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ERIES-EXTRALOADINPORTS: Assessing wind flow and induced loads on containerships under non-synoptic winds

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SUMMARY
The wind flow characterization and induced loads on containerships and port infrastructures is essential for safe port operations, including navigation in narrow waterways, maneuvering near quay cranes, and mooring during cargo handling or passenger boarding. Port operators typically rely on wind estimates based on atmospheric boundary layer (ABL) conditions, while knowledge from Atmospheric Sciences and Wind Engineering can improve the understanding of non-synoptic winds and their effects. The ERIES EXTRALOADINPORTS aims to provide an experimental benchmark for the characterization of wind fields and aerodynamic coefficients on containerships under extreme non-synoptic winds. Two configurations are analyzed: an isolated containership and one moored at a quay within a port. Four wind scenarios are considered: ABL wind, thunderstorm downburst (DB), combined ABL+DB, and a stationary tornado-like vortex (TLV). Experimental tests were conducted in January 2026 at the WindEEE Dome facility in London, Canada.

Keywords: Non-synoptic winds, containership, experimental tests.

1. INTRODUCTION

Ports handle around 80% of global sea trade and are key areas where competitiveness and environmental performance need improvement. In the last decade, port and containership sizes have grown significantly to meet global demand, posing challenges such as longer quays, larger cranes, and deeper seabed. Unlike shipping, port infrastructure requires long-term planning to safely manage vessels and containers. Accidents in ports by severe storms can cause economic losses and endanger workers and nearby residents. Besides the large benefits, the expanding capacity of containerships and ports for worldwide competitiveness is leading to an increased risk exposure. At the present, wind actions on vessels and port infrastructures are commonly calculated with standards/codes, semi-empirical functions (Blendermann, 1994), wind tunnel (WT) testing (Aage, 1968; Andersen, 2013) and CFD simulation under ABL and/or marine boundary layer (MBL) winds (Ricci et al., 2023). Two main concerns arise in this regard. First, usually ABL winds are characterized by lower velocities than downbursts and tornados near the ground. Statistical data recorded usually at 10 m above the ground indicates that in mid-latitudes, wind speeds with a return period exceeding 10 years are often attributed to thunderstorm events (Letchford et al., 2002). This can lead to large underestimation of the actual wind forces acting on ships and port infrastructures (Solari et al., 2020). Second, the aerodynamic coefficients of a moored containership in a port surrounded by infrastructures and buildings can be profoundly different than those obtained on a containership in open sea-like conditions (Torre et al., 2021).

The primary scope of the ERIES-EXTRALOADINPORTS - acronym of Investigation of EXTRreme winds for the estimation of Aerodynamic LOADs on contaINership and PORT infrastructureS - is to provide the scientific community and all port stakeholders with an experimental benchmark consisting of a characterization of the wind field and aerodynamic coefficients on containerships and port infrastructures under extreme winds. Two case studies were investigated under four types of wind: (1) an ABL, (2) a thunderstorm downburst (DB), (3) a downburst embedded in an ABL wind (ABL+DB), and (4) a tornado-like vortex (TLV). The experimental campaign was conducted at the WindEEE Dome facility in London, Canada, in from January to March 2026. A CFD campaign will be also carried out in the framework of this research project and the future numerical database along with the experimental one will be used to improve existing semi-empirical functions for load calculation on vessels.

2. METHODOLOGY

Two of the most common scenarios (S) have been analyzed: (S1) an isolated containership with capacity 24,000+ TEU (twenty-foot equivalent units) in open sea-like conditions; (S2) the 24,000+ TEU containership moored at the quay of a port area selected as case study. The two scenarios have been tested under four wind conditions: ABL wind, DB, an ABL+DB, and a stationary TLV. To characterize the reference wind, each type of wind has been tested firstly in the empty test chamber in absence of the scaled models. Figure 1 shows the four wind types and the tested scenarios. The containership and the cranes considered in this project are among the biggest worldwide. S1 and S2 have been manufactured at a 1:400 reduced scale, in agreement with the WindEEE Dome team and based on previous publications dealing with similar winds (e.g., Lombardo et al., 2014; Canepa et al., 2022). This scale is also a good "trade-off" between the geometrical model resolution (scaling down geometries without losing in resolution) and the height of maximum horizontal velocity for a DB, that at 1:400 may occur at approximately 0.1 m above the floor. The occurrence of the maximum horizontal velocity around this height was found indeed very relevant for both cranes and vessels.
For S1 (Fig. 1e,g), the containership has been tested for five different container arrangements: in S1.1 the ship is empty; in S1.2 the ship carries the full capacity of containers; in S1.3 the ship is 75% full with maximum load distribution at the bow; in S1.4 the ship is 75% full with maximum load distribution at the stern; and in S1.5 the ship is 50% full with a balanced load distribution with respect to the center of gravity (CG) (Fig. 1e,f). In adherence with naval architectural practices, the aerodynamic coefficients of containership are calculated based on the body axes:

$$C_X = \frac{F_X}{\frac{1}{2}\rho U_{ref}^2 A_F} \qquad C_Y = \frac{F_Y}{\frac{1}{2}\rho U_{ref}^2 A_L} \qquad C_N = \frac{N}{\frac{1}{2}\rho U_{ref}^2 A_L L_{OA}} \qquad C_K = \frac{K}{\frac{1}{2}\rho U_{ref}^2 A_F L_F}$$

where $\boldsymbol{F_X}$ is the frontal force, $\boldsymbol{F_Y}$ is the lateral force, $\boldsymbol{N}$ is the yawing moment of ship around the

z-axis and $\boldsymbol{K}$ is the overturning moment of ship around the x-axis. ρ is the air density in the test chamber of the facility, while $\boldsymbol{U_{ref}}$ is the reference wind velocity to be defined for each type of wind in S0. $\boldsymbol{A_F}$ and $\boldsymbol{A_L}$ are the frontal and longitudinal area of the ship, respectively. $\boldsymbol{L_{OA}}$ is the overall length of the ship, while $\boldsymbol{L_F}$ is the vertical distance between the waterline and the center of the side wind area.
For S2 (Fig. 1f,g), the ship has been tested for the container arrangement configuration showing the largest aerodynamic coefficients, namely the S1.2 (100% full). In S2, the cranes were not directly monitored with a force balance to estimate the aerodynamic coefficients like on the ship. However, both the cranes and the surrounding environment were considered to understand their influence on the aerodynamic loads acting on the ship.

