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## **How Spray Characteristics and orientation may influence spray drift in a wind tunnel**

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### **Summary**

Crop protection product application may be subjected to drift. This paper aims at studying the effect of wind direction on drift and nozzle classification accordingly to [ISO 22369-1]. Experiments were realized in Irstea wind tunnel with wind speeds varying from 2 to 7.5 m.s<sup>-1</sup> oriented in frontal or lateral position to a narrow spray boom including from 1 to 4 nozzles.

A first set of experiments were conducted with the reference nozzle in frontal or lateral position and with 1 to 4 nozzles. A second set of experiments were conducted with a wide range of low drift nozzles (19 Flat Fan Air injection and 8 Twin jets Flat Fan Air Injection) with 4 nozzles at 7.5 m.s<sup>-1</sup> wind speed. The results showed that DR<sub>F</sub> and DR<sub>L</sub> classification was significantly different depending on the nozzle type and working conditions. A global discussion is proposed for methodological aspects and practical conclusions for nozzle classification.

**Key words** : Frontal, Lateral drift, Wind tunnel, Nozzle Classification

### **Introduction**

Wind tunnels represent a convenient tool to study spray application behavior in windy environment with controlled atmospheric conditions. A comprehensive modeling work on the interaction of spray with a frontal air flow is given by (Ghosh and Hunt ,1998) but a lot of experimental data were produced by (Miller et al, 2011; Taylor et al, 2004; Nuyttens et al, 2009) and (Walklate et al, 2000) as well.

This paper aims at studying the effect of artificial wind on two main experimental conditions in IRSTEA wind tunnel. A first series of experiments were conducted in order to show the effect of wind speed, orientation of the boom and the number of nozzles (from 1 to 4) by using the French reference nozzle for drift measurements. A second series of experiments were conducted with a fixed wind speed but with several air injection (AI) nozzles either single or twin jets.

### **Material and method**

#### *Wind tunnel settings*

Experiments were conducted within Irstea circular wind tunnel. Internal dimensions are 3m x 2m and distribution test bench is 9 m (180 grooves of 5 cm width). Distribution test bench is rinsed before measurements in order to allow immediate and permanent flow into measuring tubes.

Wind is generated by 6 fans and wind speed is controlled at the height of the boom. Possible wind speeds are from 0 up to 12 m.s<sup>-1</sup> +/- 0.2 m.s<sup>-1</sup>. National drift assessment scheme is usually conducted with wind speed of 7.5 m.s<sup>-1</sup>. Wind speed homogeneity through working section has been checked. Temperature is maintained between 19.5°C and 20.5 °C and relative humidity is typically above 90 % by spraying in the circular tunnel for 1 hour before experiments.

### *Boom settings*

A short boom of 4 nozzles (50 cm spacing) is placed in the axial axis of the wind tunnel at height between 0.20 m up to 1.60 m. Boom positions can be frontal (perpendicular to the wind direction) or lateral (parallel to the wind direction). Typical working heights for nozzle accreditation are between 50 to 70 cm. Flowrate is controlled by an electromagnetic flowmeter (4000 pulses/L) and operating pressure is estimated by a pressure gauge Keller (+/- 0.01 bar). The input flowrate of the boom is maintained at +/- 2 % s.d. Before wind tunnel measurement, nozzles are checked in flowrate. Droplet size of reference nozzle was measured with a laser PDPA with a VMD of 226 µm - % Volume lower than 100 µm is 8.9%.

### *Distribution test bench*

A horizontal patternator consists of fixed 180 grooves of 5 cm width (9 m width in total). A mobile device includes 60 collecting tubes, each of them placed on an individual weight cell (precision of 1/- mg). Maximum collected volume can be adjusted either considering the filling rate of 500 ml tubes (high flowrate zone underneath the boom) or considering a maximum collecting time (low flowrate zone in the drifting area). Ordinary values when testing four nozzles are 80 % filling and/or 2800 s.

### *Experimental setup*

Different experimental setups were conducted. Tests A aim at showing either the effect of wind speed and the number & position of nozzles mounted on the boom in frontal and lateral positions with the reference nozzle FF 110 02 at 2.5 bar injection pressure and 60 cm boom height.

