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NOTE

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ABSTRACT

Objective: This study aims at investigating helicopter pilots' strategies to achieve ship deck landing.
Background: Helicopter maritime operations are challenging, especially when it comes to landing on the moving decks of small ships, such as frigates, which can lead to dramatic accidents.
Method: Expert pilots were requested to fly the full ship landing maneuver from approach to touchdown in an immersive simulator. Two sea states (3 and 4 on the Douglas Sea scale) and their resulting deck movements were used. Changes in helicopter altitude were correlated with deck heave movements throughout the maneuvers in order to scrutinize the helicopter-deck coupling. The energy at impact was measured.
Results: The dynamics of helicopter-deck coupling evolved through two phases during the maneuver: Initially, no coupling then, coupling in phase between the helicopter vertical displacements and deck heave displacements. Moreover, the coupling reached higher values within the last 15 m to landing, corresponding to a hover phase and touchdown, and the correlation increased with sea level. This coupling might help in improving pilots' safety since the greater the coupling at touchdown, the lesser the kinetic energy at impact.
Conclusion: Coupling the helicopter vertical displacements with ship heave movements seems to be an efficient strategy to minimize energy at impact. Questions arise on both the rationale and the perceptual invariant behind such behavior and indicate the necessity of further investigation.

Introduction

Landing maneuvers in aeronautics have been extensively studied to understand the nature of the perceptual-motor mechanism used by pilots. Studies have focused on the candidate information usable to visually control the landing maneuver (Galanis et al., 1998) or on the effect of expertise in information pickup (Jacobs et al., 2018). Overall, these studies report a strong visual-motor coupling between the plane's pilots and the runway. However, the question of whether such a perceptual-motor coupling also applies when landing

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a helicopter on a ship's deck remains open. Indeed, helicopter deck landing mainly differs from traditional landing maneuvers with planes on a runway because the ship is sailing on the sea and, more importantly, because its deck is oscillating with the swell. Therefore, the movement of the deck can substantially increase the difficulty of the final approach. Indeed, ship landing becomes particularly challenging for helicopter pilots in high sea states. Substantial efforts aiming at enhancing safety and success during ship helicopter landing are leaded around the world using realistic simulation tools (e.g., JSHIP programme on the NASA Ames Vertical Simulator (VMS), QinetiQ lab activities (formerly DERA) with the Advanced Flight Simulator (AFS)) which proved to be efficient and cost-effective solutions as compared to field studies, especially in Ship-Helicopter Operating Limits (SHOLs) evaluation.

This experiment aims to demonstrate the perceptual nature of helicopter pilots' behavior. A particular point of interest was whether pilots monitored their helicopter's altitude visually so as to couple it with the heave movement of the ship's deck. To explore this, expert helicopter pilots were instructed to land on a ship's deck in virtual reality, wherein the sea state, resulting in realistic deck movements, was selected. The analyses had two successive goals. The first goal aims at identifying whether pilots were perceptually coupled with the heave movement of the ship's deck, by analyzing the correlation between the helicopter's and the deck's altitude during the maneuver. Moreover, since the safety of the landing maneuver relies in part on the minimization of the energy at impact to prevent structural damage on the helicopter and avoid pilots' spinal traumas (Desjardins et al., 1989), the second goal aims at investigating the relationship between the strength of the perceptual coupling at touchdown and the energy at impact.

Method

We analyzed data originally collected to build a human-inspired automatic control model of a helicopter during a simulated ship landing task (Figueira et al., 2015). The motivation for the present article arose when hypothesizing on the role played by ship deck heave on the pilots' behavior. The present manuscript thus focuses on the perceptual basis of pilots' behavior rather than on suitable models to predict it.

Participants

Four experienced operational pilots from the Brazilian Armed Forces participated in the data collection. They had different backgrounds concerning the type of aircraft and operational missions accomplished. Two of them had extensive experience in real maritime environments, while the two others had no prior ship landing experience as shown in Table 2. None of them reported significant experience of ship landing maneuvers in flight simulators.

Experimental Setup

The experiment was run in an immersive fixed-base rotorcraft simulator. Participants sat in the right (pilot) seat of a helicopter cockpit inside a cave simulator composed of three large vertical screens (3.16 m wide × 2.37 m height) perpendicularly arranged and a large horizontal screen, which encompassed 265° of their horizontal and 135° of their vertical fields of view. The virtual scene was projected onto the screens using four identical DLP video-projectors (W1080ST+, BenQ^{TM} Taipei, Taiwan) each having a resolution of 1920 × 1080 pixels and a frame rate of 60 Hz. Participants handled usual helicopter commands: the cyclic stick with their right hand and the collective stick with their left hand and the pedals were used to control the yaw. Physical occlusions were placed in the lower half of the setup, on the cockpit monitors, to restrict the pilots' field of view similarly to the occlusion created by the cockpit of a heavy helicopter as illustrated in Figure 1.

