appreciable changes in altitude or attitude.	Occupants may feel a slight strain against seat belts or shoulder straps. Unsecured objects may be displaced slightly.
Moderate	TURBULENCE: The aircraft experiences changes in altitude or attitude, but remains in positive control at all times. The aircraft also usually experiences variations in indicated airspeed. CHOP: The aircraft experiences rapid bumps or jolts without appreciable changes in altitude and/or attitude.	Occupants feel definite strains against seat belts or shoulder straps. Unsecured objects are displaced.
Severe	The aircraft experiences large, abrupt changes in altitude and/or attitude. The aircraft also usually experiences large variations in indicated airspeed. Aircraft may be momentarily out of control.	Occupants are forced violently against seat belts or shoulder straps. Unsecured objects are tossed about.
Extreme	The aircraft is violently tossed about and is practically impossible to control. It may cause structural damage.	

Table 5: Vibration Scale

DEGREE OF VIBRATION	DESCRIPTION	PILOT RATING
NONE	No discernible vibration	0
SLIGHT	Not apparent to experienced aircrew fully occupied by their tasks, but noticeable if their attention is directed to it or if not otherwise occupied.	1
		2
		3
MODERATE	Experienced aircrew are aware of the vibration, but it does not affect their work, at least over a short period.	4
		5
		6
SEVERE	Vibration is immediately apparent to experienced aircrew even when fully occupied. Performance of primary task is affected, or tasks can only be done with difficulty.	7
		8
		9
INTOLERABLE	Sole preoccupation of aircrew is to reduce vibration level.	10

Note: Based on the Subjective Vibration Assessment Scale developed by the Aeroplane and Armament Experimental Establishment (A&AEE), Boscombe Down, England

Table 6: Visual Landing Aids Rating Scale (Reference RW-14R-90)

VLA Rating	Visual Cues Adequacy	Rating Description
1	Good	Configuration provides visual cues that require little or no pilot effort to interpret; recoveries are slightly more difficult than those attempted in daylight.
2	Satisfactory	Configuration provides minimum amount of visual cues necessary for routine safe fleet recovery operations.
3	Adequate	Configuration is adequate for fleet use in non-routine basis. Use when operationally necessary and with prior pilot training on the configuration.
4	Marginal	Configuration provides inadequate visual cues for consistently safe fleet recovery operations; recoveries could be conducted with significantly increased risk in critical or wartime situations.
5	Unsatisfactory	Configuration provides insufficient visual cues for safe recovery; unacceptable risks associated with recovery attempts in these conditions.

4.2.2 Daytime Test Progression Philosophy

Launch/recovery envelope development tests are by definition conducted outside of existing approved operating envelopes; therefore, standardized test progression procedures are required in order to ensure that a safe, incremental buildup is used to approach potentially high workload test conditions. In preparation for each event, the ship's crew maneuvers the ship onto a specific course and speed to provide the desired WOD and ship motion conditions for that event, as determined by the test coordinator and project engineers on the ship. Other conditions desired for that event such as configuration and intensity of flight deck lighting or other visual landing aids are set as necessary by the ship's crew and project engineers. All conditions for that event are then maintained to the greatest extent possible for the duration of the event. The test aircraft, which typically will have been flying in a holding pattern up to this point, now begins its approach to the ship for the new event. The approach, recovery, launch, and departure sequence is carried out, throughout which the pilot not at the controls is monitoring and recording cockpit data parameters, and project engineers on the ship are monitoring and recording data parameters for their respective stations. Following completion of the event, when the aircraft is again away from the ship in a holding pattern, the pilot and copilot assign the overall pilot rating to the event, and communicate their ratings and recorded parameters by radio to the project engineers on the ship. The test coordinator and project engineer makes the determination of the test conditions for the next event on the bridge, and the process described above is repeated for the next event.

In general terms, the typical data point progression for envelope development consists of first incrementally building up to a certain WOD speed along one azimuth (normally either the aircraft landing lineup line or ship centerline). The end WOD speed is limited by one of the following: 1) no greater WOD speed is desired along that azimuth, 2) no greater WOD speed is attainable along that azimuth with the available true wind conditions and ship maneuvering capability, or 3) the current WOD condition is assigned an unsatisfactory pilot rating (PRS-3 or PRS-4)(DIPES 4-5). If a PRS-3 or PRS-4 (DIPES 4-5) is reached, the end speed of WOD speed buildup on that azimuth is considered to be the WOD condition of the previous PRS-1 or PRS-2 (DIPES 1-3). After reaching that end point, the progression then focuses on incrementing in azimuth while maintaining that value of WOD speed. As the progression moves farther off the bow, the true wind conditions and ship maneuvering capability may not provide the means to maintain that WOD speed. When that is the case, the closest WOD speed attainable becomes the target WOD speed for subsequent events. Building out on the other side of the initial azimuth is conducted later. This order of envelope development is generally used because it is a time-efficient method for developing a reasonably large envelope.

There are two other guidelines used to determine the target WOD speed and azimuth conditions for each event. At the start of a test period for development of an envelope, the initial WOD condition must be within the approved envelope for fleet use or located within the boundaries of conditions previously tested and rated as safe (PRS-1 or PRS-2)(DIPES 1-3). Second, each new/target relative WOD condition may only be either 5 knots in WOD speed OR 15 degrees in WOD azimuth from any WOD condition within an approved envelope, or previously tested and rated as safe. These guidelines are established to ensure a safe and gradual development of a new launch/recovery envelope.

4.2.3 Nighttime Test Progression Philosophy

Night launch/recovery test methods are generally similar to day test methods, and must follow the same rules for data point progression as described for day launch/recovery tests. Several additional safety precautions are also required for night launch/recovery testing. First, pilots are not required to record test data on pilot data cards during night test operations. Second, tape measure directional control (pedal position) instrumentation may not be used during any night operations. Finally, night launch/recovery test sequences may only be conducted with WOD and ship motion conditions which are within a day launch/recovery envelope.

The use of night vision devices (NVD) for USN rotorcraft night shipboard operations has increased significantly over the past few years. This increase has led to the application of night vision compatible blue lighting to be incorporated on some ship classes. Night vision goggles (NVG) (aviators night vision imaging system generation 9, commonly known as ANVIS 9's) are used throughout launch/recovery operations. NVG's are worn by the pilot and are mounted on the forward part of the helmet. They are capable of flipping in front of the eyes, or rotated to a vertical position above the eyes. These two light intensification tubes limit the pilot's field of view requiring more head movement to scan the same area without goggles. Despite the limited field of view, experienced NVG pilots tend to prefer aided flight to unaided for safety and comfort level.

