EFFECTS OF FLIGHT DECK CONFIGURATIONS AND CONDITIONS ON HELICOPTER SECURING REQUIREMENTS AT LANDING

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SUMMARY

Securing requirements of a helicopter onboard a naval vessel can only be evaluated by performing detailed helicopter/ship dynamic interface analysis. This involves quantifying the dynamic loads acting on the helicopter and calculating the corresponding interface reactions and helicopter responses. It was concluded in previous studies by Indal Technologies Inc. that the aerodynamic loads generated by the main rotor contribute significantly to the overall loads. Although the rotor collective is normally set at its minimum after landing, the resulting rotor thrust may exceed 25% of the helicopter weight, depending on the wind speed and the roll angle. To evaluate these induced rotor loads, a computer model of the rotor could be used. However, the accuracy of the induced loads is dependant on the assumptions used, specifically in relation to the conditions of the wind over the flight deck. ITI and DCE undertook the challenge of investigating the assumption through wind tunnel testing. The testing examined the effects of wind speed, roll angle, flight deck width and height above the water line on the rotor induced loads. In addition, mapping of the flow over the flight deck was conducted to support the analysis of the results and establish a method to augment the induced rotor loads predicted by analytical methods for use in helicopter/ship dynamic analysis. These tests were performed at NRC wind tunnel facilities in January- March of 2003. The paper presents a review of test results and discusses effects of the flight deck configuration on the helicopter/ship dynamic interface. The impact of the test results on establishing limits for on-deck operation of the embarked helicopter is also addressed

1. INTRODUCTION

Many navies consider the embarked helicopter an essential asset onboard various classes and sizes of ships. In addition to performing ASW and other combat missions, helicopters are irreplaceable in search and rescue operations. Therefore, not only is the demand for helicopters onboard naval ships continuously increasing, but also increasing is the severity of the sea conditions in which the helicopter could be safely launched and recovered. This raises the need for thorough investigation and accurate definition of helicopter securing requirement during onboard operations. While in the past, the term on-deck helicopter dynamic stability was used when investigating the dynamic interface between helicopter and a ship, the real interest encompassed the helicopter on-deck securing and not just its stability. In other words, the helicopter could be considered dynamically stable on the deck if it does not roll over or slide continuously until it is lost over board. However, for safe operation, the helicopter must not slide nor tilt excessively to be considered secured. The limit for helicopter tilting is defined when one landing gear is fully extended and the others are fully compressed. This more accurately defines the conditions of helicopter securing regardless of the securing means. Based on this definition of helicopter securing, dynamic analysis of the onboard helicopter in the time domain must be performed to investigate the sliding or tilting of the helicopter under all operational conditions. To ensure the safety of helicopter operation on deck, the analysis must consider not only the maximum values but also the variations in all loads acting on the helicopter due to the ship motion and the wind over the deck. On other word, detailed dynamic interface analysis of the embarked helicopter must be performed before establishing securing requirements, on-deck handling system capabilities and the safe operational envelops.

The aerodynamic loads generated by the main rotor significantly influence the securing requirements of a helicopter after landing onboard a naval vessel. Although the rotor collective is normally set at its minimum after landing, the residual thrust of the rotating rotor may vary between 3-6% of the helicopter weight depending on the rotor design. As the ship rolls the wind forms an angle of attack with the rotor disk which cause the thrust to increase. Initially, it was assumed that the rotor disk is perpendicular to the rotor shaft and the wind is steady and parallel to the undisturbed sea level [1]. To examine these assumptions, Indal Technologies Inc. (ITI), conducted preliminary wind tunnel tests at the National Research

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Council of Canada (NRC) utilizing a rotor model placed on a model of a ship flight deck, see Figure 1. Results of the preliminary tests confirmed the significance of the rotor induced loads and as shown in Figure 2, the presence of a ship creates an upwash that increases the angle of attack and therefore the induced loads over those predicted by analytical methods. The rotor thrust may exceed 25% of the helicopter weight, depending on the wind speed and the roll angle. When the ship roll reaches high angles (about 20 degrees), the rotor loads start to decrease.

The results of the tests were shared with Centre Technique des Systèmes Navals (CTSN)),from DGA, French MOD during the course of a study activities conducted by ITI to DCE [2]. Due to the significance of the findings ITI and DCE decided to investigate the matter further by planning and conducting additional wind tunnel tests utilizing various flight deck configurations.

