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A wind tunnel study of the collection efficiency of an aerodynamically improved 'Frisbee' dust trap

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Introduction

Airborne dust is commonplace and dust storms are a well-known natural hazard in dryland regions. Efforts aimed at understanding the dust erosion and transport system are hindered by a lack of reliable data on dust sources, the timing of dust events and the link between land management practices and dust generation. Such information can most easily be gained from direct measurements of dust flux and deposition. However, the successful measurement of such processes remains elusive and is one of the most problematic procedures in aeolian geomorphology (Goosens & Offer 2000). The most important characteristic of a dust trap is its collection efficiency. This efficiency is controlled by the degree to which the trap represents an obstacle to the windflow, and so an aerodynamic design is most efficient. One of the most important components of the dust system which still needs to be understood is the rate of deposition. Existing deposition trap designs have efficiencies of commonly between 20% and 75% (Goosens & Offer, 2000). A novel trap design has been described by Hall *et al* (1994) which is similar in design to modern "shallow bowl" traps but incorporates an additional deflector ring to improve aerodynamic behaviour. The deflector ring aims to reduce the acceleration in wind speed over the trap opening. Such flow acceleration is largely responsible for reducing the efficiency of standard trap designs (Hall *et al*, 1994).

The aim of this research was to test the aerodynamic behaviour of the deflector ring and to measure any resulting improvement in the collection efficiency of a 'frisbee'-type deposition trap.

Methods

All the experiments were carried out in the portable field wind tunnel at Gunnedah Research Station, Australia. The tunnel was of the blowing fan type with a working section 9.50 m long and cross-section 1.15 m wide and 1.00 m in height. Turbulence was induced at the entrance to the working section using a flow contraction resulting in a turbulent intensity at the trap site of approximately 6%. The trap was placed on the centre-line of the tunnel, 8.50 m along the working section and with the opening at a height of 0.55 m. The design of the trap and surrounding deflector was similar to that of Hall *et al* (1994) and is summarised in Table 1.

Table 1: Design details of the trap and deflector

Parameter	Length scale (mm)
Depth (H)	93
Internal trap diameter	297
External trap diameter (D)	354
H/D	0.263
Internal deflector diameter	424
External deflector diameter	707
Upper deflector ellipse	20
Lower deflector ellipse	73

Wind velocity profiles and turbulence intensity were measured across the trap opening both with and without the deflector ring using an array of six fast-response pitot-tubes referenced to a freestream velocity measured at 0.25 m from the tunnel roof. These measurements were carried out at a sampling frequency of 1 second and averaged over 3 minute periods. Measurements were also undertaken in the empty tunnel for comparison.

The collection efficiency of the trap was tested both with and without the deflector ring by injecting a known quantity of silica flour dust (mean grain size of 14.6 μm) over a 60 second period at the upwind tunnel contraction. The amount of dust collected in the trap was then compared to the expected catch using the following equation:

$$\mathbf{E = \chi . A . V_f . t}$$

Where: E = collection efficiency; χ = dust concentration; A = trap area; V_f = particle falling speed; t = time.

The dust concentration (χ) was determined from the volume of air pushed through the tunnel during the experiment and the measured quantity of dust injected into the airstream. Particle falling speed (V_f) was calculated from data in Davies (1945). Each test measurement was repeated 3 times.

Results

Velocity profiles above the centre of the trap opening are presented in Figure 1. Here, the velocity data are expressed as a fractional speed-up ratio (δs, Jackson & Hunt, 1975) in relation to the measured velocity at a point (u) and the reference velocity measured in the free-stream (U_r):

$$\delta s = (u - U_r) / U_r$$

A fractional speed-up ratio (δs) value of +0.05 therefore represents a 5% increase in wind velocity when compared to that measured at the same point in the absence of the dust trap.

