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Computational Fluid Dynamics

Project assignment

Hydroflux AB

-Design of small scale wind tunnel

Version 1.0

1. Problem specification

Hydroflux AB is a company that are planning to build a small-scale low speed wind tunnel (see CAD-geometry in Figure 1) based in the guidelines in references [1-4]. The tunnel is a prototype and is a first step towards a larger version. However, the small-scale version is not only a test prototype, it will also be used to investigate aerodynamic behavior of small objects by measuring flow profiles, drag and lift forces.

Before Hydroflux proceed to build the wind tunnel and install all sensors necessary for their measurements they would like to use CFD-simulations to optimize the sensor geometries to minimize their interference with the main flow. However, since the company have no expertise in CFD, other than previous collaboration with staff at Umeå University, they have asked you for advice.

Hydroflux want you to investigate how a force plate sensor placed in the test section floor affects the turbulence in the wind tunnel, both near the sensor and in the bulk flow around it. If time allows it, they also would like to know how their smoke injector affect the main turbulence around it.

Since the project is limited in time Hydroflux understand that due to the computational load some of your detailed investigations might need to be done for 2D-cases, but a least for the empty wind tunnel they would like to get a 3D-evaluation of the flow.

Due to the previous collaboration with Umeå University, Hydroflux employee have got some understanding of the parameters in the *Standard* and *Low Re k-ε* model and they therefore want you to use this as a primary model. However, if you want to investigate a second model Hydroflux is open for that.

Hydroflux has made a draft CAD of the wind tunnel, see Figure 1, which is available for you as a starting point. The company welcomes suggestions of improvement of their wind tunnel system.

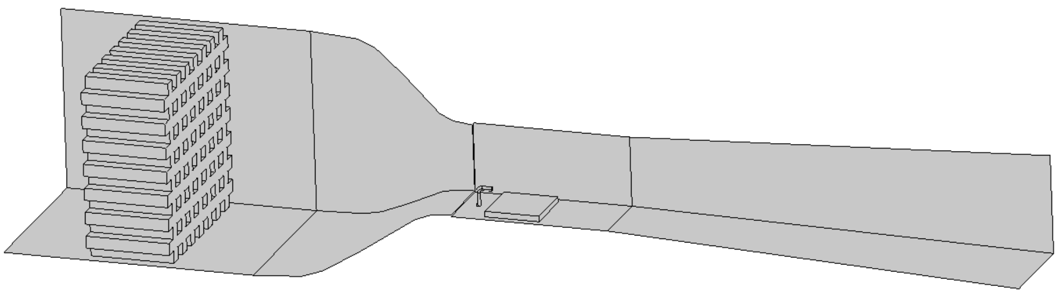

Figure 1. CAD sketch of proposed wind tunnel, top and front sides not shown for clarity.

2. System specification

Hydroflux small scale wind tunnel specifications are based on the guide-lines found in reference [1-4] together with constraints such as available space for the tunnel, cost and type of application. Figure 2 shows a general 3D-view of the proposed wind tunnel (not in scale). However, the real tunnel has a square cross-section with a varying area along the flow direction.

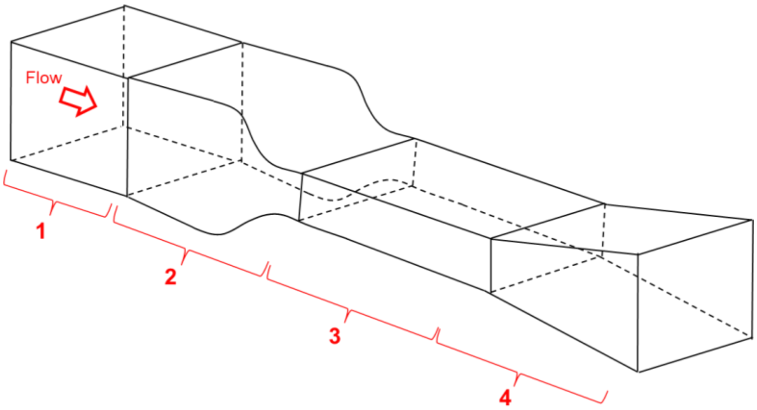

Figure 2. Illustration of the test section (not in scale) with flow direction left to right. 1) Settling chamber, 2) Contraction, 3) Straight channel, 4) Diffuser. Dimensions are specified in Table 1.

