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WIND EFFECTS ON *POPULUS* SP.

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Abstract
The aim of this paper is to present the results of an experimental study performed concerning the effects of wind on trees. In a first step a type of tree has been selected (*Populus* sp.). Then from the silhouette of a number of trees a "standard" silhouette has been defined. The experimental study has been focussed on the simulation of the aerodynamic behaviour of the standard tree as a body with porosity.

The effect of the porosity on the aerodynamic drag has been investigated in the wind tunnel of the I.D.R. (Universidad Politécnica de Madrid), testing reduced scale models. The methodology developed here, based on considering the porosity as the fundamental parameter, could be extended to other species and models.

Introduction
One of the first references known to the authors concerning wind effects on trees can be found in Meroney (1968). This author mentions to Mezger as the first experimenting person of the wind effects in the trees in 1893 in Germany. But the older publication mentioned by Meroney is Tiren & Lars in 1927. In 1971, Thom presented his method, wich uses flexible plastic models in aerodynamic tunnel to study simulated crops. Mayhead (1973) between 1964 and 1973 tested trees in a big tunnel and published tables with drag coefficents for trees in relation to its height. This study has been taked as a basis by others later on. Linch (1986) treated the easy prediction of gravity centres and inertial momentums, needed for the calculations. Mayer (1987) obtained some spectral curves of oscillations and transfer loads in the top of the trees, the place where the critical velocities appeads. Guitard (1990) presented a relation of tree caracteristics, alones or in stands, and the vibrational benting and twisting nodes. This author (Guitard,1991) offered an application for *Pinus pinaster* and *Picea sitkensis*.
Bergtröm (1989) and Koufan Lo (1990) studied the boundary layer and the turbulence in forest stands. In 1991 Ruck & Adams tested in aerodynamic tunnel wind polluting dragging. They used a mountain model and obtained results of boundary layer characteristics and pollutings deposit in agreement with the real situation. Gardiner (1994) compared real dates in a dense piceas plantation in a flat land with a scale model of 12000 tree models. He found "honami" pressure waves, which can produce important damages in some forest stands. In the same year, a manual about wind damages in Britain Columbia collected the up-to-date knowledge, including a prevention guide.
Using mathematical models, Peltola (1996) developed, for a flat land in Finland, a model for forest margins. Later, Peltola et al. (1997) and Zeng and Takahashi (2000) developed a numerical model (HWIND) that is based on mechanic hypothesis and adapted to several species with good results. Neff & Meroney (1998) made other model for irregular lands and, Zeng and Takahashi (2000) published a model for the analysis of the gases and light elements transport. Xuhui Lee (2000) analysed some existing models to infer the cases in no ideal conditions (forest margins, thin out stands, singles trees and extreme winds). Talkkari et. al. (2000) presented a general model, which integrated several components in forest margins in flat lands based on HWIND model. Using reologic principles, Spatz (2000) studied

the self-support with a model of a 28 m height tree falled by the wind. Gaffrey (2000) simulated the wind action on a 30 m douglasia.
Concerning field studies in the last years, it can be remarked an study on the determination of the tree displacement, which established relationships between the wind in several heights and the behaviour of the selected tree (Hassinen et. al., 1998). Other Peltola article (2000) showed a field study concerning the tree displacements, when it´s tested for stress forces with a cable, using load cells and hot wire anemometer. In this way, the streamlines inside and outside top trees can be drawed (Zhu et. al., 2000).
Strip cuts with regeneration bands created wind damages in some Canada regions. The evaluation of this problem is the objetive of three articles by Flesch & Wilson (1999a, 1999b, 1999c). The authors analysed the measurement techniques, the species involved and their placement, to develop a generalized model and perform tests it in aerodynamic tunnel with the aim of obtaining a predictive final model as a guide of the silviculture treatments.
Yevgeny et. al. (1999) presented a model based on aerodynamic tunnel testing for urban enviroment. He introduces the “urban canyon” effect produced by building with different heights and caracteristics and studied the wind velocity and air pollution damages. Gaffrey et. al. (2001) summarized several works about the evaluation of photogrametic dimensional measurements in trees and their corrections So, he used only a photography made with a conventional camera, with data obtained since 1984 till nowadays, assumed reliable for trees of less than 50 m.

Objectives
The aim of this experimental study was to characterize, by in wind tunnel testing, the behaviour of a so-called “standard tree” for diferents wind velocities. In this way, we can determine the wind loads on the real tree. With these data, the risk of stem breaking or of roots removing could be evaluated in terms of the silhouette and the diameter of the tree model.

