HELICOPTER MARINISATION

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Abstract: In June 2011, Apache AH Mk1 Helicopters of the British Army's 656 Sqn conducted their first raid on Libya, using as their base the Royal Navy's helicopter Carrier HMS Ocean. The Apaches went on to destroy 100 targets over a five month period, all the while based on board the ship. Meanwhile civil operators fly regularly to and from oil platforms and ships in the North Sea, covering large distances overwater, and dedicated naval helicopters are based aboard ships in the most demanding of maritime environments for months at a time. "Marinisation" may be considered the task of making a helicopter platform and its support system capable of operating in the maritime environment, including overwater and to and from ships. This paper explores the stages of marinisation of a helicopter, from the fundamental issues affecting aircraft operating in this environment, to the specification of requirements, through design and testing to declaration of operating limits. A number of case studies are presented showing how different designs have been tailored to meet customer objectives. In addition AWs aspirations for improving maritime operational capability in the future are discussed.

1 BACKGROUND

From the outset of the evolution of the helicopter, the benefits it offers for operations to small decks on ships have been apparent; indeed during the Second World War, both the US and Germany experimented with landing helicopters on ships at sea and in 1950 the Royal Navy established its first helicopter squadron[1].

Despite the benefits of helicopter use at sea, ship borne operation, in particular the landing, is amongst the most demanding situations a helicopter pilot may experience.

The primary issues that arise with shipborne and maritime operations are as follows:

1.1 Landing and Take-off

Landing and Take-off will be performed only once the vessel's commander has ensured that the ship is on a steady and safe course with the deck "on condition" and the pilot is satisfied that the landing can be performed safely. Nevertheless a high degree of precision is usually required for a deck landing, regardless of the size of the deck: even on a large deck the distance between operating spots is limited and an accurate landing is required. This must be performed in the most demanding airwake environment that most pilots will encounter due to the close proximity of large structures. The non-aerodynamic and sharp-edged structures normally associated with ships' superstructure and hangars cause turbulence as vortices shed over the flight deck, and the location of the flight deck well above sea-level modifies the air flow giving localised vertical flow components and shear effects that the pilot must compensate for when approaching the deck. Added to this is the effect of ship motion which can influence the pilot's perceptions and physically alter the vertical and lateral relative descent rate due to heave and sway as well as reducing stability margins due to pitch or roll accelerations. To further complicate matters certain wind conditions can cause large amounts of spray that will affect visibility from the cockpit. As can be seen, an aircraft optimised for this type of operation must be robust, have high power margins, excellent, predictable handling qualities and be highly responsive in all axes.

1.2 Stability on deck

From the moment the landing gear touches the deck, the ability of the aircraft to remain stable, i.e. not rolling, sliding or toppling, becomes paramount. Many Naval types are fitted with sprag brakes to prevent wheel movement, and restraint devices (such as deck locks) which engage with the deck to minimise the time the aircraft is unrestrained, however these luxuries are not available for many military and civil helicopters. In addition, stability when manoeuvring the aircraft on deck is to be considered.

1.3 Tie down

Landing and Take-off are only authorised by the ship's commander once carefully prescribed steady conditions have been achieved. However, once a helicopter is restrained on deck, the ship is free to manoeuvre and the wind and motion conditions encountered may change rapidly. Tie down schemes must ensure that the landing gear will not slide or lift, whilst preventing overloading of attachment points, undercarriage, other aircraft structure, the lashings themselves or the deck tie down points. Usually a variety of lashing schemes will be provided allowing for lashings from "normal" (benign) through to "storm" (maximum restraint) using progressively more lashing strops. Appropriate limits will apply to each scheme.

1.4 Rotor Engagement and Disengagement

Blade sailing is a well documented effect [2] that results when a combination of winds with high vertical components impact a rotor operating in conditions of low centrifugal force due to running at low speed. When a blade encounters this condition it can experience high elastic bending strains or large tip motions that can endanger the aircraft and ground crew and may result in flap stop contact.

Accelerating the blades rapidly through the most susceptible rotor speeds (typically 10 to 30% Nr) can be beneficial in minimising this effect and relies on a powerful rotor brake to hold the rotor against the engines as they are advanced to ground idle, allowing a rapid acceleration once it is released. On deceleration the brake can bring the rotor rapidly to a halt, thereby minimising the deceleration avoidance band.

1.5 Ground resonance

Ground resonance may occur due to the resonant frequencies of the airframe and undercarriage being excited at certain rotor speeds during rotor engagement or disengagement. By design this effect is minimised when a helicopter is parked with normally pressurised and loaded oleos and tyres. However any lashings attached to the helicopter can affect the stiffness of the overall helicopter "system" and lashing schemes that may be attached whilst rotor running is taking place must be analysed for their effect on ground resonance.

