Assessing the hydrodynamic performance of vegetation physical models: an experimental study of seaweed blades

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ABSTRACT

Seaweed blades and seaweed blade physical models designed following a similarity theory were tested in a flume facility. The measured drag coefficient of physical models is found to be significantly biased low compared to that of natural seaweed blades.

1 INTRODUCTION

Physical modelling is a key tool in hydraulic research. While traditional hydraulic settings mainly involve rigid structures and bodies, the studies of flow-vegetation interactions require accounting for vegetation flexibility. Natural vegetation spans a range of spatial scales that can be hardly reproduced with artificial replicas in its comprehensiveness. Hence, there are no clear guidelines on how detailed a physical model should be to adequately reproduce vegetation.

Physical models of vegetation are widely used in laboratory studies of flow-vegetation interactions [e.g. 1]. They are cheap to manufacture and much easier to handle than natural plants, whose nursing requires some botanical expertise. A major issue, which to the authors' knowledge has never been comprehensively addressed, is whether these models are adequate replicas of natural plants.

In this work, we compare the drag force experienced by natural seaweed blades and their physical models to evaluate how good the models are in reproducing seaweed blades hydrodynamic performance. Seaweed blades and their physical models with different dimensions were tested in a laboratory flume at a range of hydraulic conditions. Physical models were designed using a similarity theory and considering the most important morphological and mechanical properties of natural seaweed blades [4].

2 MATERIALS AND METHODS

We designed and manufactured nine physical models with lengths ranging from 7 cm to 39 cm (Table 1). Models were designed using data on seaweed blade length l, width w, thickness t, and Young's modulus E available in the literature [2, 3]. They were designed following Reynolds' similarity (using blade Reynolds number $Re_l=Ul/\nu$) and keeping the Cauchy number C_y idem [4]:

$$C_y = (\rho U^2 l^3)/(Et^3) \qquad (1)$$

where ρ is water density, and U is the mean (i.e. time-averaged) approach velocity of the flow. Models were tested at seven hydraulic scenarios with U varying from 0.1 m/s to 0.55 m/s ($Re=1.8\times10^4$-1.4×10^5, constant water depth of 30 cm).

Seaweed blades of the species *Saccharina latissima* were collected from Loch Fyne (Scotland) in February 2015. Fifteen blades with lengths between 16 cm and 60 cm (Table 1) were used in the tests. Blades were tested at 3 hydraulic scenarios (lowest, medium, and highest of those used for testing models, corresponding to U=0.1 m/s, U=0.33 m/s, and U=0.55 m/s, respectively). Five blades were tested at each hydraulic scenario; test samples were selected so that: (i) their lengths covered as a wide range as possible; and (ii) blades of similar dimensions were tested at every hydraulic scenario.

Before experiments, a photo of each test sample (either seaweed blade or physical model) was taken on a light table, so that its wetted surface area could be estimated via image analysis. During the tests, flow velocities 10 cm upstream from the test sample were measured with an ADV (Vectrino+, Nortek AS, Rud, Norway) and drag force acting on the tested sample was measured with a Drag Measurement Device [4] composed of a 1 N load cell (S100 thin film load cell, Strain Measurement Devices, Chedburgh, England) and a data acquisition scanner (Vishay PG 6100 scanner, Vishay Precision Group, Malvern, USA). Measurements were taken synchronously for 10 minutes; flow velocities were recorded at 100 Hz and drag force at 200 Hz. Both the point at which the sample was attached to the DMD and the sampling volume of the ADV were located 8 cm below the water surface, where flow characteristics were found to be quasi-homogenous.

In the data analysis, the drag coefficient C_D of a test sample was calculated using a static approach [5], i.e., considering test sample wetted surface area A_{wet} as a reference area:

$$C_D = F_D/(0.5\rho A_{wet} U^2) \qquad (1)$$

where F_D is the mean (i.e. time-averaged) drag force.