Virtual Environment

The virtual world comprised a skydome above an infinite sea surface animated with realistic and configurable wave motions. A 3D ship model (*Lafayette class* frigate, 3,000 tons) was animated along the 6 degrees of freedom according to the roughness of the sea, wind force and direction according to a frequential model called Response Amplitude Operator (Journée & Massie, 2001; Techet, 2005), built from experimental at-sea measurements of the deck movement of the Lafayette Class frigate and provided by Naval Group. Finally, the simulator reproduced in real time with great detail the flight dynamics of an 11-ton cargo class rotorcraft through the highly realistic Helicopter Overall Simulation Code (Benoit et al., 2000), including detailed models for the various parts of the helicopter (rotor, blades, fuselage) as well as the interactions between them, the influence of external physical variables such as wind turbulences or the airwake when flying close to a ship structure. The airwake is modeled with a spatially non-uniformly distributed mean disturbance

Figure 1. Expert pilot performing an Astern approach. The outside-the-cockpit downward field of view was limited to 14.13° below the eye level. The ground projection also allows the pilot to see partially on his side the scene below the helicopter.

derived from data of wind tunnels obtained with a generic frigate model. The airwake directly affected the helicopter center of gravity.

The helicopter started at a distance of 1 km behind the ship deck position, an altitude of 65 m and a horizontal velocity of 40 knots and zero vertical speed. The ship's forward velocity was maintained at a constant 10 knots on Earth reference. An ideal point of touchdown was located on the flight deck and was represented by white lines. This was the point where the center of the landing target was located and over which the helicopter should maintain a relative hover before landing. A safe touchdown area was defined on the ship's flight deck as being the area where landing would occur without the rotor blade collapsing the hangar roof at the front, nor the helicopter falling off the right, left or rear edges of the deck.

Flights took place in clear visual conditions in a realistic maritime environment. The wind speeds were between 0 and 80 knots (maximal speed reached by wind gust) and directed toward −25° to +25° relative to the ship's longitudinal axis.

Procedure

Before starting, the pilots familiarized themselves with the simulator through 5 to 25 practice trials (see Table 2 for pilots and sea state details). The experiment started when the pilot and the experimenter agreed that the five mission task elements that constitute a successful landing maneuver, and described below, were consistently repeated during this familiarization phase. During the familiarization phase, the Euclidian distance from the deck center at touchdown was equal to 8.32 ± 5.92 m. The five mission task elements that pilots were requested to perform consisted in (i) an approach to the deck at an approximate 3° vertical angle by relying on a Stabilized Glide Slope Indicator System, (ii) a hover near the deck, (iii) a transition flight from that first hover position to a hover position over the deck, (iv) a hover over the deck and finally (v) a vertical descent to touchdown at a quiescent period of the deck.[1] It should be noted that two ship landing approach types, *astern*[2] and *fore/aft*,[3] were tested in this experiment. In order to balance the influence of pilots' experience in real shipboard operations, pilots A and D were required to perform *fore/aft* whereas pilots B and C were required to perform *astern* approach tasks. We did not make the distinction between both approaches in the data analyses.

Independent Variables

The sea state, and thus the resulting deck movements, was manipulated. Two sea states, corresponding to levels 3 and 4 on the Douglas Sea Scale, were simulated. These sea states were featured by wave amplitudes from 0.5 m to 1.25 m and from 1.25 m to 2.5 m, for sea state levels 3 and 4, respectively. This resulted in different ship deck movements in *Calm sea* (RMS = 0.83°, 0.54°, and 0.20°; Peak: ±2.3°, ±1.5°, and ±0.7°) and *Moderate sea* (RMS: 1.60°, 0.85°, and 0.40°; Peak: ±5.0°, ±3.0°, ±1.0° for the roll, pitch, yaw axes, respectively). More specifically, the Response Amplitude Operator model showed that the Lafayette frigate is light enough to be sensitive to the sea state manipulations as described in Table 1.

Table 1. Correspondence between Significant Heave Weight (SHW), computed as the mean wave height (from trough to crest) of the highest third of the waves, and the ship heave amplitudes for each sea state. std stands for standard deviation.

	Waves		Ship heave (in m)
Sea State	Period (in sec.)	SWH (in m)	Mean ± std
Calm Sea	7.5	0.9	2.31 ±.63
Moderate Sea	8.8	1.9	2.35 ± 1.14

Table 2. Helicopter-deck coupling expressed with Spearman's correlation coefficient ρ with respect to the four pilots' experiences (in columns) and sea states (in lines). For each pilot and sea state, the number of trials performed during the familiarization phase and the number of trials analyzed in the experiment are reported. The bottom rows indicate the type of approach performed by each pilot during the experiment and their operational experience. MAD stands for Median Absolute Deviation.

