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LARGE EDDY SIMULATION OF A LYNX HELICOPTER LANDING IN THE BARROSO CORVETTE SHIP

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Abstract

The present paper presents the results of a Large Eddy Simulation – LES – for a Ship-Helicopter Operational Limitation – SHOL – envelope definition. The ship was the V-34 Barroso, a Brazilian Navy corvette. A previous study was done employing Computational Fluid Dynamics – CFD – by using the Reynolds-Averaged Navier-Stokes – RANS – equation system. The CFD RANS focused on envelope definition under several conditions, especially those not covered by tests. The objective of the present study was to use LES to simulate a helicopter landing on a corvette ship with winds at a 0° sideslip angle to verify the decrease in prediction errors at points near the landing deck.

CFD RANS deviations are found mainly at vortex-affected areas immediately downstream of ship structures. In those areas, flow phenomena are transient and not captured adequately by CFD RANS simulation due to its temporal averaging, which smoothens velocity results. With LES, wake vortexes are solved in a temporary regime. For this reason, the present paper compares CFD LES results with previous CFD RANS results and experimental wind tunnel campaign data. The Brazilian Navy performed the wind tunnel tests at the Netherlands Aerospace Centre – NLR. Laboratory tests are conventional tools to examine the landing envelope on ships, thus reducing the need for field tests on actual ships. The conclusions of the present work will directly affect the SHOL envelope definition by simulation, particularly at landing deck proximities, where the wind over ship structures produces vortexes and transient flow. Those points are also the most important for helicopter landing due to consequences regarding flight maneuverability during the critical moments of landing.

Keywords: large eddy simulation; computational fluid dynamics; helicopter landing envelope; SHOL

1. Introduction

The wind flow over ship structures such as antennas, towers, devices, weapons, and the command bridge is highly complex and produces a deviation between ship anemometer readings and local velocities at the landing site and its neighboring areas. This phenomenon becomes critical for the smallers ships, like the Brazilian Navy corvette. Viscous effects do not determine that flow, i.e., it does not follow the Reynolds Number, and this is due to the vortexes generated by ship superstructures. Depending on the shape of existing structures, local velocity intensity and local angles may differ from tower anemometer readings. Those velocity vectors are described by the power and two curves in the reference anemometer and the landing deck surroundings. To understand the helicopter's operational envelope for landing, the watch officer must know the relationship between the velocity informed by the command bridge and the local velocities the helicopter will face. It is also helpful when choosing the helicopter's path from the far field to the landing deck.

Other effects such as sea and ship movements are not modeled in the present study but pose additional difficulties in helicopter landing. However, our study focused only on the effects of the wind over the ship to estimate differences between bridge readings and local velocities. Each helicopter model has its landing envelope, which must be modified according to the ship when subject to windy conditions.

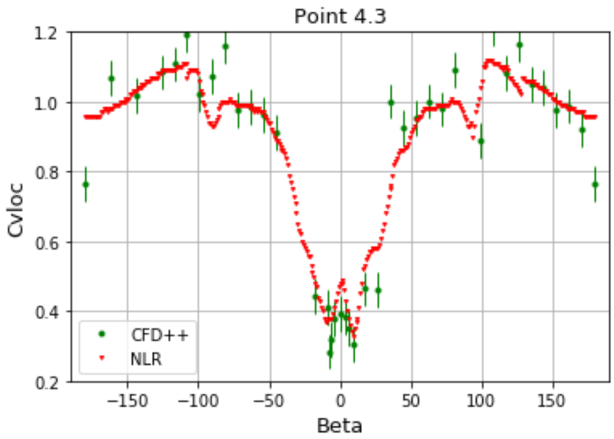

Figure 1 - Cv_{loc} results for position 4.3.

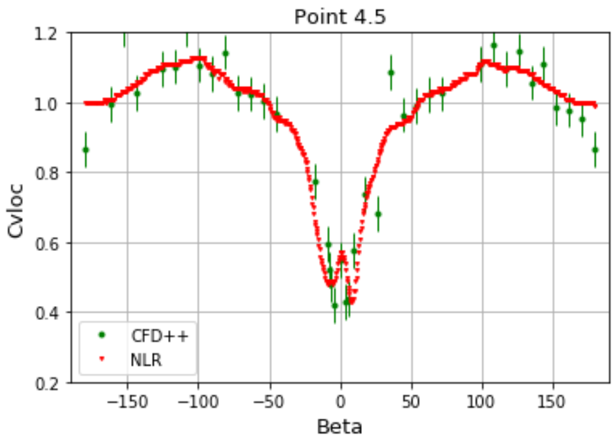

Figure 2 - Cv_{loc} results for position 4.5.

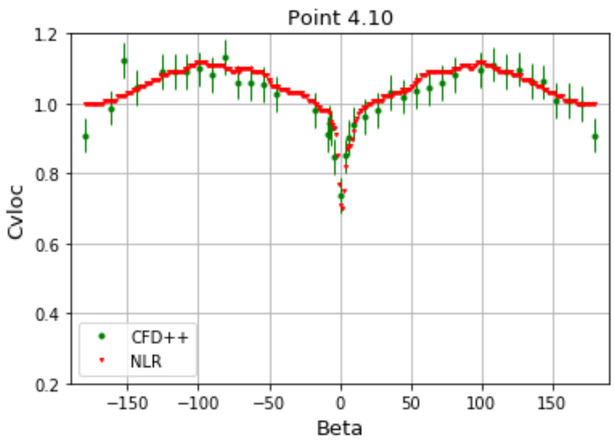

Figure 3 - Cv_{loc} results for position 4.10.

