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QUALIFICATION OF KAI KUH-1M ON BOARD ROKN SHIPS USING THE DUTCH APPROACH

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Abstract

Korea Aerospace Industries (KAI) has developed the KUH-1M, the amphibious derivative of the Surion helicopter for the Republic of Korea Marine Corps. It made its first flight on 19 January 2015. KAI and the Netherlands Aerospace Centre (NLR) have been working together in the KUH-1M Helicopter-Ship Qualification project to obtain Ship Helicopter Operational Limitations (SHOLs) for flight operations with the KAI KUH-1M on board two classes of ships of the Republic of Korea Navy (ROKN).

The Dutch helicopter-ship qualification method has been applied to obtain the required qualification documents of the KUH-1M. The method is based on a thorough understanding of the helicopter (low speed) operational characteristics and the ship's environment before executing helicopter flight trials on board the ship.

In September of 2014, wind tunnel tests have been performed to measure the airflow characteristics around two ROKN ships. In March/April 2015, shore based low speed flight trials have been executed with the KUH-1M prototype to obtain detailed information on the low speed flight characteristics of the helicopter. With the obtained information, Candidate Flight Envelopes (CFEs) have been generated which are the basis of the flight test program on board the ships. In June and September 2015, flight trials with the KUH-1M have been executed on board two ROKN ships to obtain Ship Helicopter Operational Limitations.

Fig. 1: The KUH-1M (source: KAI)

1 The KUH-1M

The Korean Utility Helicopter (KUH) is a new Medium Utility helicopter successfully developed by Korea Aerospace Industries for the Republic of Korea Army between 2006 and 2012. KAI successfully developed the amphibious version of the KUH based on Republic of Korea Marine Corps (ROKMC) requirements. This amphibious helicopter, called KUH-1M (see Fig. 1), is designed to transport troops and materials from naval vessels to the western and eastern combat areas of Korea by ROKMC. Air assault operation is the primary mission of the KUH-1M. The ability to take-off and land on board ships is indispensable to complete this mission. The ship trials of the specific helicopter and navy ship combination are required to show and maximize the shipboard operational capability of this helicopter.

2 The Dutch helicopter/ship qualification method

The Netherlands Aerospace Centre NLR was contracted by KAI to assist in the helicopter/ship qualification of the KUH-1M. NLR has more than 50 years of experience in helicopter/ship qualification testing. In those 50 years, NLR has performed qualification programs with nearly 10 different helicopter types, on more than 15 different classes of ships for several different countries, mainly working for the Royal Netherlands Navy.

The result of helicopter/ship qualification tests are the Ship-Helicopter Operational Limitations (SHOLs, see an example in [1]), indicating the relative wind conditions in which the helicopter can safely operate on the ship. SHOLs are determined for every helicopter/ship combination, since each helicopter-type/class-of-ship combination has unique characteristics.

In the 1960s and 1970s NLR, together with the Royal Netherlands Navy, has developed a method for the prediction of an initial guess for the operational limits of the helicopter/ship combination, the so-called Candidate Flight Envelope (CFE). The CFE is based on (steady) wind tunnel measurements of the airflow around the ship, combined with the helicopter low speed characteristics, known from flight tests. This approach allows safe testing close to the edges of the Ship Helicopter Operational Limitations, reducing the required number of test points during the trials at sea (see also [2] and [3]).

The Dutch helicopter/ship qualification is summarized in the diagram in Fig. 2. A scale model of the ship is tested in a wind tunnel to provide detailed information about the airflow around the ship. Along the approach path, with a focus on the hover wait position next to the ship and the landing spot on the deck, the steady flow characteristics are measured as a function of relative wind direction. Previous dedicated full-scale measurement campaigns on the ship to validate the wind tunnel measurements have increased confidence in the wind tunnel data to the point that currently only the ship's anemometers are validated at sea.

For the second step in NLR's qualification process, the low speed characteristics of the helicopter are tested in detail: controllability and performance of the helicopter are checked as a function of density altitude for different wind speed and directions.

The results of the low speed flight tests and the wind tunnel data are combined into Candidate Flight Envelopes: based on the flow conditions in the approach and take-off path of the helicopter, a preliminary limit is calculated from the helicopter's low speed characteristics. This process includes experience from previous qualification programs. For example, for nighttime Candidate Flight Envelopes, no tail wind is allowed (based on pilot comments), even though the helicopter low speed envelope