Table 1. *Experimental setups with reference nozzles*

| Modality         | Nozzle type     | Wind speed (m.s <sup>-1</sup> ) | Boom height (cm) | Nozzles position on the boom | Modality         | Nozzle type     | Wind speed (m.s <sup>-1</sup> ) | Boom height (cm) | Nozzles position on the boom |
|------------------|-----------------|---------------------------------|------------------|------------------------------|------------------|-----------------|---------------------------------|------------------|------------------------------|
| Frontal position | FF 02 – 2.5 bar | 2                               | 60 cm            | 1-2-3-4                      | Lateral position | FF 02 – 2.5 bar | 4                               | 60 cm            | 1-2-3-4                      |
|                  |                 |                                 |                  | 1-2-3-0                      |                  |                 |                                 |                  | 1-2-3-0                      |
|                  |                 |                                 |                  | 1-2-0-0                      |                  |                 |                                 |                  | 1-2-0-0                      |
|                  |                 |                                 |                  | 0-2-3-0                      |                  |                 |                                 |                  | 1-0-3-0                      |
|                  |                 |                                 |                  | 0-0-3-4                      |                  |                 |                                 |                  | 1-0-0-0                      |
|                  |                 |                                 |                  | 1-0-3-0                      |                  |                 |                                 |                  | 1-2-3-4                      |
|                  | 0-2-0-0         | 1-2-3-0                         |                  |                              |                  |                 |                                 |                  |                              |
|                  | 7.5             | 60 cm                           | 1-2-3-4          | 1-2-3-0                      |                  |                 |                                 |                  |                              |
|                  |                 |                                 | 1-2-3-0          | 1-2-0-0                      |                  |                 |                                 |                  |                              |
|                  |                 |                                 | 0-2-3-0          | 1-0-3-0                      |                  |                 |                                 |                  |                              |
|                  |                 |                                 | 0-2-0-0          | 1-0-0-0                      |                  |                 |                                 |                  |                              |
|                  |                 |                                 | 1-2-3-4          | 1-2-3-4                      |                  |                 |                                 |                  |                              |
| 1-2-3-0          |                 |                                 | 1-2-3-0          |                              |                  |                 |                                 |                  |                              |

Nozzle position : 0 means absence of nozzle.

Tests B were realized with a constant wind speed of  $7.5 \text{ m.s}^{-1}$ . Deposition data obtained for lateral and frontal positions were compared for the twenty-eight following nozzles with *ad hoc* settings. These nozzles were satisfying the minimum 66 % drift reduction that is adopted by Law in France (Table 2).

Table 2. *Experimental setups with Air Injection nozzles at constant wind speed ( $7.5 \text{ m.s}^{-1}$ ).*

| Nozzle           | Type       | Size | Pressure (bar) | Nozzle Height (cm) | Angle1 (°) | Angle2 (°) | Material |
|------------------|------------|------|----------------|--------------------|------------|------------|----------|
| Albuz AXI (Ref.) | FF         | 02   | 2.5            | 70                 | 110 °      | -          | Ceramic  |
| Agrotop Airmix   | FF AI      | 015  | 2              | 50                 | 110°       |            | Polymer  |
|                  |            | 02   | 2              | 50                 |            |            |          |
|                  |            | 025  | 2              | 50                 |            |            |          |
| Albuz CVI        | FF AI      | 02   | 2              | 60                 | 110        |            | Ceramic  |
|                  |            | 03   | 2              | 60                 |            |            |          |
|                  |            | 04   | 2              | 60                 |            |            |          |
|                  |            | 05   | 2              | 60                 |            |            |          |
| Lechler IDKT     | Twin FF AI | 03   | 2              | 50                 | 120        | 60         | Polymer  |
|                  |            | 04   | 2              | 50                 |            |            |          |
|                  |            | 05   | 2              | 50                 |            |            |          |
| Lechler IDKT     | Twin FF AI | 02   | 2              | 50                 | 120        | 60         | Ceramic  |
|                  |            | 025  | 2              | 50                 |            |            |          |
|                  |            | 03   | 2              | 50                 |            |            |          |
|                  |            | 04   | 2              | 50                 |            |            |          |
|                  |            | 05   | 2              | 50                 |            |            |          |
| Albuz AVI Twin   | Twin FF AI | 02   | 4              | 60                 | 110        | 65         | Ceramic  |
|                  |            | 025  | 4              | 60                 |            |            |          |
|                  |            | 03   | 4              | 60                 |            |            |          |
|                  |            | 04   | 4              | 60                 |            |            |          |
| Albuz CVI Twin   | Twin FF AI | 025  | 2              | 60                 | 110        | 65         | Ceramic  |
|                  |            | 03   | 2              | 60                 |            |            |          |
|                  |            | 04   | 2              | 60                 |            |            |          |
|                  |            | 05   | 2              | 60                 |            |            |          |
| Nozal ARX        | FF AI      | 015  | 5              | 70                 | 120        |            | Ceramic  |
|                  |            | 02   | 5              | 70                 |            |            |          |
|                  |            | 03   | 5              | 70                 |            |            |          |
|                  |            | 04   | 5              | 70                 |            |            |          |

