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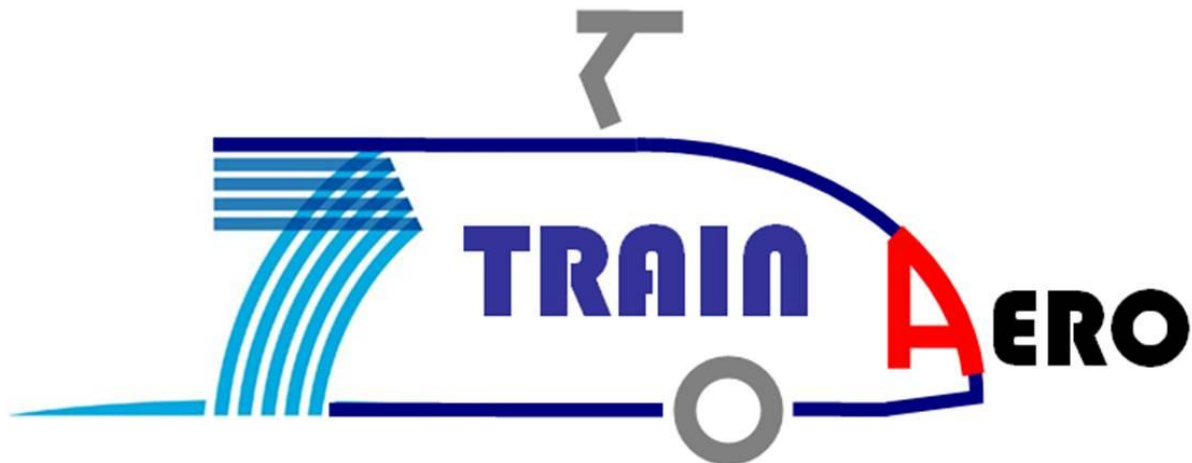
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AeroTRAIN

Aerodynamics: Total Regulatory Acceptance for the Interoperable Network



D0.5 – Final Report WP0 – Project Management

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4.1 Final publishable summary report

a. Executive summary

The certification of a rail vehicle according to European regulations, Technical Specifications for Interoperability, European Standards and national safety rules represents a significant element of both vehicle cost and time to market. Indeed, a large part of vehicle certification mandates testing for safety, performance and infrastructure compatibility. AEROTRAIN aimed to help meet the business scenarios listed in the ERRAC SRRA 2002 and 2007 by aiding the spread of European homologation and acceptance procedures to speed up interoperable product approvals while squeezing out risk through improved safety management. In the field of aerodynamics EN focuses on common definitions and descriptions of the aerodynamic phenomena and measurement procedures. Due to the application to all types of rail traffic it has not converged yet to one method per phenomenon but allows variations arising from national rules. The focus of the project is therefore on using the TSI route to consolidate the methodologies allowing the free exchange of certification data. The project is part of the TRIO-TRAIN cluster (Total Regulatory Acceptance for the Interoperable Network) which aimed to propose an innovative methodology via a computer simulation/virtual homologation to allow multi-system network and route approval in Europe to become a faster, cheaper and better process for all involved stakeholders.

The aims were largely reached through measurement campaigns in full scale, measurements in model scale and simulations. A structured approach was used to assess new and existing methodologies using uncertainty analysis, authorisation perspective and interactions with stakeholders in ERA and CEN, to ensure the appropriateness and future uptake of proposals for standards made by the project. A virtual assessment is proposed as alternative for open air pressure pulses and cross wind. Further a new procedure and limit value for the generation of tunnel entry pressure gradients by a vehicle is proposed that is based on purely on simulations, with moving model tests as an alternative. A tunnel simulation tool for tunnel loads was further developed within the project and made available to the aerodynamics community allowing a common tool for exchanges on tunnel aerodynamic loads. Within slipstreams there is a proposal to close the open point on treatment of single vehicles as well as proposal to manage the platform test with a corresponding one at the trackside, easily accessible and common over Europe allowing significant cost reductions. Within ballast projection a measurement procedure, post-treatment and framework for limit formulation has been established where there was nothing before. European wide application is needed in order to derive a future TSI limit, which was not feasible within the project. For cross wind a limit derivation was too challenging for the scope of the project. Several critical vehicles have been evaluated and possible approaches for limit derivation put forward. More extensive evaluations, inclusion of more European vehicles and possibly consideration of other factors, outside the scope of the project, can progress this issue.

The very detailed focus on TSI and CEN standardisation issues, a strong interaction with the stakeholders before and during the project has lead to a very high degree of success. A few topics were more challenging than expected where further work is needed.

b. Project context and objectives

Concept of the AeroTRAIN project

The overall objective of the *AeroTRAIN* project was to promote interoperable rail traffic by addressing identified needs in vehicle certification to enhance the competitiveness of rail traffic, in turn encouraging an environmental friendly alternative for transportation of people and goods within Europe. The certification 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 certification mandates testing for safety, performance and infrastructure compatibility. The European Railway Agency (ERA) is in charge of developing new and future TSI's that provide common regulations for the homologation of new vehicles. TSI's will provide a safe and technical compatible railway system for Europe by specifying limitations for all the different relevant technical aspects. In 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. It was 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 they in addition to covering the relevant aspects need to be efficient regarding time and cost. The *AeroTRAIN* project aimed at reducing the costs and time associated with certification without reducing the safety level.

The *AeroTRAIN* project will promote interoperable rail traffic by:

- reducing cost and time of vehicle certification;
- closing "open points" in the TSI's.

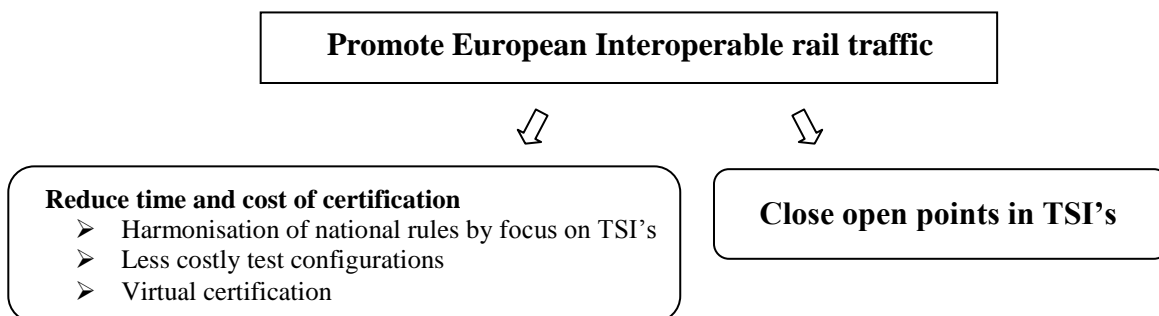


Figure 1: Concept of the AeroTRAIN project: objectives.

AeroTRAIN is part of the TrioTRAIN cluster of projects. TrioTRAIN, is an acronym for Total Regulatory Acceptance for the Interoperable Network, dealing with key railway interoperability issues. The objective of these projects is to propose an innovative methodology that will ease rail vehicle certification process in Europe to become a faster, cheaper and better process for all involved stakeholders.

The *TrioTRAIN overall objectives* are as follows:

- to foster cross-acceptance of railway vehicle authorisations, by offering standard processes for demonstration of conformity, less dependent on local testing conditions and allowing for faster evaluation of minor changes;
- to close "open points" in TSI's;
- to reduce the cost, shorten the time and overall ease the network approval process in Europe introducing and/or exploring:

- virtual homologation (replacement of assessment by testing with assessment by simulation),
- transfer of certification results in one country to another,
- virtual extension of homologation (for minor changes to existing homologated solutions).

The *TrioTRAIN* concept comprises 3 related projects: *AeroTRAIN*, *DynoTRAIN* and, *PantoTRAIN*. Aerodynamics (*AeroTRAIN*), Railway Dynamics and Track Interaction (*DynoTRAIN*) and Pantograph and Catenary interaction (*PantoTRAIN*) are the fields where it is believed that network approval process can be improved in a very positive way. These fields share common points that can be exploited in a unified way for the facilitation of the network approval process. Indeed, with the current state-of-the-art, the only sensible way for transposition of test results is via computer simulation / virtual homologation and that is a CORE SKILL to be developed in *TrioTRAIN*.

