

Terminal velocity of the first instar *Ectropis excursaria* (Guenee) (Lepidoptera: Geometridae)

R RAMACHANDRAN*

Waite Agricultural Research Institute, Glen Osmond, South Australia 5064

*Present address: Entomology Section, National Chemical Laboratory, Pune 411 008, India

MS received 29 April 1987; revised 23 July 1987

Abstract. The terminal velocity of first instar *Ectropis excursaria*, determined in a part mechanical part electrical apparatus, were 114 ± 12 cm/s and 118 ± 12.5 cm/s for two different heights. Terminal velocity decreased exponentially with increased silk lengths. For a given length of silk there was a significant difference in the terminal velocity of live and anaesthetised insects. The significance of these results to the understanding of the wind dispersal of first instar caterpillars is discussed.

Keywords. Terminal velocity; *Ectropis excursaria*; first instars; wind dispersal; silk length; anaesthetisation.

1. Introduction

Wind dispersal of the newly emerged first instars is a means of natural spread of many Lepidoptera (Leonard 1974; Mitchell 1979; Batzer 1968; Jennings *et al* 1983), Homoptera (Washburn and Frankie 1981; Moran *et al* 1982) and Acarina (Boykin and Campbell 1984). The distance travelled by a windborne insect depends on the wind velocity, the amount of atmospheric turbulence and the terminal velocity of the larva (McManus and Mason 1983). The determination of terminal velocity is critical to estimating the extent and patterns of dispersal of insects and other particulates (Harrington 1979).

Ectropis excursaria (Geometridae: Lepidoptera) is native to Australia and feeds on several species of Mimosaceae, Myrtaceae and plants of economic importance. The first instars of *E. excursaria* disperse by wind and this dispersal is influenced by host plant species and the quality of foliage of the host plant (Ramachandran 1987). In the present paper, determination of the terminal velocity of the first instars and the influence of silk length and larval activity on terminal velocity is reported.

2. Materials and methods

Live unfed first instars were obtained from a culture maintained on *Eucalyptus camaldulensis* D. Don in an insectary room. The experiment was conducted in an apparatus and the different parts and assembly of which is given in figure 1.

The experimental procedure involved the following steps:

(i) A larva was picked up with a camel's hair brush and induced to spin down on silk by tapping the brush. The tip of the silk was placed on the heating element. The silk invariably stuck to the wire because of its adhesive property. Thus, at the start of the experiment, the insect hung from the heating element such that if its attachment was broken it would fall into the tube.

