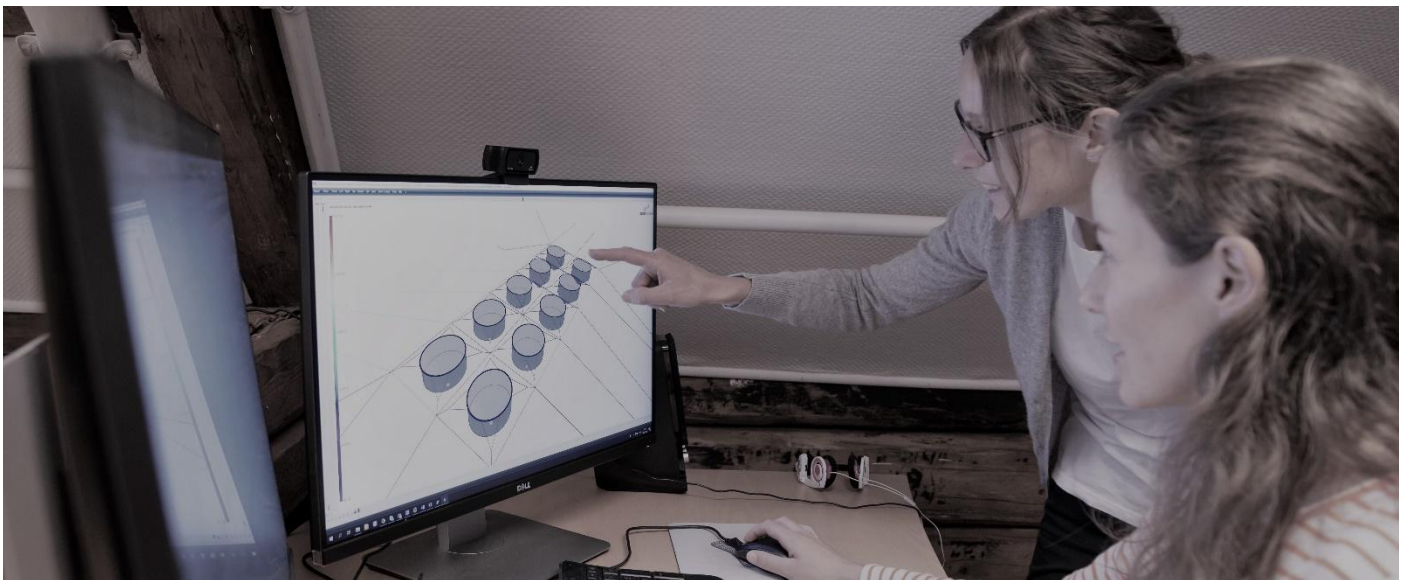


AquaSim training courses

- Lice skirt with current



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1 Prerequisites

The tutorial presents a simple case study with the purpose of demonstrating functionality in AquaSim.

It is assumed that the user is familiar with the basic principles of modelling and specifying material parameters in AquaEdit, as well as conducting analyses. If you are looking for an introduction to AquaSim we advise you to start with the Basic program tutorials.

2 Introduction

This tutorial introduces how current loads on impermeable nets, such as lice skirts, are defined and analysed in AquaSim. The purpose is to provide a step-by-step introduction to the load formulation, the role of drag- and lift coefficients, and how results can be interpreted and compared with physical model tests.

You will be introduced to:

- Definition of current loads on impermeable nets, and how these are represented in AquaSim.
- Example of a flexible tube where test data are available, showing how numerical results can be compared with experiments.
- Sensitivity studies to illustrate how changes in drag- and lift coefficients affect the analysis outcome.
- Discussion of practical use, including when such analysis is particularly relevant, and how it can guide further design work.

The aim is to make clear why the correct use of drag- and lift coefficients is important, how they are chosen in practice. In addition, how engineers can combine numerical analyses with experimental results to obtain reliable assessments.

3 Definitions regarding current loads on impermeable nets

Lice skirts are modelled in AquaSim by applying the Lice skirt-load formulation to membrane panels, as illustrated in Figure 1.

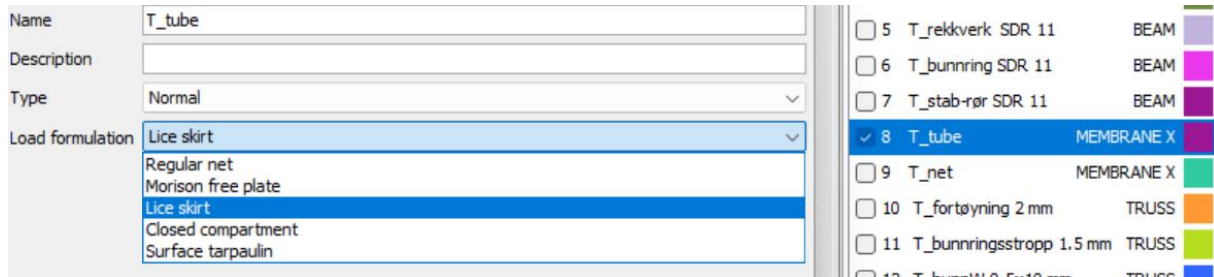


Figure 1 Lice skirt load formulation

A lice skirt is normally represented with several membrane panels, as seen in Figure 2. Each panel interacts with the surrounding flow, depending on its orientation and the local (undisturbed) velocity field.

