Review of simulations for the wind accelerator project

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7 September 2021

Outline

- Review of previous work on simulations
- Wind tunnel results

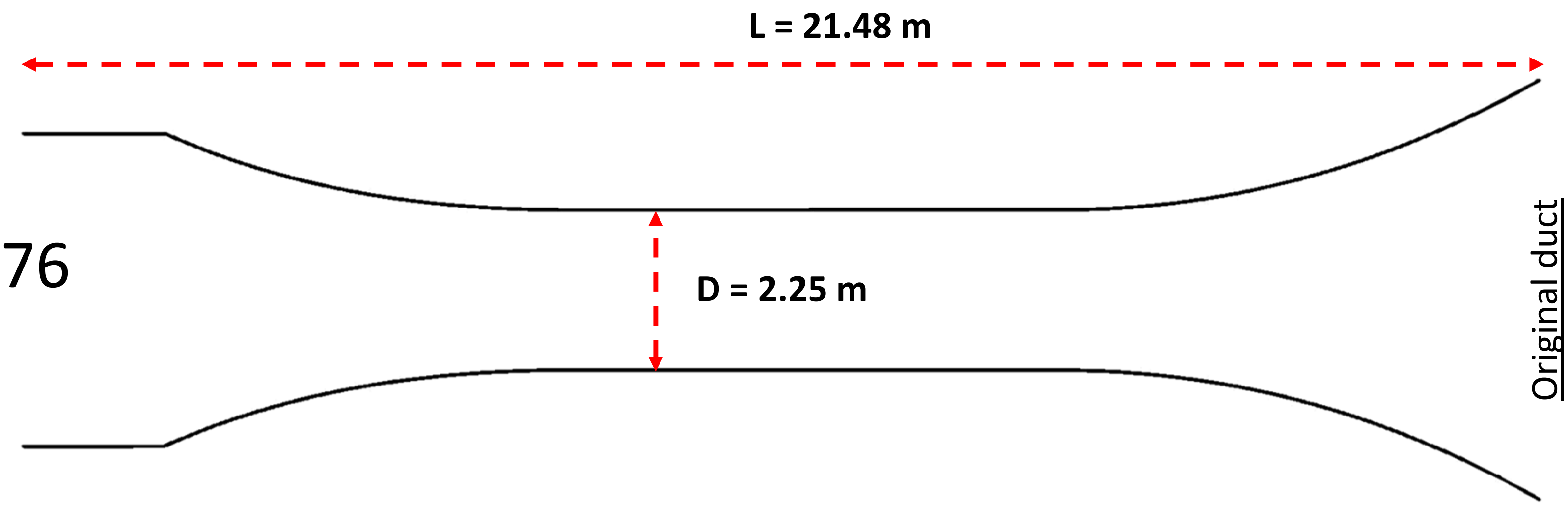
Outline: simulations

- Approach
- Original design
- Diffuser
- Flange
- Throat
- Nozzle
- Turbine
- Annual Energy Production

Approach

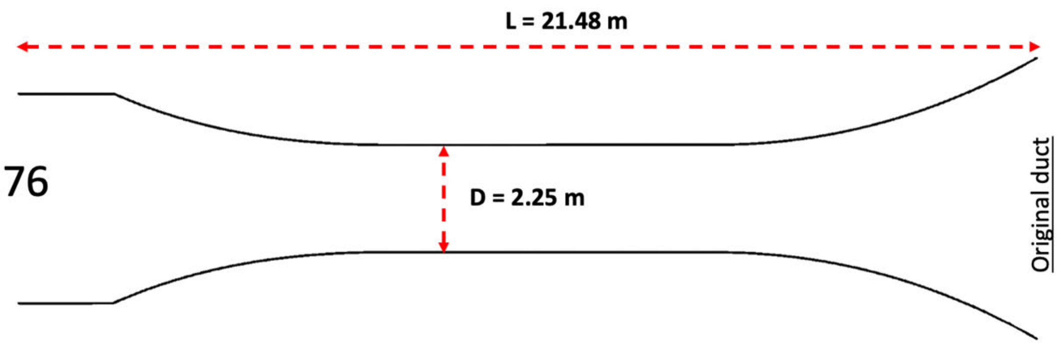
- A top-bottom design approach using > 400 CFD simulations
- Starting from the original design
- Aiming to increase the amplification factor and reduce the total size

