Col Project: Good Job w/ it

Fluid Dynamics Project Paper Meg Noah 10/10

This paper presents a simple model of scallop swimming. For years, I've found valves of placopecten magellanicus on the beach, and have been unable to explain why shells are almost always 10 cm to 12 cm in length. Scallops swim to migrate and to avoid preditors. Several models in the literature predict that adult scallops swim untill they are about 10 cm in length. Scallop swimming is more like bird flight because they are much heavier than sea water. This might explain the cause of death. Larger scallops have to burrow & are more vulnerable. A scallop failing to adapt to its size is more likely to fall prey.

Observations

Caddy (1968) and Dadswell + Weihs (1989) have studied scallop trajectories. To swim, a scallop opens its valves by relaxing the large (striped) adductor muscle and allowing the hinge tendons to open, the contracting that muscle forcing the sea water out openings in the back. The shell is somewhat streamlined and approximates & boing airfoil in cross-section - but the motion is in the opposite direction.

A contraction period is subdived:

1) Open valve, for P. magellenicus maximum gap is ~18°.
2) close valves (thrust)
3) glide

Each subdivision is about 1/3 the entire cycle period, which is typically .5 s to 1s.

Scallops have two rows of 'eyes'. These photosensitive cells can detect an object moving at a range of 15 - 90 cm.

Scallop swimming has 3 phases:

1) Rapid ascent to height of 30 - 90 cm. at a trajectory angle of ~30° for about 5 contractions.
2) Nearly level swimming for about 7 - 10 contractions.
3) Passive descent to ocean floor.

The time of flight is 5 to 20 s point to point. The point to point distance is about 3 m.

Figure 1 illustrates the internal structure and S_L = length, S_W = width.

Model

Scallop swimming is unsteady, with pulsed jets into a wake of vortices being shed from the valves. Cheng + Demont (1996) argue that the scallop is stream lined so the boundary layer doesn't separate on most of the valve, the wake is small + pressure drag can be ignored. (Figure 2)

Figure 3 & shows the force diagram for this simple model. Other models regard the scallop as having a planned trajectory. This model says – the scallop eyes probably don't give it much opportunity to & chart a course while swimming. The path they have results only from contractions made when it gets excited/disturbed by something it senses.

The gravitational force is not time dependent because the expellable water doesn't contribute to the booyant weight. Dadswell + Weihs show this weight for Placopectin magellenicus to be:

$$M_b = Av(100 \cdot S_L - 3.5) \quad \text{in m and kg}$$

A_v = valve area = $S_L \cdot S_W$ where $S_W = A_R \cdot S_L$

A_R = aspect ratio = $1.117 + 3.6 \cdot (S_L - .04)$ according to Cheng + Demont.

S_L = length in m

M_b in kg.

~~Dadswell~~ Cheng + Demont have measured + modeled the lift + drag coefficients:

$$C_L = 0.0565 + (1.21 + 3.8\, S_L) \cdot \alpha$$

$$\cancel{C_D = 0.06 + (1.22 + 3.82 \cdot S_L)}$$

$$C_D = \underbrace{.06}_{C_{D0}} + \frac{(1.47 \cdot C_L^2)}{\pi A_R}$$

The form factor was measured by Hayami (1991)

The $C_{D\alpha}$ is found by modeling + measuring this species.

Cheng & Demont (1996) give a propulsion model, but in software it over estimated larger scallops giving them the best flight — opposite of observations. Their analysis of weight/drag ratio though does explain why larger scallops don't swim.

Modeling the scallop as having motion due to contractions and a random angle of attack (observed to be 6° to 12°) explained their trajectories. Figure 4 shows the model output with the larger scallops barely on the ocean floor and a .07m scallop traveling with rapid ascent that levels off.

To model propulsion, I just set it to be proportional to the scallops volume, roughly

$$F \propto S_L^{3.21}$$

With constant of proportionality set to get the observed trajectories.

Level flight for the .07m scallop is due to a "I'm getting tired" parameter that increases the glide time between open cycle by 1.2 for contractions less than the 7th contraction. While there is no data to compare to, it seems reasonable.

