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AERODYNAMIC PERTURBATIONS ON THE FRIGATE LA FAYETTE DECK EFFECTS ON THE HELICOPTER FLIGHT DYNAMICS

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ABSTRACT

A specific study has been carried out at ONERA since 1997 under the support of the French Ministry of Defence (SPAé) in order to develop an aerodynamic model of the frigate La Fayette landing area and to improve ship landing operations simulation realism.

Wind tunnel tests have been performed in ONERA-Lille on a $1/50^{th}$ scaled model frigate to measure the 3D unsteady aerodynamic field around the landing deck with a hot films anemometer. Mean velocity and turbulence components have been measured for different wind conditions. During these tests the air-sea boundary layer was also simulated. Two test campaigns were performed one in 1997 and one in 1998.

The La Fayette aerodynamic wake model includes a mean wake model and a turbulence model for the velocity fluctuations. The turbulence model is based on the power spectral densities of velocity fluctuations measurements.

This model was connected to the Eurocopter Helicopter Overall Simulation Tool (HOST). Simulations of flights above the deck with this model demonstrated important effects of the ship air-wake on the helicopter flight dynamics.

1. Introduction

Flying a helicopter above or around a frigate deck, landing on it or taking off from it, are considered by pilots as highly risked operations. Indeed, not only the frigate moves, but also in the neighbourhood of the deck, the helicopter has to face with the changing aerodynamic wake of the ship superstructure. This unsteady flow provides high mean speed gradients to which aerodynamic turbulence (fluctuations) is added. These conditions have important effects on helicopter global performance, and behaviour.

Under SPAé funding, ONERA has performed wind tunnel tests on a $1/50^{th}$ scaled La Fayette frigate model, and has developed an aerodynamic wake model of the ship landing area. This model was then used in order to study the effects on flight mechanics.

The work has been carried out between 1997 and 1998. The 97 activities were described in a previous paper [1].

The following topics are presented in this paper :

- Wind tunnel tests and data analysis,
- Air-wake model development in HOST (Helicopter Overall Simulation Tool),
- Demonstration of the effects on helicopter loads and flight dynamics,
- Real-time version of the air-wake model.

2. Wind tunnel tests and data analysis

2.1 Test equipment

Wind tunnel measurements were carried out in the ONERA-IMFL low speed wind tunnel (SH). This wind tunnel has a closed circuit and a test section of 2.4 m in diameter. The first 50 meters of the marine atmospheric boundary layer was also simulated. The measurements were performed on a $1/50^{th}$ scaled La Fayette frigate model, configured with its Crotale Missiles (figure 1).

3D unsteady velocities were measured using crossed hot film anemometer. Two velocity components were simultaneously measured (u, v), and then (u, w) after a 90° rotation of the sensor. Thus, 2 redundant longitudinal velocity measurements (Uv, Uw) were provided. Speed measurements error is estimated as 2.6% of the infinite upstream wind.

The measurements were performed in a volume surrounding the landing deck. Figures 2 and 3 show the test volume and the selected test points positions inside ; 8 horizontal planes above the deck were considered.

Detailed data measurements were realised in 1997 with a 50 kt wind and three side-slip conditions (0°, 15° and 180°). Some tests at 25 kts and 0° of side-slip were also performed. All these measurements were done with a 0° bank angle on the ship. In order to study the effects of the ship bank angle on the air-wake a new campaign was organised in 1998 with a 50 knot wind at 15° of side-slip and 10° of frigate bank angle.

Figure 4 gives a summary of these test configurations.

2.2 Velocity decomposition

The three velocity components are decomposed into two parts : the mean value and the fluctuations around this mean value. For example, the longitudinal velocity is decomposed into:

$$U(x,y,z,t) = U_{mean}(x,y,z) + u(x,y,z,t)$$

U_{mean} : the longitudinal velocity mean value,

u : fluctuations around U_{mean}

x, y, z : space co-ordinates of the local point

t : time

The fluctuations (u, v and w) can be considered as turbulent terms.

In addition, measured velocities are normalised by the free stream velocity.

$$Um(x, y, z) = \frac{U_{mean}(x, y, z)}{V_{free\ stream}}$$

$$Du = \frac{u(x, y, z, t)}{V_{free\ stream}} = \frac{U(x, y, z, t)}{V_{free\ stream}} - Um(x, y, z)$$

The normalised velocity fluctuations are characterised by their Power Spectral Densities (PSD):

$$Du \Rightarrow pu : longitudinal\ turbulence\ PSD$$

$$Dv \Rightarrow pv : lateral\ turbulence\ PSD$$

$$Dw \Rightarrow pw : vertical\ turbulence\ PSD$$

This approach is similar to the one used in [2] and [3].

For the frequency, the results will be presented function of the scale 1 frigate (wind tunnel frequency / 50).

2.3 Ship air-wake mean velocity distribution

Wind speed and side-slip effects

Figures 5 and 6 give the mean velocity components (Um, Vm, Wm) evolution respectively along the vertical axis and the lateral axis (height 4.4 m above the deck), on the deck centre (point A), for a 50 kt wind speed without side-slip (ß = 0°) and for a zero degree ship bank angle.

These figures show a clear downward deviation of the flow (Wm<0), due to the hangar wall cliff-effect (h=6.60m). The longitudinal component of the mean air-wake decreases with the height above the deck. The maximum vertical velocity is reached on the centre line, while the longitudinal velocity decreases to a minimum in the same area. The lateral velocity component shows that the air-wake is deviated from both sides toward the centre.

Figure 7 is the 3D flow visualisation of measurements at 50 kts with 15° side-slip conditions. Arrows represent the mean velocity projections on visualisation planes, whereas coloured areas show turbulence levels. Light colours corresponds to the highest turbulence level. The effect of the lateral hangar wall can easily be seen.

Ship bank angle effect

The 1998 wind tunnel campaign was carried out to study the effect of the frigate bank angle (ϕ) on the ship air-wake. Figures 8, 9 and 10 present the mean velocity components evolution along the vertical axis on 3 different locations of the deck.

These plots show a visible longitudinal speed reduction below the hangar height but also high lateral speeds. This lateral speed decreases when moving towards the deck and even changes sign when moving to the right side of the deck.

Figures 11, 12 and 13 illustrate lateral and longitudinal sections of the air-wake. These figures show that 3D vortices exist. Figure 14 is a 3D illustration of the air-wake in term of velocity arrows and longitudinal speed levels.

Comparisons of the results with and without frigate roll angle show that this bank angle introduces major changes on the mean air-wake, with the apparition of 3D vortices above the landing deck.

2.4 Aerodynamic wake fluctuations

Wind speed and side-slip effects

Figure 15 gives an example of normalised velocity fluctuations on the deck centre (point A), at 2.4 m above it, for a 50 kt wind speed and 0° side-slip.

Figure 16 shows a 3D presentation of the vertical velocity (w) Power Spectral Density (PSD) evolution along the vertical, the lateral and the longitudinal axes on point A. We can notice high turbulence rates concentrated below the hangar wall height, above the deck.

Figure 17 presents a comparison of the 3 velocity components spectral densities on different test planes above the deck centre, at 50 knots of wind and side-slips of 0° and 15°. As general remarks for the 2 cases, it can be noticed that on planes below the hangar height (first 3 rows from the bottom), spectral densities show a maximum energy concentration approximately around 0.5 Hz. This maximum of energy decreases with the height. For the planes above the hangar height, PSDs start getting flat. Large differences can be seen on the power densities amplitudes between 0° and 15° side-slip configurations.

Ship bank angle effect

Figure 18 presents the velocity components power spectral densities along the vertical axis on the deck centre. It can be noticed again that the highest turbulence appear below the hangar height, mainly between the 3rd and the 5th test plane. Figure 19 is a 3D visualisation of the longitudinal turbulence levels.

