Potsdam Propeller Test Case (PPTC)

LDV Velocity Measurements
with the Model Propeller VP1304

Report 3754

Potsdam, April 2011

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This report includes
8 pages text
2 pages tables
44 pages diagrams/drawings
1 page photographs
13 pages annex

Potsdam, 15/04/2011

Management Author

Content

1 Summary

For the SMP'11 workshop the SVA provided the controllable pitch propeller VP1304 as a test case. Several investigations were conducted with this propeller: open water tests [2], cavitation tests [3] and LDV measurements.

For the validation of CFD calculations of the flow around propellers, intensive LDV measurements were carried out in the cavitation tunnel of the SVA. A description of the LDV measuring system at SVA can be found in [1].

The velocity field of the propeller VP1304 was measured in detail, especially the flow around the blade tip. All measured values were made dimensionless using the inflow velocity.

The measured results show the following characteristic flow regions:

- wake of the propeller blades,
- accelerated flow on the propeller blades mainly on the suction side,
- decelerated flow near the hub at the pressure side of the blade,
- highly accelerated flow within the tip vortex,
- highly decelerated flow within the tip vortex.

2 Introduction

The velocity field around the propeller VP1304 was measured with a LDV measuring system in the cavitation tunnel K15A. The results of these measurements are presented in this report.

The open water characteristics and cavitation behaviour of the propeller VP1304 are documented in the SVA reports 3752 [2] and 3573 [3].

3 Task

The model propeller VP1304 was tested in the cavitation tunnel of the Potsdam Model Basin in homogeneous flow.

Main focus of the tests was the measurement of the velocity field behind the propeller and the acquisition of the tip vortex as a function of the propeller rotation angle. The velocity field around the model propeller VP1304 was measured in seven planes x/D = -0.2, 0.094, 0.10, 0.11, 0.13, 0.16 and 0.20, with respect to the propeller plane. All measurements were conducted for the same working point.

4 Description of the model propeller VP1304

The propeller was designed by the SVA in 1998. For the manufacture of the propeller cold-rolled brass was used as raw material. The blades were manufactured on a CNC-based milling machine with HSC (high speed cutting) technology.

The propeller main properties are shown in table 1 and in the drawing on page 3.1. Photos of the propeller are shown on page 4.1.

The propeller is a controllable pitch propeller. This affects the propeller blade design near the hub and results in a 0.3 mm gap between hub and propeller blade near the leading and trailing edge of the propeller.

Table 1: Main data of model propeller

			VP1304
Diameter	D	[m]	0.250
Design pitch ratio r/R = 0.7	$P_{0.7C}/D$	[–]	1.635
Area ratio	A_E/A_0	[m]	0.77896
Chord length r/R = 0.7	$c_{0.7}$	[m]	0.10417
Skew	θ_{EXT}	[°]	18.837
Hub ratio	d_h/D	[–]	0.300
Number of blades	Z	[–]	5
Sense of rotation		[–]	right
Type			controllable pitch propeller

5 Test arrangement

The tests were carried out in the test small section of the cavitation tunnel K15A from Kempf & Remmers. The dynamometer J25 from Kempf & Remmers was used for the tests. The dynamometer was arranged in front of the propeller model (drawings on page 3.2, photos on page 4.1). The shaft inclination was zero degrees.

A 2D-LDV measuring system from TSI was used for the velocity measurements. A four beam standard compact probe was used as optical unit. The simultaneous measurement of two velocity components is possible with this probe in back scattering mode.

The LDV measurements had been carried out from the side and from the bottom. The third velocity component could measured time shifted with these two arrangements.

6 Test procedure

The LDV measurements with the propeller VP1304 had been carried out in the small test section of the cavitation tunnel K15A from Kempf & Remmers.

The 2D-LDV probe was arranged orthogonal to the test section from the side and from the bottom. The measurement of the velocity components V_x and V_z is possible with the arrangement of the probe from the side. The measurement of the velocity components V_x and V_y is possible with the arrangement of the probe from the bottom.

The exact adjustment of the probe in the space and the accurate positioning of the measuring volume are the preconditions for the configuration of both 2D-velocity fields to a 3D-velocity field.
The velocity-time-characteristic in the surrounding area of a propeller can be divided in three velocity components, the stationary velocity V_{sta}, the periodical velocity V_{per} caused by the propeller rotation and the stochastic velocity V_{sto}.

$$V(t) = V_{\mathrm{sta}} + V_{\mathrm{per}} + V_{\mathrm{sto}}$$

The propeller rotation angle in the moment of measuring a velocity will be stored together with the velocity and time information, to collect the quasi periodical velocity part.

The stochastic velocity part consists mainly of the following components:

- turbulence of the flow in the measuring point,
- fluctuations of the periodical velocity due to stochastic flow separation, vibration of the propeller and shaft, fluctuations in the inflow speed and number of revolutions,
- random noise and disturbance signals during the LDV measurements.

Main focus of the tests was the measurement of the velocity field behind the propeller and the acquisition of the tip vortex as a function of the propeller rotation angle. The tip vortex is a relatively small region with high velocity gradients. That’s why high demands on the local and temporal resolution had to be fulfilled, which as follows:

- a small measuring volume,
- a minimum distance between the measuring points,
- a high resolution of the propeller rotation angle in the moment of a velocity signal.

The probe was equipped with a transmitting lens of f = 261 mm in air (f = 347 mm in water) to get a small measuring volume. With this arrangement the measuring volume in the intersection point of the laser beams has a maximum size of 65 μm in diameter and 0.9 mm in length. The ratio between the length of the measuring volume and the propeller diameter is L/D = 0.0036.

The minimal distance between the measuring points along the r/R-axis was $r/R = 0.002$. With the measuring volume length of $L/D = 0.0036$ the measuring ranges were partly overlapping.

The resolution of the propeller rotation angle was defined within steps of 0.25°. The measured velocities were selected in 1440 angle classes. The measuring times was fixed with 90 seconds or 40000 measuring values for each velocity component. With the measuring time of 90 seconds and the number of revolutions of $n = 23\ s^{-1}$ the measurements delivered data up to 2070 propeller rotations.

All measurements had been carried out in the coincedence mode. This means that the velocity information of one velocity component is only valid if also information about the second velocity component were available in a defined time window.

A description of the LDV measuring system at SVA can be found in [1]. Table 2 presents the working parameters of the propeller for the velocity measurements.

Table 2: Working point for the LDV measurements

Inflow speed	V_A	[m/s]	7.204
Number of revolutions	n	[s^{-1}]	23
Advance coefficient	J	[–]	1.253
Thrust coefficient	K_T	[–]	0.250
Torque coefficient	$10K_Q$	[–]	0.725

The LDV measurements had been carried out along a line at the rotation angle 225 degrees. Table 3 presents the measuring planes in front and behind the propeller (see also the drawing on page 3.4).

Table 3: Measuring planes

x-position	x/D	[–]	-0.200	0.094	0.100	0.110	0.130	0.160	0.200
x-position	x	[mm]	-50.0	23.5	25.0	27.5	32.5	40.0	50.0

Table 4 shows the positions of the measuring points on the radius at the different measuring planes. On page 2.2 an overview of all tests and test parameters is given

Table 4: Positions of the measuring points

measuring plane	start radius	end radius	step size	
	r/R	r/R	$\Delta r/R$	[mm]
in front of the propeller x/D = -0.20	0.40	1.10	0.050	6.250
behind the propeller x/D = 0.094, 0.10, 0.11, 0.13, 0.16, 0.20	0.40	0.70	0.050	6.250
	0.70	0.90	0.025	3.125
	0.90	0.95	0.010	1.250
	0.95	1.05	0.002	0.250
	1.05	1.10	0.025	3.125

7 Test results

The test results are given as EXCEL-files for the different measuring planes.

Selected test results are shown in the diagrams on the pages 3.5 to 3.44.

8 References

[1] Mach, K.–P.
LDA Geschwindigkeitsmessungen am Kavitationstunnel
3. Fachtagung Lasermethoden in der Strömungsmeßtechnik, Bremen, Sept. 1994

[2] Barkmann, U.
Potsdam Propeller Test Case (PPTC) - Open Water Tests with the Model Propeller VP1304
Report 3752, Schiffbau-Versuchsanstalt Potsdam, April 2011

[3] Heinke, H.–J.
Potsdam Propeller Test Case (PPTC) - Cavitation Tests with the Model Propeller VP1304
Report 3753, Schiffbau-Versuchsanstalt Potsdam, April 2011

Details of model tests

VP1304

Cavitation tunnel	K15A (Kempf & Remmers)
Dimensions of the small test section	0.600 m · 0.600 m with rounded edges
Propeller	VP1304
Material of the propeller	brass
Type of propeller	controllable pitch propeller
Diameter of propeller	0.250 m
Measuring equipment in cavitation tunnel for:	
Number of revolutions, thrust and torque	dynamometer J25 with: T_{max} = 3000 N Q_{max} = 150 Nm
Inflow velocity	manometer (principle of venture nozzle)
Maximum inflow velocity	V_{max} = 14 m/s
Velocity measurements	TSI standard 2D fiber optic probe, beam spacing Δs = 50mm, focal length of the transmitting lens f = 261mm in air, 4W Argon laser, signal processor IFA 650, 3D computer controlled traversing unit

Overview of LDV measurements with the VP1304

LDV measurements

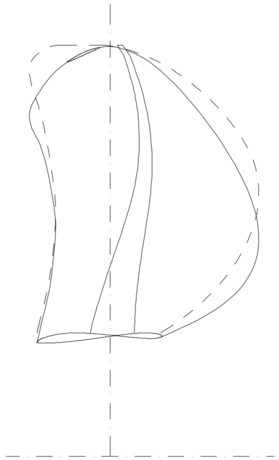
Plane	Probe from the bottom		Probe from the side	
	Date	Test No.	Date	Test No.
-0.20*D*	26/09/1998	98KM192	01/10/1998	98KM200
0.094*D*	30/09/1998	98KM199	02/10/1998	98KM206
0.10*D*	26/09/1998	98KM193	01/10/1998	98KM201
0.11*D*	30/09/1998	98KM196	01/10/1998	98KM202
0.13*D*	30/09/1998	98KM195	01/10/1998	98KM203
0.16*D*	30/09/1998	98KM197	01/10/1998	98KM204
0.20*D*	30/09/1998	98KM198	02/10/1998	98KM205

Results

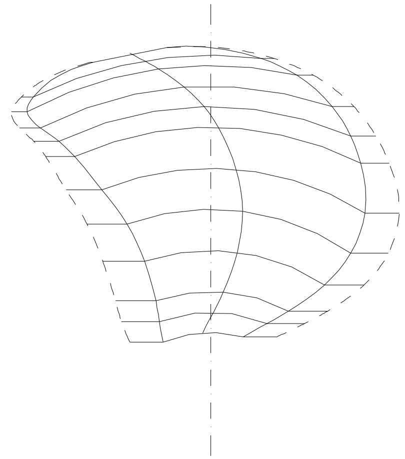
Plane	Table Data sets	Diagram
-0.20*D*	Velocities – r_R=-0.20D.xls	3.5 3.24 – 3.26
0.094*D*	Velocities – r_R=0.094D.xls	3.6 – 3.8 3.24 – 3.26
0.10*D*	Velocities – r_R=0.10D.xls	3.9 – 3.11 3.24 – 3.26 3.27 – 3.32
0.11*D*	Velocities – r_R=0.11D.xls	3.12 – 3.14 3.24 – 3.26
0.13*D*	Velocities – r_R=0.13D.xls	3.15 – 3.17 3.24 – 3.26 3.33 – 3.38
0.16*D*	Velocities – r_R=0.16D.xls	3.18 – 3.20 3.24 – 3.26
0.20*D*	Velocities – r_R=0.20D.xls	3.21 – 3.23 3.24 – 3.26 3.39 – 3.44

Model propeller VP1304

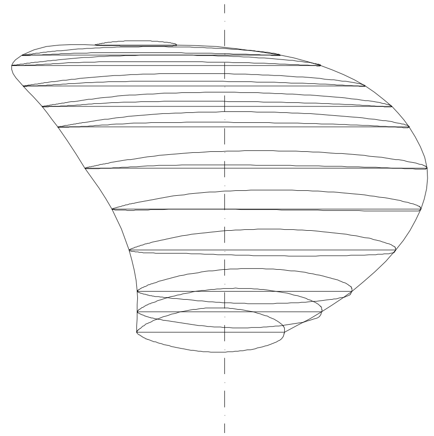
SIDE VIEW
CLEARANCE CURVE



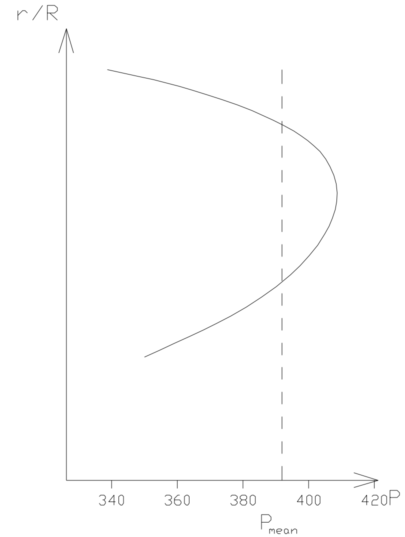
PROJECTED OUTLINE
DEVELOPED OUTLINE

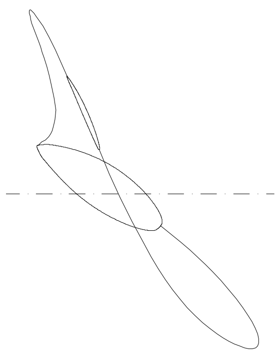


BLADE SECTIONS
EXPANDED OUTLINE



PITCH DISTRIBUTION





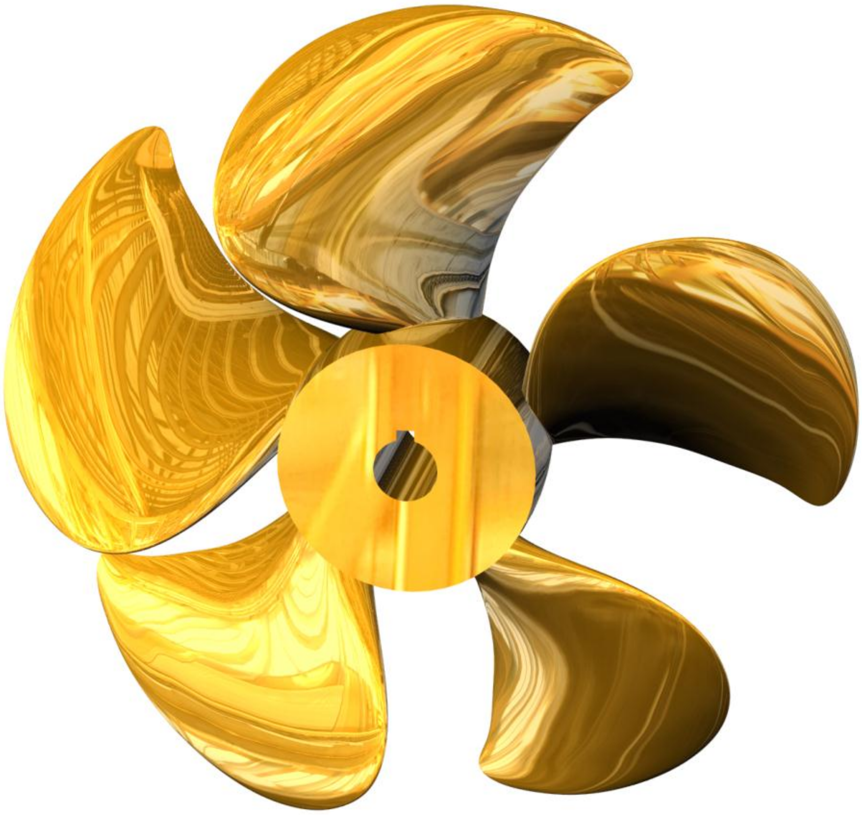
r/R	r	t	c	c_LE	f	rake	P
0.30000	37.50	13.525	45.00	18.25	0.675	0.000	350.00
0.35000	43.75	12.050	56.25	29.63	1.125	-0.500	363.75
0.40000	50.00	10.688	65.42	38.79	1.570	-1.250	376.25
0.50000	62.50	8.137	81.25	52.13	2.356	-3.350	394.50
0.60000	75.00	6.050	94.17	59.83	2.837	-5.875	405.00
0.70000	87.50	4.425	104.17	61.67	3.093	-7.500	408.75
0.80000	100.00	3.250	107.08	56.29	3.052	-7.375	403.50
0.85000	106.25	2.775	106.54	50.93	2.967	-6.625	395.50
0.90000	112.50	2.375	104.17	42.83	2.672	-5.450	382.75
0.95000	118.75	2.013	94.17	29.33	2.194	-4.033	364.50
0.97500	121.88	1.825	78.67	17.00	1.715	-3.300	352.75
1.00000	125.00	1.638	25.00	-14.58	0.500	-2.500	338.75

PROPELLER DIAMETER	D	250.0000mm
PITCH AT r/R=0.7	$P_{0.7}$	408.7500mm
PITCH AT r/R=0.75	$P_{0.75}$	407.3804mm
MEAN PITCH	P_{mean}	391.8812mm
CORDL. AT r/R=0.75	$c_{0.75}$	106.3476mm
THICKN. AT r/R=0.75	$t_{0.75}$	3.7916mm
PITCH RATIO	$P_{0.7}/D$	1.63500
MEAN PITCH RATIO	P_{mean}/D	1.56752
AREA RATIO	A_E/A_0	0.77896
SKEW		18.837°
HUB DIAMETER RATIO	d_h/D	0.30000
NUMBER OF BLADES	z	5
DIRECTION OF ROTATION		RIGHT-HANDED

MODEL SCALE 1 : 1.000000

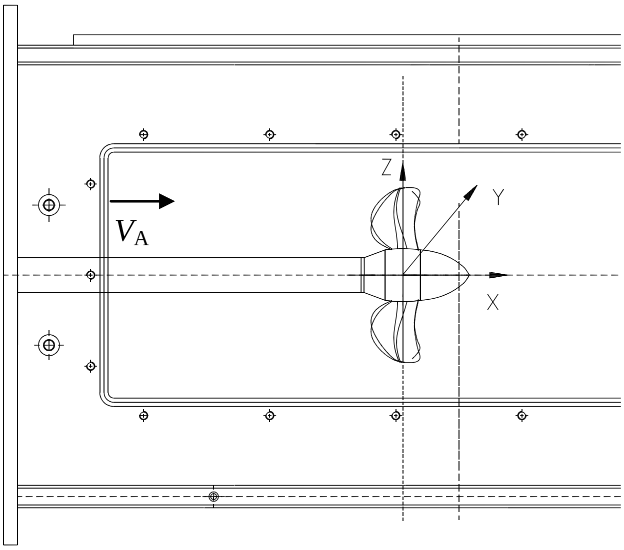
DIAGRAMS/DRAWINGS

Propeller VP1304

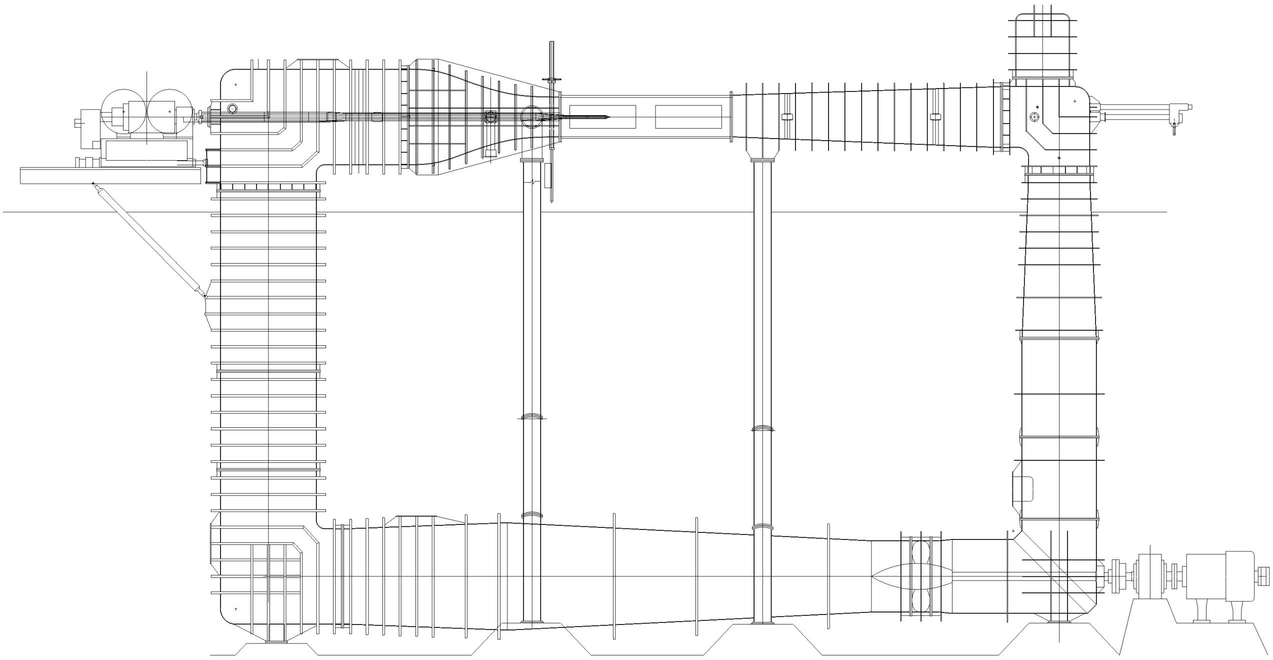


VP1304 in cavitation tunnel configuration

Test arrangement in the cavitation tunnel

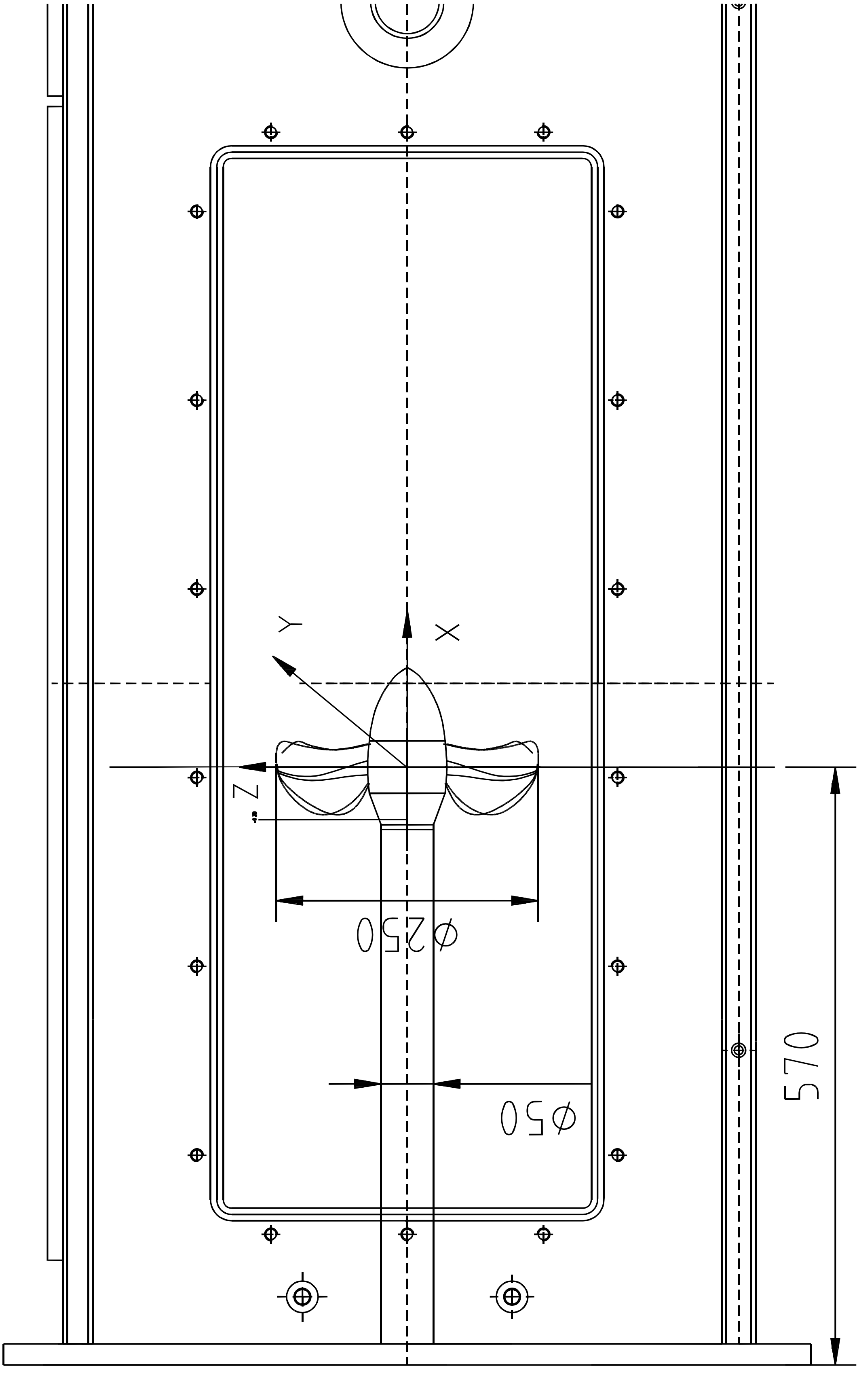


Model propeller VP1304 in the small test section with dynamometer J25 (shaft diameter 50 mm)

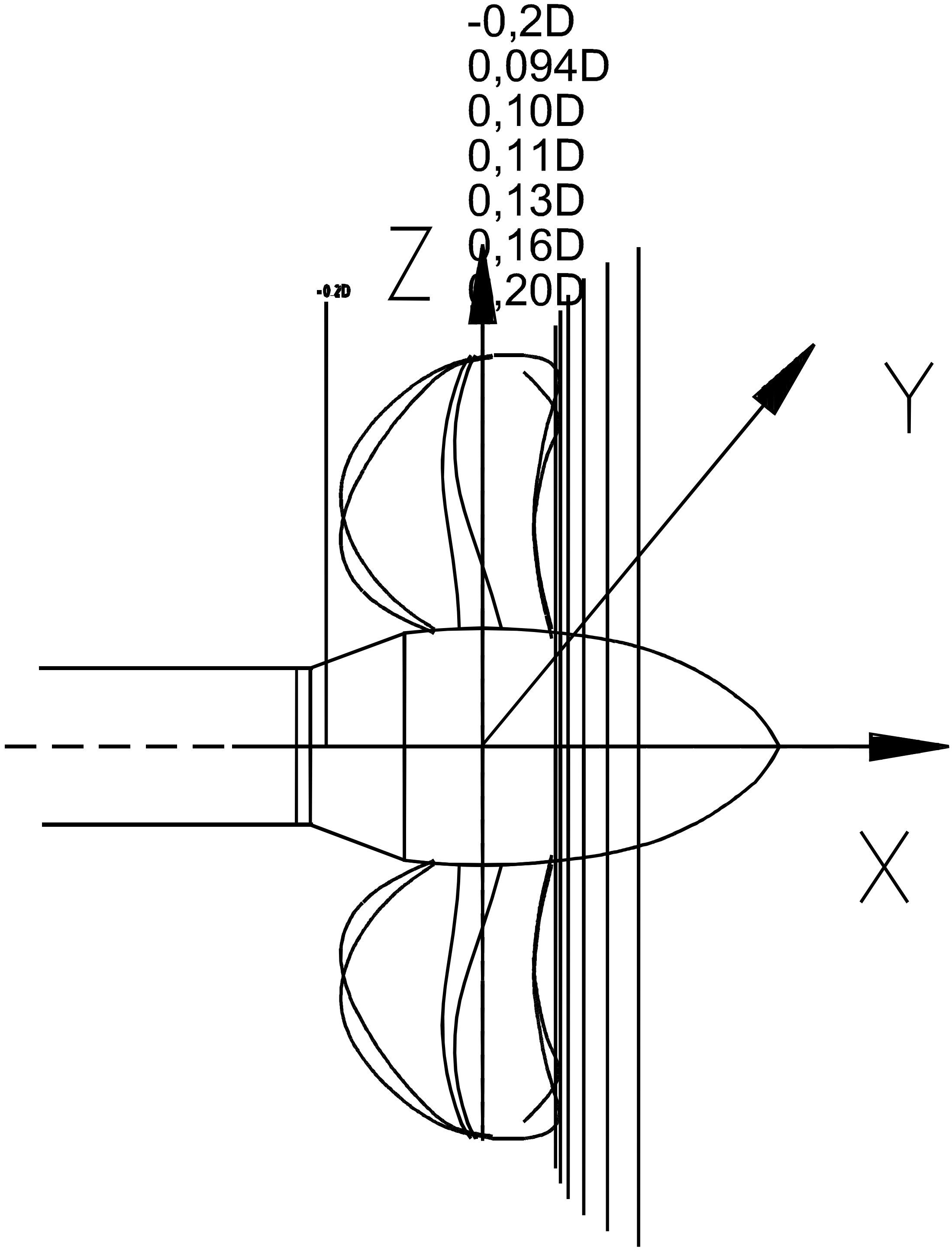


Cavitation tunnel type Kempf & Remmers K15A, small test section 600 x 600 mm

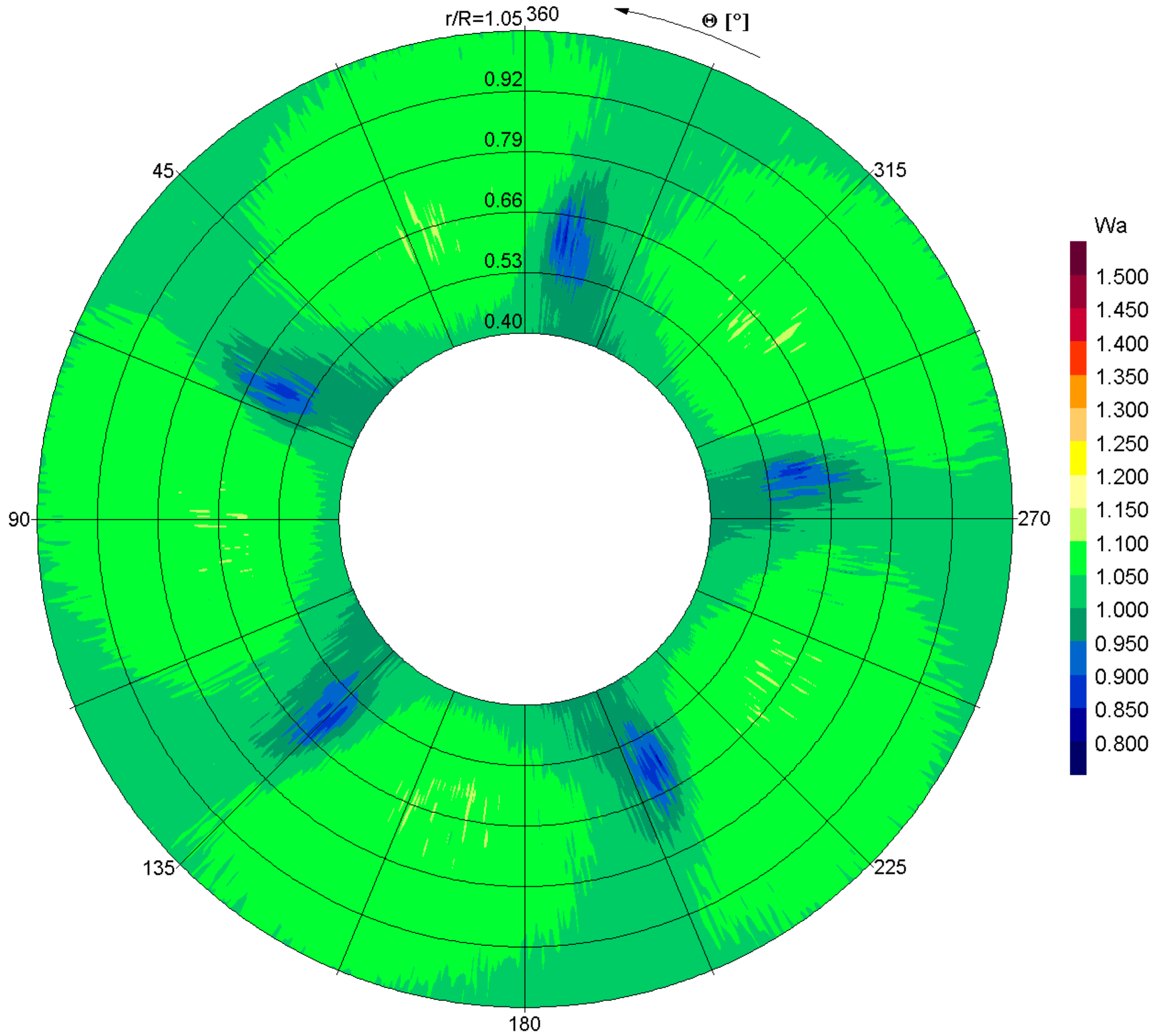
Propeller VP1304 in the cavitation tunnel



