Measurements of Wall Shear Stress in ARDE Barinco CJ-20 Mixer Using Lenterra's M-series RealShear™ Wall Shear Stress Sensor.

Lenterra Inc, Newark, NJ, December 7th, 2012- January 15th, 2013

Scope of the work

Measurements of wall shear stress in water were carried out in the ARDE Barinco reversible homogenizing mixer CJ-20 in Lenterra laboratory. There were made two holes in the mixer stator for sensor installation, as shown in photograph below. Sensor was installed to be flash with inner surface of the stator. A series of systematic measurements included:

1) measuring wall shear stress (WSS) when the sensor measurement axis is directed tangentially to the rotor movement at various RPMs at two different locations (positions 1 and 2 in Fig. 1)
2) for three fixed RPM values (118, 240 and 360), the senor was rotated over 180 degrees with 22.5 degrees increment to measure the direction of the shear force at the sensor location. .

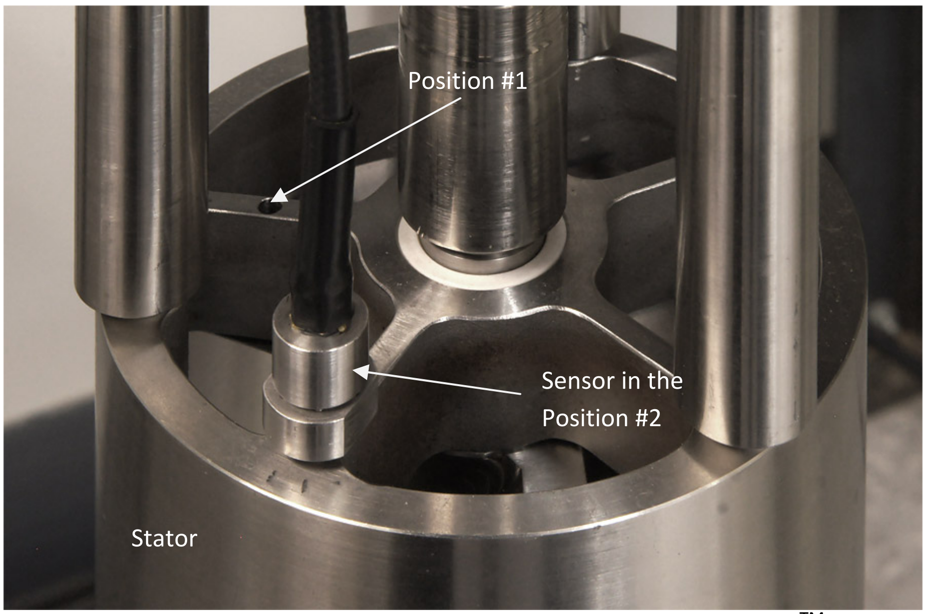

Fig. 1: Photograph of the mixer with installed RealShear™ sensor

Test parameters

- Mixer: ARDE Barinco reversible homogenizing mixer CJ-20 (serial number 5230)
- RPMs: from 118 RPM to 601 RPM
- Gap between rotor and sensor floating element: 0.017" (0.43 mm)
- Sensor: 1/8" M-600 RealShear™ wall shear stress sensor (#133)
- Data acquisition: LOC-F-2CH controller connected to a laptop computer
- Sensor locations: position #1 is 45.4 mm from the rotor axis, position #2 is 33.2 mm from the rotor axis
- Fluid: water
- Direction of the rotor rotation: clockwise looking from the top

Test results

Typical signal:

An example of time-resolved sensor output observed in measurements is shown in Fig. 2. At a time instant of t ≈ 2s the mixer was turned on, at t ≈ 11s RPM was increased from 298 to 330, and at t t ≈ 20s mixer was turned off.

