Challenge G: An even more competitive and cost efficient railway

Presentation of the EU FP7 AeroTRAIN project and first results

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Abstract

The paper presents the AeroTRAIN project in railway aerodynamics, the objectives and some first results. The project is promoting interoperable rail traffic by addressing identified needs in rolling stock authorisation, mainly focusing on the technical specifications for interoperability. The areas addressed are: open air pressure pulses, aerodynamic loads on track (ballast pick-up), crosswinds, train-tunnel interaction (loads on conventional trains and micro-pressure wave phenomena) and slipstream effects. The work contains full-scale and model-scale tests as well as numerical simulations. Complementing the area specific research is work focusing on regulatory acceptance by emphasising a scientific assessment of uncertainties and ensuring that the safety, effectiveness, efficiency and feasibility of the proposed conformity assessment processes are convincing.

Notation:

TSI – Technical Specifications for Interoperability
CR – Conventional Rail
HS – High Speed
CFD – Computational Fluid Dynamics
ERA – European Railway Agency
NSAs – National Safety Authorities

1. INTRODUCTION

The AeroTRAIN project is a 3 year collaborative medium-scale focused research project in railway aerodynamics supported by the European 7th Framework Programme started June 1st, 2009. Together with DynoTRAIN and PantoTRAIN it is part of the TrioTRAIN cluster of projects with the common aim of promoting interoperable rail traffic by addressing identified needs in rolling stock authorisation to enhance the competitiveness of rail traffic. The acronym TRAIN stands for Total Regulatory Acceptance for the Interoperable Network. The project consortium led by UNIFE - the association of the European rail industry - consists of a broad range of the European railway sector representing manufacturers, operators, infrastructure management, railway associations, vehicle authorisation and universities.

The authorisation of a rail vehicle according to Technical Specifications for Interoperability (TSI’s), European Standards (EN norms) and national safety rules represents a significant element of both vehicle cost and time to market. Indeed, a large part of vehicle authorisation mandates testing for safety, performance and infrastructure compatibility. The European Railway Agency (ERA) is in
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charge of developing new and future TSI’s that provide common rules for the authorisation of new vehicles by specifying limitations for all the different relevant technical aspects [1]. Furthermore, ERA clearly identified the aerodynamics field as being one of the main cost drivers in the authorisation process [2].

In the current high speed rolling stock TSI not all aspects concerning aerodynamics are completed and with the introduction of TSI’s for conventional rail traffic there is a great need for limit values for some aerodynamic effects. It is the aim of the AeroTRAIN project to close these “open points”, to provide limit values and where necessary new procedures. In order for the TSI’s to be successful in addition to covering the relevant aspects they need to be efficient regarding time and cost. The AeroTRAIN project aims at reducing the costs and time associated with authorisation without reducing the safety level by introducing less costly test configurations and virtual methods where possible.

In the field of aerodynamics an EN standard has recently been developed which focuses on common definitions and descriptions of the aerodynamic phenomena and measurement procedures. Due to the application to all types of rail traffic it as yet has not converged as yet to one method per phenomenon but allows variations that arise from national requirements. The introduction of Technical Specifications for Interoperability takes precedent over national rules within the European Union and sets specific limits, and therefore requires one method of evaluation. This effectively works to harmonise national requirements and thereby reduces costs of authorisation for rail vehicles intended to operate in more than one country.

The objectives of AeroTRAIN fit very well into the overall ambition of the ERA relating to railway authorisation as expressed in [1].

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<th>Background</th>
<th>Objectives</th>
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<td>• Railway vehicle authorisation is expensive, requiring many on track tests</td>
<td>• Less costly test configuration:</td>
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<td>• Time to Market of rail vehicle is long, especially in the case of additional authorisation in another country</td>
<td>- Simplification of the test scenario</td>
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<td>• Open points in the TSI are one of the main cost drivers, and highlighting the absence of a common approach for some key railway safety issues across Europe.</td>
<td>- Development of transfer function from a situation to an other one</td>
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<th>• Develop virtual testing</th>
<th>• Close Open Points in the TSI</th>
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<td>- Harmonisation of national rules by focus on TSIs</td>
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Figure 1: AeroTRAIN background and objectives.

