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# On the functional nature of perceptual-motor coupling during ship deck landing maneuvers

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**Abstract**
*The coupling between the heave movement of the ship deck and the altitude of helicopter was investigated during ship landing maneuver performed by expert pilots in an immersive simulator. The dynamics of the coupling was found to evolve during the unfolding of the maneuver : pilots firstly synchronize the helicopter's movement with the ship's one, and secondly adjust the phase between helicopter and deck movement during the final part of the maneuver. This coupling might help in improving pilots safety since the more the coupling at the touchdown, the lesser the kinematic energy at impact. Results are discussed from a Gibsonian perspective and emphasizes on the role of motion in perception for goal aimed behavior. This preliminary investigation bRough fruitful insights into possible descriptions of ship landing complexity and related interface design.*

**Keywords:** Ship deck landing ; Information-Movement coupling ; Visual Guidance ; Helicopter ; Virtual Reality ; CAVE

## 1. Introduction

Landing maneuver in aeronautics have been extensively studied to understand the nature of perceptual-motor mechanism used by pilots. Studies have focused on the candidate information usable to visually control the landing maneuver [GJB98] or on the effect of expertise in information pickup [JMCM18]. In overall, these studies report a strong visual-motor coupling between the plane's pilots and the runway. Whether such a perceptual-motor coupling also apply when landing with an helicopter on the deck of a ship remains open. Indeed, helicopter deck landing mainly differs from traditional landing maneuvers with planes on ground because the ship sails on the sea and more importantly because its deck oscillates with the swell. Therefore, the movement of the deck can substantially increase the difficulty of the final approach. In addition, ship landing becomes particularly challenging for helicopter pilots when pilots fly in an unpredictable environment (e.g., turbulent airwake due to superstructure interactions, random ship deck oscillations) with impoverished visual cues (at night operations, fog, no landmarks on sea,. . .[Bes06]). As a result, pilots can be overloaded, which sometimes leads to dramatic accidents. Overall, 80% of ship landing accidents imply human mistakes [Her10].

Task analysis has provided, for two decades, insight about pilots' habits in picking up cues and regulating landing maneuver [BKH91, MF17, MF18]. Such methodologies are relevant to provide insight about available, relevant and used perceptual-motor variables when landing. However, perceptual-motor processes may not reach the pilots' awareness and more finely grained experimental methods should be complementary used. Virtual reality setups, allowing researchers to specifically and independently manipulate optical variables, are more accurate than task analysis in tracking perceptual information picked up when landing [ML81, LW91, LL91, TLK*91, JMCM18].

This experiment aims at evidencing the perceptual nature of helicopter pilots' behavior. We especially wonder whether pilots were perceptually coupled with the heave movement of the ship's deck. For this sake, expert helicopter pilots were instructed to land on a ship deck in virtual reality. The sea state, and resulting deck movements, was manipulated. The purpose of analyses followed two successive goals. We firstly wonder whether pilots were perceptually coupled with the heave movement of the ship's deck by analyzing the correlation between helicopter and deck's altitude during the maneuver. Secondly, since the safety of the landing maneuver relies on the minimization of the energy at impact, we investigated the relationship between the strength of the perceptual coupling at the touchdown and the energy at impact.

## 2. Method

### 2.1. Participants

Simulated flight data, previously collected as part of José Marcio PEREIRA FIGUEIRA's PhD work [Fig17] were re-analyzed. Four experienced operational pilots from Brazilian Armed Forces participated to the data collection. They have different background concerning the type of aircraft and operational mission already accomplished. Two of them had extensive experience in real maritime environments, while the two others had no prior ship landing experience as shown on table 2. None of them reported previous significant experience in simulator flight.

### 2.2. Experimental setup

The experiment was run in the *PycsHel* fixed-base rotorcraft simulator of the Department of Information Processing and Systems installed at ONERA Salon-de-Provence center (Figure 1).