In Rafael, da Silva, and Guedes [1], a complete simulation with Reynolds-Averaged Navier-Stokes – RANS – was performed for the wind over a Barroso corvette model in wind tunnel conditions with 30 m/s true airspeeds. The tunnel mesh has a cylindrical patch that allows it to turn from zero to 360 degrees at the sideslip angle without remeshing in each position. The model was turned 1 degree at a time in the tunnel, but in the CFD, the delta sideslip angle was 9 degrees to save some computational time. Figures 1 to 4 show the results for local C_v from -180 degrees to +180 degrees. If some spurious tunnel results are discarded, the point with a higher deviation in the experiment was

4.3. Tunnel measurements have limitations and errors, so they should not be taken as an absolute reference.

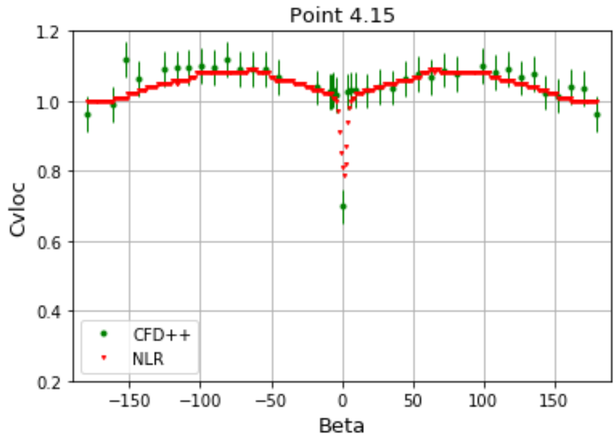

Figure 4 - Cv_{loc} results for position 4.15.

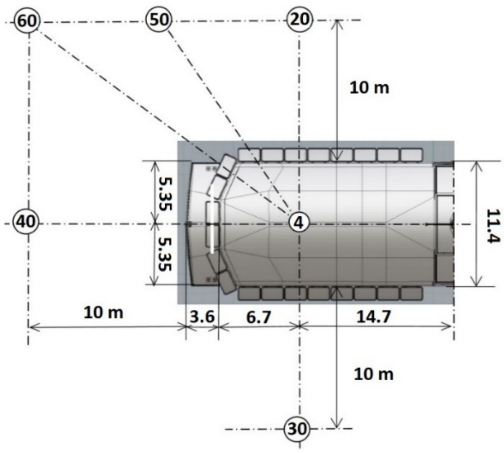

Figure 5 - Positions of measuring stations above the helicopter flight deck, Full scale distances expressed in meters

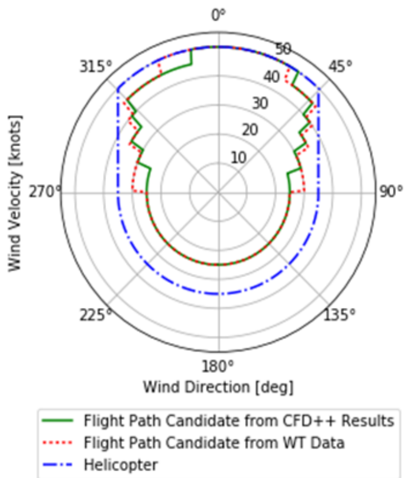

Figure 6 - Fore-and-aft procedure passing through positions 60, 50, 20, and 4.

For the RANS simulation [1], point 4.3 - point 4 at 3 meters of the flight deck - is more challenging to match with Wind Tunnel Results for lower beta angles. The reason for this involves reattachment and recirculation zones. CFD RANS results for point 4.10 are closer to Wind Tunnel Experimental Data. This point is critical in terms of accuracy because the Helicopter Landing Flight Envelope determination is highly dependent on point 4.10 - point 4 at 10 meters of the flight deck. Point 4.10

is where the helicopter stops the lateral movement and begins to go down. The other points are matched with NLR data for all ranges of beta angles Helicopter Landing Procedures.

Figure 5 shows the helicopter's most common paths for landing, and Figure 6 compares the final landing envelope from the CFD RANS with the final landing envelope from the tunnel published by Rafael, da Silva, and Guedes [1]. This type of comparative result was not expected to be obtained in the present work, but in the subsequent work after the present paper adopts the deviations deriving from the LES application to a helicopter landing.

The test campaign for defining operational limits to the launch and recovery of helicopters onboard ships or offshore oil platforms requires a step-by-step approach to guarantee safe helicopter operation. The result of such a test campaign is the launch/recovery envelope of that helicopter in the ship/platform considered, as seen in other publications [2-5].

As can be verified in previous works [6-11], recent progress in CFD provides the means to compute turbulent airflow over a surface combat ship and along the standard helicopter approach path in a time-accurate manner. Nevertheless, despite improvements in CFD techniques, the industry is still not prone to accepting that the test campaign mentioned above could only be performed using CFD simulations. Therefore, wind tunnel tests are still required to close the initial simulation phase of the test campaign fully. Furthermore, the gradual substitution of wind-tunnel tests with computational simulations also requires careful calibration and validation of the computational models.