		Pilots				
Sea State	Measures	A	B	C	D	all
Calm Sea	Median	.63	.53	.41	.10	.42
	MAD	.19	.15	.36	.32	.26
	Familiarization	5	7	25	6	43
	Experiment	4	17	5	27	53
Moderate Sea	Median	.57	.69	-	.12	.61
	MAD	.15	.01	-	.41	.15
	Familiarization	*None*	3	1	1	5
	Experiment	34	42	*None*	6	82
Maneuver	Type	*Fore/Aft*	*Astern*	*Astern*	*Fore/Aft*	
Experience	Flight hours	4150	1770	2250	1850	10020
	Deck landings	*None*	180	*None*	130	310

Signal Processing and Dependent Variables

The raw data, recorded by the simulator and used for analyses, are made of the helicopter's positions in 3D and translational speeds measured both at the helicopter's center of gravity and at the ideal point of touchdown on the ship. Our methodology to reveal the strength of the helicopter-ship coupling consisted in investigating the correlation between the vertical positions of the ship's deck and the helicopter. The signal of the helicopter vertical motion used in this correlation process must reflect the frequencies caused by the coupling with the ship, while avoiding taking into account the lowest frequencies, caused by the helicopter descent and the highest frequencies, caused by the noise in the simulator time stamping. For this sake, we identified lowest frequencies caused by the helicopter descent and highest frequencies caused by noise through a Fast Fourier Transform on the original signal of the helicopter vertical motion that revealed two extreme main frequencies: below 0.02 Hz for the descent and above 0.4 Hz for the noise. The helicopter's vertical center of gravity positions were thus processed through a high-pass filter (cutoff frequency: 0.02 Hz), that allowed us to eliminate the lowest frequencies attributed to the helicopter descent frequency, and through a low-pass filter (cutoff frequency: 0.4 Hz), that allowed us to remove the highest frequencies attributed to noise in the simulator time stamping. This 2nd order band-pass filter was applied in both the forward and reverse directions to perform a zero-phase digital filtering on the helicopter's vertical positions. Theoretically, pilots follow the 3° glideslope and are not expected to change their altitude as a function of ship vertical motion as described in previous analysis of the ship landing task (Tušl et al., 2020). The length of this phase remains however unclear. We therefore analyzed the entire approach by splitting the time-series into seven bins, as a function of the relative horizontal distances between the helicopter and the deck. Given that the helicopter's speed tended to decrease on approach, the dimensions of the bins were determined logarithmically with the first one being larger when expressed as relative horizontal distance. This enabled us to balance the number of sample points among the bins. To ensure there wouldn't be any statistical artifact caused by the number of observations among the bins on our dependent variables, we interpolated 500 observations within each bin (shape-preserving interpolation with MATLAB function interp1). A visualization of the signal processing method during a typical trial unfolding is available on Figure S1 as supplemental data.

Dependent variables included Spearman's rank correlation coefficient ρ as a measure of the level of helicopter-ship coupling and the energy at impact. Spearman's rank correlation coefficient ρ was expected to mirror the strength of the helicopter-ship coupling and was computed through the entire approach on each of the seven bins between the vertical positions of the ship at the ideal point of touchdown and the helicopter's filtered center of gravity. The unfolding of the correlation during trial allowed us to distinguish the length of the uncoupled from the coupled part in the approach. The length of these parts in helicopter-deck coupling ρ throughout the seven bins were expressed as a function of the horizontal distance between the helicopter and the deck, the relative altitude (h) between the helicopter and the deck and the Time-To-Contact (TTC) that were computed within each bin and averaged over the sea state environments. TTC was computed by equation 1, where $Drel$ is the relative Euclidean distance between the helicopter and the deck and $Vrel$ (i.e., $Dreldot$) its derivative, the relative speed

$$\mathrm{TTC} = \mathrm{Drel}/\mathrm{Dreldot} = \mathrm{Drel}/\mathrm{Vrel} \tag{1}$$

Energy at impact was computed following the kinetic energy equation 2, where m is the helicopter mass and Vh and Vs are the respective velocities of the helicopter and the ship's deck at touchdown. The structural limit of energy that can be absorbed by a real rotorcraft without damage (cf. US Navy, NATOPS Flight Manual, 2004) is bounded at Vh-Vs = 3.6576 m/sec. Because we normalized this energy by the helicopter's weight, energy results are given only as a function of the relative velocity at impact.