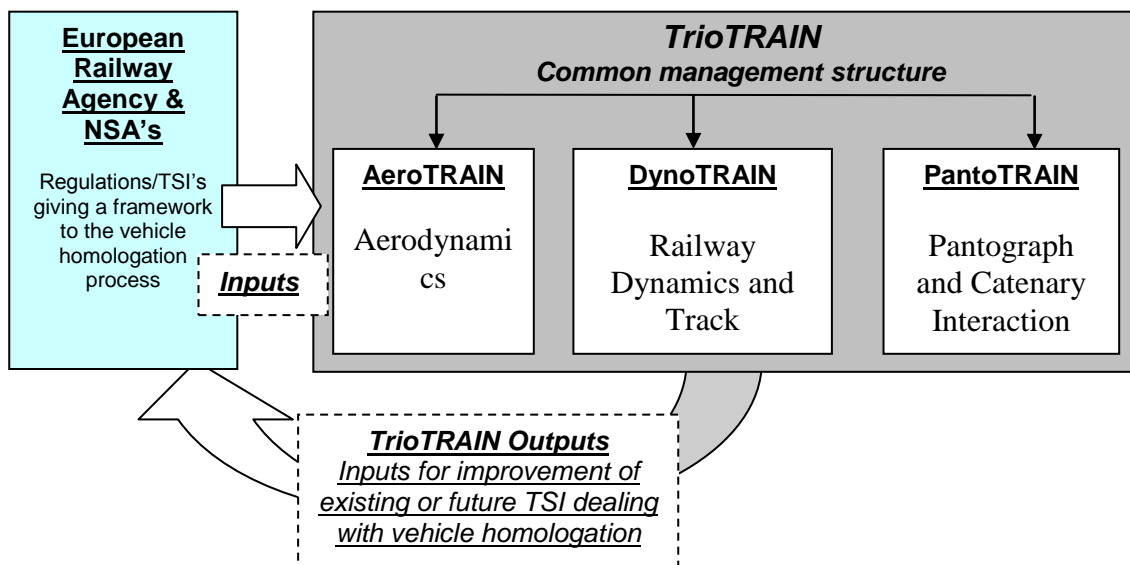
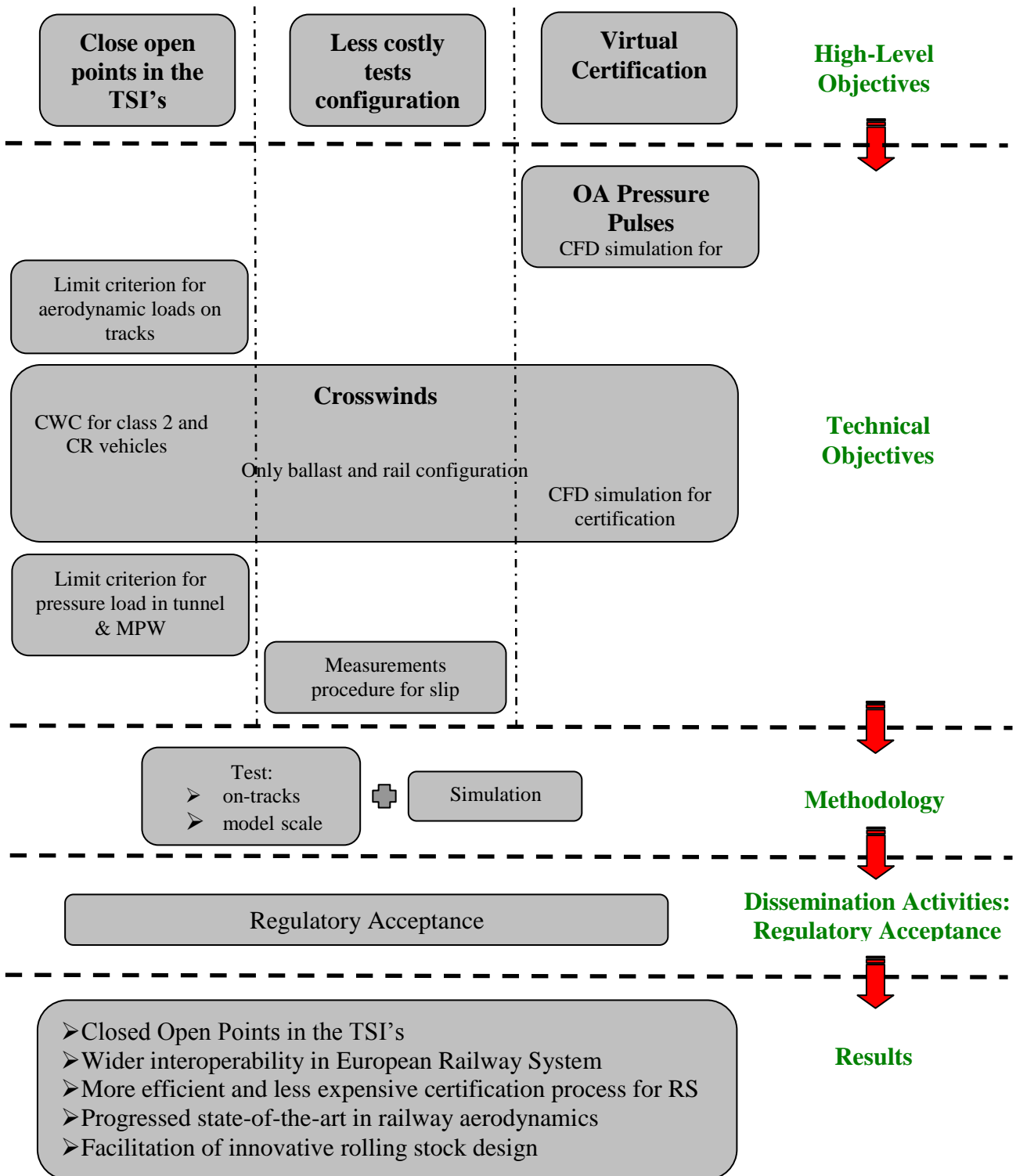


Figure 2: The *TrioTRAIN* concept.

AeroTRAIN High-level objectives

The overall goal of the project AeroTRAIN was to promote interoperable rail traffic in Europe by reducing costs and time of certification and closing “open points” in the TSI’s. The overall goal will be achieved by the following high level objectives:

1. Address HS & CR TSI’s that effectively work to harmonise European and national standards on aerodynamics to reduce costs and time of certification;
2. Reduce costs and time of certification by replacing existing cross-wind and slipstream tests with new alternatives without reducing safety;
3. Reduce costs of certification by introducing virtual testing as far as it can be validated for head pressure pulse loads and cross wind aerodynamic loads;
4. Close “open points” in the HS and CR TSI’s. Derive limit values and where necessary new certification procedures.



c. Main S&T results/foregrounds,

The *AeroTRAIN* project aimed to promote interoperable rail traffic in Europe by reducing costs of certification and closing “open points” in the TSI’s. On the basis of the requirements for the new CR TSI and revision of HS TSI, opportunities to reduce certification costs and where it is seen that virtual certification could be introduced it was decided to focus the study on five main aspects of rolling stock aerodynamics that were or needed to be subject to certification. Hence the Work Program of the project was organised around five technical Work Packages:

- **WP 1: ‘Open Air Pressure Pulse’;**
- **WP 2: ‘Aerodynamic Loads on Tracks’;**
- **WP 3: ‘Crosswind’;**
- **WP 4: ‘Train – Tunnel Interaction’;**
- **WP 5: ‘Slip Stream Effects’.**
- **WP 6: ‘Quality Assurance & Regulatory Acceptance’**

The main scientific and technologic results and foregrounds developed during the project are described in the following sections dedicated to each WP.

WP1 Open Air Pressure Pulses

The Work Package 1 of the AeroTRAIN project deals with the “Open Air Pressure Pulse”. This item is subject to Rolling Stokes authorization process. It is addressed by the EN14067- 4, the TSI HS RST and the TSI CR PAS&LOC. Nowadays, the authorization process for train speed higher than 190 km/h is based on experimental assessment.

The experimental process has to fulfill several conditions as:

- Train availability
- Track compliant to TSI requirement and available for test
- Pressure, meteo, speed measurement devices
- 10 runs compliant with EN regarding the wind speed and the train speed

This process is difficult to achieve, is time consuming and costly.

An alternative solution to the experimental process is the numerical process with CFD tools. This numerical process should be shorter and less costly. Therefore, the objective of the work package 1 is to assess the ability of the numerical tool to cover the authorisation process regarding the “Open Air Pressure Pulse”.

In order to achieve this objective, the next tasks have been undertaken:

- To build a test reference database: the purpose is to assess all the work done in the work package
- To analyse the location of maximum peak to peak pressure variation: to validate the assumption of the head pressure pulses
- To complete blind simulation: the purpose is to assess the ability of the CFD tools to predict
- To develop methodology to fairly compare test and CFD results
- To assess the ability of CFD tools and develop CFD rules
- To proceed parametric analysis: to analyse the sensitivity of the results for the deviating parameters

Additional tasks have been considered:

- Comparison between GB and TSI requirements
- Track distance influence regarding the pressure pulse

Hereafter, the main results of the work package are presented.

Database:

The test reference database has been produced. The historical data from GB, the measurements from AeroTRAIN campaigns in Spain and in Germany, and data from AnsaldoBreda were collected. This database covers High Speed Train, Conventional passenger train and freight train. The single unit and multiple unit configurations as the single and the double decker were included.

Location of the maximum peak to peak pressure variation:

All the full scale test data from the database have been analysed. The maximum peak to peak pressure variation always occurs on the head of the train. The maximum or minimum pressure could be observed in other locations but they are not recurrent except for 1 case. The S103 in double unit configuration has the maximum pressure variation at the head but the maximum pressure always occurred at the coupling area.

This analysis supports the assumption that the head of the train is the area of interest to compute simulation.

Ability of CFD tools:

Blind simulations on streamlined and unstreamlined trains have been performed with panel method tools and RANS softwares. The panel method predicts well the pressure pulse produced by streamlined train but it fails to predict the pressure pulses produced by bluff train even with morphing technics applied on the geometry. The RANS method, completed according CFD know-how, fits well with test results corrected to the ideal conditions for both streamlined and unstreamlined trains. For bluff geometry, unsteady CFD models as SAS, could catch more physical phenomenon and reproduce pressure fluctuation. It could be more accurate than RANS method.

CFD guidelines:

The CFD gives reliable results for the open air pressure pulse. But the simulations have to be performed with the best practice, with the right tool and with the skilled people. So, additional CFD guidelines to the existing ones in the EN standard have been proposed. Moreover, a simulation called "test bench", on a reference case with experimental data available have to be performed to prove that all the conditions are fulfilled to succeed in predicting. This is a key point for a reliable numerical assessment of the pressure pulse.