Shipboard lighting poses a significant problem to approaching pilots wearing NVG's. Common ship lights (stern, masthead, navigation) are very bright and cause NVG images to bloom and/or shutdown. An approaching NVD aided pilot would prefer a "dark" deck, one with no illumination. The inherent problem is the safety and efficiency of the flight deck crew. It is important that night lighting systems provide the flight deck crew (LSE, chock runners, refueling and maintenance personnel) with the capability to see the aircraft and surrounding flight deck while providing the goggled pilots and aircrew the ability to see flight deck visual cue required to land the aircraft. A VLA pilot rating scale is presented in Table 6.

5. DI Test Factors

5.1 Planning

A variety of related factors must be taken into account for a successful helicopter/ship ship test program. Detailed planning is essential to bring all the different program elements together. The US Navy DI program starts with a comprehensive test plan that includes the program background, purpose, description of test equipment, program scope, test methodology, and includes safety and test hazards check lists. The test plan is reviewed by test team members and by approval officials representing the many disciplines addressed by the test program. No testing can take place until all planning has been completed and the test plan has been signed.

5.2 Test Equipment

DI test equipment includes the rotorcraft, the ship, and the test instrumentation. The aircraft must be certified to operate aboard the ship before any testing can commence. The Naval Air Warfare Center Aircraft Division at Lakehurst, N.J, performs the ship aviation certification. Certification addresses both the aircraft environmental conditions and the ship aviation missions. The helicopter's design, including land-based low speed handling qualities and hover characteristics, are important factors in DI testing, as previously discussed. Helicopter related DI test factors include:

Aircraft – Should be marinized for the shipboard environment
Blade fold – Required for storage (flight deck and hangar)
Rotor brake – Required especially for gusting wind conditions
Blade design – Blades that flex easily may result in blade/fuselage strikes
Landing gear design – Wheel or skid and sliding/turn-over characteristics
Tail wheel location with respect to deck edge
Cockpit – Field-of-view is important, as previously discussed
Ship interface – Electrical systems and refueling system
Electro Magnetic Compatibility (EMC)

The ship provides a dynamic landing platform for the helicopter. Several ship-related factors influence DI testing, including:
Size – How big is the ship and the landing spots?
Are any obstructions near the landing pad, approach, or take-off corridors?
How high the flight deck above the water?
How high are the ship anemometers above the flight deck?
What are the ship motion characteristics?
Flight Deck – Markings and lighting for pilot visual cues
Ship Interface – Ability to connect test equipment and get access to required data

Deck Handling - Most flight deck handling issues can be evaluated through a paper analysis, with scale drawings and information on aircraft turning radius and ship motion characteristics of the ship. Some modifications to the airframe warrant shipboard operational evaluation. If a missile is mounted on a helicopter, clearance issues, ordnance upload /download, and aircraft re-spotting become important. Procedures must be developed to safely download ordnance from the aircraft to the magazine aboard the ship. Aircraft tiedown must be evaluated to avoid chain contact with ordnance, or require flight deck personnel to reach underneath a missile equipped with CADs for emergency jettison.

5.3 Test Location

General - Test location and test date will have a big impact on the size the launch/recovery developed during a specific DI test. Some areas, like the North Atlantic in winter, produce higher wind/sea state conditions than many other areas. DI tests are usually scheduled many months in advance and are often conducted in areas where the ships are located which may result in benign sea/wind conditions.

Ship Motion - In many cases during relative wind envelope development tests, ship motion parameters are among the conditions that are not controlled but are simply recorded for each event. However, when possible it may be desirable to conduct dedicated test periods for the purpose of evaluating ship roll motion limits at particular WOD conditions. For this process, a range of WOD conditions is selected from those previously tested and rated as satisfactory. At each selected WOD condition a series of events is conducted which increments the magnitude of ship roll motion until a limiting value is reached. Ship motion development tests follow the same rules for data point progression, data recording process, and criteria for assignment of pilot ratings as described for relative wind envelope development tests. However, in this case the test progression increments ship roll magnitude under a fixed WOD speed and azimuth. The means by which the ship roll motion is generated is controlled by the helmsman on the bridge and is referred to as "rudder kicks. Repeated oscillation of the ship's rudder is performed with a rapid and symmetric motion to avoid an alteration in the ship's course and speed. The rate and magnitude of these rudder kicks for a given set of sea conditions and ship course and speed determine the magnitude of the resultant ship roll motion. The increment in ship roll motion for each event should be on the order of 2 degrees. The helmsman's ability to make a small, precise change in the value of roll magnitude may vary by event depending on the sea conditions and ship course and speed required for a target WOD. For each WOD condition, it may be decided that the end point of ship roll motion development has been reached when any of the following criteria apply: 1) the test team or ship's crew determines that no greater ship roll angle is desired at that WOD condition, 2) no greater ship roll angle is attainable at that WOD condition with the available sea conditions and ship maneuvering capability, or 3) the current ship roll magnitude has been assigned an unsatisfactory pilot rating (PRS-3 or PRS-4)(DIPES 4-5). The rudder generated roll tends to be predictable and should not be substituted for high sea state actual test conditions.

5.4 Test Team Status

The test team is the key factor in any flight test program, and especially for a DI flight test program. The helicopter/ship test group provides the test continuity and retains the knowledge base associated with many years of experience. The test team consists of test pilots, flight test engineers, and others as required. Test team members are required to schedule aircraft, ship, and support equipment, plus coordinate actual testing and any follow-on reporting.

5.5 Test Limitations

Helicopter/ship testing is high risk testing and safety must be paramount in each program. The test team may include both day and night testing for a specified ship. If the testing is delayed due to weather (low true winds) or aircraft (maintenance), the test team may not be able to complete all the planned data points. The nature of DI testing results in a fast paced test program once flight testing begins. It is important for each test team member to think safety, and if some action has the potential to result in an unsafe condition, to stop the testing and review the situation.

6. Establishment of Shipboard Launch/Recovery Envelopes

Once the test team returns, all data is entered into the DI database. The WOD condition with the pilot rating is plotted as shown in Figure 10. Most limiting parameters such as control margin, pilot workload, and visual cues are assessed by the pilot during the test and subsequently included in the launch/recovery rating. In most cases, flight control, torque and pertinent data is not digitally acquired. Therefore control activity cannot be examined to accurately determine control margins during tested launch/recovery sequences. Engineers determine a boundary for all PRS-1 and PRS-2 (DIPES 1-3) test points which becomes the launch/recovery envelope similar to the one shown in Figure 10.

