LARGE SAILING YACHTS

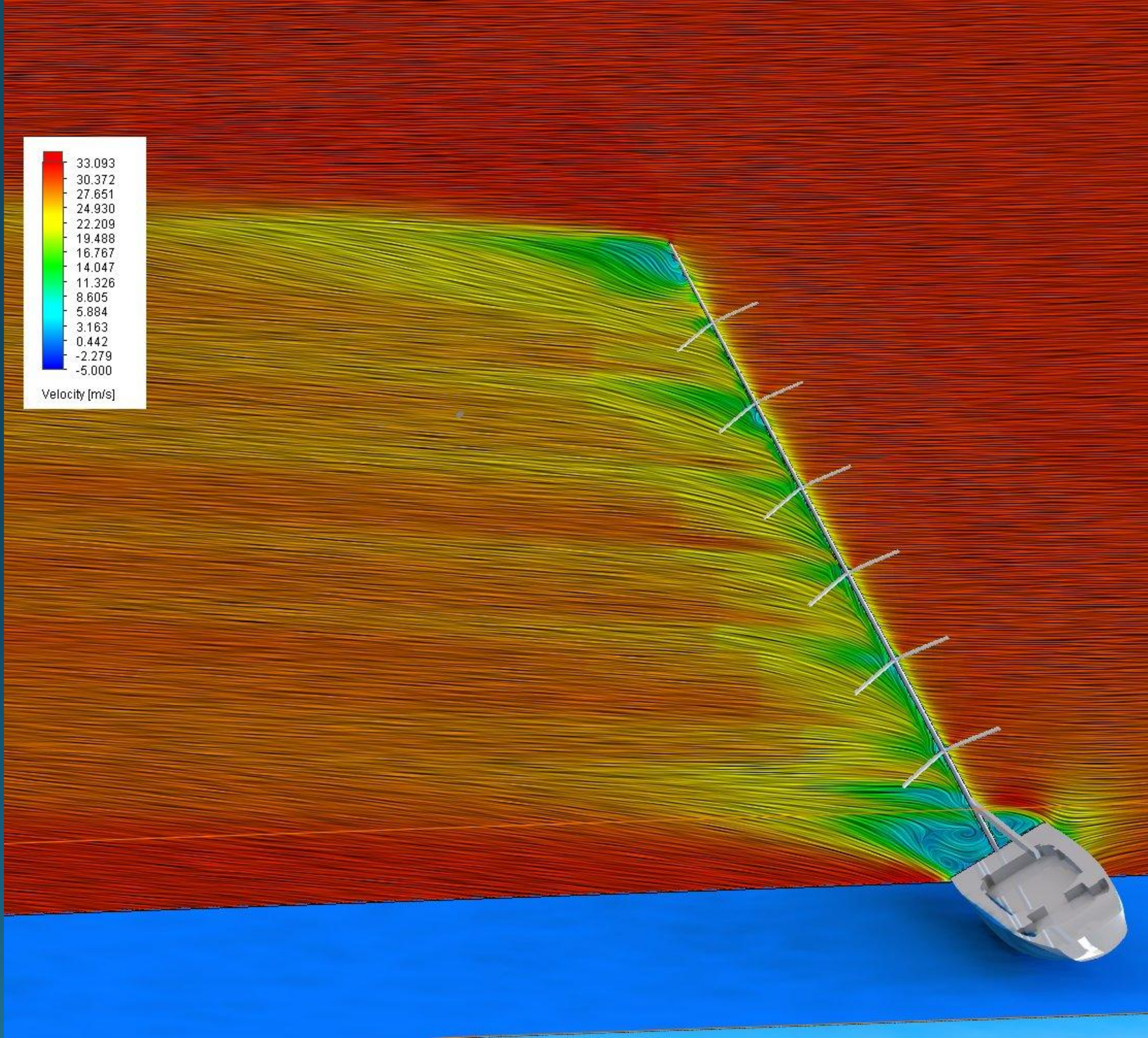
BARE MAST CFD HEELING ANALYSIS

64th International Congress of Naval Architecture and Maritime Industry

Gijón 26th – 28th March, 2025

LARGE SAILING YACHTS
BARE MAST CFD
HEELING ANALYSIS

Part One:
Aerodynamics
& Stability

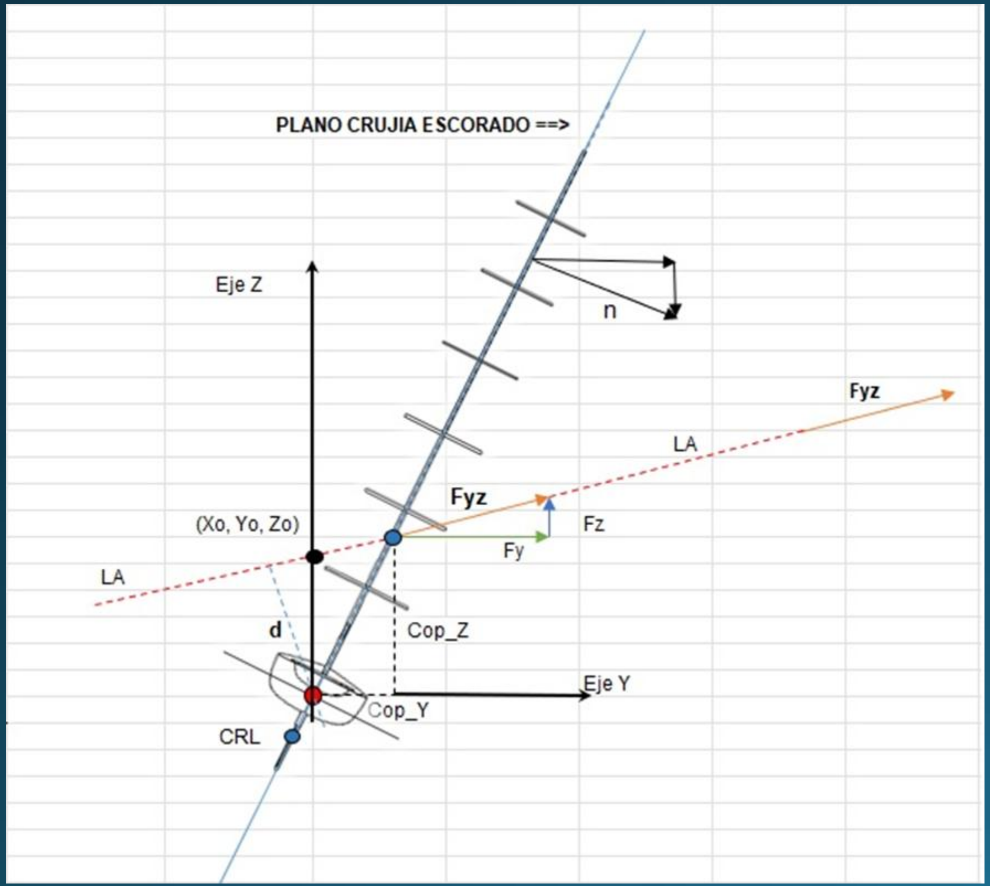


LARGE SAILING YACHTS BARE MAST CFD HEELING ANALYSIS

3D model

- When studying the possible causes of the sinking of the yacht Bayesian in August 2024, we found there was a not big but noticeable righting lever caused by the rig spreaders.
- Curious about it we decided to further investigate this effect, as well as deepening the study of the effect of a sudden strong gust when under bare mast and with the daggerboard in the up position, for an hipothetical similar yacht using a more accurate 3D model and running a detailed CFD analysis considering the mast with and without spreaders.

LARGE SAILING YACHTS BARE MAST CFD HEELING ANALYSIS

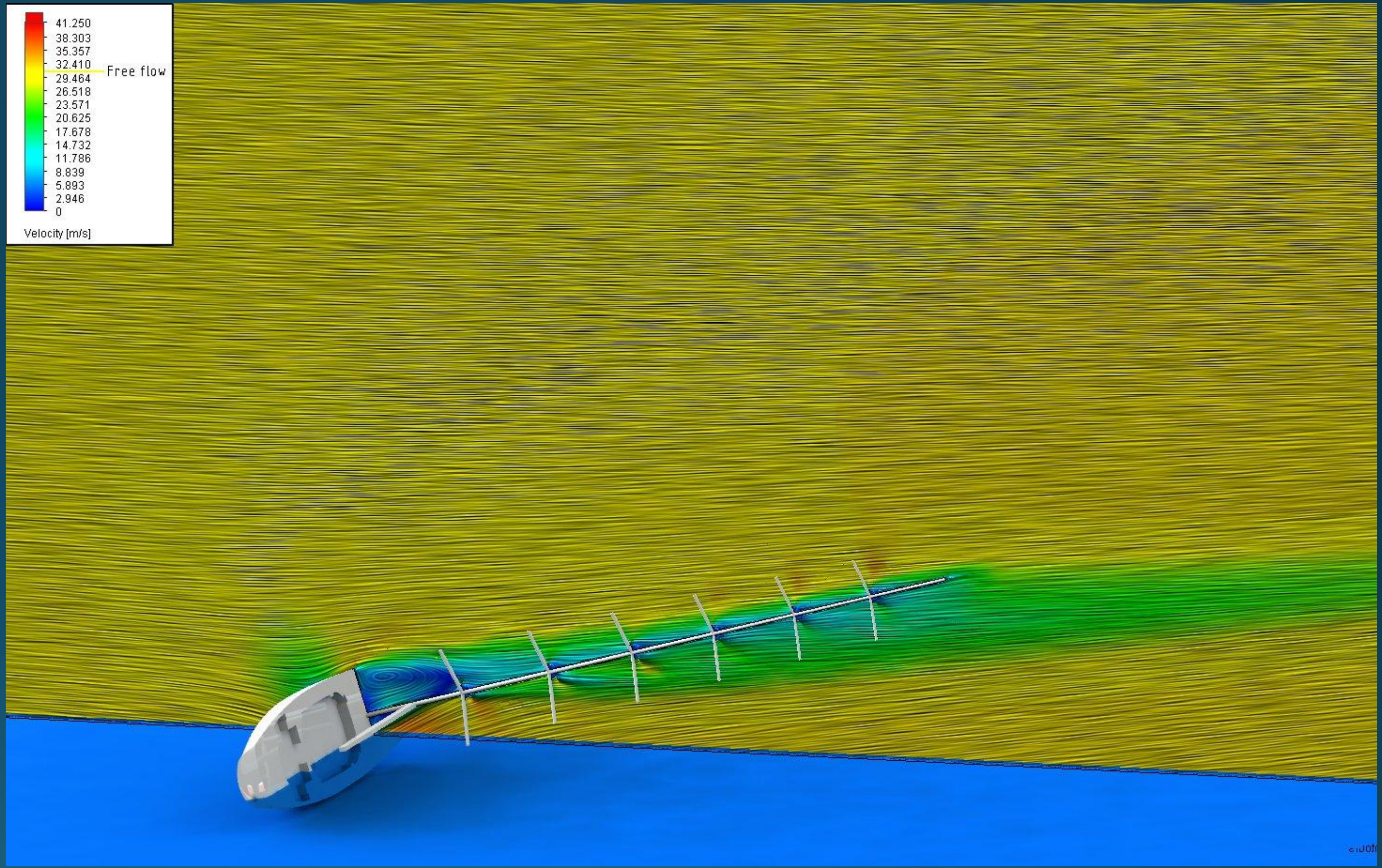


- To begin with, we considered that the centers of pressure (CoP) provided by the CFD are not physically on the object under study but outside it, so it was necessary to consider their projection following the line of action of the resulting force, as seen in the graph.

