The use of an octocopter UAV for the determination of air pollutants – a case study of the traffic induced pollution plume around a river bridge in Duesseldorf, Germany

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Abstract: - Emissions of air pollutants from the road traffic are still a major problem in Germany. It is well known that traffic induced fine particulate matter (PM10, PM2.5, PM1), ultrafine particles (UFPs) and gaseous air pollutants, like e.g. NOx, are adverse to human health. Therefore it is important to monitor these air pollutants in the cities. In this study an octocopter UAV is used as a carrier for measurement systems for UFPs, fine particulate matter and soot. This instrumented octocopter was used for studying the vertical and horizontal variation of the air pollution plume, which originated from the traffic on a river bridge, connecting two parts of Duesseldorf in Germany. This octocopter UAV had been especially designed and built at the Duesseldorf University of Applied Sciences for measurements of air pollutants. It was featuring eight 900 W electric propeller drives and was equipped with a pixhawk flight control. Its lift off weight was about 10.5 kg. About 60 measurement flights were performed by the instrumented octocopter throughout this study. These measurement flights could clearly determine the traffic induced air pollution plume originating from the bridge. Moreover, the dispersion of UFPs within the pollution plume could be monitored with the octocopter flights.

Key-Words: - air pollution, octocopter, multicopter, UAV, ultrafine particles, UFP, fine particulate matter

1 Introduction

It is well known from various studies that emissions of air pollutants from road traffic can be harmful to human health [1,2]. These traffic induced emissions comprise gaseous pollutants like e.g. NO_x or CO as well as pollutants like fine particulate matter (PMx), ultrafine particles (UFPs) and soot. This study focuses on the non-gaseous pollutants. These can cause significant respiratory, cardiopulmonary and cardiovascular problems [3-6]. It turned out in the medical studies, that not only the mass of the particulate matter is of importance, but the number concentration, surface structure and size as well. Smaller particles are even more dangerous than bigger particles, as the smaller particles can penetrate deeper into the lungs and into the body. Ultrafine particles can even pass into the blood and can be transported into the organs.

Therefore particulate matter is monitored by environmental state agencies and research organisations in Germany. This is done mostly at fixed stations, e.g. in street canyons and highly populated areas [7,8]. However, a few studies of mobile measurements in Germany of fine particulate matter, UFPs or soot are reported as well [see e.g. 8-11].

In this study now for the first time the pollution plume caused by the road traffic and comprising UFPs, fine particulate matter and soot was investigated with an instrumented octocopter UAV (unmanned aerial vehicle). As a measurement site the area around a river bridge in Duesseldorf, which was normally heavily loaded with road traffic, was chosen. This site had the advantage, that the dispersion of the traffic induced pollution plume could be investigated without disturbing effects by buildings.

2 Measurement Site

For this study the area around a river bridge in the northern part of Duesseldorf was chosen (see Fig. 1). This bridge (name: Theodor Heuss bridge) is leading across the river Rhine in Duesseldorf and

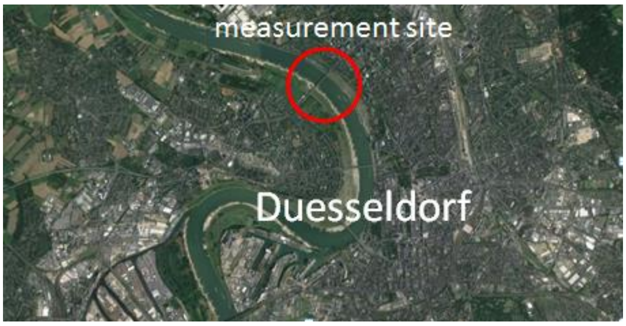

Figure 1: Top view of the main part of Duesseldorf city and the river Rhine. The measurement site (the area around a river bridge) is marked by the red circle. (map taken from Google Maps in December 2015 and modified with explaining marks)

connecting two parts of this city. The most populated part of the inner city is lying in southern directions to this measurement site. Fig. 2 shows the measurement site and the bridge in more detail. As it can be seen in Fig. 2 the bridge has two traffic lanes in both directions. More than 60000 vehicles are crossing the bridge every day. The measurements have been taken by the instrumented octocopter starting at lifting-off points at different distances perpendicular to the bridge.