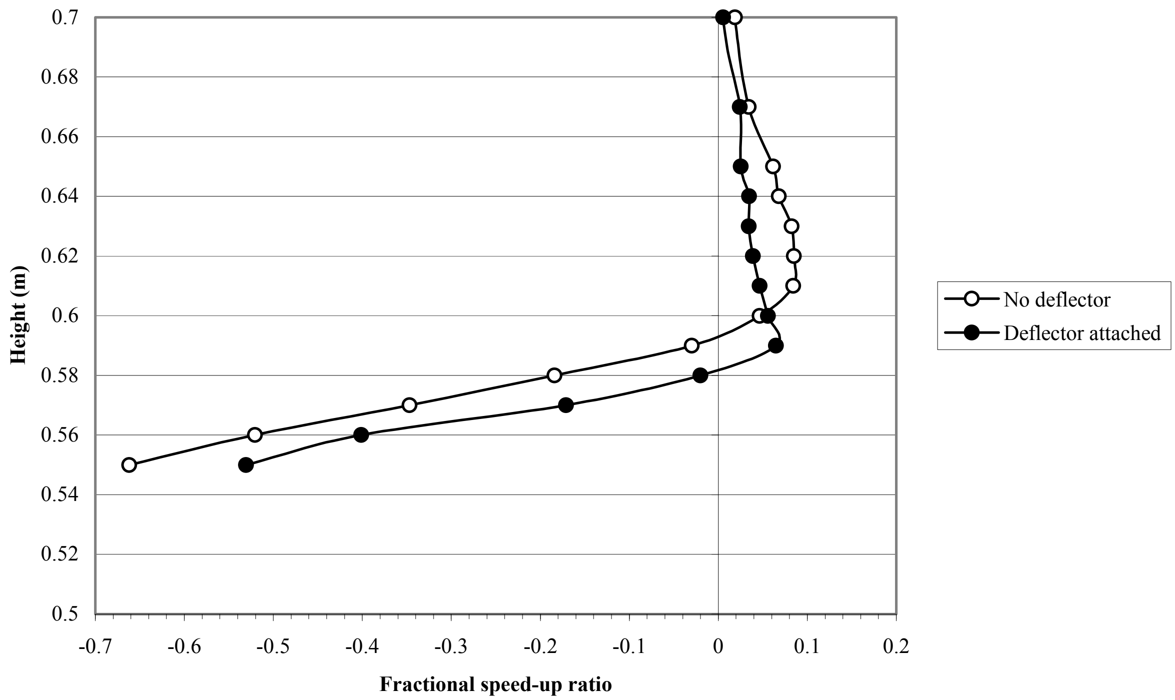

Figure 1. Velocity profiles measured above the trap opening

The data in Figure 1 clearly show that the deflector has a significant impact on the airflow above the trap. Without the deflector the measured velocity profile shows a 66% deceleration immediately above the trap opening (at 0.55 m height) and an 8.5% acceleration at 0.62 m height (7 cm above the trap opening). In contrast, the deflector has the effect of reducing the intensity of both the deceleration immediately above the trap opening (to 53%) and the acceleration higher in the profile (to 6.5%). In addition, the height of the point of maximum velocity is reduced to 0.59 m (4 cm above the trap opening) and the zone of flow acceleration above the trap is consequently much smaller. The deflector appears to have had the desired effect of diverting the flow downwards around the gauge, hence flattening the flow over the gauge and reducing the acceleration in wind speed (Hall *et al*, 1994).

The reduced impact on the flow dynamics above the trap opening when employing the deflector had a follow-on effect on the efficiency of the collector in terms of dust deposition. The data in Figure 2 show the collection efficiency of the trap, both with and without the deflector, with varying free-stream velocity. At all wind speeds the deflector had the effect of increasing the efficiency of the deposition trap. At lower wind speeds (4 – 8 ms^{-1}) the efficiency of both collectors is very high, the deflector giving a collecting efficiency of over 100% at 4 ms^{-1}. At 10 ms^{-1} the trap with no deflector experienced a decline in efficiency from 83% to 61%, falling further to 46% at 12.5 ms^{-1}. In contrast, the trap with the deflector maintained a very high collecting efficiency of 97% at 10 ms^{-1} which reduced to 0nly 69% at 12.5 ms^{-1}. At lower windspeeds the deflector had the impact of increasing the collection efficiency of the trap by approximately 13% to 14%. At windspeeds over 10ms^{-1} this was increased to 33% to 37%.

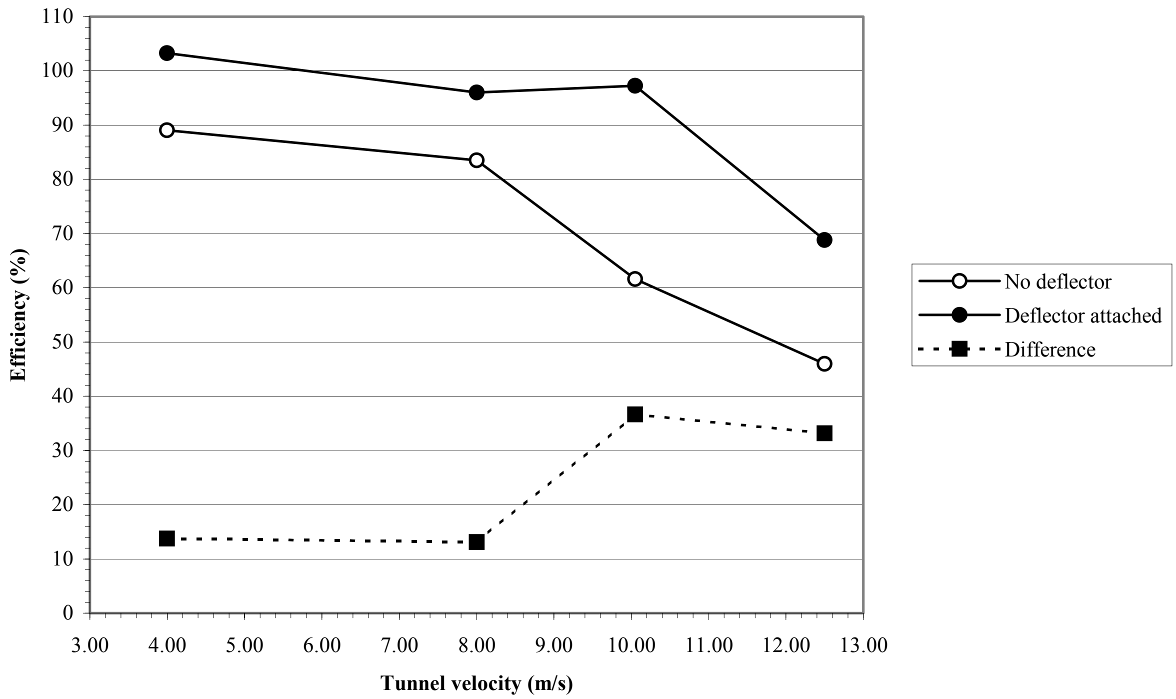

Figure 2. The collecting efficiency of the dust trap with varying windspeed

Conclusion

The addition of a deflector ring had a significant impact on both the aerodynamics and collection efficiency of a 'frisbee'-type dust deposition trap. The deflector successfully partitioned the flow around the dust trap reducing above-trap flow acceleration and helping to maintain velocity immediately above the trap opening. In wind speeds up to 10 ms^{-1} the deflector improved collection efficiency by between 13% and 37% though some reduction was evident at higher wind speeds. Further testing is required, specifically for a greater range of sediment size, but the wind tunnel results presented here suggest that improved aerodynamic design could have a significant effect on results from field dust collectors.

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