AF = 1.76

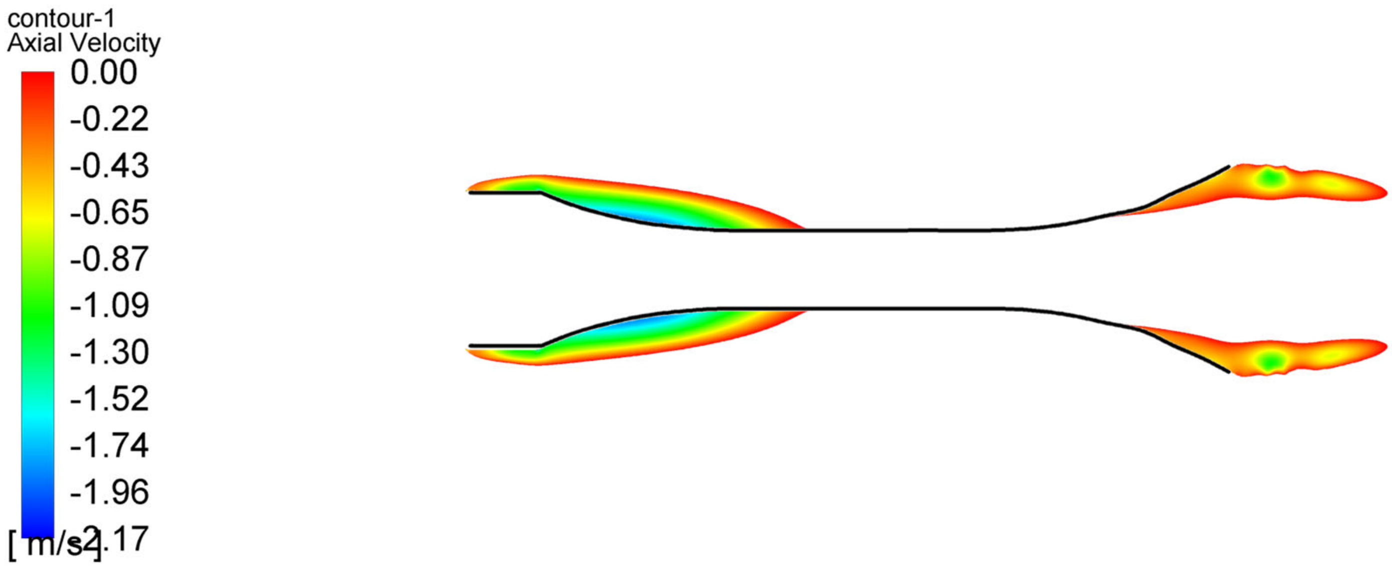


Original design

AF = 1.76

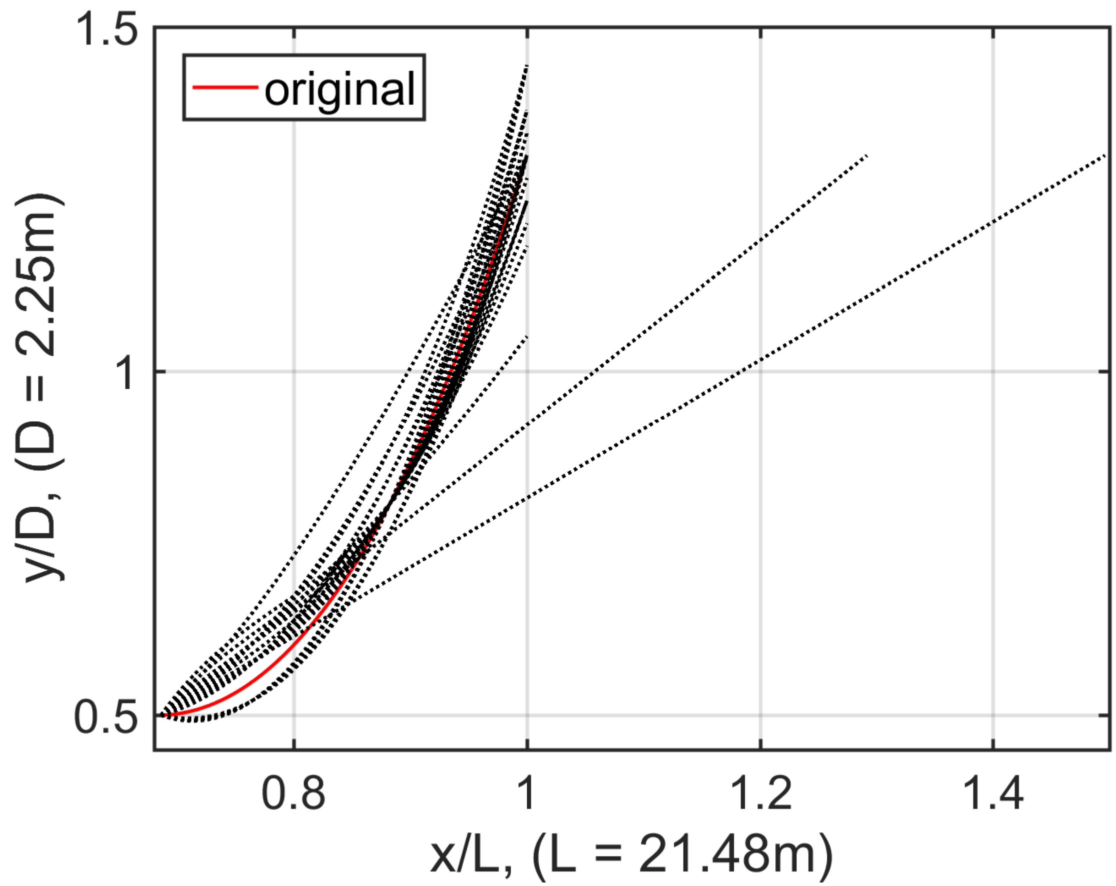


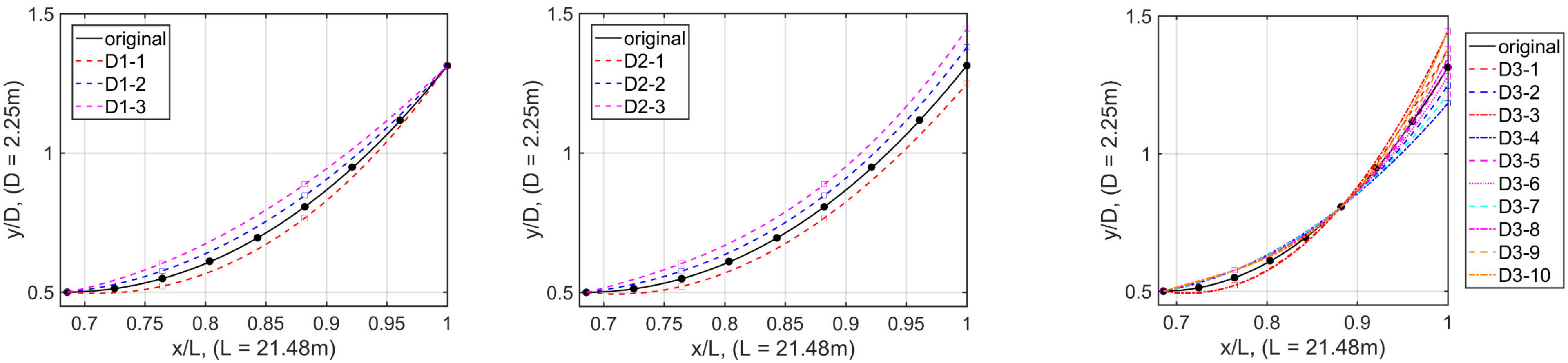
- Poor design



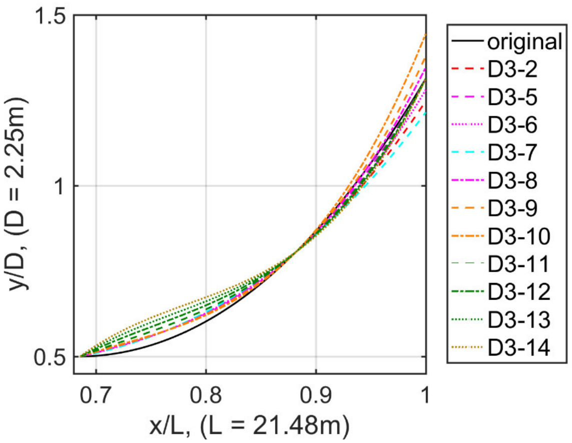
Diffuser

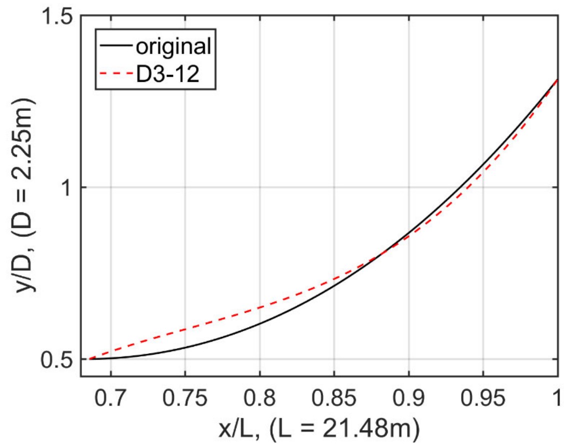
- > 30 different shapes



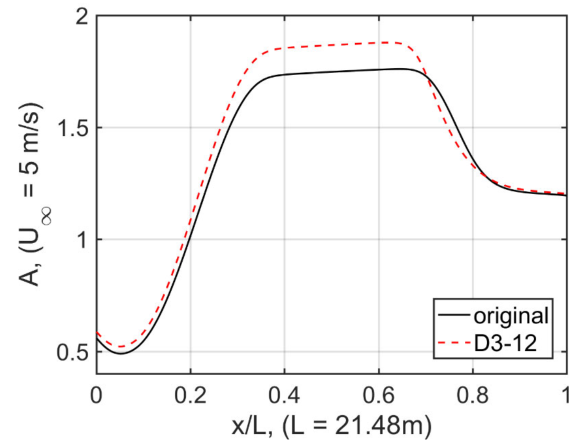


3 series of designs





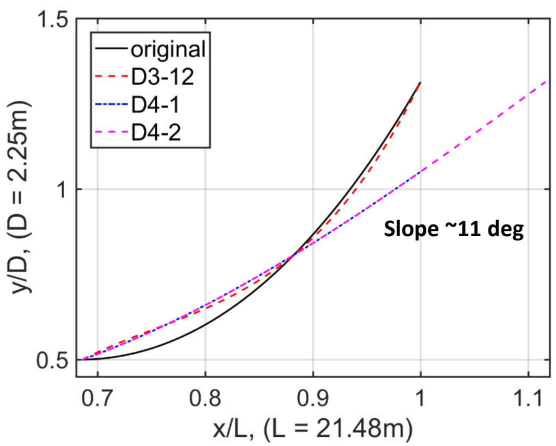
AF increases from 1.76 to 1.87

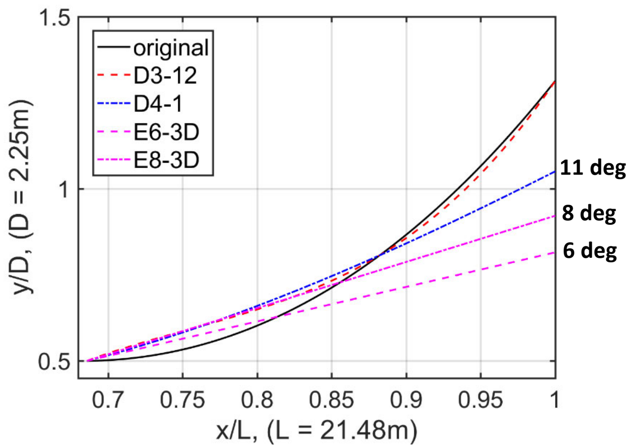


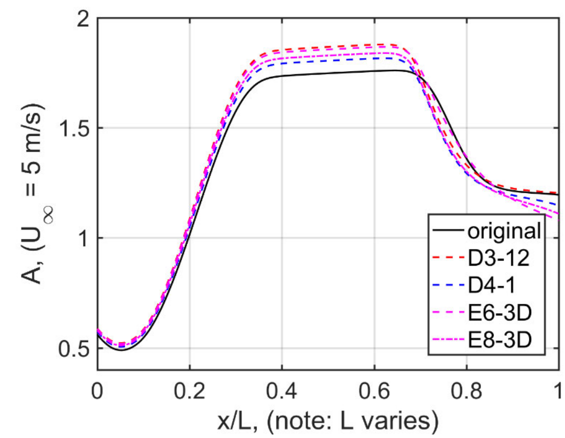
An increment of

6.7% in AF

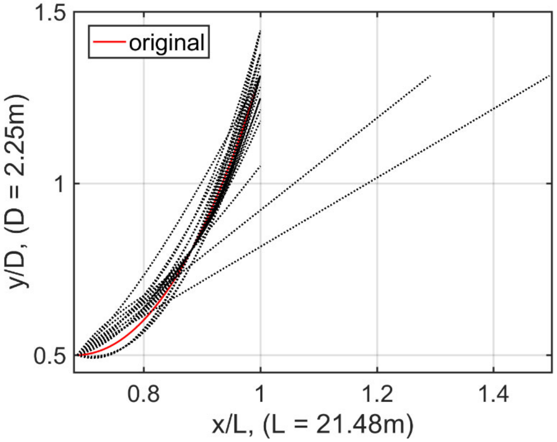
21.5% in power potential

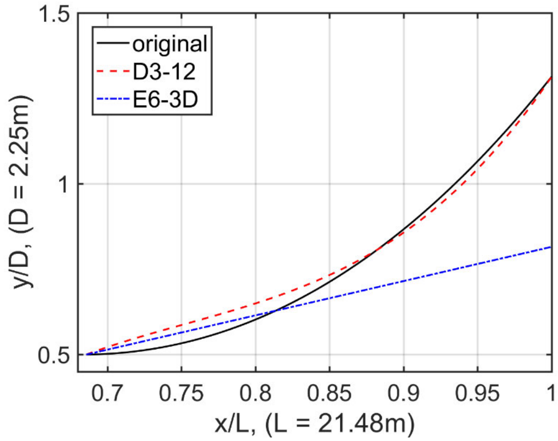


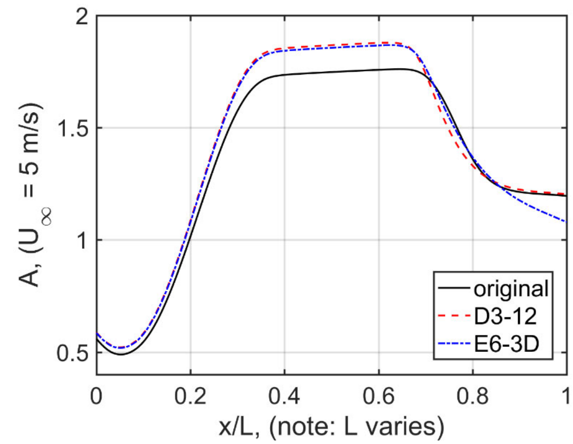


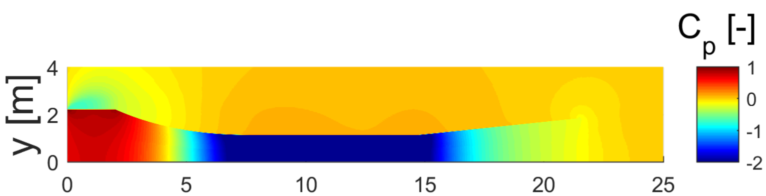


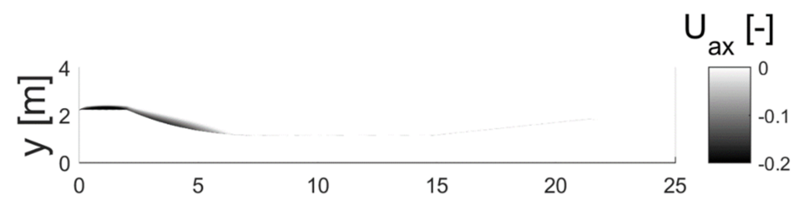
Diffuser fixed slopes were also tested











Selected diffuser shape: fixed slope of 6 deg

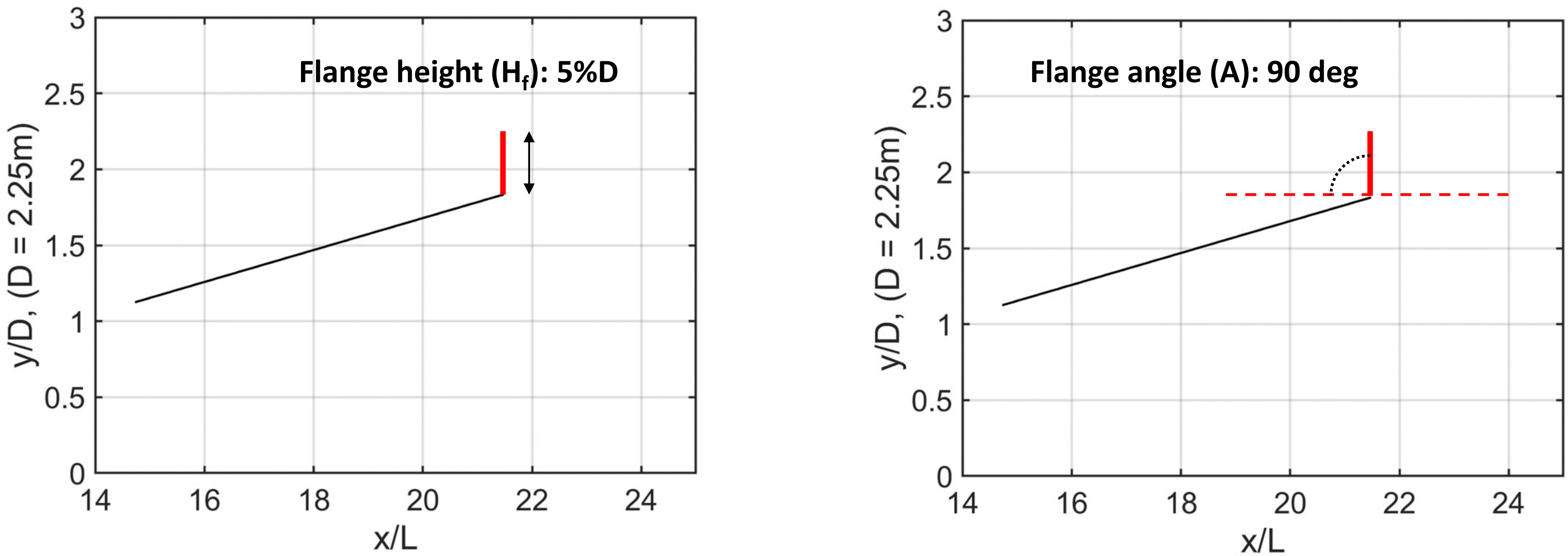
Reduction in cost: less material and manufacturing costs

Same length but less outlet area

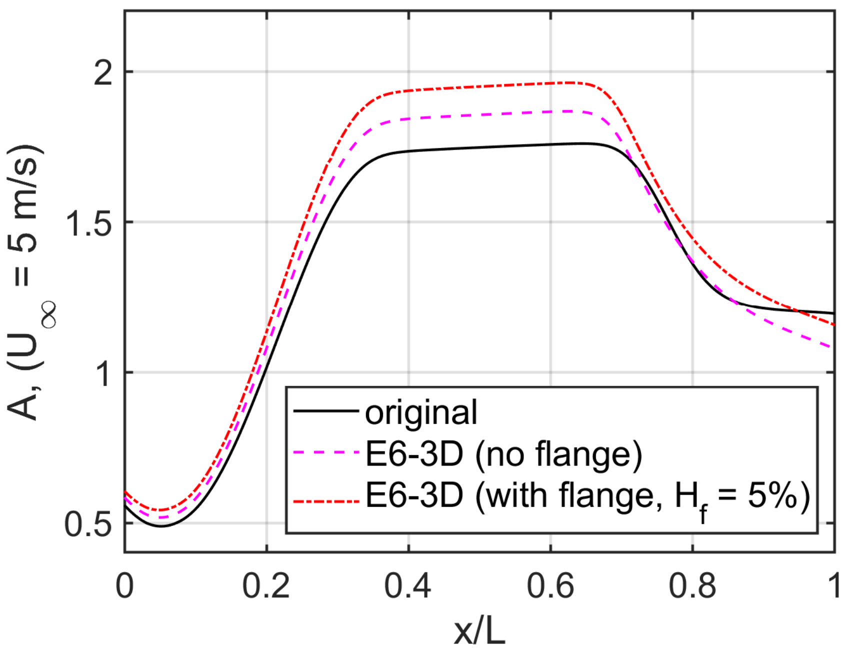
Flange

- Different flange length and angles

  Based on the selected diffuser shape



Flange: H_f = 5%D, A = 90°



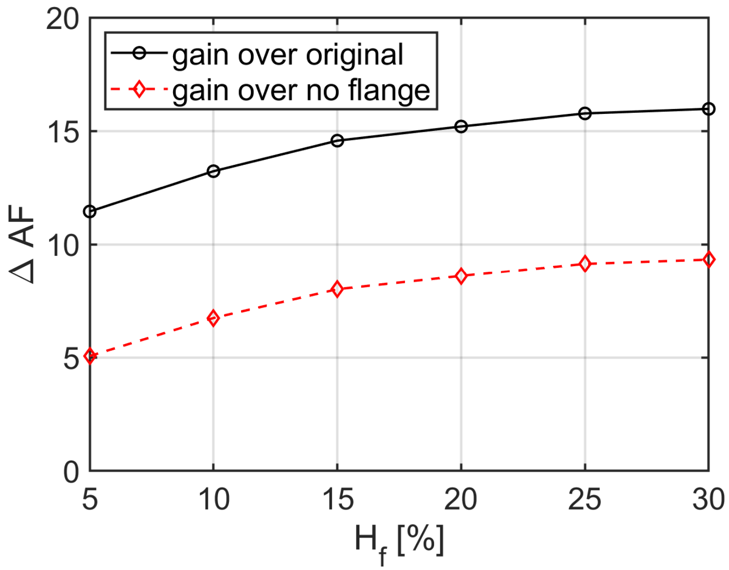
An increment of

- <u>11.5% in AF</u> with respect to <u>original</u>
- <u>38.4% in PD</u> with respect to <u>original</u>

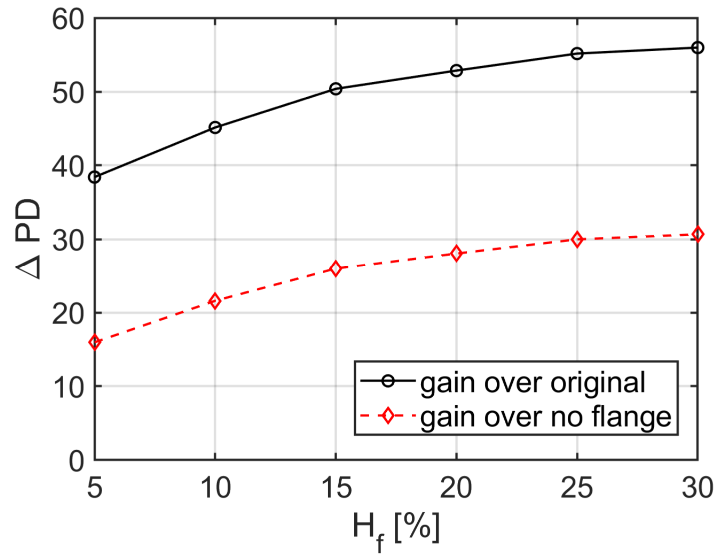
- <u>5.1% in AF</u> with respect to <u>no flange</u>
- <u>16.0% in PD</u> with respect to <u>no flange</u>

