

# Relevant Aspects of Helicopter-Ship Operations

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Within the Royal Netherlands Navy (RNLN) a literature review was done to determine the relevant operating aspects of the Westland Lynx helicopter from ship decks. The results of this review were thereafter presented to RNLN pilots in order to determine the relevance of these aspects by active fleet pilots. The most important aspects affecting helicopter-ship operation were mass of the helicopter, roll motion of the ship, the disturbances in airwake by the ships superstructure, operating in day or night conditions and the relative wind. It also followed that in order to reduce time and costs of the helicopter-ship qualification process a “one helicopter-all ships” concept would be very advantage. In this concept a Ship Helicopter Operational Limitation (SHOL) would not anymore be determined for each specific helicopter-ship combination individually, but only for a specific helicopter type and then used for all type of ships. Further research is planned to determine the feasibility of the “one helicopter-all ships” concept.



Figure 1: Westland Lynx on a Landing Platform Dock (LPD)

## 1 Introduction

Helicopter operations from ship decks can be very demanding for the pilot which may result in a considerable increase of pilot workload. Within the Royal Netherlands Navy (RNLN) a review was performed to

determine the relevant aspects for operating Westland Lynx helicopters from ship decks as shown in Figure 1. The results from the review were thereafter presented to RNLN helicopter pilots in a questionnaire to assess their opinion of the relevance of different aspects in their daily

routine. In order to increase safety during helicopter-ship operations it might be helpful for the pilots to know what kind of interaction they could expect with the ship. But also the crew of the ship could adjust the course and speed of the ship to produce favourable relative wind conditions for take-off and landing, or the ship designers could design the superstructure in such a way to produce minimal disturbances for helicopter operations. Relevant aspects for proper helicopter operations from ship decks in a maritime environment which resulted from the review are discussed. It is furthermore emphasized that research should be done to reduce the time and costs of the SHOL qualification process.

## 2 Relevant Aspects

For the questionnaire where from the pool of pilots within the RNLN, 25 pilots selected and 16 pilots replied. The selected pilots were only pilots with recent maritime flying experience. All the pilots were asked to answer the questions based on their experience with the Westland Lynx helicopter and the different type of ships. The questionnaire for RNLN pilots had two sections. In the first section the pilots were asked to give a rating on a five-point scale (from very relevant to not relevant) on various aspects of helicopter operations in a maritime environment. In the second section the pilots were asked to answer twenty questions related to maritime helicopter operations in order to support the conclusions from the first section.

The relevant aspects for helicopter-ship operations which resulted from the literature review and questionnaire could be divided into three main categories (in which the environmental conditions were included). The results from the questionnaire are shown in tables and discussed in the appropriate main paragraphs.

- **Helicopter**, mainly describing technical limitations from the

helicopter when operating in a maritime environment.

- **Ship**, mainly describing relevant aspects when operating in the vicinity of a flight deck and could be sub-divided into ship motion and ship airwake effects.
- **Human Factors**, mainly describing limitations by the aircrew and the ship's crew.

### 2.1 *Relevant Aspect 1: Helicopter*

A deck landing requires some tracking of a moving ship deck both in rolling motion about the longitudinal axis and in heave motion on the vertical axis, which in combination with disturbances in the airwake from the superstructure of the ship places heavy demands on the aircraft response. Sometimes the pitch or roll attitude in hover of the helicopter is limiting the pilot's view on the flight deck. The main aspects in this category were mass of the helicopter, engine power margins and pedal margin as shown in decreasing relevance in Table 1.

The mass of the helicopter and the engine power margins were strongly related to each other and particularly important during low relative wind speeds which demands a lot of power required [Figure 2] and/ or strong downdrafts on the leeward side of the ship superstructure as discussed in paragraph 2.3. The engine power margins and yaw control margin in low relative wind speeds could be too small to counteract adequately a certain amount of motion from the flight deck preventing the helicopter to land. For the Westland Lynx helicopter with a counter-clockwise rotating main rotor the left pedal margins were important, as the tail rotor is for some green relative winds (from starboard) not capable to compensate the torque effect generated by the main rotor.

