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Moving spraying arm with internal airflow for air-assisted orchard sprayer

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Abstract

There are different ways of pesticide application on trees depending on available equipment, tree sizes, orchard structure, etc. For efficient spraying, a sprayer with continuously moving geometry of spraying arms, adapting to shape and density of tree crown, was developed. The basic idea was that for efficient spraying a pesticide must be applied locally according to canopy characteristics. For this purpose spray orientation and position must be variable and therefore spraying arms should have sufficient degrees of freedom. A prototype sprayer was successfully tested in real orchard conditions. Further on, a new shape of spraying arms was designed to overcome some weaknesses that were found in the first version. These were connected to moving load-bearing structure on which flexible piping was mounted to provide individual air streams for each spraying nozzle. Increased pressure drop due to long piping affected blower choice and overall power consumption. Such design was also space-consuming, storage of the sprayer was difficult and it looked complicated which was undesirable from the point of view of user-friendliness. From the spraying point of view, specific geometry of the existing design was such that positions of spraying arms were mutually dependent within certain range and therefore the geometry of the sprayer was limiting its functionality. An innovative solution was proposed for the sprayer of the second generation. The spraying arm for the new sprayer was made of a hollow load-bearing structure suitable to distribute air to the end of the arm where a spout was placed. Special attention was paid to the design of robust and air-tight joints, connecting individual straight sections. At the beginning, numerical analysis of the last two segments was done for different joint angles. Further on, experimental set-up containing fan, arm prototype and positioning system was built and velocities of the air exiting from the spout were measured in laboratory conditions. Velocity measurements were done for several joint angles and at different distances from the spout. Both numerical and experimental results showed that velocities were dependent on joint angle and decreased with increasing angle. Apart from this, joint angle also affected the symmetry of velocity profile. However, the new design showed possibilities for further truly independent positioning of spraying arms and scaling of the sprayer, as well as transfer of its design to other types of plants because it could easily adapt to different heights, shapes, row distances, etc.

Keywords: plant protection, variable geometry, pesticide application, sprayer design

1 Introduction

Canopy adapted spraying of orchard trees can be based on several tree features such as their geometry, canopy density, canopy volume, leaf area, etc. (Balsari et al. 2008, Escola et al. 2011, Sanz et al. 2013). Whichever it is, the goal is to enhance pesticide application through improved coverage and drift reduction, resulting in reduced pesticide use and better

yield (Brown et al. 2008, Downey et al. 2011). This drives the development of sprayers and improvement of their components. As far as research of canopy adapted spraying is concerned, two approaches can be identified: the first one is based on variable flow rate spraying (Gil et al. 2007) and the second is based on changing geometry of a sprayer (Hočevar et al. 2010). Due to its complexity the latter is still in an initial research phase but the general principle is quite simple: as geometry of trees changes, multiple spraying arms adapt their position so that spraying is performed in an optimal way (Osterman et al. 2013). For real orchard work and from an end-user point of view, it is desirable that these spraying arms are light but rigid and that the sprayer has robust and simple (user friendly) design.
In the present paper development of spraying arms for an orchard sprayer with variable geometry of the spraying arms will be described. This development is based on experience and knowledge obtained through work with the existing prototype sprayer (Figure 1) but is not limited to it. The basic idea is to develop multi-functional components of spraying arms which would join together several functions/parts. Our focus was set on combining a load bearing construction with ducts for spray-assisting air.

Figure 1: Existing prototype sprayer

2 Materials and methods

Our work was performed in two parts. In the first one a new spraying arm was designed and numerical simulation of air flow conditions was made. In the second one the prototype of the arm was made and air velocities were measured in a laboratory environment.
The new design (Figure 2) was based on a square piping with a cross section of 100x100 mm. Straight segments were linked together with rotating joints where sealed bearings were mounted. At the end of the arm, a spout was mounted (Unigreen, type B TT). This type has an inlet diameter of 100 mm, an exit angle of 45° and a gap width of 22 mm. CFD numerical calculations were performed for a steady, incompressible, single phase, turbulent airflow in a 3D space.