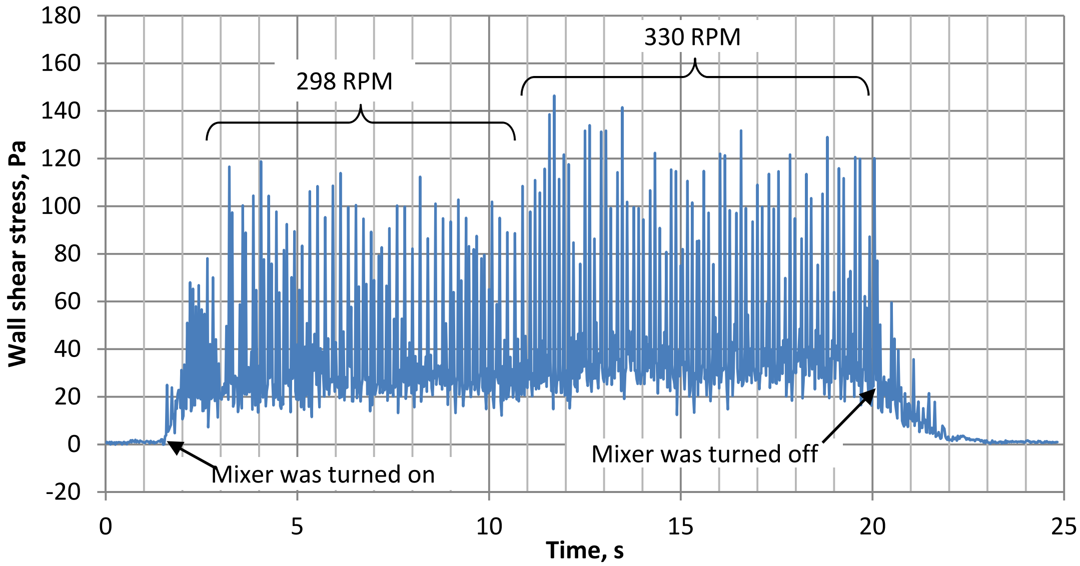

Fig. 2: Typical signal recorded from the RealShear^{TM} sensor

More detailed view of the signal is shown in Fig. 3. One can clearly see that WSS increases when rotor blade is passing over the sensor floating element. The value of the highest WSS varies from blade to blade and also from turn to turn (two full rotations of the rotor are shown in Fig 3).

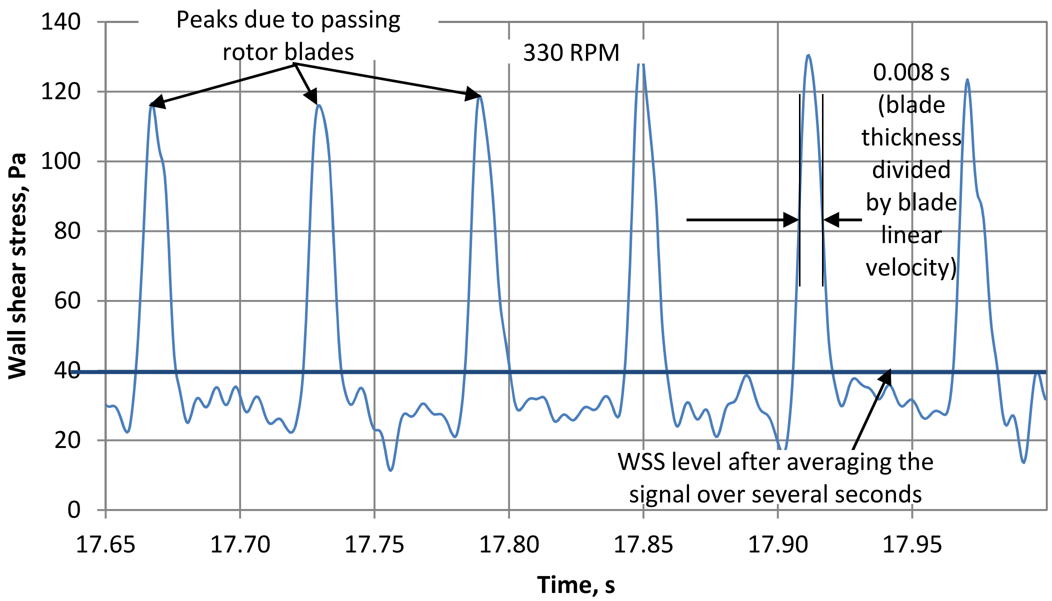

Fig. 3: Typical signal recorded from the RealShear^{TM} sensor

Test 1: Wall shear stress vs. RPM: The magnitude of the wall shear stress peak measured in the direction tangential to the blade rotation is presented in Fig. 4 as a function of RPM. Error bars represent the range between the highest and lowest value of WSS in each trial.

