Development of Wind Alarm Systems for Road and Rail Vehicles: Presentation of the WEATHER project

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ABSTRACT

The development of a new concept of wind alarm systems for road and rail transportation is presented. The alarm is funded on a risk assessment approach, taking into account wind modelling and prediction, aerodynamic forces, vehicle dynamics.

1. INTRODUCTION

The effects of high winds on road and rail vehicles have become of increasing concern to transportation system operators. Cars, high-sided lorries, as well as trains, can be at risk of a wind-induced accident on exposed sites such as embankment, or long span bridges. For example in the "Burns Night storm" that affected the UK on 25th January 1990, there were 390 accidents to high sided vehicles that resulted in injury or death and a much greater number that resulted in insurance claims [1].

Wind alarm procedures, based on a scientific probabilistic approach, are currently in use in the railway transportation, for instance for the TGV Mediterranee in France [2]. In road transportation, while a number of bridges have adopted vehicle restriction measures, it appears that there is a degree of arbitrariness concerning those ruling.

In the 6th Framework Program (FP6) for the European Research, a CRAFT project has been granted by the European Commission whose aim is to develop an innovative "Wind Early Alarm system for Terrestrial transportation, Handling the Evaluation of Risks" (WEATHER project).

The objective is to develop a wind alarm system according to the following principles:

- The user of the wind alarm system defines vehicle classes, time delay for alarm (prediction horizon), and the accepted risk for a vehicle passing through the exposed zone (bridge, line section...),
- The "risk assessment software", taking into account vehicle characteristics and topographic features, determines the direction-dependent wind threshold values associated to this risk, for each class of vehicles.
- Continuous meteorological measurements are made in one or more points of the exposed zone (wind, pressure, temperature, ...)
- The "alarm program" extrapolates wind at the prediction horizon and compares the predicted wind speed to the threshold value.
- An alarm is triggered off each time the risk is over passed, with an identification of the concerned vehicle class.

The WEATHER project started in October 2004 and will last two years. It involves six SMEs which have a commercial interest in the product marketing: Meteodyn, Atmos, and EMI (France), Nubila (Italy), Geonica (Spain), Campbell Scientific (UK). Researches are conducted by three RTD performers: Universities of Birmingham and Nottingham (UK), Politecnico di Milano (Italy). Two end-users partners Alstom-Transport (France) for railway aspects and Leciñena, the main trailers manufacturer in Spain participate to the project.

The project is divided in four work packages according to the following items:

- Wind modelling: The aim is to develop models and methods for a precise description of the wind characteristics along a path, including short-term forecasting.
- Aerodynamic forces: To evaluate the aerodynamic efforts, a data base has been collected to characterize each class of vehicle. Also, methods are developed with a comparison work between wind tunnel measurements, CFD calculations and field tests measurement.
- Risk assessment: On the basis of Monte-Carlo simulation, the risk of wind accident is evaluated, including the effect of other pertinent meteorological parameters.
- Wind Alarm System Prototype: The system needs to meet the requirements of end-users, both for data logging and communication procedures.

2. WIND MODELLING

The wind modelling includes the computation of topographical effects on the wind flow, the time-prediction model, and the space-time simulation of the wind turbulence, needed for the risk assessment phase.

2.1 Topographical effects modelling

Meteodyn has developed Meteodyn NS, an automatic CFD software for the prediction of wind in complex terrain [3]. It solves the full 3D Reynolds-averaged Navier-Stokes equations. Unlike linearized models, no small perturbation hypothesis is made, so that any kind of orography can be considered. The turbulent kinetic energy is computed via a transport equation. The implementation of a drag coefficient term in the momentum equations makes possible to simulate cases of forests, high vegetations, and urban canopy.