LARGE SAILING YACHTS BARE MAST CFD HEELING ANALYSIS

Up to 32 (16+16) CFD computings using a RANS (k-ἐ) method were run for the aerodynamic study, some of which exceeded 80 hours of computation.

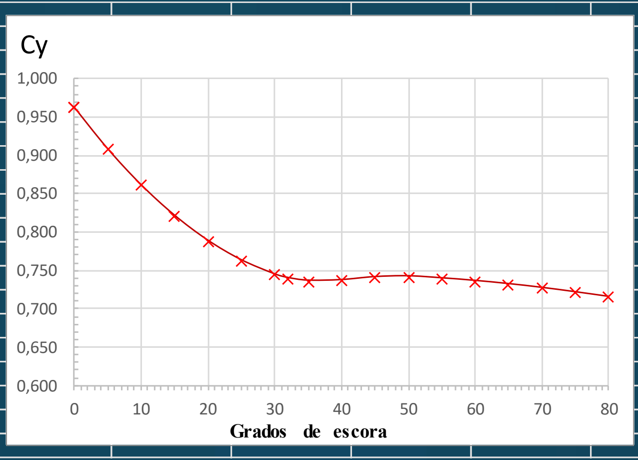
Wind speeds of 10, 25, 30 and 40 m/s (19.4, 48.6, 58.3 and 77.8 knots) and heels of 0, 30, 50 and 75 degrees were considered.

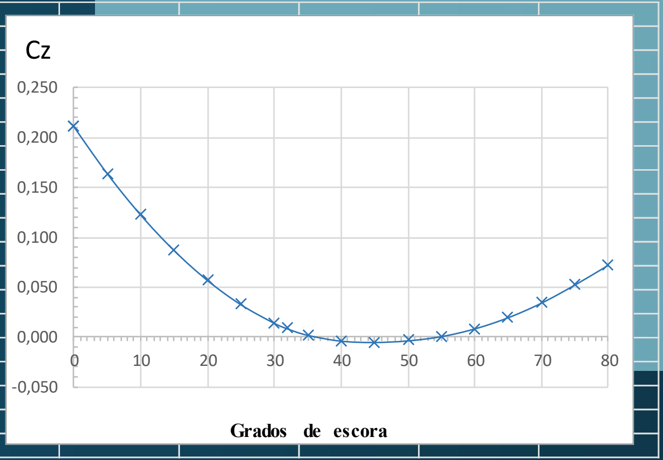


LARGE SAILING YACHTS BARE MAST CFD HEELING ANALYSIS

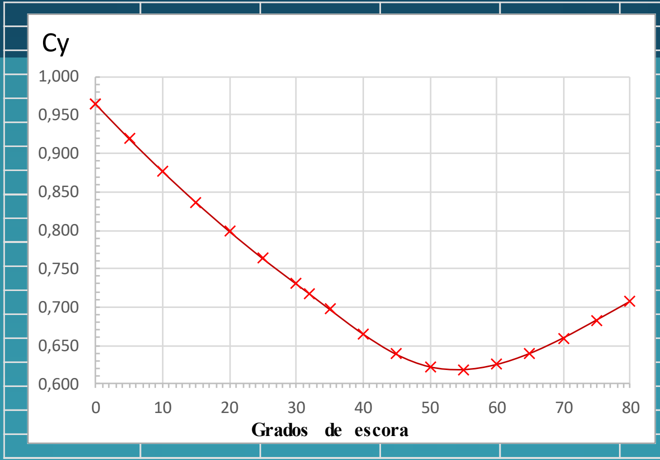
- We calculated the aerodynamic coefficients of force Cy and Cz with and without spreaders for each wind speed and heeling we had considered.
- The value of the coefficients to be applied for intermediate heels were calculated by double interpolation, instead of by the Reynolds number because of the small number of points.
- We found the Cz coefficient is generally higher (more positive) when there are no spreaders, that is: the spreaders generate a certain upwards thrust.

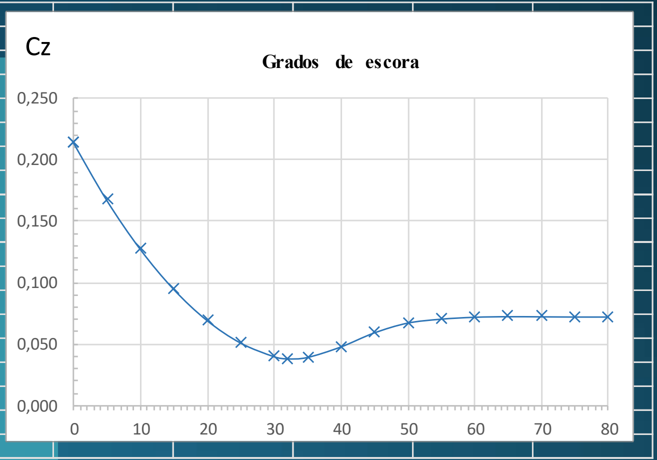
V = 10 m/s, with spreaders





V = 10 m/s, no spreaders

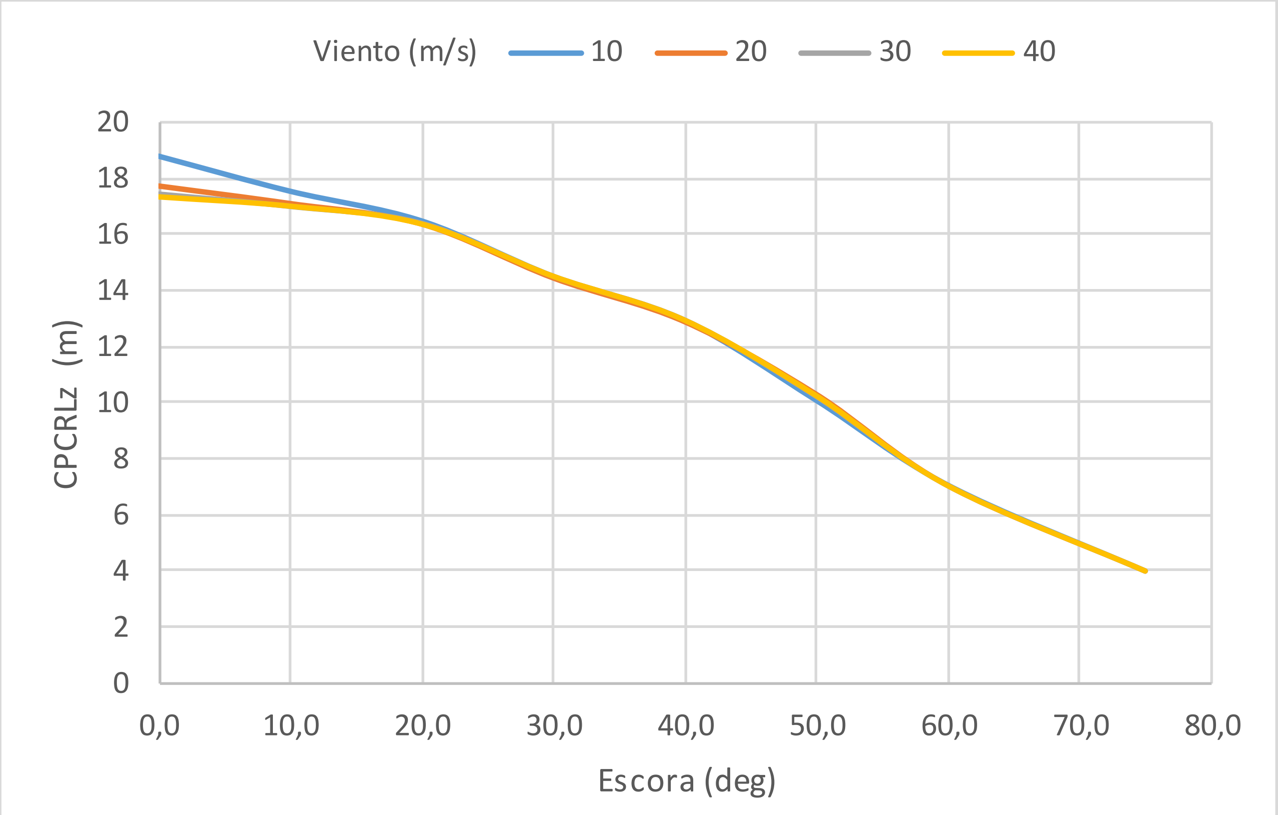




LARGE SAILING YACHTS BARE MAST CFD HEELING ANALYSIS

- We calculated the centers of pressure (COP) for these same heels and wind speeds, the lateral hull resistance centers for each heel (CRL) and the areas projected to the wind of the hull plus mast and rigging assembly (A).

