Parametric Investigation of the Sensitivity of Shipboard Helicopter Securing Requirements to Helicopter Configuration

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Abstract

Extensive experience analyzing the securing requirements and on-deck stability of maritime helicopters on ships has revealed a strong dependence of securing requirements on aircraft configuration. While studies have been conducted comparing various in-service aircraft, interpretation of results was complicated by significant differences in aircraft configurations. To overcome this difficulty, a parametric study was undertaken where controlled variations of key aircraft parameters were considered for a single typical aircraft configuration. Parameters considered in the study were the aircraft mass, track width, wheelbase, longitudinal and vertical positions of the centre of gravity, magnitude of induced rotor loads, lateral projected area, and the vertical location of the centre of pressure. These eight parameters were varied using a 2^8 full-factorial experimental design and helicopter responses to two potentially severe ship motion conditions were predicted using the Indal Technologies Inc. *Dynaface* simulation software. The effect of the above parameters on landing gear reactions, securing forces, and relative motions were determined and are discussed in this paper.

Introduction

Maritime helicopters are designed based on a wide range of performance objectives and subject to numerous constraints. As a result, considerable variability exists in the size and configuration of in-service and proposed shipboard aircraft. Current in-service helicopter weights range from 5 tons to 15 tons, and this range is further increased if autonomous vehicles and tilt-rotor vehicles are included. Configurations include twin, co-axial, and single rotor aircraft with various suspension types arranged in tricycle and tail-dragger configurations using three to six wheels. Geometrical properties are also highly variable.

In the course of analyzing the embarked securing requirements of a wide variety of aircraft types ranging in size from the Bombardier CL-327 autonomous aerial vehicle weighing 0.165 tons in its lightest condition to the EHI EH-101 helicopter weighing over 17.5 tons in its heaviest condition, the significant effect of variations in aircraft geometrical and inertial design parameters has become apparent.

The studies from which largely subjective observations have been made are routinely performed by Indal Technologies Inc. (ITI) in the course of designing helicopter securing and handling equipment for specific combinations of ship, aircraft, and operational requirements. These studies usually are based on existing or proposed air vehicles and ships and typically do not address the effect of aircraft design on securing requirements. Previous research[1] has developed and applied sets of nondimensional parameters and various additional performance measures for quantifying the relative performance of representative in-service shipboard aircraft. Though relatively successful for the intended purpose, that activity was limited by the significant differences in the configurations of the aircraft considered. The difficulty related to isolating the effect of specific parameters in the presence of numerous and significant differences between aircraft.

To overcome that problem, this pilot study was developed whereby a factorial experimental design was used for investigating the sensitivity of on-deck securing requirements to key aircraft geometrical and inertial parameters using a single typical aircraft design. Helicopter securing data for the study were obtained using dynamic interface analysis methodology and simulation tools that have evolved at ITI over the past decade.

'Dynamic interface analysis' is a comprehensive term referring to investigation of all aspects relating to the effect of ship motion and the wind conditions over the flight deck on embarked helicopter operation. It includes consideration of the approach, hover and landing, and on-deck securing and handling operational phases. This study focuses on the third aspect of operation that relates to on-deck securing and handling. While important dynamic interface issues are involved in the first two, they relate primarily to aircraft handling qualities when flying in relatively close proximity to the complex ship wind environment. The on-deck phase includes aircraft capture and securing upon touchdown, alignment of the aircraft with a deck-mounted track, traversing to the hangar, and long-term stowage in the hangar. Analysis of each phase of operation is important for safe and effective integration of helicopters on ships. However, for the purpose of this analysis, attention is limited to the flight-deck securing operation. This aspect of dynamic interface analysis contributes to ensuring that embarked helicopters satisfy a stringent definition of securing and aims at determining the forces that result from securing the helicopter.

While it is widely known that a variety of conditions affect the securing requirements for a helicopter on a frigate-sized ship such as the one illustrated in Figure 1, the effects of ship design have been discussed extensively in Reference 2, the effect of sea conditions and ship operating conditions have been addressed to some extent in Reference 3, and the effect of the securing concept used has been discussed in Reference 4. As mentioned previously, the interface parameters of a secured helicopter (landing gear reactions, helicopter motions relative to the deck, and securing loads) vary considerably depending on the helicopter configuration. Consequently, this paper attempts to quantify the effect of helicopter geometrical and inertial parameters on the securing requirements.

Figure 1. Typical frigate

Subsequent sections of this paper present an overview of the mathematical model and corresponding simulation program used for evaluating the helicopter responses to ship motion, a description of the typical procedure used for dynamic interface analysis, the scope and description of the parametric study focused on helicopter geometrical and inertial parameters, results, and finally discussion and conclusions.

Mathematical Modelling

During on-board operation, helicopter loading involves time-dependant landing gear and securing forces acting in three orthogonal directions. These forces depend on characteristics of the ship, characteristics of the aircraft, and specific operating conditions. To develop an adequate description of the dynamic loading appropriate for analysis, transient dynamic computer simulation of the interface between the secured aircraft and the ship is required. An appropriate simulation model has been developed and is implemented in the ITI *Dynaface*® simulation code[5]. The simulation produces time histories of generalized forces and generalized displacements at the interface between the aircraft and ship in response to ship motion and aerodynamic loading. This section attempts to overview the mathematical model underlying *Dynaface.*

Figure 2 shows a typical embarked helicopter secured to the deck by a rapid securing device (RSD). The RSD is part of an Aircraft/Ship Integrated Secure and Traverse (ASIST) system which secures the helicopter from a helicopter-mounted probe as shown in Figure 3. The objectives of on-deck dynamic interface simulation are to mathematically represent the in-service aircraft and ship system with sufficient fidelity to gain insight into the dynamic interface behaviour yet also maximize simulation speed such that very large numbers of simulation cases can readily be investigated within the scope of a single study.