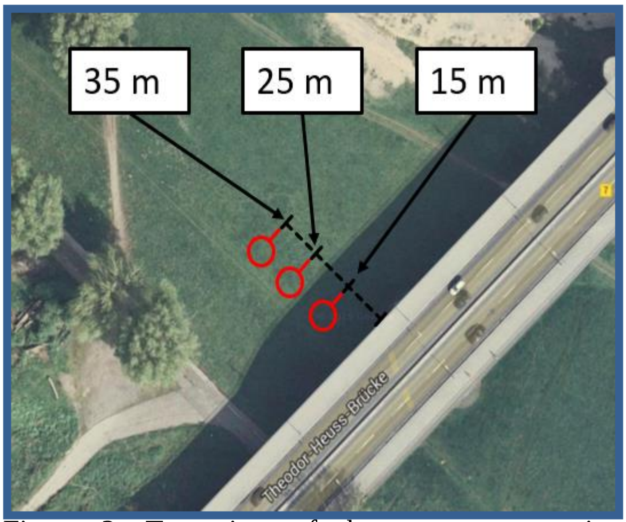

Figure 2: Top view of the measurement site: Theodor Heuss bridge in the Northern part of Duesseldorf with three northern octocopter starting points. The Theodor Heuss bridge is leading across the river Rhine and connecting two parts of Duesseldorf (map taken from Google Maps in December 2015 and modified with starting points)

Fig. 2 shows three northern starting points perpendicular to the bridge. In a similar way southern starting points were established perpendicular to the bridge. For most part of the measurements meteorological situations have been chosen, when the wind was blowing from the direction of the traffic loaded bridge (downwind situations)

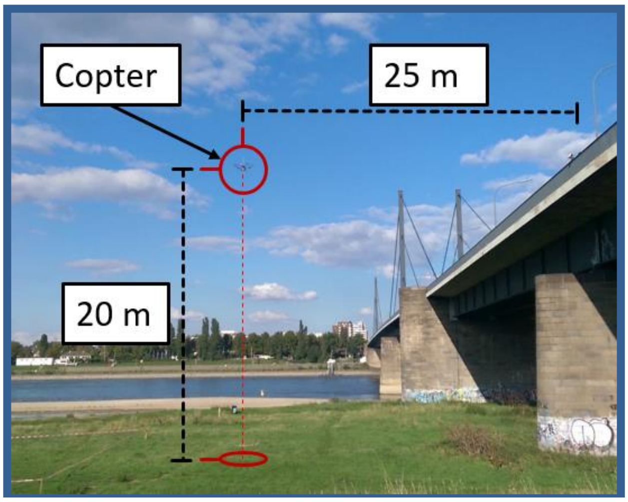

Figure 3: Photograph of the measurement site: Theodor Heuss bridge across the river Rhine in the northern part of Duesseldorf with the flying octocopter.

As it can be seen from Fig. 2 and Fig. 3 this measurement site showed the outstanding possibility for investigations in the air pollution plume originating from the road traffic on the bridge, without disturbances by any additional buildings. The starting points for the instrumented octocopter flights were chosen for most time of the study at 15m, 25m and 35m downwind to the bridge. However, some octocopter measurements have been taken in upwind situations to the bridge in order to get information about background concentrations, not influenced by the road traffic on the bridge.
The instrumented octocopter was climbing up from approximately 15m below the bridge to approximately 30m above the bridge.

3 Octocopter and Instrumentation

The octocopter (see Fig. 4) was designed and built at the Duesseldorf University of Applied Sciences. It was equipped with eight 900 W electric engines and a pixhawk flight control. It could be flown manually or as an alternative automatically with user-defined pre-programmed waypoints. Its lift off weight was about 10.5 kg. When fully instrumented the possible flight time was about 20 minutes. This octocopter was equipped with instrumentation,

which was especially modified for this study:
A weight optimized optical particle counter Grimm 1.109 was installed at the octocopter for the measurement of particulate matter from 250 nm to 32 µm in 31 bins as well as PM10 [1], PM2.5 and PM1. This OPC is based on orthogonal scattering of a small laser beam by the particulate matter during the measurements. Additionally an ultrafine particle monitor DISCmini from Matter Aerosols was mounted onto the octocopter. This ultrafine particle monitor measures the number and mean diameter of UFPs by electrostatical charging of the UFPs. In addition to that a micro aethalometer (AE51 from AethLabs) was installed onto the octocopter for the measurement of soot. This instrument is based on the light attenuation of a small laser beam by soot particles on a filter in the measurement system. More information can be found in [12-14].

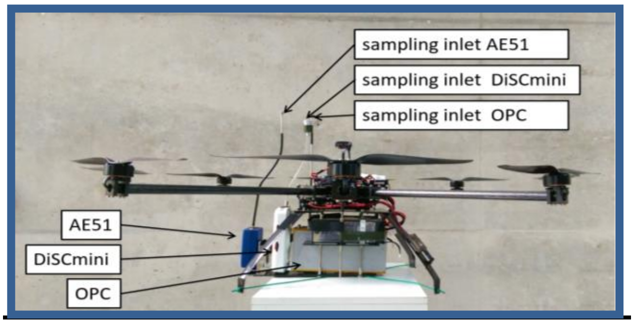

Figure 4: Octocopter with measurement instruments

4 Results

About 60 climbs have been performed with the instrumented octocopter within the fall 2015. The climbs were performed in upwind and downwind situations relative to the bridge at distances of 15m, 25m and 35m to the bridge. The bridge level was 15m above ground level. The instrumented octocopter climbed up to about 30m above ground level at the various distances to the bridge. In this way the horizontal and vertical variation of the air pollution plume could be determined. The results of the measurements demonstrated that evidently during the measurement period a significant background of fine particulate matter PM10, PM2.5 and PM1 was present, which was not strongly enhanced by the car traffic on the bridge. The same was true for the soot concentrations measured throughout the octocopter measurements.