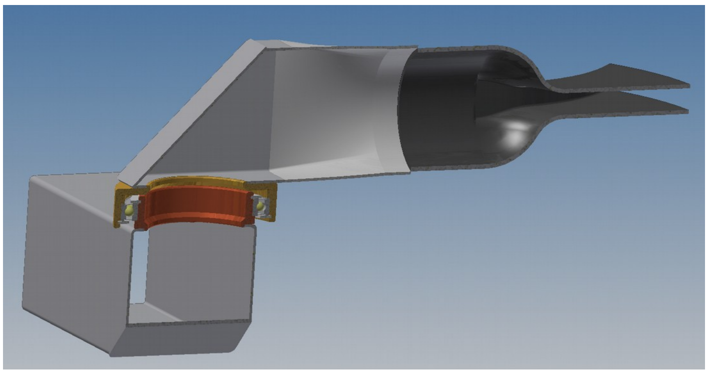

Figure 2: New design of the spraying arm

For the experimental part (Figure 3) the following set-up was used:
a radial fan Klima Celje 104 CVX160/4, driven by a frequency converter at 60 Hz. Air flow rate was 435 m^3/h. Flow rate was calculated on the basis of pressure drop measured on an orifice. It was measured with a differential pressure transmitter Endress Hauser PMD235 with range 0-10 mbar. Air flow velocities were measured with a rotating vane anemometer Schiltknecht MiniAir 20. Vane diameter was 22 mm, measurement range was 0-20 m/s and velocities were averaged over a time period of 6 s. Measurements were done on a grid of 21x15 points (width x height), placed perpendicularly to the spout/last straight section of the arm. Air velocities were measured for several positions of the spraying arm from straight to right-angled. The angle of the arm was changed by joint rotation with increments of 15°. These angles were already used in previous numerical calculations.

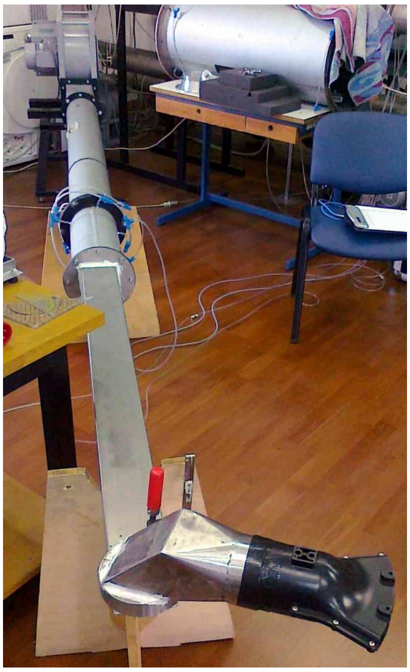

Figure 3: Experimental set-up

3 Results and discussion

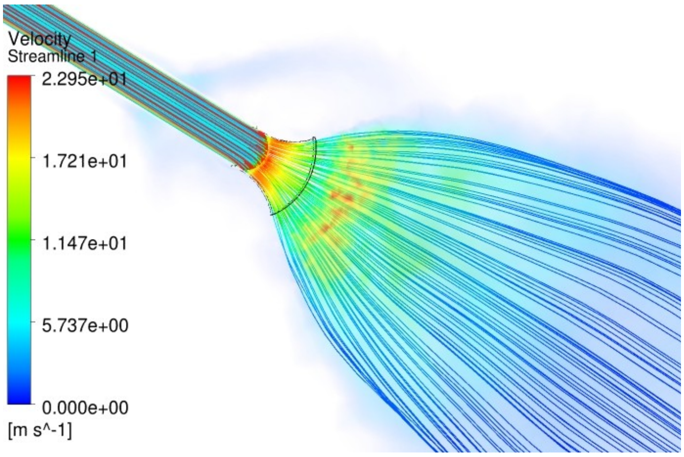

Figure 4: Streamlines and velocities for straight air supply pipe

As presented in Figure 4, CFD numerical simulations showed that in the first part of the spout where its cross section is getting smaller (converging nozzle) there is a large pressure drop which has a positive effect on velocities inside the arm (represses turbulence). As the area increases due to widening of the gap towards the exit, the flow slows down and becomes very turbulent soon after it exits the spout. Unlike streamlines from a steady-state simulation pictured in Figure 4, a practical observation of the spraying process reveals complex paths of droplets moving stochastically in all directions.
In Figure 4 it is also possible to observe a consequence of a flow separation in exit regions where the spout is very curved (both edges). Apparently the flow stops following a diverging

geometry of the side wall and continues straight on. As a consequence the air flow emerges from the spout at a significantly smaller angle than the designed 90°. This effect is also pronounced in Figure 5 where the spraying arm with the last section position at 90° is shown. When the flow passes the joint, it rotates and gets unsymmetrical (inlet velocity profile was always symmetrical).