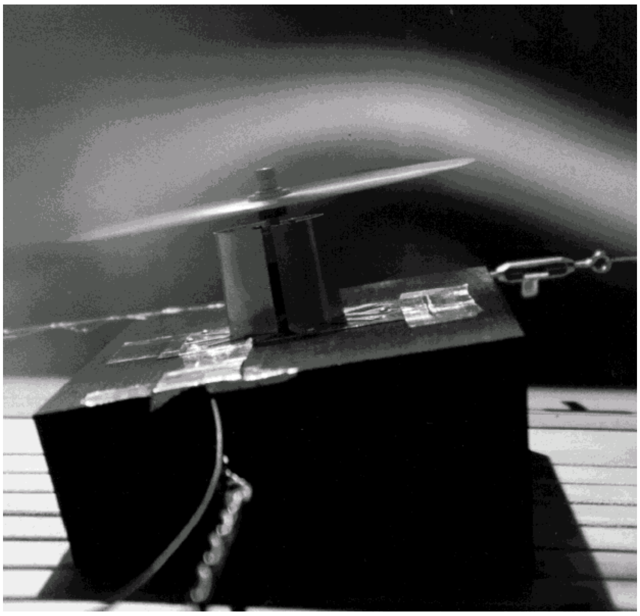

Figure 1: Rotor and deck model during wind tunnel testing

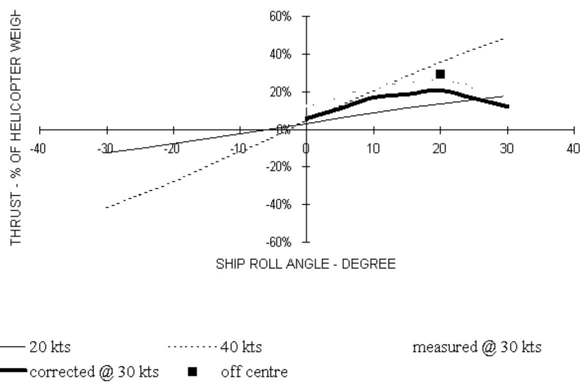

Figure 2: Rotor thrust from analytical model and from testing

2. ON-DECK HELICOPTER/SHIP DYNAMIC INTERFACE

Dynamic interface analysis' is a comprehensive term referring to investigation of all aspects relating to the effect of ship motion on embarked helicopter operation. It includes consideration of the approach, hover and landing, and on-deck securing and handling phases. During approach, a glide slope indicator may be used to guide the helicopter to the ship. The effect of ship motion may impact the pilot interpretation of the light zones. During hover and landing, the objectives are to investigate the effect of turbulence and the effectiveness of pilot visual cues and recovery assist system performance in reducing pilot workload and landing dispersion. The remaining aspects of operation relate to on-deck securing and handling. These include aircraft capture and securing upon touchdown, aligning of the aircraft, traversing to the hangar, long-term stowage in the hangar, and a similar set of operations during the launch sequence. Analysis of each phase of operation is important for safe and effective integration of helicopters on ships. However, for the purpose of this paper, attention is focused on the effect of ship motions on the on-deck operations specifically at landing while the helicopter rotor is still turning. In addition, it is important to be able define the main parameters which quantify the severity of the deck conditions relevant to onboard helicopter handing operations.

2.1 QUANTIFYING THE ON-DECK SECURING REQUIREMENT

Equivalent accelerations and T factor [3] provide effective means for quantifying the severity of the deck conditions for on-deck helicopter operations. These will be elaborated on further in the paper. However, the securing requirements of the helicopter on-deck are dependent on the aircraft response to the deck conditions and can only be evaluated from time domain dynamic interface analysis.

Forces resulting from six degree-of-freedom ship motion, aerodynamic forces, and forces generated by securing devices dominate the helicopter dynamics. Figure 3 provides a schematic illustration of various forces acting on a secured helicopter while it is on the flight deck. To evaluate the securing requirements, the equations of motion are established and solved analytically in the time domain. ITI developed a computer program "Dynaface" that solve the nonlinear governing differential equations describing the 15-degree-of-freedom model required to simulate the aircraft/ship system. In France, CTSN (Technical Centre for Naval Systems), developed a similar program IDYNA. These programs have been validated by various means including comparisons with sea trials. These types of programs are considered essential in investigating the on-deck helicopter/ship interface. ITI utilizes its program as a design tool for developing securing and handling systems as well as to perform studies to support its customers to achieve effective integration of embarked helicopters. IDYNA is owned by the French government and is used to obtain safe operating limits of the French Navy embarked helicopters. Performing simulations using such programs help reduce the need for expensive and often time-consuming sea trials. The utilization of such capabilities is expected to increase with the arrival of NH90 onboard the French ships and the development of 2 new frigates programs, the anti-air frigate Horizon and the Multi Mission Frigate “FREMM”. Therefore, ITI and DCE recognized the importance of continually enhancing the capabilities and the accuracy of their programs and hence cooperated to further investigate the rotor loads in relation with the flight deck configuration.

