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HELICOPTER - SHIP QUALIFICATION TESTING

by

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SUMMARY

For any helicopter type, a set of limits for its safe operation is given by the manufacturer. The limits with respect to take-off and landing generally apply to a rigid and unobstructed landing site only. However, for operations from ships, the helicopter must be manoeuvred close to the flight deck where extremely turbulent conditions may prevail. Moreover, the flight deck is not at rest but moves in an irregular way. These circumstances may lead to additional operational restrictions resulting from limitations in helicopter performance or human ability.

The paper describes a test method developed by NLR for the establishment of these additional restrictions on a routine basis. The method includes the recording and analysis of relevant parameters of the helicopter and the ship. To quantify the human factors in controlling the helicopter, a pilot rating technique is applied.

An example of results is discussed. Special attention is paid to a method for defining and presenting ship motion limits.

CONTENTS

1. INTRODUCTION

During almost 15 years NLR has from time to time been involved in flight testing helicopters operating from various types of navy vessels. In recent years the need for this kind of work has steadily increased worldwide due to the vast expansion of naval helicopter operations. Nowadays, a large variety of helicopter types of various weights and capabilities has entered service. Especially the improved capabilities of present-generation helicopters offer a wide range of possibilities for attractive ship-helicopter combinations to cope with the growing demand being put on modern navies. Therefore, many even relatively small navy ships 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 are often required even under adverse weather conditions and at night.

Before permitting a helicopter type to operate from a certain class of ships, it is advisable to determine the operational capabilities and limitations of that combination. Reference 1 describes a test method which has been developed by NLR to establish on a routine basis, procedures and restrictions for optimal availability of the helicopter with adequate safety to personnel and equipment involved.

The operation of any helicopter is restricted by limitations, as specified in the Flight Manual after extensive factory testing.

Apart from engineering limitations (weight, centre of gravity, airspeed, power, etc.) usually also a few general operating limitations must be observed, e.g. regarding flight in icing conditions, or for landing on slopes. The limits with respect to take-off and landing generally apply to a rigid and unobstructed landing site only. However, for operations from ships, the helicopter must be manoeuvred in the environment close to the flight deck where extremely turbulent conditions may prevail. Moreover, the flight deck is not stationary and often moves in an irregular way. These circumstances may lead to additional operational restrictions resulting from limitations of the helicopter or the pilot in safely controlling the helicopter. These restrictions are not given by the manufacturer of the helicopter since they depend on the specific environment in which the helicopter is operated. The configuration of the ship, the location of the flight deck, available facilities, and the motion of the ship under various conditions of wind and sea determine this environment. Figure 1 gives a survey of the various factors of interest.

Features of aerodynamic origin which may influence helicopter operations from ships are:

- flow deviations and turbulence caused by the ship's superstructure
- smoke at or over the flight deck or in the regions of approach
- insufficient definition of true relative wind conditions by ill-positioned wind measuring gear.

During the design stage of a ship, these subjects are best studied by means of a scale model in a wind tunnel. On several occasions, NLR has performed this work in its low speed wind-tunnel facilities. The testing comprised the following aspects:

- observation of the air flow in the neighbourhood and above the flight deck. Figure 2a shows a model equipped with tufts for this purpose
- measurement of flow deviations and turbulence with hot wire anemometers (Fig. 2b)
- determination of exhaust plume paths for all relevant directions and velocities of the relative wind and at various ship power settings Figure 3 depicts a full-power condition of a gas turbine powered frigate
- measurement of plume dispersion in order to be able to predict plume temperatures over the flight deck or in the approach path
- determination of the quality of flow at the proposed positions of the wind measuring gear on the ship. The importance of the proper location of these instruments if often overlooked, sometimes resulting in difficulties later.

Major benefits of wind-tunnel investigations are the early detection of unfavourable conditions and the simple determination of the effects of modifications.

To verify the wind-tunnel results for the flight-deck environment, some full-scale checks are usually carried out on the completed ship. A special movable mast carrying measuring equipment, as shown in figure 4, is used. Low-inertia anemometers measure wind velocities and fluctuations in three directions and at two height levels. A temperature sensor may be installed in the mast in order to probe plume temperatures. Experience has shown that the wind-tunnel results compare fairly well with full-scale results.

To calibrate the ship's wind measuring gear, additional anemometers are installed, usually at the bow of the ship.

All data are recorded on magnetic tape for computer-processing. The results are particularly important for the subsequent helicopter tests because they provide a basis for the definition of the flight-test programme.

Finally, flight tests by day and by night have to be executed in order to determine to what extent the helicopter operations are actually limited by the turbulent (and smoke) environment close to the flight deck, and by the motion of the ship. Important aspects in this connection are:
- take-off and landing
- transport of the helicopter between flight deck and hangar
- starting and stopping of the rotor system
- transport operations by means of the helicopter (vertical replenishment).

In this paper the attention is focussed on the take-off and landing aspects which in fact constitute the main part of the tests.

2. TAKE-OFF AND LANDING PROCEDURES

The procedures followed for take-off and landing depend on the type of helicopter and the configuration of the flight deck. A preferable method in general is a take-off or landing into the relative wind. When required by the relative wind direction, landings across deck or even toward the stern of the ship may be performed. When straight-in or straight-out procedures can not be flown, e.g. because of obstructions constituted by the superstructure of the ship, a sideward take-off or landing could be carried out. This means that after lift-off the helicopter is manoeuvred sideways to a hovering position at one side of the flight deck and commences forward flight from there. The approach ends at the hovering position alongside the deck, and is followed by a sideward flight to a hovering position above the flight deck from where the actual landing is carried out.

