# Annex 1

# Experimental investigation of downburst outflows in a wind tunnel/wind simulator

## 1. Introduction

The activity carried out in the framework of this tender is funded by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program (grant agreement No. 741273) for the project THUNDERR - Detection, simulation, modelling and loading of thunderstorm outflows to design wind-safer and cost-efficient structures – supported by an Advanced Grant 2016.

THUNDERR is an acronym of THUNDERstorm that expresses the innovative Roar of this research project. It aims to detect thunderstorms, to create a database of wind records and weather scenarios, to conduct unprecedented laboratory tests and CFD simulations, to formulate a thunderstorm model suitable for atmospheric sciences and structural design, to change the format of wind actions, of the engineering practice and of the codification, to make building safer and more sustainable, to bring about a profound impact on society and its economy.

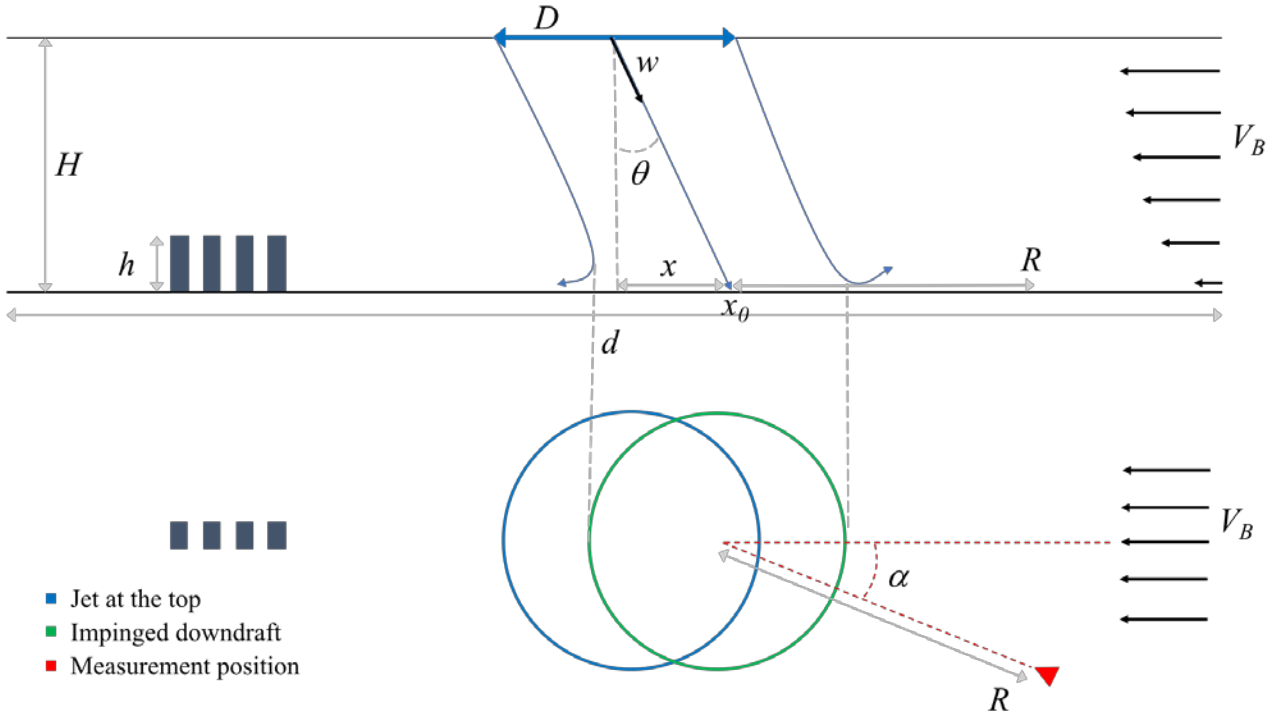
## 2. Tests and facility specification

In the framework of Project "Detection, simulation, modelling and loading of thunderstorm outflows to design wind-safer and cost-efficient structures" THUNDERR, a public tender offer is launched and finalized to carry out wind tunnel tests of large-scale downburst outflows with and without background synoptic winds (i.e. atmospheric boundary layer).

