

SECURING AND HANDLING HELICOPTERS ON BOARD SHIPS, ESSENTIAL FACTORS FOR MEETING SAFETY AND OPERATIONAL REQUIREMENTS

Atef R. Tadros, Ph. D., P. Eng., and Robert G. Langlois, Ph. D., P. Eng.,
Indal Technologies Inc.

Abstract

The importance of the role helicopters play in naval operations is continuously increasing. This demands the integration of helicopters with ships of various sizes and displacements. The challenge of achieving safe operations has increased with the need for day and night operations at high sea state and wind conditions. Better understanding of the factors affecting on board helicopter operations ensures that the integration of the helicopter with the ship meets the safety and operational requirements.

This paper addresses the various factors affecting on board helicopter operations. The dynamic effect of the ship motion on the helicopter mass is one of the main parameters for establishing helicopter securing requirements. Therefore, the motion characteristics of large and small ships are analysed and presented. The parameters involved in determining the worst case ship motion conditions for on board helicopter operations are identified. Furthermore, the rotor induced loads and how they are influenced by the flight deck motions are quantified. As the securing requirements are dependent on the securing principle, the two fundamental concepts for securing helicopters (Passive and Active) are explained and discussed. Finally, the factors to be considered for timely and safe maneuvering and traversing of the embarked helicopter are defined.

Introduction

Embarked helicopters are considered one of the essential combat systems in many classes of modern naval ships. Helicopters may be equipped to perform one or more task, for example ASW, S&R and over the horizon reconnaissance, which could be vital for the success of the ship mission. The availability of the helicopter to perform its task is largely dependent on the ability to secure and handle the helicopter on board under all ship operating conditions. Securing and handling of the helicopter requires special facilities due to the ship operational and environmental conditions. The facilities must provide the necessary safety for the personnel and the helicopter in addition to meeting critical operational requirements such as the cycle time for flying readiness, re-arming, re-fueling, etc. To meet the demanding operational requirements, the physical characteristics of each required facility are derived from features directly related to the interactions between the helicopter and the ship. From helicopter/ship activities performed by ITI over the last 10 years, two important findings are evident:

- Ship design is not and will not be optimized for helicopter operation; and
- Helicopter design is not and will not be optimized for on-deck handling.

To meet naval operational requirements, more emphasis must be directed towards the design of the securing and handling facilities to accommodate the interface conditions between the helicopter and the ship. The design of such facilities should ensure that the helicopter operation is limited only by the ship and the helicopter operating envelopes. Optimization can be applied to the design of the on board facilities only through better understanding of the helicopter/interface factors and their influences on the securing and handling requirements. In the following, factors derived from the ship conditions, the helicopter characteristics, and the performance of the securing and handling system are identified and their influence on the helicopter operation will be discussed.

Ship Motion and Ship Size

For a given sea state condition, the ship response to the seaway depends mainly on the ship's hull design, displacement, and mass distribution. In this section, how a ship's size and the location of its flight deck affect its response to a sea condition, as it relates to helicopter securing, is discussed. To this end, the motions of four ship classes, with capacities between 1400 and 7500 tonnes, were generated and analysed. Key parameters for each ship class are presented in Table 1. Geometrical parameters a, b, and c are defined in Figure 1.

For each of the ship classes, a representative hull was used to calculate the ship Response Amplitude Operators (RAO's) using SMP[1] and from these, time histories of the motions were generated for a 20,000-second period. The motions were generated for each of three ship speeds (10, 15 and 20 knots) at 15-degree heading intervals. Polar plots representing the various maximum or minimum amplitudes were plotted and comparisons between the responses of the various ships were made.

Table 1 Comparison of various ship parameters

| Ship Description | a | b | c | Length at Waterline | Beam at Amidships | Draft at Amidships | Displacement |
|------------------|--------|--------|--------|---------------------|-------------------|--------------------|---------------|
| | Meters | Meters | Meters | Meters | Meters | Meters | Metric tonnes |
| OPC | 28.07 | 5.70 | 7.42 | 75.00 | 11.41 | 3.40 | 1439.20 |
| Frigate A | 46.94 | 5.50 | 7.22 | 109.00 | 14.80 | 4.10 | 3164.90 |
| Frigate B | 49.24 | 4.58 | 6.30 | 124.36 | 13.78 | 4.52 | 3595.60 |
| Frigate C | 35.26 | 9.35 | 11.07 | 161.24 | 16.73 | 6.20 | 7513.39 |

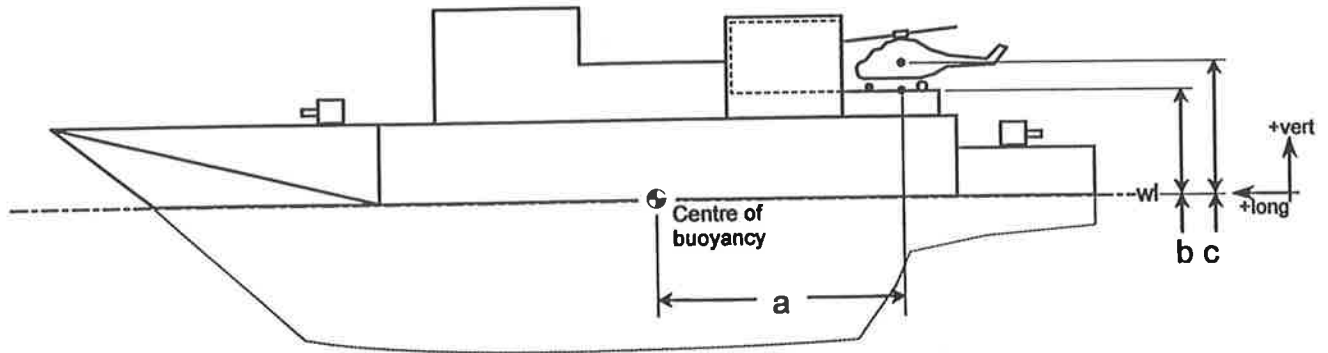


Figure 1 Schematic showing location of flight deck and centre of buoyancy

As shown in Figures 2 and 3, the pitch displacement, pitch acceleration, maximum lateral (Y) acceleration, maximum vertical (Z) acceleration, and maximum vertical equivalent acceleration ($Z_{eq acc}$) are inversely proportional to ship displacement. The minimum vertical equivalent acceleration ($Z_{eq acc}$) is directly proportional to the ship displacement. The roll acceleration and lateral to vertical equivalent acceleration ratio ($Y/Z_{eq acc}$) are proportional to displacement for the frigates; but the OPC vessel does not follow the same trend. Maximum roll displacement and lateral equivalent acceleration ($Y_{eq acc}$) are inversely proportional to hull displacement for all vessels except frigate A, which experiences lower values. The Length/(Beam*Draft) ratio for the frigate A is disproportionately larger than the trend calculated based on the other vessels would predict. It is believed that this high ratio results in the lower maximum roll response and consequently lower lateral equivalent acceleration.