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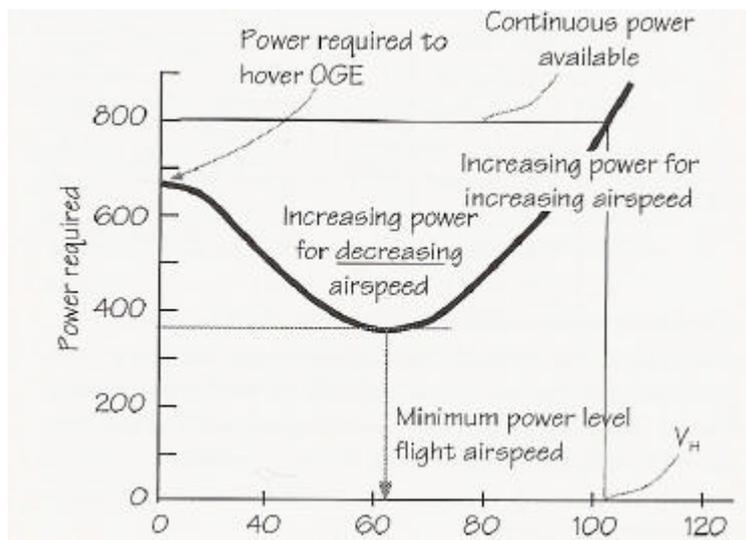
**Table 1: Assessment of relevance by pilots of helicopter aspects (16 pilots)**

Helicopter aspects	Very Relevant	More Relevant	Less Relevant	Not Relevant
mass	14	2	0	0
engine power margin	8	6	2	0
left pedal margin	5	10	0	0
spray-heli downwash	1	5	6	1
aft cyclic margin	2	2	7	2
right pedal margin	0	3	5	2
ground effect	1	2	2	8
left cyclic margin	1	1	3	6
C.G. location	1	0	4	3
right cyclic margin	0	1	2	6
forward cyclic margin	0	0	3	6

Aft cyclic control margins were important during tail wind conditions leading to high nose-up attitude, which also reduced the visual reference from the pilot with the flight deck. The tail wind conditions resulted in a reduction in tail clearance of the tail rotor with the flight deck, influence from helicopter downwash and spray, heading control with more power required and reduced safety as the necessity to gain airspeed during a 'flyaway' close to the water would be more difficult. For night operations it was even difficult to determine the closing rate relative to the ship; therefore usually a somewhat smaller

SHOL was developed for night operations in which tail wind conditions were limited.

The spray generated by the helicopter downwash mainly occurred on the leeward side of the ship with low relative wind speed. This spray was especially troublesome for the pilots during night conditions, even further decreasing the visual references with the ship. The ground effect above the flight deck was considered only relevant for low relative wind speeds with only a small amount of ship motion. For the remaining condition ground effect was hardly noticeable or could not be distinguished from other aspects.



**Figure 2: Power required vs. Indicated airspeed (Coyle 1996)**

Table 2: Assessment of relevance by pilots of ship motion characteristics (16 pilots)

Ship motion aspects	Very Relevant	More Relevant	Relevant	Less Relevant	Not Relevant
roll ship	8	8	0	0	0
pitch ship	3	5	7	1	0
ship's speed	2	4	2	6	2
spray-ship	0	3	7	6	0
yaw ship	0	4	4	7	1

### 2.2 Relevant Aspect 2a: Ship Motion

The flight deck of a ship would be constantly moving depending on the length of the ship, sea state and the direction from which the waves are hitting the ship. The main aspects in this category were the roll motion, followed by the pitch motion of the ship as shown in Table 2.