Comparisons of results with and without frigate roll angle show that major changes occurs with the frigate bank angle. Both the maximum speed fluctuations areas the PSDs maximum amplitudes change when the frigate has a roll angle.

2.5 Synthesis

From all the wind tunnel measurements, the following conclusions can be done :

- A detailed database is available at 50 kts of frontal wind (ß=0°) and 0° ship bank angle (ϕ = 0°).
- A detailed database is also available at 50 kts with 15° of side-slip and ϕ = 0°. The mean flow and the speed fluctuations PSDs change considerably with the side-slip. However, interpolations between 15° and 0° of side-slip at 50 kts will be "tolerated", in order to extend the database to intermediate side-slips.
- A partial database has been generated at 25 kts, without side-slip and ship bank angle (ϕ = 0°). PSDs results have shown the respect of Strouhal number similarity. The measurements show that except above the deck, the mean wind and the PSDs normalised components have similar evolutions. Above the deck, these components will have to be interpolated or extrapolated using the results at 25 and 50 kts in order to extend the database at other speeds.
- A detailed database is available at 50 kts with 15° side-slip and 10° ship bank angle. The ship angle introduction brings important changes on both mean wake and turbulence terms. However, despite these discrepancies, the air-wake parameters observation tend to show quit close evolutions of mean velocities and PSDs. Therefore, assuming quasi-static conditions, an interpolation of the results at 50 knots of wind speed and 15° side-slip in 0° and 10° bank angle configurations can be envisaged.
- A 50 kt rear wind database at ϕ = 0° has been also generated.

3. Air-wake model development in a flight dynamics code

3.1 Model realisation

The La Fayette air-wake model includes a mean wake model and a model of velocity fluctuations (turbulence).

a- Mean air-wake model

The test area above and around the ship deck is actually a grid according to the test points definition. At any point (H) of this area the 3 mean air-wake components are interpolated, using the mean air-wake measurements of neighbouring points.

The approach consists in locating for example the helicopter centre of gravity in the test area elementary parallelepiped (figure 20). The mean air-wake on this point is defined via its components in the frigate axes, using a linear combination of measured mean velocities on the elementary parallelepiped tops, in respect with their distance to the considered point.

In order to avoid any velocity discontinuity when going in/out of the test area, a transition region has been defined, where velocities are interpolated between the test area and the free stream. Figure 21 illustrates this method.

b- Velocity fluctuations model (turbulence)

Velocity fluctuations are generated using the 3 velocity components PSDs.

The approach consists in locating the helicopter centre of gravity in the test area elementary parallelepiped. Fluctuations PSDs on this point are defined using a linear combination of measured PSDs on the elementary parallelepiped tops, in respect with their distance to the considered point. Fluctuations are then processed using a signal generation method ensuring the similarity between PSDs of measurements and of the generated signal.

The method consists in:

a- Calculation of measured velocity fluctuations PSD.

b- Identification of a mathematical model (S) fitting the experimental PSD.

c- Velocity fluctuations computation from the identified PSD, using the following method [4]:

Example of u generation:

$$u(x,y,z,t) = 2\sum_{i=1}^{N}\sqrt{S(x,y,z,f_i)\cdot\Delta f}\,.\cos\left[2\pi f_i t + \varphi_i(x,y,z)\right]$$

N: Number of samples in S

f_i: Temporal frequency for i^{th} sample

φ_i: Random phase between 0 and 2π with a uniform probability density

Figure 22 is an example of vertical turbulence generation on the deck centre (height = 2.4m) at 50 knots of wind speed.

The frigate air-wake model has been connected to the Eurocopter simulation code HOST (Helicopter Overall Simulation Tool) [5]. The connection was first done by assuming the helicopter as a mass point. A first model was developed with the test results obtained during the 1997 test campaign at ϕ = 0° [1].

3.2 Model improvements

For this task the objective was first to complete the previous ship air-wake model with the test campaign data on ship bank angle effect and to improve some aspects of the physical modelling.

Model validity domain extension

With the last wind tunnel tests data, the model validity domain can be extended to the configurations in which the ship has bank angles up to 10° starboard.

The new validity domain of the model becomes :

AT $\phi = 0°$:

$\beta = 0°$	→ AIR-WAKE CALCULATION AT ANY WIND CONDITION,
$\beta = 15°$	→ AIR-WAKE CALCULATION AT 50 KNOTS OF WIND,
β in]0°,15°[	→ AIR-WAKE CALCULATION AT 50 KNOTS OF WIND BY INTERPOLATION,
$\beta = 180°$	→ AIR-WAKE CALCULATION AT ANY WIND CONDITION,

AT $\phi = 10°$:

$\beta = 15°$	→ AIR-WAKE CALCULATION AT 50 KNOTS OF WIND,

AT ϕ in]0°,10°[:

$\beta = 15°$	→ AIR-WAKE CALCULATION AT 50 KNOTS OF WIND BY INTERPOLATION.

Model user domain extension

In order to improve operational simulations realism, one of the requirements was to realise an air-wake model able to take into account the complete ship motion (roll, vertical, swerve, pitch,..).

Because of the limited data base available, and the fact that the ship motion can lead to configurations where the air-wake model comes out of its validity domain, this requirement could be fulfilled only under very extensive and simplifying hypotheses. The task consisted in extending the validity domain by extrapolations on the parameters such as the side-slip (β) and the bank-angle (ϕ).

The main hypotheses are the followings :

- No ϕ effect on the air-wake for frontal winds (β = 0°),
- For V=50 kts, β=15° : interpolation/extrapolation on ϕ,
- For V=50 kts, 0<β<30°: interpolation/extrapolation on ϕ and β,
- For V=50kts, -30°<β<0: interpolation/extrapolation on ϕ and β, using symmetry to the longitudinal axis,
- For V=50 kts, $|\beta| > 30°$: only atmospheric boundary layer effect,
- For any other V, extension of the results at 25 and 50 knots,
- The remaining ship state parameters (vertical, swerve, pitch, ...) act only on the deck test area position, without any additional effect on the aerodynamics.

Separation of the effects of the wind velocity and of the ship velocity

Wind tunnel tests have been performed using an atmospheric boundary layer simulation facility. In such a case the relative blown wind to the ship is considered to be the atmospheric wind in the boundary layer.

But in reality, the relative wind is a combination of the atmospheric wind and of the ship speed :

$$V_{relative} = V_{air/ship} = V_{wind} - V_{ship}$$

In an extreme situation, when there is no wind and the ship is moving, the model as described above provides an air-wake submitted also to the atmospheric boundary layer effect, whereas no influence should exist.

The following approach was used to cancel this effect. Let's consider $\Delta u = U_{air\_wake} - U_{bound\_layer}$ as the isolated frigate effect.

$$\left(\frac{\Delta u_{tests}}{V_{wind\_tunnel}}\right) = \left(\frac{U_{air\_wake}}{V_{wind\_tunnel}}\right) - \left(\frac{U_{bound\_layer}}{V_{wind\_tunnel}}\right)$$

$\left(\frac{U_{bound\_layer}}{V_{wind\_tunnel}}\right)$ is independent of the wind intensity and is only a function of the altitude (f(Z)).

$\left(\frac{U_{air\_wake}}{V_{wind\_tunnel}}\right)$ is given by the test measurements.

So, in real conditions, when $V_{relative}$ is a combination of the wind and the ship speed,

$$\Delta u = \left(\frac{\Delta u_{tests}}{V_{wind\_tunnel}}\right) \cdot V_{relative} \,.$$

Then, the air-wake speed is calculated by $U = \Delta u + U_{bound\_layer}$

or

$$U = \left(\frac{\Delta u_{tests}}{V_{wind\_tunnel}}\right) \cdot V_{relative} + f(Z) \cdot V_{wind}$$

Multi-element air-wake model

In the first version of the air-wake model the 3 unsteady airspeed components are calculated on the helicopter Centre of Gravity (CoG) and applied to its different elements (main rotor, horizontal stabiliser, ...). The evolution considered here consists in determining the local airspeed of each element using its relative position to the CoG.

