Opportunities for expanding shipboard-helicopter operational envelopes using modelling and simulation tools

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ABSTRACT

Over the previous several decades, Canada has been developing modelling and simulation tools to provide better information for shipboard-helicopter operations. These tools are used for assessing the impacts of airwake, anemometer measurements, and ship motion on helicopter operations. They also include the communication of better information to pilots and ship personnel. Through existing international partnerships such as NATO AVT, the former NATO Subgroup 61 on Virtual Ships, and the former TTCP AER TP-2, many NATO nations have been developing similar technologies in parallel. In many cases, nations have engaged in benchmarking activities to understand the relative performance of different national approaches.

NATO nations apply these technologies to facilitate the development of their own operational envelopes to varying degrees. Initiatives to support interoperability across various ship and helicopter platforms, such as NATO Helicopter Operations from Ships other Than Aircraft Carriers (HOSTAC), to date do not include a standardized application of these modelling and simulation (M&S) technologies, even though many nations customarily use such technologies. This paper will explore the opportunities to standardize existing M&S technologies to support cross-deck interoperability. For example, standardization in techniques for wind measurement (including applying corrections for superstructure-induced biases) can increase confidence in the wind measurement allowing an expansion of generic operational envelopes.

1.0 INTRODUCTION

Shipboard helicopter operations are extremely challenging owing to the complex conditions pilots are required to navigate during launch and recovery operations. These conditions include highly varying airwakes with turbulence and shear layers as well as complex ship motions. Figure 1 shows shipboard-helicopters conducting at-sea operations. Countries with shipboard-helicopter capabilities normally clear their helicopters to a specified Ship Helicopter Operating Limit (SHOL) envelope which is unique to each class of ship and helicopter pairing. This effort requires extensive, costly, and time consuming flight test trials. The resulting SHOL envelope creates an organic shipboard helicopter capability, and features operational limits that are as wide as possible given the specific ship and helicopter. Cross-deck interoperability of helicopters to host ships from other nations, however, presents a much greater challenge because dedicated flight testing is not typically conducted and many critical aspects of the host ship may differ.

Figure 1: Cyclone helicopter landing on a Canadian HALIFAX-class frigate [1]

There are many factors at play for shipboard helicopter operations as shown in Figure 2. The environment and ship characteristics combine to make the operating conditions for the aircraft, which influence the pilot response during launch and recovery activities. These result in an operational envelope, normally based on Deck Interface Pilot Effort Scale (DIPES) ratings [2] assigned by flight test pilots. Shipboard sensors can provide information on global conditions such as relative wind and ship motions (for example roll and pitch). These are necessary, but do not fully capture important factors that can affect flying difficulty, such as the effects of seaway on ship motion, the dynamic effects of ship motion, the effects of superstructure features and ship motion on airwake flow characteristics and aircraft loading. The nature of dedicated at-sea SHOL envelope development ensures that most of these factors are captured in the SHOL envelope itself, by excluding unsafe conditions as they are encountered during testing. While this approach is effective for an organic ship & helicopter pairing, large uncertainties are present when nations wish to land helicopters on ships owned by international partners. This is due to cross-deck differences in many of the factors shown in Figure 2.