Future

If this were to become a paper, the force of propulsion would be modeled in terms of vortex formation. (Dabiri, 2009) Vortex formation is important in biological propulsion because they have unsteady motion with high Reynold's numbers. The impact of ridges + symbiotic creatures attaching to the shell can be studied (Fig 5) Modeling the motion of scallops as a passive flight response, a reflex of the flight/fight/fright reaction to a threat, may lend insight into bivalve evolution, and mechanisms needed to productively protect scallop populations in our changing environment.

higher (it is still low)

Cheng + Demont, "Jet Propelled Swimming in Scallops: Swimming mechanics and ontogenic scaling" Can. J. Zool. Vol 74, 1996, pp 1734-1748

Dadswell + Weihs "Size-Related Hydrodynamic Characteristics of the Giant Scallop Placopecten Magellanicus), Can. J. Zool. Vol 68 1990

Caddy "Underwater Observations on Scallop (Placopecten Magellanicus) Behavior + Drag Efficiency" Journal Fisheries Research Board of Canada, Vol 25, No [illegible] 1968

Dabiri, "Optimal Vortex Formation as a Unifying Principle in Biological Propulsion Ann. Rev. Fluid Mechanics, 2009 41:17-3

[illegible] in Scallops" Paleontology Vol 4 1971

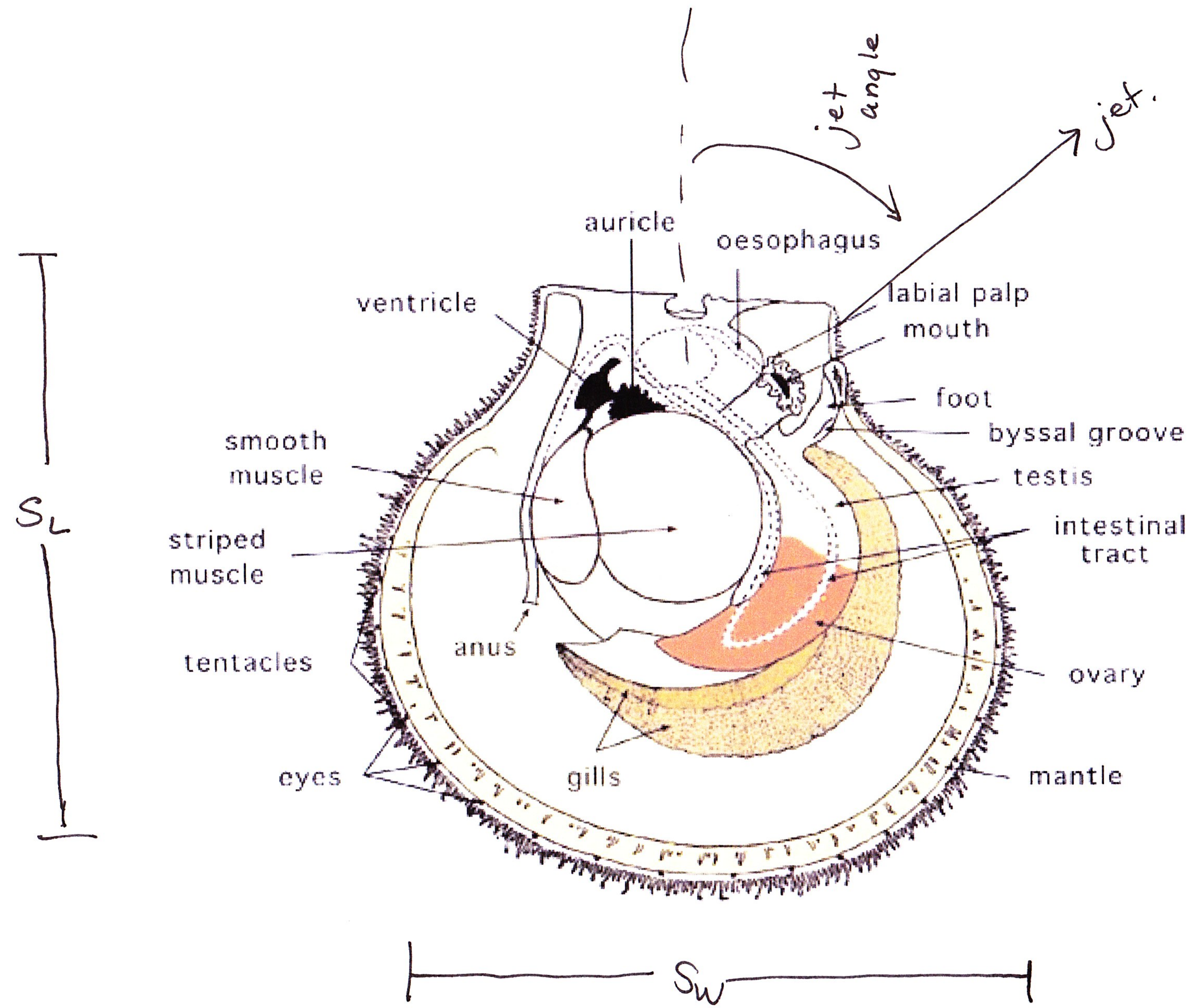
jet angle
jet.
auricle
oesophagus
ventricle
labial palp
mouth
foot
byssal groove
smooth muscle
testis
striped muscle
intestinal tract
anus
tentacles
ovary
eyes
gills
mantle
S_L
S_W

