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Field experiments with a wind tunnel on the flight speed of some West African mosquitoes (Diptera: Culicidae)

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Abstract

An open wind tunnel, down which air was blown from over a bait animal, was used in the field in the Gambia to measure the flight speed of host-seeking mosquitoes. Insects were trapped on an electrocuting grid fitted halfway up the tunnel. As the speed of air movement through the electrocuting grid was increased from 0·5 m/s, catches of *Mansonia* spp. fell off steeply, reaching negligible levels above 1·4 m/s. At air speeds lower than 0·5 m/s, catches at the grid were greatly reduced. Similar results were obtained for *Anopheles ziemanni* Grünb. and other species of *Anopheles*. It is concluded that the maximum flight speed of host-seeking females of all these species was in the range 1·4–1·8 m/s.

Introduction

Data on the flight speed of mosquitoes have recently been reviewed by Snow (1980). Estimates for most species lie in the range 0·4–1·1 m/s, although maxima for certain North American species have been as high as 2·5 m/s. From his own observations on the relationship of biting rates on man to ambient wind speeds, Snow concluded that the West African species *Anopheles melas* Theobald and *Culex thalassius* Theobald were achieving flight speeds of 1·2 m/s.

We record here further experiments in the Gambia to determine the flight speed of certain other species. Our approach was a more direct one, involving the use of a controlled air current containing host attractants that was passed down an open wind tunnel in the field. The experiments were conducted near the village of Wali Kunda, Macarthy Island Division, in an open area adjacent to a wide expanse of rice swamp.

Methods

The experimental set-up consisted of three sections: (1) housing for the bait animal acting as the source of attractant, (2) the wind tunnel, and (3) a funnel-shaped approach area comprising two netting fences, converging on the mouth of the tunnel, and three suction traps for sampling the population of mosquitoes approaching the tunnel (Fig. 1 & Plate III).

The bait animal, an adult goat, was housed in a polyethylene-covered stall, standing about 1 m behind the tunnel, open at one end. The closed end was joined through a mosquito netting screen to the inlet of the fan at the back of the wind tunnel by wide-bore ducting. Air containing host attractants was extracted from the animal stall and blown gently down the wind tunnel.

The wind tunnel, 1 m long by 0·61 m wide by 0·45 m high, was constructed on a

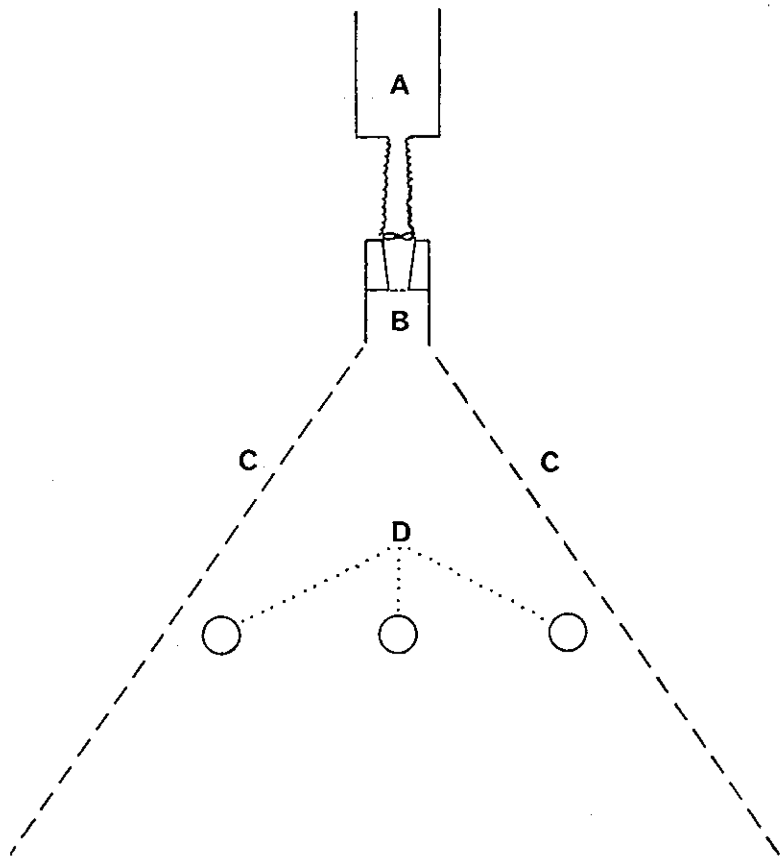

Fig. 1.—Plan of experimental field wind tunnel. (*A*, animal stall; *B*, wind tunnel; *C*, 1-m high fence; *D*, suction traps.)