Note : Working height and pressure are given by manufacturers.

#### *Analysis of deposition values*

Data from distribution test bench correspond to deposition volume in ml. Collected volume are converted into flowrate while taking into account the acquisition time and the effective pressure. Deposition flowrates are then normalized with the input flowrate. Normalized deposition flowrates are then cumulated along the distance and the complementary curve is then obtained. As a result, a drift ratio (Dr) curve is obtained starting from direct spraying zone up to about 8 m downwind (Douzals, 2012).

## Results

### Test A : Frontal drift with reference nozzles

Raw deposits of frontal drift measurements with four nozzles are introduced in Fig.1 for different wind speeds. Reference distance ( $X = 0$ ) corresponds to the vertical to the position of nozzles when the boom is in frontal position.

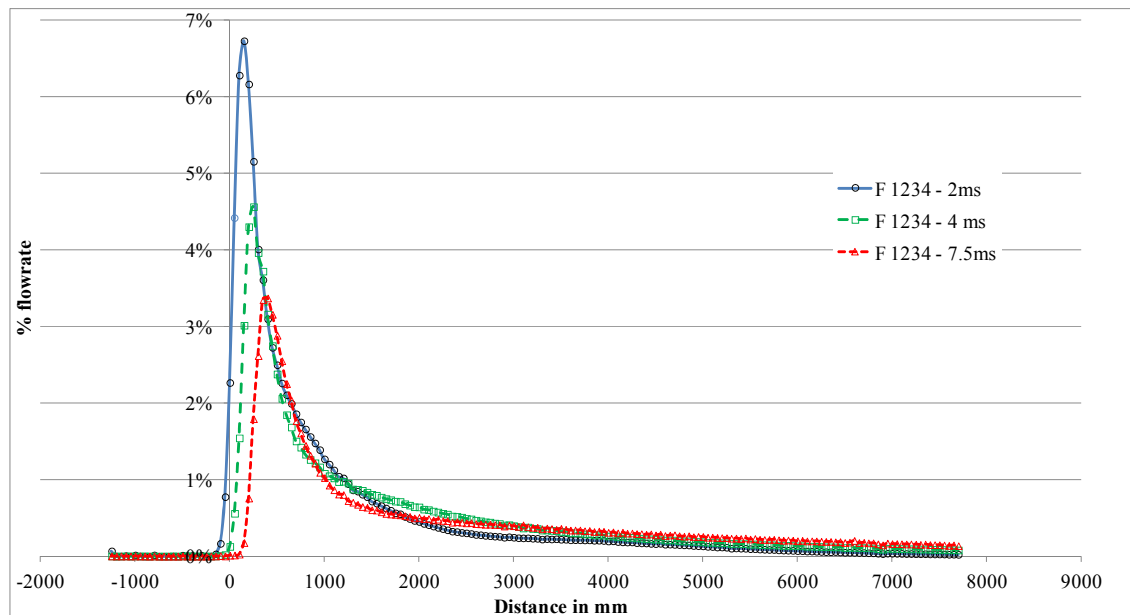


Fig. 1. Effect of wind speed on sedimentation flowrate of a 4 nozzle boom fitted with FF 02 – 2.5 bar – 60 cm height – Frontal position.