Fig. 1

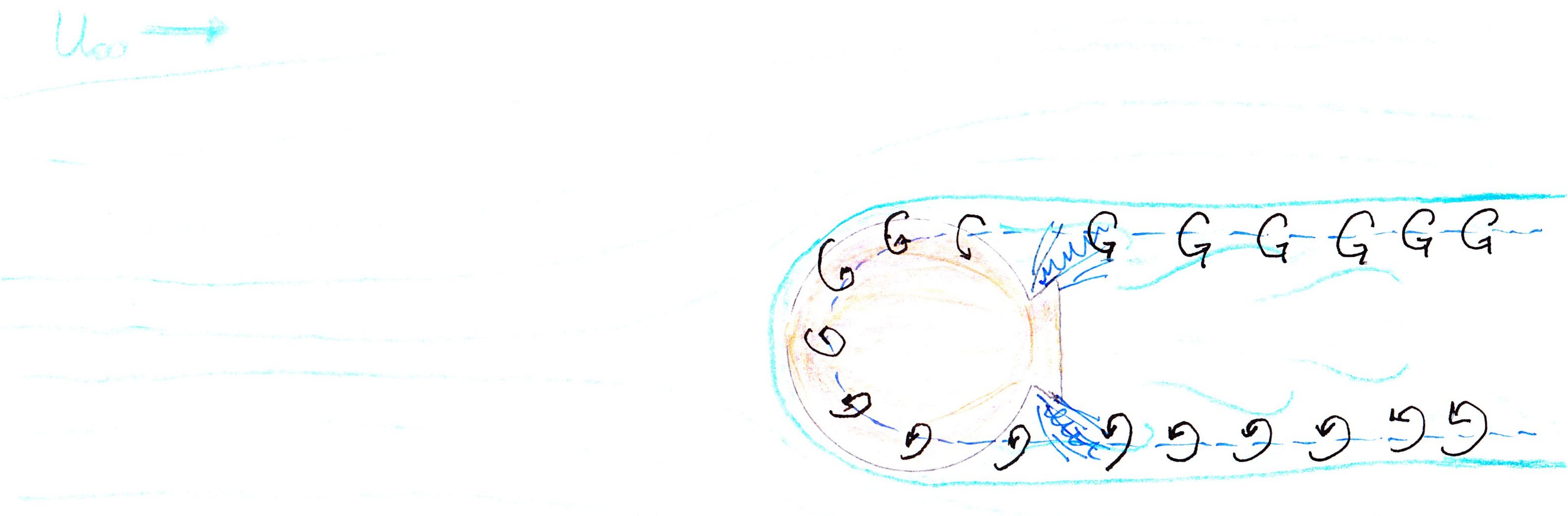

Fig 2.