wooden base with sides and roof of 6·3-mm Perspex (Fig. 2). The sides were reinforced with wooden struts at the mouth and halfway down the tunnel. The roof was removable and was kept in place by wing nuts. Air flow was provided by a 30·5-cm Ventaxia fan fitted to the back of the tunnel. A rectangular plywood duct extended from the mouth of the fan to halfway down the tunnel, terminating in a central aperture (*G*) of 20 × 15 cm. Tests with an anemometer probe showed that, over this restricted cross-section, an even distribution of flow was achieved. An electrocuting grid was fitted immediately in front of this aperture. On the other (outer) side of the grid, a plywood baffle with a matching aperture was fixed across the tunnel and close up against the grid. A 2-cm rim on the back of the baffle pressed up against the wires of the grid. This sealed off the outer face of the grid so that mosquitoes could not find their way round the sides of the aperture. Points of contact between the two were insulated with strips of Perspex. In this way, insects flying up the tunnel against the wind would encounter the grid and be electrocuted. In the other (outer) half of the tunnel, vertical Perspex plates were fitted on each side, leading from the outer corners of the mouth of the tunnel to the edge of the aperture (*G*), thus channelling mosquitoes towards the aperture. Similarly, a wide-mesh netting ramp led from the floor at the mouth of the tunnel up to the lower edge of the aperture. Dead mosquitoes that might

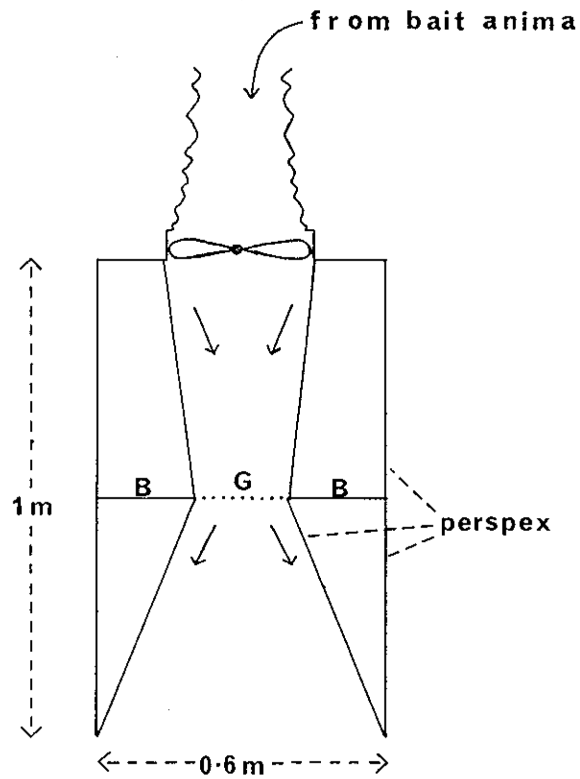

Fig. 2.—Plan view of wind tunnel. (*G*, electrocuting grid; *B*, transverse baffle.)

get blown from off the grid by the current of air dropped through the netting and were collected in trays on the floor.

The electrocuting grid and step-up transformer were of the design described by Gillies et al. (1978), except that, in order to decrease the chances of mosquitoes flying through the grid unharmed, a second grid of fine wires, 3 mm apart and not connected to the high voltage source, was fitted 2 cm behind the live grid. Dead mosquitoes were collected directly from the grid and from the tray on the floor of the tunnel at the end of each trapping period.

Air flow rates were controlled by a rheostat fitted to the fan circuit. Air speed through the tunnel was measured just in front of the grid, i.e. at the point at which mosquitoes would be killed and trapped, using a hot-wire anemometer probe (manufactured by Airflow Developments Ltd). The rheostat was calibrated against wind speed in the tunnel, the calibration being checked before each night's work.