As mentioned earlier, pilots record average hover torque values during daytime test periods. These data are used to evaluate shipboard hover torque requirements against landbased data. The difference between the shipboard and landbased hover torque is shown in Figure 11. This tool is used to determine WOD conditions where shipboard torque requirements exceed published landbased requirements. This difference is assumed to be independent of GW.

Recall that launch/recovery envelopes are valid for all GW's. However the pilots are cautioned or warned for regions of WOD conditions where shipboard torque requirements exceed publish landbased requirements. This is necessary to ensure pilots have adequate torque margins to launch under all GW conditions. These cautions or warnings are listed on the published envelope similar to the caution in Figure 11.

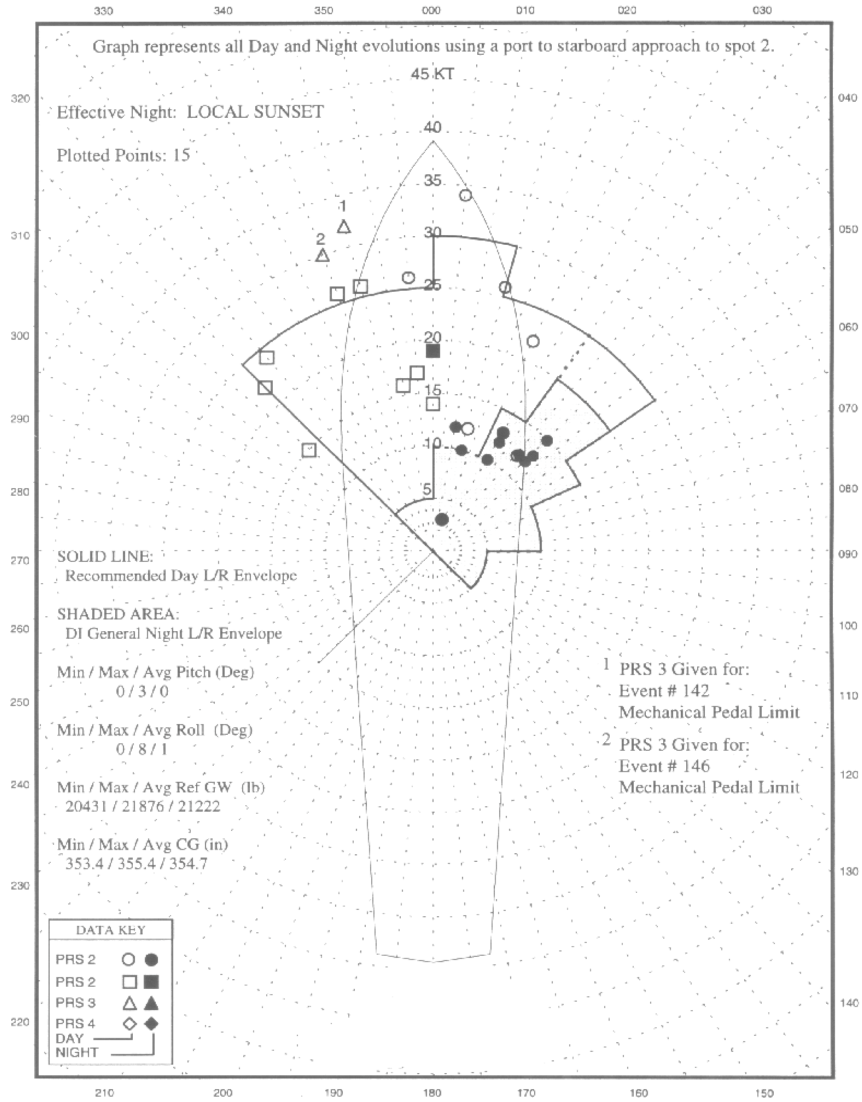

Fig. 10 Dynamic Interface Launch/Recovery Envelope Fairing

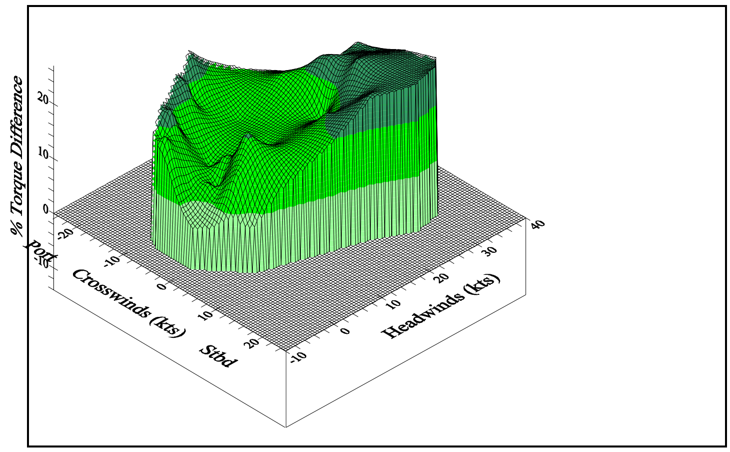

Fig. 11 Comparison of Shipboard to Landbased Torque Requirements

7. Modeling and Simulation

7.1 Background

The US Navy initiated the concept of combined quantitative and qualitative evaluations of rotorcraft simulators in the mid 1970's. These operational flight trainers (OFT) and weapon systems trainers (WST) featured cockpits, motions systems, visual systems, and related air vehicle math models. The goal was to use simulator time to reduce the actual flight time required in an era of fuel shortage. The flight simulators were designed to train in all Navy helicopter missions, including shipboard landing scenarios. This rigorous flight test evaluation approach pointed out OFT/WST shortcomings and it also suggested options for improved fidelity [5]. The basic OFT/WST air vehicle performance and flying qualities, engines, and avionics could be evaluated quantitatively based on flight test data. At this time, no shipboard landing data were available to quantitatively evaluate this important Navy mission scenario. The shipboard landing task was evaluated qualitatively by one or more pilots. The subjective nature of the early flight trainer ship airwake model development and test process tended to reduce the credibility of US Navy flight trainers for ship based training applications.

