BBAA VI International Colloquium on:
Bluff Bodies Aerodynamics & Applications
Milano, Italy, July, 20-24 2008

AERODYNAMIC LOADS ON POROUS FABRICS AND MESHES

Ana Scarabino*, J. Sebastián Delnero, Mauricio Camocardi, Matías Giannecchini, Mariano Martínez

*Departamento Aeronáutica
Facultad de Ingeniería, Universidad Nacional de La Plata, Calles 1 y 47, 1900 La Plata, Argentina
e-mail: scarabino@ing.unlp.edu.ar

Abstract: *This work presents drag coefficients of woven and knitted fabrics of extended use in facade protections, windbreak fences, hail shelters, etc. Wind loads are measured and analyzed for a square and a 4:1 rectangular frame respectively, covered with fabrics of optical porosity between 12 % and 75 %, for different angles of incidence of the wind. In one case, wind drag on a wet sample is compared with that on a dry sample. Results are compared with loads on an impermeable canvas, in order to obtain load reduction factors as functions of geometry and porosity. Loss coefficients k, when the flow is confined and forced through the fabric samples, are measured and reported for the different analyzed materials and related to the measured drag coefficients. Results are compared, when possible, with those of other researchers and with different semiempirical models.*

Keywords: meshes, fabrics, aerodynamic forces, wind loads

1 INTRODUCTION

The Argentine Code, CIRSOC 102 [1], determines design wind loads on frame structures as a function of solidity ratio φ, defined as the ratio of blocked area over total exposed area of a structure. However, these loads are not useful for meshes and porous fabrics, because of the much smaller Reynolds number based on hole sizes and element diameters. Pressure losses and changes introduced in confined flow by screens and wire gauze have already been studied by Annand [2], and Morgan [3]. More recently, Wilson [4] and Boldes et al [5], among others, investigated the changes in the flow and the incident turbulent produced by porous walls and wind shelters. Richards and Robinson [6] measured and reported the normal force coefficient of porous structuresg them to the loss coefficient, k.

The purpose of this work is to obtain reduction factors of aerodynamic loads on rectangular frames of porous meshes, of different porosities, different aspect ratios and different angles of incidence of the wind, compared with loads on a non porous material. We have measured so far drag forces at different angles of attack on a square and a 4:1 rectangular frames covered with four different kinds of plastic and woven fabrics of extended use in engineering and architecture applications, and have compared the drag coefficients with those of an impermeable material, in order to obtain reduction factors as a function of porosity and shape. We have also measured pressure losses for the tested samples, in order to compare our results with those and with the semiempirical models reported in [6]. Drag and lift forces will be measured in the next weeks for these samples on frames of three different aspect ratios at different angles of incidence. The influence of porosity, Reynolds number and geometry will be analysed and discussed.

2 METHODOLOGY

Samples of different meshed fabrics were tested in the wind tunnel of the Department of Aeronautics, School of Engineering, Universidad Nacional de La Plata, Argentina. Each fabric covered two different frames, one square and other rectangular with an aspect ratio of 4:1, with a maximum blockage factor of 0.15. This value was considered low enough to disregard any corrections for this effect. For each mesh the optical porosity β, defined as the ratio between open area and total area, was measured by means of pixel counting in high contrast photographs, as shown in figure 1:

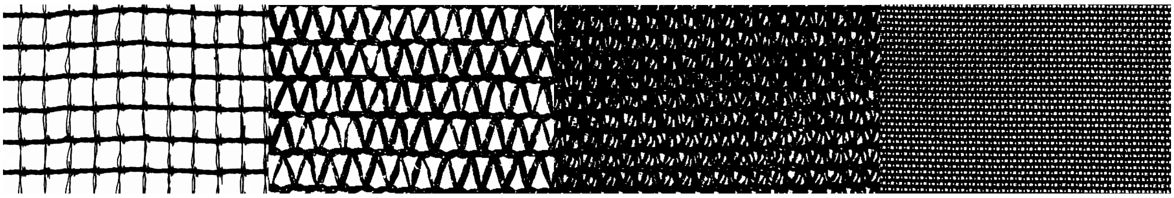

Figure 1: High contrast photographs of the studied meshes. From left to right, the optical porosity and mean pore size are respectively: 75 % - 10mm, 44% - 6mm, 12% - 3mm and 34% - 1mm

As a first step, each frame was settled on the aerodynamic balance without the fabric coverage in order to determine its own aerodynamic drag, for three different wind speeds (5, 10 and 15 m/s) measured with a Dantec Flowmaster anemometer, and for three different angles of incidence (90, 60 and 30 degrees). Later, the same frames, covered with the different meshes, were tested in the same conditions. The difference between the values obtained for the covered and for the uncovered frames was calculated for each case, in order to obtain the aerodynamic force acting on the mesh alone.