Parametric sensitivity:

Parameters which could influence the simulation results and the test results were listed. The deviation of each parameter on the pressure pulse has been estimated.

For example, about the numerical assessment, the deviation due to the software, to the people and to the CFD methodology have been assessed with a cross simulation on the ICE3 wind tunnel model. The deviation obtained was lower than the deviation we have with several test runs.

About the experimental assessment of the pressure pulse, this parametric analysis demonstrates that crosswind could lead to a main deviation. This could be corrected if a clear correlation is demonstrated.

Finally, the deviation produced by the numerical assessment procedure is expected to be less than the deviation produced by the experimental assessment procedure.

Standard Proposals for the full assessment and the simplified assessment:

Finally, the results of all the previous studies demonstrate that the CFD tools could be reliable to fully assess the pressure pulse at the head of the train. Then a procedure for standard has been

proposed in which the ability to conduct numerical assessment has to be proven by a test bench. Then, the result of the simulation is weighted to be compared with the limit criteria.

For a train derived from an existing one which is fully assessed, three levels of modification are identified:

- Small differences: Modifications which have hardly no influence on the pressure pulses. These allowed modifications are listed in the proposal. No assessment is required, but modifications are to be documented.
- Medium changes: Modifications which change the pressure pulse less than 10%. Simplified assessment is allowed. This simplified assessment relies on the analysis of the deviation due to the modifications on the pressure pulse.
- Bigger changes: full assessment is mandatory.

These standards have been presented to CEN and ERA for integration to the standards.

WP2 Aerodynamic Loads on Tracks

It has been known for many years that ballast stones can cause severe damage to trains if the movement is initiated sufficiently for a stone or stones to reach the train. The induced momentum can cause an avalanche effect. These problems were associated with snow and ice falling from the train. For this reason the ballast level was lowered below the sleeper level by about 4 cm in countries with cold climate as Germany and Sweden such that ice falling from a moving train would always hit a sleeper and be destroyed. This resolved the problems and also at high speeds there was no significant problem summer or winter. During homologation runs in Belgium with ICE 3 the problem re-occurred and damaged the underside of the train costing several 100 k€ to repair. Flying stones can also be a danger to persons near the track. Later incidents have also been reported from new high speed lines in Spain, Italy, UK and South Korea. This has led to speed restrictions which impair the high speed train operation.

Since TGV has been running in Belgium without problems and likewise ICE 3 in Germany the phenomenon is partly associated with the train induced aerodynamic loads and partly with the specific track conditions. The acceleration of air by the train causing a load on the track is mainly associated with the non-streamlined parts of the lower part of the train, e.g. bogie regions and gangways, and ventilation airflows directed towards the track. As the train speed increases the problem will increase in importance. Therefore the limitation of aerodynamic loads on track is necessary in order to have continued development high speed train operation.

The phenomenon of ballast pick-up has been recognised in clause 4.2.3.11 in the HS RST TSI but at the time of writing the TSI it was impossible to define any criterion and it remains an “open point”. The phenomenon is recent and considerable effort to understand it was made in the *DEUFRAKO* project *Aerodynamics in Open Air* (AOA) using wind tunnel tests of air over a ballasted track, CFD simulations, modelling of the stone dynamics, full scale test, and an overall simulation model that predicts the risk of ballast projection for a given train and track condition. Practical tests with different measurement techniques of the aerodynamic part of this phenomenon were carried out and recommendations were made based on the results of these tests. Several AeroTRAIN partners have carried out individual investigations on ballast projection effects in the recent years. It has been recognised that this topic is not only relevant for the rolling stock but also for the infrastructure. Within AeroTRAIN measurements of the aerodynamic load induced by different high speed trains on different track conditions were performed. The current state of the art measurement techniques were further developed with recommendations from AOA and information in literature from other areas. A common measurement procedure of the aerodynamic loads on track has been applied to several different high speed trains for the first time. A robust measurement and post processing procedure was developed which captures the basic parameters of the ballast pick-up phenomenon

suitable for authorisation. Standard track conditions for vehicle testing have been developed. Finally a framework for the derivation of a limit criterion for TSI's has been suggested.



Figure 3: Sensors used to measure the flow patterns under a High Speed train.

The introduction of a test procedure for the aerodynamic load on the track by trains will put focus on the aerodynamics of the flow under the train and will require future trains to have even more streamlining of the train underside promoting lower aerodynamic drag and thereby lower energy consumption. It is also a prerequisite for a further increase of travel speeds in the future.

The main innovations brought by AeroTRAIN with regards to aerodynamic loads on tracks are the following:

- a measurement technique to assess the aerodynamic load in relation to the risk of ballast pick-up;
- measurements of the aerodynamic load on tracks by different high speed trains with a common measurement procedure;
- a robust measurement and post processing procedure which captures the basic parameters of the ballast pick-up phenomenon suitable for authorisation;
- standardised track conditions to measure on;
- a deeper insight into the physical properties of the ballast flight phenomenon;
- a framework to derive a limit criterion for TSI.

The above aspects have been fed into a norm text proposal for the current update of the railway aerodynamics norm EN14067 and future TSIs. To ensure that results are taken up by the standardisation bodies the text proposal has been presented to ERA and CEN and feedback has been taken into account for the final proposal. The work-package output and background information will be publicly available to facilitate a smooth transition from the proposal to a valid norm text.

It is expected that the norm text proposal is taken up by CEN to form a norm in the near future. This is the basis for future application of the standardised procedure and further development of high speed rail traffic. The application of the procedure for relevant European high speed traffics allows an assessment based on relative performance between vehicles or infrastructures even without a limit criterion. Building a data base by application of the procedure and gain of experience is the basis for a future derivation of a limit criterion for TSI.

WP3 Crosswinds

Work Package 3 “Crosswinds” has four major objectives. Two of these relate to the closure of open points of the TSI HS RST and TSI CR PAS&LOC in terms of deriving limit values for the cross wind stability of both conventional railway (CR) and high speed trains (HS). Additionally, there was the objective to investigate CFD methods for crosswind assessment and to improve existing guidelines

using these approaches. Last, the work aimed at assessing the limits of experimental simulation of reference ground configurations, and at establishing the methodology for considering aerodynamic loads on embankments.

To achieve the two first objectives, it was firstly decided to define and describe trains that were to be investigated in the project. In order to define candidates for investigation, basic principles were identified to describe the requirements for potential candidates, e.g. availability of general information such as brand types, operation and pre-evaluation of crosswind stability. Additionally trains were analysed for their appropriateness to be potential reference trains for the derivation of limit values and / or for the application and evaluation of CFD methods. This resulted in a reduced list of possible candidates that was then additionally prioritised with respect to their significance for investigation within the project. For this prioritisation indicating factors were determined and applied. The final list of trains to be investigated therefore includes a listing of candidates ranked in order of precedence of their relevance for investigation.

Some of these vehicles have been selected to be measured during a wind tunnel test campaign which took place at CSTB (Centre Technique et Scientifique du Bâtiment, Nantes, France). The forces and moments have been measured for all vehicles, and a comprehensive dataset on the flow qualification has been obtained for two vehicles (VT612 and IC4), including pressure taps and PIV measurements, surface visualisations. The complete set of experimental results has been then used within the project for the CFD validation and for the CWC assessment. This comprehensive dataset of aerodynamic coefficients is available for several conventional vehicles. Some of this data might be used in the future as reference data for comparison and validation of experiments or numerical simulations. In addition, the predictive equations as defined in the EN14067-6:2010 standard have been checked and showed to lead to conservative results as foreseen in the standard, and might be usefully reformulated to reduce the conservativeness. In addition, further requirements have been considered within the specifications of the wind tunnel tests performed within the Work Package. These requirements aimed at improving the quality of the results, and come in addition to the ones required by the EN14067-6:2010 standard. They could therefore be considered as potential improvements to the standard requirements for the crosswind wind tunnel experiments, and be introduced in the EN text.

Following work consisted in assessing the implementation of the methods used for the CWC calculations and in performing the CWC calculations for the various vehicles as defined previously. In addition, the process of validation of the MBS modelling was established and analysed for all the vehicles. All the MBS models for the vehicles have been created and used for the CWC calculations. Besides, specifications of the test case for the assessment of the method implementation are finalised. A specification for a benchmark of the implementation of the Chinese Hat gust scenario has been also defined. This benchmark gives much more information about the quality of the implementation chosen than comparing results on wind speed level which can be done on the basis of the example given in EN 14067-6.

The comprehensive dataset of CWCs is now available, and can be possibly used in a near future for the derivation of reference values. Further work would have to be carried out on the validation of the MBS models (within the appropriate working group, for instance for the writing process of the TSI RST PAS&LOC), even if this topic on validation has been also intensively discussed within the project.

Guidelines and principles for the derivation of limit criterion were established and described. These include basic commitment to established methods and approaches as used in standards such as EN 14067-6 and TSI HS RST and also the agreement to consider carefully the principles that were used for national regulations. The underlying difficulty is that cross wind has been recognised as a safety issue and is already partially regulated and thus the derivation of new limit criteria for rolling stock is influenced by established systems of risk evaluation and existing infrastructure design. It is

agreed that these fundamental specifications need to be broadly accepted to ensure that the AeroTRAIN proposal for limit criteria will find the support to become a TSI limit.