The Navy established a helicopter/ship or Dynamic Interface test group at Patuxent River in 1982, with the goal of conducting a combined flight test and analytical effort [2]. The large helicopter/ship test backlog, limited available funding, and low interest in analysis, limited the early analytic effort. The early flight simulators were very limited in their ability to support helicopter/ship training and testing due to limitations in visual systems, aerodynamics models, and ship airwake models [6]. Problems associated with ship airwake models were identified for both fixed wing and helicopter flight trainers [7].

Simulation continues to advance at a rapid pace and has a good potential and may become an excellent tool in the future for evaluating various shipboard helicopter compatibility issues and for preparing for flight tests. Simulation can be an economical way to evaluate new shipboard landing aid marking or lighting configurations. Pilots can perform repeated launch/recovery operations to various lighting or marking configurations and optimize them for safety and operational efficiency. Simulation can assist pilots in preparation for shipboard operational procedures and improve comfort level with low light level NVG flights, various VLA configurations, or a high sea state/ship motion environment. In addition, simulation can provide a pilot with a "sight picture" to aid in positioning a large aircraft aboard a small ship properly. Long and Williams [8] provide many detailed examples of how visual simulation technology is used to design and optimize aviation facilities, train pilots for shipboard operations, and investigate other clearance issues. During shipboard flight testing, crew coordination becomes critical, especially during low light level aided and unaided operations. Practicing pattern work, typical radio calls, and data collection improves the overall efficiency and safety of the flight test. An evaluation of this nature does not require an accurate aircraft aerodynamic model, however, field of view should be the same or similar to the aircraft model that operates from the particular ship

7.2 U.S. Navy Small Business and Related Efforts

The U.S. Navy has made much progress over the past few years in developing an analytic capability to help support future helicopter air vehicle flight testing in general. Small business and related programs have been used to develop several analytic enhancements. These improvements include rotor blade and rotor map comparisons, tail rotor loss of effectiveness analysis, off-axis coupling analysis, vortex ring state modeling, improved fuselage load prediction, and improved validation options. One program focuses on setting-up a blade element V-22 model on the NAVAIR Manned Flight Simulator to investigate the rotorcraft and airwake model level of complexity required to simulate the shipboard landing task. The program also focuses on developing an analytic test tool to support future rotorcraft/ship testing.

7.3 JSHIP

The Joint Ship Helicopter Integration Process (JSHIP) Test and Evaluation Navy program was initiated in 1998. This 5 yr program addresses joint service helicopter/ship operability issues and includes a Dynamic Interface Modeling and Simulation (DIMSS) effort. The DIMSS effort included demonstrating an Army UH-60A helicopter model operating with an LHA class ship and NAVAIR CFD airwake on the NASA Ames Vertical Motion Simulator. DIMSS variables included simulation system motion, visual system, and aural cues, with fixed ship airwake methodology (CFD) and fixed helicopter model (UH-60). Pilot comments were favorable during the simulation session conducted during the 2000-2001 time frame.

7.4 Computational Fluid Dynamics

Computational Fluid Dynamics (CFD) provides an analytic option to generate airwake data for the complete ship environment. Accurate ship airwake modeling may be helpful in improving the fidelity of shipboard simulation. NAVAIR [9] applied the unstructured-grid Navier-Stokes CFD solver COBALT, in conjunction the Monotone Integrated Large Eddy Simulation (MILES) turbulence model to define the airwake for an LHA class ship for the JSHIP DIMSS program. The complexity of the LHA CFD solution in terms of iso-surfaces of vorticity for winds over the bow and at 030 deg is shown in figures 12 and 13. Note the large variation in flow characteristics as a function of wind over the deck direction. The CFD steady u, v, and w airwake components compared favorably to wind tunnel data for the same conditions, as shown in figure 14. A recently (2001) initiated long term NAVAIR ship airwake CFD model enhancement program sponsored by the Office of Naval Research should have a positive impact.