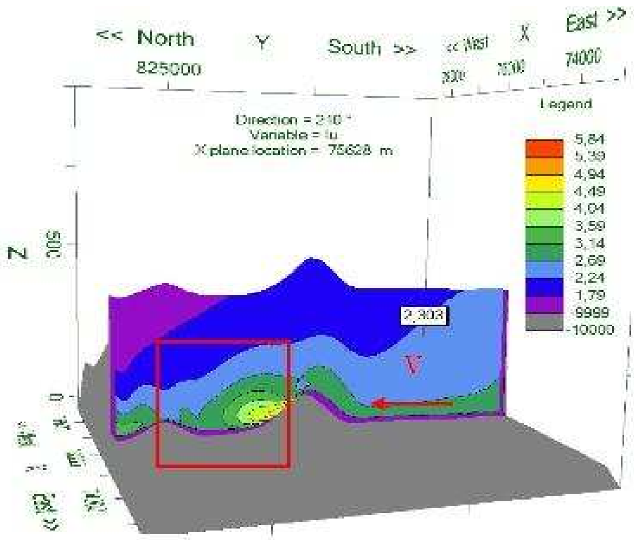

Figure 1: Metodyn_NS computation of Askervein Hill flow: Turbulent kinetic Energy

2.2 Time prediction

Ideally, the wind alarm must be activated before the dangerous situation occurs. Depending on the scenarios, the delay can be from 10 minutes to a few hours. In the framework of the project, models are elaborated in order to predict the wind evolution at horizons lying between 10 minutes and 2 hours. They are based either on multi-variate regressive models, or on a neural network approach with predictive variables being pressure, wind speed and direction, and temperature. Simultaneous data at several sites can be considered by the model.

Models are being calibrated according to data collected in nine European sites, representative of different climates (semi-oceanic, oceanic, Mediterranean, continental or mountain). Atmos, EMI, Nubila, Geonica and Campbell Scientific have equipped these sites with wind, pressure, and temperature sensors. Data is acquired with a 1 minute or 10 minutes sampling rate. In those sites, continuous time series of wind (speed and direction), pressure and air temperature will be collected during more than one year.

The knowledge of the prediction errors is also a crucial data that is integrated in the risk assessment analysis

2.3 Generation of spatio-temporal wind series

The algorithm of Jin, Lutes and Sarkani [4] has been implemented to generate spatially correlated wind time series along a track or a road section. The generated wind series respects theoretical spectral and interspectral density functions. These functions are determined according to the terrain characteristics, using the classical theory of the atmospheric boundary layer [5]. Those simulations will be integrated in the stochastic simulation program. Future developments will be performed to allow variation of mean wind speed and turbulence along a section.

3. AERODYNAMIC COEFFICIENTS

3.1 Objectives of the researches

Once wind characteristics are known at each point all over the section, we have to make the link with the aerodynamic forces acting on the vehicle. These forces vary as the square of the wind speed, according to aerodynamic coefficients which depend on the angle between the vehicle direction and the apparent wind vector.

For road vehicle a survey of available data is carried out. Data were collected and criticized in order to acquire an exhaustive set of aerodynamic coefficients for distinguished vehicle classes.

A particular research work is underway to determine the most efficient method to get these aerodynamic coefficients in the future, in order to extend the data base. Wind-tunnel measurements and numerical results via computational fluid dynamics on a typical van, and an articulated lorry are being compared to field measurements. The objective consists in validating CFD calculations as a computing tool for the estimation of aerodynamics coefficients and to provide a fuller range of aerodynamics coefficient values than those obtained in wind tunnel.

3.2 Wind tunnel tests

The Mechanical Engineering Department of Politecnico di Milano is performing wind tunnels tests considering two types of vehicles: a van and an articulated lorry in three different configurations: flat ground, embankment, bridge. The model reproduces at 1/10 scale the real vehicles tested in Silsoe (UK).

Fig.2 : Articulated lorry 1/10 model

Tests are conducted in the new very large wind-tunnel of Politecnico di Milano. A particular attention is paid to the turbulence characteristics. The aerodynamic coefficients are measured with a 6-component dynamometric balance located under the vehicle.

