

50-YEARS DUTCH HELICOPTER-SHIP QUALIFICATION

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Abstract:

The Royal Netherlands Navy (RNLN) was one of the first operators of ship-borne helicopters on small ships. Together with the Netherlands Aerospace Centre NLR, the RNLN pioneered the development of helicopter-ship qualification procedures. This collaborative effort has led to the Dutch helicopter-ship qualification method. The method is based on a thorough understanding of the helicopter (shore-based) operational characteristics and the ship's environment before executing helicopter flight trials on board a ship.

The first trials were executed in 1964 with a Sikorsky S-58 helicopter on board the replenishment ship "Hr. Ms. Poolster". Many trials followed with helicopter types with gross weights ranging from 2500 kg to 11000 kg. The flight deck lengths of the ships ranged from 7.6 m to almost 200 m.

In 2015, NLR has been working together with Korea Aerospace Industries (KAI) 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 KUH-1M is the amphibious derivative of the Surion helicopter, developed by KAI for the Republic of Korea Marine Corps. It made its first flight on 19 January 2015.

In September of 2014, wind tunnel tests have been performed with models 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 programme 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.

This paper will describe history and methodology of the Dutch helicopter-ship qualification method.

1. INTRODUCTION

In 1952, in The Netherlands, military helicopter operations from ships started with a single Sikorsky S-51 helicopter on board of the aircraft carrier "Karel Doorman". In 1954 the S-51 was followed by three Sikorsky S-55's and in 1960 the Sikorsky S-58. Again, both helicopter types operated from the aircraft carrier "Karel Doorman". In 1963 the first Dutch replenishment at sea (RAS) ship "Hr. Ms. Poolster" made its maiden voyage. It was also the first Dutch navy ship equipped with a relatively small helicopter flight deck and a hangar at the stern of the ship. Concerns about the feasibility of helicopter operations in disturbed air from the ship's superstructure resulted in 1964 in an order for investigation of the air flow around the helicopter flight deck in a wind tunnel. This started the NLR involvement in helicopter operations from ships. In the following 52 years, NLR has performed helicopter/ship qualification tests with nearly 10 different helicopter types, on more than 15 different classes of ships for several different countries.

2. THE DUTCH HELICOPTER/SHIP QUALIFICATION METHOD

Operating helicopters in a maritime environment increases risk and pilot workload to higher levels than normally encountered during land-based operations. For example, at the end of a long mission, landing the helicopter on a small, moving platform in the turbulent environment behind a ship's superstructure under low visibility conditions is a significant challenge. To obtain the maximum operational capability within this environment, while maintaining best safety practices, helicopter/ship qualification testing is

required. It is used to develop safe operational envelopes for helicopters operating off ships under a variety of weather conditions.

The result of helicopter/ship qualification testing are the Ship-Helicopter Operational Limitations (SHOLs, see an example in ref. 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. NLR, together with the Royal Netherlands Navy, has developed a method for the prediction of an initial estimate 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 (because most often the manufacturers' data are insufficient). 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 ref. 2, 3 and 4).

The Dutch helicopter/ship qualification is summarized in the diagram in Figure 1. 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.