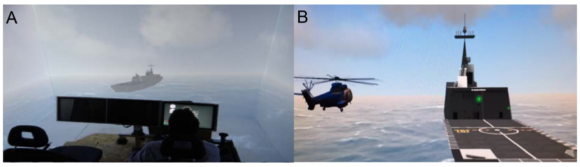


**Figure 1 :** *The fixed-base PycsHel helicopter simulator is based on a CAVE configuration. (A) A set of three LCD monitors in front of the users are reproducing the occlusion of the pilot's vertical field of view like in the cockpit of an actual rotorcraft. User can still continue picking up information on both sides of the cockpit. (B) The visual scene is enslaved to the virtual helicopter displacement and is displayed onto three vertical screens perpendicularly arranged and on a horizontal screen on the floor in a CAVE fashion.*

Participants sat in the right (pilot) seat of the cockpit of an helicopter cockpit in front of 3 vertical large screens (3.16 m wide × 2.37 m height) perpendicularly arranged and an horizontal large screen, which encompassed 265° of their horizontal and 135° of their vertical field of view. The virtual scene was projected onto the screens using four identical DLP video-projectors (W1080ST+, BenQ$^{\text{TM}}$, 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 of the aircraft with their left hand whereas the pedals was used for the control of the movement around the yaw (vertical) axis. Physical occlusion (opaque screen) were placed in the lower half of the setup in order to restrict the field of view of pilots in a similar way a heavy helicopter cockpit would do.

### 2.3. Virtual environment

The virtual world comprised a sky dome above an infinite sea surface animated with realistic and configurable wave motion. A 3D ship model (*frigate*) was animated along the 6 degrees of freedom (3 translations and 3 rotations) according to the roughness of the sea. Finally, the helicopter motion reproduces with great detail the flight dynamics of a 11-ton, cargo class rotorcraft, including the aerological wake perturbations when flying close to the ship structure.

The helicopter started at a distance of 1000 m behind the ship deck position, at an altitude equal to 55 m and at an horizontal velocity of 40 knots without vertical speed. The ship translational forward velocity was maintained constant at 10 knots on Earth reference. An ideal point of touchdown was located on the flight deck at ($X_s = 12.4$ m, $Y_s = 0.9$ m) on ship's reference and was represented by white lines drawn on the deck. 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 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 of the deck at the right, left and back edges of the deck. Any landing outside this safe area was considered to be failed and is excluded from the analysis.

Flights took place in clear visual conditions in realistic maritime environment. Weather conditions were heavy wind conditions varying from 0 to 80 knots in speed and -25° to +25° in direction relative to ship longitudinal axis.

### 2.4. Procedure

Practice trials were firstly given to pilots to allow them familiarizing themselves with the simulator. The experiment started when valid flights could be consistently repeated during this phase. Pilots were requested to approach the deck with about 3° angle, hover near the deck, perform a transition from that first hover position to a hover position over the deck, hover over the deck and finally perform the touchdown. It should be noted that two common approach types, *eastern* and *fore/aft*, were tested in this experiment but we did not make the distinction between them in our study.

### 2.5. Independent variables

The sea state, and resulting deck movements, were manipulated. Two sea state levels (called *Calm sea* and *Rough sea*) and corresponding to level 3 and 4 on the Douglas Sea scale were simulated. These sea states were featured by wave amplitudes comprised between 0.5 m to 1.25 m and 1.25 m to 2.5 m respectively. This resulted in different ship deck movements defined as *Calm sea* ($RMS = 0.83$, 0.54 and 0.20° ; Peak : ±2.3, ±1.5 and ±0.7°) and *Rough sea* ($RMS$ : 1.60, 0.85 and 0.40° ; Peak : *Roll* = ±5.0, ±3.0, ±1.0° for the Roll, Pitch, Yaw axes, respectively).

### 2.6. Signal processing and Dependent variables

The raw data recorded by the simulator and used for analyses are 3D positions, translational and rotational speeds measured at the helicopter's center of gravity and at the ideal point of touchdown on the ship. The time-series were then split into 19 bins, as a function of the relative horizontal distances between the helicopter and the deck. Given that the helicopter speed tended to slow down along the flight, bins were chosen logarithmic with the first one being larger in terms of horizontal relative distance. This enable to balance the number of sample points among bins. To ensure there wouldn't be any artifact of the number of observations among bins on our dependent variables, we interpolated 500 observations within each bin (Shape preserving interpolation with MATLAB function `interp1()`).

Time-to-contact (TTC), relative distance to deck along the X (depth) axis and relative altitude to deck computed within each bin and averaged over Sea States environments.

