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DITCHING AND FLOTATION CHARACTERISTICS OF THE EH101 HELICOPTER

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ABSTRACT

The EH101 Helicopter has been designed from the outset with safe ditching and flotation characteristics in mind.

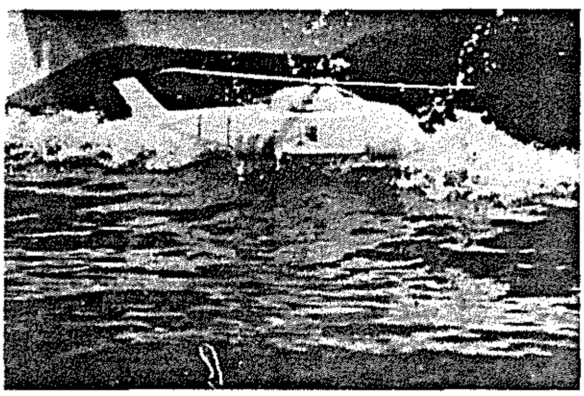
Airworthiness regulations demand stringent safety standards during and after an inadvertent landing on water. Westland have designed an automatic float inflation system and commissioned scale model tests to ensure that these standards are met.

The paper outlines the flotation system design philosophy, descent procedures and subsequent ditching and flotation performance.

1. Introduction

The EH101 helicopter both in its naval and civil version is equipped with a reliable and effective emergency flotation system. Westland's extensive design experience in the provision of safety equipment supported by the undoubted expertise of Westland Aerospace, Cowes in scale model testing has resulted in a design providing safe ditching characteristics and subsequent flotation behaviour well exceeding statutory requirements.

The paper describes the equipment provided for emergency flotation of EH101 and also discusses descent procedures designed to minimise velocity at touchdown. The major findings of the scaled model testing are also enunciated.



2. Flotation System Design

2.1. Buoyancy and Stability Considerations

2.1.1. Positions and Sizes of Floats (see Fig. 1)

In order to ensure maximum lateral and longitudinal stability, the floats should be placed as far apart as possible, in both the above senses. It is clear that for a stable platform, at least three floats need to be used. For the EH101, practical planform considerations dictate the use of two large floats off the sides of the sponsons providing most of the lateral stability, and two smaller floats off the sides of the nose to give longitudinal stability. The actual sizes of the floats are such that the overall centre of buoyancy is below the aircraft lateral and longitudinal centre of gravity, taking into account aircraft inherent buoyancy, such as fuel tanks, tyres etc. In the vertical sense, the floats are placed low down on the structure on EH101, to ensure the waterline is below floor level, as required by BCARs.

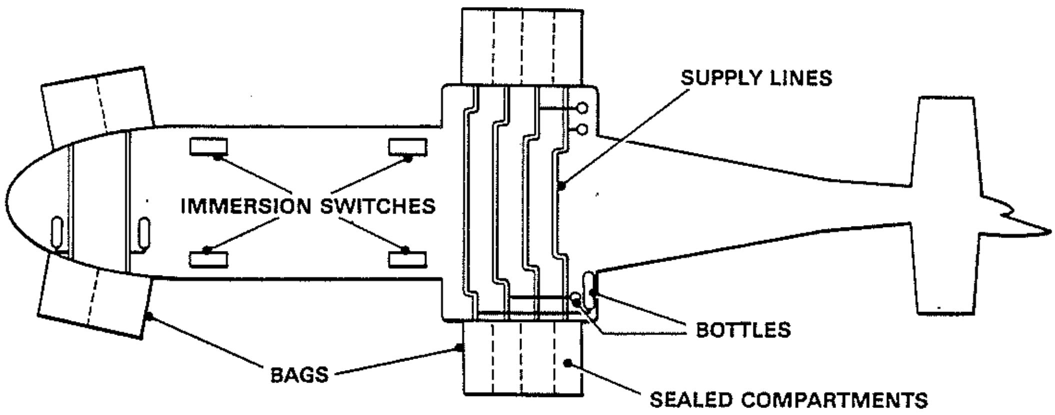


Fig. 1. Civil EH101 Flotation Layout

2.1.2. System Redundancy

CAA/RN/MMI regulations dictate the need for redundancy in the flotation systems, such that after any single failure, some upright flotation capability is retained. To retain longitudinal stability, redundancy must be provided in both the forward and aft floats. In particular, in the aft floats, sufficient redundancy should be provided so that in the event of an aft system failing, the loss of buoyancy will not be such as to cause the aircraft to sink. Equal buoyancy side to side should also be maintained as much as practicable after single failures, so as to retain maximum lateral stability.