Once the helicopter has landed on the deck, the rotor collective is decreased to a minimum while the rotor continues to turn at normal operating speed. The minimum collective and operational RPM are maintained during hot refueling or until the helicopter is secured to the ship and the rotor shutdown procedure is initiated. During the time between the landing and the shutdown of the rotor, the unsteady airwake and moving ship may result in an altered inflow to the rotor. This inflow can produce large loads which significantly impact the securing requirement at landing. The situation is illustrated schematically in Figure 2. Typical rotor thrust as a function of ship roll angle is presented in Figure 2. As the windward edge of the ship rises due to the ship rolling to leeward, the local angle of incidence of the wind on the rotor disk will increase (at least on the upwind side) which produces an increase in thrust and rolling moment.

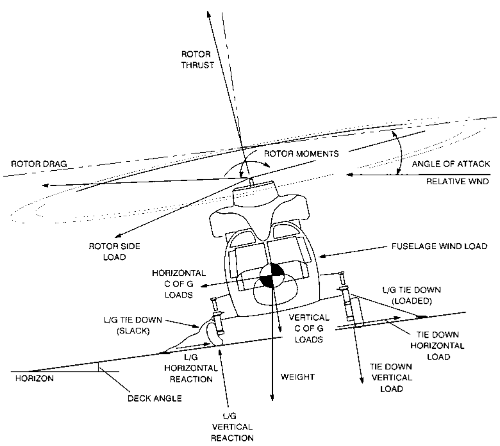

Figure 3: Loads acting on the embarked helicopter

The evaluation of these aerodynamic loads is a challenging problem. Currently, there are no computational fluid dynamics codes which can be coupled with a blade-element or vortex-wake rotor model in order to predict the coupled airwake/rotor-downwash flow field. The partial ground effect of the ship flight deck is an additional complication to the problem. Analytical methods to estimate the rotor loads are limited by the ability of any such method to represent the complex flow field of the airwake which may contain recirculating and vertical flows. Years ago, the rotor loads after landing were normally ignored by assuming that the wind is parallel to the flight deck. While this assumption is sometimes acceptable for aircraft carriers, it is unacceptable for smaller ships. Wind tunnel testing showed that the magnitude of the rotor thrust could reach 30% of the helicopter weight on these smaller ships. The first attempt to estimate the rotor loads due to the ship motion was made by United A/C of Canada in the early seventies. Formulas based on the rotor geometry were developed as reported in its Report H-1012. The work utilized data generated by NACA study of the loads induced by the tail rotor included in NACA TN3156. This work was not validated by wind tunnel testing or sea trials. The other approach, used by ITI, is to use a linearized rotor model from the helicopter manufacturer to calculate the rotor loads assuming a steady flow parallel to the undisturbed sea surface and a rotor disk perpendicular to the rotor shaft.

2.2 QUANTIFYING THE SEVERITY OF FLIGHT DECK CONDITIONS

Typical measures of the deck conditions 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 and handling since aircraft excitation and securing forces are primarily related to linear and angular accelerations at the flight deck. Based on the definition of securing, potentially severe-motion time periods should be defined using criteria that measure the actual severity of conditions at the flight deck. There are two cases to be considered, the case when the helicopter rotor is not turning and when the rotor is turning. In the first case, the acceleration acting on a helicopter on the flight deck is comprised of two components. The first is the linear acceleration that results from the instantaneous components of the acceleration due to gravity. The second is the linear acceleration resulting directly from ship kinematics. For the purpose of dynamic interface analysis, 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 equivalent horizontal acceleration and equivalent vertical acceleration respectively.