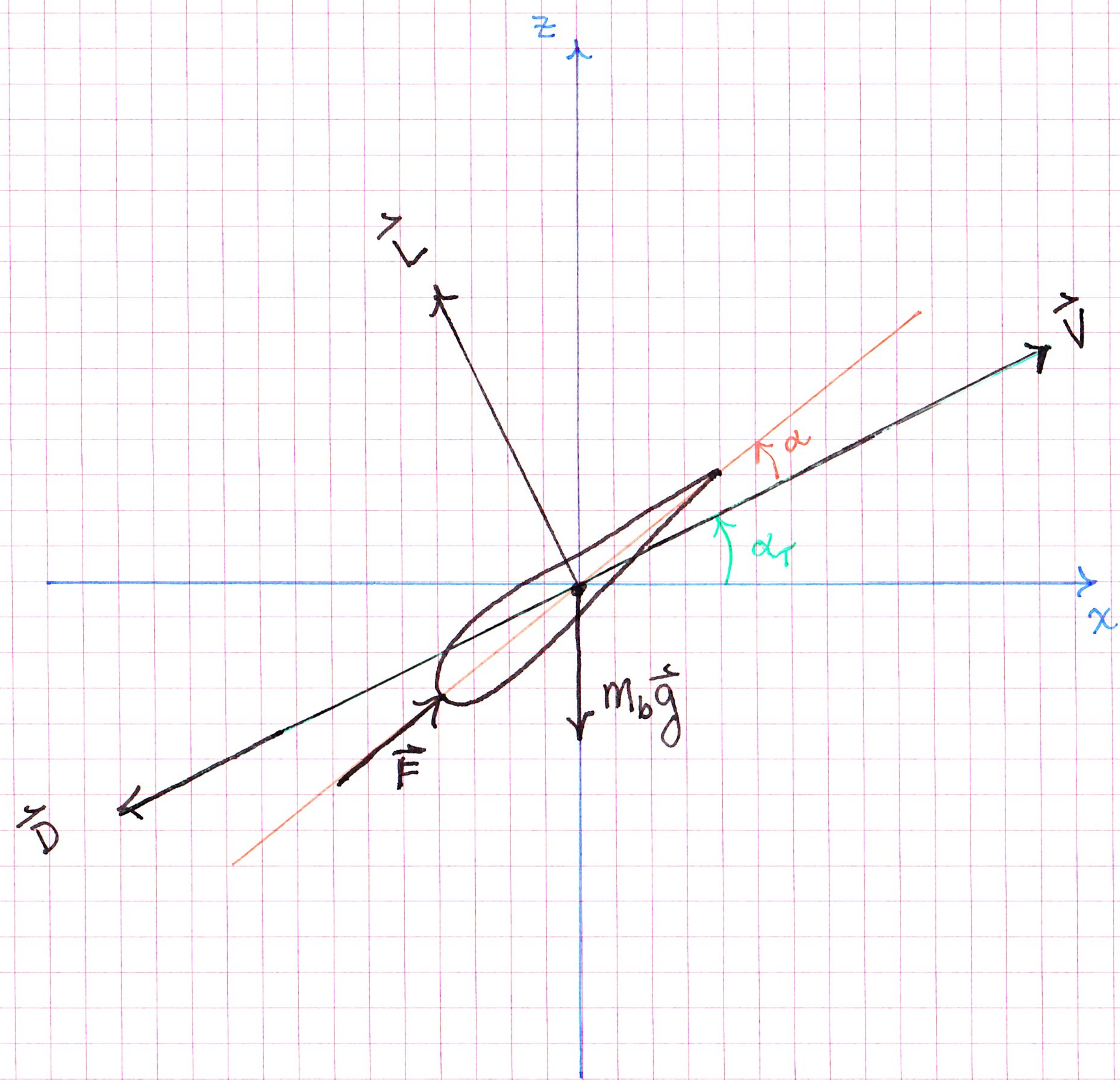

Fig. 3

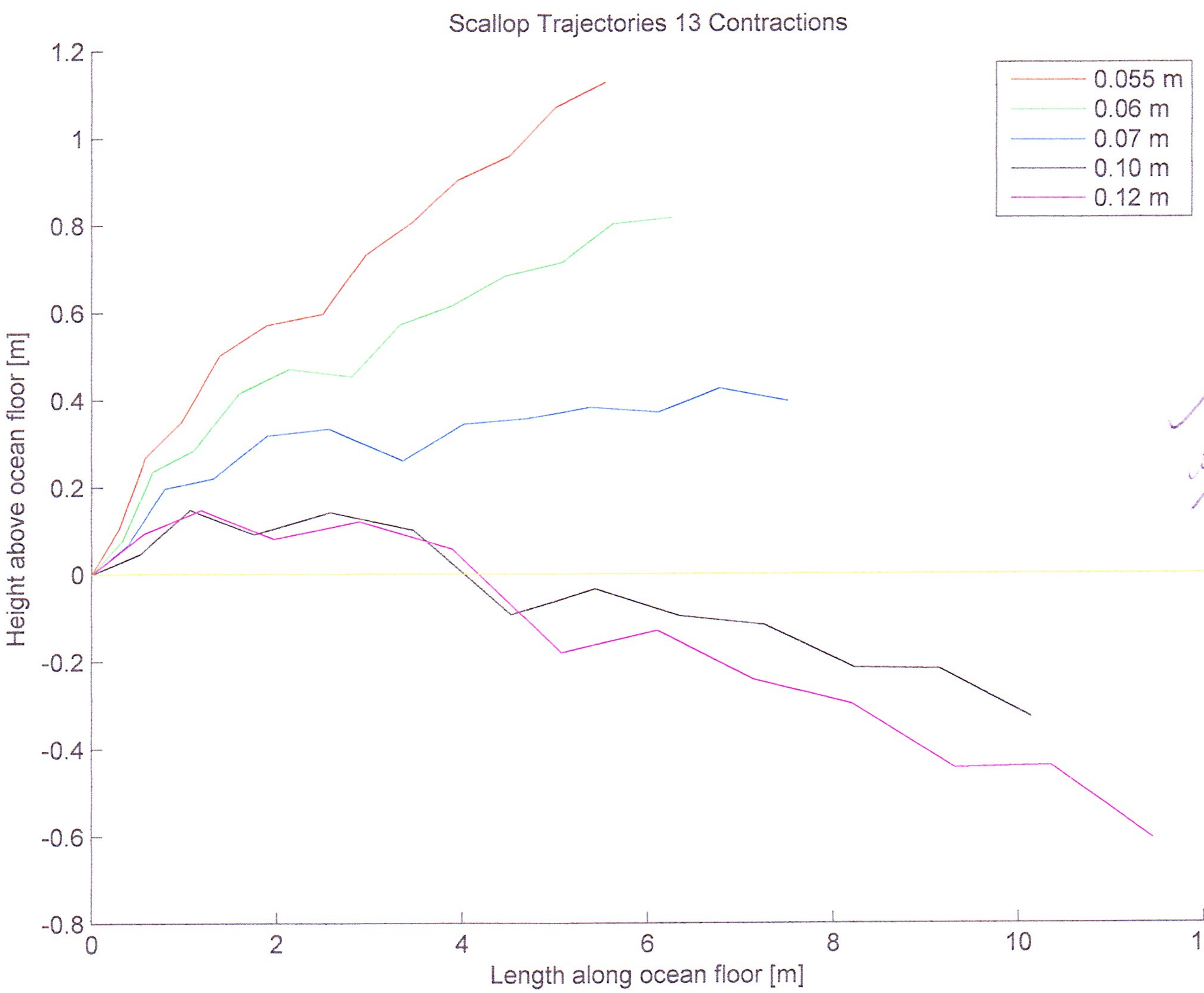
Scallop Trajectories 13 Contractions
Height above ocean floor [m]
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
0
2
4
6
8
10
12
Length along ocean floor [m]
0.055 m
0.06 m
0.07 m
0.10 m
0.12 m

