CETRA 2014

3rd International Conference on Road and Rail Infrastructure
28–30 April 2014, Split, Croatia

Road and Rail Infrastructure III

Stjepan Lakušić – EDITOR

Organizer
University of Zagreb
Faculty of Civil Engineering
Department of Transportation

CETRA 2014
3rd International Conference on Road and Rail Infrastructure
28–30 April 2014, Split, Croatia

TITLE
Road and Rail Infrastructure III, Proceedings of the Conference CETRA 2014

EDITED BY
Stjepan Lakušić

ISSN
1848-9850

PUBLISHED BY
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN, LAYOUT & COVER PAGE
minimum d.o.o.
Marko Uremović · Matej Korlaet

PRINTED IN ZAGREB, CROATIA BY
"Tiskara Zelina", April 2014

COPIES
400

Zagreb, April 2014.

Proceedings of the
3rd International Conference on Road and Rail Infrastructures – CETRA 2014
28–30 April 2014, Split, Croatia

Road and Rail Infrastructure III

EDITOR
Stjepan Lakušić
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Zagreb, Croatia

ORGANISATION

CHAIRMEN

Prof. **Stjepan Lakušić**, University of Zagreb, Faculty of Civil Engineering
Prof. **Željko Korlaet**, University of Zagreb, Faculty of Civil Engineering

ORGANIZING COMMITTEE

Prof. **Stjepan Lakušić**
Prof. **Željko Korlaet**
Prof. **Vesna Dragčević**
Prof. **Tatjana Rukavina**
Assist. Prof. **Ivica Stančerić**
dr. **Maja Ahac**
Ivo Haladin
dr. **Saša Ahac**
Josipa Domitrović
Tamara Džambas

All members of CETRA 2014 Conference Organizing Committee are professors and assistants of the Department of Transportation, Faculty of Civil Engineering at University of Zagreb.

INTERNATIONAL ACADEMIC SCIENTIFIC COMMITTEE

Prof. **Vesna Dragčević**, University of Zagreb
Prof. **Isfendiyar Egeli**, Izmir Institute of Technology
Prof. **Rudolf Eger**, RheinMain University
Prof. **Ešref Gačanin**, Univeristy of Sarajevo
Prof. **Nenad Gucunski**, Rutgers University
Prof. **Libor Izvolt**, University of Zilina
Prof. **Lajos Kisgyörgy**, Budapest University of Technology and Economics
Prof. **Željko Korlaet**, University of Zagreb
Prof. **Zoran Krakutovski**, University of Skopje
Prof. **Stjepan Lakušić**, University of Zagreb
Prof. **Dirk Lauwers**, Ghent University
Prof. **Zili Li**, Delft University of Technology
Prof. **Janusz Madejski**, Silesian University of Technology
Prof. **Goran Mladenović**, University of Belgrade
Prof. **Otto Plašek**, Brno University of Technology
Prof. **Vassilios A. Profillidis**, Democritus University of Thrace
Prof. **Carmen Racanel**, Technical University of Civil Engineering Bucharest
Prof. **Tatjana Rukavina**, University of Zagreb
Prof. **Andreas Schoebel**, Vienna University of Technology
Prof. **Mirjana Tomičić-Torlaković**, University of Belgrade
Prof. **Audrius Vaitkus**, Vilnius Gediminas Technical University
Prof. **Nencho Nenov**, University of Transport in Sofia
Prof. **Marijan Žura**, University of Ljubljana

COMPARATIVE WIND INFLUENCE ON USE PHASE ENERGY CONSUMPTIONS OF ROADS AND RAILWAYS

A. Coiret[1], P.-O. Vandanjon[1], R. Bosquet[2], A. Jullien[1]
1 LUNAM University, Ifsttar institute, France
2 RFF, Réseau ferré de France, France

