Automatic Data Acquisition Systems for Study of the Flight Ability of Brown-Wingled Green Bug, \textit{Plautia stali} Scott (Heteroptera: Pentatomidae)\textsuperscript{1}

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An automatic data acquisition and calculation system for a flight mill was assembled to measure the flight abilities of \textit{Plautia stali}. Data for calculating the total flight distance and total duration of flight were automatically recorded. The simultaneous operation of five flight mills has become possible under the control of a programmable controller. Through introduction of a microcomputer into the system, eight flight mills can be operated simultaneously. Flight abilities of laboratory-reared stink bugs were easily measured by this system.

INTRODUCTION

Insect flight activities have been studied by various means in the laboratory. Since Kennedy et al. (1948) developed a roundabout, many authors have applied this flight mill method to the measurement of insect flight activities (for example, Krogh and Weis-Fogh, 1952; Hocking, 1953; Chambers and O'Connell, 1969). Although this method is surely useful to obtain information on flight distance, duration, speed and pattern, laborious and time-consuming analysis is inevitably required to produce the data so long as the system is manually operated. Hocking (1953) first described automatic recording equipment in which a photocell was used to detect the rotation of the flight mill arm. The equipment saved time and also realized more accurate data. Recently, a microcomputer has become cheap enough to be incorporated as a constituent of a simple flight mill system (Clarke et al., 1984).

In some insect species, individuals tethered to a flight mill arm which had stopped flying resumed flying with high frequency when stimulated by external factors (Ito, 1980; Nakamori and Smizu, 1983). This phenomenon should be taken into account when the maximum flight potential is to be measured. However, no system has yet incorporated a stimulation process to make an insect resume flying automatically. Except for their lack of this automatic stimulation system, several flight mill systems which have recently been constructed appear satisfactory in data acquisition capability (Kishaba et al., 1967; Rowley et al., 1968; Sharp et al., 1975; Michel et al., 1977; Clarke et al., 1984). The present study aimed at constructing an automatic data acquisition system with a stimulation system in order to evaluate the maximum flight ability of the brown-winged green bug, \textit{Plautia stali}, one of the most important pests of fruit trees in Japan.

\textsuperscript{1} Contributions from the Fruit Tree Research Station, A-201.
MATERIALS AND METHODS

Flight mills. The flight mill shown in Fig. 1 is the same in principal as those described by Chambers and O'Connell (1969) and Ito (1980), although three modifications were made: i) The rotor was made of balsa wood (Fig. 1-B). ii) At one end of the arm, a piece of flexible vinyl-coated wire, Viny-tie®, was attached for adjusting the position of the bug. Its pronotum was glued to the tip of the wire with chloroprene cement, Bond G17® (Fig. 1-E). iii) A small piece of adhesive, chewing gum-like substance,

![Fig. 1. Top (upper) and front (lower) views of the flight mill. A: piece of adhesive for counterbalance, B: rotor made of balsa wood, C: set of two magnets vertically supporting the axis of the flight mill with minimum friction, D: axis made of an iron needle, E: piece of flexible vinyl-coated wire to tether the insect. Dimensions are expressed in millimeters.](image)

Fig. 2. Schematic diagram of the flight mill system. Rotation of the unit is detected by a photoelectric switch. Every 20 min the fan is activated for 5 sec if the bug is resting. The programmable controller can operate up to five flight mills simultaneously. Model specifications of the parts are described in Appendix 1.

![Fig. 2. Schematic diagram of the flight mill system.](image)

Fig. 3. Schematic diagram of the improved flight mill system controlled by a micro-computer. Eight flight mills can be connected to the computer. Model specifications and the internal constitution of the converter box are described in Appendices 1 and 2, respectively.

![Fig. 3. Schematic diagram of the improved flight mill system controlled by a micro-computer.](image)
Hittsuki-mushi®, was used for counterbalance (Fig. 1-A).

Original system. Figure 2 is a schematic diagram of the flight mill system which consists of the following five fundamental sections: i) flight mill, ii) a photoelectric switch, which is a detector of the rotation of the flight mill, iii) a timer and a counter for data recording equipment, iv) a fan (20 cm in diameter), which is a stimulator to make the insect resume flying by sending gusts of air when it stops flying, and v) a system controller, which consists of a programmable controller and an external clock.

![Flow chart of the flight mill control program](image)

Fig. 4. Flow chart of the flight mill control program. $T_i$ and $T_{i-1}$ in the figure refer to the time of $i$th and $(i-1)$th data sampling, respectively.
Five sets of sections i) to iv) are connected to a single programmable controller (often called a sequencer). Whenever the rotor passes between the light source and the receiver of the photoelectric switch, an electric signal is sent to the programmable controller. If the signal interval is less than 3.5 sec, the controller judges that the insect is in flight. As a result, the controller outputs two kinds of signals, one to the counter to increase the count by one and the other to the timer for time accumulation. Then, if the following interval exceeds 3.5 sec, the controller generates a signal to cancel the time accumulated in excess of the 3.5 sec of the previous interval. The interval can empirically be regarded as indicating that the bug has ceased to fly. The controller also generates another signal to activate the fan for 5 sec every 20 min, which is checked by the external clock. Thus the gusts of air stimulate the resting bug, and if the bug resumes flying the counter and timer start to work again.

