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# Computational Fluid Dynamic Modeling Application as a Design Tool in Air Assisted Pesticide Sprayer Development

Elizabeth Musiu[1, 2*] Qi Lijun[1]
1.Department of Engineering, China Agricultural University, No.17 Qing Hua Dong Lu, Haidian District, Beijing 100083 P.R.China
2.Agricultural and Biosystem Engineering Department, Jomo Kenyatta University of Agriculture and Technology, P.O box 62000-00200 Nairobi, Kenya

**Abstract**
The complex dynamic behaviors of air assisted pesticides spraying, especially inter-droplets interactions as well as effects of prevailing surrounding fluid environment before and after the spray breakup makes development of an ideal sprayer unattainable. Moreover, plants' canopy architectures are sophisticated mainly due to variations in features' orientation amongst species. A prior insight of the sprayer's performance behavior at design phase can significantly help in avoiding unanticipated future failures. This situation has recently, inevitably paved way for the application of numerical analysis such as Computational Fluid Dynamic (CFD) modeling as a robust design tool. Furthermore, movement of spray droplets from the generator to the targets involve fluid flows, heat transfer and mass flow which are the principle fields in CFD simulation of transport phenomena. As the droplets travel, the surrounding environment is likely to interfere with their physical and chemical properties. The concern to fully utilize the technology has nowadays not only drawn the attention of manufacturing industry but has also captured the interests of researchers. Previous applications of CFD modeling have demonstrated its potential to ease the challenges of cost and time consumption that would have been encountered in physical experimental trials tests. Nevertheless, developing a standard ideal model still remains unattainable. Most researchers have developed simple model mainly of Lagrangian approach whose applications have primarily been on open-fields spraying despite the situation still remaining far underway. This paper gives a state-of-art review of the application of CFD modeling in air atomized pesticide spraying with an aim of highlighting future research needs.
**Keywords:** Computational Fluid Dynamic, Air assisted sprayers, Lagrangian approach, Spray droplets

## 1. Introduction

The application of atomized spraying in crop pest control in recent years has been widely spreading in outdoor crop protection and gradually gaining popularity in greenhouse farming especially in developed countries. The technique has lately proven potentially effective in improving spray droplets deposition while reducing drift. Previous research reveals that air assisted pesticide spraying; improve pesticide distribution, lower environmental degradation that is primarily caused by of off-target deposition and evaporation of tiny droplets, reduce chemical losses to the soil as well as lower healthy risk exposure especially to workers in controlled environments such as in greenhouses. Unfortunately, the dynamic behavior of the technique is sophisticated especially the inter-droplets and resultant effects of the prevailing surrounding fluid fields before and after the spray breakup. A keen understanding of optimum sprayer's parameter settings and their corresponding performance is therefore paramount; otherwise the droplets might disintegrate further into small droplets which are more susceptible to evaporation (Bayata & Bozdogan, 2005) especially on subjection to extreme prevailing environmental condition. The challenge remains on how to effectively predict the performance of the sprayer as early as at its design phase before releasing it to the market. Furthermore, the conventional use of physical experiment trials have proven to be time consuming, expensive or inefficient and to some extent unachievable. To curb the challenge, numerical analysis such as CFD modeling has widely been a useful tool that effectively projects the performance of the sprayer at its preliminary development phases. However, for reliable simulation results, physical experiment trials data has to be used as initial condition data inputs to compliment the simulation process (Garcia-Ramos *et al.,*2012). CFD modeling has a proven history as a simulation tool whose technique is utilized to simulate, analyze and optimize engineering designs (In-Bok Lee *et al.,* 2013; Xu *et al.,* 1998 ; Dekeyser, et al., 2013; Melese *et al.,* 2010). It uses computer and applied mathematics to model fluid flow situations, heat, mass and momentum transfer (Xia & Sun, 2002; Lee *et al.*, 2013; Sazhin, 2009; Date, 2005; Endalew *et al.,* 2006; Andalew *et al.,* 2009). Moreover, it takes the advantage of its ability to incorporate relative complex systems such as the sprayer's nozzle characteristics (Ellis, 2010; Sidahmed *et al.,* 2005) to predict the performance of a new design before its finally manufactured (Lee *et al.,* 2013; Schaldach *et al.,* 2000). The conspicuous results obtained through simulation gives reliable information that can be used in making good design decision as well as in project planning. In recent years, numerous CFD models coupled to commercial code such as FLUENT (inc. Lebanon, USA) code, have been used in research to simulate the performance of air assisted pesticide sprayers during and after their development phases. Keen focus has mostly been on droplets movement, airflow velocity after dispession from the sprayer's nozzle(s), droplets displacement under simplified prevailing field conditions as well as droplets deposition. However, the available information is far underway and still lacks coherence. A comprehensive summary of previous research on CFD simulation applications on air assisted pesticide sprayer pre-testing would give an insight on future research needs. On this regard, the objective of this review paper was to give a comprehensive state-of-the-art review of the application of CFD modeling as an engineering design tool on air assisted pesticide sprayers' development as well as give highlights on future research needs for further studies.