This improvement raises the question of speed perturbations phases in different spatial locations. Additional wind tunnel tests would have to be organised in order to consider this topic. The tests should contain simultaneous speed measurements on different deck points. The analysis of speed fluctuations phases from one point to another will provide some lights on the turbulence spatial propagation.

Despite the lack of simultaneous measurements data, this evolution have been implemented in the model, with the possibility of changing the phase between the different points, or just taking into account the mean velocity field, which is independent of perturbations phase problem.

This version of the model is a major evolution but it needs a large computer memory capacity and higher calculation time.

Results of simulations with and without this improvement are presented in paragraph 4.

4. Demonstration of the effects on helicopter loads and flight dynamics

In order to demonstrate the frigate aerodynamic wake effects on helicopter flight dynamics, off time open loop simulations of flights above the deck were carried out with HOST.

4.1 Mass point model – ship in roll motion

Results of a Dauphin descending flight , obtained with the mass point version of the model, at a speed of 10 knots and -1° slope angle are presented on figures 23 and 24.

The frigate faces with a 50 knot wind at 15° side-slip. It has a sinusoidal roll motion of 5 seconds period and 5° amplitude ($\phi = -5\sin\frac{2\pi t}{T}$, $T = 5s$).

The helicopter is trimmed with the local mean air-wake conditions at the starting point located on the longitudinal symmetry axis (y=0), 11.9 m above the deck (Z=9.5 m in the frigate axes) and 23 m behind its rear extremity (X=25 m in the frigate axes).

The simulation being realised in open loop, the helicopter controls keep their trim values. Figure 23 illustrates the local wind components (UF-FGW, VF-FGW, WF-FGW), the helicopter flight parameters (helicopter attitudes, ground speed components, ...) and trajectory coordinates. Figure 24 shows the aerodynamic loads on different helicopter elements (main rotor, fuselage and horizontal stabiliser). Blades flapping are also presented on this figure.

The plots show the unsteady airspeed effects on different flight parameters. Aerodynamic loads and moments are very sensitive to airspeed fluctuations, therefore these parameters are highly disturbed. Helicopter angular rates follow these variations with a first order dynamic. The effect on the vertical speed is similar. These primary parameters variations end up by changing helicopter attitudes and speed.

During this simulation the helicopter tends to come into the wind direction (15° left) by turning on the left side (-7° in roll and -10° in heading).

4.2 Multi-element model simulations, without ship motion

Simulations of hovering flights above the deck have been performed with the multi-element model and the flight parameters were compared with those generated with the mass point model.

The mutli-element model is based on the calculation of the local wind speeds for the fuselage, the main rotor and the horizontal stabiliser. Since the tail rotor and the fin are located close to the horizontal stabiliser, the airspeed calculated for this element was also applied to the 2 others.

Since no conclusion on turbulence spatial length was available, the speed fluctuations phases were considered to be the same at the different locations.

The hover flights were generated with a 50 knot wind at 13° side-slip. The helicopter was trimmed with the local mean airspeeds at the starting point located on the longitudinal symmetry axis (y=0) at 4.50 m above the deck and 2.5 m in front of its rear extremity (x=0 in frigate axes).

Figures 25 and 26 illustrate the local wind components and the helicopter flight parameters (attitudes, ground speed components, trajectory coordinates, loads, moments and blade flapping) for the multi-element model. Figures 27 and 28 are the same evolutions generated with the mass point model.

The 2 simulations show important changes on the helicopter dynamics and consequently on the trajectories. The main difference is seen on the helicopter initial reaction. With the mass point model the helicopter starts by pitching down and so going forward whereas, with the multi-element model it initiates first a pitch up which results in a deceleration and a rearward flight.

So, the introduction of actual airspeeds for the helicopter's main components has a non negligible effect on the reactions to the ship air-wake. However, it has to be emphasised that this study was performed with the assumption that the turbulence phase doesn't change with the spatial position. So, further investigations should be performed to study this effect.

5. Model for real-time simulation

In order to carry out piloted simulation tests in the real-time environment of Eurocopter simulator "SPHERE", the ship air-wake model was modified and partly simplified to reduce its calculation time.

In this purpose, the computer memory capacity use and calculation algorithms were optimally rearranged.

In addition, the 3 turbulence components power spectral densities are no longer calculated by interpolations, but several characteristic PSDs were defined according to the area flown by the helicopter. So, the PSDs are calculated once and stocked in the memory.

Thus, with these modifications the turbulence generation procedure is much quicker.

First piloted simulation tests were carried out by Eurocopter. All the pilots emphasised the significant improvement of ship landing operations simulation realism provided by the ship air-wake model.

6. Conclusion

This paper presents an ONERA activity on helicopter ship landing operations simulation improvement.

The first phase of this activity started with wind tunnel tests in ONERA-IMFL, on a 1/50th model of the French frigate La Fayette. A detailed database was provided at 50 kts for 3 wind side-slip configurations (0°, 15°,180°). A partial database was also generated at 25 kts of wind with 0° side-slip. The effect of the frigate roll angle was also studied for a side-slip angle of 15° and a roll angle of 10°. The data analysis showed important aerodynamic effects due to the hangar cliff-effect and ship lateral wall effects.

These data were used in order to define and to develop a ship air-wake model of the La Fayette deck area. It includes a mean air-wake model and a model of velocity fluctuations (turbulence).

This model, connected to the Eurocopter HOST code (Helicopter Overall Simulation Tool) demonstrated important effects of the ship mean and turbulence aerodynamic wake on helicopter loads, moments and on its flight dynamics.

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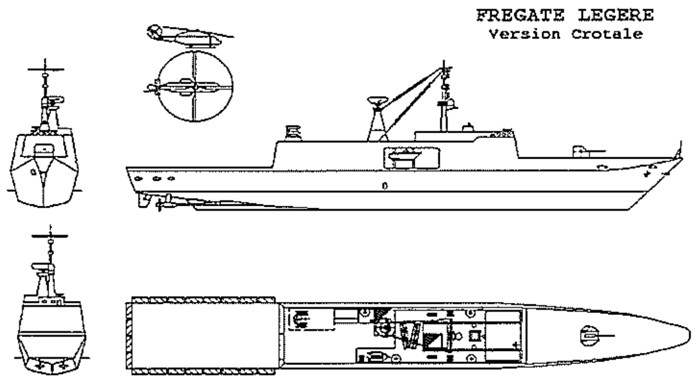


Figure 1: Frigate La Fayette 1/50th model

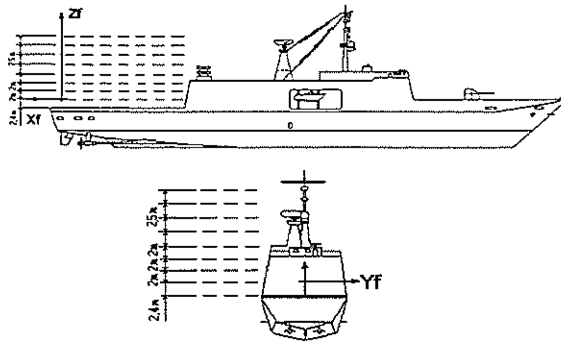


Figure 2 : Test planes position

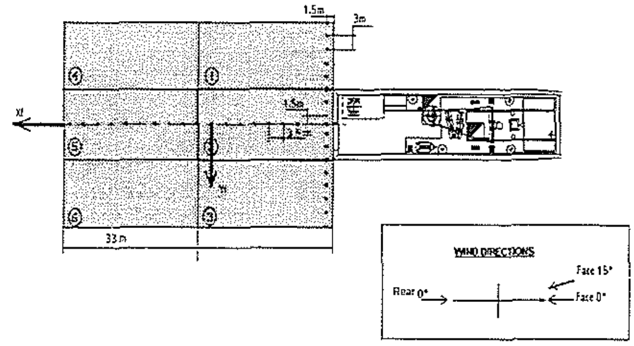


Figure 3 : Test points position

Test Configurations

Ship bank angle (ϕ) = 0°

• Frwd wind 0°	(50 and 25 kts)	: Areas 1 to 6	2*2584 points
• Frwd wind 15°	(50 kts)	: Areas 2, 3, 5 and 6	1824 points
• Rear wind 0°	(50 kts)	: Area 1 and ½ Area 2	720 points