As shown on Fig. 1, wind speed increase involved a decrease in the peak value and a shift in peak position. Total recoveries on the distribution test bench were respectively 97%, 88% and 79 % for wind speed of 2, 4 and 7.5  $\text{m.s}^{-1}$ . The effect of the number of nozzles is introduced in Fig. 2.

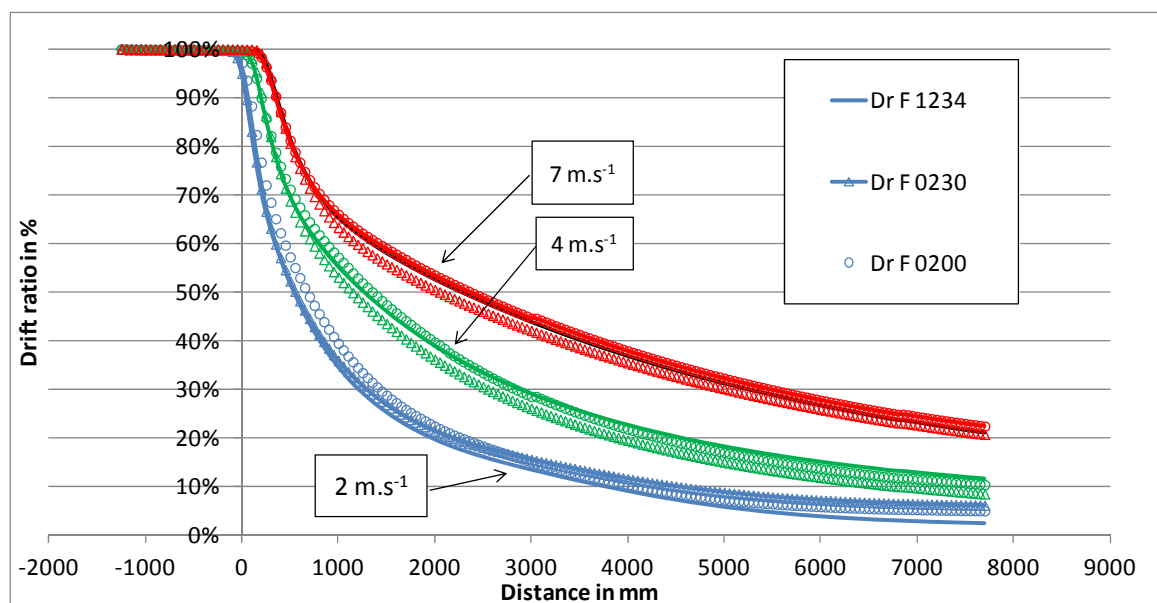


Fig. 2. Evolution of Drift Ratio depending on the number of nozzles and wind speed – FF 02 – 2.5 bar – 60 cm – Frontal position

As shown on Fig. 2, increasing the number of nozzles induced only slight variations in drift ratio compared to wind speed effect. Flowrate data analysis (not represented here) showed that drift

ratio were quite similar between 1234 – 0230 and 0200 configurations with a standard deviation range of 1.13% to 1.62%. The number of nozzles induced a cumulative effect on raw flowrate depositions but variations between nozzle configurations did not involve significant differences when drift curves are normalized according to the input flowrate.

#### *Test A : Lateral drift with reference nozzles*

The evolution of sedimentation flowrates in lateral position is presented on Fig. 3 for different boom configurations. The reference position ( $X = 0$ ) corresponds to the half nozzle spacing distance (250 mm) after the last nozzle mounted on the boom:

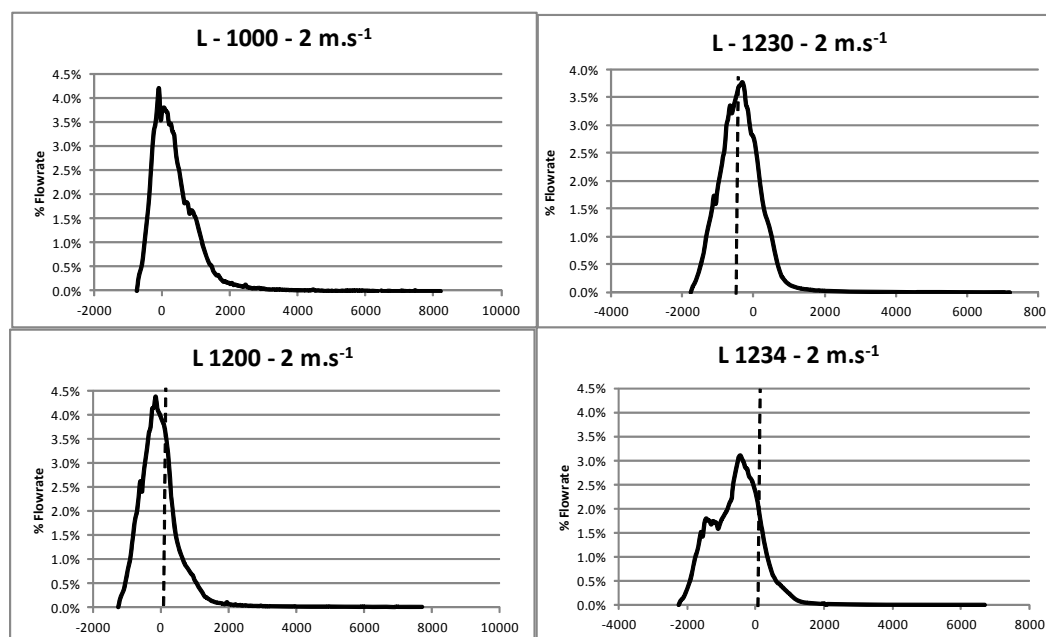


Fig. 3. Sedimentation flowrates for different boom configuration with 2 m.s<sup>-1</sup> wind speed – lateral position.

As shown on Fig. 3, flowrate values at the reference position (0) and beyond distances downwind are dependent on the number of nozzles. As a result, drift ratios will be modified accordingly. In lateral position, the first spray appears strongly modified by the wind shear compared to subsequent sprays behind that are more protected. When the number of nozzles increases, the drift ratio at the reference point decreases because the impacted spray is located at a greater distance.

#### *Effect of wind speed – lateral position*

Following Fig. 4 shows a comparison of deposition flowrates at 2, 4 and 7.5 m.s<sup>-1</sup> for (1-2-3-4) configuration of nozzles.

