Enabling rotary wing maritime aviation for HMS Queen Elizabeth – turning complexity into capability

A L Dyer* BEng CEng FRAeS, M Walsh*# MEng, S McQuaid* MEng

** Air Test and Evaluation Centre, QinetiQ, Boscombe Down, UK*
[#] Corresponding Author. Email: mwalsh@qinetq.com

Synopsis

HMS Queen Elizabeth is the first of two new generation aircraft carriers for the Royal Navy. Whilst the primary role of the Queen Elizabeth Class is to provide fixed wing carrier strike capability, it has a secondary role supporting amphibious operations using the full range of front line UK rotary-wing types. In order to derive Ship Helicopter Operating Limits (SHOL) to support this capability, Air Test and Evaluation Centre (ATEC) utilised a combination of practical First of Class Flying Trials (FOCFT) and analytical approaches. Whilst a broad overview of the SHOL derivation process is presented, this paper focusses on the conduct of the FOCFT which, due to the size and complexity of the ship and limited time available in the ship's programme, presented significant challenges requiring novel solutions. The Chinook HC Mk 5 and Merlin HM Mk 2 were selected as the trials aircraft as these were both highly relevant to the amphibious assault role and had previously been used to support analytical clearances to other UK types. Typically during SHOL testing, significant time may be spent in positioning the ship to achieve desirable meteorological conditions for test and manoeuvring to give specific relative winds. Further, the test aircraft may spend more than half its time in the circuit. Whenever possible, concurrent trials flying with one Merlin and one Chinook was undertaken to maximise the output from each atmospheric and relative wind condition, with each aircraft conducting multiple landings from a single circuit and approach. Co-ordinating and sequencing the aircraft and test conditions provided a significant challenge, particularly when reaching limiting conditions. Automated analysis techniques were developed and implemented to allow rapid assessment of landing data for each aircraft and operating spot to inform test planning between flights. In total 987 landing evolutions were conducted in little over 2 weeks, including operations by day and night to the maximum all up mass of both the Merlin and Chinook in conditions up to Sea State 5. Analytical methods were then utilised to provide clearances for Apache, Wildcat and recommendations for Helicopter Operations from Ships other Than Aircraft Carriers (HOSTACS) based on the FOCFT data.

Keywords: SHOL; SAI; Helicopter; Flight Trials; Flying Trials; Deck Landing

1. Introduction

1.1. QinetiQ

QinetiQ is a global company of over 6,000 dedicated people providing technological and scientific expertise that helps customers protect, improve and advance their vital interests. QinetiQ was born out of the UK Government establishments and provides services not only to UK military and civilian customers but those of other countries. Ship Air Integration (SAI) is just one part of the QinetiQ portfolio. SAI services include:

- Test & Evaluation
- Advice for operating limits and manuals;
- Data & Evidence Generation;
- Air Flow & Air Pattern assessments
- Ship and aircraft Flight Test Instrumentation (FTI) design and manufacture;
- Aircraft modification and maintenance;
- Consultancy for SAI safety, optimal design and trials programmes;
- Safety Assessments.

Authors' Biography
Anthony Dyer is a Principal Engineer at QinetiQ at MoD Boscombe Down. A Fellow of the Royal Aeronautical Society, and Flight Test Engineer (FTE) Graduate of the Empire Test Pilots' School (ETPS), he has over 30 years' experience in fixed and rotary wing Test and Evaluation.
Mark Walsh is a Senior Engineer at QinetiQ and FTE Graduate of ETPS. He has over 10 years' experience in rotary wing Test and Evaluation.
Scott McQuaid is a graduate in Aeronautical Engineering. Since joining QinetiQ he has been involved in a significant number of ship air integration programmes. He is currently undertaking the FTE course at ETPS.

 https://doi.org/10.24868/issn.2515-818X.2020.061

1.2. The Air Test and Evaluation Centre

QinetiQ and the Air & Space Warfare Centre conduct military aircraft test and evaluation activities under the UK Ministry of Defence (MoD)-QinetiQ Long Term Partnering Agreement (LTPA). This element of the LTPA, which includes the approved framework for operating UK military-registered aircraft and the Government aerodrome at Boscombe Down, is referred to as the Air Test and Evaluation Centre (ATEC).

SAI encapsulates not only Ship Helicopter Operating Limits (SHOL) envelopes for take-off and landing but also limitations for deck operations and the suitability of the ship's aviation facilities. For a given aircraft type, SHOL relative wind envelopes (and associated deck motion limits) are defined for different mass bands, approach/departure paths and visual environments (Day, Night conventional and Night Vision Goggle (NVG) aided).

ATEC and its predecessor organisations have been at the forefront of assessing all aspects of helicopter operations to ships since 1951 and have been instrumental in defining and maturing best practice, flight test principles and instrumentation for safe and efficient testing through in excess of 100 SHOL trials. Where required, ATEC have supported a particular ship/helicopter SAI clearance with a full Safety Assessment covering both air and ship system platforms. The majority of ATEC's work has concerned UK MoD ships and aircraft. However, recent SAI work has been conducted internationally, such as for the Royal Air Force of Oman.

1.3. Background

The MoD has procured two Queen Elizabeth Class (QEC) aircraft carriers for the Royal Navy: HMS Queen Elizabeth, shown in Figure 1 and HMS Prince of Wales.