There was a correlation between the speed of the ship, the relative wave direction, the sea state and the ship's motion as shown in Figure 3. This illustrates that when the ship is sailing into the wave direction the pitch motion of the ship would be more dominating than the roll motion of the ship. When the relative wave direction was perpendicular to the ship, the roll motion dominated the pitch motion of the ship. This was why for Relative wind and Cross-Deck procedures, in which the helicopter take-offs and lands into the wind direction and more perpendicular to the sailing direction of the ship lower relative wind speed limits were used. Otherwise the ship would react heavily in roll motion due to the waves hitting the ship from the side. The most

common take-off and landing procedure (Fore-Aft), in which the helicopter take-offs and lands in the sailing direction of the ship is discussed in Paragraph 3.

The seawater spray generated by the ship became more pronounced when the speed of the ship was increased and in higher sea states when the bow of the ship hits the water and the splashing water reached the flight deck. When the seawater spray comes on the cockpit window it would reduce the visual reference from the pilot with the ship.

### 2.3 Relevant Aspect 2b: Ship Airwake

The type and size of the superstructure was of great importance for helicopter operations from flight decks as it influenced the airflow and turbulence around it. The recirculation zone behind the hangar, known as the 'bubble-effect' was considered the most important factor, closely followed first by the downdraft on the leeward side of the ships superstructure and secondly by the disturbances in the relative airflow in the vicinity of the flight deck as shown in Table 3.

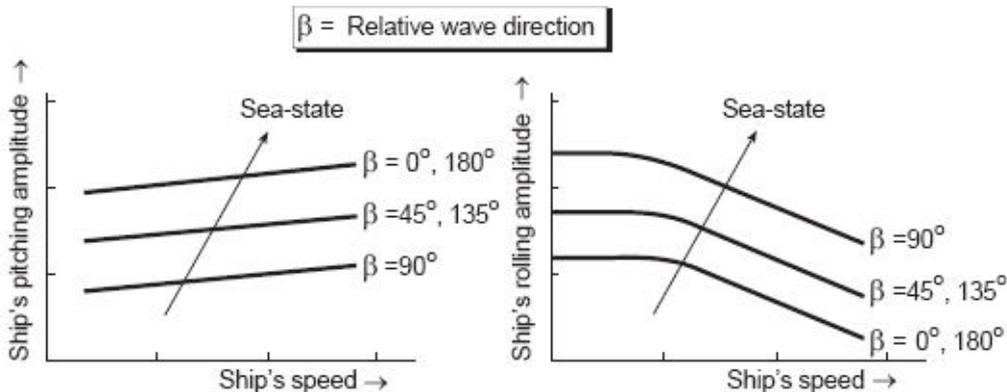


Figure 3: Relations ship motion and relative wave direction (Fang, Krijns et al. 2003)

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**Table 3: Assessment of relevance by pilots of airwake effect near superstructure (16 pilots)**

Ship airwake aspects	Very Relevant	More Relevant	Relevant	Less Relevant	Not Relevant
bubble-effect	5	8	3	0	0
downdraft leeward side	6	7	2	1	0
airflow disturbances	5	9	1	1	0
dual-spot operations <sup>1</sup>	2	5	3	1	1
ship exhaust fumes	1	4	6	5	0
RAS operations <sup>1</sup>	3	3	3	5	1

<sup>1</sup>Not all pilots had flown during multi-pilot or RAS operations

The effects of airflow and turbulence around the ships superstructure were influenced by the dimensions of the ship and the relative speed and wind direction. If the flight deck had cranes and containers it could negatively influence the airflow. The effects were stronger when the speed increased, but were mainly divided by the relative wind direction. The ship motion contributes to this effect and makes the airwake constantly changing and more unpredictable. It was generally possible to divide the relative wind direction into four different sectors as shown for wind tunnel measurements for a Landing Platform Dock (LPD) with two landing spot (Hegen, Hakkaart et al. 1999). The Netherlands Aerospace Laboratory (NLR) claims that the correlation between full-scale air flow test and these wind tunnel measurements is higher than 95% (Fang, Krijns et al. 2003).