CPCRLz VARIATION WITH WIND SPEED AND HEELING



Note: CPCRLz is the vertical distance beteen the CP and the CRL
So, it is also the heeling arm Ha

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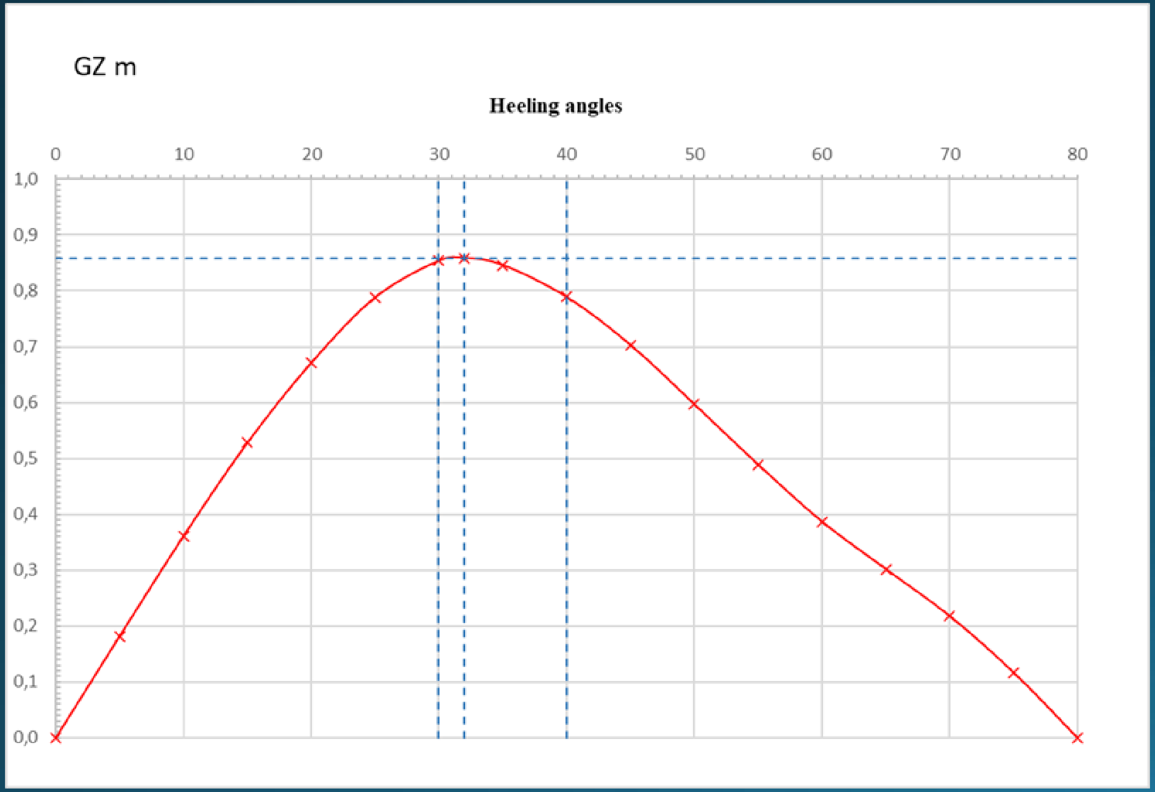
- The forces exerted for each speed and heel are determined, as well as the distances between the COPs and the CRLs, which allow us to calculate the moments and the heeling arms corresponding to such moments for the regulatory Departure of Port load condition considering isocarene heeling.
- We found the spreaders exert a net heeling force which shall be not ignored when studying the impact of the wind on the mast.

For Zero heel				
Wind m/s	Moment (Nm)	CRL-COP m	Force N	Force kgf
10	2388	21,804	1065	109
25	150428	22,632	6646	677
30	218684	22,604	9674	986
40	384044	22,551	17029	1736
With the vessel upright, a gust of about 30 m/s, i.e. about 60 knots, exerts a				
force on the spreaders of almost one ton, applied at a height of about 22,6 m.				
almost doubling for 40 m/s				

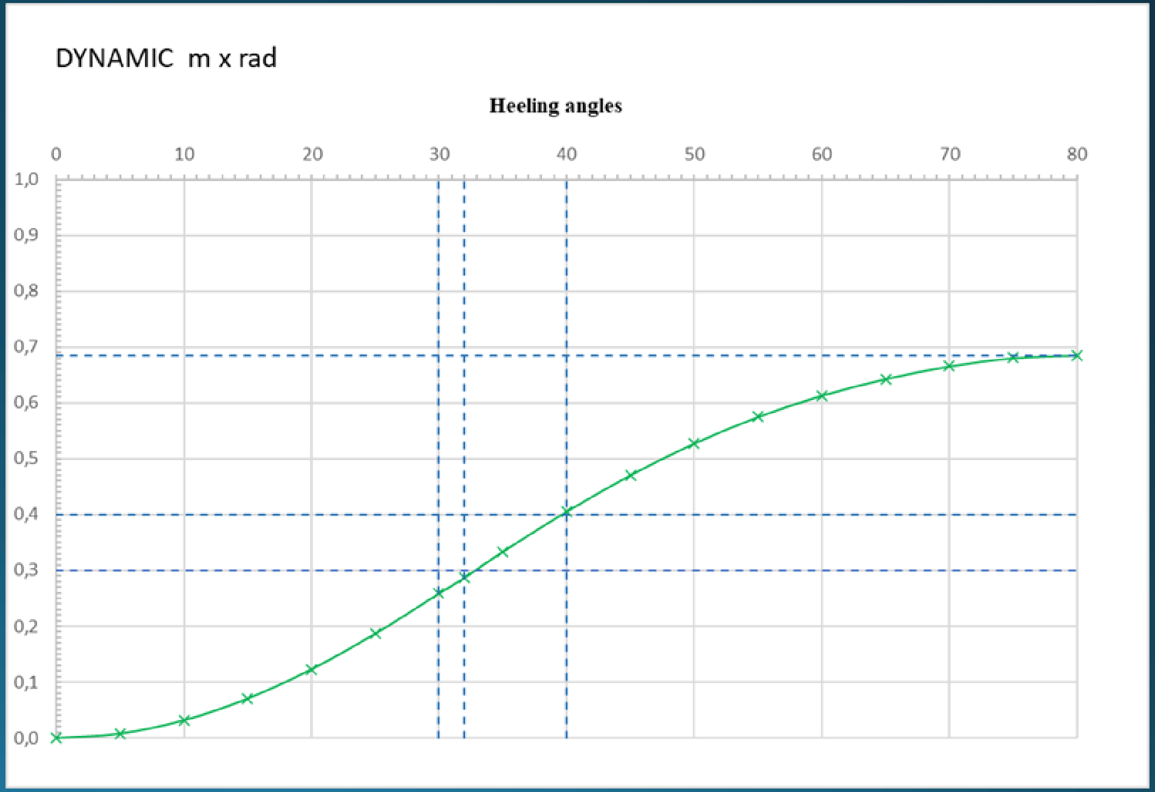
LARGE SAILING YACHTS BARE MAST CFD HEELING ANALYSIS

Stability curves considering LCG at 2,533 m (aft mid) & VCG at 5,751 m over BL, complying the regulatory MCA's LYC criteria

Curve of arms



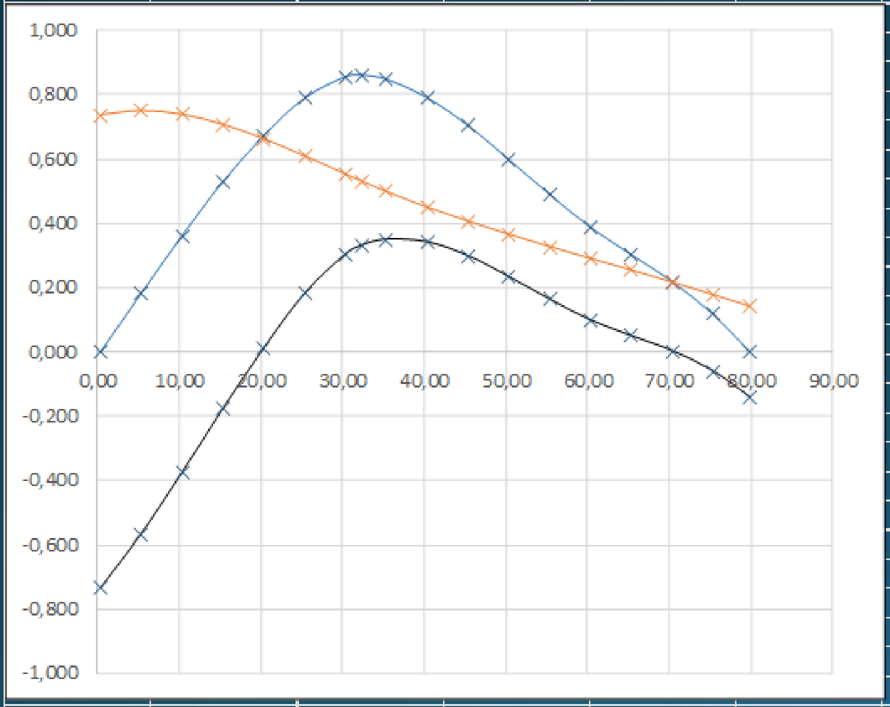
Curve of areas



LARGE SAILING YACHTS BARE MAST CFD HEELING ANALYSIS

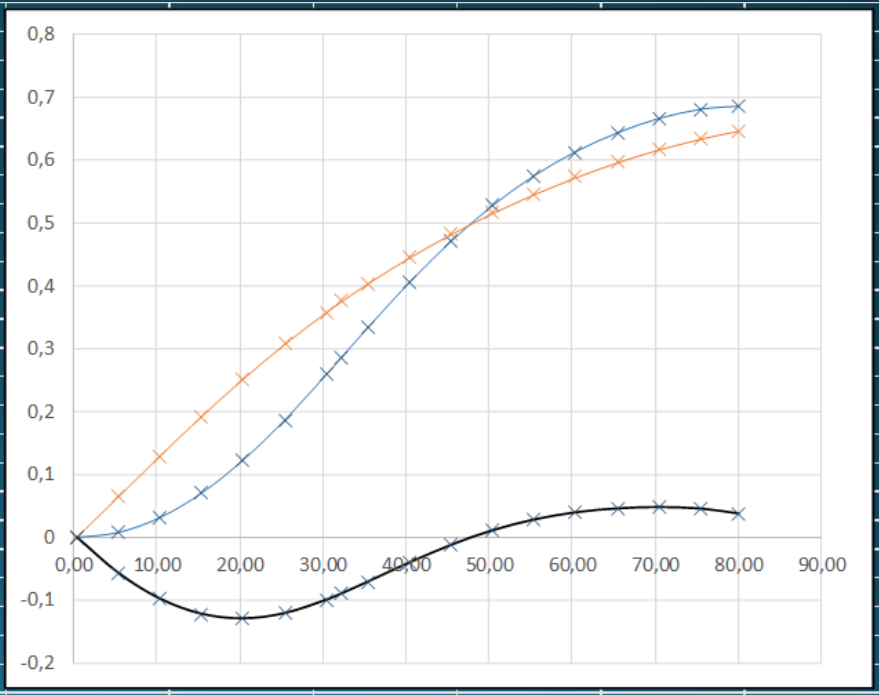
Heeling vs. Righting curves. With spreaders. Wind 30 m/s