Impact of flange height

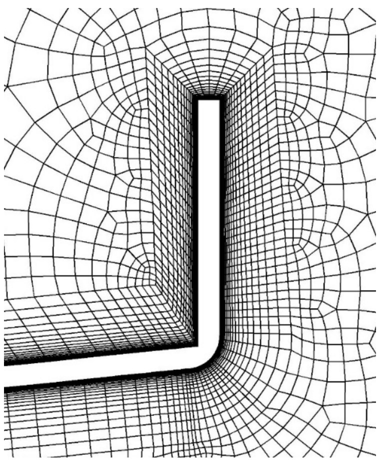
Asymptotic trend

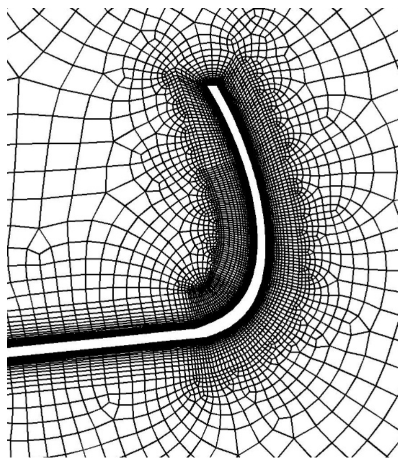


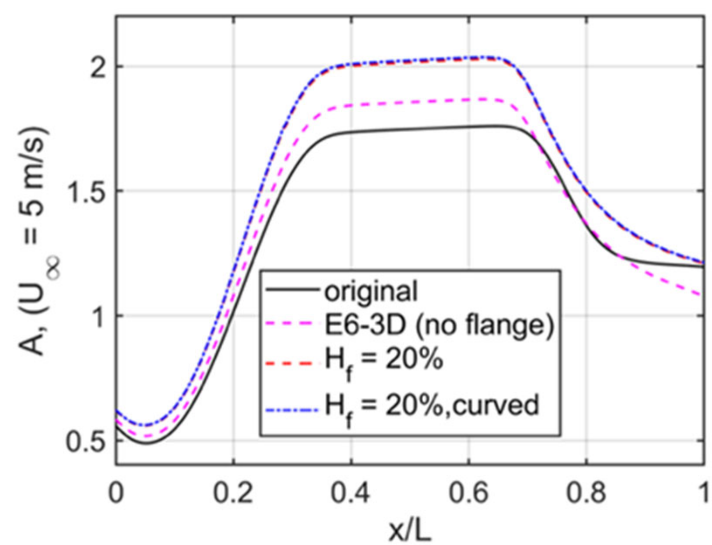
Asymptotic trend



Modified flange shapes

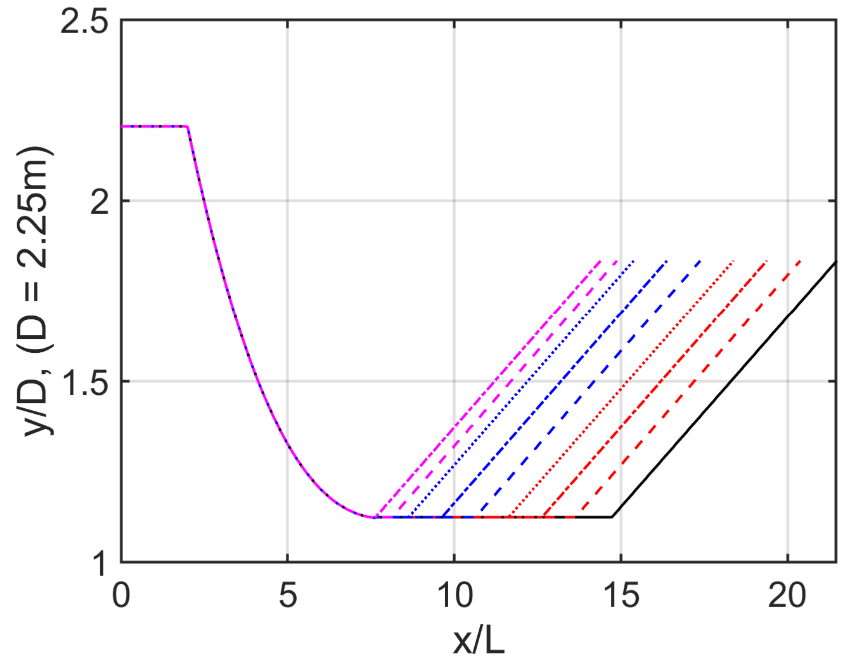




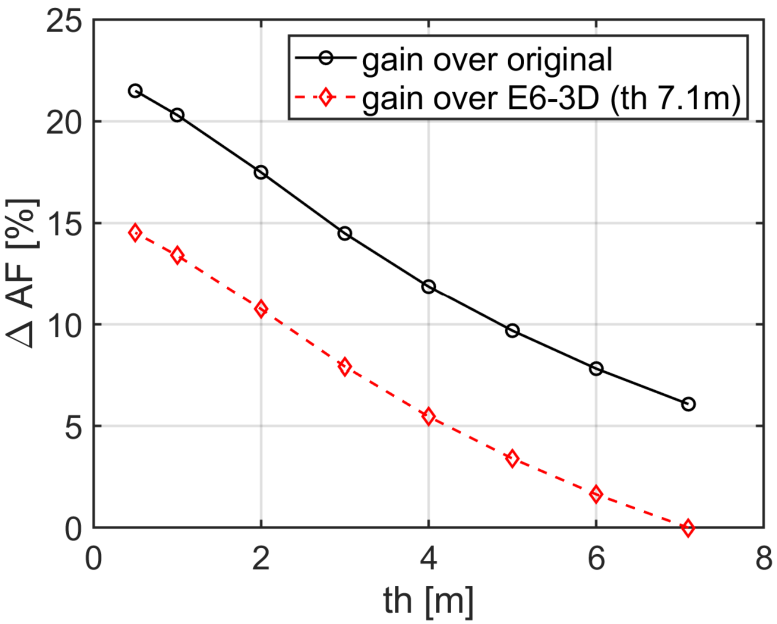


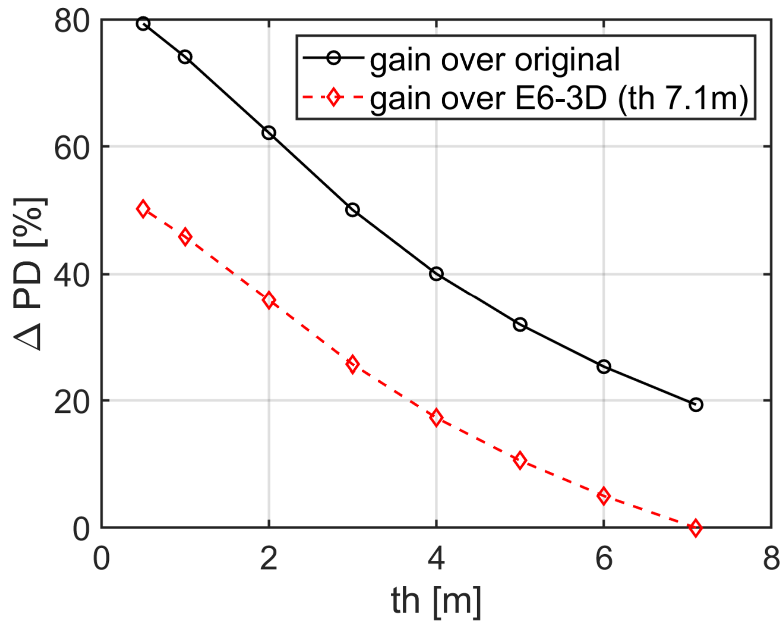
Throat length

- Various throat length:
- <u>8 different throat lengths</u>
- 7.1, 6, 5, 4, 3, 2, 1, 0.5 m