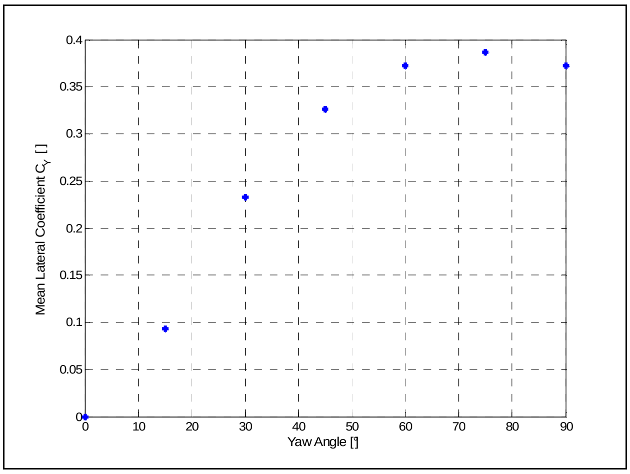

Fig. 3 : Aerodynamic coefficient of the lateral force

As an example, figure 3 shows the measured aerodynamic coefficient C_{Fy} of the lateral force F_y acting on vehicle, as a function of the yaw angle □. Wind-tunnel tests also allowed to identify vehicle's aerodynamic admittance function (Turbulence filtering effect by the vehicle).

3.3 Computational Fluid Dynamics

The School of Civil Engineering (University of Nottingham) is carrying out computations of the aerodynamic forces on the Silsoe van. A fine meshing reproduces accurately the real van (fig.4) A great number of simulations will be conducted, for flat terrain and embankment configurations, for a static vehicle and also with a moving vehicle. The meshed domain is composed of a cylinder domain which contains the van and that can rotate in the fixed environment. This constitutes a virtual wind tunnel, with the added bonus that the bottom wall can also be set in motion to represent the motion of the road relative to the truck.

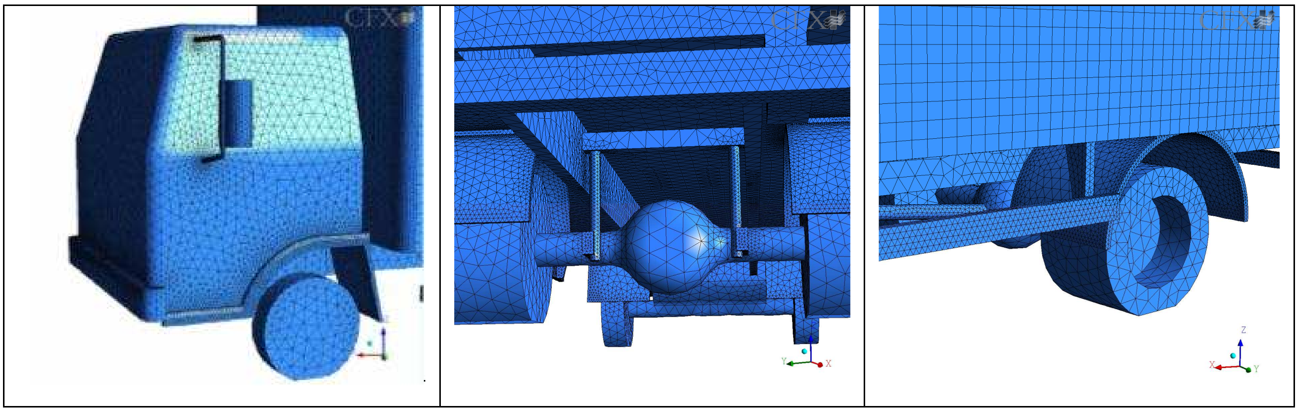

Fig. 4 : Details of the surface mesh for CFD computations

Computations are made with the code CFX. Detached Eddy Simulations and Unstationnary Reynolds Average Methods are used in order to reproduce unsteady fields and will be compared.

