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Full-scale aerodynamic measurements on-board a freight train during specific operating scenarios using the DLR FR8-LAB

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Abstract

The DLR FR8-LAB is a self-contained swap-body container, equipped with an on-board power supply, data acquisition system and remote-access communication capability has been transported on normal operating freight-trains in Europe. Initial measurements have demonstrated the ability for the on-board systems function in the challenging industrial conditions. Surface pressure measurements, as well as lidar and thermal cameras have demonstrated the FR8-LAB can be used to characterize the aerodynamic conditions and coupled them with the operating scenario. Generic, representative conditions that a container on a typical freight train would experience can be characterized. Further, specific operating scenarios such as: entering/exiting tunnels, travelling over bridges, or passing other rail vehicles - that could exhibit aerodynamic characteristics with increased aerodynamic drag (low operating efficiency) or reduced crosswind stability (potential safety concern) - can be characterized in detail.

Keywords: aerodynamics, freight, crosswind, drag.

1 Introduction

There are a variety of complex conditions that Freight trains typically operate in: speeds of up to 120km/h, interaction with infrastructure, local topography, exposure to the environment, and different possible train configurations. In spite of the relatively simple geometries in a freight-train consist, these operating conditions result in complex aerodynamics, that are critically important for a train’s energy efficiency and safety of operation [1,2].

The airflow a freight train experiences corresponds to pressure acting over the surface resulting in forces and moments that affect drag (energy efficiency) and side-wind stability; the risk of overturning of the container (safety). Real-world operation consists of different train configurations (loading configuration, length), interacting with infrastructure (bridges, tunnels) and local topography (valleys, hills, forests) and exposure to the environment (prevailing winds and gusts). Recent measurements on a shipping container on a freight train in Australia [3] have identified that real-world conditions can result in significant differences in the pressure/forces compared to idealized experimental/numerical investigations [4,5,6].

Accurate (representative of real-world) and efficient aerodynamic optimization requires experimental and computational methodologies that utilize real-world measurements for validation. Real-world measurements are performed across all possible operating conditions by their nature. This enables important, individual efficiency and safety scenarios to be identified, in addition to generic scenarios that can be subsequently modelled respectively. This novel experimental campaign utilizes a sensor-equipped shipping container performing on-rail measurements in Europe to provide new insight into real-world freight-train aerodynamics in order to improve operational performance, efficiency and safety.

2 Methods

A full-scale shipping container, the DLR FR8-LAB, fitted with measurement equipment has been transported on normal operating freight-trains in Europe. The FR8-LAB is a ‘swap-body’ shipping-container (Fig 1), that can be loaded in different configurations. The FR8-LAB is self-contained, with an on-board power supply (recharged by roof solar panels), data acquisition system and remote-access communication capability.

Figure 1: The DLR FR8-LAB, a measurement system equipped ‘swap-body’ container certified for operation on freight trains.

The primary measurements are time-resolved (200-1000Hz) surface-pressure measurements at up to 330 positions on the container (Fig 2.a). Pressure on the front and rear surface can be integrated and provide insight into the pressure drag. Longitudinal rows and rings along the side and roof of the container provide insight into the side force, yaw and roll moments.

The container's operating conditions are also measured and associated to the surface-pressure and corresponding aerodynamic characteristics (drag, side force, roll/yaw moments). A global navigation satellite system (GNSS) determines the location and the velocity over ground (VOG). Seven single-point LIDAR distance sensors with ~40m range are located on the container's sides, roof and front/rear surface to quantitatively characterize the physical environment. Two wide-angle 75° field-of-view (FOV)) thermal cameras (able to operate at night and in poor weather conditions) provide additional qualitative information on the local topography (Fig 1.b). Accelerometers and temperature sensors also measure the conditions inside the container.

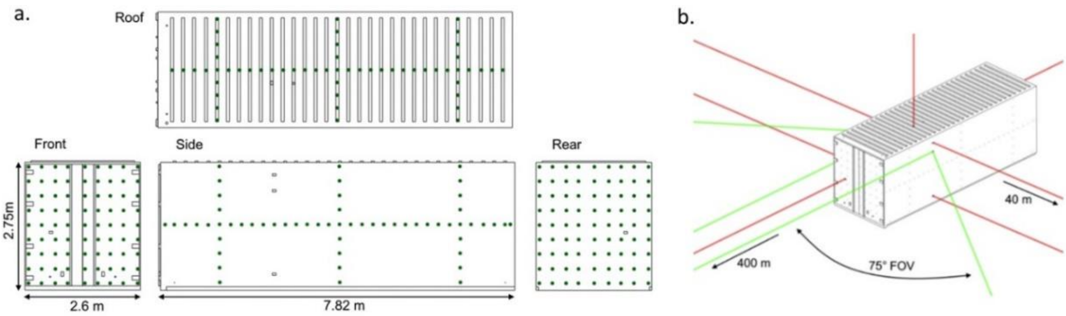

Figure 2: The DLR FR8-LAB measurement specifications: a. swap-body dimensions and pressure-measurement locations, b. LIDAR (red) and camera (green) configuration.

3 Results

Measurements have been performed with the FR8-LAB loaded onto an operational freight trains in Germany in 2021/22 already in a variety of loading configurations - see Fig 3 as an example. The measurement, power and communications systems on-board the FR8-LAB have successfully functioned during these real-world experiments.

Figure 3: The DLR FR8-LAB loaded on an operational freight train in Germany.

The pressure measurements presented in Figure 4 demonstrate the ability for the FR8-LAB system to successfully measure transient pressure in the challenging industrial environment. The expected varying magnitudes in pressure can observed at different locations of the container; high pressure at the forward facing surface, low pressure at the sides and rear (Fig 4a,b,c respectively). Variation in their transient characteristics can be observed; the front exhibits large scale fluctuations in high pressure coherent at different locations across the surface, potentially from transient coherent flow convected from the upstream container. In contrast, the rear and the sides exhibit smaller more random fluctuations, likely from highly turbulent separated flow.