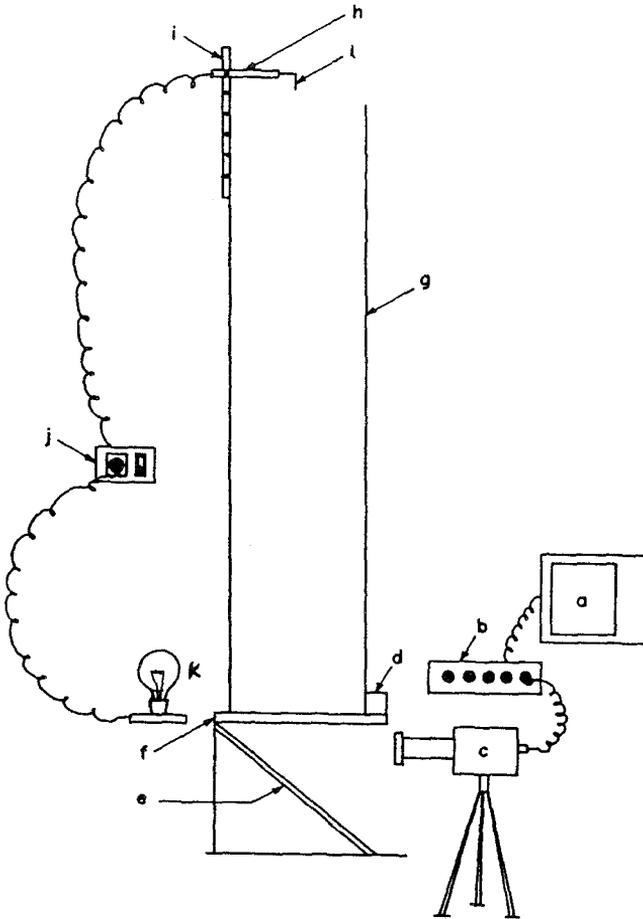


Figure 1. An apparatus for estimating the terminal velocity of insects. **a.** Television monitor. **b.** Video camera recorder. **c.** Video camera. **d.** LED timer. **e.** Mirror. **f.** Glass plate. **g.** Perspex cylinder. **h.** 'Wax melter' used as an insect releaser. **i.** Calibrated rod on which the wax melter slides. **j.** Common power source for insect releaser and light source. **k.** Light source. **l.** A first instar caterpillar hanging on silk from the wax melter.

- (ii) By sliding the hot wire along the calibrated scale, such that the insect hung near the rim of the perspex tube, the length of the silk could be measured and recorded.
- (iii) The power to the light source and the heating element was switched on.
- (iv) At some time after switching on the heating element (the time was recorded manually) the insect was released. In each test, the data on the video recorder allowed determination of 3 stages, (i) when only the digits on the timer were visible i.e. before the start of the experiment, (ii) when the rim of the perspex and the timer were visible i.e. after the light and the heating element had been switched on and (iii) when the timer, rim of the perspex tube and the insect were visible i.e. after the insect had landed on the surface of the glass plate. The time elapsed between each of these 3 events could be calculated from the video tapes by reading the timer and the time recorded in step 4, and hence the time taken by the insect to travel the distance that it had fallen.

The fall velocity of the first instar larvae of uniform size, from 3 heights viz. 100, 160 and 180 cm with a constant silk length of 2 cm was measured in one experiment. In another experiment the fall velocity of larvae with varying silk lengths (1–30 cm) from 100 cm height was recorded. The size of these larvae were measured under a stereo microscope. In a third experiment the time taken to travel 100 cm by live and anaesthetised insects with 2 cm silk was determined. Anaesthetisation was carried out by holding a caterpillar, hanging on silk from the end of the brush, into a beaker containing cotton dipper in chloroform.

3. Results and discussion

The velocity of an object dropped in a fluid medium increases linearly with distance (acceleration phase) to reach a constant value i.e. the terminal velocity. Values of terminal velocity reported by Batzer (1968), Mitchell (1979), Moran *et al* (1982) and McManus and Mason (1983) are the average velocity of the acceleration phase and the terminal velocity phase whereas one strictly requires the period during which the insect travels at terminal velocity. The true terminal velocity was calculated from the experimental fall velocities from the 3 different heights (table 1) in the following manner. For two heights S_1 , S_2 (where S_2 is greater than S_1) with times t_1 and t_2 , the fall velocities are S_1/t_1 and S_2/t_2 . These are average velocities which include an initial phase where the velocity is less than the terminal velocity. If the terminal velocity is approached after a fall of S_1 (the mean distance travelled per second from the 3 different heights did not differ significantly, $F=0.4845$, table 1, suggesting that the terminal velocity might have been reached at less than 100 cm height), the velocity over S_1 – S_2 gives an estimate of terminal velocity. The terminal velocity of *E. excrucaria* calculated in this manner were 118 ± 12.5 cm/s for 100–160 cm and 114 ± 12 cm/s for 100–180 cm (from table 1) and were higher than the fall velocities as would be expected.

Although dispersal is the prerogative of winged adults, in insects where the adults are either apterous or do not fly, dispersal is achieved mainly by early first instars. Thus these stages of insects may be expected to show morphological and/or behavioural adaptations that increases the time spent in air and thus the distance travelled from the point of launching. McManus and Mason (1983) reported that the numerous filamentous hairs and long hollow setae in the gypsy moth first instar larvae might increase the buoyancy of these wind dispersing caterpillars. The production of silk by wind dispersing apterous insects (lepidopteran hatchlings and arachnids) is considered to reduce their terminal velocity (Batzer 1968; Mitchell 1979;

Table 1. Fall velocities of the first instar caterpillars dropped from different heights.