1.6 Safe Flight Overwater

For helicopters expected to operate from land bases it is reasonable to anticipate that time spent flying over large tracts of water will be minimised. However for an aircraft flying to a ship there is a need to ensure that appropriate provisions are in place for coping with an emergency that may result in a ditching into water. This will usually imply not only the fitment of flotation gear, but of a range of analyses and testing to demonstrate safe and effective piloting techniques for water entry, including consideration of the effect of contacting potentially large waves, adequate structural strength of airframe and flotation gear fittings and acceptable flotation characteristics once the floats have deployed.

1.7 Other considerations

Other considerations for embarked operations that may differ from land based operations may include the need to navigate over water, be identified by the "mother" ship (e.g. fitted with I-Band Transponder), have appropriate communications and be sufficiently robust in the electromagnetic environment of a ship, particularly for military operations. In addition, Navigation Systems must be able to be initialised on a platform moving in six degrees of freedom, potentially some hundreds of miles from where on the globe they were last switched off. Maintenance procedures and equipment must be suitable for use in confined spaces and must be adapted to cope with the effects of sea spray leading to salt accretion which can affect the performance of engines and rotors, and lead to a high corrosion rate in susceptible components. The space constraints aboard ships can also lead to Naval helicopters having specific requirements for folding rotors and tail.

2 THE REGULATORY FRAMEWORK

As can be understood from the above aspects, operating any helicopter overwater and to a ship is to expose it to certain risks that may not exist when flying over land. For this reason civil and military Authorities have devised a number of regulations to promote safety, formalise requirements on manufacturers and operators and regulate the use of helicopters in the maritime environment.

Essentially ship-helicopter operations fall into one of three main categories, as follows:

- Military
- Commercial
- Private - Non commercial

2.1 Military Operations

Military operations may be subdivided into:

i. "Blue Water" type Naval operations requiring aircraft designed to operate in the most stringent of environments (Figure 1). Operational use may include, for example, submarine hunting in the mid-Atlantic.

Figure 1. Naval helicopter (AW159 Wildcat)

ii. "Littoral" operations (e.g. tactical lift from ships positioned a short distance offshore) in which a much wider range of helicopter types may be used to operate in normally more benign conditions (Figure 2).

Figure 2. Littoral Operations (Apache AH Mk1)

These types may not necessarily be optimised for maritime operations but will still possess sufficient qualities to enable them to operate effectively in the conditions they will most likely encounter.

It is normal practise for military operators the world over to authorise helicopter operations to ships through extensive testing such as Ship Helicopter Operating Limits (SHOL) trials which enable individual aircraft types to be operated to specific ship classes. This approach enables the maximum possible safe operating envelope for any helicopter type to be established on board a particular vessel, allowing the ship's commander the flexibility to authorise helicopter operations in demanding conditions and with minimal impact on tactical considerations such as ship's heading and speed. However this tends to preclude or at least severely limit operations where a SHOL has not been established for a particular combination.

The Naval requirements in Def Stan 00-970 contain a very demanding set of specifications that embody the worst types of conditions that a Naval helicopter can realistically be expected to operate in. Within Def Stan 00-970 Land based helicopters may be specified to a lower performance requirement.

Limits are normally specified in terms of maximum roll angle, maximum pitch angle and wind strength and azimuth (relative to the ship's heading).

2.2 Commercial Operations to offshore installations including vessels

Figure 3. Commercial Offshore Operations (AW189)

In Europe, the Joint Aviation Requirements JAR-OPS3 Commercial Air Transport Regulations govern the authorisation of the operational use of helidecks for commercial helicopter operators to offshore platforms, whilst in the USA this is done under PART 135 Charter Operations Regulations. Helicopters must meet the requirements of JAR/FAR/CS29. In the UK, offshore helidecks are additionally regulated under the requirements of CAP437 [3] and helideck design considerations are detailed in CAA Paper 2008/03[4].

It is clearly stated within CAP437 that "Operational limitations are ...set by the helicopter operators..." These limits are promulgated through the "Helicopter Limitations List" (HLL)[5], compiled by the Helideck Certification Agency (HCA) on behalf of the main UK North Sea Helicopter Operators. Deck motion limits are not only defined in terms of maximum Pitch and Roll angle but, in contrast to the military, there is also a maximum inclination (i.e. an assumed combination of pitch and roll but not with both reaching maxima simultaneously) and a maximum heave rate (previously heave amplitude in earlier iterations of the HLL). Limits are generic , with helidecks falling into one of three categories (1,2 or 3 depending on vessel type, size or helideck location) and helicopters only being categorised as "category A" (Large) or "category B" (Medium). The resulting limits are by nature somewhat conservative as they have to cover a multitude of helicopter types operating to a large number of different helidecks. These limitations are incorporated into the operators' Operations Manuals and generally only relate to landing and remaining on deck, unrestrained, for a period of time intended to allow loading and unloading of personnel and cargo. In contrast to military operations, lashings are not normally applied unless the helicopter is expected to remain on deck for a period of time longer than approximately 20 minutes.