This document adopts the following definitions to describe downburst outflows:

| | |
|---|---|
| $\theta$ | downdraft inclination in respect to the vertical axis |
| $w$ | downdraft intensity (along-jet axis velocity in the centre of the downdraft) |
| $x_0$ | Touchdown position of the centre of downdraft |
| $D$ | downdraft diameter |
| $d$ | Test chamber diameter |
| $H$ | Height of the test chamber |
| $h$ | Mean height of roughness elements |
| $R$ | Radial distance from $x_0$ |
| $Z$ | Height above the floor |
| $\Delta t_l$ | Opening time of the louvers system |
| $\Delta t_s$ | Sampling time |
| $V_B$ | Background boundary layer wind |
| $\alpha$ | Direction of wind measurements |
| $N_r$ | Number of repetitions |
| $N_x$ | Number of $x$ variations (where $x$ is any of the above defined variables) |

The following picture shows a scheme of the wind tunnel (vertical and horizontal section) with the explanation of the geometric parameters above. The position of roughness elements is indicative only.




## 2.1. Minimum measurements requirements and characteristics of the facility

Wind tunnel facility minimum requirements:

| | |
|---|---|
| $\theta$ | Continuously from 0 to 90 |
| $w$ | Not smaller than 10 m/s |
| $D$ | Not smaller than 2 m |
| $d$ | Not smaller than 20 m |
| $H/D$ | Not smaller than 1 |
| $h$ | Variable height of roughness elements |
| $\Delta t_l$ | Fully automated opening and closing of the louvers |
| $V_B$ | Fully developed boundary layer matching the geometric scale of downburst. |

The facility shall support simultaneous generation of downburst and boundary layer winds.

The facility shall have a wide variety of equipment capable of high spatial and time resolution velocity and pressure measurements as well as large scale flow visualization. Listed below are the minimum requirements of facility equipment:

- Multiple (at least ten) high frequency (up-to 10 kHz) multi-hole pressure probes for three-dimensional flow measurements
- Multiple large-volume particle tracking and image velocimetry techniques to characterize the flow field
- High channel count pressure scanning system for surface pressure measurement
- Capability of simultaneous PIV, surface pressure, and other flow-related measurements

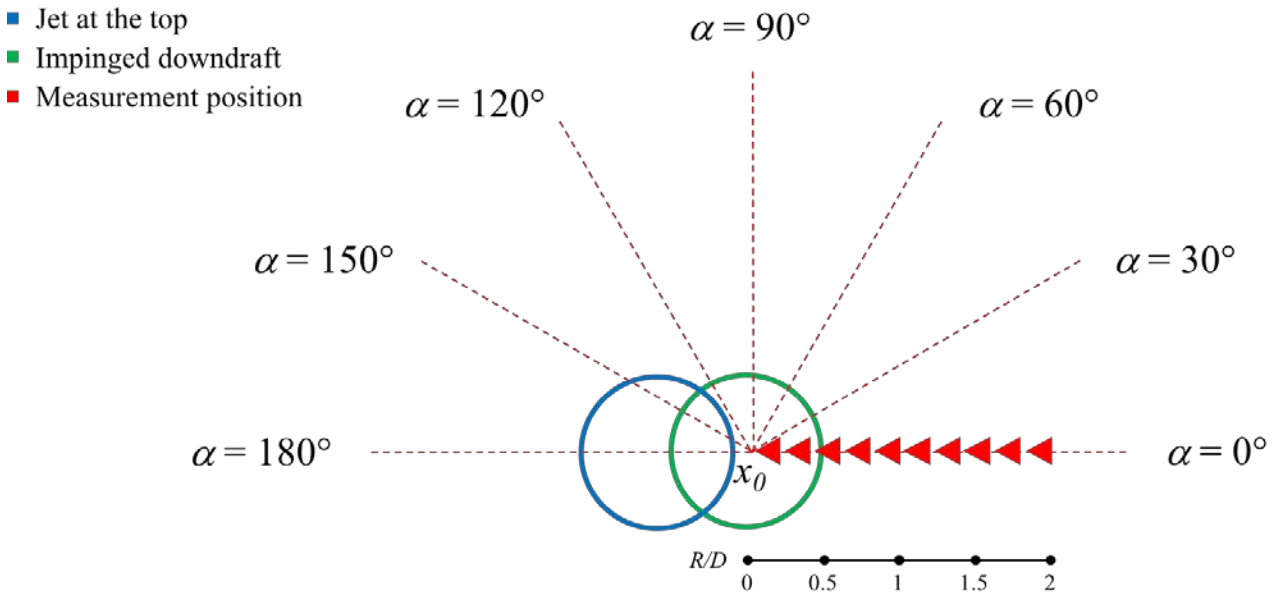
All downburst flows shall be measured with 7 or more multi-hole probes.
All boundary layer winds shall be measured with 3 or more multi-hole probes.