$$\mathrm{Ek} = 0.5\mathrm{m}(\mathrm{Vh} - \mathrm{Vs})^2 \tag{2}$$

We computed precision at landing, measured as the Euclidean distance (in meters) between the actual and the ideal point of touchdown, to ensure that we analyzed only successful maneuvers. Only trials with significant correlation coefficients within the final bin and with an Euclidian distance relative to the deck center at touchdown below 25 m were kept for the rest of the analysis. Altogether, one trial was rejected due to poor precision on landing (Euclidean distance from deck center at touchdown equal to 38.00 m, well above the 4.90 ± 4.56 m landing precision gained on the remaining trials) and 12 trials due to a non-significant correlation level (all performed by the pilot D, landing precision equal to 9.01 ± 3.10 m). The total number of analysed trials was 135 (see Table 2 for pilots and sea state details), comprising not only un-coupled (but significant) and coupled trials but also rough (30 trials for which Ek > structural limitations of the helicopter) and soft landings. This set of data therefore allows investigating how often a coupling strategy resulted in a good landing when considering the energy at impact.

Results

Dynamics of the Helicopter-deck Coupling

To investigate the coupling between the helicopter and the vertical movements of the ship's deck, analyses focused on the evolution of the correlation coefficients between the helicopter and the deck's vertical movements during the maneuver. Table 2 recaps the individual computations of correlation coefficient ρ as a function of sea state. Figure 2 shows the pattern of changes of the interindividual median correlation coefficient ρ during the maneuver as a function of different metrics (i.e., *TTC*, relative altitude of the helicopter with regards to the ship's deck, distance from ship's deck). The dynamics of the coupling were found to develop during the maneuver into two distinct phases. Firstly, the correlation coefficients were close to $\rho = 0$, suggesting that the helicopter's movements were not coupled with the ship's deck movements. Finally, the correlation coefficients quickly increased when the helicopter was close to the deck (below 15 m of horizontal distance) to reach $\rho = 0.61$ in *Moderate sea* and $\rho = 0.42$ in *Calm sea*. This suggests that pilots had phased the helicopter's vertical movement to that of the ship during this final part of the maneuver. During the final part of the landing maneuver, the correlation coefficients increase from the first occurrence of a positive correlation coefficient until they reach a significantly higher value within the final bin (Spearman's ρ equal to 0.42 ± 0.26 and 0.61 ± 0.15 for the *Calm sea* and *Moderate sea* environments, respectively, see Figure 3 for Friedman test of significance and Nemenyi post hoc test).

Besides, the fact that the coupling between the helicopter and deck at the touchdown appears to be stronger in *Moderate sea* than in *Calm sea* (Spearman's ρ equal to 0.61 ±0.15 vs. 0.42 ±0.26), these results also suggests that pilots coupled their helicopter vertical displacements with the deck heave only during the final part of the maneuver, starting from below 85 m to touchdown and reaching a peak from 15 m to touchdown. This coupling during the final part of the maneuver appears to be actively controlled through the collective control in order to phase the helicopter vertical displacements with those of the ship. Indeed, the profile of the collective control signal during a sample trial duration (see figure S1 provided as supplemental data) changes near the hover position to exhibit sharpened oscillations at the frequency of ship motion and phased with the direction of the ship motion. This result is consistent with previous field studies (Berbaum et al., 1991; Minotra & Feigh, 2018) which observed that flight was visually regulated when entering its final phase. Moreover, the stronger coupling observed in *Moderate sea* in comparison to *Calm sea* (see Table 2) was consistent with the need for a stronger perceptual-motor coupling in *Moderate* sea so as to compensate for higher heave movements of the deck and thus minimize the energy at impact.

Functional Nature of the Helicopter-Deck Coupling

Analyses thus secondly focused on the link between the helicopter-deck correlation at hover-touchdown moment and performance indicators so as to investigate the functional nature of the helicopter-deck coupling. Theoretically, as the pilots' safety mainly relies on the minimization of energy at touchdown, being coupled with the deck's vertical oscillations may be an efficient strategy to better control energy at impact. Indeed, the coupling helps to minimize the relative velocity between the two vehicles. In that sense, a strong helicopter-