CAP437 also specifies that all helidecks must record the above parameters using a Helideck Motion System (HMS) and report them to an approaching helicopter as part of a Offshore Weather Report, allowing the pilot to determine whether to make the landing. The HMS should also display a colour indicating whether the deck is in limits (green or blue) or out of limits (red) for landing.

As reported in CAA Paper 2008/03[4], the CAA is also advocating improved methods for determining operating limits in terms of deck motion and wind. The deck motion is reported in the form of a Motion Severity Index (MSI) which determines the ratio of accelerations in the plane of the deck to the acceleration acting normal to the deck. A Wind Severity Index (WSI) is directly related to wind speed. Plotting MSI against WSI gives a curve that can be used to determine the limits[6] [7] [8].

Implications for Aircraft Supplier

As can be seen from the above, to a large extent the emphasis for safe offshore operations is on the helideck designer, the authorising agencies and the helicopter operators. The main implication for the helicopter manufacturer is to demonstrate that the design meets the relevant CS29 requirements. However, it is possible for the Manufacturer to act as an advisor to these parties and to enter actively into the process of ensuring that the helicopter design is suitable for the intended operation, and indeed to indicate what margins may exist in the normally expected operational environment.

2.3 Other civil requirements - Private, non-commercial operations

Helicopters certified to JAR/FAR/CS certification requirements may be landed on a ship's deck at the discretion of the pilot. Ship Building regulations for vessels such as large Yachts[9] regulate the design of the landing area and state that operational limitations may be applied to such a vessel by the Aviation Inspection Body.

As may be seen, there is no specific requirement on the manufacturer beyond achieving certification for the helicopter in accordance with the relevant civil certification requirements for land based operations.

2.4 Overwater Operations

One essential component of ensuring safe operations in the maritime environment is to ensure adequate provisions are in place to promote survival in the unfortunate event of a ditching whilst flying overwater.

The following aspects are of most concern to an airframe manufacturer:

- Vehicle behaviour on entering the water and establishing the best possible piloting advice.
- Airframe strength to minimise damage to primary structure and survival systems
- Provision of Emergency exits
- Provision of Flotation gear - sufficient to maintain the aircraft floating at the desired attitude.

Requirements are laid out in the relevant military (e.g. Def Stan 00-970) and civil (JAR/FAR/CS29) requirements, including forward and vertical descent rates to be demonstrated and the means to show compliance.

In addition there has been a strong drive in the UK to improve the safety of overwater operations in the North Sea and a recent review by the CAA of these operations has resulted in a range of recommendations[10]. which will quite probably impact the approach taken to the above listed aspects, especially those relating to emergency escape.

3 CASE STUDY - MILITARY SHIP BORNE OPERATIONS - AW101 - MERLIN MK4

Figure 4. Merlin Mk4

3.1 Background

The Merlin Mk3 battlefield tactical transport helicopter was procured for the Royal Air Force (RAF) in the 1990s and was specified against the then applicable AvP 970 requirements for land based operations. Operation from ships was not envisaged and structure such as Landing Gear was accordingly rated for landings to non-moving surfaces. Lashing ring provisions are provided for transportability of the aircraft and there is no folding main rotor head and tail.

However, this is all about to change with the aircraft being transferred to the Royal Navy to replace the venerable "Commando" Sea King Mk4. A modification programme is being introduced to upgrade the Merlin Mk3 aircraft to Mk4 and will include the following modifications to make the aircraft ship-optimised:

- Upgraded undercarriage to make the aircraft fully capable for ship borne operations as per Def-Stan 00-970. However it will retain its twin wheel main undercarriage configuration.
- Folding Main Rotor (As per Merlin Mk2)
- New Rear Fuselage and Folding Tail
- I-Band Transponder to enable identification by the ship
- Upgraded Lashing Rings
- Extensive avionics upgrades

In order to provide an appropriate operating envelope for the aircraft to operate to all aviation capable Royal Navy (RN) and Royal Fleet Auxiliary (RFA) ships a three-fold approach will be taken:

i) AW Generates "Deck-Operating" limits
ii) Carry out SHOL Trials
iii) Read across data.

3.2 Deck Operating Limits
Stability, lashed and towing limits

A partly generic method has been taken to applying ship motion (accelerations, deck roll and pitch angles) as a pragmatic approach to clear the aircraft to as many of the specified UK ship types as possible. Customer supplied ship motion data relating ship roll and pitch motions for various "Large" ships has been analysed to find a limiting deck motion condition for application to all analyses (including the Type 45 Destroyer but excluding the Queen Elizabeth Class aircraft carriers that will be analysed separately). Separately a similar approach has then been taken to "small ships" motion which mainly applies to the Type 23 Frigate.