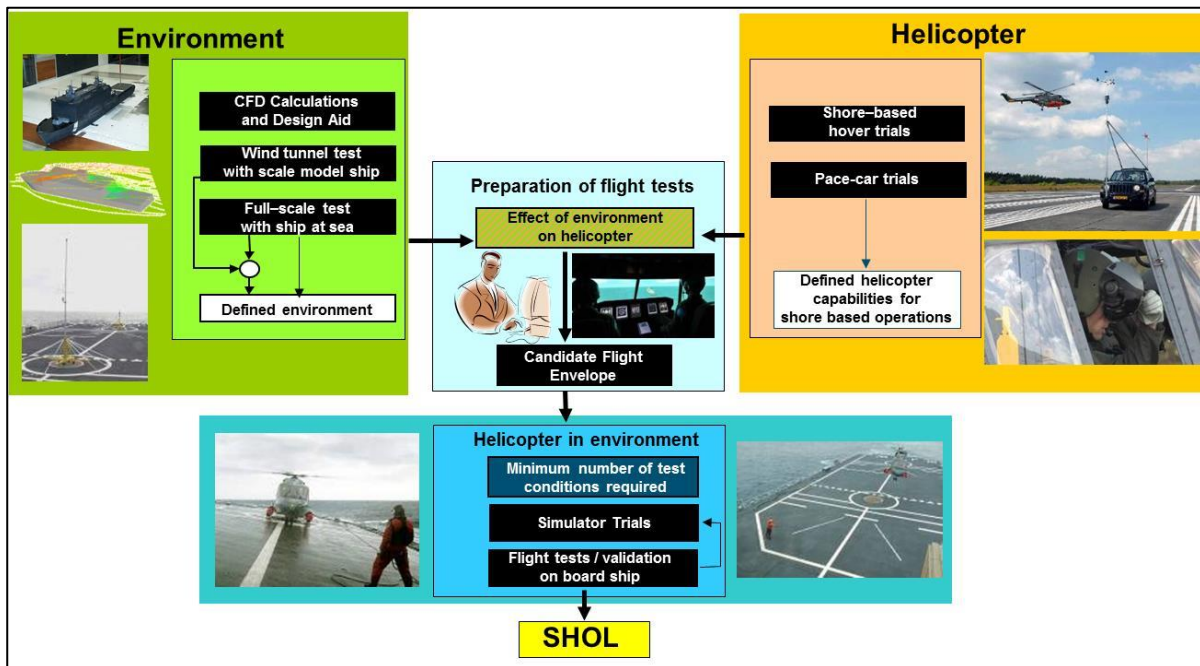


Figure 1: NLR's set-up of helicopter/ship qualification programs

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 in hover 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 night time Candidate Flight Envelopes, no tail wind is allowed (based on pilot comments), even though the helicopter low speed envelope 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.

3. FIRST TRIALS IN 1964 WITH SIKORSKY S-58

As was mentioned in the introduction, the first ship with a relatively small helideck at the stern introduced in the RNLN was the replenisher "Hr. Ms. Poolster". Concerns about the feasibility of helicopter operations in disturbed air from the ship's superstructure resulted in 1964 in an order for investigation of the air flow around the helicopter flight deck in a wind tunnel.

It was realized that with respect to aerodynamics, a ship can be considered as a bluff body with sharp edges. The airflow will always separate at these edges, independent of scale effects, the air flow can be considered to be (almost) independent from Reynolds number. This means representative air flow data can be obtained with a relatively small model in a relatively small wind tunnel, resulting in lower cost.

A 1/100 scale model was manufactured by the MLTB ("Marine Luchtvaart Technisch Bedrijf", Naval Aeronautical Maintenance Organization) at Naval Air Station "De Kooy". The test programme was executed in the low speed wind tunnel at NLR Amsterdam. It consisted of smoke dispersion measurements and airflow measurements. The airflow speed and direction is measured at several locations above and near the helicopter flight deck (helicopter approach paths) and at the ship anemometer positions.

The airflow speed was measured with a hot wire probe. The local wind directions were visualized with tufts on a swinging wind vane arm. Their position was photographed with a top – and a side camera, and their angles measured from the pictures. The wind tunnel test resulted in a data base, a better understanding of the air flow around the helicopter deck and in qualitative recommendations for the execution of helicopter flight operations.

To validate the wind tunnel data, full scale wind climate measurements were executed on board the ship. A 25 ft high mast was equipped with 5 tufts at 24, 22, 18, 15 and 12 ft height, a cup anemometer on top and a cross on top to aid alignment with the ship. The mast was mounted on a fork lift truck to enable positioning at several locations on the helicopter flight deck. Like a windsock, the straight length of the tufts was an indication of local air flow speeds. Information on the local air flow direction was

obtained with the same method applied in the wind tunnel: measuring the direction of the tufts from photographs taken in horizontal and vertical direction (Figure 2).