Arms curves



MaxGZ	0,348	Escora	35,41
Equilibrio Est	20,1	AVS	70,6

Areas curves

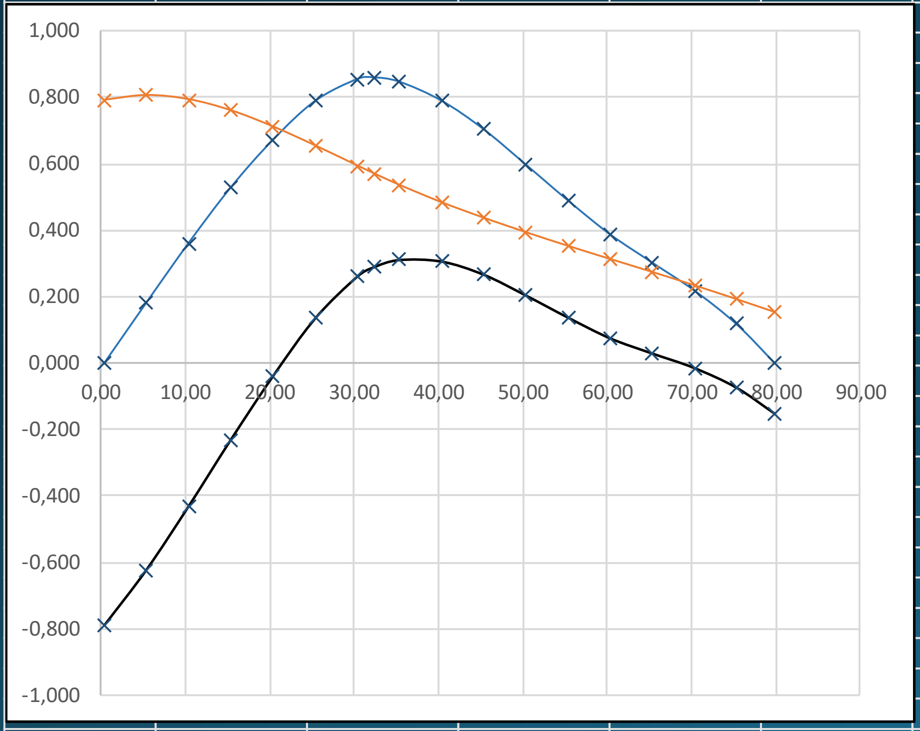


Max Din	0,048	Escora	70,41
Equilibrio DIN	48,0	AVD	NA
Min DIN	-0,129		20,41

LARGE SAILING YACHTS BARE MAST CFD HEELING ANALYSIS

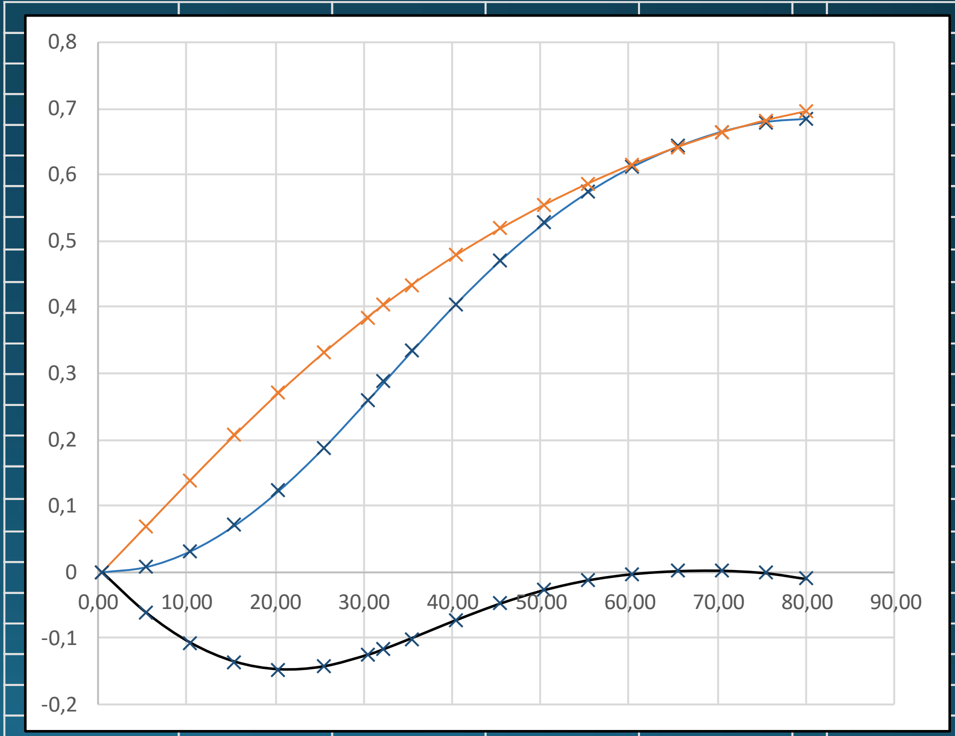
Heeling vs. Righting curves. With spreaders. Wind 31,1 m/s

Arms curves



Max GZ	0,311	Escora	35,41
Equilibrio Est	21,6	AVS	68,8

Areas curves

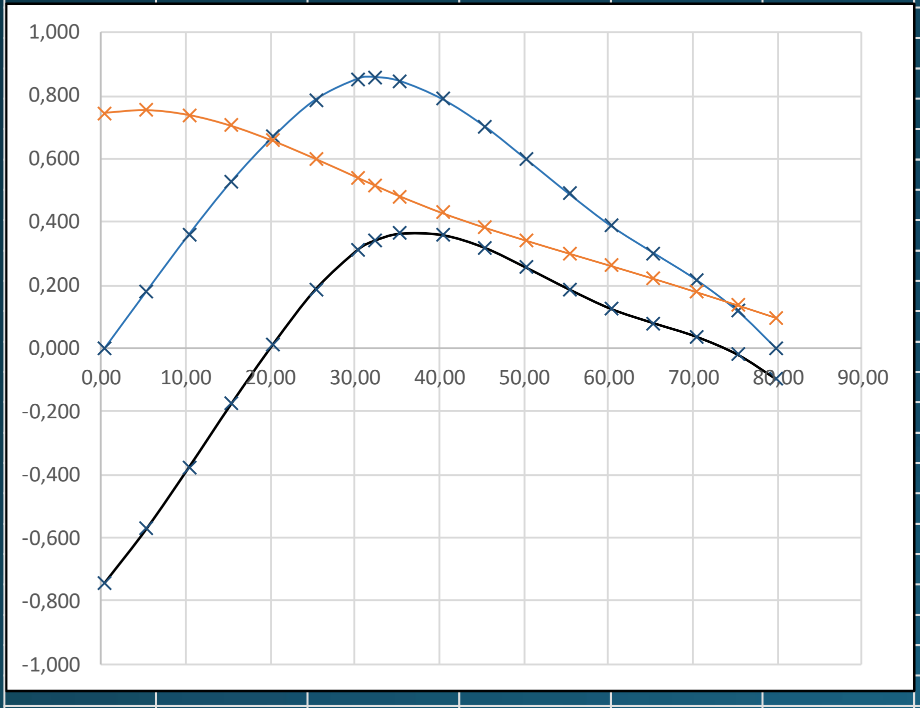


Max Din	0,002	Escora	70,4
Min Din	-0,148	Escora	20,4
Equilibrio DIN	64,1	AVD	64,1

LARGE SAILING YACHTS BARE MAST CFD HEELING ANALYSIS

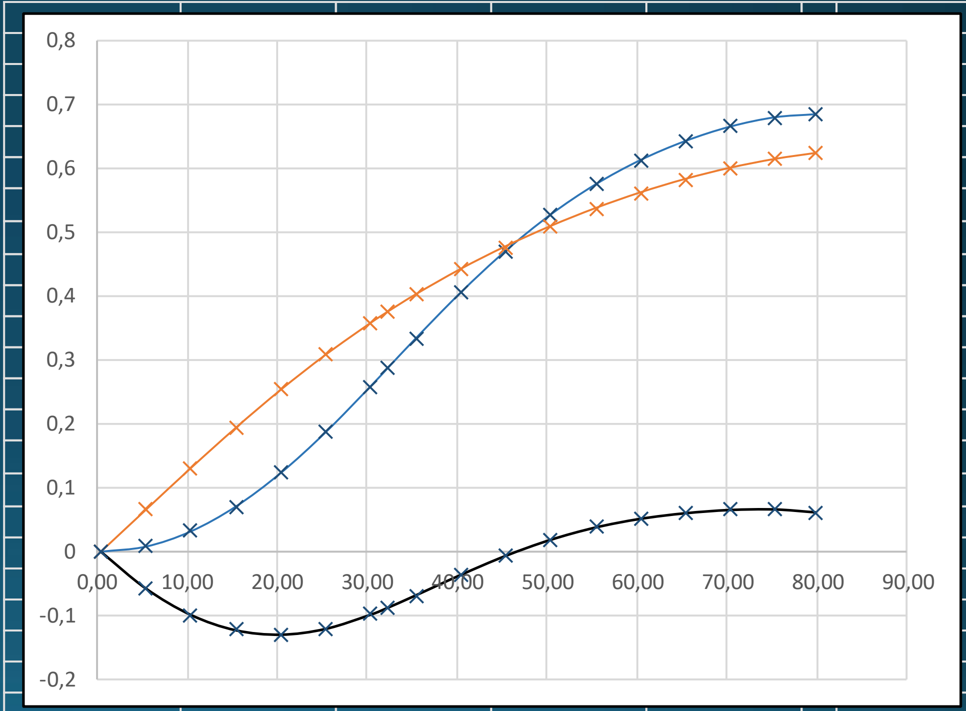
Heeling vs. Righting curves. No Spreaders. Wind 31,1 m/s