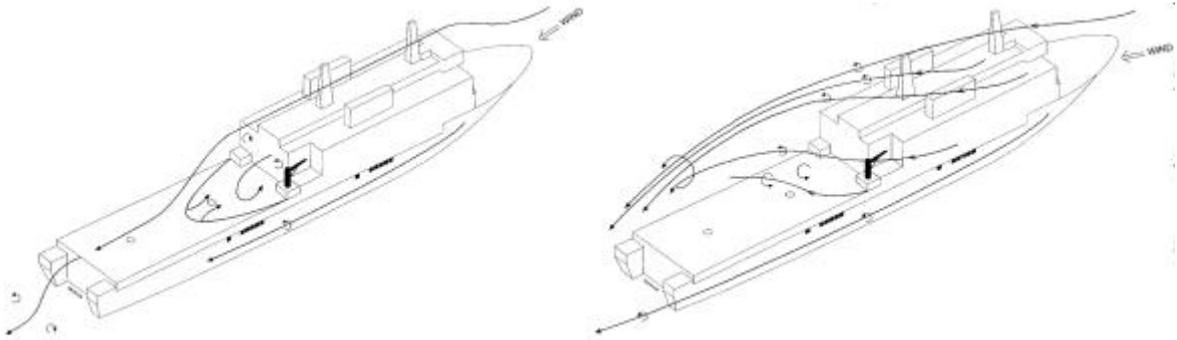
**1. Head winds +/- (0° to 30°):** For winds in this sector it was expected that the flow over the flight deck would be strongly influenced by the superstructure of the hangar as shown in Figure 4. The hangar generated a closed wake bubble over the flight deck, in which a turbulent airflow with low speeds and with reverse flow regions was present. When the height of the hangar or the relative wind speed increased the recirculation zone ('bubble effect') behind the hangar generally increased in strength, resulting in more power required from the helicopter to compensate. Flight operations from the aft landing spot (furthest away from the hangar) were less hampered by this effect,

and as a result flight operations were usually conducted within a larger flight envelope (although the pilot was closer to the hangar at the forward landing spot and had better visual reference with the ship).

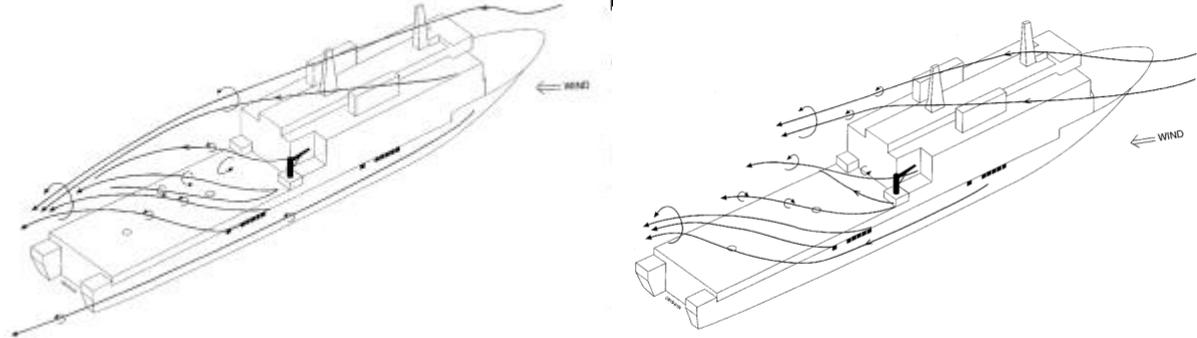
**2. Quartering winds +/- (30° to 60°):** For winds from port and starboard in this sector the sharp hangar edges and also the ships superstructure would generate a dominant vortex, which could roll over the flight deck as shown in Figure 5. At the leeward side of the ship high down flow (downdraft) has been observed, which may exceed 400 ft/min depending on the height and type of the superstructure (Fang and Booy 2000).

**3. Beam winds +/- (60° to 120°):** For beam winds there was a relatively strong upflow and downflow close to the ship observed as shown Figure 6. The sharp flight deck edges could generate a vortex over the whole deck length.