On this basis two main approaches for deriving limit criteria were developed. One approach suggests reference wind curves as a pass / fail criteria, while the other deduces a minimum wind speed independent of the operation from the characteristic wind curves as limit criterion. Both approaches have their own merits but also show disadvantages. The pros and cons were documented and have led to variations of the two main approaches that at least partially resolve disadvantages. No consensus was found to define the more appropriate approach for proposing TSI limits, and deriving limit values. Therefore, the main principles and the two approaches were presented and discussed with a broader selection of stakeholders for further evaluation.

To reach the third objective, extensive CFD numerical simulations of the two mostly investigated in wind tunnel tests, (namely the VT612 and the IC4 vehicles), relating to meshing, turbulence models and boundary conditions served to give internal simulation guidelines for RANS. Further the impacts of various choices were quantified as well as the simulation accuracy for these two differently shaped trains. Results show that the streamlined train is predicted with high accuracy whereas the blunter train is a bit more challenging. As in the wind tunnel tests, the IC4 leading car was simulated with and without roof corrugation. The loads are significantly different and this was well captured by simulations.

The guidelines were applied to the common train ICE3 (current EN 14067-6 benchmark train) by several project partners giving a cross check of both application of the guidelines as well as the results from different simulation codes, turbulence models and meshing approaches.

With this application experience, other conventional vehicles were additionally simulated to see the accuracy of the RANS simulations for different train shapes. The results confirmed that streamlined trains are predicted with high accuracy by RANS simulations whereas blunter trains can be more challenging, with roof arrangement having an influence. It is suggested to have benchmark trains (to validate approach) with similar shapes to the new one being simulated. Further the set-up is more strictly defined; mesh refinement check made more feasible and averaging requirement of loads defined.

Resulting from these were final simulation guidelines, a compilation of RANS simulation results for the range of investigations in relation to the aim, and a proposal in regards to usage of numerical simulations in place of wind tunnel tests for vehicle assessment. Proposal is an update and improvement of the current EN14067-6, but with the idea to be used by both TSI and EN norms.

Use of more advanced turbulence modelling resolving large scale fluctuations as with DES or LES is expected to improve the accuracy but with a significantly higher computational effort. With the continuous development of computers, these methods are becoming more and more feasible. A few cases were simulated with DES and DDES that show promise with improved accuracy. However, more studies are required to find the best approach for cross wind and the accuracy that can be achieved for different train shapes than was in the scope of this work.

At last, the last objective was not completely reached. Whilst the project has not been able to meet one aim of developing transfer functions between wind tunnel aerodynamic data measured on level ground with various track configurations and that data measured on a 6 m embankment, there have been many positive outcomes from the studies, despite ultimately the lack of time to develop the full worth of the work undertaken. These outcomes were:

1. A complete pressure measurement database has been derived from the TRAIN Rig tests for a leading Class 390 vehicle on level ground and on an embankment. To achieve this has required the development and construction of a cross wind facility, as well as a pressure data logger capable of acquiring data during moving model tests.

2. A full database of aerodynamic coefficients has been measured in the DLR low turbulence wind tunnel for the TFG, the STBR and DTBR (wind ward and leeward tracks) on level ground as well as on a model 6 m embankment on the windward and leeward tracks.
3. CFD verification simulations were undertaken of the TRAIN Rig tests which indicated general trends of behaviour, although they suffered to some extent in overall quality from the difficulties of correctly replicating the very non-uniform inlet velocity profiles occurring in the Rig tests.
4. CFD studies of the Class 390 on an embankment exploring the effect of vehicle movement and onset flow profile.

These databases will permit additional studies in the future, outside the AeroTRAIN framework, to enhance the performance of moving model studies for this application; for additional comparative studies of the effects of ground configuration on train aerodynamic coefficients and for the development of the above-mentioned transfer functions. Project partners intend to progress with this analysis outside AeroTRAIN in order to bring this transformation into future CEN standards.

As a result of this work it seems that the effect of vehicle movement, either on level ground or on an embankment is relatively small, of the order of 5% on the aerodynamic coefficients. On the other hand, the effect of the difference between an atmospheric boundary layer profile with atmospheric turbulence and a block profile with low turbulence could be significant.

WP4 Train – Tunnel Interaction

Work Package 4 “Train-Tunnel interaction” had two major objectives represented in two tasks. The first objective was to close an open issue within EN / CR TSI regarding pressure loads on CR RST running in tunnels. The second one was to set up a TSI criterion regarding micro-pressure waves (MPW) for interoperable trains to limit MPW effects in tunnels.

A train entering a tunnel acts as a piston in an engine, with additional effects due to the free space between the train body and the tunnel wall. The train head generates a steep pressure rise, followed by a leaner ramp caused by friction on the coaches and a strong drop associated to the tail entrance. This so-called pressure signature travels ahead of the train at the speed of sound, i.e. more than four times faster than a high speed train at 300 km/h. Arriving at the tunnel end, this pressure signature is reflected and travels the tunnel back, crossing and interfering with the running train, and is again reflected at the entrance. This forth and back travelling generates a complicated pressure wave pattern, which is impressed on the train structure, on the doors, windows and on all air-breathing or exhausting systems. It is also provoking aural pain to the passengers, making it necessary to seal coaches. These phenomena are even worse for crossing trains in a double track tunnel.

The aerodynamic pressure loads associated with tunnel passing and crossing in tunnels have been extensively investigated and reliable models have been developed to predict them. Load limits have been set in the TSI for high-speed trains, but the question of sustainable fatigue over years of operation remains unanswered. This is however a crucial point for the European railway network, concerning rolling stock interoperability and security in a wide range of operating conditions, from high-speed on dedicated tracks to combined freight and high-speed operation on the conventional network.

The objective of the present project was to make an exhaustive survey of the train/tunnel combinations met on the European railway network, to define consistent operational scenarios and to derive rolling stock classes in terms of fatigue loading. In order to properly handle the numerous crossing combinations associated to the representative scenarios of trans-European operation, a solid database system has been developed. The complete package, named TRUNS, includes a fully

functional train-tunnel simulation tool, making it a powerful tool for scenario analysis. It is freely available to all interested parties.

The work to be done in the second task regarding the limitation of micro-pressure waves was quite straightforward. A limit definition could be possible for several stages of the MPW-phenomenon. It was identified that a general regulation on the MPW itself would fail due to very different national acoustic rules. In the working group it was agreed to propose a limit for the compression wave which is generated at the entry portal when a train enters a tunnel. The relevant parameter regarding the MPW is the maximum entry pressure gradient. Generally spoken, a larger gradient results in a stronger MPW. Of course there are additional parameters which can dampen or enforce the effects but it should be sufficient to define a limit at the entry portal.

In task 4.2 there were several working steps which could be summarized as follows.

The work started with the definition of a simple reference scenario for an assessment regarding the maximum entry pressure gradient. For the tunnel a simple circular shape with a filled bottom and a vertical wall in front of it was proposed. A simple shape based on few geometric parameters was proposed for the train head.

Next, several CFD (computational fluid dynamics)-tools were tested and compared for simulating the entry of a first test train into the reference tunnel. It could be shown that there is a quite good agreement within 1% among the tools. The tests also aimed at testing the simulation procedure and compiling a general guideline for this kind of simulations. After all working members had proven their setup to lead to reliable results several existing high-speed trains like TGV, ICE3 and Velaro were investigated next to check the state of the art. It was found that the investigated trains perform in the same order of magnitude.

In the next step, a margin was added on top of the existing train results to allow also for future train concepts with larger cross sections like double-decker high-speed trains. A reference train geometry based on the same principles as the former test train was agreed and simulated next. The simulations were done again using different tools to obtain an additional cross check. The results showed again a quite good agreement and the maximum entry pressure gradient of the reference train was in the order it was aimed for.

To not only rely on simulations, the next step was to do moving model tests using one of the real trains and the reference train to validate the simulations. Both train models were catapulted into several tunnel portal configurations including the reference scenario. The measured pressure signals were then compared to the simulated ones and it was found that there were unexpected discrepancies. Unfortunately, these could not be resolved until the project end.

Nevertheless, the differences are taken into account in the proposal for a limit criterion. With the provided proposal train manufacturer can assess new trains by comparing them with the reference train and infrastructure operators can use the reference train to assess a tunnel and introduce appropriate counter-measures if needed. It should be noted, that for an infrastructure assessment the whole tunnel and the emission portal must be taken into account additionally. In this case the entry compression wave will be just the starting point.

All steps and results have been discussed in several workshops with experts from CEN and ERA.

WP5 Slip Stream Effects

Background

Knowledge of the magnitudes of velocities in the slipstream of a train is important for a number of reasons. For example high slipstream velocities can result in dangerous conditions for passengers waiting on platforms and for workers at the trackside, and can cause objects such as push chairs to move. These effects thus need to be taken into account in the development and authorisation of new trains. A consideration of these effects, as well as other aerodynamic issues, has led to the development of a series of standards on train aerodynamics, material from which has been incorporated into the Technical Specifications for Interoperability (TSI), giving limiting values for

slipstream velocities. These are being developed to allow trains to run across national boundaries in Europe. The TSI methodology for the assessment of slipstream velocities is based on a method for assessing the magnitude of the slipstreams of a train and requires that full scale measurements be made at specific points on a platform and at the trackside for 20 train passes within defined vehicle speed ranges, for low wind speed conditions only. The maximum one second moving average velocity for each train pass is then calculated. A value of the mean plus two standard deviations of the ensemble of one second values is then compared with limiting values specified by the TSI. The need for two measurement locations, one at trackside and one on a platform, makes this type of testing somewhat cumbersome, particularly accessing the required platform test site. A method based on one set of measurements at the trackside that is transferable to any country would be rather more convenient and cost-effective. For this reason, a work package of AeroTRAIN was devoted to investigating the testing procedure for slipstream measurements, with a view to reducing the number of measurement locations.