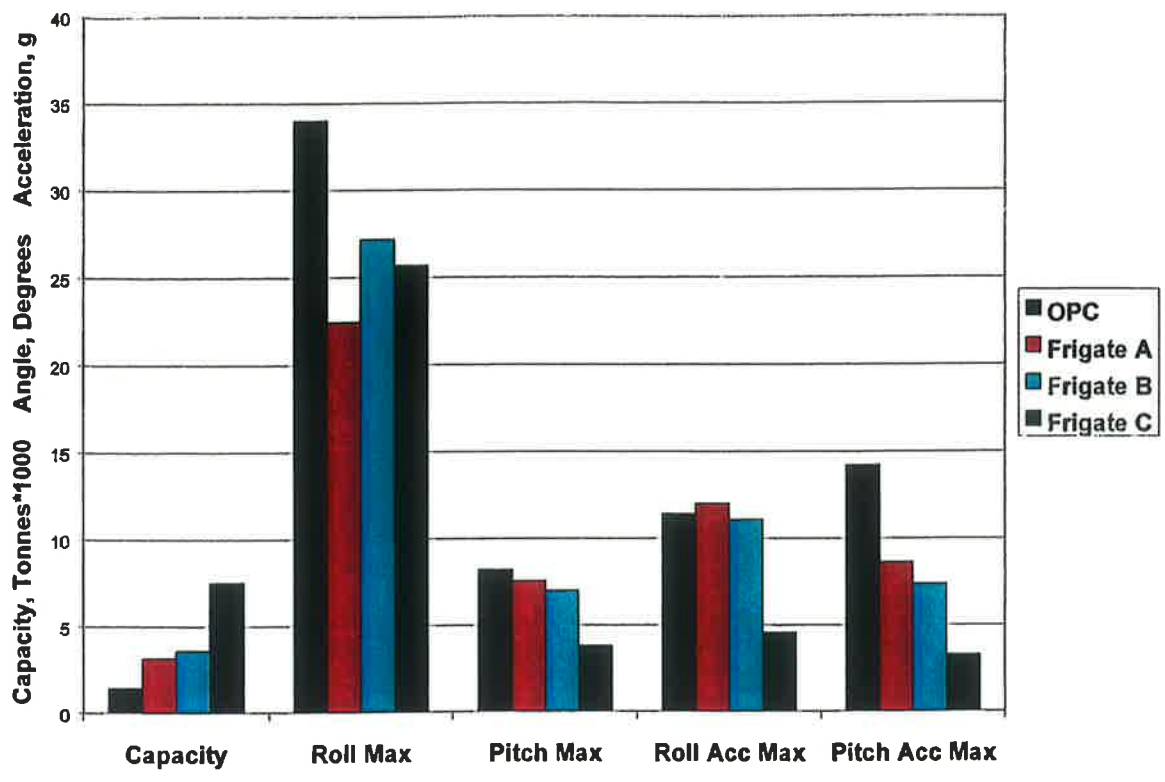


Figure 2 Comparison of ship accelerations

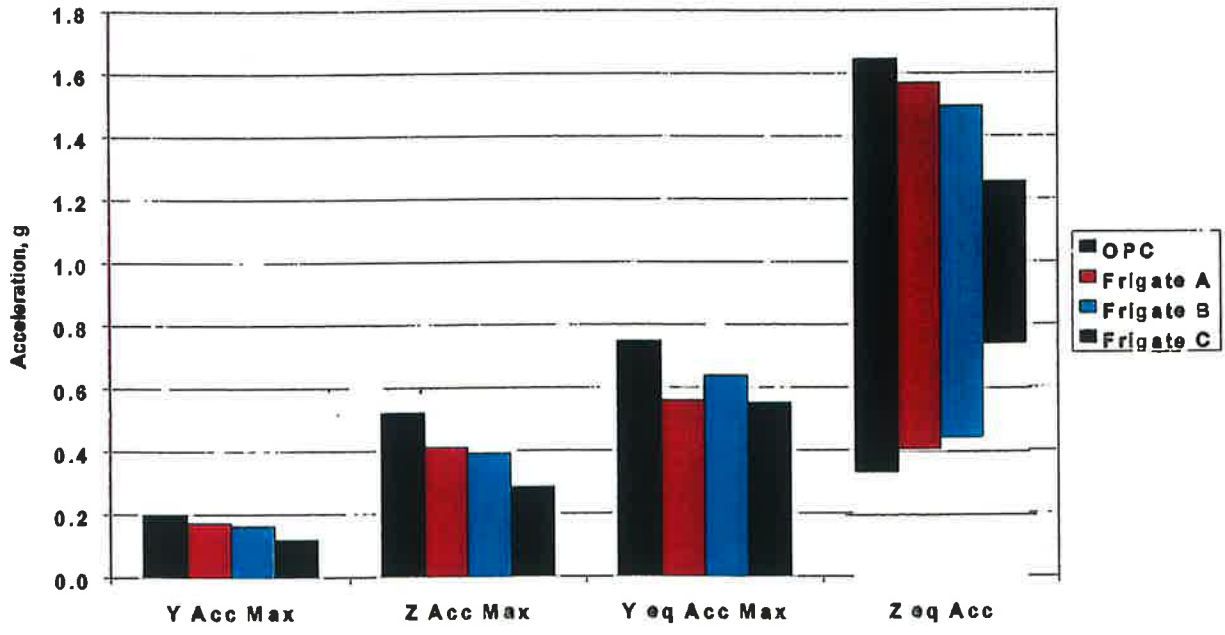


Figure 3 Comparison of ship acceleratons

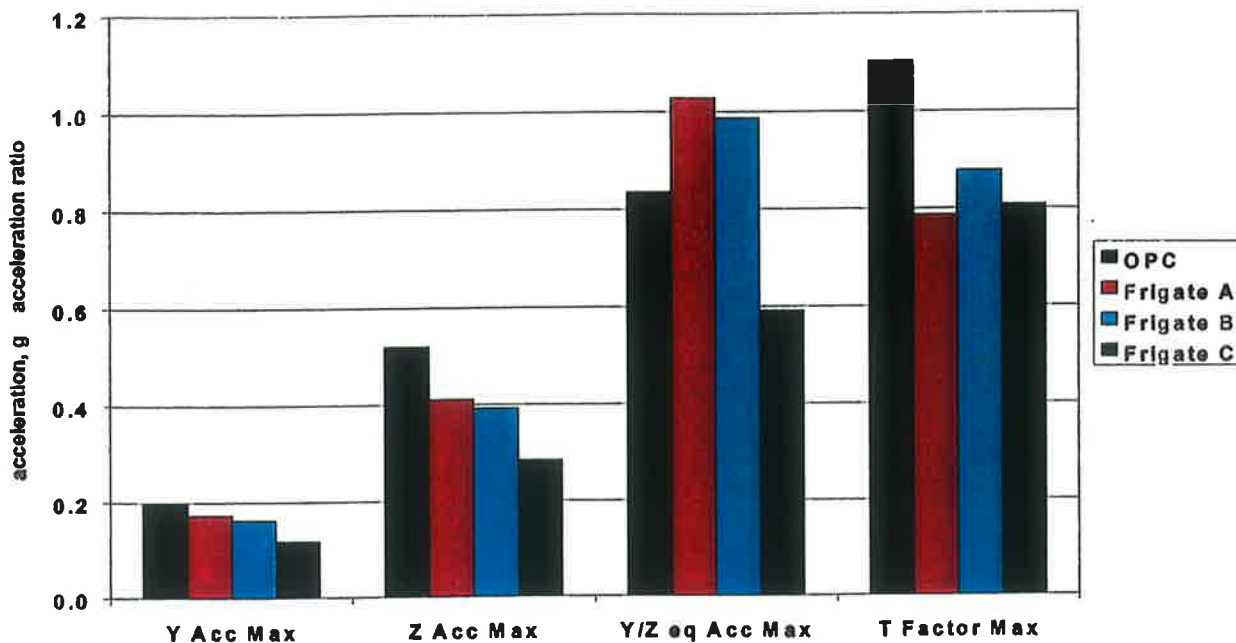


Figure 3 Comparison of ship acceleration ratios

Investigations of the severity of ship motion, as it relates to aircraft securing, attempt to quantify the inter-relationships of parameters that affect securing requirements. However, analysis must proceed cautiously as individual parameters can produce competing effects. For example, with increasing ship displacement, the amplitude of ship motion tends to decrease but the distance between the ship centre of rotation and the flight deck tends to increase. The smaller ship motions tend to reduce securing requirements but the longer distance increases the coupling between angular motions of the ship and linear motions at the flight deck, which tends to increase securing requirements and partially offsets the advantages of larger ship displacement. For the four vessels considered in the current investigation, it is indicated that the smaller ships result in more severe securing conditions. However, due to the many parameters involved (both aircraft and ship parameters), detailed investigation of the dynamic interface is required to determine exact securing requirements unique to a specific combination of aircraft and ship. Dynamic interface analysis is therefore an essential step in the securing device design process. The analysis is accomplished by subjecting a dynamic model of the aircraft and ship to prescribed representative severe ship motions and simulating the response of the aircraft in the time domain. The results of a dynamic interface simulation program, such as *Dynaface* [2,3], provide the relative displacements between the aircraft and deck-mounted equipment as well as suspension and securing forces for periods of severe ship motion. In order to select periods of severe motion for use with the simulation, a criteria must be developed for quantifying the severity of ship motion with respect to securing so that potentially severe periods of ship motion can be identified.

Tendency of an Aircraft on Deck to Slide

In a simplified analysis, an embarked aircraft can be considered to be a single rigid body resting on a flat surface that is experiencing the motion of the ship deck. Such a body would theoretically begin to slide when the ratio of the lateral to vertical forces exceeds the deck's coefficient of friction (typically 0.6 to 1.0). Therefore, the securing requirement increases as this ratio increases in order to prevent sliding and secure the aircraft.

As shown in Figure 5, the main forces acting on a helicopter on a moving deck consist of:

- the helicopter weight;
- inertia loads due to deck motion; and
- aerodynamic loads acting on the rotor and the fuselage.