2. Objective and Scope of Work

Even though previous works using the CFD RANS approach have allowed for envelope construction in the regions of abrupt change of values, called vortices or vortexes, this approach could not consider these quick changes. As these vortexes happen to be in a critical region of the helicopter's landing path, it needs to be more thoroughly studied, hence the inclusion of the LES approach in the present work.

Therefore, the present paper aims to explore the possibility of running a Large Eddy Simulation (LES) of the wind over the Barroso corvette to verify deviations from experimental data in points near the flight deck. It provides initial results that may indicate the suitability of LES application to helicopter landing on a small ship.

This application simulates only one sideslip angle at zero degrees and nominal wind conditions of 30 m/s. It does not include the complete application shown in the previous paper [1], which had a range of sideslip angles from zero to 360 degrees. In the latter, the objective was to define the landing envelope of the helicopter comprehensively. Herein, only one point is simulated using LES instead of RANS to check for deviations. Currently, the authors are simulating the complete envelope.

The present simulation focuses only on Cv, not on the angles χ_{loc} and φ_{loc}. Therefore, the objective is straightforward and does not aim to define the landing envelope, as done in previous work [1] and the tunnel experiment.

3. Wind Tunnel Tests

Wind tunnel tests simulated a wind flow over the corvette model ship on a 1/75 scale. Figure 7 shows the model. The ship model was 1.38 m in length, and the present authors conducted simulations in CFD RANS at 9° intervals from 0- to 360°-side slip angles with 30 m/s of freestream true airspeed [1]. The Brazilian Navy also performed tests at approximately every 1° but with the same geometry, airspeed, and range of sideslip angles. CFD RANS simulations were validated against test data but showed significant deviations at 3, 10, and 15 m above landing deck – point 4 – where the flow is directly affected by a vortex wake. The CFD RANS result at 5 m above the deck at point 4 is close enough. Therefore, the current CFD LES focused mainly on the points near position 4 to reduce deviations from CFD RANS to experimental data in a critical issue.

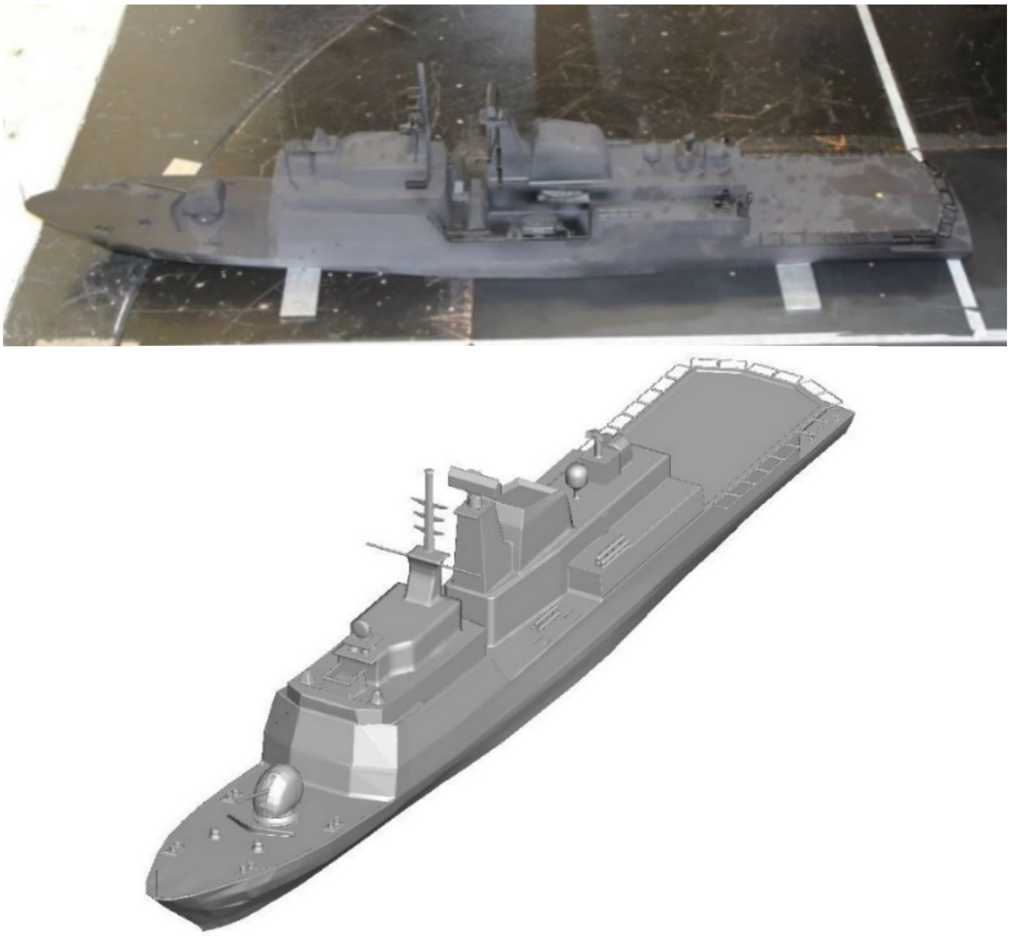

Figure 7 - Model inside the wind tunnel and CFD model, on a scale of 1/75.