Dependent variables included precision at landing, Spearman's rank correlation coefficient $\rho$ as a measure of the helicopter-ship coupling level and energy at impact. Precision at landing was measured as the euclidean distance (expressed in meters) between the actual and ideal point of touchdown. Energy at impact (expressed in J) was computed given the kinetic energy equation 1, where $m$ is the helicopter mass and $\vec{v}$ and $\vec{v}_s$ are the respective velocities of the helicopter and the ship deck at touchdown. Finally, since data are not normally distributed, the strength of the helicopter-ship coupling was given by Spearman's rank correlation coefficient $\rho$ and computed on each of the 19 bins between the vertical positions of the ship at ideal point of touchdown and filtered helicopter gravity center. In order to get rid of the "descent" trend along the approach, helicopter gravity center vertical positions were filtered with a high-pass filter (cut-off frequency : 0.02Hz) and a low-pass filter (cut-off frequency : 0.4Hz) to remove the noise. This $1^{st}$ order band-pass filter was applied in both the forward and reverse directions to perform a zero-phase digital filtering on helicopter vertical positions.

$$E_k = \frac{1}{2} m(\vec{v} - \vec{v}_s)^2 \quad (1)$$

Only trials with significant correlation coefficients within the final bin and with a precision at landing below 25 m are kept for the rest of the analysis. Altogether 26 trials are rejected due to poor precision at landing (25 trials in *Calm sea* and 1 trial on *Rough sea*) and 14 trials due to non-significant correlation level (9 trials in *Calm sea* and 5 trials in *Rough sea*).

## 3. Results

### 3.1. Dynamics of the Helicopter-Deck coupling

In order to investigate the coupling between the helicopter and the ship's deck movements, analyses firstly focused on the evolution of correlation coefficient between the helicopter and the deck vertical movements during the unfolding of the maneuver. Figure 2 shows the pattern of changes in the interindividual average correlation coefficient during the unfolding of the maneuver as a function of different metrics (i.e., time-to-contact, relative altitude of the helicopter with regards to the ship's deck, distance from ship's deck). The dynamics of the coupling was found to evolve during the unfolding of the maneuver into three phases. Firstly, correlation coefficient evolved around 0, suggesting that helicopter movements were not coupled with the ship's deck movements. Secondly, correlation coefficient narrowed -0.5. This suggest that pilots started to move the helicopter altitude at a frequency close to the deck heave frequency but not in phase. Finally, the correlation coefficient quickly increased to reach 0.75. This suggests that pilots phased the helicopter's movement with the ship's one during this final part of the maneuver. The occurrence of the phase (i.e., first occurrence of positive correlation coefficient) appears in the final phase of the landing maneuver (see table 1 for an equivalence of events between variables). During the final part of the landing maneuver, the correlation coefficients increases from the first occurrence of positive correlation coefficient up to reaching a maximum within the two final bins (Spearman's $\rho$ equal to $0.33 \pm 0.22$ and $0.63 \pm 0.12$ for the *Calm sea* and *Rough sea* environments, respectively). Hence, the coupling between the helicopter and deck at the touchdown appears to be stronger in *Rough sea* than in *Calm sea* ($0.63 \pm 0.12$ vs. $0.33 \pm 0.22$).

| Coupling events | 1st $\rho$ >0 | | Maximum $\rho$ | |
|---|---|---|---|---|
| Sea states | *Calm sea* | *Rough sea* | *Calm sea* | *Rough sea* |
| TTC (in sec.) | 13.65 | 13.68 | 8.64 | 8.03 |
| Altitude (in m) | 21.86 | 24.33 | 19.32 | 19.20m |
| Distance (in m) | 47.30 | 80.93 | 17.84 | 13.07 |
| Bin | 17±1 | 15±2 | 19 | 19 |

**Table 1 :** *Interindividual average of the occurrences of the coupling events (i.e., coupling without phase and phased coupling) as a function of representatives variables (TTC, Relative altitude, relative horizontal distance and bins).*

The gradual increase of coefficient correlating from a hundred meters to ship deck and below 30 meters altitude until touchdown suggests that pilots phased the helicopter's vertical movement to the ship's deck