3.2.1 Unrestrained Stability

Analysis of stability while unrestrained determines the onset of toppling or sliding at all aircraft weights due to wind and/or ship motion in the following scenarios:

- With rotors stationary (e.g. just about to commence an aircraft move)
- With rotors running (i.e. having just landed or being at the point of departure after lashings have been removed)

AW uses ADAMS (Automated Dynamic Analysis of Mechanical Systems) to determine lashing, unrestrained and towing limits. ADAMS is a proprietary tool used for analysis of dynamic systems[11] and allows a high resolution, three dimensional visual construction of a system with dynamic components incorporating masses, springs and dampers.

In ADAMS, determination of the allowable motion and wind limits may be evaluated using quasi-static methods. The aircraft is considered to become unstable at the point that the load in one wheel becomes zero or a wheel slides. It is assumed the brakes are on and that the nose wheel is locked fore-aft.

Using the ship motion data the associated accelerations due to sway (lateral), heave (vertical), roll and pitch are calculated. Iterations of modelling allow the combination of the accelerations and wind forces producing a limiting load to be established. It was assumed that head seas (including following seas) produce predominantly pitch motion, while beam and quartering seas will result in roll motion dominating.

Analysis of stability with rotors turning uses a similar approach. However the effects of lift generated by the rotor at Minimum Pitch On Ground (MPOG) are also considered.

Graphs are produced showing relative windspeeds plotted against pitch limits for head seas, and roll limits for beam and quartering seas. Examples of unrestrained stability limits are contained within Figure 5, showing different results for rotors turning and stopped on large and small ships.

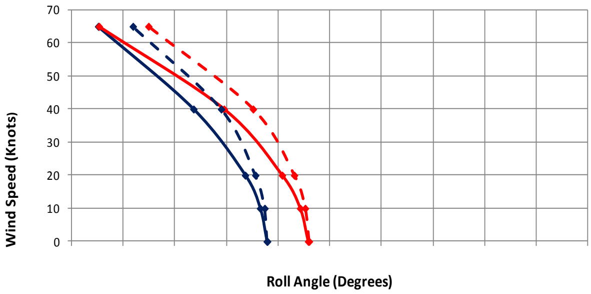

Figure 5. Example unrestrained stability limits.

It should be noted that, due to the coupled nature of ship pitch and roll motion and the unlikely event of encountering a perfect head or beam sea, the pitch and roll limits account for accelerations due to the related roll or pitch motion respectively. As such they can be used in any sea direction conditions. The applicable pitch and roll limits are used simultaneously and operations restricted at the point that either limit is encountered. These limits are tabulated to make it straightforward for the ship's command to apply them in a given condition.

3.2.2 Aircraft Towing

Towing on large ships may be achieved by means of a tractor and tow bar or by a battery powered mechanical handler, such as the Douglas Remote Aircraft Mover (RAM) Handler.

Analysis for towing with tractor and tow bar considers a combination of restrained stability and loads generated through the tow bar and aircraft nose landing gear assembly. It is assumed that an attentive brake man is available to apply the aircraft brakes as required and hence the worst case is always assumed to be sliding with the brakes on.

The output from the stability and towing analysis (tractor and tow-bar) is presented in the same manner as the plots for lashing (Figure 6), and accounts for the worst case alignment of the aircraft on the ship, including across the deck and with the tow-bar at high angles of incidence to the aircraft.

Figure 6. Graphical presentation of limits for unrestrained stability and towing with tractor and tow-bar

Usually a mechanical handler is only for use below decks where wind may be assumed to be negligible, however the analysis also accounts for its use in relative winds from all azimuths and hence allows for the eventuality of using it on a flight deck. This is modelled dynamically using ADAMS (Figure 7).

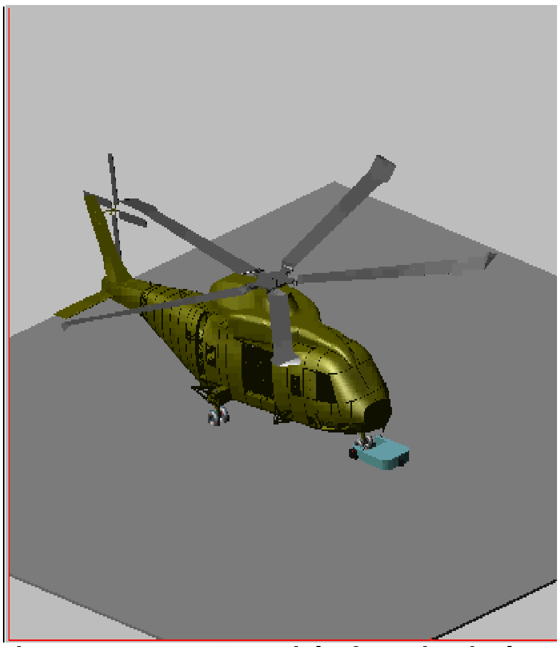

Figure 7. ADAMS model of Mechanical Handler attached to AW101 nose wheel

Results have shown that the stability of the aircraft / handler combination is highly dependent on angular alignment relative to the ship's centreline and hence the clearance is presented as a polar plot of allowable pitch or roll angle against alignment azimuth for a number of different wind speeds (Figure 8).

