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Investigating crosswind-stability of vehicles on bridges, applying a moving model and side wind-tunnel methodology with full-scale validation

Jónas Þór Snæbjörnsson[1,3], James R. Bell[2], Isak Tolo[3], Jasna B. Jakobsen[3]

[1]Reykjavík University, [2]German Aerospace Center (DLR), [3]University of Stavanger

Overview

A multi-disciplinary approach – combining wind engineering and vehicle aerodynamics – is being developed for investigations into the stability of vehicles operating in extreme crosswind conditions. In this case, studying heavy vehicles travelling over a 56m high bridge across a Norwegian fjord. Using a moving-model wind tunnel facility in DLR Göttingen, and full-scale observations from the Lysefjord bridge, where wind gusts of up to 40m/s have been recorded. Potential changes to climate and weather conditions could increase the frequency of extreme wind events, possibly leading to more wind-related accidents on high-level bridges.

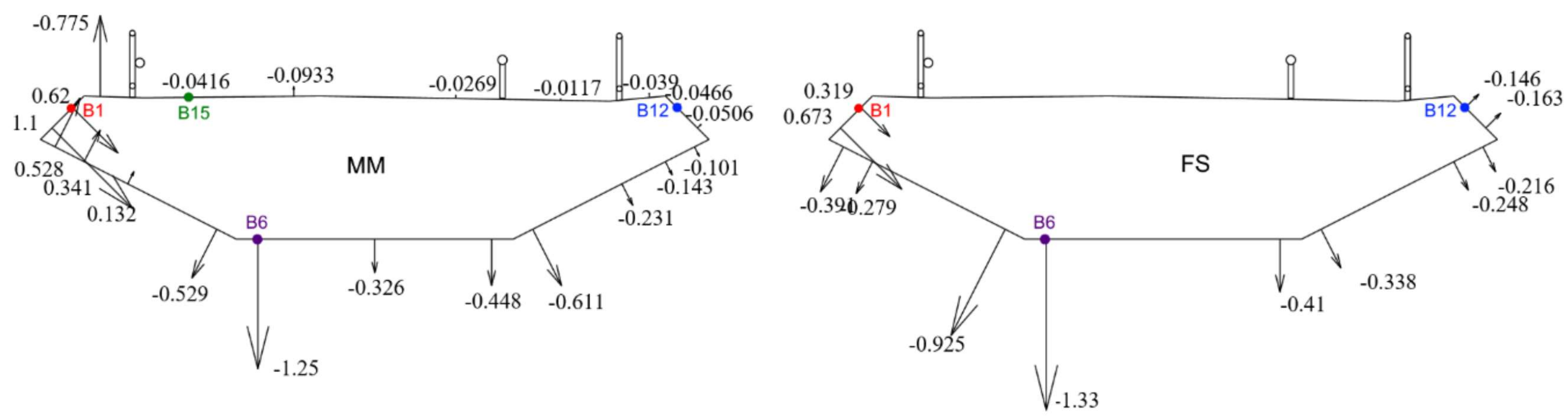
Introduction

Driving comfort and the risk of accidents in high winds are of concern for the safe operation of high-level bridges. Driving conditions in the wake of the towers are known to be particularly challenging due to the sharp variations in mean wind speed and turbulence levels at these positions. Wind-related accidents involving the overturning of light, high-sided vehicles, such as auto-trailers, occur regularly (Figs. 1, 2 & 3).