[1] PM10 shall mean particulate matter which passes through a size-selective inlet as defined in the reference method for the sampling and measurement of PM10, EN12341, with a 50 % efficiency cut-off at 10 µm aerodynamic diameter [15]

However, the UFP concentrations turned out to be clearly influenced by the car traffic.
In Fig. 5 the vertical concentration profiles of UFPs measured by the instrumented octocopter are demonstrated in different distances to the bridge. As it can be seen in Fig. 5 a background level of UFPs of about 5000 counts/cm^3 could be monitored. However, slightly above the bridge level the concentrations of UFPs increased to values of up to 20 times of the background level. Moreover, comparing the results of the climbs in different distances to the bridge Fig. 5 demonstrates clearly the following features: A clear plume of UFPs can be detected originating from the road traffic on the bridge. Moreover, this plume broadens with distance to the bridge and tends to be no longer discernible from background concentrations at more than 35m.

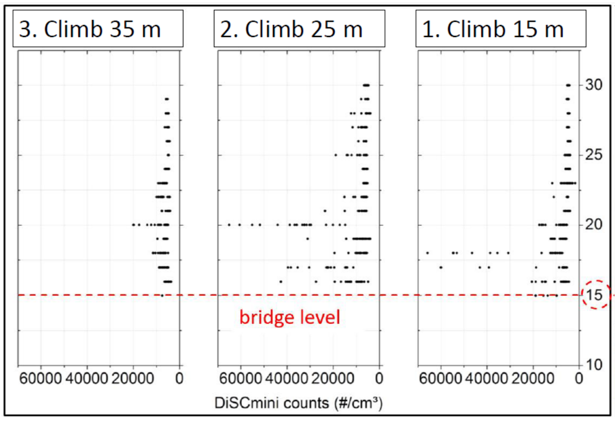

Figure 5: Vertical concentration profiles of ultrafine particles measured by the instrumented octocopter in 15m, 25m, 35m distance to the bridge, repectively

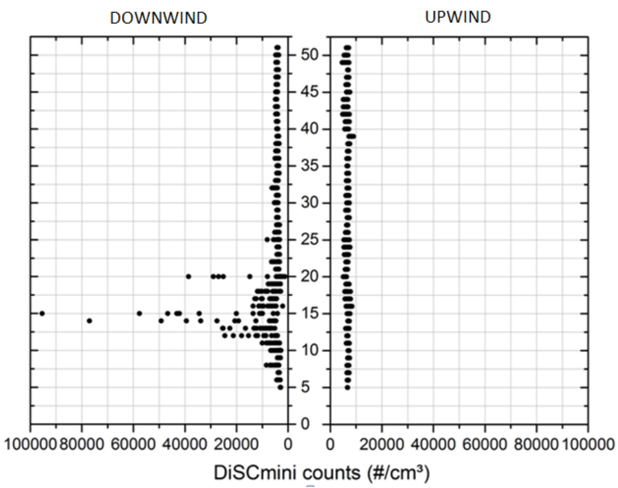

Figure 6: Downwind and upwind concentrations of ultrafine particles relative to the bridge

The UFP plume emitted by the road traffic on the bridge becomes even more evident by comparing upwind and downwind measurements, performed by the instrumented octocopter. These upwind and downwind measurements are presented in Fig. 6. It can be clearly seen that downwind to the bridge there is a significant enhanced UFP concentration at the level of the bridge in about 15m, whereas upwind to the bridge only background concentrations of UFPs can be monitored by the instrumented octocopter.

5 Conclusion

It could be demonstrated within this case study that well designed octocopters combined with lightweight instrumentation can give a new and powerful method for studying air pollution. Moreover it could be shown that instrumented octocopters can deliver valuable results for the measurement of the horizontal and vertical variation of air pollution plumes, especially for the strongly varying concentrations of UFPs, originating from road traffic. This kind of octocopter measurements will be extended by the Duesseldorf University of Applied Sciences to the measurement of gaseous air pollutants as well. Other fields of applications can be e.g. air pollution measurement above landfills, in special street canyons or at active volcanoes.

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