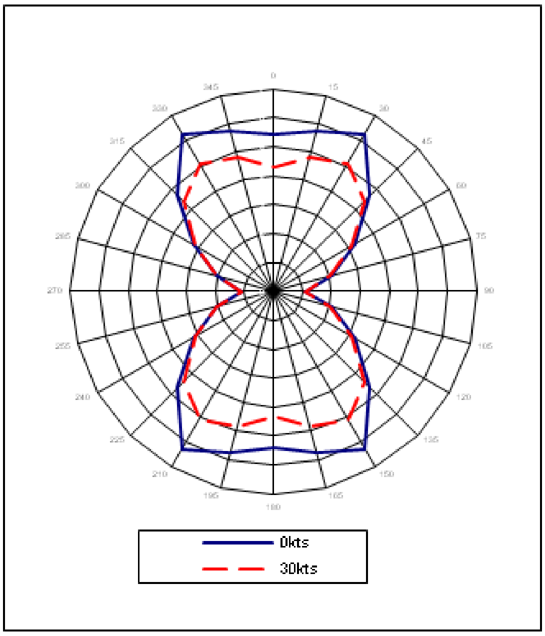

Figure 8. Mechanical Handler Towing Limits showing maximum roll angle for a given aircraft alignment on deck

3.2.3 Lashing patterns

Whilst a generic ship motion has been derived for "Large" ships, the different link plate patterns on different ships leads to very different lashing patterns and therefore loads applied through the lashing rings into the aircraft structure will vary from ship to ship. Lashing patterns have been derived for every ship type specified based on customer supplied deck link plate patterns. Limits are required for three primary lashing schemes:

- Four point
- Eight point
- 16 point storm lashings

The four and eight point lashing schemes allow for loads with rotors running or stationary and also allow for "positional" variations due to irregular lashing point layouts and landing scatter. The 16 point "storm" lashing scheme is assumed to apply to an aircraft optimally positioned.

3.2.4 Lashing limits and loads predictions

Lashing limits are produced in terms of maximum allowable ship pitch and roll angle and relative wind speed.

Allowable loads in lashings are determined by first identifying the design limit loads for structural components in the landing gear and airframe.

Determination of the allowable motion and wind limits is performed quasi-statically using ADAMS.

As for the unrestrained cases, graphs were produced showing relative windspeeds plotted against pitch limits for head seas, and roll limits for beam and quartering seas.

3.2.5 Rotor Engagement and Disengagement

The ability to safely start and stop rotors on board a ship is dependent on avoidance of two critical phenomena:

a) Blade Sailing.

b) Ground Resonance.

3.2.6 Ground resonance

The effects of Ground Resonance during start up or shut down may be significantly affected by the change in system spring rates and damping due to the attachment of lashings to an aircraft. Once lashing schemes have been derived for the aircraft an analysis of the forcing effects on the system is performed. For Merlin this will apply to 4 point and 8 point lashings. No concerns have been found relating to ground resonance when lashings are attached to AW101 with either single or twin main wheel arrangements.

3.2.7 Blade Sailing

Prediction of rotor deflections and loads requires consideration of the effect of winds from various azimuths and with various combinations of ship and rotor phases. Conditions in which blade sailing is likely to occur can then be predicted and appropriate wind limits determined.

Computational Fluid Dynamics (CFD) is used to produce a steady air stream model of the ship with the aircraft modelled in position (Figure 9).