Figure 2. Image of a typical shipboard securing condition

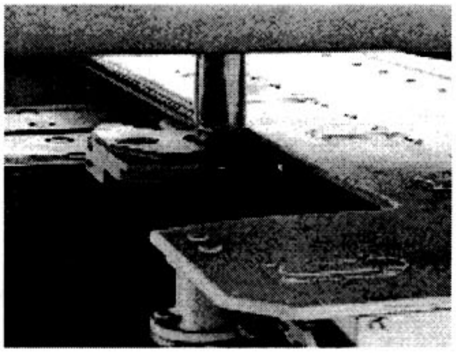

Figure 3. Image of the ITI ASIST Securing system

Dynaface includes a special-purpose 15-degree-of-freedom mathematical model of the aircraft/ship system. The degrees of freedom comprise three translations and three rotations for the ship, three translations and three rotations for the aircraft body, and one prismatic or revolute degree of freedom per suspension station depending on the suspension type. Forces acting on the aircraft portion of the system include deck reaction forces, securing forces, aerodynamic forces, inertial forces, and gravitational forces. Seven primary coordinate systems are used to derive the equations of motion: an inertial frame, a ship frame, an aircraft frame, a rotor tip path plane frame, and wheel frames corresponding to each suspension station (marine aircraft have at least one steerable or castorable wheel). All suspension, external, and securing forces are modelled, analytically or empirically, depending on the quality and availability of data, and the resulting equipollent forces and moments are evaluated and applied through Newton-Euler equations. While the simulation is special-purpose to promote solution efficiency, it includes sufficient generality such that a large variety of aircraft and virtually all ships can readily be modelled. The simulation currently contains prismatic oleo and leading/trailing arm suspension models having up to two wheels each that can be attached to the fuselage in either nose-wheel or tail-wheel configurations, up to two main rotors, and a large variety of possible securing devices. The model includes detailed representation of the oleo stiffness, damping, and friction characteristics; induced rotor forces; and a nonlinear tire model that supports complex tire behaviour including lift-off and touch-down, rolling due to suspension travel, brake slippage, and sliding.

Computationally, speed is maximized by removing physically impossible discontinuities from model characteristics, carefully controlling coupling between model degrees of freedom, and carefully matching the numerical integration with the equation structure. These considerations have led to a simulation that meets the objectives of accuracy and speed.

In using the simulation, the aircraft and ship configurations, environmental conditions, and simulation control parameters are specified in a set of input files. The simulation uses this information to describe the physical system. Ship motion, which is the dominant excitation for the aircraft/ship system is either input as experimentally measured sea trial data or developed from linear frequency-domain response amplitude operators (RAOs). The simulation then generates the time-varying prescribed ship motion and propagates a time-domain solution by numerically integrating the governing Newton-Euler equations of motion for the system. An exhaustive set of optional results; including aircraft relative angular displacements, securing forces, landing gear reaction forces, suspension forces, tire deflections, induced aerodynamic forces, and animation data; are saved in a selected subset of 21 available output files. Simulation results are post-processed by a suite of utility programs or animated using either two- or three-dimensional animation software tools.

The *Dynaface* simulation has been validated by comparison with other simulation results, analytical solutions, rig suspension drop test results, and both land-based and sea trial experimental results.

Dynamic Interface Analysis

The highly nonlinear and time-dependent nature of the dynamic interface makes it impossible to determine analytically the peak aircraft loading as the exact conditions that produce them are not known a priori. The alternative is to simulate the aircraft response over a wide range of conditions in which the aircraft is expected to operate and observe the resulting peak loadings.

Such simulations can be used to investigate the effectiveness of different securing devices under a variety of operational conditions including touchdown, securing, manoeuvring, traversing, and hangaring; identify potential on-deck stability issues; develop design loads for securing devices and aircraft landing gear; assess the sensitivity of aircraft securing to variations in system parameters; define fatigue loading on critical system components; investigate clearances between aircraft- and ship-mounted equipment; and establish safe operational limits for shipboard aircraft.

The methodology used for the dynamic interface analysis is summarized in the block diagram shown in Figure 4. The overall process includes two major phases: ship motion analysis (left) and aircraft response analysis (right).