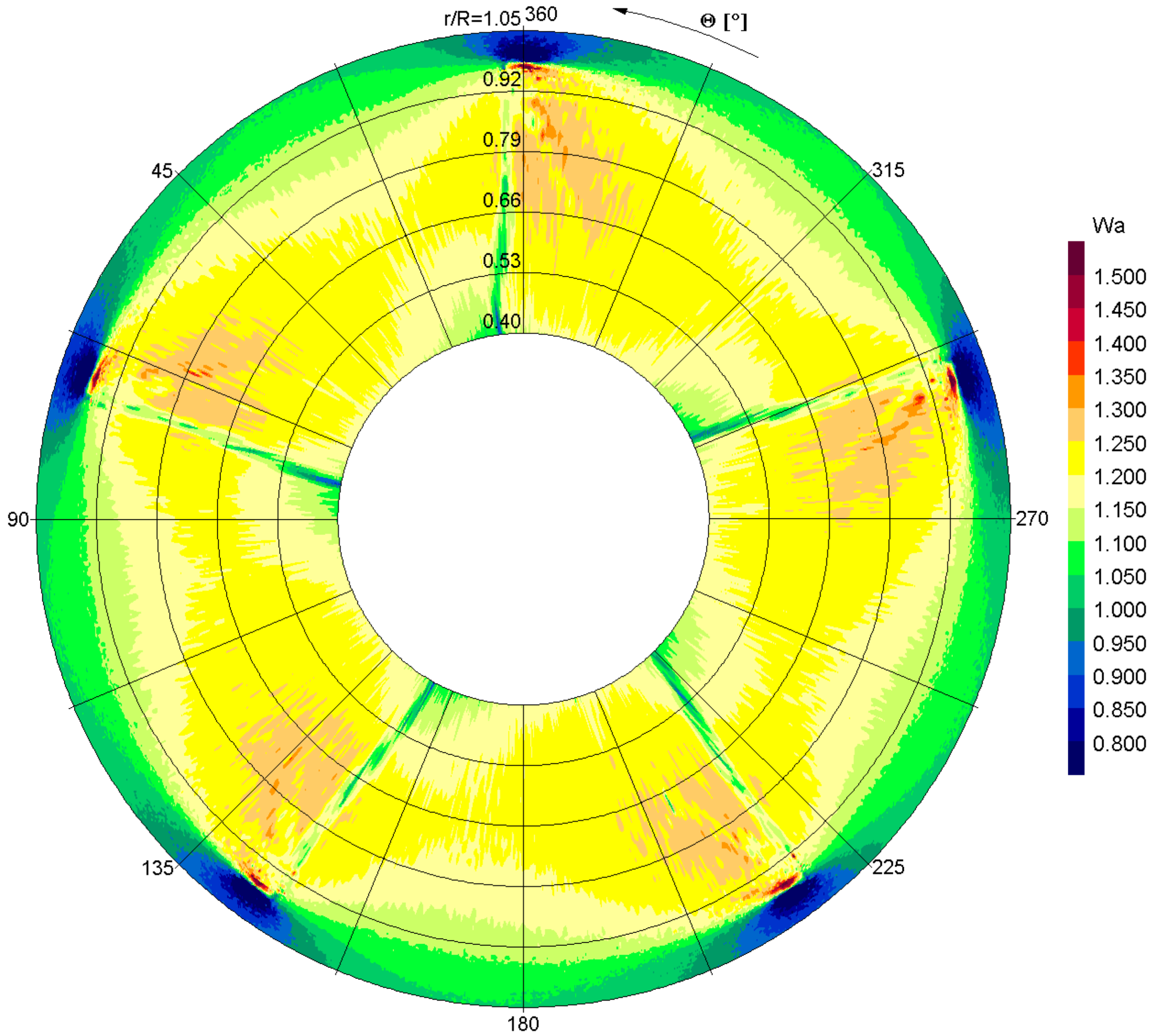
Measuring planes



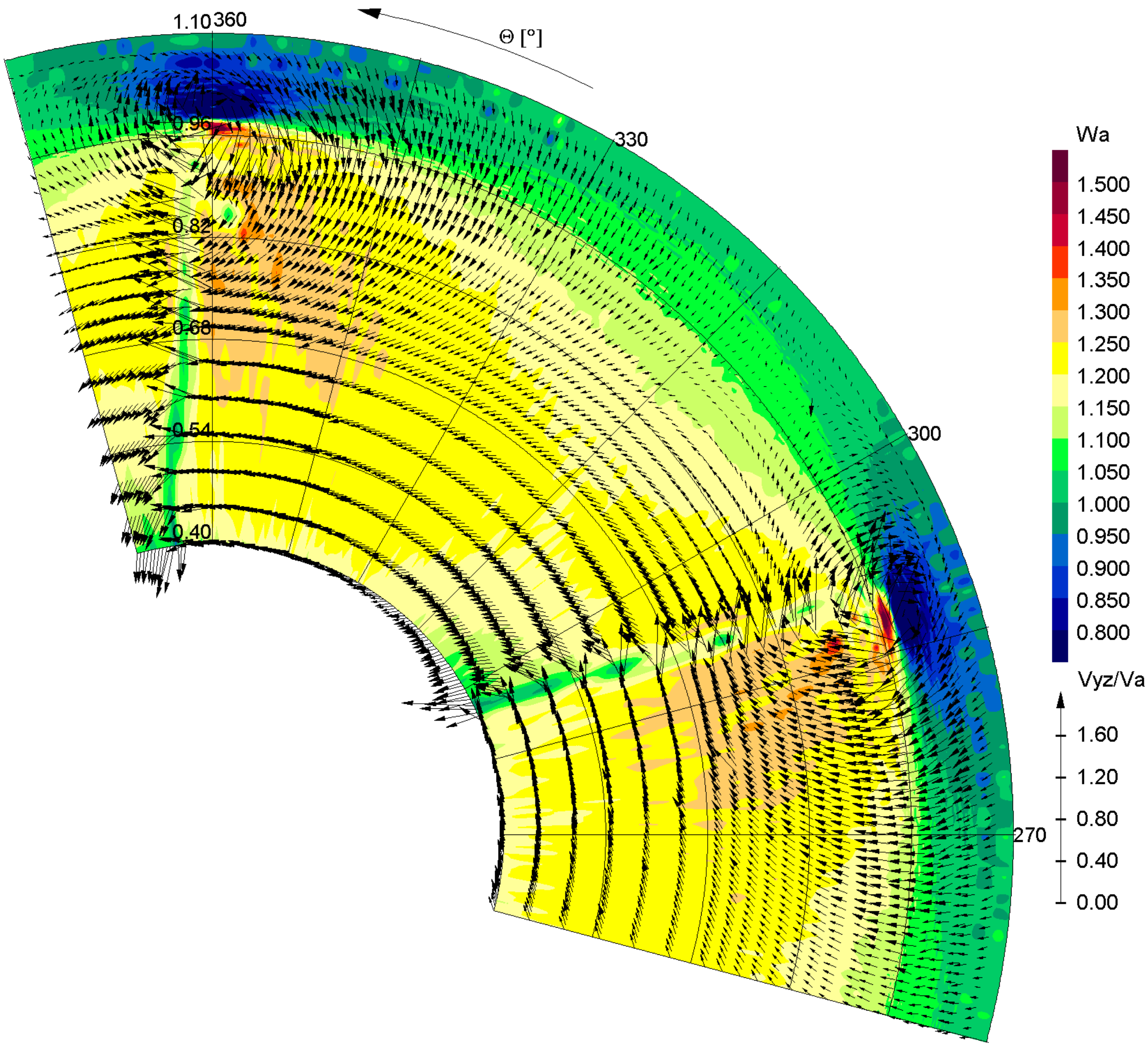
Axial velocity components, *x*/*D* = -0.2



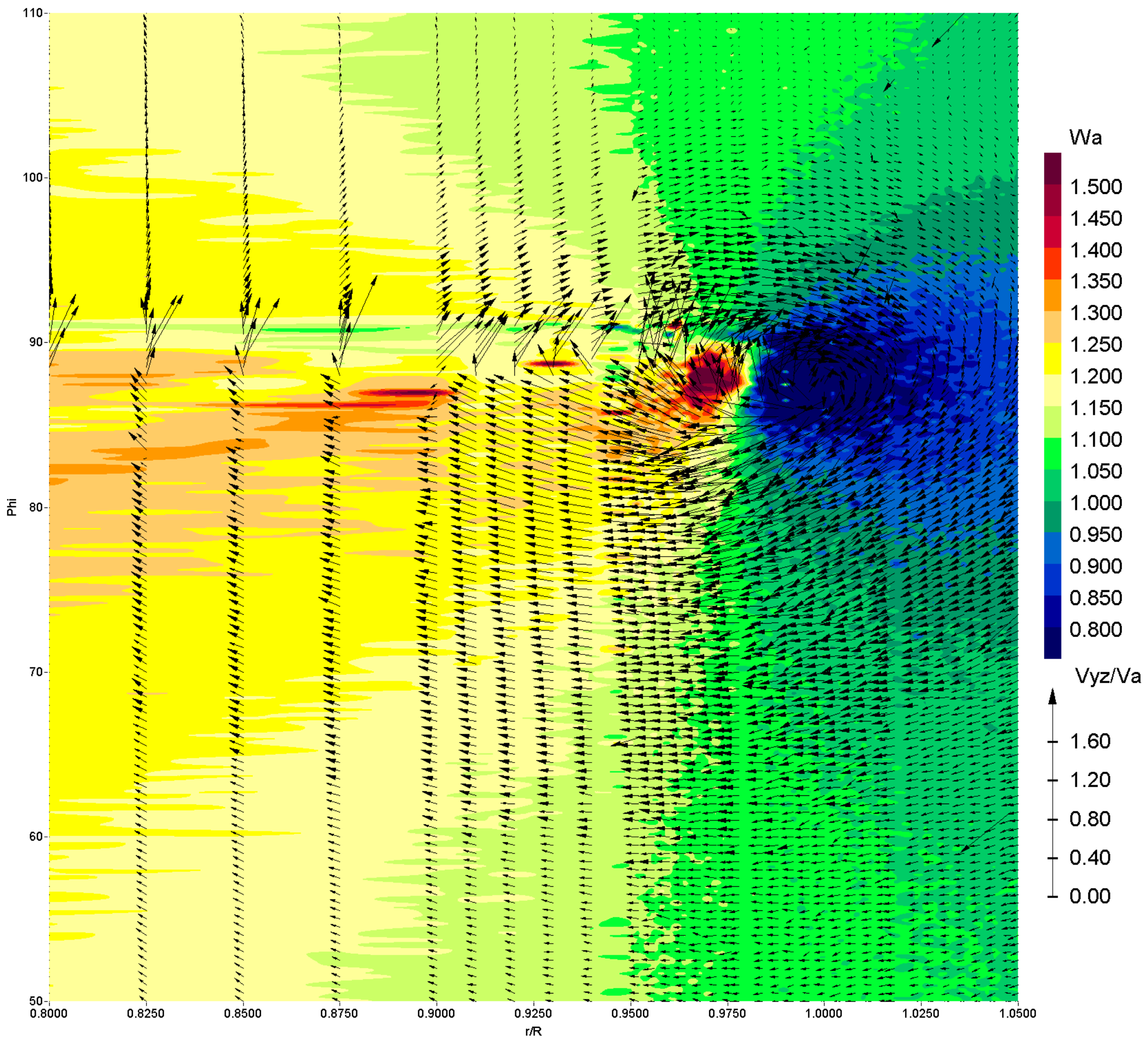
Axial velocity components, *x*/*D* = 0.094



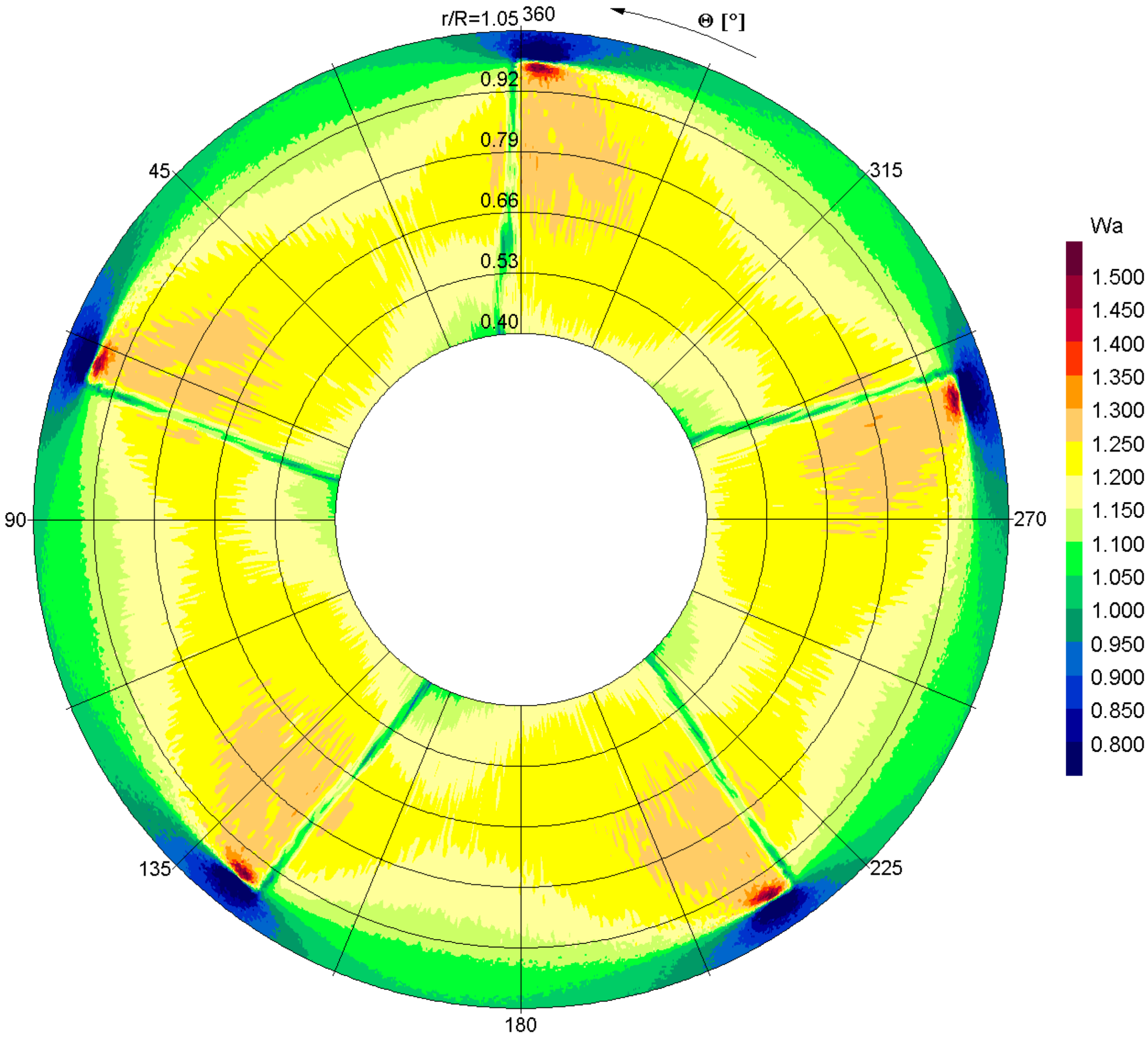
3D velocity components, *x*/*D* = 0.094



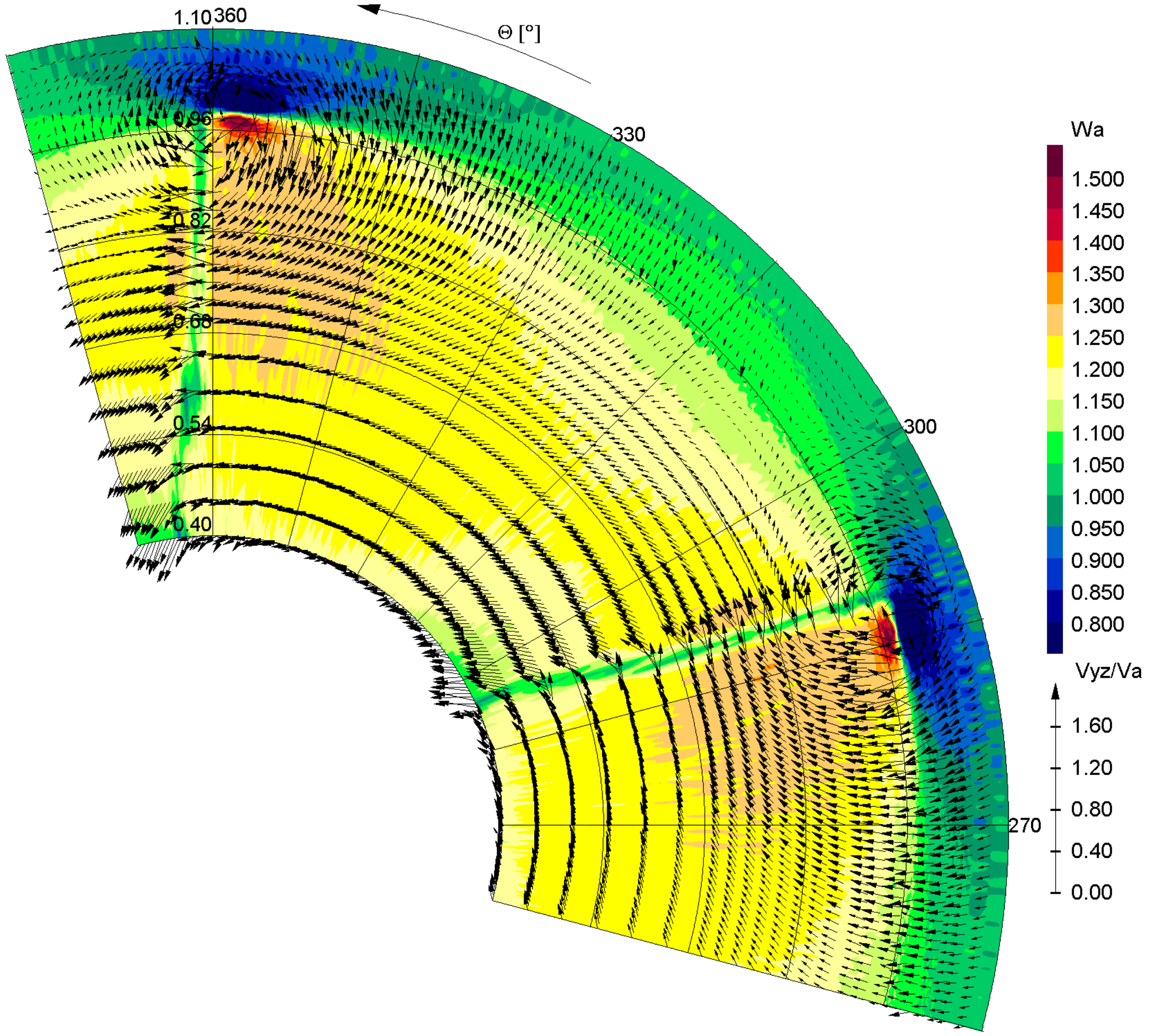
Detailed 3D velocity field, *x*/*D* = 0.094



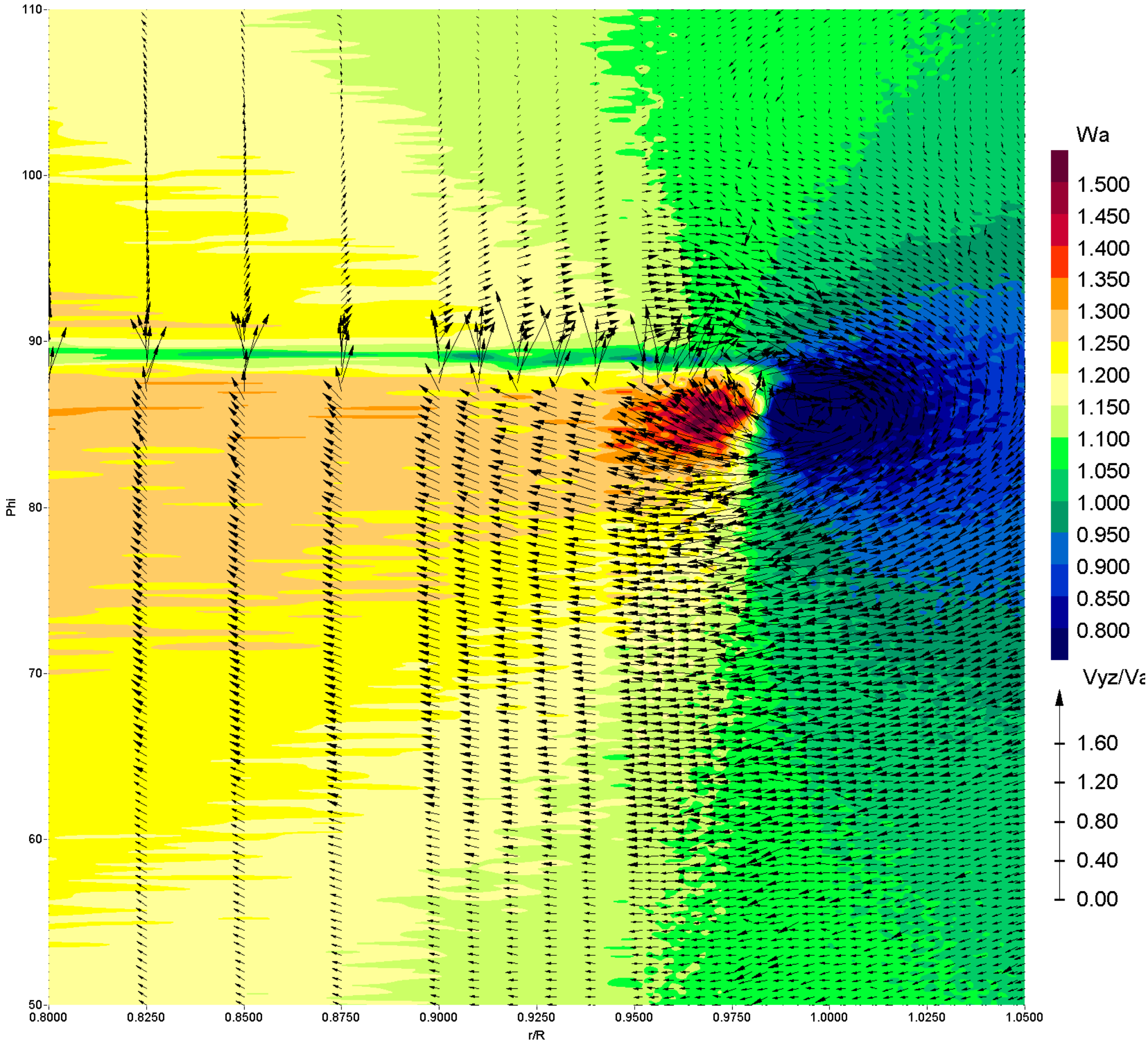
Axial velocity components, *x*/*D* = 0.10