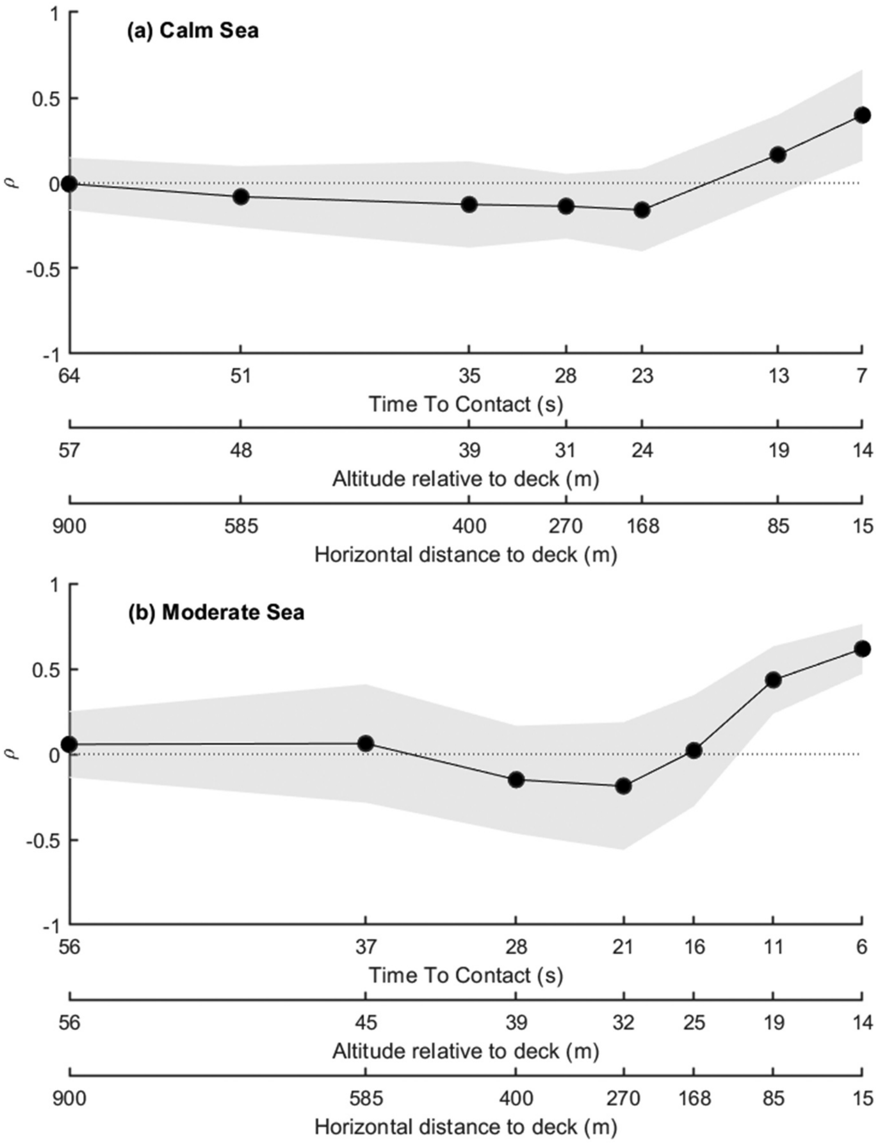

Figure 2. Changes in interindividual median values of Spearman's rank correlation coefficient (ρ) between the helicopter and ship deck's vertical movement during the unfolding of the landing maneuver in *Calm sea* (top) and *Moderate sea* (bottom). ρ values are expressed as a function of the average time-to-contact value during each bin, and as a function of the largest altitude relative to deck and the largest distance relative to deck observed for each bin. Grey areas represent median absolute deviation.

deck coupling could thus be seen as an effective way of the pilots putting the helicopter into good energetic conditions before touching down.[4]

We thus scrutinized the link between the helicopter-deck coupling at touchdown (i.e., correlation coefficient ρ gained in the final bin before touchdown) and the energy at