4. Wind Parameters

The relative wind vector results from the ship's speed and undisturbed accurate wind velocity vectors in a full-scale situation. The wind tunnel generates the relative wind directly: the relative wind speed and direction are given by V_{rel} and obtained from the tunnel reference data. The local wind velocity (V_{loc}), horizontal flow angle (χ_{loc}), and vertical flow angle (φ_{loc}) at a given position are determined by the data obtained through a 5-hole pitot probe. Local wind speed is expressed as a fraction of relative wind speed by the coefficient:

$$coverCv_{loc} = \frac{V_{loc}}{V_{rel}} = \frac{\sqrt{U^2 + V^2 + W^2}}{V_{rel}} \tag{1}$$

And horizontal and vertical flow deviations are defined by:

$$\chi_{loc} = -\cos^{-1}\left(\frac{\sqrt{U^2 + V^2}}{V_{loc}}\right) \tag{2}$$

$$\varphi_{loc} = \cos^{-1}\left(-\frac{U}{\sqrt{U^2 + V^2}}\right) \tag{3}$$

5. Flight Deck and Surroundings

One geometric reference from the real corvette ship is essential for the present study: the measurement position on and above the flight deck, or point 4 in Figure 8. This is the most critical point for the pilot when landing the helicopter. Due to their lower criticality, the other surrounding positions, 20, 50 ,60, 40, and 30, were not studied herein. In point 4, there are four heights, 3, 5, 10, and 15 meters. To convert measures from a real ship to CFD or tunnel, these measures must be divided by 75.

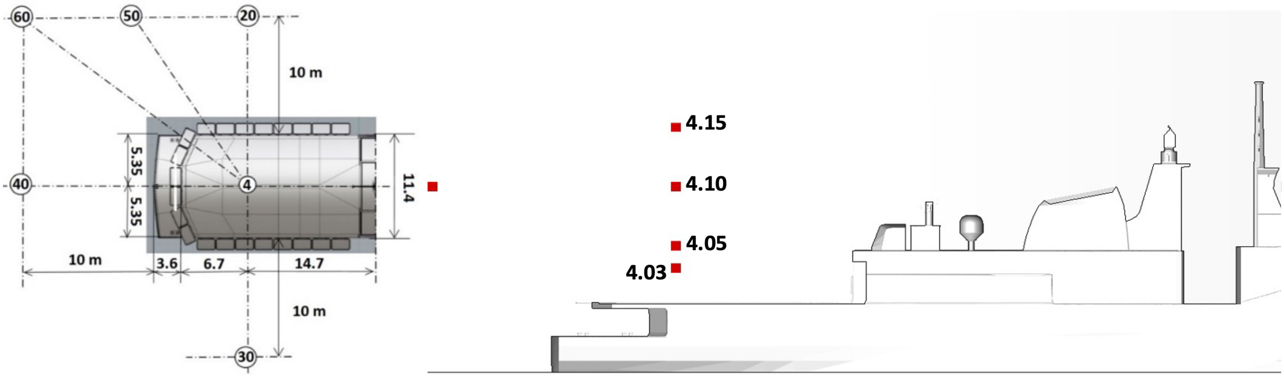

Figure 8 – Positions of measuring stations above the helicopter flight deck, full scale distances expressed in meters.

6. CFD Simulation

CFD results are essential because they save time and lower costs related to the wind tunnel and accurate ship tests. Given this, the present paper simulates the ship model in a wind tunnel with a fine mesh and a suitable strategy for LES simulation. Even though LES requires more computational power and time, the study provides a deeper understanding of flow phenomena and deviations from CFD RANS for envelope definition. It is also essential to use CFD LES simulations for the points affected by vortexes behind obstacles. Finally, LES also provides result motion graphics to show pilots' transient flow during landing.

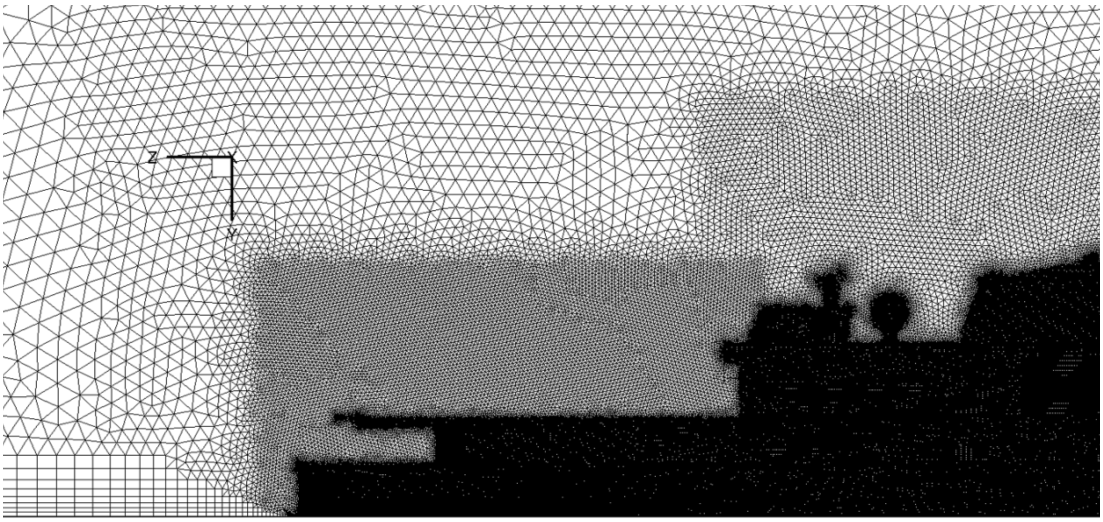

Figure 9 - Mesh near the landing deck of the corvette ship in CFD.
The region of interest has a high-density mesh box around it.