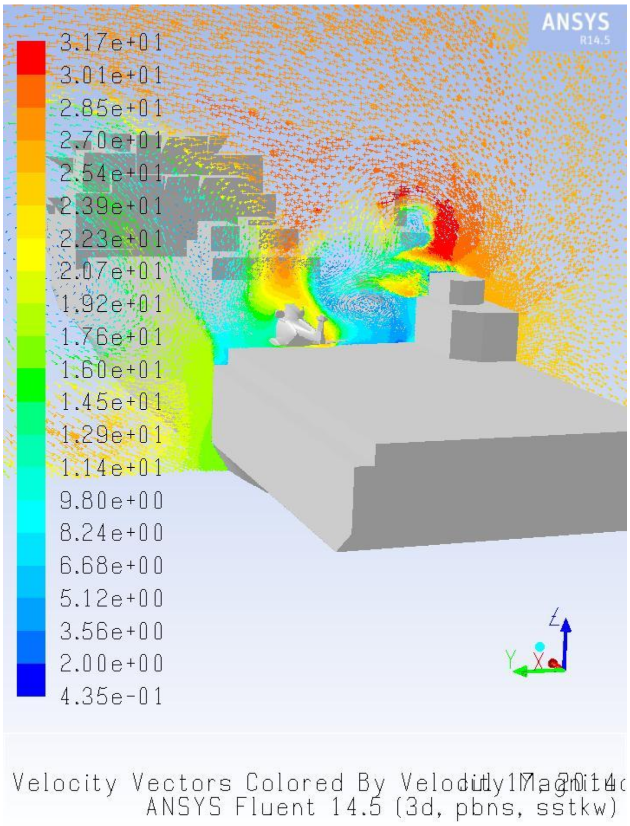

Figure 9. Example of CFD computed airflow over RFA Argus deck with aircraft positioned on spot 1.

This is performed using the Navier-Stokes solutions in ANSYS FLUENT, a commercially available analysis tool capable of analysing steady or unsteady airflows. The ship geometry is obtained in CAD form, simplified and a surface mesh created using Hypermesh or GAMBIT. TGRID is then generally used for the final 3D meshing.

Wind flow over the deck is generated at a number of relative wind angles of incidence, usually at 30 degree increments.

At each aircraft operating spot requiring analysis, the aircraft rotor is represented using a flow extraction "rake" (Figure 10). Each cell in the rake outputs the x, y and z components of flow at that point.

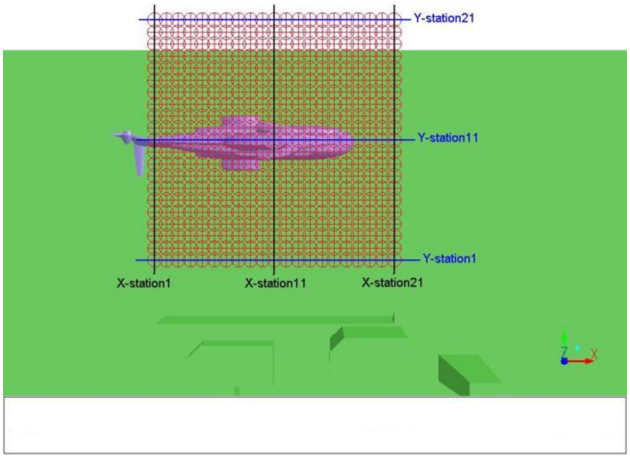

Figure 10. Example of flow extraction rake in the plane of the rotor

An example of the flow over the deck is illustrated in Figure 11, showing the significant asymmetry of the flow field that can occur across the rotor disk (shown as a red circle.

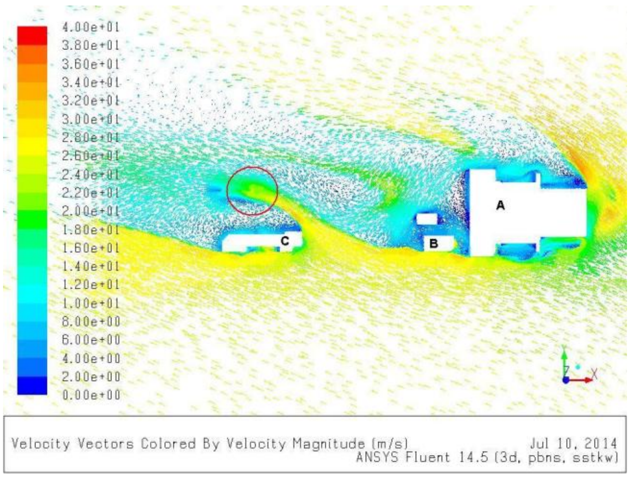

Figure 11. Flow field across the rotor disk (red circle) due to Green 30 wind.

The results from the CFD models are transferred to the AW Blade Sailing Model "SAIL". This is an in-house developed transient dynamic analysis programme that has the facility to predict the individual response of each of the blades to the predicted air flows during run-up or run-down. It also takes into account phasing of the blades' acceleration or deceleration relative to dynamic deck motion up to 15 degrees, with the blades accelerating from different start positions defined by the engineer running the cases. Whilst it uses a steady flow input it also has built-in turbulence criteria to capture transient effects.

Rates of acceleration and deceleration are based on use of the rotor brake. The model predicts both tip deflection (Figure 12) and load during the process.

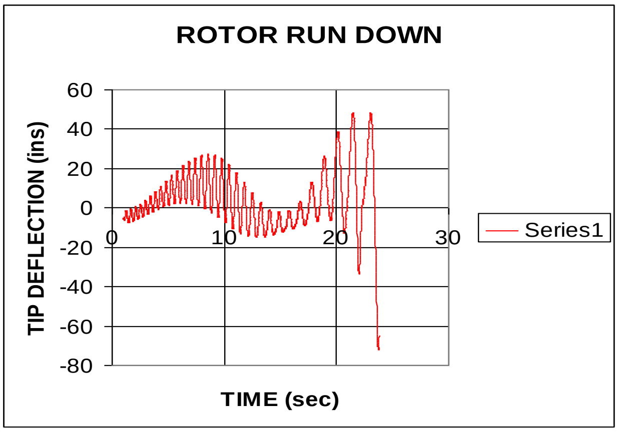

Figure 12. Tip deflection against time during rotor run-down

Compilation of the limiting conditions for all wind azimuths enables both wind and deck motion limits to be derived. This results in a polar plot of wind limits for each spot (figure 13).