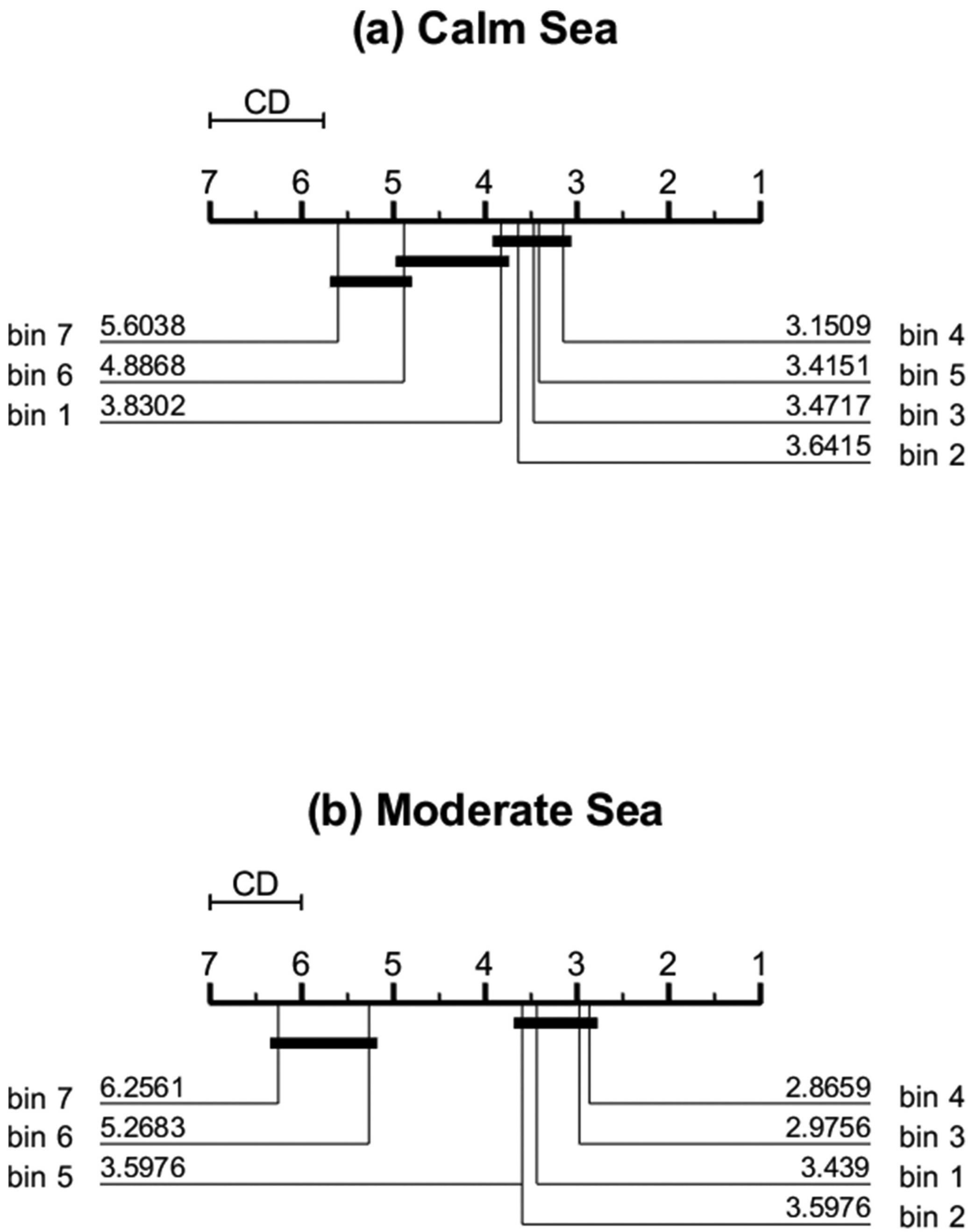

Figure 3. Visualization of the Nemenyi test for *Calm sea* (top graph, Friedman *p*-value <0.01, Nemenyi critical distance = 1.23) and *Moderate sea* conditions (bottom graph, Friedman *p*-value <0.01, Nemenyi critical distance = 0.99). For bins included in horizontal brackets there is no evidence of significant differences at 5% level. Bins that can't be grouped under the same bracket therefore have significantly different correlation scores.

impact. Figure 4 firstly shows that most of the landing maneuvers were performed with an energy at impact inferior to the structural limits of the helicopter. This suggests that pilots