Abstract

Sustainable development is largely depending on transportation systems ensuring mobility and safety. This mobility requires a sufficient access to the energy, at an affordable price. According to the peak-oil hypothesis, rarefaction and increasing in price of the non-renewable energies are nevertheless expected.
Even if transportations systems could partly rely on renewable energies, their optimization should involve energy and mobility criteria. In this study, surrounding wind fields and traveling speed are conjointly investigated in order to evaluate achievable reductions in fuel consumptions for both railways and road transportation systems.
In the first part of this work, aerodynamic forces on trains are evaluated with the help of an energy model, validated with experimental tests data. For that, numerical determination of aerodynamic coefficients for several wind and topological situations have been computed with Solid-Works and associated to atmospheric characteristics determined over the considered high-speed line (Rhine-Rhone line; about 140 km) with the AROME model (meteo-france), from measurements at several weather stations.
Simulation results show that for a weak wind and a train traveling at high speed, wind influence is about 5% on aerodynamic forces power. Moreover, for a moderate train speed (about 45 m/s), a slightly stronger wind (about 5 m/s) has an influence of about 30%, compared to the without wind case.
In a second time, road experiments have been conducted with a passenger car equipped with an air flow meter and an oil flow meter, in addition of dynamical measurements as speed, position, altitude... Similarly to the railway case, wind exposition could be considered as a significant road design parameter.
In conclusion, this work based on large sets of full-scale experimental data and the numerical simulation of the aerodynamic forces, points out that wind influence on total aerodynamic power consumption is noticeable, both for railways or road transportation systems.

Keywords: railway, roads, energy, use phase, wind

1 Introduction

Transportation systems as roads and railways are usually designed by considering criteria of time-efficiency, mobility and safety [1,2], and to a lesser extend, energy savings. Negative perspectives on oil availability and climate changes justify the need to enhance the consideration of this last criterion.
Indeed, the production of non-renewable energies as oil, gas and coil is peaking as their demand is growing, this unbalance between oil demand and production being often qualified as the Peak Oil Theory [3, 4]. According to the International Energy Agency New Policies

Scenario [5], world oil production should reach 96 million barrel/day in 2035 on the back of rising output of natural gas and unconventional oil, as crude oil production remaining stable. A large part of the demand growth could come from China alone, driven by rising use of transport fuels [6].

In order to better integrate the energy criterion in the design of road and rail infrastructures, preceding researches on safety have been adapted to the energy evaluation [7, 8]. For example contact forces models have been transposed from safety to energy evaluation [9] and extended to the LCA assessment of railways [10]. Nevertheless, if aerodynamic forces are generally considered as the result of the vehicle speed, with substantial achieved drag reductions [11], surrounding wind field influence studies are often limited to transverse stability [12]. But for modeling the infrastructure-based energy demand, wind field influence remains to be evaluated.

In this paper, the wind influence on energy consumption is evaluated from experimental measurements and for both use phases of a high-speed railway and a road. For that, Ifsttar and RFF have performed full scale tests on a newly built high-speed railway and the wind influence has been later determined numerically from wind field reconstitutions. Wind influence on a passenger car has been verified similarly but with the advantage of having direct measurements of relative wind on the vehicle.

In perspectives, energy models will be helpful for qualifying infrastructure alternatives on energy criterion, for the two predominant transportations modes.

2 Wind influence assessment on train consumptions

2.1 Experimental tests and aerodynamics modeling

The acceptance of work tests of the newly build Rhine-Rhone high-speed line have been an opportunity for verifying the wind influence on train consumptions: electrical consumptions and vehicle speed have been recorded for various speeds and environmental conditions. Wind speed and direction have been afterwards determined over the whole line (140 km long) with the help of the numerical model AROME [13], from measurements at several weather stations (one of the wind field computation in given in Fig.1).

15 runs have been selected for evaluating the wind influence on consumptions, among the 144 runs of the performed tests. This selection managed to keep various combinations of train speeds and wind incidence angles and speeds.

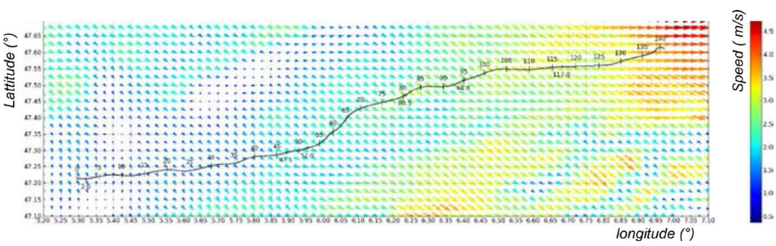

Figure 1 Example of the discretized wind field computed with the AROME model, around the 140 km high-speed line

Aerodynamic coefficients of the train (ALSTOM TGV Duplex) are computed with the help of Navier-Stockes simulations of the air flow on auto-adaptive Cartesian meshes. Particularly, a longitudinal coefficient C_x of 0.148 is found, in accordance with values determined for other studies [14].