When the pilot is cleared for take-off or landing, he will also be informed about the prevailing relative wind. On this basis he selects his take-off or landing procedure. The manoeuvring flight close to the flight deck, as well as the initiation of lift-off and touch-down, are directed by a flight-deck officer (FDO). A good co-operation between pilot and FDO is essential for flight safety, especially in rough sea conditions.

3. FLIGHT TESTING

3.1 Instrumentation

To determine safe take-off and landing envelopes for helicopter operations aboard ships, NLR has developed a standard instrumentation package. Relevant parameters of both the helicopter and the ship are recorded. In the helicopter an airborne photo-sensitive paper recorder with time base is used (Fig. 5). The main quantities measured are:
- engine torque and maximum-torque warning
- collective pitch lever position
- engine inlet temperature

- tail rotor control (pedal) position
- radar altitude
- vertical and lateral acceleration
- instant of take-off and landing.

On board the ship the relative wind speed and direction as indicated by one of the ship's anemometers are recorded. Furthermore, quantities are measured which define the motion of the flight deck viz.:
- pitching and rolling angles
- vertical and lateral accelerations at several positions.

The recordings are made on magnetic tape using a digital data logger. Sampling rate is 4 times per second for motion parameters and 2 times per second for the wind parameter. Figure 6 shows the recording equipment which includes an ultra-violet recorder for quick look.

3.2 Pilot rating

An important factor for determining the degree of acceptance of a test condition with respect to controllability of the helicopter is the opinion of the test pilot. In order to make the pilot's opinion for different situations easily comparable, a pilot rating method is used. In principle the test pilot is asked to qualify the degree of difficulty of his flying task, during several pre-defined flight segments, using a ten-point rating scale. For the present test set-up, the scale has been chosen according to the method of Hess (Ref. 2). On this scale no adjectives (bad, reasonable, etc.) have been added to the numbers (Fig. 7). The pilot is asked to use the entire scale according to his personal insight, but as consistently as possible. By comparing the numerical values or scores after the test period, a qualitative measure is obtained of the degree of difficulty of the pilot's task under the various test conditions. The scores possess a relative value, because of the absence of adjectives on the scale number. The advantages of the present method as compared with e.g. the Cooper-Harper rating scale, on which each number is in fact a defined handling quality mark, are twofold:
- better sensitivity, because the full scale can be used to judge the degree of difficulty of the landing or take-off
- no extensive experience in the use of rating scales by the test pilot is required.

The flight segments mentioned above, for which the pilot is asked to give a rating, have been chosen as follows:

Take-off:
1. lift-off and hover over the flight deck
2. sideward flight, heading into the relative wind and climb out, or direct climb out, depending on the take-off technique applied.

Landing:
1. approach to hover alongside the ship
2. sideward flight to the hover position above the flight deck
3. final descent and touch-down.

In case of a straight-in approach the first segment is considered to extend down to hover above the flight deck, so that in such a situation only two segments are involved.

Additional pilot comments are recorded during the flights or during the post-flight de-briefing to document the rationale behind the scores. The latter aspect is essential for applying a pilot rating method with success.

3.3 Test programme

To achieve the object of the flight testing, viz. to determine safe take-off and landing envelopes for helicopter operations, a rather extensive programme has to be executed. For successive flights, the principal variables are the relative wind speed and direction (wind-over-deck). The safety aspect demands that the (as yet unknown) limits must be approached gradually. Therefore, the flight test programme is divided into several parts with increasing demand on the skill of the pilots and the capability of the helicopter. If possible, the following phases are executed in the sequence given below:

- familiarization flights at low weight, fair weather
- tests at low mass, fair weather, first during day-time, later-on at night
- tests at maximum take-off weight, fair weather, day and night
- tests at low weight, rough weather and sea conditions, day and night
- tests at maximum weight, rough weather and sea conditions, day and night.

In addition, the constraints on helicopter operations close to the flight-deck due to the exhaust gases of the ship's propulsion system are evaluated.

4. SHIP MOTION

When operational guide lines are to be established for maximum acceptable ship motion, they should be defined in terms of one or more quantities which include all aspects relevant for helicopter operation. It has been practice to characterize the relevant ship motion by heave, pitching and rolling. Mostly, as in this paper, the vertical motion of the flight deck is assumed to be mainly dependent on the pitching motion of the ship. Qualitatively some important observations can be made when the pitching and rolling motions of a ship are considered in more detail.

First, one or more dominant frequencies can be seen to characterize the various modes of ship motion. They depend in principle on wave length, ship inertia, speed and course relative to the wave direction. The frequencies of the ship motion are important factors for a helicopter, manoeuvring close to the flight deck. Higher frequencies at a given amplitude result in higher accelerations and deck velocities in vertical or lateral direction. Since higher frequencies demand a quicker response from the pilot and the helicopter, the consequence can be that the maximum acceptable amplitude has to be reduced. Because frequencies are very much dependent on the type of ship, experimental data cannot be simply applied to other types of ships. Also no generalization can be made for different maritime geographical areas where the frequency characteristics of the waves are different. Additional flight tests are then required to account for these influences.

A second important observation is that in general the ship motion amplitudes vary with time in a more or less regular way. For helicopter operation during rough sea conditions it is mandatory to make use of periods during which the motion is relatively quiet for some time (stills). Pilot and flight deck officer should therefore have a good sense of the cadense of the ship. Figure 8 shows two touch-downs, made at quiet periods in the ship pitching motion. When exceeding the limiting conditions, take-off and landing become too risky, despite those quiet periods.