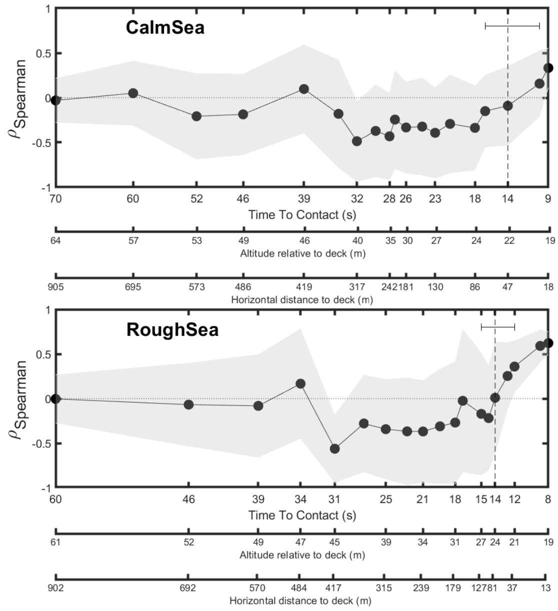


**Figure 2 :** *Changes in interindividual median of Spearman's rank correlation coefficient ρ between the helicopter and ship's deck vertical movement during the unfolding of the landing maneuver expressed as a function of time-to-contact, relative altitude and distance in Calm sea (top) and Rough sea (bottom). Grey areas represent Median Absolute Deviation).*

vertical oscillations during the final phase, hover and touchdown of the approach. This result is consistent with previous field studies [BKH91, MF18] who observed that flight was visually regulated when entering this final phase. Moreover, the stronger coupling observed in *Rough sea* than in *Calm sea* was consistent with the need of a stronger perceptual-motor coupling in rough sea so as to compensate for higher heave movements of the deck in order to minimize the energy at impact. However, it is worth noting that some participants of other studies [PWT*16], confirmed by verbal reports we gained from expert pilots, claim that deck's movements are supposed to be ignored during this final phase. In addition, the stronger coupling in *Rough sea* than in *Calm sea* might be an artifact of the correlation methods. Indeed, while the frequency of the waves were constant across sea state environments, the larger waves amplitude may have produced additional data samples which may result in an increase of the correlation. Thus, one can wonder the functional roots of the observed visual coupling between the helicopter and deck heave movements.

### 3.2. Functional nature of the Helicopter-Deck coupling

Analyses thus secondly focused on the link between the helicopter-deck correlation at the touchdown and performance indicators to investigate the functional nature of the helicopter-deck coupling. Theoretically, as the pilots safety mainly rely on the minimization of energy at impact during the touchdown, being coupled with the deck's vertical oscillations may be an efficient strategy to better control energy at impact. The coupling indeed allows to cancel out the relative velocity between both vehicle and results in a minimal kinetic energy at impact. In that sense, the helicopter-deck coupling could thus be seen as an effective way to put pilots into good energetic conditions before triggering the touchdown.

We thus scrutinized the link between the helicopter-deck coupling at the touchdown (i.e., coefficient correlation gained in the final bin before touchdown) and the energy at impact. The figure 3 shows that Spearman's rank coefficient $\rho$ at touchdown were distributed in the lower right part of the graph in most of the trials, underlining the strong coupling between the helicopter and deck heave movement reported in the previous section. Moreover, a negative, significant correlations between the helicopter-deck coupling at the touchdown and energy at impact was found ($\rho = -0.25$, $p = 0.02$ and $\rho = -0.28$, $p < 0.01$, for *Calm sea* and *Rough sea* environments, respectively). In other words, the better the helicopter-deck coupling, the lower the energy at impact. Note that we tested expert pilots, that are more disposed to be coupled with the ship's movement than novices, explaining thus the lack of low Spearman's rank coefficient $\rho$ at touchdown and weak resulting correlation with the energy at impact (i.e., the dataset might lack of "*un-coupled*" trials to observe strong correlations). This results however suggest that the observed coupling during the final part of the landing maneuver may play a functional role, by helping pilots to minimize the energy at impact, allowing them to complete a safe landing.