Material and Method

Material

The first step of this study was the selection of a type of tree to be tested in the experimental study. The specie selected was *Populus* sp. Because the shape of the trees is random, a model tree with the average properties of the specie has been defined. To obtain a typical shape, the average of several tree silhouettes, randomly selected, has been realized. These silhouettes have been obtained of eight *Populus* photographs, with the same age, in the “Ciudad Universitaria” (Madrid. Spain). The silhouettes of the photographs have been digitised, converted to vectors and averaged. In this way, the average silhouette of a “standard tree” has been determined.

For wind tunnel testing a reduced scale (1:35) model tree has been produced. It has been assumed that the tree behaves under wind as a flat porous plate.

Five MDF models with the same silhouette have been cut (10 mm thickness each of them). In order to obtain models with appropriate porosity, on four models a 2 cm x 2 cm hole pattern has been drilled. Holes with 10 mm, 12 mm, 14 mm and 16 mm diameter are employed to obtain five silhouette models with different porosity (0%, 20%, 28%, 38%, 50%). Each silhouette model is then installed on a simplified balance for force measurement. After that, tests at four wind speeds have been performed at the wind tunnel of the I.D.R. (Polytechnic University of Madrid) (Fig. 1).

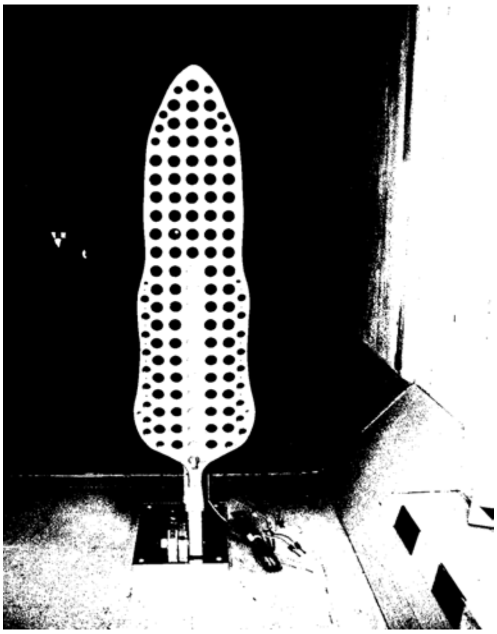

Fig. 1. Model tree in the wind tunnel section

Method

The tests in the wind tunnel consist of measuring simultaneously the drag force that the wind produced on the tree silhouette and the dynamic pressure of the wind speed (obtained by a Pitot tube in the test section). In order to obtain the drag coefficient, the dynamic pressure *P* and the wind force on the silhouette are measured.

The experimental data are obtained at a data rate of 50 Hz. The mean and standard deviation of 100 samples are obtained and stored. The tests are named Test-0, Test-A, Test-B, Test-C, Test-D, corresponding to the silhouette models sorted by increasing porosity.

We have assumed that the dynamic pressure distribution is uniform on the model and therefore the result aerodynamic forces (Pressure Centre) is applied at the centre of gravity of the silhouette. The Fig. 2 shows the diagram of the simplified balance employed to measure the drag force in the model.

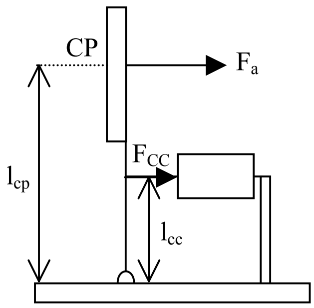

Fig. 2 Scketch of the set-up employed to measure the drag force in the model.
CP: Pressure Center ; Fa : aerodynamic force ; Fcc :load applied at the load cell ; CC : Load cell

Results

Usually, the wind force on a model is defined in terms of drag coefficent, c_D, that is defined as the relation between the measured force F_a and the reference force (formed by the dynamic pressure, P, multiplied by the area of the silhouette A (463 cm^2) as the expression:

$$c_D = \frac{F_a}{P \cdot A}$$

In Fig.3 the variation of the drag coefficient, c_D, with the wind speed, U, is shown for the five models tested.