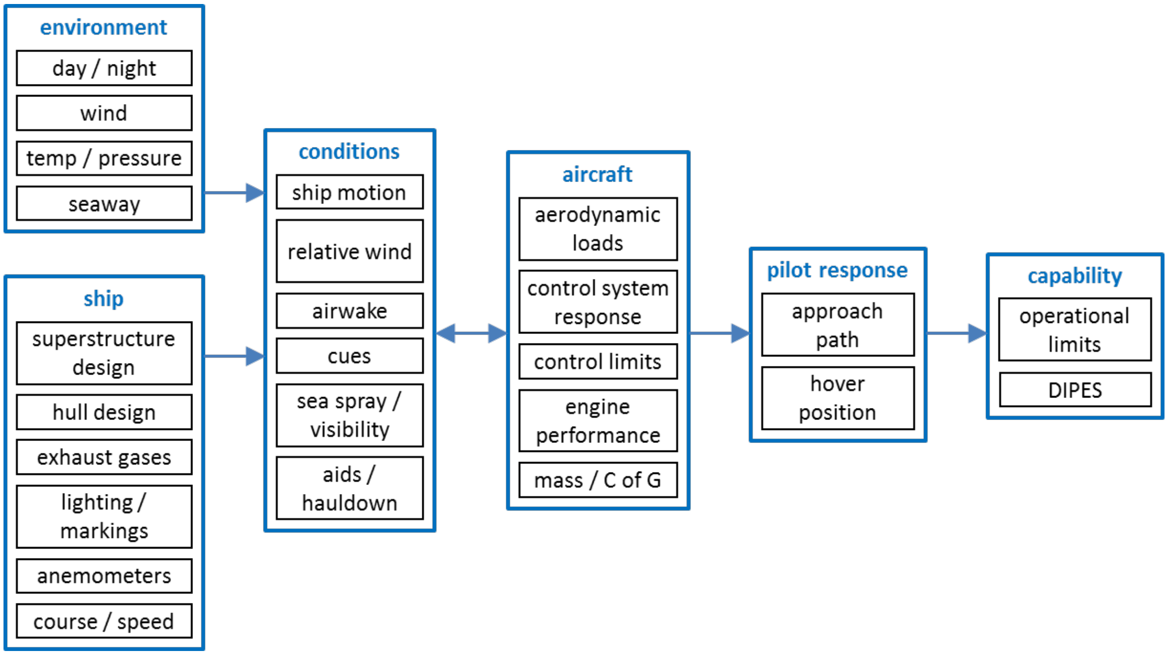


Figure 2: Components of the ship-aircraft interface (SAI)

In order to support safe flying operations and SHOL trials, Canada, as well as other nations, have independently been developing M&S tools to provide insight into operational conditions resulting from the different factors shown in Figure 2. Canada has, for the past two decades, been focused on the first four factors of “conditions” in Figure 2: relative wind, airwake, ship motion, and cueing. These tools are used to more accurately assess the conditions in which the aircraft is operating and increase the confidence in operational limit setting and optimize those limits.

Many international initiatives (primarily NATO), exist on the subject of individual aspects of M&S to promote better tools for each individual nation, and in some cases, standardization. National approaches vary based on national needs and available capabilities resulting in differences that can make it difficult to share tools and information needed to assess SHOL for another nation's ships and aircraft.

Over the years, there have been some international initiatives in an effort to improve cross-deck interoperability. For example, the DIPES rating scale [2] sought to standardize pilot ratings in order to provide more insight into those factors affecting the establishment of operational limits. While the DIPES scale definitions are standardized, the flying difficulty at which each rating increment is reached may vary from nation to nation based on the flight test pilot's assessment of the ability of that particular nation's pilot training standards and acceptable operational safety levels. The HOSTAC (Helicopter Operations to Ships other Than Aircraft Carriers) [3], under NATO, has standardized a process for clearing helicopters to cross-deck platforms. HOSTAC addresses many elements of standardization for shipboard-helicopter operations, but because there is variation in the information used to derive the limits ("conditions" in Figure 2), the operational envelopes are generally quite conservative compared to organic SHOL envelopes. HOSTAC envelopes are based on a combination of the host nation's organic SHOL envelope and generic envelopes, where the degree to which the different factors in Figure 2 are taken into account is not standardized. Although current practices for cross-deck operations do not make allowance for different operational envelopes depending on the helicopter type and nation, these standard practices can no doubt be improved to allow more operational capability by leveraging the modelling and simulation standardization discussed in this paper.

One opportunity to improve cross-deck interoperability is to standardize some of the factors under "conditions" in Figure 2. This standardization could allow wider standardized envelopes or each nation could independently determine safe interoperability limits that take into consideration any national differences in DIPES scale increments. This paper discusses, in this context, the four factors of "conditions" shown above: relative wind, airwake, ship motion, and cueing.