*1.1 Air assisted spraying*

Air assisted spraying involve atomization of the droplets through injecting air streams at a high velocity toward the spray path so as to increase the droplets velocity and modify its trajectory for optimum spray delivery. The injected air streams consequently reinforce the spray droplets trajectories especially when directed at the optimum inclination angles towards the targets and enhance the spray capture. Hislop *et al*. (1995) noted that, inclining the sprayer nozzle away from its vertical can alter the droplets trajectory as well as increase the crops' spray capture especially where the crops are vertical. The generated air jet blows the spray droplets throughout the plant and lift the foliage consequently, improving penetration and deposition of the droplets (Arthur *et al.,* 2006; Andalew *et al.,* 2011; Ashenafi *et al.,* 2015) on the surface of the plant. According to Ade (2007), air-assisted spraying entrain and deliver the droplets to the target; attaining improved spray penetration and a substantial reduction of spray drift and achieve a more uniform coverage on the plant surfaces. Nevertheless, the distribution and fate after application of the pesticides to both target and non-target depend on several factors especially; the sprayer's design, application techniques (Gary *et al.,* 2013; Dekeyser *et al.,* 2014), respective sprayer's components settings and prevailing weather conditions. Sanchez-Hermosill *et al.* (2013), attributed; poor pesticide distribution of low uniformity on plant canopy, heavy losses to the soil and high healthy risk exposure to workers, to the of use of low technology equipments. This concure with the analogy by Zhao *et al.* (2008); D.B. Watson *et al.* (1984) and Yvan *et al.,* (2008), that optimum droplet size delivery in air assisted spraying would ensure maximized on-target deposition and minimize spray drift. Furthermore, air assisted spaying will reinforce and modify the trajectories of the droplets for an effective delivery. For an improved deposition and a good electrostatic control of the droplet trajectory, Zhao *et al.* (2008) highlighted that, a high charge-mass ratio is required. Moreover, if the velocity magnitude and direction are not properly adjusted, off-target deposition is likely to occur (Delele *et al.,* 2005). Nevertheless, development of an ideal sprayer that is capable to achieve minimum drift and maximum deposition is complicated (Gan-Gan-Mor *et al.,* 1996; Delele *et al.,* 2007); the challenge still remains on how to predict the performance of the sprayer at early development stages before finally manufacturing for marketing. Due to limitation on the use of physical experiment trials, the use of CFD modeling coupled to commercial simulation code have been on the rise.

*1.2. Spray CFD modeling fundamentals*

The success of modeling majorly depends on the quality of initial data input. There are four basic elements that form the initial conditions data requirement in CFD simulation of pesticides spray characterization; the droplet size, droplet velocity, spray liquid density (Dorr *et al.,* 2013) and nozzle characteristics (size, number and orientation).

