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The design and construction of a hang glider flight simulator

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THE DESIGN AND CONSTRUCTION OF A HANG GLIDER FLIGHT SIMULATOR

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GLOSSARY OF TERMS

AIRSPEED - Speed of the glider relative to the air.

ANGLE OF ATTACK The angle of the wing relative to the direction of motion through the air.

DEGREE OF SIMULATION - The number of a particular operational aircraft's characteristics that are present in a simulator.

FIDELITY - The accuracy with which a simulator reproduces the experience of flying the operational aircraft.

GROUNDSPEED - Speed of the glider relative to the ground.

LAMINAR AIR FLOW Smooth layers of air moving past a wing.

LIFT - Laminar airflow past an airfoil creating a low pressure area above the wing.

OPERATIONAL AIRCRAFT - The actual aircraft that a simulator is intended represent.

PITCH - Rotation of an aircraft around its lateral axis raising or lowering the nose.

RIDGE LIFT - Wind flowing up over a hill or ridge.

ROLL Rotation of an aircraft around its longitudinal axis raising one wing and lowering the other.

STALL - Occurs when the wing's angle of attack is increased to the point that the laminar airflow becomes turbulent and no longer produces lift.

THERMAL A column of rising hot air.

TRANSFER - The use of skills learned on a simulator to fly operational aircraft.

YAW Rotation of an aircraft around its vertical axis.

INTRODUCTION

Hang gliding is probably the closest a person can come to experiencing bird-like flight. Unfortunately, the precise skills needed to fly a hang glider are difficult to teach through demonstration or verbal instruction. Consequently, many people's first few flights are awkward and sometimes dangerous.

A hang gliding student's first flight is a solo flight, so control errors are understandable. However, every effort must be made to minimize these errors.

Classroom instruction about hang glider aerodynamics and control is helpful, but the first time the student's feet leave the ground the classroom lessons tend to get left behind. What is needed is some means for the student to gain hands-on flying experience prior to the first training flight.

This need prompted me to develop the Gooney Bird Trainer, a hang glider flight simulator that will imitate a hang glider's pitch, roll and yaw characteristics in response to a student's control movements. The simulator will also allow students to practice the launch and landing sequences.

To understand fully the thinking behind the design of the simulator, a cursory understanding of hang glider construction and control as well as an introduction to the process of hang gliding instruction are presented.

This thesis also includes a summary of relevant human factors studies. Because virtually no research has been done involving hang glider simulators, it was necessary to use the available research about traditional aircraft simulators.

CHAPTER 1

AN OVERVIEW OF HANG GLIDER CONSTRUCTION AND CONTROL

Construction

A hang glider is a foot launched motorless aircraft. The pilot is suspended in a harness from a single attachment point near the center of the glider. In flight, the harness supports the pilot in a prone position. The glider is constructed of a Dacron™ sailcloth on a rigid aluminum frame. Several ribs running from the front to the back of the wing giving it its airfoil shape (fig. 1).

Control

There are no control surfaces (ailerons, stabilizers, flaps or rudder). The only moving "part" on a hang glider is the pilot. The glider is controlled by the pilot changing body position relative to the airframe of the glider, thereby changing the apparent center of gravity of the glider.

Rotating an aircraft around its longitudinal axis is called roll, rotation around its lateral axis is called pitch, and rotation around its vertical axis is called yaw (fig. 2). By pulling back on the fixed control bar, the pilot's weight is actually forced forward toward the nose of the glider. The change in the pilot's position lowers the nose (pitch) resulting in an increase in speed.

Pushing the pilot's weight to one side lowers that wing (roll) and initiates a turn (yaw). Sharper turns require pitching the nose up as well.