The wind tunnel was supported on a steel angle frame 0·5 m above the ground with the mouth facing down the prevailing wind. A ramp of woven plastic netting was stretched from the ground up to the floor of the tunnel at its entrance at an angle of 45°, so as to prevent mosquitoes flying under the tunnel. Preliminary experiments had shown that it was possible to channel low-flying mosquitoes towards a trapping point by means of low fences. Accordingly, in order to increase the catch in the tunnel, two fences of woven plastic netting, 1 m high by 6 m long, were attached to the side walls at the mouth of the tunnel, extending out to make an angle of approximately 70°

between them (Fig. 1). In order to assess the density of mosquitoes approaching the tunnel, three 22·9-cm suction traps were placed in line across the approach to, and 3 m in front of, the mouth of the tunnel, at a point where the netting fences were 4·3 m apart. The suction traps were mounted on steel-angle scaffolding over pits 0·5 m deep at a height of 0·5 m above ground level. Mosquitoes drawn into the suction traps were collected in cages fitted beneath them.

Catching periods varied from 1 to 3 h, depending on the density of mosquitoes. Most collections were made during the first 5 h after nightfall.

Results

Electrocuted mosquitoes were frequently badly damaged, which made it impossible to separate the two species of *Mansonia* (*Mansonioides*) in the catches, *M. africana* (Theobald) and *M. uniformis* (Theobald). Results for these two species are therefore presented together. Apart from *Anopheles ziemanni* Grünberg, the species of *Anopheles* trapped comprised *A. squamosus* Theobald, *A. pharoensis* Theobald and small numbers of *A. gambiae* Giles s.l.

TABLE I. *Derived mean catch of mosquitoes in tunnel at different wind speeds*

	Total catch		Mean catch* at different wind speeds (m/s)						
	Grid	Approach traps	0·2 (5)**	0·5 (13)	0·8 (14)	1·0 (16)	1·4 (14)	1·8 (13)	2·0 (12)
Mansonia spp.	1070	9970	4·0 ±0·5	30·4 ±4·4	24·4 ±3·1	12·4 ±2·0	3·7 ±0·7	0·2 ±0·1	0
A. ziemanni	269	7407	1·1 ±0·5	7·4 ±1·7	13·2 ±3·7	5·4 ±1·1	1·3 ±0·4	0·3 ±0·2	0
Other *Anopheles* spp.	40	1087	0	12·0	12·0	4·2	0·8	0	0

*Catches are expressed as $\frac{\text{grid catch} \times 100}{\text{grid catch} + \text{suction-trap catch}}$

**The figures in brackets denote the number of trials at each wind speed.

The results of the experiments are set out in Table I. The method of calculation was as follows. For each trapping period, the numbers of each species caught on the grid and in the tray on the floor of the tunnel were recorded and added to the catch from the three approach traps. The grid catch was then expressed as a percentage of the total catch, i.e. $\frac{\text{grid catch} \times 100}{\text{catch on grid} + \text{catch in approach traps}}$. The mean catches shown in the table are the mean of the percentages for each test at each wind speed. Catches with a total of less than 10 mosquitoes were discarded.

Mosquitoes were most successful in reaching the grid against air currents moving at 0·5–0·8 m/s (Table I). At higher speeds, the arrival rate fell off steeply, and beyond 1·8 m/s none at all reached the grid. Moreover, it is likely that the presence of mosquitoes on the grid when the wind speed was 1·8 m/s was fortuitous, resulting from the rare event of an insect avoiding the full strength of the air current by keeping in contact with the walls or floor of the tunnel. At the other end of the scale, the low entry rate at 0·2 m/s is clearly not related to flight capacity. The choice whether to enter the tunnel or not would have been made at its mouth, which had a cross-section 9 times greater than at the grid, the point at which air speed was measured. The air flow at the mouth would, therefore, have been so low in this case that directional responses by host-seeking mosquitoes would have been scarcely possible and many of them would have carried on searching for the stimulus source outside the tunnel. It is evident that the same factor was involved in the case of *A. ziemanni* when the wind speed at the grid was 0·5 m/s.

At flow rates above 0·5 m/s, the curves for both *Mansonia* spp. and *A. ziemanni* are closely similar and provide no evidence for specific differences in flight capacity.

If the curves for density over wind speed for both *Mansonia* spp. and *A. ziemanni* are plotted on a semi-log scale and regression coefficients calculated for air flows from 0·8 to 1·8 m/s, no significant difference between the regression lines for the two species is observed ($b = -2{\cdot}034$ and $-1{\cdot}629$; $P > 0{\cdot}1$).