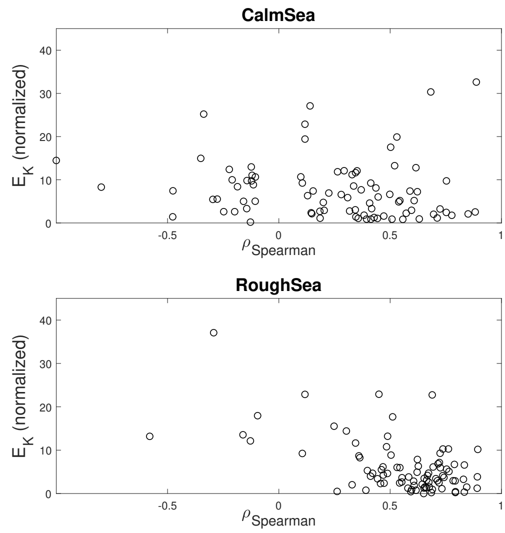


**Figure 3 :** *Energy at impact expressed as a function of the Spearman's rank correlation coefficient ρ computed at the touchdown for all trials in the Calm sea and Rough sea environments.*

## 4. Discussion

In this study, the visual coupling between helicopter and deck ship movements during a landing maneuver was investigated. Expert pilots were instructed to perform landing maneuver in a realistic rotorcraft simulator. The sea environments, inducing ship deck heave movements was the sole variable manipulated. The assumption that a visual coupling should exist and have a functional role is consistent with the success and safety of the landing maneuver.

### 4.1. Insight about perceptual-motor process

The analyses of changes of the correlation between helicopter-deck vertical's movement during the unfolding of the maneuver firstly revealed that deck movement are taken into account only during the final part of the maneuver. More precisely, the dynamics of helicopter-deck coupling shows three phases : lack of coupling at the beginning of the trial, coupling between the helicopter and deck but lack of phase between both displacement and finally phased helicopter-deck coupling. Such a gradual coupling between agent and their environment is a well know phenomenon in Human Movement Sciences. For instance, a gradual decrease of behavioral variability (also called *functional variability* or *compensatory variability*) was previously reported in various sport tasks (decrease of body orientation in somersault as approaching the ground [?], continuous decrease in the temporal variability of the bat direction during a forehand drive in tennis table [BHWW91], increases of the directional variability of the putter head during the swing with the length of the putt [SK10]. Often, this behavioral adaptation is a signature of expertise. Functional variability allows for the emergence of a movement which is tailored towards the end goal (touchdown with a minimum energy at impact), explaining the numerous evidence of late information pickup ([VLWSW15] or even [dOOB06]).
In addition, we evidenced that not only the strength of the coupling at the touchdown was higher in *Rough sea* than in *Calm sea* but also that the strength of the coupling is tiny linked to the success of the maneuver. Indeed, a negative correlation was found between the strength of the coupling at the touchdown and the energy at impact. We argue that such a perceptual-motor coupling between the pilots and ship's desk around the touchdown have a functional nature, aiming at minimizing the kinematic energy at impact. Additionally, the helicopter vertical movements may have serve 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 Gibsonian's view considering perception as an active process of obtaining information about the surrounding environment [Gib66] and that gave rise to the famous formula that agent have to move in order to perceive and perceive in order to move [Gib79]. The evidence of a perceptual-motor coupling between pilots and their environment does not reveal the kind of mechanism. It remains to investigate whether a law of control [War88] or affordance-based-model [Faj07] architectures better account for the pilots perceptual-motor coupling.

### 4.2. Implication for the design of visual assistance

As part of a PhD program funded by DGA (France's defence procurement agency) and ONERA (the French Aerospace lab), this preliminary investigation aims at laying the behavioral foundations for designing visual augmentation to assist helicopter pilots to land on ship deck. This long-term objective would participate to the decrease of pilots' workload and risks of accident as well as improving landing performances. Designing interface for crew can be challenging especially when complex work environments, such as maritime environments, are considered. Given the characteristics of both the work environment and the task, we think an ecological interface, displayed as a visual augmentation, could be an appropriate solution. First and foremost, because it has been shown that visual augmentations (in Head-Up Displays and Head-mounted Displays) yield to significant improvements in terms of pilots' workload and performance for inshore maneuvers, especially in degraded visual conditions [SRP*18, Vie17]. Then, an ecological interface seems appropriate because it applies to complex and unpredictable work environments [VR90]. In addition, it has been proved that an ecological interface is an insightful approach in the case of control tasks such as manual aircraft piloting [Ame]. Finally, from a pragmatic point of view, an *ecological interface* would enable flying in anticipation rather than in reaction, which is preferred by pilots but not always possible [Her10, MF18].