Figure 1. HMS Queen Elizabeth

ATEC was tasked to undertake Rotary Wing First of Class Flight Trials (FOCFT) on QEC using Merlin and Chinook aircraft. The trials were to gather the evidence required to support SAI of the aircraft to the QEC carriers, providing the largest frontline capability possible. The assessment was to include Day, Night conventional and NVG (including Display NVG) operations at the maximum All Up Mass (AUM) achievable for each aircraft type for the full range of anticipated worldwide meteorological conditions.

From the FOCFT results, ATEC was to provide safety assessment based SAI recommendations for all current UK Marks (Mks) of Merlin, Chinook, Wildcat and Apache to QEC.

Whilst a broad overview of the SHOL derivation process is presented, this paper focusses on the conduct of the FOCFT which, due to the size and complexity of the ship and limited time available in the ship's programme, presented significant challenges requiring novel solutions.

2. Queen Elizabeth Class

The primary role of QEC is to provide Fixed Wing carrier strike capability using the Short Take-Off and Vertical Landing (STOVL) variant of the F-35 Lightning II. The flight deck is provisioned with a Short Take-Off (STO) runway with a "ski-jump" and 6 Vertical Landing Spots (numbered 1-6) for both Fixed and Rotary Wing operations. The runway is also available for Rotary Wing running take-offs and landings.

Each Vertical Landing Spot was sufficiently large to allow the full range of UK military helicopters (including Chinook) to land in any orientation on the deck, though only Spot 3 was provided with secondary Pilot Eye Line (PEL) markings for aft facing operations. From fore to aft, Spots 1-5 were positioned along the port side of the STO runway, and Spot 6 was on the starboard quarter. The flight deck layout and facilities are shown in Figure 2.

 https://doi.org/10.24868/issn.2515-818X.2020.061

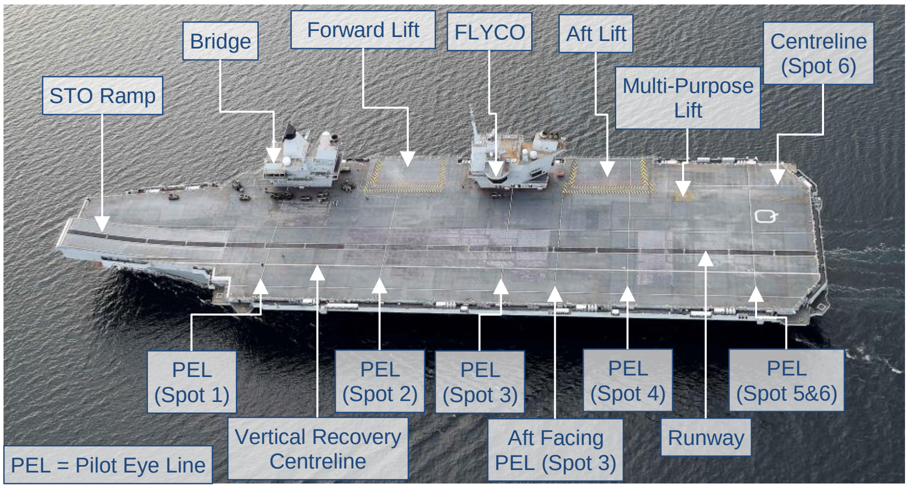

Figure 2. Queen Elizabeth Class flight deck

To support amphibious assault operations in the Landing Platform Helicopter (LPH) role, 14 alternate spots (designated A-P) have been proposed to permit rapid launch of a larger number of Rotary Wing assets. Whilst not formally marked during FOCFT, a number of these extra spots were identified by the intersection of other deck markings, which permitted a limited assessment of this configuration.

There were two superstructures on the flight deck: the bridge was located in the forward island whilst the aft island accommodated Flying Control (FLYCO) and a secondary (emergency) bridge. FLYCO coordinated and controlled all aspects of aviation on the ship (for example; air and deck operations including deck moves to/from the hangar). The hangar was accessible via either the forward or aft lifts.

NVG compatible lighting marked the deck edge, STO runway, the centre line and PEL for each of the spots. White ‘wash’ lighting was provided by the deck edge lights as well as downlights on the forward and aft superstructures. Traffic light signals were provided for signalling aircraft on deck. Large screens were mounted on the islands to provide additional information to the deck crew. The ship was also provisioned with the normal array of maritime navigation and obstruction (mast) lights and additional servicing lights.

The ship was fitted with two stabilised Glide Path Indicators (GPIs) located on the port side catwalk, one adjacent to Spot 5 and one midway between Spots 1 and 2. Each GPI allowed a helicopter to conduct a controlled descent to the ship and was steerable between Red 090° through the stern to Green 090°.

A QinetiQ instrumentation system was fitted which provided an independent record and real-time display of ship’s relative wind speed/direction, as measured by a reference anemometer mounted atop an 18m mast located on the forward flight deck, adjacent to the STO ramp. Additionally, recordings from the ship’s systems of deck motion and relative wind were taken for comparison. The instrumentation data included a Global Positioning System (GPS) time base to allow direct correlation with aircraft data and video cameras during post flight analysis. GoPro cameras were fitted to the flight deck at Spot 1 and Spot 5 to provide a method of estimating landing scatter and rates of closure.

3. Ship Air Integration

3.1. General

SAI covers all aspects of interoperability between a sea system and an air system. The boundary is normally defined from when the aircraft first appears on the ship’s radar through to circuit, approach, landing, deck operations, take-off and departure.