For the purpose of defining the level of maximum acceptable ship motion, it is not feasible to use criteria in terms of amplitudes as experienced during the quiet periods since these periods are too short and often variable to yield consistent test results. An obvious way to define the limiting level seems to be the use of the σ-value of one or more characteristic motion parameters. But then the question arises to what extent the σ-value is indeed a useful criterion to define limiting ship motion for take-off and landing.

To answer that question the following procedure has been carried out. It is assumed that a measure for the variability of the amplitude is obtained by observing the ratio of the maximum peak-to-peak and the σ-value during a sufficiently long time interval. In case of a constant amplitude harmonic oscillation this ratio equals $2\sqrt{2}$. For time-varying amplitude oscillations the ratio is always larger.

From the data recordings of an actual qualification test programme, the above-mentioned ratio has been calculated for the pitching and rolling angles of a series of 44 test runs, covering a wide range of sea and wind conditions. The measuring time for each run was 256 s. The results are given in figure 9 in the form of histograms. The mean values of the ratio are 5,8 and 5,7 respectively. Deviations about the mean values are rather small viz. less than 15 percent for 80 percent of the test runs. No correlation was found between motion level and deviation. It was then concluded that the variability of the motion amplitudes of a particular ship, in a given maritime area, is essentially the same for all wind and sea conditions. This means that this aspect does not need separate consideration when an operational condition is evaluated. A level of ship motion defined only in terms of the σ-value can therefore be regarded as a representative measure for the feasibility of safe helicopter take-off and landing operations. The experimental process of quantifying the actual value of maximum acceptable motion levels in this way, should of course be based on the use of the quiet periods by the pilot and FDO.

Although the σ-level is a mathematically suitable quantity to express ship motion, it is not a very convenient quantity for a user who has no special measuring device at his disposal. It then is very difficult to associate the observed motion with the limit value given. Therefore, the choice has been made to define limit ship-motion levels in terms of 2σ-values. Now, for a motion just at the limit, the amplitudes will only occasionally exceed the 2σ-limit value, which can be observed rather easily (section 5.2).

5. OPERATIONAL LIMITS

5.1 Determination of limits

At the completion of a series of qualification tests a fair idea about the operational limitations has usually been obtained. For definite results the measured data have to be analyzed in more detail. As mentioned before, the measurements are performed by day and by night and for various nominal helicopter weights. After the tests the available data contains information on:
- relative wind
- motion of the ship
- helicopter parameters
- test pilot's opinions (ratings and comments)
- observations made by the test team.

In order to derive actual values for operational limits from the test data the following three criteria are applied. A test condition is defined as limiting when:
- helicopter engine torque reserve is less than 5 percent during a significant part of the manoeuvre

- pedal travel reserve is less than 10 percent of available travel
- the test pilot judges the test condition unacceptable.

In the interpretation process, corrections for appreciable weight or outside air temperature deviations from nominal are taken into account.

Operational limits are defined by maximum acceptable values of the following parameters:

- relative wind speed
- relative wind direction
- ship motion in terms of roll and pitch angles.

Within these limits it is ensured that under extreme but still acceptable conditions adequate power and controllability margins are available.

For calm sea conditions the minimum and maximum relative wind for take-off and landing can be determined straightforwardly by applying the criteria mentioned above. High relative wind speeds are generally only obtained at high speeds of the ship. Then, the relative wind angle is small.

In rough sea conditions, which occur mostly in combination with high natural winds, the situation becomes considerably more complex. When the relative wind condition is varied by changing the ship's speed or course (or both), the motion of the ship also changes. It is not possible to vary these essential parameters independently. In a rough sea environment also the flying procedures chosen may have a larger impact on the test results than in calm sea conditions. Good ground reference is needed and the helicopter heading may result in large pedal deflections. Furthermore, an inconvenience is that a test with an inconsistent result cannot easily be repeated at a later stage of the test programme because then the natural wind has changed. This means that a fair amount of engineering insight is required during the interpretation process of the test data.

When deriving rough sea limits from the test data, it is practical to start from the calm sea limits established earlier. An example of test results during sea state 4-5 is presented in figure 10, showing ship motion levels for different wind conditions and for two values of helicopter weight. The magnitudes of pitching and rolling motion are different for the various relative winds. Yet, the figure provides a good indication of the limitations. From the pilot ratings and comments, it was learned that the rolling motion of the ship was limiting. Obviously, the maximum acceptable motion level is highest when the relative wind direction is between 0 and 30 degrees.

An example of the final presentation of results is shown in figure 11. In theory, maximum acceptable ship motion levels could be given as a function of relative wind speed and direction. For the sake of convenience of the user, only two areas of motion limits are given in the diagram.

5.2 Estimation of conditions

Before starting helicopter operations in a rough sea environment, the person in charge should verify that operational limits are not exceeded. If required, the wind conditions over the flight deck can often be brought within the limits by changing the speed or course of the ship.

With respect to ship motion the availability of a device which is capable of measuring the 2σ-value of pitching and rolling motions would be most helpful. However, up to now, such instruments are not available on ships. In practice the estimation is often made without any instrument, by an experienced observer. Although many times a good indication of the ship motion level may be obtained, the estimate will most probably be inconsistent for various situations or when given by different persons.