2.0 RELATIVE WIND AND ANEMOMETER BIASES

Relative wind involves an assessment of the prevailing true wind conditions combined with the ship speed. The relative wind is strongly correlated with the airwake characteristics over the flight deck; therefore, a measurement of relative wind allows pilots to evaluate whether a launch and recovery procedure is safe based on established limits. Shipboard anemometers are subject to inherent biases due to a number of factors, including the distortion of the wind around the superstructure of the ship as shown in Figure 3. When SHOL envelopes are determined for each ship-helicopter pair, the existing anemometer biases are inherent in the resulting operational limits and therefore do not affect the definition of the widest possible limits. However, if the anemometer biases change, then the previously defined SHOL envelope becomes invalid and the SHOL must either be re-established through extensive testing, or the change in the biases must be carefully assessed and the SHOL envelope corrected. A mid-life refit or some other engineering change to a ship may necessitate such a process. SHOL envelopes are typically defined with a resolution of 5 degrees on relative wind and 5 knots on wind speed. Therefore, a bias or other factor that induces an uncertainty on the order of this resolution will likely affect a standardized SHOL accordingly.

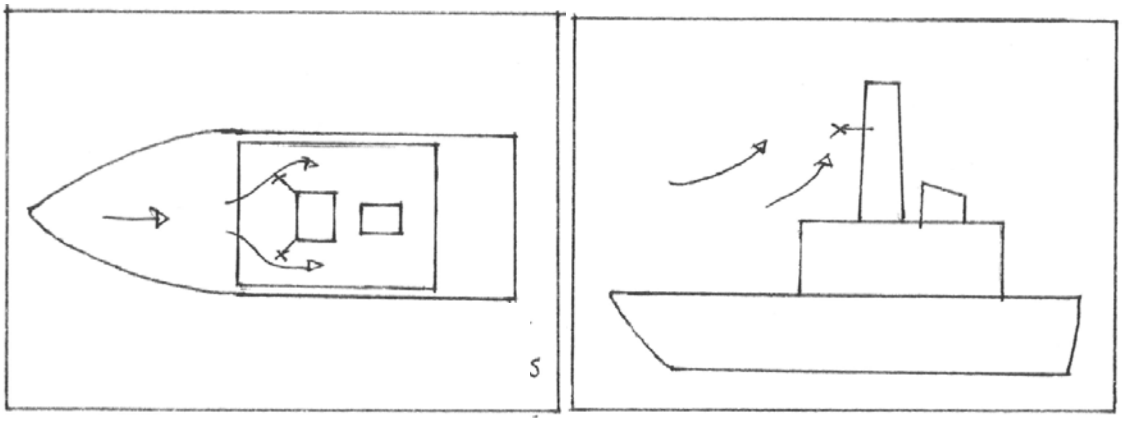


Figure 3: Distortions to wind speed and direction at anemometer locations caused by the ship superstructure.

Anemometer biases can be assessed using computational or experimental aerodynamic simulations. These simulations are used to compare the prevailing (undistorted) relative wind to the distorted wind reading at the proposed or installed anemometer location. The calculated biases can be used to recover the relative wind or, in combination with ship course and speed, the true wind conditions. Parameters for appropriate ship airwake simulation, both computational and experimental, have been well documented by NATO working groups AVT-148 [4] and AVT-217 [5], where both references contain extensive literature lists on the subject of ship airwake simulation.

The desire to perform cross-deck launch and recovery operations to different NATO ships could introduce an uncertainty associated with anemometer readings since there is no standard for assessing and accounting for anemometer biases. Fundamentally, two different ships in the same actual wind conditions could have significantly different readings of that wind due to these biases; the impact of this potential difference on cross-deck operations could be significant.