Arms curves



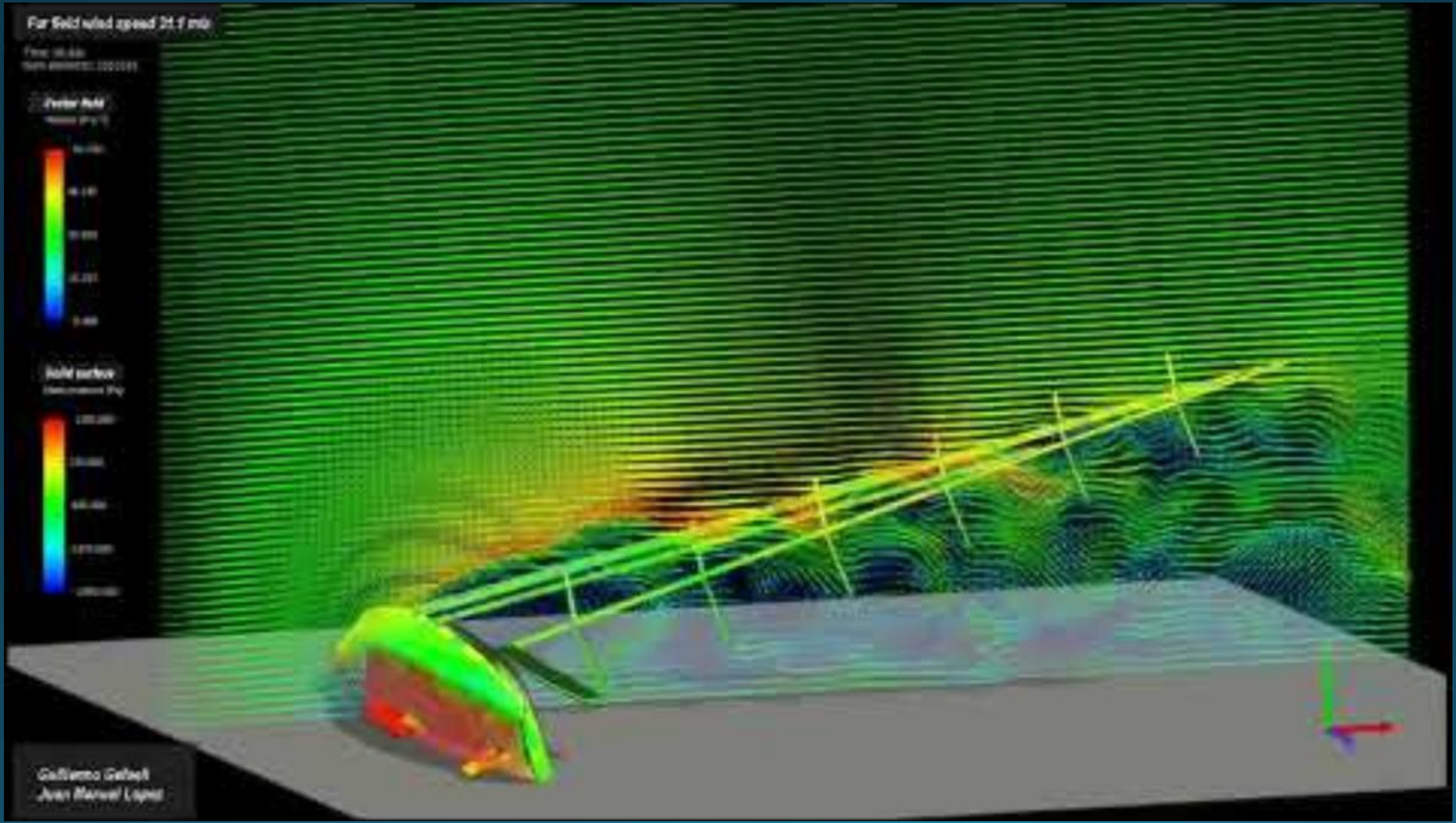
Max GZ	0,364	Escora	35,41
Equilibrio Est	20,0	AVS	73,6

Areas curves



Max Din	0,066	Escora	75,4
Min Din	-0,130	Escora	20,4
Equilibrio DIN	45,4	AVD	46,7

LARGE SAILING YACHTS BARE MAST CFD HEELING ANALYSIS
31,1 m/s (60,5 kn) Wind



LARGE SAILING YACHTS BARE MAST CFD HEELING ANALYSIS

PART ONE: CONCLUSION

- Spreaders create a small righting force of no relevance on the total wind effect.
- But they have a significant effect on the safety of the vessel when it is hit by an intense and sudden gust of wind.
- A side gust of 60 kn or more may dynamically heel this type of sailing yachts down to a no return angle very quickly, even if keeping a watertight condition.
- The stability of these vessels should be studied for the effect of a strong wind gust when under bare mast, particularly when the daggerboard is in the up position.

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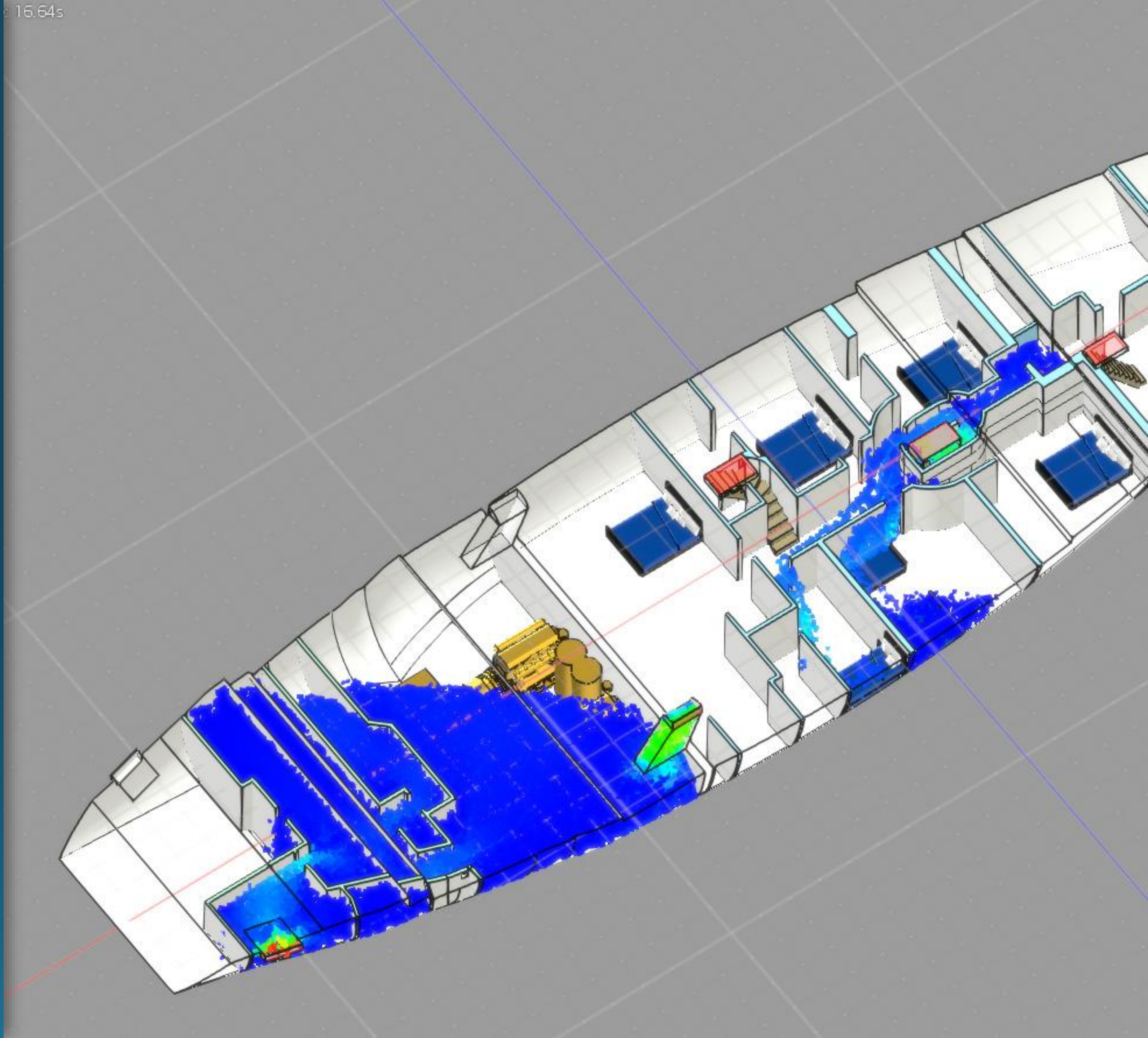
PART TWO :