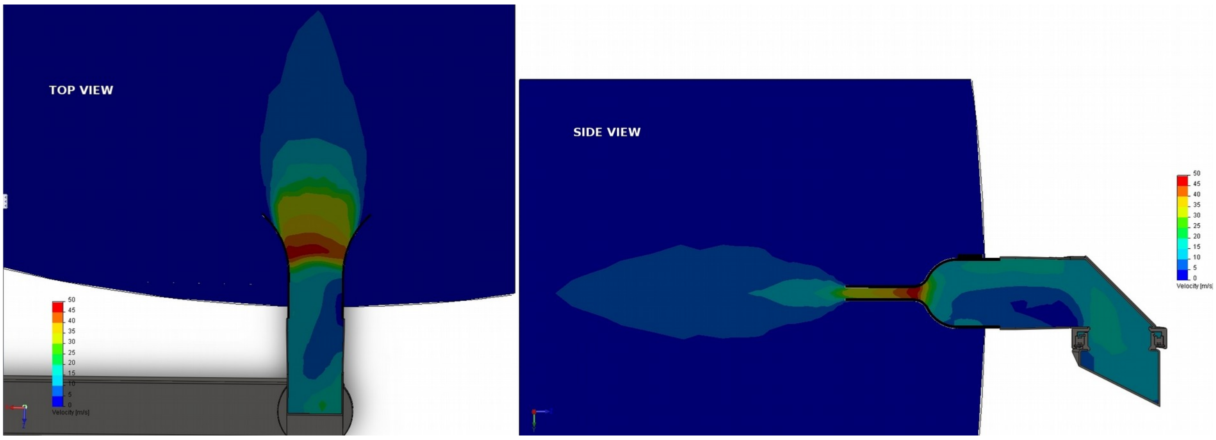

Figure 5: Air velocities for the prototype spraying arm with a joint angle of 90° (top and side view)

This asymmetry is partially reduced because of the pressure build-up in the most narrow part of the spout, but can still be observed in the air flow exiting the spout. Because of this, separation of this flow is even greater than before. This indicates the need to have a longer last section with some internal elements for flow conditioning (vanes etc.) and to reduce the curvature of the spout to avoid flow separation.

Experimental measurements of velocity profiles 0.5 m away from the exit revealed similarly uneven conditions (Figure 6). First of all, by increasing the joint angle, the highest velocities were reduced for about 1 m/s. Secondly, when the arm was not straight the flow was asymmetrical with two unequal peaks at each side and a saddle with lower velocities in the middle.

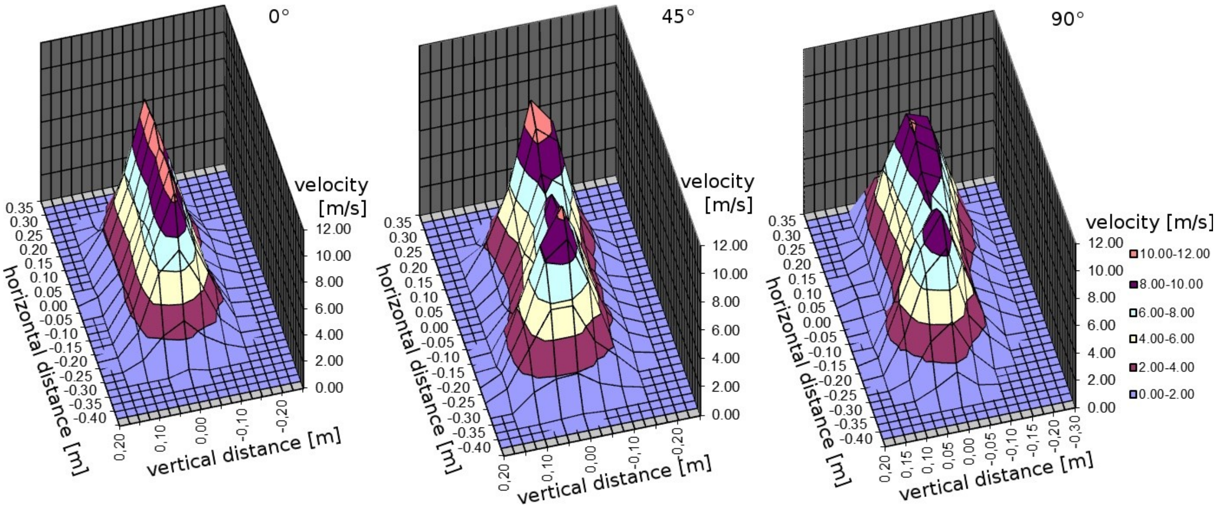

Figure 6: Velocity profiles for different joint angles measured 0.5 m away from the exit

4 Conclusions

As a part of further development of a sprayer with a moving geometry of spraying arms used for canopy adapted air-assisted orchard spraying, numerical and experimental analysis of the new spraying arm prototype was done. Flow conditions inside the arm and of the air emerging from it were found to be dependent on the angle of the arm. Because of this some modifications of the spout and arm geometry were proposed to obtain more uniform velocity profile of the air flow exiting the arm, namely guide vanes in the last section before the spout and a spout with a smaller curvature of its diverging part.

5 Acknowledgements

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