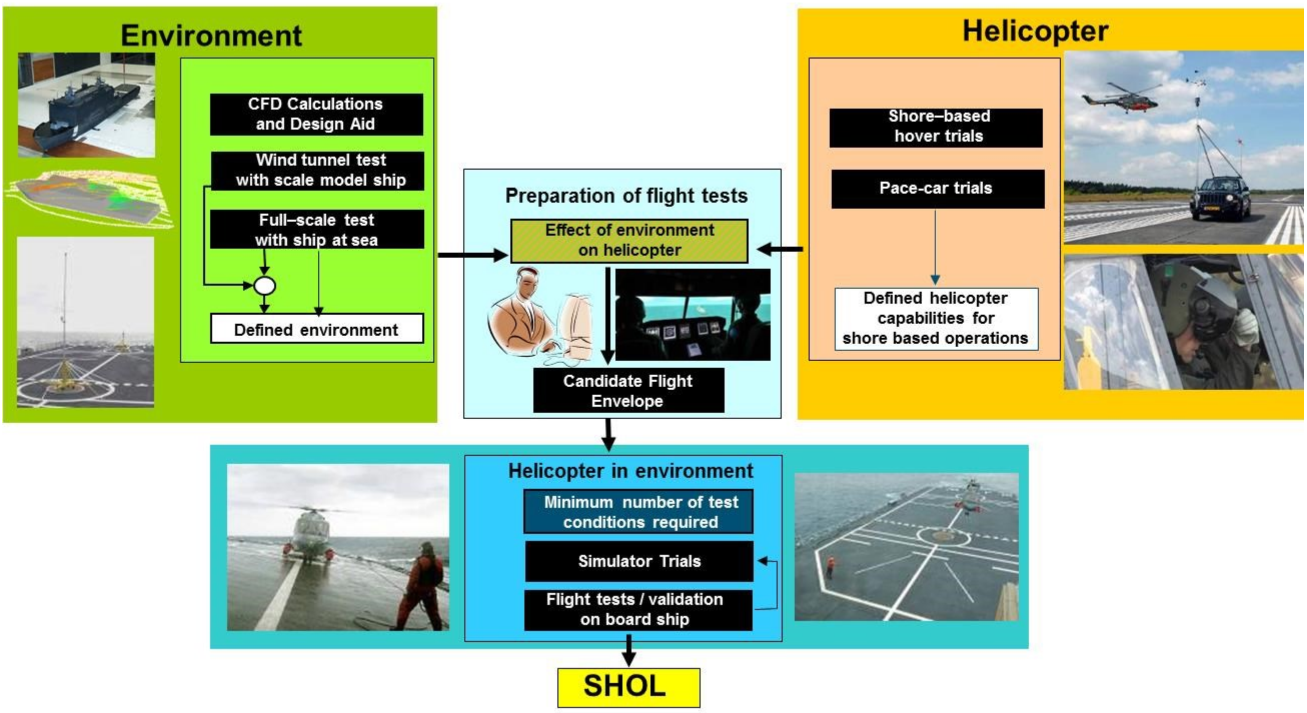

Fig. 2: NLR's set-up of helicopter/ship qualification programs

includes rear wind conditions.

Many countries perform qualification trials for unique helicopter/ship combinations (for example USA & UK). Their approach is to start in a relatively safe part of the SHOL ('in the middle') and expand the SHOL test point by test point in small steps, requiring a large amount of test points, and therefore testing time. The advantage of the NLR approach is that, using the Candidate Flight Envelopes, testing can proceed faster towards the limits of the SHOL, saving cost by saving flight time for the helicopter and sailing days for the ship, while maintaining safety. Test time is typically reduced by 25% to 40%. Note however, that testing time is very dependent on the weather conditions encountered during the ship trials.

The NLR approach was used for the qualification of the KUH-1M for shipboard operations. The individual steps in the process (wind tunnel, low speed trials, ship trials) are described in more detail in the following paragraphs.

3 Wind tunnel tests

In September 2014, a short wind tunnel test campaign on two models of the ROKN LPH (Landing Platform Helicopter) and LST (Landing Ship Tank) class have been carried out to determine the airflow characteristics above the helicopter landing spot(s) and at the hover wait positions next to the ship.

3.1 Ship models

A waterline scale model of each ROKN ship was manufactured. Based on limited information of both ship classes from ROKN, public sources and information available at KAI, 3D drawings of both ship classes were made by NLR. Only the relevant details that are considered to be necessary to obtain reliable full-scale test results have been modelled. For airflow measurements, it is not required to model all external details present on the real ships. NLR decided on the simplifications, based on engineering experience of many years: no fences, no small antennas, rear ramp modelled as a block.

From the 3D drawings models were manufactured by a craftsman using CNC (computer numerical control) milling and 3D printing in combination with traditional manual techniques. The models were manufactured of several different materials, including MDF, plastics, wood and metal.

3.2 Test set-up

Aerodynamically, a ship is a bluff body with sharp edges, where airflow around a sharp edge will always separate at the edge. As a result Reynolds scaling effects have no significant influence on the airflow characteristics. This conclusion is backed-up with NLR experience on many comparisons of full scale measurements with wind tunnel data on ships. This means that the airflow measurements could be executed at wind tunnel speeds optimized for the test method used while still being representative for the wind envelope at any operating speed of the ship. Also, relatively small models can be used for reliable measurements: the size of the model was dictated by the size of the wind tunnel test section. The scale of the LPH model was 1:150 and the scale of the LST model was 1:80.