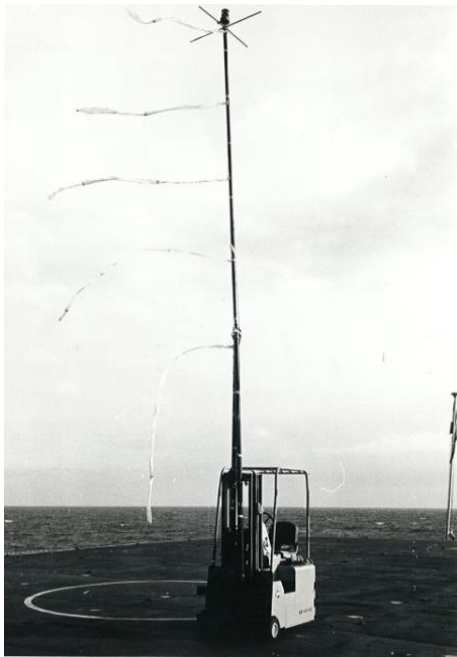


Figure 2 Mast used in 1964 to measure air flow at the helicopter deck with tufts and anemometer on top

It was concluded that there was a good agreement between wind tunnel and full scale air flow data, especially for local air flow speed and horizontal air flow direction.

Flight trials with the S-58 helicopter were executed at daytime in good visibility conditions. Several approach procedures were tested in varying relative wind conditions up to 19 m/s (37 kts) wind speed. The helicopter was instrumented with longitudinal and lateral cyclic stick position pick-ups and an automatic camera in the cabin which recorded cyclic stick positions, airspeed, height, vertical acceleration, rate of roll and the time (Figure 3). The ship was not instrumented. Ship data was read from the ship's instruments and recorded on forms. During 4 days, 4.5 flight hours were executed.

The test results were recommendations for the execution of helicopter flight procedures and ship roll motion limitations. Limitations on wind direction and speed and ship pitch motion were not reached. A standard presentation of SHOLs was not yet developed.



Figure 3 First Dutch helicopter-ship qualification trial with Sikorsky S-58 on board "Hr. Ms. Poolster".

4. FIRST ASW HELICOPTER WESTLAND WASP – NEW TEST METHOD

In 1966, the Westland Wasp AH-12A was introduced into Dutch naval service for operations from the ordered six new frigates of the "Van Speijk" class, based on the British Leander class frigates (Figure 4). The Wasp was designed as an Anti Submarine Warfare (ASW) helicopter for operations from frigates.



Figure 4 Westland Wasp helicopter

In 1971 flight trials with the Wasp helicopter were executed on board the "Hr. Ms. Poolster". For the first time in The Netherlands wind limitations were presented in a polar plot which is now a familiar SHOL presentation, in combination with all relevant information

except the ship motion limitations. These are mentioned separately in the report.

During the seventies, several new ship classes were introduced within the Royal Netherlands Navy, among others the Standard (S) Frigate and the Guided Weapon (GW) Frigate.

The test method in the wind tunnel was changed as well. To obtain information on air flow direction and – speed at several locations above and near the ship model, either a five-hole pressure probe or a hot wire probe was applied. The models of the new frigates were now manufactured by NLR instead of the MLTB. These new frigates had all turbine propulsion. The effect of exhaust gas dispersion, especially the resulting air temperature increase above the helicopter flight deck, was becoming an important factor influencing helicopter operations. In the wind tunnel, quantitative exhaust gas dispersion measurements were added to the existing qualitative measurements (smoke visualization, Figure 5).

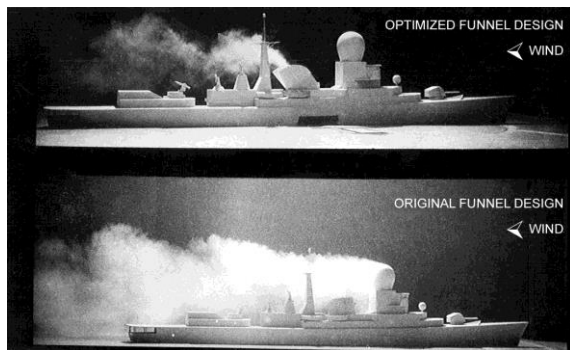


Figure 5 Visualization of exhaust gas dispersion on a model of the GW frigate in the wind tunnel

With quantitative measurements, also called concentration measurements, a known quantity of tracer gas is ejected from the ship model funnel. Its concentration is measured at several locations above the ship model. With this information, the air temperature increase resulting from the presence of the exhaust gas can be calculated. In the same period, a new moveable measuring mast was developed for the full scale wind climate measurements. It was equipped with two Gill-Young 3D propeller anemometers. Each anemometer was equipped with a temperature sensor (Figure 6).

In addition to the mast, a reference anemometer was installed on the jackstaff at the bow of the ship, for the following reasons:

- The air flow deviations, due to the presence of the ship's superstructure, are minimal over a wide range of azimuth angles;
- The air flow deviations are measured in the wind tunnel.