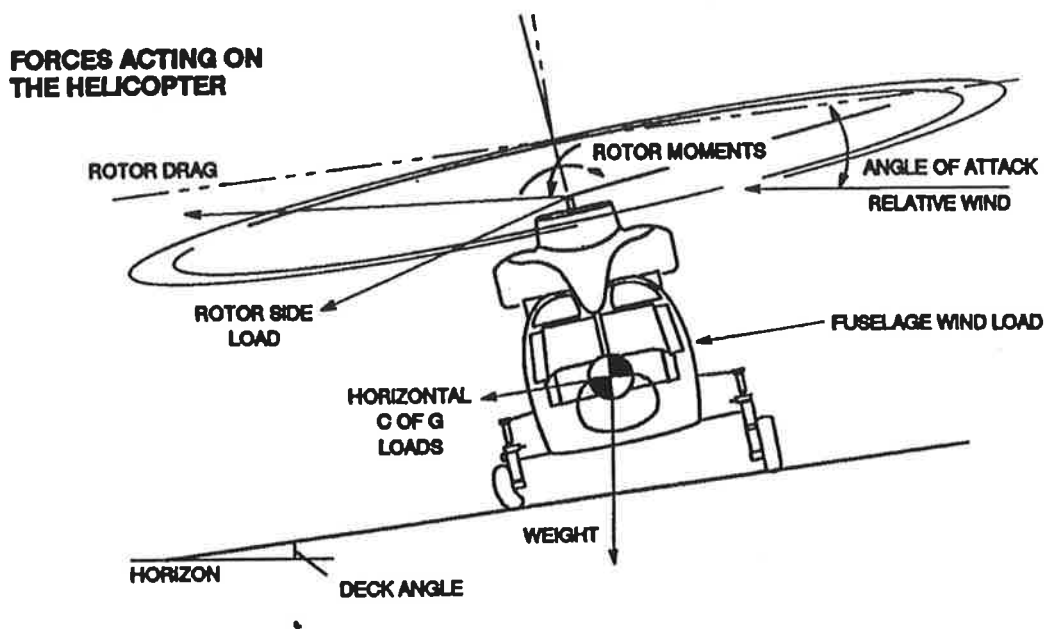


Figure 4 Schematic showing various forces acting on a shipboard aircraft

To define the securing requirement or to determine the effectiveness of a securing system, ship motions that generate the most severe securing conditions must be used in the dynamic analysis. Since the ship motion is generated in the time domain for all ship headings and speeds, a criteria is needed to select the worst case motion to be applied in the simulation.

While ship displacements (for example roll and pitch angles) may provide an indication of the severity of the ship motion, it is the total linear acceleration at the flight deck that directly affects helicopter securing. The acceleration of a body on the flight deck is comprised of two components. The first is the linear acceleration resulting directly from the ship dynamics. The second is linear acceleration that results from the instantaneous components of the acceleration due to gravity. For the purpose of studying the helicopter securing, it is convenient to resolve the total linear acceleration into components parallel and perpendicular to the plane of the deck. These components are defined as the

horizontal equivalent acceleration and vertical equivalent acceleration respectively. ITI's concept of equivalent acceleration is illustrated schematically in Figure 6.

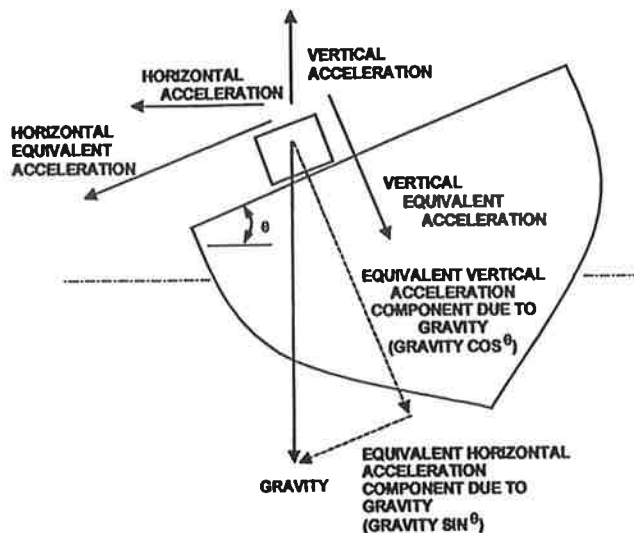


Figure 6 Schematic representation of the concept of equivalent acceleration illustrated for the case of pure ship roll

Increased horizontal equivalent acceleration indicates increased lateral loads on the helicopter in the plane of the deck resulting from ship motion. Reduced vertical equivalent acceleration indicates reduced contact force between the aircraft and the deck and, correspondingly, reduced potential for developing friction force to resist helicopter sliding. Consequently, the ratio of horizontal equivalent acceleration to vertical equivalent acceleration quantifies the tendency of the aircraft to slide as the result of ship motion. Equivalent acceleration also provides a means for defining safe limits for helicopter operation without imposing limits on flight deck displacement and acceleration independently. Accurate limits can be developed while simultaneously expanding the range of conditions for which safe helicopter operation is known to exist.

Effect of Aerodynamic Forces

Aerodynamic forces acting on the aircraft result from aerodynamic drag and rotor induced forces and moments. Aerodynamic drag is calculated based on the equivalent areas of the aircraft fuselage and the relative wind speed. The rotor thrust is modelled using a constant thrust value during the descent phase of the touchdown transient followed by decaying rotor thrust as the pilot reduces the rotor collective to its minimum. In the case of marine aircraft, even with the rotor at its minimum collective, ship motion generates an angle of attack of the rotor disc relative to the apparent wind. Consequently, potentially large rotor forces and moments are developed. The rotor model calculates the instantaneous angle of attack of the rotor to the constant wind in the aircraft frame and evaluates the three linear forces and three moments based on tabulated rotor data for various wind speeds and angles of attack. Typical rotor thrust as a function of ship roll angle is presented in Figure 7. Figure 7 also shows a preliminary test set-up of ongoing research by ITI[5] investigating the

wind over the flight deck and the associated rotor loads. In the case of rotors with negative thrust capabilities, the effect of the wind-induced down-force combined with the negative thrust must be evaluated by examining the landing gear reactions and the tire deflections at the worst case rotor angle of attack.