3.2. SHOL Definition

A SHOL is the defined Relative Wind Envelope (wind speed/direction) and associated pitch & roll deck motion limits for a given landing spot that may be used by a specific aircraft type with:

a. A Corrected AUM (CAUM) within a particular band;
b. A particular approach and departure path;
c. Defined visual conditions (By Day or Night (conventional or NVG).

 https://doi.org/10.24868/issn.2515-818X.2020.061

Use of a CAUM ensures the power and control margins established during SHOL trials are not eroded by the variation of atmospheric conditions when in service. The CAUM is the algebraic sum of the actual AUM and a correction provided by the relevant Mass Correction Diagram (MCD) which accounts for the variation in aircraft performance, power and control margins with ambient conditions. Figure 3 shows an example of a SHOL.

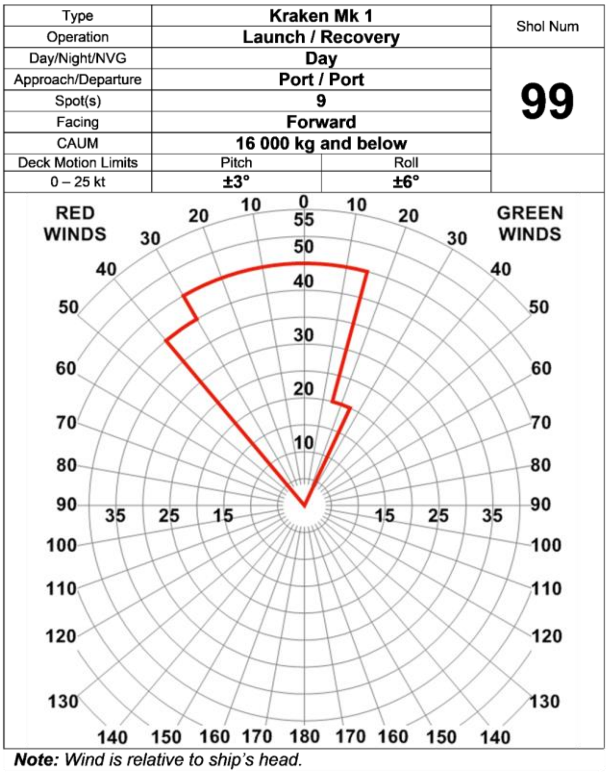

Figure 3. Example SHOL

3.3. Other SAI Aspects

Other SAI aspects require assessment. These include:

a. Securing of the aircraft on deck, lifts and in hangar (i.e. lashing schemes);
b. Aircraft movement on deck, to/from hangar deck;
c. Maintenance;
d. Refuelling/defueling the aircraft;
e. Deck services (i.e. power supplies);
f. Communications;
g. Aircraft re-role (including stores and weapons);
h. Aviation related emergencies;
i. Deck markings and lighting;
j. Approach/Departure type;
k. Visual environment (day or Night/Conventional or Night/NVG);
l. Other SAI aspects (for example rotor start/stop, taxiing etc).

4. Challenges

4.1. Introduction

When operating with a single aircraft type to a single spot ship, notwithstanding other ship duties, the trial team would have sole use of the flight deck and ship programme. Conversely, with a multi-spot ship, two trials aircraft types, other flight deck users (including aircraft) and a busy ship's programme covering all platform systems/requirements, the trial's complexity increases exponentially.

 https://doi.org/10.24868/issn.2515-818X.2020.061

The FOCFT on HMS Queen Elizabeth had to result in sufficient evidence to support SAI clearances for Chinook (all Mks), Merlin (all Mks), Apache AH Mk 1, Wildcat (all Mks) and generic recommendations for operations with aircraft from NATO or other international partner nations (HOSTACS). Leaving aside HOSTACS, if the trials team had been required to rely purely on SAI test data for each aircraft type/Mk and spot (otherwise known as 'test and declare'), this would have resulted in a trial lasting several months requiring tens of thousands of landings at vast cost for the MoD. Instead, the team had to satisfy all the above aims in a trials programme fitted within a 3.5 week window in the ship's programme during which other ships system trials, Replenishment At Sea trials and international visits were scheduled. This presented numerous challenges which required extensive planning prior to the team embarkation to maximise the output from the trial.

4.2. Choice of Trials Aircraft

The Chinook HC Mk 5 and Merlin HM Mk 2 were selected as the trials aircraft as these were both highly relevant to the amphibious assault role and SHOL data from them had previously been used to support clearance by analysis to other UK types. The Merlin HM Mk 2 will also be regularly deployed on QEC to support its primary role.

4.3. Test Efficiency

A big challenge with a multi-spot ship is to reduce the number of spots that require testing for the derivation of SHOL. It is not possible to test every spot in every condition. Considering only a single wind condition there were 21 forward facing vertical landing permutations for each CAUM band for each aircraft (Port Forward Facing to Spots 1-6 and Starboard Forward Facing to Spot 6 under day, conventional night and NVG conditions); not to mention the additional possibility of aft facing, into wind or running landing/take-off operations. Add to this the need to maintain aircraft mass to within 2%, requiring refuels every 20 to 30 minutes (approximately every 5th approach) and a single wind condition could require over 2 hours of test. To reduce the number of spots to be tested, for a given wind condition, Computational Fluid Dynamics (CFD), results from the Air Flow Air Pattern trial and basic aerodynamic theory were used to group spots together and identify those considered worst case. The effect of deck motion was then taken into account (i.e. those with the worst case pitch, roll and heave). This resulted in a small subset of spots to assess for each wind condition. This approach was validated during initial flights. Further efficiency could be made by maximising the assessment of the spots at the highest possible CAUM. Generally, satisfactory results at a higher mass can indicate the same, or better, results may be achieved at lower masses.