The areas addressed are: Open air pressure pulses, Aerodynamic loads on track (ballast pick-up), Crosswinds, Train-tunnel interaction (loads on conventional trains and micro-pressure wave phenomena) and Slipstream effects, organised in five technical work packages (Figure 2).

The work contains full-scale and model-scale tests as well as numerical simulations. Complementing the area-specific research is a work package focusing on regulatory acceptance by emphasising a scientific assessment of uncertainties and ensuring that the safety, effectiveness, efficiency and feasibility of the proposed conformity assessment processes are convincing.

The following Sections will present the work for each of the six WP’s in order and describe the specific aims, approach and where available some first results.
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Figure 2: AeroTRAIN structure.

Figure 3 gives a break-down of the high level objectives for the technical areas.

![Diagram of high level objectives]

**Figure 3: Breakdown of high level objectives.**

2. OPEN AIR PRESSURE PULSES

A moving train produces pressure variations on the open air environment, Figure 4. This pressure field is attached to the train. It depends on the train geometry, train speed and ground shape. This pressure variation induces load on the infrastructure and on workers along the tracks or on people on the platforms. To limit this load, the High Speed Rolling Stock (HS RST) TSI (§ 4.2.6.2.3) fixes the maximum value of the peak-to-peak variation in the open air.

The European Norm 14067-4 defines the methodology to measure this pressure variation. The measurement is based on statistical analysis of minimum ten valid runs regarding wind speed and train velocity. The cost and the time spent to assess this pressure variation could be reduced by a reliable simulation methodology, particularly considering that simulations are already the common tool in the design phase of a train. EN 14067-4 indeed do allow the head pressure change to be assessed.
with CFD. The work in AeroTRAIN is to validate, and if necessary refine, the simulation approach in EN 14067-4 and attempt to develop a formulation of a requirement suitable for CFD (single value) corresponding to the current statistical based requirement in the TSI. Therefore, introducing “virtual testing” for the TSI requirements of open air pressure pulses is the aim of the AeroTRAIN project.

To achieve this aim the following is undertaken:

- Verify that the maximum pressure variation can be determined from the head passage of the train. Currently the whole train passage is considered.
- Blind simulations have been performed on conventional trains and high speed trains for which measurement data was later be collected, to assess the ability to predict the results.
- A database of pressure measurements is developed on a representative list of trains (streamlined and unstreamlined). The database is a collection of existing data and results from AeroTRAIN test campaigns in Spain and Germany performed during 2010.
- Analysis of measurements.
- Assessment of the simulation methodology and validation against the measured data.
- Formulation of a limit criterion based on simulations. The simulation supplies one result for one set of boundary conditions whereas the current limit criterion is based on statistical analysis. The main tool to find a corresponding formulation for simulations is a structured analysis of the main parameters influencing the peak-to-peak variation for the measurement and numerical processes.

3. AERODYNAMIC LOADS ON TRACK

Ballast pick-up or ballast projection, i.e. ballast stone movement initiated by the train and usually referring to stones hitting the train, associated with the aerodynamic load of the train is an identified open point in the HS RST TSI (§4.2.3.11).

The phenomenon is quite recent and emphasised by increasing speeds of high speed trains, on new high speed lines and cross border operation. Much knowledge was attained in the past DEUFRAKO AOA Project [3] and [4]. Further introduction to the topic can be found in [5] and [6].

Under a running train the air is accelerated. The air movement close to the track creates a force on the ballast grains. The force required to initiate the stone movement is dependent on the grain size, shape and position in the track as well as the influence of the sleepers. It is likely that it will also be reduced by track vibrations. The aerodynamic load on the track increases with the roughness of the train and the train speed. It is the understanding from the studies of grains and high speed video underneath trains and in wind tunnels that after the initiation of stone movement, they roll and bounce. Some stones may gain enough momentum to reach the train. Due to inertia the acceleration of the stone is not instantaneous. Consequently both peak loads and average loads are important. The probability of stone impact on the train increases with train length. It has been shown in the AOA project [4] and noticed on actual tracks, that ballast lowered below sleeper level reduces the susceptibility of the track whereas this is not an option with all track forms e.g. bi-block sleepers.

