6.1 Experimental setup for studying locust flight
Locust flight can be measured and photographed while the animal is flying (while tethered in place). Flight is triggered by wind directed at the head of the animal. After Wilson 1968.
6.4 Major flight muscles
Some of the major flight muscles innervating the forewing and hindwing of the locust. The three thoracic ganglia, which control the flight muscles, are indicated (see also Figure 6.3). After Wilson 1968.
6.5 Innervation of the major flight muscles
This diagram shows the position and projection pattern of each motor neuron (indicated by colored circles) in its respective thoracic ganglion. Elevator muscles and their respective motor neurons are shown on the left, depressors and their motor neurons on the right. The numbers indicate the nerves through which the motor axons project, the rectangles indicate specific muscles, and the dots indicate the number of motor neurons innervating each muscle. After Burrows 1996; data from Burrows 1975.

6.6 A chain reflex
The basic idea of the chain reflex is that sensory input ($S_1$) arising from the execution of a particular component of a behavioral act can trigger a reflex response ($R_1$) that in turn gives rise to sensory input ($S_2$), which triggers either the same originating reflex ($S_1 \rightarrow R_1$), or another component of behavior (not shown).
6.16 Connectivity of wing hinge receptors to motor neurons

Wing hinge receptors are functionally connected to motor neurons. (A) Each action potential in a wing hinge receptor (extracellular record, top trace) is accompanied by a depolarizing synaptic potential in a wing depressor motor neuron (intracellular record, bottom trace). (B) Electrical stimulation of a wing hinge receptor axon evokes a flightlike rhythm of excitatory and inhibitory synaptic potentials in depressor (top) and elevator (bottom) motor neurons, respectively. (C) Electrical activation of the axons of the campaniform sensilla induces synaptic inhibition in depressor motor neurons and synaptic excitation in elevator motor neurons. After Camhi 1984; data from Burrows 1975, 1976.
6.17 Tegula afferents are activated during flight

(A) Top trace is an intracellular record from an elevator motor neuron. Bottom trace is an extracellular record from hindwing tegula afferents showing that they are phasically activated (arrowheads) during the depression phase (d) of each wingbeat cycle. (B) Hindwing tegula afferents recorded in nerve 1C make excitatory connections to flight interneuron 566. (C) IN566 makes a direct excitatory synaptic connection to a forewing elevator motor neuron. After Pearson 1991.

6.8 Muscular and neuronal actions during flight

The actions of specific wing muscles and motor neurons during flight. (A) Action potentials in six identified depressor muscles (numbered at left) from the two pairs of wings are recorded during flight. (B) Intracellular recordings from elevator and depressor motor neurons (innervating the same side of the body) during a single wingbeat cycle. Spikes in the fore- and hindwing elevators occur at the same time (see overlapping traces at bottom); spikes in the hindwing depressors precede those in the forewing depressors (see overlapping traces at bottom). After Burrows 1996. Data in A from Zarnack and Möhl 1977; data in B from Hedwig and Pearson 1984.
6.10 The action of motor neurons and interneurons during flight
Intracellular recordings from flight motor neurons and interneurons were made during flight. (A) During successive wingbeat cycles, a motor neuron (MN128) that produces hindwing depression (top) and one (MN83) that produces forewing elevation (bottom) fire out of phase with each other. Output to a flight muscle (M112) is shown in the bottom trace. (B) Flight interneurons (IN301, IN511) fire at fixed phases of the wingbeat cycle. Motor output is shown in the muscle record at the bottom. After Robertson 1986.

6.9 A reset experiment
(A) Action potentials occurring during a particular phase of a rhythm (shaded boxes) are shown on top. Direct activation of the hypothetical cell does not affect the rhythm; the bursts of action potentials still align with the rhythmic output. Thus no reset has occurred. (B) In the top example, direct activation of the cell delays the bursts of action potentials with respect to the projected rhythmic output. In the bottom example, direct activation of the cell advances the bursts of action potentials with respect to the projected rhythmic output. In both cases, reset has occurred.
6.12 Synaptic interactions of flight interneurons
Different flight interneurons are interconnected as indicated. In all cases, several intracellular traces are superimposed. (A) IN504 makes an excitatory connection to IN301. (B) IN301 produces inhibition in IN511. (C) IN301 produces delayed excitation in IN501. (D) IN501 produces inhibition in IN301. After Robertson 1986.