4.4. Team Configuration

Due to the compressed timescale of the trial, the number of trials aircraft and the constraint of crew duty time, 56 ATEC personnel embarked the ship. This team consisted of test pilots, FTEs, test engineers, project engineers, FTI engineers, aircraft maintenance engineers, armourers and survival equipment technicians. The majority of the team was split, with half designated to supporting Merlin and the other half supporting Chinook. This allowed for a focus of expertise and consistency of approach for each platform and shift working to make best use of the ship asset.

4.5. Concurrent Testing

Often the longest part of a test condition is manoeuvring the ship to set up the required relative wind. Therefore, operating the Merlin and Chinook aircraft concurrently could save time. However, this relied on both types requiring the same relative wind condition at the same time and being coordinated to make best use of the spots and their fuel band. Additionally, the Merlin and Chinook took different durations to move to the spot for start-up and system alignment. Refuels (that could take up to 30 minutes), aircraft moves, aircraft unserviceability and locations of where to stow the aircraft to avoid denying the other aircraft type access to important spots all had to be considered and planned. This led to complex but flexible choreography to try to satisfy all eventualities.

The majority of the trial was conducted concurrently. The trials were directed from FLYCO with separate lead engineers and support personnel for each aircraft type.

4.6. Ambient Conditions

Often the trials team have no choice of when a trial will take place. This is always dictated by the ship's schedule. However, once known, detailed planning can indicate the best, nearby locations to find optimum conditions. To maximise an aircraft's CAUM, high temperature and low pressure was required. Once in a suitable

 https://doi.org/10.24868/issn.2515-818X.2020.061

location for temperature and pressure, the development of an expansive capability requires the full spectrum of relative wind speeds and sea states.

4.7. Target SHOL

Experience with the Merlin and Chinook on other ship classes as well as detailed SAI and aircraft capability knowledge allowed target SHOL to be derived. These SHOL did not bound the testing but indicated areas where larger steps might be possible during the cautious and progressive development of the SHOL. This aided in the planning and running of the trials from FLYCO. Target SHOL were continuously reviewed against the test results and revised post-flight, if required, to inform subsequent testing.

4.8. Analytical Methods

SAI trials on a multi-spot ship generate vast amounts of data from the aircraft types and also the ship systems. This data is required for trials progression during a flight and also presentation of results/planning for subsequent tests. Over many years, QinetiQ has developed and refined analytical methods and tools to accurately and efficiently process the data. These tools range from assisting basic planning to automatically analysing data post flight. QinetiQ's Graphical Data Analysis System (GDAS) has been modified to take raw data time slices and automatically process them into SHOL plots and other data presentations. As well as saving significant time and giving the Trials Director real-time access to critical data for test progression, the system has largely eliminated human error. These Analytical Methods and the derivation of Target SHOL prior to embarking have also reduced the length of SHOL trials.

The test evidence collected using Chinook HC Mk 5 and Merlin HC Mk 2 aircraft operating on QEC would also need to be used to support clearance for other Chinook and Merlin Mks, Wildcat and Apache AH Mk 1 and underpin generic QEC related HOSTAC advice. This is known as SHOL by analysis. Therefore, the testing was tailored to ensure data was suitable for SHOL by analysis purposes.

4.9. Prioritisation

The MoD had capability priorities covering not only each aircraft type but also the ship requirements. The ship command also had essential aviation personnel training and development requirements that had to be fed into the test programme whilst minimising test impacts. Coupled with this, the team had to be cognisant of the evidence requirements to allow SHOL to be derived for other aircraft types. Again, the task was made easier by establishing a priority list prior to embarkation to maximise trials output. The team also considered factors beyond its control such as unsuitable ambient conditions, ship and/or aircraft unserviceability issues to aid in planning and managing the trials expectations.

5. Test Strategy

The evaluation philosophy was to show, through test, that the Merlin HM Mk 2 and Chinook HC Mk 5 were safe to be operated from QEC at sea. Consequently, aircraft control margins, handling qualities, systems performance and operating characteristics had to be shown to be within acceptable limits for take-off and landing operations. In addition, evidence was required to show all other SAI aspects could be safely conducted. As well as sufficient evidence to enable formulation of clearance recommendations for other Mks of Merlin, Chinook and Wildcat and Apache AH Mk 1 and HOSTACs.

6. Trials Assets

6.1. Merlin HM Mk 2

The Merlin HM Mk 2 is a conventional medium lift maritime helicopter designed primarily for the Anti-Submarine Warfare (ASW) role. The Merlin is powered by three RTM 322 engines and has an Advanced Flight Control System (AFCS).