The drag coefficient in each case was calculated from the measured drag force, D, from the temperature corrected air density, ρ, and from the wind velocity, V, as:

$$C_D = \frac{D}{\frac{1}{2}\rho V^2 A_{ref}} \tag{1}$$

where the reference area, $A_{ref,}$ is the total area enclosed by the frame. The obtained CD values are compared with the ones of a non-porous piece of fabric provided, to obtain the aerodynamic drag reduction factor for each case. The non-porous fabric is an impermeable plastic film, representing the situation of highest aerodynamic load.

For the case of the 34% porosity mesh (1mm. holes), the drag force was measured only for 90^o. The test was performed first with the mesh dry and later with it completely wet, in order to measure the influence of this condition.

3 RESULTS

Table I shows the drag coefficients obtained for the different types of fabric, on the 1:1 and the 4:1 frames, for incidence angles of 90^o (normal), 60^o and 30^o. The percentual dispersion of results measured for different speeds, and their relation with a non-porous piece of fabric in the same conditions are also shown. For each case, the mesh is characterized by its optical porosity and for the size and the shape of its pores. In all cases, the variation of Cd with wind velocity was not higher than 13%. Figure 3 shows the results obtained in our experiments and a relation proposed in [6] the $\beta > 0.4$ and Cd = 1.

Mesh	Frame	Incidence Angle (º)	C_D	% dispersion of C_D in tests	C_D / $C_D(imp)$
75%, squares 10mm k = 1.2	**Square**	90	**0.294**	11.13	**0.139**
		60	**0.204**	6.94	**0.129**
		30	**0.113**	7.65	**0.166**
	Rectangular	90	**0.256**	11.15	**0.107**
		60	**0.190**	10.16	**0.106**
		30	**0.112**	10.11	**0.203**
44%, Triangles 6mm k = 6.7	**Square**	90	**1.469**	7.56	**0.695**
		60	**1.010**	4.19	**0.637**
		30	**0.365**	2.71	**0.533**
	Rectangular	90	**1.671**	8.02	**0.696**
		60	**1.256**	6.24	**0.703**
		30	**0.458**	3.55	**0.830**
12%, Triangles 3mm. k = 39.0	**Square**	90	**1.677**	7.61	**0.794**
		60	**1.154**	2.98	**0.727**
		30	**0.469**	5.41	**0.684**
	Rectangular	90	**1.813**	7.67	**0.755**
		60	**1.297**	6.16	**0.726**
		30	**0.446**	7.67	**0.809**
34%, Dry Square 1mm. k = 9.8	**Square**	90	**1.745**	2.32	**0.826**
	Rectangular	90	**1.908**	8.21	**0.795**
34%, Wet Square 1mm	**Square**	90	**1.984**	10.71	**0.939**
	Rectangular	90	**1.924**	12.88	**0.802**

Table I: Drag coefficients and their relation with the non-porous fabric.

When the flow impacts on a porous frame with an incidence angle different than 90 degrees, two opposite situations are produced: On one hand, the frontal area decreases, and so does the normal component of velocity; on the other hand, the fabric apparent solidity increases. In other words, the mesh apparent optical porosity decreases, as the open area perpendicular to the flow is reduced in the same proportion as the total surface does. However, the area occluded by the mesh threads remains approximately constant. For small displacements of the perpendicular direction, the factor $(1-\cos^2\theta)$, where θ is the incidence angle, results a good approximation, but in open meshes, this factor considerably underestimates the drag force. Figure 3 shows the variation of C_D with the incidence angle for the analyzed meshes. Indeed, the perpendicular component of the force must be also considered, what will be carried out for the final version of this work.