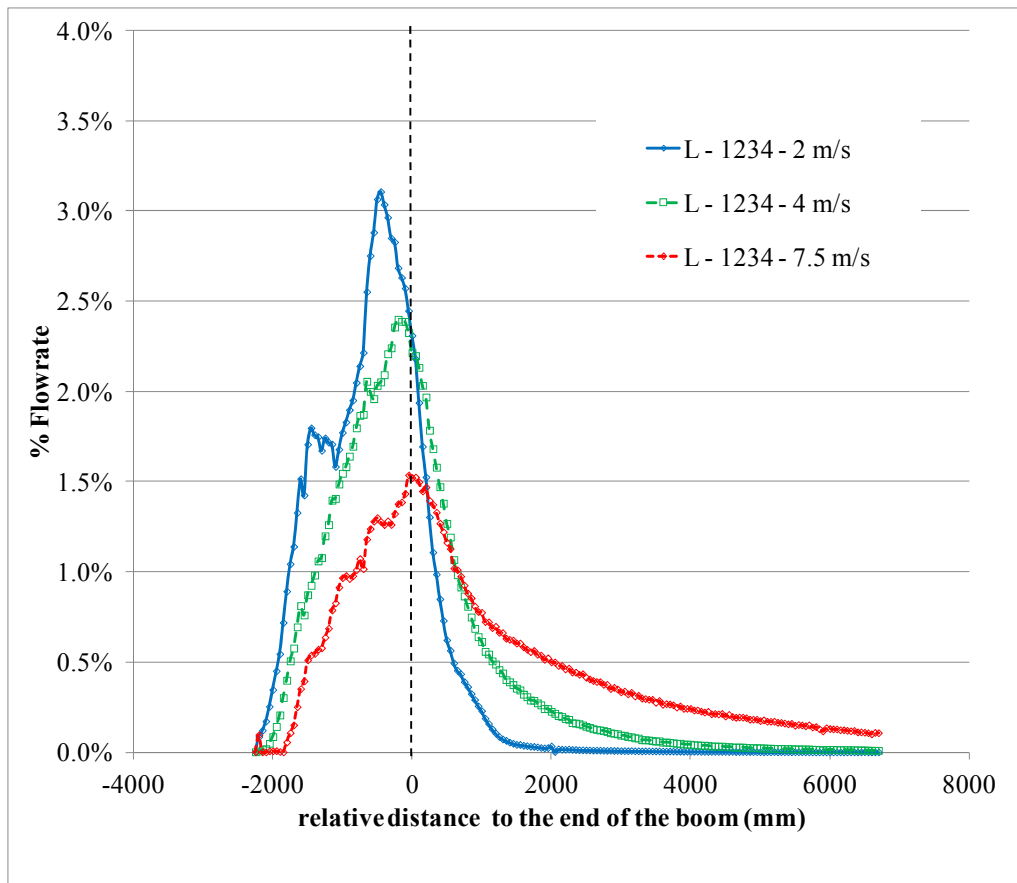


Fig. 4. Effect of wind speed on sedimentation flowrate for a 4 nozzles configuration with FF 02 – 2.5 bar – 60 cm – Lateral position.

As found in frontal position, the effect of wind speed is visible either on the deposition peak value and position. Recovery rates were 98%, 97.4 and 91.2% for 2,4 and 7.5 m.s<sup>-1</sup> wind speed respectively.

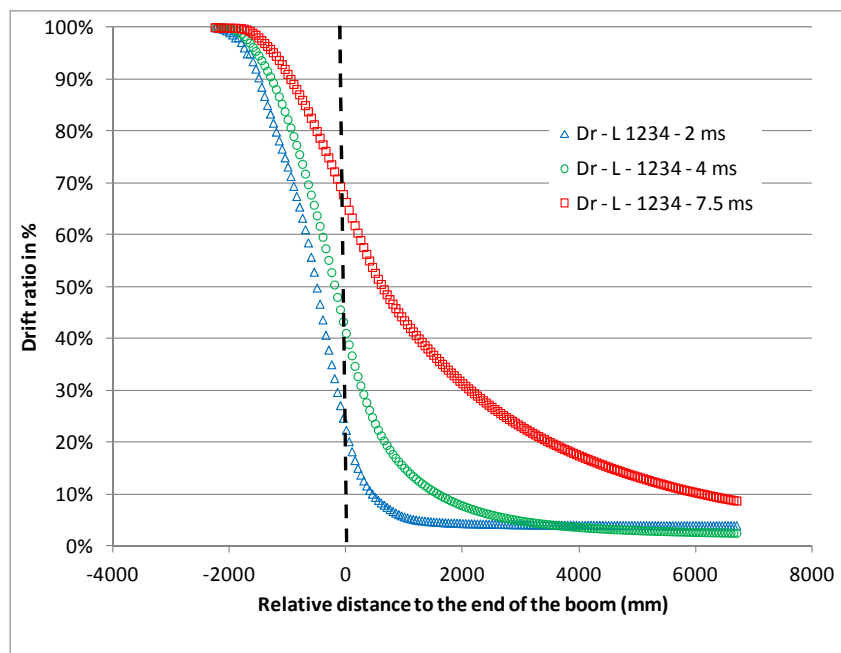


Fig. 5. Evolution of drift ratio of a 4 nozzle boom (1-2-3-4) configuration with different wind speeds – Lateral position.

The effect of wind speed on a complete set of nozzles drift ratio is given in Fig. 5 after normalization of flowrates and distances. Increasing wind speed involved increasing values of deposit at all distances.

### *Partial conclusion*

In frontal position, an additive effect is observed on deposition flowrates. All nozzles are at the same position and contribute equally to the sedimentation. When raw data are normalized with flowrates, no significant difference was observed when 1, 2 or 4 nozzles were mounted on the boom with similar air speed.

In lateral position, a protective effect is observed as the first spray is much more disturbed by the air flow. In this case, raw curves are hardly comparable but the effect of the reference distance tends to minimize drift values with equal air speed. With a given configuration of nozzles in lateral position, the effect of air speed is also visible.

### *Test B : Low drift nozzle classification*

A second set of experiments were exclusively realized with a standard wind speed of 7.5 m.s<sup>-1</sup>. Frontal and Lateral drift were measured in wind tunnel with a complete set of four nozzles.