3D velocity components, *x*/*D* = 0.10

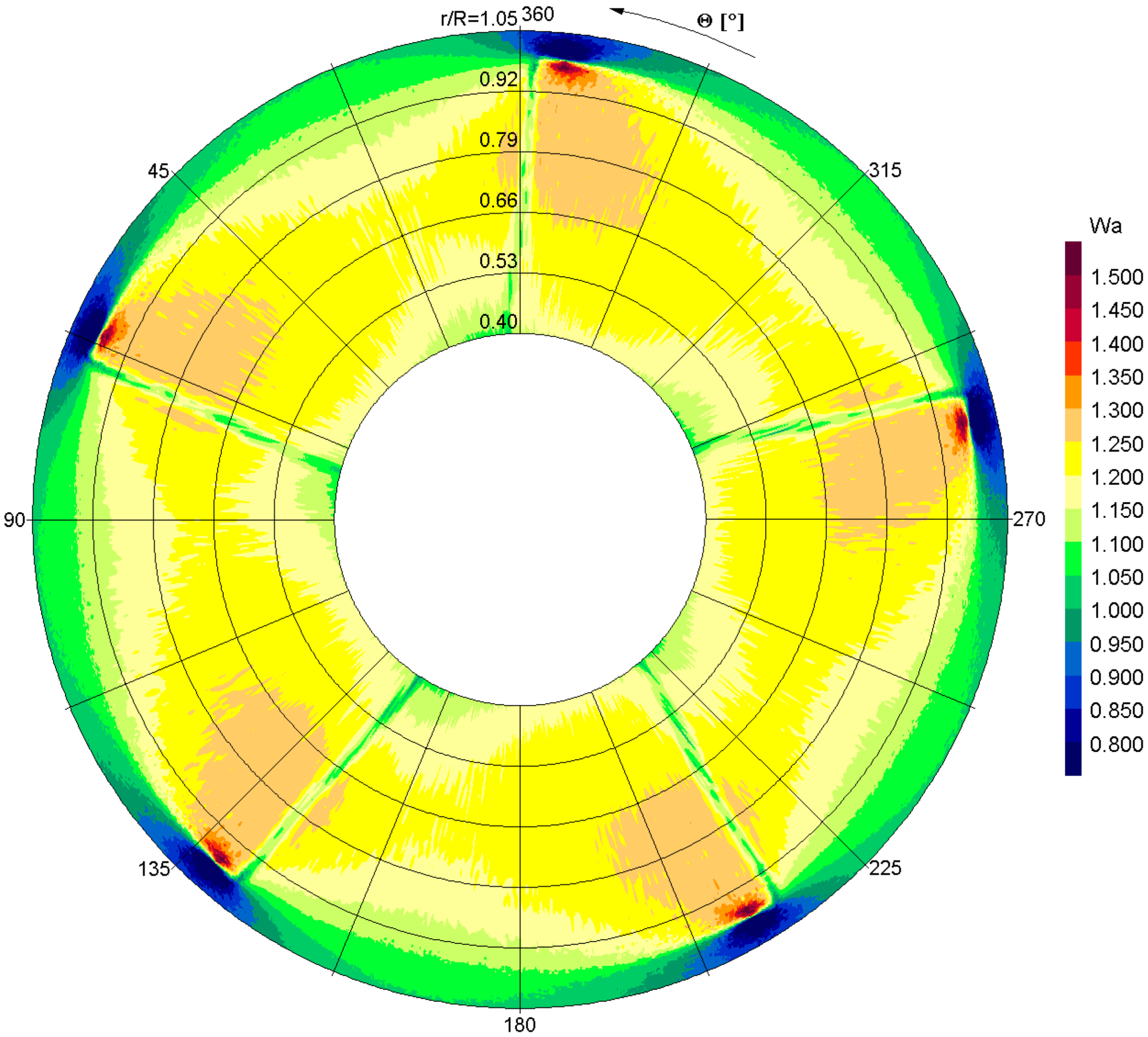


Detailed 3D velocity field, *x*/*D* = 0.10



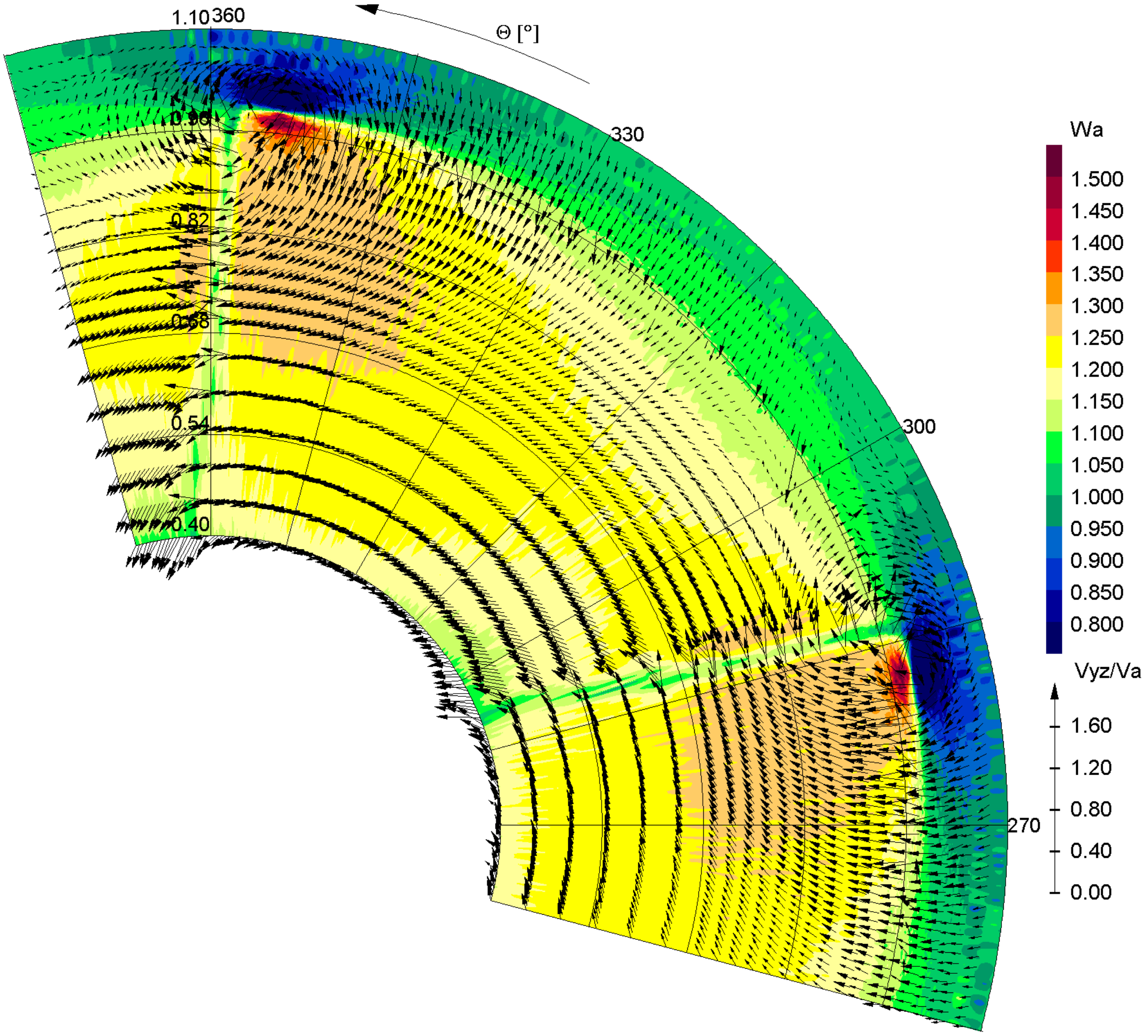
DIAGRAMS/DRAWINGS

Axial velocity components, *x*/*D* = 0.11

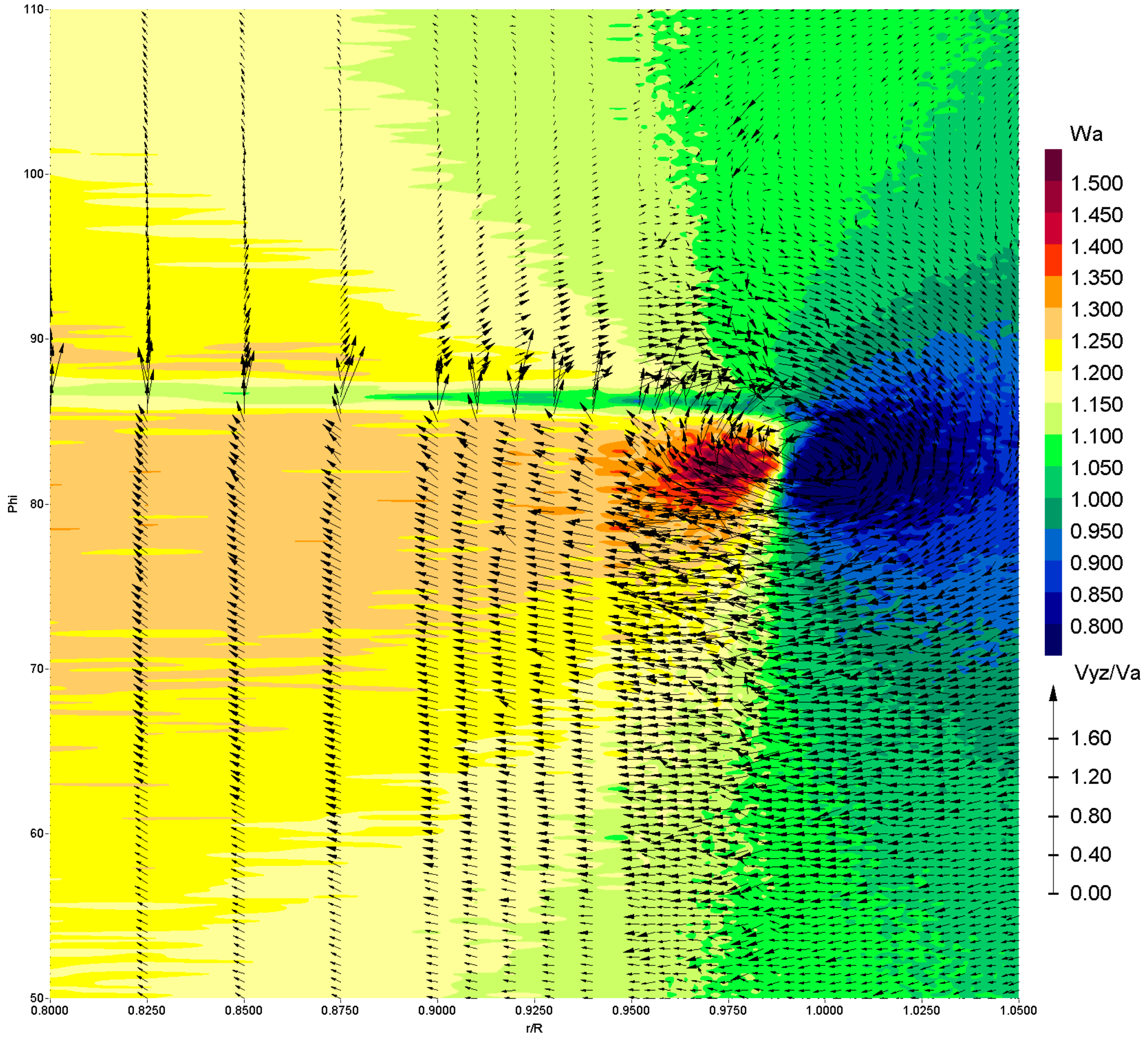


DIAGRAMS/DRAWINGS

3D velocity components, *x*/*D* = 0.11

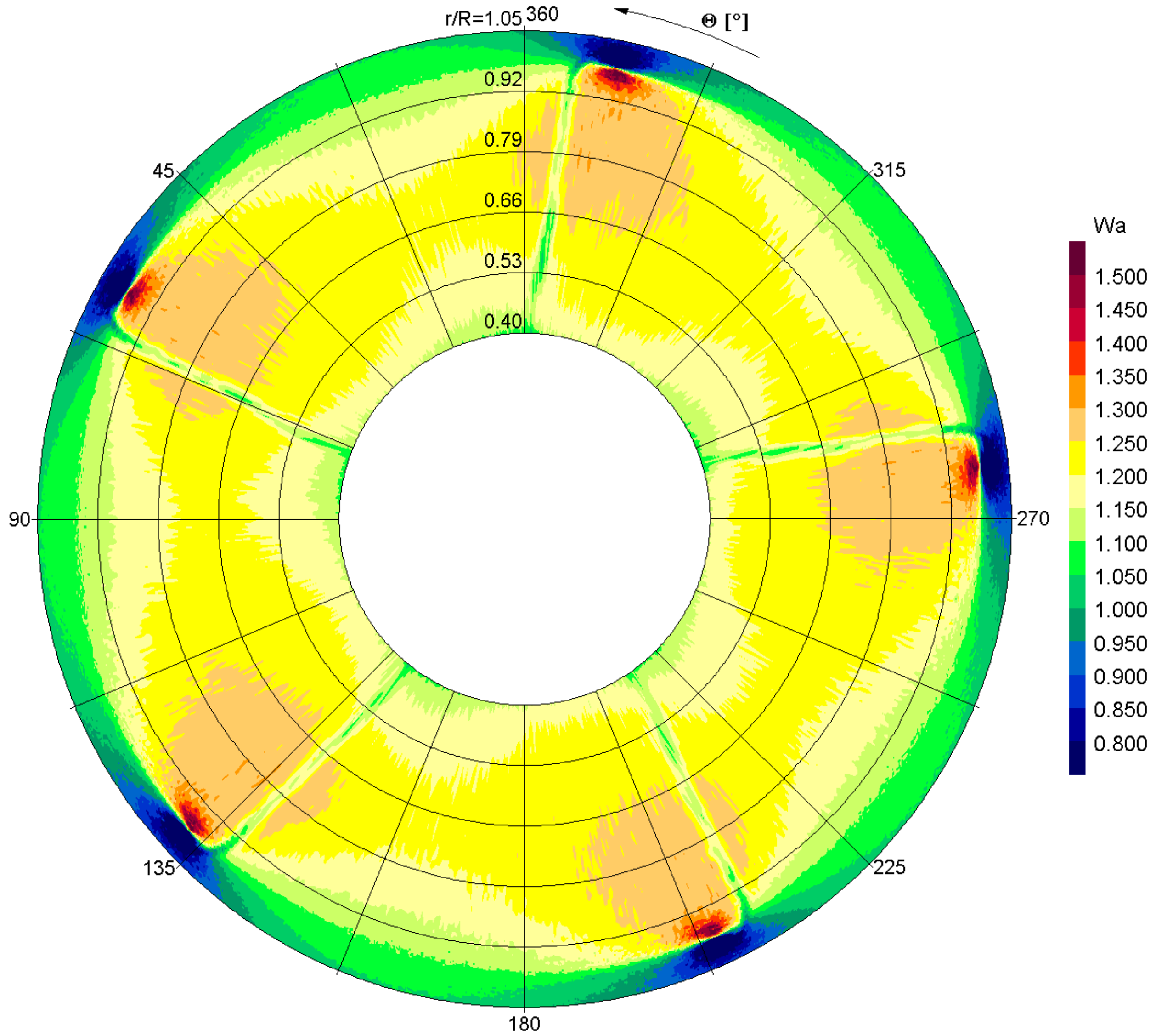


Detailed 3D velocity field, *x*/*D* = 0.11

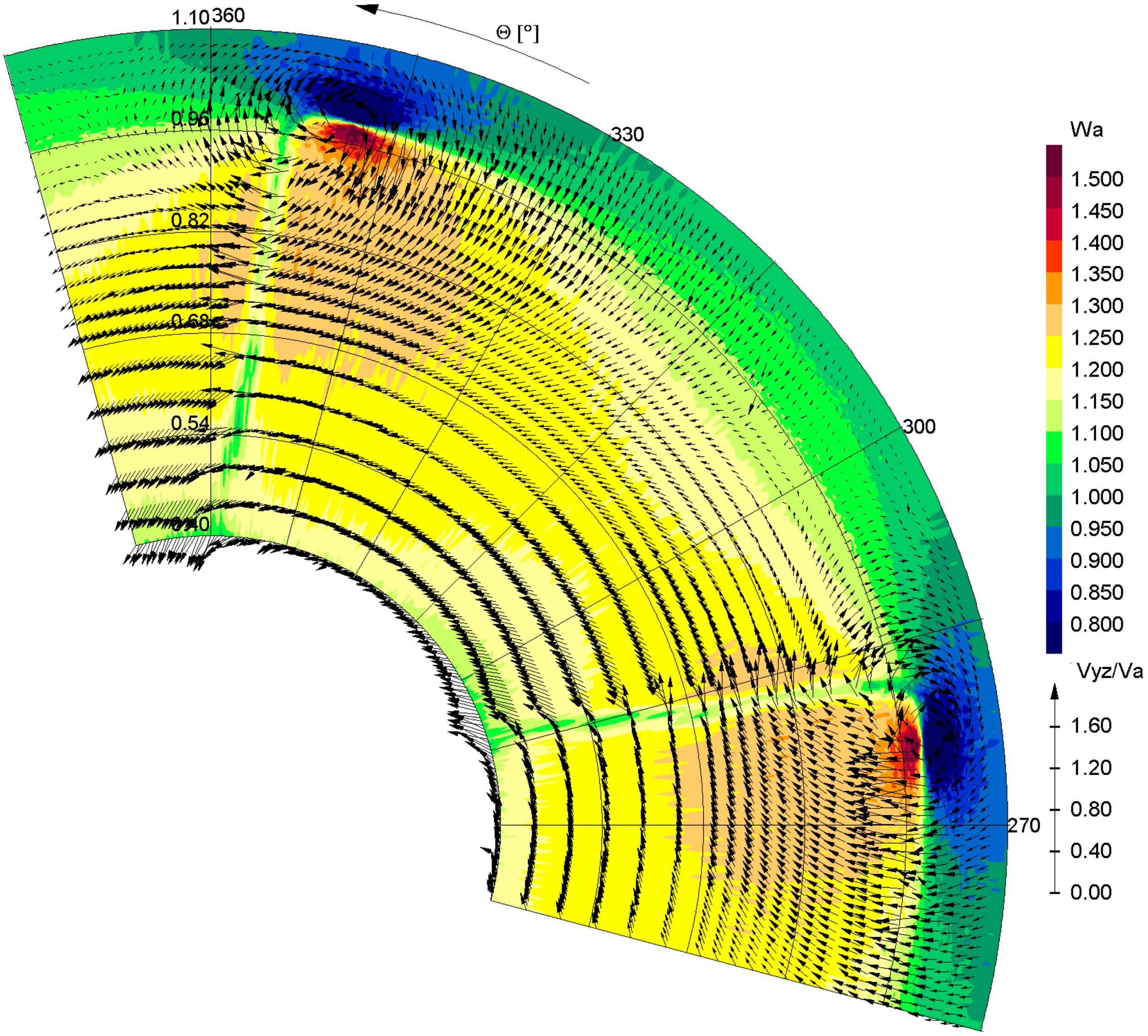


DIAGRAMS/DRAWINGS

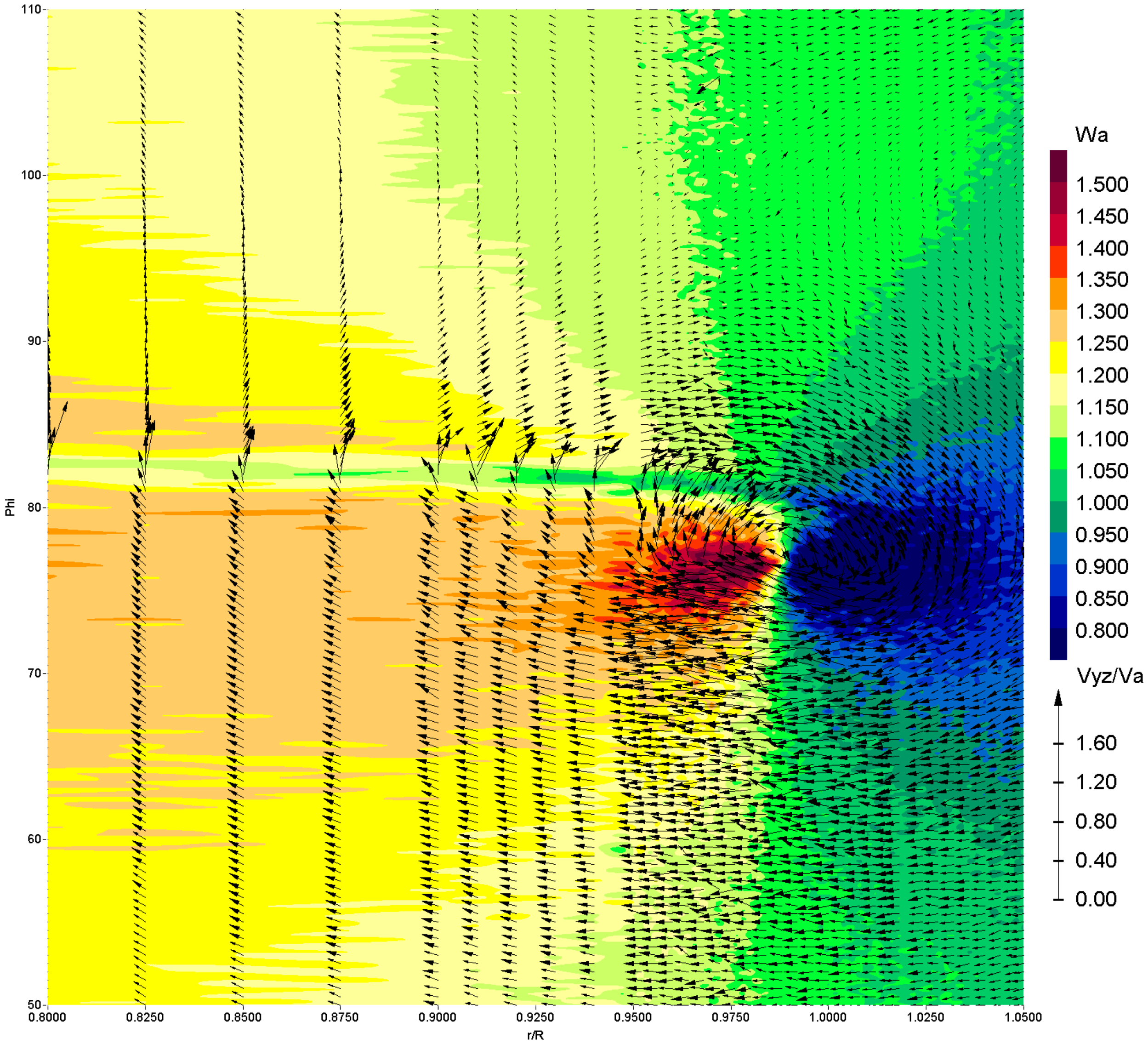
Axial velocity components, *x*/*D* = 0.13