Objectives

The objectives of the investigation of WP5 were as follows.

- To collate existing slipstream data from earlier projects – specifically material from the RAPIDE project and material from UK tests carried out in the 1980s and 1990s.
- To undertake measurement campaigns on lines in Spain and Germany, to measure the slipstreams for a variety of high speed train and conventional train types at trackside and above platforms.
- To analyse the experimental data in order to
 - identify the magnitudes of slipstreams from different vehicles at different heights above the track for both trackside and platform situations;
 - determine a possible revised TSI methodology with a simplified test procedure, ideally at just one location;
 - develop a methodology to assess single vehicles within trains with respect to their relevance / impact on the slipstream effects of a particular train configuration.

Experimental results

The experiments in Spain and Germany were carried out for a range of different train types – high speed single unit trains, high speed double unit trains, conventional passenger units and locomotive / coach combinations. The data that was obtained was supplemented by other data from previous projects – specifically data from the RAPIDE project and earlier measurements made in the UK. Two basic types of calculation were carried out. The first involved a study of the ensemble averages of the slipstream velocities, measured both at trackside and above platforms. The differences between the flows around different train types were elucidated, and the effect of platforms on slipstream behaviour analysed. A brief analysis of the effects of cross winds on slipstream behaviour was also carried out. Through a detailed analysis of slipstream velocity components, the detailed nature of the flow around the nose and in the near wake of the train was investigated, again revealing differences in flow pattern between different trains. Significant similarity in the far wake flows was revealed. The second type of analysis concentrated on the analysis of maximum gusts, in order to make suggestions for modifications to the current TSI methodology. The very large dataset obtained for one particular sort of train (the S-103) enabled the variation of slipstream gusts with vehicle speed and wind speed to be determined. It was also possible to carry out a statistical analysis of the gusts that enabled the standard uncertainty of the TSI gust parameter to be determined. It was shown that for most trains the maximum gusts occurred in the train near wake, but for double unit trains the maximum gusts could occur around the gap between the units and for locomotive / coach combinations the maxima could occur around the nose of the locomotive or at the discontinuity between the train and the locomotive. It was further found that the measurements made at two measuring stations around 30m apart were uncorrelated, which implies that the use of multiple measurement stations could result in a reduction in the number of train passes required.

Perhaps the most significant result, which will allow a considerable simplification of the TSI methodology, was that if both trackside and platform measurements for a particular train were plotted against height above the rail, then, with very few exceptions, they fell onto one curve, which implies that a trackside measurement could replace the current required platform measurement.

The proposals

Based on the experimental results a revised TSI testing procedure has been outlined, with the following components.

- As in the current procedure, the methodology should be based on the determination of the 1second moving average of the velocity for a number of train passes, with the TSI characteristic velocity being the mean plus two standard deviations of the ensemble of runs.
- At least 20 valid train passes should be used in the formulation of the ensemble. The uncertainty analysis has shown that this results in a standard uncertainty of about $\pm 6\%$ ($\pm 12\%$ at 95% confidence) on the characteristic velocity values.
- For a valid train pass the wind speed for the 15 seconds before the train passes the measurement site should be less than 2m/s, and the train speed should be within 10% of the maximum operating speed.
- The measurements of air speed shall be carried out at two heights above at a trackside location – 0.2m and 1.4m above the rail. No platform measurements are required. The acceptable track geometry for such tests shall be as currently specified. Multiple measurement stations can be used at separation distances greater than 20m, which will result in a reduction of the number of train passes that are required.
- Fixed composition trains shall be tested in the configurations that are likely to exist in operational conditions i.e. as single or double units. When testing locomotives, the junction between the locomotive and the carriages is important, and all possible configurations of locos and carriages should be tested. A rake of carriages of 100m in length is required.
- In terms of the effect of small design changes, the large confidence limits on the characteristic velocity measurements imply that such will only be able to differentiate between vehicles for relatively large design changes. A fuller definition of what is meant by small and large design changes is still required.
- The limit values for characteristic velocity shall be the same as specified at present, with the current “platform” limits being applied to the measurements made at 1.4m above the top of the rail.

Perhaps the most important point to emerge from these investigations is a fuller understanding of the stochastic nature of the flow within train slipstreams, that results in large scatter within the ensemble of gust values, and the need to have a full appreciation of the uncertainty and confidence limits of any TSI characteristic velocities that are derived.

WP6 Quality Assurance & Regulatory Acceptance

The main purpose of WP6 has been to make sure that the project results are in a form that is suited to the need of its end-users - mainly, ERA and CEN. This purpose is related to the "regulatory acceptance" expression in the title of the WP. Research results are in fact often written in a "language" - that of the scientific community - aimed mainly at allowing the research to be reproduced by anyone wishing to do so. Moreover, researchers seldom focus directly on the direct implications that their work may have in terms of the regulatory framework; rather they stop at the strictly technical issues. Although essential for uptake in regulatory documents, documents written in "scientific language" are not practical for the people responsible for such documents to pick up the essential aspects in a reasonable time thus understanding whether it is a useful contribution or not. Therefore, in AeroTRAIN a significant amount of further work was done on the output. Usually this

additional work is done outside the project, most often less efficiently not being able to rely on the help of the researchers. In the TrioTRAIN projects, the idea was that if the projects produced results that could immediately be of interest for uptake into the regulatory framework, it would be more efficient to have the people producing the results take their work further by interacting with the end-users, understanding their needs, and going as far as possible in documenting the results in a format suited to them, including targeted and structured information on the accuracy of the proposed processes. At the same time, this would imply a useful revision of the scientific work performed with positive repercussions on the quality of the output.

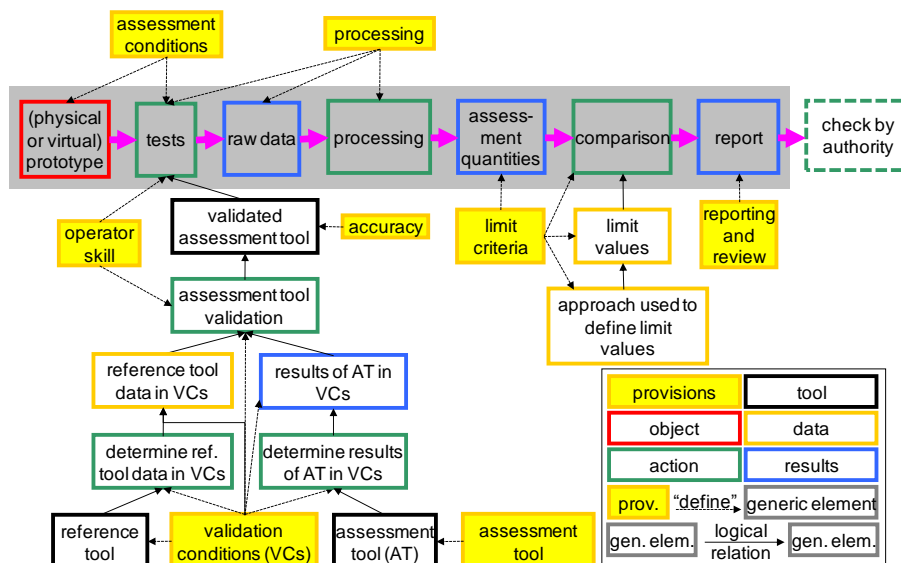
The strategy adopted in TrioTRAIN to ensure the effectiveness of the transfer of results to end-users rests on three conceptual pillars:

- structure: a structured representation of the current status of the regulatory framework related to the three projects and of the proposed status which could derive through implementation of the results;
- accuracy, that is careful quantitative considerations (where possible, uncertainty figures) of the tools used for the assessment, whether experimental or virtual;
- liaison and dissemination: the information and knowledge from the projects needed to be targeted to and shared with the end-users where possible as they were generated, to ensure due consideration of end-user advice and an early identification of their concerns.

These three points were reflected in the three "tasks" of Work Package 6, with a structure common across the three TrioTRAIN projects - that is why the WP is also known as "WPX".

In addition to liaising, analysing and reviewing, WPX also produced interesting results mainly in terms of frameworks and methods for use in future projects. Moreover, the task targeting accuracy aspects led to outputs in terms of quantification of indicators related to assessment accuracy, which is seldom found in the current state of the art for these highly complex assessments. All of these aspects are described in detail in the outputs of the WP, i.e. the deliverables associated to the three tasks.

In the early stages of the WP the current state of the art was examined in order to identify the underlying principles of the processes to place in service new or modified designs. These processes have been evolving significantly in recent years. The technical aspects of such processes ("Technical Sub-Process" TSP) are the ones dealt with in TrioTRAIN, as can be seen in the WP descriptions above.



The activities associated with such TSPs are summarised in the block diagram below.

This diagram identifies the logical elements that are common to the regulatory framework addressed in TrioTRAIN. With this classification, the regulatory framework itself was analysed provision by provision and compared with the integrations proposed by the project.