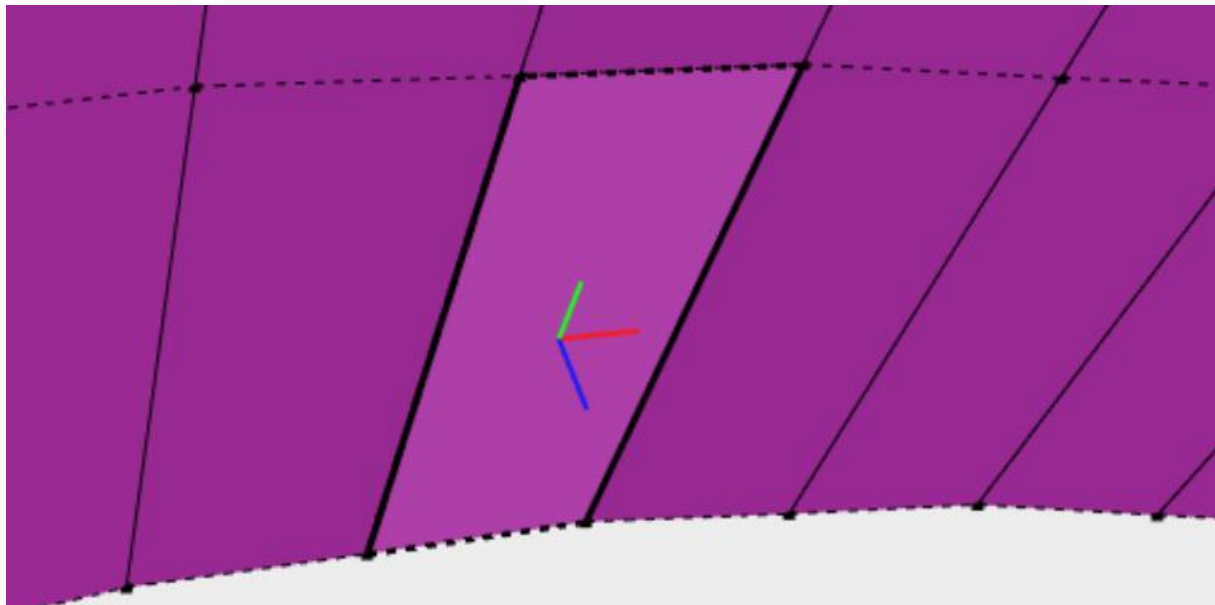


Figure 2 Membrane panels, local coordinate system indicated with red, green and blue lines in the center

Consider one membrane panel as shown in Figure 3. The flow velocity vector U approaching the panel can be split into two components: U_t and U_n .

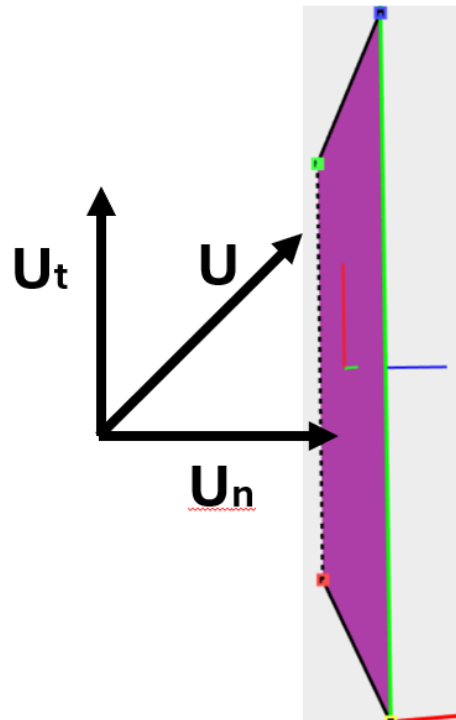


Figure 3 Flow approaching a membrane panel

where

- U_t is the tangential component of the velocity, sliding along the surface of the panel.
- U_n is the normal component of the velocity, pushing directly against the surface.

In AquaSim, the total velocity acting on one panel is given by:

$$U = U_c + U_w - U_s$$

where

- U_c is the current velocity
- U_w is the fluid velocity from wave motions
- U_s is the velocity of the structural element

Impermeable nets have 4 parameters related to drag loads originating from U as shown in Figure 4.

Drag	
Drag coefficient upstream	1.2
Drag coefficient downstream	0.5
Skin friction coefficient	0.0
Lift coefficient	0.0

Figure 4 Drag parameters

In this tutorial we apply the following denotations:

- C_d for drag coefficient
- C_f for skin friction coefficient
- C_l for lift coefficient

The respective drag- and lift forces are then found as:

$$F_{Drag} = C_d \frac{1}{2} \rho A \cdot U_n |U_n|$$

$$F_{Fric} = C_f \frac{1}{2} \rho A \cdot U_t |U_t|$$

$$F_{Lift} = C_l \frac{1}{2} \rho A_t \cdot U_t |U_t|$$

where

- A is the area of the surface (panel)
- A_t is the area cross tangential to the current direction in the undeformed condition
- ρ is the fluid density

3.1 Drag coefficient C_d

Consider flow along the red line in Figure 5.

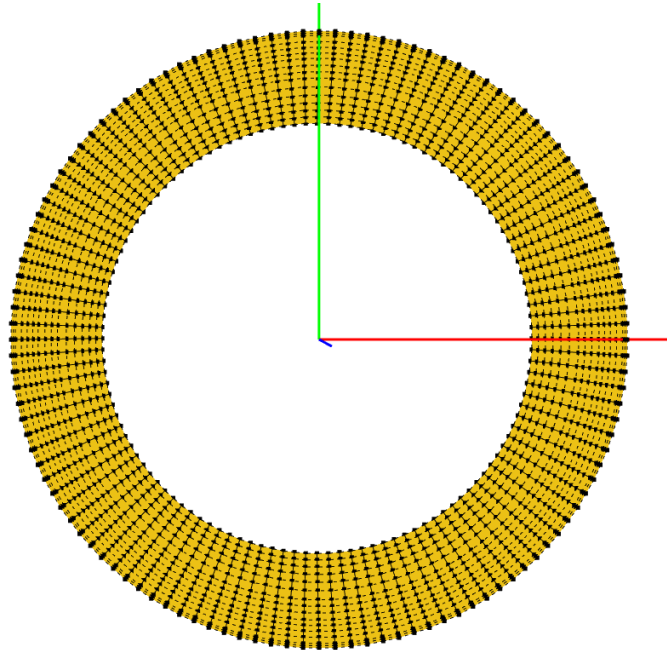


Figure 5 Circular volume enclosed by tarpaulin

For flow along the red line, the parameter “Drag coefficient upstream” in AquaSim will be used for all panels to the left of the green line. For the other panels, the “Drag coefficient downstream” will be used.