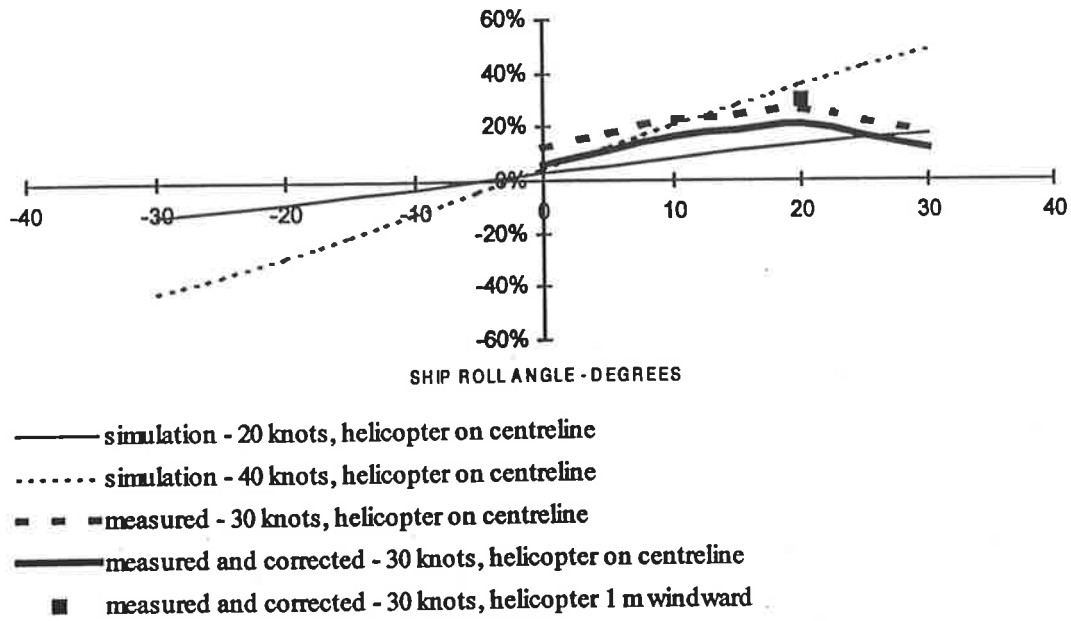


Figure 7 Typical rotor thrust as a function of ship roll angle and flow visualization of wind over the flight deck

The "T" Factor

For the case of a helicopter after landing, ITI's studies, including wind tunnel testing, have proven that the rotor loads are significant in establishing the helicopter securing requirement after landing. The thrust generated by a turning rotor, while the helicopter is on deck with the rotor set at its minimum collective, depends on the rotor disc angle relative to the wind. The thrust ratio, which is the ratio of the rotor thrust to the helicopter mass, can be calculated for each ship heading and speed assuming a 30 knot beam wind. The thrust ratio is then added to the vertical equivalent acceleration before calculating the ratio between the lateral and vertical components of the accelerations. The new ratio characterizes the Tendency of an Aircraft on Deck (with the Rotor On) to Slide and may be called the T Factor:

$T \text{ Factor} = \text{lateral equiv. acceleration} / (\text{vertical equiv. acceleration} - \text{thrust ratio})$

where the thrust ratio is given by $0.25 * |\text{Roll}| / 20$ up to a maximum of 0.25G with the accelerations in Gs and the roll angle in degrees. This expression reflects linear variation of induced rotor thrust with rotor angle of attack (approximately equal to the roll angle) up to a maximum 0.25G at 20 degrees (refer to Figure 7).

The ship motions, including the T Factor, were analysed and the results interpreted. In general, the absolute value of the T Factor is larger than that of the lateral to vertical equivalent acceleration ratio. This increase in ratio is greater for larger roll angles. The greater maxima of the T Factor are an indication of the reduction in landing gear reactions due to the induced thrust of the rotor disc. While the T factor reaches its maximum value at the heading where the peak roll angle is largest, peaks in the lateral to vertical equivalent acceleration ratio may not coincide with the same heading.

Figure 8 illustrates that the OPC has a greater response to the sea than the larger Frigate B. Although the OPC response is, on average, approximately 25% larger, Figure 8 shows that the roll of Frigate B in head seas is larger than that of the OPC. This observation explains the larger T Factor maxima for Frigate B in head seas. Another point about the dangers of construing too much of the ship's performance from measures of a single parameter is the very different shapes that ship responses can take. From Figure 8 we see that the roll responses of the two ships are markedly different, with the OPC showing more roll in following seas. Figures 9 and 10 show the effect of the ship heading and speed, for both Frigate B and the OPC, on the resultant accelerations, the ratio of the lateral to vertical equivalent accelerations, and the T factor.

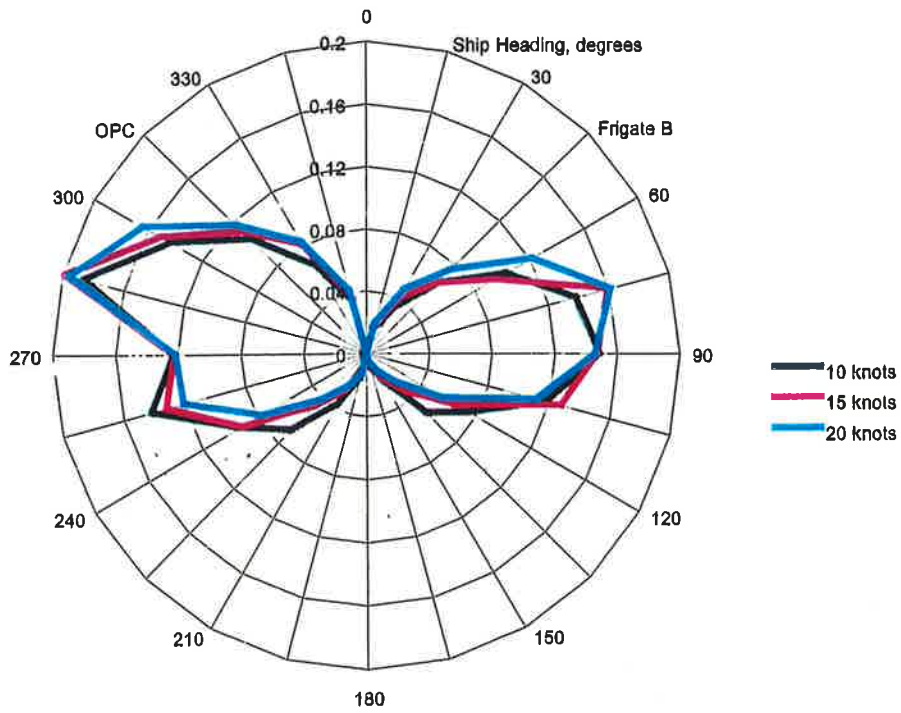
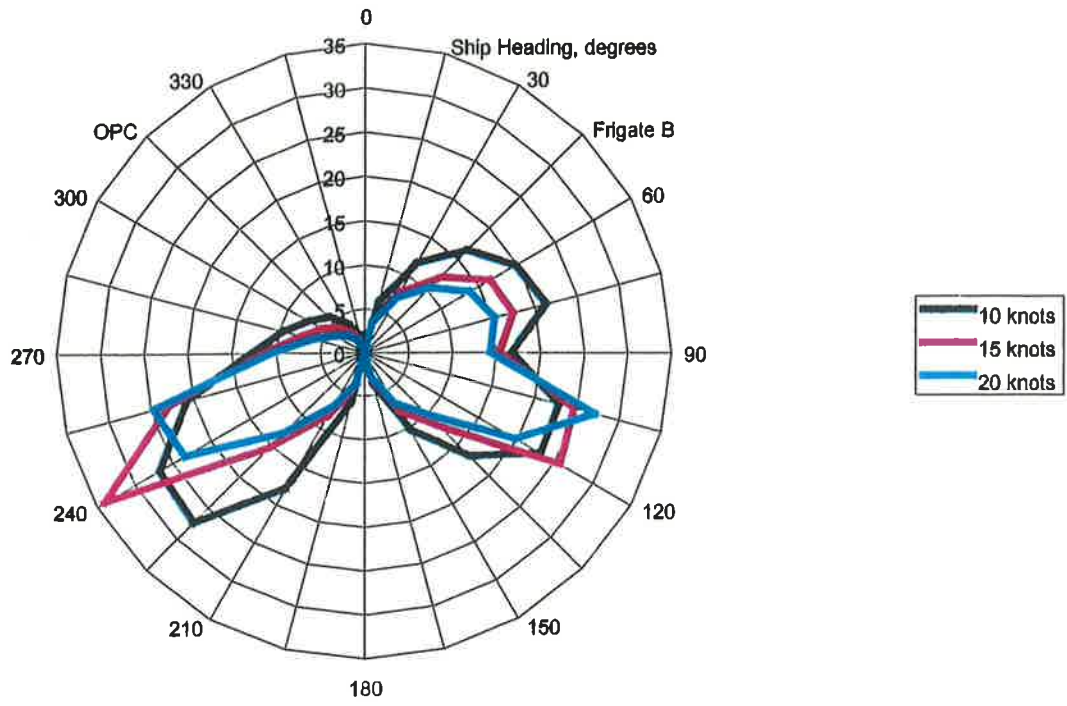