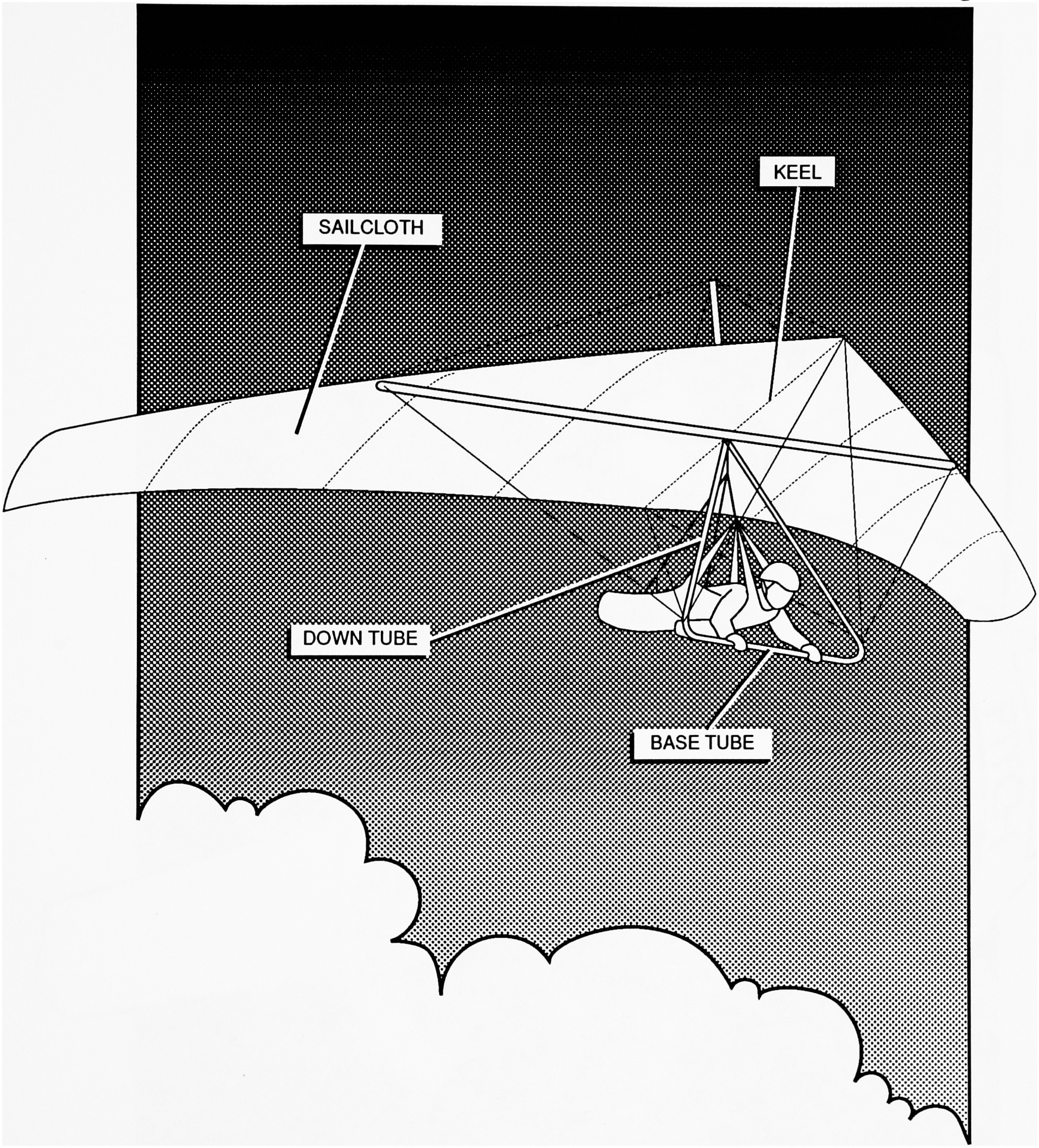

Fig. 1 HANG GLIDER

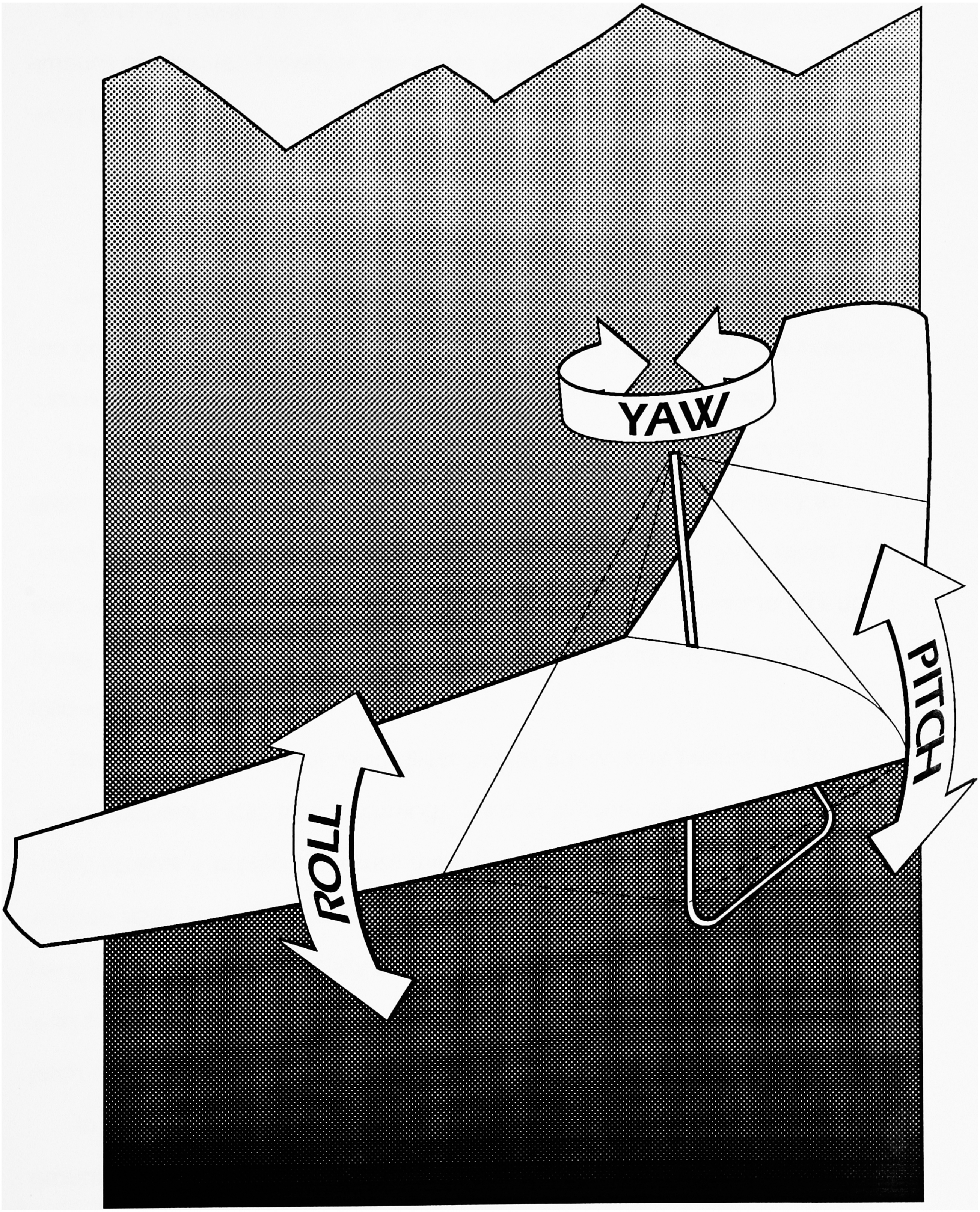

Fig. 2 AXES OF ROTATION

By shifting toward the rear of the glider the pilot can actually gain a small amount of altitude. However, the glider quickly loses air speed causing the wing to stall.

Stalls

Laminar air flow over the wing produces lift. If the wing's angle of attack is too great (such as when flying too slowly) the smooth laminar air flow becomes turbulent and the wing no longer produces lift. This is called a stall.

Hang gliders are designed to be inherently stable. This means that a glider that is flying too slowly, diving, or turning, has a built-in tendency to return to straight and level flight and resume an appropriate flying speed. A stall will automatically be followed by a dive in order for the glider to pick up flying speed. The more severe the stall, the more severe the dive that follows.

The inherent stability of hang glider design is a positive feature but it cannot prevent a stall from occurring. Stalls at altitudes of more than 100 feet rarely present a problem because there is enough room to recover. Low altitude stalls, however, are the number one cause of accidents and injury in hang gliding. This is especially true for beginning students who, beginning with their first flight and in close proximity to the ground, must learn about pitch control, air speed and stalls.

In the dive following a low altitude stall, the glider accelerates toward the ground. Usually, the hang glider takes the brunt of the impact. The control bar contacts first, pitching the glider forward and driving the nose of the glider into the ground. (Small wheels mounted on the bottom tube of the control bar can save the student's knuckles.) At this point the glider will stop abruptly but the pilot will not. Usually one of the down tubes of the control bars will be bent as the student pilot swings forward through the control bar. In more severe crashes the student may break an arm. In rare cases it is possible for the student to sustain head injuries by swinging forward forcefully enough to strike the forward section of the keel. Needless to say, proper pitch control is an important skill to learn.

Launch and Landing

During launch, the glider is supported on the pilot's shoulders. By running down a gently sloping hill with the glider at the correct angle of attack, the pilot will gain enough airspeed within a few steps to lift into the air. Launch sites are typically on hills that are 500' or more above the surrounding terrain.

Once in the air, the pilot must change from the upright running position to the prone flying position. On most harnesses this involves leaning forward into the harness and placing the feet into an attached stirrup for support.

The landing, of course requires the pilot to step out of the stirrup and push up into the upright position. Just prior to touching down the pilot must push the control bar forward to bring the nose of the glider up into a stall position to minimize ground speed.

CHAPTER 2

THE NEED FOR HANG GLIDER FLIGHT SIMULATION

The Current State of Hang Gliding Instruction

Novice Instruction. A typical hang gliding course for beginning pilots varies greatly among schools. Nearly all schools provide a ground school (classroom instruction) and actual flight instruction. The ground school may take anywhere from 30 minutes to several hours. It often includes instruction on glider construction, set-up, aerodynamics and ground handling.

Flight instruction is normally a gradual progression and may vary in length between one hour to several days, depending on the particular program. The student begins by making several practice runs with the glider on level ground to become accustomed to running with the helmet, harness and glider. If properly executed, the glider will gain enough airspeed to float up off the student's shoulders, imitating the first phase of a takeoff run. Once the instructor is confident that the student is ready, a takeoff run is made from part way up a small gentle slope. The additional speed generated by running down the slope allows the glider to produce more lift. Additional runs are made from higher on the hill until the student is able to become airborne.

Initial training flights are typically very short, little more than a take-off followed by a landing. As the flight instruction progresses, the student launches from higher points on the training hill. As the flights get increasingly longer the student is required to make minor turn corrections to keep the glider flying straight. Longer flights allow the pilot to practice gentle turns.

Current attempts at hang glider flight simulation. Few hang gliding schools make use of any kind of flight simulator. Typically, the simulators that are used consist of nothing more than a control bar and harness statically suspended from a fixed structure. The student will move the control bar to turn, and the instructor will rotate the student on the suspension line to approximate the effect of the control input. If the student pushes out on the control bar, the instructor can only describe verbally that this would cause the glider to gain altitude, lose speed and eventually stall.

In spite of the gradual progression of the instruction process, many hang gliding students are still overwhelmed by the many new sensations during a first flight. Consequently, there are a number of common errors made by novice students that could easily be corrected by use of a realistic flight simulator.

Common Errors of Beginning Students

Leaping into the air. There is a brief period during the take-off run that the glider lifts itself up off the student's shoulders but is not yet traveling fast enough to lift the weight of the student. The student feels the glider lifting into the air and not wanting to be left behind, leaps into the air. Since, the glider does not yet have adequate airspeed to lift the weight of the student, both the student and glider drop abruptly to the ground. Students must learn to continue the take-off run until the glider actually lifts them into the air.

Reversed turn response. The steering control in nearly any kind of vehicle requires the operator to move the control in the desired direction of turn. A hang glider, however, requires that the student's weight be pushed in the desired direction of turn, meaning that the student must push the control bar to the left to make a right turn. This control movement is not an intuitive response and frequently results in students reversing their turn responses at critical times during training flights. At a time when a gentle left turn is required, the student may make a gentle right turn. Believing that the wind has blown them further off course, the student pilot may respond by making an even harder right turn rather than the appropriate left turn.

Pivoting around center of gravity rather than shifting weight for a turn. Traveling head first in the prone position is also a new and unnatural experience for most people. It takes time to learn exactly where the body is located in space. Frequently, the result is errors in turning.

To make a right turn, a student must pull himself to the right side of the control bar. Because hang glider pilots are suspended from a single point, students often make the mistake of pivoting around their center of gravity rather than actually shifting their weight. The head moves to the right and the feet move to the left. The student feels that the necessary control movement was made to initiate a sharp right turn and is shocked to find that the glider is still headed straight for a tree.

Over-control. High aspect ratio wings (long and slender) are most efficient. Some hang gliders have wing spans of nearly forty feet. Because they are controlled by weight-shift rather than control surfaces, they do not respond immediately to the pilot's roll control movements. There is a slight delay before the glider begins to respond. There is a second delay period while the glider is actually rolling into the desired position. These two delay periods are called the primary and secondary response times.