6.11 The structures of flight interneurons
In each of these four different flight interneurons, the cells have first been identified physiologically, then filled with a dye that spreads throughout the cells, showing their branching patterns. After Robertson 1986.
6.13 Connectivity in the activation of flight interneurons
A pair of interconnected flight interneurons are activated cyclically during flight. (A) IN301 is depolarized and fires action potentials during the elevation phase of a wingbeat cycle; IN501 is depolarized and spikes during the depression phase. Activity in a depressor muscle is shown in the trace at the bottom. (B) Schematic diagram depicting excitatory (open circle) and inhibitory (colored circle) connectivity between IN301 and IN501. This simple circuit has a rudimentary oscillatory capability. A after Burrows 1996; data from Robertson 1988.

6.14 Direct intracellular activation of a IN501 resets the flight rhythm
Rhythmic spikes and oscillations of the membrane potential, concomitant with rhythmic activity in a depressor muscle (bottom trace), are observed in IN501 during flight. The rhythm cycle is shown in the black bars beneath the traces. After intracellular depolarization of IN501, the oscillations and spikes in IN501, as well as activation of the flight muscle, are delayed (dashed lines) with respect to the projected rhythm (colored bars). After Robertson and Pearson 1984.
6.15 Connectivity of neurons thought to contribute to the flight motor program

In this diagram showing the connectivity of some of the identified flight interneurons, IN301 and IN501 (see Figures 6.13 and 6.14) are indicated by color. After Burrows 1996; data from Robertson and Pearson 1985.

6.18 Stimulation of the tegula afferents resets the flight rhythm
(Conventions are the same as in Figure 6.14.) After Pearson 1991.
6.19 Axes of orientation for flight
For stable flight the locust must make adaptive corrections in three axes of orientation: pitch, roll, and yaw. After Camhi 1971.
6.20 Sensory systems that detect deviation in the flight orientation axes

Deviations-detecting interneurons contribute to steering adjustments during flight. (A) The deviation-detecting neurons (DDNs) receive input from wind-sensitive hairs and light detectors (compound eyes and ocelli) on the head of the animal. (B) The structure and projection patterns of three different DDNs are shown (ganglia are shown in color at left). DNIs receive input from the ipsilateral ocellus; DNM, from the medial ocellus; and DNC, from the contralateral ocellus. (C) A DNC neuron fires tonically when the horizon appears to roll to the left. After Reichert and Rowell 1986.
6.21 Important features of the DNC deviation-detecting neuron

(A) The axon of this DNC interneuron runs in the connective contralateral to its cell body in the brain (protocerebrum).
(B) An intracellular record from the DNC neuron shows that it responds briskly during a perceived leftward roll of the horizon. (C) The response of the DNC neuron to light input (to the left ocellus) is modulated both by an apparent movement of the horizon (top) and by air currents delivered to the front of the head (bottom). (D) The response of a DNC neuron to an air current to the head depends on the perceived orientation of the horizon. After Burrows 1996. (A) data from Griss and Rowell 1986; (B-D) data from Rowell and Reichert 1986.

6.22 Hypothetical model of how the DDNs might affect the steering system

Deviation information from sensory structures on the head activates a specific subset of DDNs, which signal a specific type of deviation from the intended flight path. This information is passed along to the flight interneurons (INs) and motor neurons (MNs) through thoracic interneurons (TINs), whose output is "gated" by the actions of the central pattern generator (CPG). If the flight motor neurons (MNs) receive this deviation-specific information, a corrective steering maneuver is produced. Although much more information is necessary to validate this model, it provides a framework for considering how critical steering adjustments might be executed in the face of changing forces during flight.