The reference anemometer was also a Gill Young 3D anemometer equipped with a temperature sensor. The temperature sensors were added to enable validation of the wind tunnel data on the air temperature increase resulting from the presence of the exhaust gases.

The concerns with regard to the influence of ship exhaust gases on helicopter flight operations were confirmed with flight trials with the Wasp helicopter.



Figure 6 10m high measuring mast equipped with 3D anemometers to measure air flow at the helicopter deck. A second 3m high mast was added later.

The Wasp helicopter had a limited power margin and was often flown with doors removed to save weight. The pilots were directly exposed to the ship exhaust gases during the flight tests, causing much nuisance. The air temperature increase experienced with the helicopter was in line with the data obtained in the wind tunnel.

The report contained restrictions on the ship's propulsion configuration during helicopter operations in forward wind conditions, in addition to the SHOL's. The latter were presented in a format still familiar in current times.

In the late seventies, in addition to the helicopter-ship qualification activities for the RNLN, the first helicopter-ship qualification programmes are executed by NLR on an former RNLN ship for a customer in South America.

5. LYNX HELICOPTER– COMPLETION DUTCH SHOL METHOD

In 1976, the Westland Lynx helicopter was introduced into Dutch naval service as a successor to the Wasp helicopter. In the period November 1978 - February 1981, helicopter-ship qualification trials were executed on board of 4 RNLN ship classes with the Lynx UH-14A utility and heavier SH-14B ASW versions. During these trials, it became clear that the Lynx helicopter had controllability issues which resulted in dangerous situations on board the ships.

In 1981, it was decided to execute extensive shore based hover trials to find the cause of the controllability issues. The trials were executed by hovering in the prevailing wind at different helicopter headings. In the meantime, the Norwegian Air Force had introduced a Westland Lynx with increased take-off mass of 4876 kg and their crews were trained by the Netherlands Naval Air Service. A second shore based hover trials campaign was a joint Norwegian-

Dutch exercise and executed with a Norwegian Lynx Mk. 86 (Figure 7).



Figure 7 Shore based hover trials with the Lynx helicopter in 1981

The trials proved that the Lynx helicopter had insufficient yaw control in several wind sectors within the low speed envelope given in the flight manual. The resultant new low speed envelope excluded these wind sectors. Westland helicopters amended the flight manual and later versions of the Lynx helicopter obtained among others a tail rotor with opposite direction of rotation (bottom forward) and a larger diameter to cure the controllability issues.

With the shore based hover trials, detailed information had become available of the Lynx helicopter's performance and handling in hover as a function of helicopter mass, air temperature and pressure (combined in the parameter density mass) and wind direction and – speed. In 1984, it was realized that a combination of this information with existing air flow data of the ship could result in a preliminary estimate of the SHOL which excludes the dangerous wind sectors (Ref. 3): Also, knowing the limitations of the helicopter-ship combination beforehand, the SHOL boundaries could be reached in fewer steps than was required previously. This would increase the safety and shorten the duration of ship borne helicopter flight trials.

The preliminary estimate of the SHOLs are called Candidate Flight Envelopes (CFE). The calculation process can include experience from previous qualification programs as well. For example, for night time CFEs, no tail wind is allowed (based on pilot comments), even though the helicopter low speed envelope includes rear wind conditions. The CFE's contain technical limitations (based on e.g. torque and pedal margin) and an estimation of flight technical limitations, i.e. pilot workload. The CFEs are verified and validated with flight tests on board the ship. Next to verification of the technical limitations, the other important parameter defining SHOL limitations is the pilot workload resulting from the combination of a.o. wind conditions, ship motions, vibrations, field of view, etc. These elements are not included in the CFE and therefore need to be tested at sea.

The Dutch SHOL method as described in the second chapter was now complete:

1. Execute wind tunnel tests to obtain data on the airflow around the ship. Each ship class has its own air flow characteristics;
2. Execute shore based hover trials to obtain data on the low speed characteristics of the helicopter. Each helicopter type has its own set of parameters which can be limiting for ship borne operations, and not for land based operations.
3. Construct CFE's based on the previously obtained data
4. Execute helicopter flight trials on board the ship to validate the CFE's and obtain SHOLs.