3.2 Lift coefficient C_l and lift force

For lice skirts and closed compartments, the lift coefficient is only applied in the horizontal plane. Projected area parallel to the flow in undeformed condition. It is a squared consideration, meaning that the area used at 45 degrees (DEG) is 0.5.

3.3 Skin friction coefficient C_t (tangential drag)

The tangential drag coefficient is applied to the full wet area.

4 Drag-, lift- and tangential coefficients

Drag and lift coefficients are not fixed values that can be calculated once and for all. Instead, they are mostly determined from **experimental data**. This is because many different factors influence how a body interacts with fluid, and simple theory alone cannot capture all these effects.

Some of the most important influences are:

- **Shape of the object:** a sphere, a flat plate, and a streamlined foil all create very different flow patterns, leading to very different drag- and lift values.
- **Surface roughness:** a smooth surface (like polished metal) and a rough surface (like netting or tarpaulin) can cause the flow to behave differently, which changes the coefficients.
- **Reynolds number (flow speed and size effects):** at low flow speeds the flow may remain smooth and orderly (laminar), while at higher speeds turbulence develops, which increases drag.
- **Steady vs. unsteady flow:** in constant, uniform flow, published drag- and lift values are usually reliable. In unsteady situations (like waves, oscillatory currents, or vortex shedding), the effective coefficients may be quite different.
- **Interference effects:** nearby structures, walls, or the free surface can disturb the flow and change the effective forces on the object.

Because of all these influences, engineers usually select drag- and lift coefficients from tables, experiments or databases, and may adjust them to match the specific flow situation being studied.

A common practice is also to perform a sensitivity study: repeating the analysis with slightly different coefficient values. This helps check how sensitive the results are to uncertainty in the coefficients and ensures that the design remains on the safe side.

In the next sections, we will look at each type of coefficient in more detail and discuss how they are used in AquaSim.

4.1 Notes on the drag coefficient

Normally, drag coefficients are reported for the whole body (e.g. a cylinder or a sphere). In AquaSim, however, drag coefficients are applied locally to each membrane panel, which means that the relationship between local values and the overall drag on the full structure must be considered.

For a deforming cylinder, this relation can be checked by setting up a simplified version of the model where the full drag force on the body can be derived. Results from such comparisons show that using a higher drag coefficient upstream and a reduced value downstream gives a good match with the expected drag for a complete cylinder.

In practice: when assigning drag coefficients in AquaSim, it is important to check that the combination of local values produces realistic overall drag forces for the structure as a whole.

Now we are going to illustrate this by considering a stiff cylinder in AquaEdit. The cylinder is built up by membrane panels, and beams on top of that. The purpose of introducing beam elements is to make the cylinder stiff, so that the panels do not deform under influence of current flow. The aim is to apply different drag coefficients upstream- and downstream and compare this with drag coefficients for cylinders from tables.

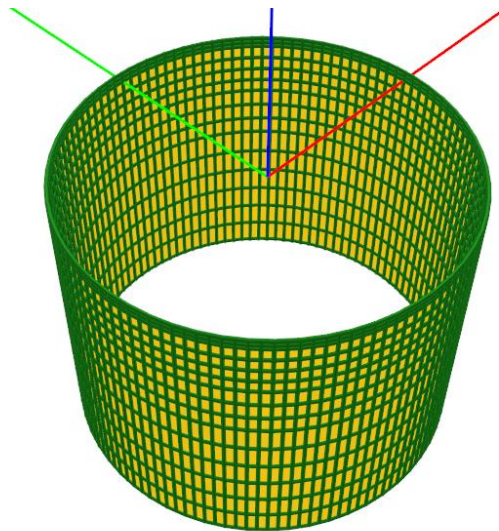


Figure 6 Stiff cylinder in AquaEdit. Yellow: membrane panel with load formulation Lice skirt. Green: beam elements

The beams are only assigned stiffness, there is no volume or weight that will contribute to forces, see Figure 7.

Weight and volume per meter length	
Volume	0.0
Mass density	0.0 kg/m ³
Weight in air	0.0 kg/m
☐ Weight in water	0.0 kg/m

Figure 7 Volume and weight of beam elements

Then a rope (Truss element) is modelled along the negative x-axis, see Figure 8.

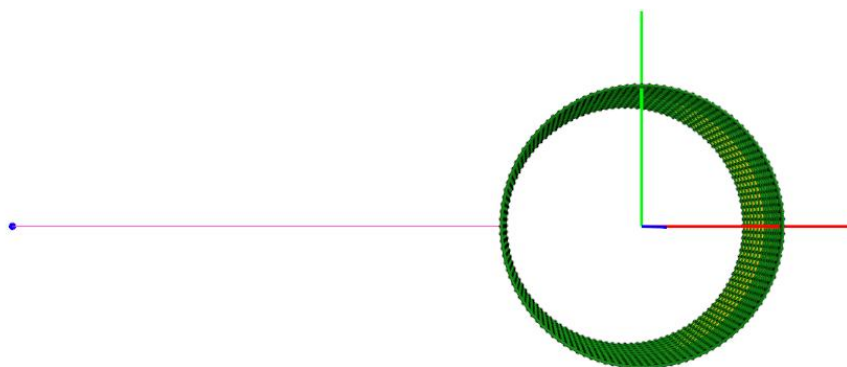


Figure 8 Truss established

All forces introduced to the cylinder now need to travel through the truss element. The end-node on the truss is restrained in all degrees of freedom, see Figure 9.