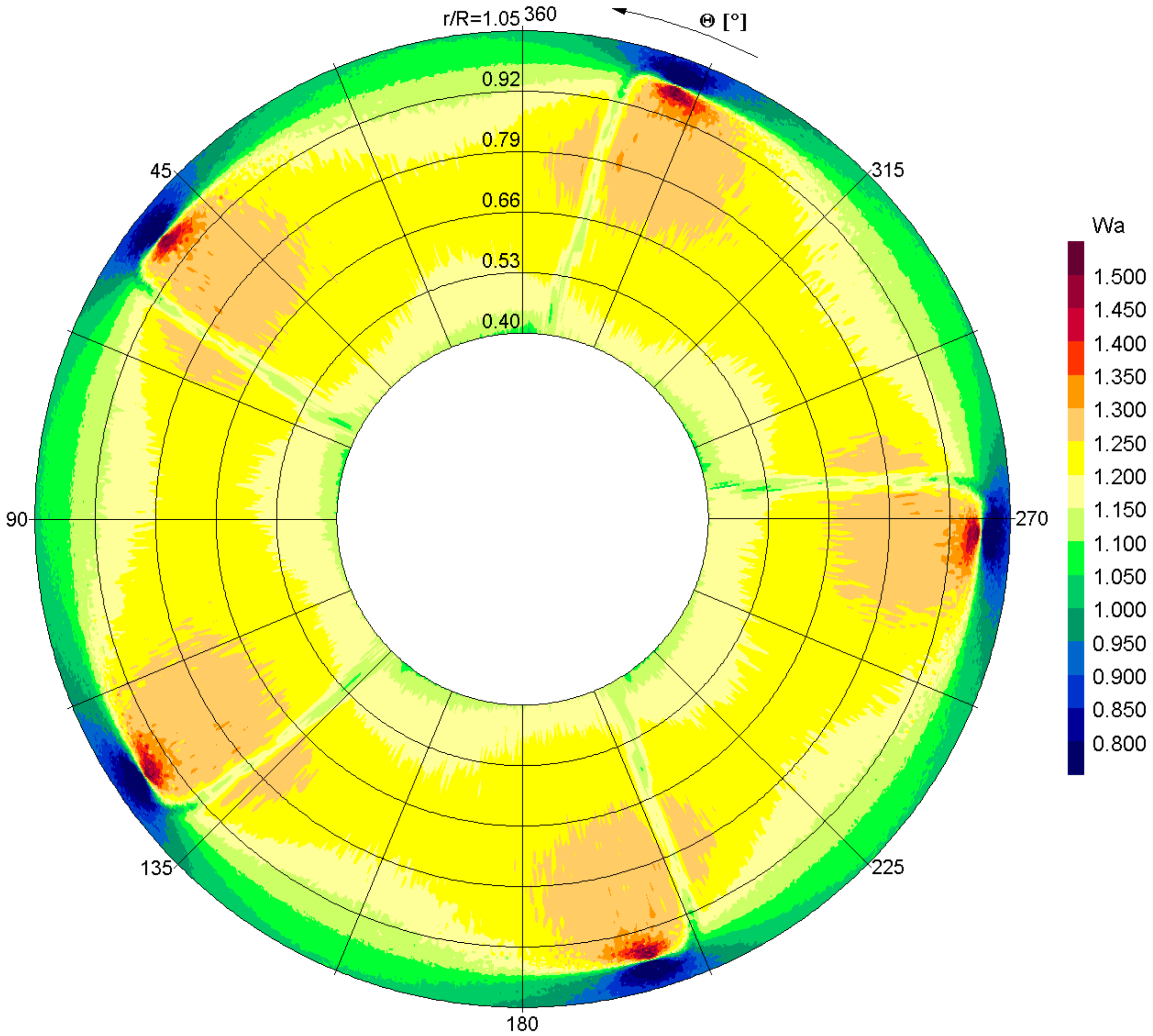
3D velocity components, *x*/*D* = 0.13



Detailed 3D velocity field, *x*/*D* = 0.13

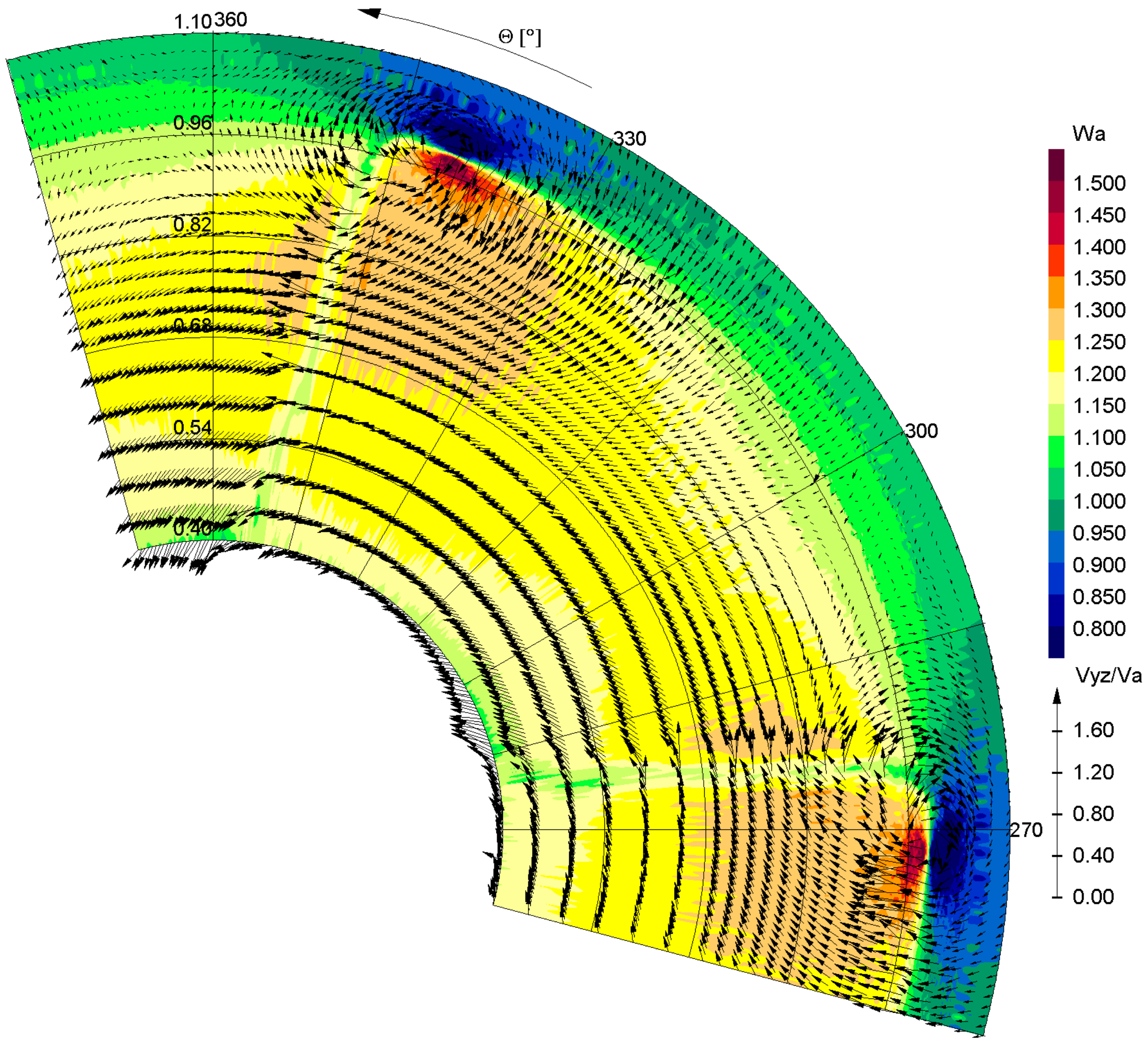


Axial velocity components, x/D = 0.16

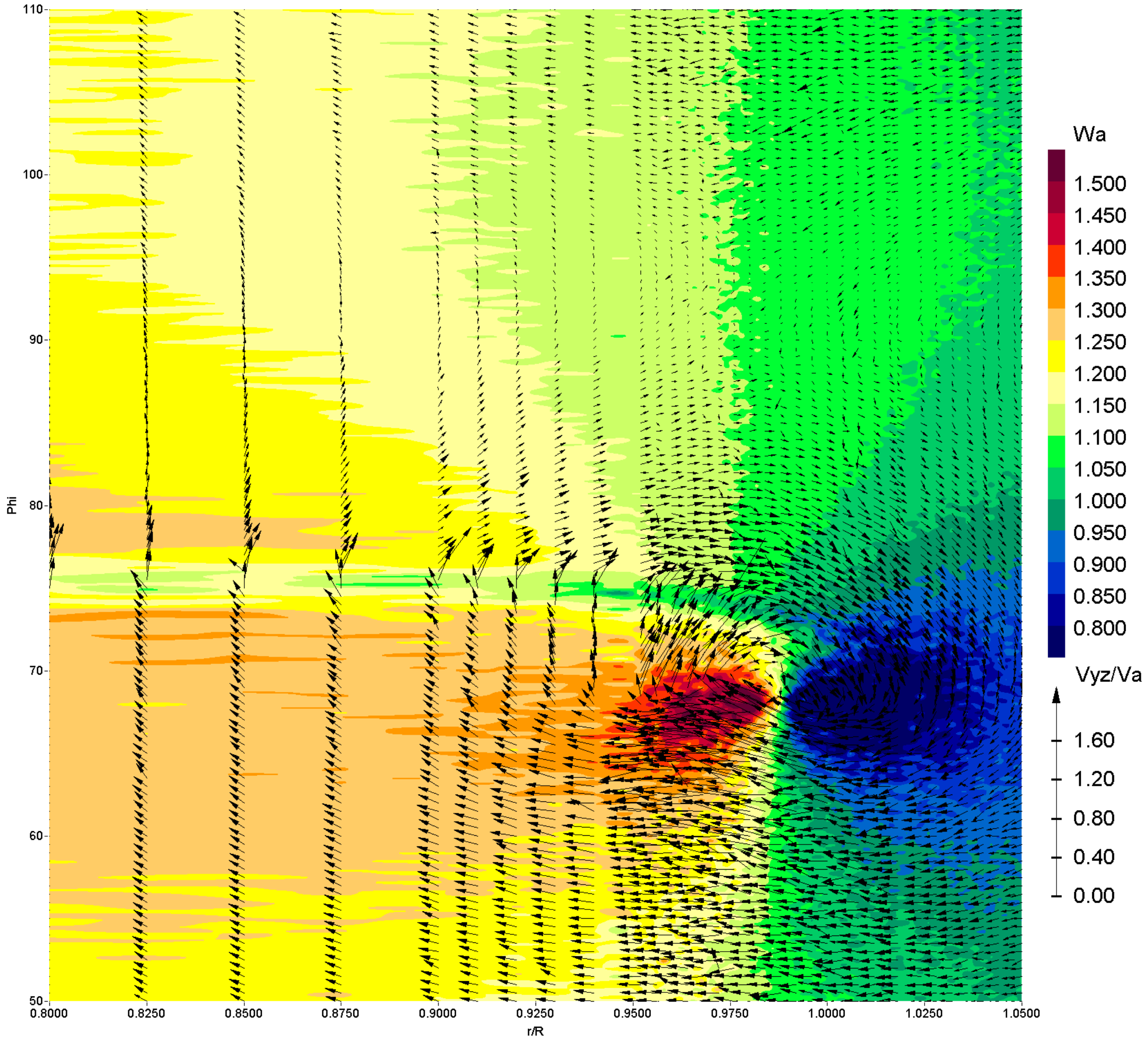


DIAGRAMS/DRAWINGS

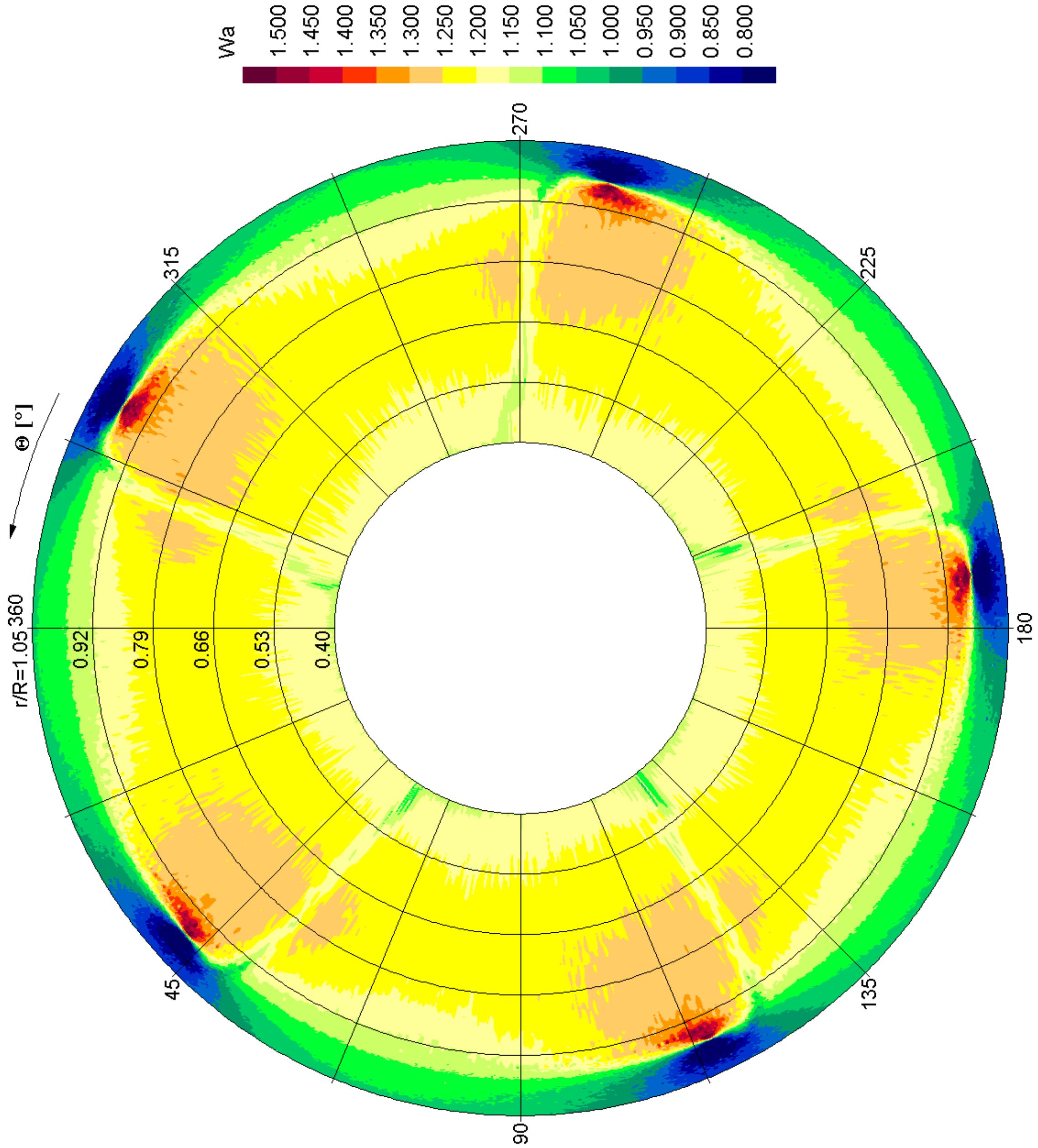
3D velocity components, *x*/*D* = 0.16



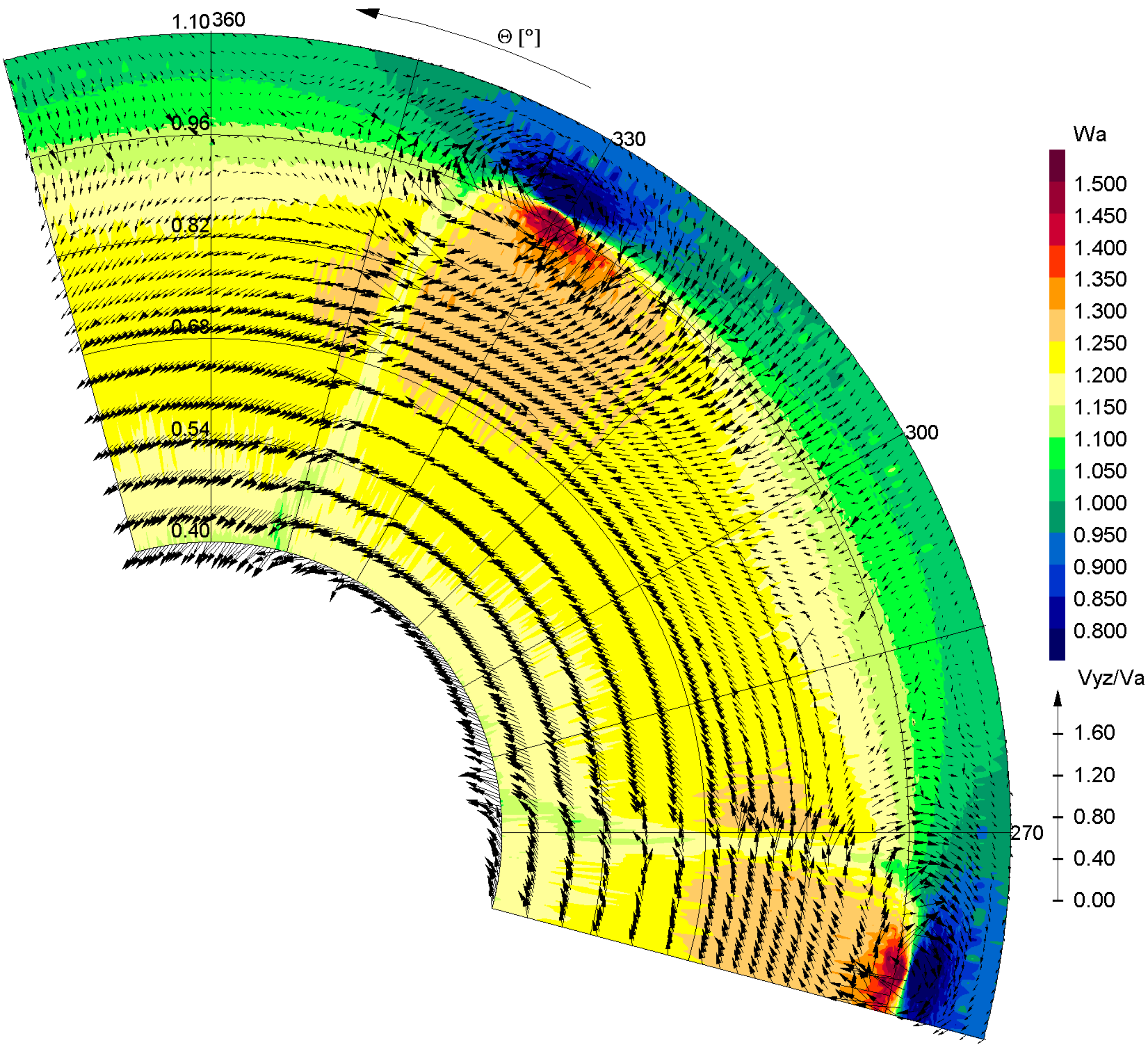
Detailed 3D velocity field, *x*/*D* = 0.16



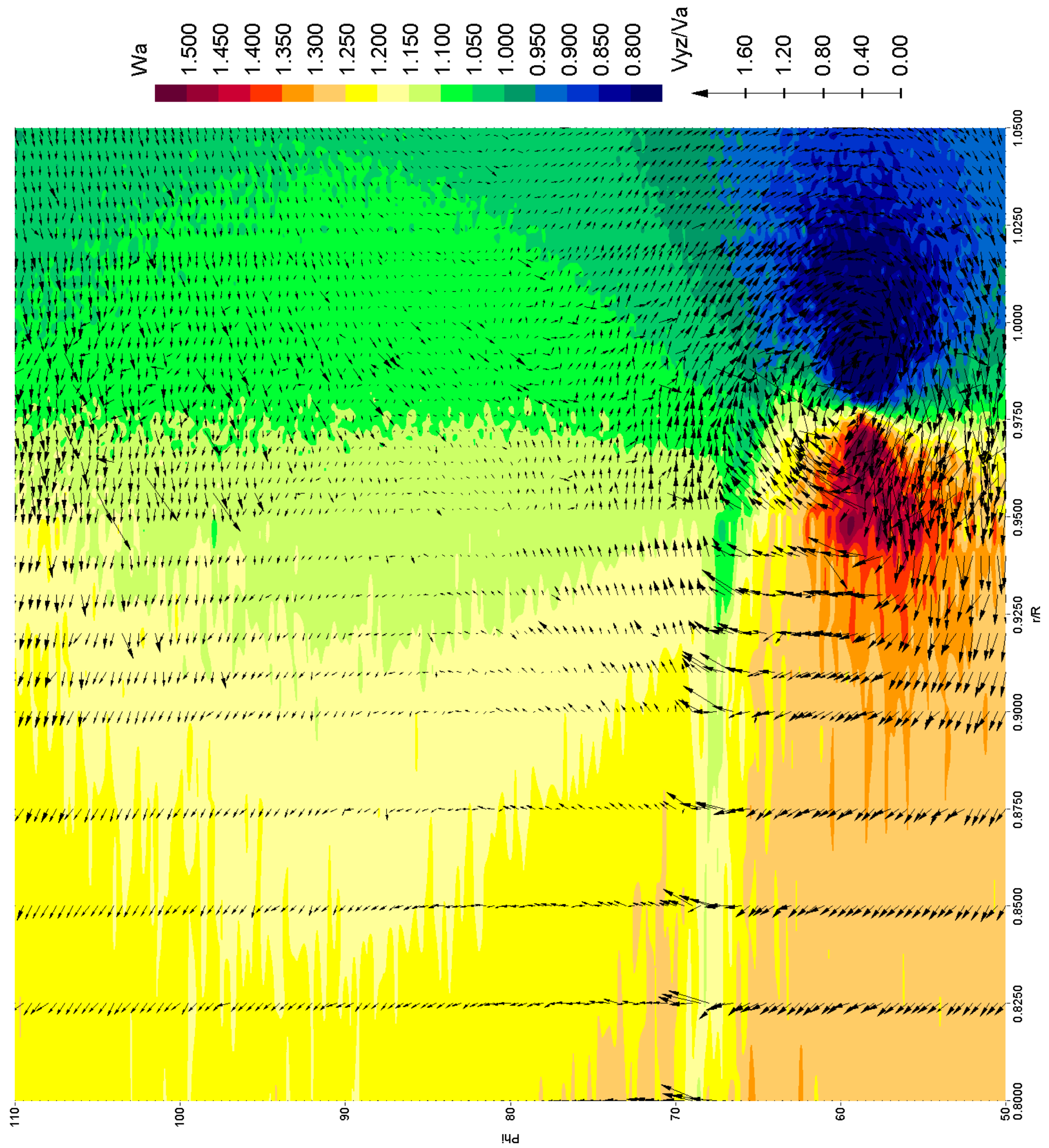
Axial velocity components, *x*/*D* = 0.20



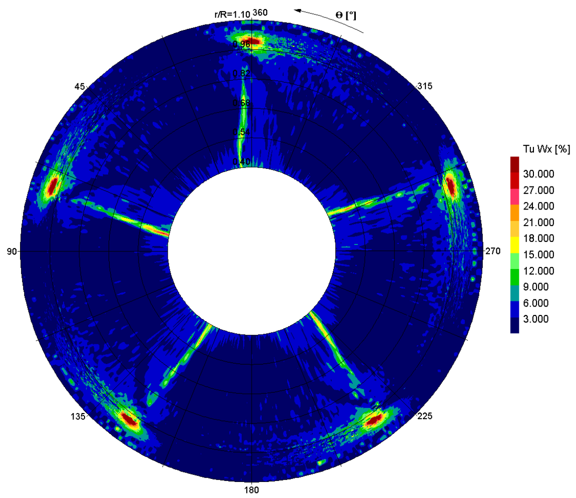
3D velocity components, x/D = 0.20



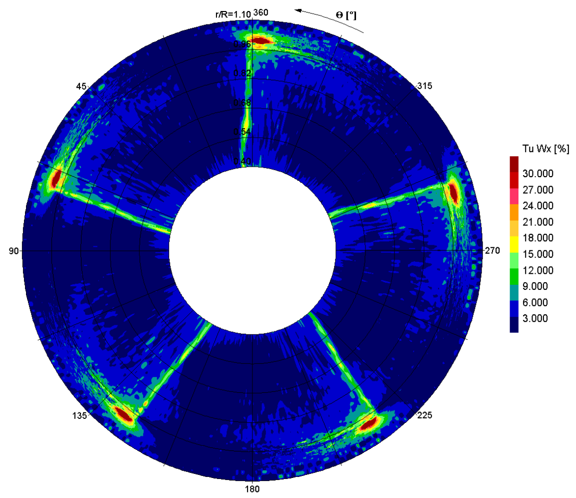
Detailed 3D velocity field, *x*/*D* = 0.20



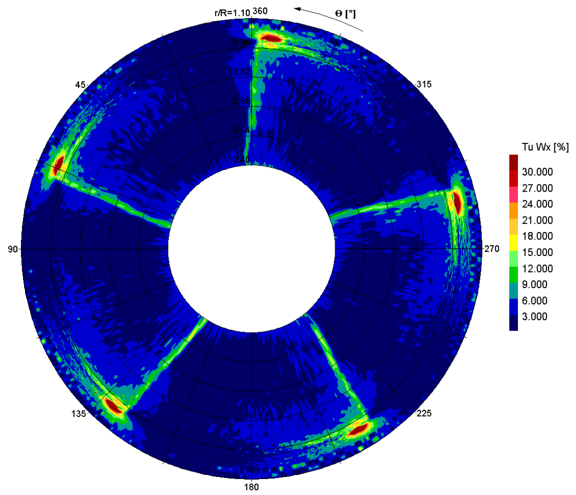
Turbulence degree of the axial velocity field, *x/D* = 0.094 - 0.20



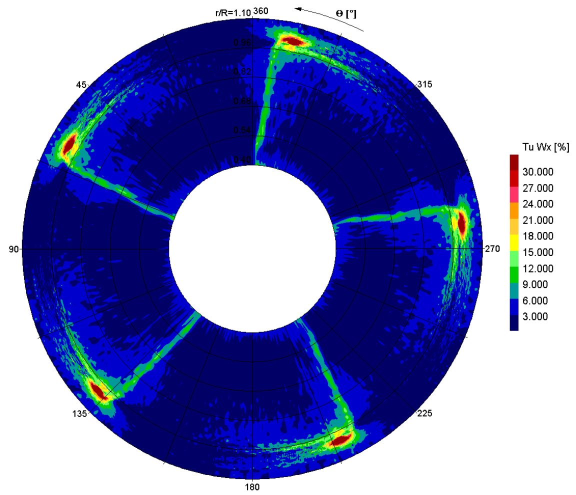
x/D = 0.094



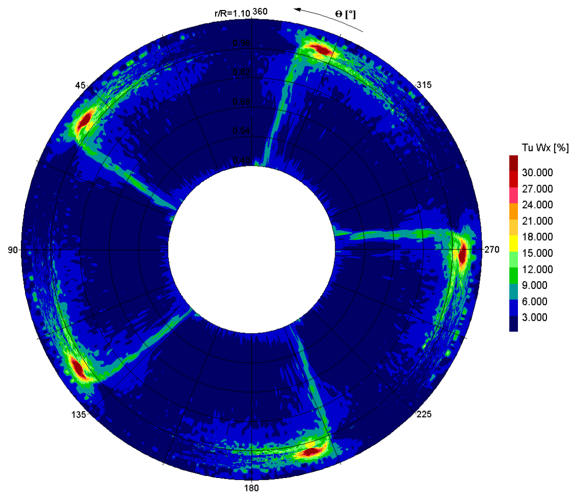
x/D = 0.10



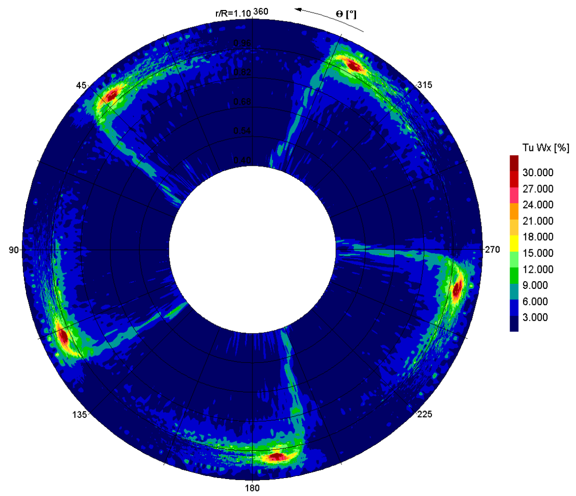
x/D = 0.11



x/D = 0.13



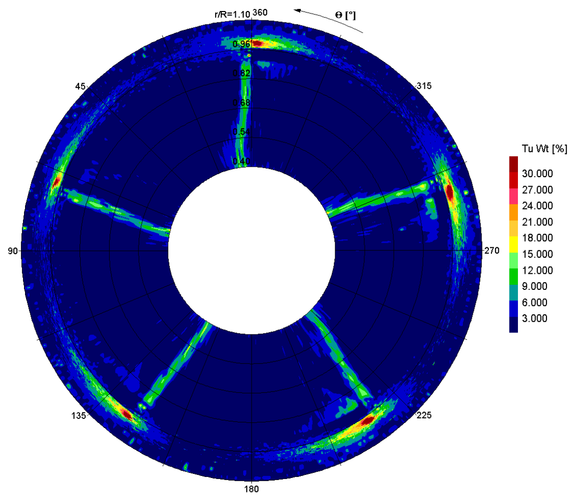
x/D = 0.16



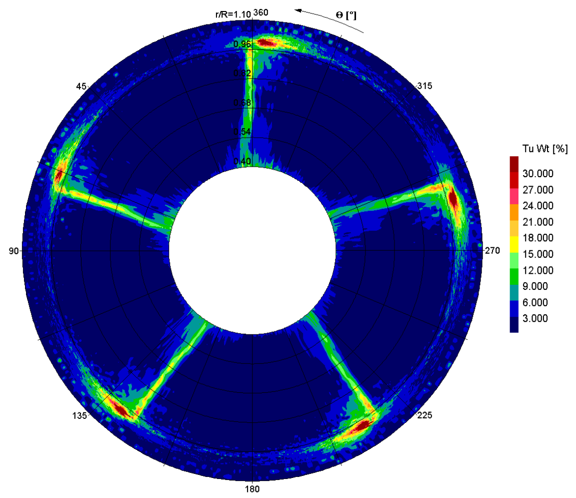
x/D = 0.20

DIAGRAMS/DRAWINGS

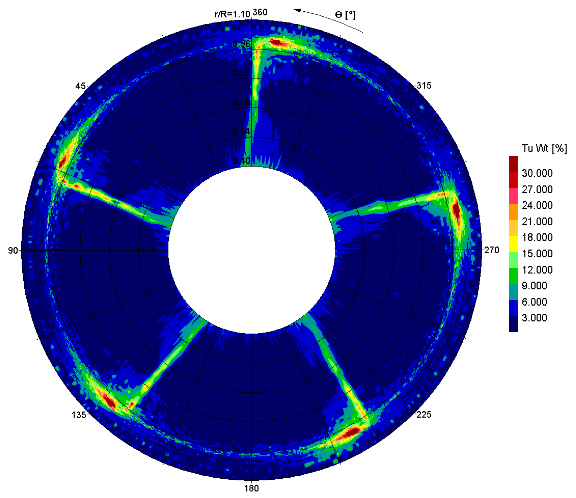
Turbulence degree of the tangential velocity field, *x*/*D* = 0.094 - 0.20



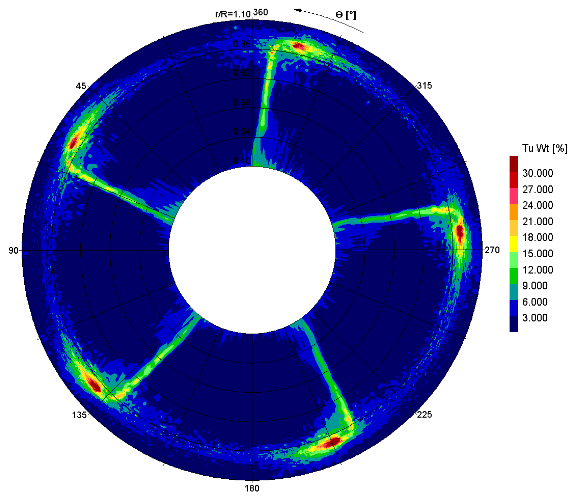
x/*D* = 0.094



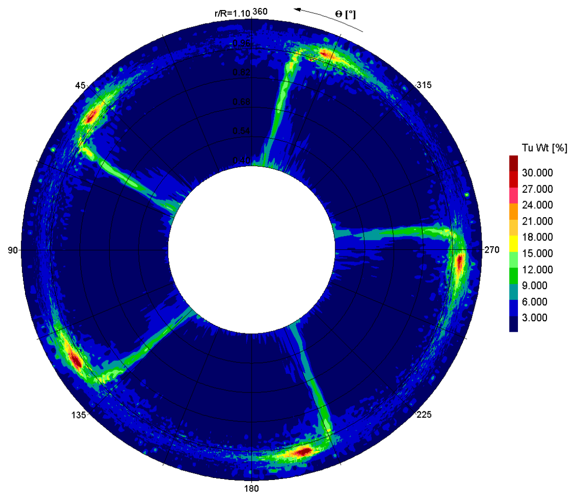
x/*D* = 0.10



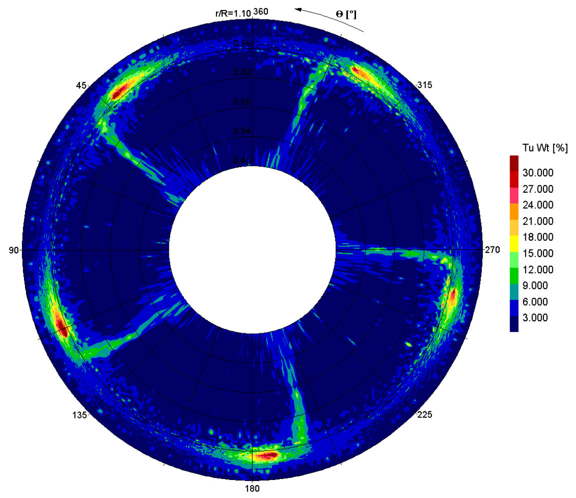
x/*D* = 0.11



x/*D* = 0.13

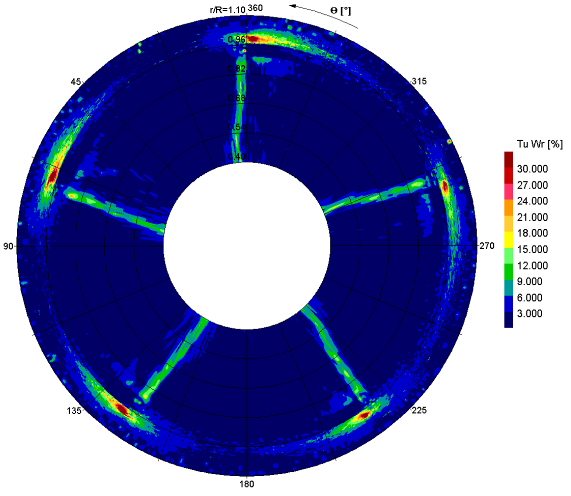


x/*D* = 0.16

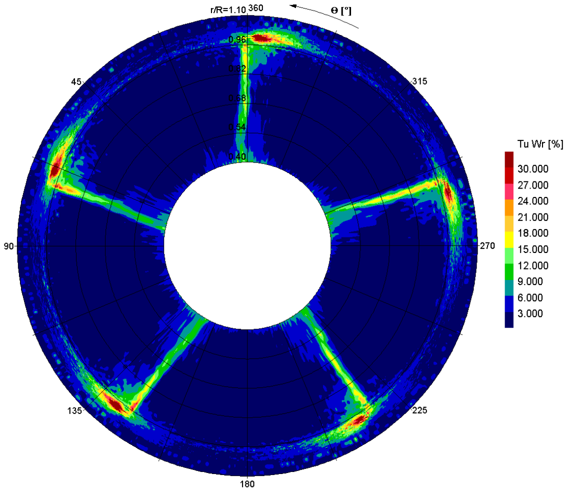


x/*D* = 0.20

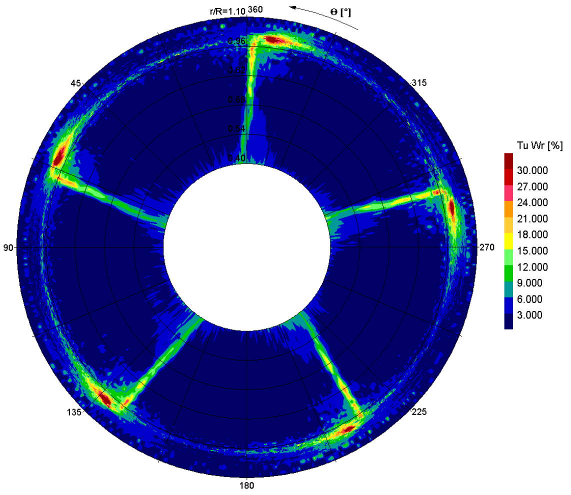
Turbulence degree of the radial velocity field, *x*/*D* = 0.094 - 0.20