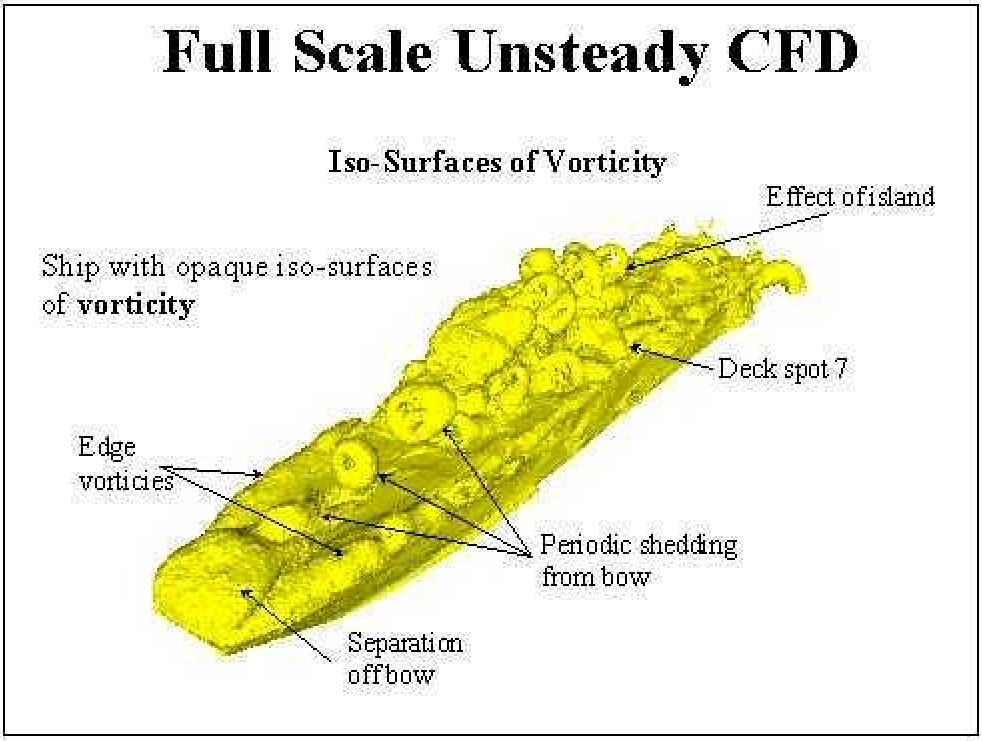

Fig. 12 CFD Iso-Surfaces of Vorticity Surfaces for LHA with WOD 30 kt at 000 deg

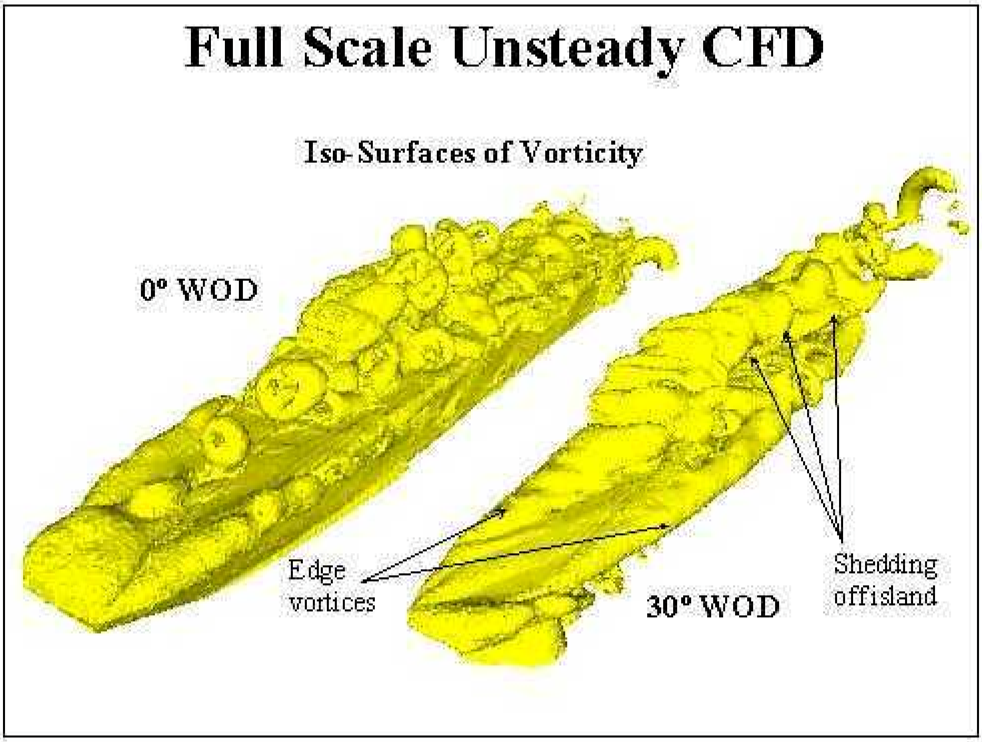

Fig. 13 CFD Iso-Surfaces of Vorticity Surfaces for LHA with WOD 30 kt at 030 deg

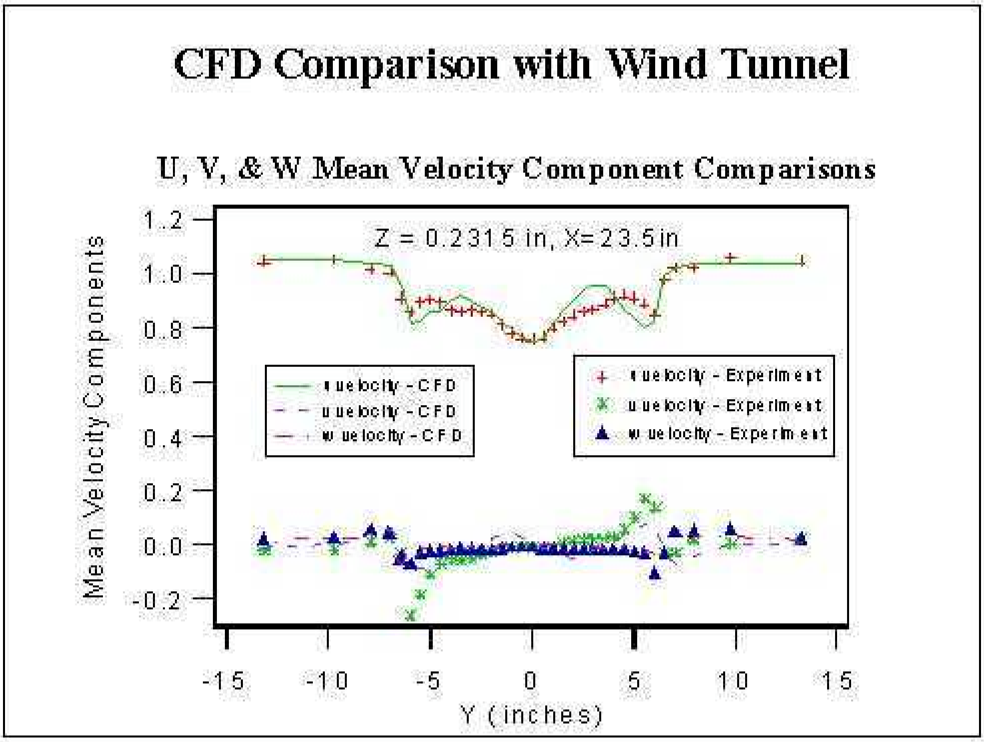

Fig. 14 CFD Comparison to Wind Tunnel for Steady Airwake

7.5 Wind Tunnel

The U.S. has studied ship airwake phenomenon on ship models both in wind tunnels and in water tunnels beginning in the early 1960's. Each model has distinct advantages and disadvantages. At full scale wind over deck velocities, air acts as an incompressible fluid. Water can be a satisfactory substitute for air in this case. Because of Reynolds number scaling, water tunnel studies have an advantage over wind tunnel studies because of the difference in the kinematic viscosity of the two fluids. If the tests are run at the same Reynolds number for the wind and water tunnels, the same boundary layer growth along the walls of the tunnel will exist. Historically, water tunnels were used to study both the steady flow and the wake turbulence with static and oscillating ship models. Wind tunnel measurements were typically made of steady flow characteristics with a static ship model. Flow visualization studies were performed using neutrally buoyant helium bubbles, special lighting, and time lapse photography. The problem researchers faced were a way to develop a realistic atmospheric boundary layer. Healey [10] developed a convincing scale atmospheric boundary layer by placing several hundred 1/2 by 3 inch dowel rods upwind of the ship model. The rods tripped the flow to simulate that of sea water tripped atmospheric boundary layer. Airwake velocities along glide path of an approaching helicopter were measured using a hot wire anemometer. Data from tests such as these are manipulated in the frequency domain to find power spectral densities (PSD's) of the airwake which indicate the frequencies that contain the highest energy. Knowing the PSD spatial variation, coupled with ship motion effects on the flowfield, the simulation engineer can develop, through random number generation and various filters, a real-time flow variation or "airwake" modeling the ship class studied in the wind tunnel.