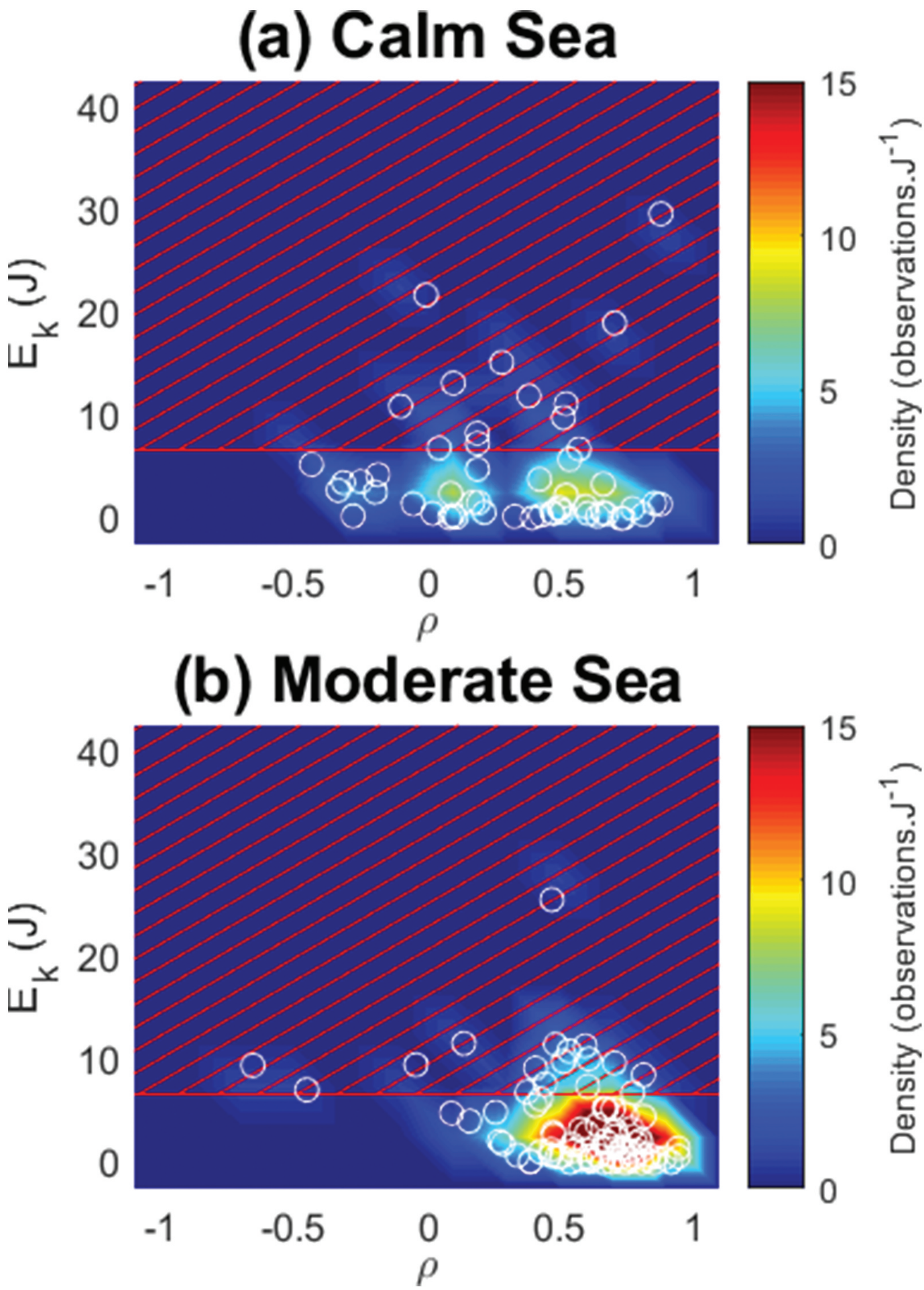

Figure 4. Energy at impact (E_k, in joules) expressed as a function of the Spearman's rank correlation coefficient ρ computed at the touchdown for all trials in the Calm sea and Moderate sea environments. Color temperature is a function of density of observations. The horizontal red line represents the structural limit of energy that can be absorbed by a real rotorcraft (from US Navy, NATOPS Flight Manual, US Navy, 2004) above which (hatched area) the energy at impact is too rough and results in structural degradations.

not only coped with the instruction to minimize the energy at impact but also that their behavior were ecologically valids. Figure 4 also shows that Spearman's rank coefficient ρ at touchdown was distributed in the lower right part of the graph in most of the trials, underlining the strong coupling between the helicopter and deck heave movements reported in the previous section. Moreover, negative, significant correlation between the helicopter-deck coupling at touchdown and energy at impact was found ($\rho = -0.27$, $p < .01$). In other words, the better the helicopter-deck coupling, the lower the energy at impact. A finer analysis revealed that this effect is observed in *Moderate Sea* environments ($\rho = -0.37$, $p < .01$) but not in *Calm sea* environments ($\rho = -0.17$, $p = .21$). Note that we tested real pilots, and among them experts in ship deck landing, who were more able to control the helicopter movement so as to couple with the ship's movement more finely than novices would probably be able to do, thus explaining the lack of low Spearman's rank coefficient at touchdown and weak resulting correlation with the energy at impact. In other words, if novice participants attempted to land, they would probably be unable to pick up information required to synchronize themselves with the deck motion that would in return prevent them to minimize the energy at impact. In this case, we would have observed that un-coupled trials would result in a negative correlation with energy at impact. Such additional data set would result in stronger covariance measures which then result in stronger Spearman coefficients, especially in *Moderate sea* conditions. Nevertheless, these results suggest that the observed coupling during the final part of the landing maneuver plays a functional role, by helping pilots to minimize the energy at impact, allowing them to complete safe landings.

Discussion

In this study, the dynamics of the visual coupling between a helicopter's altitude and ship deck heave movements during a landing maneuver were investigated to understand their functional role. Expert pilots were instructed to perform landing maneuvers in a realistic rotorcraft simulator. The sea environment, generating ship deck heave movements, was adjusted and correlated to changes in the helicopter's altitude.

The analyses of changes in the correlation between helicopter position and vertical deck movements during the maneuver revealed that pilots only coupled their helicopter's altitude with deck movements during the final phase of the maneuver. The dynamics of helicopter-deck coupling developed through two main phases: no initial coupling and finally a phase-locked helicopter-deck coupling. Such a gradual coupling between an agent and its environment is a phenomenon accompanied by a gradual decrease of behavioral variability (also called *functional variability* or *compensatory variability*) that was previously discussed in landing tasks (Grosz et al., 1995). Often, this behavioral adaptation is a signature of expertise. Indeed, functional variability allows for the emergence of a movement that is tailored toward the end goal (touchdown with a minimum energy at impact in our case).