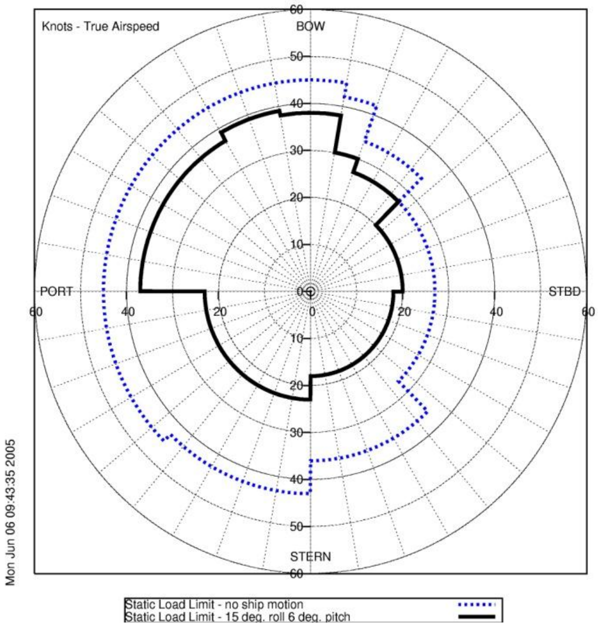

Figure 13. Example of rotor start stop envelope polar plot

3.3 SHOL Trials

While extensive analysis is performed to provide safe operating limits for the helicopter when in contact with the deck, there is currently no analytical method for reliably establishing the flying limits that apply to landing and take-off. This process is reserved for First of Class or First of Type Flying

Trials FOCFT/FOTFT). Whilst these are usually conducted by an Independent Test Establishment, AW has the capability to support these in any way that is required and indeed has formed part of the Combined Test Team for projects such as Apache SHOL Trials in 2004 and AW159 Wildcat SHOL Trials in 2011 to 2013.

3.4 Read Across

Notwithstanding the above discussion, it is possible for AW and the Military operator to read-across operating limits from one helicopter / platform combination to another if sufficient confidence to do so is in place, for example when the likely characteristics of the new combination are easily derived from similar combinations already trialled. However, it should be pointed out that military authorities are under increasing pressure to scrutinise historic Helicopter releases and establish reliable source data, so this approach, which relies heavily on the judgment of experienced personnel, may become less favoured. Nevertheless the Merlin Mk4 is a good example of an aircraft where aspects of its operation that are similar to the already established naval Merlin Mk2 can be read-across. Examples of this will include rotor engagement limits where they already exist for Merlin Mk2, and, once a handful of SHOL Trials for the type have been completed, Mk2 SHOLs may be read-across as long as sufficient similarity is proven.

4 CASE STUDY - SHIP BORNE OPERATIONS - APACHE AH MK1

Unlike their American counterparts the UK's Apache AH Mk1 helicopter was procured with a desire to operate them from ships where the need arose. However the specification for the aircraft recognised that a Def Stan 00-970 compliant solution was not appropriate since this would have to have been built in to the design from the outset. Instead a bottom-up approach was taken including the production of feasibility studies and initial analysis to determine the level of embarked operation that the helicopter may support [12].

Issues considered during this feasibility phase included:

- Landing Loads
- Restrained and unrestrained ship motion and wind limits
- Towing
- Jacking
- Rotor engagement and disengagement (blade sailing)
- Ground resonance
- Ability to fold main rotor
- Space constraints on board
- Maintenance on board and in the marine environment including jacking limits
- Corrosion protection
- Arming on board ship
- Electromagnetic Compatibility when operating in close proximity to ship's transmitters
- Emergency escape in the event of a ditching

The result of this early work was a significant confidence boost and the decision to proceed with Preliminary Ship Interface Trials and then successful SHOL trials that resulted in effective operating limits for the aircraft[12].

Without this "marinisation" activity and subsequent ship integration activities and deployments by the Armed forces it could be argued that Apaches may never have been able to deploy to Libya as alluded to in the Abstract, however, following this deployment an article in "Flight" magazine[13] mentioned that a number of modifications would be required for embarked operations. This was unsurprising since the Apache was never conceived with maritime operations in mind. The level of "marinisation" the aircraft has undergone is appropriate for its role and it will only benefit from further extensive modification should the consistent need for these operations occur. Nevertheless further "marinisation" work continues, including the design of a flotation system.