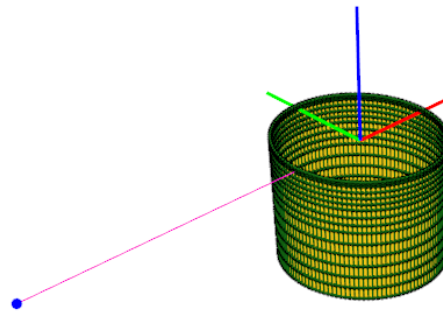
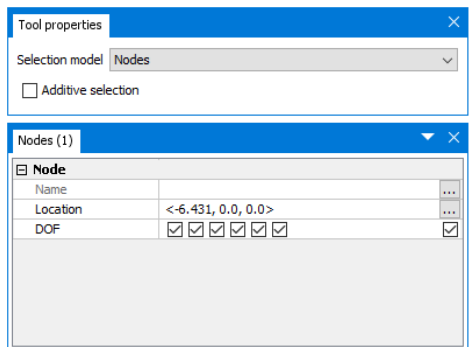


Figure 9 Analysis model, with end-node of the truss restrained

Then an analysis with current is run, parameters for the model and analysis is presented in Table 1.

Table 1 Main parameters for the model and analysis

Diameter, D [m]	2.86
Depth, H [m]	2.07
Drag area, A [m²]	5.92
Velocity, U [m/s]	0.10
Cd upstream	1.20
Cd downstream	0.50

The resulting axial force in the truss (drag force), with the specified input parameters is presented in Figure 10.

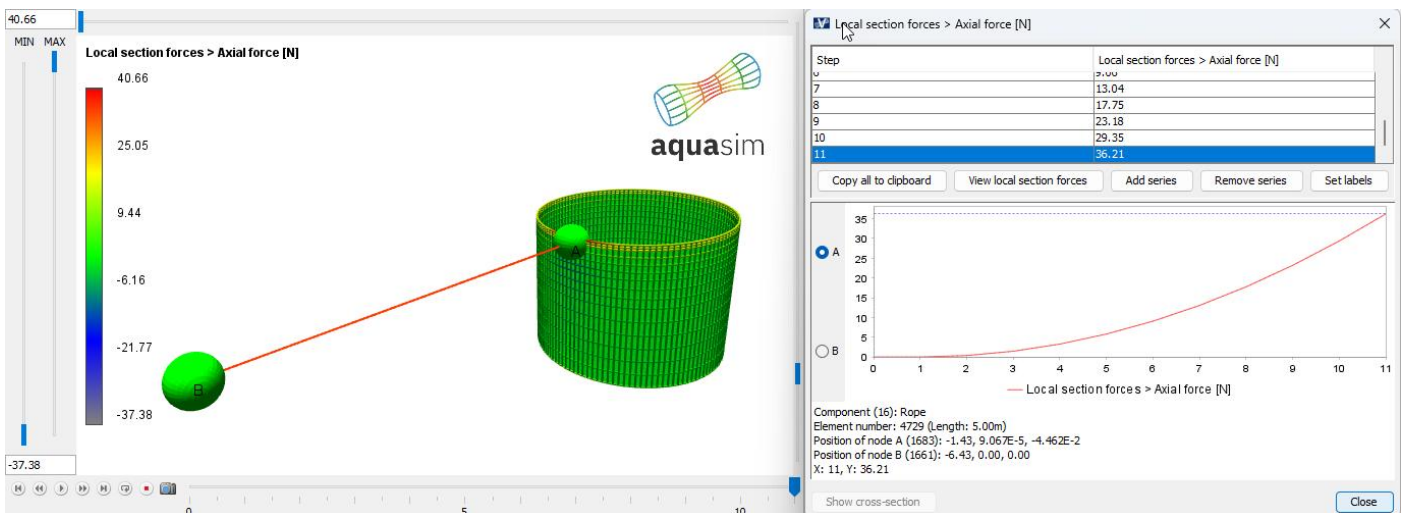


Figure 10 Axial force in the truss, from AquaView

The relation between the drag force F_D and drag coefficient C_d is:

$$F_D = C_d \frac{1}{2} \rho A U^2$$

Knowing the drag force from AquaView, one can calculate ‘backwards’ to find the equivalent drag coefficient for a cylinder. Applying different drag coefficients upstream and downstream, lead to the relation given in Table 2.

Table 2 Relation between panel drag coefficient and equivalent drag coefficient for a cylinder

Cd Upstream	1.20	0.80	1.00	2.00
Cd Downstream	0.50	0.50	0.50	0.60
Cd Cylinder definition	1.19	0.93	1.06	1.79

As seen from Figure 2, a C_d in front with half valued C_d for the back seems to correspond appropriately to C_d by cylinder definition.

4.2 Notes on the lift coefficient

Note that the definition of how lift forces are derived for impermeable nets, are described in section 3.2. This means it can be a good idea to investigate the lift for each panel to what is the total lift to a half-sectioned cylinder. A half-sectioned cylinder is modelled by cutting off half the model as applied in section 4.1. For the model-response not leading to any rotations, all nodes are restrained as shown in Figure 11. In addition, the truss-ends are restrained in all directions.