Fig 4

Wing-surface device

Longitudinal grooves on a scallop shell

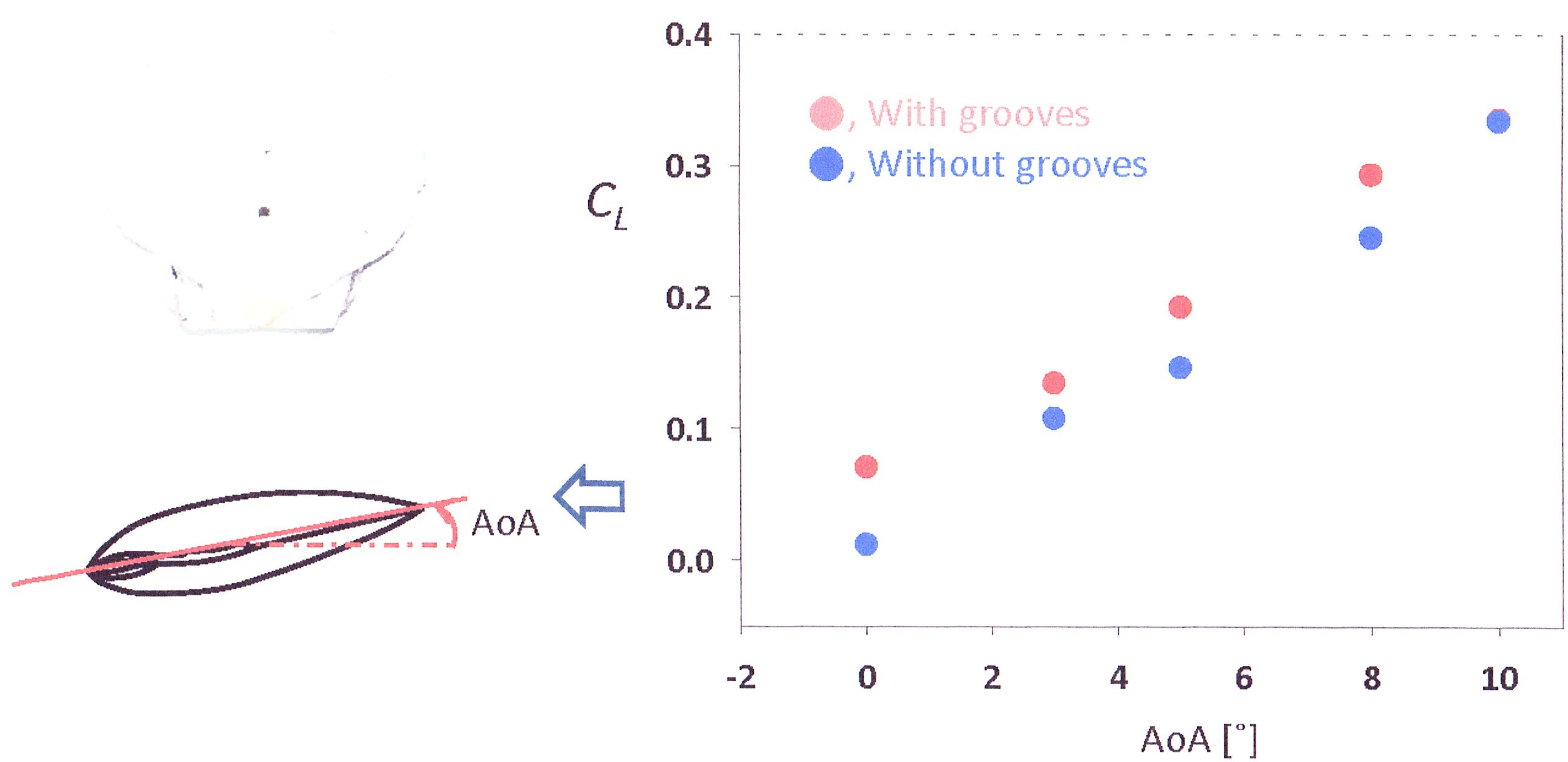

Fig 5