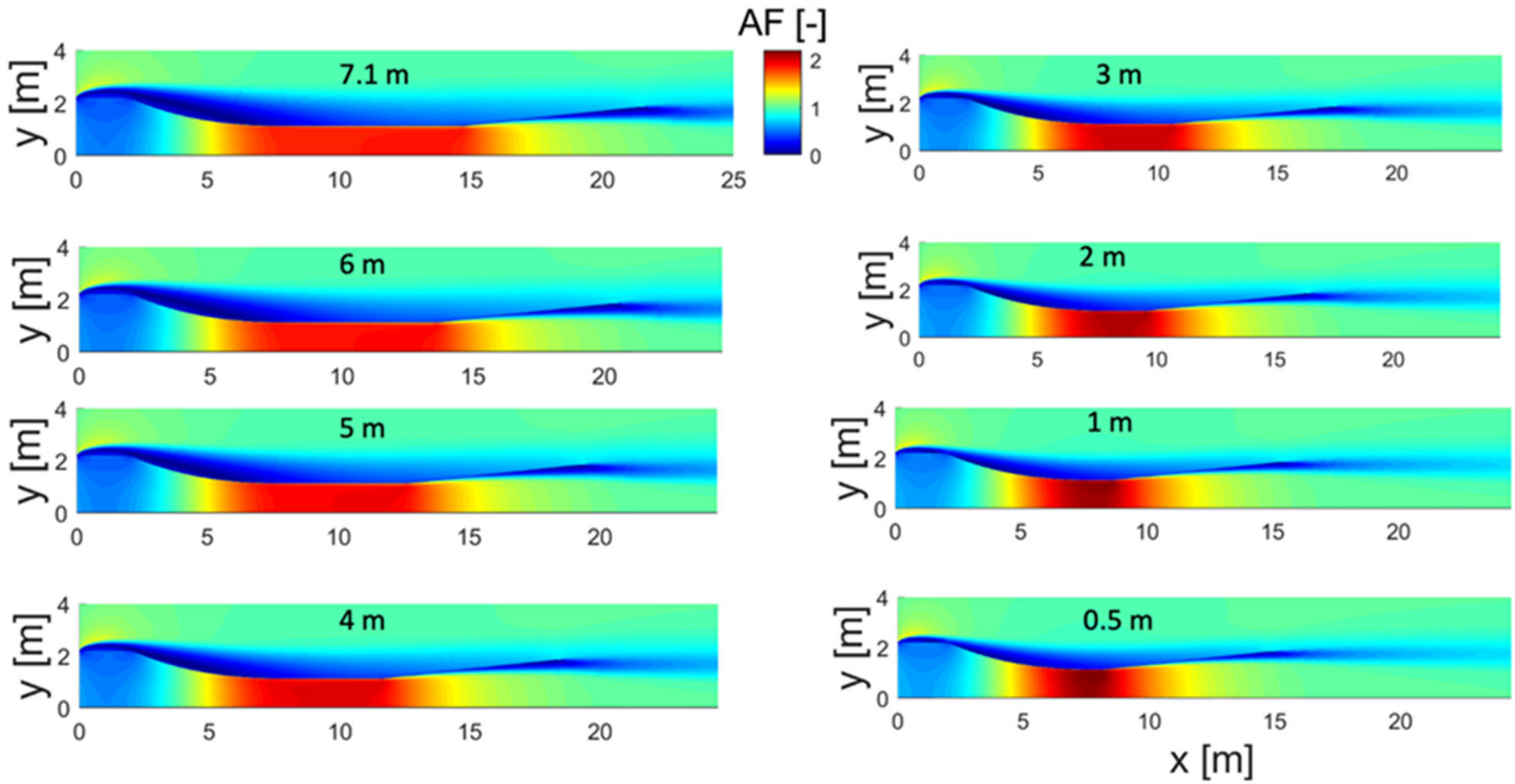


Impact of throat length

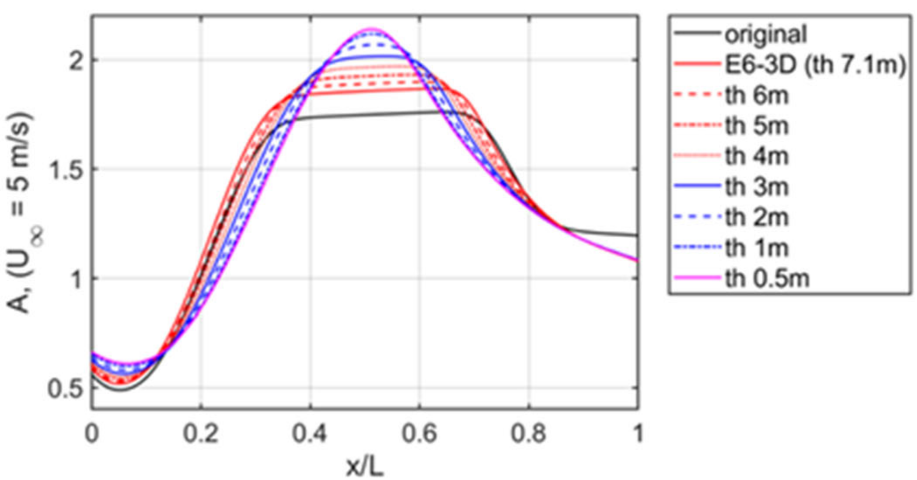


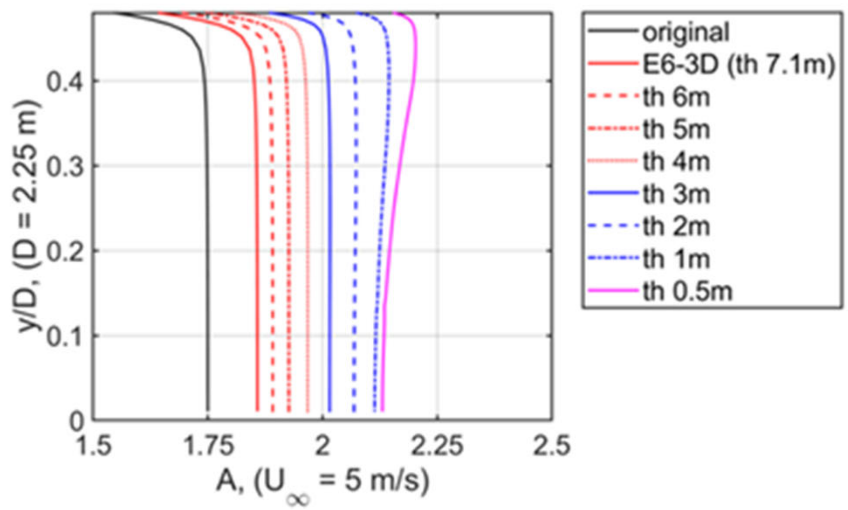


Impact of throat length

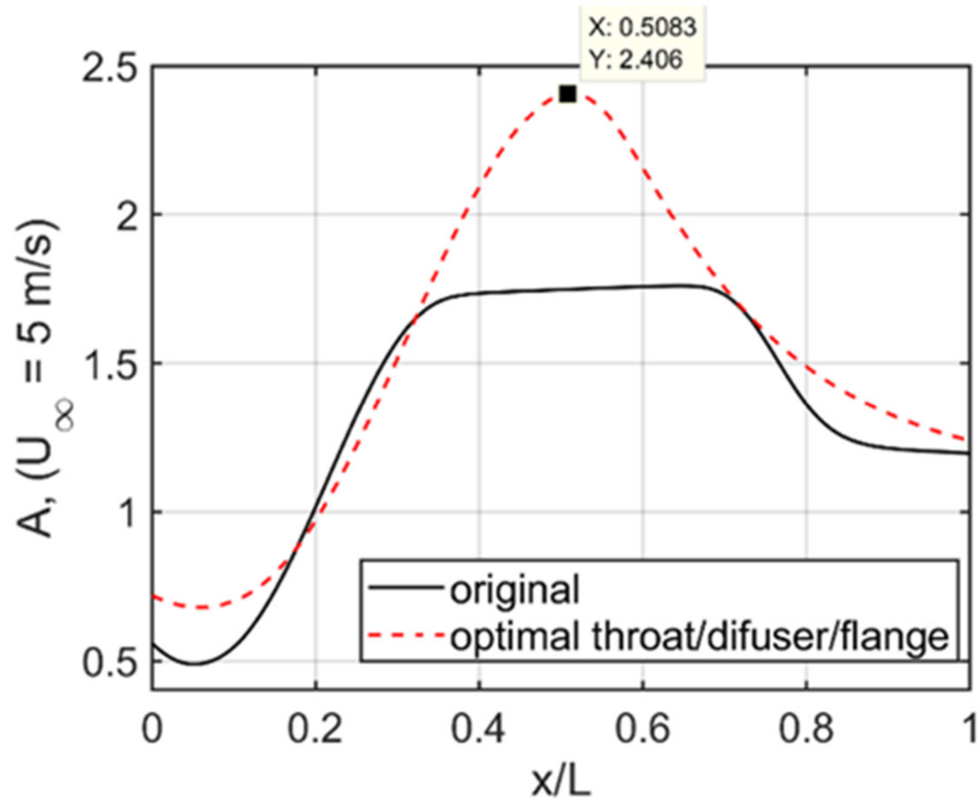


Impact of throat length



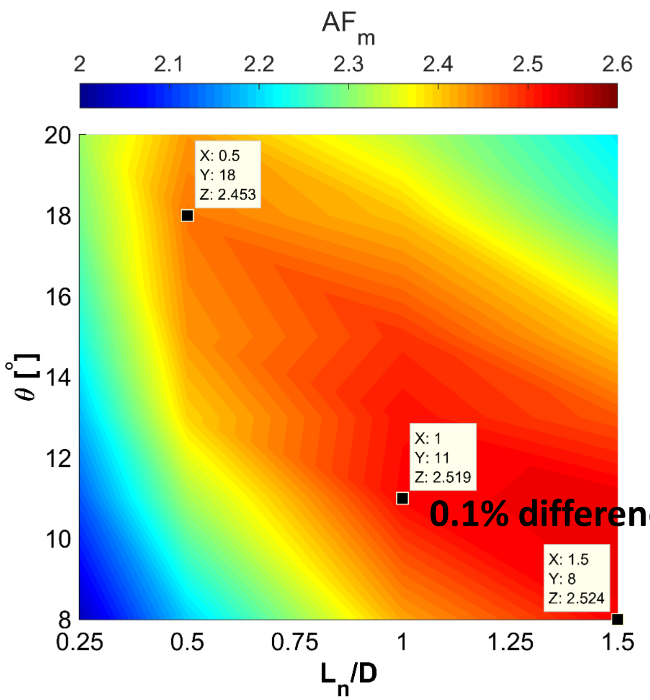


Impact of throat length with flange

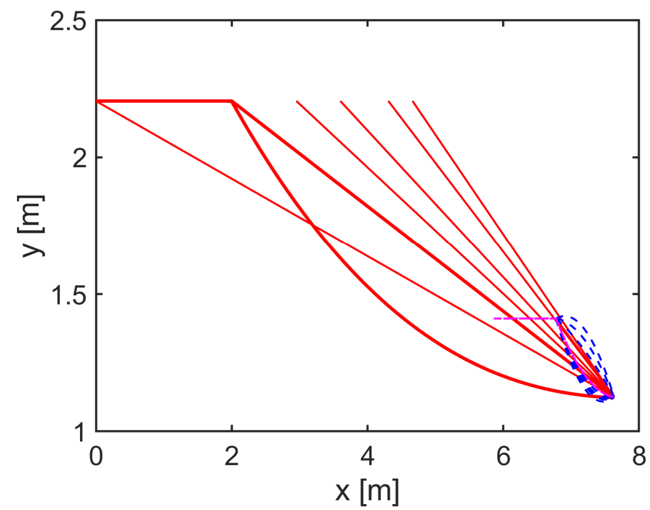


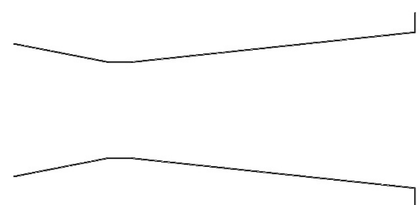
Nozzle

- Nozzle length, angle and curvature



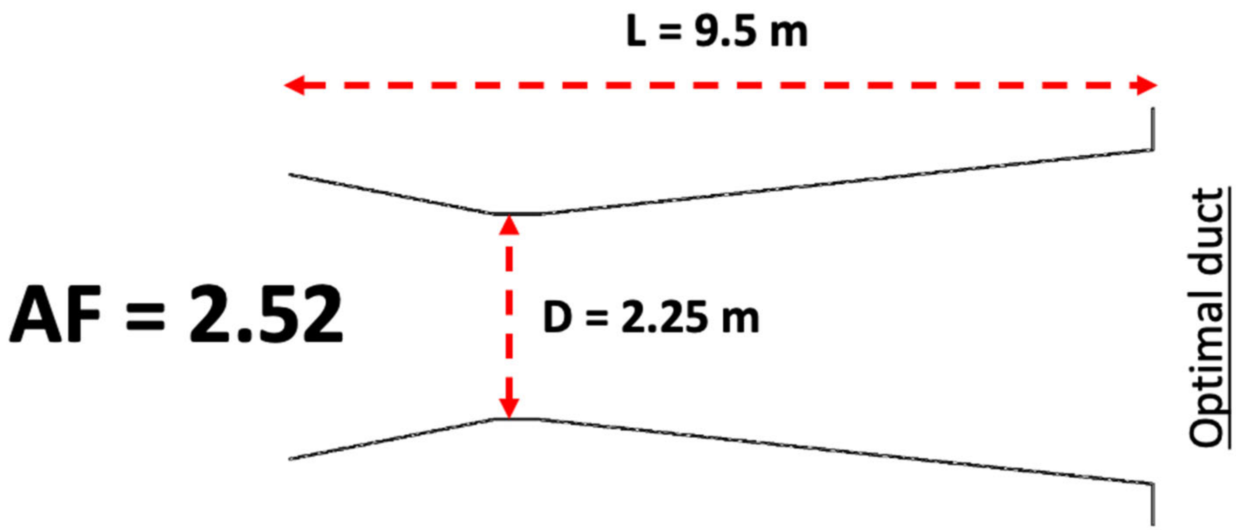
0.1% difference



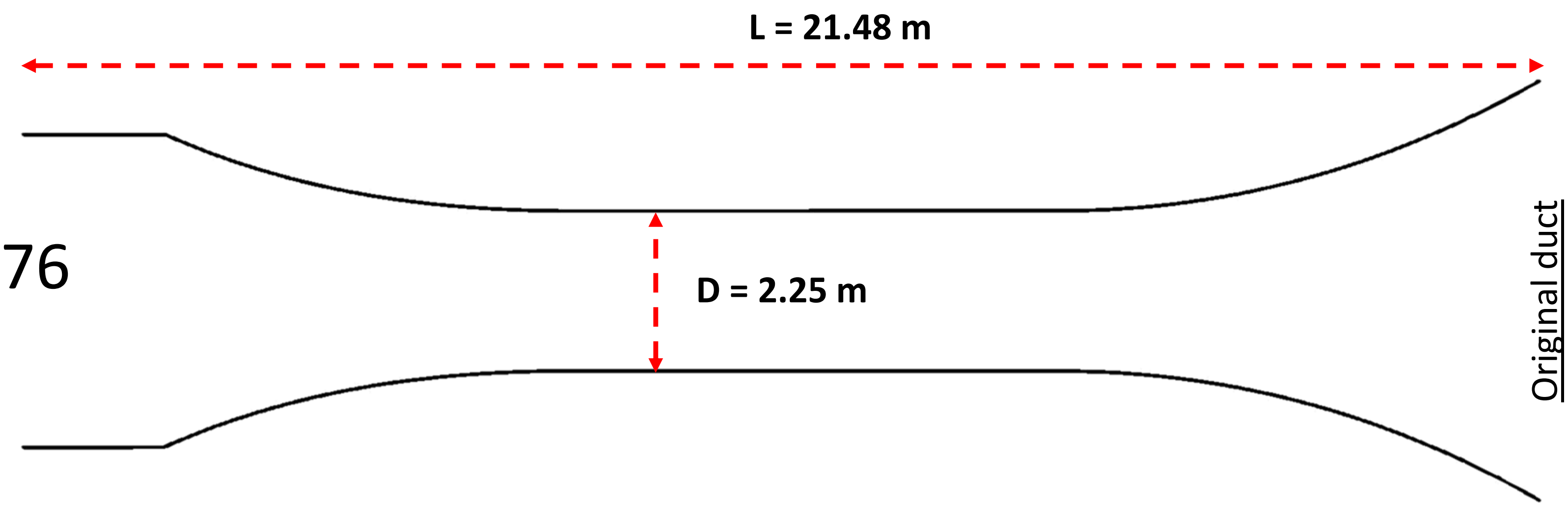


Length 1D
Angle 11 deg

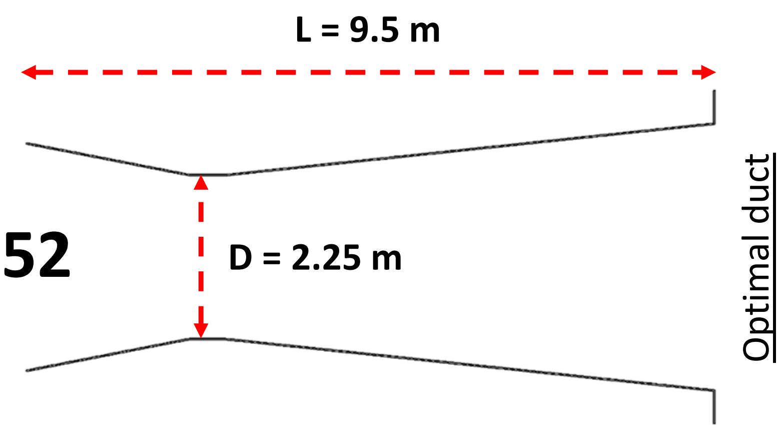
Optimal shape



AF = 1.76



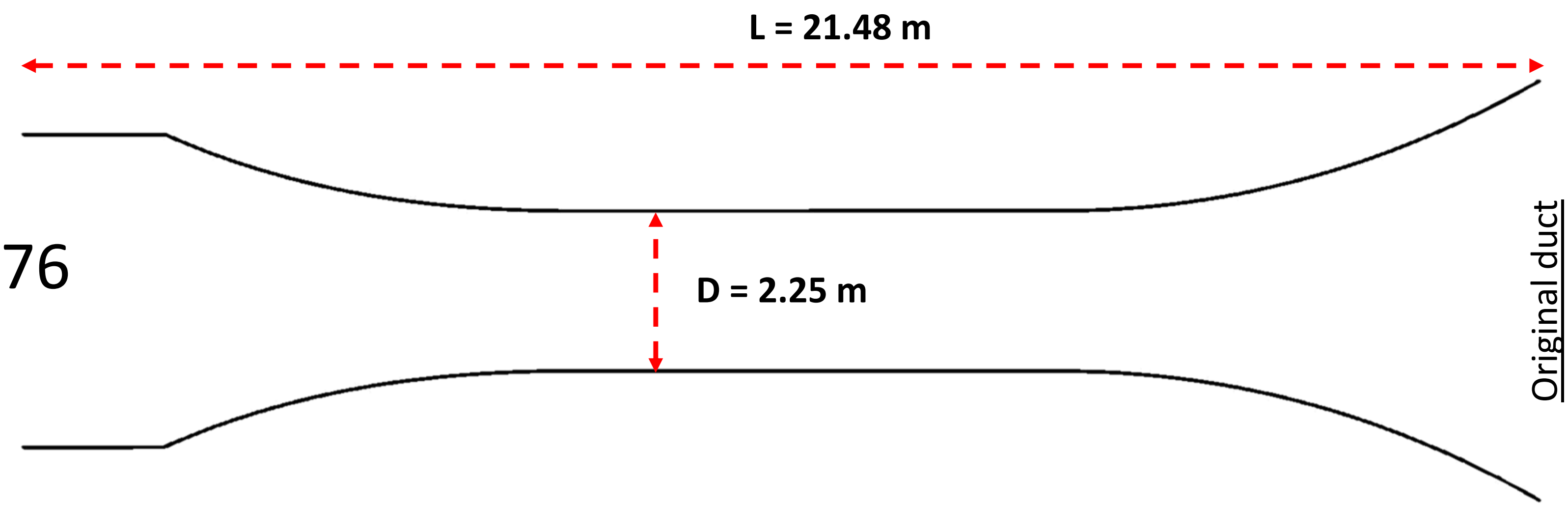
AF = 2.52



Summary of the optimal duct

Nozzle	Throat	Diffuser	Flange	Total
2.25 m (1D) 11 deg	0.5 m	6.75 m (3D) 6 deg	0.45 m (0.2D) 90 deg	9.5 m

AF = 1.76



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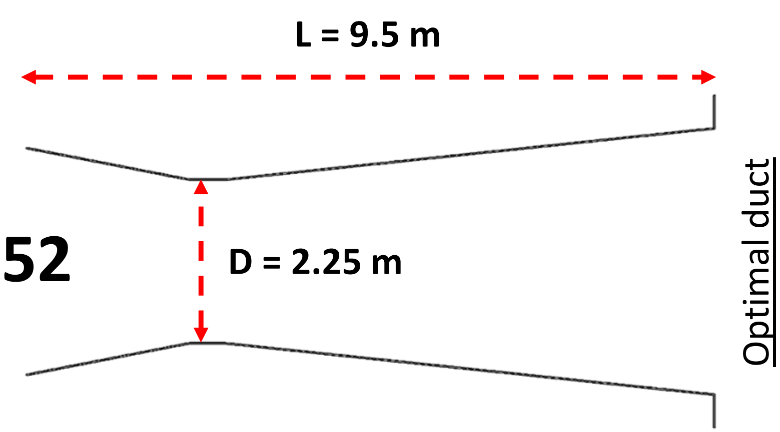
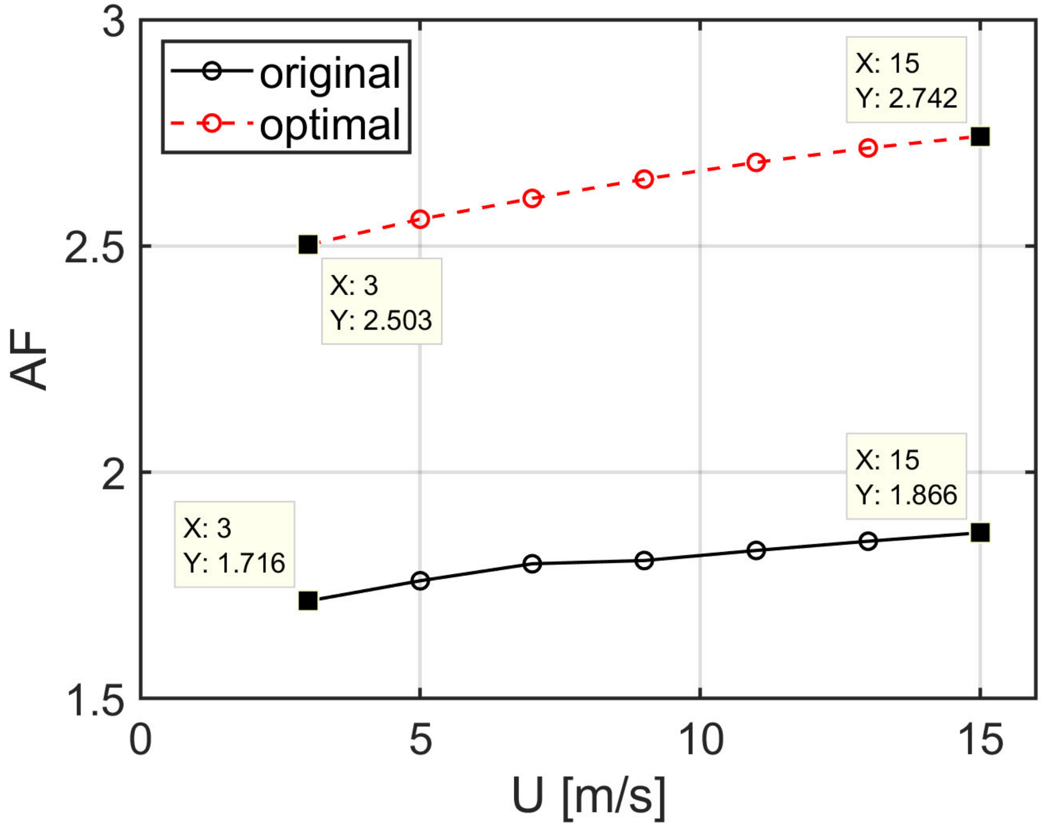


Optimal duct vs. original duct:

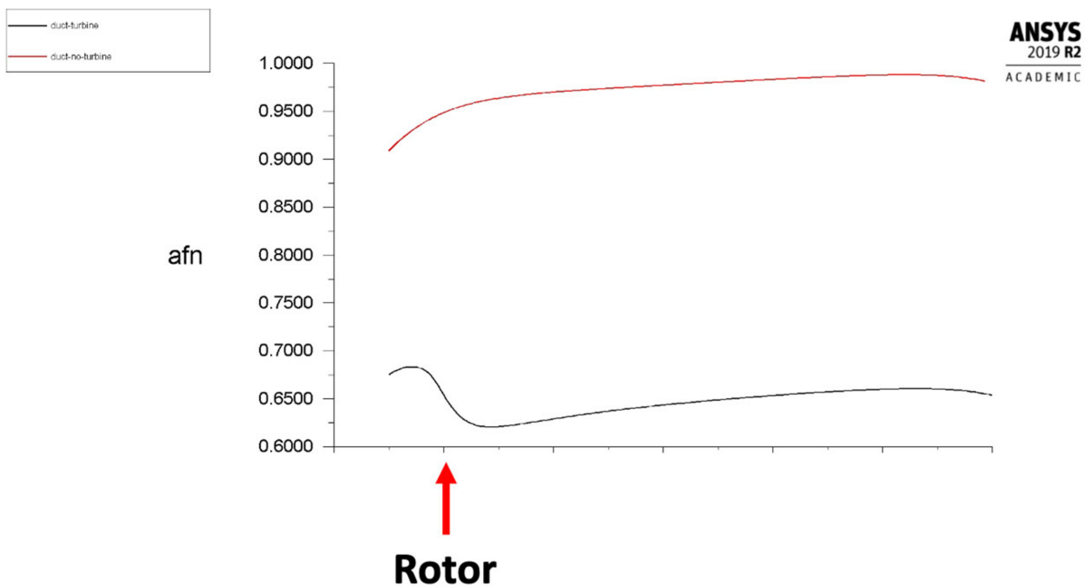
- **Same** throat **diameter**
- **22.7% reduction** in maximum diameter
- **55.8% reduction** in duct total length
- **47.4% increase** in amplification Factor
- **193.5% increase** in wind power potential