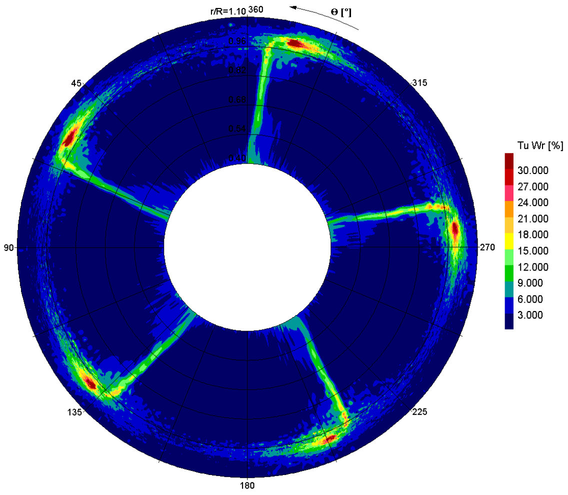
x/*D* = 0.094



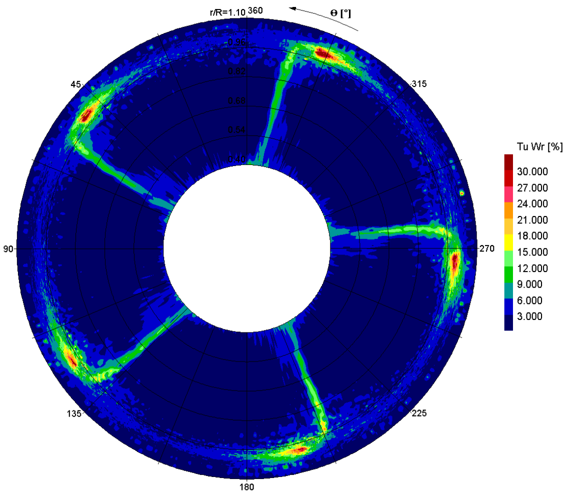
x/*D* = 0.10



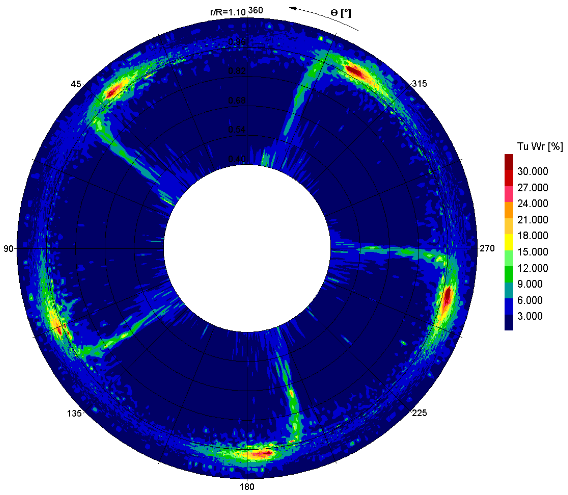
x/*D* = 0.11



x/*D* = 0.13

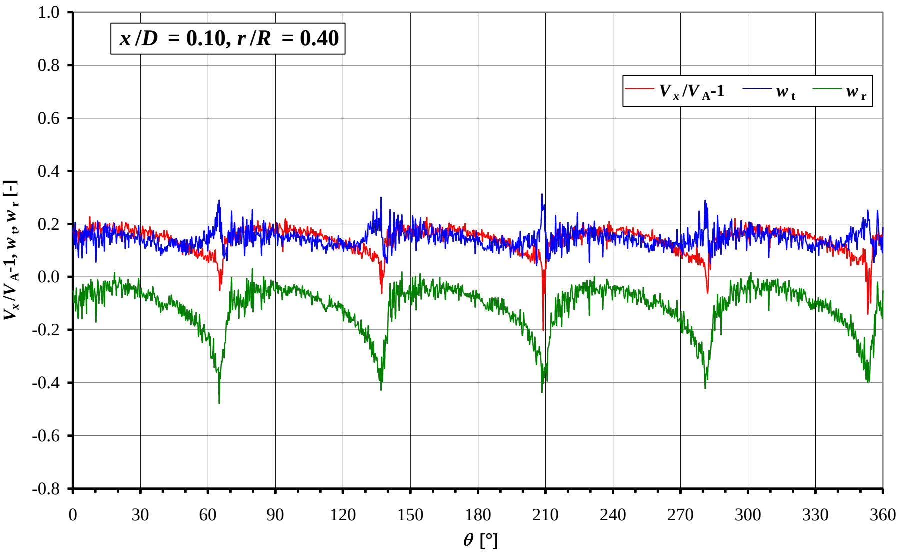


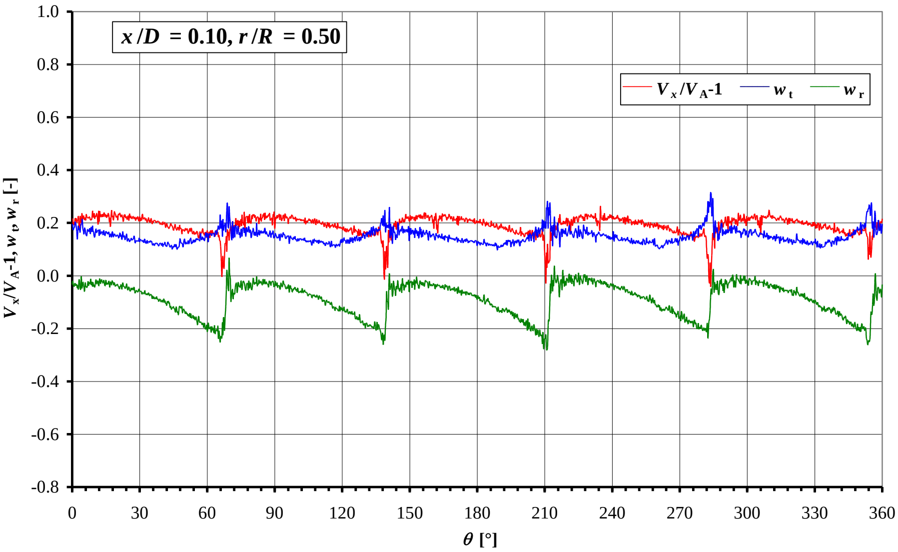
x/*D* = 0.16

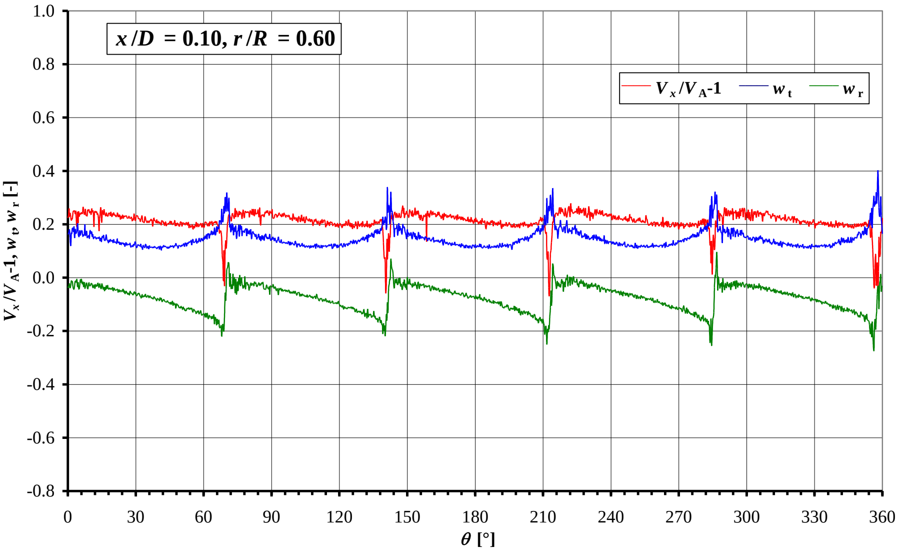


x/*D* = 0.20

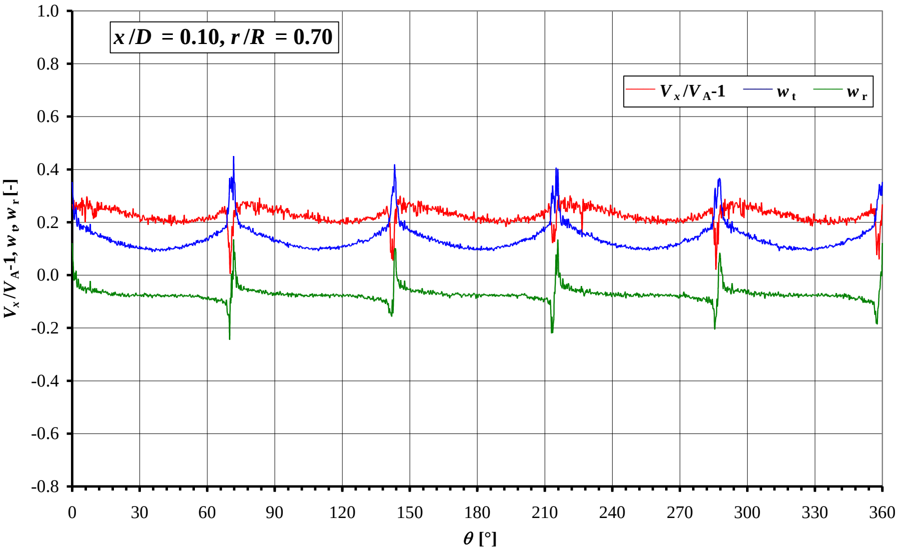
Velocity components V_x/V_A-1, w_t, w_r = f(θ), x/D = 0.10

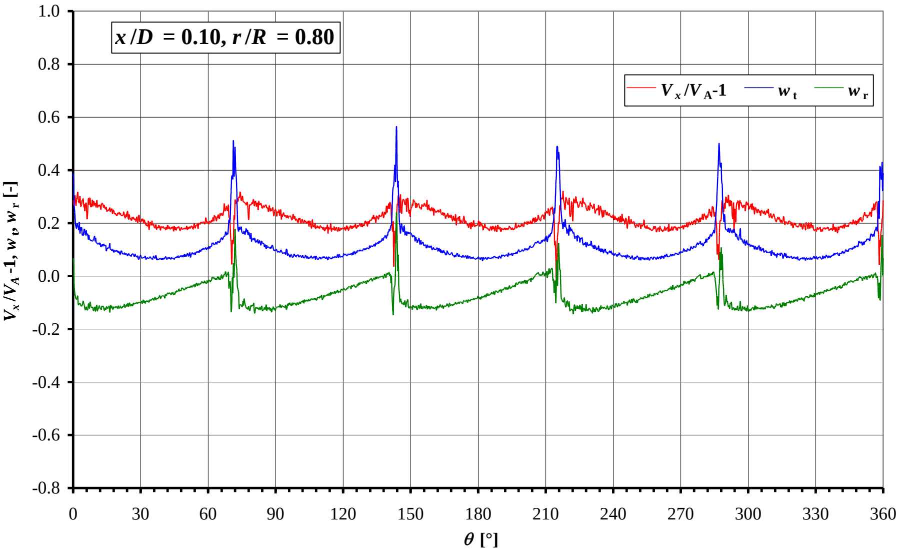


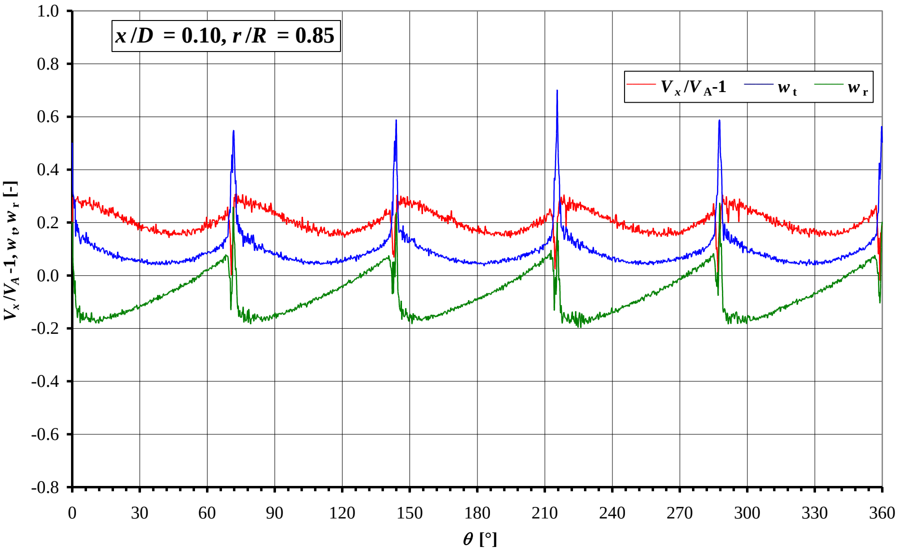




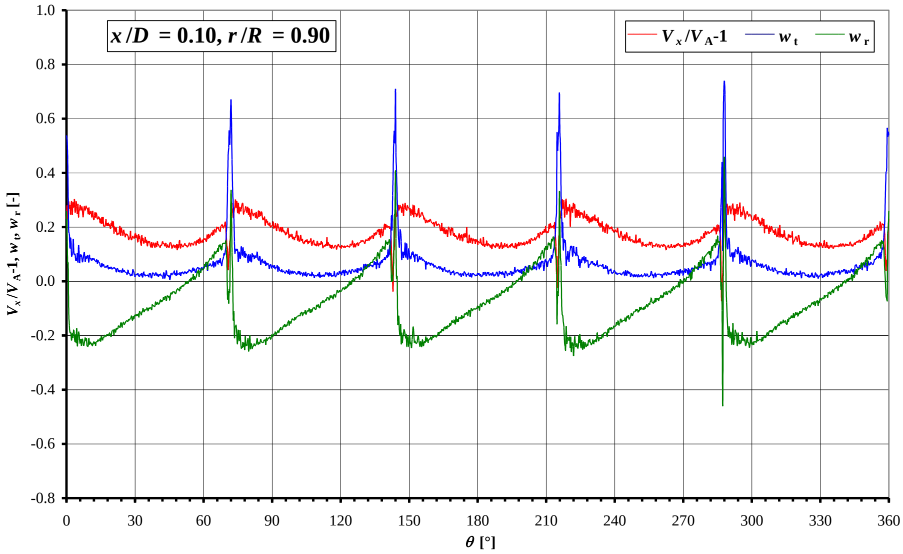
Velocity components V_x/V_A-1, w_t, w_r = f(θ), x/D = 0.10

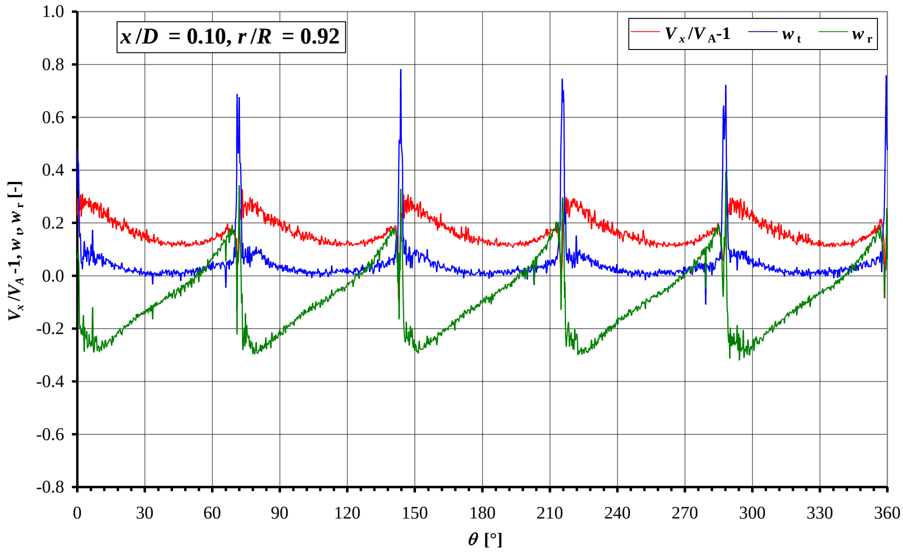


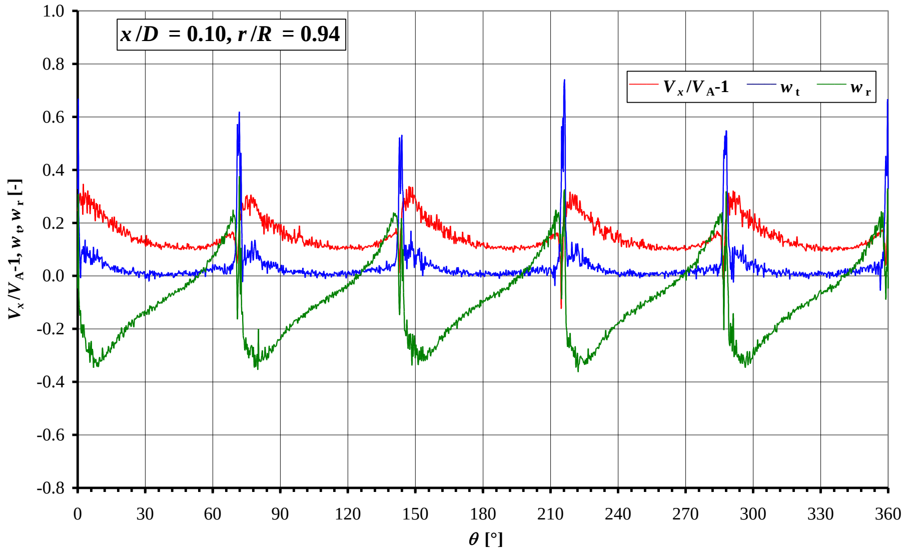




Velocity components V_x/V_A-1, w_t, w_r = f(θ), x/D = 0.10

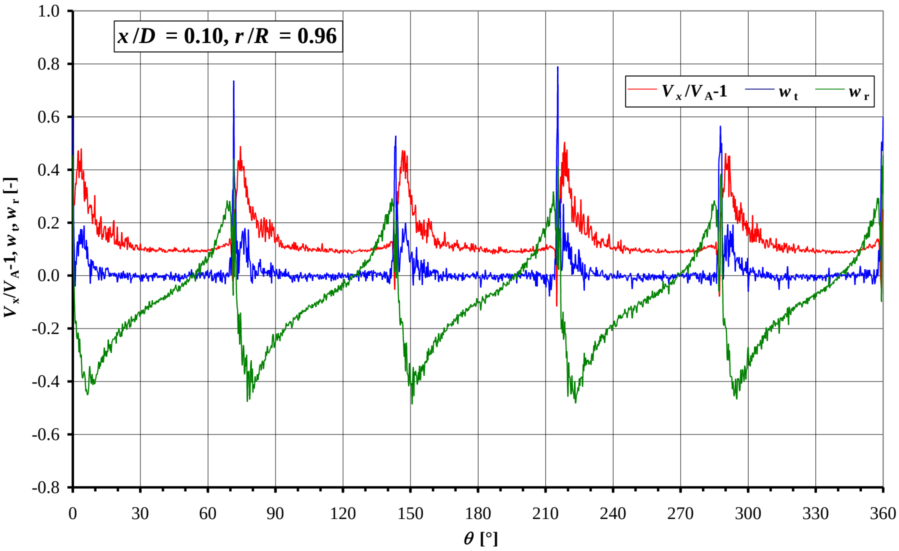


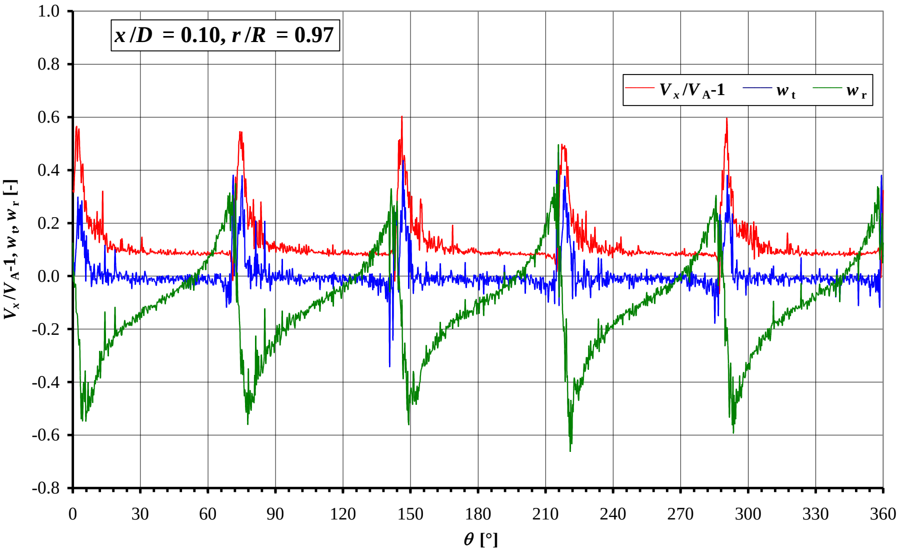


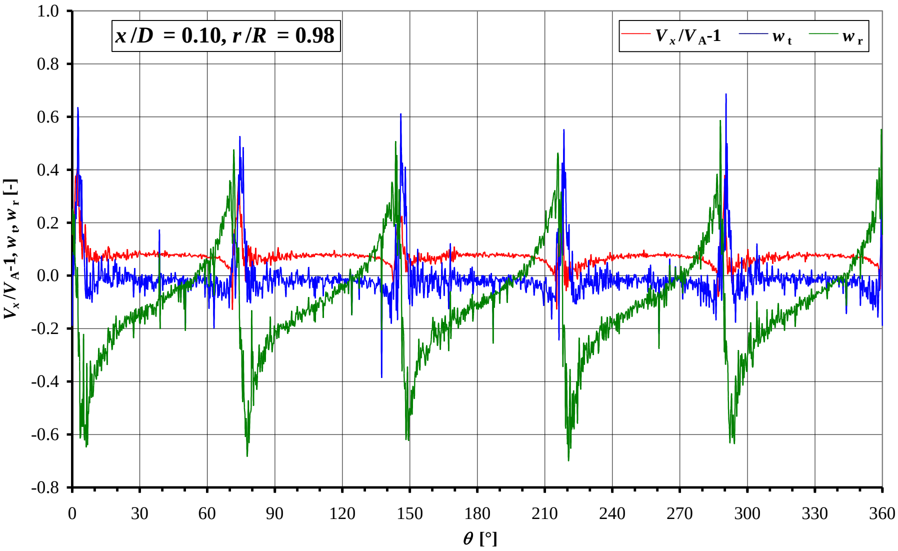


DIAGRAMS/DRAWINGS

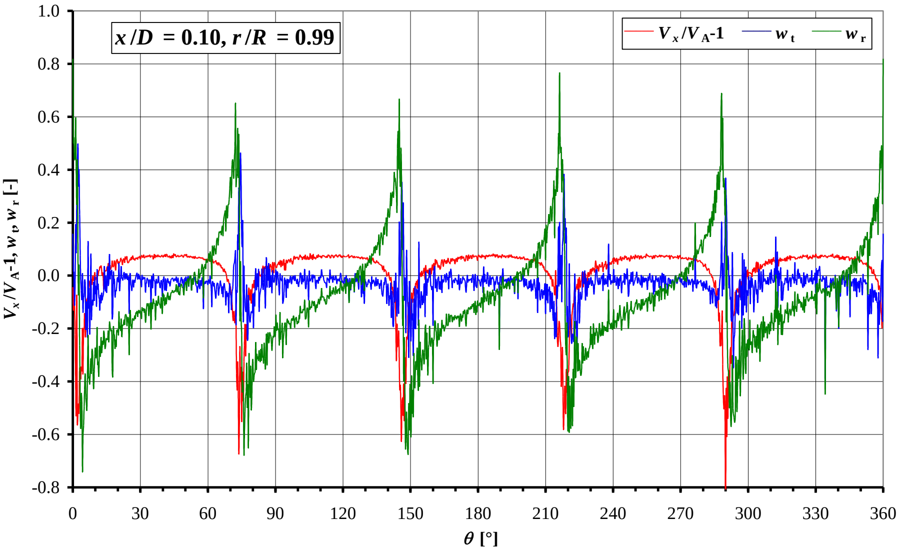
Velocity components V_x/V_A-1, w_t, w_r = f(θ), x/D = 0.10

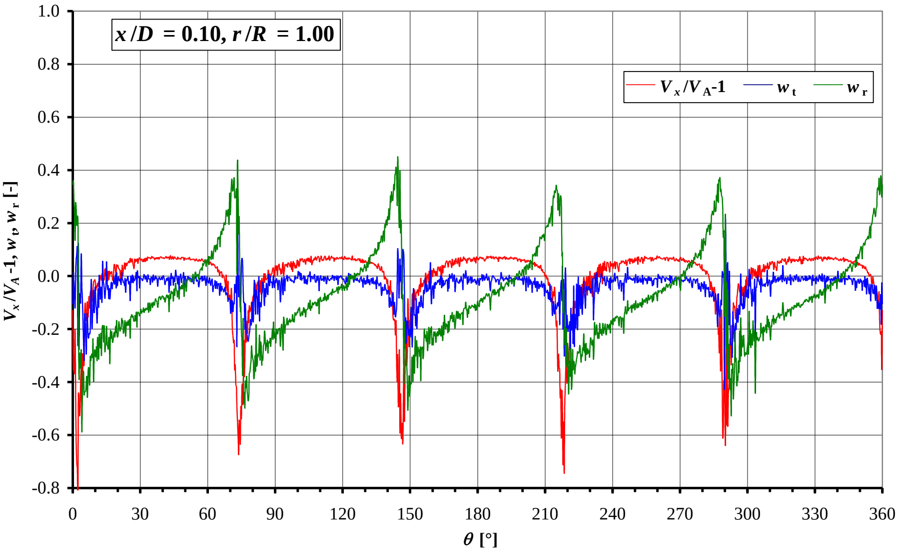


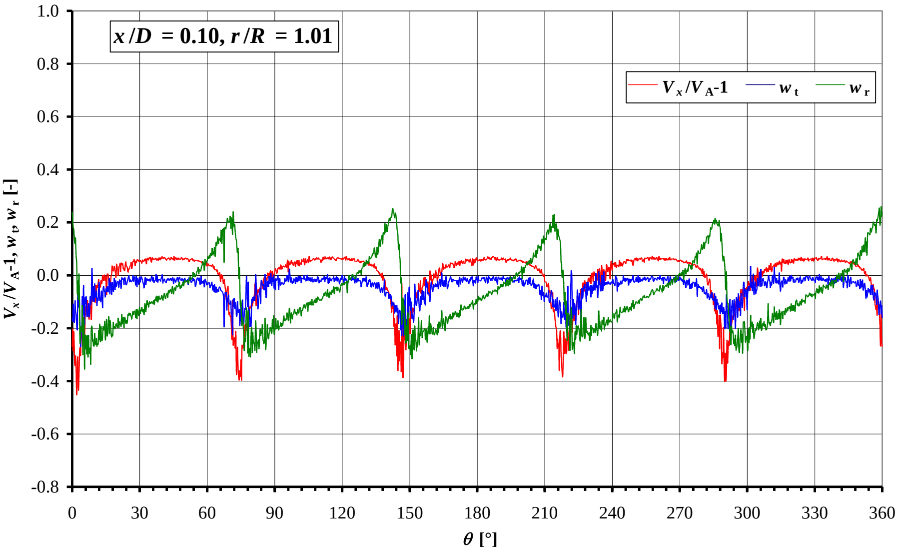




Velocity components V_x/V_A-1, w_t, w_r = f(θ), x/D = 0.10

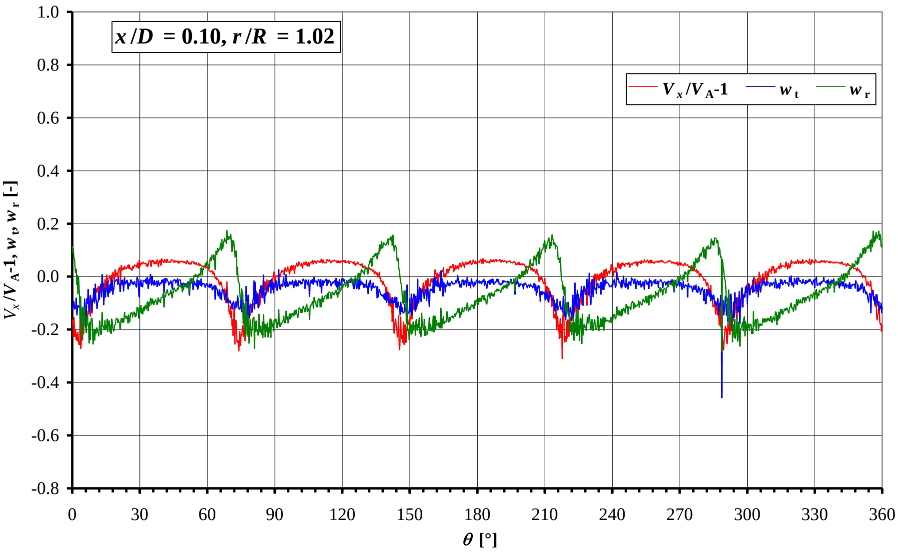


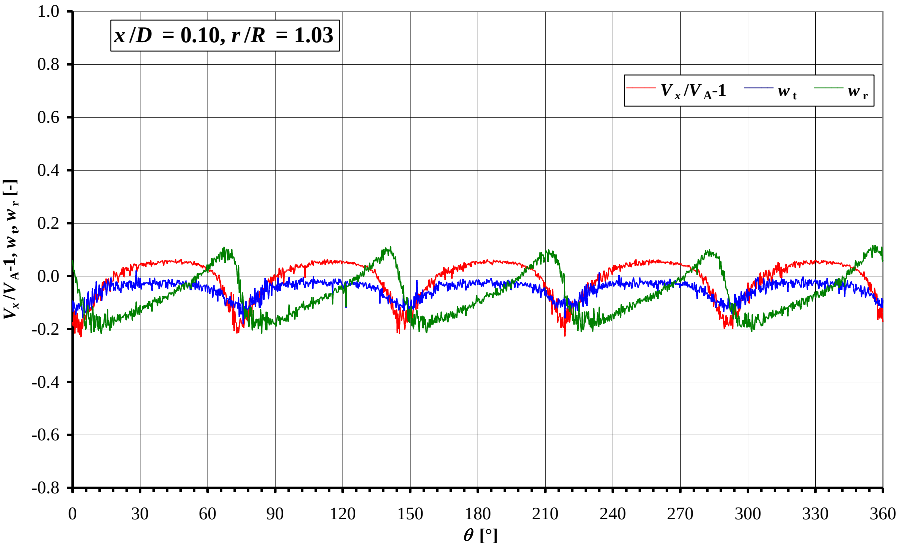


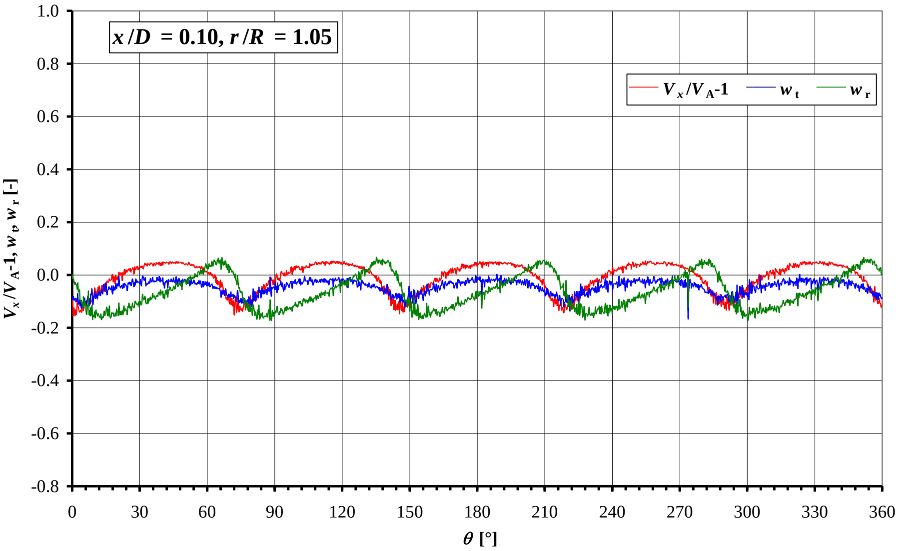


DIAGRAMS/DRAWINGS

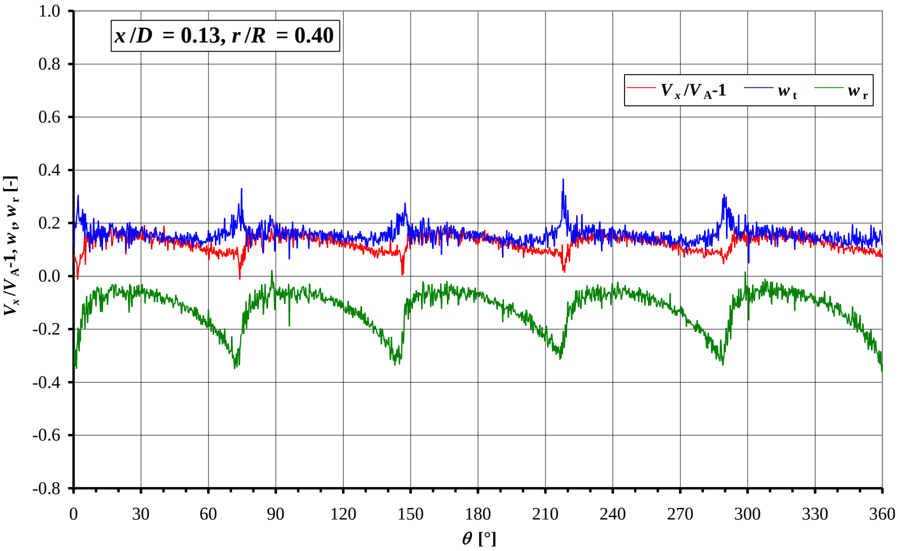
Velocity components V_x/V_A-1, w_t, w_r = f(θ), x/D = 0.10