It was found possible to use a very simple rule-of-thumb to estimate whether or not a prevailing pitching or rolling motion exceeds the limit, provided that one has an indication of pitching and rolling angle, which often will be the case. The rule-of-thumb involves counting the number of times that the amplitude exceeds the limit (which is a 2σ-value), and is based upon the following considerations.

Figure 12, derived from 44 test runs of 256 seconds each, as measured on one particular ship in the North Sea area shows that during one run the motion amplitudes (to either side of the mean) exceed their 2σ-value between 4 and 18 times. Hence, for that ship operating in the North Sea area it can be inferred with 100 percent probability (within accuracy limits from sampling) that a prevailing motion is fully allowable when the 2σ-limit value is exceeded less than 4 times during 4 minutes. With the same probability the motion is prohibitive for helicopter operations when the limit value is exceeded more than 18 times in that period.

However, a confidence interval of the estimate of less than 100 percent may also be acceptable. If, for example, a confidence interval of 80 percent is considered satisfactory, it follows from figure 12 that a motion of the ship is acceptable when the amplitudes of pitching and rolling exceed their given limit values not more than 9 and 7 times respectively, during a time interval of 4 minutes. The actual choice of confidence interval remains to be determined by the user.

The counting process can probably be automated very easily, by using off-the-shelf electronic components.

6. CONCLUDING REMARKS

A description has been given of a test method for the experimental determination of additional limitations which should be taken into account when operating a helicopter from a particular ship.

Actual implementation of the method has yielded satisfactory results. Experience with the data recording systems used has been favourable.

It has been shown that operational limits for the helicopter in terms of relative wind speed and direction can be established straightforwardly. With respect to ship motion, it has been found satisfactory to use the 2σ-value of motion parameters as a representative measure to define limits.

Some factors of importance with respect to the limits, such as the influence of the natural wind, the list of the ship and the motion frequencies, have not yet been fully evaluated.

In the near future new projects are planned which probably will provide additional information to further refine the qualification process.

7. REFERENCES

1. Hoekstra, Tj., Fang, R., Leijnse, C., Renirie, L.T. — Qualification tests with helicopters for use on board ships. Paper presented at the Europort Naval Conference, Amsterdam, 14-17 November 1978, also NLR MP 78032 U, 17 August 1978.

2. Hess, R.A. — Non adjectival rating scales in human response experiments. Human Factors, 1973, 15(3), p. 275-280.

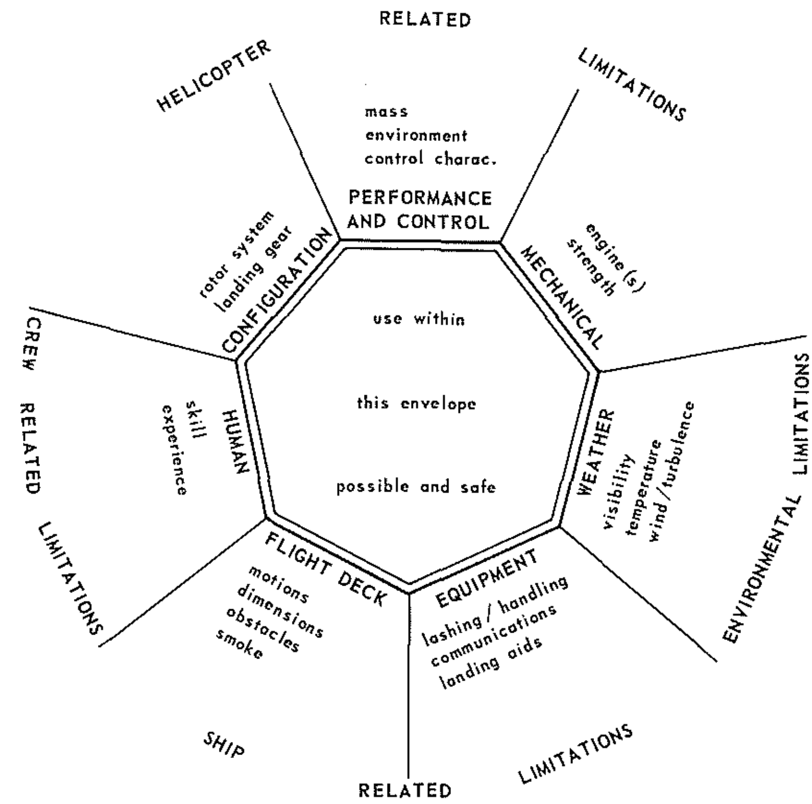


Fig. 1 Various factors limiting the operation of helicopters on board ships

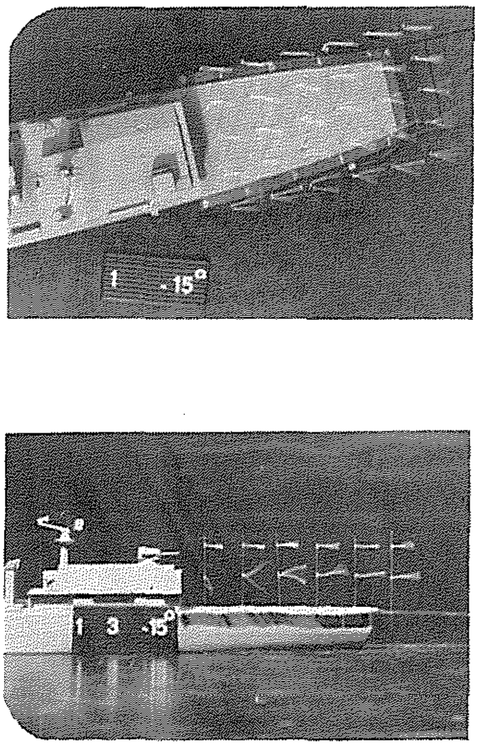


Fig. 2a Air flow visualized by means of tufts on a model in a wind tunnel

Fig. 2b Measurement of flow deviation and turbulence with crossed hot wire anemometer