The most appropriate quantity representing the load on track is the wall shear stress. This is very difficult to measure. It is much easier to measure the air velocity above the track. However, the

![Figure 4: Schematic pressure variation seen near a train](image-url)
measured velocity is also influenced by the track roughness. In addition it is highly turbulent and transient.

Taking this knowledge into account it is the objective of AeroTRAIN to define
- a standard specification for a measurement technique which captures the basic parameters of the ballast pick-up phenomenon;
- a standard track on which trains should be tested;
- a standard post processing procedure for the measured data;
- a formulation of a needed TSI limit criterion.

It is important that the criterion can represent variations in train speed and train length as well as variations in induced flow patterns between trains.

To achieve these objectives a measurement campaign was carried out on the Spanish high speed line between Madrid and Barcelona during the summer of 2010 (Figure 5). In particular three very high speed train having different arrangements of running gear were measured (S-100, S-102 and S-103), some in double composition (two coupled trains). Two different track preparations were used, ballast in line with sleepers and ballast below sleepers. In addition smooth plates were mounted on a section of the track. The idea is to have a ground condition that can be replicated everywhere, where in addition the air speed over the smooth surface is influenced more by the train roughness and less by the ground. Air velocity measurements were made using different techniques, 2-D ultrasonic anemometers (USA), pressure based sensors and hot-film sensors, at different vertical, lateral and axial positions. Sensors and set-up are shown in Figure 5. In addition one train was equipped with stone impact detection devices, in one arrangement coupled with high speed cameras.

Figure 5: Sensors and set-up in Spanish campaign, 2-D USA (a&b), Pitot and Preston tubes (c), hot-film and Pitot tubes (d), 45 m of installed plates (e) and high speed camera (f).
Particularly with the 8 car S-103 there were a couple of hundred measurements giving interesting statistics. The measured impacts on the equipped train give a good reference between measured aerodynamic loads and actual stone impacts on the train.

4. CROSSWINDS

In order to deliver limit criteria for crosswinds to CR LOC&PAS TSI [7] and for Class 2 trains of HS RST TSI [8], a first objective is here the assessment of new Reference Characteristic Wind Curves (CWC’s) for identified Class 2 and conventional vehicles with low, but sufficient, crosswind stability (proven by their operational records) on the EN14067-6:2010 [9] single track with ballast and rails standard configuration. In the same manner, Reference Characteristic Wind Curves and limit criteria for class 1 trains of HS RST TSI will be determined. This will lead to a reduction in the costs of authorisation compared with the existing HS RST TSI requiring two ground configurations to be studied.

A second objective is the validation of virtual testing by proving that Computational Fluid Dynamics (CFD) investigations are suitable for faster time-to-market with respect to rolling stock conformity assessment. The work aims to (i) check the accuracy of state-of-the-art RANS CFD approaches for vehicle authorisation according to EN 14067-6:2010 using the single ballast and rail configuration for both HS and CR vehicles, (ii) investigate the improvement of accuracy that can be gained from more sophisticated CFD turbulence modelling through Detached Eddy Simulations or Large Eddy Simulations, (iii) produce guidelines of how to perform CFD for vehicle authorisation and the expected accuracy that can be achieved with the aim to improve or confirm EN14067-6 guidelines.

The last objective concerns the assessment of the limits of experimental simulation of reference ground configurations, and the establishment of the methodology for considering aerodynamic loads on embankments. A transformation of the aerodynamic load on the train on an embankment from the single track with ballast and rails configuration will be investigated. The outcome will give confidence in the applicability of such a transformation, and will provide the necessary embankment input for risk analysis on a high-speed railway line, in addition to the results obtained for the single track with ballast and rail configuration through the rolling stock authorisation. The validity of static model testing on embankments will be also investigated, which extends to a natural question about the relationship between static model and moving model measurements. More realistic scenarios will therefore be considered through CFD simulations.