5 CASE STUDY - CIVIL SHIP BORNE OPERATIONS - AW189

The AW189 is a CS-29 specified Category A rotorcraft that has been selected as part of the UK Search and Rescue (SAR) solution. In this role it may be necessary for the operator to operate over water and to embark to helidecks on ships and floating structures.

The requirements of CAP437[5] and CAP1145[12] therefore apply to this commercial operation in the UK. Unlike Military operations, the platforms are not specified and there is not the opportunity to conduct specific "deck operating limits" analyses or "SHOL" trials. Landing limits are defined with the HLL[7] which also apply for unrestrained operation throughout the period when a helicopter may be on deck.

In support of the AW189 programme AW has determined to generate indicative generic limits taking into account the following:

- Landing Loads
- Unrestrained Stability

5.1 Helideck Motion Calculation

The motion of the helideck is specified within the HLL in terms of roll, pitch and inclination angles and heave rate (m/s).

Since no actual ship motion algorithm is specified, DOD-STD-1399 motion conditions for Sea State 3 and a ship length up to 150m have been applied. Heave accelerations are assumed to behave sinusoidally.

This has resulted in a design value for maximum heave rate of 2.04m/s which may apply during landing or prolonged exposure on deck.

5.2 landing Loads

Landing Gear is designed to meet CS29 requirements. Ground Loads are generated using ADAMS modelling and then assessed for their impact on the gear and the airframe.

5.3 Unrestrained Stability

Aircraft Stability when unrestrained on deck is carried out in much the same way as detailed for military operation, however the generic ship motion derived from DOD-STD-1399 is used to derive the necessary motions, periods and accelerations. The results are indicative since they may not apply to all possible helidecks due to the large variation in ship motion characteristics and helideck locations. Nevertheless they should assist the operator in establishing the margin of safety for embarked operation.

6 SIMULATION

Whilst not the primary focus of this paper, there have been ongoing efforts to improve the simulation of shipborne landings[14]. This may be of particular application to the civil operational environment in that the handling qualities characteristics of an aircraft may be explored in the vicinity of a ship and aircraft design adjusted accordingly at an early stage in development. This may not result in improved limits but could increase safety margins or identify features of the aircraft that could be improved.

Other potential benefits of simulation include:

- Understanding how an aircraft may respond in the ship airwake when a landing onto moving platform is attempted. This will help to establish the potential relative landing rates and corroborate assumptions made in the landing loads analysis.
- Finding target areas for exploration in SHOL Trials
- Defining a candidate SHOL for export customers

7 CONSIDERATION OF POTENTIAL FURTHER WORK

The above examples illustrate the potential for AW to enhance the maritime operation capability of its helicopters but also highlights some areas in which further strides could be taken. The following are three examples:

7.1 Military Shipborne Operations

As can be seen, military clearances are usually predicated upon evidence based on specific tailored analysis and extensive and specific trials. The military authorities are being driven to improve their confidence in the source data and methods and hence the ability to read across from one ship/ helicopter combination to another will only reduce as the evidence comes under closer scrutiny and "judgement based on experience" becomes less acceptable. At the same time availability of suitable "decks" for SHOL Trials becomes ever more limited as ships are fully utilised on operations and tasking can change due to operational requirements.

With this in mind it is important for AW to explore means of producing more robust data to offer to the military authorities and, as far as possible, work to minimise the necessary physical trials work, while maintaining the credibility of the releases offered.

7.2 Civil Ship-borne operations

As can be seen, if the military world is constrained by the difficulties in obtaining credible specific data for given helicopter ship combinations, then the civil operators are faced with the opposite problem of satisfying themselves that generic limits can be applied safely to a host of helideck and helicopter combinations without the luxury of conducting extensive analysis and trials. This suggests that the helicopter manufacturer can contribute a great deal more by assessing the sensitivities of their helicopter to environmental inputs such as local airwakes, and deck motion. There may also be other approaches to be explored to ensure deck motion stays within limits, for example, exploring how best to implement the MSI/WSI scale and any future means of determining deck motion limits.

7.3 Ditching

With increased emphasis on safety for overwater operations, it is timely to consider how helicopter design and analysis of ditching may evolve. Ditching analysis is still at an early stage, meanwhile testing is expensive and realism is also constrained, particularly with regard to the effects of the rotor and any potential for the pilot to control the entry into the water. Improved analysis techniques would enhance early design predictions and enable flotation gear design to be effectively analysed prior to design freeze.

8 CONCLUSION

It is hoped that the above illustrates how "marinisation" can be achieved at different levels for different platforms and can be tailored to the customer's requirements.

AW is keen to contribute its expertise in this field and to respond to the changing needs of its customers, the certifying authorities and regulators and is working to improve its methods in all fields of maritime operations.

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10 COPYRIGHT STATEMENT

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