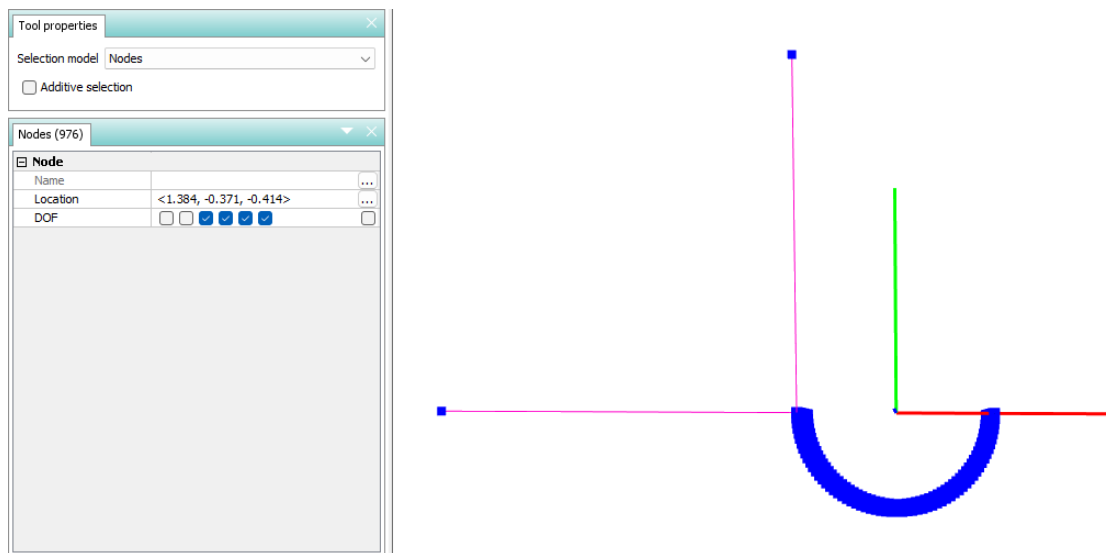


Figure 11 Analysis model for investigation of lift

Coefficients as shown in Figure 12 are applied.

Drag	
Drag coefficient upstream	1.0
Drag coefficient downstream	1.0
Skin friction coefficient	0.0
Lift coefficient	1.0

Figure 12 Lift coefficient equals 1.0

Analysis with current in x-direction, 0.1 m/s, is run. Resulting lift force for half cylinder is shown in Figure 13.

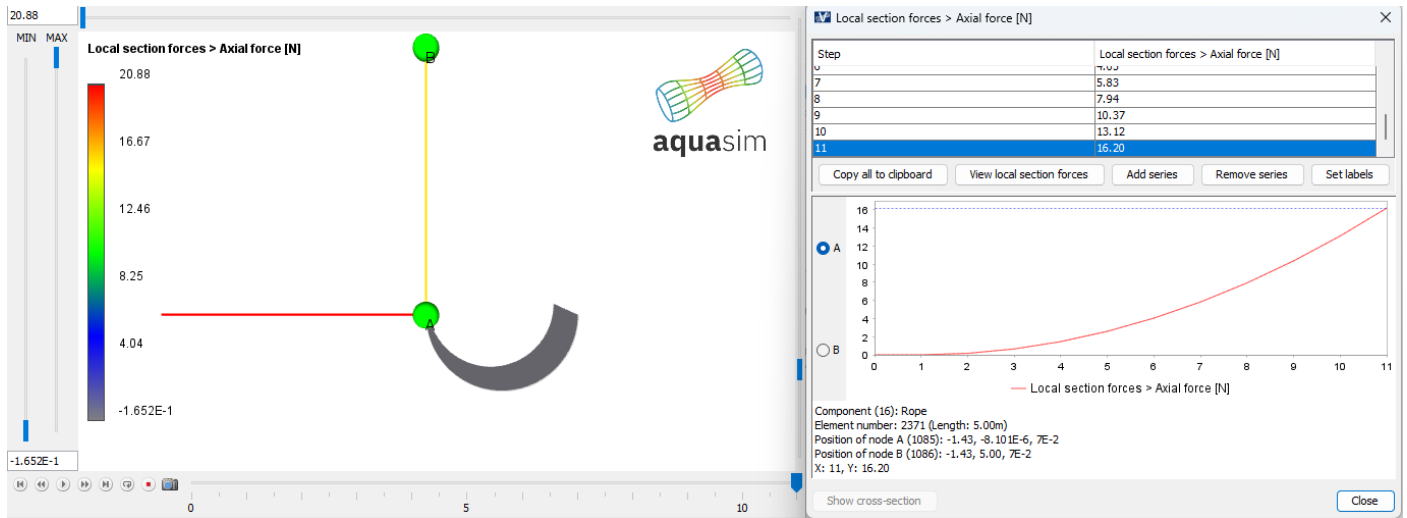


Figure 13 Resulting lift force for half cylinder, AquaView

As seen from Figure 13, the lift force is approximately 80% of the drag force, over half section with 1.0 in all coefficients (from Figure 12). From literature, blue curve in Figure 14, it is seen that theoretically the suction pressure at 90 degrees can be up to 3 times the drag.

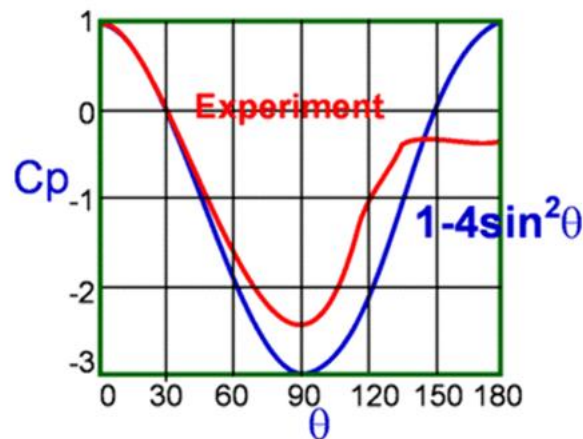


Figure 14 Pressure coefficient for 2D flow around a circle (Flow around a cylinder, 2024)

The integrated lift effect is the pressure multiplied with the direction vector in the range from 0 to 180 degrees. Hence, lift can be of importance to stretch out tarpaulins sideways. However, in real life that will depend on whether the fluid flows around the cylinder or under the cylinder. From Figure 15 it can be noted that likely more of the fluid will flow under the tarpaulin at high current velocities, than low current velocities.