The computation of the aerodynamic forces is based on the Eq. (1), which establish the link between the longitudinal aerodynamic force F_x and the relative air flow velocity with the C_x coefficient, the air density (ρ) and the S reference surface ($S=10\ m^2$).

$$F_x = \frac{1}{2}\rho S V^2 C_x \quad (1)$$

Simulations are then done for the 15 selected train runs, for various wind angle directions, wind speeds and train dynamics. At last, aerodynamic power is computed all along the itineraries, while considering situations with or without wind.
Power variations of aerodynamic forces, between simulations cases with or without wind, are given in the Fig. 3 for three tests runs. The green curve labeled HS1 corresponds to a train traveling at a high speed of 95 m/s in a weak mean wind (2 m/s). The blue and red curves, labeled respectively LS1 and LS2, correspond to a train traveling at a moderate, steady speed of 47 m/s for two quite different wind mean speeds (wind speed profiles given in Fig. 2).
As a result, for a weak wind (2 m/s) and a train traveling at high speed (95 m/s), wind influence is yet of +5% and -5% on power due to aerodynamic forces on the train, respectively on sections of the itinerary where wind is forwardly and rearwardly oriented (test run labeled HS1 on Fig. 3). This result is deduced from the analysis of the HS1 test run between the 70 and 120 km abscissa, section for which the mean speed is of 95 m/s.
A more remarkable result is that for a moderate train speed (about 47 m/s), a stronger rear wind (5.5 m/s) lowers the needed power by 30% compared to the case without wind, and a front wind of 3 m/s raises it by 20% (respectively test runs labeled LS1 and LS2; see Fig. 2 and 3, at the considered pk position of 70 km). These results will be integrated in the train/infrastructure energy model, linking railway geometry, environment (wind), vehicle dynamics and energy of use consumptions.

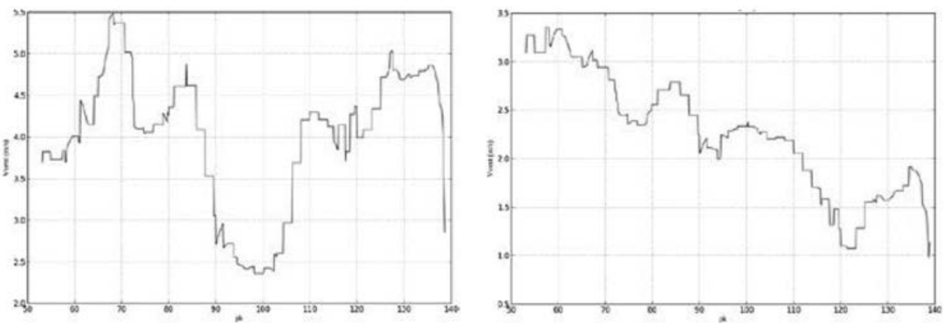

Figure 2 Wind speed for the LS1 (left) and the LS2 (right) test runs along the curvilinear distance pk (km)