Students respond to the movements of the glider. When the student initiates a turn and nothing happens immediately, it is a natural response to push the control bar a little bit more resulting in over control.

The high aspect ratio of today's hang gliders also means that they are very short from front to back making the pitch control extremely responsive. Because the control input required for pitch and roll are very different, it can be quite a task for the student to coordinate the two. The most common error of beginning students is low altitude stalls caused by over-reacting on pitch control.

CHAPTER 3

HUMAN FACTORS

Considerations in Developing a Hang Glider Flight Simulator

All of the available research on flight simulators pertains to simulators of traditional aircraft. Even though there are obvious differences (instrumentation, military applications, etc.), many of the physical sensations and learning theories are relevant to hang gliding as well.

As a result of my research, I found that any discussion of flight simulators must include an investigation of all factors involved in the training process including the student, the instructor, the flight characteristics of the operational aircraft, the simulator, and the training objectives.

The three primary reasons for using a simulator are: 1) greater control over the flight conditions that the student encounters, 2) lower risk compared to the actual operational situation and, 3) reduced training costs (Willigies 1973), (Valverde 1973).

The safety issue is probably the greatest concern for hang gliding schools since the hang gliding student's first flight is a solo flight. Hang glider flight simulators may make a significant contribution toward preparing students for this first flight. Other benefits of hang glider simulators include: the ability to train at night or during inclement weather, and public demonstrations in any location.

Some important considerations in developing a simulator that warrant further discussion are: degree of simulation, fidelity, transfer, cost effectiveness, and instructional considerations.

Degree of Simulation: How many aircraft characteristics are present in the simulator? During the course of a flight, a pilot of traditional aircraft gathers general flight information through visual cues, airspeed may be determined by listening to the air as it moves past, kinesthetic cues can indicate linear acceleration, and the pilot's vestibular sense detects angular (rotational) acceleration (Jacobs 1973). Because hang glider pilots use few if any instruments, they must rely heavily on these same physical cues.

It was discovered in research for traditional simulators that kinetic cuing improved performance in landings and other ground referenced training (Povenmire 1973), (Willigies 1973), (Valverde 1973). This means that a pilot's physical sensation of the pitch, roll and yaw motion of the aircraft provides information that is useful in flying the aircraft.

Two types of motion cues can be built into simulator design: maneuver motion and disturbance motion. Maneuver motion is pilot induced and represents the aircraft's response to pilot input. Disturbance motion represents environmental factors such as turbulence or aircraft mechanical problems.

Two characteristics of hang gliders illustrate a need for both disturbance and maneuver cues in hang gliding simulators. First, when air turbulence lifts one wing (disturbance motion), a pilot can respond much more quickly to the physical sensation of this motion than to the visual sensation. To be able to learn this skill in a simulator is a definite benefit. Secondly, because of the unique construction of hang gliders, roll control requires that the control bar be moved to the left for a right turn, and to the right for a left turn, just the opposite of most other types of vehicles a student may have experienced. This is a common and critical source of confusion for hang gliding students. A simulator with maneuver motion provides the student with immediate feedback as to the appropriateness of the control input.

Visual simulation is essential for ground-referenced control in any simulator (Willigies 1973), but this is especially true for hang gliders since there is never an option for an instrument landing. The visual cues for landing are helpful primarily for indicating ground speed, altitude and rate of descent.

Flying a hang glider requires that a pilot respond to visual, kinetic and auditory cues. If these cues are the helpful in flying an actual hang glider then, as far as practical, they should be represented in the simulator.

<u>Fidelity: How accurately does the simulator reproduce the experience of flying the aircraft?</u> The perfect high fidelity simulator design is not possible, necessary, or even desirable. First, it is not possible for a simulator to duplicate the range of motion of an aircraft. The most that can be duplicated is the initial acceleration. However, this initial acceleration is a very strong physical stimulus and one of the more important cues for evoking an immediate and appropriate response from the student. Since the primary purpose of the simulator is training, there is no need for a hang glider flight simulator to imitate motion beyond that which a pilot is normally able to perceive.

Kinesthetically, the human body has no way of perceiving straight-line consistent motion. The body perceives accelerations only. The motion of an elevator is felt only as the elevator is starting or stopping, no motion is felt while moving between floors. Consistent motion is perceived through the visual sense only. There is no need to physically simulate motions that are below the student's vestibular and kinesthetic thresholds for acceleration since they can't be perceived. Once the initial acceleration has ended, most high-end simulators return to the neutral position at a subliminal rate to prepare for the next required movement. This design feature is called washout (Hopkins 1975), (Lintern 1980).

To simulate a right turn, a typical aircraft simulator would imitate the initial rolling motion. The visual image would continue the illusion of the turn as the simulator gently returned to neutral. To pull out of the turn, the simulator would roll left as the visual image returned to level (relative to the pilot). The simulator would then, once again gently roll back to neutral.

The mechanisms necessary to design washout into a simulator would be too expensive to incorporate into a hang glider flight simulator. Excluding this feature from the design is not a significant problem since the primary objective for beginning hang glider students is to maintain straight and level flight. The instructor can move the simulator from the intended "flight path" and require the student return it to the neutral position.

Effective visual cues are typically accomplished with simple animated perspective line drawings produced on one or more CRT's (Willigies 1973), (Lintern 1980). The primary concern in maintaining high fidelity in simulators that provide both visual and motion cuing is the difficulty in avoiding any delay between the two different types of cues (Blaiwes 1973).

With a 10' to 12' range of motion, a hang glider simulator capable of pitch, roll and yaw movements in direct response to student control input will provide most of the visual and motion cueing necessary for training. The one cue that is not provided by such a simulator is forward motion. Maintaining the appropriate airspeed is the best means for avoiding stalls. The sound of the air rushing past the pilot and glider is the best indicator of airspeed.

During actual training flights groundspeed is the strongest visual cue for forward velocity and is closely associated with air speed. Groundspeed, however, is not a reliable indicator of airspeed. A glider with a groundspeed of 20 mph, flying in the same direction as a 15 mph wind will have an airspeed of 5 mph and consequently be in a full stall.

As a result, visual cues for ground speed are of questionable value in a hang glider simulator and may even reinforce poor habits. Auditory cues for airspeed are more important, less costly and should, therefore, be incorporated into the design if possible.

Though it is occasionally disputed, a basic premise of simulator design is that the greater the similarity between the training and operational situations, the greater the transfer (Adams 1979). As mentioned earlier, the three primary benefits in using flight simulators as opposed to operational aircraft for training are reduced cost, reduced physical risk to the student, and the instructor's increased control over the training task. Generally speaking, the higher the simulator fidelity, the greater the cost and physical risk, and the less control the instructor has over the situation (A hang glider flight simulator with 100% fidelity would be a hang glider). The real difficulty lies in determining the optimum balance between the simulator benefits and simulator fidelity.

Transfer: How much of what is learned on the simulator is used in a real flight situation? Transfer is a key consideration in simulator design. The cost, safety and convenience of a simulator are of little consequence if none of the training is transferred to the operational situation. Under most circumstances, there appears to be a strong correlation between high fidelity and high transfer (Adams 1979), but this is not always the case. Other instructional factors weigh heavily in the facilitation of transfer. It is possible for effective transfer to occur with a very simple mockup (Adams 1979).

Conversely, it is possible for a very elaborate simulator to produce negative transfer. If non-realistic motion is present in the simulator, the student may learn to respond to motion that doesn't exist in the operational aircraft (Willigies 1973).

The method of instruction when using a relatively simple hang glider flight simulator is very important. Fidelity will be limited by cost constraints. Visual, auditory and motion systems will be only crude approximations of reality compared to the multi-million dollar simulators used for many of today's sophisticated aircraft. The hang glider simulator should be used only to acquire the basic skills necessary for a safe first flight or to correct a recurring in-flight error. If the student spends enough time on the simulator to become an "accomplished" simulator pilot, much of what was learned may have to be unlearned to fly a hang glider.

Cost Effectiveness. Aside from safety, the main reason for using a simulator for traditional aircraft training is that it is more cost effective than training on operational aircraft. However, there is a point in simulator training when, even though the student is still learning, transfer no longer occurs at a high enough rate to be cost effective. To use a simulator beyond this point is considered over-training (Blaiwes 1973).

Though the cost of operating a hang glider is a small fraction of what it costs for traditional aircraft, the basic principle is the same. The greatest cost factor in using a hang glider for training comes from the high risk of minor, but costly, damage during a student's first few flights. A bent control bar or leading edge tube can cost between $20 and $80. This must be weighed against the cost of the instructor's time while teaching with the simulator. At some point transfer will become minimal or negative transfer will become significant enough to warrant termination of a student's simulator training.