2.1 Dimension specification

Hydroflux is aiming for a flow straightener and screens which together produces a homogeneous turbulence with maximum intensity of 5%. The curved shape of the contraction in section 2 is specified by a Matlab script developed from guide-lines in references [1-4], see Appendix.

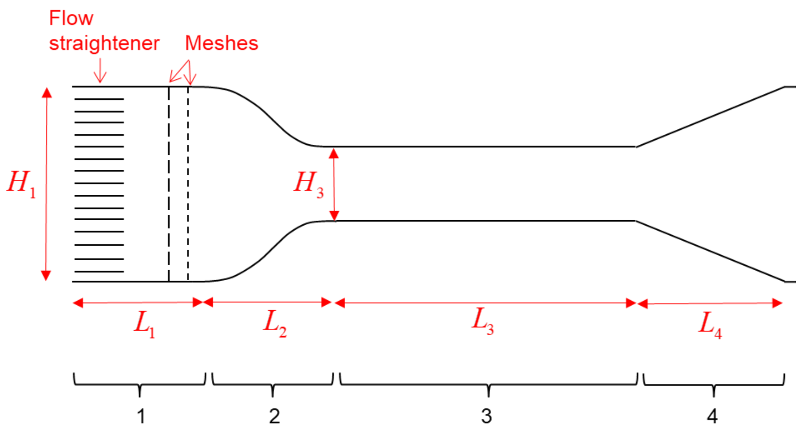

Figure 3. Side view illustration of the test section (not in scale) with flow direction left to right. 1) Settling chamber, 2) Contraction, 3) Test section, 4) Diffuser. Dimensions are specified in Table 1. The shape of section 2) can be found in Appendix.

Table 1. The dimensions of section 1-4 in the wind tunnel (see Figure 2-3)

Dimension	Size [mm]	Comment
L1	180	Length of settling chamber
L2	130	Length of contraction
L3	110	Length of test section
L4	300	Length of diffuser
H1	130	Height of inlet to the settling chamber
H3	50	Height of inlet to test section
W	130	Width of settling chamber

2.2 Injector and force sensor specification

The injector is placed in the test section and has two purposes, to insert visualization smoke in a narrow region in the flow, and to be used as guiding tube for an optical fiber with a small lens attached at its end. The optical fiber is be connected to an external camera and gives possibility for give close up inspections of the flow.

The force sensor is a removable block placed in the test section that measures the forces on an object put on top of it.

The dimensions of the injector and the force sensor are specified in Figure 4 and Table 2.

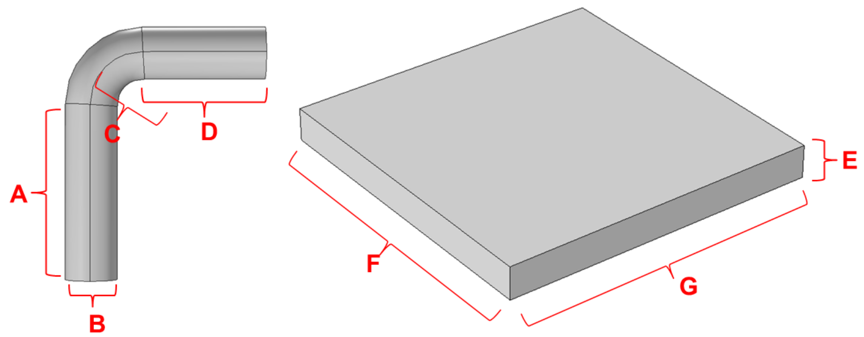

Figure 4. Illustration of the Injector and the force sensor. The dimensions A, B, etc are specified in Table 2.

Table 2. The dimensions of the injector and the force sensor.

Dimension	Size [mm]	Comment
A	10	Injector vertical length
B	3	Injector diameter
C	3	Injector bend radius
D	10	Injector horizontal length
E	4	Force sensor height
F	39	Force sensor depth
G	39	Force sensor length

2.3 Flow specification

The flow parameter values for the wind tunnel are specified in Table 5.