The concept of equivalent acceleration is illustrated schematically in Figure 4 for a two-dimensional case. Increased equivalent horizontal acceleration indicates increased lateral loads on the helicopter in the plane of the deck resulting from ship motion. Reduced equivalent vertical acceleration indicates reduced contact force between the aircraft and the deck and, correspondingly, reduced potential for developing frictional force to resist helicopter sliding. Consequently, the ratio of equivalent horizontal acceleration to equivalent vertical acceleration quantifies the tendency of the aircraft to slide as the result of ship motion. Therefore, the ratio of equivalent horizontal acceleration to equivalent vertical acceleration could be considered a single parameter which quantifies the severity of the ship motion for helicopter securing and could be used to define accurately the on-deck operational envelope. While active stabilization may reduce the maximum roll angle (Figure 2), its effect on equivalent acceleration may be less pronounced.

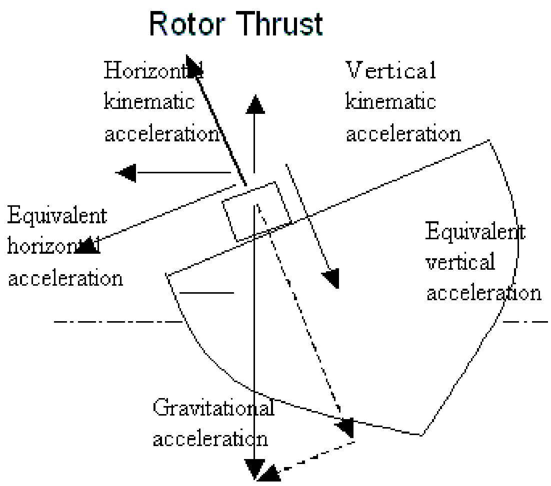

Figure 4: 2D representation of equivalent accelerations

In the rotor turning case, the main rotor thrust induced by the wind over the deck needs to be included. Therefore the thrust, calculated based on the beam wind speed and the roll angle, is divided by the helicopter mass and added to the vertical equivalent acceleration. The new ratio represents a factor indicating the tendency of the aircraft on-deck with the rotor on to slide and is called "the T factor". This factor provides an effective means to quantify the severity of the deck when the helicopter rotor is turning. Therefore the T factor could be used to define accurately safe envelopes for deck conditions after landing and before shutting down the rotor, or during hot refueling or before take off. The accuracy of evaluating the T factor and hence the safe envelopes is dependent on accurately calculating the rotor induced thrust due to the wind and the ship motion.

In order to assess better the aerodynamic loads and to understand better the flow physics, ITI, of Canada and DCE, of France planned a parametric series of wind tunnel experiments which were undertaken by NRC of Canada based on their experience in similar testing but for helicopters during hovering above the flight deck [4].

3. TESTING

A number of ship models were constructed in order to examine the relative importance of ship beam, roll angle and deck height above water on the induced rotor loads. For the non-zero roll angles, the models were designed such that the vertical distance from the sea surface to the crown of the flight deck along the ship centreline was the same as for the corresponding zero roll angle models. For each roll angle, the rotor was located over the centre of the flight deck. It was driven by a small DC electric motor which in turn was mounted on a six-component balance. In order that the rotor height above deck be representative of the typical helicopter, part of the motor and the entire balance were inset into the flight deck. A sheet metal shroud was installed around the part of the motor exposed to the onset flow in order to eliminate any aerodynamic loads acting on the motor. Figure 2 presents a typical installation photograph.