Instructional Considerations. There are five important instructional considerations that should be incorporated into simulator training.

1) Knowledge of results If the student is to learn anything, feedback must be given as to the appropriateness of the student's behavior (Adams 1979). The more immediate, direct, and logical the feedback, the better. Verbal praise or direction from the instructor is helpful but it isn't nearly as effective or direct as the objective and immediate feedback from a relatively high fidelity hang glider flight simulator.

2) Identical elements vs. cognitive learning - Some researchers contend that the transfer of training is greatest when the training task and the operational task are most alike. Others believe that transfer should be produced by any means that develop the mental process required for dealing with the operational task (Blaiwes 1973), (Adams 1979). An appropriate solution will probably be a combination of the two. A hang glider simulator that is slightly more difficult to fly than an actual hang glider may better prepare the student pilot for flying a hang glider.

3) Stimulus - response learning "If a response is to be made to a stimulus, then the stimulus and the control for response to it must be in the simulator" (Adams 1979). Ideally a hang glider flight simulator should be able to simulate drifting off the intended flight path, excessive and inadequate speed, and a stall. The simulator should be able to represent these characteristics during the launch, flight, or landing phase. If the student pilot responds correctly, the simulator should return to a simulation of straight and level flight.

4) Student motivation and acceptance - The student must be motivated and the training should be a source of motivation (Hopkins 1975). People learn to fly hang gliders for enjoyment. The simulator should reduce anxiety and risk. It should give the neophyte a preview of the fun to come.

5) The simulator does not train the student - The entire training program (student, instructor, curriculum and training environment) must be viewed as a system. How the system uses the simulator is far more

important than the design characteristics of the simulator itself. The simulator is not an essential tool for flight training, but sound instruction is (Blaiwes 1973), (Caro 1973). The hang glider simulator needs to be designed as a part of a system not simply as a machine that imitates flight.

CHAPTER 4

THE FINAL DESIGN

Six fundamental design objectives were established early in the design process. These objectives represent the characteristics of an optimal hang gliding flight simulator :

1) Is an effective tool for training.

2) Is easy to operate for the instructor as well as the student.

3) Is easy to transport and set up.

4) Possesses a non-threatening attractive appearance.

5) Presents no threat to the safety of the students or instructor.

6) Is low cost, low volume manufacturing.

This chapter describes how and to what extent my prototype hang glider flight simulator, the Gooney Bird Trainer, meets these six design criteria.

Effective for Training

If the students don't benefit from using the simulator there is little point in using it. The goal was to design a hang glider flight simulator that would enable a student to practice four essential flying skills prior to the first flight: the take-off, straight and level flight, gentle turns, and the landing.

Basic configuration. The basic design of the simulator is a 10' lever arm attached to the top of a 10' tripod. A hang glider control bar is attached to one end of the lever arm. A student wearing a hang gliding harness is suspended inside the control bar. An adjustable counterweight at the other end balances the student's weight (fig. 3). The connection between the lever arm and tripod is a two axis pitch, roll, and yaw joint (PRY joint) that was developed for this simulator. This joint is instrumental in simulating pitch, roll, and yaw motions. The horizontal axis allows for simulated pitch movement. The second axis is nearly vertical and allows for the simulation of the roll/yaw movement.

Pitch control. By moving forward through the control bar the student moves away from the fulcrum (horizontal axis). The center of gravity of the lever arm is moved toward the student which causes the simulator to lower the student a distance that is proportional to the control movement. The downward motion simulates the pitch down and loss of altitude experienced during a dive (fig. 4). Conversely, moving back through the control bar causes the simulator to raise the student. The upward motion simulates the moderate altitude gain and pitching up experienced prior to a stall (fig. 5). The simulator produces realistic motion in response to the student's control movements through approximately 90° of pitch (45° up or down).

Stall simulation. The simulator itself is not designed to simulate stalls, although there is the potential for adding this feature in future designs. The mechanism needed to physically and realistically simulate a stall would be relatively complex and add considerable cost to the simulator. The benefits must be weighed against the cost.