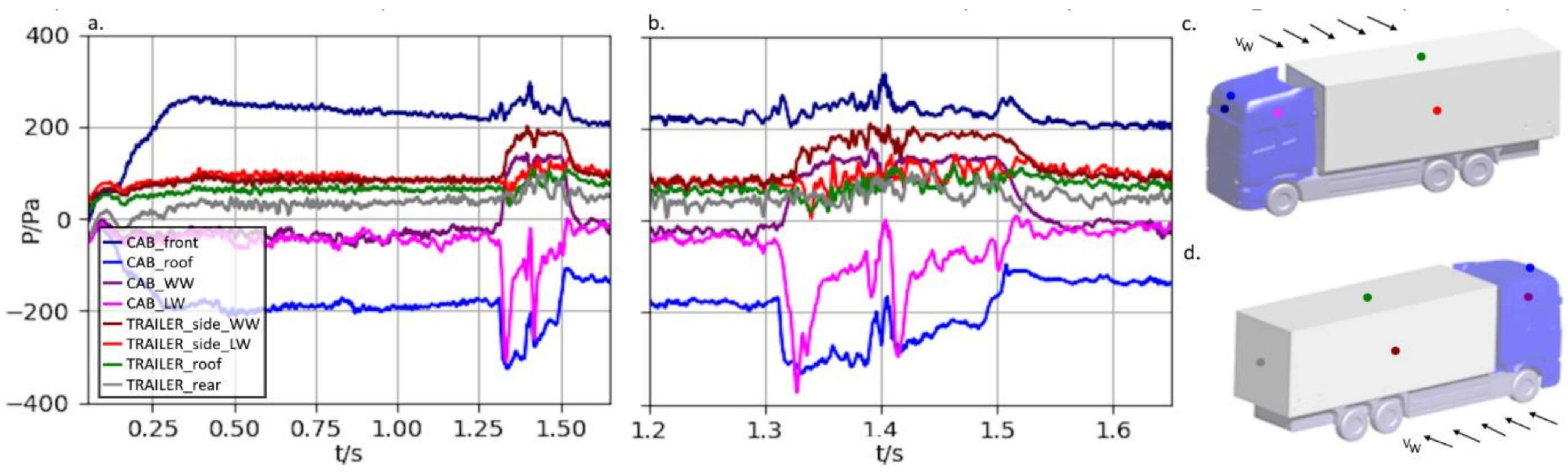
The Lysefjord bridge has been instrumented since 2013 [1], equipped with various sensors for monitoring wind, wind-induced surface pressures, and acceleration response (Figs. 4 & 5). In this work, full-scale observations are utilised to validate experiments conducted in a moving-model wind tunnel facility at DLR, Göttingen [2], specifically designed to simulate wind loads on moving vehicles. The moving-model experiments utilise a 3D-printed 1:15 scale section model of the Lysefjord Bridge, including the north Tower, and a generic truck model within the side-wind tunnel jet (Figs. 6 & 7) [2, 3]. Previous work on passenger automotive vehicles in the facility has identified transient characteristics of the crosswind exposure and vehicle-infrastructure interaction, a feature that cannot be modelled in traditional, quasi-steady wind-tunnel experiments [4].

Results

Surface-pressure measurements on the 1:15 scale moving-model (MM, Rew=5.5x10^5) show reasonable comparison to the full-scale (FS, Rew=8.2x10^6) bridge from a 1-hour sample with moderate winds of 10m/s, considering the different angle of attack in the natural wind in addition to the wider variability in the natural wind fluctuations. These results are presented (below) as vectors of normalised pressure, C_P.



Transient pressures on the moving truck (below) clearly show the acceleration of the model, as well as the complex, unsteady interaction with the crosswind (t = 1.3-1.5s), and the local effects of the bridge's vertical towers (t = 1.4s).



Conclusions

This work demonstrates the functionality of the novel methodology, providing an encouraging comparison to full-scale results. Future work is planned for further optimisation, and parametric variability (e.g. turbulence, yaw/pitch of oncoming flow) and subsequent optimisation and assessment of bridge geometry and infrastructure effects, such as towers, as well as engineering solutions like wind fences, and safety operational guidelines. Additionally, real-world validation is planned, with measurements on an operational truck loaded with the DLR FR8-LAB – a measurement-equipped shipping container [2].

References

1. https://windengineeringuis.github.io/, Wind Engineering, University of Stavanger.
2. Bell J.R., Tolo I., Snæbjörnsson, J.Þ., Jakobsen, J.B., "Investigating extreme crosswind-stability of vehicles on bridges: applying a moving model and side wind-tunnel methodology with full-scale validation", 22. STAB-Workshop, November 2025.
3. Tolo, I., Wind Tunnel Testing of a Bridge with a Moving Vehicle: Safety of Road Vehicles on a Bridge. MS Thesis, UiS, 2025.
4. Bell, J., et al., "Experimental Investigation of Automotive Vehicle Transient Aerodynamics with a Reduced-Scale Moving-Model Crosswind Facility," *SAE Int. J. Adv. & Curr. Prac. in Mobility* 2(3):1460-1471, 2020.