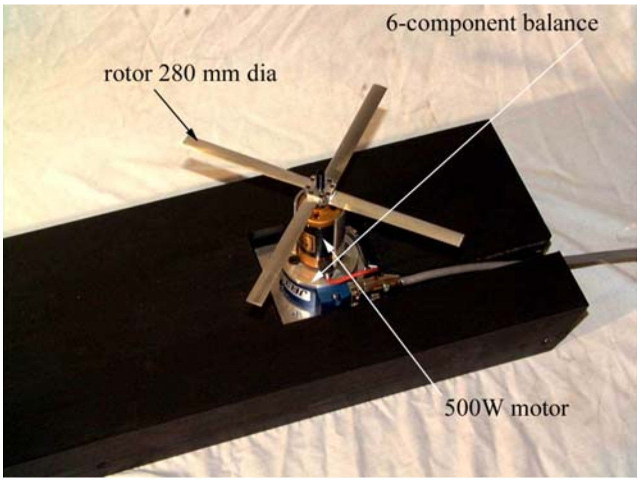

Figure 5: Rotor, electric motor, and balance mounted to the flight deck

3.1 FLIGHT-DECK MODEL

The flight-deck models were constructed to represent typical 2000 – 8000 ton frigate sizes with various heights from the waterline. The flight-deck model width and height is normalized with respect to rotor diameter. The baseline model has a ship-width-to-rotor-diameter ratio (W/D) of 0.9. To allow for flexibility in modeling various deck widths, appendages have been constructed and can be attached to the port and starboard sides of the baseline W/D model to increase the W/D ratio as required. Similarly, the flight deck model includes the flexibility of varying the height above the waterline as a function of rotor diameter (H/D). This is accomplished by constructing appropriate shims that can be attached to keel of the baseline model having a H/D ratio of 0.3. Only static roll angles were introduced to the deck model since the investigation was limited to beam winds. The models had roll angles of 0° through 25° in 5° increments. Several experiments were conducted to include a generic hangar to investigate the effect of the presence of a hangar on the airflow over the flight deck. The hangar model is 350 mm long, 224 mm wide, and 124 mm high.

3.2 TEST FACILITIES AND EQUIPMENT

The wind tunnel tests were performed in the NRC 2m x 3m open-jet vertical wind tunnel. The tunnel was configured with a 2-meter wide groundboard to represent the sea surface. The mean onset flow approaching the ship was representative of the atmospheric boundary layer which would develop over a moderately rough sea

A four-blade constant-section, constant-chord (15 mm) variable-twist rigid rotor, diameter 0.2804 meters, was used to model the rotor of the helicopter. The pitch angle of the rotor blades could be set to any desired position. This is done when the rotor is not turning, as there is no method for changing the collective pitch on such a model while the rotor is turning. The rotor blade washout extends over the outer 80% of the blade radius and is equal to 13°. As the study is a generic investigation, there is no specific rotor and ship modelled; however for convenience a geometric scale of 1:60 was chosen, yielding a prototype rotor diameter of 16.8 meters. The velocity scaling was 1:2, yielding a frequency scaling of 30:1. With a nominal model rotor rotational speed of 7500 RPM, the corresponding prototype value is 250 RPM. The rotor was mounted to a 500 W DC electric motor which in turn was mounted on a six-component commercially-available strain-gauge balance. The accuracy of the balance is about 1%.

With these scale parameters, the blade-chord Reynolds number at the three-quarter radius is about 80 x 10^3 and the corresponding Mach number is about 0.25. As the investigation is concerned with the relative performance of the rotor as a function of ship roll angle, exact modeling of the blade-profile and Reynolds number is not important, although it is remarked that aerodynamic drag and hence rotor torque would be over-estimated at these Reynolds numbers.

For each ship roll angle, balance data were acquired a sample rate of 100 Hz per channel for a total of 10.24 seconds (total of 1024 samples per channel). A run would consist of measuring the rotor output (balance data) at wind tunnel speeds of 0, 5, 7.5 and 10 m/s, corresponding to prototype values of approximately 0, 20, 30 and 40 knots. The rotor rpm was determined by monitoring a voltage-sense line attached to terminals within 5 cm of the motor. The approach wind speed at an elevation corresponding to the rotor hub was determined from the free-stream wind speed and the measured boundary layer profile. This height was 0.4 rotor diameters above the flight deck and the onset velocity at this height is the reference wind speed used in this paper.

The model-scale loads were converted to prototype values based on the scaling adopted above. Defining λ_i as the ratio of the prototype-to-model scale value for quantity i, and given the fact that the fluid density is the same in the experiment as at prototype scale, the following can be derived:

$$\lambda_F = \left(\lambda_L\right)^4 \bullet \left(\lambda_T\right)^{-2} = 14.4 \times 10^3$$

$$\lambda_M = \left(\lambda_L\right)^5 \bullet \left(\lambda_T\right)^{-2} = 864 \times 10^3$$

where F is a force, M is a moment, L is length, and T is time

In order to remove the effects of variations in air density and model rotor RPM (typically within 1%), the model loads were first converted to aerodynamic coefficients and then scaled up to prototype loads based on the parameters presented above. The barometric pressure and air temperature were also recorded during the tests in order to determine the air density for each run. The prototype loads were determined for air at standard temperature and pressure.

The advance ratio of the rotor for these experiments, based on the rotor angular velocity, reference wind speed and rotor radius, varied from 0 to 0.091.

3.3 TEST CASES AND CONDITIONS

As shown in Table 1, a total of 120 tests were performed. Load measurements were conducted for the first 117 cases. The airwake flow mapping was conducted for only three cases.