To achieve these aims on EH101, the Naval Variant has dual compartmented forward floats cross connected, and triple compartmented rear floats, also cross connected. To retain bottles of common size and shape, and give the extra volume for the higher 'All Up Weight' Civil/Utility

Variants, the rear floats on these aircraft are divided into four compartments each, cross connected.

2.1.3. Bag Loading (see Fig. 2)

The subject of bag loading during the various phases of ditching and flotation is a very complex subject which can only be briefly addressed here. The three most critical sets of forces on the flotation bags are as follows:

- Drag Loads during the ditching phase with up to 15° Yaw,
- Buoyancy Loads, coupled with
- Wave Drag Loads during the flotation phase.

Drag loads are alleviated by the "Inflation on Touchdown" philosophy applied to the EH101. (See Section 4.3 of this Paper.) The drag loads on the forward floats are further alleviated by delaying their inflation by a few seconds after touchdown, until the forward speed in water has moderated.

Buoyancy loads are simply a function of the proportion of the aircraft weight supported by the appropriate float.

The additional Wave Drag loads, those loads imparted to the floats during the aircraft's rolling action on the water, are more difficult to quantify. However, computer simulation techniques, refined from model test results (Ref: Westland Aerospace) can be used to define a maximum relative float/water velocity for different Sea States. This method has been used when stressing the bag loads (and structural attachments) on EH101.

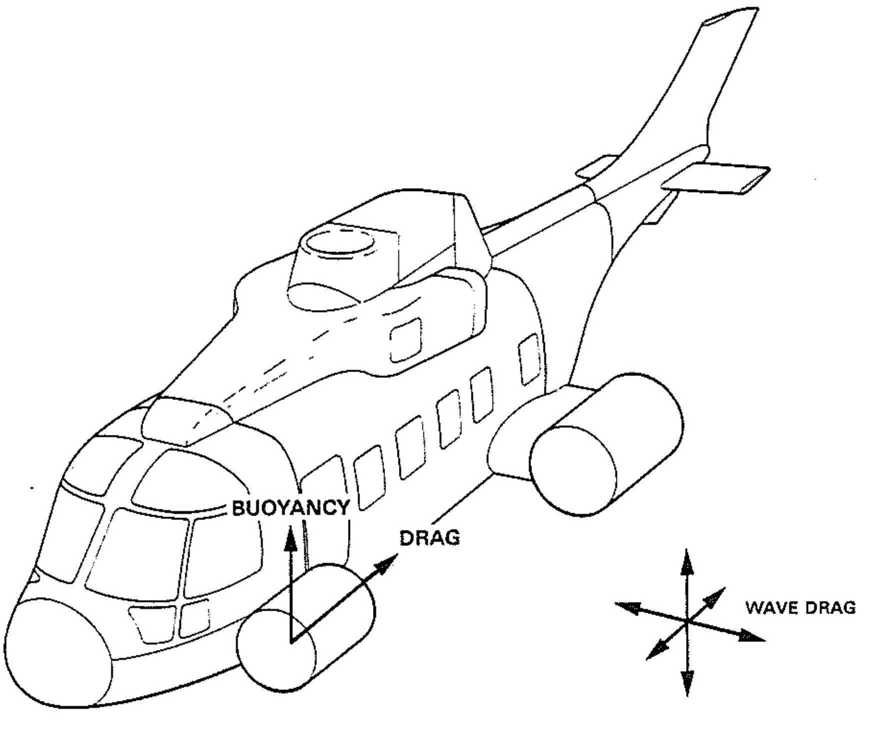


Fig. 2. Loading

2.2 Float Inflation Techniques (see also Fig. 1)

The medium used for inflating the floats must satisfy the criteria of minimum installed weight, performance throughout the aircraft temperature range (for EH101, -40°C to +70°C) and serviceability.

Compressed Helium gas, stored in composite wound pressure vessels has been chosen for EH101, which is considered the optimum solution for satisfying the above criteria. Also, because of its high sonic velocity and low specific gravity, it gives the design advantage of being able to minimise distribution pipe size.