Figure 8 Comparison of peak rolls (top) and peak lateral accelerations (bottom) for the OPC vessel and Frigate B

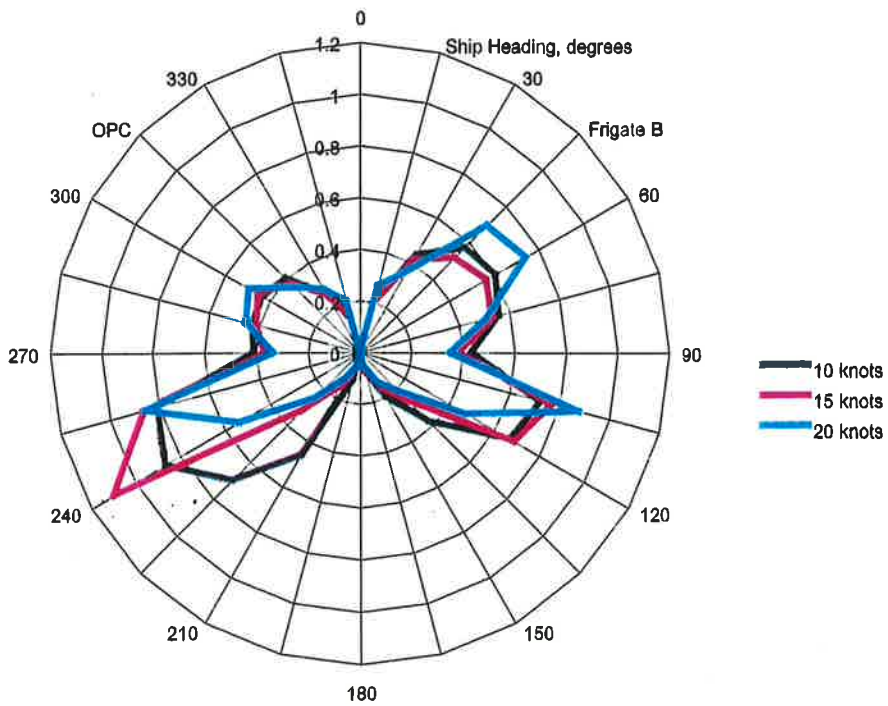
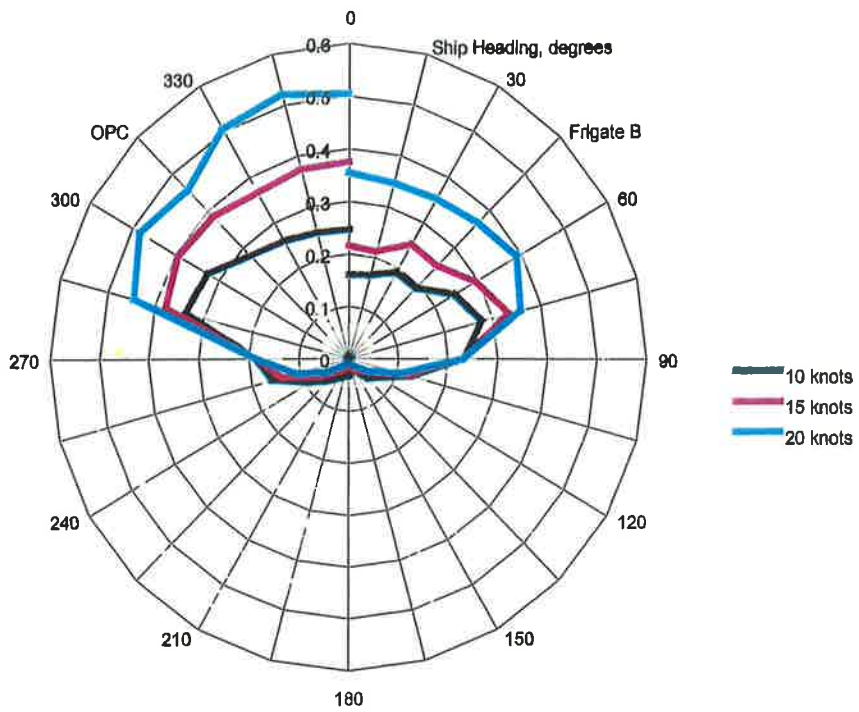