*1.2.1 Droplet size*

The biological efficacy of air assisted pesticide sprayer can be influenced by respective droplet size (Nuyttens *et al.,* 2007). The droplet size has a direct influence to the fate of the droplet thus the rate of deposition and/or drift of the applied chemicals. For CFD modeling purpose, the actual droplet size is required hence the need for data precision and accuracy. The challenge remain that, most sprays are 'polydisperse' (Gant, 2006; Sirignano, 1999) comprising of numerous sizes; from very fine to very coarse droplet sizes. Previous CFD modeling research has used different creteria to estimate the droplets diameter but the simplest and most commonly used is the use of respresentative droplets diameter method though this inevitably creates data descripancy. Occassinaly, empirical equations which characterize size distribution in terms of variables have been applied where the most widely prefered is the Rosin-Rammler distribution equation expresed as:

$$1 - v = exp\left[-\left({}^{D}/_{\delta}\right)^{\gamma}\right] \qquad (1)$$

Where

$v$ is the fraction of the total volume contained in droplets smaller than diameter D

D is the droplet diameter

$\delta$ is Rosin-Rammler diameter

$\gamma$ is a constand indicating the amount of spread of droplet sizes

*1.2.2 Spray droplet velocity*

Spray's droplets velocity are very sophisticated and are dependent on respective droplets' sizes; bigger droplet size corresponds to higher droplet velocities and vice versa (Nuyttens et al., 2009), although smaller droplets tend to have a more rapid acceleration or deceleration than larger droplets (Sirignano, 1999). Most CFD models assume that initial velocity is equal to average liquid sheet velocity (Sidahmed *et al.,* 1999; Dorr *et al.,* 2013) and remain constant in the entire time steps. Under normal conditions, the velocity of the droplets is subject to change due to the drag force in the atmosphere especially the effects of prevailing air flow; furthermore once a liquid spray is injected into a gaseous environment it tends to destabilize (Sirignano, 1999). Fig. 1 shows simulation results and experiment values of airflow velocity variation at various vertical height of an artificial plant.

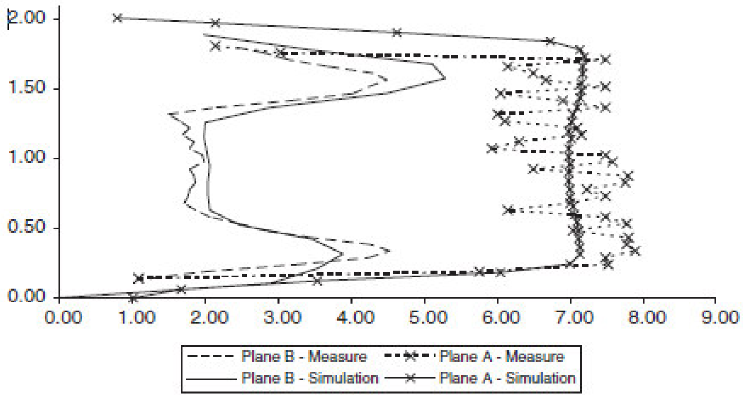


Fig.1 CFD simulation results and measured values of air flow velocity in front (A) and behind (B) an artificial canopy (Silva *et al.,* 2006)

*1.2.3 Spray liquid density*

Spray liquid density diminishes when air bubbles form within the droplet (Dorr *et al.,* 2013) thus the amount of air in a droplet may vary depending on the characteristics of the sprayer's nozzle. Unfortunately, some CFD simulation have been conducted on the assumption that the density of the spray liquid is the same as the density of water. This could be misleading or probably cause a descripancy between real life application and simulation.

*1.2.4 Nozzle characteristics*

The nozzle(s) type, number, size and inclination angle play a fundamental role in air assisted spraying especially in optimizing it's performance. Some CFD simulations have been conducted on the basis of nozzle characteristics to give an insight on their influence to the droplets behaviours.