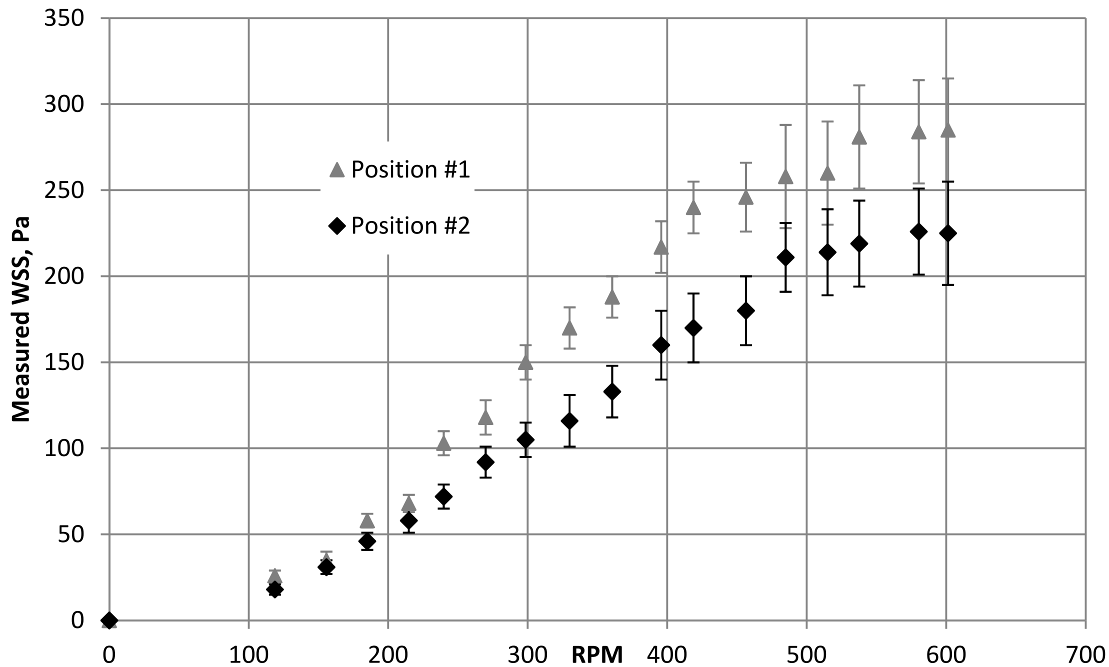

Fig. 4: Measured WSS vs. RPM

Test 2: Angular dependence: RealShear^{TM} sensor is directional sensor, and the observed value should be understood as projection of the actual force to the sensor sensitivity axis. To find the direction and measure the magnitude of the actual shear force, the sensor should be rotated over certain angle. In these tests, the sensor sensitivity axis was rotated in the clockwise direction (looking from the top, see Fig. 5) from 0 to 180 degrees in 1/16th of the turn (22.5 degrees) increments. Measurements were done for three different RPMs.

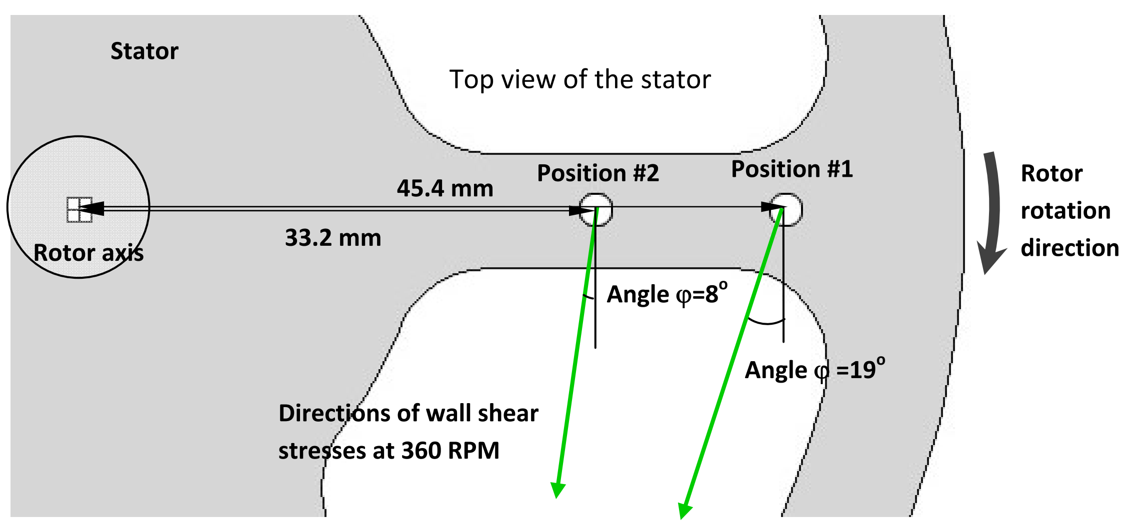

Fig. 5: Schematic of the stator and directions of the WSS for two different locations on the stator.