Table 1: Summary of the conditions for the test cases

Rotor Loads Measurements					
H/D	W/D	Ship Roll Angle	**Wind Speed**	Presence of Hangar	**Total Cases**
0.3, 0.4, 0.6, 0.8	1.20	0 through 25 in 5 increments	20, 30, 40	**No**	72
0.4	0.9, 1.0	0 through 25 in 5 increments	20, 30, 40	**No**	36
0.3,0.6,0.8	1.0	15	20, 30,40	**No**	9
				Total	117
Airwake Flow Mapping					
0.4	1.20	5	30	**No**	1
0.4	1.20	20	30	Yes, No	2
				Total	3

3.3 (a) AIRWAKE FLOW MAPPING

There was also interest in characterizing the flow over the flight deck for several configurations at roll angles of 5° and 20°. For the latter wind angle, a simple representation of a hangar was included as Zan (2001) [5] has shown that for beam winds, a tightly-wound, squat vortex originates at the intersection of the aft hangar face and flight deck. Viewed from above, this vortex propagates across the flight deck with its axis about 20° to leeward of the flight deck windward edge. While the vortex is below the rotor disk plane, the presence of the vortex could change the flow impinging on the disk plane.

A flow survey using thermal anemometers mapped out the time-averaged and RMS streamwise and vertical velocities in a plane normal to the ship lateral axis. This plane coincided with the rotor axis of rotation. The airwake was measured at 13 vertical positions ranging from 0.1 H/D to 1.4 H/D above the flight deck and 7 streamwise positions that are equally spaced along the width of the flight deck. The flow mapping was done at a H/D ratio of 0.4. The hot-film data were sampled at 1 kHz per channel for 10 seconds. The hot-film data were analysed and produced time histories of the streamwise and vertical velocities from which a time-averaged flow field could be computed. Additionally root-mean-square values for the two velocity components were determined at each location, partly to support definition of recirculation zones, although these data are not reported here.

3.3 (b) ROTOR LOAD TESTS

Measurements of the time-averaged rotor thrust, rolling moment, and pitching moment were made and recorded at six ship roll angles; 0°, 5°, 10°, 15°, 20°, and 25°. The rotor drag and side forces were not measured since, in previous testing conducted by the NRC for Indal, these force components did not produce large enough values on the balance to be measured with confidence. Tests were conducted using scaled wind speeds corresponding to 20, 30, and 40 knots. These wind speeds are representative of those expected in sea states 4, 5, and 6.

4. TEST RESULTS

4.1 AIRWAKE MEASUREMENTS

Figures 6 (a-c) present the time-averaged streamwise velocity, vertical velocity and flow angle contours for the 5° roll angle. The freestream wind direction is from left to right. The nominal wind condition is 32 knots at the reference height. In the Figures, the flight deck outline is presented as a trapezoid, and the disk plane location as a solid line. Streamwise velocities are parallel to the sea surface and vertical are orthogonal to the sea surface. A dashed contour indicates the approximate boundary of recirculating flow (defined as a 33% turbulence intensity). Locations below the dashed line are in the recirculation zone. From the Figures it is clear that the upwind edge of the disk is immersed in accelerated flow that is directed upward. The leeward side of the rotor disk plane is immersed in relatively lower velocity flow which is directed downward. One could expect positive rotor thrust in this case with negative rolling moments. It is clear that significant flow velocity gradients exist across the disk plane, both in terms of magnitude and direction.

For the 20° roll angle, much of the rotor disk lies in the recirculating flow. The vertical velocities through the disk plane are greater for the 20° roll case than for the 5° case suggesting increased rotor leads.

Measurements for the 20° roll case with hangar showed that the vortex emanating from the hangar/flight deck junction has reduced the size of the recirculation zone, thereby increasing the streamwise velocities and decreasing the vertical velocities through the disk plane.