At the same time, the U.S. Navy has a very strong ongoing wind tunnel effort, in conjunction with NASA Ames, to support DI testing. This effort has included over 3000 hr of wind tunnel tests between July 1998 and Sep 2001. The focus has been on LHD and DDG class ships and on the V-22, H-60, and H-46 rotorcraft. Figure 15 shows a variety of aircraft models on an LHD class ship in the NASA Ames Fluid Mechanics Lab wind tunnel. The basic LHD model showing the airwake vortex using oil flow techniques is presented in figure 16. The variation of the flow vortex caused by parked aircraft is shown in figure 17. The recent availability of Particle Image Velocimetry (PIV) technology (figure 18) is expected to greatly enhance wind tunnel data acquisition in the future. The advent of stereo lithography technology (figure 19) presents the option of going from electronic computer aided design (CAD) data of a ship to an actual wind tunnel model of the ship overnight. The integration of ongoing and future air vehicle model enhancements with improved PIV and stereo lithography wind tunnel options, and enhanced CFD options, should result in an analytic capability that will help the future test teams explore helicopter/ship options that are not available to current test team members.

Fig. 15 LHD Ship Model with Parked Aircraft

Fig. 16 Wind Tunnel Oil Flow Patterns on LHD Flight Deck

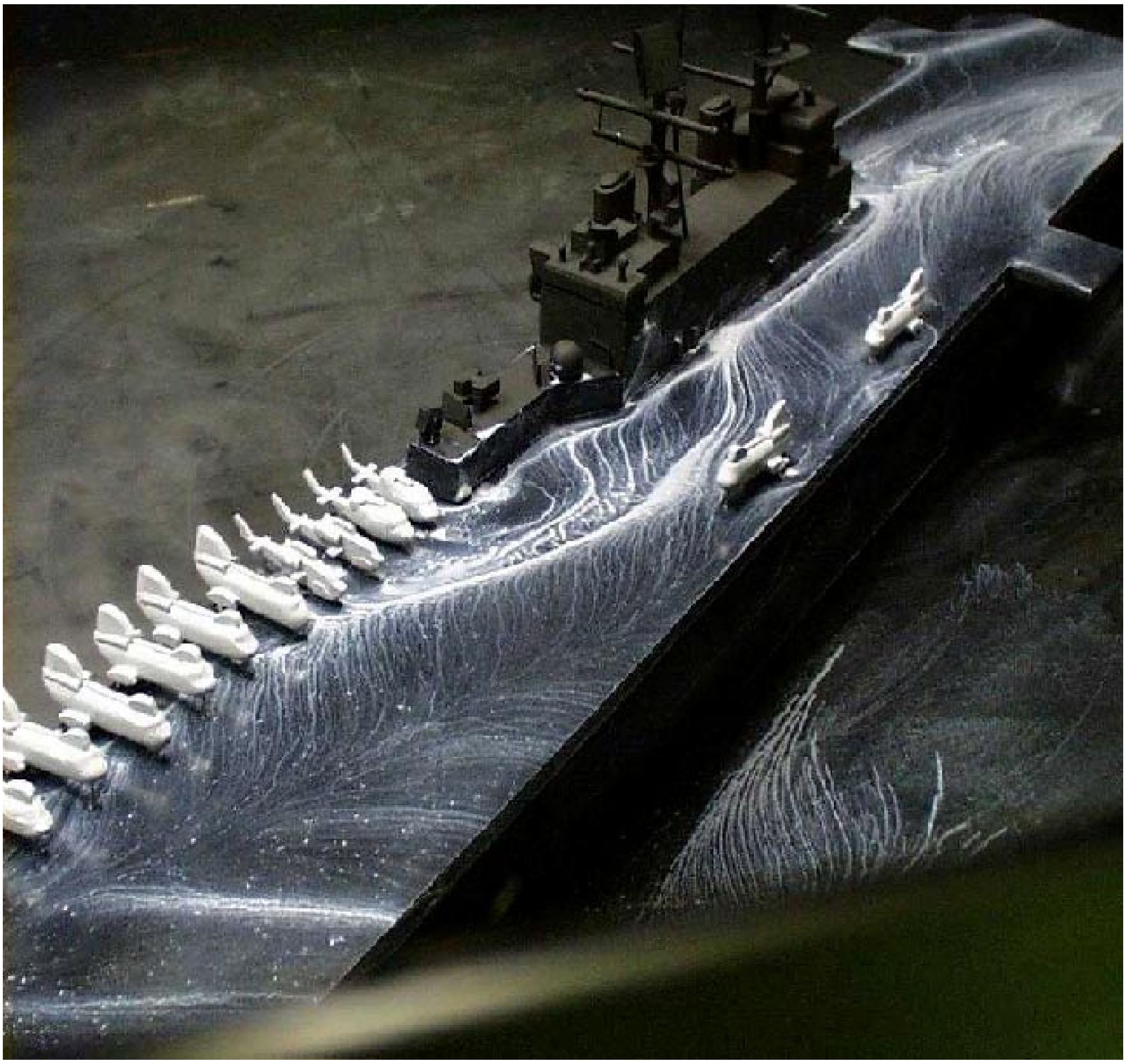

Fig. 17 Wind Tunnel Oil Flow Patterns with Parked Aircraft on Flight Deck

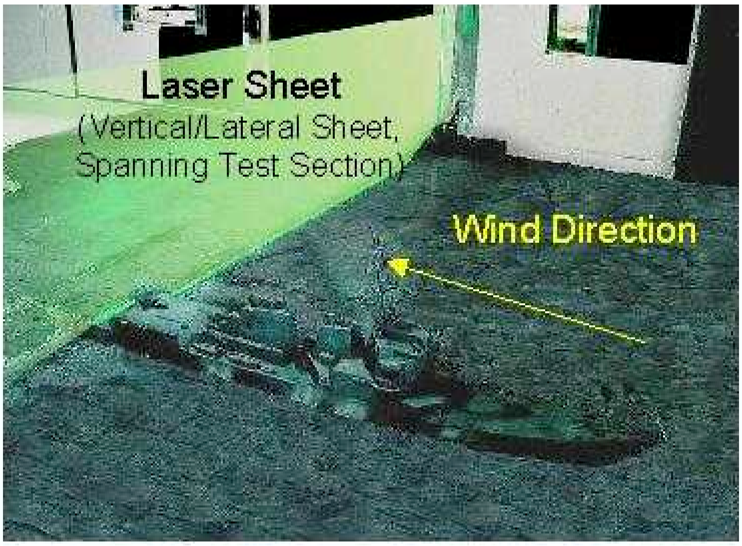

Fig. 18 Particle Image Velocimetry for DDG Airwake in Wind Tunnel

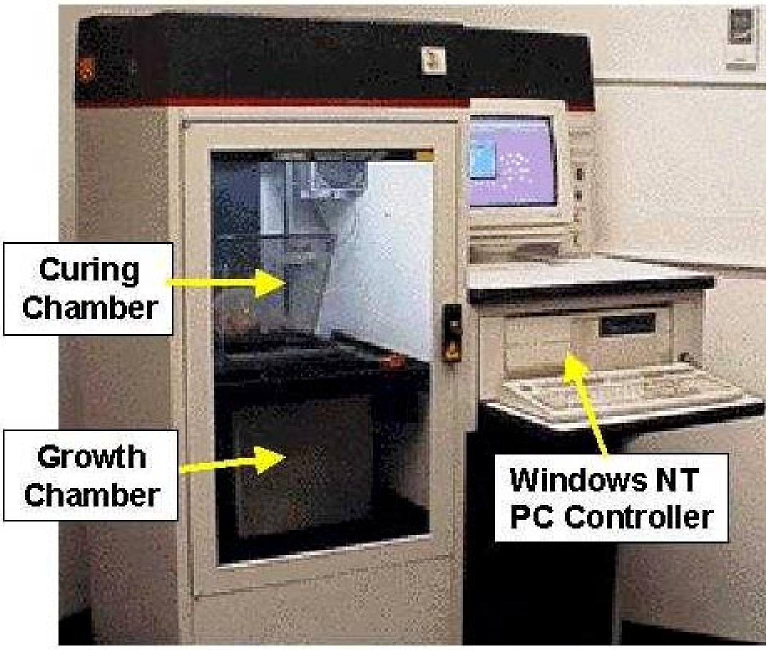

Fig. 19 Stereo Lithography Apparatus

7.6 Full Scale Measurements

In the past, the U.S. Navy has used the Ship Airwake Measurement System (SAMS) for full-scale ship airwake measurement [11] [12], as shown in figure 20 and described in Appendix A. Nine ship airwake surveys have been conducted aboard eight classes of ships. However, this system is limited to measuring only the airwake over the deck and can only measure three points simultaneously. Quantifying the airwake of an air capable ship for one WOD condition takes approximately one hour and fifteen minutes. This method of ship airwake quantification is a very tedious process and requires the ship to maintain specific WOD conditions. Ship airwake quantification should be conducted on a not to interfere basis with the ship's operational commitments. However, once at sea, the test team coordinates with the ship's crew to obtain the level of support required.

The JSHIP program developed a ship airwake measurement system that consisted of four eighteen foot poles with R.M. Young ultrasonic anemometers mounted atop the poles [13]. This system was used to acquire full scale ship airwake data aboard USS PELELIU (LHA 5) as shown in figure 21. Tests aboard LHA 5 were also used to determine the ship's bow boundary layer reattachment point. The goal was to acquire full scale ship airwake data under controlled conditions to provide validations options for the computational fluid dynamics derived ship airwake data.

The concept of scanning lasers may present future options to measure full scale 3-D ship airwake data. The Shipboard Aircraft LIDAR Turbulence Sensor (SALTS) system has been under development/testing for some time. The goal of the SALTS program is to be able to measure future 3-D ship airwake data both in the helicopter approach and touchdown areas.

Fig. 20 Ship Airwake Measurement System on Amphibious Class Ship

Fig. 21 JSHIP Ship Airwake Measurement System on LHA 5

7.7 M&S Summary