The results of this experiment may have implication in the design of visual assistance dedicated to the improvement of pilots' performance and safety. The implication might firstly concern the informational content of the visual assistance. Here, we evidenced that the better the helicopter-deck coupling, the lesser the energy at impact. Therefore, a visual assistance aiming at improving pilots' safety should help pilots to synchronize the helicopter heave movements to those of the deck, allowing them to improve their capability to minimize the energy at impact. Moreover, since the lower coupling at the touchdown in the *Calm sea* environment regarding to the *Rough sea* one was interpreted as a lesser need of a stronger perceptual-motor coupling to compensate for small heave movements of the deck, we suggest that the visual assistance should be available only in difficult conditions, avoiding thus unnecessary additional information in *Calm sea* environment.
The implication might secondly concern the timing at which the visual assistance is provided. Indeed, the

gradual coupling between the helicopter and deck during the final part of the landing maneuver suggests that a visual assistance is mainly relevant during the final part of the maneuver. In the case of commercial airplane landing, an adaptive HUD, displaying information specific to the currently flown phase, had a positive effect on crew workload and performances [RL16]. Pilots would have access to the information they need at the moment they need it which should decrease workload and time delays related to search for information. Identifying the timing at which information is displayed is relevant in that extend.

## 5. Conclusion

From a theoretical point of view, our results emphasizes on the role of motion in perception for goal aimed behavior. From an applied point of view, our approach, consisting in evidencing the perceptual root of helicopter pilots' behavior so as to understand their potential need for a performance improvement aimed visual assistance echoes to the Vincente claims : "*Perhaps, understanding how perception of the natural environment takes place can lead to insights into how to design effective interfaces for complex work domains.*"[VR90]

## Références

[Ame] Amelink M. H. J. : Visual control augmentation by presenting energy management information in the primary flight display. 161.

[Bes06] Best C. : The Influence of Ship Deck-Edge Lighting on Perception of Position and Movement During Helicopter Recovery. Tech. Rep. DSTO-TR-1906, Defence Science and Technology Organisation Victoria (Australia) Plateform Sciences Lab, juillet 2006.

[BHWW91] Bootsma R., Houbiers M., Whiting H., Wieringen P. : Acquiring an attacking forehand drive : The effects of static and dynamic environmental conditions. Research quarterly for exercise and sport. Vol. 62 (10 1991), 276–84.

[BKH91] Berbaum K., Kennedy R., Hettinger L. : Visual tasks in helicopter shipboard landing. Applied Ergonomics. Vol. 22, Num. 4 (août 1991), 231–239.

[dOOB06] de Oliveira R., Oudejans R., Beek P. : Late information pick-up is preferred in basketball jump shooting. Journal of sports sciences. Vol. 24 (10 2006), 933–40.

[Faj07] Fajen B. R. : Affordance-Based Control of Visually Guided Action. Ecological Psychology. Vol. 19, Num. 4 (septembre 2007), 383–410.

[Fig17] Figueira J. M. P. : The use of offline simulation tools to estimate Ship-Helicopter Operating Limitations. (Utilisation d'outils de simulation pour estimer les limites d'exploitation des hélicoptères). PhD thesis, Aix-Marseille University, France, 2017.

[Gib66] Gibson J. J. : The Senses Considered as Perceptual Systems. Houghton Mifflin, 1966.

[Gib79] Gibson J. J. : The Ecological Approach to Visual Perception. Houghton Mifflin, 1979.

[GJB98] Galanis G., Jennings A., Beckett P. : A mathematical model of glide-slope perception in the visual approach to landing. The International Journal of Aviation Psychology. Vol. 8, Num. 2 (1998), 83–101.

[Her10] Herry B. : L'appontage dans la marine française : une approche opérationnelle. Rapport Technique RT 1/16616 DAAP, ONERA, Département aérodynamique appliquée, juillet 2010.

[JMCM18] Jacobs D., Morice A. H. P., Camachon C., Montagne G. : Eye position affects flight altitude in visual approach to landing independent of level of expertise of pilot. PLoS ONE. Vol. 13, Num. 5 (mai 2018), e0197585.