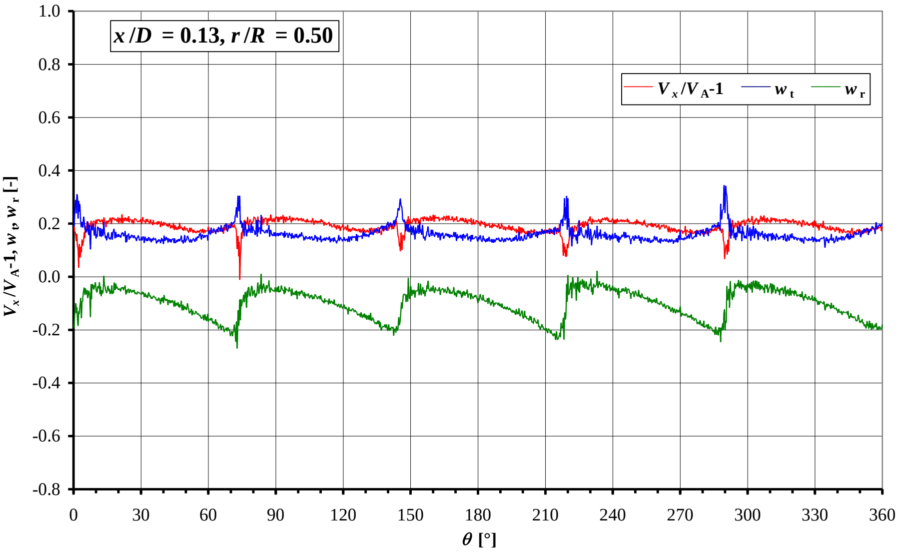


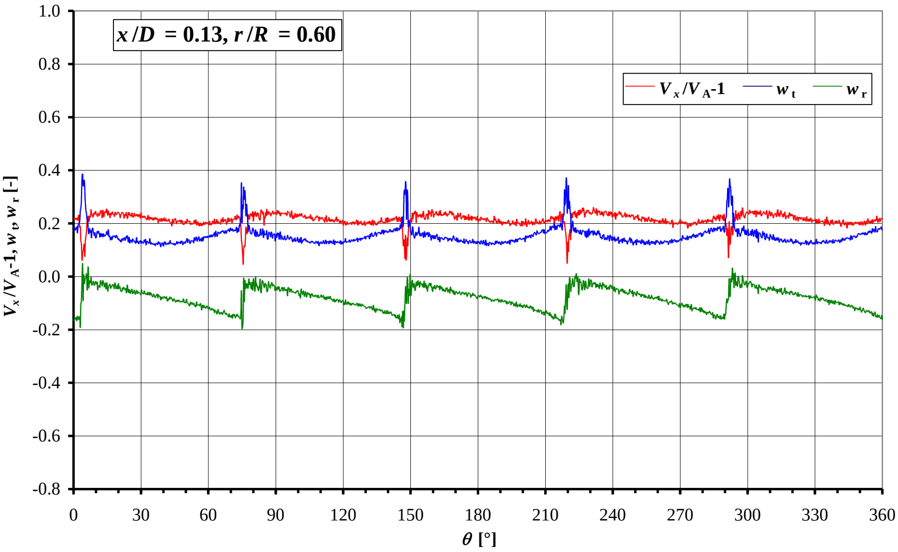




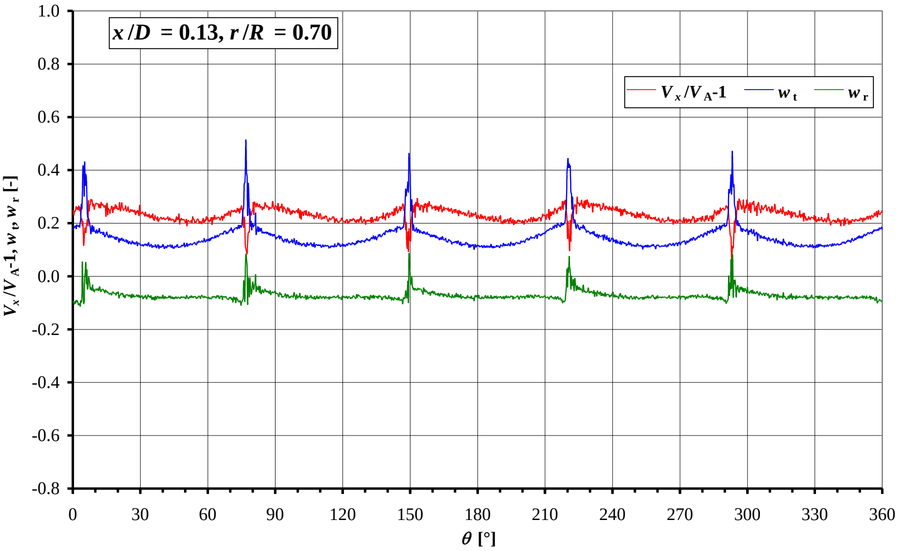
Velocity components V_x/V_A-1, w_t, w_r = f(θ), x/D = 0.13

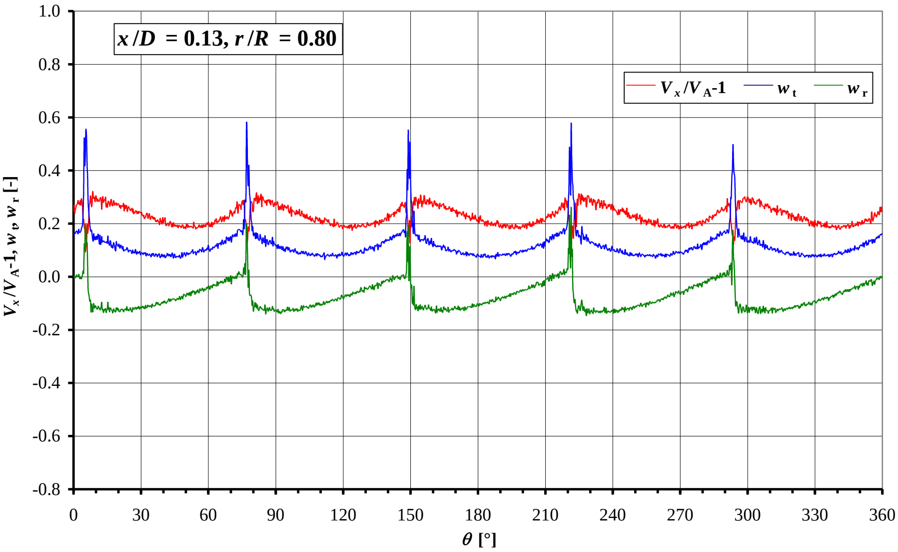


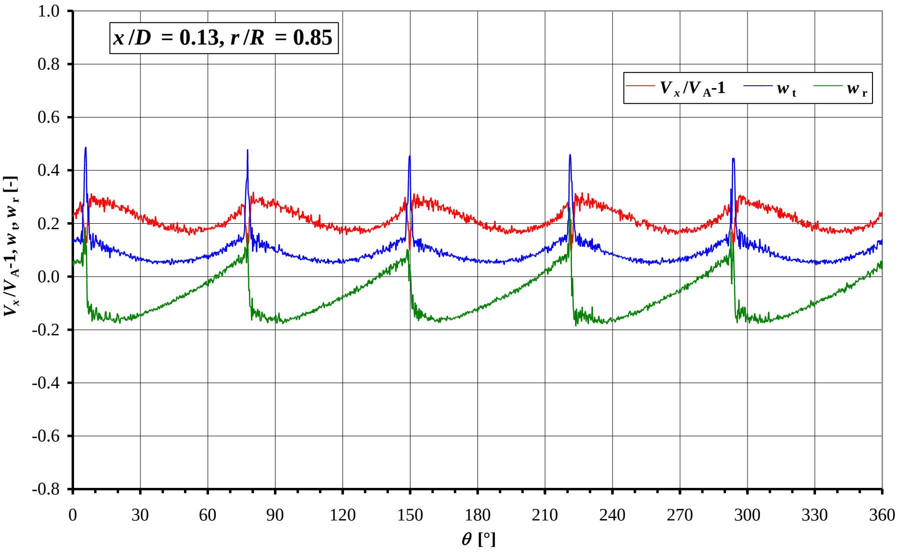




Velocity components V_x/V_A-1, w_t, w_r = f(θ), x/D = 0.13

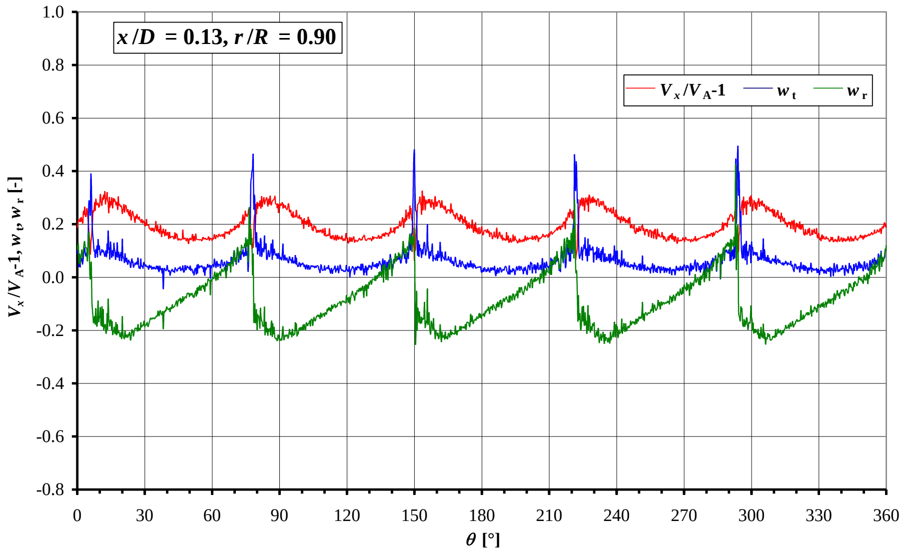


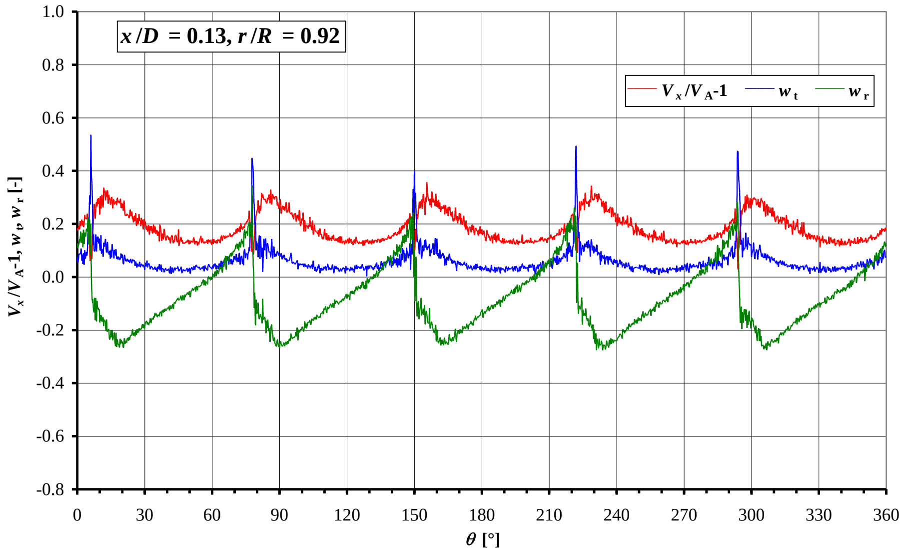


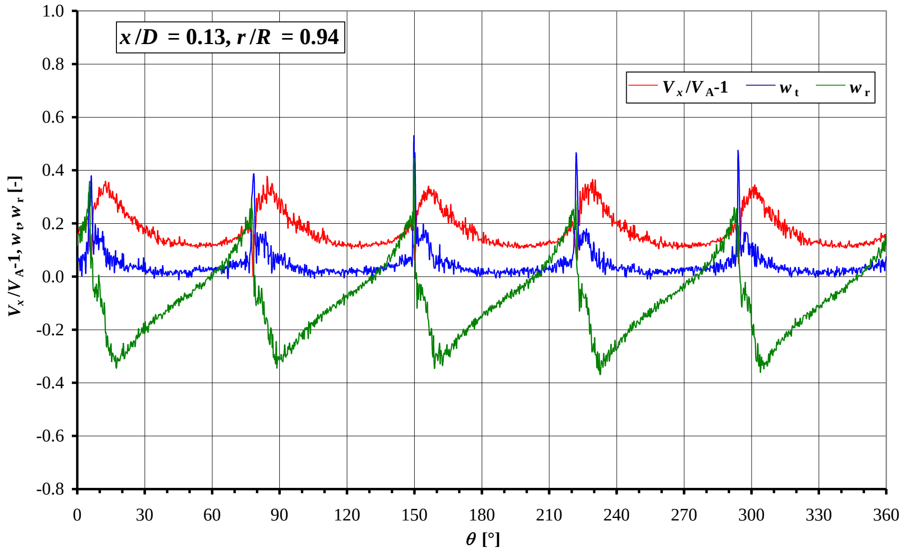


DIAGRAMS/DRAWINGS

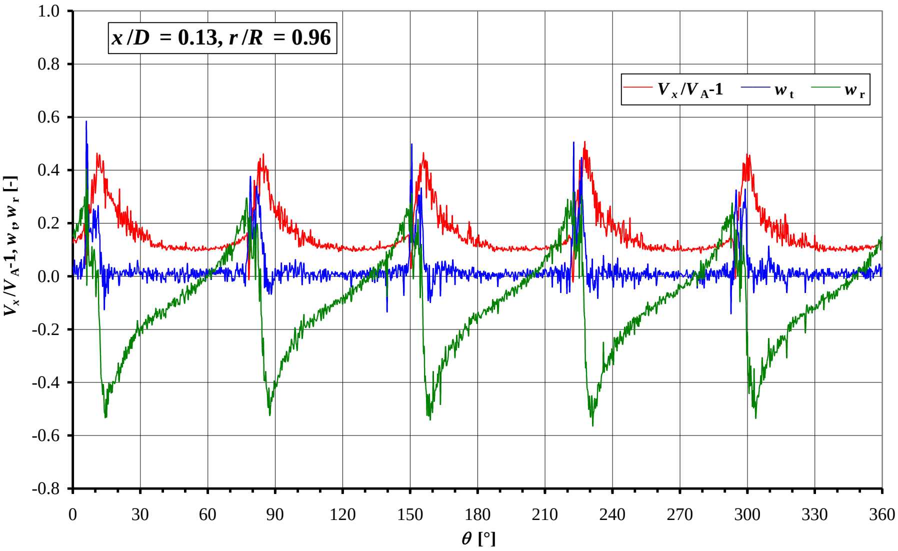
Velocity components V_x/V_A-1, w_t, w_r = f(θ), x/D = 0.13