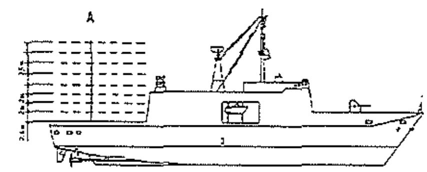
Ship bank angle (ϕ) = 10°

• Frwd wind 15°	(50 knots)	: Areas 2, 3, 5 and 6	1824 points

Planes height to the deck

2.4 m / 4.4 m / 6.4 m / 10.9 m / 13.4 m / 15.9 m / 18.4 m

Figure 4 : Summary of test configurations



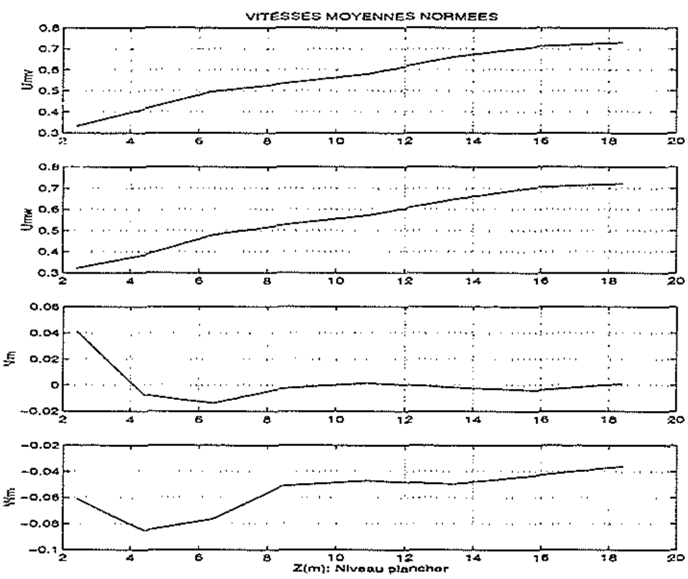


Figure 5 : Mean velocities evolution along the vertical axis on the deck centre (pt A) - Wind = 50 kts, ß = 0°

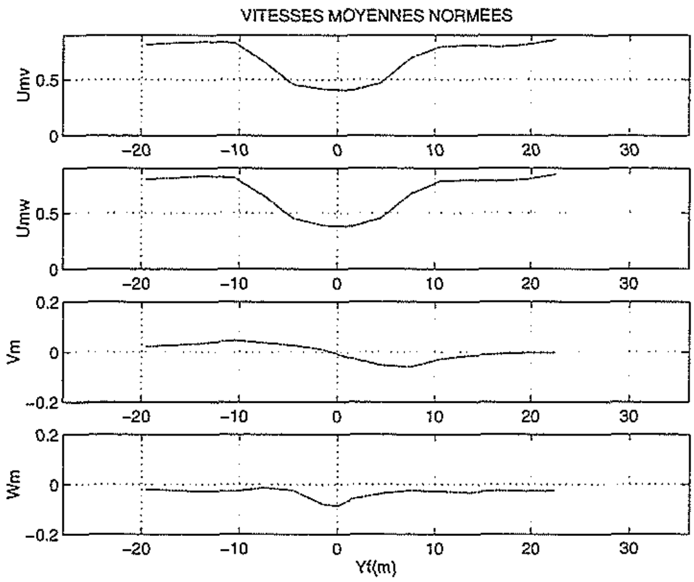


Figure 6 : Mean velocities evolution along the lateral axis on the deck centre (pt A, height=4.4m) - Wind = 50 kts, ß = 0°

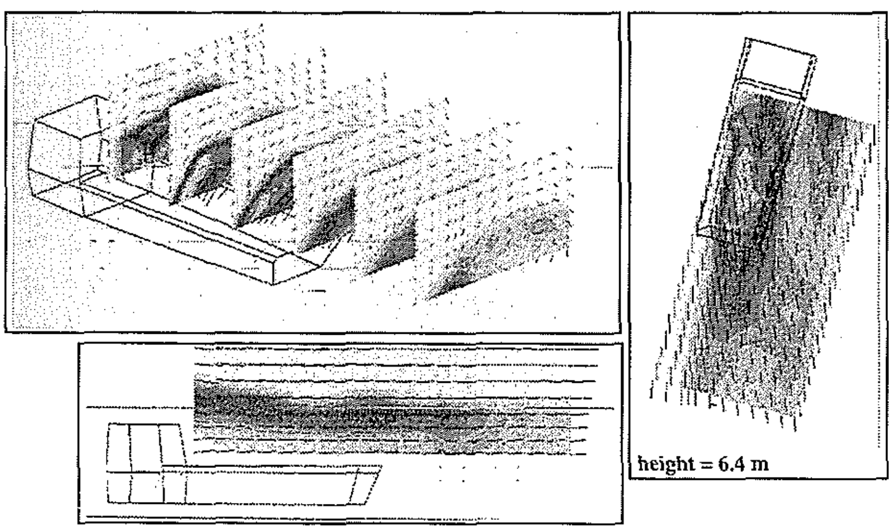


Figure 7 : 3D visualisation of tests at 50 kts ; ß = 15° ; ϕ = 0°

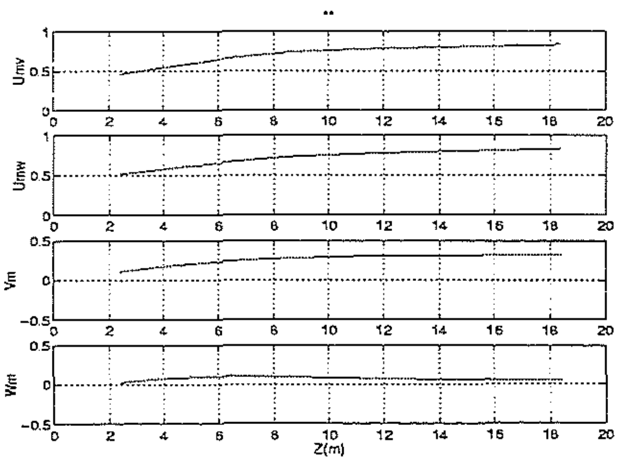


Figure 8 : Evolution of mean velocity components along the vertical axis on point A

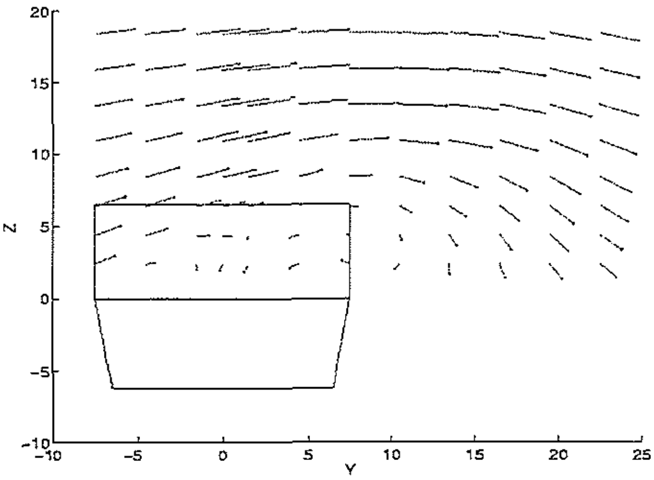


Figure 11 : Lateral section of the flow on plane n° 8
Wind =50 knots, $\beta = 15°$, $\phi = 10°$