Serviceability is enhanced by allowing "topping up" of pressure vessels, if required, with "dry" air or nitrogen up to 10% by volume. This has no significant effect on system performance. Helium gas also gives the speed of inflation required such that the "Inflation on Touchdown" philosophy may be used (Ref Section 4.3 of this paper).

Inflation initiation on EH101 is electrical, and primarily automatic. Immersion switches are fitted on the underside of the fuselage which, when wetted on touchdown on water, operate the circuit to fire the bottle "Squibs" hence releasing the gas to inflate the bags.

It must be stressed that these are "immersion" switches, which will fire the system in any water except "very soft" water. A manual backup switch is also provided for the pilot.

In order to maintain the necessary reliability, both in the "sure fire" case when the system is required to operate, and the "inadvertent operation" case, electrical reliability analyses were carried out in conjunction with the circuit design to ensure the reliability in both the above cases was adequate. Fundamentally, to meet both these cases the firing circuits are entirely duplicated, and both positive and negative sides of the circuit are switched. In this way, no single failure of any component can prevent all the bottles firing when required, or cause any of them to fire inadvertently.

3. Design Requirements (see Appendix 1 for Sea State Definitions)

3.1 Naval Staff Requirements for EH101

The aircraft must be able to:

- Withstand a controlled ditching in Sea State 3.
- Remain afloat upright with rotors stopped in Sea State 3 for at least 2 hours.
- Remain upright with any single flotation system failure in Sea State 3.

3.2 Civil Requirements

BCAR G4-10 and G6-12, FAR29,231,751,753,801

The main requirements may be summarised as:-

- Ability to withstand water pressure loads imposed by ditching at 2/3 minimum autorotation speed and a rate of descent of 5 ft/sec.
- Flotation and Trim characteristics to be investigated up to Sea State 7, but limited to 30 ft wave height and wave height/length ratio of 1:10.
- Helicopter to remain upright and stable in at least Sea State 2 with any single failure.
- Buoyancy of each float to be 125% of that proportion of the maximum All Up Weight of the helicopter normally supported by the float in fresh water.

- Probability that the floats will not inflate correctly, or asymetrically, not to be more than remote (10^{-5}).
- Time of inflation to be sufficiently small (2½ seconds recommended) to prevent the helicopter becoming more than partially submerged, and to be such that the occupants may be expected to remain dry.

4. Ditching and Flotation Philosophy

4.1 Definition of Ditching Philosophy

The ditching philosophy is based on the concept of a safe ditching following a total engine failure whilst retaining control of the main and tail rotors.

It has been shown, by computer analysis and in practice, that touchdown speeds at a rate of descent of 5 ft/sec can be reduced to the order of 30 Kts (much lower than the CAA recommendation of two-thirds of minimum autorotative speed) by the procedure outlined below.

4.2 Power -Off Ditching Technique (see Fig. 3)

The computer simulation (described in Appendix 2) considers a 70 Kt autorotation at a rate of descent of 40 ft/sec and 105% N_R. At about 200 ft, a cyclic flare is initiated to increase pitch attitude to about 25° nose up.

At about 150 ft, collective pitch is adjusted to restrict N_R to about 118% and continue the deceleration in both forward speed and rate of descent.

At 60-70 ft, collective pitch is applied to achieve a greater reduction in rate of descent with a final adjustment being made just prior to touchdown to achieve a vertical velocity of 5 ft/sec and minimum forward speed at touchdown. The pitch attitude desired is 5-10°. See figure 4 for a typical output.

Westland have accumulated considerable practical experience with this technique and have found that the predicted behaviour is well supported by flight testing. Also the manoeuvre has been shown by Westland pilots to be well within the capabilities of the average pilot and not a particularly difficult or onerous task.