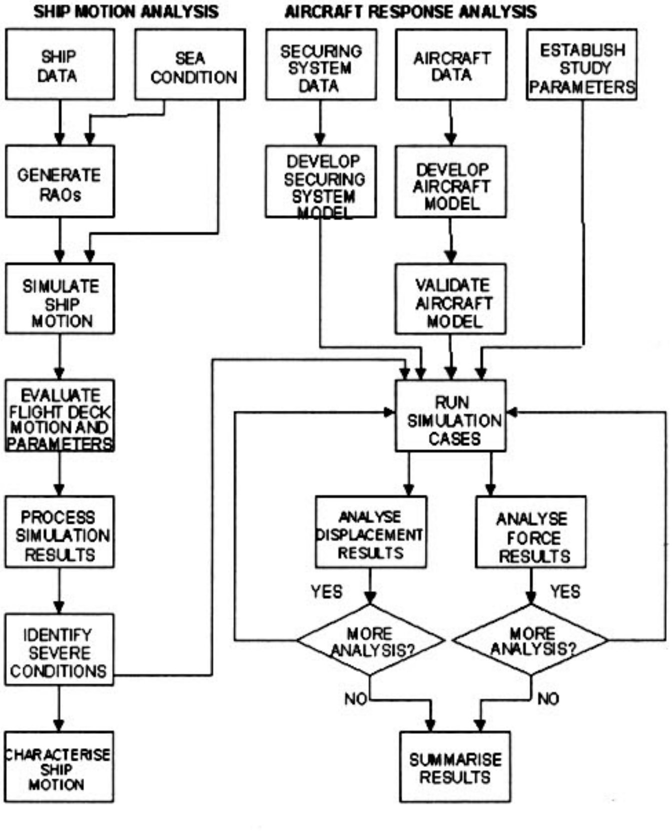

Figure 4. Overview of dynamic interface analysis methodology

A typical analysis involves generating a mathematical model of the ship that is used to simulate extended periods of ship motion for all combinations of applicable operating conditions. Ship motion is governed by the seakeeping characteristics of the ship and seaway conditions including sea state (described in terms of significant wave height and modal period), wave spectrum (a geographical characteristic), a range of ship speeds (typical of operation), and a complete range of ship headings relative to the principal sea direction. Recognizing that the mass of an aircraft is negligible in comparison to the mass of the ship (even for relatively small ships), it is reasonable to neglect the influence of the aircraft dynamics on the ship motion. Consequently, the six degrees of freedom describing the ship motion (surge, sway, heave, roll, pitch, and yaw) can be considered prescribed functions of time, independent of the helicopter dynamics.

The conventional and most widely used method for generating ship motion is to calculate the motion based on a linear frequency domain approach. This method has been demonstrated to work well for small to moderate ship motions resulting from sea conditions up to and including sea state 5 in the case of frigates. Historically, this method has been used extensively for ship analysis and design activities.

The results of the ship motion simulations are analyzed to identify ship motion time periods corresponding to potentially severe conditions for embarked aircraft operations. Typical measures of the severity of ship motion have historically been peak angular motions (mainly roll and pitch angles). While these are related to ship motion severity, they do not necessarily coincide with the worst flight deck conditions for aircraft securing, as aircraft excitation and securing forces are primarily related to linear and angular accelerations at the flight deck. Recognizing the limitation of conventionally-established operating limits, ITI has developed the concept of equivalent acceleration. This concept combines factors affecting flight deck conditions into meaningful parameters. Analysis has shown that the concept is very effective for establishing securing system design requirements and consequently also for defining the deck motion limits for safe helicopter operations[4].

The concept of equivalent acceleration, in its simplified planar form is illustrated schematically in Figure 5. The total acceleration at the flight deck is comprised of the linear acceleration resulting from ship kinematics and from the instantaneous component of the acceleration due to gravity. Equivalent acceleration effectively combines the effects of both deck inertial acceleration and angular displacement of the ship as it affects the aircraft/ship dynamic interface. For analysis, it is more appropriate to resolve the total acceleration into components parallel and perpendicular to the plane of the deck. The components are referred to as horizontal equivalent acceleration and vertical equivalent acceleration respectively. Increased horizontal equivalent acceleration indicates increased lateral loading on the aircraft in the plane of the deck. Reduced vertical equivalent acceleration indicates reduced contact force between the aircraft and the deck, and correspondingly reduced potential for developing frictional force to oppose aircraft sliding. Consequently, the ratio of horizontal equivalent acceleration to vertical equivalent acceleration generally quantifies the tendency of a conventional unsecured aircraft to slide as the result of ship motion. During a simulation study, all potentially severe time periods are identified and filed for subsequent use in replicating the ship motion for on-deck helicopter response simulations.

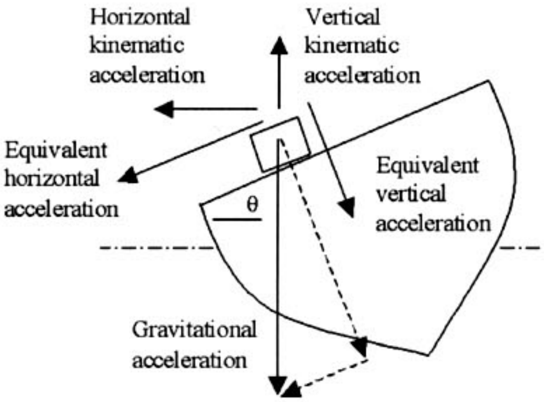

Figure 5. Schematic planar representation of the concept of equivalent acceleration

Physical characteristics of the aircraft are modelled such that they are compatible with *Dynaface*[5]. Then, for all applicable combinations of aircraft configurations and operating conditions, simulations are run for each potentially severe ship motion time period. Parameters that are varied during a simulation study may include aircraft mass, tire and oleo servicing, rotor status, aircraft alignment on-deck, wheel brake status, wheel steer angles, apparent wind speed and direction, sea conditions, and others as appropriate. As a result, a very large number of simulation cases can emerge from a typical comprehensive study. The particular set used is always dependent on the specific objectives of the analysis. Each simulation is generally run for 30 to 40 seconds centred in time on the ship motion event of interest. However, in the case of fatigue analysis, the objective is to simulate a smaller number of cases for extended time periods to obtain a probabilistic description of the securing forces during normal operations. The potentially vast volume of simulation output data is then post-processed for the intended purpose and analyzed.