Although no standards currently exist, the concept of anemometer biases has been discussed in the international setting, particularly by NATO working group AVT-217 [5]. This task group discussed anemometer placement from the perspective of ship design guidance, where poor anemometer placement can lead to readings that are unusable for various reasons. This working group established that most nations have processes for ensuring reasonable anemometer placement and reliable usage for ship operations, which usually includes some assessment of bias characteristics. Since the time of publication, many nations including the US and Canada, have expanded their work on anemometers to include the concept of bias correction for more accurate wind readings onboard.

2.1 Effect of Standardization

In order to fully standardize ship anemometer readings so that the relative wind information is consistent among NATO ships, a number of aspects of an anemometer system could be considered:

- Speed and direction quantity: Typical anemometer readings provide a wind speed and direction measured in the horizontal plane. Significant updrafts, present for certain relative wind angles for certain anemometer placements, may affect horizontal speed readings for some instruments; or the wind speed magnitude may differ from the horizontal component of the speed.

- Anemometer type: Studies in Canada have shown that the dynamic effect associated with dynamic devices such as propeller-vane anemometers can cause errors in wind angle readings of over 7 degrees for reasonable anemometer placements for certain relative wind directions. Heated ultrasonic anemometers are now being used by many NATO nations in place of legacy propeller/vane/cup-style instruments to, in part, avoid such uncertainties.
- Alignment: Visually aligned anemometer units can easily have alignment errors in excess of 5 degrees. A standardized alignment procedure could easily eliminate this source of uncertainty.
- Angle biases due to ship superstructure distortion: Relative wind direction biases are caused when the flow direction at the anemometer location is changed by the ship superstructure. Canadian studies have shown angle biases of over 10 degrees for reasonable anemometer placements for certain relative wind. This level of bias is equivalent to two SHOL angle increments.
- Speed biases due to ship superstructure distortion: Speed biases can be caused when the flow speed is altered by the ship superstructure and can be in the order of 5 knots (~20% at 25 knots) for reasonable anemometer placements for certain relative wind directions. This level of bias is equivalent to one SHOL angle increments at 25 knots relative wind speed and scales as a percentage.
- Speed biases due to atmospheric boundary layer: Speed biases also depend on the anemometer height due to the changing wind speed associated with the atmospheric boundary layer. Depending on the anemometer height and boundary layer profile, this level of bias could be equivalent to one SHOL angle increment at 25 knots relative wind speed and scales as a percentage.

The process of systematically measuring and accounting for anemometer biases is part of a process called anemometer bias management in Canada. A standardized process that requires that anemometer biases due to ship superstructure distortion be established and published for each ship could allow relative wind measurements to be compared more directly with an improved accuracy of one or two SHOL increments. Standardized anemometer type and alignment procedures can also reduce the uncertainty between ships.

Documentation of anemometer biases is not costly, and is indeed already being carried out by many NATO nations for their own purposes. The most cost-effective standardization would allow sharing of these biases between nations without the requirement for individual ships to modify their instrumentation or operations. A more involved standardization could include correcting anemometer readings aboard all NATO ships and/or standardizing anemometer type, alignment, and reference height.

3.0 AIRWAKE

The airwake over the flight deck of warships is highly turbulent and characterized by flapping shear layers and recirculation zones. Shipboard helicopter pilots are required to navigate this changing flow field during launch and recovery operations, and this element of the task is often a dominant reason for the establishment of operational limits, particularly for high relative winds from the bow.

Aerodynamic modelling of ship airwakes is a mature field that has been addressed by many countries over the past several decades. The former TTCP AER TP-2 working group developed a standardized ship model (SFS2) for the purpose of comparing ship airwake CFD solutions calculated using different techniques. Aerodynamic modelling can be done experimentally or computationally, provided appropriate attention is paid to basic simulation details, such as scaling, model fidelity, incoming flow profile, and computational details or experimental instrumentation. Both computational and experimental methods have been shown to adequately reproduce flow field characteristics when compared with at-sea measurements, provided they adhere to common practices, as outlined by NATO AVT working groups on the subject [4,5].

A new AVT working group, AVT-315, is using a new standardized ship model (the Generic Destroyer) which will be used to compare different national airwake calculations or measurements and also to compare different national operational limit analysis methods.