Results are shown in Figs. 6 and 7 for the sensor positions 1 and 2, respectively. The angles of maximum measured WSS correspond to the local flow directions. The values for the maximum WSS $\tau_{\max}$ and angle $\varphi_{\max}$ were found from fitting test results (e.g those shown in Figs. 6 and 7) with the model function of $\tau_{measured} = \tau_{\max}\cos(\varphi - \varphi_{\max})$ are presented in Fig. 8.

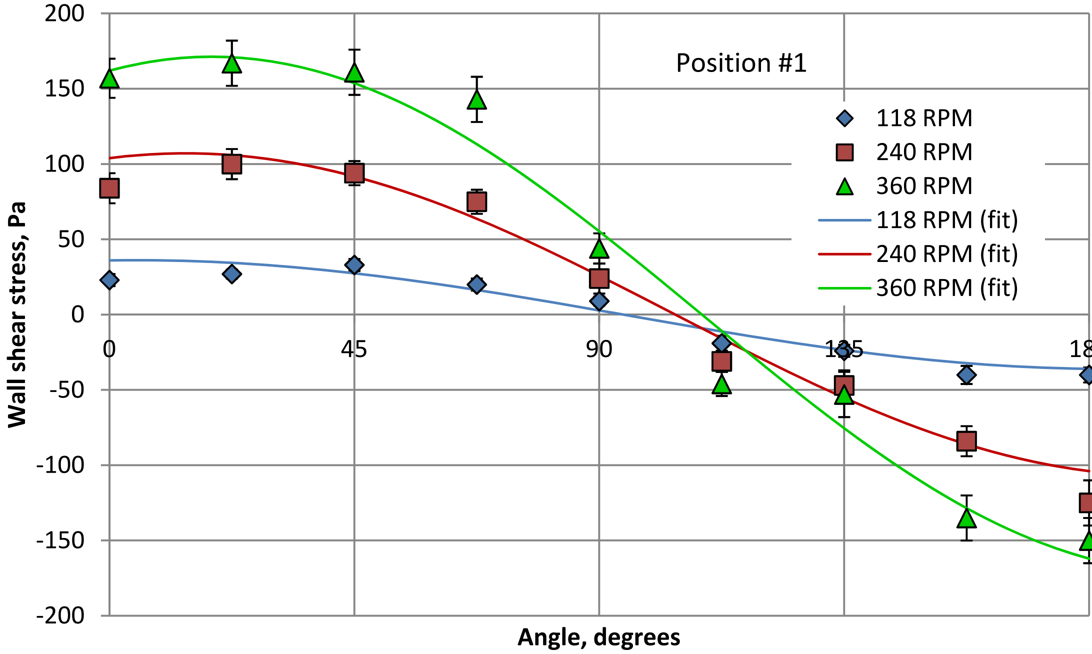

Fig. 6: WSS vs. sensor orientation (position #1)