Figure 9 Comparison of the peak vertical accelerations (top) and the T Factors for the OPC vessel and Frigate B

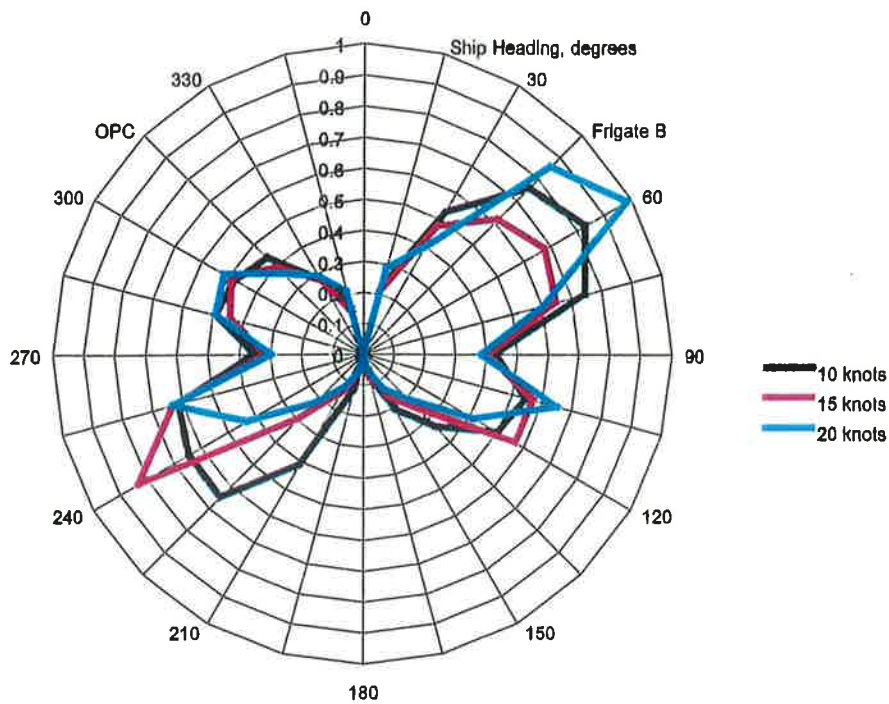


Figure 10 Comparison of the peak lateral to vertical equivalent acceleration ratios for the OPC vessel and Frigate B

Securing Concepts

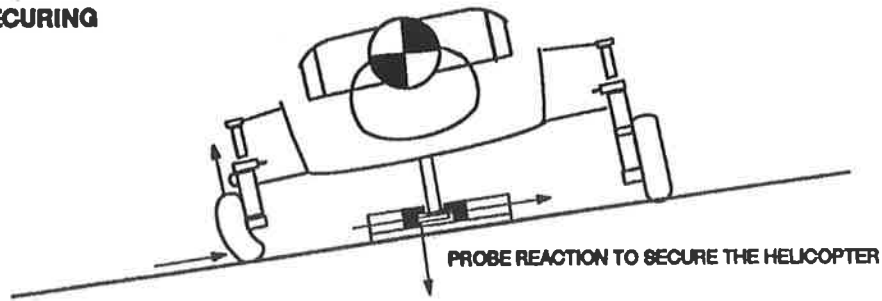
The performance of a helicopter securing system must account for the dynamic interface conditions between the helicopter and the ship to meet the fundamental requirement for securing. The interface loads (landing gear and securing loads) vary considerably depending on the underlying principle upon which the securing system is based.

The systems used for securing helicopters on board small ships fall into two categories based on the securing principle as shown in Figure 11:

- a) Passive securing systems: those in which a structural member fitted to the helicopter and fixed to the ship reacts the helicopter loads, restraining it from movement and transferring the loads into the ship's structure. Securing is limited only by the strength of the securing element(s) and the supporting structure.
- b) Active securing systems: those in which a mechanical/hydraulic device, fitted to the helicopter and attached to the ship, continuously applies a force in an effort to create sufficient friction to prevent tire sliding. Securing is limited by the magnitude of the force, the landing gear capacity, the tire deflection limits, and the deck coefficient of friction.

For intermediate and heavy helicopters, the force required to generate enough friction would require impractical devices and may cause landing gear reactions to exceed their design limits. Therefore, passive securing is recommended for such cases.

PASSIVE SECURING



ACTIVE SECURING

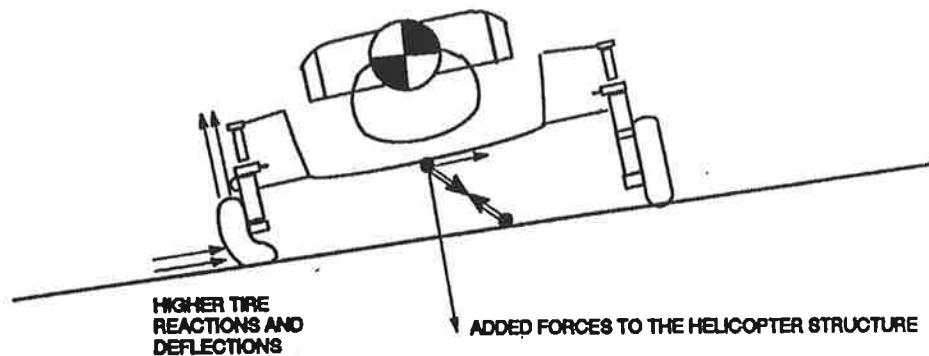


Figure 11 Function of passive and active securing systems

Helicopter Maneuvering and Traversing

Normally the helicopter lands on the flight deck at a random angle from the ship centerline and with an offset distance from the centre of the landing area. Due to the tight clearance between the hangar door opening and the helicopter, the helicopter must be aligned with the traversing path before entering the hangar to avoid damage to the helicopter. Therefore an adequate handling system must be able to provide the following with the helicopter main wheel brakes and the tail wheel lock disengaged:

1. Controlled rotational movement of the helicopter;
2. Controlled longitudinal movement, with lateral restraint, of the helicopter;
3. The ability to castor the tail wheel (combined rotational and longitudinal motions); and
4. Secure the helicopter and restrain its movement against the full ship motion at the operational sea state (5/6).