The test was performed in the Low Speed wind Tunnel (LST) of German-Dutch Wind Tunnels (see Fig. 3). The test section is 3 m wide and 2.25 m high and is equipped with a turntable, which is flushed into the floor.

The airflow measurements were executed in a clean wind tunnel, i.e. without the system to simulate a natural atmospheric boundary layer. This is a deliberate decision by NLR: the influence of the ship's superstructure on time-mean airflow characteristics is much more dominant than the vertical wind speed variation over the height of the ship superstructure. At sea, the size of the atmospheric boundary layer is dependent on the wave height (sea state) and varies with the weather conditions. Therefore, it was decided to use no atmospheric boundary layer in the wind tunnel, and to apply a boundary layer correction at sea when required.

The ship models were mounted on the turntable in the floor of the wind tunnel. To ensure that the height of the wind tunnel boundary layer was below the measurement locations, the measurements were executed in the forward test section of the LST. The models were mounted in such a way that the current measurement location was located at the rotating axis of the turntable.

A 5-hole probe was mounted on a traversing beam spanning the width of the test section. For these trials a miniature 5-hole pyramid probe was used. The tip of the probe was always positioned above the centre of rotation of the turntable and the probe was always aligned with the tunnel axis. The vertical position of the probe was set according to the height of the current measurement location.

Data was taken in a continuous testing mode: the model rotates continuously and no stops are made in order to take a data point. When the rotational speed being used for the turntable is sufficiently low, the pressure lag due to the pressure tubing, does not affect the results. Execution of continuous measurements allows an increase in detail (small step in relative wind direction) and a reduction in measuring time.

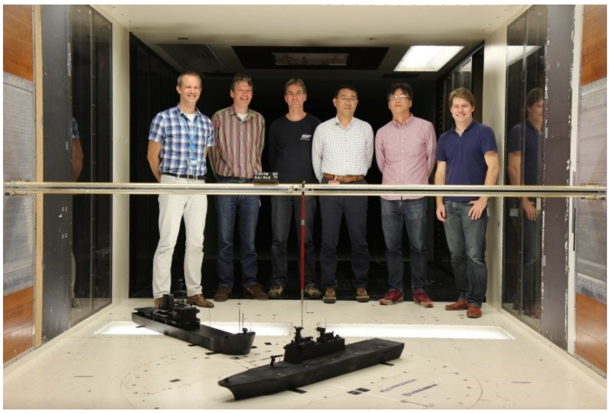

Fig. 3: Test set-up for airflow measurements in the Low Speed wind Tunnel of DNW.

3.3 Test program

To obtain a general impression of their characteristics, the air flow around both ship models was visualized with a smoke rod (see Fig. 4).

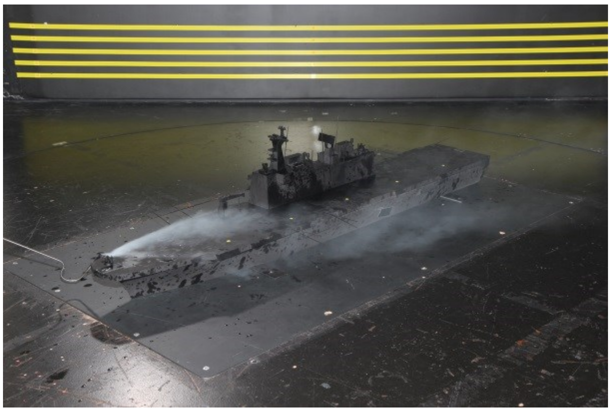

Fig. 4: Visualization of the air flow with a smoke rod

At several measuring stations, the local airflow speed and the horizontal and vertical air flow deviation with respect to the undisturbed airflow are measured. The test program focused on the local airflow characteristics at:

- Ship's anemometer locations, since they are the source of wind information on board the ship, required to execute helicopter operations.
- NLR reference anemometer, to be installed on the jack staff on the bow of the ship.
- Several heights above the helicopter landing spots, where the main rotor of the helicopter is located during flight operations.
- At the hover wait positions next to the ship.

For the LST class, a new landing location for KUH-1M operations was defined to ensure sufficient clearance between the main rotor and the ship's nearest superstructure (see Fig. 16).

The hover wait position is located at the end of the helicopter approach path, approximately 1.5 main rotor radius next to the ship. The locations of the hover wait positions were defined based on the information on helicopter landing and take-off position obtained from the ROKN. The hover wait positions are included in the test program, because they are the closest location next to the ship. At these locations, up- and downflow conditions are most severe.