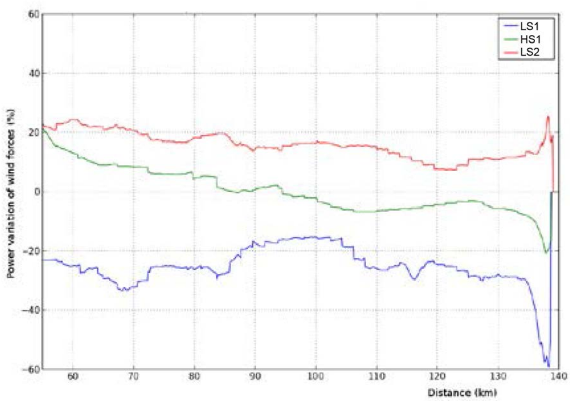

Figure 3 Power variation of wind forces for the LS1, LS2 and HS1 test runs

3 Wind influence assessment on road passenger cars

3.1 Experimental tests

Wind influence on a passenger car has been verified similarly, for various test runs of a middle size gasoline passenger car, a "Renault Clio". The aim of these tests is, as for the railway case, to enhance a consumption model that could be use for the energy-based comparison of alternative infrastructures.
Tests have been carried out for various sets of wind fields, for intended vehicle speeds of 50, 60, 75, 80, 100, 120 and 125 km/h, for the 4th and the 5th gear ratios, and in the two directions of a 400 meters section of a specific test lane.
All measurements have been recorded with a National Instrument acquisition board at the simultaneous frequency of 100 samples by second. Fuel consumptions are measured with a Kistler DFL transducer for fuel consumption measurement (accuracy ±0.5 % of reading; resolution 330×10^{-3} ml; non-contact Hall sensors technology). Vehicle speed is determined with an optical Correvit sensor, air flow speed is measured with two windmill anemometers mounted perpendicularly on the vehicle roof. Other data as Buscan consumption or vehicle speed are recorded too, as a reference basis.
Compared to the railway case, road tests have the advantage of having direct measurements of relative wind on the vehicle, instead of a numerical reconstitution.

3.2 Wind influence assessment

Tests performed for various wind conditions, for several days, confirm a rather large variation of fuel consumption at a given test speed. For example, Fig. 4 exhibits consumptions variations of 3 to 4 l/100km for nevertheless steady test speeds of 48, 73 and 97 km/h (intended test speed of 50, 75 and 100 km/h, variations due to vehicle display shift).
In Fig. 5, these fuel consumptions are plotted in function of the whole corresponding anemometer speed range. As expected, a 2nd order polynomial regression can be established between axial airflow speed and consumptions, since car aerodynamic force is expressed in the same form as given in (1) and that consumption is linked to the aerodynamic force (by engine and drivetrain efficiency, and aside other forces as tire rolling resistance).
For the case of intended vehicle speed of 75 km/h, the wind influence on consumptions is merely pointed out in Fig 6, as consumptions are plotted in function of the A/V ratio of the airflow speed to the vehicle speed. The airflow speed being the addition of the vehicle and wind speed vectors, values of the A/V ratio lower to 1 indicate a rearward wind, and values upper to 1 indicate a frontward wind.
This influence is noticeable since, at a moderate speed of 75 km/h (Fig. 6), A 30% forward wind compared to a similar no-wind case is therefore raising the fuel consumption of 18% (1.3 l) and a rearward wind of 30% is lowering the fuel consumption of 12% (0.9 l).

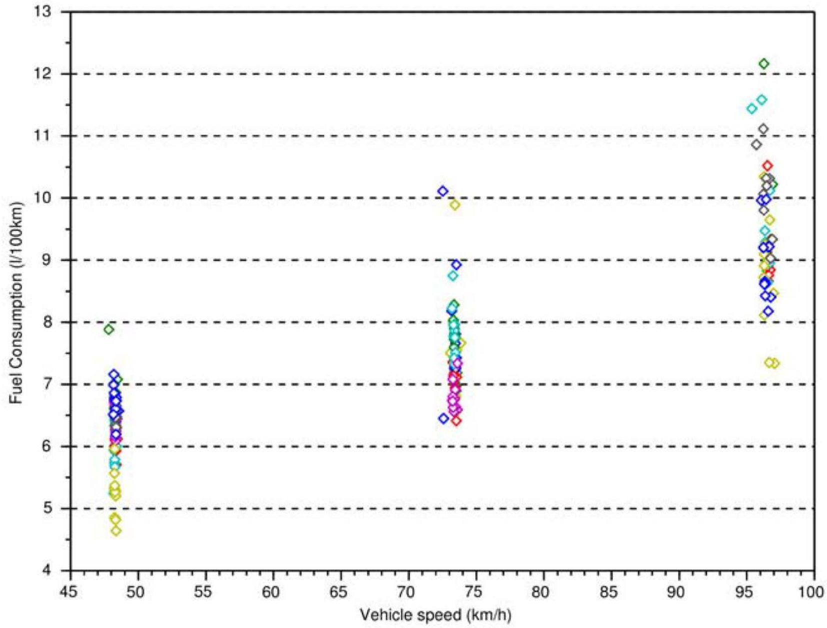

Figure 4 Ranges of fuel consumptions for three intended vehicle speeds of 50, 75 and 100 km/h (4th gear ratio)