Optimal vs. original: different wind speeds

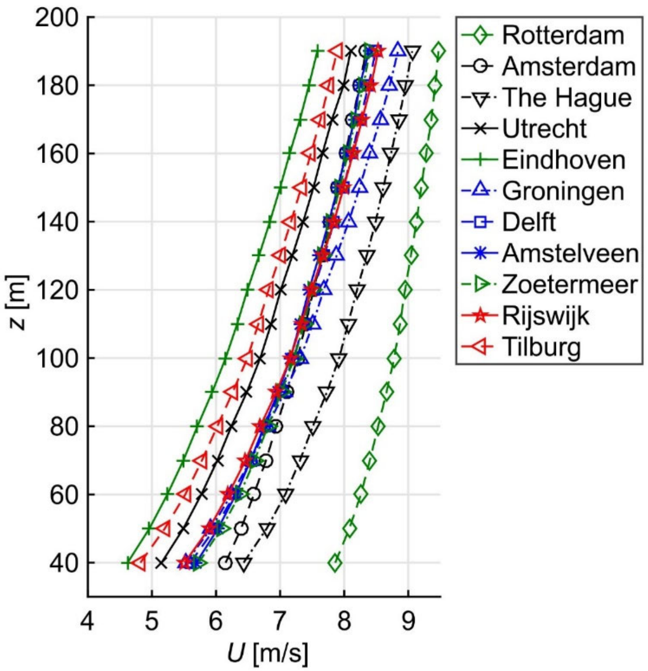


Impact of turbine

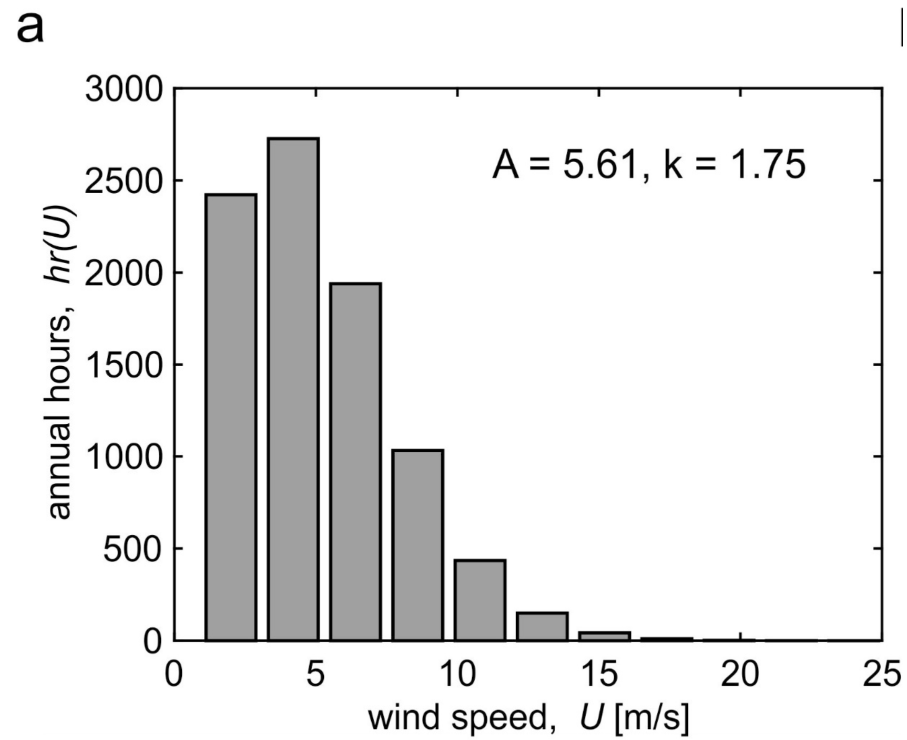
- Reduction in the predicted AF due to the turbine induction
- AF with turbine was ~ 0.65 AF without turbine



Annual energy production



Rezaeiha et al., 2019



For roof mean speed of 5 m/s

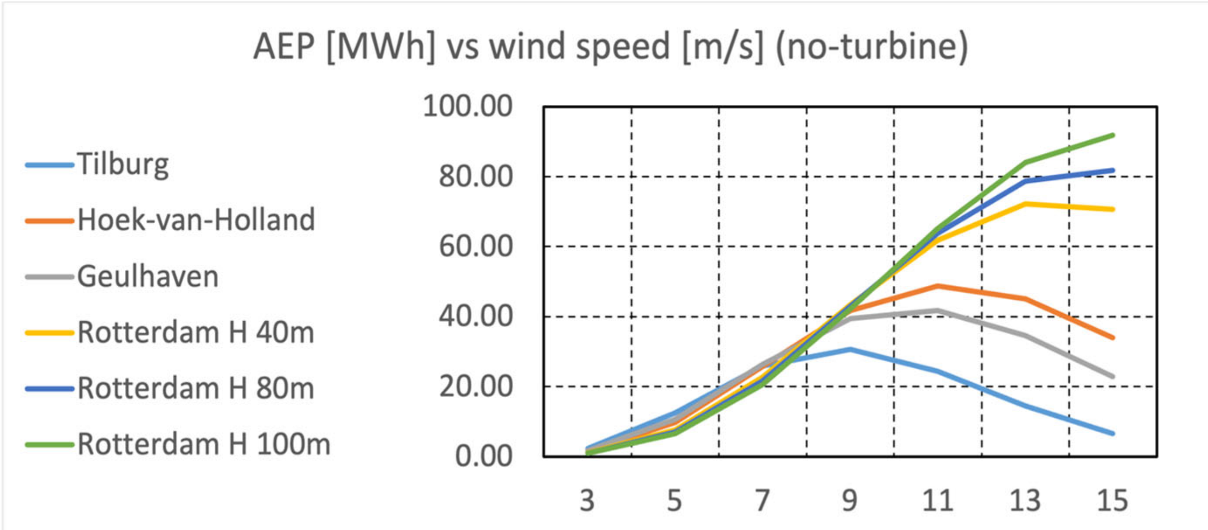
Duct throat area [m^2]	3.98

Wind speed bins [m/s]	2-4	4-6	6-8	8-10	10-12	12-14	14-16
Representative wind speed [m/s]	3	5	7	9	11	13	15
Amplification Factor **(turbine excluded*)**	2.50	2.56	2.61	2.65	2.68	2.72	2.75
Extractable power, P_N [W] **(turbine excluded*)**	462.322	2298.215	6683.075	14867.086	28076.512	48450.413	76918.813
Amplification Factor **(turbine included**)**	1.63	1.66	1.70	1.72	1.74	1.77	1.79
Extractable power, P_T [W] **(turbine included**)**	126.965	631.147	1835.340	4082.874	7710.512	13305.695	21123.829

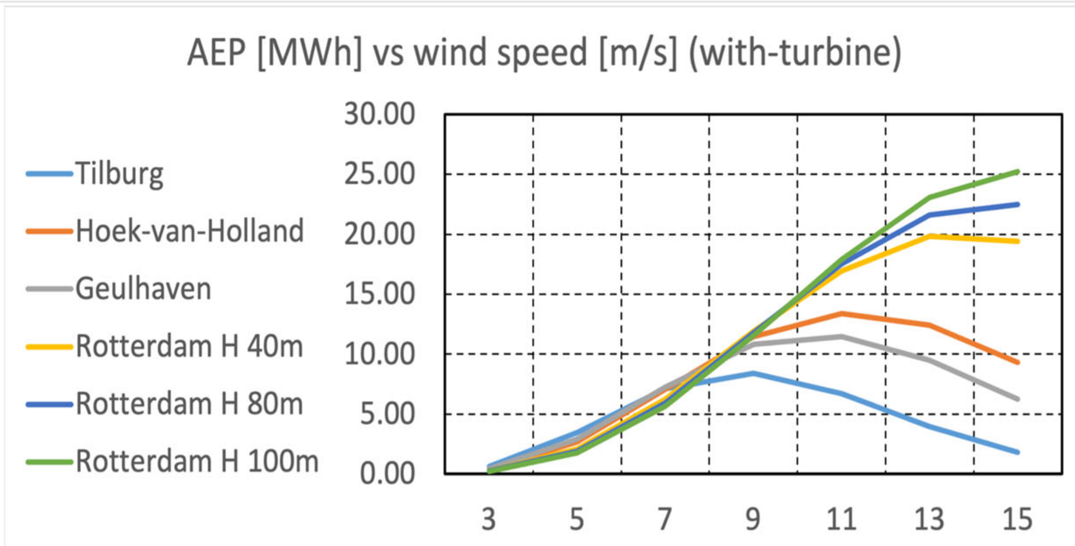
Annual number of hours (NH) [h]								
	Tilburg (H = 40m; Umean = 5m/s)	2422	2727	1939	1032	435	150	43
	Hoek-van-Holland (H = 15m; Umean = 6.5m/s)	1606	2125	1926	1404	867	466	221
	Geulhaven (H = 10m; Umean = 6m/s)	1823	2315	1972	1326	743	356	148
	Rotterdam (H = 40m; Umean = 8m/s)	1150	1655	1701	1460	1100	744	459
	Rotterdam (H = 80m; Umean = 8.5m/s)	1042	1530	1619	1443	1137	812	532
	Rotterdam (H = 100m; Umean = 9m/s)	951	1419	1539	1416	1161	867	597

Based on duct amplification factor with turbine excluded*									AEP (MWh)
AEP [Wh] = P_N*NH*N_D	**Tilburg (H = 40m; Umean = 5m/s)**	2239727	12532860	25918806	30675765	24427647	14504396	6581601	116.88
	Hoek-van-Holland (H = 15m; Umean = 6.5m/s)	1485021	9768681	25746166	41746717	48705341	45140956	33965030	206.56
	Geulhaven (H = 10m; Umean = 6m/s)	1685762	10639239	26352332	39419882	41705591	34488070	22797525	177.09
	Rotterdam (H = 40m; Umean = 8m/s)	1062999	7605431	22735276	43413850	61764045	72139143	70584519	279.31
	Rotterdam (H = 80m; Umean = 8.5m/s)	963855	7030602	21634475	42894744	63873570	78677660	81774960	296.85
	Rotterdam (H = 100m; Umean = 9m/s)	879329	6520328	20564751	42099167	65169374	83988857	91897968	311.12

Based on duct amplification factor with turbine included**									AEP (MWh)
AEP [Wh] = P_T*NH*N_D	**Tilburg (H = 40m; Umean = 5m/s)**	615085	3441837	7117952	8424332	6708443	3983270	1807472	32.10
	Hoek-van-Holland (H = 15m; Umean = 6.5m/s)	407824	2682724	7070541	11464692	13375704	12396835	9327646	56.73
	Geulhaven (H = 10m; Umean = 6m/s)	462952	2921801	7237009	10825685	11453398	9471286	6260770	48.63
	Rotterdam (H = 40m; Umean = 8m/s)	291926	2088641	6243675	11922529	16961951	19811212	19384274	76.70
	Rotterdam (H = 80m; Umean = 8.5m/s)	264699	1930779	5941368	11779969	17541279	21606852	22457448	81.52
	Rotterdam (H = 100m; Umean = 9m/s)	241486	1790645	5647595	11561484	17897139	23065440	25237479	85.44



AEP [MWh] vs wind speed [m/s] (no-turbine)
Tilburg
Hoek-van-Holland
Geulhaven
Rotterdam H 40m
Rotterdam H 80m
Rotterdam H 100m
100.00
80.00
60.00
40.00
20.00
0.00
3
5
7
9
11
13
15



AEP [MWh] vs wind speed [m/s] (with-turbine)
Tilburg
Hoek-van-Holland
Geulhaven
Rotterdam H 40m
Rotterdam H 80m
Rotterdam H 100m
30.00
25.00
20.00
15.00
10.00
5.00
0.00
3
5
7
9
11
13
15

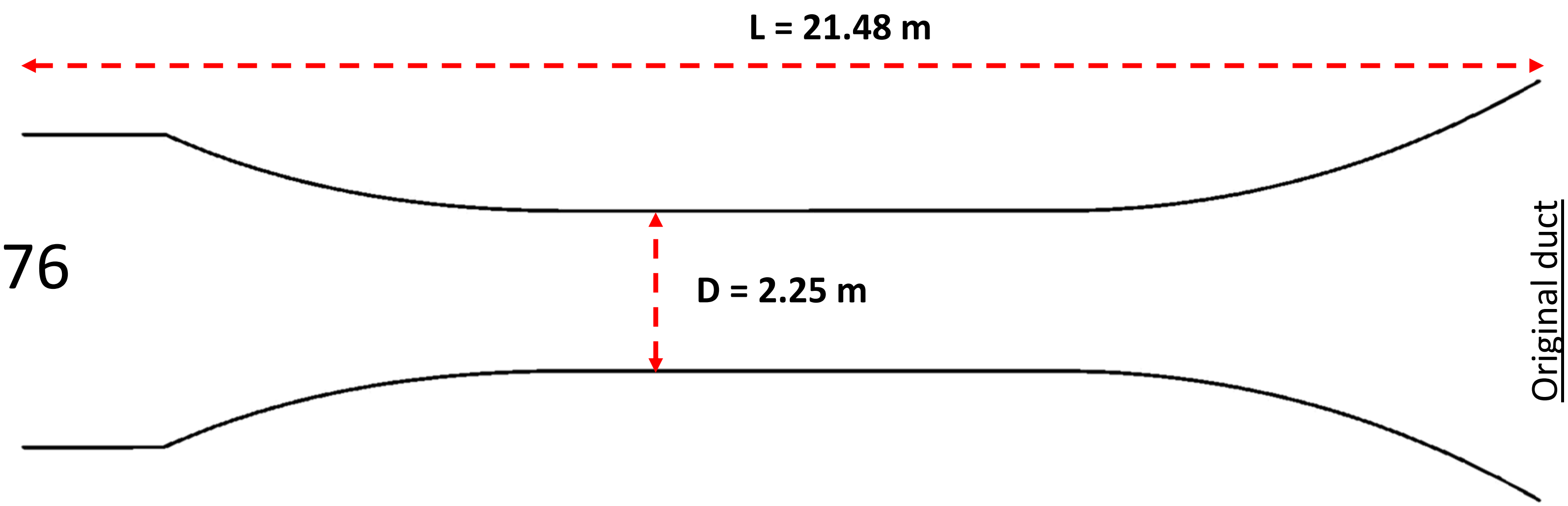
Summary and conclusions

- An extensive number of CFD simulations (> 400) was used for a top-bottom design optimization for the provided original duct shape
- The first analysis showed poor aspects in the original design
- All the modules were completely redesigned to improve the performance

Summary and conclusions

- Diffuser was replaced with a fixed slope of 6 deg and lengh of 3D
- Nozzle was repalced with fixed slope of 11 deg and length of 1D
- The inlet extension was removed
- Flange was added to enhance the AF
- Throat was made much shorter to 0.5 m

AF = 1.76



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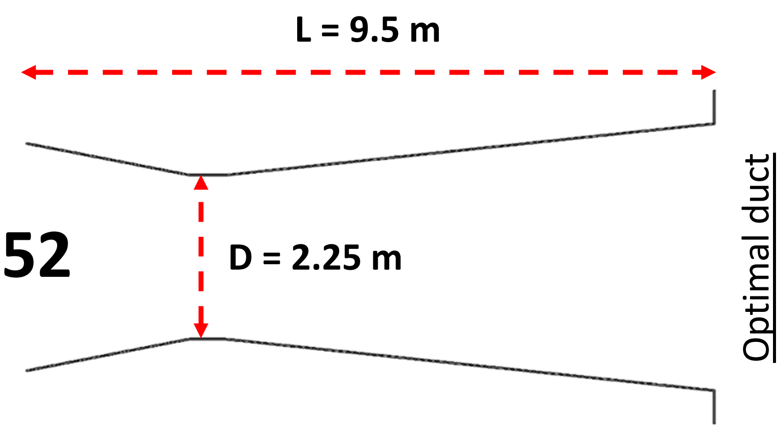

Optimal duct vs. original duct:

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- **22.7% reduction** in maximum diameter
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- **47.3% increase** in amplification Factor
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Summary and conclusions

- An estimation of the impact of turbine in the predicted AF was made.
- Annual energy production for 6 different urban locations was made for the duct with and without turbine.
- The resulting AEP (kWh) remains low compared to the existing large turbines but this is attributed mainly to the very small turbine considered in this study (3.98 m)

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- Annual energy production for 6 different urban locations was made for the duct with and without turbine.
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Wind tunnel measurements