3.4 Test results

The wind tunnel tests resulted in a database of the air flow characteristics at several locations above and next to the LPH an LST classes of ships, to be used in the definition of Candidate Flight Envelopes.

It is NLR's experience that general characteristics of airflow are sufficient for analysis of helicopter/ship operations. However, detailed geometry of the area around the ship's anemometers has a significant influence on the local airflow around them. This is one of the reasons that the ship anemometer behavior as a function of relative wind direction is still checked on-board the ship during the first phase of the flight trials.

4 Low speed trials

Low speed flight trials are performed to determine controllability and power performance characteristics of the helicopter in hover as a function of density altitude (especially at high outside air temperatures) and wind speed and direction relative to the helicopter. The obtained information is essential for determination of the Candidate Flight Envelopes, the basis for the flight trials on board of the ships to establish the SHOLs.

Early 2015 the KUH-1M low speed trials were performed at the KAI site at Sacheon Air Force Base (AFB) in the south of South-Korea. Since Sacheon AFB is a training site for the Korean Air Force and a runway is required for testing only weekends were available for the trials. Testing was finalized in two weekends, in a total of 18 flight hours.

The tests were performed out of ground effect (OGE): with respect to performance, helicopter operations on board ships can be considered to be executed OGE. Data was gathered for relative wind directions in 15 to 30 degree steps and wind speed in 5 to 10 knot increments. When required to obtain more details smaller increments were applied.

After obtaining a stable condition, engine torque, rotor rpm, helicopter attitudes, and flight control positions were recorded in addition to ambient conditions (pressure altitude, OAT, ambient wind speed and direction etc.) and pilot handling quality ratings. This procedure was followed for a range of relative wind conditions. The tests were planned based on the existing wind envelope limitations for land-based operations from the Flight Manual with an extension in forward winds to 50 knots.

The low speed characteristics of the helicopter were determined by pure hover trials (hover in ambient wind) and pace car trials, dependent on the ambient wind conditions. With the latter methodology, relative wind conditions were generated by flying the helicopter along the runway behind a pace car at different headings (see [3]).

The tests were performed at two helicopter density masses and at the extreme aft center of gravity position, thereby covering the complete operational mass range at prevailing atmospheric conditions in operational theatres. This was achieved by changing the gross weight depending on the environmental conditions during the tests by adding fuel and ballast weight.

Helicopter data was obtained from KAI's Flight Test Instrumentation. Via a telemetry datalink the helicopter data was available in the KAI mobile control room. The output of the telemetry receiver is provided to the NLR system for real time monitoring purposes. Ground instrumentation consisted of a GPS system in the pace car (see Fig. 5) and a meteo mast on the airport (see Fig. 6).

Fig. 5 Pace car (left picture), display for pace car driver (right top picture) and data processing and recording system based on a laptop computer (right lower picture).

The true wind speed and direction were measured at a height of 10 meter above ground level using a Gill Young anemometer installed on the airport close to the test runway (Fig. 6). Via a 500 meter long anemometer cable the anemometer information is fed via RS422 signal into a "meteo box". The meteo data was then sent to the KAI mobile control room via a WiFi connection.

Fig. 6: Mast with anemometer at Sacheon Airport

The low speed trials have generated a detailed low speed envelope in a relatively short testing time, providing a good understanding of the helicopter low speed characteristics. In four test days the complete envelope was tested for two test weights (see Fig. 7), forming the basis for the test plan for ship trials, in the form of Candidate Flight Envelopes.

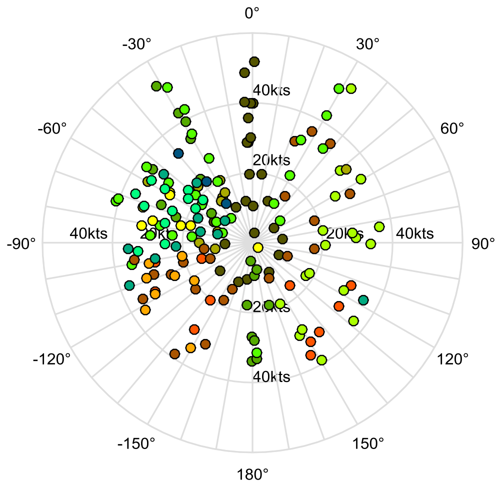

Fig. 7 Overview of low speed trial test points (colors indicate flight number)

5 Helicopter/ship qualification trials

The KUH-1M helicopter/ship flight trials were performed in June 2015. The test location was east of the South-Korean peninsula, 40 nautical miles off the coast. This area was sufficiently far from the shore that no negative influence (turbulent wind fields) was experienced.

In two 6-day test periods the KUH-1M was tested on two classes of ships:

- The 199 meter long Landing Platform Helicopter (LPH) class ship. The LPH is a helicopter carrier with 5 landing spots.
- The 113 meter long Landing Ship Tank (LST) class ship. The LST is an amphibious transport ship with 1 landing spot.