Maneuvering:

Most of the marine helicopters have a three point landing gear configuration with a steerable/castorable nose wheel or castorable tail wheel. The centre of rotation for such configurations is the intersection point of the centrelines of the three wheel axles. When maneuvering a helicopter, the helicopter will rotate about an instantaneous centre of rotation depending on the orientation of its wheels as shown in Figure 12.

For safe operation, the fundamental requirement of a handling system is to allow such rotation while maintaining helicopter securing and preventing overshoot of helicopter motions under the dynamic conditions of the ship. In addition, the system must be able to achieve helicopter straightening within the limited space of the flight deck and before entering the hangar door. Depending on the system concept and design, the sea state allowed for helicopter maneuvering could be defined by the system ability to meet these requirements.

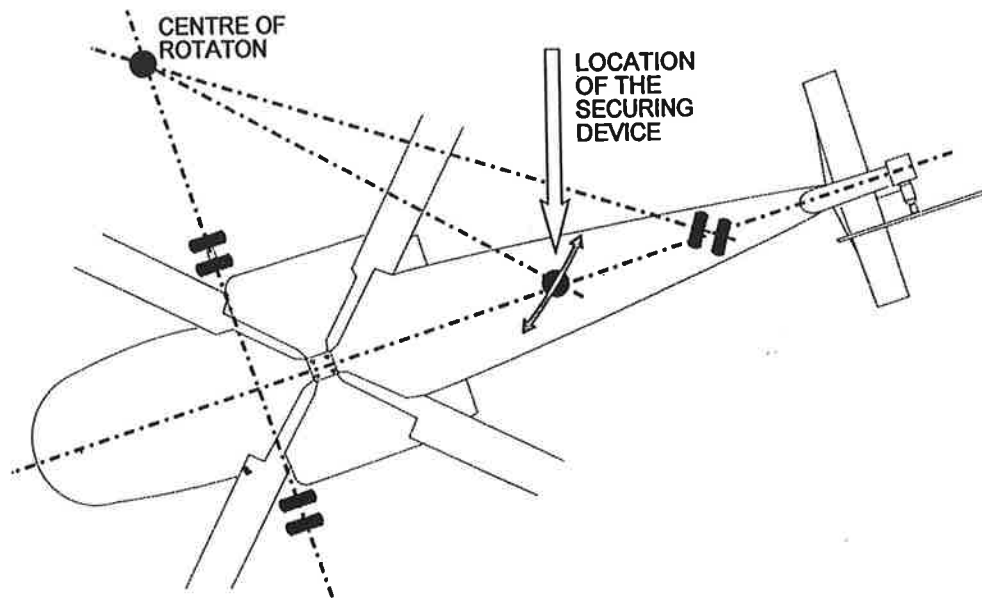


Figure 12 Securing device motion during maneuvering

Traversing:

Traversing the helicopter to and from the flight deck and the hangar is one of the high risk operations for an improperly secured helicopter. This is due to the fact that the traversing distance is relatively long, the clearances at the hangar are normally small, and manual traversing is a labor intensive operation. Most of the incidents reported, while traversing the helicopter manually (even with walking lashings), occurred during this operation.

In addition to the cycle time, the following factors must be considered in integrating a handling system to ensure safe operation during helicopter maneuvering and traversing:

1. The vertical and lateral restraining loads required to prevent tire sliding and excessive rolling motion of the helicopter relative to the deck under the operating conditions of the ship;
2. The maximum deviation from the theoretical traversing path and the helicopter parked position;
3. The number of personnel required for the operation, their location relative to the helicopter, the type of task, and their exposure to the flight deck conditions;
4. Clearances between the helicopter external attachments (antenna, radar dome, missiles, torpedoes, etc.) and the handling system components; and
5. Accessibility for helicopter maintenance, routine checks, fueling, arming and loading.

Conclusion

A comparison of four ships highlights the complex relationship between ship parameters and the resulting ship motion and corresponding aircraft securing conditions in severe sea states. In addition to ship motion, rotor aerodynamics are shown to have a pronounced effect on aircraft securing requirements. To maintain safe operations in severe conditions, securing must be defined such that tire sliding is prevented and excessive motion of the helicopter relative to the deck will not occur. Passive securing is recommended for the safe operation of intermediate and heavy helicopters.

References

- [1] Meyers, W. G., Applebee, T. R. and Baitis, A. E. *User's Manual for the Standard Ship Motion Program, SMP*. David W. Taylor Naval Ship Research and Development Centre, Bethesda, Maryland, USA, September 1981. Report No. DTNSRDC/SPD-0936-01.
- [2] Langlois, R. G. and Tadros, A. R. *User's Manual for the Aircraft/Ship Dynamic Interface Simulation Program*. Indal Technologies Inc., Mississauga, Ontario, Canada, January 1998.
- [3] Tadros, A. R. and Langlois, R. G. *Helicopter/Ship Dynamic Interface*. RINA, WARSHIP '97 International Symposium on Air Power at Sea. London, June 11-12 1997.
- [4] Tadros, A. R., Sopher, G. and Langlois, R. G. *New Approach for Passive Securing at Landing and Powered Handling of Helicopters on Board Small Ships*. RINA, WARSHIP '98 International Symposium on Surface Warships: The Next Generation. London, June 11-12 1998.

- [5] Zan, S. J. *A Wind Tunnel Investigation of Loads for an On-Deck Helicopter Rotor in Beam Winds*. Report No. LTR-A-007 (Prepared for Indal Technologies Inc. under contract P115858). National Research Council of Canada Institute for Aerospace Research, Ottawa, Canada, April 1997.

Info

curtisswrightds.com

Email

ds@curtisswright.com