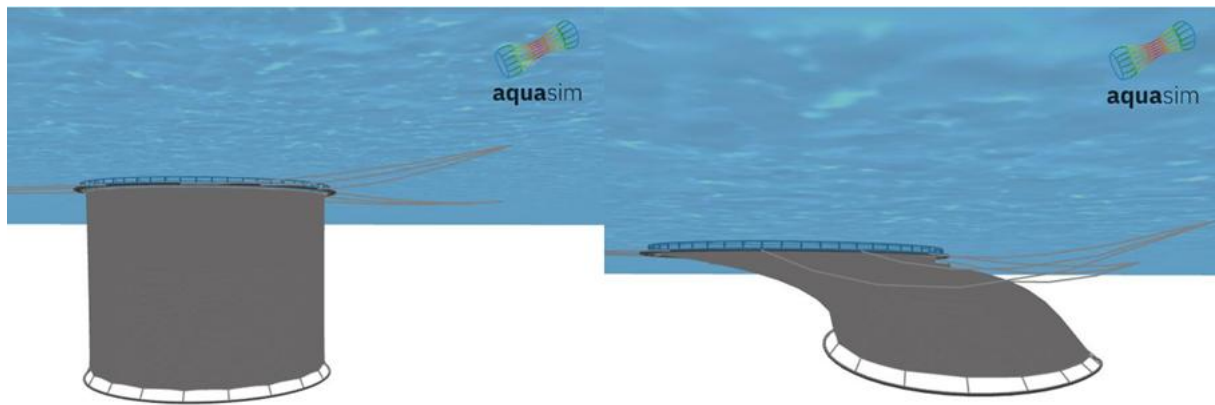


Figure 15 Tube/ life skirt at low vs. high current velocities

This means that in terms of applying a lift coefficient, there is a range that a realistic lift coefficient falls between. Estimates for this, rests on the engineer.

4.3 Notes on the skin friction coefficient (tangential drag)

The tangential drag coefficient describes the resistance due to flow sliding along the surface (skin friction). Although this effect is often smaller than drag normal to the structure, it can still contribute noticeably to the total load on the structure. For example, comparisons with a cylinder show that a tangential drag coefficient of 1.0 can contribute as much to total drag as the drag normal to the structure itself. This means that neglecting tangential drag can underestimate forces in some cases.

Table 3 shows the effect of total drag on a cylinder for the tangential drag coefficient, relative to the cross flow (i.e. normal direction) drag coefficient.

Table 3 Tangential drag coefficients, cross flow and total drag coefficient for a cylinder

Ct	0.00	1.00	0.00
Cd upstream	1.20	0.00	1.00
Cd downstream	0.50	0.00	1.00
CD cylinder definition	1.19	1.39	1.39

As seen from Table 3, a tangential drag coefficient of 1.0 contribute as much drag to the cylinder as a coefficient of 1.0 for the cross flow drag both on the front half and back half.

5 Analysis compared with tank testing

To validate how well the numerical model represents reality, the tube in this tutorial was tested in a towing tank (Aquastructures, 2024a). The forces measured in the physical tests were compared to AquaSim analyses using different sets of drag-, lift- and tangential coefficients. Results are compared in terms of axial force in the bridles as shown in Figure 16.

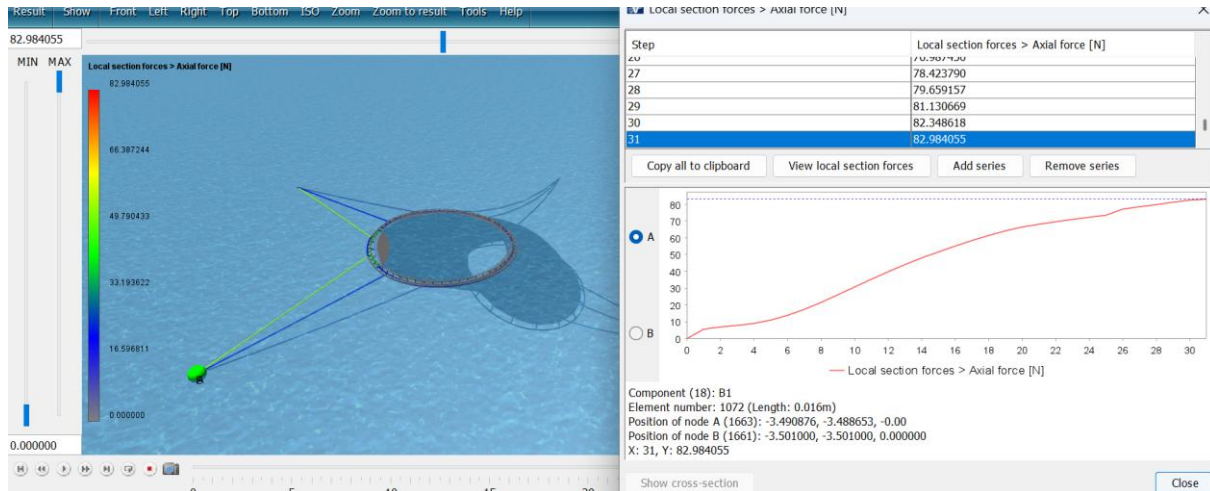


Figure 16 Axial force in bridles

The measured test data has been compared with analysis with a variation in drag coefficients, as seen in Figure 17.