The Dutch SHOL method has been applied on many helicopter-ship qualification programmes of the Dutch Defence and for international customers. Trials were executed with almost 10 helicopter types with gross weights ranging from 2500 kg to 11000 kg. The flight deck lengths of the ships ranged from 7.6 m to almost 200 m.

5. DEVELOPMENTS IN DUTCH SHOL METHOD

Over the years, many refinements and modernizations have been introduced in the Dutch SHOL method. An overview is given per element.

5.1. Air flow around the ship

Wind tunnel trials on ship models are minimized: Data on air flow direction and -speed are obtained as a function of relative wind direction. Data is taken in a continuous testing mode. This means that the model rotates continuously to vary relative wind direction and no stops are made in order to take a data point. For example, a data point can be taken at every degree. When the rotational speed being used for the turntable is sufficiently low, the movement of the model 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 (Figure 8).

The number of test points can be minimized to a location of a reference anemometer at the bow, the ship anemometer positions, several heights above the helicopter landing spot(s) and at the hover wait positions, approximately 1.5 rotor radius next to the ship.

A cost effective application of CFD within the Dutch SHOL method is currently under investigation.

In 2007, the last full scale wind climate measurement campaign was executed on board the RNLN "Johan de Witt". Again it was proven that there was a very good agreement between airflow data obtained in the wind tunnel and at full scale. NLR decided that full scale wind climate measurements were no longer required (Figure 9).

It is NLR's experience that airflow in the approach path of the helicopter as measured in the tunnel is always in good agreement with the full-scale situation. 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 behaviour as a function of relative wind direction still has to be checked on-board the ship, because small

differences in the ship's wind tunnel model in the area of the anemometers can create large differences between model and full-scale. The air flow data obtained in the wind tunnel are used as a reference for this activity. Verification of the wind measuring system requires up to one day sailing time as opposed to up to two weeks sailing time to execute full scale wind climate measurements.

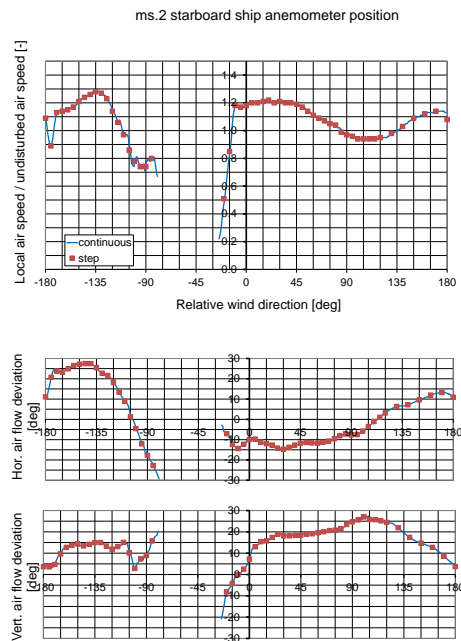


Figure 8 Comparison of 5-hole probe test results in the wind tunnel using the continuous measurement technique and the step by step measuring technique.

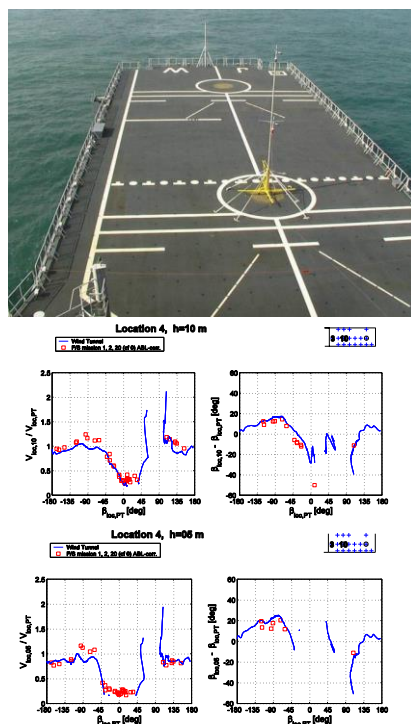


Figure 9 Example of results of last full scale wind climate measurements on board "Zr. Ms. Johan de Witt" (red dots, 2007) compared with wind tunnel data (blue line)

5.2. Helicopter low speed characteristics

In 2009, the final flight test campaign with the Dutch Lynx helicopter was executed on land. In preparation of the introduction of the NH90 helicopter, a flight trials campaign was executed to compare several flight test methods to obtain helicopter low speed characteristics at the most efficient way (Ref. 4). The compared methods were:

- Hover trials: hover in ambient wind, varying the heading to obtain different wind conditions
- Pace car method: generate relative wind conditions by flying the helicopter along the runway behind a pace car at different headings
- Usage of a helmet mounted and panel mounted display to provide the pilot with a reference instead of using a pace car.