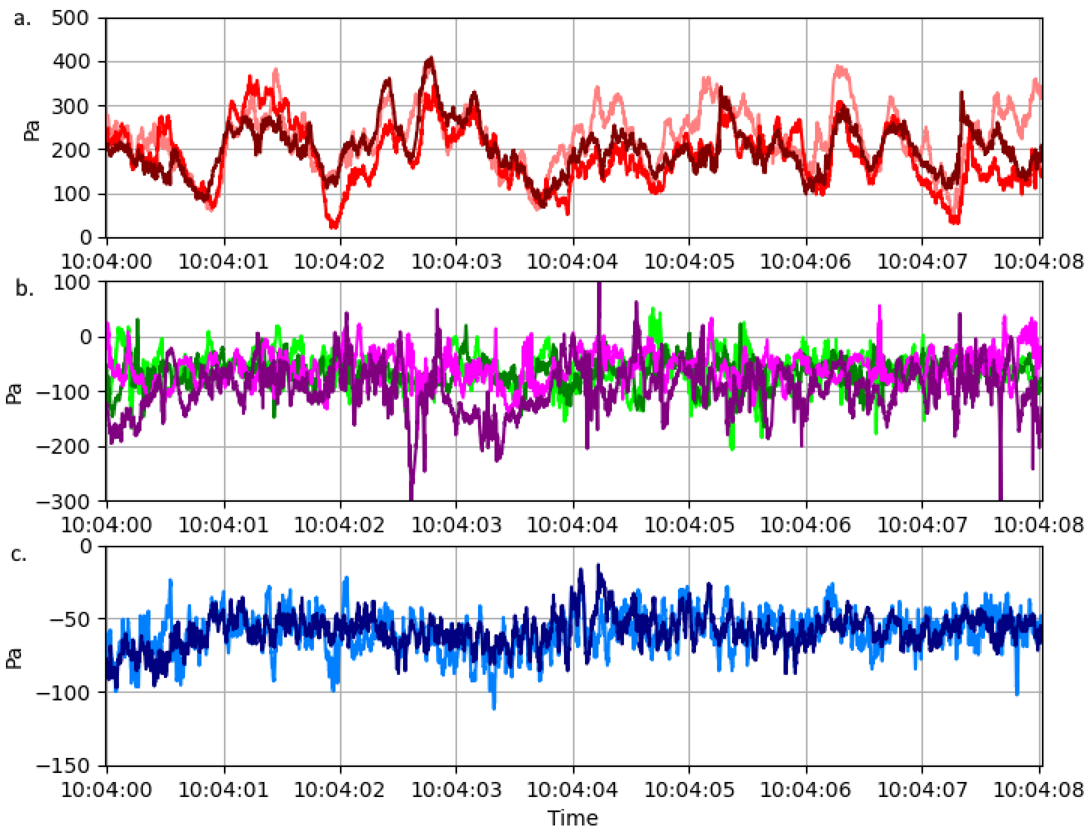

Figure 4: Transient surface pressure measurements during operational velocity of ~30m/s at a. the forward-facing surface, b. the left (green) and right (magenta) side surfaces, and c. the rear surface.

The Lidar measurements can successfully characterize the local operating environment that the moving train can be affected by. Horizontal distances presented in Figure 5 identify the scenario of the train operating in a "urban canyon" (vertical walls either side), with relatively consistent blockage at ~9m and ~5m to its left and right respectively. Further, the images from thermal cameras – as illustrated in Figure 6 – located either side can be used to quantitatively confirm the distance measurements, and enable specific, detailed characterization of the local environment.

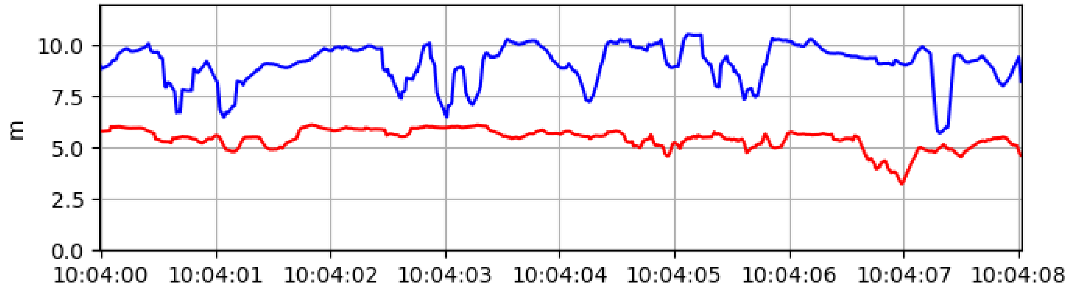

Figure 5: Left (blue) and right (red) transient horizontal distance measurements from the Lidar sensors.

Figure 6: Thermal images from left and right facing cameras.

4 Conclusions and Contributions

The initial measurements obtained by the DLR FR8-LAB on operational freight trains have demonstrated the ability for the measurement, power and communication systems to successfully function in the challenging industrial conditions. The results establish the FR8-LAB can be used to characterize not only generic, representative conditions that a container on a typical freight train would experience, but importantly characterize in detail; specific operating scenarios that could have important aerodynamic characteristics and outcomes. Possible scenarios could be entering/exiting tunnels, travelling over bridges, or passing other rail vehicles - that could exhibit aerodynamic characteristics with increased aerodynamic drag (low operating efficiency) or reduced crosswind stability (potential safety concern). The FR8-LAB measurements are ongoing and such important operating scenarios will be identified and characterised in the future.

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