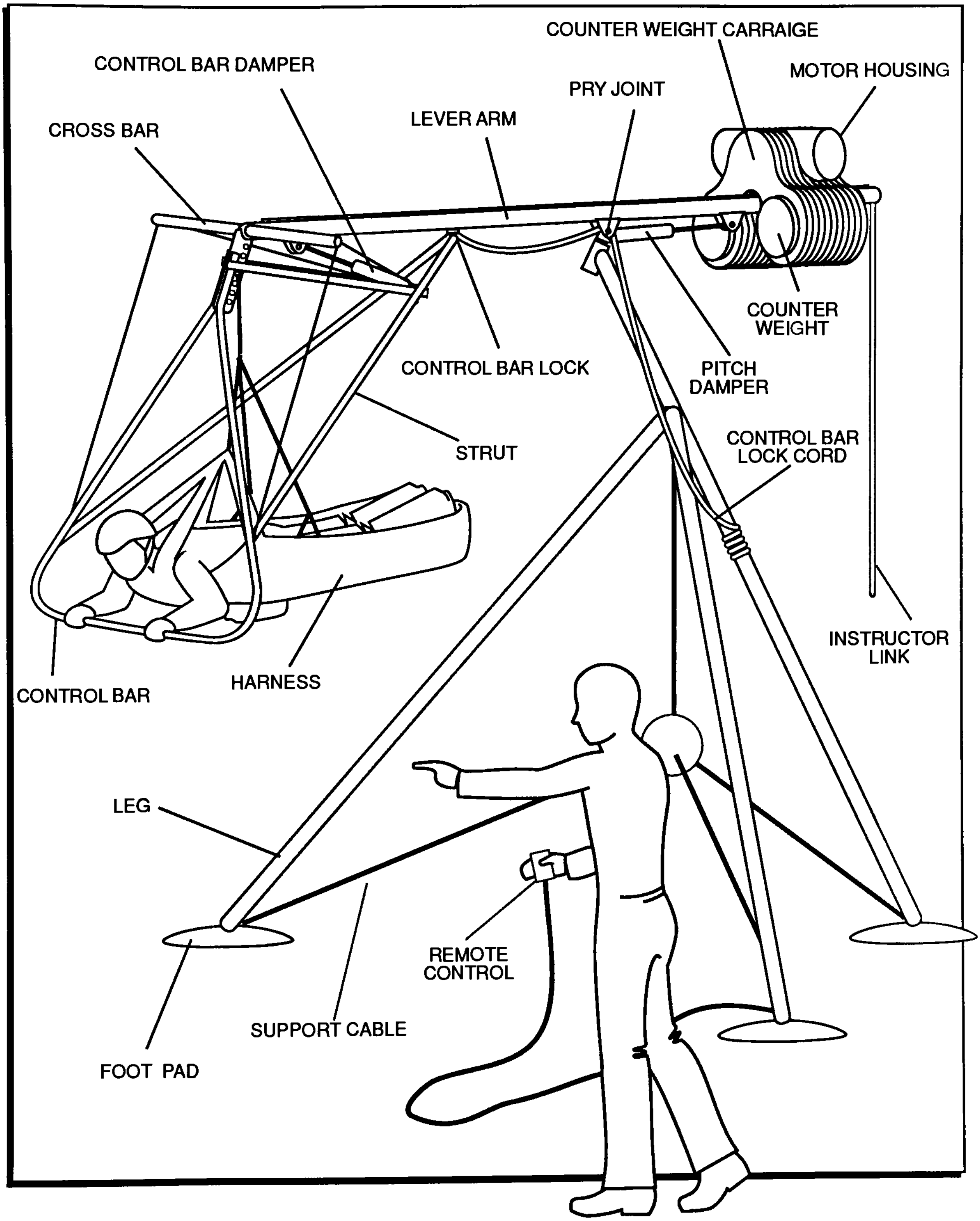

Fig. 3 THE GOONEY BIRD TRAINER HANG GLIDER FLIGHT SIMULATOR

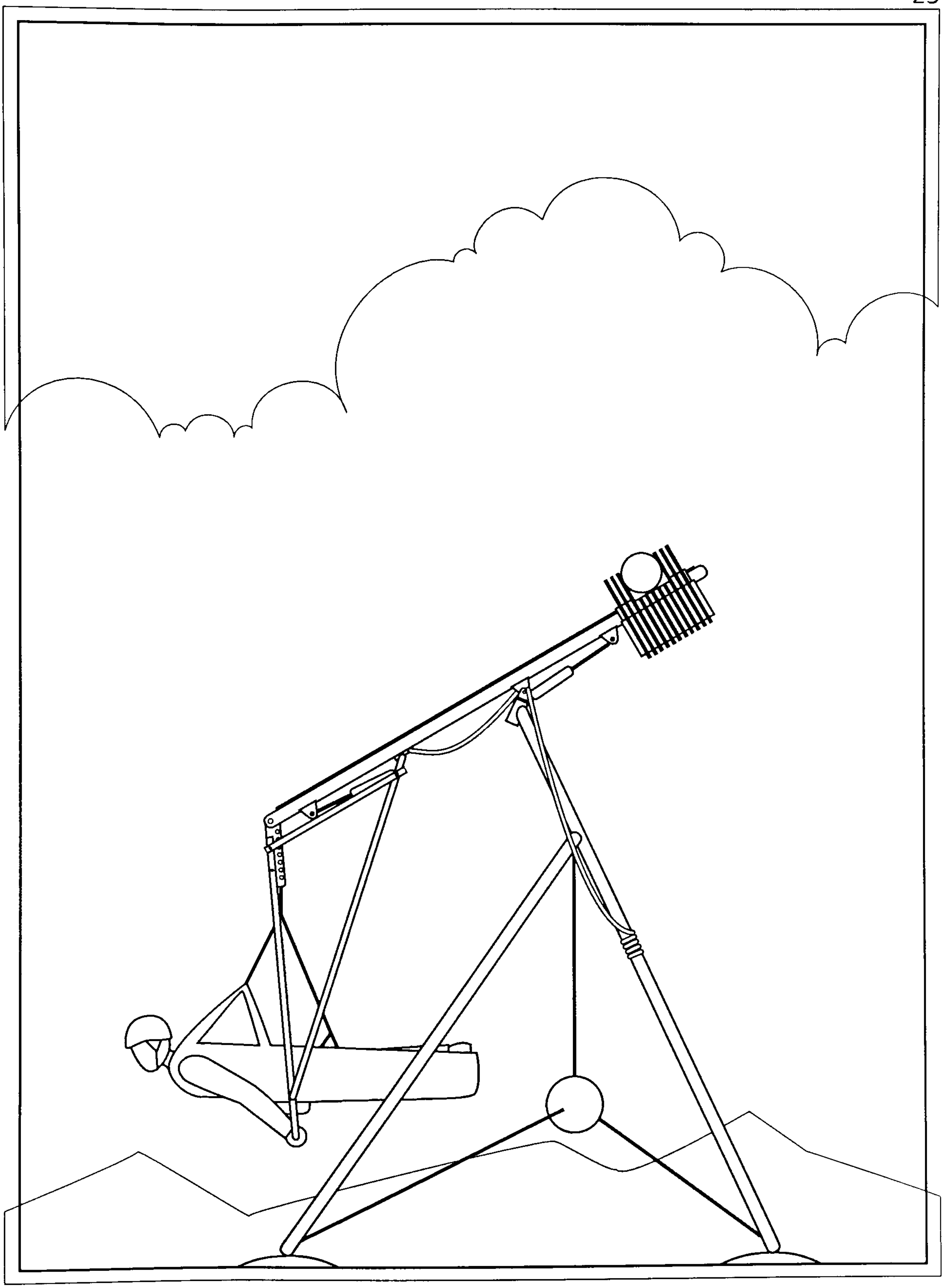

Fig. 4 DIVE POSITION

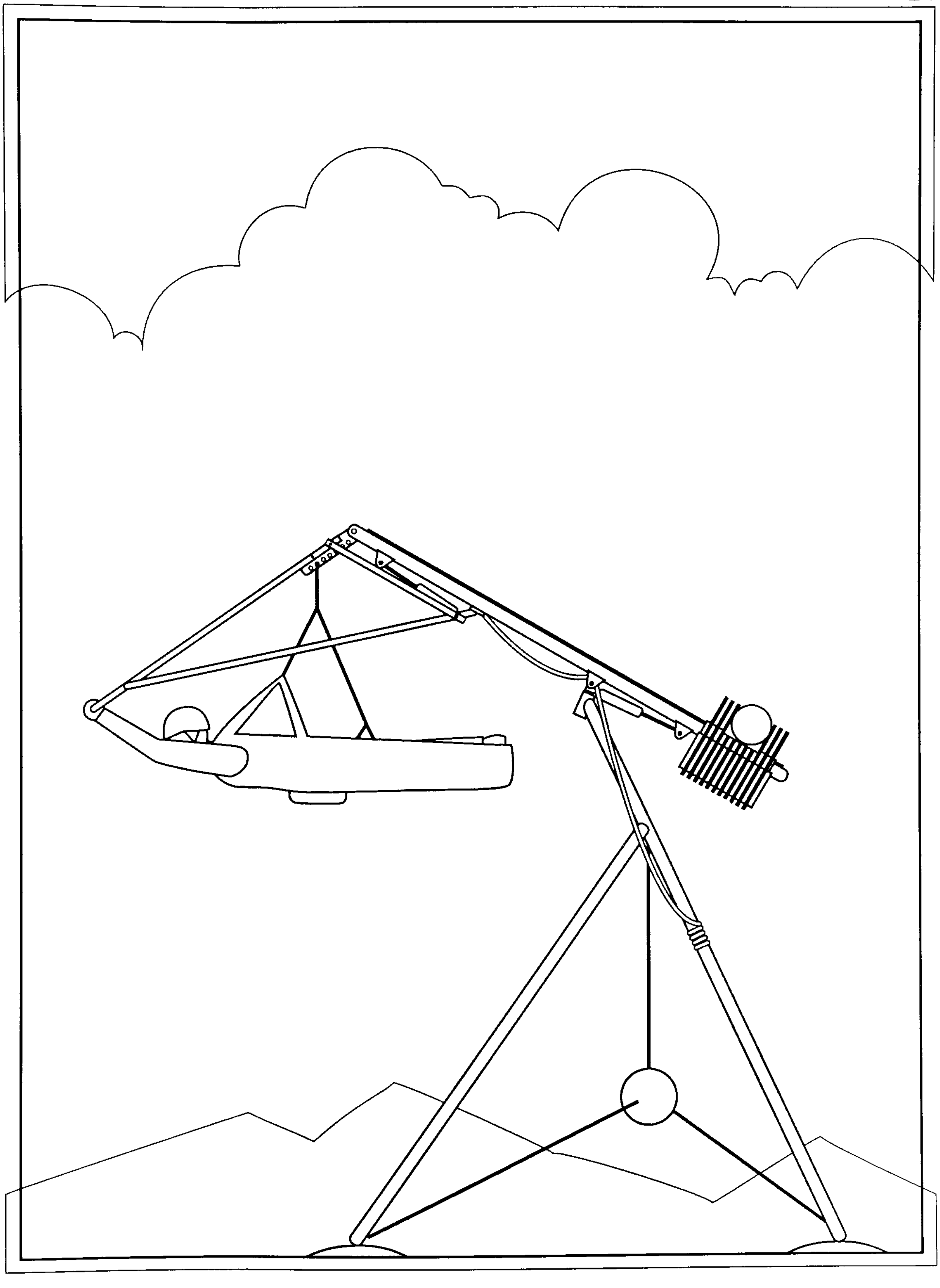

Fig. 5 STALL POSITION

As mentioned in chapter three, a device such as a noise generator may contribute to stall simulation by indicating airspeed. In an actual hang glider the best indicator of airspeed is the sound of the air moving past the glider and pilot. The volume of the noise generator would increase in a dive and decrease to nothing in a stall. The varying volume would provide students with an important auditory cue for avoiding and recovering from stalls.

Roll/Yaw control. Roll and yaw are linked in the simulator because roll control is the way in which the student initiates a turn (yaw) in an actual hang glider. The nearly vertical roll/yaw axis of the PRY joint is key to the roll/yaw response of the simulator. As the student shifts to the right, a twisting force is applied to the lever arm. Because the roll/yaw axis is leaning back slightly from vertical, the resultant force moves the pilot to the right.

The simulator produces realistic motion in response to the student's control movements through approximately 45° of yaw (22.5° left or right). High banked or sustained turns cannot be realistically simulated. This is of little consequence however since the beginning student is concerned primarily with maintaining straight and level flight or making gentle turns.

Not all hang glider motion is pilot induced. Breezes and air turbulence will continually change the heading of the glider if the pilot doesn't make corrections. This is an important skill for students to develop during simulator training. A mechanical link between the instructor and the lever arm can be used to simulate wind-induced yaw. The current simulator prototype, the Gooney Bird Trainer, uses a rope as the instructor link and is quite effective in producing yaw and pitch (nose up only) motions.