Parametric Investigation

The parametric study that is the focus of this paper is described in this section. In general, ship motions are first selected that are expected to generate potentially severe securing conditions. These are then used as input to the helicopter response simulation. Variations of aircraft configuration parameters are then identified for use in the parametric study.

The first step in the experimental design involves generating a mathematical model of the ship to simulate extended periods of ship motion for all combination of applicable operating conditions. Ship motion was generated for a typical 135-metre frigate such as the one shown in Figure 1, having a displacement of approximately 4700 tons. The environmental conditions at the time of aircraft operation include the significant wave height, ship heading and speed, and wind speed and direction. The ship motion was generated for upper sea state 5 characterized by a significant wave height of 4 metres and a wave modal period of 11 seconds[6]. Ship headings varied from 0 deg through 180 deg in 15 deg increments and a range of ship speeds were considered. A 27-knot beam wind was selected, representing the wind condition associated with sea state 5. To ensure that typical severe motions were captured, ship motion simulations were run for 30,000 seconds (8.33 hours).

To limit the amount of computer simulation that must be performed to conduct a complete analysis, it is essential to quantify the severity of the motion in a way that guides the selection of simulation cases. The ship motion results were post-processed and potentially severe heading and speed combinations were identified based on roll and equivalent acceleration ratio. Figure 6 shows the ship motion polar plot for roll and a ship speed of 15 knots and Figure 7 shows the plot for equivalent acceleration ratio. The peak ship roll angle occurs in quartering seas at a ship heading of 120 deg while the peak equivalent acceleration ratio occurs in beam seas at a heading of 75 deg. These two severe ship motion cases are used as input for the helicopter dynamic interface simulations.

Figure 8 shows the representative 9-tonne nose wheel helicopter used in the analysis. There are several key aircraft parameters that are perceived to affect the sensitivity of on-deck securing requirements. These are: aircraft mass and mass moments of inertia (mass), track width (tk_wdh), wheelbase (wh_bs), longitudinal position of the centre of gravity (CGx), vertical position of the centre of gravity (CGz), induced rotor loads (rtr), aircraft projected side area (y_area), and vertical location of the centre of pressure (CPz). For the parametric study, simulations were run for all permutations of two levels of the above eight parameters. The lower level was the nominal one and the upper level was 20% higher than the nominal value. The study was repeated for both the peak roll and peak equivalent acceleration ratio[1] ship motion cases. In total, 512 simulations were run for 3,600 seconds centred around the peak ship motion amplitudes using the latest version of *Dynaface* (Rel 6.4). The simulation duration was selected to ensure that statistically meaningful results were obtained[7].

Simulation results were post-processed to extract the peak landing gear vertical reactions (LGR), vertical component of the main probe securing force (MPZ), resultant of the longitudinal and lateral components of the main probe securing force (MPR), and

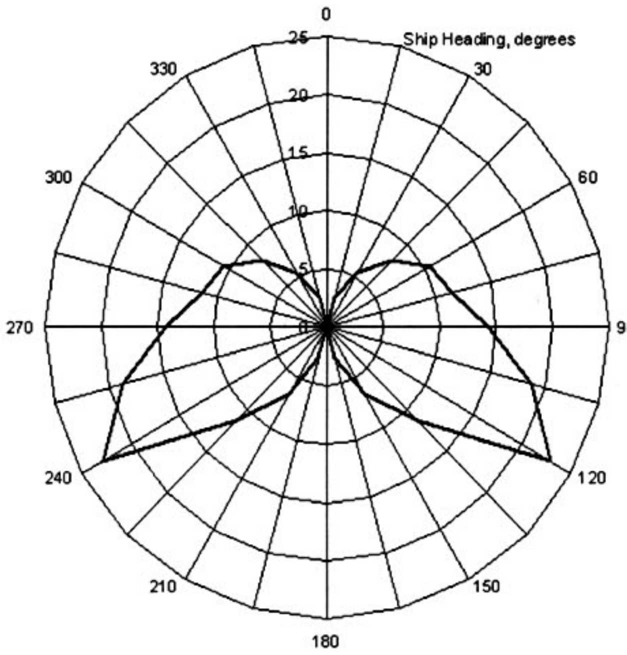

Figure 6. Peak ship roll angle [deg] as a function of ship heading corresponding to sea state 5 and a ship speed of 15 knots

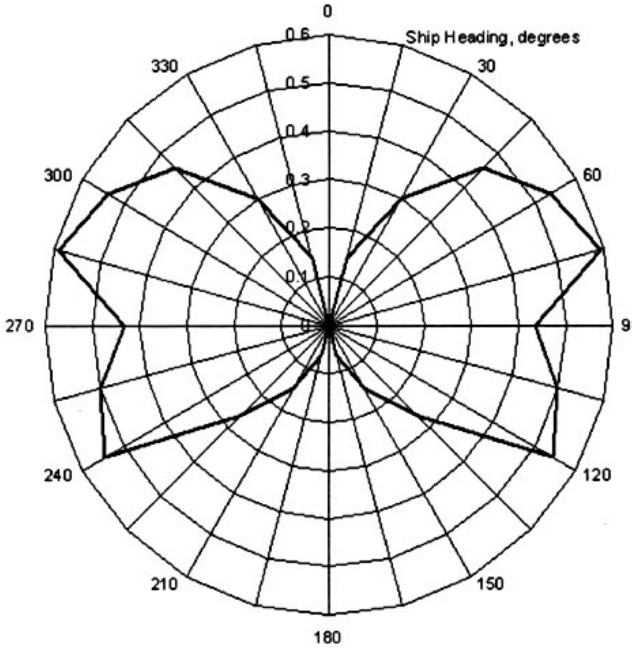

Figure 7. Peak ship ratio of horizontal equivalent to vertical equivalent acceleration corresponding to sea state 5 and a ship speed of 15 knots

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[1] The equivalent acceleration ratio case will subsequently be referred to simply as the acceleration case.