Height	Larval condition	n	Fall velocity \pm SEM
100	Live	28	108 \pm 2.3
100	Anaesthetised	25	114 \pm 1.6
160	Live	32	111 \pm 2.4
180	Live	13	110 \pm 5.0

n is the number of replicates.

McManus and Mason 1983). In the present studies the effect of silk length of upto 30 cm on the fall velocity of the first instars was determined. The relationship between the length of silk and fall velocity showed an exponential decrease and the equation $Y = 153.7 X^{-0.507}$ (in its logarithmic form) was fitted to the data (figure 2). A similar exponential decrease in the effect of silk length on the fall velocity of airborne caterpillars has been reported by Batzer (1968) and Mitchell (1979). The relationship suggests that there may be an optimal length of silk (somewhere between 15–25 cm) above which the increase in the time spent in air due to additional silk length is offset by the risk of the silk being caught on objects near the point of launching and the energetics of silk production. Indeed Batzer (1968) observed that 79% of spruce budworm larvae produced less than 30 cm of silk on initial disturbance.

McManus and Mason (1983) showed a linear increase in terminal velocity with the range of weight of unfed first instar gypsy moth. Size of the insect would also have an important effect on the terminal velocity as the drag force depends on the size and shape of the object. To this end, when the experiment on the effect of silk length was conducted, the length of the insects were measured. A multiple regression of the time taken to travel one meter to the silk length and the length of the insect indicated that the range of sizes tested explained only 0.2% of the observed variation, while silk length explained about 84.5% of the variation (regression of silk length to terminal velocity significant ANOVA, $F = 387.10$, $P < 0.001$; regression of size of the insect to terminal velocity not significant ANOVA, $F = 1.96$). The first instars used in the experiment ranged in size from 1.40–2.5 mm, with a mean \pm SD of 1.97 ± 0.24 mm

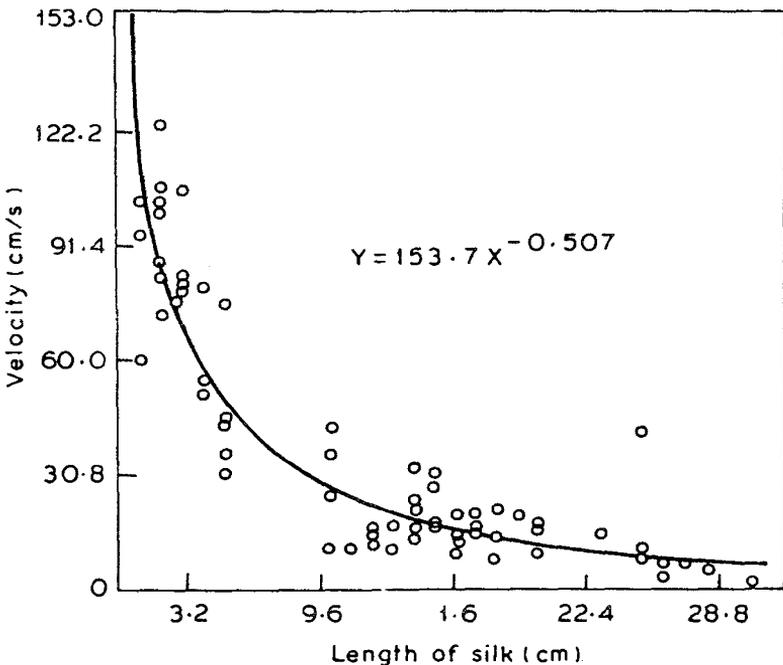


Figure 2. Relationship between the length of silk attached to the caterpillar and the terminal velocity of first instars of *E. excrucaria*.

($n=71$). This size range is probably not enough to exert any significant influence on terminal velocity.

Anaesthetisation of caterpillars significantly increased the fall velocity as compared to live caterpillars ($t_{51}=2.61$, $P<0.05$, table 1). Similar differences in the terminal velocity of live and dead wingless first instars of coccids (*Pulvinavella mesembryanthemi*) were reported by Washburn and Washburn (1984). They have reported that live coccids arched their body backwards and extended their legs and antennae outwards while freshly killed ones fell almost like a sphere. In flightless grasshoppers, jumps from elevated positions followed by aerobatic manoeuvring has been shown to carry them several metres through the air (Cohn and Cantrall 1979; Arbas 1983). Live first instars of *E. excrucaria* also seem to exhibit adaptive behaviour such as assuming a posture or flexing their body to reduce the terminal velocity and enable them to stay in the air longer. However, further evidence for such aerial reflexes can only be obtained by photographing the dispersing insects.