Before each 6-day trial, one day was reserved to install the instrumentation on board the ship. After each trial, 1 day was used for removal of the instrumentation of the ships. In the total 12 test days nearly 22 test flight hours were made and more than 100 test points were cleared.

5.1 Test schedule

On the first day of the test period on board each ship, the instrumentation error of the ship's anemometers was determined using the dedicated test anemometer on the bow as a reference. This activity was required because the wind information presented to the ship's crew is the prime parameter of the SHOLs and as such is a flight safety activity.

The flight trials subsequently started with a familiarization flight. This flight was scheduled to let the test pilots get used to the ship's operational environment. The flight was also useful for introducing the test crew on-board the ship and the helicopter's ground crew to the procedures involved in the shipboard flight testing, such that subsequent tests are more streamlined. The test conditions for these first few flights were not directly at the outer edges of the CFE, to ensure an incremental build-up of workload for the test pilots.

Similar to the procedure for the low speed trials, the helicopter weight was kept close to the target test weight by frequent refueling. To save time, this was performed with the rotor running (hot refuel).

Operational envelopes were determined mainly for the take-off and landing phase of the helicopter operation. Attention was also paid to the testing of deck handling equipment & procedures, which includes equipment used for guidance, lighting, lashing, deck transfer / transport for ranging, blade folding, etc.

For both ships 4 SHOLs were tested: 1 approach, for day and night conditions, for 2 density masses. On the LPH class ship testing focused on the most critical spot, with limited checks on other spots.

5.2 Helicopter configuration

The KUH-1M was tested at 2 test density masses, both higher than the KUH-1M's take-off weight. As with the low speed trials, the aircraft was ballasted for an aft center of gravity, because it is the most critical for handling qualities. A water tank with a capacity of 1200 liter was installed in the cabin, fitted with outlets on both sides of the cabin (see Fig. 8). A quick release operated from the cockpit opens two valves, releasing the water outside the left and right side of the cabin within seconds. The water tank provides an additional safety feature for testing at the edge of the envelope: when testing in conditions with high required torque or pedal, the pilot can quickly reduce the helicopter weight by 1200 kg.

Fig. 8 The KUH-1M at sea with the water tank installed (source: KAI)

The crew in the helicopter consisted of:

- Test pilot
- Safety pilot
- Flight Test Engineer

5.3 Instrumentation

Helicopter data was again obtained from KAI's Flight Test Instrumentation. Via a telemetry datalink the helicopter data was available in a dedicated container on the deck of the ship (see Fig. 9).

Fig. 9 Test container on the deck of the ship (source: KAI)

The system set-up of the Ship Helicopter Flight Test Trials is functionally depicted in Fig. 10.

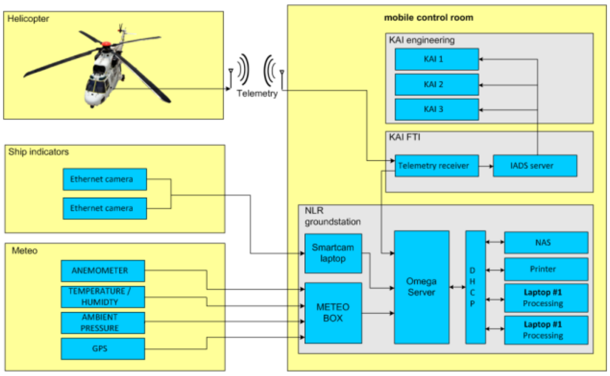

Fig. 10: Flight Test Instrumentation system layout.

During the trials both ships were equipped with non-intrusive NLR instrumentation (i.e. no interfaces with the ship sensors or indicator is necessary): the required ship information was obtained by using real-time video processing. The only physical connection with the ship is the mounting arm on which the camera is mounted. On board the LST class ship two cameras were mounted in the Flyco overlooking the helicopter deck. One directed toward the wind speed and wind direction indicator. The other camera was directed towards the ship's heading indicator. Both indicators are shown in red circles in Fig. 11.

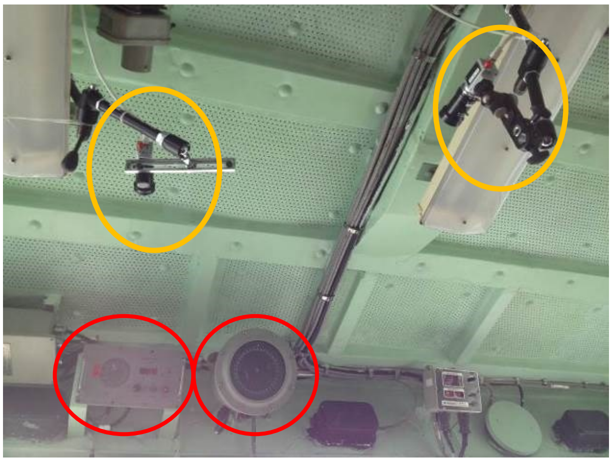

Fig. 11 Non-intrusive ship instrumentation (smart cameras) installed in the flyco on board the LST

On board the LPH class ship the two cameras were mounted in the ground crew room. One camera was used for the wind speed and wind direction indicator and one for the ship's heading and velocity indicator.