Figure 8. Typical 9-tonne tricycle configuration helicopter

relative orientation angle between the aircraft and the deck (ANG).

Results

The objective of the 2^8 factorially-designed experiment was to assess the impact of each of the eight aircraft parameters on the four conventional measures of securing requirements (identified in the previous section). This was accomplished by first performing a Yates analysis[8, 9] on each of the four peak value data sets arising from both the roll and acceleration ship motion cases. The Yates analysis procedure was coded in a flexible form in the computer program YATES. The analysis resulted in the effect attributable to each of the eight parameters individually as well as in all combinations of two through eight parameters. In this way the effects of individual parameters as well as their interdependencies could be identified. The force results were nondimensionalized by the nominal aircraft weight and expressed as a change in force as a percentage of the aircraft weight. The angular results were nondimensionalized by the average of the nominal relative angles obtained from the roll and acceleration cases. The results are signed such that they indicate whether specific parameters or combinations lead to an increase or decrease in the securing force or relative angle. Figure 9 shows the sensitivities for the four effects for each parameter or combination of parameters (255 in total as 1 simulation case represented the nominal case) for the roll ship motion case. As can be seen from the figure, many effects (particularly combinations of parameters) are negligible. Similar results were obtained for the acceleration motion case. It should be recalled that the sensitivities are the percent change in effect resulting from 20% changes in parameter values.

An approach was required to determine the threshold values above which results must be considered significant. Provided the roll and acceleration cases produced consistent results for the sensitivities, comparison of these two cases could be used to obtain the standard error on effects[8] and those values could be used as the threshold for identifying significant results. To check for this agreement, the percentage change in effects resulting from the acceleration motion case were plotted against the corresponding values for the roll case. The resulting correlation plots for vertical landing gear reaction, vertical probe force, radial probe force, and relative angle are presented in Figures 10 through 13 respectively. Trend lines are also included on the plots. Agreement between the data and the trend lines indicates consistent results independent of the motion case considered whereas dispersion indicates results are only somewhat dependent upon the motion case considered. From the figures it is apparent that the vertical probe force and relative angle effects agree well between motion cases whereas the landing gear reaction and radial probe force do not agree as well, though a trend remains clearly evident[2]. Based on this comparison, the calculation of standard errors was performed resulting in levels of significance provided in Table I.

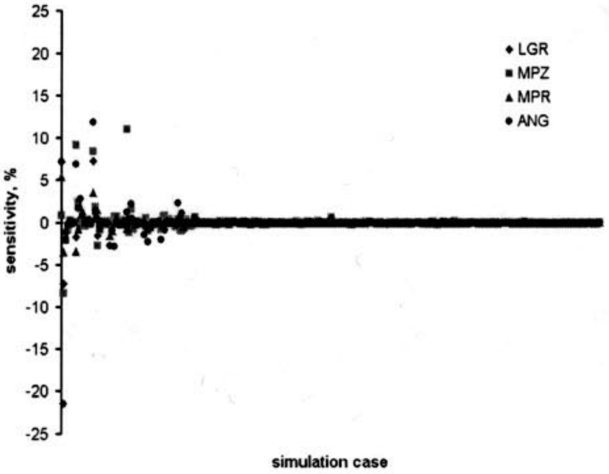

Figure 9. Graphical summary of simulation results for the roll ship motion case

Table I
Standard errors (S.E.) indicating threshold for significance of results for each effect

Effect	S.E.
landing gear reaction	5.1 %
vertical probe force	2.7 %
radial probe force	3.4 %
relative angle	6.7 %

The sensitivities of primary effects resulting from the roll case and the acceleration case are presented in Tables II and III respectively. The similarity of results between Tables II and III motivated calcu-

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[2] It should be noted that in these plots 100% corresponds to the effects arising from the nominal design condition.

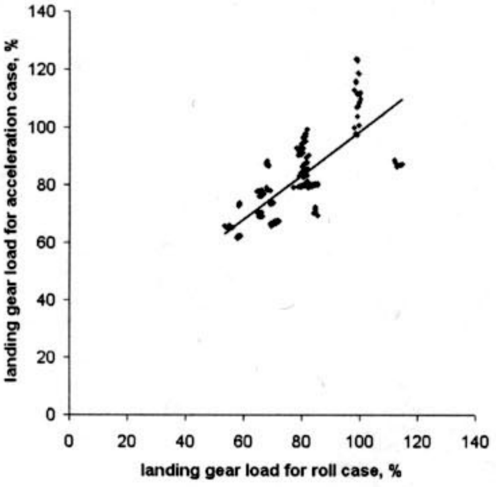

Figure 10. Correlation of peak vertical landing gear reaction forces between peak ship roll and peak ship equivalent acceleration motion cases