Finally, for the thinner mesh -34% porosity and 1mm holes-, a comparison was made between both frames -square and rectangular- for dry and wet conditions. For the squared frame case, a 14% incremented drag was observed, while for the rectangular frame case the increment was imperceptible. A possible explanation is that in this latter case, a higher fraction of the flow is diverted around the frame, so that the porosity has a lower influence in the pressure distribution, compared with a solid structure, while the square frame forces a higher percentage of the flow to pass through it, reducing its total drag.

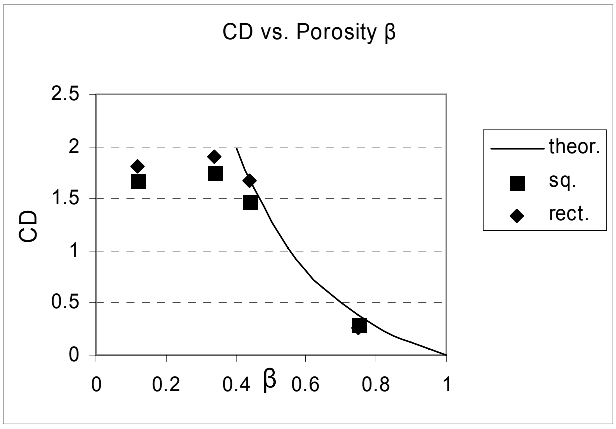

Figure 2: C_D vs. Optical porosity β

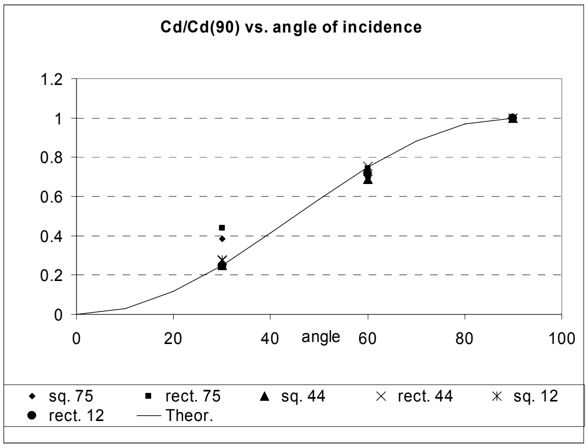

Figure 3: C_D/ C_D (normal) vs. angle of incidence

4 CONCLUSIONS

This work provides information of use in the design of structures covered by porous fabrics and meshes, such as shade houses, windbreak fences, banners, facade protections, hail shelters, etc. Drag forces for two rectangular frames of aspect ratio 1:1 and 4:1 at three different angles of incidence, and loss coefficients have been measured for materials of different porosities. Other aspect ratio frames will be investigated and also lift coefficients will be measured and reported in the final version of this work. For high porosities, the obtained results match acceptably those of other researchers. The variation in drag coefficient with the angle of incidence of the wind shows that for low porosities the relation ($1-\cos^2\theta$), used in non porous structures, is valid, but it underestimates the drag in meshes of higher porosity.

ACKNOWLEDGEMENTS

This work was partially sponsored by MEKANO Scaffold Structures SRL. The authors are grateful to Mr. Federico Muñoz, Mr. Matías Cardacce and Miss Daniela François for their valuable help in the experimental work.

REFERENCES

[1] Reglamento CIRSOC 102: Acción del Viento sobre las Construcciones. Dic. 1984

[2] Annand W.J.D., The resistance to air flow of wire gauzes, *J. Roy. Aeronaut.* Soc. 57 pp. 141-146, 1953.

[3] Morgan P.G., Flow through screens of low solidity, *J. Roy. Aeronaut Soc*. 66, 54-56, 1962.

[4] Wilson J.D., On the choice of a windbreak porosity profile, *Bound. Layer Meteorol*. 38 pp. 37–49, 1987.

[5] Boldes U., Golberg A., Marañón Di Leo J., Colman J., Scarabino A.: Canopy flow and aspects of the response of plants protected by herbaceous shelterbelts and wood fences, *J. of Wind Eng. and Ind. Aer,* 90/11, pp. 1253-1270, 2002.

[6] Richards P.J., Robinson M., Wind loads on porous structures, *J. of Wind Eng. and Ind. Aer.* 83, pp. 455-465, 1999.