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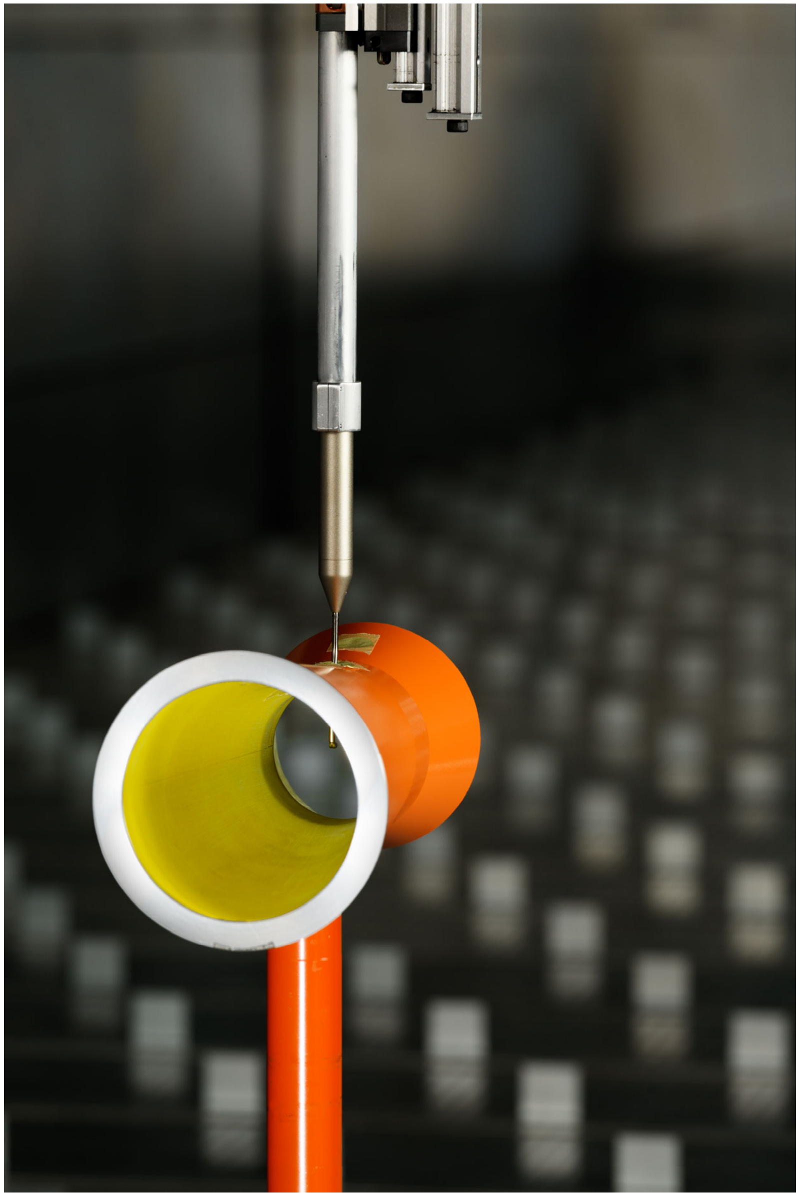
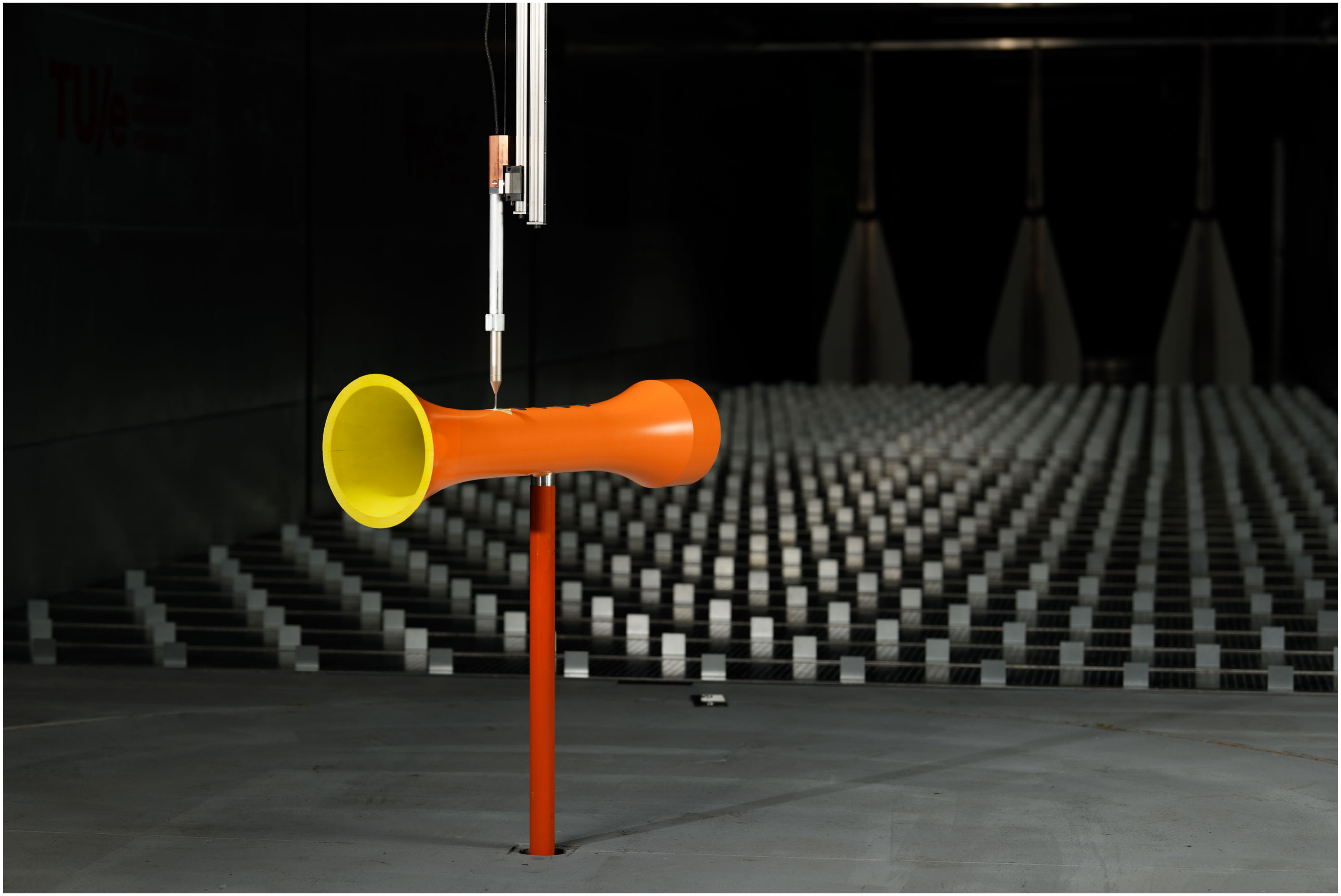
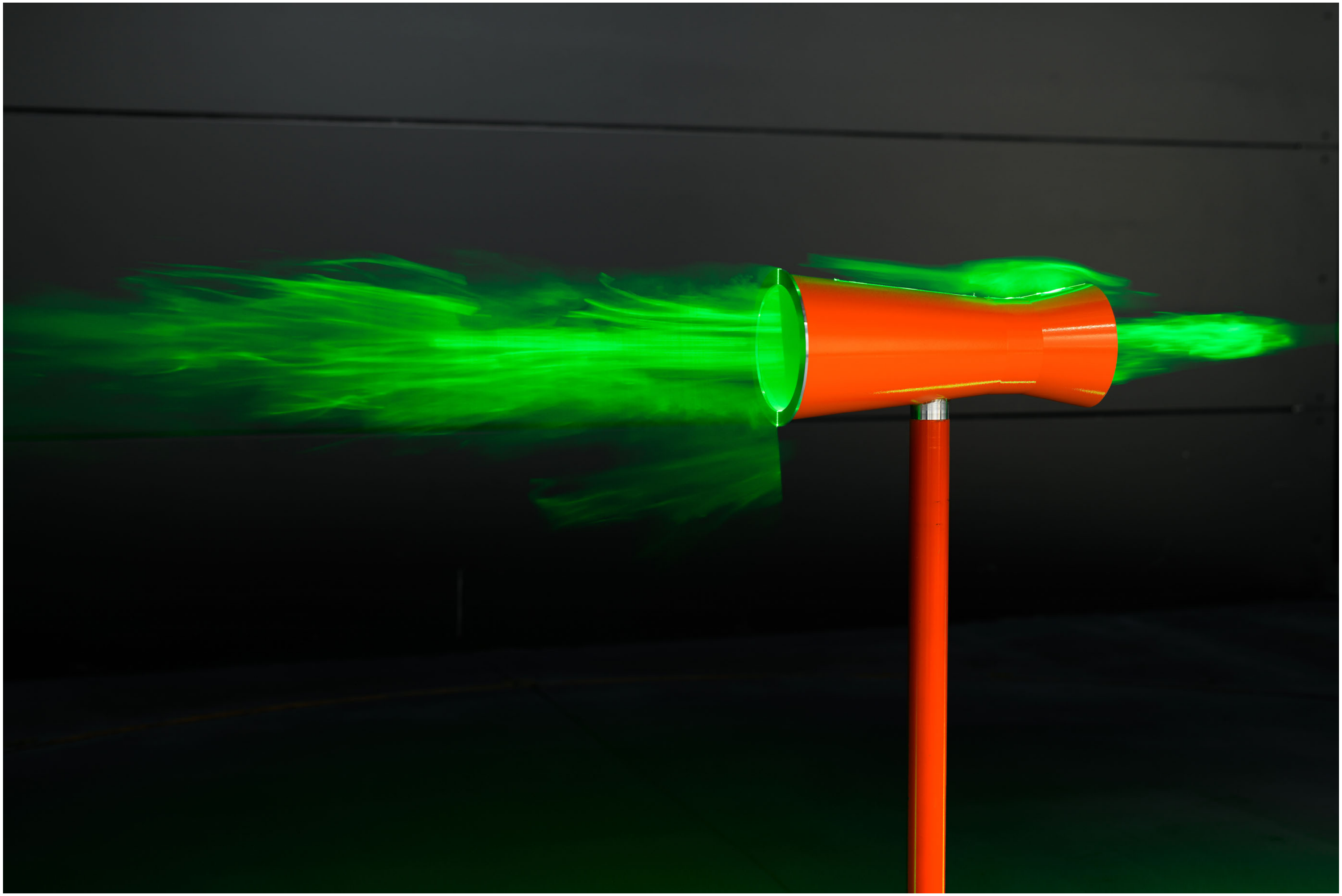
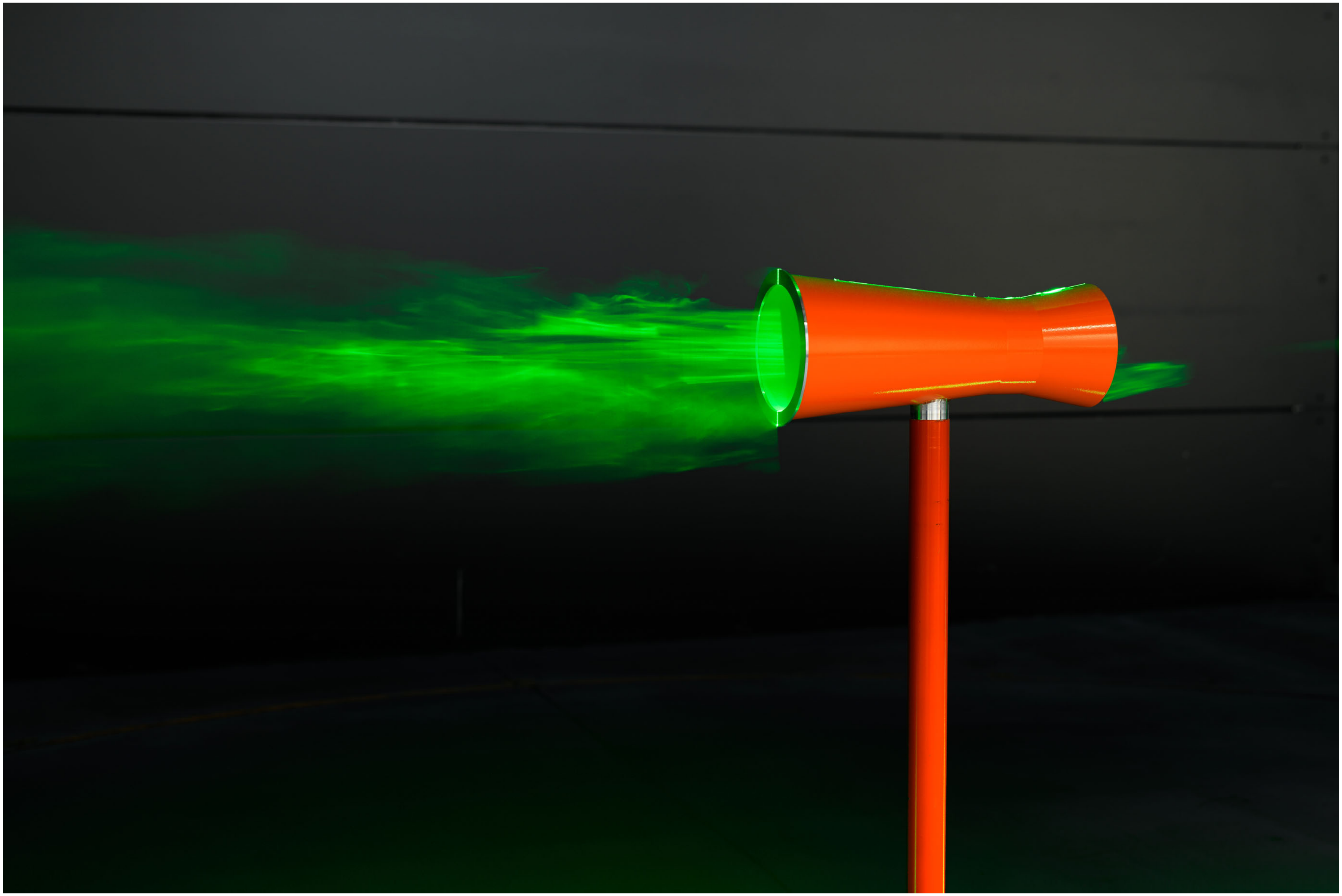
EINDHOVEN
UNIVERSITY OF
TECHNOLOGY