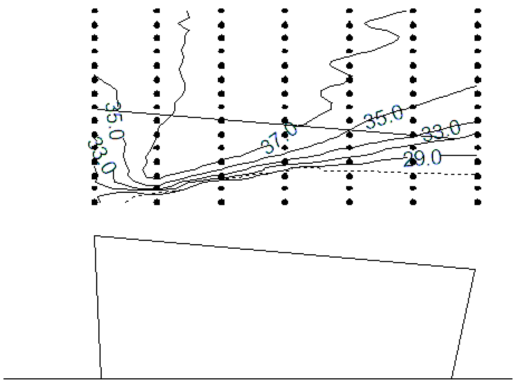

Figure 6 a: Time-averaged streamwise velocity contours for the 5° roll angle

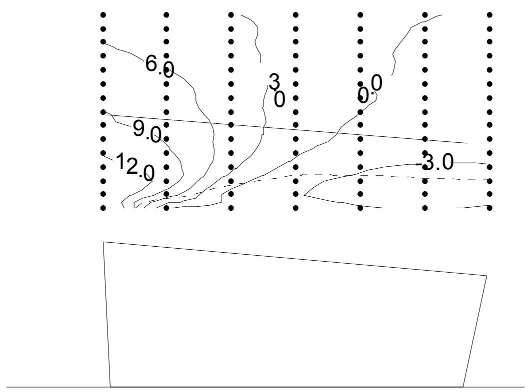

Figure 6 b: Time-averaged vertical velocity contours for the 5° roll angle

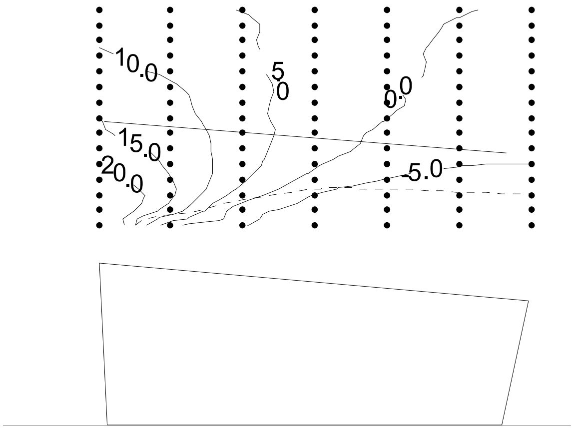

Figure 6 c: Time-averaged flow-angle contours for the 5° roll angle

4.2 ROTOR LOADS - RESULTS AND DISCUSSION

Only the main component of the rotor loads, the thrust, will be addressed in this paper. The thrust component was found to be the most significant load in defining the helicopter securing requirements.

4.2 (a) EFFECT OF ROLL ANGLE ON THE ROTOR THRUST

Measurements of the rotor forces and moments were recorded for all the test cases. The preliminary results showed that the thrust increases with the roll angle up to a roll angle of 15 degrees after which the thrust generally decreases with the increase in the roll angle. As the roll angle increases, part of the rotor disc is immersed in relatively lower velocity flow which is directed downward as was shown in the flow patterns presented in the previous section. When the roll angle exceeds 15 degrees, a large portion of the rotor disc becomes immersed in the separated flow region resulting in relatively lower thrust than that reached at 15 degree roll. However it should be noted that the rate at which the thrust decreases after reaching 15 degrees, is much slower than the rate of increase at lower roll angles.

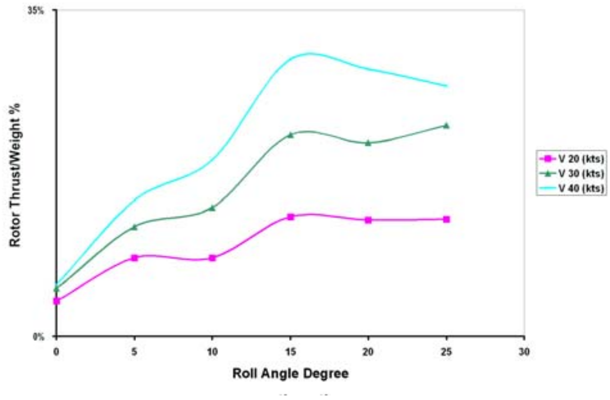

Figure 7: Effect of the roll angle on the rotor thrust

4.2 (b) EFFECT OF THE FLIGHT DECK WIDTH

The results showed that flight-date width had little effect on the thrust for low roll angles with more noticeable effect at higher roll angles 20-25 degrees, as shown in figure 8. However, it should be noted that the variations on the deck width was limited (0.9-1.2 of the rotor diameter) which is the range of interest applicable to frigate/destroyer size ships.