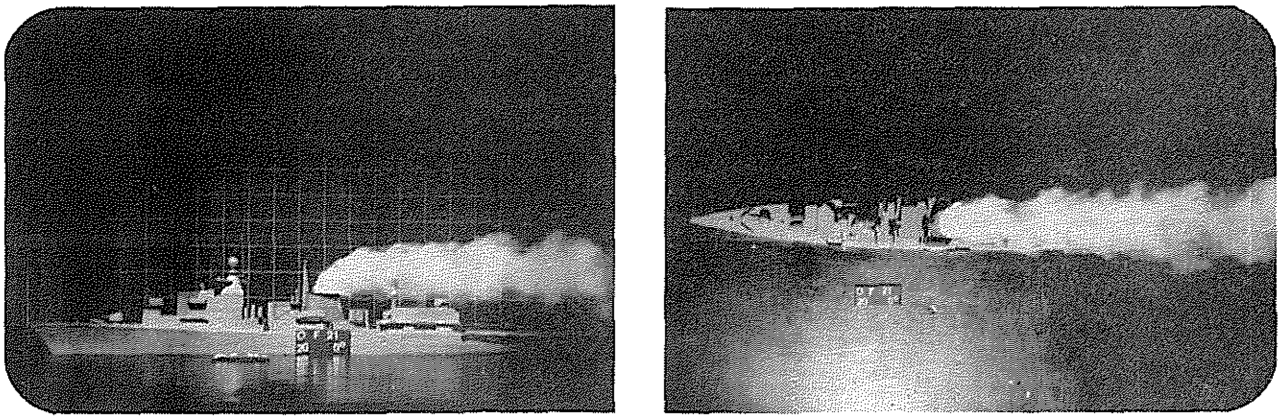


Fig. 3 Exhaust plume investigation at simulated full-power condition in a wind tunnel