In addition to measured parameters, pilot workload ratings were obtained using the DIPES rating scale. All three tested methods produced comparable test results and DIPES ratings with the Westland Lynx SH-14D helicopter. It was concluded that each or any combination of the test methods can be applied to obtain optimum results in given weather conditions in a scheduled test period (Figure 10). Currently NLR executes the pace car method (in combination with hover trials if the wind conditions are present) to obtain the low speed flight characteristics of a helicopter in an efficient test campaign.



Figure 10 Pace car trials with Lynx SH-14D helicopter executed in 2009

5.3. Calculation of CFE's

The construction of CFE's requires many calculations with the available ship airflow data and helicopter low speed data. It also requires a proper way to visualize the results to enable drawing of a CFE. To achieve this, a CFE editor tool has been developed in MATLAB®. This tool calculates the CFE contour in combination with upflow and downflow (Figure 11). The time required to calculate and construct CFE's has been shortened significantly.

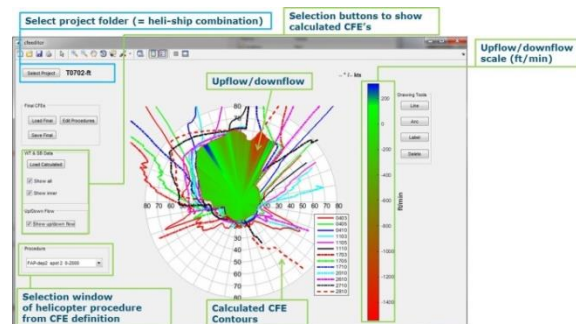


Figure 11 GUI of CFE editor tool

5.4. Ship borne Helicopter flight trials

Over the years, developments in instrumentation resulted in improved efficiency and safety of helicopter flight trials we take for granted now. Improved quick look facilities and application of telemetry allows the NLR test team on the ship to monitor in real time relevant helicopter parameters in combination with ship parameters. Measured data can be processed during the execution of the test flight. The test results are available at the debriefing after the test flight. NLR has developed MATLAB® based test management and – planning tools to efficiently manage helicopter flight trials on board ships (Figure 21). These tools help to minimize the time required for the flight trials. The most recent helicopter ship qualification programme was executed in 2015 and is described in the next chapter.

6. QUALIFICATION OF KAI KUH-1M ON BOARD ROKN SHIPS USING THE DUTCH SHOL METHOD.

6.1. 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 (Figure 12), 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.



Figure 12: The KUH-1M (source: KAI)

6.2. 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 at several measuring stations:

- 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 approximately 1.5 main rotor radius 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 Figure 22).

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. NLR decided on the simplifications, based on engineering experience of many years: no fences, no small antennas, rear ramp modelled as a block.

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 (Figure 13). The test section is 3 m wide and 2.25 m high. For these trials a miniature 5-hole pyramid probe was used. It was mounted on a traversing beam spanning the test section.

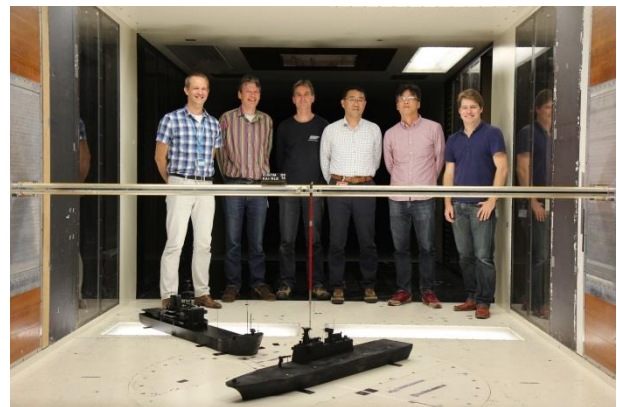


Figure 13: Test set-up for airflow measurements in the Low Speed wind Tunnel of DNW.