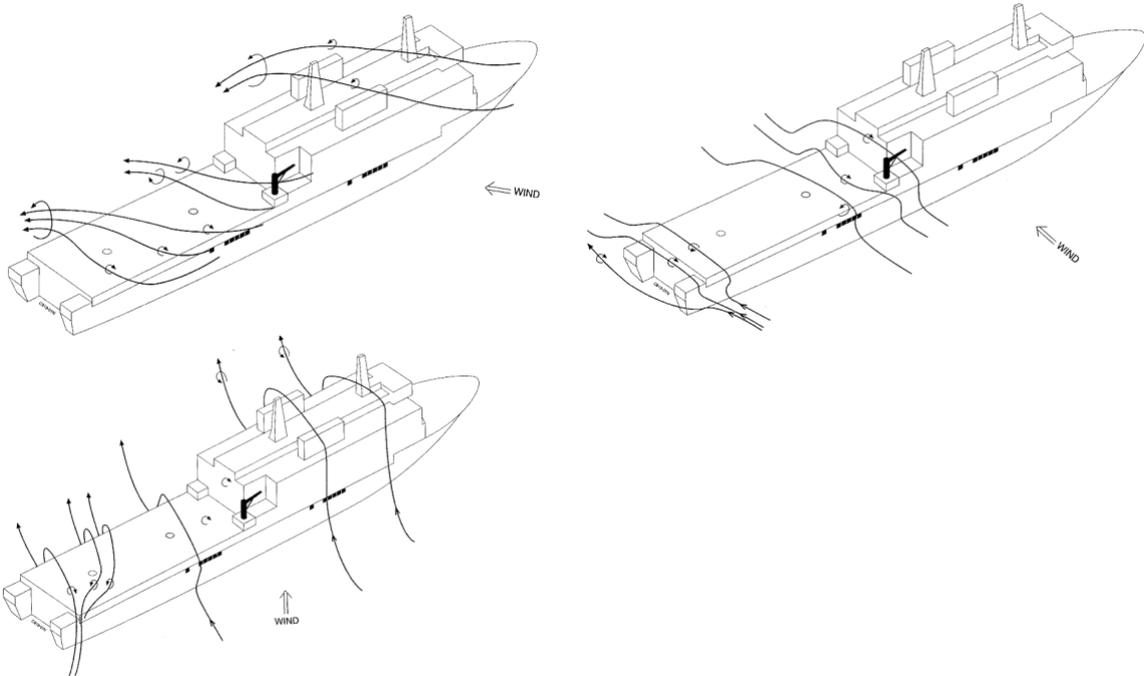
**4. Aft quartering winds and tail winds +/- (120° to 180°):** For aft quartering winds and tail winds the flight deck edge could generate a relatively strong vortex increasing with height of the flight deck above water level as shown in Figure 7. Operations from the forward landing spot (closest to the hangar) were less hampered by the vortex generated by the aft deck, and as a result flight operations in tail wind conditions were usually possible within a somewhat larger flight envelope as the aft landing spot.



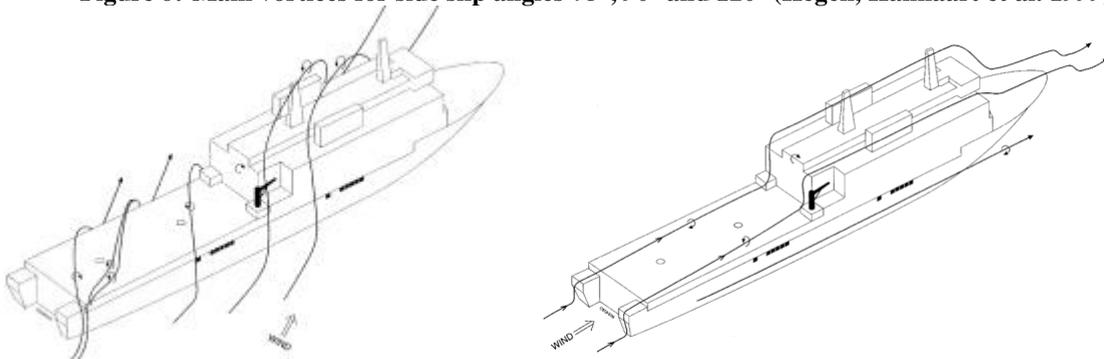
**Figure 4: Main vortices for side slip angles 0° and 30° (Hegen, Hakkaart et al. 1999)**