3.1 Effect of Standardization

Although NATO nations, through the AVT working groups, have parallel airwake simulation capabilities, the interpretation of such information is not standardized, nor are airwake flow fields calculated or measured for host ships made available to nations who might wish to perform cross-deck operations. Additionally, individual national approaches for incorporating airwake information into operational limit analysis are far from standardized.

As a minimum, creating an airwake database where the individual airwakes from different international ships were made available to other nations would allow cross-operating nations to complete their own national operational limit analysis on host ships thereby allowing pilots foreknowledge of the host airwake conditions are they compare to their own national standards. Even if this process does not affect the standardized SHOL envelope, cross-platform operations would benefit from reduced risk by arming pilots with more information about host platforms. Such a database could be easily created, by using existing airwake data already owned by many nations. For higher fidelity information with higher effort associated, airwake data conforming to certain requirement with respect to flow characteristics such as data type and grid density would allow international operational limit analyses to be conducted much more readily.

Airwake information could also be used to set standardized SHOL envelopes by informing the level of flying difficulty due to airwake behind different platforms, provided international working groups can standardize methods for interpreting airwake data in an international context. The working group AVT-315 will likely produce results that could further this concept.

4.0 SHIP MOTION

Simulation of ship motions related to helicopter motions is relatively mature, with various approaches available. The simplest reliable methods for predicting ship motions in waves provide linear motions in the frequency domain using strip theory, which assumes that a ship is slender and can be modelled using a number of two-dimensional sections along its length [6]. Strip theory methods assume potential flow, and should be supplemented with semi-empirical approaches for appendage (for example the rudder) and viscous hull forces, which significantly influence sway, roll, and yaw motions [7]. In spite of its simplicity, linear strip theory works surprisingly well for applications such as helicopter operations because the subject ships are generally slender and operations are limited to moderate wave conditions. Response amplitude operators predicted in the frequency domain can form the basis for generating ship motion time series for a ship with prescribed mean speed, mean heading, and seaway modelled by a series of sinusoidal wave components.

Increased theoretical knowledge and computational capability have enabled application of more sophisticated ship motion models. Canada’s ShipMo3D ship motion library [8] uses a panelled hull model coupled with a three-dimensional method for evaluation of ship hydrodynamic forces. Figure 4 shows a ShipMo3D ship model.

Hull hydrodynamic forces arising from radiation and diffraction are evaluated in the frequency domain. Subsequent evaluation of ship motions can be performed directly in the frequency domain, or by evaluation of time domain force terms that can then be used for time domain simulation of a freely manoeuvring ship [9].

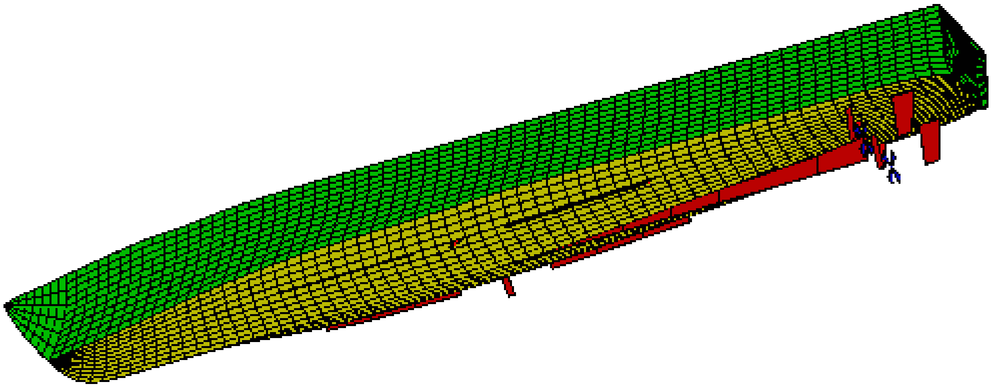


Figure 4: ShipMo3D ship motion model, including wet hull, dry hull, and appendages