## 2.2. Tests description

### 2.2.1. Test 1 – Inclined downburst

The inclined downbursts will be studied with the following configuration of flow parameters:

- One downdraft inclination, $\theta = 30°$, of transient downbursts
- One downdraft velocity, $w$
- One height of the test chamber, $H$
- No roughness elements
- No background boundary layer flow, $V_B = 0$
- The number of measurements directions shall be 7 ($\alpha$ = 0°, 30°, 60°, 90°, 120°, 150°, 180°) according to the figure below
- The number of tested downdraft diameters shall be one, defined according to the minimum $H/D$ requirement above (see table in Section 2.1)
- The number of radial measurement positions shall be not less than 10 ($R/D$ values are purely indicative in the figure below)
- The number of repetitions per each measuring position shall be not less than 10

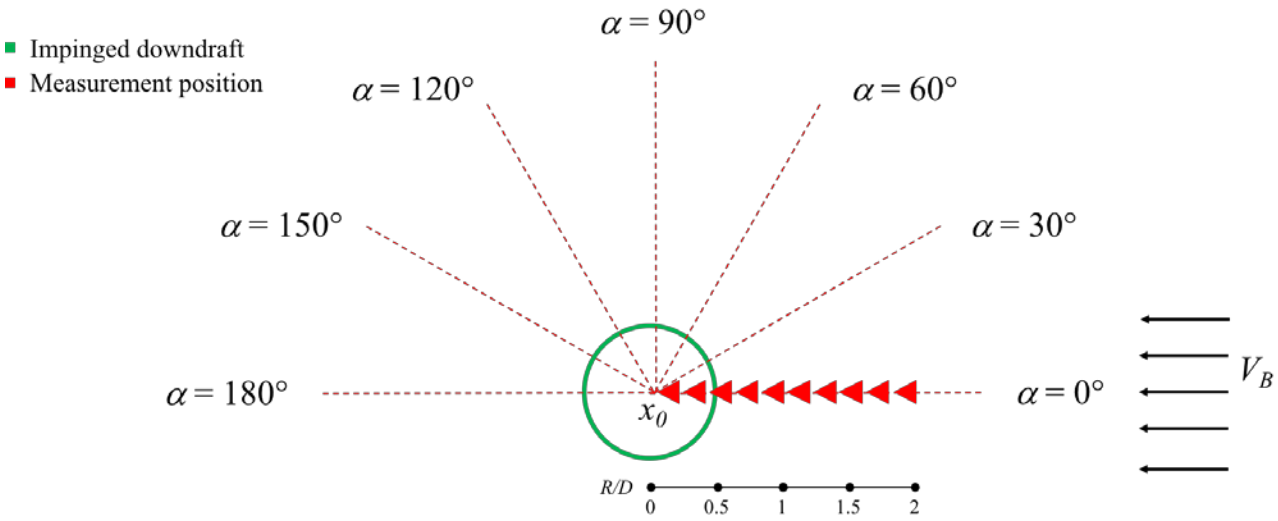



### 2.2.2. Test 2 – Vertical downburst with background flow

The vertical downbursts with background boundary layer flow will be studied with the following configuration of flow parameters:

- No inclination, $\theta = 0°$, of transient downbursts
- One downdraft velocity, $w$
- One height of the test chamber, $H$
- No roughness elements
- Two background boundary layer flow, $V_B$, shall be tested
- The number of directions in respect to the incoming boundary layer wind shall be 7 ($\alpha$ = 0°, 30°, 60°, 90°, 120°, 150°, 180°) according to the figure below
- The number of tested downdraft diameters shall be one, defined according to the minimum $H/D$ requirement above (see table in Section 2.1)
- The number of radial measurement positions shall be not less than 10 ($R/D$ values are purely indicative in the figure below)
- The number of repetitions per each measuring position shall be not less than 10

Both downburst outflows and boundary layer flow shall be measured simultaneously. The multi-hole probes used to measure the downburst outflow shall always (i.e. regardless of $\theta$ and $R/D$) face the centre of the impinged downdraft, whereas the probes used to measure the boundary layer wind shall always face the incoming direction of the wind.

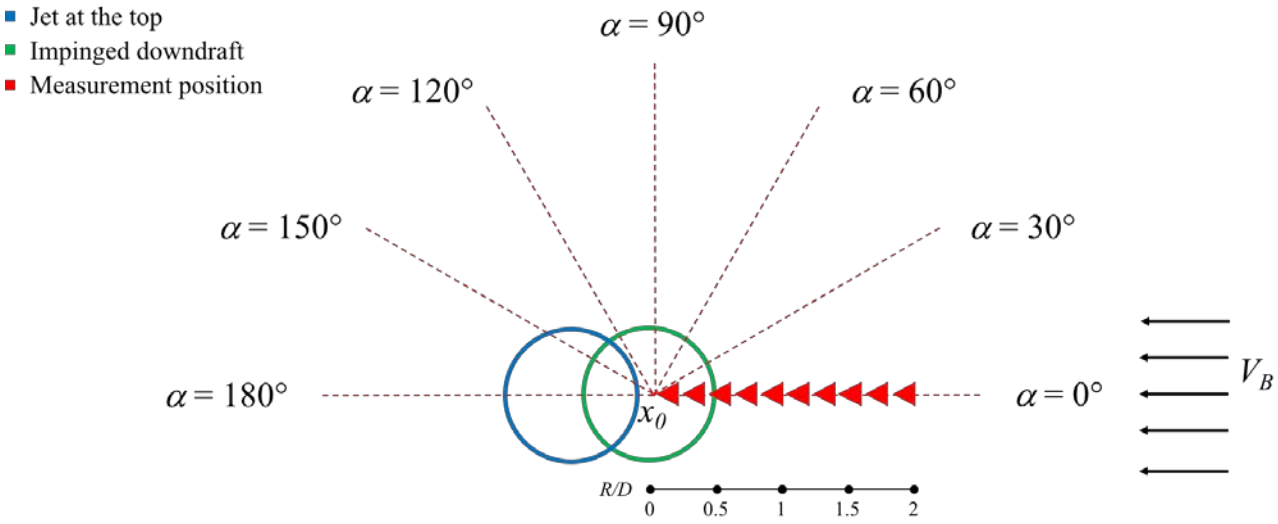



### 2.2.3. Test 3 – Inclined downburst with background flow

The inclined downbursts with background boundary layer flow will be studied with the following configuration of flow parameters:

- One downdraft inclination, $\theta = 30°$, of transient downbursts
- One downdraft velocity, $w$
- One height of the test chamber, $H$
- No roughness elements
- One background boundary layer flow, $V_B$, shall be tested
- The number of directions in respect to the incoming boundary layer wind shall be 7 ($\alpha$ = 0°, 30°, 60°, 90°, 120°, 150°, 180°) according to the figure below
- The number of tested downdraft diameters shall be one, defined according to the minimum $H/D$ requirement above (see table in Section 2.1)
- The number of radial measurement positions shall be not less than 10 ($R/D$ values are purely indicative in the figure below)
- The number of repetitions per each measuring position shall be not less than 10

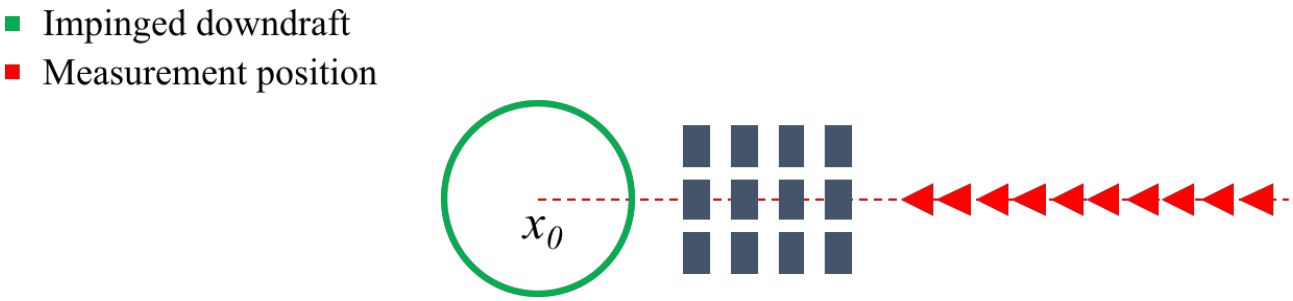
Both downburst outflows and boundary layer flow shall be measured simultaneously. The multi-hole probes used to measure the downburst outflow shall always (i.e. regardless of $\theta$ and $R/D$) face the centre of the impinged downdraft, whereas the probes used to measure the boundary layer wind shall always face the incoming direction of the wind.




### 2.2.4. Test 4 – Effect of roughness on downburst outflows

The roughness tests will be studied with the following configuration of flow parameters:

- No inclination, $\theta = 0°$, of transient downbursts
- Two different downdraft velocities, $w$
- One height of the test chamber, $H$
- Two different non-zero heights of roughness elements, $h$
- No background boundary layer flow, $V_B = 0$
- The number of directions of wind measurements shall be one
- The number of tested downdraft diameters shall be one, defined according to the minimum $H/D$ requirement above (see table in Section 2.1)
- The diameter of downdraft shall be the same as in the case without roughness
- The number of radial measurement positions shall be not less than 10 (the positions in the figure below are purely indicative)
- The number of repetitions per each measuring position shall be not less than 10




### 2.3.5. Tests summary

The following table summarises the number of measurements for each of the four previously described tests

| | $N_\theta$ | $N_w$ | $N_h$ | $N_\alpha$ | $N_D$ | $N_{V_B}$ | $N_r$ | $N_{R/D}$ | $N_{Tot}$ |
|---|---|---|---|---|---|---|---|---|---|
| Test 1 | 1 | 1 | - | 7 | 1 | - | 10 | 10 | 700 |
| Test 2 | 1 | 1 | - | 7 | 1 | 2 | 10 | 10 | 1400 |
| Test 3 | 1 | 1 | - | 7 | 1 | 1 | 10 | 10 | 700 |
| Test 4 | 1 | 2 | 2 | 1 | 1 | - | 10 | 10 | 400 |

## 3. Additional notes

All the variables (e.g. $w$, $R/D$, $\Delta t_l$, $h$, $V_B$) that are not specified in the text shall be subject of agreement between the Client and the Contractor depending on the characteristics of the selected wind tunnel facility.

## 4. Data handling and deliverables

The Contractor shall provide the complete report on experiment setup, all the data measured, and data formats and handling instructions.