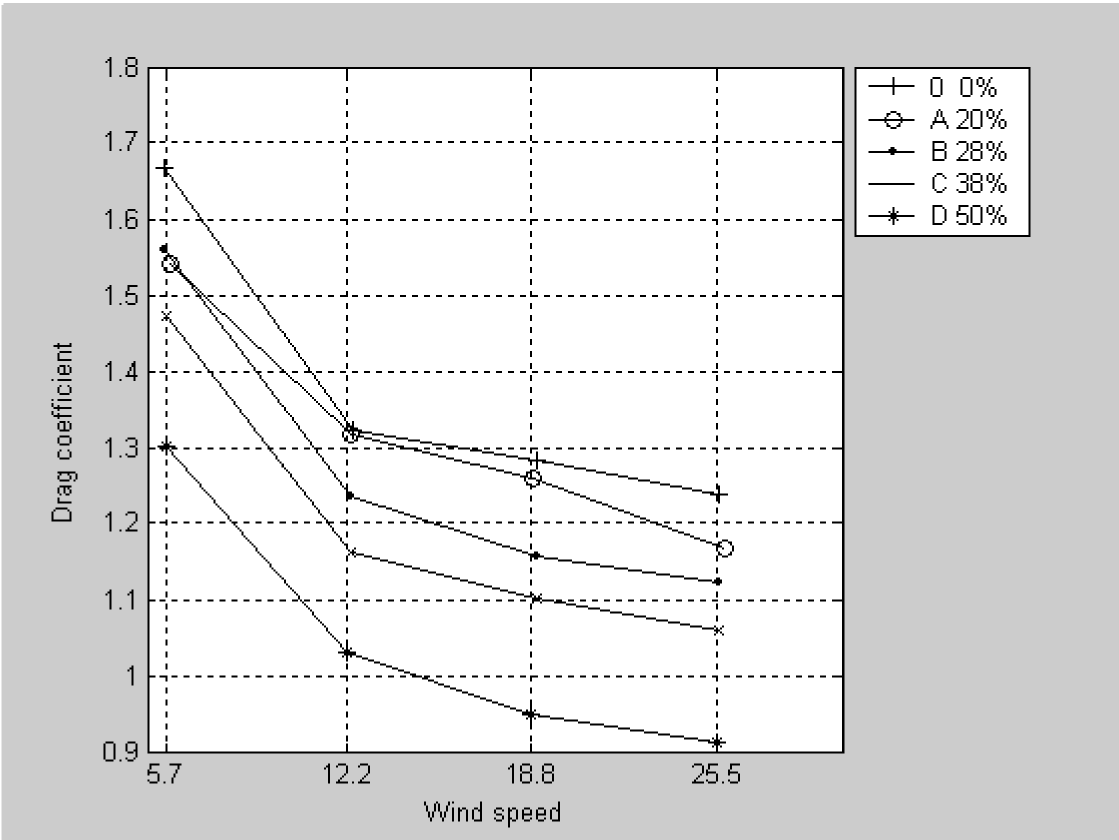

Fig. 3. Drag coefficient dependence on the wind speed U (m/s)

As it could be anticipated, in the type of body tested, c_D values are close to one. It can be shown that as the velocity is increases the drag coefficient smaller. Besides it is observed that when the porosity is increases c_D is decreases. This behaviour can be explained in the following way. At some value of Reynolds number, defined as $\mathrm{Re} = \frac{UL}{\nu}$ *(U and L*, caracteristic velocity and lenght, respectively, ν cinematic viscosity) named Critical Reynolds number Re_c, the drag coefficient c_D must keep constant. The variation showed on Fig. 3 denotes that to reach the Re_c value it is neccesary to exceed the value Re = 10^5 (for $\nu \cong 1,5 \cdot 10^{-5} \frac{m^2}{s}$, L is the thick model (0,1 m) and U = 15m/s)

.

If a more detailed point of view is considered, as the cause of the variation of c_D is the change of the Reynolds number *Re* when the flow going throught the model holes, it will be appropriatted to define the Critical Reynolds number Re_a in terms of the diameter of the holes, d_a and the velocity throught them U_a

$$\mathrm{Re}_a = \frac{U_a \cdot d_a}{\nu} = \frac{U_a}{U} \cdot \frac{d_a}{L} \cdot \mathrm{Re} = \frac{U_a}{U} \cdot \frac{d_a}{l_m} \cdot \frac{l_m}{L} \cdot \mathrm{Re} = \sqrt{\frac{\phi}{\pi}} \cdot \frac{U_a}{U} \cdot \frac{l_m}{L} \cdot \mathrm{Re} = 0,2 \cdot \sqrt{\frac{\phi}{\pi}} \cdot \frac{U_a}{U} \cdot \mathrm{Re}$$

where ϕ is the porosity *and* l_m is the cell size. The relation $\frac{U_a}{U}$ is a function of porosity that it´s determined by testing. The change in pressure losses through the holes due to the Reynolds number variation Re_a could be the reason of the variation of c_D in relation with *Re*. That question is not studied yet.

The test-A, corresponding to 20% porosity, has a different trend than the other tests. It will be considered in the future. The drag coefficient has been obtained for the different velocities and porosities. To close the work, a simple methodology to know the real porosity of the selected tree has to be developed. With this value, with the area of the silhouette and with c_D we could obtain the wind load on the tree.

Conclusions

We have progressed in a new methodology, simple and quick, to determine the wind force on a tree and so to know its resistance to breaking or up rooting. This study is based on wind tunnel tests of a model tree whose silhouette is defined by statistical considerations and with the appropriate porosity.

The most remarkable result obtained is the reduction of the drag coefficient when the Reynolds number (or the wind speed) and the porosity of the tree increase.

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