The same structure was used to harmonise the outputs of the AeroTRAIN "proposals", i.e. the results of the work that was considered to be mature enough to be able to arrive at actual potential texts for the regulatory framework. It was in fact realised through the liaison managed under Task 2 that this was the best way to make the output more easily understood to the end-user and that this did not imply that the project had the intention of writing regulatory documents, which is clearly not its role.

These structured proposals were thus subjected to a systematic analysis and review process, and not only to simple review. It was believed to be particularly important, given the potential use of the project's outputs, to have the outputs themselves carefully analysed. Four types of analysis were performed:

- a formal logical analysis (FLA), in which the proposals were systematically compared with the existing part of the regulatory framework to which they were addressed;
- a quality assurance and NSA/NoBo perspective analysis (QAA), in which editorial and regulatory acceptance aspects such as consensus or confidentiality issues were dealt with and through which a systematic check was made for issues that would make a third-party check difficult or impossible;
- an internal peer review (PR) by independent project Partners (i.e. not having actively participated in the technical work), to varying degrees according to the available time-frames, in which all project Partners had the chance of commenting particularly on the technical aspects;
- an uncertainty analysis, in which the quantitative aspects of assessment accuracy (i.e. numerical indicators of uncertainty) were addressed.

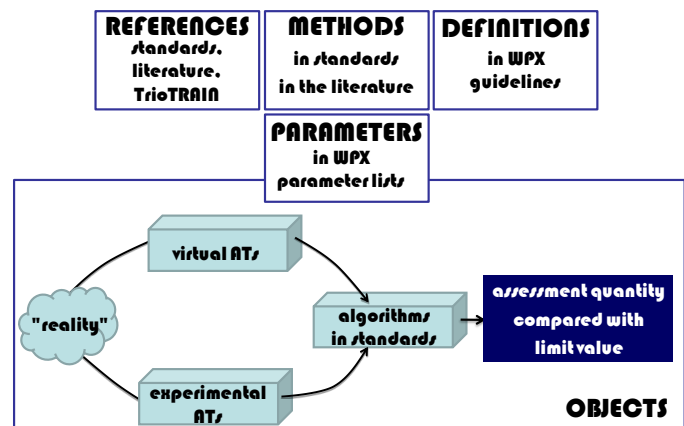
The latter analysis was performed within Task 6.1, described hereafter.

Among the provisions of the regulatory framework and the proposed AeroTRAIN provisions, the ones regarding the accuracy of the assessment tool were the focus of particular attention and a specific task (Task 1). The aim was to provide structured and concise information on these aspects, as they are key for many aspects and in particular for safety.

A key part of this demonstration is based on the analysis of the accuracy, or rather of its quantitative counterpart, uncertainty. The accuracy associated with the assessment of a specific physical quantity has been recognised to be the scientific aspect which most influences the confidence people have in the assessment results.

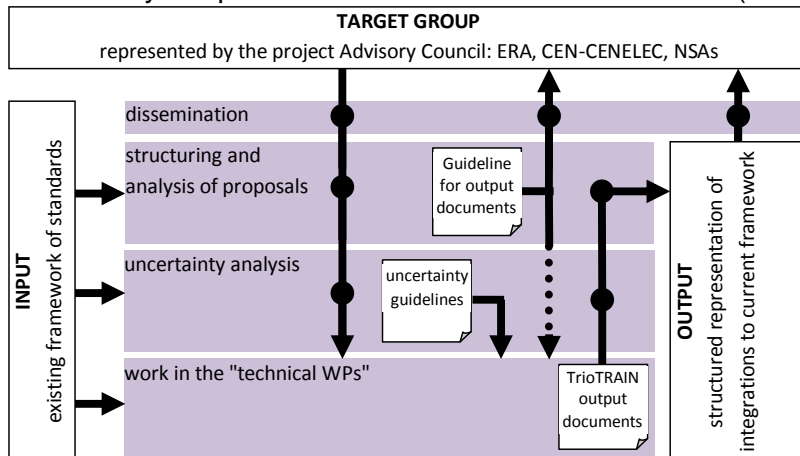
Given the large scope of the projects, the issues regarding uncertainty were managed through a "TrioTRAIN Uncertainty Framework". The block diagram illustrates the content of the framework. The objects of analysis shown in the diagram are essentially:

- today's assessment tools;
- the new assessment tools;
- the inherent structure of the algorithms prescribed by today's standards for each and every Technical Sub-Process.



The uncertainties thus quantified were compared and assessed so as to support the use of the new assessment tools whose accuracy has proven to be consistent with that required by the algorithm used and with that of today's assessment tools.

The "super-structure" described in the previous sections would be useless if it were not linked on one side to a foundation, which is the substantial amount of work performed in the "technical Work Packages" of AeroTRAIN, and on the other side to the projects' target group. The latter link is ensured by a specific liaison and dissemination task (Task 2). The relationships mentioned are



schematically represented in the block diagram below, along with the document workflow. With the work of the dissemination task, the target group was invited to be as close as possible to the project group. The main stakeholders were represented in an Advisory Council which met regularly with the project management to provide input and examine outputs. The Advisory Council meetings represented the official links with the stakeholders. Other formal and less formal

contacts were fostered, for example with CEN working groups. These contacts were ensured through the project Partners that were also members of the working groups. In this way, the information was targeted to and shared with the end-users as they were generated in TrioTRAIN, to ensure due consideration of their advice.

In conclusion, WPX led to the production of harmonised high-quality output, taking into consideration as far as possible end-user input, and created a framework for future research projects with potential implications on the regulatory framework.

Conclusion

The three years of the project AeroTRAIN has through measurement campaigns in full scale and in model scale, simulations, uncertainty analysis, authorisation perspective and interactions with stakeholders in ERA and CEN brought significant progress towards these aims.

Virtual assessment:

- Open air pressure pulses: Extensively compared numerical simulations with measurements – both largely achieved within the projects – using the tools of uncertainty analysis to quantify the main sources of influence and developing a methodology for using simulations as an alternative to measurements in all cases.
- Cross wind: Produced guidelines for current industrial standard methods to achieve repeatable high quality results and clarified the accuracy that can be achieved in relation to train shape and yaw angle. This was accomplished through a wind tunnel measurement campaign of a range of trains and extensive simulations. The work allowed a proposal to use numerical simulations as an alternative to wind tunnel tests in all cases following a proof of accuracy with a suitable benchmark.
- Micro-pressure waves: A vehicle assessment of the train entry gradient with associated limits is proposed based on numerical simulations (with moving model tests as an alternative).

Less costly test configurations:

- Slipstream: Extensive measurement campaigns have brought forward the knowledge about the stochastic nature of the phenomena and the associated uncertainties in measurements of the TSI criteria. Comparison of platform test and trackside test resulted in a proposal to manage the platform test with a corresponding one at the trackside. The resulting removal of the platform location has significant benefits as it reduces costs of an additional location (that is difficult to access and different in each country) and harmonises tests conditions to be the same across Europe.
- Cross wind: Characteristic wind curves were derived based on the new single reference set-up in EN (single track ballast and rail) for several trains, including the HS class 1 trains on which the current HS RST TSI is based. Investigations on modelling infrastructure situations with ground movement, embankment in a wind tunnel and influence of atmospheric conditions has given insight about these influences. Further reference to HS RST TSI flat ground and embankment wind tunnel test set-up's is not needed.

Closing open points in TSI:

- Ballast projection: An extensive measurement campaign have brought forward the knowledge further within the area. A proposed procedure for measurements has been developed, together with post treatment of the data and a framework for the overall approach to deal with a wide range of track conditions. This is a significant step towards a limit, however, application according to the proposed methodology of more trains and tracks is required to set an actual limit.
- Cross wind: Characteristic wind curves were derived based on the new single reference set-up in EN (single track ballast and rail) for several trains of different speeds and countries with high susceptibility to winds. Still there are limitations to the data available and if it is sufficiently representative of conditions in different countries. An approach for limit formulation has large impacts on development of trains and treatment of infrastructure, which needs further considerations than was feasible within the project.
- Micro pressure waves: Limitations of train entry pressure gradients has long been a topic in Japan and is with new tunnels becoming one in Europe. Although not yet identified as an open point in the TSI it was considered important to derive an approach for the vehicle assessment in the European railway community and this was achieved.
- Slipstream: A proposal has been made based on the findings within the project for the treatment of single vehicle assessment. There is a great need for clear requirements that can also harmonisation national rules, which currently in some cases can be very costly.

The following table present the main results of the project (in relation to be deliverables) to be integrated into standards:

Deliverable name	Standard	Main results to be integrated
<i>D1.2 (& output document O1.2)</i>	<i>EN 14067-4, TSI RST</i>	<i>Proposal for use of numerical simulations in all cases to quantify open air pressure pulse.</i>
<i>D2.4 (& output document O2.4)</i>	<i>EN and/or TSI for application of methodology to in the future derive a TSI limit</i>	<i>Measurement procedure, post-treatment and framework for limit formulation.</i>
<i>D3.3.1(1), D3.3.2(1) (& output document O3.3)</i>	<i>EN 14067-6, TSI RST</i>	<i>Proposal for use of numerical simulations in all cases in place of wind tunnel tests to assess the aerodynamic coefficients.</i>
<i>D4.2 (& output document O4.2)</i>	<i>EN 14067-5</i>	<i>Proposal for assessment and limits of train entry into tunnel pressure gradients.</i>
<i>D5.4 (& output document O5.4)</i>	<i>EN 14067-4, TSI RST</i>	<i>Proposal for to assess platform requirement using trackside test.</i>
<i>D6.1(1) – Uncertainty analysis</i>		<i>Uncertainty analysis to support uptake of deliverables.</i>
<i>D6.3(1) – Proposals</i>		<i>Compilation of proposals (including output documents) giving the WP 6 review process results.</i>

d. The potential impact of the project and main dissemination activities and exploitation of results

Potential impact of the project

Development and implementation of Technical Specifications for Interoperability and EN norms

Within AeroTRAIN the goal was to close “open points” in the TSI’s as well as, where possible, develop the certification procedure to be efficient regarding time and cost, which is necessary in order for the TSI’s to be successful. To ensure the implementation into the TSI’s a specific WP (WP 6) was dedicated to ensure that the proposals for new or revised standards were of a high quality, directly applicable and convincing of the safety, effectiveness, efficiency and feasibility of the

proposed certification process. To this end there was also a structured communication with the various stakeholders.