For time domain simulation based on force evaluation at each time step, hull forces arising from buoyancy, incident waves, wave radiation, and wave diffraction are often assumed to be linear. Some of the hydrodynamic nonlinearities can be captured relatively easily by evaluating the buoyancy and incident wave forces using the instantaneous wetted surface of the hull. This approach can give more realistic roll motions when simulating ship motions for helicopter operations. In general, wave conditions during helicopter operations are sufficiently moderate that radiation and diffraction forces can be treated as linear with motion amplitude and wave amplitude respectively. Time domain simulations incorporating nonlinear buoyancy and incident wave forces run approximately 10 times faster than real time on a single processor.

To enable broader application of modelling and simulation to naval platform operations, NATO Subgroup 61 on Virtual Ships developed a related standard [10,11,12]. The standard aims to facilitate commonality and interoperability of simulations, with emphasis on modelling the ocean environment and platform motions. Detailed specifications are given for coordinate systems and data shared among simulated entities. The Virtual Ships standard includes modelling of entities that can have physical interactions during operations such as replenishment at sea, and launch and recovery of air or water vehicles. For example, two ships performing replenishment at sea will experience hydrodynamic interactions and will also experience force interactions with replenishment gear. For ships engaged in naval air operations, it is usually reasonable to make the simplifying assumption that forces imparted by air vehicles will not affect the ship motions. Consequently, ship motion time series can be produced and then provided to air vehicle practitioners for further application.

4.1 Effect of Standardization

When simulating ship motions for helicopter operations there are several areas in which standardized approaches could be adopted. Modelling and simulation of ocean waves is a key and relatively simple area for standardization. McTaggart [13] describes modelling and simulation of ocean waves for prediction of ship motions. Ocean wave properties are dependent on water depth. For simulation of shipboard-helicopter operations, it is reasonable to assume deep water, with water depth being greater than 0.5 times the longest wavelengths in the given ocean environment. A simulated seaway can be uni-directional or multi-directional. The assumption of a uni-directional seaway is generally reasonable for simulation of helicopter operations. To approximate random ocean waves in the ocean, the modelled seaway should consist of a multiple wave components. Approximately 40 or more wave components are recommended. Frequencies associated with wave components can be evenly distributed, or can have randomized increments to avoid repetition of wave elevations associated with a uniform frequency increment. The Bretschneider wave spectrum is commonly used for seaway modelling, and can be used for determining amplitudes of modelled wave components. Phases of wave components should be randomly generated to produce a realistic seaway.

Assuming standardized seaway characteristics and ship motion modelling techniques discussed above, different ship platforms can be compared with respect to the landing difficulty associated with ship motion. Similar to airwake, access to this standardized information for different platforms, either in database format or as incorporated directly into a standardized SHOL envelope, has the potential to derisk and expand helicopter operations to host platforms in ship motion conditions.

5.0 CUEING

Once the operational limits are established for a given helicopter/ship pairing, taking into account the effects of anemometer bias, airwake, and ship motion through the various approaches of modeling, simulation, test flights, and sea trials, they must then be applied in practice. Ensuring compliance to SHOL requires that operators have real-time awareness of the limiting parameters, typically expressed in terms of relative wind and flight deck motions.

5.1 Wind Limits

The aircraft must be able to maintain stable and controlled flight over the flight deck within the airwake of the ship. When that wake flow becomes too strong or too turbulent then a limit is imposed based on the relative wind condition generating the wake as measured by the ship’s anemometers. Different limits may be needed for different operations (for example launching or in-flight refueling) as well as for different conditions (for example heavy or lightly loaded aircraft; or day or night). Operators therefore need a tool that allows them to select the appropriate wind limits for the current activity, and then to show the current wind conditions with respect to those limits.

5.2 Motion Limits

In addition to the relative wind, the motion of the flight deck can also be a limiting factor for helicopter operations. Limits are typically defined for some or all of: pitch angle, roll angle, flight deck lateral acceleration (FDLA), and flight deck vertical acceleration (FDVA). These large motions could lead to various hazards such as tipping, sliding, or over-loading the landing gear. As with the wind limits, different sets of deck motion limits may apply depending on the operation and conditions.