With the anticipated future emphasis on increased use of analytic options to support DI testing, it is important to continue work to validate all models and model components. It is also important to develop data for a wide variety of ships and aircraft. The continued modeling, simulation, and related analytic work by the many countries involved in DI activities should have a positive effect on future DI testing and related analyses.

8. Concluding Remarks

This AGARDograph describes the U.S. approach to helicopter/ship qualification testing that has been used successfully over many years to help provide aircraft and ship operators with expanded operational envelopes for their mission requirements. It is difficult to schedule ships for testing and it is not possible to control the weather in the ship environment. It is also important to work to minimize test cost. NAVAIR continues to conduct conventional DI testing, while working to acquire improved instrumentation plus an improved helicopter/ship simulation/analysis capability. The helicopter/ship qualification testing in the future is sure to present some very interesting challenges to the test teams involved in the programs. This AGARDograph provides a sound foundation to help ensure safe and cost effective DI testing in the future.

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Annex A: DI Instrumentation

A.1 Ship Airwake Measurement

Ship airwake is one of the most critical parameters affecting the difficulty of helicopter launch/recovery operations. Gaining an understanding of a full scale ship flowfield is approached two different ways. These are flow visualization and flow measurement. Flow visualization provides a basic idea of the gross flow patterns, whereas flow measurement provides quantitative information. The US Navy emphasizes flow measurement to apply to shipboard rotorcraft flight simulation. In the past, the instrument used by the US Navy was called the ship airwake measurement system (SAMS). SAMS consisted of a 30 foot pole, with 3 sets of 3 orthogonal Gill UVW propeller anemometers mounted at 10, 20, and 30 feet above ground level. The units were sealed and incorporate internal blowers to maintain positive pressure within the unit to limit environmental contamination of the bearings. The procedure for collecting ship airwake data included establishing and maintaining a particular wind over deck condition. The SAMS mast was then moved to the first designated flight deck measurement location, secured to the flight deck, and remained for 5 minutes to collect data. The data collection software was then reset and the mast was moved to the next location. When all of the data collection locations had been completed, a new wind over deck was arrived at and the process repeated. True wind was continually monitored throughout the data collection period to assure it remained constant. The data collection package not only measured wind but also collected ship course and speed, and wind over deck speed and direction from the ship repeaters. The critical information recorded from these tests was then reduced to statistical averages, scale lengths, and intensity factors. The scale length describes the distance between turbulent eddies (thus establishing a characteristic “frequency” of the flow). Intensity factor describes statistical variation of the flow velocity. Together, these parameters are used to simulate spatially and temporally varying ship airwake turbulence in a flight simulator.

A.2 Ship Instrumentation

The most common shipboard instrumentation used during a DI flight test is the ship motion instrumentation package (SMP). The DI SMP was designed to collect and store time histories of specific ship parameters. The sensors of the SMP are contained in a small, portable housing that may be set up anywhere on the test ship, with the ship center of buoyancy the optimal location. When placed other than the center of buoyancy, coordinate transformations are performed to determine motion at the helicopter landing spot.