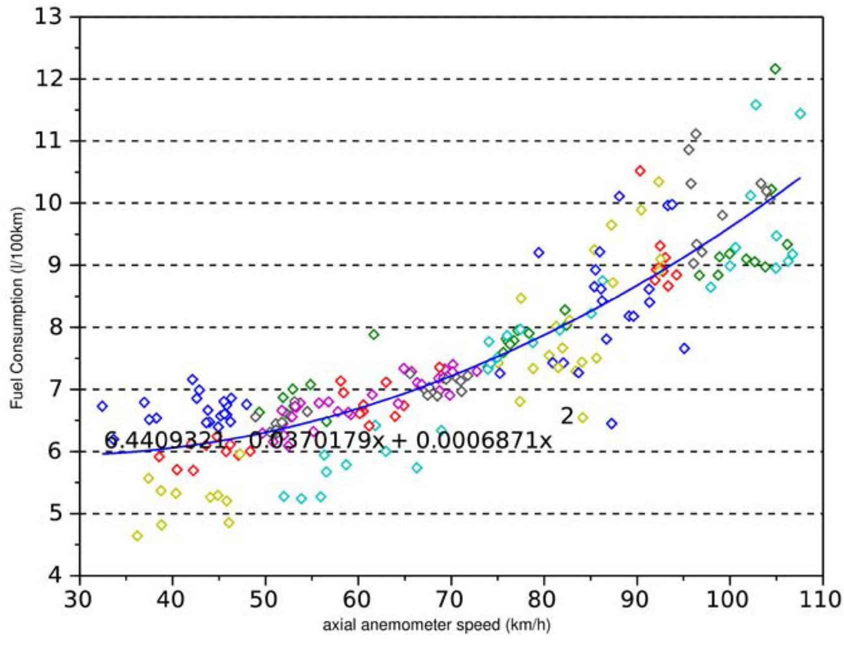

Figure 5 Fuel consumptions variations for the whole anemometer speed range (planned vehicle speeds of 50, 75 and 100 km/h ; 4th gear ratio)

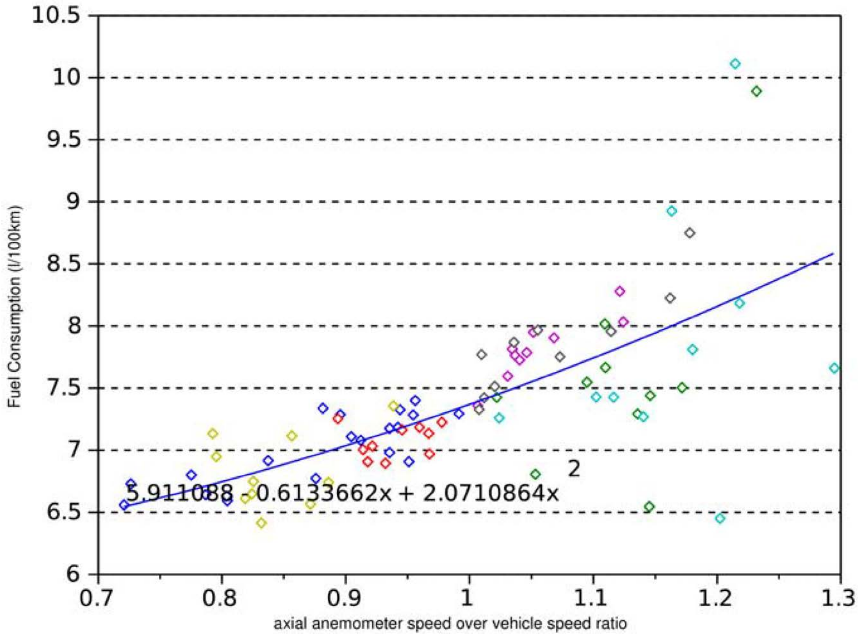

Figure 6 Influence of airflow speed over vehicle speed ratio (A/V ratio) on fuel consumptions (vehicle speed of 75 km/h ; 4th gear ratio)