**Figure 5: Main vortices for side slip angles 45° and 60° (Hegen, Hakkaart et al. 1999)**



**Figure 6: Main vortices for side slip angles 75°, 90° and 120° (Hegen, Hakkaart et al. 1999)**



**Figure 7: Main vortices for side slip angles 150° and 180° (Hegen, Hakkaart et al. 1999)**

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**Table 4: Assessment of relevance by pilots of Usable Cue Environment (16 pilots)**

Human Factor aspects	Very Relevant	More Relevant	Relevant	Less Relevant	Not Relevant
day or night conditions	14	2	0	0	0
deck markings	5	7	4	0	0
landing aids	8	2	5	1	0
visibility	4	8	3	1	0
ship dimensions	1	5	9	0	1
flight deck officer	1	3	10	2	0
comm. with ship	1	5	5	5	0

When operating in dual spot operations the downwash from the helicopters could influence each other. But there were other problems like the interaction between ground personnel on two spots, the anti-collision light from the helicopter on the forward landing spot was blinding the pilot on the aft landing spot and more stress for the pilots while accurately positioning at the forward landing spot with the aft landing spot occupied. The exhaust fumes from the ship could be influenced by the airwake following the contour of the superstructure. These exhaust fumes increased the outside air temperature decreasing the helicopter performance somewhat and the smell could cause problems for the personnel working on the flight deck. While performing Replenishment At Sea operations (RAS), ships were sailing within 35 meters from each other. The ship in the up-wind sector of the other ship would, depending on the relative position influence the airwake, causing an extra disturbance which was one of the reasons that the validity of the SHOL during these conditions should be carefully reconsidered.

### **2.4 Relevant Aspect 3: Human Factors**

In this paragraph first the perception of the visual cues for the pilot are discussed, and secondly the relative wind conditions. The results for the visual references with the ship were based on procedures used by the RNLN, in which night operations were conducted without Night Vision Goggles (NVG). The reason that the relative wind

conditions are discussed as part of the human factors is that when operating helicopters from a flight deck the ship's crew was able to manoeuvre the ship such that favourable relative wind conditions could be achieved by altering the ships course and speed depending on navigation, shipping and other operational constraints. The most important factors in this category were the difference between operations in day or night conditions as shown in Table 4, and relative wind conditions as shown in Table 5.

**Visual Cues.** During the approach to the ship the pilot was initially concerned with capturing and holding the flight path. As the ship was approached smooth transition to outside visual cues was important to achieve a safe hover alongside the ship. The approach to the ship and the landing were separately treated.

**Approach to the ship.** The visual cues for the approach to the ship degraded with decreasing light level and visibility but was largely independent of ship motion (Padfield and Wilkinson 1997). It should be noted that ship motion may had a much greater effect on the approach task if the pilot used a ship mounted approach aid such as a Glide Path Indicator (GPI) which was not stabilized, as the glide path would be moving constantly due to the ship motion (stabilized GPI systems were preferred by the pilots).

**Landing.** For the landing the visual cues were primarily dependent on ship motion and light level while less dependent on visibility than for the approach to the

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**Table 5: Assessment of relevance by pilots of influence of the wind (16 pilots)**