Figure 1: Karmsund bridge, July 6, 2020.

Figure 2: Lysefjord bridge, August 9, 2014.

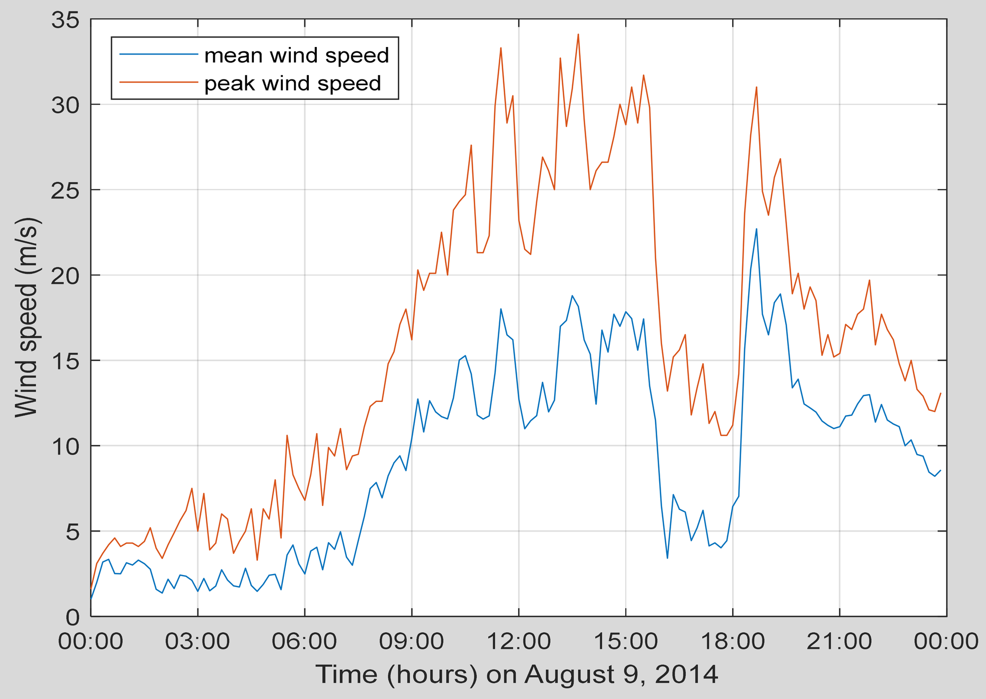


Figure 3: Lysefjord bridge, recorded wind speed on August 9, 2014.

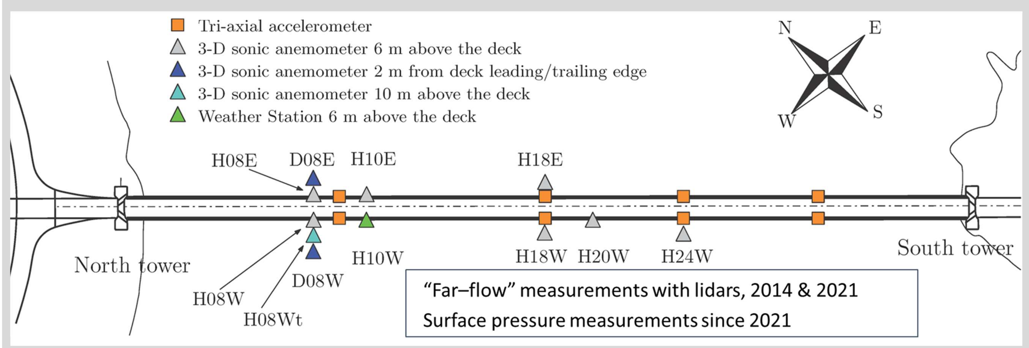


Figure 4: The Lysefjord Bridge: A full-scale laboratory since 2013. Overview of instrumentation.