4 Conclusion

This work has been achieved in the general context of energy assessment of transportation. If considering the peak-oil hypothesis, energy for transportations could become less accessible and more expensive.
Models are used to assess the energy use phase of rail or road transportations, and, in this study, the aim is to evaluate if surrounding wind fields have to be taken into account in these models, in addition of own vehicle speeds.
In a first part, wind influence on trains consumptions have been evaluated. Numerical determination of aerodynamic coefficients for several wind and topological situations have been associated to atmospheric characteristics determined over a high-speed line. Simulation results show that, despite unfavorable conditions, with a train traveling at high speed in a weak wind field, wind influence can yet reach 5% of the aerodynamic forces power, compared to the without wind case. Moreover, for slightly more favorable conditions, a moderate train speed (about 45 m/s) and a slightly stronger wind speed (about 5 m/s) are leading to a computed wind influence of about 30% on the aerodynamic forces power, still while comparing to the without wind case.
In a second part, road experiments have been conducted with a medium-size passenger car equipped with an air flow meter and an oil flow meter, in addition of dynamical measurements as vehicle speed. Similarly to the railway study, wind influence is noticeable since, at a moderate speed of 75 km/h, a 30% forward wind compared to a similar no-wind case is therefore raising the fuel consumption of 18% and a rearward wind of 30% is lowering the fuel consumption of 12%. The non-symmetric aspect of these results can be imputing to the transversal wind field component, which should be investigated in a next step.
In conclusion, this work, based on full-scale experimental data and numerical simulations, points out that wind influence on total aerodynamic power is noticeable, both for railways

or road transportation systems. Magnitude order of these influences is given, in the aim to justify the necessity to take into account wind fields for modeling use phase energy of these transportation systems.

References

[1] Esposito, T., Mauro, R., Russo, F., Dell'Acqua, G.: Speed prediction models for sustainable road safety management, Proc. Soc. and Behavioral Sc. 20, pp. 568–576, 2011.

[2] Tingvall, C., Stigson, H., Eriksson, L., Johansson, R., Krafft, M., Lie, A.: The properties of Safety Performance Indicators in target setting, projections and safety design of the road transport system, Accident Analysis and Prevention 42, pp. 372–376, 2010.

[3] Hubbert, M.K.: Nuclear energy and the fossil fuels, Presented at the spring meeting of the American petroleum institute, San Antonio, Texas, 1956.

[4] Gallagher, B.: Peak oil analyzed with a logistic function and idealized Hubbert curve, Energy Policy, 39, pp. 790–802, 2011.

[5] IEA (International Energy Agency): World Energy Outlook 2010, http://www.iea.org/weo/2010.asp, 2010.

[6] Ou, X., Zhang, X., Chang, S.: Scenario analysis on alternative fuel/vehicle for China's future road transport: Life-cycle energy demand and GHG emissions. Energy Policy, 38, pp. 3943 – 3956, 2010.

[7] Coiret, A., Orfila, O., Kane, M.: Concept of controllability: From pavement skid resistance to safety diagnostics on roads, RGRA 891, pp. 36-40, 2011.

[8] Orfila, O., Coiret, A., Do, M.T., Mammar S.: Modeling of dynamic vehicle–road interactions for safety-related road evaluation, Accident An. and Pr. 42, 1736–1743, 2010.

[9] Coiret, A., Vandanjon, P.-O., Bosquet, R., Jullien, A.: Energy consumption induced by operation phase of railways and road infrastructures, 2nd International Conference on Road and Rail Infrastructure, 7–9 May 2012, Dubrovnik, Croatia, pp. 693-699.

[10] Vandanjon, P.O., Coiret, A., Muresan-Paslaru, B., Fargier, A., Bosquet, R., Dauvergne, M., Jullien, A., François, D. & Labarthe., F: Practical guidelines for life cycle assessment applied to railways project, in: Proc. International Symposium on Life Cycle Assessment and Construction. Nantes, France, jul.2012.

[11] Khaled, M., El Hage, H., Harambat, F., Peerhossaini, H.: Some innovative concepts for car drag reduction: a parametric analysis of aerodynamic forces on a simplified body, J. Wind Eng. Ind. Aerodyn. 107-108, pp. 36-47, 2012.

[12] Tomasini, G., Cheli, F.: Admittance function to evaluate aerodynamic loads on vehicles: Experimental data and numerical model, J. of Fluids and Structures 38, pp. 92 -106, 2013.

[13] Seity, Y., Brousseau, P., Malardel, S., Hello, G., Bénard, P., Bouttier, F., Lac, C., Masson, V.: The AROME-France convective scale operational model, Mon. Wea. Rev., 139, pp. 976-991, 2011.

[14] Raghunathan, R.S., Kim, H.-D., Setoguchi, T.: Aerodynamics of high-speed railways train, Progress in Aerospace Sciences, 38, pp. 469 – 514, 2002.