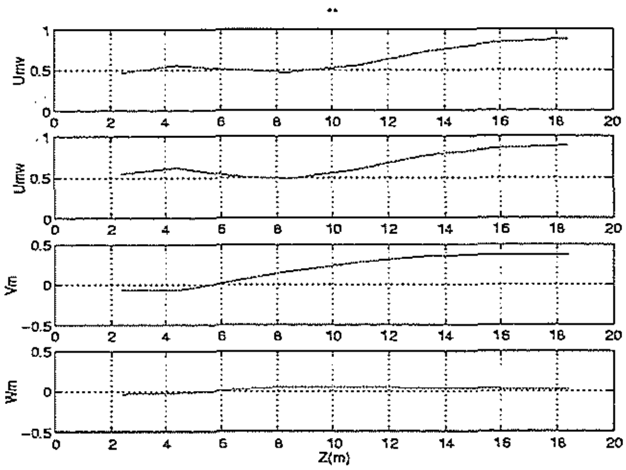
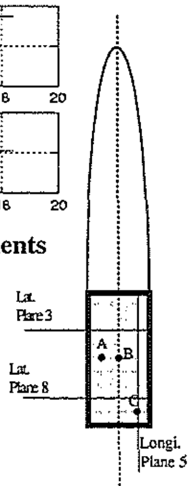


Figure 9 : Evolution of mean velocity components along the vertical axis on point B



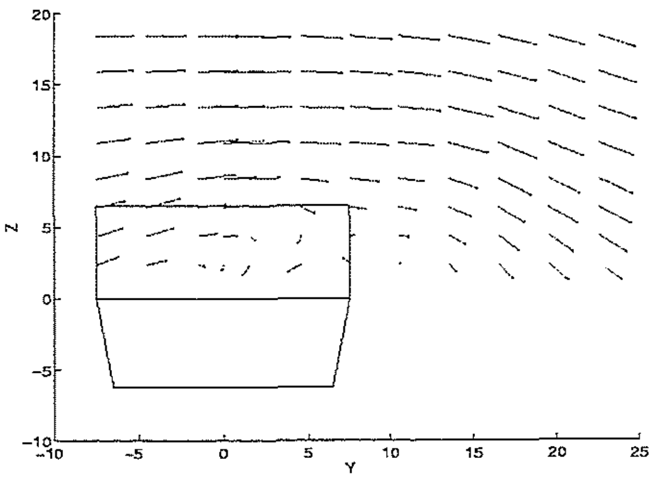


Figure 12 : Lateral section of the flow on plane n° 3
Wind =50 knots, $\beta = 15°$, $\phi = 10°$

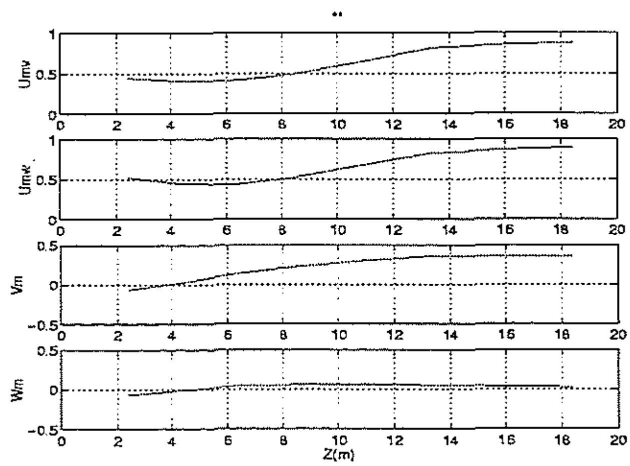


Figure 10 : Evolution of mean velocity components along the vertical axis on point C

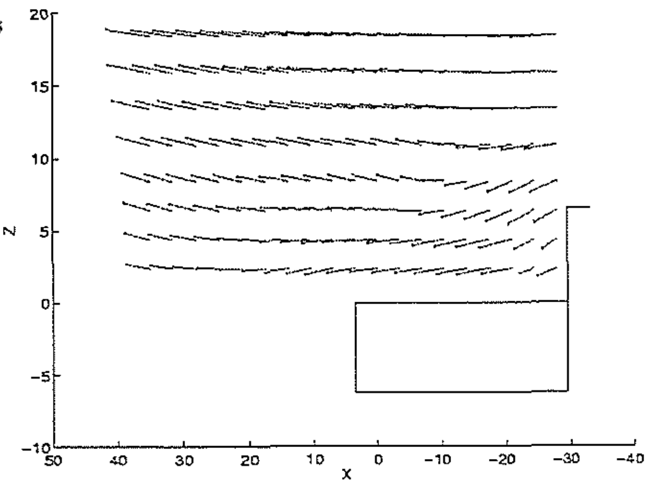


Figure 13 : Longitudinal section of the flow on plane n° 5
Wind =50 knots, $\beta = 15°$, $\phi = 10°$