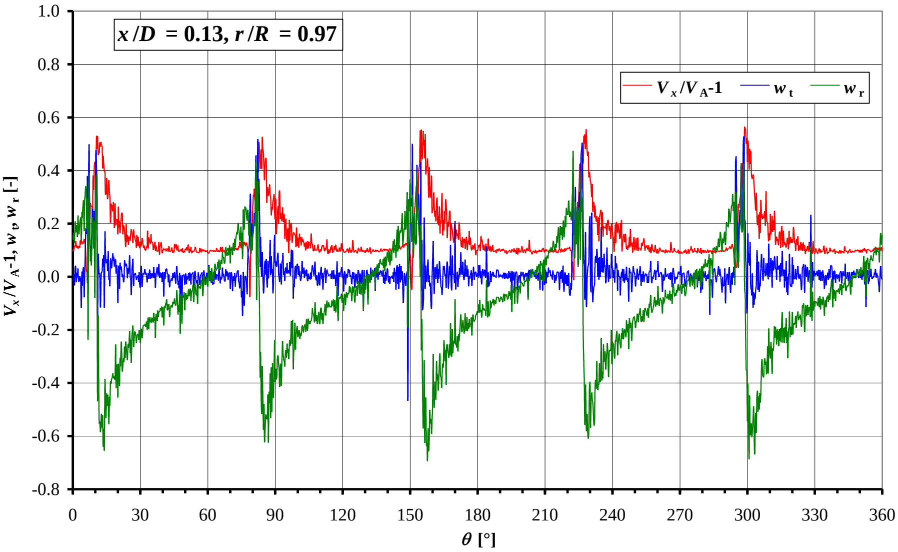


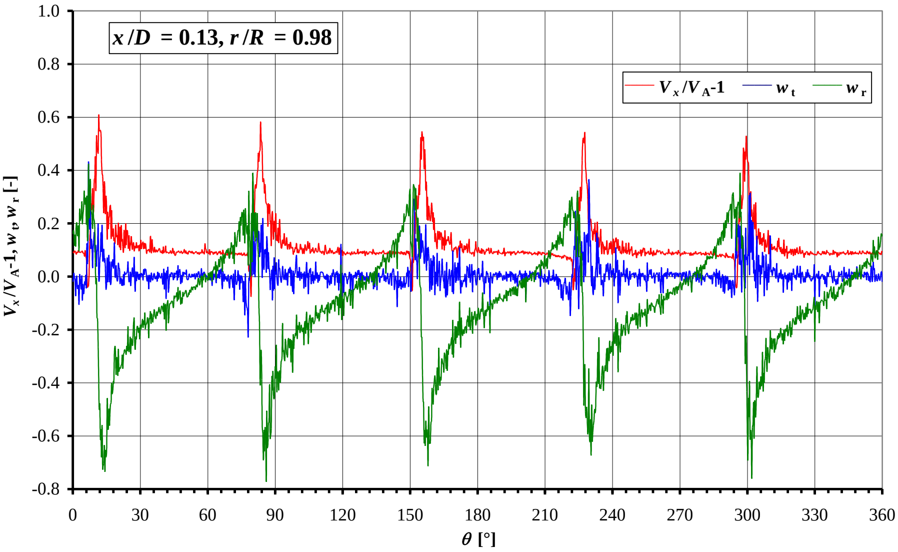




Velocity components V_x/V_A-1, w_t, w_r = f(θ), x/D = 0.13

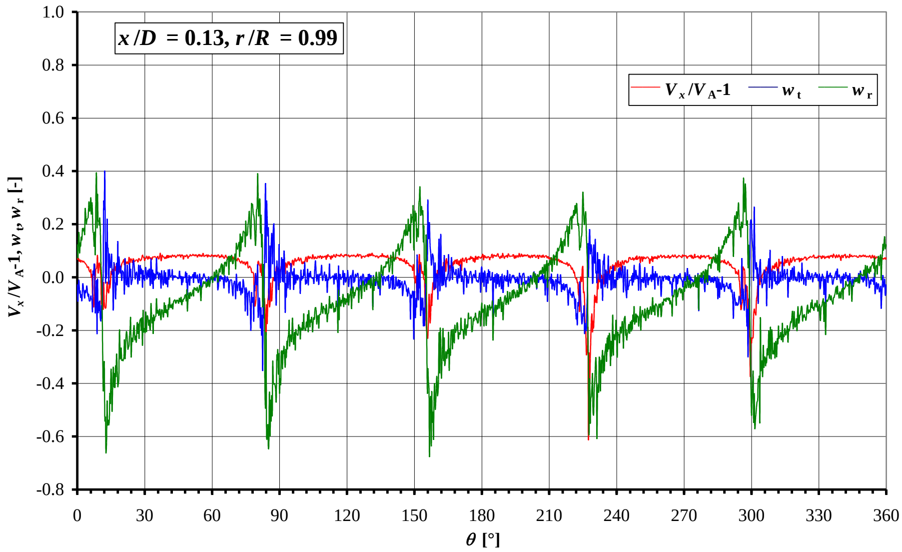


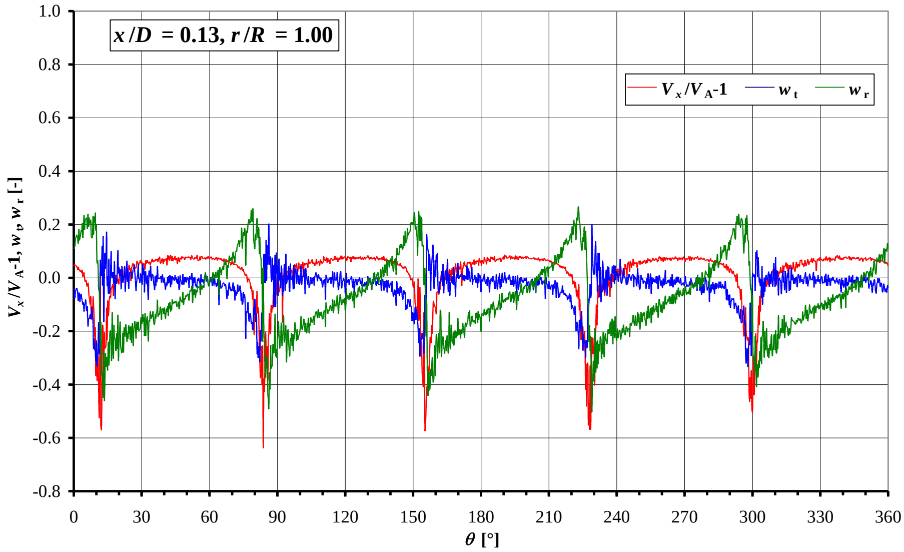


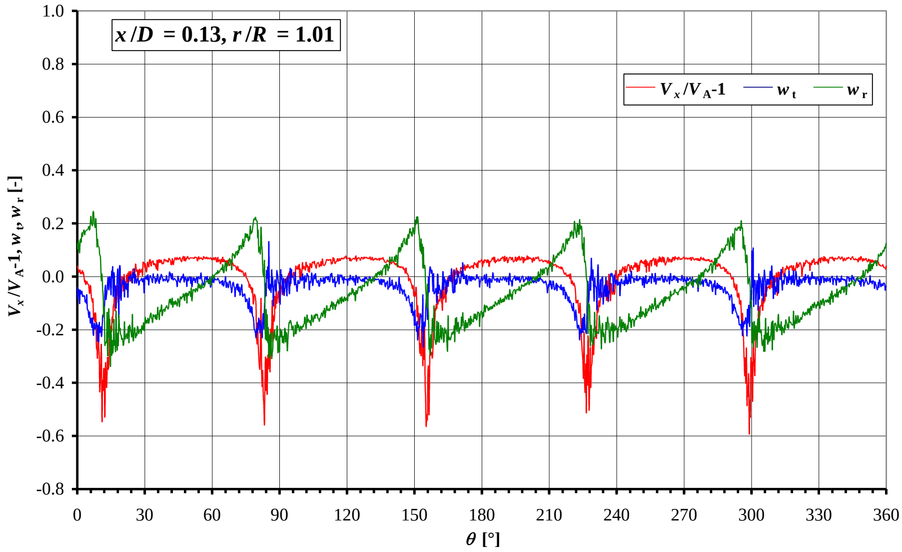


DIAGRAMS/DRAWINGS

Velocity components V_x/V_A-1, w_t, w_r = f(θ), x/D = 0.13

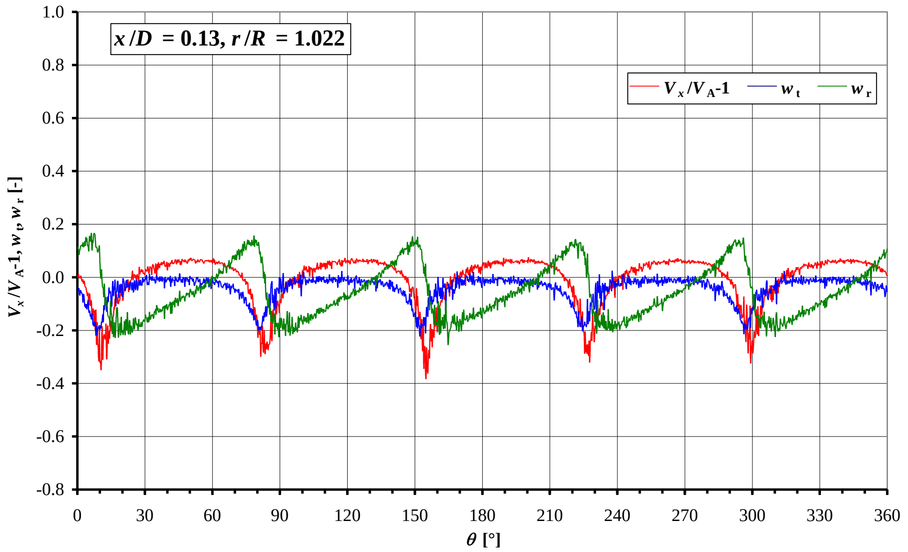


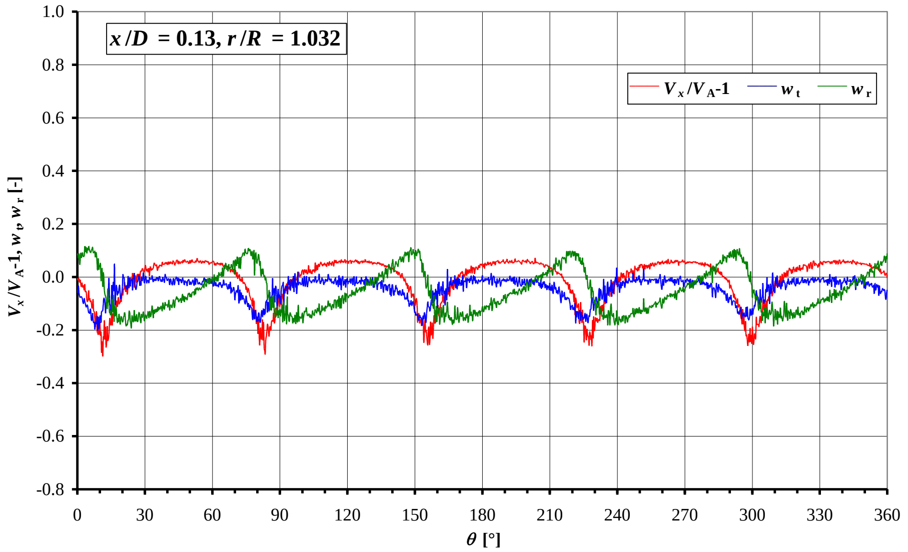


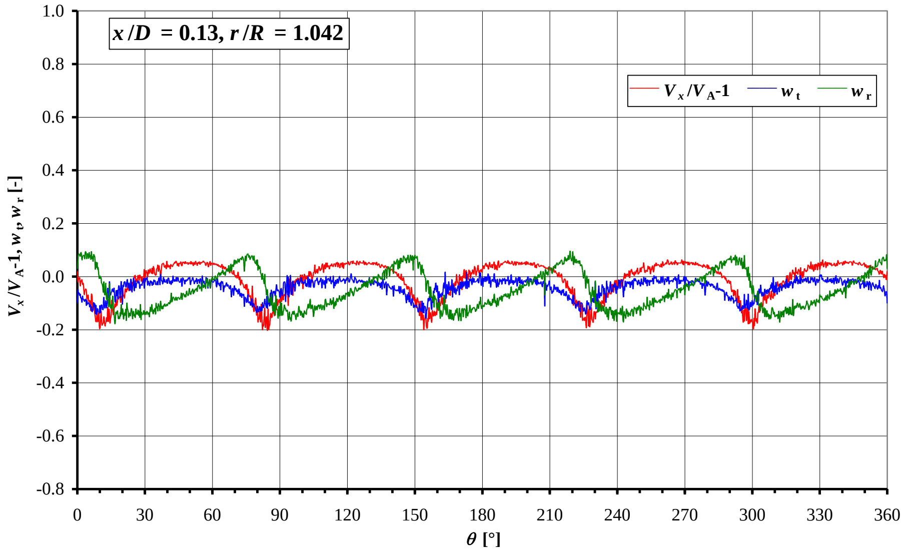


DIAGRAMS/DRAWINGS

Velocity components V_x/V_A-1, w_t, w_r = f(θ), x/D = 0.13

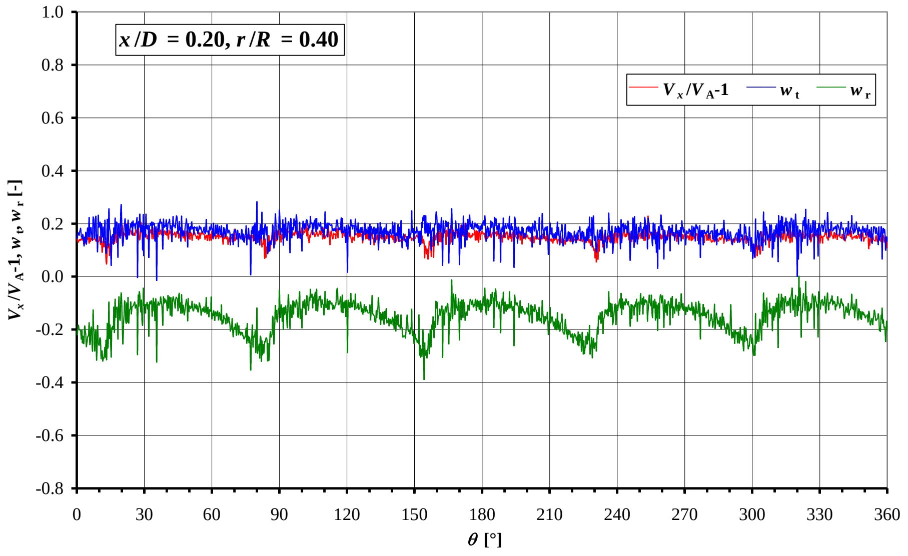


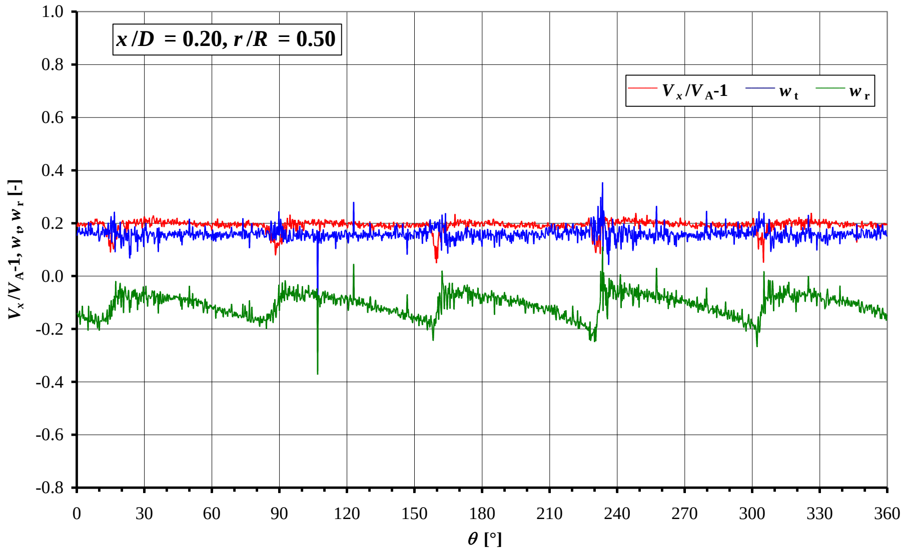


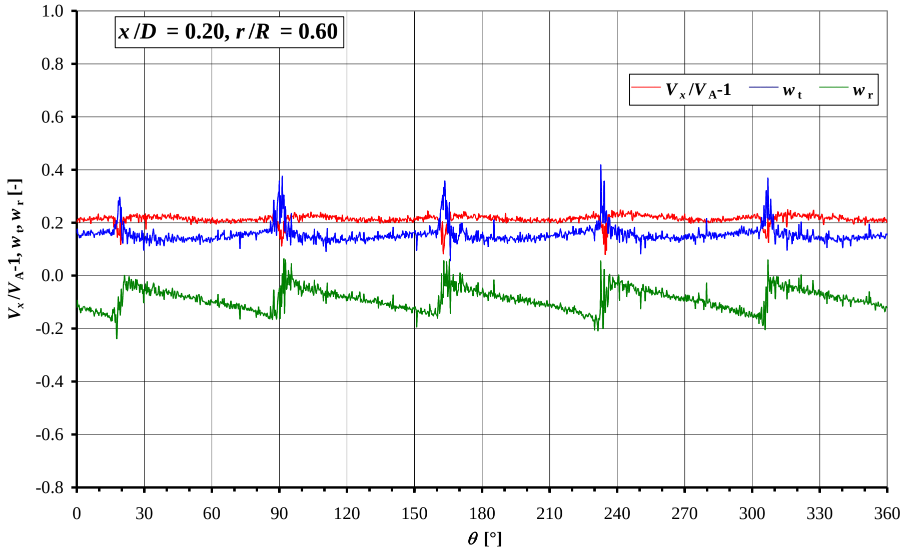


DIAGRAMS/DRAWINGS

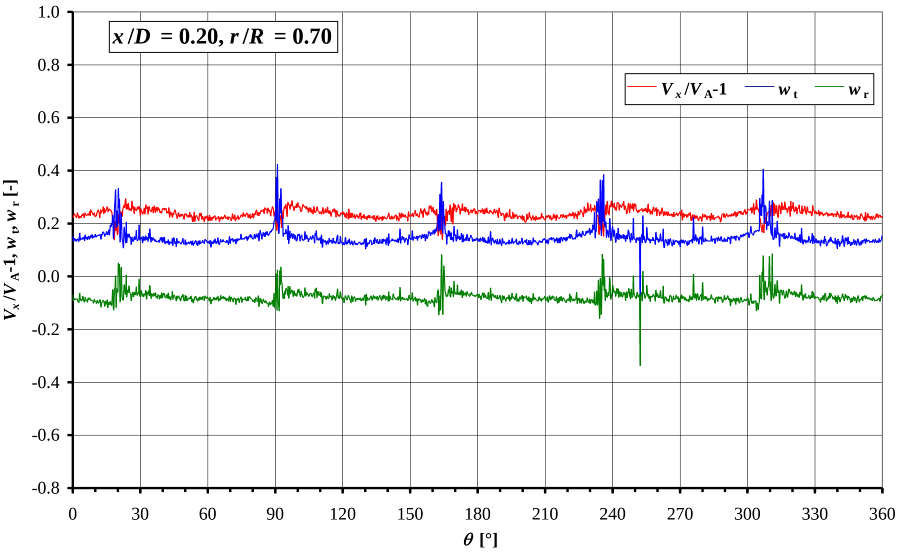
Velocity components V_x/V_A-1, w_t, w_r = f(θ), x/D = 0.20

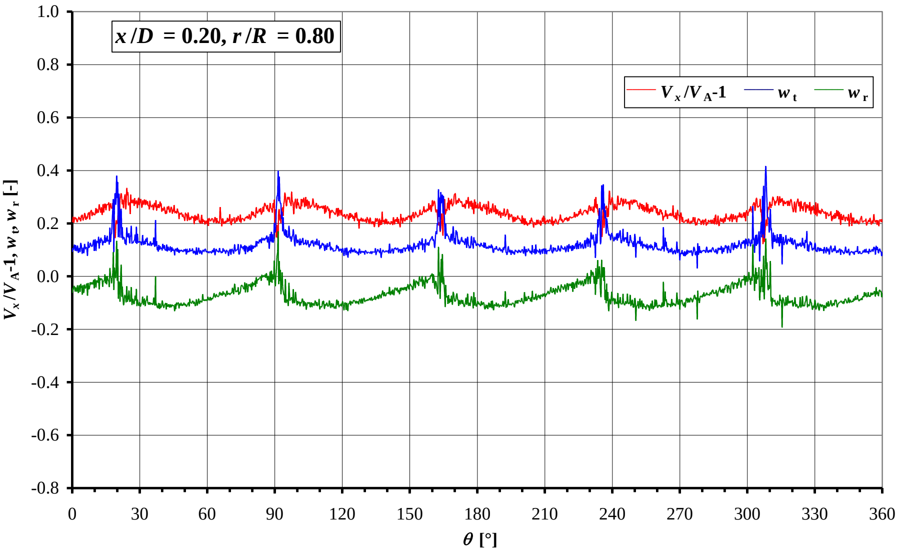


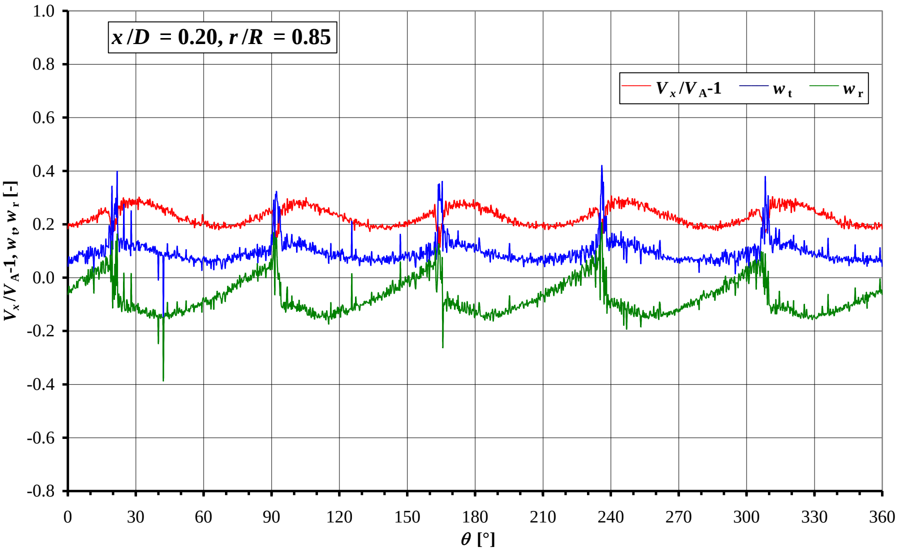




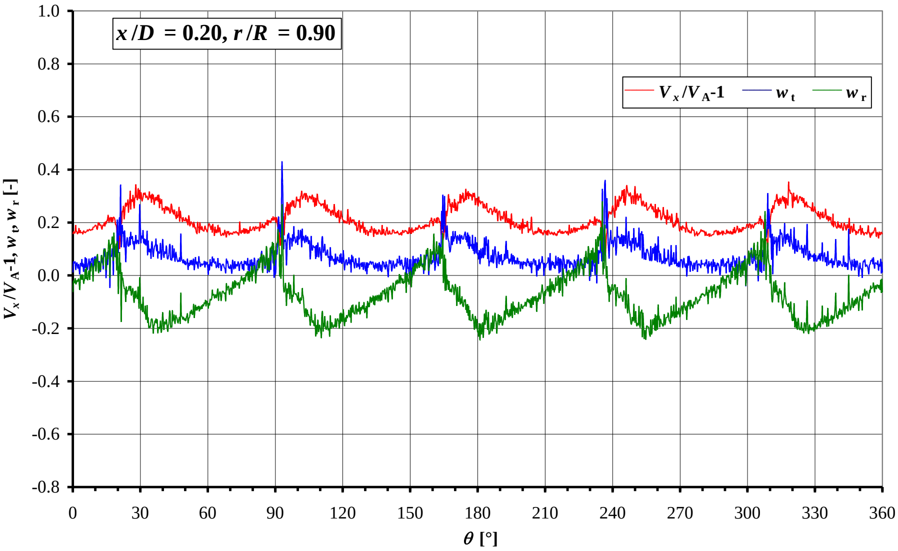
Velocity components V_x/V_A-1, w_t, w_r = f(θ), x/D = 0.20

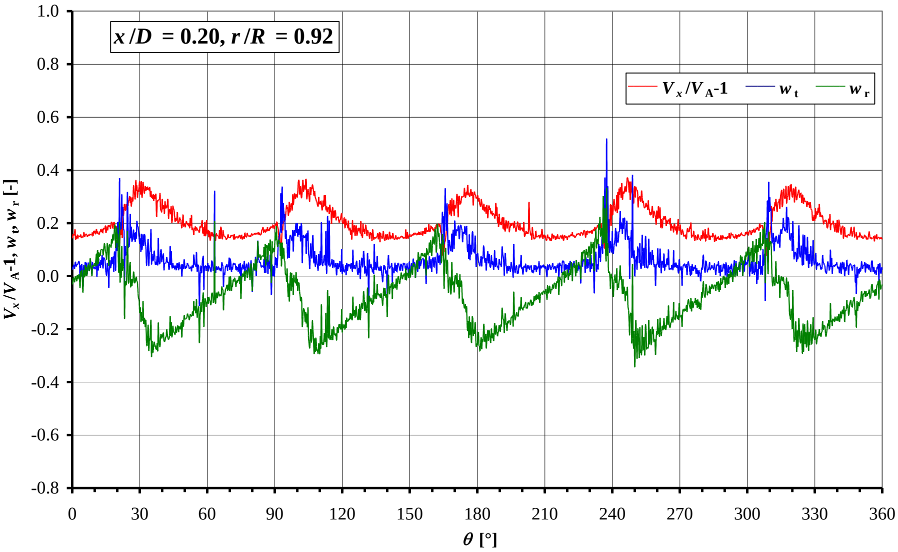


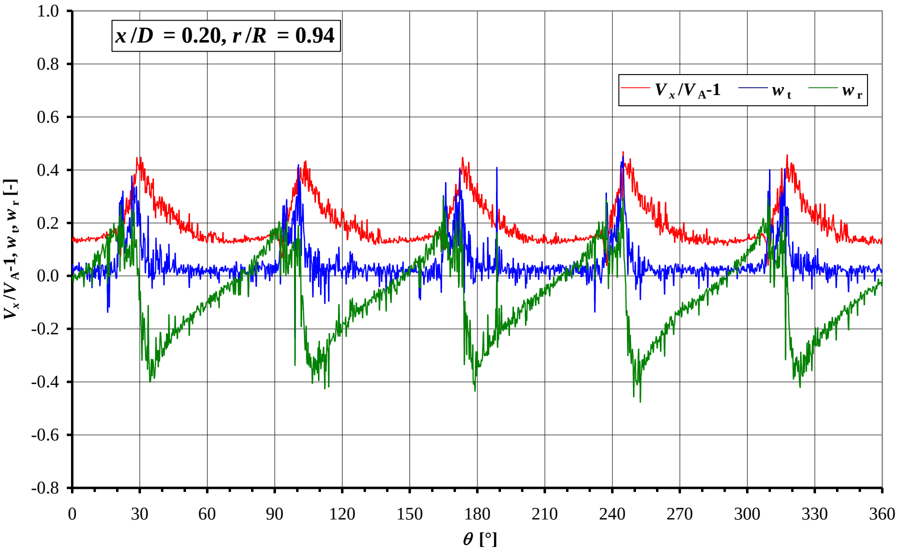




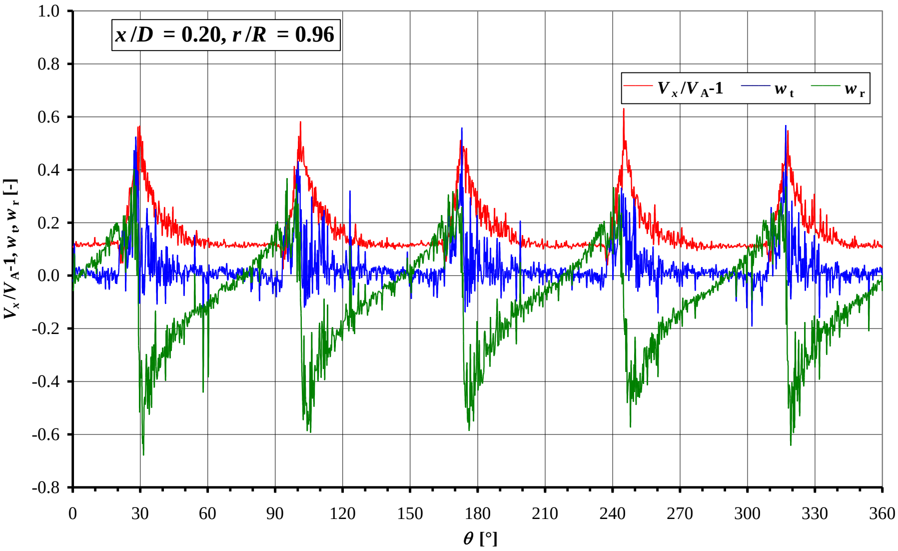
Velocity components V_x/V_A-1, w_t, w_r = f(θ), x/D = 0.20

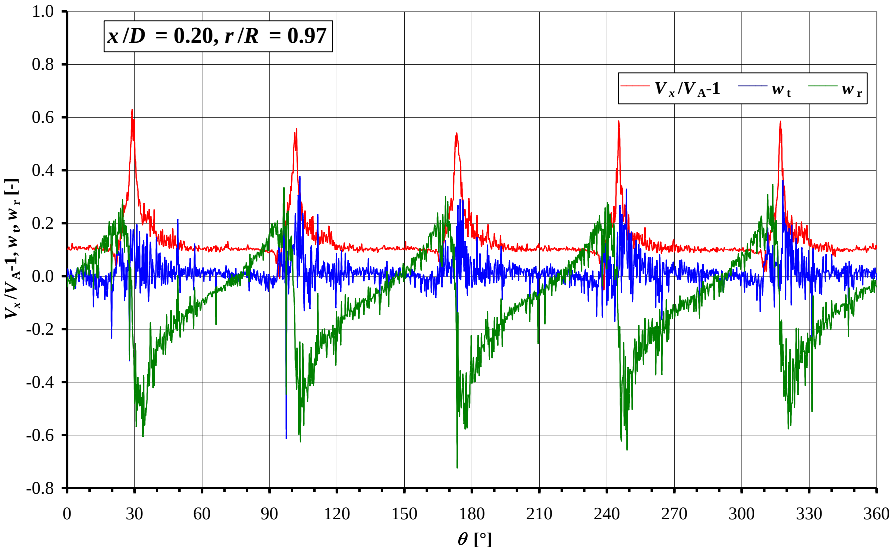


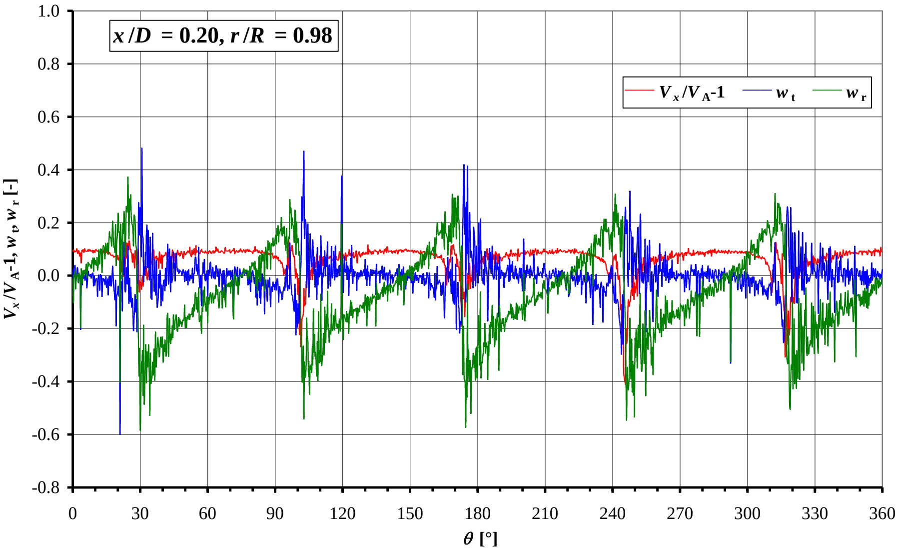




Velocity components V_x/V_A-1, w_t, w_r = f(θ), x/D = 0.20

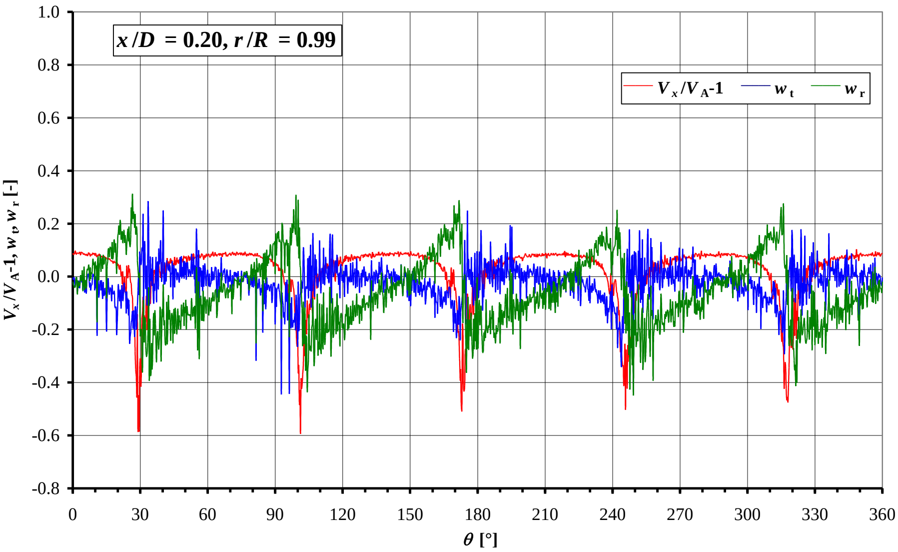


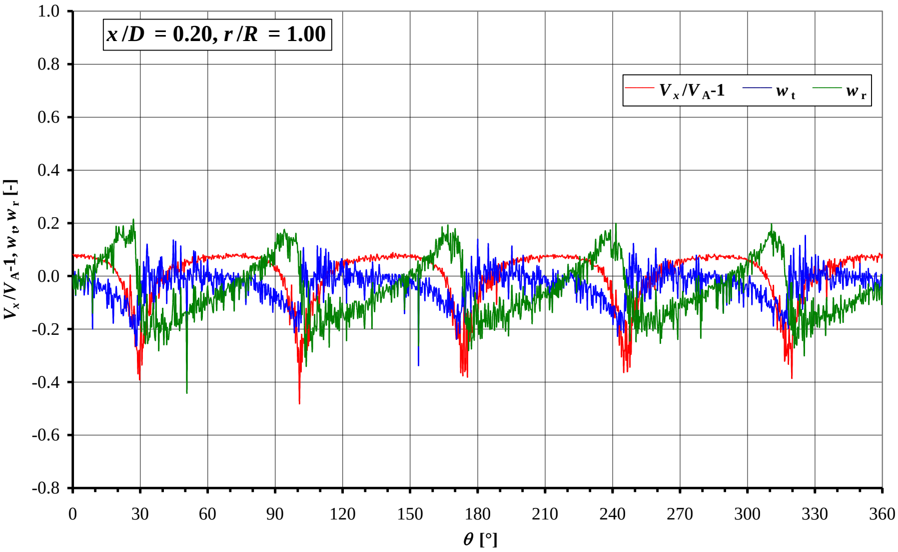


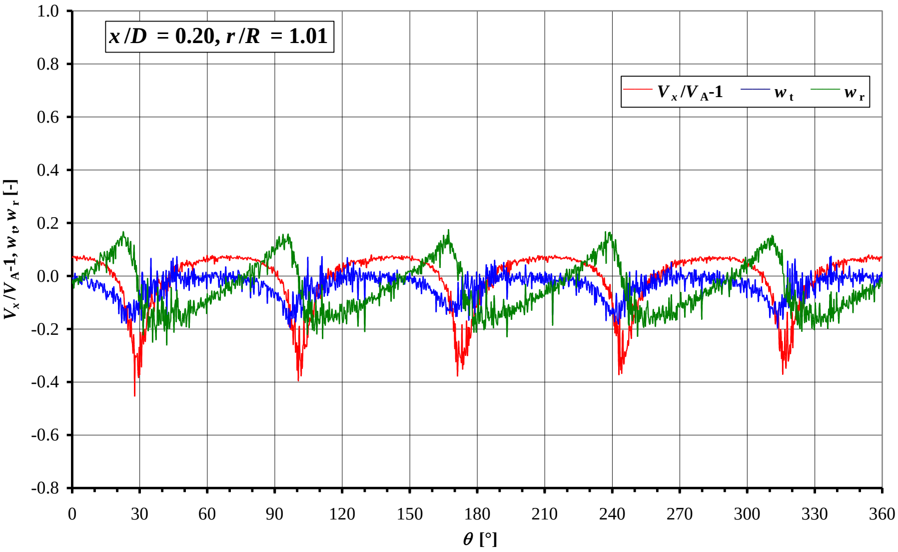


DIAGRAMS/DRAWINGS

Velocity components V_x/V_A-1, w_t, w_r = f(θ), x/D = 0.20



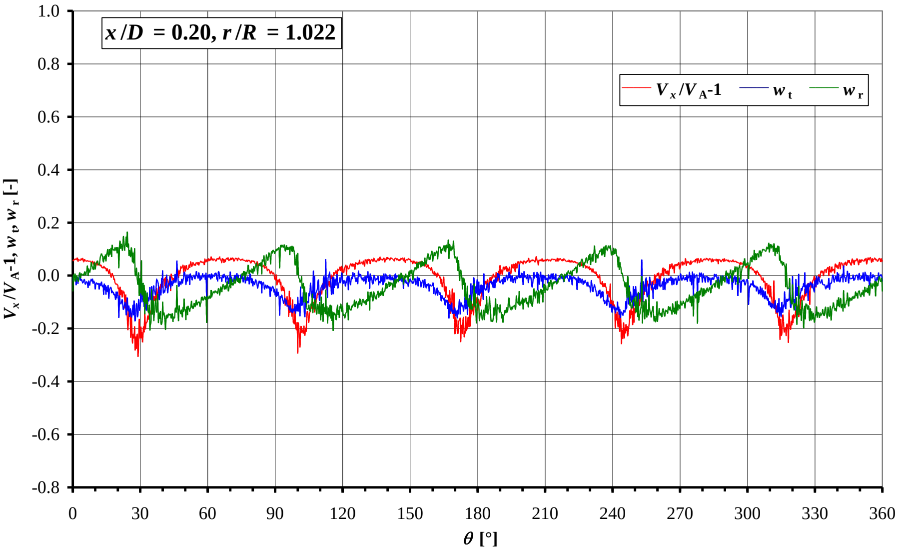


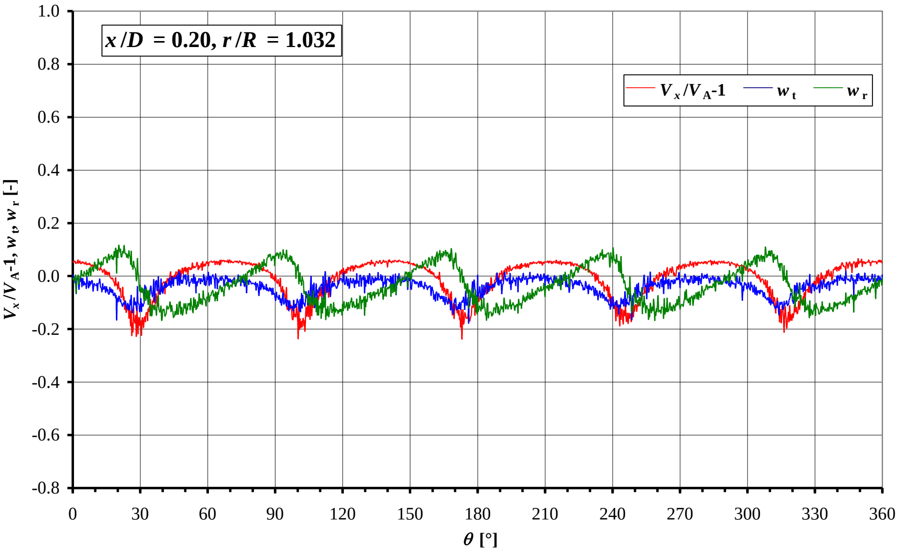


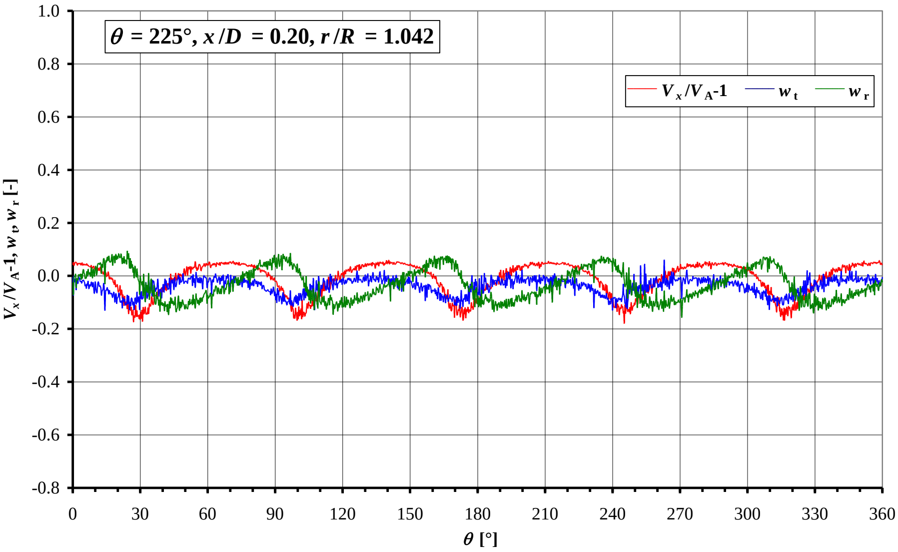
DIAGRAMS/DRAWINGS

DIAGRAMS/DRAWINGS

Velocity components V_x/V_A-1, w_t, w_r = f(θ), x/D = 0.20

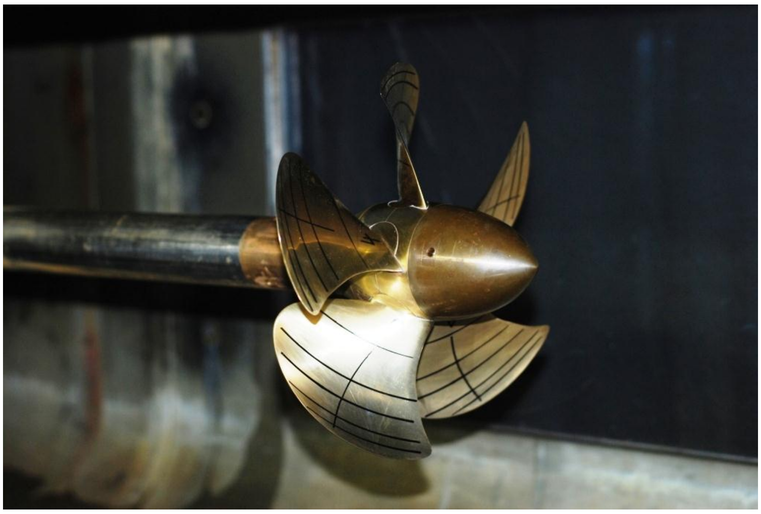






Test arrangement in the cavitation tunnel

Measurement of idle torque with a dummy hub



Model propeller VP1304

Symbols

symbol	name	definition or explanation	SI - unit
A_0	Propeller disc area	$\pi D^2 / 4$	m^2
A_E	Expanded blade area	Expanded blade area of a screw propeller outside the boss or hub	m^2
c	Chord length		m
C_{Th}	Thrust loading coefficient	$T / (A_P q_A) = (T_P / A_P) / q_A$	1
D	Propeller diameter		m
d_h	Boss or hub diameter	$2 r_h$	m
D_{H2}	Pressure difference	Measured in the nozzle of the cavitation tunnel	Pa
f	Camber of a foil section		m
f	Transmitting lens		m
g	Acceleration of gravity	Weight force / mass, strength of the earth gravity field	m/s^2
h_0	Immersion	The depth of submergence of the propeller measured vertically from the propeller centre to the free surface	m
J	Propeller advance ratio	$V_A / (D n)$	1
K_Q	Torque coefficient	$Q / (\rho n^2 D^5)$	1
K_T	Thrust coefficient	$T / ((\rho n^2 D^4)$	1
n	Frequency or rate of revolution	Alias RPS (RPM in some propulsor applications)	s^{-1}
P	Propeller pitch in general		m
p	Pressure		Pa
p_A	Ambient pressure		Pa
p_C	Pressure within a steady or quasi-steady cavity		Pa
p_0	Ambient pressure in undisturbed flow		Pa
p_V	Vapour pressure of water	At a given temperature!	Pa
P/D	Pitch ratio of propeller		1
P_D	Delivered power, propeller power	$Q \omega$	W
Q	Torque	P_D / ω	Nm