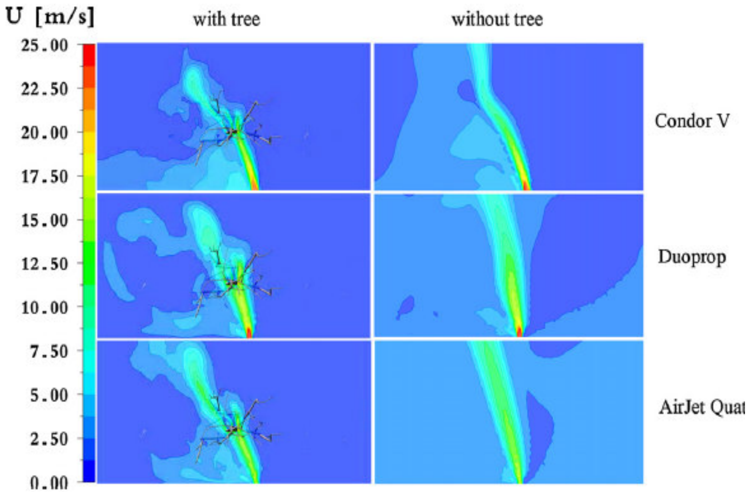


Fig. 2 CFD simulation results showing velocity contour plots from; single (Condor v), double (Duoprop), four fan (Airjet quat) sprayers (Endalew *et al.,*2010)

*1.3 CFD Modeling approach applied in previous air assisted pesticide sprayers' simulation research*.

Previous air assisted sprayer perfomance simulations have been carried out through two fundamental CFD modeling approaches; the Eulerian continous phase and Lagrangian approach.

*1.3.1 Eulerian continous phase approach*.

Eulerian continous phase modeling approach treats the droplets as a continous flow that involves a gas and a droplets phase, on the assumption that each computational cell comprises of gas and droplets. Their homogenous models assumes that the droplets and carrier phase share same velocity, turbulence properties and temperature while the inhomogeneous models assume that fluids share same pressure field and that different fluids interact through interphase transfer terms; momemtum, heat and mass.They have a less computaotinal demand hence turbulence can be modeled simpler. However, if separate equations are to be solved for each droplet, the approach can be very computational expensive hence certainities in their diffusion coeffciency.

*1.3.2 Lagrangian particle tracking approach.*

The Lagrangian particle tracking approach approach is used to estimate droplets' movement in both laminar and turbulent flow fields. Individual droplets are trapped through a flow domain from their injection point to their point of escape from the domain or until an intergation creterio is reached. Their gas phase is modeled using Eulerian approach although an additional void fraction source terms has to be applied to the Eulerian equation to account for the presence of the droplets. Despite of its short falls on grid dependance of results for dense sprays (Sazhin, 2009), the approach has the advantage of focusing on droplet break up and has widely been favoured in air assisted pesticide sprayers CFD simulation.

Table 1. Simple models developed and applied in previous simulations

| **Author** | **Sprayer indicator** | **Equation /Model** | **Simulation approach** |
|---|---|---|---|
| Silva et al. 2006 | air flow characteristis | RANS equation and k-ε model | - |
| Delele et al. 2007 | air flow velocity | Reynold averaged fluid flow | Lagrangian |
| | | k-ε turbulent model | Lagrangian |
| Melese andalew et al. 2009 | air flow | Full closure model (FCM) | - |
| | effects of canopy | intergrated model, | |
| | | RANS & k-ε turbulent model | |
| Zhao et al. 2008 | droplets size | Renomalized k-ε turbulent model | Lagrangian |
| | charge -to mass ratio | | |
| | nozzle-taget distance | | |
| Endalew et al. 2010 | flow velocity | RANS equation and k-ε model | - |
| Isukapalli et al. 2013 | deposition | renomalized k-ε turbulent model | Lagrangian |
| Dekeyser et al. 2013 | nozzle characteristics | RANS equation & k-ε turbulent model | - |
| Larbi, 2011 | air velocity, mass flow | - | Euler |
| Farooq & Salyani, 2004 | - | - | Lagrangian |
| Brown & Sihadman, 2001 | - | - | Lagrangian |

Table1. Shows a high application preference of both k-ε turbulent model and the legrangian particle tracking appraoch

*1.4. Significant CFD modeling contribution to air assisted pesticide sprayers' development*

*1.4.1 Simple CFD models developed and applied in previous simulation work.*

Developing an ideal model suitable for all air assisted pesticide sprayers' performance pre-trials may not be attainable, probably due to the complex nature of the architecture of plant canopy alongside fluctuating field's conditions. Furthermore, an ideal model would be too computational expensive consequently, prompting the need for use of very powerful computers. With respect to this, numerous researchers have devoted themselves in developing simple models at stipulated assumptions to basically meet the research needs at hand.