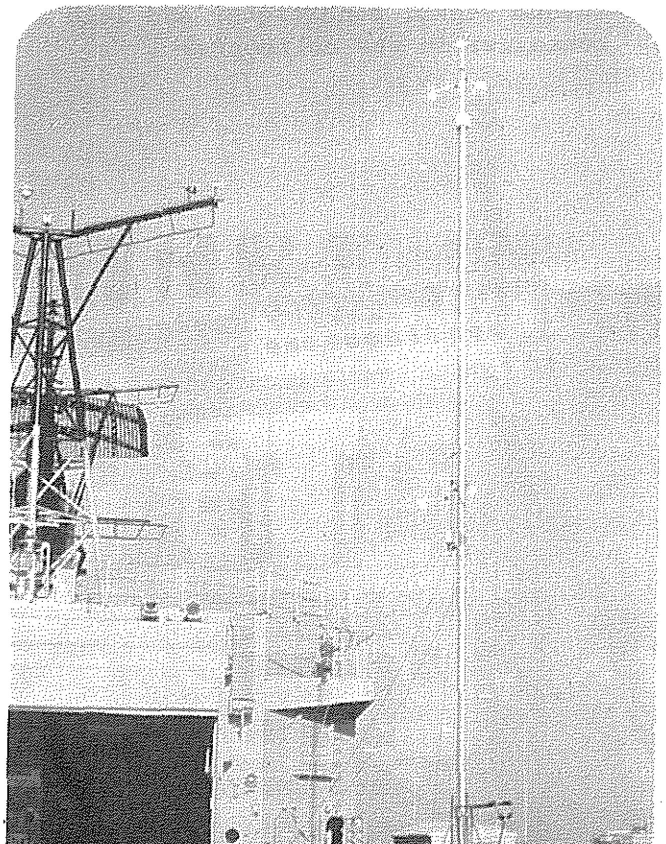


Fig. 4 Movable mast for full-scale air flow measurements above the flight deck

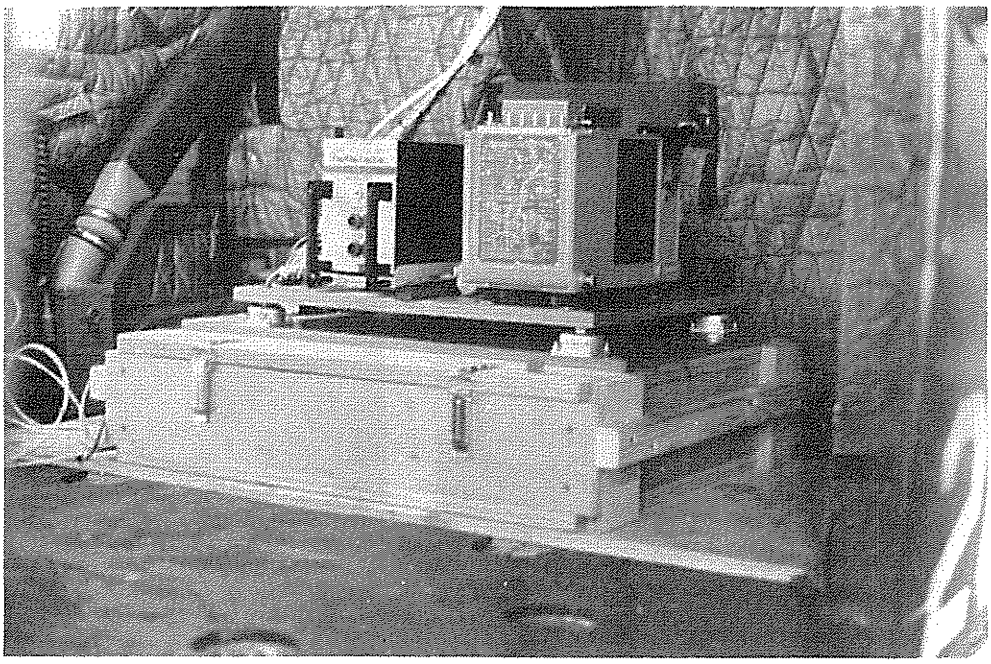


Fig. 5 Arrangement of Hussenot-Beaudouin recorder, engine torque signal conditioner and lead ballast weight container in the helicopter

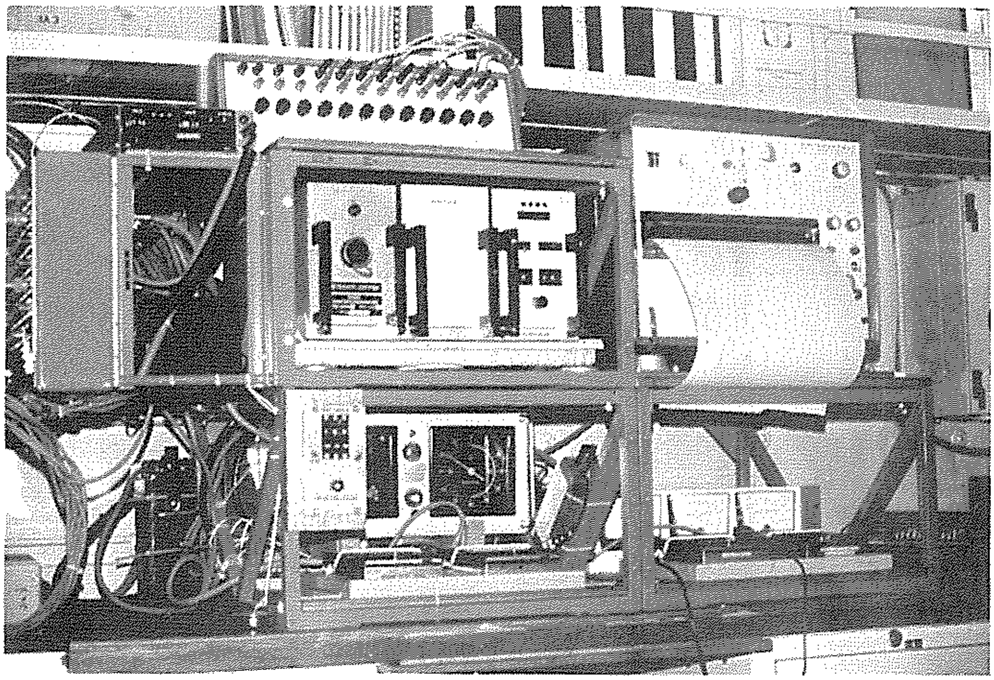


Fig. 6 Arrangement of recorders on the ship

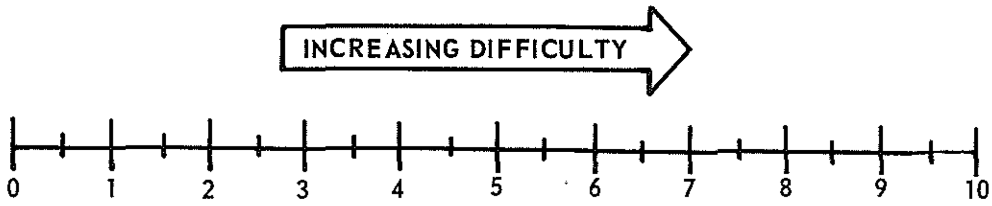


Fig. 7 Nonadjective, nonordinal rating scale (Ref. 2)