The AeroTRAIN partners ensured regular and intensive interaction with the standards and regulatory bodies. Within each Work Package, a participant was designated to be the representative of the WP towards CEN Working Group 6, Aerodynamics. This individual was typically a member of the CEN Working Group, also taking part in the AeroTRAIN project. Details of the work being undertaken were presented to meetings of the CEN Working Group by the designated representative. This gave the project an excellent understanding of the context and requirements of standardisation. It also gave the consortium direct access to, and intimate knowledge of, the CEN working Group. This has played an important role in facilitating the uptake of the results. The CEN WG6 Convenor was, moreover, a key participant in WP6 of AeroTRAIN, Quality Assurance and Regulatory Acceptance.

The project partners have had regular contact with the standards and regulation bodies through the twice-yearly meetings of the TrioTRAIN Advisory Council. This saw the Technical Leader, Co-ordinator and some TMT members meet face-to-face with the Chairman of TC256 of CEN and the Head of Unit for Cross Acceptance at the European Railway Agency, ERA. Regular contact with members of the NSA network was also made possible by these Advisory Council Meetings.

Between these regular meetings, ad-hoc subject-specific meetings took place between the project and CEN, ERA and NSAs. One of these was on the topic of crosswind and ballast projection, with a follow-up meeting also taking place on crosswind. This allowed the work on these topics to progress with the benefit of a greater input from the standards and regulation bodies, as well as NSAs.

Two ERA workshops took place during the final year of the project, during which the TMT presented AeroTRAIN work with a bearing on TSI open points to ERA Project Officers and Working Party members. This allowed the current status of work to be presented, ensuring that ERA remained informed of the status of the work as well as of the likely outcomes. It also allowed the project to take feedback into account for the continuation of the work.

Following the end of the project, there will be a meeting with CEN WG6, to facilitate the integration of the relevant results into Part 4 of the standard. A September meeting with ERA to consider the impact on the relevant TSI open points will also take place. At this meeting, the extent to which the project results will allow the closure of these open points will be discussed.

UNIFE will remain in contact with ERA to ensure that results can be integrated where possible. Several of the project partners are ERA experts within the field of aerodynamics. It should be pointed out that positive feedback on the project's interaction efforts was received from ERA.

Reduction of the migration time for the implementation of new interoperable solutions

One of the main objectives of AeroTRAIN was to reduce the time and cost for certification of new interoperable rail vehicles. This was to be achieved by:

- harmonising the national requirements through focusing on the TSI's, making it possible to transfer certification data from one country to another, obviating repetition in the certification process;
- replacing existing test configurations with new procedures that are more easily accessible and less costly. For crosswind validation having only one configuration which is generally accepted, and for slip stream airflows only having one configuration for all countries instead of two;
- introducing virtual certification for open air pressure pulses and if possible for crosswind aerodynamic loads also. Since the simulation models are already commonly used in the industry, the possibility to use them for certification as well as design validation will save cost and time for the required tests. In addition it gives the opportunity to have better controlled environmental testing conditions in the future by introducing new scenarios to cover, for example, wind conditions in full scale tests or more realistic conditions for cross wind than

can be achieved in a wind tunnel. This can increase safety levels, and in the case of cross wind safety, reduce the uncertainty that can lead to unnecessary and costly infrastructure measures.

By proposing new certification test scenarios/configurations for TSI, AeroTRAIN has helped to advance interoperability as well as promising to allow future certification processes for aerodynamic effects to be less costly and time-consuming. By producing work which brings the definition of TSI limit criteria for areas such as ballast projection closer to achievement, it has also furthered the goal of interoperability.

Impact on competitiveness

AeroTRAIN has contributed to establishing technical standards and compatibility between the various European systems, by proposing input for TSI and EN norms. These proposals go in the direction of the simplification of certification procedures. This contributes to a reduction in the time and cost of certification and therefore of the putting into service of a rail vehicle. These anticipated changes in the process can save hundreds of millions of Euros for the European rolling stock manufacturing industry, making it more competitive abroad and, assuming that the savings are passed to Railway Undertakings and then to passengers in turn, will make the rail transport mode in Europe more competitive.

Global strategic impact

By strengthening interoperability within the EU, AeroTRAIN is helping to further consolidate the rail industry and to promote European standards and practice outside Europe. This is very important for the competitiveness of the European industry. Moreover, by leading to cost-cutting, efficiency gains and improvements in quality, substantial benefits will be generated for both users and suppliers in general. Within Europe this means benefits for Railway Undertakings, Infrastructure Managers and the manufacturing industry.

By advancing interoperability, as well as by showing how cost and time of putting vehicles into service can be reduced, the results of this project will contribute to the required increase in competitiveness of the rail transport mode within Europe. If it has been noticed that passenger numbers were declining, it is necessary to increase the attractiveness of the rail transport mode within Europe. By passing savings from simplified certification test configurations all the way through Railway Undertakings to passengers, the results of this project are able to contribute to this.

The following table, contained within the Description of Work, shows the potential cost saving to industry if the AeroTRAIN project is successful. These figures still require time following the implementation of the project results in order to be validated by experience and data on future market performance.

Equipment Category	Number of Orders Placed in Period	Average orders per annum	Initial Approval Cost (M€)	Cost for additional Countries if required (M€)
Diesel Locos	42	6	30	12
Diesel Multiple Units	94	13	67	27
Electric Locos	68	10	49	19
Electric Multiple Units	115	16	82	33
High Speed Trains	19	3	14	5
Light DMUs	32	5	23	9
Loco Hauled Coaches	92	13	66	26
Freight Wagons	111	16	3	32
	573	82	333	164
Grand Total of Test & Approval Cost per annum for Manufacturers & Operators =				497
Potential Annual Savings by AeroTRAIN (5%) =				25

Figure 4: Analysis of Orders for Railway Orders within the EU27 from 1991 to 1997.

In line with the project results, and as stated in ERRAC's Joint Strategy¹, a virtual certification process using computer models of the finished products could lower the "time-to-market" of new or slightly modified rolling stock significantly. Implementation of the interoperability standards will also reduce the range of goods and services required and generate economies of scale. Both of these measures will lead to reduce the cost and the time of development and manufacture. This last point shows also how the project contributes to the overall competitiveness of the European industries. This is especially important at a time of stiff competition in the global market for rolling stock and sub-system components.

By producing results that work towards the implementation of efficient interoperability standards and introduction of certifications based on simulation rather than on physical track tests (or an optimised mix of simulation and track tests or a simplification of the current track tests) AeroTRAIN should bring the following benefits:

- increased competitiveness of the railway mode;
- increased interoperability;
- reduction in the cost of train ownership;
- improved availability and reliability of rolling stock.

Strategic impact of AeroTRAIN on the rolling stock manufacturing industry

The results of AeroTRAIN will strongly impact the European rolling stock manufacturing industry. The main benefits expected are:

- facilitation of the cross-acceptance of railway rolling stock by decreasing the number of items submitted to cross-acceptance;

¹ ERRAC, "A Joint Strategy for European Rail Research 2020 - Towards a Single European Railway System", September 2001.

- reduction of the duration and the costs of certification procedures thanks less costly test configurations and part transfer of expensive and time-consuming physical track tests to numerical simulation, this has already been described above;
- reduction of the time-to-market for new products, this has also been described in the preceding sections of this report;
- harmonisation of certification procedures and mutual recognition of certificates across Europe;
- optimisation of R&D resources and identification of priorities for future innovation in the field of certification;
- development of the state-of-the-art in railway aerodynamics. This is an important element of the project, as we can say that several Work Packages have advanced the knowledge in railway aerodynamics. Much more is known about many of the key topics than was the case before the project. Two examples of this are the areas of ballast projection and crosswinds. AeroTRAIN has also shown the way to gaining even greater knowledge of railway aerodynamics, for example in showing how TSI limit criteria for some phenomena will be derived.

Strategic impact of AeroTRAIN on railway undertakings

In the other hand, the project results bring also a lot of benefits to the railway undertakings:

- reductions in the cost of vehicle procurement and ownership;
- improved reliability of rolling stock thanks to safety and interoperability standards improvement;
- reduction in time and costs for further certification of replacement materials: not all the testing will have to be done again; instead only some parameters might be changed in the simulation.

The lack of competitiveness in rail transport that one can observe in Europe is partly due to increased freight delivery times caused by the necessity to change the locomotive and drivers each time that the border is crossed. Enhancing interoperability, AeroTRAIN results' integration into standards will allow railway undertakings to be more competitive in both freight and passenger transport: they could offer faster, wider and cheaper journeys across the enlarged Europe.