To fulfil the first objective, a list of trains to be investigated has been defined. Guidelines on validation of appropriate candidates for investigation and for evaluating them with respect to significance for the study have been established, including a pre-evaluation of crosswind stability. About twelve vehicles have been identified this way.

A wind tunnel test campaign has been prepared, and is planned to be performed in early 2011. All selected vehicles will be measured the same way on the standard ground configuration.

In connection with the second objective, additional measurements will also be performed to obtain validation data for CFD. The flow will be qualified at the surface and around two trains that are selected to be studied more in detail for the CFD validation. This qualification will include wall pressure measurement on models, PIV velocity measurement on the leeward side of models, and visualisations at the surface. In order to support the corresponding wind tunnel specifications, preparatory simulations were performed for the two selected trains. By using different turbulence models and seeing where the predicted surface pressure varies between them, it was possible to identify pressure tap positions that would give the most interesting results. An illustration of these simulations is given in Figure 6.

Regarding the last objective, moving model tests have been prepared using the TRAIN (Transient Railway Aerodynamics Investigation) Rig at Derby (UK) to determine the effects of train movement on aerodynamic load on level ground and on embankments. Baseline measurement data from the tests will provide validation data for CFD simulations. In addition, a second test campaign is to be performed in a conventional wind tunnel with static measurements on a conventional train model in
the embankment configuration and on the standard ballasted track configuration. These test campaigns are also to be performed in early 2011.

![Figure 6: Illustration of preparatory CFD simulations of conventional vehicles on the single track with ballast and rails standard ground configuration. Plots show the pressure coefficient at 5m from the front of the IC4 leading car at different yaw angles of the approaching flow. Wind is from the left side in the plots.](image)

5. TRAIN-TUNNEL INTERACTION

There are two separate tasks in the AeroTRAIN project related to train-tunnel interaction.

The first task concerns pressure loads on conventional trains, particularly on interoperable and mixed traffic lines. The work consists of three steps:

- gather information on existing lines, tunnels and CR trains and identify representative reference operations.
- extensive numerical simulations to obtain pressure loads and to assess their frequency of occurrence.
- assess load collectives and reference operations to derive a proposal for dimensioning guidelines of CR RST with respect to aerodynamic loads in tunnels.

To get wider tunnel data has proved to be quiet challenging. A questionnaire for European tunnel data did not give any input. Further efforts are made but the outcome is uncertain. A simulation tool has been adapted and validated and can readily provide the load data for any desired tunnel operation according to the procedure in the norm EN 14067-5. The applicability of the output will in the end depend on to which extent representative tunnel operations can be defined.

The second task is to set up a proposal for a TSI criterion regarding micro-pressure waves (MPW) for interoperable trains to limit MPW effects in tunnels. Although it has not been addressed in the existing HS RST TSI this phenomenon has been known in Japan since some time and the essential understanding of the phenomena exists. In Europe, significant micro-pressure waves were observed in Germany first. This phenomenon becomes more and more relevant as new high speed train lines emerge where naturally there are more tunnels, of longer length (about 5-15 km are the most critical lengths), increasingly being built with slab-track and for safety reasons often smaller twin-bore tunnels rather than single bore double-track. Also the speed of trains is increasing and it is more common among high speeds trains with larger train cross-sections like double-deckers. A criterion suitable for European conditions will be derived for the train entry pressure gradient under standardised conditions either through a limit value or a generic benchmark train. The work is mainly performed through numerical simulation (CFD) with additional model scale measurement and full-scale data used for validation of the results and simulation procedures. The simulation approach has previously been successfully used by DB [10].

- A simple standard tunnel geometry has been defined, Figure 7. A train entering this tunnel at 250 km/h is proposed to be the reference scenario for future train assessment with respect to
micro-pressure wave characteristics, consistent with the existing HS RST TSI requirement on train pressure signature (§4.2.6.4).