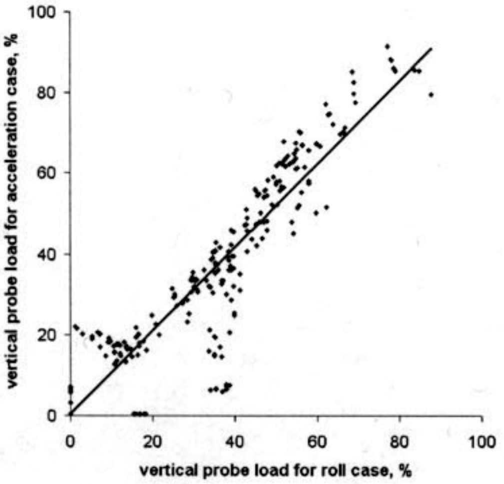

Figure 11. Correlation of peak vertical securing forces between peak ship roll and peak ship equivalent acceleration motion cases

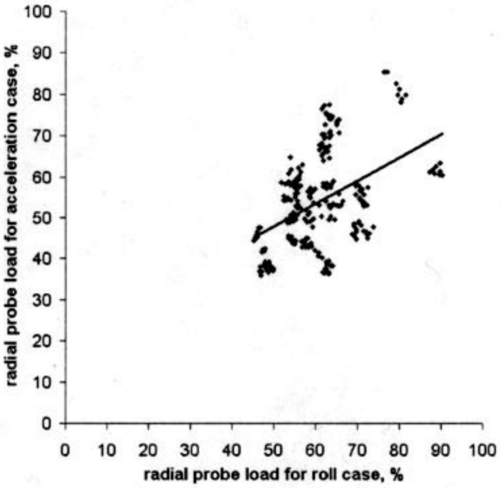

Figure 12. Correlation of peak radial securing forces between peak ship roll and peak ship equivalent acceleration motion cases

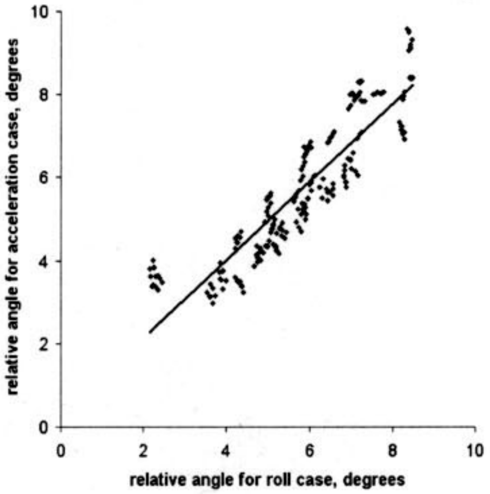

Figure 13. Correlation of peak relative angular displacements between peak ship roll and peak ship equivalent acceleration motion cases

lating the average sensitivity provided in Table IV. From Table IV the most important helicopter parameters affecting on-deck securing requirements are apparent. Consider, for example, the track width. Increasing the track width by 20% resulted in a 6.1% reduction in vertical landing gear reaction, 11.0% reduction in vertical securing load, 6.1% reduction in radial securing load, and 22.1% reduction in relative angle. In reviewing the results, it is important to note that magnitudes smaller than the standard errors provided in Table I should not be considered significant.

Inspection of the complete set of results shows that single parameters and some combinations of two parameters have significant effects. However, the effects of all combinations of more than two parameters are negligible. Therefore, only combinations of two parameters need to be considered further. Figures 14 through 21 show the absolute value of the sensitivities of individual effects and combinations of two effects for both the roll and acceleration cases. From these plots it is further demonstrated that similar results are obtained for both the roll and acceleration ship motion cases for each effect. Few departures from this generalization exist. Recalling Table I, it is observed that all combinations of two sensitivities cannot be considered significant though measurable values occur for several combinations. One such example is the combination of centre of mass height and track width with regards to vertical landing gear reaction (Figure 15).

Conclusion

The pilot study presented in this paper addressed the effect of helicopter configuration parameters on shipboard securing requirements. Proven dynamic inter-

Table II
Effect of 20% change in single parameter values for the roll case

Parameter	LGR,%	MPZ,%	MPR,%	ANG,%
mass	7.2	0.8	5.4	7.2
tk_wdh	-7.3	-8.4	-3.5	-21.6
wh_bs	-0.2	-0.9	0.1	-0.2
CGx	-1.7	9.2	-3.5	6.9
CGz	7.3	8.4	3.5	12.0
rtr	-0.7	11.1	-0.7	1.2
y_area	0.3	0.6	0.2	0.6
CPz	0.3	0.6	-0.1	0.6

Table III
Effect of 20% change in single parameter values for the acceleration case

Parameter	LGR,%	MPZ,%	MPR,%	ANG,%
mass	7.6	0.9	4.5	6.6
tk_wdh	-6.1	-11.0	-6.1	-22.1
wh_bs	-1.8	-2.2	-0.3	-1.9
CGx	4.6	12.4	3.2	9.5
CGz	5.5	10.2	5.0	11.8
rtr	1.9	8.6	4.5	5.7
y_area	0.2	-0.4	0.3	-0.1
CPz	0.2	-0.4	0.1	-0.1

Table IV
Average effect of single-parameters for 20% change in parameter values

Parameter	LGR,%	MPZ,%	MPR,%	ANG,%
mass	7.4	0.9	5.0	6.9
tk_wdh	-6.7	-9.7	-4.8	-21.9
wh_bs	-1.0	-1.6	-0.1	-1.1
CGx	1.5	10.8	-0.2	8.2
CGz	6.4	9.3	4.3	11.9
rtr	0.6	9.9	1.9	3.5
y_area	0.3	0.1	0.3	0.3
CPz	0.3	0.1	0	0.3

face analysis methodology and corresponding transient dynamic simulation were used to generate a set of aircraft response results for helicopter geometrical and inertial parameter variations chosen based on a full-factorial experimental design. The study led to several main conclusions enumerated below.