Take-off and landing. The take-off and landing procedures are special cases because the pilot is very close to the ground and must respond to the glider's air speed, ground speed, and altitude accordingly. The Gooney Bird Trainer is capable of providing rather crude simulations of a hang glider's response during take-off and landing. For this reason the basic skills necessary for pitch and roll control can and should be learned during normal flight simulation rather than during the take-off and landing phases. The simulator is still able to assist in the correction of some common errors made during the take-off and landing phases.

The transition between the vertical and prone pilot positions, and getting the feet into and out of the harness are some of the more critical skills to be learned during the take-off and landing phases of flight simulation. The control bar is used by the pilot to push into the upright position and pull down into the prone position. Care must be taken to avoid pushing the control bar forward or back causing the glider to stall or dive. This is especially important considering the close proximity to the ground during launch and landing.

Pilots sometimes look toward their feet when getting into the harness after launch. This in itself is not a good practice. But, the situation is sometimes worsened by the fact that the control bar is in the pilot's line of sight. Less experienced pilots have a tendency to inadvertently move the control bar to get a clear view of their feet. Because full attention is focused on the feet, the pilot no longer has a visual frame of reference with the ground. So even though the movement of the control bar may be slight, the results can be especially unpleasant.

The problem of students leaping into the air prematurely on their first flights can easily be corrected with full motion flight simulation. Even though the student pilot may feel the control bar rising up the Gooney Bird Trainer will not support the student's weight until the counterweight is in place. The simulator responds in much the same way as an actual hang glider would. Jumping into the air too soon is followed by an abrupt descent to the ground. The difference is that the simulator pilot is not moving forward at 10-15 miles an hour and therefore cannot be injured.

Ease of Operation

Flight simulation can be divided into three basic stages: the launch stage, the flight stage, and the landing stage. Each of these stages requires a different set of responses from the student and the instructor.

Flight simulation for the student. A hang gliding instructor needs to concentrate on the student. The flight simulator may be a person's first exposure to the sport of hang gliding. If the simulator appears complex, cumbersome, or at all unpredictable, it may give an unfavorable impression of the sport as a whole.

For the student, flying the Gooney Bird Trainer is generally easier than flying a real hang glider. While the control bar is resting on the ground the student pilot is hooked into the simulator by hooking the flight harness to the hang strap at the top of the control bar. The student then lifts the control bar (fig.6). Though the simulator feels a bit more stable while resting on the

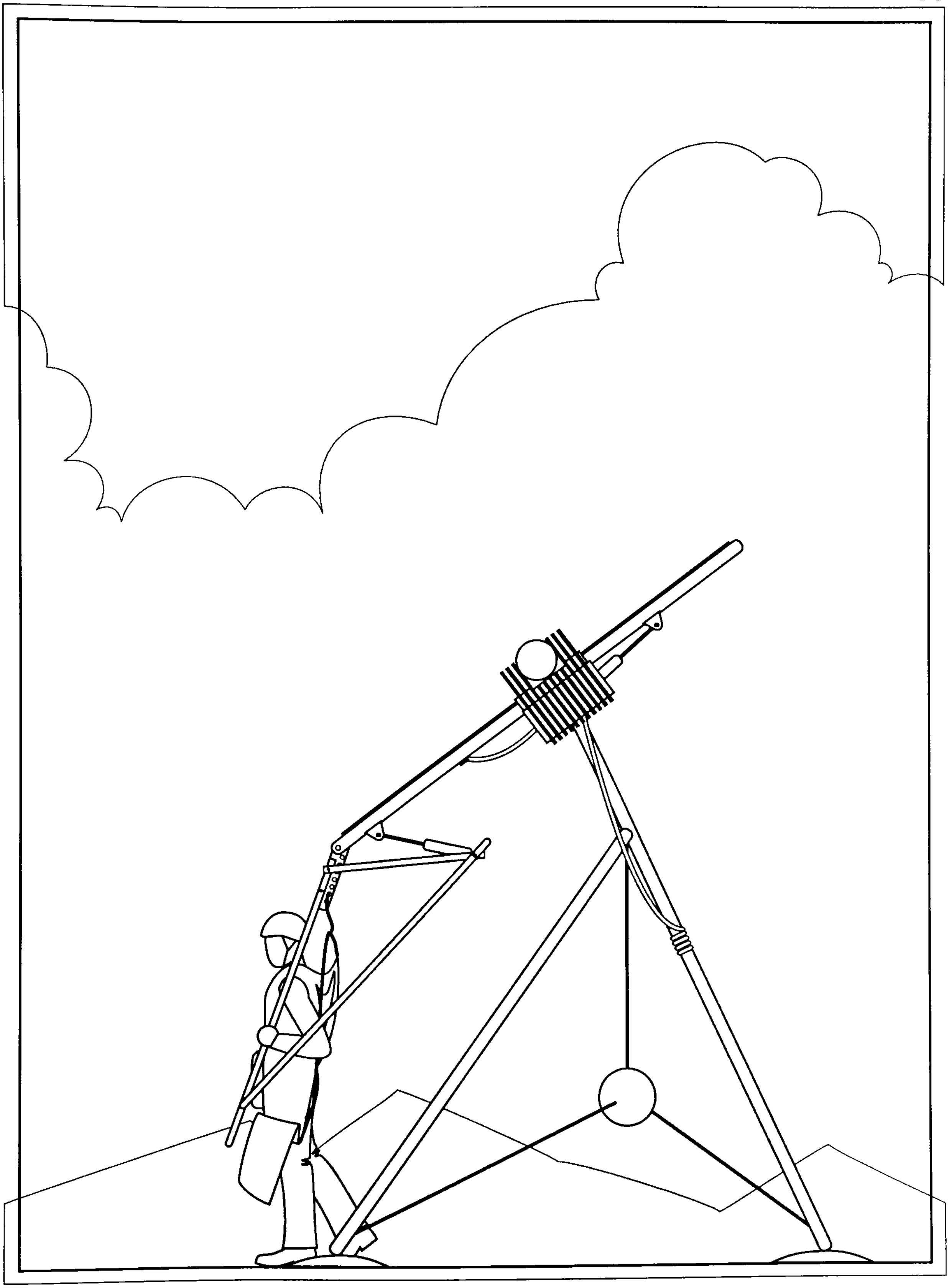

Fig. 6 LAUNCH POSITION

shoulders than an actual hang glider, the student still feels the 50 to 60 pounds of weight that can be expected when lifting a glider. While running in place during a simulated launch the control bar gets steadily lighter (as the counterweight moves back) until it "flys" up off the student's shoulders. After running a few seconds more, the harness lifts the student into the air as well.

Once in the air the student can lean forward into the prone position and practice gentle turns, pitch control, and straight and level flight (fig. 7).

While coming closer to the ground toward the end of the simulated flight, the student must first push up into the upright position. The landing stage requires the student to gradually push the control bar forward to maintain altitude and "reduce flying speed". Just prior to touching down, the pilot must push the bar forward to a full stall position to minimize ground speed (fig. 8).

Flight simulation from the instructor's point of view. The simulator's counterweight is attached securely to a motorized carriage. Using a remote control switch, the instructor can position the carriage anywhere along the full length of the lever arm. Prior to the launch run, the counterweight is positioned just ahead of the PRY joint to simulate the 50 to 60 pounds of weight of a hang glider.

During the launch run the counterweight is moved back gradually to simulate the increasing lift as a hang glider accelerates to flying speed. Once the student is airborne, the counterweight is moved to a position that perfectly balances the weight of the student with the lever arm in a horizontal position. The counterweight is left in this position until the beginning of the landing phase.