Two Merlin trials aircraft were used and were representative of the production build standard with the exception of QinetiQ FTI that was designed and installed specifically for the trial. The Merlin trials aircraft are shown in Figure 4. The FTI recorded a wide range of parameters from the aircraft's systems/ARINC 429 Databus as well as dedicated transducers for tail rotor actuator and undercarriage oleo positions. A bespoke display system was fitted at the Mission Console to allow the on aircraft FTE to monitor key parameters in real-time to aid the testing to progress safely and efficiently. The display of the installation is shown in Figure 5.

To allow test data to be collected at up to the maximum possible CAUM, the trials team sought clearance from the Design Authority (DA) for the aircraft to operate at up to 14 850 kg actual AUM as opposed to the normal in service limit of 14 600 kg.

Both trials aircraft were also fitted with port and starboard weapons carriers for all testing. For testing at high AUMs, two or four Stingray Training Variant Torpedoes were fitted to increase the aircraft's zero fuel mass. These torpedoes also provided a safety function in that, in the event of an engine failure or other issue, they could be jettisoned to rapidly reduce weight. Additionally, during take-offs and landings, the impact of torpedoes from a performance and handling perspective is negligible. Therefore, the derived SHOL were not predicated on a specific external stores configuration.

Figure 4. Merlin HM Mk 2 Trials Aircraft

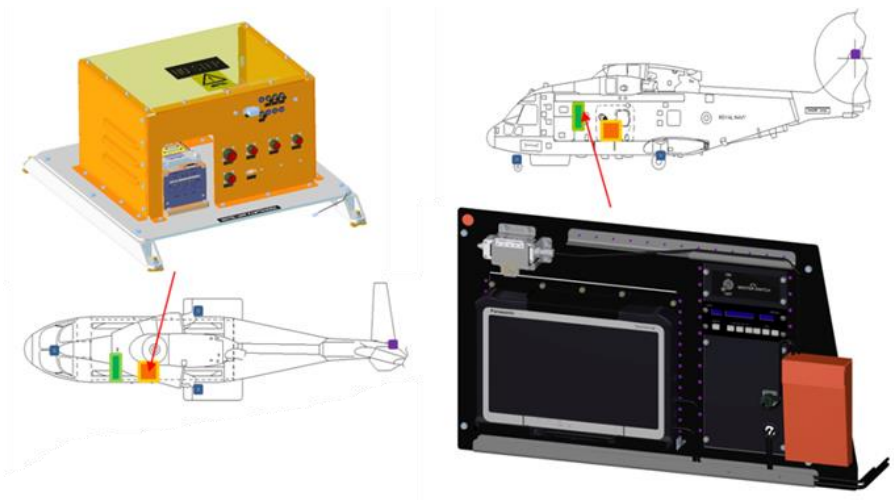

Figure 5. Merlin HM Mk 2 FTI Installation

6.2. Chinook HC Mk 5

The Chinook HC Mk 5/6/6A variants are tandem rotor heavy support helicopters, powered by two Honeywell 55-L-714A Turboshaft engines with Full Authority Digital Engine Control (FADEC). Other common features are the Thales Cockpit Display System, Mission Avionic System and a variant of the CH-47F Digital Advanced Flight Control System (DAFCS).

The Chinook HC Mk 5 differs from the other Mk 6/6A variants by having long range fuel tank sponsons, a longer undercarriage track, nose profile and minor variations in the DAFCS control laws to cater accordingly.

 https://doi.org/10.24868/issn.2515-818X.2020.061

The two trials aircraft were production standard Chinook HC Mk 5 aircraft with the exception of FTI, a ballast scheme and markings that were designed and installed specifically for the trial. The Chinook trials aircraft are shown in Figure 6.

Both trials aircraft had identical QinetiQ FTI fitted which was similar to the Merlin System, recording a wide range of parameters from both dedicated instrumentation transducers and aircraft systems. A portable display system was provided to the on-board FTE and used a common layout to the Merlin system with the relevant engine and control limits adjusted accordingly. The display is shown in Figure 7. The aircraft DA also provided a Portable Bus Monitor that enabled data from the Flight Control Computers on one of the aircraft to be recorded and analysed post trials by the DA.

A ballast scheme, consisting of a mixture of fixed solid ballast and jettisonable water ballast, was fitted to one of the trials aircraft. In combination with aircraft fuel load, the ballast scheme permitted operations up to the maximum AUM of the aircraft of 24 500 kg. In the event of an engine failure or other issue, the water could be jettisoned to reduce weight.

A QinetiQ designed modification using chemical light sticks fitted to the existing cabin sound proofing and structure was embodied to aid aircrew in finding cabin exits during emergency underwater emergency egress.

High-contrast decals were added to the outside of the Chinooks to aid in visual analysis of landing scatter using cameras fitted to the flight deck.

Figure 6. Chinook HC Mk 5 Trials Aircraft with High-contrast decals

Figure 7. Chinook HC Mk 5 FTE Display

 https://doi.org/10.24868/issn.2515-818X.2020.061

7. SHOL Derivation

Whilst conducting air operations to or from a ship, several safety factors are present due to the need to operate in close proximity to the ship. The two main factors are the ship's deck motion and the local air wake effects apparent at and around the ship's flight deck. These factors drive the safety issues of exceeding aircraft control and power margins as well as contributing to increased pilot effort to maintain aircraft position. For positioning tasks, particularly by night (including NVG aided operations), pilot effort can be reduced by appropriate ship deck markings and lighting systems. To maintain adequate control and power margins as well as maintaining an acceptable level of aircraft control, an operating wind envelope with associated motion limits must be derived. These wind and motion limits, the SHOL, are separated into CAUM bands for use with a MCD to determine the appropriate wind and motion limits. Associated advice accompanying the SHOL cover important handling and operating issues.