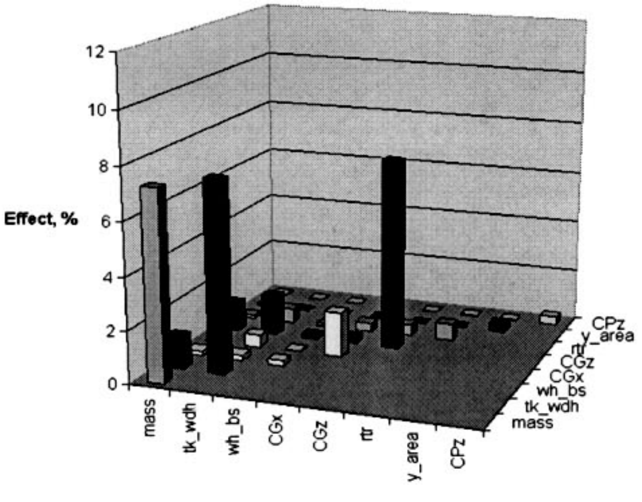

Figure 14. Summary of landing gear vertical reaction force sensitivities for peak roll angle case

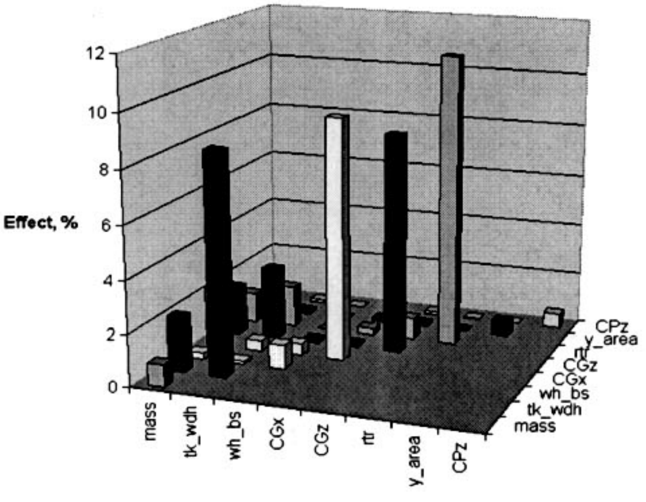

Figure 15. Summary of vertical securing force sensitivities for peak roll angle case

1. Transient dynamic nonlinear aircraft response simulation provides a valuable tool for performing parametric studies of this type and allows freedom in selecting system parameter values.
2. Securing requirements are very dependent on helicopter configuration.
3. Increases in mass and inertial properties adversely affect vertical landing gear reactions, radial probe load, and relative angular motion between the aircraft and ship but have a much smaller though still significant effect on the vertical probe load.

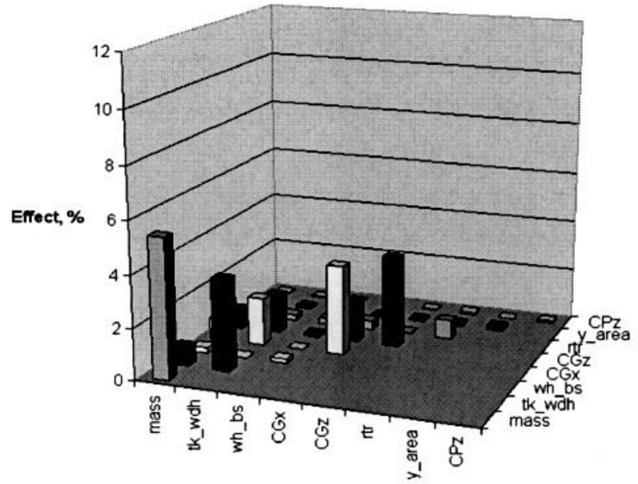

Figure 16. Summary of radial securing force sensitivities for peak roll angle case

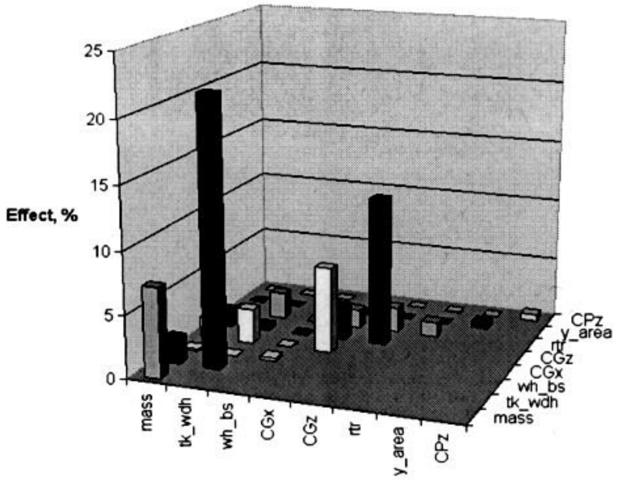

Figure 17. Summary of relative angular displacement sensitivities for peak roll angle case