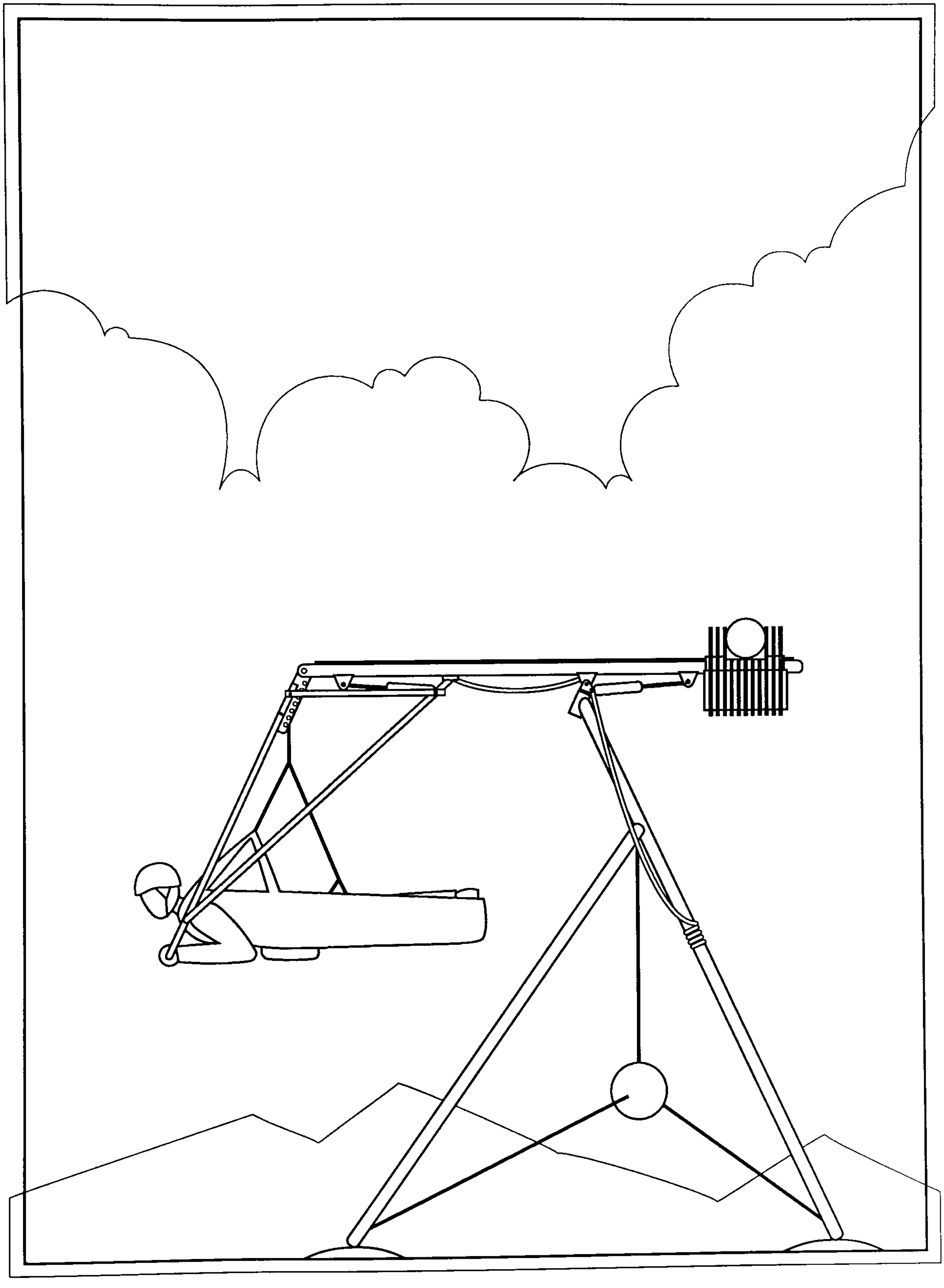

Fig. 7 NORMAL FLIGHT POSITION

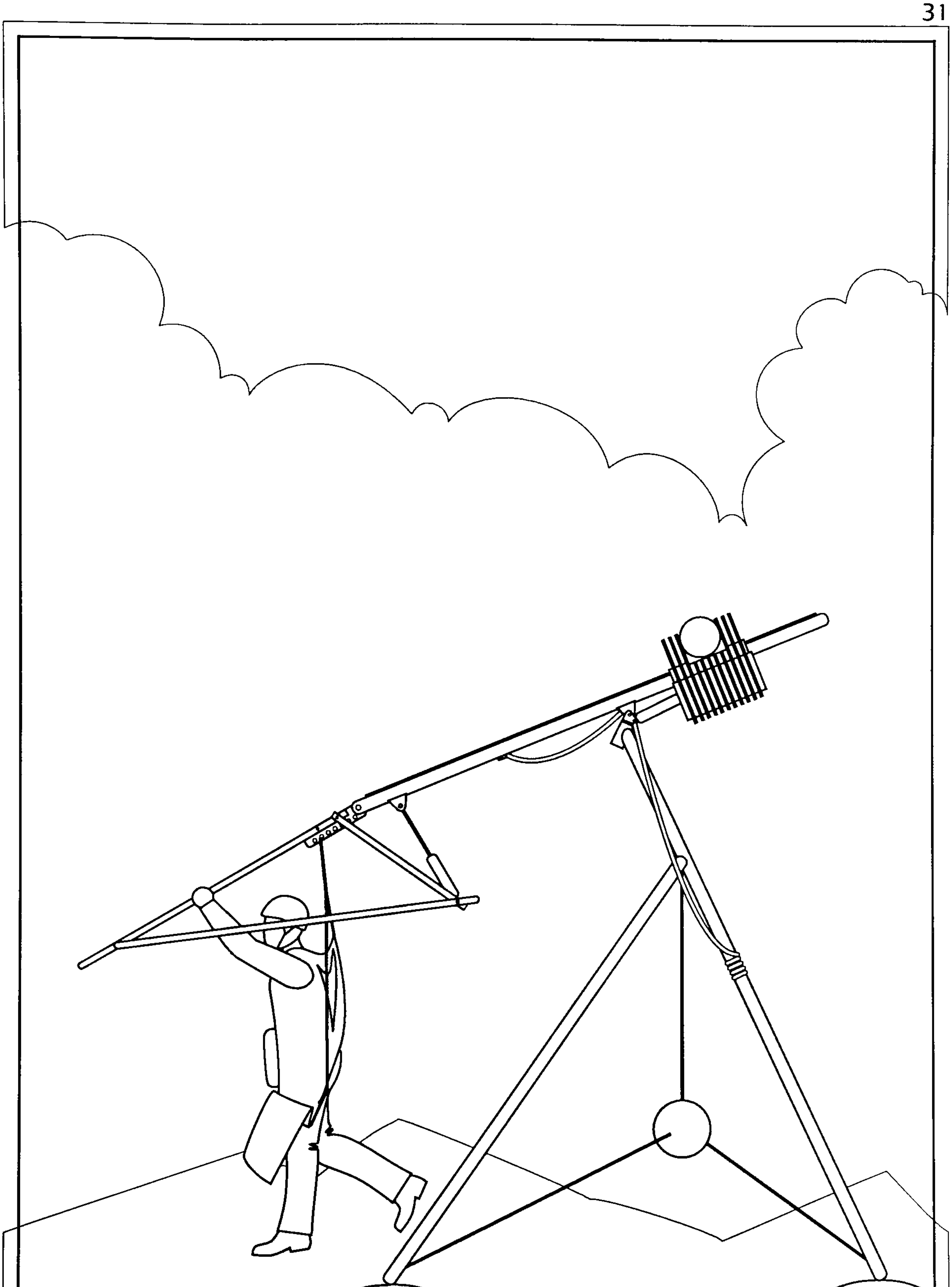

Fig. 8 LANDING STALL

Up to this point in the flight simulation, the control bar has been able to rotate around its own pitch axis at the end of the lever arm. This feature allows the control bar to hang in a more natural position during the launch sequence. A hydraulic damper serves to restrain the motion of the control bar. Damping provides the student with some pitch control by transmitting the force of the control movements to the lever arm. At the end of the launch stage, however, the control bar needs to be rigidly fixed to the lever arm to give the student more positive pitch control during the flight stage of the simulation. This stabilizing effect is accomplished by using the control bar lock to connect the control bar struts to the lever arm (fig 3).

During the flight stage of simulation, in addition to verbal directions, the instructor can use the instructor link to simulate crosswinds for which the student must compensate.

Just prior to the landing stage of simulation the control bar lock must be released (fig. 9). The instructor then begins moving the counterweight forward to lower the student. Once the student pushes the control bar into the full stall position, the counterweight is quickly positioned just forward of the PRY joint. The student settles to the ground, and is once again supporting the weight of a 50-60 pound "glider".