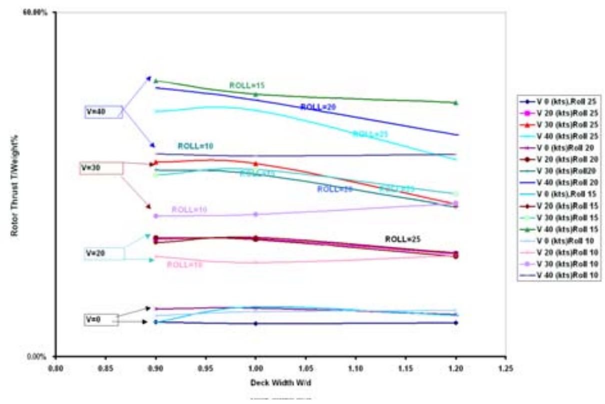

Figure 8: Effect of the deck width on the rotor thrust

4.2 (c) EFFECT OF THE FLIGHT DECK HEIGHT

Opposite to the effect of the deck width, Figure 9 shows that increase in the flight deck height results in increase in the thrust only for lower roll angles (between 5 and 10 degrees). This finding is important because changes in the flight-deck height may result from the heave/pitch motion of the ship. In other words, as the ship heaves significant increase in the thrust may be produced by the rotor, even for relatively low roll angles.

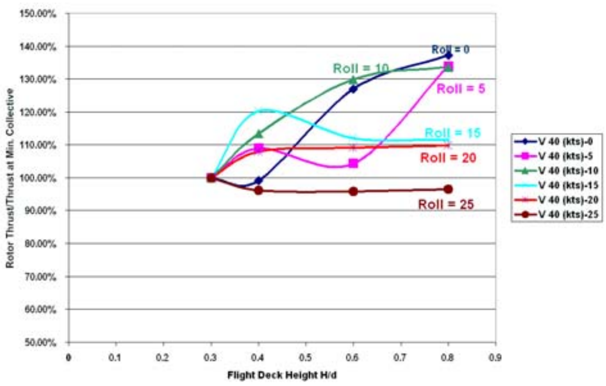

Figure 9: Effect of the deck height on the rotor thrust

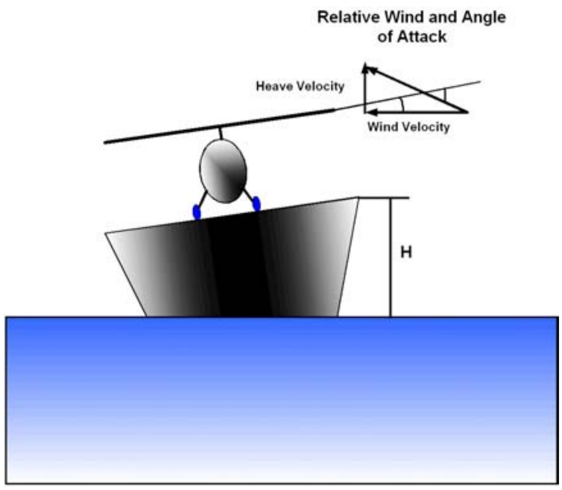

Figure 10: Heave Motion and Angle of Attack

5. DISCUSSION OF THE ROTOR THRUST

Although the tests were conducted for static cases, the effect of the dynamic motion of the deck can be predicted from the results of these tests using a quasi-steady approach. Test results showed that the rotor thrust is affected with the variation in wind velocity, roll angle, flight-deck width and height. The variation in these parameters could result from the ship motion even for the same flight deck configuration. For example, the ship heave displacement changes the flight deck height while the flight-deck velocity changes the angle of attack as shown in Figure 10. Similarly, the apparent angle of attack is dependent not only on the deck angular displacement but also on the rate of deck angular motion. Therefore, the rotor thrust in the time domain could be more accurately estimated if the relevant ship instantaneous motions (displacements and velocities) are included in the calculation. From the test results, it can be seen that establishing a formula to calculate the thrust will be a challenging effort. This is because, as the results of the tests showed, the effect of the some parameters changes depending on the values of others such as the dependence of the effect of the deck width and height on the roll angle. However, developing such formula will be the goal of ITI and DCE in the next phase of their collaboration. Once such formula is developed and verified, it will be used in the dynamic interface models and to calculate more accurately the T factor.

6. CONCLUSIONS

Test results showed that the rotor loads, specifically the thrust, are significant and may not be ignored in estimating the securing requirements of the helicopter on-deck while the rotor is turning at minimum collective. The ship configuration causes the air flow to accelerate vertically over the flight deck and increases the rotor loads. The thrust is dependent on the wind velocity, deck angular motion (displacement and velocity), heave motion (displacement and velocity) and on the configuration of the flight deck. The presence of a hangar has an effect on the flow over the flight deck and requires further investigations to assess its influence.

7. RECOMMENDATION FOR FUTURE WORK

The current investigations showed the need for further testing to include the effect of the dynamic motion of the ship and the effect of the hangar. In addition, comparison with sea trials is necessary to validate conclusions of the current activities.

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