Wind aspects	Very Relevant	More Relevant	Less Relevant	Not Relevant
relative wind	12	4	0	0
wind system accuracy	6	7	3	0
true wind	0	4	6	5

ship (Padfield and Wilkinson 1997). When a clear horizon was not available, the ship was the primary reference and there would be a tendency to follow its movement. Similarly, as the light level was degraded, less of the ship could be seen and the focus would be mainly on the horizon bar. The horizon bar was usually fixed to the ship and followed the motions of the ship, making it difficult for the pilot not to follow these movements (stabilized horizon bars were preferred by the pilots). Fore and aft positioning cues for the landing task at the flight deck were taken from a line painted across the flight deck, while lateral position cues were derived from the flight deck centerline painted along the deck and from the relative position of the hangar door through the cockpit window. The deck markings were not lit and could not be seen clearly with reduced light levels, or the deck markings were lost and could only be recaptured in a low hover over the landing spot. The Flight Deck Officer (FDO) gave mandatory instructions for the positioning of the helicopter in hover above the flight deck by hand signals and/ or voice instructions. The option to provide hand signals was preferred by the pilots as it reduced the voice communication with the pilot.

**Wind.** The relative wind condition was important as the flight operations from the flight deck were based on this as shown in Table 5. True winds became more relevant for high wind speeds (above 30 kts) usually causing more turbulent winds and higher sea states. The relative wind condition measured by the anemometers on the ship would be influenced by the disturbances in the airflow around the superstructure. It was not possible to

consider the measured wind by the anemometers as the actual wind over the flight deck, due to the different disturbances of the wind around the superstructure of the ship. Instead of actual wind over the flight deck, it would be recommended to use the term ‘indicated wind’ measured by the anemometers. By the RNLN usually two anemometers were used, one on port side and one on starboard side of the ship just above the navigation bridge. This was necessary for redundancy, but mainly to switch between the anemometers depending on the relative wind condition. For example, in the case of green winds (winds from starboard) the anemometer on the starboard side of the ship was used to minimize the effect of the disturbances caused by the superstructure. It would be necessary in the design stage of the ship to carefully consider the position of the anemometers to minimize this effect, and that after initial alignment of the anemometers they could only be replaced in an unambiguous way. It would not be the first time that after replacement of the anemometers, there was an error of 20° with the ship longitudinal axis.

### 3 SHOL

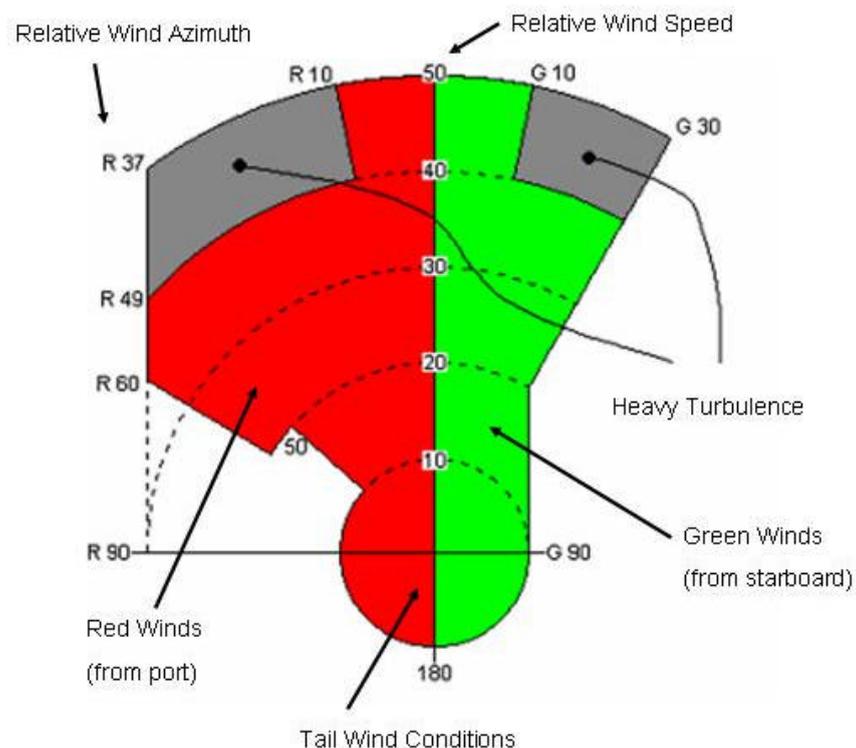
The Ship Helicopter Operational Limitation (SHOL) was based on a maximum mass at which the helicopter would not encounter safety problems as long as the relative wind and ship motion were within specified limits. The determined SHOLs contained in general the following information: helicopter type, day or night condition, applied procedure during take-off/ landing, allowable maximum mass of the helicopter, relative wind limitations and allowable ship motions. This was presented as a polar plot

with relative wind speed (knots) in the x and y direction, and the relative wind azimuth as shown in Figure 8. The indicated areas with heavy turbulence would be avoided during night conditions.