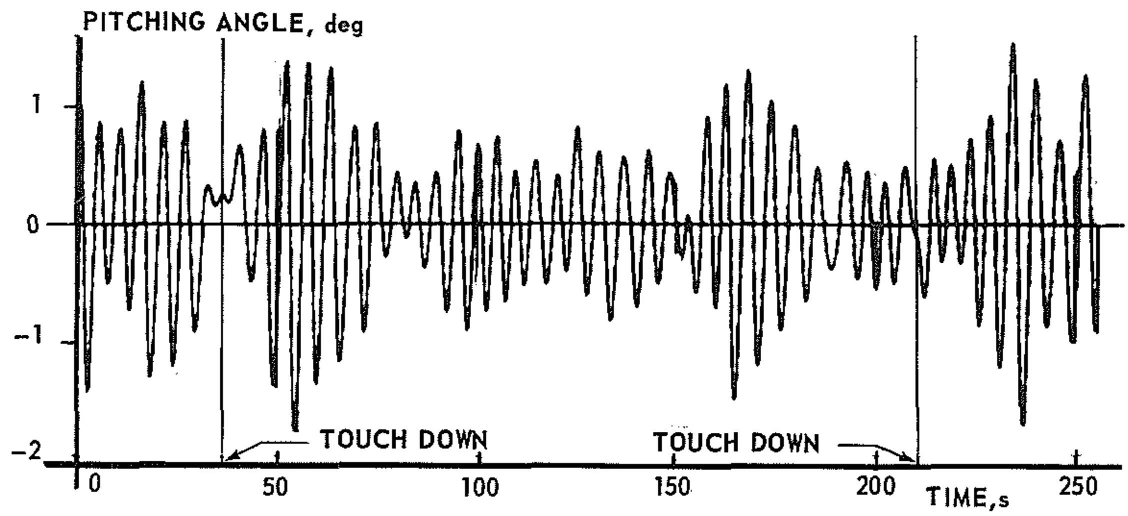


Fig. 8 Measured pitching angle of ship vs time with moment of touch down

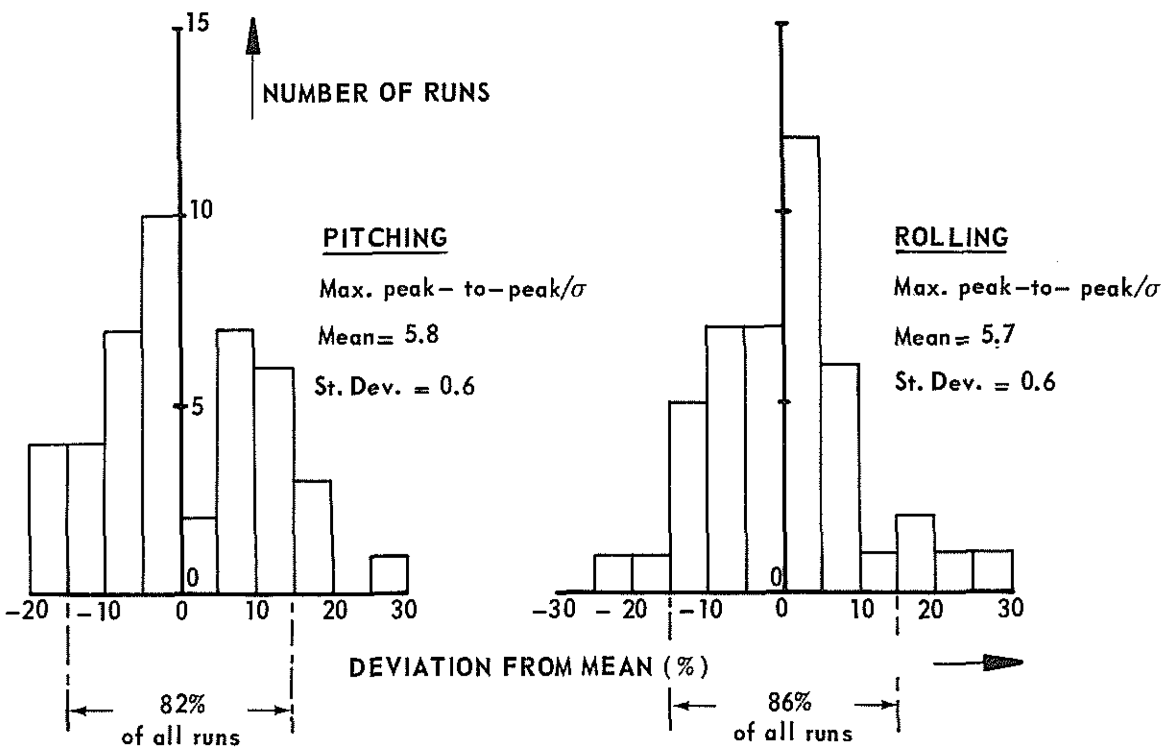


Fig. 9 Histogram of the ratio between max. peak-to-peak and σ-value of measured pitching and rolling angles of a ship