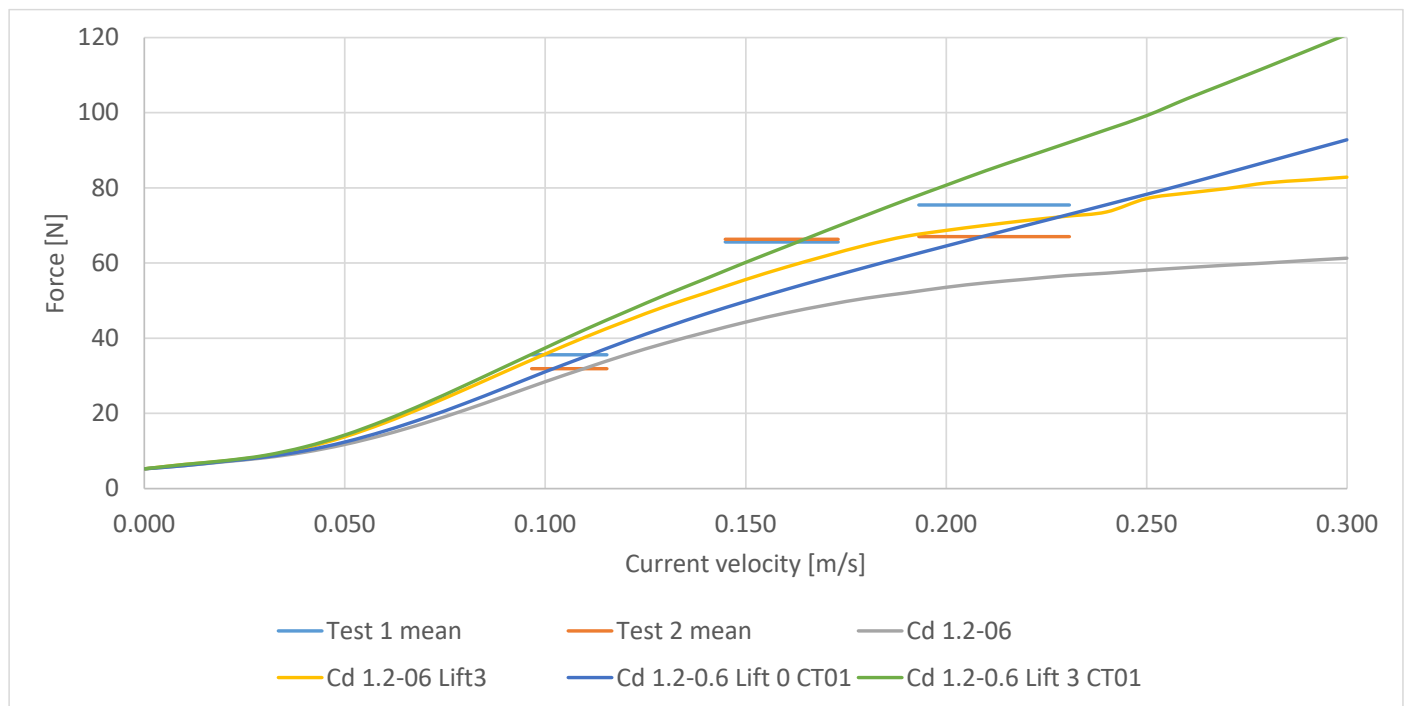


Figure 17 Test data compared with analysis

In Figure 17 we have that:

- Test 1 mean: Mean forces in test data #1

- Test 2 mean: Mean forces in test data #2
- CD 1.2-06: Analysis with C_d upstream 1.2, C_d downstream 0.6 $C_t = 0$, $C_l = 0$.
- CD 1.2-06 Lift 3: Analysis with C_d upstream 1.2, C_d downstream 0.6 $C_t = 0$, $C_l = 3$.
- CD 1.2-06 Lift 3 CT01: Analysis with C_d upstream 1.2, C_d downstream 0.6 $C_t = 0.1$, $C_l = 0$
- CD 1.2-06 Lift 3 CT01: Analysis with C_d upstream 1.2, C_d downstream 0.6 $C_t = 0.1$, $C_l = 3$.

From this figure we see how forces vary depending on current velocity and how coefficients are set. The set of coefficients in Figure 18 has been used for visual comparison to test photo. These are presented in Figure 19-Figure 21.

☐ Drag	
Drag coefficient upstream	2.0
Drag coefficient downstream	1.0
Skin friction coefficient	0.0
Lift coefficient	3.0