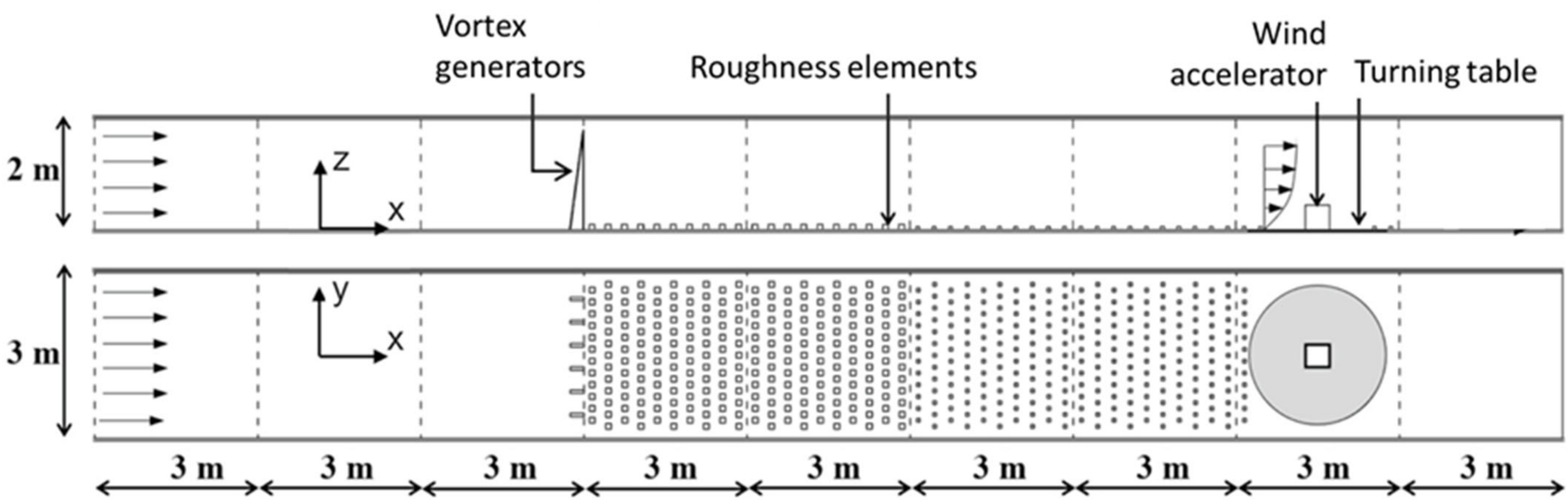



TU/e

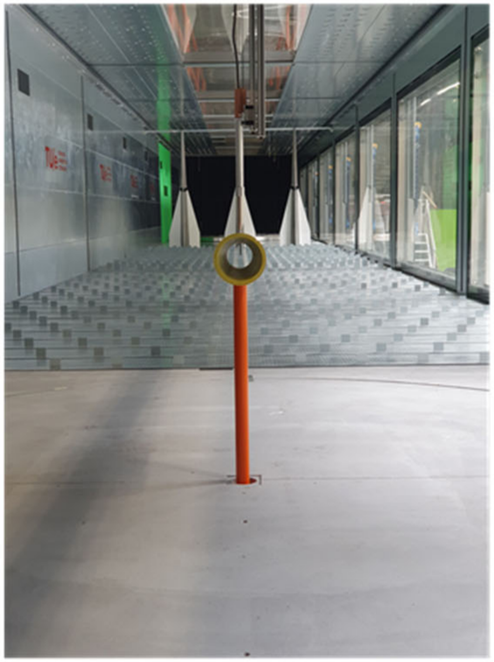




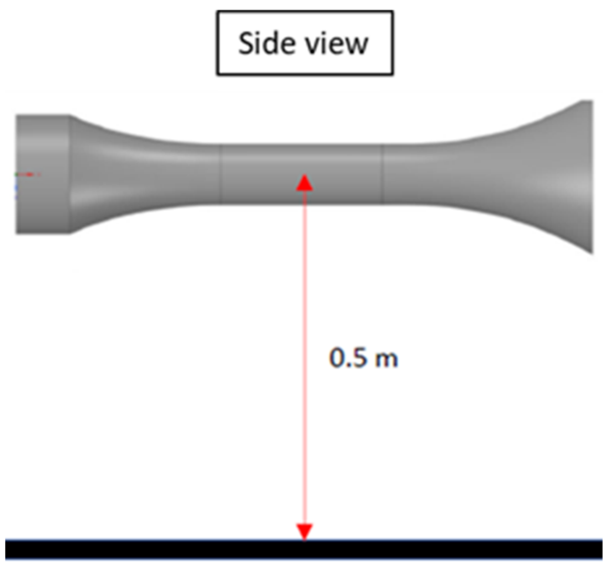
Wind tunnel geometry

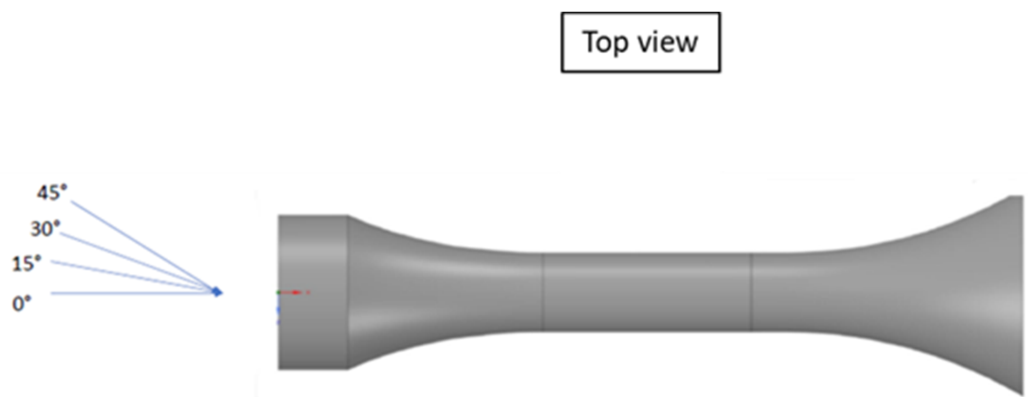


Wind tunnel set-up

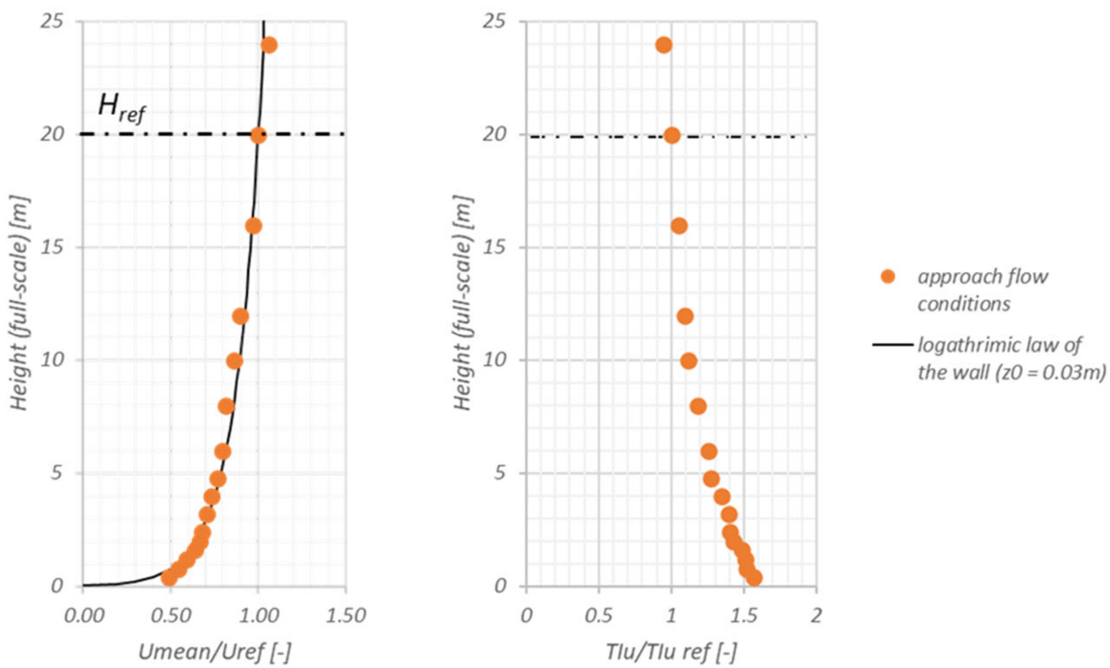


Model position and wind directions

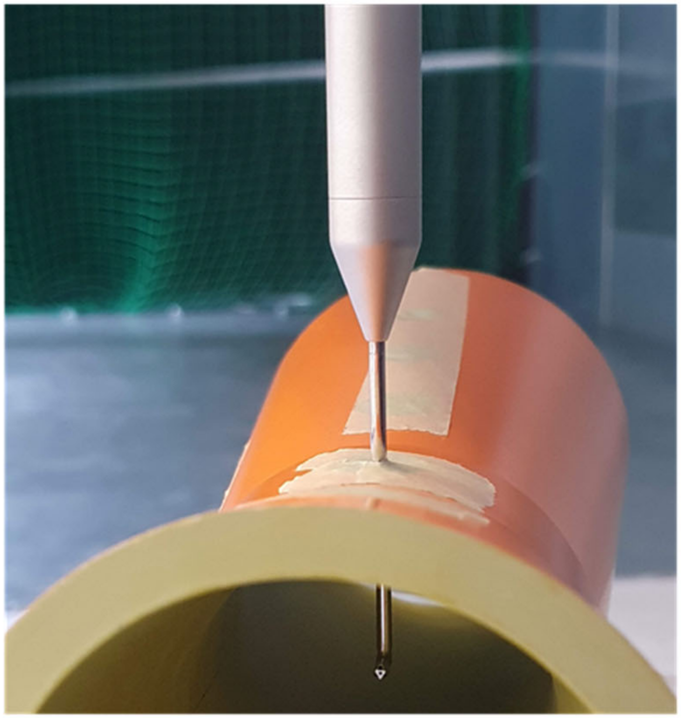


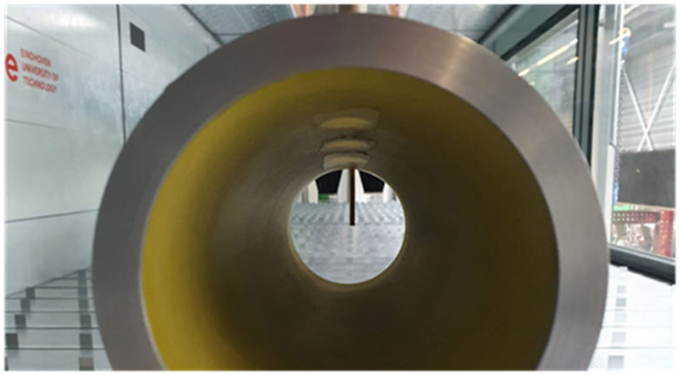


Approach flow wind speed and turbulence intensity

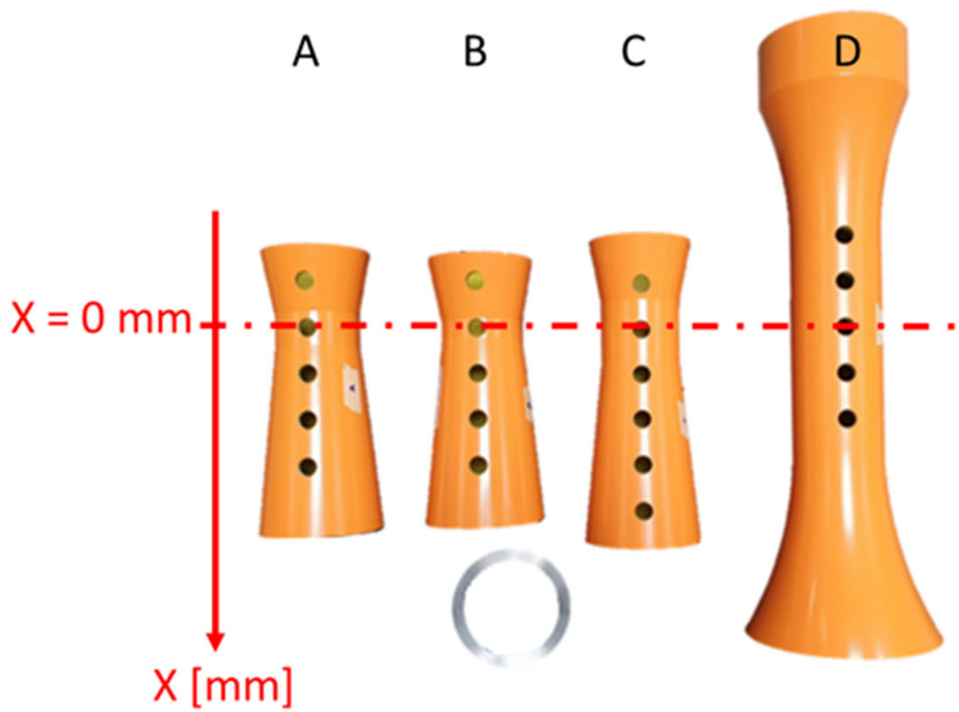


Measurements with Cobra probe

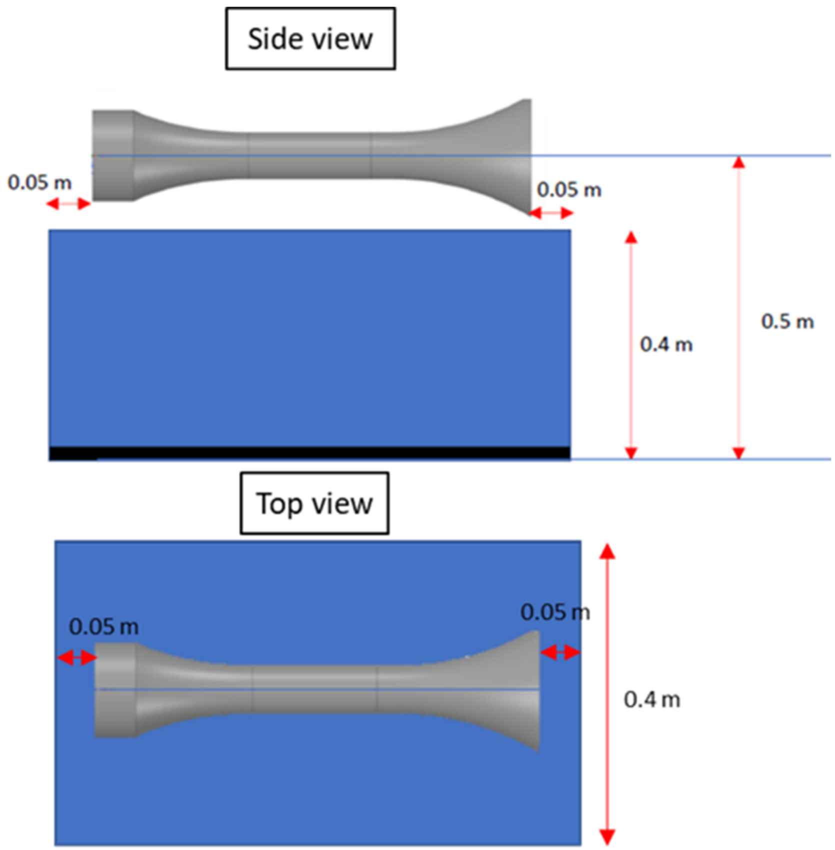




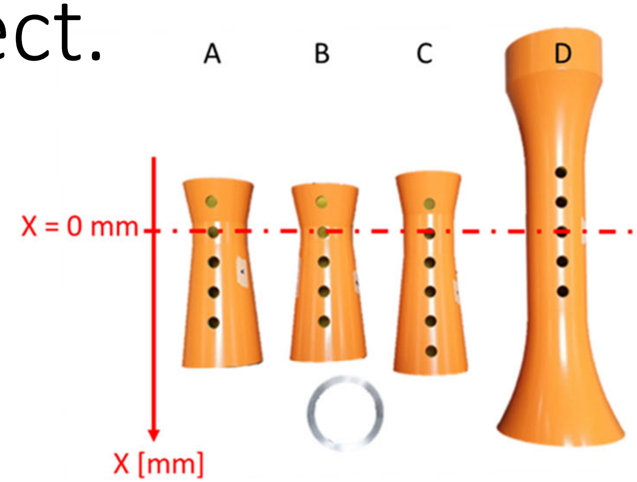
Measurement locations of the three models