Improved system. The system has been improved by introducing a microcomputer (Fig. 3). The converter box is a device which has been specially constructed to connect the photoelectric switch with the computer. This system can operate up to eight flight mills simultaneously.

A flow chart of the flight mill control program is given in Fig. 4. In this case, the system is programmed to stop working 24 hr after the start, because this period is regarded as long enough to evaluate the flight ability of the bug. However, the period can be changed easily by a slight modification of the program. The interval of data sampling from the converter box is fixed at 5 sec in the program. It can also be modified within the data processing speed of the computer. The program is written in an N-88 BASIC language (NEC, PC-8801mkII) and a complete description of this program is available upon request.

RESULTS AND DISCUSSION

In the present system, the flight mill is believed to satisfy all the requisites described by Hocking (1953), and Chambers and O'Connell (1969). The revolving part has been designed to be as light as possible to minimize the moment of inertia; its total weight (A–E in Fig. 1) is only 1.5 g. This weight is 37 percent lighter than the unit of same length made by Ito (1980). However, because of this very light weight the rotor is easily moved by anything other than the flight of the tethered insect. In these cases, the intervals of the signals were usually irregular and exceeded 3.5 sec, so that the controller could distinguish them from those caused by the flight of the insect.

In the original system (Fig. 2), two kinds of parameters, total flight distance and the total duration of flight, were displayed in digital numbers at the counter and timer, respectively. The average flight speed was calculated from them. The wind stimuli automatically generated by the fan succeeded in forcing the resting insect to fly. In studies of insect flight, this method of measuring the flight potential would be essential when the insect tested is one easily made to resume flying by being given a shock, except when spontaneous take-off is to be studied (Gathouse and Hackett, 1980).

Because of its highly flexible software the improved system (Fig. 3) can measure the flight ability with a higher accuracy than earlier ones through the introduction of a microcomputer. Furthermore, the computer has also added new measurement items by processing the data obtained from the converter box. The main items are maximum flight speed, the longest continuous flight duration and the total duration of a flight.
Table 1. Flight abilities of *P. stali* \(^a\) measured by the flight mill system\(^b\)

<table>
<thead>
<tr>
<th>Items</th>
<th>Males ((n=169))</th>
<th>Females ((n=218))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Range</td>
</tr>
<tr>
<td>Flight duration (min)</td>
<td>131</td>
<td>0–1,091</td>
</tr>
<tr>
<td>Flight distance (km)</td>
<td>5.6</td>
<td>0–54.3</td>
</tr>
<tr>
<td>Average flight velocity ((m/sec))</td>
<td>0.55</td>
<td>0–1.22</td>
</tr>
</tbody>
</table>

\(^a\) Laboratory-reared strain was reared at 22.5°C under 16L–8D light condition (Moriya et al., 1985).
\(^b\) The system was set in an incubator (22.5°C, 24L, 50–80% RH).

continuing more than five minutes.

The flight ability of laboratory-reared *P. stali* (Moriya et al., 1985) is shown in Table 1. Some of the bugs of both sexes flew over 30 km and/or over 10 hr during a 24 hr period, but there was wide variation among individuals.

The flight mill presented here is applicable for insects other than *P. stali*. A slight modification of the rotor, however, will be necessary in accordance with the size, weight, flight ability and other attributes of the insect species to be studied.

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REFERENCES


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APPENDICES

Appendix 1. Model specifications of the parts used in the original and improved flight mill systems

<table>
<thead>
<tr>
<th>Part</th>
<th>Model specification</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photoelectric switch</td>
<td>E3S-1E11</td>
<td>Omuron Tateishi Electronics</td>
</tr>
<tr>
<td>Programmable controller</td>
<td>CZ-1000A</td>
<td>Omuron Tateishi Electronics</td>
</tr>
<tr>
<td>Power supply</td>
<td>CZ-512-13C</td>
<td>Omuron Tateishi Electronics</td>
</tr>
<tr>
<td>Counter</td>
<td>H7A-T8</td>
<td>Omuron Tateishi Electronics</td>
</tr>
<tr>
<td>Timer</td>
<td>H5A-4D</td>
<td>Omuron Tateishi Electronics</td>
</tr>
<tr>
<td>Relay I (solid state relay)</td>
<td>G3A-210B</td>
<td>Omuron Tateishi Electronics</td>
</tr>
<tr>
<td>Relay II (non contact relay)</td>
<td>C8-904</td>
<td>Omuron Tateishi Electronics</td>
</tr>
<tr>
<td>External clock</td>
<td>H5A-4D</td>
<td>Omuron Tateishi Electronics</td>
</tr>
<tr>
<td>Fan</td>
<td>D20-AV</td>
<td>Mitsubishi Electric</td>
</tr>
<tr>
<td>Computer</td>
<td>PC-8801mk II</td>
<td>NEC</td>
</tr>
<tr>
<td>CRT display</td>
<td>PC-8050n</td>
<td>NEC</td>
</tr>
<tr>
<td>Printer</td>
<td>RP-80 II</td>
<td>Epson</td>
</tr>
<tr>
<td>Converter box</td>
<td>CU-III (made to order)</td>
<td>Iio Electric</td>
</tr>
</tbody>
</table>

Appendix 2. Block diagram of converter box CU-III.