From the cameras an Ethernet cable was routed to the ground station container, in which a dedicated laptop was used for real time video processing. The data output of the video processing was subsequently provided via RS422 serial link to the NLR Ground Based Data Processing System to monitor and record the ship parameters. Initially, some issues with reflections (from the sea or people in the Flyco) and issues with the large difference between night and day had to be resolved. Software settings and a non-reflective coating on the instruments improved the results.

The roll and pitch from the ship was measured by a dedicated IMU-sensor installed in the mobile test container. The output from this IMU sensor was fed into to the NLR Ground Based Data Processing System.

A reference anemometer was installed on the top of the jack staff at the bow. An example of the installation on board the LST class ship is given in Fig. 12.

Fig. 12: Reference anemometer at the jackstaff on the bow of ROKN LST

A set of Gill-Young low-inertia anemometers was used to measure the air flow at this position. This reference position was chosen for the following reasons:

- Correction factors to be applied are known (from wind tunnel results).
- The air flow deviations, due to the presence of the ship's superstructure, are minimal over a wide range of azimuth angles.

The anemometer was connected by a cable to a dedicated PC which was used for data acquisition and storage. The data from the bow anemometer was merged with the helicopter data obtained by telemetry for post-processing purposes.

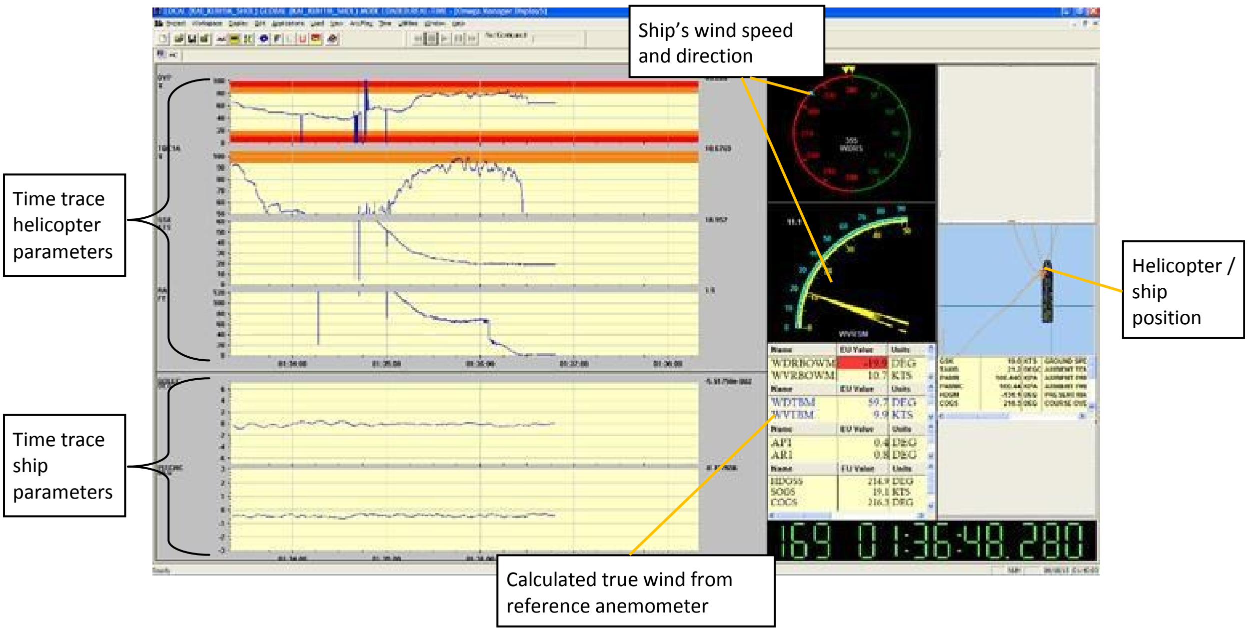

Fig. 13 Example of on line data presentation for test supervision.

During the execution of the flight trials the helicopter and ship information was presented in a real time/ quick look station to monitor the parameter values and limitations / warnings. This real time quick look station is also used to merge the data of the meteo system consisting of the reference anemometer at the bow, temperature, humidity and air pressure sensors, with the helicopter and ship data. An example of the quick look display used during the execution of the flight trials is given in Fig. 13.

5.4 Data processing

During the trials all tested conditions were directly plotted in NLR's test management tool for comparison to the relevant CFE's (Fig. 14). The same tool also allows for efficient test planning with respect to wind conditions (some points require high wind speeds, while others require low wind speeds, see [2]).