In the future, LES could improve the design of ship command bridges, structures, antennas, and towers and enhance the location of devices and sensors.

The mesh was done using Ennova CFD meshing software with 34,324,102 elements. Figure 9 shows the mesh. All the walls were viscous. Inflow velocity was 30 m/s with backpressure. The process is adiabatic with a temperature of 288 K, and 101,325 Pa. Asymmetry ZX plane located in the middle of the ship was used because zero sideslip angle allows for it. The coarse mesh was used as the first approach, which may be later refined if it shows improvements in predictions. The simulation was run at zero sideslip angle only, thus in asymmetric flow. The computational domain and the boundary conditions are presented in Figure 10.

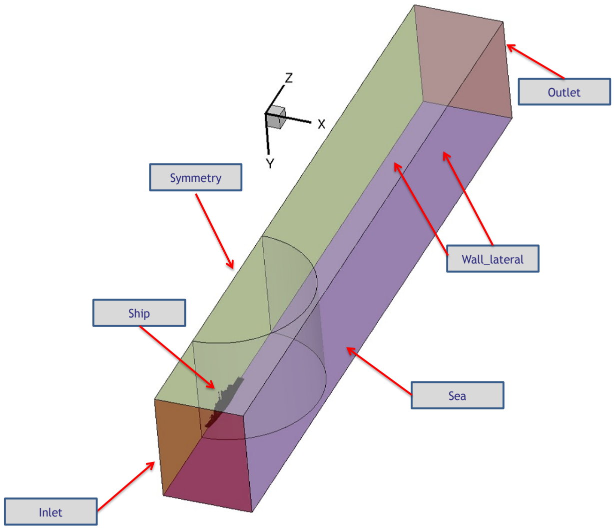

Figure 10 - Computational Domain and Boundary Conditions it was adopted in CFD simulation at zero sideslip angle.

The selected CFD solver was Metacomp Technologies' CFD++ [12-14], which has accurate performance in aerodynamic flow prediction. The selected LES model was the Preconditioning-LES Turbulence Model, specifically the Batten-Goldberg Hybrid RANS-LES [15]. RANS Cubic K-□ was run first as an initial condition for the LES.

In some positions, some transients exist in the first 3 points of the simulation, which are highly influenced by vortexes. Therefore, in points 4.3 and 4.5, the initial three points are discarded as LES solutions, but these are still a transition between RANS and LES solutions. This approach reduces the computational power needed for LES simulation. The time scale was 0.00002 seconds with 15 internal iterations. The sampling time was 50 times the external iteration time. The total simulation time was 0.057 seconds. First, a RANS simulation with a cubic k-ε turbulence model was run. Then, results converged, and the CFD LES model was started. Total duration was considered completed when the vortexes at the anemometer position became steady or approximately constant in time. However, the actual simulation time may be extended. Also, sampling frequency in the simulations of the work to follow will be increased since the present authors will then have a more powerful machine of 5000 cores available at LNCC – National Laboratory of Scientific Computation (Santos-Dumont Supercomputer).

7. CFD Results

Up to this point, only the headwind was simulated for point 4. The headwind and its vicinity at point 4 are the most critical factor for helicopter landing safety. This point is precisely above the landing deck, and because it is located right behind the hangar superstructure, this is where the most prominent vortexes occur with a headwind. Thus, a more precise definition of the results for this point was deemed necessary. In essence, larger vortexes are observed on the top of the ship, whereas smaller eddies are located near the wall of the landing deck.

points	Test	LES Interp	LES points	RANS
4.3	0.49	0.485	0.481	0.405
4.5	0.57	0.574	0.571	0.566
4.10	0.71	0.696	0.709	0.742
4.15	0.79	0.747	0.745	0.696

Table 1 - Cv LES Average values compared to RANS [1] and Test. LES Interp is the average of interpolated LES values. LES points are the average considering only the studied points. RANS are the values from the RANS simulation.