Figure 5: Lysefjord bridge, North tower & deck section.

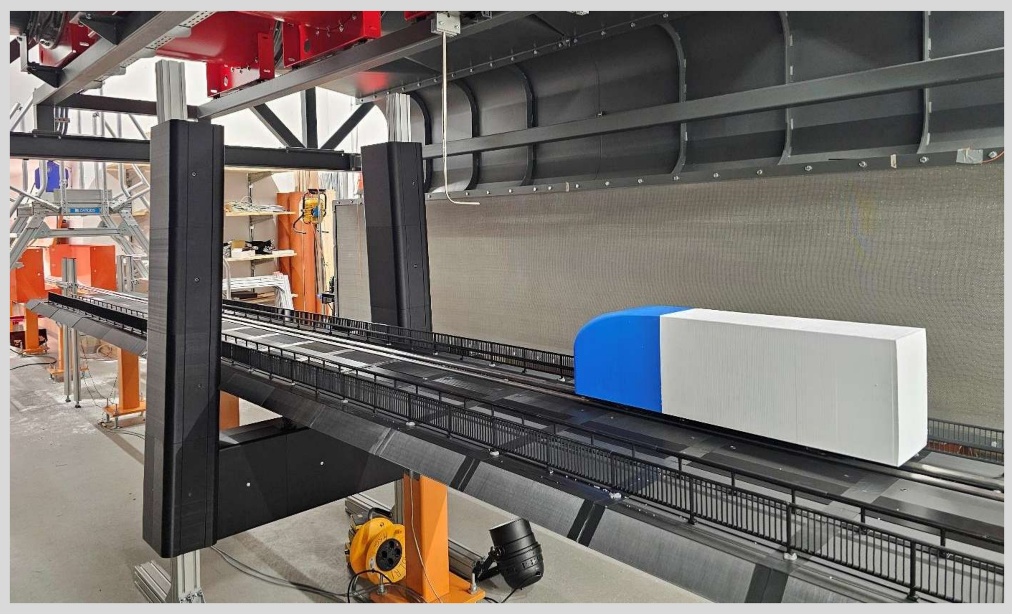


Figure 6: The model in the wind tunnel test section.

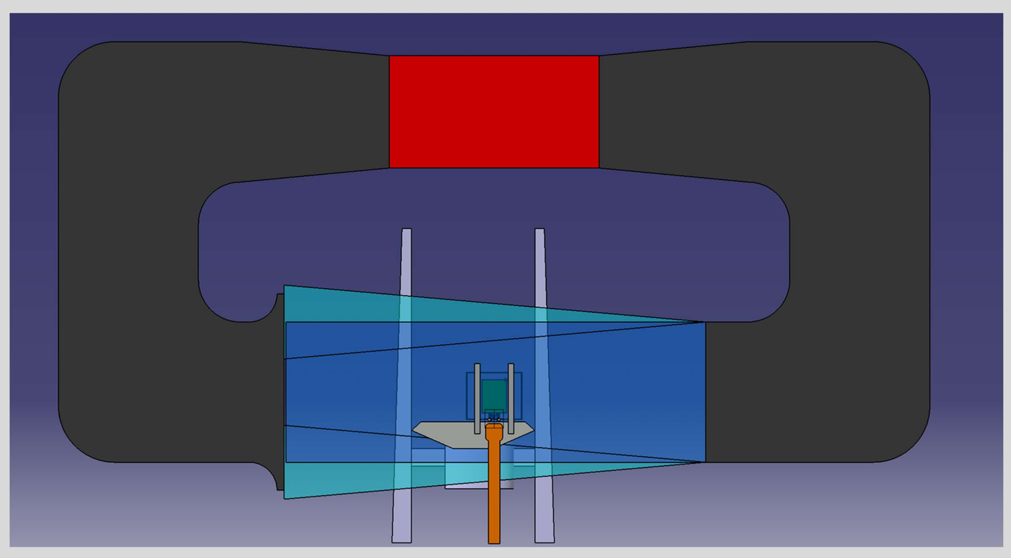


Figure 7: A side view of the wind tunnel test section.