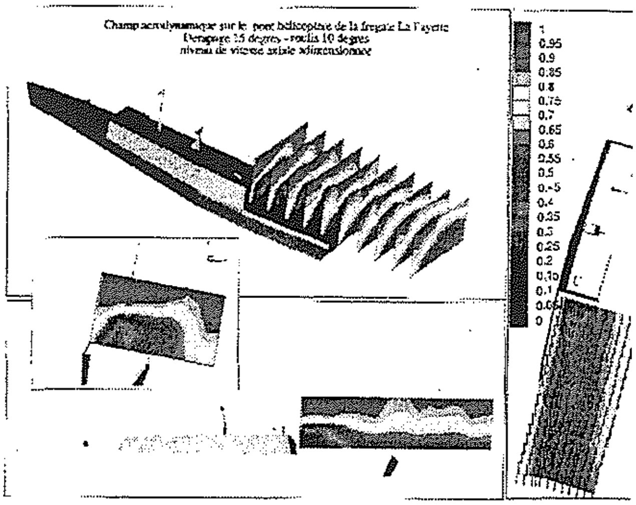


Figure 14 : 3D flow visualisation
Wind = 50 knots, β = 15°, φ = 10°

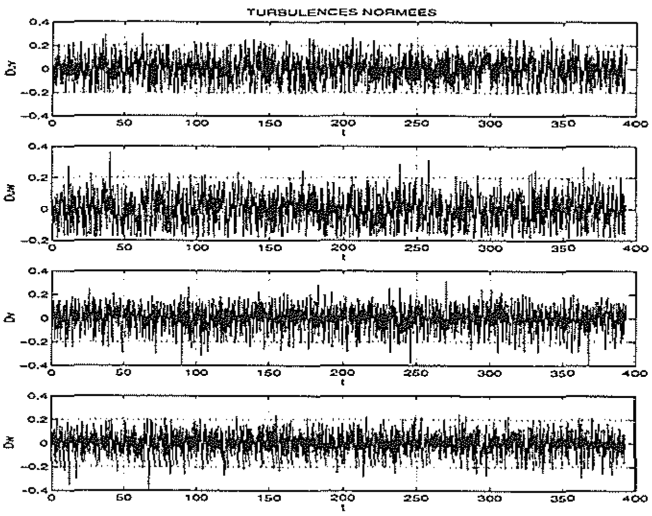
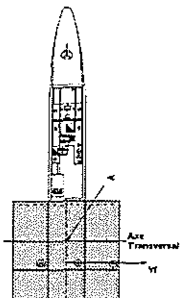
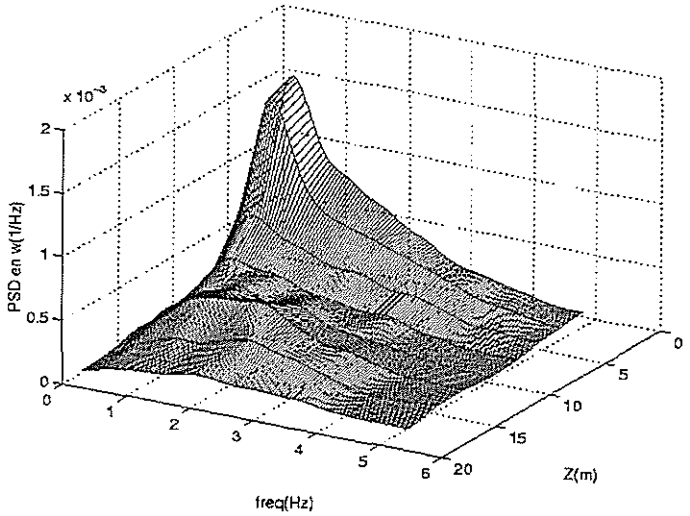
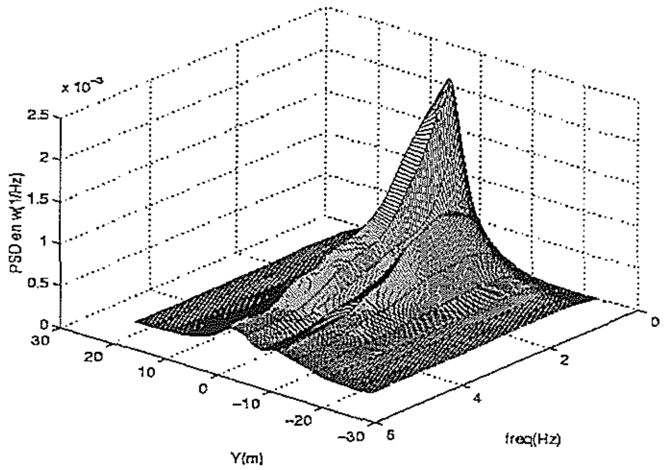


Figure 15 : Example of normalised velocity fluctuations, on the deck centre. Wind = 50 kts ; ß = 0° ; φ= 0°

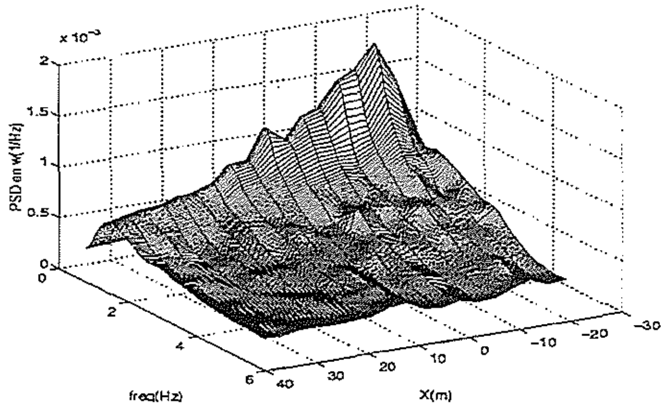




Evolution with altitude above the deck centre



Evolution along the lateral axis on the deck centre (height 2.4m)



Evolution along the deck median axis (height 2.4m)

Figure 16 : Vertical velocity PSD evolution along the vertical, the lateral and the logitudinal axis.
Wind = 50 knots, β = 0°, φ = 0°

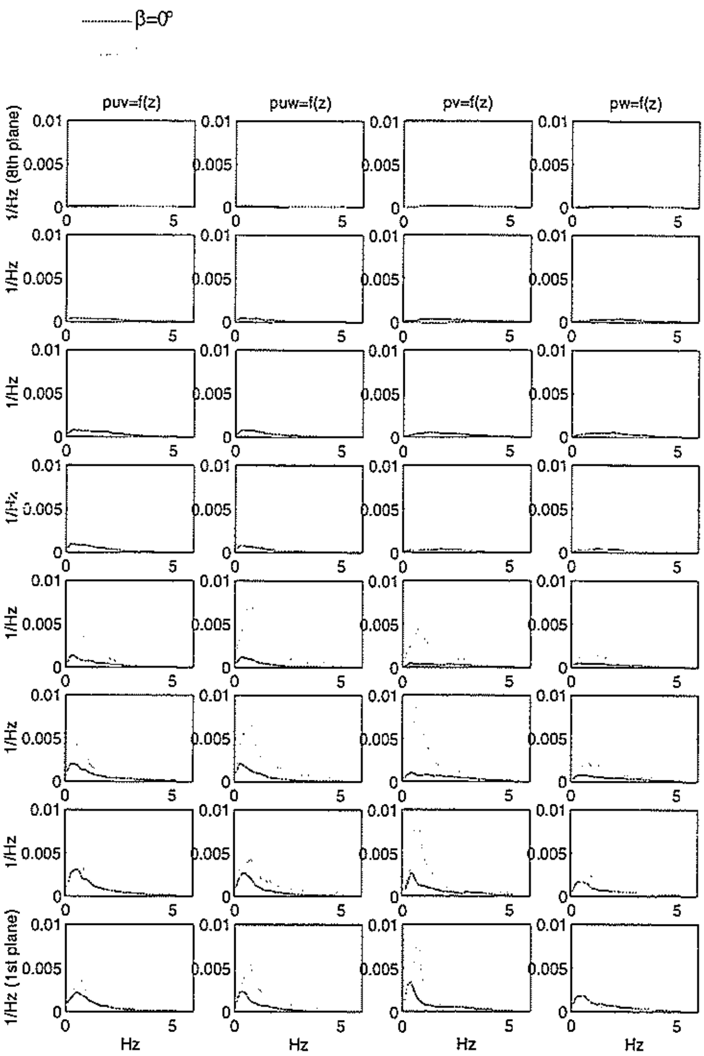


Figure 17 : Comparison of u, v, w PSDs evolution in altitude on the deck centre. wind = 50 kts ; side-slip 0°/15° ship bank angle = 0°

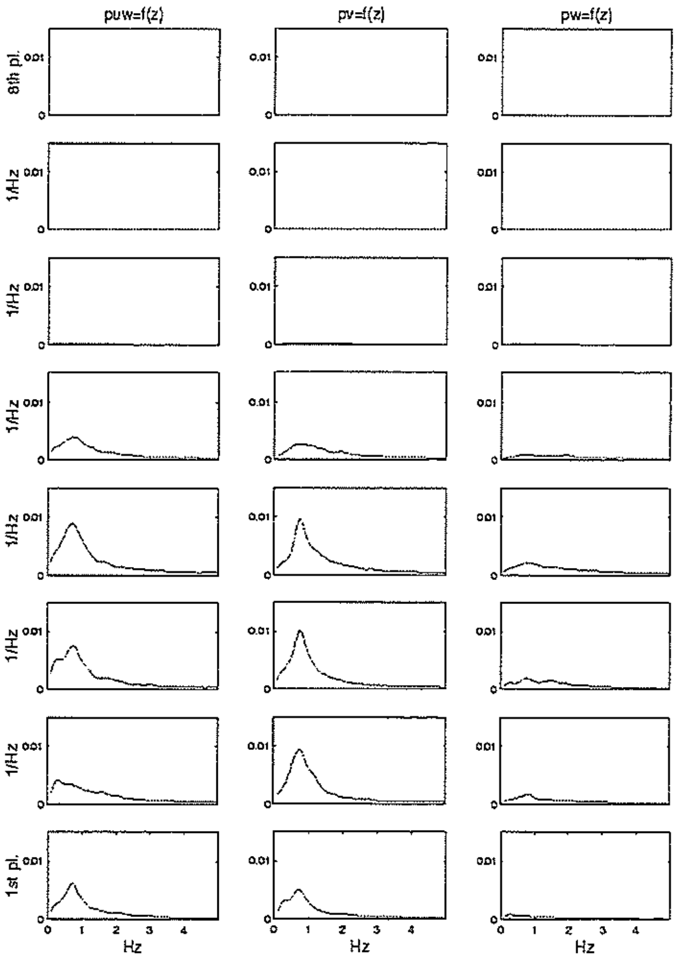


Figure 18 : u, v, w PSDs evolution in altitude on the deck centre. wind = 50 knots, side-slip = 15° ship bank angle = 10°