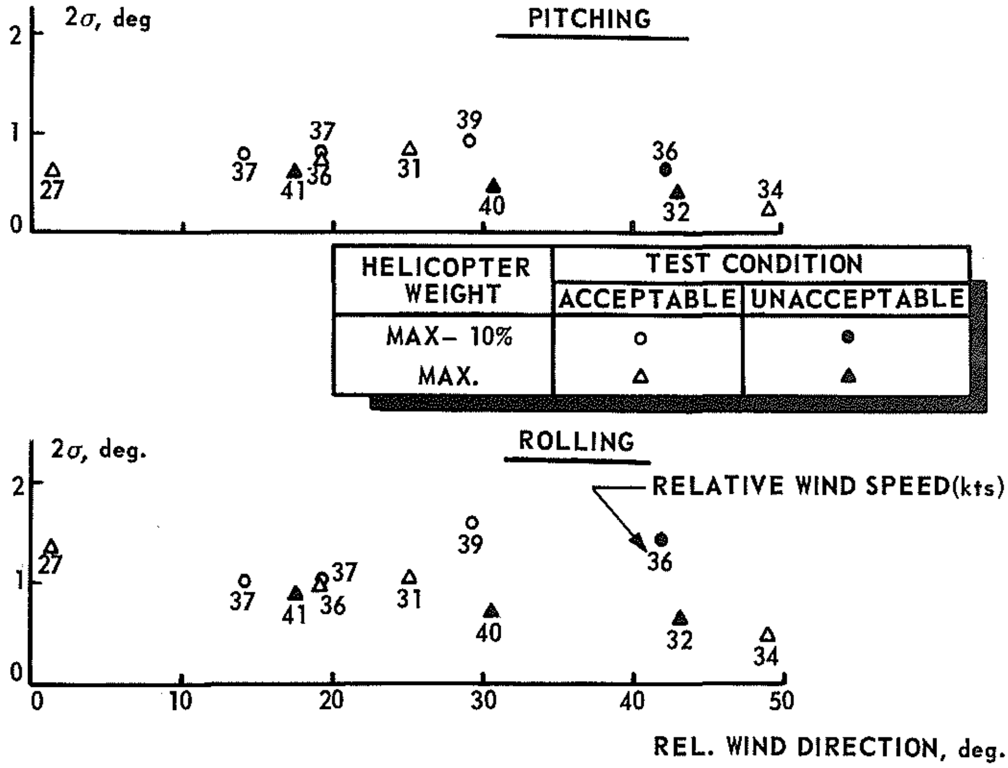
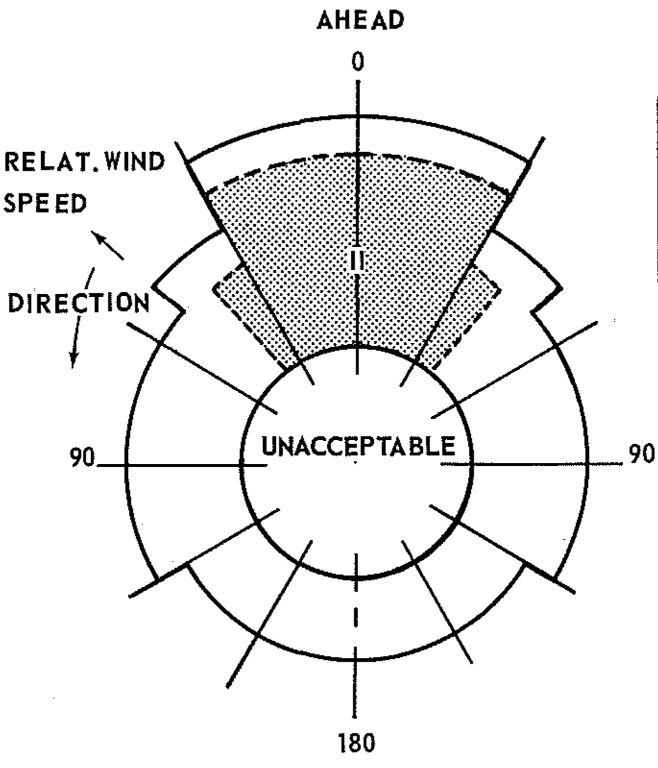


Fig. 10 Test results at various relative wind conditions



SEA LEVEL, ISA

SHIP MOTION LIMITS(2σ– VALUE), deg		
SECTOR	PITCHING	ROLLING
I	0.35	0.7
II	1	2

Fig. 11 Take-off and landing limits for day-time, max. helicopter take-off weight

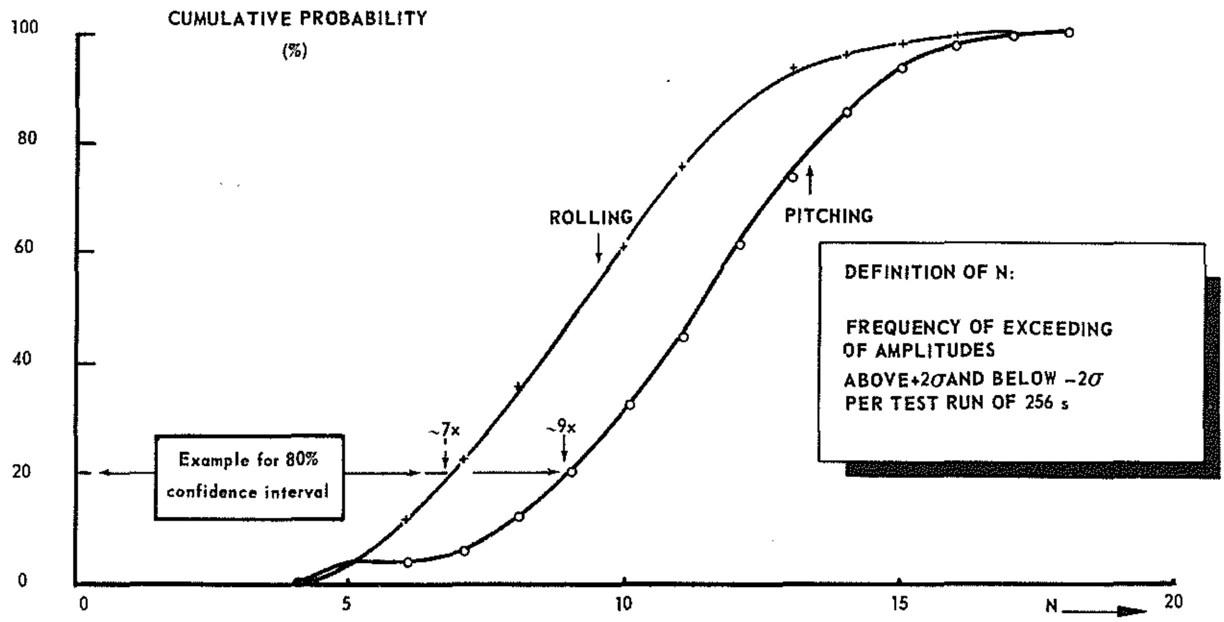


Fig. 12 Cumulative probability distribution of amplitudes exceeding $+2\sigma$ and -2σ levels, based on 44 test runs