3.4 Field tests

The University of Birmingham is performing full scale experiments in Silsoe (UK) with both the static and a moving van ("The Silsoe van"). The vehicle box is 6.1m long, 2.5m wide and 2.5m tall positioned on a chassis which raises it approximately 1m higher.

The vehicle body has been instrumented with 48 surface mounted pressure tapping points located in a grid pattern across the sides and roof of the load space (fig.5). The on-line calibration is achieved through the use of an ultrasonic anemometer and directional pitot-static pressure probe mounted above the cab of the vehicle (fig. 6).

Figure 5: Instrumented moving van

Figure 6:Front view. Front tapping points, anemometer

The dynamic tests undertaken were carried out on the A6 open road outside Barton-le-Clay, Bedfordshire in the UK. The road at this location consists of a largely North-South stretch of dual-carriageway bounded at each end by a large roundabout. Complete set tests for a vehicle speed of 90 km/h, have been collected for both cross-winds and still conditions. These tests show a good repeatability of measures. The estimations of pressure distribution and aerodynamic forces are underway.

The static tests have been conducted on a well documented full scale test site with typical rural terrain at Silsoe where the turbulent wind characteristics are well known. Four load cell platforms have been used to mount the vehicle on a concrete platform at the site with a second reference anemometer for replication of the wind-tunnel measurements. Measurements are getting underway and will be completed with measurements on the “articulated lorry”.

4. RISK EVALUATION

The task consists in developing a stochastic simulation method to compute the risk of accident. This simulation will integrate temporal and spatial prediction of wind speed and direction, a computation of aerodynamic forces as well as a characterization of the dynamic behaviour of the vehicle. Other meteorological parameters (surface road conditions, precipitations, snow…) which can have a negative influence for the vehicle safety could be integrated.

4.1 The vehicle response: dynamical effects

A medium complexity model is developed in order to characterize the dynamic response of a road vehicle to an unsteady wind input. It is the result of a compromise between realism and the identification of a limited numbers of parameters. It makes a balance of the efforts acting on vehicle:

- *Wind efforts*: They are deduced from the simulated wind time series (see 1), taking into account relative wind incidence and speed, aerodynamic coefficients and the vehicle location.
- *Tire/road interaction efforts:* The Dugoff model is implemented. It is an empirical model that includes a coupling between the longitudinal and lateral efforts and allows to respect friction ellipse. It offers the advantage to require the identification of a few parameters.
- *Suspensions efforts:* Different models are foreseen. For heavy vehicles, a model based on Ackermann’s model [6] is a first approach. The suspensions and the stabilizers bars are modelled with damping and stiffness elements which limit the roll movement. A second approach distinguishes the stabiliser bars and the vertical suspensions actions. This model takes in account, at the same time, the anti-roll moment and a two-degree of freedom vertical oscillators for each wheel. Finally, for light vehicles, the suspension action is less relevant because the loss of lateral control is greatest risk of accident In this case, the suspension elements could be left out.

The driver interaction will be integrated in the model.

4.2 The stochastic analysis

The purpose of the stochastic simulation is to establish "threshold wind speed/direction curves" at the anemometer site. These curves represent the mean wind speed vs wind direction for which a given risk is obtained on the considered section.

For a given mean wind speed and direction at the anemometer, the probability of accident is computed using a Monte-Carlo procedure: A great number of simulated wind time series is generated all over the zone. For each simulated sequence, the aero-dynamical efforts and the vehicle dynamic behaviour are computed. The risk is given by the fraction of times that the undesired event (overturning or deviation from trajectory) occurs.

4.3 Other meteorological risks

Nubila develops an X-band Pluvi-Disdrometer (PLUDIX). This system is dedicated to precipitation measurement (instantaneous or in a given time interval) and allows to identify climatological events such as rain, snow, hail, drizzle...