Mason and McManus (1979) incorporated the values of terminal velocity into an atmospheric dispersion model to predict the distance dispersed by first instar gypsy moth. Based on the results they concluded that most of the dispersal of first instars were only short range. The terminal velocity of *E. excrucaria* is higher than that of gypsy moth (70–110 cm/s, McManus and Mason 1983) suggesting that wind dispersal in this insect also leads to only short distance movement. However, results of the present investigation that silk length and larval activity could reduce the terminal velocity of the larvae indicate possibilities of longer distance dispersal by an interaction of factors such as silk length attached to the caterpillar, larval activity in air and the nature and velocity of wind.

Acknowledgements

I am grateful to Drs Roger Laughlin and Peter Miles for their help and advice during the course of this study and to W J D Kirk for his comments on the manuscript. A University Research Grant Scholarship from the University of Adelaide is gratefully acknowledged.

References

- Arbas E A 1983 Aerial manoeuvring reflexes in flightless grasshoppers; *J. Exp. Biol.* **107** 509–513
- Batzer H O 1968 Hibernation site and dispersal of spruce budworm larvae as related to damage to sapling balsam fir; *J. Econ. Entomol.* **61** 216–220
- Boykin L S and Campbell W V 1984 Wind dispersal of the two spotted spider mite (Acari: Tetranychidae) in North Carolina peanut fields; *Environ. Entomol.* **13** 221–227
- Cohn T and Cantrall I J 1974 Variation and speciation in the grasshoppers of the Conalcaeni (Orthoptera: Melanoplinae): The lowland forms of Western Mexico, the Genus *Barytetix*; *San Diego Soc. Nat. Hist. Mem.* **6** 1–13
- Harrington J B 1979 Deposition principles of microbiological particles: in *Aerobiology—The Ecological Systems Approach* (ed.) R L Edmonds (New York: Academic Press) pp 112–145
- Jennings D T, Houseweart M W and Dimon J B 1983 Dispersal losses of early first instar spruce budworm (Lepidoptera: Tortricidae) larvae in strip, clearcut and dense spruce-fir forests of Maine; *Environ. Entomol.* **12** 1787–1791
- Leonard D E 1974 Recent developments in the ecology and control of the gypsy moth; *Annu. Rev. Entomol.* **19** 197–230

- Mason C J and McManus M L 1979 The role of dispersal in the natural spread of the gypsy moth; *Proc. of the II IUFRO conference on Dispersal of forest insects: Evaluation, theory and management implications* (eds) E A Berryman and L Safranyik (Pullman: Wash. State Univ. Coop. Ext. Serv.) pp 94–115
- McManus M L and Mason C J 1983 Determination of settling velocity and its significance to larval dispersal of the gypsy moth (Lepidoptera: Lymantridae); *Environ. Entomol.* **12** 270–272
- Mitchell R G 1979 Dispersal of early instars of Douglas-fir Tussock moth; *Ann. Entomol. Soc. Am.* **72** 291–297
- Moran V C, Gunn B H and Walter G H 1982 Wind dispersal and settling of first instar crawlers of cochineal insect *Dactylopius austrinus* (Homoptera: Dactylopiidae); *Ecol. Entomol.* **7** 409–419
- Ramachandran R 1987 Host-plant influences on the wind dispersal and survival of the first instars of an Australian Geometrid caterpillar; *Entomol. Exp. Appl.* (in press)
- Washburn J O and Frankie G W 1981 Dispersal of a scale insect *Pulvinariella mesembryanthemi* (Homoptera: Coccoidea) on ice-plant in California; *Environ. Entomol.* **10** 724–727
- Washburn O and Washburn L 1984 Active aerial dispersal of minute wingless arthropods: Exploitation of boundary layer velocity gradients; *Science* **223** 1088–1089