Symbols

symbol	name	definition or explanation	SI - unit
q	Dynamic pressure, density of kinetic flow energy,	$\rho\, V^2 / 2$	Pa
R	Radius		m
r	Radius		m
Re	Reynolds number	$Re = c_{0.7} / \nu \cdot \sqrt{V^2 + (0.7 D \pi n)^2}$	1
r_h	Hub radius		m
T	Propeller thrust		N
Tu	Turbulence degree		%
t_W	Temperature of water		°C
t_A	Temperature of air		
t	Blade section thickness		m
V	Velocity of a body, speed in general of the model or the ship		m/s
V_A	Advance speed of propeller	Equivalent propeller open water speed based on thrust or torque identity	m/s
V_{per}	Periodical velocity		m/s
V_R	Radial velocity component		m/s
V_S	Ship speed		m/s
V_{sta}	Stationary velocity		m/s
V_{sto}	Stochastic velocity		m/s
V_T	Tangential velocity component		m/s
V_x	Velocity component in x-direction		m/s
V_y	Velocity component in y-direction		m/s
V_z	Velocity component in z-direction		m/s
w	Wake fraction in general	$w = 1 - V / V_A$	1
w_a	Wake fraction in axial direction	$w_a = 1 - V_x / V_A$	1
w_t	Wake fraction in tangential direction	$w_t = V_T / V_A$	1
w_r	Wake fraction in radial direction	$w_r = V_R / V_A$	1

ANNEX

Symbols

symbol	name	definition or explanation	SI - unit
Z, z	Number of propeller blades		1
α	Solved gas content		mg/l
α_S	Solved gas content at saturation		mg/l
ε	Angle of rake		deg
η_O	Propeller efficiency in open water	$P_T / P_D = T\ V_A / (Q\ \omega)$ all quantities measured in open water tests	1
θ	Angle of propeller blade position		deg
θ_{EXT}	Skew angle extent	The difference between maximum and minimum local skew angle	deg
λ	Scale ratio, *l*inear scale of ship model	Ship (index $_S$) dimension divided by corresponding model (index $_M$) dimension $\lambda = L_S / L_M = B_S / B_M$	1
ν	Kinematic viscosity	μ / ρ	m^2/s
π	Circular constant	3.1415926535	1
ρ	Mass density of fluid	dm / dV	kg/m^3
ω	Circular frequency	$2\ \pi\ f$	1/s
ω	Propeller rotational velocity	$2\ \pi\ n$	1/s

Indices

index	Name	definition or explanation
A	Air	
c	Velocity correction by Glauert method	
c	Construction, design	
M	Model	
S	Ship	
max	Maximum	
min	Minimum	
V	Venturi	
W	Water	
0.7	Related radius $r/R = 0.7$	

Methods and formulas

Open water test in the cavitation tunnel

The open water tests were carried out with the dynamometer J25 from Kempf & Remmers in the cavitation tunnel K15A. The influence of the test section on the propeller coefficients was corrected with the method from Glauert.

Measuring values: T, Q, n, V, p

with Glauert correction

Advance coefficient $J = \frac{V}{n \cdot D}$ $J_c = \frac{V_c}{n \cdot D}$

Thrust coefficient $K_T = \frac{T}{\rho \cdot n^2 \cdot D^4}$

Torque coefficient $K_Q = \frac{Q}{\rho \cdot n^2 \cdot D^5}$

Propeller efficiency $\eta_O = \frac{J}{2\pi} \cdot \frac{K_T}{K_Q}$ $\eta_{Oc} = \frac{J_c}{2\pi} \cdot \frac{K_T}{K_Q}$

Reynolds number $Re = \frac{c_{0.7}}{\nu} \cdot \sqrt{V^2 + (0.7 \cdot D \cdot \pi \cdot n)^2}$ $Re_c = \frac{c_{0.7}}{\nu} \cdot \sqrt{V_c^2 + (0.7 \cdot D \cdot \pi \cdot n)^2}$

Thrust loading coefficient $C_{Th} = \frac{8}{\pi} \cdot \frac{K_T}{J^2}$ $C_{Thc} = \frac{8}{\pi} \cdot \frac{K_T}{J_c^2}$

Cavitation numbers $\sigma_V = \frac{p_{\text{stat}} - p_v}{\frac{\rho}{2} \cdot V^2}$ $\sigma_{Vc} = \frac{p_{\text{statc}} - p_v}{\frac{\rho}{2} \cdot V_c^2}$

$$\sigma_n = \frac{p_{\text{stat}} - p_v}{\frac{\rho}{2} \cdot (n \cdot D)^2} \qquad \sigma_{nc} = \frac{p_{\text{statc}} - p_v}{\frac{\rho}{2} \cdot (n \cdot D)^2}$$

$$\sigma_{0.7} = \frac{p_{\text{stat}} - p_v}{\frac{\rho}{2} \cdot (V + 0.7\pi \cdot n \cdot D)^2} \qquad \sigma_{0.7c} = \frac{p_{\text{statc}} - p_v}{\frac{\rho}{2} \cdot (V_c + 0.7\pi \cdot n \cdot D)^2}$$

Laser Doppler Velocimetry System

At the cavitation tunnel of the SVA Potsdam a 2D-LDV measurement system of the firm TSI is available for multi-component velocity measurements. With the LDV-system quasi punctual, contactless flow measurements can be carry out without disturbance of the flow. The measuring position is the intersection point of the laser beams. A lamellar interference field forms in this intersecting volume. The velocities of small scatter particles with a size down to the µm region, which pass the measuring volume, are recorded. As measuring signal the scatter light of the particle from the interference field in the measuring volume are detected by light sensible photomultiplier and with it the velocity of the scatter particle itself transformed in a proportional frequency. An advantage of the LDV is that the calibration factors for the determination of the velocity in the measuring volume are only depending from the optical configuration and the wave length of the laser light. Both parameters are known and do not changed over the utilisation time. For further comments regarding the physically basis of a LDV systems and their realisation possibilities there is to refer to [4] and [5].

As optical unit a 4-ray-standard compact probe comes into application. With this probe a simultaneous recording of 2 velocity components in back scatter operation is possible. An adaptation of the dimensions of the measuring volume or of the required focal distance can be reached with a compatible set of transmit lenses and an additional beam broadening unit (table A2.1).

The laser measurements can be carried out from the side and bottom-up. As far as the optical access to the flow permits, the 3rd velocity component can be measured in a second run. The arrangement of the LDV probe and the definition of the coordinate system can be seen in the figure A2.1. A 4 Watt Argon Laser is used. The signal processing is carried out via the two channel signal processor IFA 650. The control system of the test procedure including the traversing unit and the data analysis is conducted with a PC.

Over 3 Piacryl windows the optical access is given into the measuring section (2 times on the side and on the bottom).

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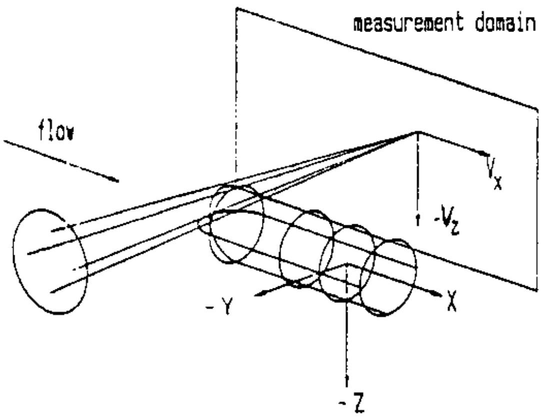
Table A2.1: Possible optical sensor configurations, data in water for colour green

Focal distance f [mm]	Ray distance Δs [mm]	Strip distance Δx [µm]	Intersecting angle $\Theta/2$ [°]	Dimensions of measuring volume	
				Diameter [µm]	Length [mm]
261	50	2.69	4.1	65	0.9
365	50	3.73	3.0	90	1.7
512	50	5.27	2.1	128	3.4
610	50	6.28	1.8	152	4.9
480	130	1.90	5.8	46	0.4



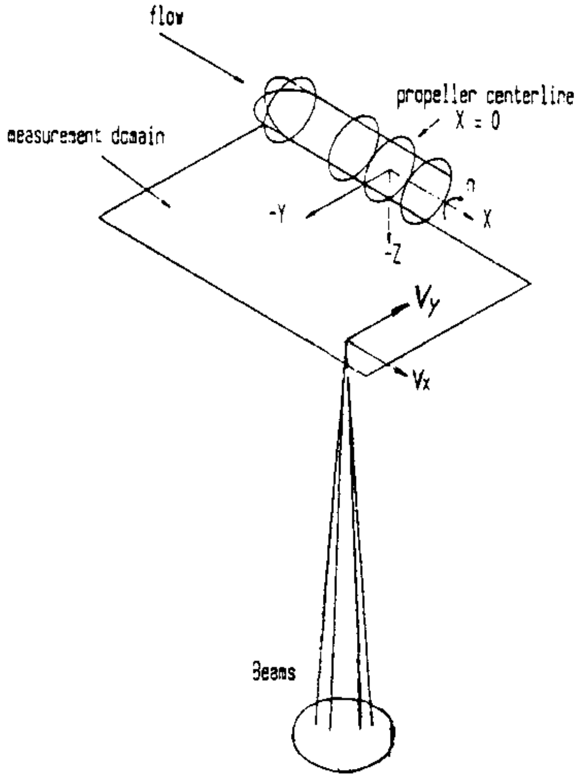


Figure A2.1: Beam arrangement of the LDV probe and co-ordinate system

Literature regarding LDV measurements

Further information regarding the set-up of the LDV-Systems at the SVA Potsdam, about realised LDV measurements and achieved results are given in [A1], [A2], [A3], [A4], [A5], [A6], [A7].

[A1] Durst F.; Melling A.; Whitelaw, J. H.
Principles and practice of Laser Doppler Anemometrie
Academic Press, London – New York – San- Francisco 1976

[A2] Albrecht, H. E.
Ein Beitrag zur Laser-Doppler-Anemometrie
Dissertationsschrift (Prom. B) Rostock: Wilhelm Pieck Universität

[A3] Fuchs, W.
Praxis von Geschwindigkeitsmessungen mittels Laser-Doppler-Anemometer im Kavitationskanal
Schiffbauforschung, Rostock 26 (1987) 3, S.131-142

[A4] Böer, W.-B.; Selke, W.; Junglewitz, A.
Einsatz der LDA-Meßtechnik bei hydrodynamischen Untersuchungen am Kavitationstunnel der SVA Potsdam
Schiffbauforschung 29 (1990) S. 59-65

[A5] Mach, K.-P.
Einsatz eines 2-Komponenten LDA im hydrodynamischen Versuchswesen
Posdam-tech 93, 5.-6. November 1993

[A6] Mach, K.-P.
LDA Geschwindigkeitsmessungen am Kavitationstunnel
3. Fachtagung Lasermethoden in der Strömungsmesstechnik, 6.-8. Sept. 1994, Bremen

[**A**7] Schulze, R.; Mach, K.-P.
Vergleich von Rechnungen und LDA-Messungen der Geschwindigkeitsverteilung im Propellerstrahl
Postersitzung DGLR-Kongreß 1994, 4.-7. Oktober 1994, Erlangen

[AA8] Mach, K.-P.
LDA Geschwindigkeitsmessungen im Modellpropellernachstrom
4. Fachtagung Lasermethoden in der Strömungsmesstechnik, 13.-15. Sept. 1995, Rostock

LDV measurements

The target of the analysis is to calculate the several velocity components including the statistic data both as run over the angle of rotation of the propeller and as mean velocities at the measuring point.

The initial point for the calculations are the LDV raw data, in which stored details regarding velocity, regarding discharge time of the scatter particles by the measuring volume, regarding arrival time of the scatter particle in the measuring volume as well as regarding momentary angle of rotation of the propeller in relation to zero impulse for each velocity components.

The calculation of the data occurs at the angle dissolved LDV measurements in several steps. At first all LDV data are afferent sorted, which are collected over a multitude of numbers of revolutions of propeller, regarding the moment of data recording stored angle of rotation of the propeller.

In a second step the validity of the single value from the measuring value ensemble is checked Thereby are tested, how far the single value lies inside of free selectable upper and lower speed limits. This is mainly necessary to eliminate noise components and mismeasurements (signals of large scatter particle or reflections of fixed or moved surfaces).

In the figure A2.2 the screen menu is presented for determination of the validity limits. By V_{1U} and V_{1O} or. V_{2U} and V_{2O} the absolute limits for the velocity runs are indicated.

In a further step the validity of the single value from the measuring value ensemble is checked by statistical methods. Usually the mean value and the standard deviation are composed for this over all values and the validity area determined over die numbers from +/- n standard deviations in relation to the mean value. At this method there is a problem if the validity region of the single value is held too small, than the existing velocity peaks marked as invalid and the velocity run are reflected false over the angles. If the validity area is elected in contrast to large, so that the velocity peaks are certain inside of the validity region, a separation of the disturbing signals is given no longer certain. With the scheduled angle dissolving of 1-2 degrees or the analysis and relative few measuring values inside of an angle category this leads to an intensified scattering of the values till to total false values at the averaging of the values inside these angle categories.

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Because a manual correction of the values is excluded aground a lots of data, the method for the estimation of the validity area was enlarged. With it the validity limits are determined no longer over the whole area, but rather gliding over the sub-domains of the velocity run as function of the angle of rotation of the propeller. The numbers of the angle categories are inserted as windows domain as well as the valid standard deviation for each signal for this.

In the figures A2.2 to A2.4 these values are to find under statistic, validity area V_1 or V_2. With the help of the calculated mean value and the standard deviation the validity area will be estimated new for each angle category as well as the mean value and the standard deviation for each angle class.

In the figures A2.2 to A2.4 results of the LDV measurements are presented exemplary. The single velocity values of V_1 and V_2 are marked with blue colour over the angle of rotations. The red curves below and above of the blue marked velocity curves show the validity region for the comprehension of the single measuring value in the averaging. Like to see from the runs, this method is an effective mean for the selection of the valid single measuring values. Besides the velocity run over the angle of rotation of the propeller, the frequency distribution of the several velocity categories is specified in [%].

In the figure A2.2 there is identified clear the reflections from the surface or noise components around the velocity $V_1 = 0$ for the velocity V_1. With the described signal analysis these velocity parts allow to divide easy. Against it in the figure A2.3 (measurement at z = -7.5 mm and $J = J_{min}$) an elimination of their disturbing signals and the rather measuring signals for some points is no longer possible.

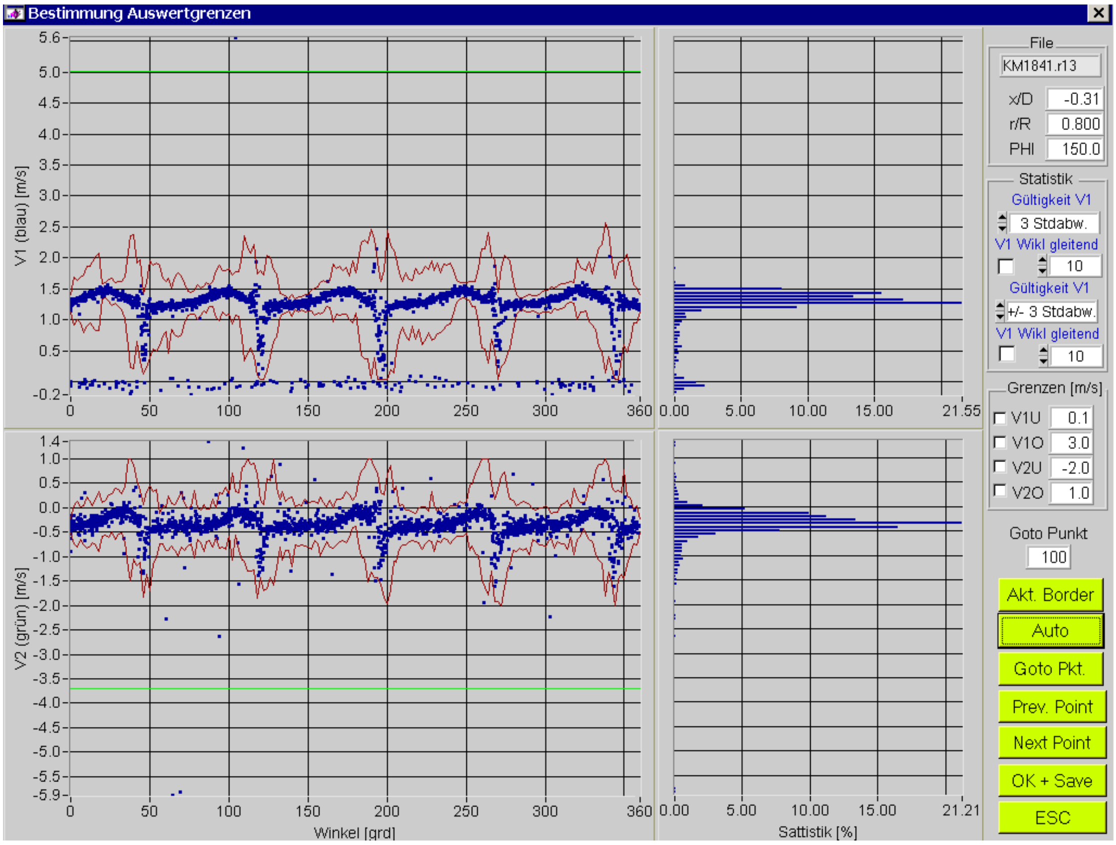

Figure A2.2: Screen menu for the determination of the validity limits for the single measuring value

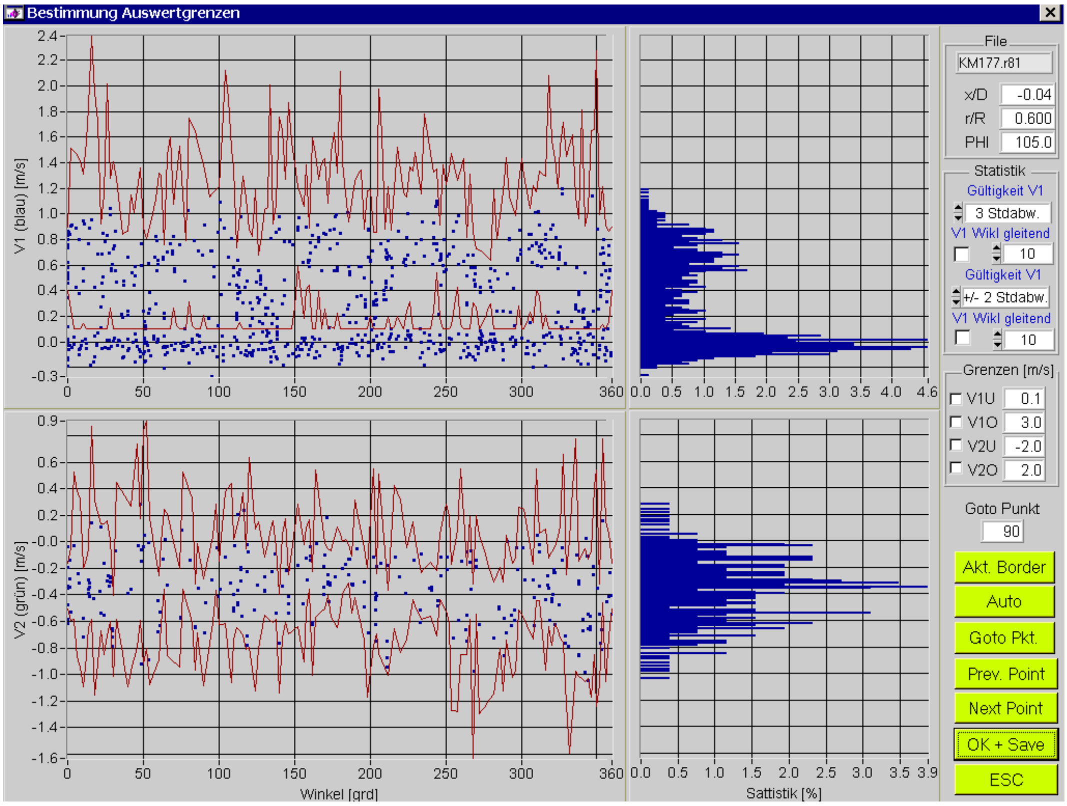

Figure A2.3: Screen menu for determination and elimination of disturbing signals

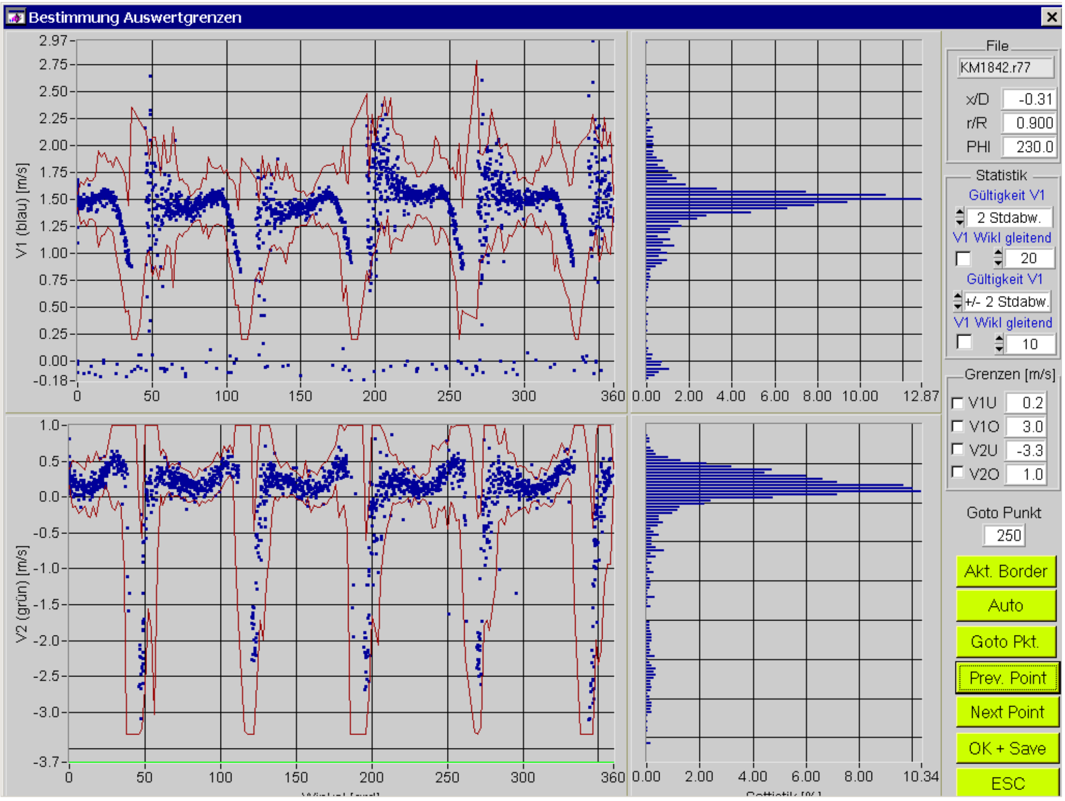

Figure A2.4: Screen menu for determination a elimination of disturbing signals

ANNEX

Like the figure A2.4 shows, it is possible to determine the validity region (inside of the red marked areas) by above described method for the single measuring value as far as, that the disturbing signals eliminate for the real calculation. Measuring values for missing angle categories are interpolate from the last valid till to the next valid measuring value linear. Aground of possible high velocity gradient the failure is to join here adequate high at the interpolation. But without additional supporting points it is not possible to improve the interpolation.

The calculation of the statistical parameters over the angle as well as die for a measuring position averaged values happens about the following described equations 1 to 10. A bias correction of the measuring values will not carried out at the determination of the velocity mean values.

Equation 1: Velocity mean value inside of an angle category

$$\overline{V}(k)=\frac{\sum_{j=0}^{n-1}V(k,j)}{n}$$

k elected angle category *k*
n numbers of values inside of the angle category *k*
V(*k*,*j*) single values inside of the angle category *k*

Equation 2: Standard deviation inside of an angle category

$$S(k)=\sqrt{\frac{\sum_{j=0}^{n-1}\left(\overline{V}(k)-V(k,j)\right)^2}{n}}$$

k elected angle category *k*
n number of values inside of the angle category *k*
V(*k*,*j*) single values inside of the angle category *k*
$\overline{V}$ (*k*) mean velocity in the angle category *k*

Equation 3: Turbulence intensity of *V* in the angle category *k* in relation to 1D-velocity vector

$$Tu(k)=\frac{S(k)\cdot 100}{\overline{V}(k)}\ [\%]$$

k elected angle category *k*
S(*k*) standard deviation in the angle category *k*
$\overline{V}$ (*k*) mean velocity in the angle category *k*

For the calculation of the turbulence degree of the single component V_1, the standard deviation of these velocity components always related to the resulting velocity vector of 2 or 3 velocity components, if it is a question of a multi-dimensional velocity field measurement or of a composed 3-dimensionalen velocity field from 2D fields. So it results following equations:

Equation 4: Turbulence intensity von V_1 in the angle category *k* in relation to 2D-velocity vector

$$Tu_1(k)=\frac{S_1(k)\cdot 100}{\sqrt{\left(\overline{V}_1^2(k)+\overline{V}_2^2(k)\right)}}\ [\%]$$

k elected angle category
$S_1(k)$ standard deviation in the angle category *k*
$\overline{V}(k)$ mean velocities of V_1 and V_2 in the angle category *k*

Equation 5: Turbulence intensity of V_1 in the angle category k in relation to 3D-velocity vector

$$Tu_1(k) = \frac{100 S_1(k)}{\sqrt{\left(\overline{V}_1^2(k) + \overline{V}_2^2(k) + \overline{V}_3^2(k)\right)}} [\%]$$

k elected angle category k
$S_1(k)$ standard deviation in the angle category k
$\overline{V}_1$ mean velocities of V_1, V_2 and V_3 in the angle category k

Below there are described die equations for the mean velocities and their statistic values at a measuring point:

Equation 6: Ensemble mean value of the velocity at a point

$$\overline{V} = \frac{\sum_{j=0}^{n-1} \overline{V}(j)}{n}$$

n number of angle category
$\overline{V}$ velocity mean value

Equation 7: Standard deviation of the velocity at a point

$$S = \sqrt{\frac{\sum_{j=0}^{n-1} \left(\overline{V} - V(j)\right)^2}{n}}$$

$V(j)$ mean velocity in the angle category j
n numbers of angle category
$\overline{V}$ velocity mean value

Equation 8: Turbulence intensity of V in relation to 1D-velocity vector

$$Tu = \frac{S \cdot 100}{\overline{V}} \ [\%]$$

S standard deviation
$\overline{V}$ mean velocity

For the calculation of the turbulence degree of the single component V_1, the standard deviation of these velocity components always related to the resulting velocity vector of 2 or 3 velocity components, if it is a question of a multi-dimensional velocity field measurement or of a composed 3-dimensionalen velocity field from 2D fields. So it results following equations:

Equation 9: Turbulence intensity of V_1 in relation to 2D-velocity vector

$$Tu_1 = \frac{S_1 \cdot 100}{\sqrt{\left(\overline{V}_1^2 + \overline{V}_2^2\right)}} \ [\%]$$

S_1 standard deviation of V_1
$\overline{V}_1, \overline{V}_2$ mean velocities of V_1 and V_2

Equation 10: Turbulence intensity of V_1 in relation to 3D-velocity vector

$$Tu_1 = \frac{S_1 \cdot 100}{\sqrt{\left(\overline{V}_1^2 + \overline{V}_2^2 + \overline{V}_3^2\right)}} \ [\%]$$

$S_1(k)$ standard deviation in the angle category k
$\overline{V}_1(k)$ mean velocities of V_1, V_2 and V_3

The results for the calculated mean velocities are available in Microsoft word data sets format as journal data sets for the several measurements. The data for the angle disbanded velocity curves are stored in excel-data-sets, in which each work sheet data for a measuring point contains.

Co-ordinate system

Cylindrical propeller coordinate system looking on pressure side