**SHOL Qualification.** The SHOL qualification process was in general time consuming and associated with high costs. There were some different approaches in different countries. The United States used an approach in which usually minor, primarily ship-wind climate testing was conducted before a two week sea trials period, sometimes only relying on the opinion of the pilot without instrumentation in the aircraft (Szymendera 2007). The Netherlands did extensive wind tunnel and full-scale ship climate testing before conducting sea trials which usually lasted four weeks, in which the pilot was backed up with real time data recorded from the helicopter (Fang, Krijns et al. 2003). Although during these sea trials the pilot was backed up by recordings of the helicopter performance and behavior, his/her opinion remained the most important contributions to the process

of finally determining operational limitations.

The pilot(s) used for SHOL determination could have an impact on the envelope released for operational use for two reasons. First, the test pilot would have to take into account the capabilities and skill of the “worst qualified pilot” who operates to the limitations produced. Secondly, the different background and style of flying helicopters could influence the results. This was demonstrated during a simulator test where four pilots were assigned to make a SHOL for a specific helicopter-ship combination, which resulted into four different SHOLs (Roscoe and Wilkinson 2002). It is therefore recommended not to rely on the opinion of only one pilot and when using more pilots to carefully take into account their previous experience. The SHOLs were also limited by the relative wind and sea state conditions encountered during a specific sea trial period for one helicopter-ship combination and it would be difficult to change or expand the SHOL afterwards without conducting another sea trial.



**Figure 8: Typical SHOL for Fore-Aft procedure**

When a new helicopter was added to the fleet each individual helicopter-ship combination had to be tested separately, resulting in a time consuming and costly process, while there were large similarities between the SHOLs of each ship for a specific helicopter type. There needs research to be done for the “one helicopter-all ships” concept, in which a specific SHOL would not anymore be determined for each specific helicopter-ship combination individually, but only for a specific helicopter type and then used for all type of ships. The result could be a SHOL for a helicopter-ship combination without conducting a complete sea trial, when the ship wind climate is known from wind tunnel measurements and/ or previous sea trials with other helicopter types and then combined with the helicopter characteristics.

## 4 Conclusions

In this article the relevant aspects for helicopter-ship operations were divided into three main aspects: helicopter, ship and human factors. The relevance of the different operational aspects was shown based on the results from a questionnaire by sixteen Royal Netherlands Navy pilots. The results also show that there were differences in pilot opinion. While this proves that the pilots were different, which is no revelation, it does indicate that the pilot(s) used for SHOL determination could have an impact on the envelope released for operational use. The following four general conclusions resulted from the questionnaire. First, the relationship between the mass of the helicopter, engine power margins and left pedal margins for a counter clockwise rotating main rotor confirmed the theoretical models presently used. Secondly, the pilot maintained horizontal reference with the horizon during the landing phase and roll motion of the ship would not be compensated, which could result in difficulties during the landing. The pitch motion of the ship could be compensated with collective inputs and

was considered less important. Thirdly, the disturbances in the airflow caused by the ship’s superstructure had a large impact and further research is encouraged to minimize this effect. Finally, the visual reference with the ship decreased drastically for night operations and the use of i.e. NVG and contour lighting needs to be considered. It is furthermore emphasized that research should be done for the “one helicopter-all ships” concept, in which a SHOL would be determined for a specific helicopter type and then used for all type of ships. This concept could reduce costs and pressure on the organization to ensure that the helicopter, different ships and crew would be available for longer periods. Further research is planned to determine the feasibility of the “one helicopter-all ships” concept.

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