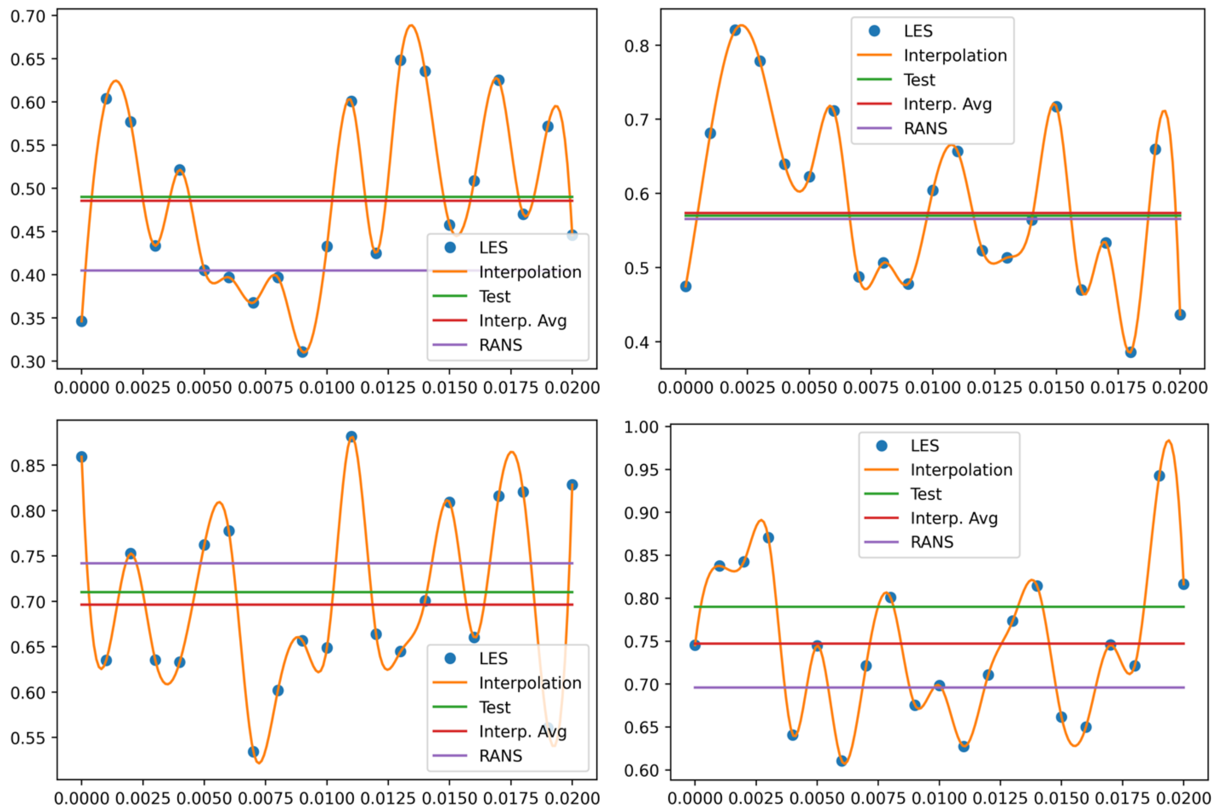

Figure 11 - Cv results for LES during simulation total time for points at the middle of the flight deck. Comparisons between mean values of RANS, LES, and Test.
Top-left: 4.3, Top-right: 4.5; Bottom-left: 4.10; Bottom-right:4.15.

More massive vortexes require more simulation time and small whirlpools require a higher sampling frequency to capture all their effects. Due to the complex geometry upstream of the landing deck, the flow is not steady across the landing location and its surroundings. So this confirms the need for a transient flow analysis by LES.

Figure 11 shows the instant values of Cv in four points at the landing deck: 4.3, 4.5, 4.10, and 4.15. The present authors implemented an interpolation based on cubic splines to get the complete curve variation between points. The average interpolation – LES Interp – was calculated to represent better the average value and the average of the experimental points – LES Points. Also, RANS average values are shown in the same plots. The values obtained are shown in Table 1 for accurate comparison.

points	**LES Interp**	**LES points**	**RANS**
4.3	-0.9%	-1.9%	-17.4%
4.5	0.6%	0.3%	-0.8%
4.10	-1.9%	-0.2%	4.5%
4.15	-5.4%	-5.6%	-11.9%

Table 2 - Cv relative error of LES and RANS with Test values as references

Table 2 shows that CFD RANS results for velocity C_v are 17.4% higher than experimental results for point 4.3 (point 4 at 3 m above the landing deck plane), but CFD LES results are only -0.9% concerning the same data. In point 4.5, CFD RANS deviation is 0.8% and CFD LES is 0.6%. In point 4.10, CFD RANS deviation is 4.5% and CFD LES is 1.9%. Finally, for point 4.15, CFD RANS deviation is 11.9%, and CFD LES is -5.4%. Results for all points are presented in table 2 below. Still, it improved the prediction of local C_v at landing deck plane.

Figure 12 shows the Cv contours in six moments of the simulation for comparison, at 0.011, 0.012, 0.013, 0.014, 0.015 and 0.016 seconds. The unsteady nature of the flow can be seen near the landing deck site due to the vortexes produced by the obstacles to the main flow over the ship. In addition, Figures 13 and 14 show a zoomed view of the landing deck at moments 0.011 and 0.014 seconds. The variation in the Cv field due to vortex influence is also visible. Where there are shades of blue, local Cv values go through a through, and where there are shades of green, Cv values peak.

8. Conclusions

CFD LES results were considered accurate and significantly improved previous CFD RANS results for the structure wake at the landing deck area near point 4. Selecting LES for high accuracy will make it possible to obtain a realistic representation of the flow and, consequently, an accurate envelope definition. It may also help lay down better specifications for ship structures before final design and manufacturing during bidding processes.