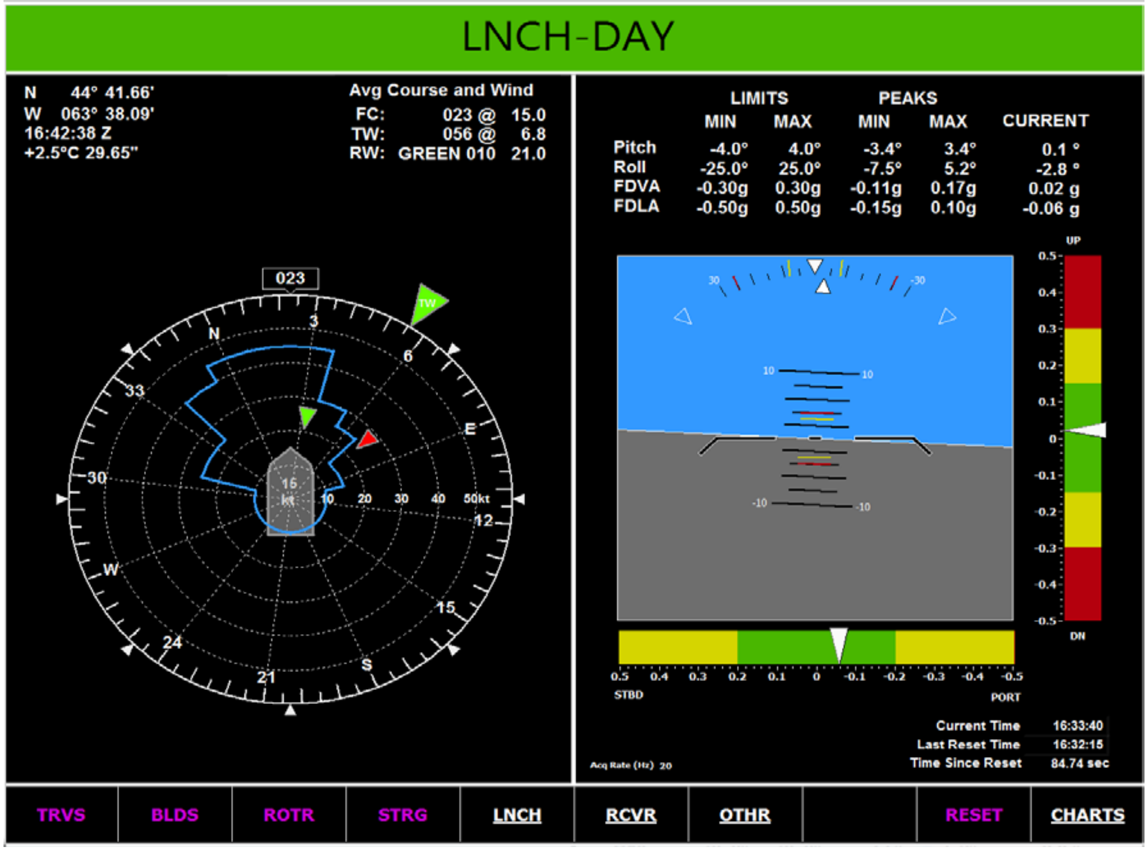
5.3 Operator Guidance

The approach being used on Canadian warships to provide operators with real-time data and SHOL is called the Flight Deck Motion System (FDMS) developed by DRDC over several years of flight test sea trials [14]. A simplified screenshot example of the FDMS is shown in Figure 5.