The AGDISP and Agdrift models which were developed by US department of Agriculture forestry service in collaboration with the US army for predicting deposition and drift of aerial spray are the most advanced spray models. The two models were developed using the lagrangian approach and the original ensemble average turbulence equation to avoid the need of any random component (Larbi, 2011). On the model's prediction behavior simulation, Ekblad *et al.* (1987) noted that AGDISP is adequate for simulations involving droplets diameter of between 100 and 600 µm released from an aircraft speed greater than transmission speed. Thompson & Ley (1983), on the assumption that discrete displacement can represent the trajectories of an individual droplet and Holterman *et al.* (1994) on 2D, developed random walk models for simulating spray drift. Walklate (1992), assumed that initial velocity prevail the entire steps, to develop a model for simulating the impacts of droplets as well as deposition on crops. The key mandate of the model was to simulate the behavior of the airplane wake close to the ground as well as the movement on the spray. Later (Walklate *et al.,* 1996) established a model for simulating jet penetration into the plant canopy. With a velocity opinion different from that previously made by Walklate, (1992); that is, velocity fluctuation is isotropic with Gaussian probability density, Xu *et al.* (1997) developed a model to simulate deposition on plant surface. Their model development applied the principles of transmission probability to account for droplets impact. Thereafter (Xu *et al.*, 1998), they incorporated lagrangian approach coupled to stochastic particle tracking model to predict spray dispersion at various distances from the sprayer's nozzle center line. Delele *et al.* (2007) developed a 3-D CFD model for predicting droplet dispersion from a vertical cross flow air assisted sprayer. Their model accounted for velocity variation at the fan outlet as well as the nozzle characteristics (type, size and direction) and liquid atomization. In this model, particles tracking were by use of lagrangian multi particle model. Miller *et al.* (1996) adapted a model that successfully simulated entrained air velocity due to droplets movement from a flat-fan nozzle through air in both vertical and radial direction inside the spray. Their model; assumes a mono dispersed spray, account for kinetic energy exchange between droplets and neglects the effect of gravity. While on an assumption that plant canopy offer an aerodynamic resistant which is proportional to the square of airspeed and that fluid density experience an exponential decay with canopy width, Vieri & Spugnoli (1996) developed a model to monitor both spray and airstream suitability. This model successfully simulated droplet behavior relative to temperature, humidity, and wind variations.

O Rourke & Amsden, (1987) developed Taylor Analogy Breakup (TAB) and droplet drag model which are based on the analogy that oscillating droplet is exposed to an airflow field and a forced fixed oscillating spring mass system. In search for a simple and an applicable alternative to model the effects of leaves in architectural canopy model on airflow, Melese *et al*. (2008) conducted a direct CFD simulation while applying averaging principles at individual branch level. Their simulation need was compelled to their previous 3D canopy simulation work which demonstrated a minimum accuracy of 92 %. Moreover, to model leaves, drag force equations were added in the momentum and turbulent energy equations on a porous sub domain created around the branches.

Thereafter, the team (Melese *et al.,* 2010) developed a model to simulate airflow within plant canopy using 3D canopy architecture with a keen insight on the effects of canopy on airflow. While using 10m/s as the mean velocity at inlet, airflow was simulated using Reynolds-Averaged Nervier Stoke (RANS) equation and k-ε turbulence model. The model's average air velocity was validated using experiment trial values in a wind tunnel with two artificial model trees. There was a good agreement on the average longitudinal velocity (u) between the measured and simulated results with a relative error of less than 2 % and 8 % in the upstream and downstream of the tree respectively. The accuracy of the model's results on turbulent kinetic energy (k) and turbulence intensity (1) was acceptable within the tree height on a roughness length (y0=0.02 mm) for the surface roughness of the branches and through applying a source term to porous sub-domain created around the tree. Nevertheless, a small difference due to spatial disparities within the canopy architecture was noted. Brown & Sihadmed, (2001), studied and evaluated a computational fluid dynamic code (FLUENT TM) in simulating the airflow from free round jets and compared the simulation results to Abramovich's, 1963; (Larbi, 2011) theory of free turbulent jets. Despite experiments and simulation results being in good agreement, discrepancy within droplet of diameter between 24 and 70µm was noted. Brown & Sihadman, (2001) simulation provided droplets' horizontal travel distance released from a forestry air blast sprayer using lagrangian approach although only some of the trajectories were computed. Sihadmed *et al.* (2005) developed a model that would mimic the collective behavior of droplets in a spray cloud from a flat fan hydraulic nozzle. This transport model employed an effective drag coefficient to account for aerodynamic drag, air entrainment, interference of droplets, evaporation and vertical wind velocity fluctuation to successfully simulated deposition pattern. Furthermore, it was noted that measured droplets size and number distribution were similar to simulated results. Sammons *et al.(*2005), model was developed on the approach of probability density function (PDF). The model relates particle and gas particles through drag while setting parameter on dispersion, in addition it indicated that 2$^{nd}$ order moment closure are more flexible. Unfortunately, neither transport of gas particles nor fluctuating velocity correlations on the transport particle velocity correlation were modeled. They concluded that the use of drag expression in k-ε dispersion in far distance is better that dispersion in nozzle exit and that fluctuating velocity is affected by the injection type in the nozzle.