Table 2. Drift results for *different Air Injection Nozzles – wind speed 7.5 m.s<sup>-1</sup>*.

| Test          | pressure | height | DR Frontal 5 m | DR Lateral 5 m | drift reduc frontal | drift reduc lateral | F/L ratio |
|---------------|----------|--------|----------------|----------------|---------------------|---------------------|-----------|
| AXI 02 (ref.) | 2.5      | 70     | 36.9           | 17.1           | 0.00%               | 0.00%               |           |
| AVI twin 02   | 4        | 60     | 9.8            | 4              | 73.44%              | 76.61%              | 2.45      |
| AVI twin 025  | 4        | 60     | 11.2           | 5              | 69.65%              | 70.76%              | 2.24      |
| AVI twin 03   | 4        | 60     | 10.3           | 4              | 72.09%              | 76.61%              | 2.58      |
| AVI twin 04   | 4        | 60     | 10.7           | 5.1            | 71.00%              | 70.18%              | 2.10      |
| CVI 03        | 2        | 60     | 8.3            | 5.2            | 77.51%              | 69.59%              | 1.60      |
| CVI 02        | 2        | 60     | 8.9            | 4.5            | 75.88%              | 73.68%              | 1.98      |
| ARX 015       | 5        | 70     | 11.3           | 5.7            | 69.38%              | 66.67%              | 1.98      |
| ARX 02        | 5        | 70     | 9              | 4.3            | 75.61%              | 74.85%              | 2.09      |
| ARX 025       | 5        | 70     | 11.7           | 5.2            | 68.29%              | 69.59%              | 2.25      |
| ARX 03        | 5        | 70     | 11.6           | 4.5            | 68.56%              | 73.68%              | 2.58      |
| CVI 04        | 2        | 60     | 9.9            | 4.1            | 73.17%              | 76.02%              | 2.41      |
| CVI 05        | 2        | 60     | 11.2           | 4.8            | 69.65%              | 71.93%              | 2.33      |
| IDKT 02       | 2        | 50     | 9.3            | 3              | 74.80%              | 82.46%              | 3.10      |
| IDKT 025      | 2        | 50     | 7.9            | 5.1            | 78.59%              | 70.18%              | 1.55      |
| IDKT 03 K     | 2        | 50     | 6.2            | 3.4            | 83.20%              | 80.12%              | 1.82      |
| IDKT 03 POM   | 2        | 50     | 6.8            | 4.7            | 81.57%              | 72.51%              | 1.45      |
| IDKT 04 POM   | 2        | 50     | 8.9            | 5.1            | 75.88%              | 70.18%              | 1.75      |
| IDKT 05 POM   | 2        | 50     | 8.9            | 5              | 75.88%              | 70.76%              | 1.78      |
| IDKT 04       | 2        | 50     | 6.3            | 3.5            | 82.93%              | 79.53%              | 1.80      |
| IDKT 05       | 2        | 50     | 8.1            | 4              | 78.05%              | 76.61%              | 2.03      |
| Airmix 015    | 2        | 50     | 10.3           | 7              | 72.09%              | 59.06%              | 1.47      |
| Airmix 02     | 2        | 50     | 11             | 5.8            | 70.19%              | 66.08%              | 1.90      |
| Airmix 025    | 2        | 50     | 10.2           | 5.2            | 72.36%              | 69.59%              | 1.96      |
| CVI Twin 025  | 2        | 60     | 7.5            | 4.7            | 79.67%              | 72.51%              | 1.60      |
| CVI Twin 03   | 2        | 60     | 8.5            | 5.3            | 76.96%              | 69.01%              | 1.60      |
| CVI Twin 04   | 2        | 60     | 5.8            | 4.6            | 84.28%              | 73.10%              | 1.26      |

Note : Injection pressure as well as boom height were set accordingly to manufacturer requirements.

As seen in Table 2, ranges of drift ratio at 5 m downwind varied from 5.8% to 11.7% (frontal) and from 3% to 5.8% (Lateral). Drift reduction was calculated on the basis of the reference (FF 02 at 2.5 bar and 70 cm height) for lateral and frontal positions.