Correlating the helicopter and vertical deck movements at touchdown and the energy at impact secondly provided insight into the functional role of visual coupling between the helicopter and the landing spot on the deck. Consequently, we have shown that, not only was the strength of the coupling at the touchdown higher in *Moderate sea* than in *Calm sea* (i.e., a stronger correlation between the helicopter's changes in altitude and deck heave movements) but also that the strength of the coupling is closely linked to the success or at least the safety of the maneuver. Indeed, a negative correlation was found between the strength of the helicopter-deck coupling at the touchdown and the energy at impact. In other words, the stronger the correlation between helicopter and deck vertical movement before the landing, the lesser the energy at impact. We are suggesting that such a perceptual-motor coupling between the pilots and the vertical movements of the ship's deck approaching touchdown has a functional nature, aiming at minimizing kinetic energy at impact, by nulling the relative speed between helicopter and deck during the hovering phase, and therefore minimizing the total amount of relative energy in the system, before triggering the vertical descent toward touchdown at a quiescent period, for instance. Additionally, the helicopter's vertical movements may have served as exploratory movements designed to enhance the pick-up of the deck's heave pseudo-frequency, that is, the frequency at which the deck is most likely to oscillate. This is in line with the Gibsonian view considering perception as an active process of obtaining information about the surrounding environment and which gave rise to the famous hypothesis that an agent has to move in order to perceive and perceive in order to move (Gibson, 1979).

Application of these results is possible in the design of visual aids for ship landing. Hence, this experiment could be understood as a work domain analysis preceding the Ecological Interface Design (Vicente & Rasmussen, 1990). We indeed evidenced the importance of strong coupling between the helicopter and deck vertical motions from the hover position to succeed in minimizing energy at impact when landing on-sight. Depending on the functional role of such a behavior, several visual aids available from the hover position can be proposed. In the case pilots perform vertical exploratory movements aiming at extracting information about the ship's deck oscillation properties, then visual guidance should facilitate the information pick up by revealing for instance, the future quiescent period favorable for landing. Such a visual guidance would replace the natural coupling strategy and avoid the extra demand induced by helicopter vertical motion on the engine. In case pilots perform vertical movements aiming at putting the helicopter-ship system into favorable conditions for landing (by nulling the relative speed and therefore the total amount of relative energy in the helicopter-ship system before triggering the touchdown phase for instance), then a visual guidance should facilitate the helicopter-ship coupling. The vertical oscillations of the helicopter induced by such a visual guidance might be worth the extra demand it produces.

Further investigations will be needed to reveal the visual information – like Tau (Padfield, 2011) – that guide helicopter's control, to model the architecture of the perceptual-motor mechanism underlying the coupling between pilots and their environment – law of control (Warren, 1988) or affordance-based-model (Fajen, 2007) – as well as the effectiveness of visual guidance to ship's deck landing based on the elicited mechanism.

Notes

1. "In seakeeping terminology, the Quiescent Period is known as the period of calm in rough waters to allow the ship to perform operations such as landing aircraft and unmanned aerial vehicles (UAVs), as well as the entry of landing craft in the basin. Quiescence refers to the interval of time where all ship motions are within acceptable limits to perform a desired activity" (Riola et al., 2013).
2. The astern procedure consists of approaching the ship's deck from the stern along the ship's center line until reaching the hover position over about 10–15 ft above the flight deck before performing a vertical descent to land. This procedure is usually adopted world-wide for

precautionary or emergency landings, given that the helicopter is already in the right profile for emergency procedures.

3. The fore-aft procedure consists of approaching the ship's deck from the stern, along a line to the left or right of the ship's centreline (called fore-aft port or fore-aft starboard procedures, respectively), approximately 1.5 times the diameter of the main rotor at the center of the deck. Then, the helicopter flies side-wards following the "bum-line" horizontal deck marking from the hover alongside right or left position to the hover over about 10–15 ft above the flight deck before performing a vertical descend to land. Since in most cases, the pilot flying is sitting in the right seat, the fore-aft port procedure enables the best visual cues with the ship (Hoencamp, 2015).
4. Good Energetic conditions imply a sufficient velocity at impact to stick on the deck, especially in the case of deck roll at touchdown but acceptable velocity at impact to avoid structural damages on the helicopter (US Navy, NATOPS Flight Manual, US Navy, 2004) and trauma on pilots' spines (Desjardins et al., 1989).

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Disclosure Statement

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