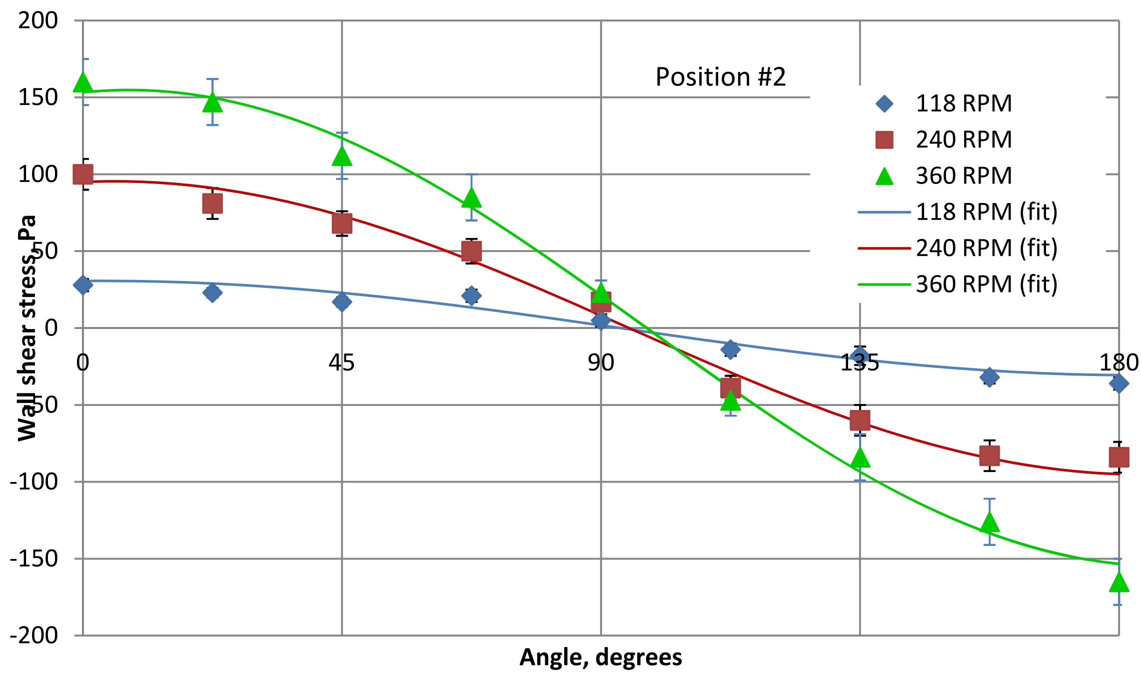

Fig. 7: WSS vs. sensor orientation (position #2)

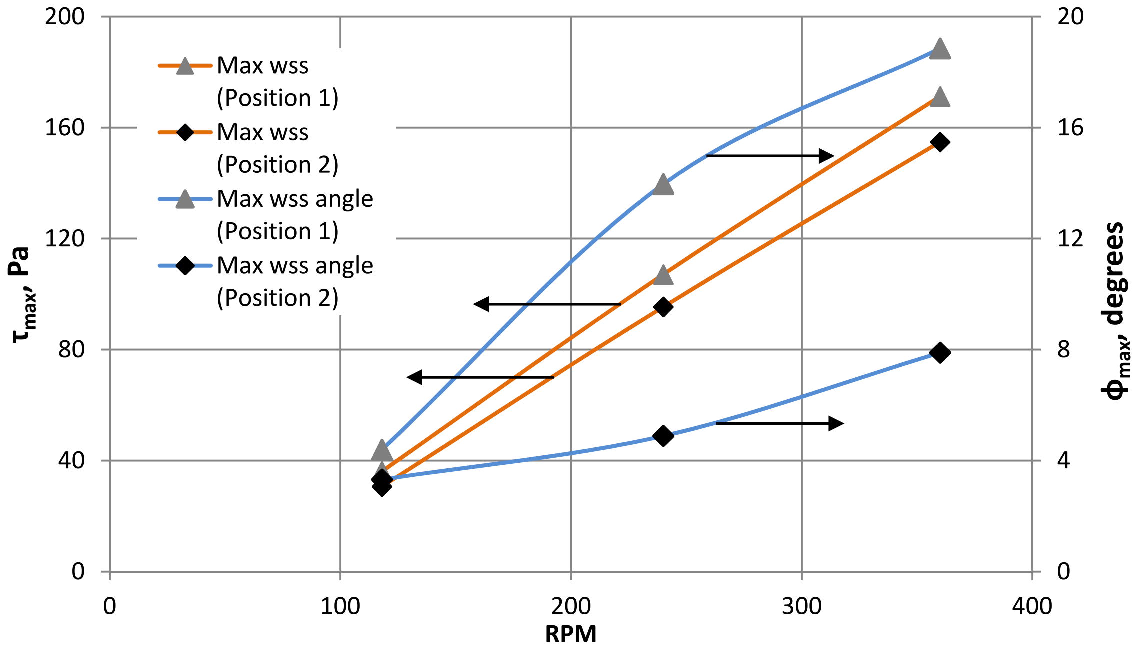

Fig. 8: Maximum WSS and direction of the flow vs. RPM

Results presented in Figs 6-8 demonstrate that the maximum wall shear stress realized in the mixer is higher than that measured in the direction tangential to the rotor rotation (shown in Fig. 4). Based on Fig. 8 data and assuming linear dependence of the flow direction angle vs. RPM, the following flow direction angle vs. RPM functions were restored for each of the two locations: $\varphi_{max} = 0.053\,RPM$ for position 1 and $\varphi_{max} = 0.021\,RPM$ for position 2 and the values of the maximum WSS at various RPM were computed by dividing the measured WSS by cos(φ_{max}).Results are shown in Fig. 9.