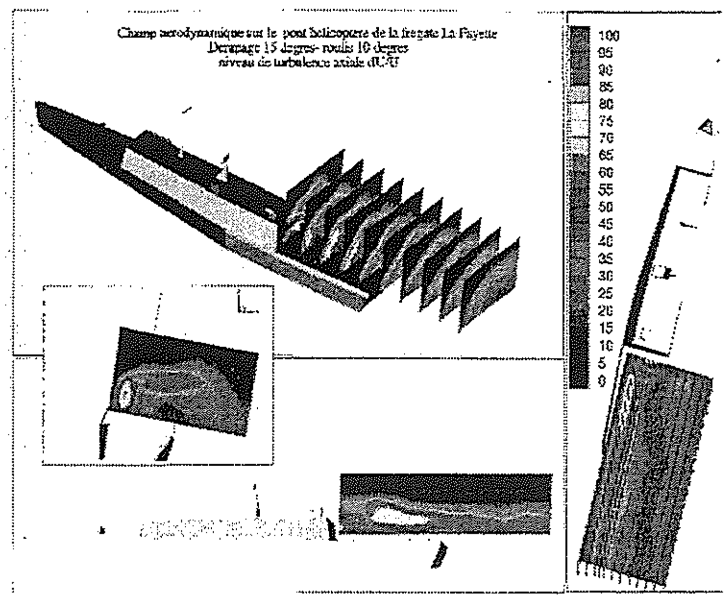


Figure 19 : 3D visualisation of longitudinal turbulence levels. wind = 50 knots, β = 15°, ϕ = 10°

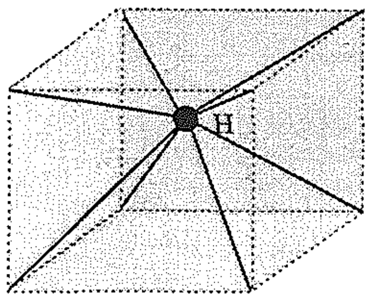


Figure 20 : Test area elementary parallelepiped

__Objective__ :
Avoiding velocity discontinuity when entering the test area

__Method__ :

1- Creation of a transition area.
2- Interpolation of air-wake mean velocity between the test area and infinite free stream.

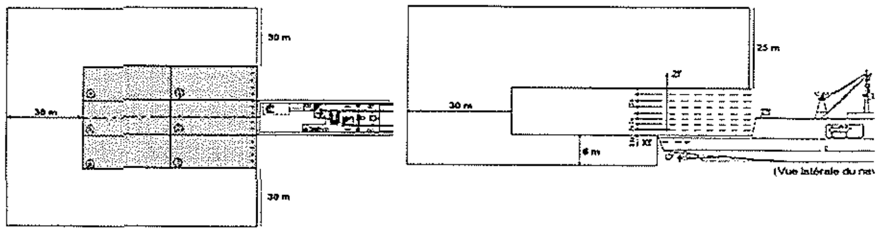


Figure 21 : Model limit conditions

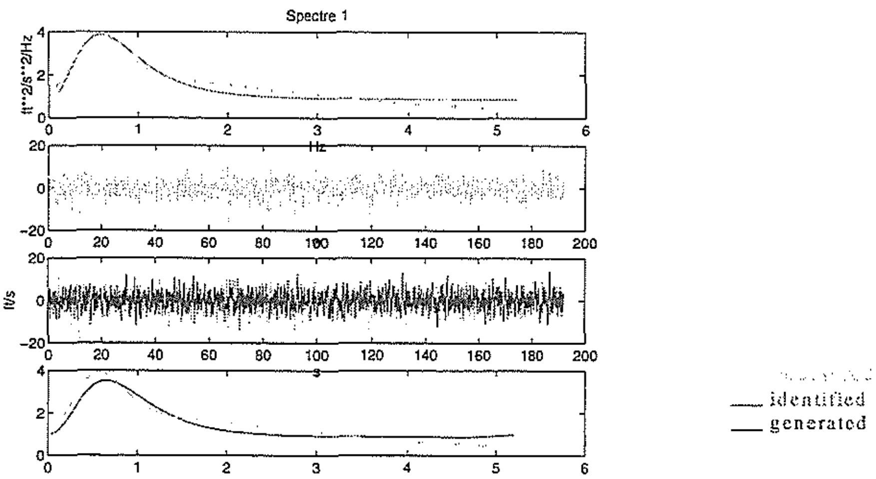


Figure 22 : Example of vertical velocity turbulence generation on the deck centre

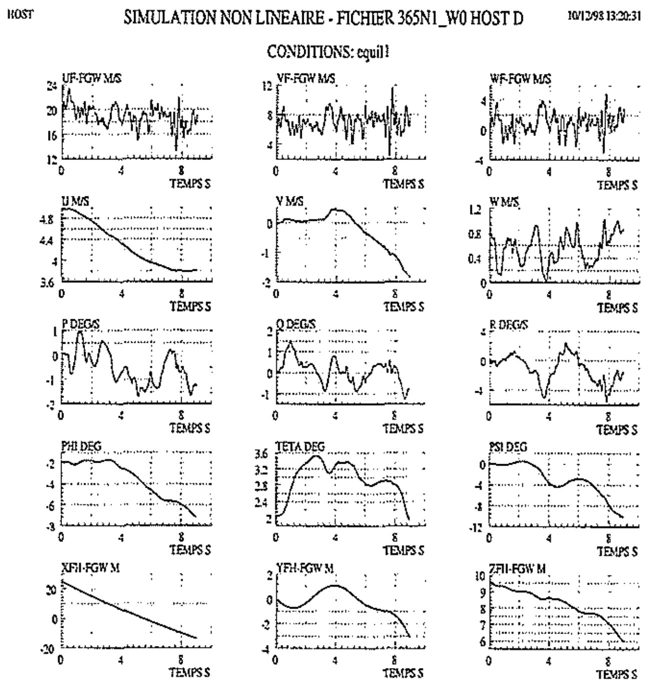


Figure 23 : HOST simulation – Helicopter parameters
Flight above the deck at 10 knots ; slope angle = -1°
Relative wind = 50 knots ; β = 15°
frigate in sinusoidal roll motion

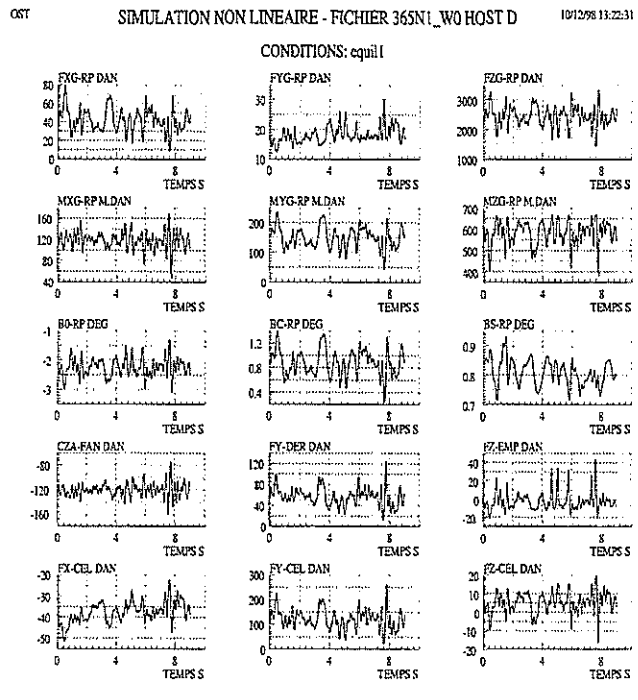


Figure 24 : HOST simulation – Helicopter forces and moments
Flight above the deck at 10 knots ; slope angle = -1°
Relative wind = 50 knots ; β = 15°
frigate in sinusoidal roll motion