Westland Helicopter Airfield Performance Simulation (HAPS)

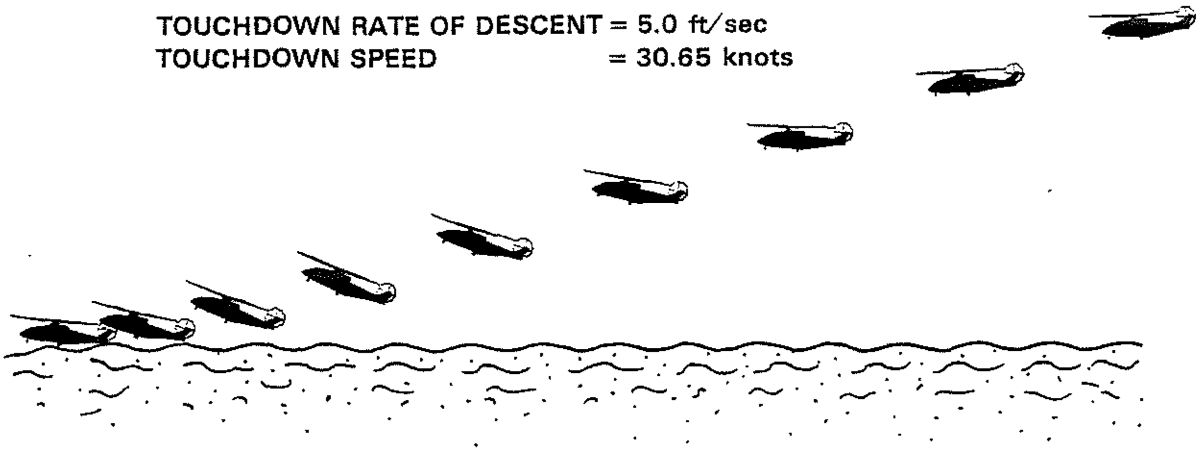


Fig. 3. EH101 Power-Off Descent

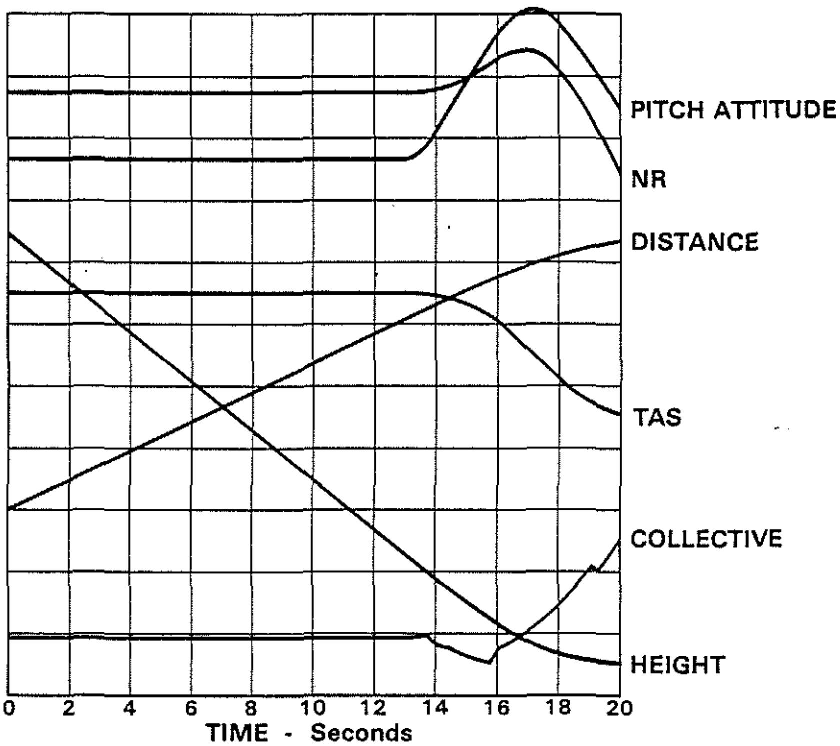


Fig. 4. EH101 H.A.P.S. Output

4.3 Float Deployment

The floats are deployed after making contact with the water surface by saline switch operation as described in section 2.2.

Initial high decelerations occur in the first second after touching down during which time the floats will not be present. After this time however, the rear floats will appear rapidly and will affect to some extent the behaviour of the aircraft after ditching.

However, earlier tests with a similar model have indicated that ditching with floats fully deployed before ditching does not have a serious effect on ditching behaviour.

Therefore it is assumed that model tests without floats give a reasonable indication of true aircraft ditching behaviour.

Forward floats appear 5 seconds after the rear floats and are not considered to affect ditching behaviour at all. Rear float loadings were calculated from horizontal g level data measured in the aforementioned tests with a suitable allowance being made for the finite time required before the floats are fully inflated.

5. Scale Model Tests at Westland Aerospace, Cowes

Using Froude scaling techniques as outlined in Appendix 3, the one-tenth scale model was ballasted to produce correctly simulated mass, c.g., and inertia in roll pitch and yaw.