Table 1. Ranges of values of morphological and mechanical characteristics and Cauchy number of tested samples.

	l (mm)	w (mm)	t (mm)	ρ (kg/m^3)	E (MPa)	C_y
Seaweed blades	160-601	62-181	0.12-1.82	925-1322	1.65-8.19*	6×10^3-10^6
Physical models	70-390	6.1-26.4	0.07-0.28	819-1059	78-319	2×10^1-5×10^4

*measured on specimens prepared from seaweed blades not used for hydrodynamic experiments.

3 RESULTS

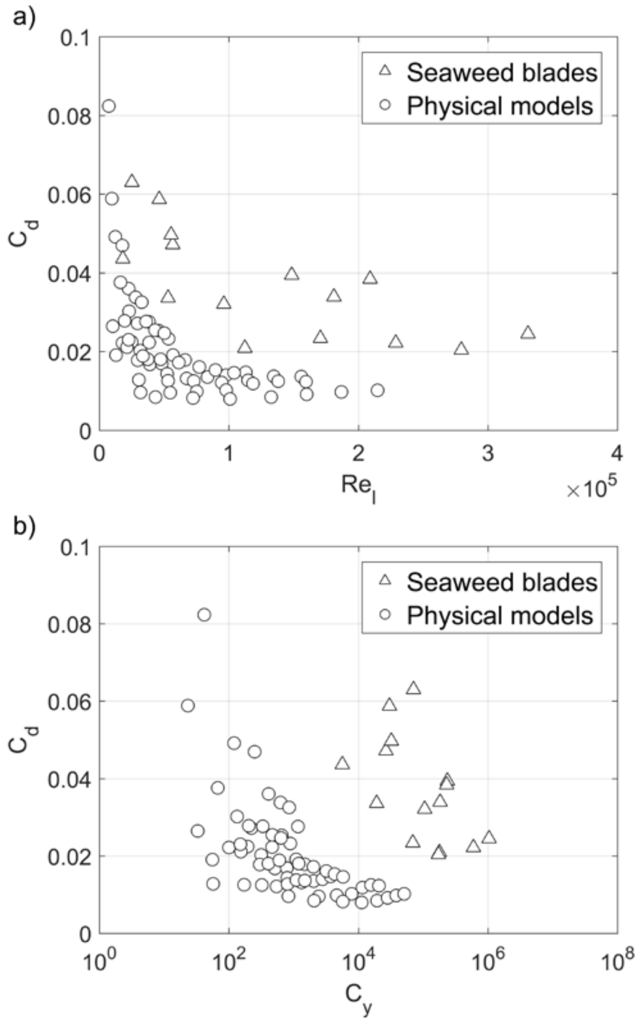

Figure 1. Drag coefficient of seaweed blades and their physical models as a function of the blade Reynolds number (a) and the Cauchy number (b).

Since the physical models are scaled replicas of seaweed blades, the use of non-dimensional parameters is the most adequate way to compare their hydrodynamic performances. For both seaweed blades and their models the drag coefficient decreases as a function of Re_l. However, for the models the trend is similar to that of a flat plate, while for the natural blades the drag coefficient is considerably higher (Figure 1a). Also, when analysed as a function of the Cauchy number, C_D of physical models significantly underestimate that of seaweed blades (Figure 1b). However, in this case the ranges of C_y investigated do not overlap as well as those of Re_l.

The significant differences found in experiments suggest that small-scale morphological details, not fully reproduced in the models, may play crucial role in overall hydrodynamic performance of blades. Apparently, secondary morphological features of natural seaweed blades, such as variation of their shape, bullations and ruffled edges [6] seem to have an important role in increasing the drag force exerted by the flow. These features were not considered in the design of our physical models, but should be taken into account for obtaining replicas with hydrodynamic performance similar to that of real vegetation.

In conclusion, we think that a novel form of the Cauchy number that takes into account morphological features more comprehensively should be implemented in such a way to make C_y an adequate non-dimensional parameter for designing physical models of vegetation and other flexible bodies.

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