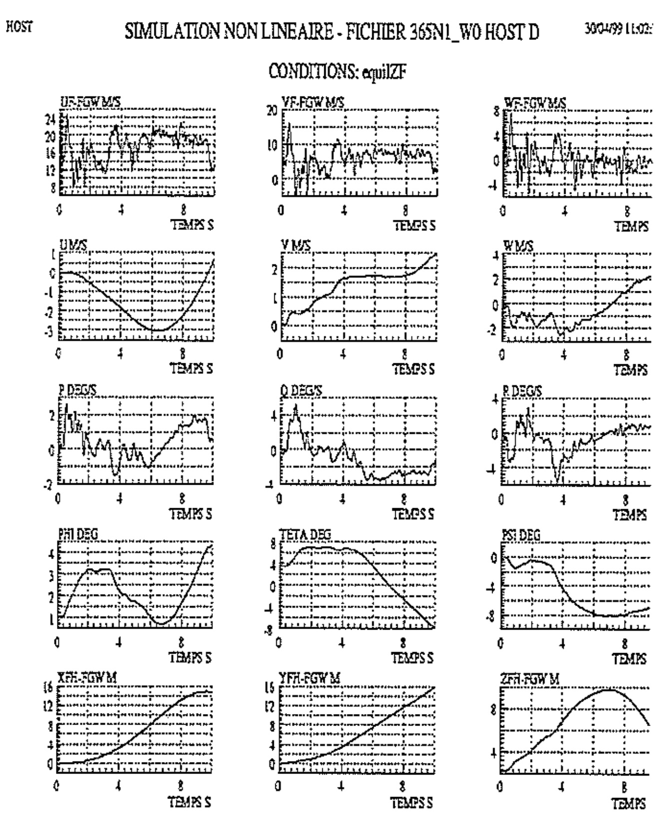


Figure 25 : HOST simulation (multi-element model)
Helicopter parameters
Hover flight above the deck
Relative wind = 50 knots ; β = 13° ; frigate still

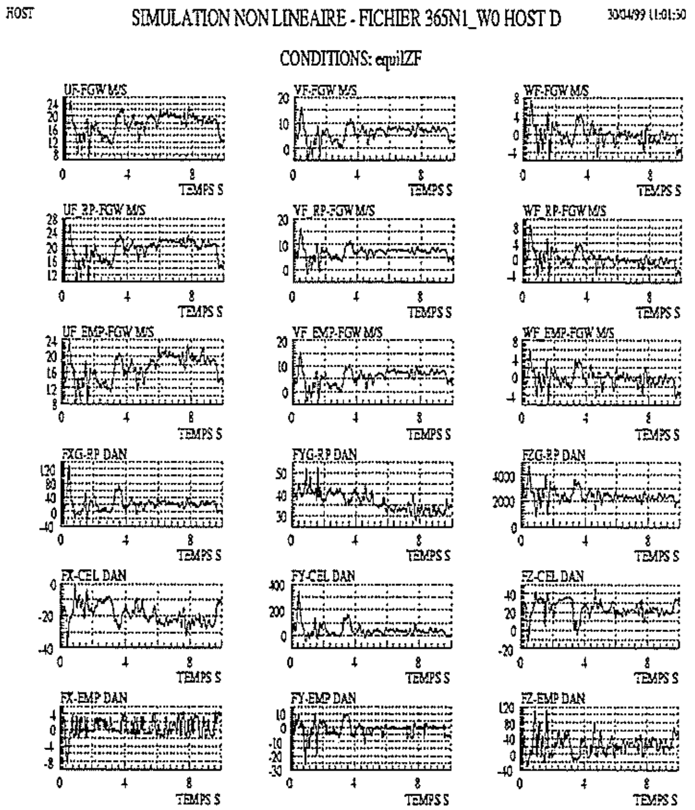


Figure 26 : HOST simulation (multi-element model)
Helicopter forces and moments
Hover flight above the deck
Relative wind = 50 knots ; β = 13° ; frigate still

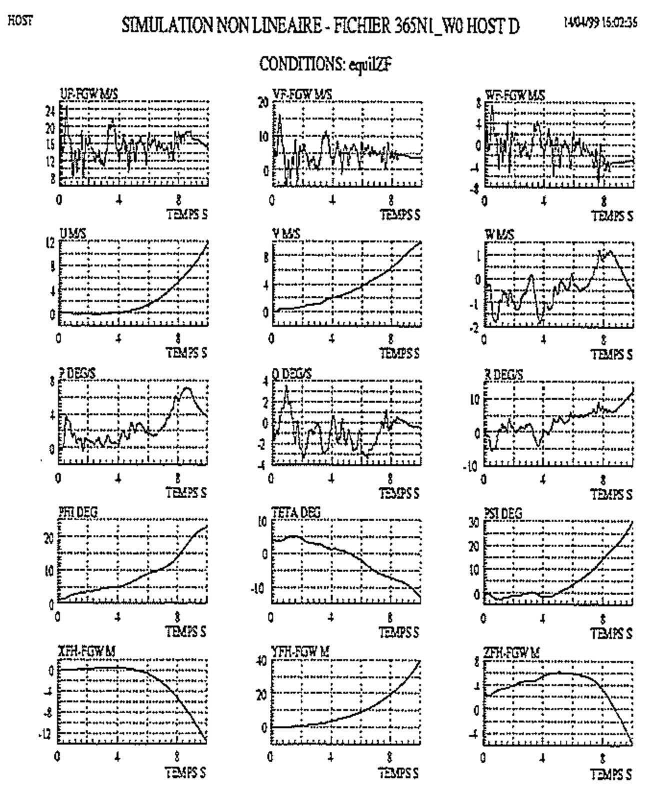


Figure 27 : HOST simulation (mass point model) Helicopter parameters. Hover flight above the deck. wind = 50 knots ; β = 13° ; frigate still

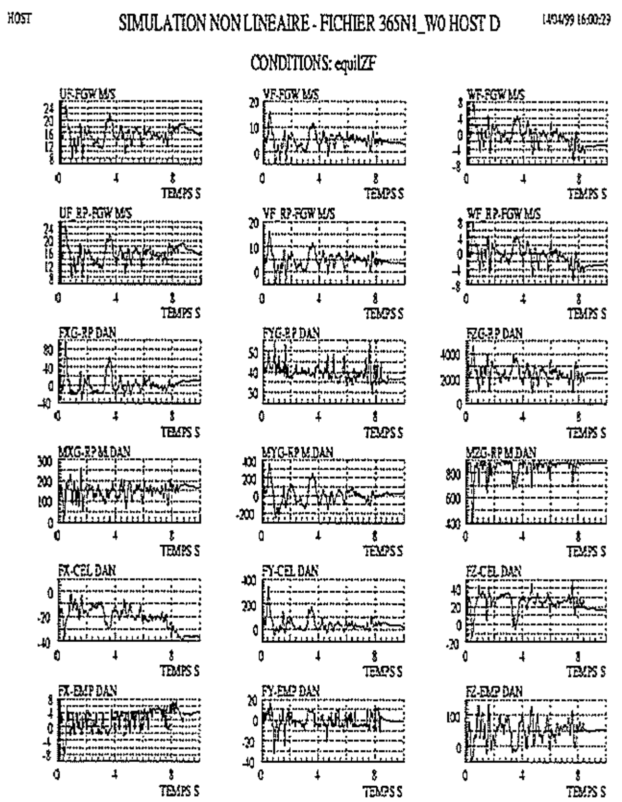


Figure 28 : HOST simulation (mass point model). Helicopter forces and moments. Hover flight above the deck. Relative wind = 50 knots ; β = 13° ; frigate still