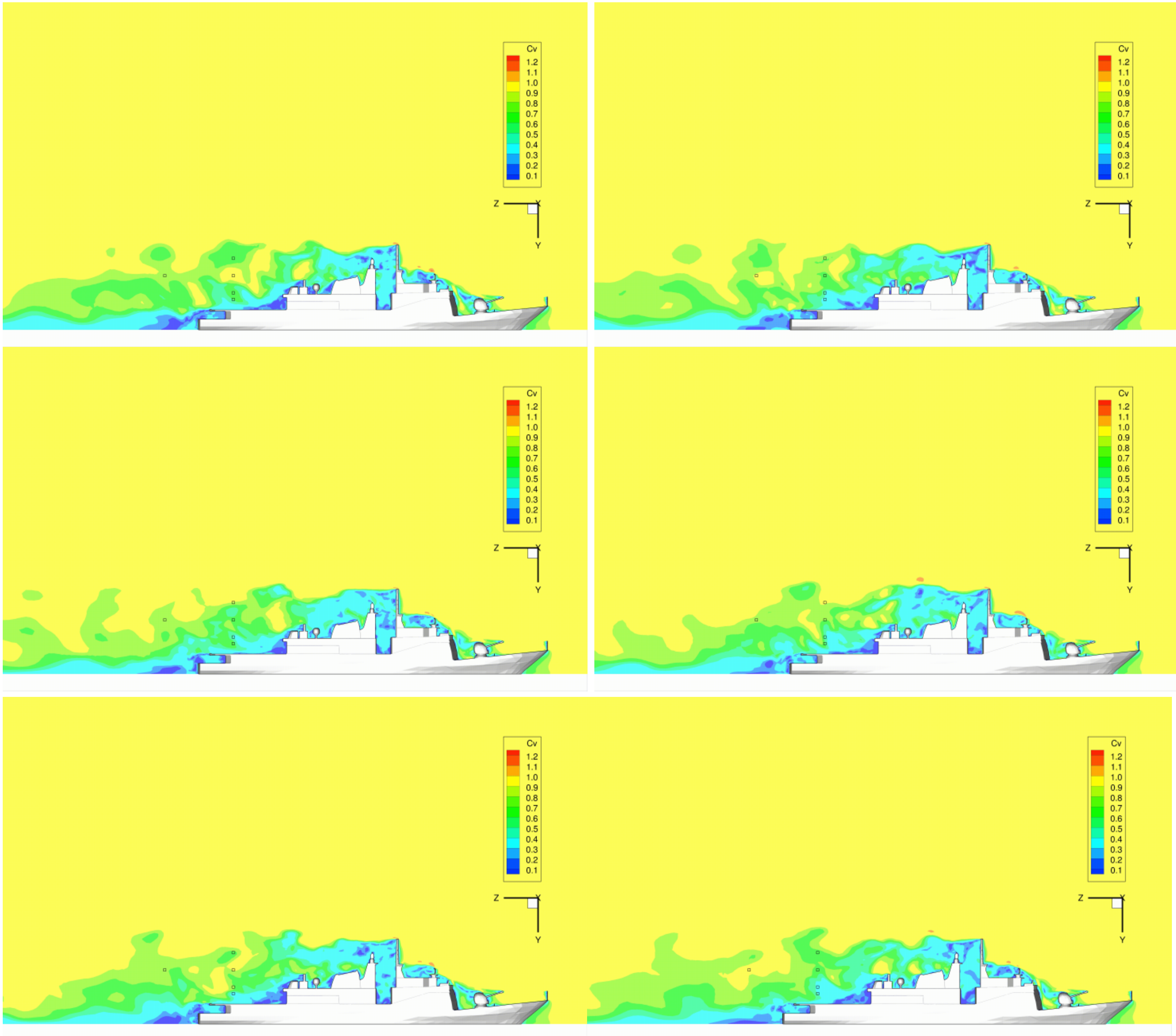

Figure 12 - Cv results for LES during simulation for times 0.011, 0.012, 0.013, 0.014, 0.015 and 0.016 seconds. When results are shown in CG animation, the variation of the vortexes becomes clear.