ATEC has developed methods for determining SHOL wind envelopes and deck motion limits by considering aircraft handling characteristics, aircraft ratings (torque and control margins) in addition to visual cueing and lighting levels. This intelligently applies DIPES and aircraft ratings across CAUM bands, between conditions/spots and in some cases allows extrapolation.

8. Test Conduct

8.1. SHOL

For each aircraft type, the aims for the flight were defined in terms of the factors to be assessed:

a. CAUM band(s);
b. Approach/Departure type;
c. Visual environment (day or Night/Conventional or Night/NVG);
d. Other SAI aspects (for example rotor start/stop conditions, taxiing etc).

The required SHOL was explored in a cautious and progressive manner under the direction of the aircraft Trials Director located in FLYCO. Close cooperation between the Trials Director and ship staff was required to ensure the required flight deck conditions were set up. The Trials Director is a subject matter expert (SME) not only in SAI aspects but also conducting complex trials.

For every relative wind condition, each test point (approach, landing, take-off and departure) was assigned a pilot compensation rating (using the Deck Interface Pilot Effort Scale (DIPES) shown at Figure 8) by the handling Test Pilot. The on-board FTE assigned a dominant aircraft rating based on the real-time display of essential parameters (i.e. Torque peak/mean and/or control margin rating) and pilot feedback. These ratings and key handling notes were passed back to the Trials Director in FLYCO who used this and ship data to decide the next condition to be tested. Frequent refuels were required to keep the mass band within tolerances.

More general details of SHOL derivation and trials conduct are provided in Reference 1 (Dyer, 2007).

 https://doi.org/10.24868/issn.2515-818X.2020.061

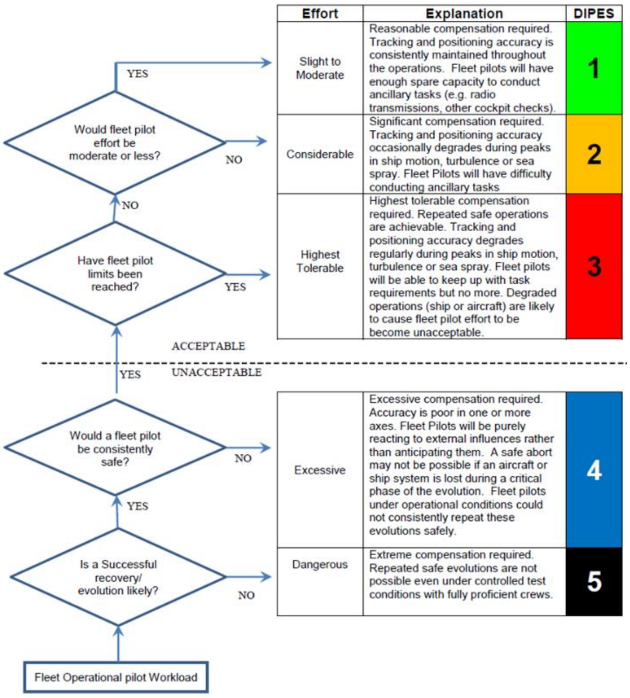

Figure 8. Deck Interface Pilot Effort Scale (DIPES)

8.2. Concurrent Operations

Where the Merlin and Chinook were being assessed concurrently, the Trials Directors would discuss the requirements and flight deck conditions that were needed. Pre-flight, this discussion included prioritisation and sequencing of conditions common to both aircraft as well as determination of any conditions required by only one platform. Often further discussion was required during the flight and the requirements passed to the ship command through established channels. Although the challenges of testing two dissimilar aircraft types at the same time had been anticipated, inevitably there were relative wind conditions that were only required by one aircraft. Additionally, the need to refuel each aircraft did not always coincide. Other aspects served to complicate the execution of the flight, not least changeable ambient conditions (i.e. natural wind strength/direction and increased swell/deck motion); unserviceability and SHOL boundaries.

To alleviate work load, each Trials Director had another FTE/engineer who aided in ship data collection, communications and test discussion. The QEC trials team were fortunate to have FTEs who were experienced in most of the SME roles.

8.3. Landing Sequence/Spot Combinations

To reduce time and fuel spent in the circuit between test conditions, landings on multiple spots were often conducted from a single approach. The specific sequence of landings would be based on prior results to individual spots and CFD and air wake analysis supporting the target SHOL. Aircraft and DIPES ratings obtained for the initial approach to, and final departure from, the deck were applied to all landings and relevant transitions between spots were also considered. To ensure this approach was sufficiently representative a number of approaches to and departures from each individual spot were flown under critical wind conditions.

When conducting operations to multiple spots off a single approach the additional time taken for the test sequence for one aircraft could lead to significant additional time in the circuit for the other. In order to reduce time airborne and hence fuel burn, a “caterpillar” approach was trialled for a number of test conditions. The first aircraft would hold on deck forward during its sequence, allowing the second aircraft to land aft, where it would hold whilst the first took off into the circuit. The second aircraft would then move forward and hold for the first to approach and land aft again (if required). The additional co-ordination required for this technique often led to an overall increase in the total time for each aircraft to complete a given test sequence and therefore offset much of the intended benefit. The quality of test points gathered in this manner were also reliant on wind and sea conditions remaining consistent throughout each combined sequence. Both aircraft also still had to necessarily remain airborne during ship’s course changes. Whilst this “caterpillar” technique did not fully yield the intended benefits it provided a significant training benefit to both the trials team and ship’s company in terms of managing

https://doi.org/10.24868/issn.2515-818X.2020.061

simultaneous operations of dissimilar types to multiple spots. Overall the technique has some merit though may be more effective for a reduced number of landing spots.