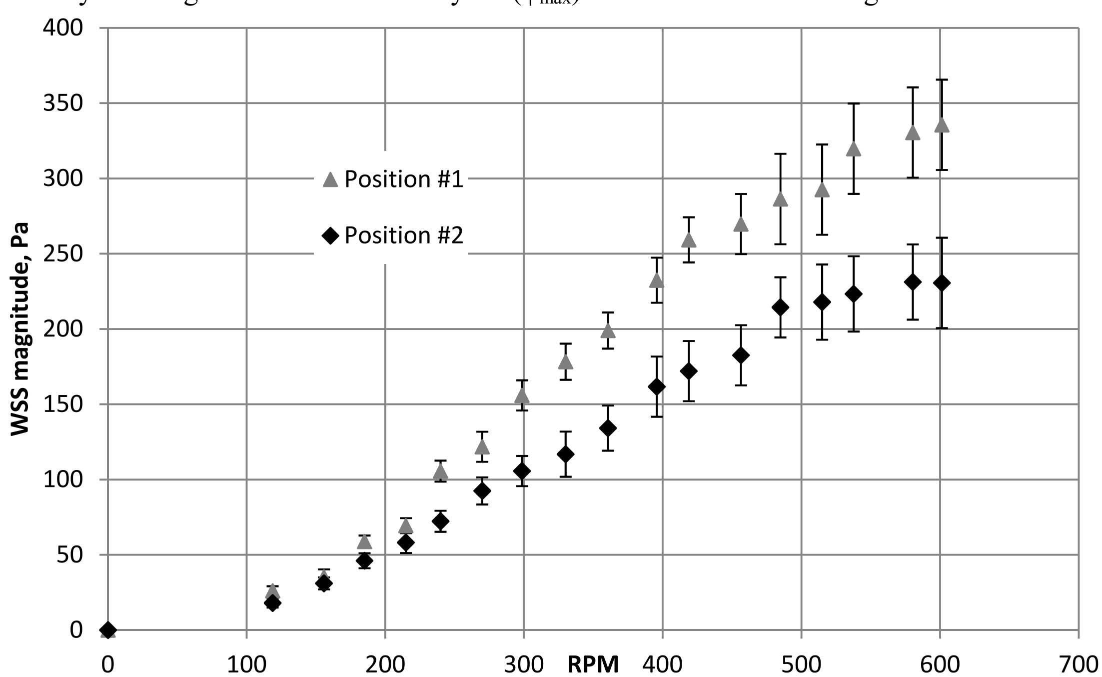

Fig. 9: Estimated magnitude of WSS (value at maximum angle) vs. RPM

Discussion

Test 1:

Figs. 2, 3: The value of the wall shear stress estimated using assumption of liner velocity distribution between rotor and stator is 3 Pa which is much smaller than ~120 Pa peak values measured for 300 RPM. This discrepancy indicates that the blade edge generates a compression wave leading to a significantly higher instantaneous shear forces than those predicted by the stationary model.

Test 2:

Figs. 5-8: The direction of the flow at both sensor locations is somewhat inwards, that is the radial component of the flow is directed towards the axis of the rotor/stator. The proportion of the radial component of the force to its tangential component increases with RPM which is manifested in increasing the flow direction angle φ. This effect (increase of the radial-to-tangential component) is much stronger for more peripheral Position #1 as compared to Position #2.

Fig. 9: As expected, WSS is greater for more peripheral Position #1 for every RPM. Between 100 and ~500 RPM, peak WSS increases linearly At RPMs higher than ~480, strong water aeration was observed which probably caused the observed saturation in the value.

General Conclusions:

- Tests in water provided a reliable signal well resolved for each blade.
- The measured peak WSS values are significantly higher than those predicted by the simple model.
- The maximum WSS in the position 1 is 30-50 % higher than in position 2 which corresponds to the ratio of the distances from positions 1 and 2 to the rotor axis which is equal to 1.4.
- WSS saturates at high RPMs when water is strongly aerated.
- Directions of the flow are different for the positions 1 and 2.