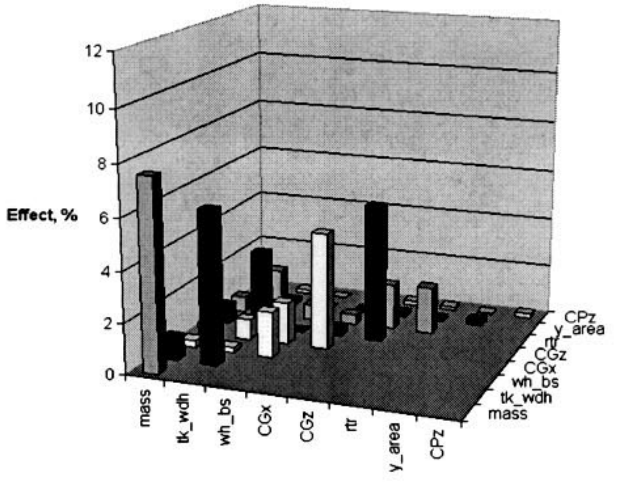

Figure 18. Summary of landing gear vertical reaction force sensitivities for peak acceleration ratio case

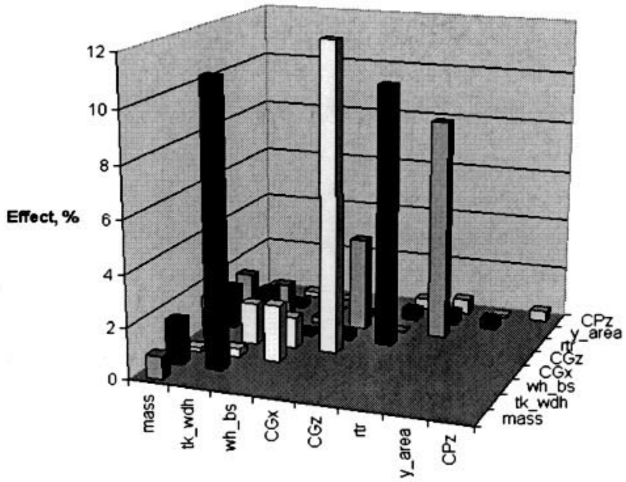

Figure 19. Summary of vertical securing force sensitivities for peak acceleration ratio case

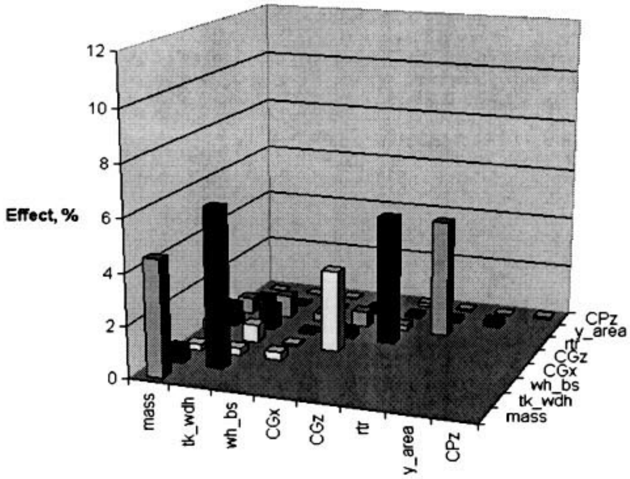

Figure 20. Summary of radial securing force sensitivities for peak acceleration ratio case

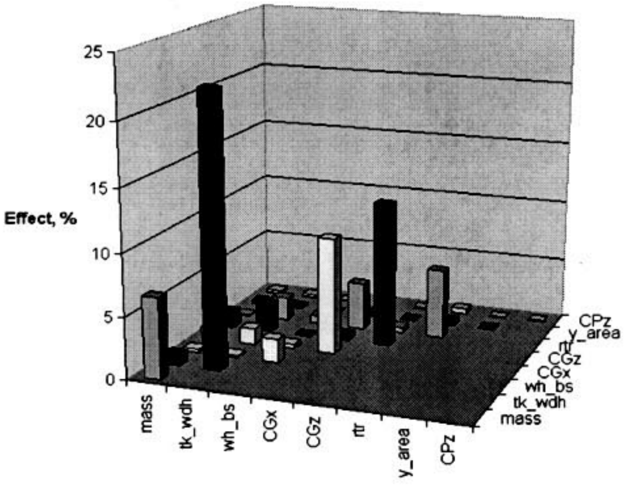

Figure 21. Summary of relative angular displacement sensitivities for peak acceleration ratio case

4. Increases in track width have a very favourable effect on all effects considered. In decreasing order of significance, relative angles, vertical probe loads, landing gear reactions, and radial probe loads are affected. The largest effect found in the complete study was that a 20% increase in track width resulted in a 22% decrease in relative angle for the conditions considered.
5. The aircraft wheelbase had a small favourable effect on all outcomes considered.
6. Increases in the longitudinal location of the centre of mass had a large detrimental effect on the radial probe load and relative angle and a much smaller effect on the landing gear reactions. The ship motion case considered affected the sign of the effect on the radial probe load.
7. The height of the centre of mass detrimentally affected all outcomes considered, but most significantly affected the vertical probe load and relative angle.
8. Increases in the magnitude of induced rotor loads had a very detrimental effect on the vertical probe load; the effect on other outcomes was somewhat dependent on the ship motion case considered.
9. The lateral projected area and centre of pressure height had very small effects on the securing requirements.
10. The effect of coupling of parameters was presented in the paper but generally had a very small effect on the securing requirements.

Based on the success of this preliminary study, further parametric studies will be formulated to more comprehensively investigate the effects of aircraft and securing equipment design on securing requirements. The current study was based on a single aircraft configuration and a single ship. Therefore the extent to which results of this type can be generalized to other aircraft and ships must also be investigated. The ultimate objective of this type of research is to provide guidance toward the design of helicopters for embarked operation and correspondingly improving the safety of the on-deck operation.

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