Table 3. Specification of the flow parameters used in the wind tunnel system.

Parameter	Value	Comment
Density	$1.184\,kg/m^3$	Air 25°
Dynamic viscosity	$18.5\cdot 10^{-6}\ Pas$	Air 25°
Flow rate	$0.05\,m^3/s$	Determined by the choice of fan used to drive the flow
Turbulence intensity after settling chamber	1-5 %	Depends on flow straightener, choice of screens, and the number of screens.

References

[1] L. Cattafesta, C. Bahr and J. Mathew, "Fundamentals of Wind-Tunnel Design", Encyclopedia of Aerospace Engineering, ISBN: 978-0-470-686652010, 2010.

[2] J.E. Sargison, G.J. Walker and R. Rossi, "Design and calibration of a wind tunnel with a two dimensional contraction", 15th Australasian Fluid Mechanics Conference, 2004.

[3] E.-S. Zanoun, "Flow characteristics in low-speed wind tunnel contractions: Simulation and testing", Alexandria Engineering Journal, 57, 2265-2277, 2018.

[4] S. Mauro, S. Brusca S, R. Lanzafame, F. Famoso, A. Galvagno and M. Messina M, "Flow characteristics in low-speed wind tunnel contractions: Simulation and testing", Alexandria Engineering Journal, 57, 2265-2277, 2018.

Appendix

The shape of the contraction section (see Figure 2-3) is determined by a sixth order polynomial and some restrictions on the curvature [2]. To test different shapes in simple way Hydroflux has put together a short Matlab-script, see below.

```
clear all
%Design of wind tunnel contraction shape based on the following two papers:
% [1] "Design and calibration of a wind tunnel with a two dimensional
% contraction", J.E. Sargison, G.J. Walker and R. Rossi, 2004
% [2] "Flow characteristics in low-speed wind tunnel contractions: Simulation and
% testing", Alexandria Engineering Journal (2018) 57

% Following [1] a sixth orde polynom is chosen as shape model for a
% 2D-contraction with inlet crossection Di*W, outlet crossection Do*W:
% y=a*x^6+b*x^5+c*x^4+d*x^3+e*x^2+f*x+g

% From [2] the recommendation of contraction number CR is between 6-12
% and the contraction length L is between 0.75*Di and 1.25*Di
% CR is chosen to 5, i.e. CR=(Di*W)/(Do*W)=5
% and the contraction length is chosen to L=Di
% Model 3 in [1] is chosen, i.e xi/L=0.6 and alpha=0, where xi is the
% inflexion point along contraction axis and alpha is the inlet curvature.

CR=7;
Do=0.050; %50mm
Di=sqrt(Do^2*CR);
L=1.0*Di;
xi=0.6*L;
h=1*(Di/2-Do/2);

% The constratints on the shape model is the following:
% x=0:  y(0)=h, y'(0)=0, y''(0)=0
% x=L:  y(L)=0, y'(L)=0, y''(L)=0
% x=xi: y''(xi)=0

% When the constraints are applied we obtain a system of equations
% for the coefficients a,b,c,d in terms of L and xi, and that g=h, f=e=0.
% The system looks like Asys*Coeff=B:

Asys=[30*xi^4 20*xi^3 12*xi^2 6*xi;
   L^6 L^5 L^4 L^3;
   6*L^5 5*L^4 4*L^3 3*L^2;
   30*L^4 20*L^3 12*L^2 6*L];
B=[0 -h 0 0]';

Coeff=linsolve(Asys,B);
a=Coeff(1); b=Coeff(2); c=Coeff(3); d=Coeff(4); e=0; f=0;g=h;

%Contraction shape model from [1]
x=[0:0.001:L];
y=a*x.^6+b*x.^5+c*x.^4+d*x.^3+e*x.^2+f*x+g;

%Plot shape
figure(1)
hold on
plot(x,y+Do/2,'b')
plot(x,-y-Do/2,'b')
xlabel('x'); ylabel('y'); axis equal
title(['CR=', num2str(CR), ', L/Di=',num2str(L/Di)])
```