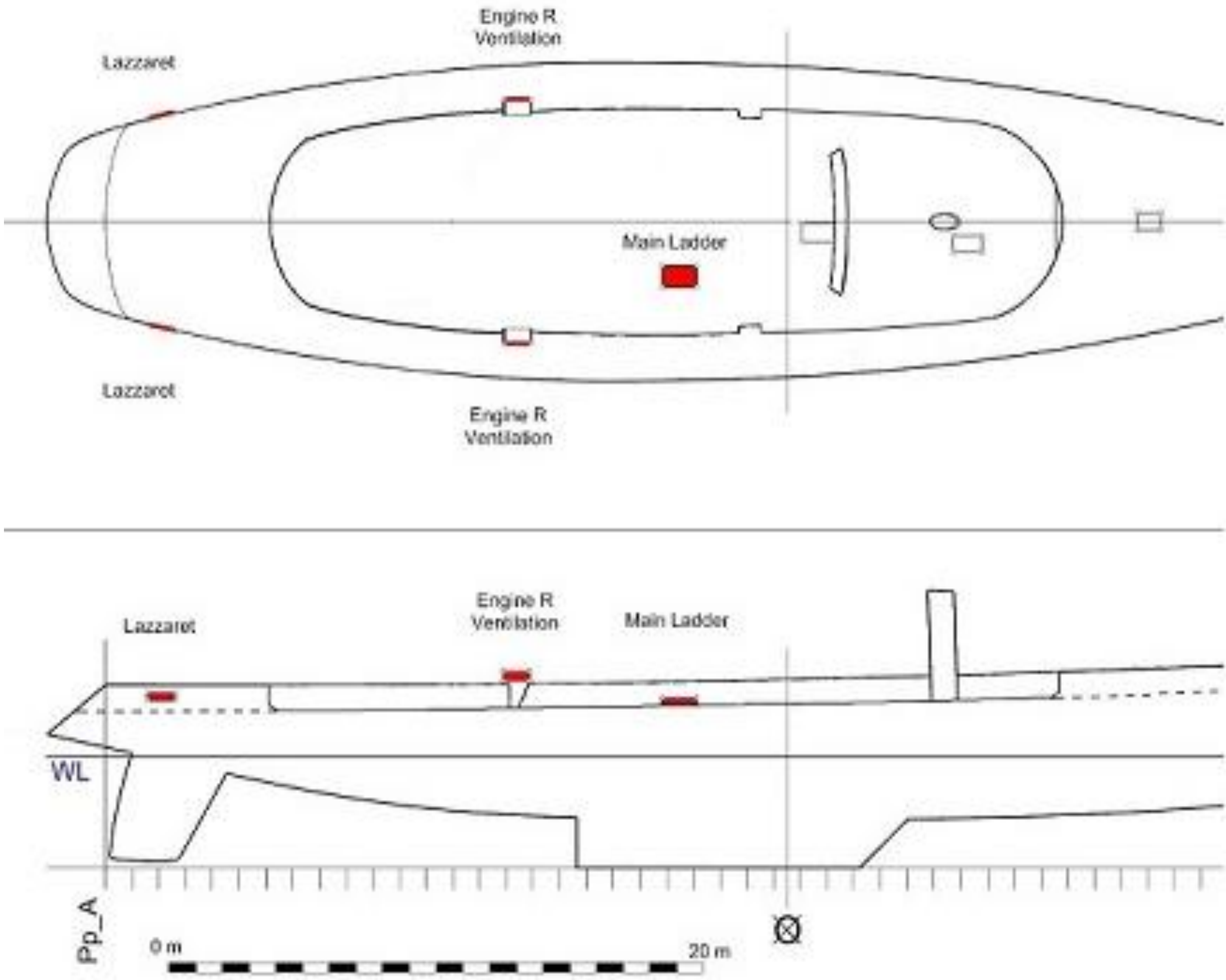
FLOODING



LARGE SAILING YACHTS BARE MAST CFD HEELING ANALYSIS

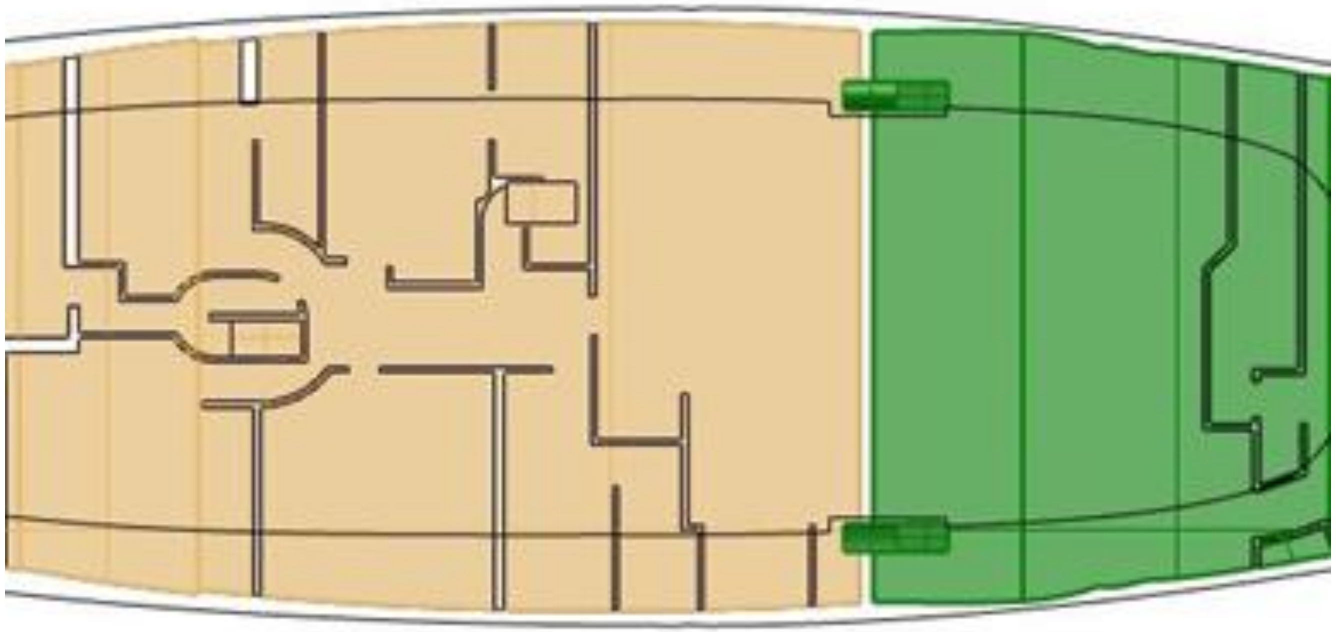
- Although these ships have a variety of openings that are considered flooding points, we are going to consider only the three that usually have the largest area, which are:
  - Aft Lazaretto ventilation openings (port and starboard)
  - Engine Room ventilation/extraction openings (port and starboard)
  - Main staircase down to the lower deck (inside the deckhouse well, not centered)

NOTE: height of openings is measured from the freeboard deck (central well floor) and ITS EXTENSIONS.



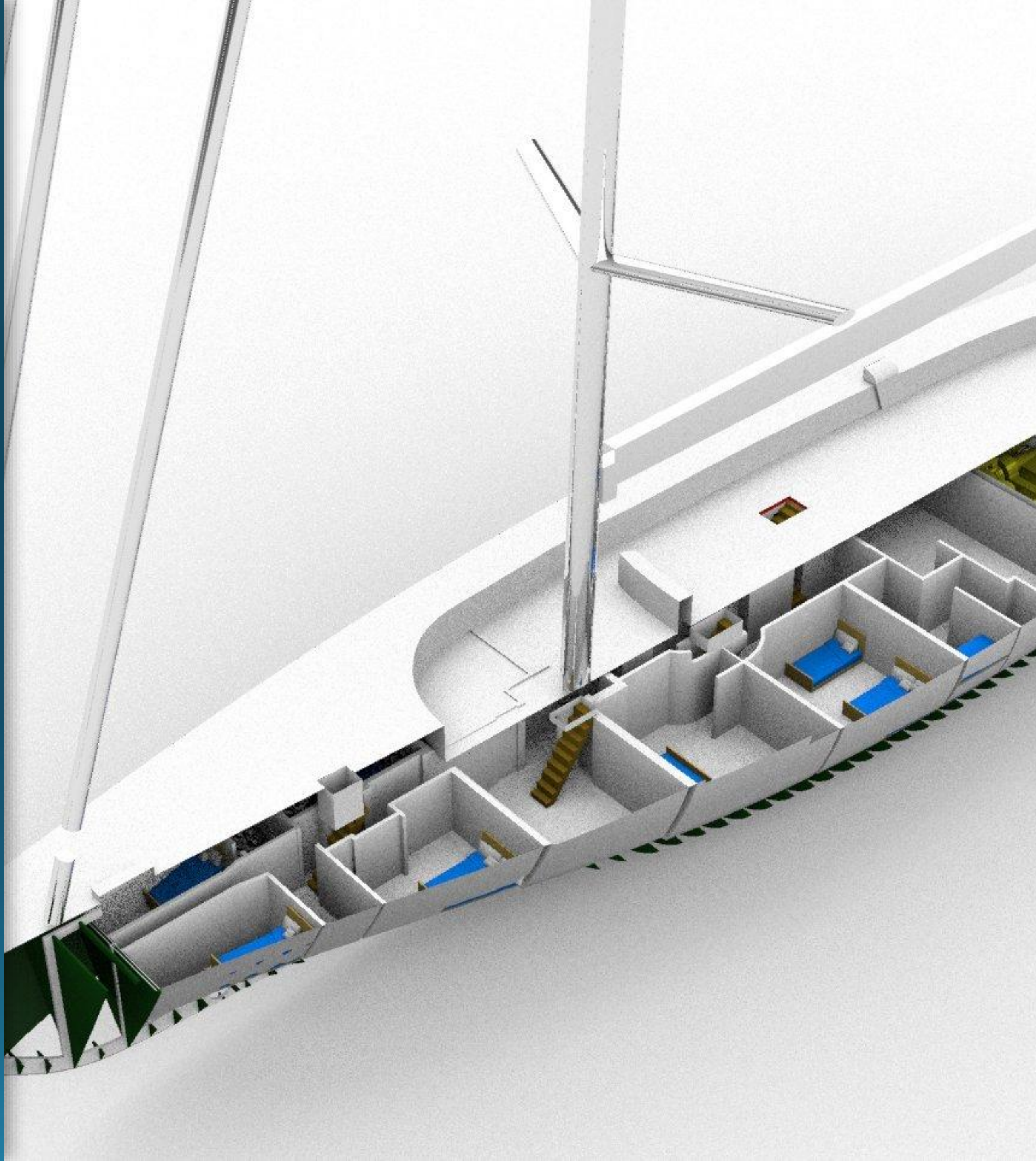
LARGE SAILING YACHTS BARE MAST CFD HEELING ANALYSIS

- We first calculate the upright and heeled hydrostatics for the model we have built…
- …carefully define the coordinates of the deck and well lines.
- …calibrate the floodable spaces under the main deck.
- With this information we simulate the flooding process using the Lattice Boltzmann algorithm (LBM D6Q27)



LARGE SAILING YACHTS BARE MAST CFD HEELING ANALYSIS

- We divide the displacement mass of 543 tons into four components:
  - Hull with its furniture and equipment
  - mast
  - deckhouse and
  - ballast.
- The origin of coordinates is the center of gravity of the ship in the cargo situation considered.
- The moments of inertia have been calculated assigning mass to the surfaces until they coincide with the weight of the element.
- The ballast has been calculated as solid or hollow depending on its position in the daggerboard box.