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

6.3. Low speed trials

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. 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.

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.

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 was provided to the NLR system for real time monitoring purposes. Ground instrumentation consisted of a GPS system in the pace car (Figure 14) and a meteo mast on the airport, close to the runway (Figure 15).



Figure 14 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 latter contained a Gill Young anemometer installed at 10m height above ground level to measure the true wind speed and direction. Via a 500 meter long anemometer cable the anemometer information was fed via a RS422 signal into a "meteo box". The meteo data was then sent to the KAI mobile control room via a WiFi connection.

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, forming the basis for the test plan for ship trials, in the form of Candidate Flight Envelopes.



Figure 15: Mast with anemometer at Sacheon Airport

6.4. Helicopter/ship qualification trials

The KUH-1M helicopter/ship flight trials were performed in June 2015 and September 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.

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.

In June 2016, a 6-day test period was executed on each ship class.

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.

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 additional trials were performed in September 2015 in a total of 5 days during which 9 flight hours were made. More than 50 test points were cleared.

Slightly better conditions than in June 2015 were encountered: sea state up to 4 and up to 15 knots of wind were found.

Test schedule

On the first day of the first 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.

The flight trials in the first period subsequently started with a familiarization flight. This flight was scheduled to introduce the test crew on-board the ship and to on-board operational procedures, to ensure 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.

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 (Figure 16). 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.



Figure 16 The KUH-1M at sea with the water tank installed (source: KAI)

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 (Figure 17).



Figure 17 Test container on the deck of the ship (source: KAI)

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 Figure 18.

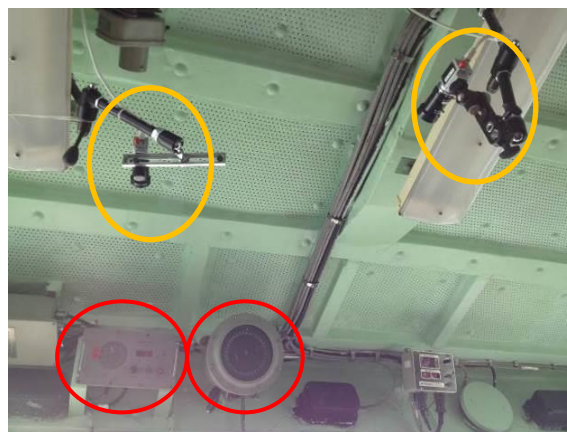


Figure 18 Non-intrusive ship instrumentation (smart cameras) installed in the flyco on board the LST

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. 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.

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 Figure 19. A set of Gill-Young low-inertia anemometers was used to measure the air flow at this position. The data from the bow

anemometer was merged with the helicopter data obtained by telemetry for post-processing purposes.



Figure 19: Reference anemometer at the jackstaff on the bow of ROKN LST

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 Figure 20.

Data processing

During the trials all tested conditions were directly plotted in NLR's test management tool for comparison to the relevant CFE's (Figure 21).

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 ref. 2).

After each mission the flight test data was post-processed and discussed with pilots and engineers.

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 (ref. 1).

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.

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.