- A simple generic train has been simulated to compare simulation tools and adjust simulation settings. The shape being as in Figure 8, but with slightly different dimensions.
- Existing European high speed trains where simulated using the defined entry scenario, resulting in entry pressure gradients ranging from 7150 Pa/s to 7600 Pa/s.
- On this basis a new limit value on the train entry pressure gradient for the defined reference scenario will be defined, which on one hand leaves enough margins for existing and future trains and on the other hand does not put unnecessarily high efforts on the infrastructure side. A generic benchmark train will be defined corresponding to this limit value.
- Reduced-scale moving model tests will be performed on the proposed benchmark train (see Figure 8) and an existing high speed train to further validate the simulations and verify the results.
- As a last step the results will be consolidated into a proposal for train assessment procedure and limit criterion for MPW.

![Figure 7: Simple standard tunnel. Reference scenario has train entering at 250 km/h.](image)

![Figure 8: Generic reference train for MPW simulations. Current benchmark train dimensions: H = 3.83 m, W = 3 m, (A_{cross} = 11 m^2), L_{nose} = 4 m, R = 0.75 m, S = 0.25 m.](image)

6. SLIPSTREAM EFFECTS

The air velocities in train slipstreams and wakes are potentially dangerous for passengers and trackside workers, and the TSI process specifies a test method for new train designs that requires measurements to be made at specific points at trackside and above a platform of a specified height. Each measurement requires around twenty train passes to obtain reliable statistics for the slipstream velocities. For each train pass the velocity measurements are filtered using a 1 second moving average filter, and the peak value found. The characteristic slipstream velocity is then taken as the mean plus two standard deviations of the ensemble of peak values. The large number of runs and the need for two experimental sites means that the test process is both complex and extensive. The overall aim of the slipstream measurements in AeroTRAIN is thus to propose developments in the TSI methodology such that the current procedures which require measurements at trackside and platform sites can be simplified. An additional aim is to suggest how to assess non-fixed train consists and single vehicles. The work involves the collation of a significant amount of existing slipstream data from
earlier measurements made by different railway administrations and the obtaining of new experimental data from slipstream measurements made in Spain and Germany.

The earlier measurements from which the data was obtained were as follows.

- From the full scale tests carried out as part of the RAPIDE project, which measured slipstreams around ICE trains at a variety of locations. [11]
- From the model scale TRAIN rig measurements on ICE trains, also carried out as part of the RAPIDE project. [1]
- From TRAIN Rig measurements made on a generic ICE train shape, during the course of a UK Research Council funded project. [11]
- From historical UK data supplied by RSSB obtained over the last two decades, for a wide variety of trains and locations. [12]
- From full scale UK tests on specific configurations of container train. [11]

Additional data to support the investigations will come from CFD Large Eddy Simulation calculations of the slipstreams of ICE trains next to platforms, carried out by the University of Birmingham as part of the UK Rail Research UK project [13].

The Spanish experiments, carried out by DB AG (DB) and Bombardier, measured the slipstreams at trackside behind a variety of high speed train (nominal speeds of 300 km/h) on the Madrid – Barcelona line using arrays of ultrasonic anemometers, together with measurements of ambient conditions. A very large number of measurements have been made (>600 train passes), in particular for the S-103 train (Velaro), and the dataset is thus far richer than anything that has been achieved in the past. Photographs of the experimental set up are shown in Figure 9. The German experiments were carried out at two sites near Munich – Westendorf by DB and University of Birmingham (UOB) and Kutzenhausen by UOB – and measurements were made mainly of the slipstreams of conventional trains of a variety of types, with some measurements of high speed trains running at 200 km/h. Again arrays of ultrasonic anemometers were used, both at trackside and on the station platforms. Photographs of the experimental sites are shown in Figure 10.