Figure 18 Coefficients for analysis compared visually with test photos

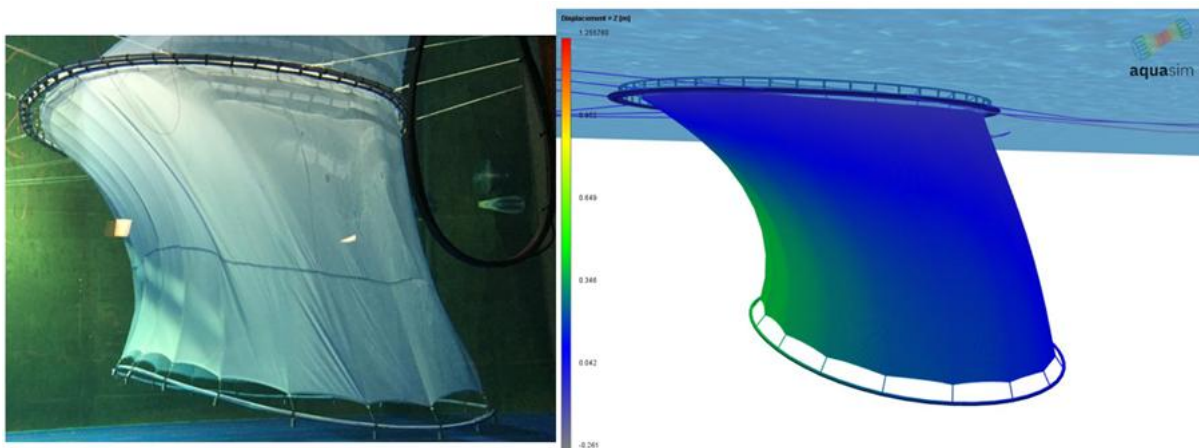


Figure 19 Current velocity 0.097 m/s

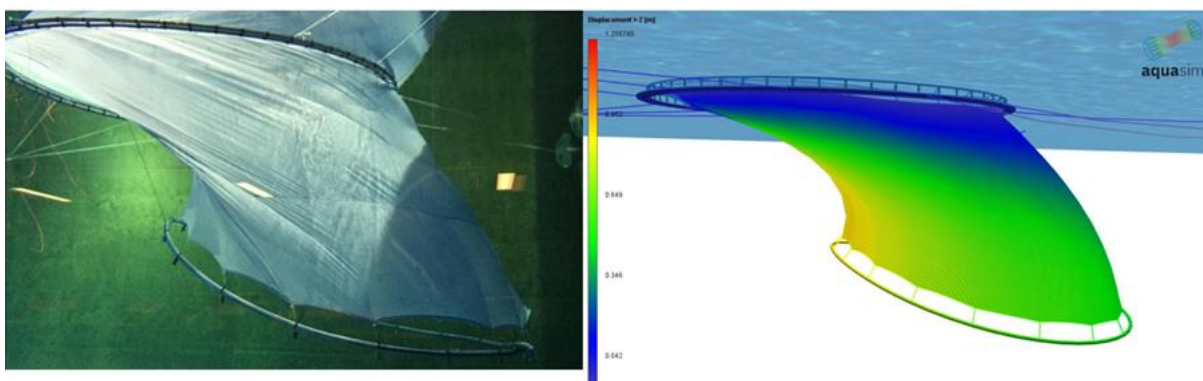


Figure 20 Current velocity 0.145 m/s

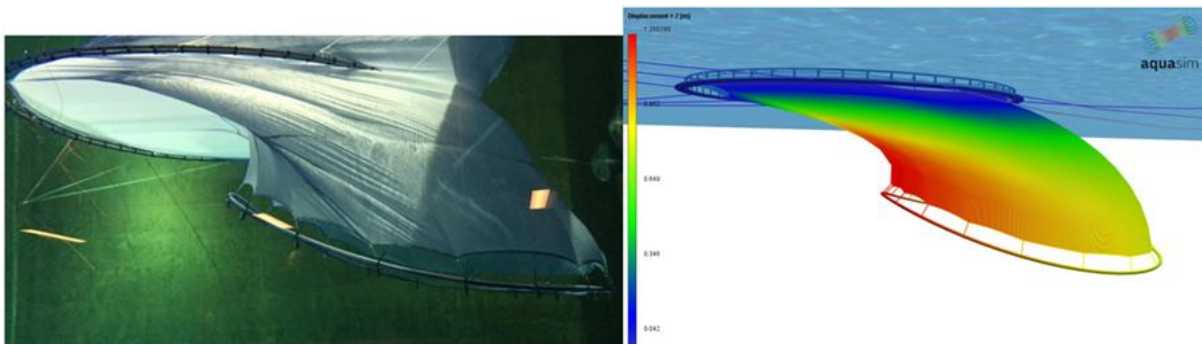


Figure 21 Current velocity 0.193 m/s

The comparison highlights a few important points:

- **Choice of coefficients matter:** changing C_d , C_l or C_t leads to noticeably differences in predicted forces.
- **Calibration improves accuracy:** by adjusting coefficients within reasonable ranges, the numerical model can be brought closer to the experimental measurements.
- **Lift can play a role:** including lift in the analysis improves agreement with the test data in certain cases, showing that sideways forces should not always be neglected.
- **Sensitivity is expected:** small changes in coefficient values can shift the results. This is expected and underlines the importance of performing sensitivity studies.

What we can learn from this: numerical analysis with AquaSim is fully capable of predicting loads on impermeable nets, but it depends heavily on applying appropriate coefficients. Comparing with experimental data helps calibrate the model, and testing different coefficient values ensures reliable results.

6 Summary

In this tutorial we have seen how current loads on impermeable nets, such as lice skirt, can be described in AquaSim using drag- lift- and tangential drag coefficients. These coefficients are not fixed numbers that will cover all types of structures, but are strongly influenced by factors such as object shape, surface roughness, flow speed and whether the flow is steady or unsteady. Because of this, they are typically taken from experiments, model tests or reliable databases, rather than derived purely from theory.

The worked examples demonstrate how different choices of coefficients can significantly change the predicted loads and how these predictions compare to tank test data. This emphasizes the importance of calibration against experiments and to perform sensitivity studies to ensure that results are reliable.

Overall, the use of drag-, lift- and tangential coefficients provides a practical framework for including complex fluid-structure interactions. Looking ahead, further validation with full-scale measurements and applications to other types of impermeable structures will help refine coefficient choices and broaden reliability of this approach.

7 References

Aquastructures. (2024a). *Loads on Impermeable Nets and Large Volume Objects in AquaSim*. TR-FOU-2328-5 Revision no. 6.

Flow around a cylinder. (2024, 01 26). *Aerodynamics for students*. Hentet fra Retrieved from Figure 4.31A: http://wwwmdp.eng.cam.ac.uk/web/library/enginfo/aerothermal_dvd_only/aero/fprops/poten/nod

8 Revision comments

Revision no.	Comment
1.0	First publication

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