Farooq & Salyani (2004), proposed a model for citrus canopies. Their simulation research revealed that deposition on leaves depend on their collection efficiency and on the air velocity within the canopy and that lagrangian approach provides more reliable results despite small number of trajectories. Arther Silva *et al.,* (2006) proposed a lagrangian model for simulating droplets deposition on vine canopies. In their simulation, air speed within canopy and tractor speed were accounted for by means of unsteady boundary condition. In addition the model accounted for the effects of vegetation on deposition through adding a sink term in the momentum conservation equation and a source term for turbulence kinetic energy. After all k-ε model is usually based on time averaged equation. Moreover, air flow characteristics were obtained through solving Navier stroke equation and simulation of spray cloud using lagrangian-stochastic model with added terms to account for vine yard vegetation. This model did not take into account droplet movement between sprayer and canopy but only focused on the behavior inside the canopy. Moreover, its development was on the assumptions that droplets of a particular cloud poses diameter size uniformity and carry equivalent mass of liquid. Asman *et al.* (2003) developed an evaporation droplets model. Brown & Taher (1999), developed a virtul nozzle model to simulate droplets deposition on leaves for a steady wind and sprayer's motion. While Moa'ath *et al.*(2011) proposed a simple model to simulate droplets movement on the surface of a leaf.

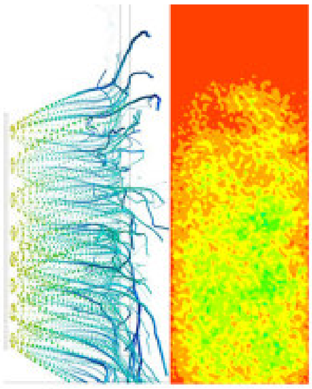


Fig. 3 CFD simulation results showing velocity magnitude (a) and droplets deposition on a patternator (b) (Dekeyser *et al.,* 2013).

*1.4.2 Other significant CFD simulation contributions*

Although the results were not validated, Weiner & Parkin, (1993) applied CFD code to model droplets trajectory from a mist blower. Zhao *et al.,* (2008) carried a CFD simulation on charged droplets trajectory towards a spherical target at different droplet sizes, charge to mass ratio and nozzle to target distance. They noted that in air assisted spraying application, a high charge to mass ratio is desired for a good electrostatic control of droplet trajectory. Increasing charge to mass ratio may increase deposition although at the expense of drift; spray drift may increase with increase in charge to mass ratio and increase in distance if not optimally set. Zhu *et al.* (1994) and Reichard *et al*. (1992 b) applied commercial CFD simulator to model spray dispersion and drift.