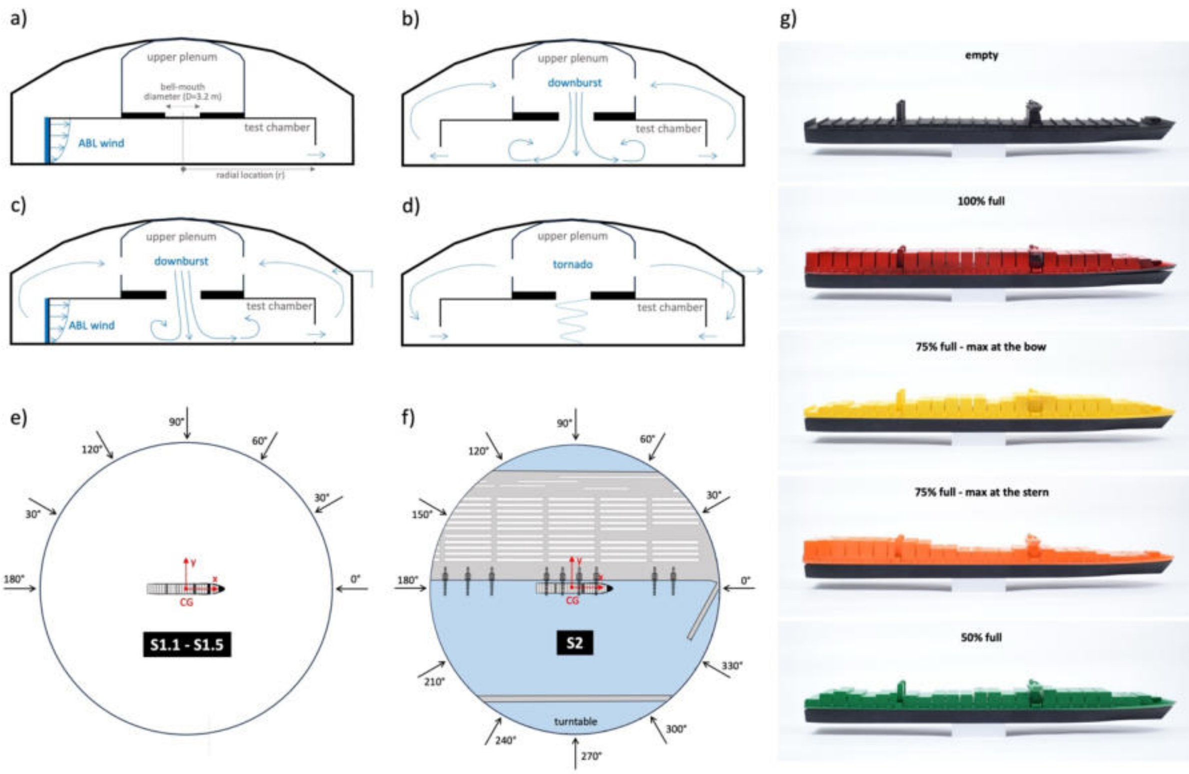

Figure 1. Schematic of wind conditions and tested scenarios: (a) ABL wind; (b) DB wind; (c) ABL+DB winds; (d) stationary TLV; (e) scenario S1 corresponding to an isolated containership in open sea-like conditions with different container arrangements (S1.1-S1.5); (f) scenario S2 corresponding to the containership moored at the quay of a port area including cranes and container stacks. (g) Photographs of 1:400 scale prototype models of each container arrangement.

3. EXPECTED OUTCOMES AND IMPACT

The experimental campaign of the EXTRALOADINPORTS project was concluded at the end of March 2026, at the time of writing this paper. Data post-processing is currently underway and is expected to conclude in the coming months, along with the particle image velocimetry analyses and flow (smoke) visualization (Fig. 2). The results of wind fields and aerodynamic coefficients collected in the experimental campaign will be made publicly available by means of an open-access database. This project will offer the scientific community and port stakeholders a unique and innovative benchmark - both experimental and numerical - of aerodynamic coefficients, providing crucial support for the optimization of port operations worldwide.

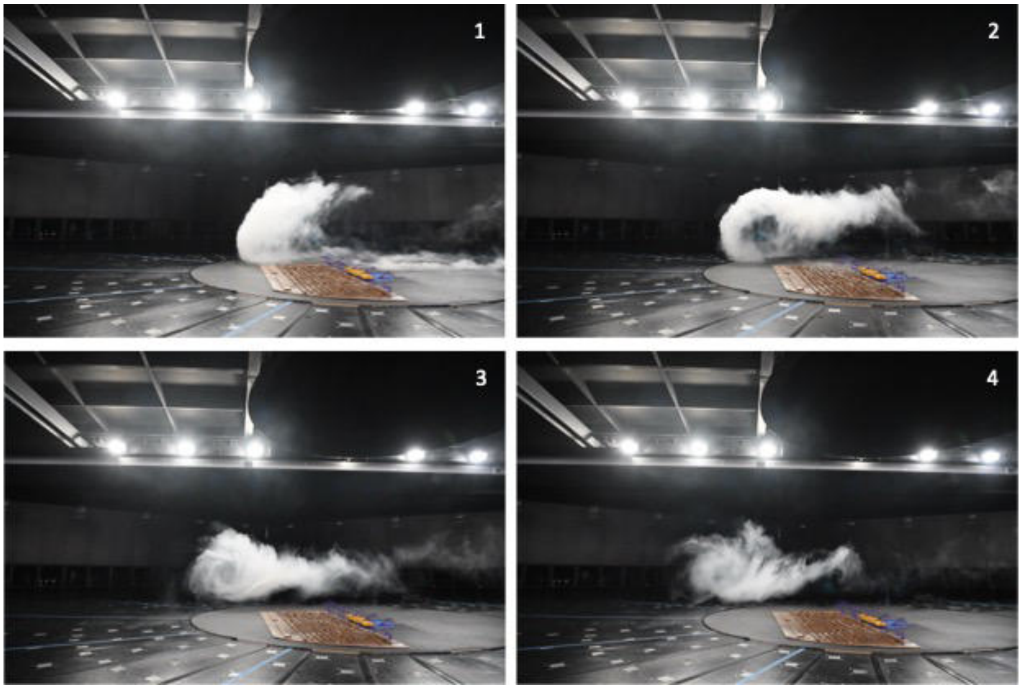

Figure 2. Flow visualization of a DB flow field using smoke to enable qualitative analysis.

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