A scaled rotor was fitted to the model producing a calibrated thrust of two-thirds of the aircraft weight as laid down by BCAR's.

The model was then flown on to the water surface by the specially designed rig.

Accelerometers fitted inside the model recorded the maximum g levels sustained during the ditching process and transducers measured the pressures on the lower fuselage and undercarriage sponsons. These were used in stressing calculations.

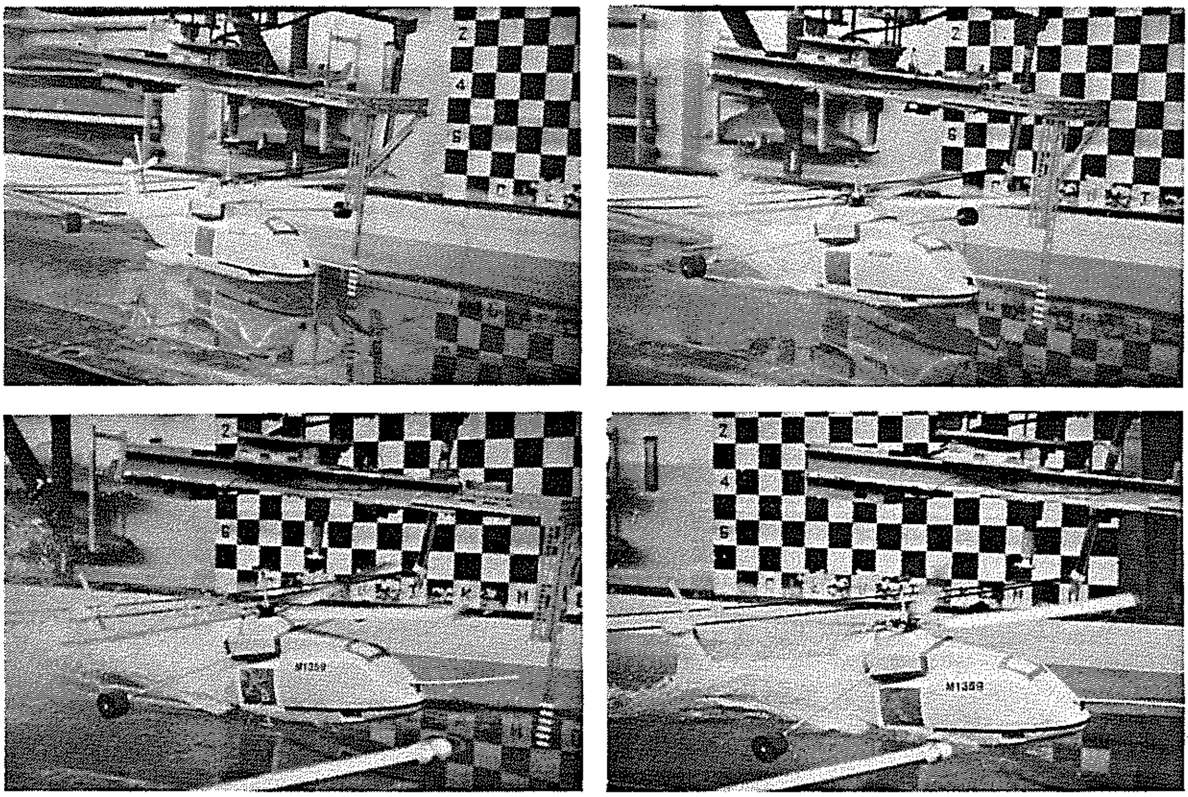
To satisfy the BCAR requirement of aircraft and equipment surviving a water touchdown up to two-thirds of the best autorotational speed, velocities up to 47 Kts were tested measuring lower surface and sponson pressures and deceleration levels.

Maximum vertical decelerations of the order of 8g were recorded at the cockpit of the civil version during a face landing in regular head seas equivalent to Sea State 4, but this maximum recorded value is well within the 15g design criterion. Calm water decelerations are much lower being of the order of 2g.

Lower surface pressures were significantly less than expected from previous tests and measured sponson pressures were used to ensure that the sponsons, and hence the flotation equipment, will remain intact during ditching. A typical ditching sequence can be seen in Fig. 5.