LARGE SAILING YACHTS BARE MAST CFD HEELING ANALYSIS

The areas considered for the openings are:

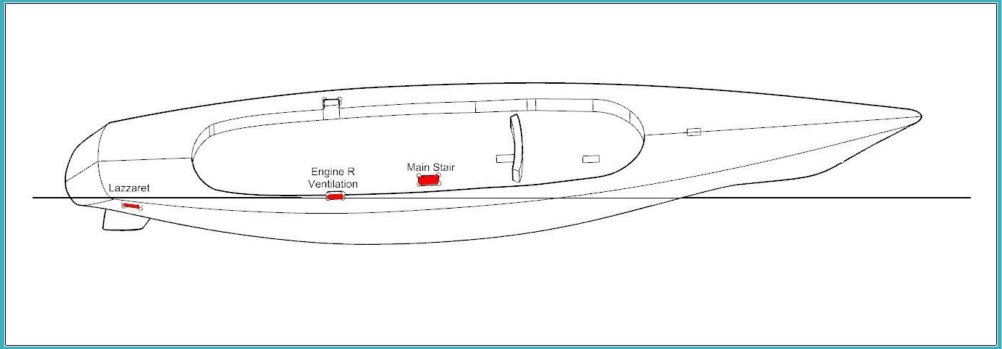
- Lazzaretto: 0,32 m2 per side
- Eng. Room vent: 0,34 m2 per side
- Staircase: 1,33 m2

We calculate the tons of water that enter per second through each of the openings at each heel, depending on time.

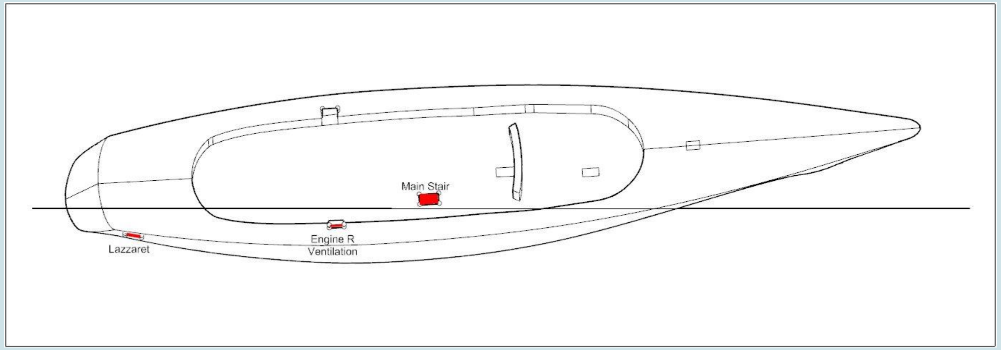
Lazzaretto and E.R. vents submerge in 9 seconds and the staircase in 22 seconds

90 deg are reached in 23,4 s and from there we consider the vessel sinks keeping that position

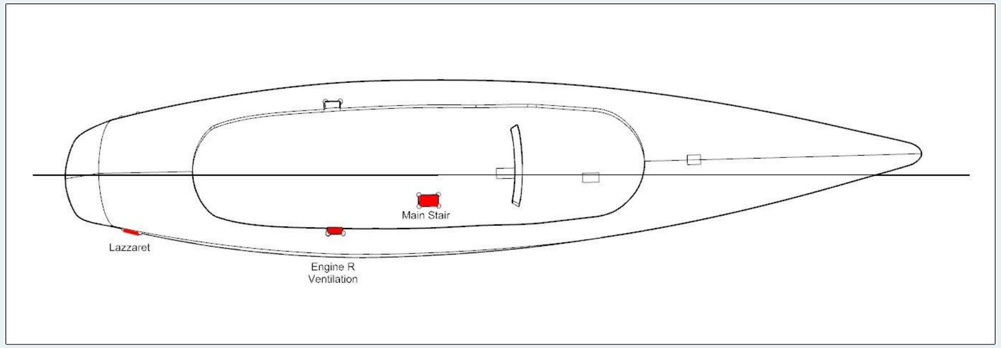
45 deg



60 deg



85 deg

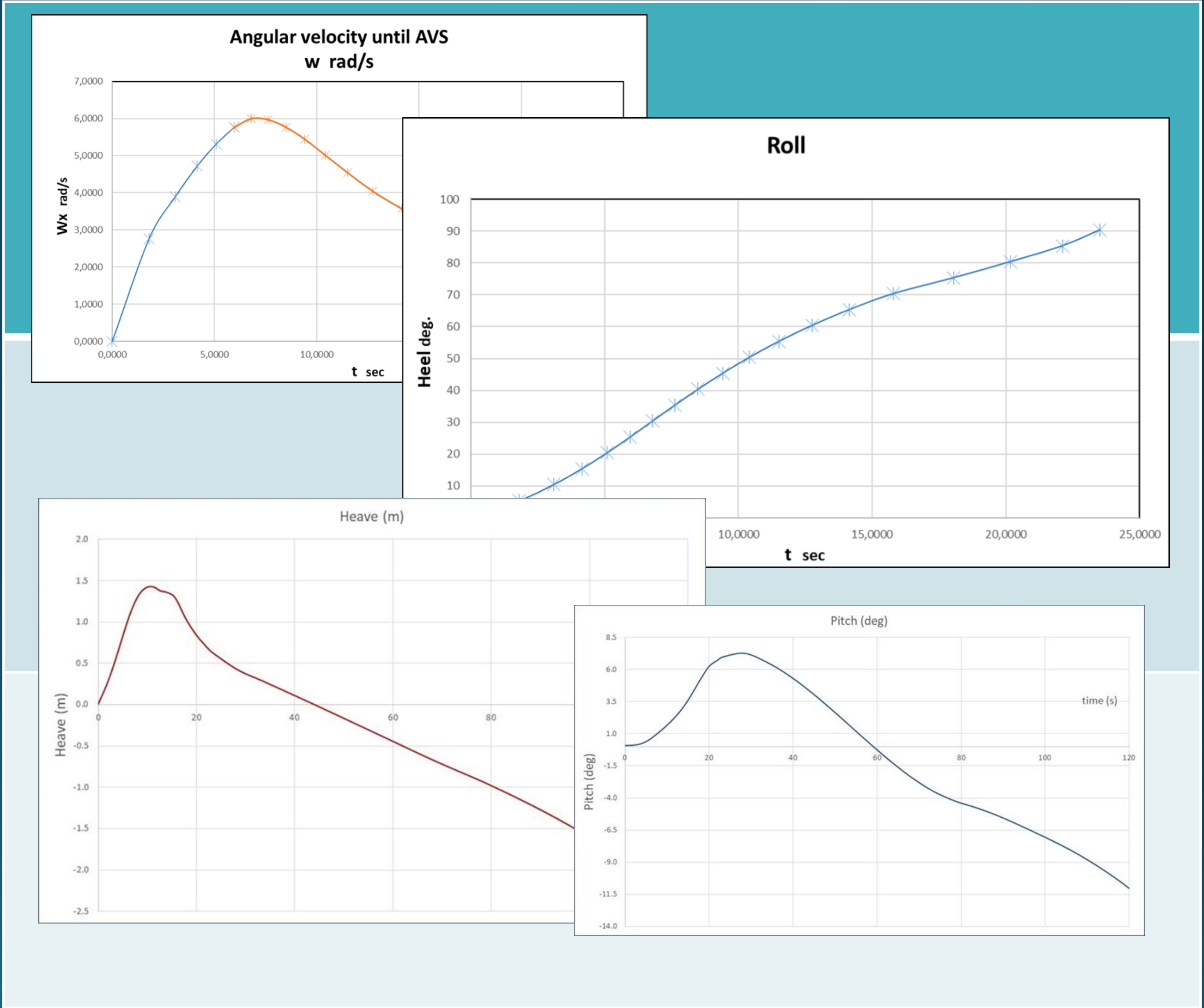


LARGE SAILING YACHTS BARE MAST CFD HEELING ANALYSIS

KNOCKING DOWN PROCESS

The knocking down is very fast. The ship heels up to 90 degrees in 23.4 seconds, with an increasing angular velocity in the first 7 seconds and then slowly descending to approximately 18 seconds, at which point, when the mast touches the water, it continues to list at an almost constant angular velocity of just over two radians/second until 23.4 seconds.

The center of gravity first slightly rises and then falls as the heel and flooding progress. Meanwhile, the boat trims astern and then recovers until the center plane is close to horizontal when the boat is completely knocked down.

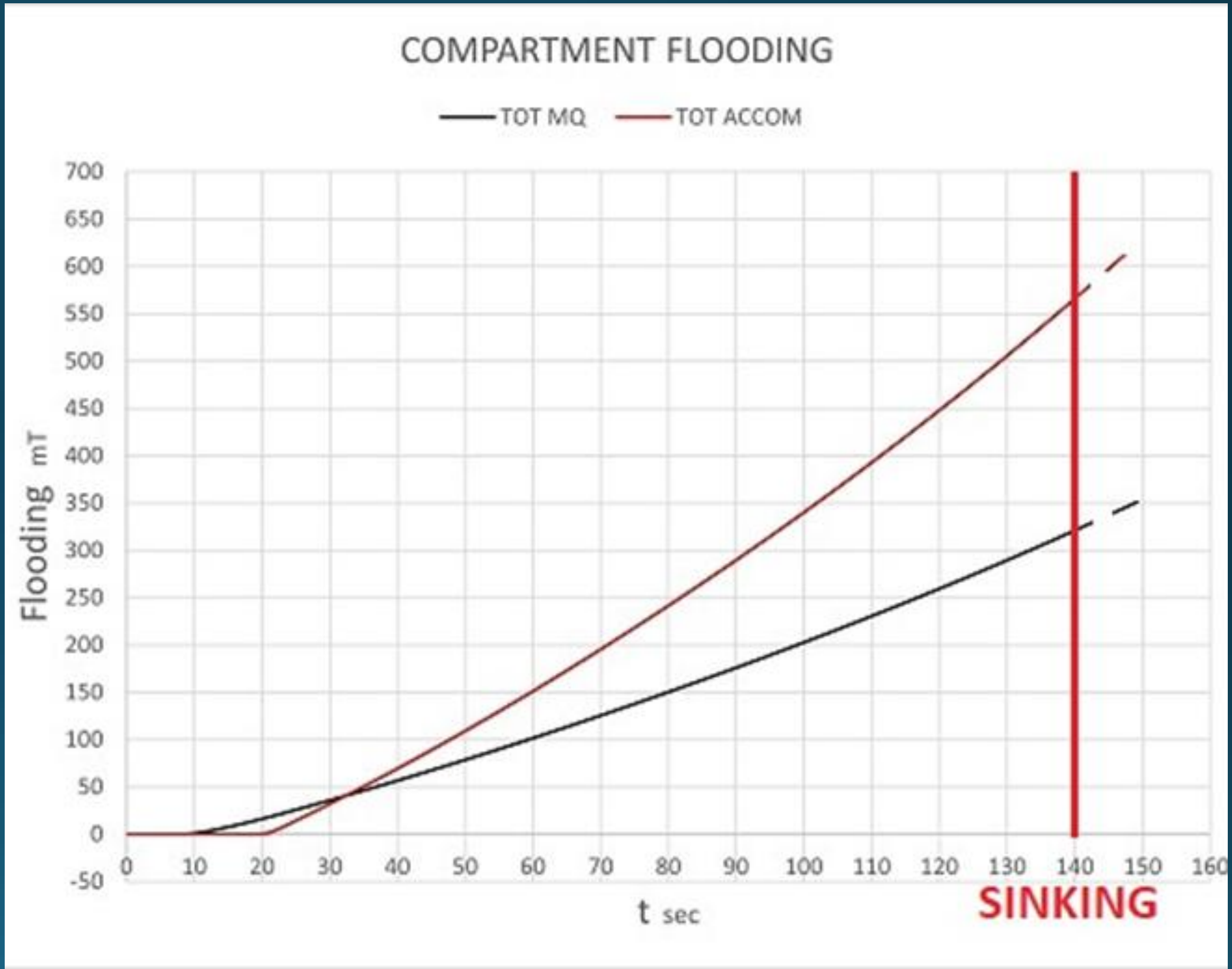


LARGE SAILING YACHTS BARE MAST CFD HEELING ANALYSIS

SINKING

Total displacement of the hull is about 1.444 tons. So deducting the 543 tons of the load condition considered, the boat sinks when embarking 901 tons of water.