After each mission the flight test data was post-processed and discussed with pilots and engineers. Rejection criteria for test points were:

- Aircraft structural limits:
  Limiting condition established when aircraft or structural limits are encountered.
- Control margins:
  Limiting condition when control margins reduced to 10% (steady state) or 5% (transient).
- Power margins:
  Steady state power margins are 10 %. Transient margin is not utilized.
- Pilot workload:
  Limiting condition when workload excessive, based on pilot of average ability and limited embarked experience.

Pilot workload was evaluated using the Dynamic Interface Pilot Effort Scale (DIPES). This rating scale is a qualitative rating scale used to determine pilot workload for individual test points [1]. After execution of each test point, the pilot's ratings were transmitted by radio to the flight test team. Included with the ratings were the rationale for the pilot rating: torque, pedal position, attitude of the helicopter, water spray limiting visibility, etc. The DIPES rating has been used successfully by the pilot to rate his workload during the flight trials.

5.5 Results: weather

Unfortunately the weather conditions in June 2015 were not optimal for ship/helicopter qualification testing: on average wind speeds around 10 knots were encountered in sea states 2 to 3. These conditions lead to small ship motions and low relative wind conditions and

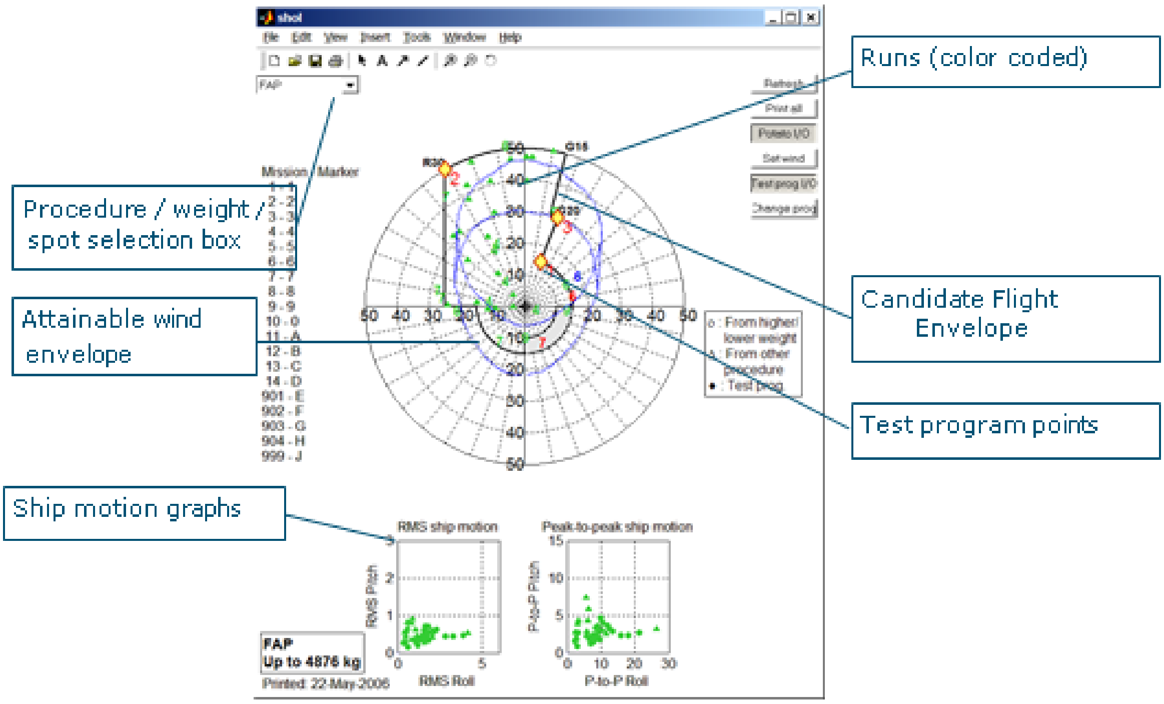

Fig. 14 Example of test management tool used during the flight trials (from [2]).

therefore only a part of the intended SHOL could be tested.

5.6 Results: ship's anemometers

On both ships, the full scale airflow characteristics around the ship's anemometers differed from the data obtained with the wind tunnel tests, especially in wind direction. Deviations in local wind direction were higher than the deviation in local wind speed. The full scale airflow characteristics at the anemometer positions are strongly influenced by superstructure items in their vicinity. As a result, the airflow characteristics are highly dependent on detail design of the area around the ship anemometers. Fully representative data can only be obtained in the wind tunnel when the models are representative of the real ships in this respect. This was not the case since detailed drawings of both ROKN ships could not be obtained.