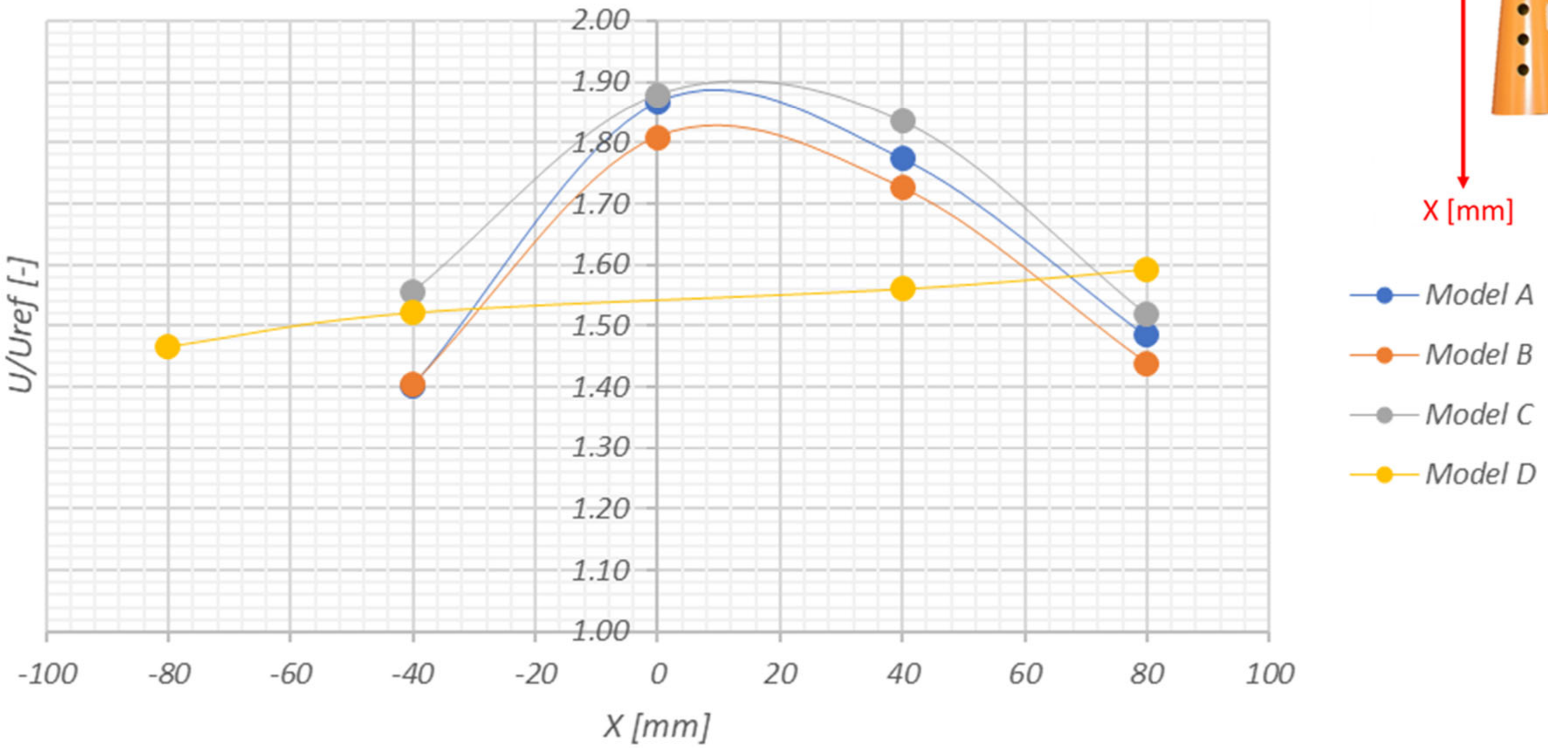


Measurements for wind acc. on building roof

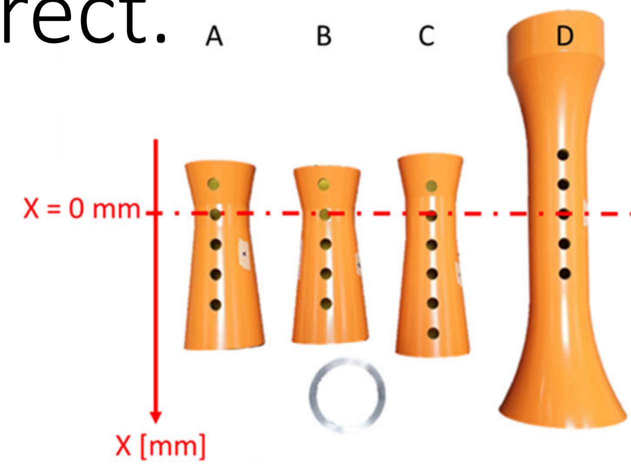


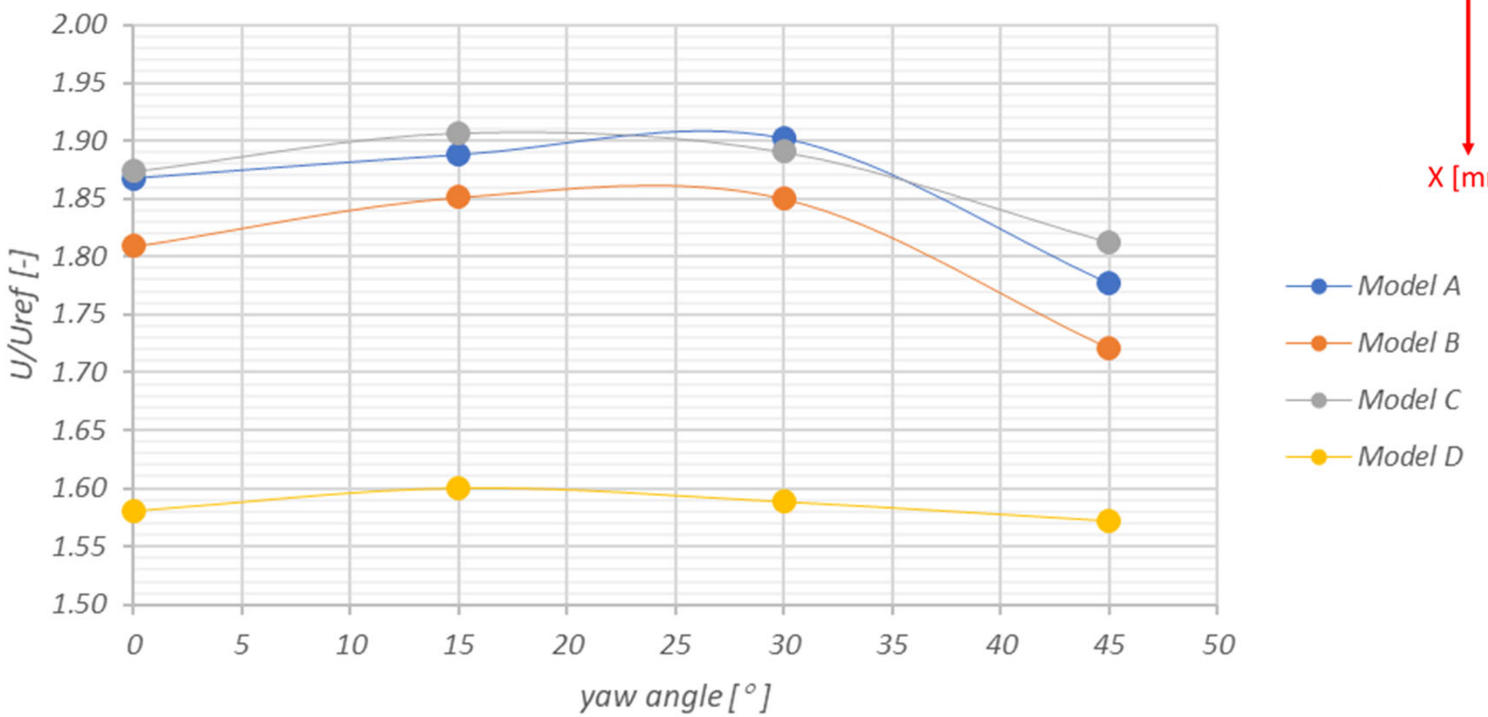
Measurements for 0° wind direct.



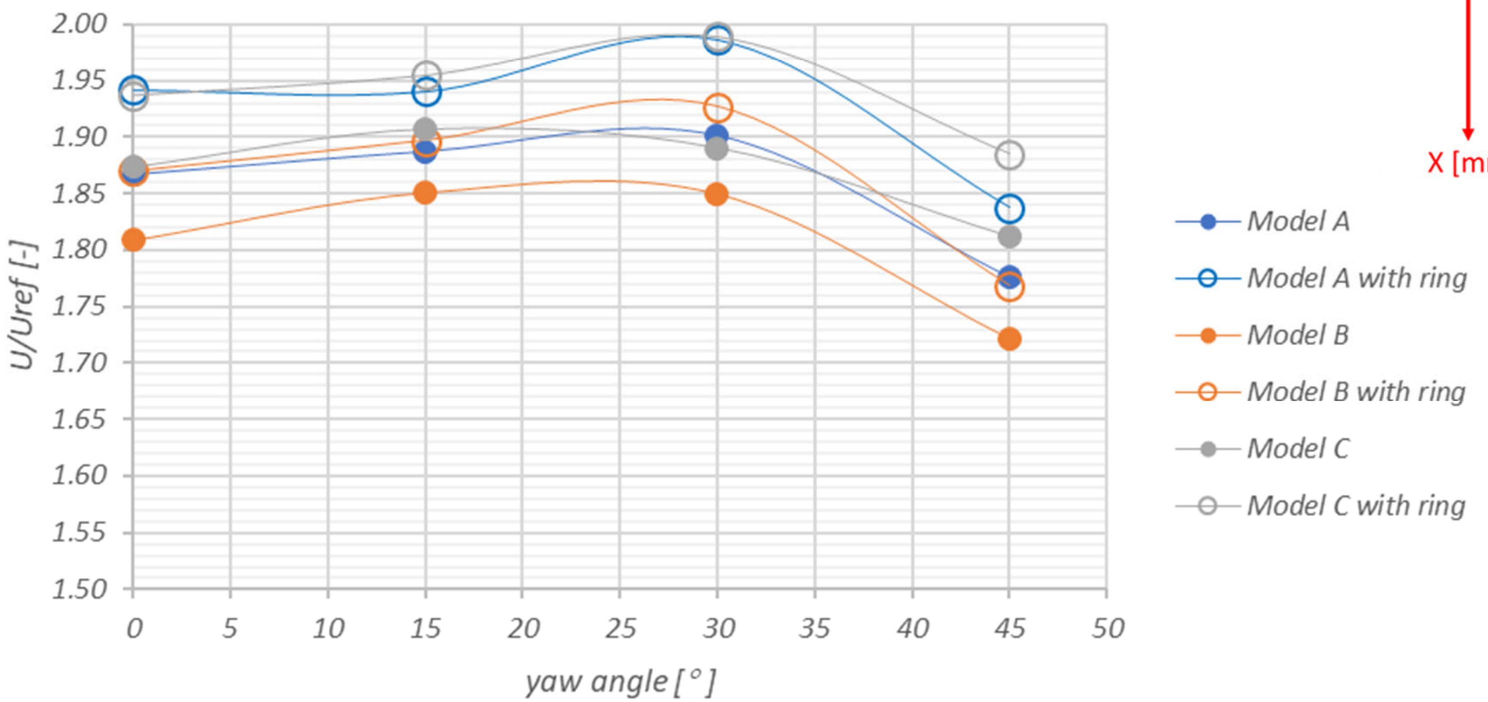


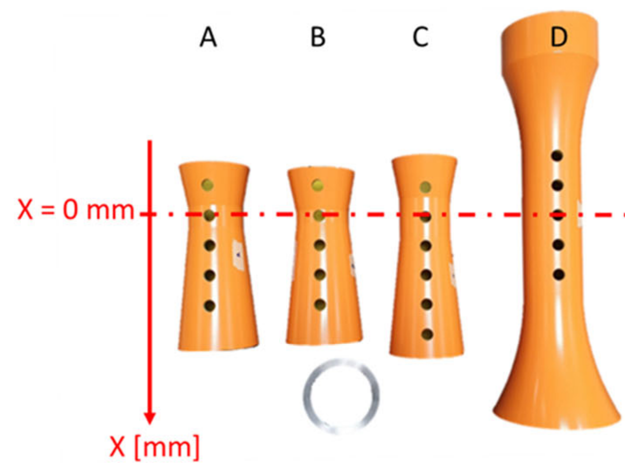
Measurements for diff. wind direct.

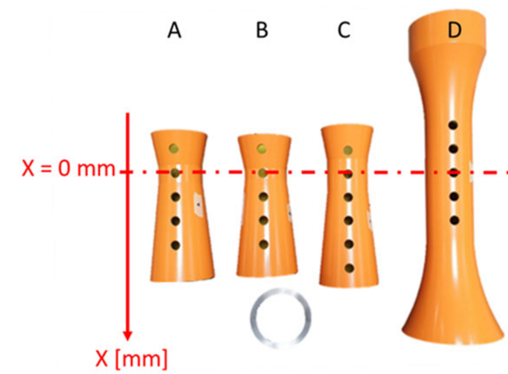


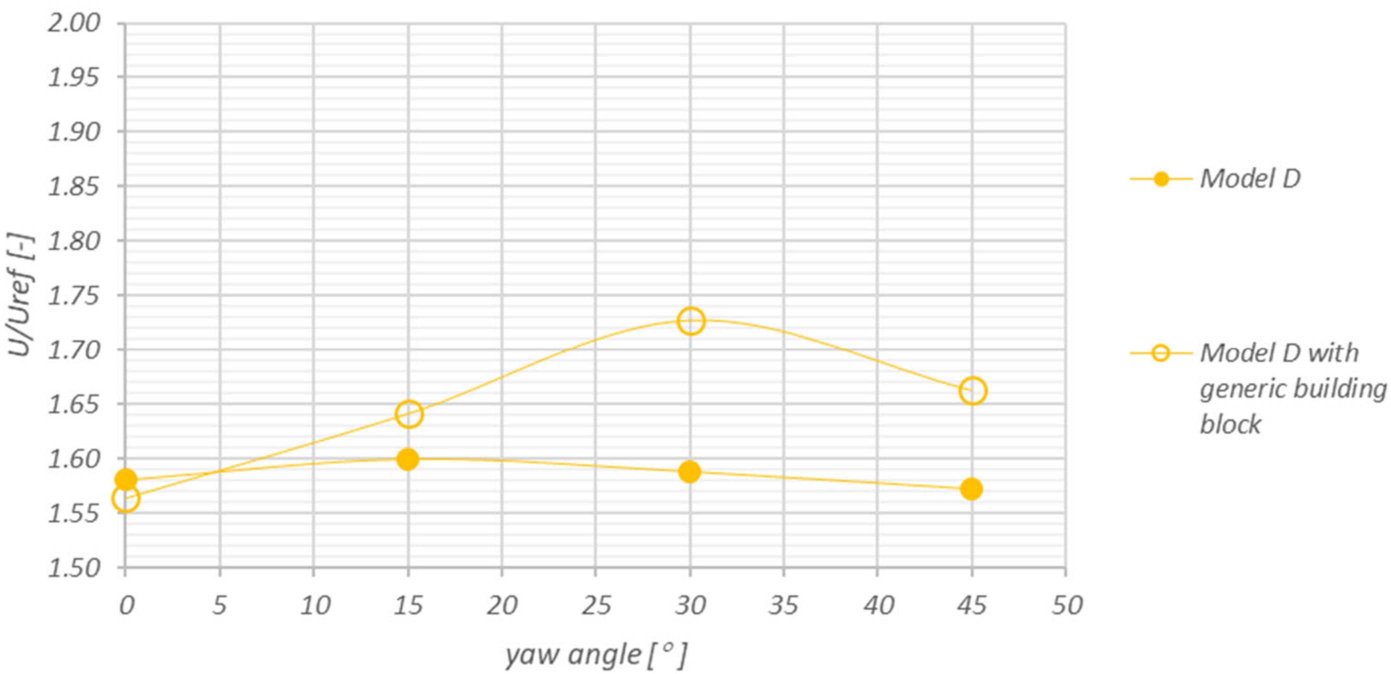


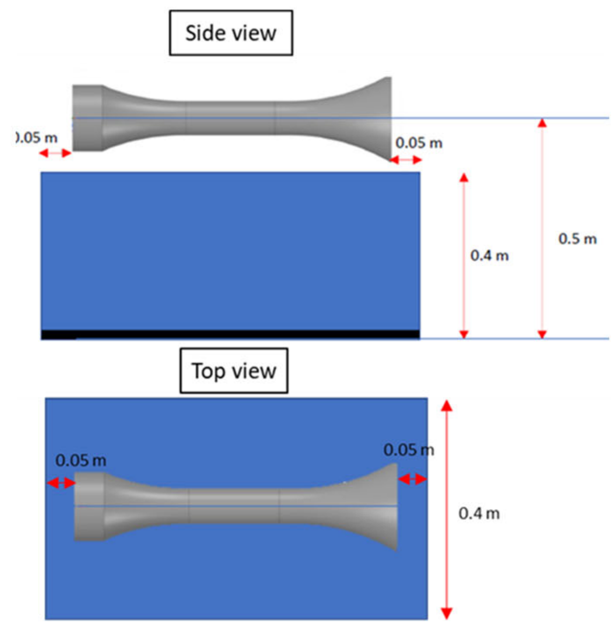
Measurements with flange






A
B
C
D
X = 0 mm
X [mm]


U/Uref [-]
yaw angle [°]
Model D
Model D with generic building block


Side view
0.05 m
0.05 m
0.4 m
0.5 m
Top view
0.05 m
0.05 m
0.4 m