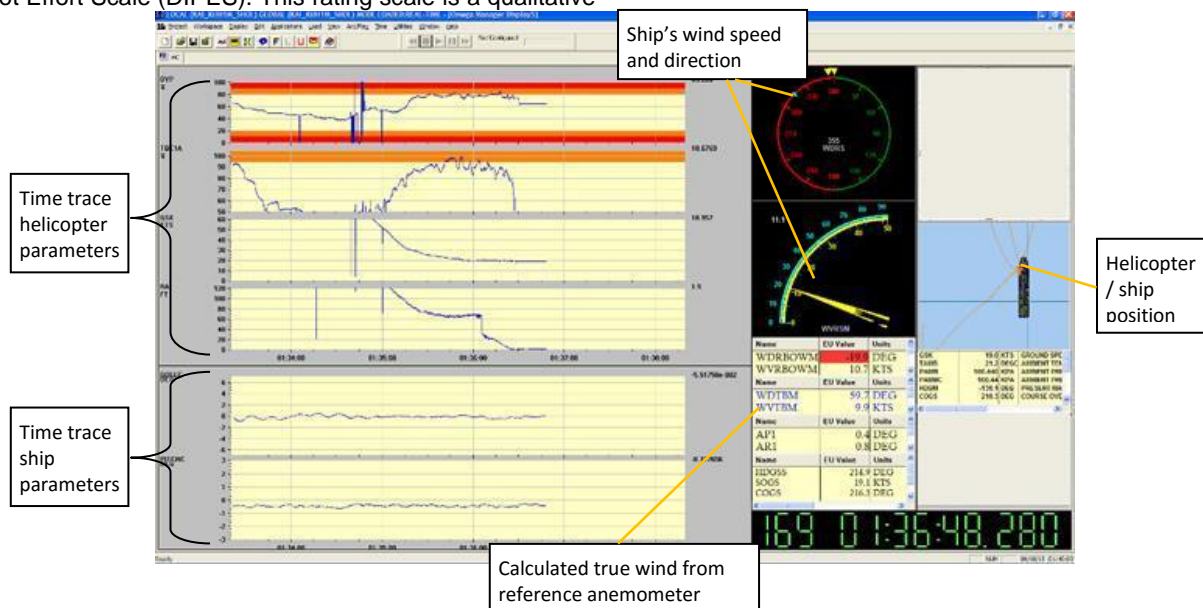


Figure 20 Example of on line data presentation for test supervision.

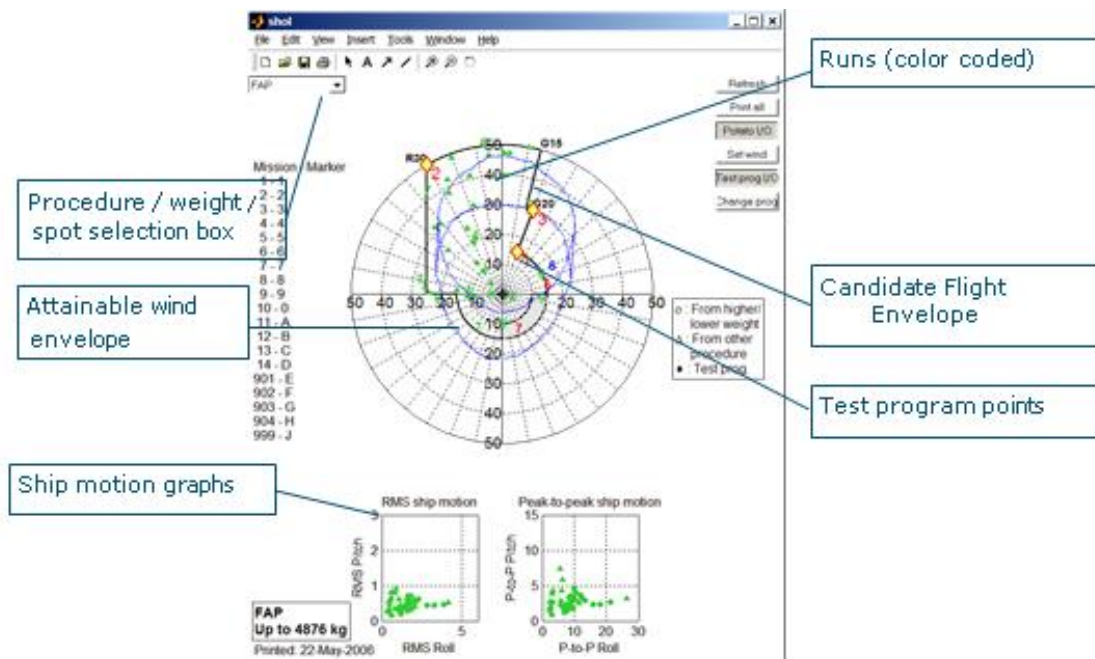


Figure 21 Example of test management tool used during the flight trials (from ref. 2).

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 (Figure 22).



Figure 22 KUH-1M landed at its correct position on the flight deck of the ROKN LST class

7. CONCLUSION

More than 50 years of experience in helicopter-ship qualification has resulted in a safe and efficient test programme to obtain SHOL's for operations of a helicopter on board a ship. A unique approach that combines the airflow around the ship and the helicopter's characteristics

into 'Candidate Flight Envelopes' enables a reduction in test time at sea.

This can be illustrated with the qualification of the KAI KUH-1M on the ROKN LPH and LST classes of ships, executed in June and September 2015. 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.

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