[LL91] Lintern G., Liu Y.-T. : Explicit and implicit horizons for simulated landing approaches. Human factors. Vol. 33, Num. 4 (1991), 401–417.

[LW91] Lintern G., Walker M. B. : Scene content and runway breadth effects on simulated landing approaches. The International Journal of Aviation Psychology. Vol. 1, Num. 2 (1991), 117–132.

[MF17] Minotra D., Feigh K. : Eliciting knowledge from helicopter pilots : Recommendations for revising the acta method for helicopter landing tasks. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting (2017), vol. 61, SAGE Publications Sage CA : Los Angeles, CA, pp. 242–246.

[MF18] Minotra D., Feigh K. M. : Studying Pilot Cognition in Ship-Based Helicopter Landing Maneuvers. In Proceedings of the American Helicopter Society International, 74th Annual Forum (Phoenix, Arizona, USA, 2018), vol. 3, AHS International, Inc, pp. 1560–1572.

[ML81] Mertens H. W., Lewis M. F. : Effect of different runway size on pilot performance during simulated night landing approaches. Tech. rep., FEDERAL AVIATION ADMINISTRATION WASHINGTON DC OFFICE OF AVIATION MEDICINE, 1981.

[PWT*16] Pritchard J. A., Wallace R. D., Tritschler J. K., O'Connor J. C., Arteche D. R. : Characterization of Pilot Strategy for Simulated Shipboard Approaches with Realistic Ship Motion. 17.

[RL16] Richards D., Lamb P. : Functional Symbology - Evaluation of task-specific Head-Up Display information for use on a commercial flight deck. In AIAA Modeling and Simulation Technologies

Conference (Washington, D.C., juin 2016), American Institute of Aeronautics and Astronautics.

[SK10] Sim M., Kim J. : Differences between experts and novices in kinematics and accuracy of golf putting. Human movement science. Vol. 29 (12 2010), 932–46.

[SRP*18] Stanton N. A., Roberts A. P., Plant K. L., Allison C. K., Harvey C. : Head-up displays assist helicopter pilots landing in degraded visual environments. Theoretical Issues in Ergonomics Science. Vol. 19, Num. 5 (septembre 2018), 513–529.

[TLK*91] Taylor H. L., Lintern G., Koonce J. M., Kaiser R. H., Morrison G. A. : Simulator scene detail and visual augmentation guidance in landing training for beginning pilots. SAE transactions (1991), 2337–2345.

[Vie17] Viertler F. X. : Visual Augmentation for Rotorcraft Pilots in Degraded Visual Environment. PhD thesis, Technischen Universität München, 2017.

[VLWSW15] Vine S., Lee D., Walters-Symons R., Wilson M. : An occlusion paradigm to assess the importance of the timing of the quiet eye fixation. European Journal of Sport Science. Vol. 17 (08 2015), 1–8.

[VR90] Vicente K. J., Rasmussen J. : The ecology of human-machine systems ii : Mediating'direct perception'in complex work domains. Ecological psychology. Vol. 2, Num. 3 (1990), 207–249.

[War88] Warren W. H. : Chapter 14 Action Modes and Laws of Control for the Visual Guidance Of Action. In Advances in Psychology, Onno G. Meijer and Klaus Roth, (Ed.), vol. Volume 50 de Complex Movement Behaviour 'The' Motor-action controversy. North-Holland, 1988, pp. 339–379.

| | | Pilots | | | | |
|---|---|---|---|---|---|---|
| Sea State | Measures | A | B | C | D | all |
| | Median | .29 | .56 | .19 | .20 | .33 |
| *Calm sea* | MAD | .40 | .16 | .31 | .24 | .22 |
| | Observations | 8 | 20 | 27 | 31 | 86 |
| | Median | .55 | .67 | - | .09 | .63 |
| *Rough sea* | MAD | .11 | .07 | - | .32 | .12 |
| | Observations | 33 | 43 | None | 6 | 83 |
| Maneuver | Type | *fore/alt* | *Eastern* | *Eastern* | *fore/alt* | |
| Experience | flight hours | 4150 | 1770 | 2250 | 1850 | 10020 |
| | Deck Landings | None | 180 | None | 130 | 310 |

**Table 2 :** *Helicopter-Deck coupling with respect to the pilots' experiences. The bottom raw indicates the operational experience of pilots.*