The ratio between Frontal and Lateral drift values at 5 m were calculated and named F/L ratio. ANOVA made upon data showed no significant difference between single and twin jets regarding drift values in frontal and lateral positions (not represented here), drift reduction or F/L ratio. F/L ratio was related to the combined effect of boom height and operating pressure on frontal drift values (Table 3).

Table 3. Influence of boom height and operating pressure on F/L ratio of air injection nozzles

| F/L ratio (Nb of values) | Pressure (bar) |             |             | Average     |
|--------------------------|----------------|-------------|-------------|-------------|
|                          | 2              | 4           | 5           |             |
| Height (cm)              |                |             |             |             |
| 50                       | 1.87 - (11)    |             |             | 1.87        |
| 60                       | 1.82 - (7)     | 2.34 - (4)  |             | 2.01        |
| 70                       |                |             | 2.23 - (4)  | 2.23        |
| <b>Average</b>           | <b>1.85</b>    | <b>2.34</b> | <b>2.23</b> | <b>1.99</b> |

*Impact on drift reduction classification of low drift nozzles*

When comparing the drift reducing performance in frontal or lateral position with the reference in the same conditions, a double classification can be drawn (Fig. 7).

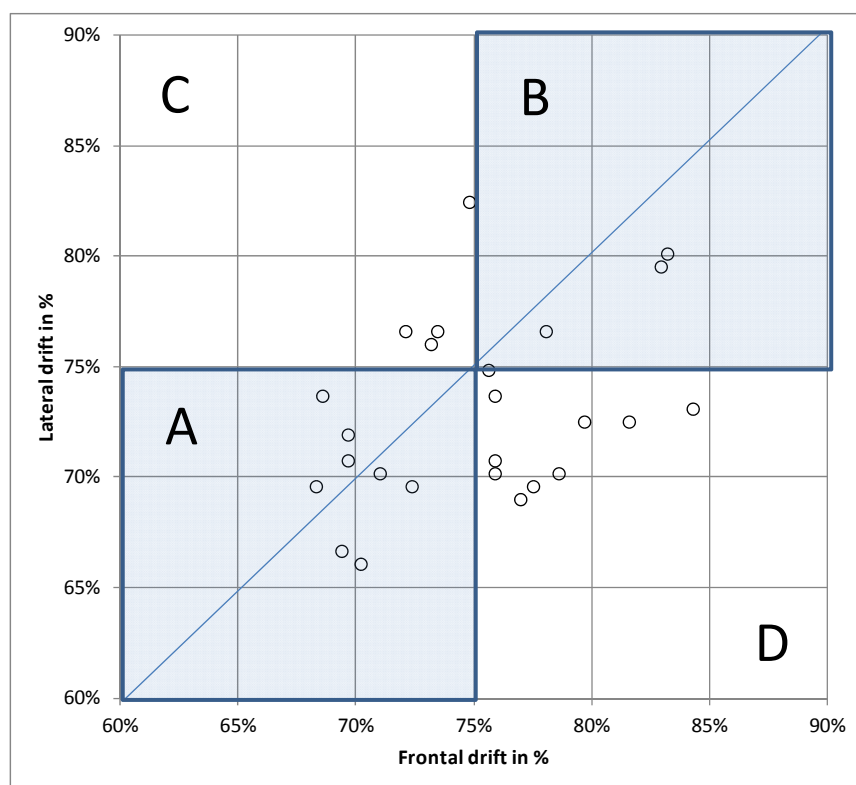


Fig. 7. Classification of nozzles according to frontal or lateral position.

Using frontal or lateral protocol three different cases can be found. In square A and B in Fig.7, all points are situated in the same range 60% to 75 % or 75 to 90 %. In square C, drift reduction is overestimated in lateral position. In the square D, drift reduction in frontal position is overestimated. In total 14 points (50 % of 28) are not equally classified depending on the protocol.

## Conclusion

This paper introduces different aspects of drift measurement in a wind tunnel. Measurements with the reference nozzles showed the effect of wind speed as well as boom configuration in terms of number of nozzles and of the orientation of the boom. Measurements made with low drift nozzles in a reduced number of configurations (4 nozzles only) showed different drift reducing classifications for half of samples when considering lateral or frontal drift values.

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