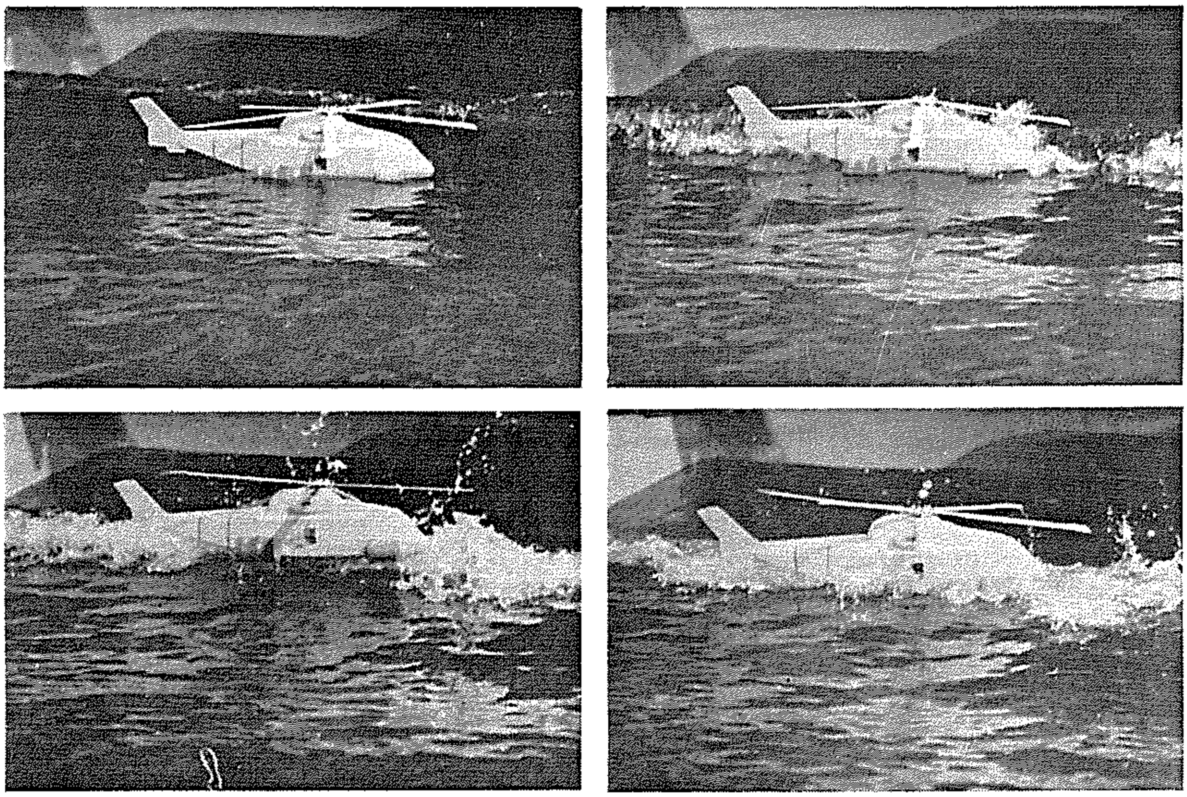
Flotation testing has revealed that the craft weathercocks naturally and quickly into wind taking oncoming waves at the most favourable angle - unlike some helicopters which require a sea anchor. In most cases EH101 survived Sea State 5 or 6.

FIG.5 DITCHING TESTS ON THE EH101 HELICOPTER



1:10 Scale Model   Landing Speed = 28 Knots   R.O.D. = 5ft/sec   Attitude = 2°
Test Weight = 12 839 Kg

FIG.6 FLOTATION TESTS ON THE EH101 HELICOPTER



1:24 Scale Model   Sea State 6   Wind Speed = 25 Knots   All Floats Intact
Test Weight = 14 290 Kg

Even with float damage (critical compartments of forward and aft floats being deflated) the aircraft in a head-to-wind orientation can survive in Sea State 4 at all weight and C of C configurations tested.

Fig. 6 shows a typical flotation sequence in Sea State 6.

6. Conclusion

The EH101 helicopter has been shown by scaled model testing to have good ditching characteristics both on calm water at speeds up 35 Kts generally (47Kts in some cases) and in regular head seas with representative winds equivalent to Sea State 4 (civil version) or Sea State 3 (naval version).

Moreover, flight path analyses have indicated that power-off touchdown speeds of around 30 Kts are attainable by following a recommended procedure.