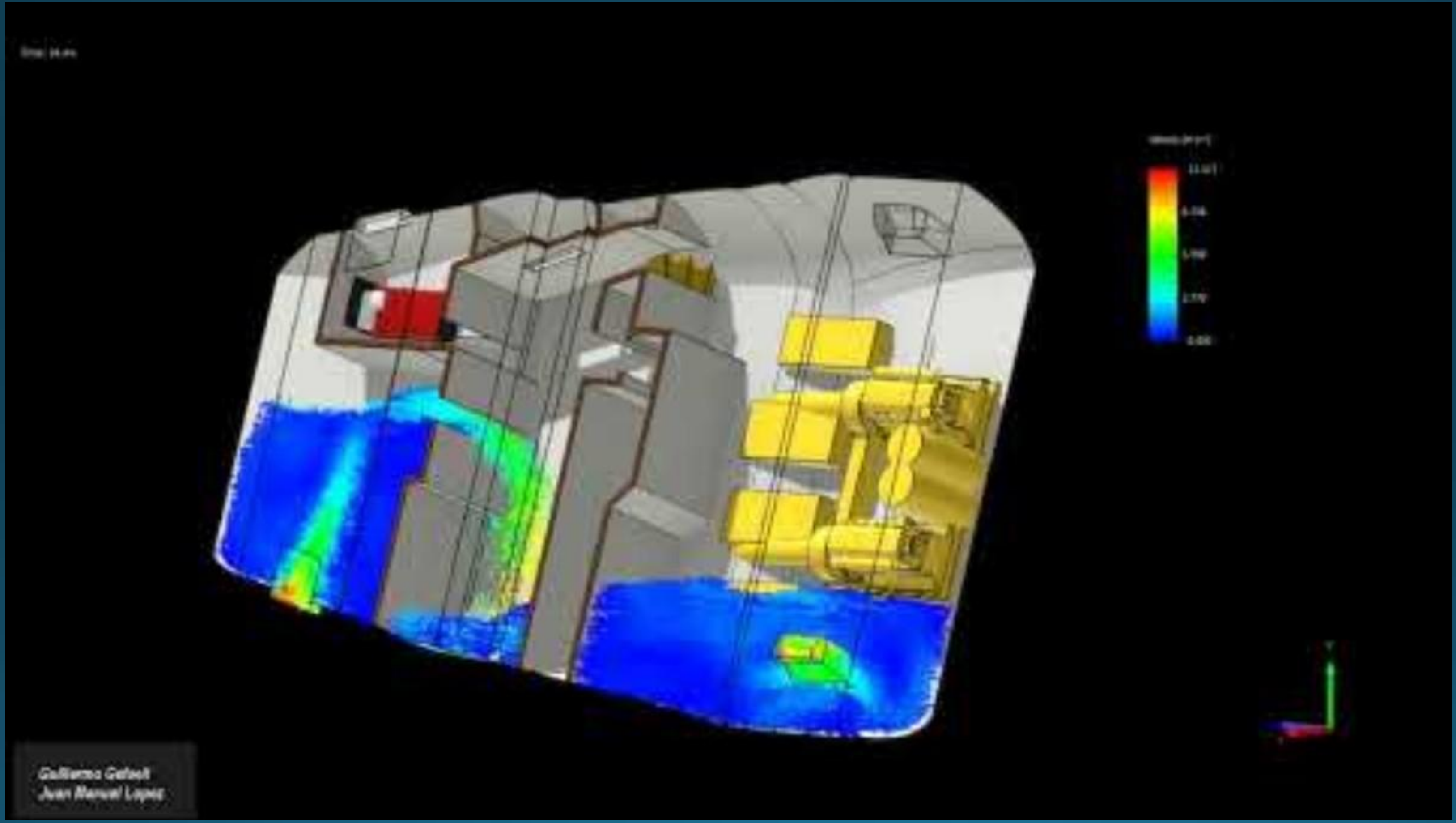
This is reached in about 140 seconds, which is less tan 2,5 minutes.



LARGE SAILING YACHTS BARE MAST CFD HEELING ANALYSIS

MACHINERY SPACES FLOODING VIDEO

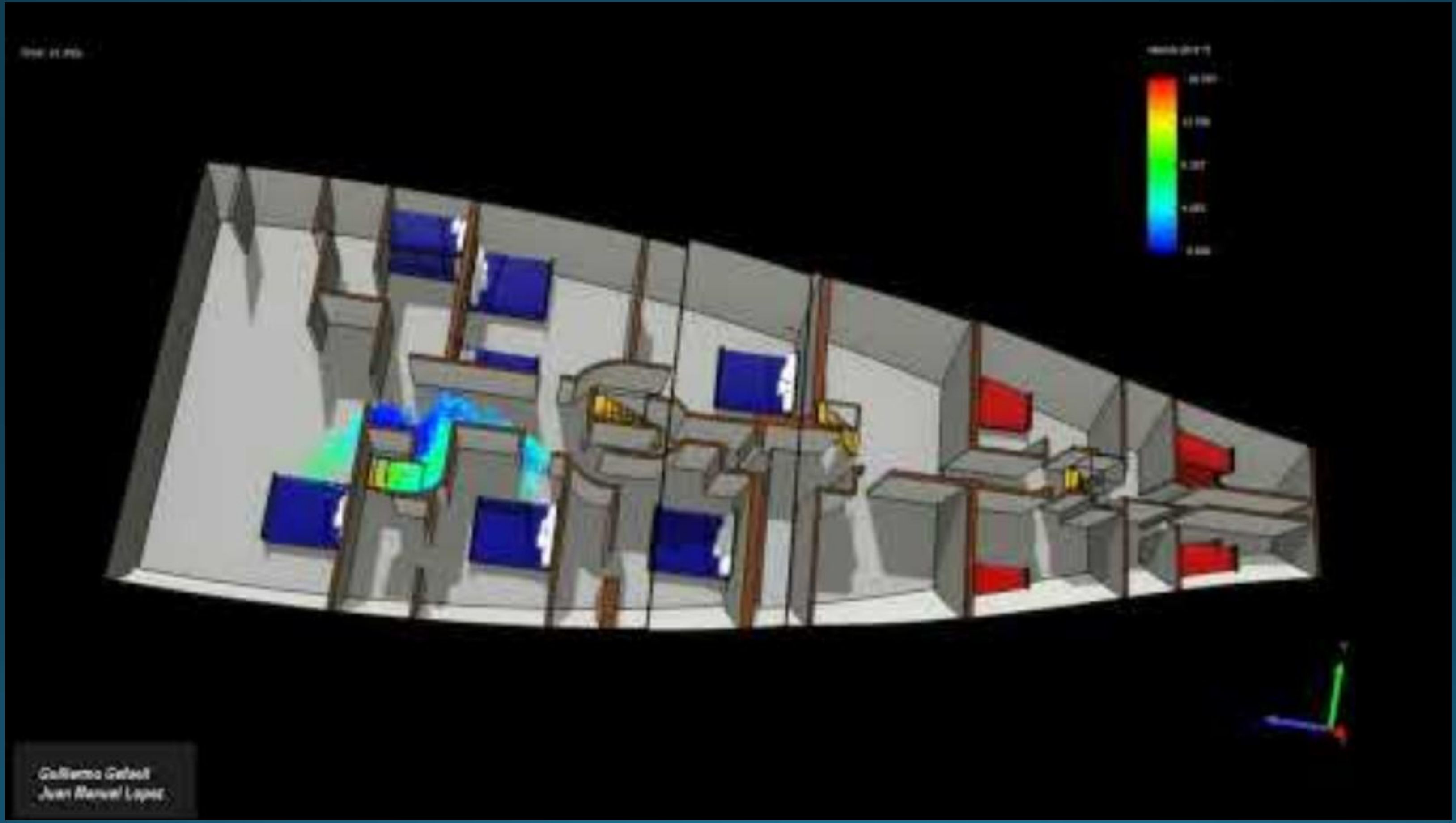
Note: we have fixed the list at 70 deg., but the water speed flow is as per the list at any given time.



LARGE SAILING YACHTS BARE MAST CFD HEELING ANALYSIS

ACCOMODATION SPACES FLOODING VIDEO

Note: we have fixed the list at 70 deg., but the water speed flow is as per the list at any given time.



LARGE SAILING YACHTS BARE MAST CFD HEELING ANALYSIS

CONCLUSIONS

Sailing monohull vessels of around 55 m length with high masts, folding daggerboards, a maximum GZ of 0.9 m or less at about 35 degrees and AVS angles of less than 90 degrees, have a high risk that, when under bare mast, if the boat is hit from the side by a wind gust of 60 knots or more, it can knockdown in an unrecoverable manner even when in watertightness condition.

If big vents close to the sides are open very dangerous flooding will occur and will become catastrophic if staircases inside a not watertight closed deck house get submerged.

THANK YOU VERY MUCH!