Tsay *et al.* (2002) and Molari *et al.* (2005) used CFD model developed without accounting for the effects of canopy to evaluate the operation of air assisted sprayer's design parameters. The simulation results obtained by Tsay, (2004) played a fundamental role in the design of a pneumatic shielded spraying system for increased spray deposition and drift reduction. Weiner & parking, (1993) used models developed without accounting for canopy to predict opperating conditions of an air assisted sprayer. Thereafter (Parkin & Wheeler, 1996) modeled the effects of spray induced vortices on droplets movement in a wind tunnel. Hobson *et al*. (1993), simulated spray drift at different nozzle characteristics (type, angle and operating pressure) of a boom sprayer using random-walk approach over a wide range of meterological and crop condition. Teske & Hill (1995), modelled spray droplets evaporation on the assumption that physical properties of pesticide spray wash behave like water. Isukapalli *et al.* (2013), applied CFD simulation to study flow and deposition of pesticides under sinorior with different spraying pattern and cabin air exchange rate. Dekeysey *et al*. ( 2013), applied CFD models to simulate the effects of orchard spraying application techniques and setting of airflow and spray liquid distribution.

Finally, Andalew *et al.,* (2010), simulated droplets trajectory inside a pear canopy with an aim of determining the optimum nozzle settings for an air assissted sprayer. The CFD model to simulate airflow through pear canopies was validated for three different sprayer; single-fan(condeor V), double (Duo-drops) and four fan (AirjetQuaatt) sprayers (Andalew *et al.,* 2010) Fig.2.

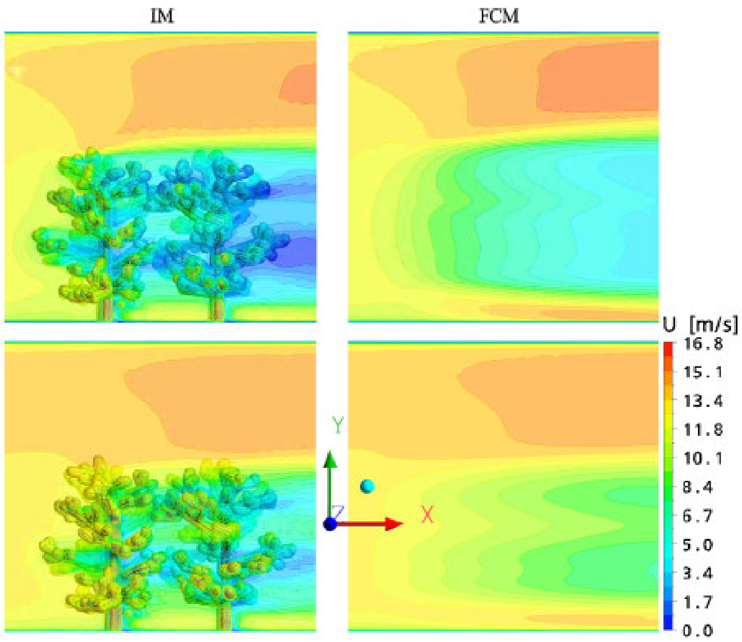


Fig. 3 CFD simulation results showing of velocity contours for both Integrated Model (IM) and Full Closure Model (FCM) (Melese *et al*., 2009)

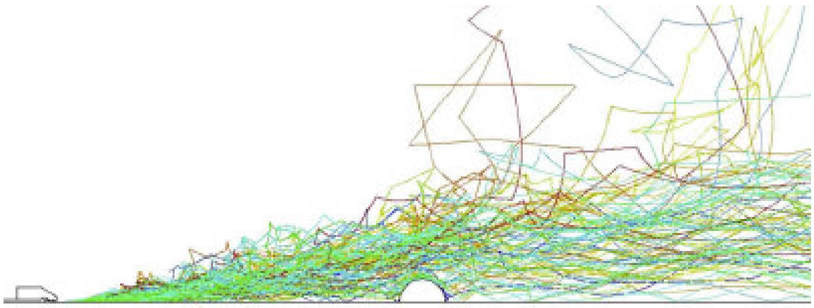

Fig. 4 CFD simulation results indicating droplets trajectories (Zhao et al., 2008)