Subsequent flotation performance meets or exceeds statutory requirements, the civil version remaining stable, for example, in Sea State FOUR condition even with the critical compartments of the rear floats damaged thus more than satisfying the requirements of Sea State Two.

Fig. 7 shows the significant improvement in the EH101 capsize boundary Sea State and its associated probability of occurrence in the North Sea, indicating at least an order of magnitude increase in safety over existing technology.

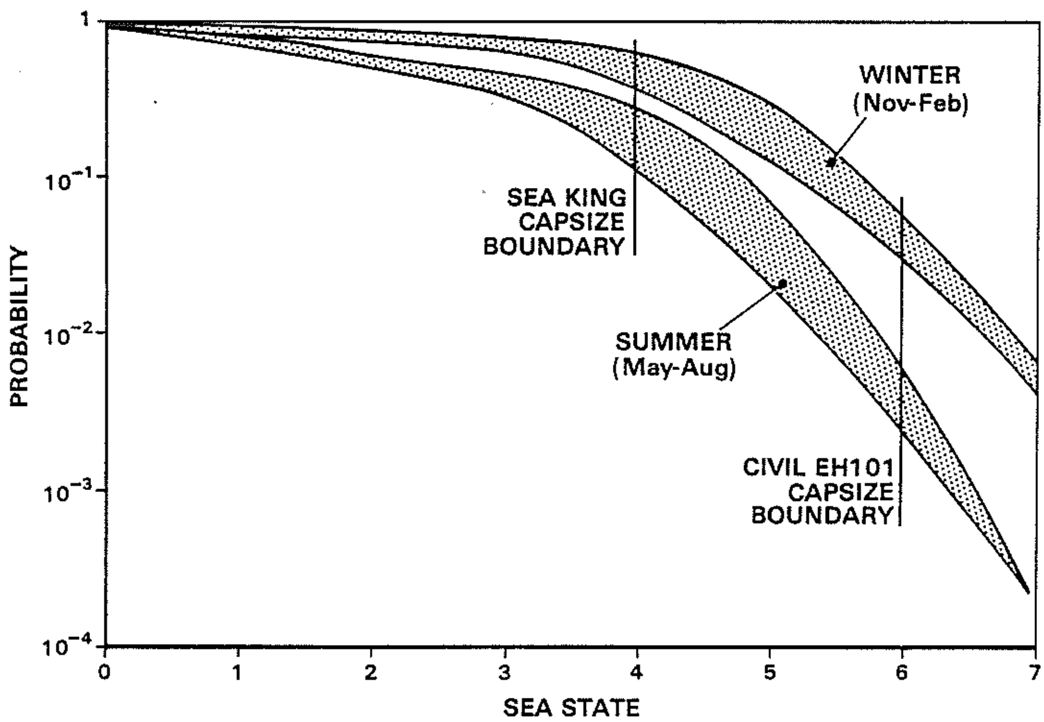


Fig. 7. Probability of Capsize Sea State for the North Sea

7. Acknowledgement

The authors wish to thank Westland Aerospace, Test Facilities Division, Cowes, Isle of Wight for their major contribution to this paper, in particular to the production of test data and to the supply of relevant film material.

Appendix 1. Sea State Definitions

Sea States have been defined by BCAR representing normal seas with a spectrum of wave heights within upper and lower limits. These are indicated in Fig. 8.

Regular head seas, on the other hand represent a succession of exactly similar waves of a given height and height to length ratio. These type of waves are generally used for ditching experiments for better test data quality and repeatibility and for the determination of capsize boundaries.

(B.C.A.R. appendix to Chapter G4-10)

SEA STATE	HEIGHT OF WAVES (Feet)	DESCRIPTION OF SEA
0	0 - 1	Glassy calm - Rippled
1	1 - 2	Smooth
2	2 - 3	Slight
3	3 - 5	Moderate
4	5 - 8	Rough
5	8 - 12	Very rough
6	12 - 20	High
7	20 - 40	Very high
8	40 +	Precipitous
9	ALL	Phenomenal (Confused Sea)

Fig. 8. B.C.A.R. Sea States

Appendix 2. The Westland Helicopter Airfield Performance Simulation (H.A.P.S)

This simulation is used for general flight path studies and in particular for the analysis and optimisation of the techniques employed following a single or multiple engine failure. It has been validated by supporting evidence from actual flight testing.