Furthermore, by stimulating a collaborative approach among the European system integrators, the AeroTRAIN project has the potential to generate competitive gains on a worldwide basis. This contributes to make European railway products attractive to emerging or established markets (e.g. Asia, North America) and developing economies in serious need of affordable rolling stock (Asia, Africa, Latin America).

Community societal needs

The results obtained during the project will facilitate the certification of railway rolling stock against EN standards and TSI. The introduction and increased used of simulation-based certification tests will contribute to improve the attractiveness of rail vehicles, and therefore of rail-based transport as a whole. This will serve community economic needs, as the high numbers of people employed by the rail sector can continue or even grow. Moreover, cost reductions and efficiencies are essential, as there is more and more pressure on public finances. Rail services are very often part-financed by the public purse, and must be provided at not only a cost which passengers can afford, but at one which provides value for money for the taxpayer. This will participate to promote rail transport both for passengers and freight purposes as an alternative to other modes thus fostering environmental and economic sustainability of transport. It is already known that rail is the most

environmentally-friendly form of public transport, and by helping to enhance the attractiveness of rail, AeroTRAIN is bringing a massive potential environmental benefit. This is very important as modal shift away from roads and onto rail is essential if the European Union's transport and climate goals are to be met.

Health and quality of life: Higher safety and availability at lower cost for the users

The main expected benefits for European citizens are:

- reliable and safe services through increased availability and reduced time-to-market of high-performance rolling stock. In particular, changes will come about in the expectations of passengers regarding the quality of their journey due to various factors as forecast by ERRAC in SRR2 II;
- better quality of scheduled services by avoiding operational disruption caused by physical track tests;
- enhanced utilisation of rail-based traffic capacity on the basis of free choice of transport mode and thanks to the quality/ price ratio increase.

Moreover, the rail transport mode is now becoming the natural 'partner' for international flight connections: high-speed lines are gradually replacing many short airline journeys (under 500 km). Reinforcing the competitiveness of rail transport could and should in this case bring a considerable contribution to the reduction of overall noise levels for neighbouring communities by replacing the excessive use of flight, in particular night flights².

Security and safety

Safety and security are major societal needs. In our developed countries, as the other major needs are more or less solved, safety is even being considered as the number one issue. As far as mass transit and public transport networks are concerned, the safety and security of passengers and staff is a key factor of the "competitive and sustainable growth" for the various operating companies.

The propositions made by AeroTRAIN for improvement in European certification standards and the submission of resolutions to close uncertainties in technical specification linked to interoperability and safety have the potential to lead to a significant improvement in safety and security. By contributing to the closing of open points in TSIs, AeroTRAIN is certainly contributing to the improvement in safety and security on the European rail network. The advances in knowledge and state-of-the-art in railway aerodynamics achieved under this project will certainly help to make the rail transport mode even safer than it currently is.

In terms of general safety, it is recognised that rail is safer than road and air transportation. AeroTRAIN can contribute to helping reduce the number of transport accidents, by playing a part in encouraging modal shift towards rail.

Environmental issues

The AeroTRAIN results' integration into European certification standards will ensure at least a neutral impact on climate change. Indeed, the introduction of a new certification process based on computer simulation will reduce the need for physical on-track tests:

- numerical models will allow to take into account a large range of conditions (climatic, geometric, etc.), thus reducing the need of repetitive on-track test;
- by improving the TSI's and cross-acceptance, the number of on-track tests to be performed in each country will be decreased.

Perhaps this has the additional benefit of helping to reduce the noise emissions to lineside neighbours, as there could well be fewer numbers of trains running for the purposes of certification.

² ERRAC, "A Joint Strategy for European Rail Research 2020 - Towards a Single European Railway System", September 2001.

At the EU level, the shift for both passengers and freight transport from road to railways will have an important impact on environment through:

- reduction of green houses gases: NO_x, SO_x, and particles emissions from trucks and cars. Road transport was responsible of 40 % of GHG emissions in Europe at the time of submission of the TrioTRAIN project proposal, without speaking about the contribution of air transportation;
- reduction of energy consumption: freight trains consume less energy than the equivalent number of trucks for a same mass transported. The same statement can be made for passenger trains and cars.

Furthermore, in the framework of short and middle range distances journeys, the competitiveness of transport by train compared to air transportation must be highlighted, knowing that commercial air transportation produced, at the time of the submission of the TrioTRAIN project proposal, 2.5 % of the global CO₂ emissions due to human activities.

AeroTRAIN will play its part in facilitating modal shift of passengers and freight to rail, which is a clear contribution to improving the environment in Europe. Through better rolling stock, which comes more quickly to the market, it will also play a role in ensuring that the rail transport mode is equipped to take the increasing number of passengers coming to rail from road and air transport for other reasons.

Main dissemination activities and exploitation of results

In order to maximise the yield and to provide information between societies, the partners of project used several effective communication systems: participation to congresses, technical fairs, publications in scientific journals, design and operation of a public area in the web site.

Efforts were addressed to specific targets for the dissemination of the results: authorities and public institutions, universities, scientific societies, professional and industrial associations.

A public website was created and maintained, and information relevant to the project was made available through this. The website was updated as the project progressed. A flyer was produced and distributed at the numerous events at which AeroTRAIN was presented. Articles on the project were published in mainstream railway sector publications.

Examples of the fora in which AeroTRAIN was presented include:

- UNIFE General Assembly 2009, 2010, 2011 and 2012;
- InnoTrans 2010;
- World Congress on Rail Research 2011;
- Transport Research Arena 2012 (at which the project was presented on the European Commission stand, at the request of the European Commission).

AeroTRAIN will also be presented at InnoTrans 2012.

Please see below a list of examples of the interaction that has taken place between the project and the regulatory and standards bodies:

- Meeting with NSAs on crosswind and ballast projection, organised within the framework of the Advisory Council (June 2011). This allowed the project to present its work on crosswinds and ballast projection to National Safety Authorities and to ERA, as well as to receive feedback on this;
- Task X.3 (6.3) meeting for presentation of status to X.3 partners and to Advisory Council delegates (representatives of CEN, ERA and NSAs) (September 2011). This allowed the work taking place across the various Work Packages to be presented to and discussed with representatives of CEN, ERA and National Safety Authorities;

- Advisory Council meeting (September 2011). In this meeting, the AeroTRAIN Technical Leader presented technical results and work status to representatives of CEN, ERA and some National Safety Authorities;
- Follow-up meeting on crosswind between the project and ERA and NSAs (October 2011). This meeting was to follow up the June meeting, mentioned above, and allowed the progress made since the June meeting to be presented to representatives of CEN and ERA;
- CEN TC256/WG6 regular meetings. Project progress was presented to CEN in September 2011. Each Work Package of the project had a member of the CEN Working Group assigned to present the WP to the WG. This took place at each opportunity throughout the project life, including during the September 2011 CEN WG meeting;
- Task X.3 meeting for presentation of status to X.3 Partners and to Advisory Council delegates (CEN, ERA and NSAs) (November 2011). This was similar to the September 2011 X.3 meeting referred to above. The status of the technical work and possible proposals was presented to the standardisation and regulation bodies' representatives;
- ERA Aerodynamics Workshop, in which the project status and interim outputs were presented to the Aerodynamics Working Party of ERA (November 2011). Each Work Package was presented to the ERA Project Officers and assembled ERA Aerodynamic experts. Technical results were presented, likely proposals were also presented. Timetables for inclusion of the proposals into TSI were discussed and delivery schedules synchronised. For example, it was agreed that in order to incorporate any of the work into the current TSI revision, ERA needed to receive and digest the information by October 2012;
- Meeting for economic assessment issues between TrioTRAIN Technical Leaders and the Heads of the Cross-Acceptance and Economic Evaluation Units of ERA, in which a plan was agreed on how to provide as much information as possible on the impacts of TrioTRAIN (December 2011) This was an 'initial attempt' at examining the economic 'effects' of incorporating project proposals into TSI. For example, which part of the system would take the greatest part of the financial burden of a specific measure – would it be rolling stock or infrastructure?
- Advisory Council meeting (January 2012). In this meeting, the AeroTRAIN Technical Leader presented technical results and work status to representatives of CEN, ERA and some National Safety Authorities;
- Workshop at ERA, during which the project status and interim outputs were presented to the ERA Aerodynamics Working Subgroup (February 2012). This provided a follow-up to the November aerodynamics workshop. The project gave ERA a more detailed picture of what it should expect as output and when this would be delivered. This allowed ERA to plan for the receipt and integration of the project TSI proposals;
- Advisory Council Review and Lessons Learned meeting with participation from ERA (Advisory Council Chairman), at which progress to date was reviewed and possible future improvements considered. This was designed to ensure that the working methods of the structured interaction between AeroTRAIN and the standards and regulation bodies was even better suited to the achievement of objectives;
- AeroTRAIN final meeting at which the results of each of the Work Packages were presented to, among others, a representative of ERA Economic Evaluation Unit (May 2012). At this meeting, the ERA representative learned of the work that had been carried out and the proposals for standards and regulation to be made by each Work Package.

It should also be stated that during the February ERA workshop, a further workshop in September 2012 was agreed. This was to allow ERA aerodynamic experts to consider the final project proposals for integration into the current TSI revision and therefore to assist in the closing of one or more aerodynamic open points. AeroTRAIN has already delivered many scientific and technical results. At this meeting in September, more will be understood about how these will be integrated into European regulation.

e. Project website address and coordinator details

More information is available on the project's website: www.triotrain.eu

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