**2.0 Discussion**

The implication of computer technology application in preliminary stages of air assisted pesticide sprayers' development has lately been a solution to the sprayer's performance projections. The rapidly increasing use of CFD simulation has not only demonstrated to be time and cost effective than physical experiments trials, but has also proven to be an inevitable key design tool in projecting the flow behaviors of air atomized pesticide spray droplets. Its application in recent year has proved to be reliable and convenient in understanding the complex nature of air assisted pesticide spraying phenomena. Furthermore, the real time fields' conditions are uncontrollable and at constant variation in nature and are likely to interfere with both the physical and chemical properties of the spray droplets as they travel from the generator to the target. For an effective sprayer's performance, maximum deposition of droplets to the target at minimal drift has to be attained despite of unavoidable resistance likely to be encountered on their delivery. CFD simulations have given the correlation between droplets characteristics and environmental condition to drift. Several literatures on CFD simulations of droplets trajectories and air flows velocity have highlighted effectively the potential droplets movement and their resultant characteristics at early stages of the sprayer's development. Fig.4 demonstrates droplets trajectories from CFD simulation results. Unfortunately, CFD models hardly precisely provide accurate droplets movement or air flow and droplets characteristics; their results may have a discrepancy to physical experiment trials values. Fig.1 gives a comparison of both simulated results and physical experimental trials values. For reliable and acceptable predictions, simulation results should be within an acceptable limit otherwise the information might be misleading. Several simple models have been developed in previous simulation, furthermore, though unachievable, a standard ideal model would be highly computational expensive. On this regard, simulation has to be complemented by the use of experimental data especially as initial data input. It was noted that lagrangian simulation approach and k-ε turbulent model are highly favored in reviewed literature (Table 1). The preference of lagrangian approach over Eulerian continous phase approach can be attributed to its ability to determine droplets movement in both laminar and turbulent flow fields despite a grid dependance of results for dense sprays (Sazhin, 2009) and its focus on droplet break up.

Of all availabe turbulent model none is more superior to the other. Otherwise the choice of the model to be used is determined by the need of the simulation at hand. Furthermore, the most prefered in reviewed literature; k-ε turbulent model cannot treat flow accurately in an entire flow computational domain especially where the flow is to be separated from a region of high Reynold number to a region of low Reynolds number or in a transition zone (Bartzanas *et al.,* 2013). Similarly, the numarous available simple models developed in previous research are only suitable to particular situations and research needs due to the basis of assumptions made during their development.

Although a lot of work has been done, there still remain a lot to be done to make full use of the technology. The validity of all proposed simple model need to be conducted to fully verify their applicability in the simulation process. In addition to this, of the available information more attention has focused on air flow velocity and trajectory simulation. Some recent attempts have been made to incorporate the architecture of the canopy in the simulation (for example Melese *et al.,* 2010), but still more research is needed since there exist an acute canopy orientation variation amongst plants species, besides leaves closest to the nozzle are likely to experience an over dose. Simulation of target-nozzle distance at various sprayer setting will be a source of information for a clear cut on optimum sprayer settings.

Moreover, assuming uniform droplet sizes and velocities might be misleading especially in an uncontrollable varying environmental field conditions. Besides, the environmental conditions in a controlled environment such as greenhouse differ from conditions in an open field; despite an increasing application of air assisted pesticide spraying in these structures. This therefore calls for a need to develop simple models that can conveniently be applied in such environment.

## 3.0 Conclusion

It's worth noting that CFD modeling still remains a predominant technique in equipments development. It's potential as a design tool in air assisted pesticide sprayers' development has been proven in the recent years. Furthermore, the efficiency of a new sprayer design primarily depends on its ability to deliver droplets to the target which can precisely be demonstrated through CFD modeling. The technique has demonstrated its ability to effectively project real time spray characteristics especially the droplets' trajectories thus the fate of the droplets. Several simple models have been developed and successfully applied to contact performance projections in orchard pesticide application at various corresponding sprayers' parameters settings and field conditions. Its application as a key design tool does not totally replace the use of physical experiment trials, but still require them as sources of initial conditions data inputs requirements. Much of its application in understanding air assisted pesticide spraying has been done but still the full potential of the technology has not been explored and the available information is far much underway. Highlights of reviewed literature show more preference on its application on open field environment despite incorporation of air assisted pesticide spraying in greenhouses. Moreover, plants' canopy structures are of a wide range consequently variation in simulation functions' requirements. We believe CFD simulation will be an essential source of information on the suitability of air assisted pesticides spraying in different environmental conditions and on various plants canopy structures.

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