The model employs expressions derived from simple aerodynamic strip theory to calculate rotor thrust, collective pitch, rotor in-plane force and fore-and-aft flapping. The induced velocity is calculated from momentum theory and an empirical factor, based on forward speed and weight, is used to correct for non-uniformities in the downwash field. The tail rotor power is calculated from the thrust required to balance the main rotor torque and the lift, drag and pitching moments of the fuselage are derived from stored wind tunnel data.

An iterative process is used to establish the initial steady state (unaccelerated) flight condition. The dynamic section of the model is then entered and time is incremented in discrete steps. At each time step, control movements are used to calculate the aircraft and rotor accelerations and a simple constant derivative integrating process is then used to calculate the aircraft's rate, position values and rotor speed prior to the next time step.

The control inputs may be applied in a number of ways:-

1) Collective pitch defined in data arrays prior to running the program.
2) Collective pitch automatically evaluated (pilot simulation) to achieve a pre-defined rotor speed or power level.
3) Cyclic pitch defined in data arrays prior to running the program.
4) Cyclic pitch automatically evaluated to achieve a pre-defined pitch attitude of longitudinal acceleration pattern (pilot simulation).

The engine power is calculated from a representation of the static droop law, which includes a droop canceller for the EH101 helicopter, and is therefore primarily dependent upon rotor speed and collective pitch position. Engine failures may be scheduled at any point during the program run after which the power of the failed engine follows an exponential decay whilst the live engine is allowed (if the governor demands it) to increase to a pre-determined maximum (typically the brochure maximum contingency level). At less than nominal rotor speeds this maximum power level is reduced to simulate the reduction in turbine efficiency.

The program is used in 2 fundamentally different modes:-

a) Prediction:-

In order to predict the aircraft's performance a "standardized" pilot technique must be employed. This typically consists of a combination of pitch attitude, longitudinal acceleration, rate of descent, rotor speed and normal acceleration demands derived from flight test experience.

b) Matching:-

In order to verify that the model correlates satisfactorily with flight test data the program must be "matched" with individual flight test manoeuvres. This is accomplished by exactly duplicating the collective pitch movements and the aircraft's pitch attitude and then assessing the correlation of rotor speed, height, speed etc. Although cyclic position could be used instead of pitch attitude, the standardized technique method utilizes pitch attitude patterns and it is therefore more meaningful to match this parameter.

To generate a coherent data base of predicted performance it is necessary to be able to model the pilot techniques used for any set of conditions (i.e. gross weight, altitude, windspeed, temperature). The magnitude and rate of control changes applied by the pilot, when carrying out a particular manoeuvre, will obviously vary throughout the range of possible conditions. He will, however, be flying to similar cues and perceived limitations such as rotor speed and rate of descent and will, via control movements, maintain these parameters at similar values regardless of the prevailing conditions.

By studying numerous flight test cases it has been possible to identify and quantify these parameters and modify the simulation to control them in the same fashion as the pilot does.

A typical output for the power off ditching is shown in Fig. 4.

Appendix 3. Froude Scaling Technique

The flow characteristics of bodies passing through water close to its surface are governed by the Froude number. This number represents the relationship between fluid dynamic forces and buoyancy forces and when used in scaled model testing of surface vessels, produces reliable hydrodynamic load data.

For details see Fig. 9.

DYNAMIC FORCES $\alpha \quad \rho V^2 l^2/g$

STATIC FORCES $\alpha \quad \rho l^3$

$$\sqrt{\left\{\frac{\text{DYNAMIC FORCES}}{\text{STATIC FORCES}}\right\}} = \text{FROUDE NUMBER } (F_l) = \frac{V}{\sqrt{(gl)}}$$

Ratio of	**LENGTHS**	=	**SCALE**
Ratio of	**MASSES**	α	**(SCALE)** ^{3}
Ratio of	**VOLUMES**	α	**(SCALE)** ^{3}
Ratio of	**SPEEDS**	α	**(SCALE)** $^{1/2}$
Ratio of	**TIMES**	α	**(SCALE)** $^{1/2}$
Ratio of	**ACCELERATIONS**	=	**UNITY**
Ratio of	**PRESSURES**	α	**SCALE**
Ratio of	**FORCES**	α	**(SCALE)** ^{3}

Fig. 9. Froude Scaling