The airflow properties at the bow, above the landing spots, and at the hover wait positions are mainly influenced by the general shape of the ship. The influence of small superstructure items on the airflow is relatively minor. As a result, the airflow at these locations is less dependent on the detail design of the ship.

Both ships have two anemometers located on a mast above the bridge on the starboard and port side of a yard. An advantage of this layout is that one of the anemometers is always in relatively clear air, when the other sensor is in turbulent flow behind the mast. On one of the ships, however, for relative wind conditions from the starboard side, the upwind sensor is also in a turbulent wake (see Fig. 15). The same effect does not occur for the port anemometer, due to the asymmetry of the ship geometry.

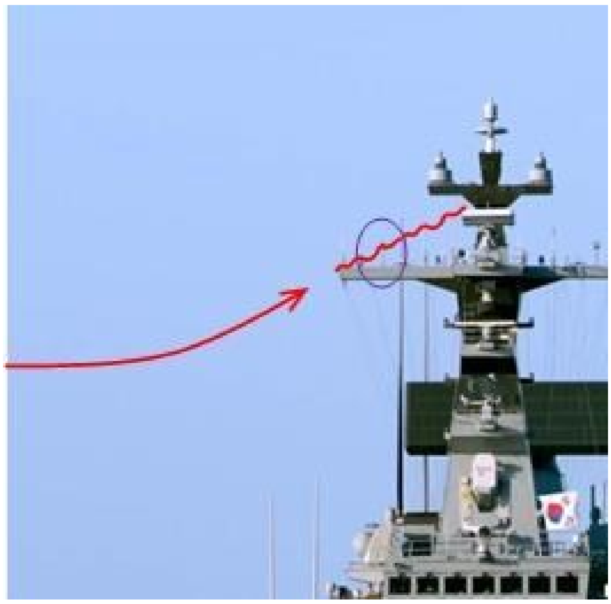

Fig. 15: Upwind anemometer in turbulent wake from yard.

5.7 Results: KUH-1M

The rear center of gravity location used for the flight trials resulted in a high nose attitude. Nevertheless, the helicopter had sufficient tail clearance during landing and take-off. Additionally, the pilot's view of the deck was limited due to the high nose-up attitude. This was not considered limiting by the pilot, even on the smaller deck of the LST.

As part of the Operational Test and Evaluation test program, spreading and folding of the helicopter on-deck was tested in several conditions. Also, on the LPH class ship, the helicopter was moved on to the elevator and lashed in the hangar below the helicopter flight deck while the measurements for the ship anemometer validation were executed.

The LST class helicopter deck is laid out for the Lynx helicopter. Because the KUH-1M is larger than the Lynx, it has to land at a more rearward position with respect to the landing grid to ensure sufficient clearance to the superstructure of the ship. The pilot found a good reference to obtain the recommended location: if the pilot's eye is at a line through the center of the grid and the landing circle, perpendicular to the longitudinal axis of the ship, the helicopter is positioned correctly. At this position, the nose wheel is located on the center of the landing grid (Fig. 16).

Fig. 16 KUH-1M landed at its correct position on the flight deck of the ROKN LST class

6 Additional trials

Although overall the tests in June 2015 were successful, the final result was limited. This was mainly due to a lack of wind. Also, nearly no nighttime testing was performed on the LPH class ship and only minimal nighttime testing on the LST class ship. To increase operational availability of the KUH-1M for helicopter/ship operations, it was decided to perform additional trials on both ROKN ships in September 2015 in heavier weather conditions than encountered during the trials in June 2015. The purpose of the additional ship trials were, in order of priority:

1. Obtain night SHOLs on board the LPH class ship and extend the night SHOLs for the heavy weight on board the LST class ship.
2. Expansion of ship motion limitation for both LPH and LST classes.
3. Expansion of the current SHOL for LPH and LST.

The additional trials were performed in a total of 5 days during which 9 flight hours were made. More than 50 test points were cleared.

Helicopter configuration, test weights and center of gravity were identical to the trials in June.

Slightly better conditions than in June 2015 were encountered: sea state up to 4 and up to 15 knots of wind were found. The initial SHOLs from June were successfully expanded with nighttime SHOLs.

7 Conclusion

In June and September of 2015 helicopter/ship qualification tests have been performed on board with the KUH-1M on the ROKN LPH and LST classes of ships. The execution of the tests was successful. The SHOLs provide an operational capability for operation up to sea state 4, even though the final result is limited, mainly due to a lack of wind.

KAI has successfully completed development of the amphibious version of the KUH. Only 8 months after the KUH-1M's maiden flight, these trials, together with other efforts, led to the successful acceptance of the KUH-1M by the Republic of Korea Marine Corps.

Acknowledgement

NLR would like to thank KAI for the excellent cooperation and good working atmosphere, and the Republic of Korea Navy and the Republic of Korea Marine Corps for their hospitality on board the ships. For both KAI and NLR this test campaign was an adventure and an interesting learning experience.

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