Analysis of data from multi-spot landing sequences was simplified by use of QinetiQ's automated SHOL analysis toolset. When provided with the ship's spot layout, instrumentation data and landing sequence, ratings for each spot could be automatically determined. This process was significantly more efficient and less error prone than previous manual analysis methods, allowing the trials team to rapidly generate results and inform test planning. However, the process was dependent on accurate event marking by the on aircraft FTE and correct entry of FTE logs, into the system. Future methods to eliminate this burden may include electronic log cards and/or event tagging for the on-board FTE. Systems for determining relative position of the aircraft and ship are also under consideration as these have the potential to permit automated detection of the flight condition and real, or near-real, time analysis.

8.4. Other SAI Aspects

Although a major part of the FOCFT was to define the aircraft SHOL, as stated above, other SAI aspects required assessment and were scheduled carefully to minimise impact on the ship, trials team and time available for SHOL derivation.

9. Test Results

9.1. General

The FOCFT took place between 2 and 27 February 2018; although the SHOL development activity was constrained to between 12 and 24 February due to external factors. The majority of testing was conducted in the Atlantic Ocean to optimise ambient conditions for wind, deck motion and high CAUM data gathering.

9.2. Merlin HM Mk 2

Over 87 hours of flight testing, the Merlin achieved 539 deck landings across all spots during day, night conventional and NVG operations. The full set of test points are shown at Figure 9.

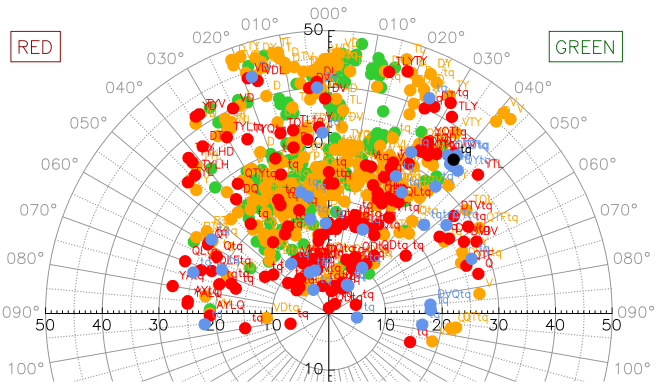

Figure 9. Merlin Landing Data, relative wind in knots.

The trials enabled SHOL to be recommended for aircraft AUM up to the maximum for the Merlin HM Mk 2 in day and night operations. This evidence and technical judgement was used to derive SHOL for other UK Merlin Mks. Associated advice for Merlin air and ground operations, including taxiing on deck was also provided

9.3. Chinook HC Mk 5

Over 67 hours of flight testing, the Chinook achieved 449 deck landings across day, night conventional and NVG operations. The test points are shown at Figure 10. Notable firsts included that it was the first time a Chinook had been accommodated in a ship's hangar, see Figure 11, and taxied on the flight deck at sea.

The trials enabled Chinook HC Mk 5 SHOL to be recommended for AUM up to the aircraft maximum for both day and night operations. This evidence and technical judgement was used to derive SHOL for other UK Mks of Chinook. Associated advice for air and ground operations, including taxiing on deck was also provided.

https://doi.org/10.24868/issn.2515-818X.2020.061

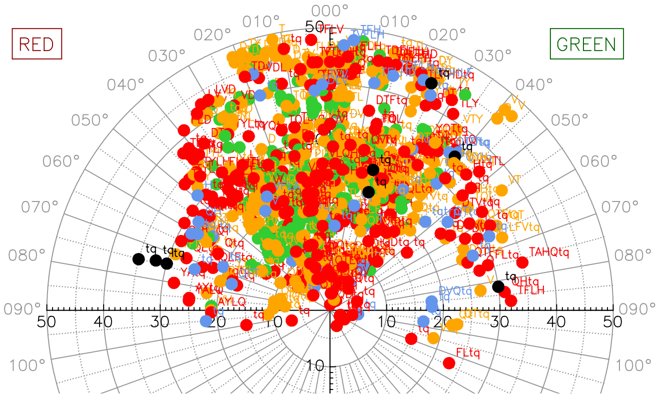

Figure 10. Chinook Landing Data, relative wind in knots

Figure 11. Chinook in QEC Hangar

10. SHOL By Analysis

SHOL by Analysis is used to derive SHOL for a target aircraft type in the absence of any practical data on the required ship class. Over the years, ATEC have established relationships between aircraft and ship types. The methodology uses proprietary techniques to enable trials evidence collected on one aircraft type/Mk to be used to underpin SHOL clearances on another aircraft type/Mk. Put simply, the methodology compares the target aircraft capability in the low speed envelope to other types that have SHOL on the required ship class. The capability of the target aircraft in the ship environment, albeit on other ship classes, is also assessed and relationships are established. Whilst this methodology is cost effective and negates the need for dedicated target aircraft trials on the required ship, it does result in conservative/restrictive SHOL to contain risk levels and may not use the aircraft/ship combination to the best advantage. This methodology was successfully employed to provide SHOL for Wildcat and Apache aircraft on QEC and also underpin generic QEC related HOSTAC advice. The data gathered from an individual landing can be typically reused 10 times to support additional clearances.