The bottom row holds buttons for selecting the appropriate SHOL for the current activity on a touch-screen monitor on the ship. The currently selected SHOL is also displayed in the top bar (for example daytime launch in the figure). The right-hand side shows the current ship course and speed, wind limits (blue outline), as well as the relative wind data from the ships port and starboard anemometers (the small red and green triangles). The left-hand side shows the flight deck motions. Roll and pitch angles are animated using an aircraft-style attitude indicator (preferred by the pilots using the system). FDLA and FDVA are shown on the horizontal and vertical slider bars. The coloured band at the top of the display is referred to as the Quiescent Period Indicator (QPI). It acts to show the current state of the deck with respect to the motion limits; green is within limits, yellow is near limits, and red is exceeding limits.

A given operation generally consists of three stages. After selecting the appropriate set of limits, the first stage involves using the left-hand side of the display to help set the ship course and speed so as to best maintain the relative wind within limits as well as to minimize motions in the current sea state. The next stage will involve the right-hand side to evaluate the resulting deck motions with the potential for further adjustment of the ship course and speed. Once these have been established for the final stage, the operator will keep primary focus on the helicopter glancing at the QPI bar to sense the real-time status of the deck and direct the helicopter accordingly to complete the activity.

In addition to the FDMS display used by the operators on the ship, preliminary testing of an external indicator directly visible to the pilot was also conducted during recent Canadian flight trials. The indicator, located on the hangar face, was linked to the FDMS QPI signal and showed different colour and symbol combinations corresponding to the green, yellow, and red states of the QPI. Though limited in scope, the initial tests suggested improved situational awareness of the pilot using this display.



LNCH-DAY

N 44° 41.66'
W 063° 38.09'
16:42:38 Z
+2.5°C 29.65"

Avg Course and Wind
FC: 023 @ 15.0
TW: 056 @ 6.8
RW: GREEN 010 21.0

	LIMITS		PEAKS		
	MIN	MAX	MIN	MAX	CURRENT
Pitch	-4.0°	4.0°	-3.4°	3.4°	0.1 °
Roll	-25.0°	25.0°	-7.5°	5.2°	-2.8 °
FDVA	-0.30g	0.30g	-0.11g	0.17g	0.02 g
FDLA	-0.50g	0.50g	-0.15g	0.10g	-0.06 g

Current Time 16:33:40
Last Reset Time 16:32:15
Time Since Reset 84.74 sec

Acq Rate (Hz) 20

Figure 5: Flight Deck Motions System (FDMS) Display

5.4 Effect of Standardization

Shipboard cueing for helicopter operations varies between nations including how, what, and where the information is shown as well it how it is then used during a given evolution. Certain elements, such as the polar coordinate display for the wind envelope, are commonly used, while others, such as which flight deck motions are measured and how they are shown, can vary significantly. In addition, the different components may not be integrated in a common display, but instead shown on separate indicators or consoles.

A working group to examine a variety of shipboard cueing systems (including external cueing systems for pilots) could result in standardization of some cueing information for cross-platform ships. This has the potential to expand cross-platform limits based on higher operator confidence in the prevailing conditions.

6.0 CONCLUSIONS

Using the model of shipboard helicopter operations shown in Figure 2, it is clear that opportunities to improve the understanding of this complex system using modelling and simulation exist and are currently being developed and leveraged by many nations. Current initiatives, such as DIPES and HOSTAC, to standardize shipboard helicopter operations have focused on the “capability” factors (far right) which must inherently account for variation in all the other factors that contribute, as shown, to safe operational limits. The fact that modelling and simulation efforts exist for several of the key factors under “conditions” introduces the opportunity to improve the fidelity of the determination of standardized SHOL limits.

Consideration of these factors in the development of standardized SHOL envelopes provides the opportunity to expand operational envelopes or de-risk flying operations, depending on the level of integration in the process. Modelling and simulation tools could provide helicopter pilots with more information about what conditions they will encounter while flying to host ships or the opportunity to tune standardized SHOL envelopes.

Building on a rich history of collaboration in this area, the NATO community represents the ideal place for discussions about how modern modelling and simulation tools can practically be used to improve international operations. Should attention to the factors under “conditions” prove successful, standardization of factors under “aircraft” would have further benefits for cross-deck SHOL envelopes.

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