Sensors organic to the SMP are:

a. Pitch and roll angle pendulums
b. Pitch, roll, and yaw rate gyro
c. Linear accelerometers

Wind over deck speed and direction along with ship course and ship speed are recorded directly from the ships repeaters. Repeater signals are passed through synchro to analog converters and then processed with the other signals. Four blank channels are provided so that additional sensor inputs (such as flight deck mounted anemometers or pitch and roll information from the ships gyros) may be recorded. Output for the sensor package is then passed to a portable computer. The computer provides post-processing capabilities along with data storage.

A.3 Helicopter Instrumentation

Quantitative helicopter/ship test data are needed for envelope development and for validating analysis and simulation models used to support DI testing. NAWCAD rotorcraft typically have extensive instrumentation. These aircraft normally are not used for DI testing because they may be required to support other test programs, may be considered a “dry” aircraft, or the DI test location may be too far from NAWCAD. A portable instrumentation system that can be easily installed and removed from fleet aircraft is needed to support remote site DI testing.

A small business program was used to develop a prototype Portable Aircraft Flight Test Instrumentation System (PINS) during the 1997-1999 time frame. PINS is designed to be installed, calibrated, and operational in just a few hours. It features an INS/GPS unit for acceleration, rates, velocities, angles, and positions. It can be attached to a MIL-STD 1553 bus if one is available in the rotorcraft. It also includes video monitoring that reads the cockpit displays and converts the reading to digital data. Typical examples of cockpit data include altitude, airspeed, vertical velocity, engine torque, and fuel quantity. Control position and control force data are also available. The PINS package weights approximate 115 lbs and was designed to be easily installed in fleet aircraft.

Annex

AGARD and RTO Flight Test Instrumentation and Flight Test Techniques Series

1. Volumes in the AGARD and RTO Flight Test Instrumentation Series, AGARDograph 160

Volume Number	Title	Publication Date
1.	Basic Principles of Flight Test Instrumentation Engineering (Issue 2) Issue 1: edited by A. Pool and D. Bosman Issue 2: edited by R. Borek and A. Pool	 1974 1994
2.	In-Flight Temperature Measurements by F. Trenkle and M. Reinhardt	1973
3.	The Measurements of Fuel Flow by J.T. France	1972
4.	The Measurements of Engine Rotation Speed by M. Vedrunes	1973
5.	Magnetic Recording of Flight Test Data by G.E. Bennett	1974
6.	Open and Closed Loop Accelerometers by I. Mclaren	1974
7.	Strain Gauge Measurements on Aircraft by E. Kottkamp, H. Wilhelm and D. Kohl	1976
8.	Linear and Angular Position Measurement of Aircraft Components by J.C. van der Linden and H.A. Mensink	1977
9.	Aeroelastic Flight Test Techniques and Instrumentation by J.W.G. van Nunen and G. Piazzoli	1979
10.	Helicopter Flight Test Instrumentation by K.R. Ferrell	1980
11.	Pressure and Flow Measurement by W. Wuest	1980
12.	Aircraft Flight Test Data Processing - A Review of the State of the Art by L.J. Smith and N.O. Matthews	1980
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15.	Gyroscopic Instruments and their Application to Flight Testing by B. Stieler and H. Winter	1982
16.	Trajectory Measurements for Take-off and Landing Test and Other Short-Range Applications by P. de Benque D'Agut, H. Riebeek and A. Pool	1985
17.	Analogue Signal Conditioning for Flight Test Instrumentation by D.W. Veatch and R.K. Bogue	1986
18.	Microprocessor Applications in Airborne Flight Test Instrumentation by M.J. Prickett	1987
19.	Digital Signal Conditioning for Flight Test by G.A. Bever	1991

2. Volumes in the AGARD and RTO Flight Test Techniques Series

Volume Number	Title	Publication Date
AG237	Guide to In-Flight Thrust Measurement of Turbojets and Fan Engines by the MIDAP Study Group (UK)	1979

The remaining volumes are published as a sequence of Volume Numbers of AGARDograph 300.

Volume Number	Title	Publication Date
1.	Calibration of Air-Data Systems and Flow Direction Sensors by J.A. Lawford and K.R. Nippress	1988
2.	Identification of Dynamic Systems by R.E. Maine and K.W. Iliff	1988
3.	Identification of Dynamic Systems - Applications to Aircraft Part 1: The Output Error Approach by R.E. Maine and K.W. Iliff	1986
	Part 2: Nonlinear Analysis and Manoeuvre Design by J.A. Mulder, J.K. Sridhar and J.H. Breeman	1994
4.	Determination of Antenna Patterns and Radar Reflection Characteristics of Aircraft by H. Bothe and D. McDonald	1986
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Dynamic interface	Operational effectiveness
Flight Deck Qualification	Sea states
Flight decks	Seakeeping
Flight maneuvers	Ship decks
Flight tests	Ship maneuvering
Helicopter flight tests	Ship motion
Helicopter/Ship Clearance	Shipboard landing
Helicopter/Ship Qualification	SHOL (Ship Helicopter Operating Limitations)
Helicopters	Trials

14. Abstract

The purpose of this AGARDograph is to document the preparation, execution, and data analysis of helicopter/ship flight-testing. The attention is focused on helicopter take-off and landing which constitutes the main part of the test programme.

Described are:
• the factors influencing the helicopter/ship operations;
• how these factors are determined in various qualification programme elements;
• how these factors are used to set up a flight test programme on board the ship;
• how the ship-borne flight tests, within the constraints of safety and efficiency, are carried out;
• in what way, during the tests, repeated use is made of the data obtained in the previous qualification programme elements and of the experience of the test team, resulting in the smallest possible number of flying hours without affecting the quality of the results.

A brief outline of helicopter-ship qualification programmes as carried out by the Netherlands National Aerospace Laboratory (NLR), by QinetiQ (formerly the UK Defence Evaluation & Research Agency (DERA) at Boscombe Down in the UK and by the US Naval Air Warfare Center Aircraft Division (NAWCAD) at Patuxent River is given. It describes how detailed information of the helicopter capabilities, ship's motion characteristics and the wind-climate above the ship's flight deck, is used to set up and to execute a safe and efficient flight test programme. The programme leads to a safe and maximum operational availability of the helicopter on board the ship in terms of take-off and landing capabilities as a function of relative wind and sea-state.

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