11. Simulation

The simulation of helicopter operations in the ship environment is complex. Various models need to be included and interact with each other in an immersive and realistic manner:

- Aircraft models (handling, visuals);
- Ship models (reaction to deck motion, airwake);
- Environmental models (sea, natural winds);
- Visuals (ship, aircraft, environment).

Whilst some simulators are used to purely check procedures and just need to be reasonably representative, the aim is to provide realistic simulations to enable flying currency or qualification training. A longer term aim is to use simulation to reduce the testing required in the real world. The amount of validation required (that is, real world data comparison to simulator results) would depend on the intended use of the simulator. To validate the

 https://doi.org/10.24868/issn.2515-818X.2020.061

simulator for training and SHOL derivation would need to consider many aircraft and environmental variables and draw upon qualitative and quantitative assessments.

Whilst ATEC has been involved in the assessment of several SAI simulations, those involving QEC have focussed primarily on fixed wing operations. That said, QEC CFD model results were used extensively in the derivation of Target SHOL for exploration on the trials. Experience of the aircraft types and also capabilities on other ship classes together with CFD results enabled potential risk areas of the envelopes to be removed. The trials results were then used to check where the Target SHOL were accurate and refine techniques to validate simulations and where aspects need to particularly well modelled.

This iterative procedure has resulted in expanded target SHOL for the Merlin which are currently being validated through flight test. The lessons learned enable the number of test iterations to validate the Target SHOL for service use to be minimised whilst delivering capability. The results also will be fed back into current simulations to not only validate models but also develop future simulators.

12. Continuous Improvement

Although involved in SAI trials from the inception of helicopter operations on ships, ATEC has continued to refine techniques and the approach to such assessments. The FOCFT contributed greatly to best practice, not least in the following:

- Incorporation of Lessons from Experience from previous trials and iterative improvements to a central log;
- The use of experience, modelling and particularly CFD to identify spots with similar airflow/turbulence in order to reduce the testing required;
- Derivation of Target SHOL to allow benign areas to be explored quickly and indicate potential problem areas;
- The need for early involvement of ATEC in the long term planning of an SAI programme and good collaboration with the numerous stakeholders. Involvement in planning and ship construction phases can aid in optimal locating of SAI related facilities (such as anemometry equipment for accurate indications);
- Standard/generic risks have been developed for SAI trials;
- The modular ship and aircraft FTI has been improved in its design and installation. Therefore; it can be easily tailored to the specific ship or aircraft application yielding reduced costs;
- Improvements and automation of analysis techniques has greatly accelerated processes and reduced human error. This means that accurate results are available sooner and trials progression is quicker;
- Techniques to maximise concurrent testing of two aircraft (same or different types) were developed.

13. Concluding Remarks

The QEC FOCFT was the largest ship trial ever conducted by ATEC in terms of both number of trials aircraft and team size. Detailed planning and trials design for flexibility enabled the team to succeed in the majority of requirements. The trials were made easier by a long planning phase that used previous experience to identify challenges and potential issues. Scenarios and resultant issues were played out in the pre-trials phase and mitigations established to minimise negative impacts. As with all flight test, it is not possible to second guess or predict all issues, however, the team was prepared for most eventualities.

Learning from experience has contributed to further refinements in all aspects of the trials process that will benefit flight test safety, progression, analysis and efficiency in future ATEC assessments.

The FOCFT provided sufficient data to support SAI clearances for all current UK Mks of Merlin and Chinook to operate on QEC.

Using the FOCFT data and established proprietary analysis techniques, SAI capabilities were provided for the Wildcat (All Mks) and Apache AH Mk 1. These techniques also allowed recommendations for HOSTACS on QEC.

The Chinook, although not specifically designed for maritime operations, demonstrated new capabilities, not only in maximum CAUM but also the ability to taxy the aircraft on deck and stow it within the hanger at sea.

The FOCFT has further developed and matured best practice which has already helped in the preparation, conduct and analysis of other SAI trials. For the Merlin Mks, a Phase 2 SAI trial on QEC was conducted in 2019 that built on the successes of the FOCFT and has led to greatly increased capability. The extra data sets have also contributed to the SHOL by analysis capabilities for many other UK aircraft types and has shown the cost effectiveness of this approach.

 https://doi.org/10.24868/issn.2515-818X.2020.061

Acknowledgments

The authors acknowledge the contribution/assistance provided by the whole QEC SAI team especially: The Captain and Ship's company of HMS QUEEN ELIZABETH, Royal Navy Command Headquarters, The MoD Chinook and Merlin Delivery Teams. Additional ATEC contributors to this paper included: Natalie Taylor, Gordon Stewart, Harry Boden, Adam Hare, Lt Cdr Steven Baldie and Keith Hardiman.

Reference

Dyer A L: "SHOL Trials – Ship Helicopter Operating Limits", AHS vertical Lift Aircraft Research, Development, Test and Evaluation Specialist Meeting 2007, Patuxent River, Maryland USA.

 https://doi.org/10.24868/issn.2515-818X.2020.061