Discussion

Studies in laboratory wind tunnels, Kennedy (1940), Bässler (1958), have shown that when mosquitoes are exposed to rising wind speeds they increase their air speed up to a point at which advance is no longer possible, whereat they settle. In an open wind-tunnel in the field, the insects would have been flying up a gradient of wind speed, reaching a maximum at the electrocuting grid. Except on rare occasions, we noticed no mosquitoes settling on the floor or at the mouth of the tunnel. It follows that failure to advance against the air-stream would have led to mosquitoes turning and leaving the tunnel. Absence of mosquitoes in the catch at the grid could, therefore, be equated with failure to achieve the necessary flight speed to reach it.

Two features should be noted in the curves showing the relationship of density of arriving mosquitoes to wind speed in the tunnel. These are, respectively, that the slope of the curve is a function of the flight capacity of the species, while the level of the catch at any particular wind speed (below the maximum) reflects the readiness of a species to enter the system. As already shown (Fig. 2), for the two taxa for which data were adequate, the slope of the curve is virtually the same. In the case of the third group, other species of *Anopheles*, although the catches were too small for statistical analysis, it is evident that their flight capacity is much the same. For all groups studied, the maximum flight speed was in the range 1·4–1·8 m/s. This is slightly higher that the findings of Snow (1980) on *A. melas*, elsewhere in the Gambia, that at wind speeds above 1·2 m/s biting attacks on man virtually ceased. In these African mosquitoes, maximum flight speed appears to be unrelated to size. Wing lengths ranged from 5 to 6 mm in *A. ziemanni*, 4 to 4·5 mm in *Mansonia* and 3 to 5 mm in other species of *Anopheles*. Perhaps because of the small range of sizes in the species studied, our findings do not appear to illustrate the general rule of Lewis & Taylor (1967) that flight speed in insects is directly correlated with body size. On the other hand, flight-mill data on the North American species *Aedes impiger* (Walker) and *Ae. flavescens* (Müller), both of which are rather large mosquitoes, showed flight speeds of up to 2·5 m/s.

The flight speed of mosquitoes is of major importance in relation to the strategies of host-seeking. In areas such as the West African savanna, where villages and breeding sites may be separated by 2 or more kilometres of open ground, the outcome of flying upwind or downwind will be strongly influenced by the relative motion of the insect and of the air stream in which it is flying. This might also influence its flight level and hence the wind speed to which it is exposed (Klassen & Hocking, 1964). The present experiments were concerned with the approach flight of mosquitoes to a host. It does not necessarily follow that flight speed during extended dispersal flights is the same. The results, however, would appear to set a limit to the wind speed below which mosquitoes would be able to control their direction of movement relative to the ground.

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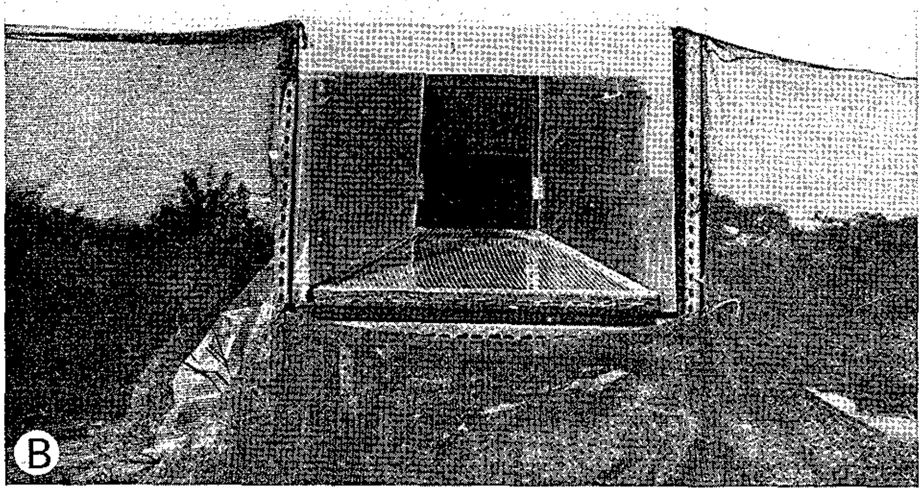

A, field wind tunnel from the side, showing, from left to right, polythene-covered stall for bait animal, connecting duct, wind tunnel with baffle (halfway along tunnel) for electrocuting grid, and part of approach fence. *B*, entrance to wind tunnel, showing central aperture containing electrocuting grid.