![Figure 9: Anemometry for the Spanish experiments](image1)

At the time of writing, an extended analysis of the earlier experimental data is being carried out. These results show the necessity of obtaining data from a large number of train passes if reliable statistics for the highly unsteady slipstream velocities are to be obtained. A TSI style analysis, that analyses one second maxima from individual runs, has been carried out on the RAPIDE full scale data, some of the RSSB data and the freight container data. It is clear that for freight trains the one second maxima occur along the side of the train (in the “boundary layer” region). For high speed passenger trains, measurement locations near the train show maxima at a wide range of points along the train and in the train wake – in the “boundary layer” and “near wake” regions. For measurement positions further away from the train, and close to the specified TSI positions, the one second maxima group to a very large extent in the near wake of the train, a region where the flow is very intermittent and unsteady. A brief preliminary analysis of the UOB slipstream calculations suggests that the variation of slipstream velocities with different platform heights is complex. The analysis of the two sets of experimental data from Spain and Germany is in the early stages and will concentrate on
assessing the adequacy of the TSI methodology, the development of a revised and simplified methodology, and the study of the variation of slipstream velocities for different train types.

Figure 10: Anemometry for the German Experiments

7. QUALITY ASSURANCE AND REGULATORY ACCEPTANCE

A significant portion of AeroTRAIN work is dedicated to maximising the exploitability of the results of the research activities described above. This work, common to all the TrioTRAIN projects, is not strictly research work. However, it is performed with the same high degree of scientific and methodological rigour. Although the targeted end user of the project is clearly the railway sector, as a research project, TrioTRAIN will not deliver documents directly applicable by the railway sector. The intermediate step between the project’s outcomes and the end user are the standard & regulatory bodies. Thus exploitability of the results means their acceptance by the corresponding regulatory and standardisation bodies for the formulation of new specifications and standards, which then could be applied and bring the corresponding benefit to the railway sector. Specifically the key bodies in Europe are ERA, CEN-CENELEC (the European Standards Organisation) and the NSAs. AeroTRAIN results have to reach a high degree of consensus particularly among these bodies – thus, a high degree of “regulatory acceptance” – and the key to this is their high general and scientific quality.

Regulatory acceptance is being sought essentially through the targeted dissemination of results that have passed through a quality assurance process. The strategy developed for this is in many aspects innovative in research projects. It rests on three “pillars” that are described in some detail in the following points.

- **Structure.** The AeroTRAIN key output documents are structured according to a Guideline that is in common with the other TrioTRAIN projects. The structure essentially mimics that of the current type-test processes defined in the existing standards and specifications – the documents define proposals for alternative processes in terms of the assessment tools to be used and how to validate them, how to process the data obtained from the assessment tools to obtain the assessment quantities, how to compare the latter with the limit values. These documents will be checked for essential quality features and feasibility of the proposed processes and also to ensure that potential impacts on safety are carefully highlighted and analysed with the aim of maintaining, at the least, the current safety levels.

- **Accuracy.** AeroTRAIN has assigned particular importance to the quantification of accuracy (i.e. to uncertainty) of all assessments performed in the project, be they experimental or numerical. This aspect is recognised as the most important scientific aspect influencing the convincingness of results and aims at bringing evidence that TrioTRAIN proposals are at least as (if not more) safe than the existing authorisation processes. All project documents include dedicated uncertainty assessment sections inspired to uncertainty guidelines. The latter condense the current state of the art on calculation and representation of uncertainty and add scientifically based practical considerations on the elements of experimental/numerical analyses that are necessary to transmit confidence in the results to the assessor. The accuracy information populates a TrioTRAIN uncertainty framework, which aims at allowing
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comprehensive analyses in the later project phases, particularly for the comparison of the uncertainties in experimental and virtual assessments.

- **Targeted dissemination.** Particular care has been given to interactions with the project's target group of standards and regulations bodies right from the start. The key bodies - CEN, CELELEC, three NSAs (UK, France and Germany), under the Chairmanship of ERA - have been invited to provide representatives for the TrioTRAIN Advisory Council. This Council meets roughly every six months - thus the target group was informed of objectives very soon after the project started and is now being kept up to date on progress, results and problems. Regular liaison with the standardisation bodies is also maintained by project partners that are involved themselves in those bodies.

ACKNOWLEDGEMENT

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