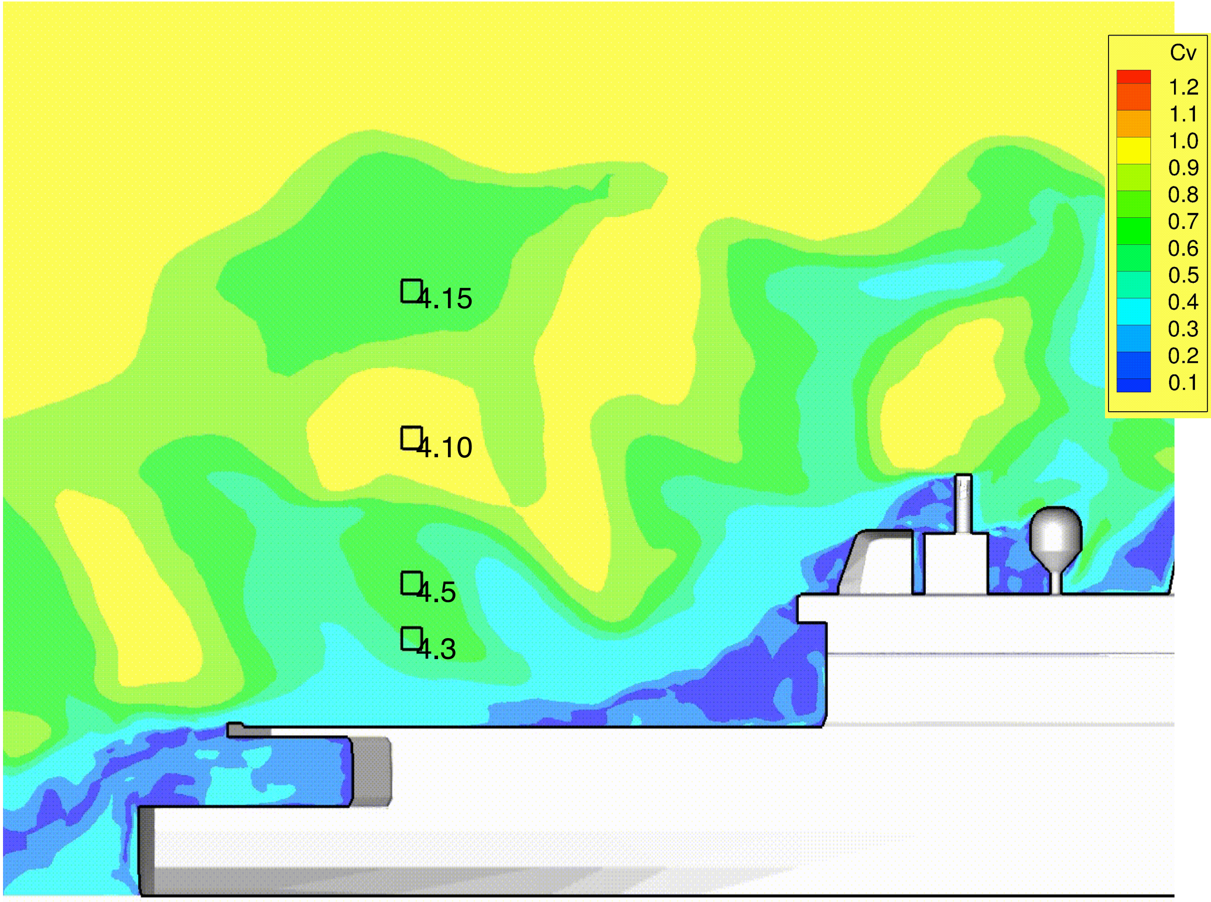

Figure 13 - Cv results for LES during simulation for time 0.011 seconds.

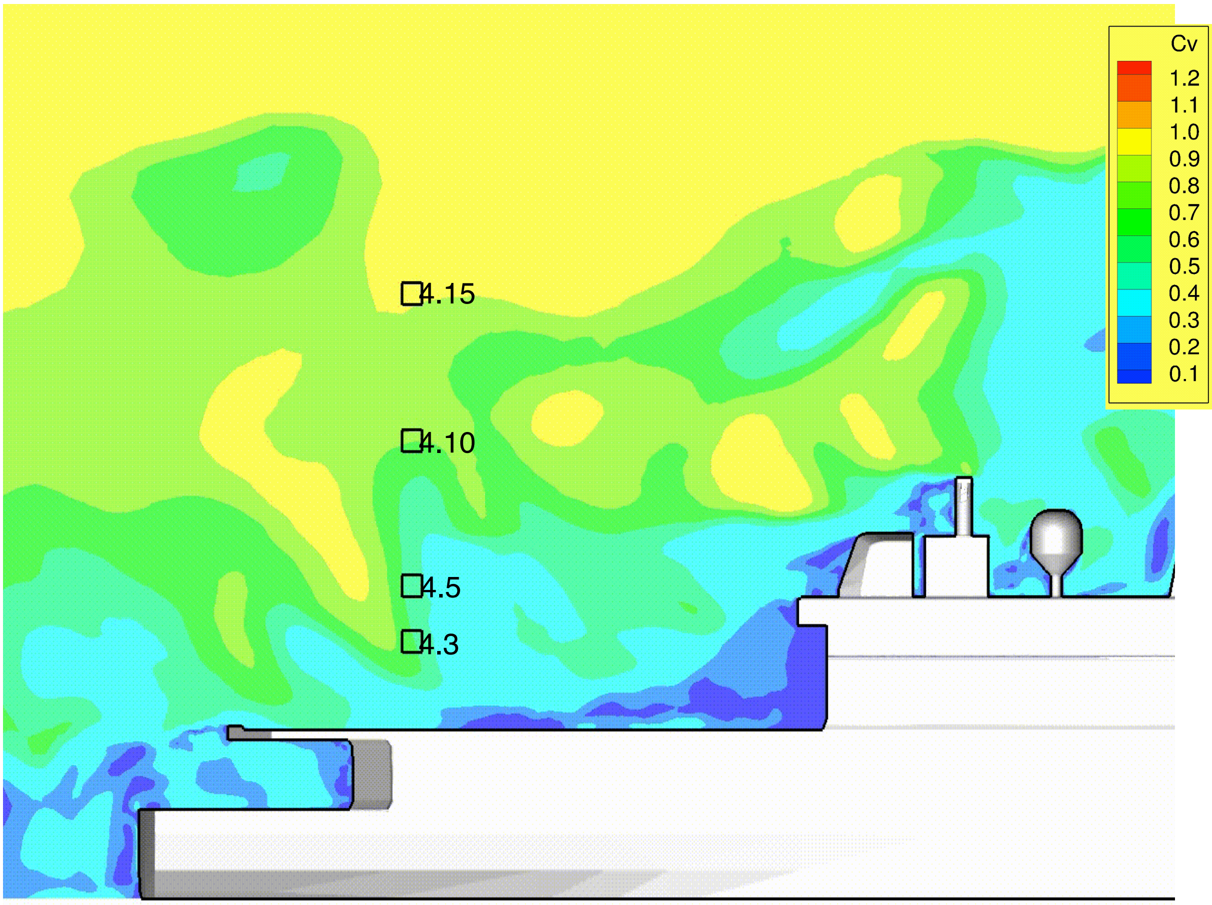

Figure 14 - Cv results for LES during simulation for time 0.014 seconds.

In brief, the present paper describes an advanced study by the Brazilian Navy to define the SHOL envelope with highly accurate CFD LES results. With this study, the Brazilian Navy strategically positions itself as one of few Defense Forces to have a ship-helicopter envelope definition obtained through simulation.

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10. Copyright Statement

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