Atmos studies new techniques to estimate road surface state. The instrument, based on reflectivity and emissivity properties of the surface, evaluates the surface state by comparing the radiative fluxes emitted by the sky and by the soil.

All these meteorological related parameters will be integrated in the stochastic simulation taking into account its influence on the adherence or on the variation in visibility for the driver.

5. WIND ALARM SYSTEM PROTOTYPE

The Wind Alarm System Prototype will be ready at the beginning of 2006. Discussions with "Autostrada dei Fiori" are in progress to install it on an exposed site of the Ventimiglia-Savona motorway in Italy.

The prototype will include meteorological sensors (mainly wind and pressure), a data logger implemented with the wind alarm program, a "Risk Assessment Software" which computes the limiting wind curves implemented in the wind alarm program, and a transmission and information management procedure, based on a web platform with almost real time data transmission (fig.7).

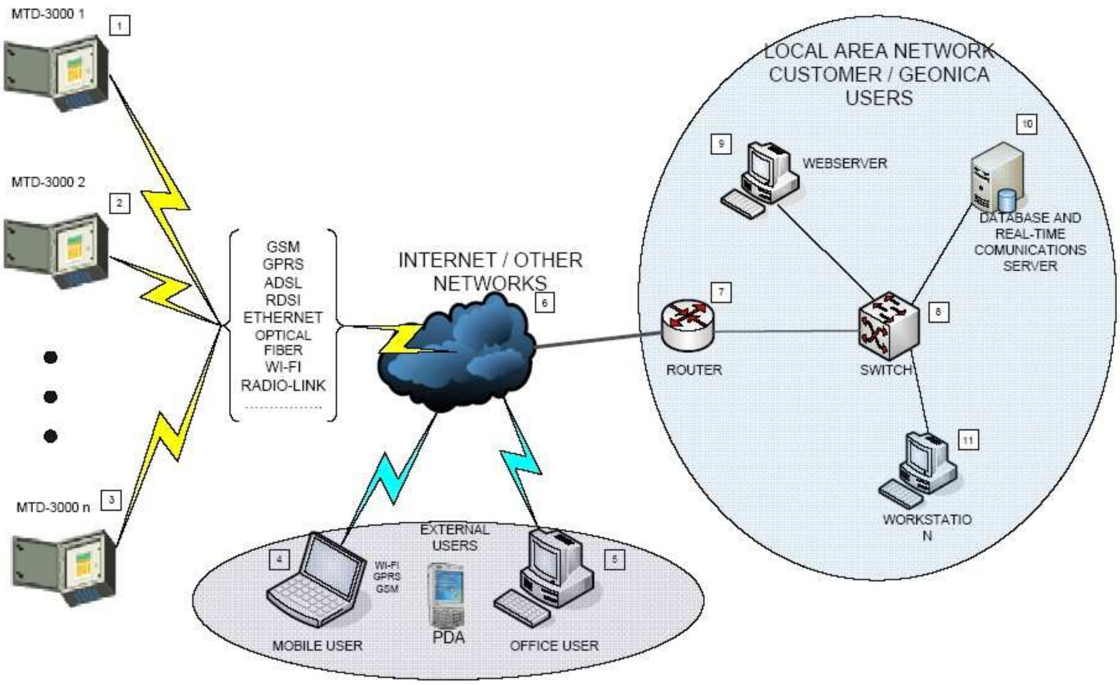

Figure 7: Transmission and information management

6. CONCLUSION

The development of a new approach for wind protection of terrestrial transports has been presented. This development involves French, Italian, Spanish, and British SMEs, collaborating with European Universities, leaders in their field, and end-users.

The originality of this approach is to propose, a scientifically founded alarm, depending on vehicle class, a given accepted risk level, and the topographic effects on the wind flow. In a delay of two years, we can expect to propose an operational product.

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