Portability and Assembly

Portability. The simulator doesn't have to be very realistic to pique the interest of a potential student, but it does have to be portable to be accessible

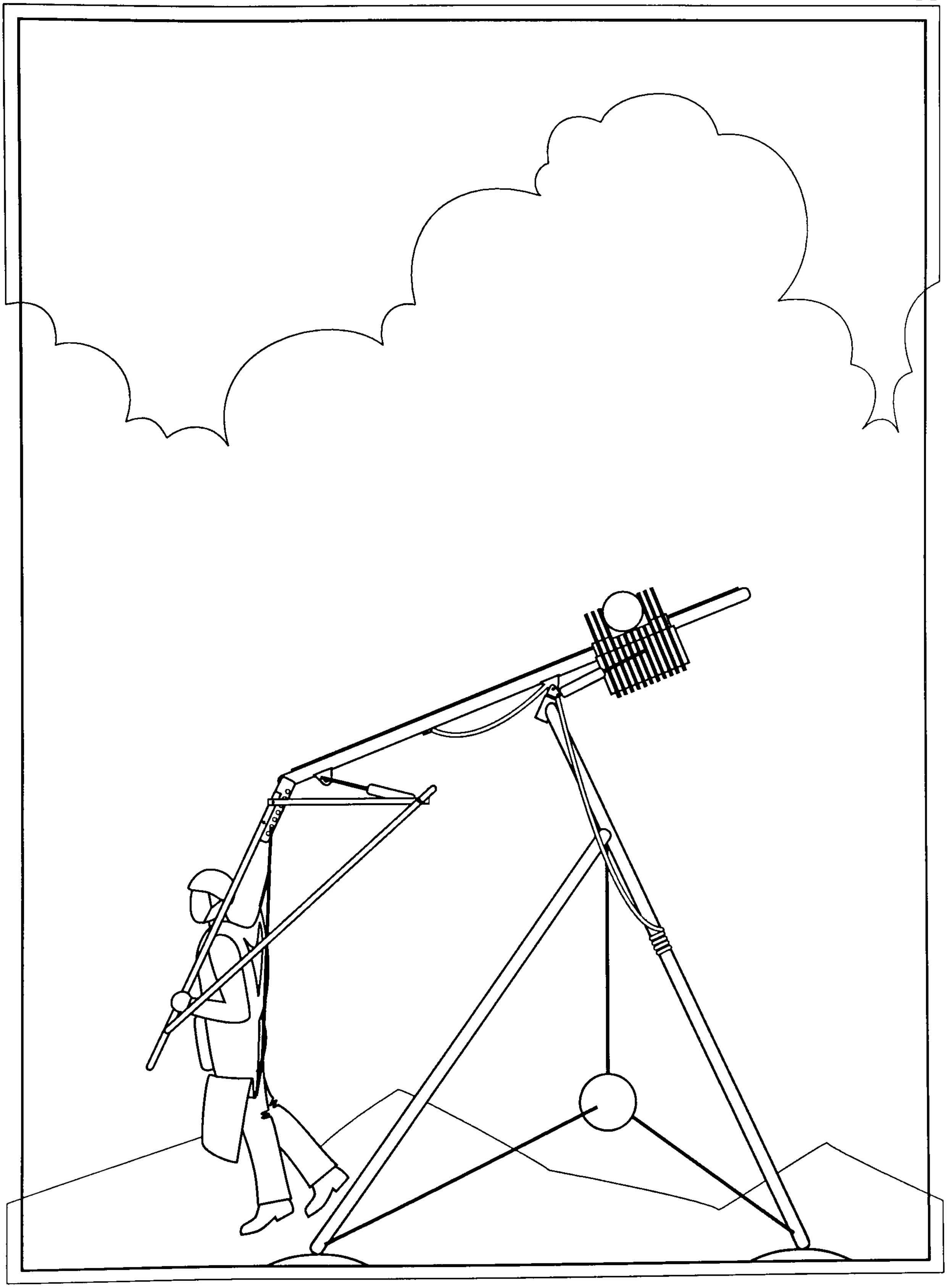

Fig. 9 LANDING APPROACH

to the public. The entire simulator can be transported in the back of a full size pick-up truck and assembled at the training or demonstration site.

Assembly. Four people can assemble the the simulator in about 30 minutes. Two people are needed to assemble the three legs of the simulator. The two front legs are slid onto short posts that are permanently attached to the rear leg; the support cables are then pinned in place (fig. 10). A large foot pad fits onto a pin at the end of each leg to prevent the legs from sinking into soft ground or damaging wood floors.

The positioning of the lever arm is the most difficult part of the assembly. Two people on ladders are needed, one on either side of the rear leg to guide the two halves of the PRY joint together. Two people are also needed on the ground to help lift the lever arm into place. Once the lever arm is secured, the pitch damper is bolted in place.

A total of 312 pounds of weight must be loaded onto the counterweight transport carriage. To make loading the weight more convenient the simulator is designed so the carriage can be moved to the front end of the lever arm allowing the weights to be loaded from the ground rather than a ladder (fig. 11). There are 24 lead weights that weigh 13 pounds each. Each weight has a slot that allows it to rest securely on the weight carriage without the use of tools for attachment.

The control bar assembly can be transported fully assembled. Two bolts fasten the assembly to the front of the lever arm. Another bolt fastens the control bar damper at the rear.

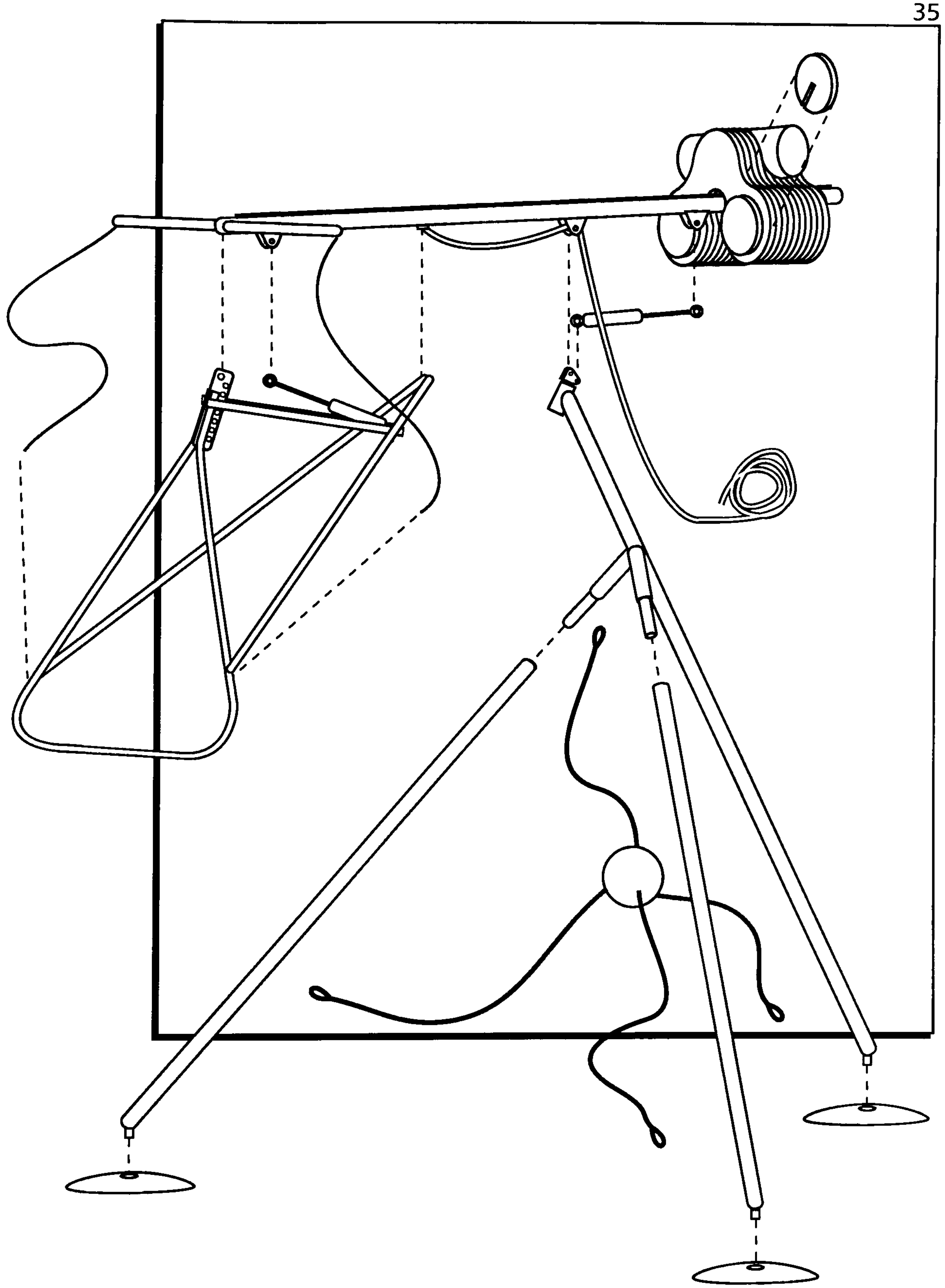

Fig. 10 THE GOONEY BIRD TRAINER ASSEMBLY

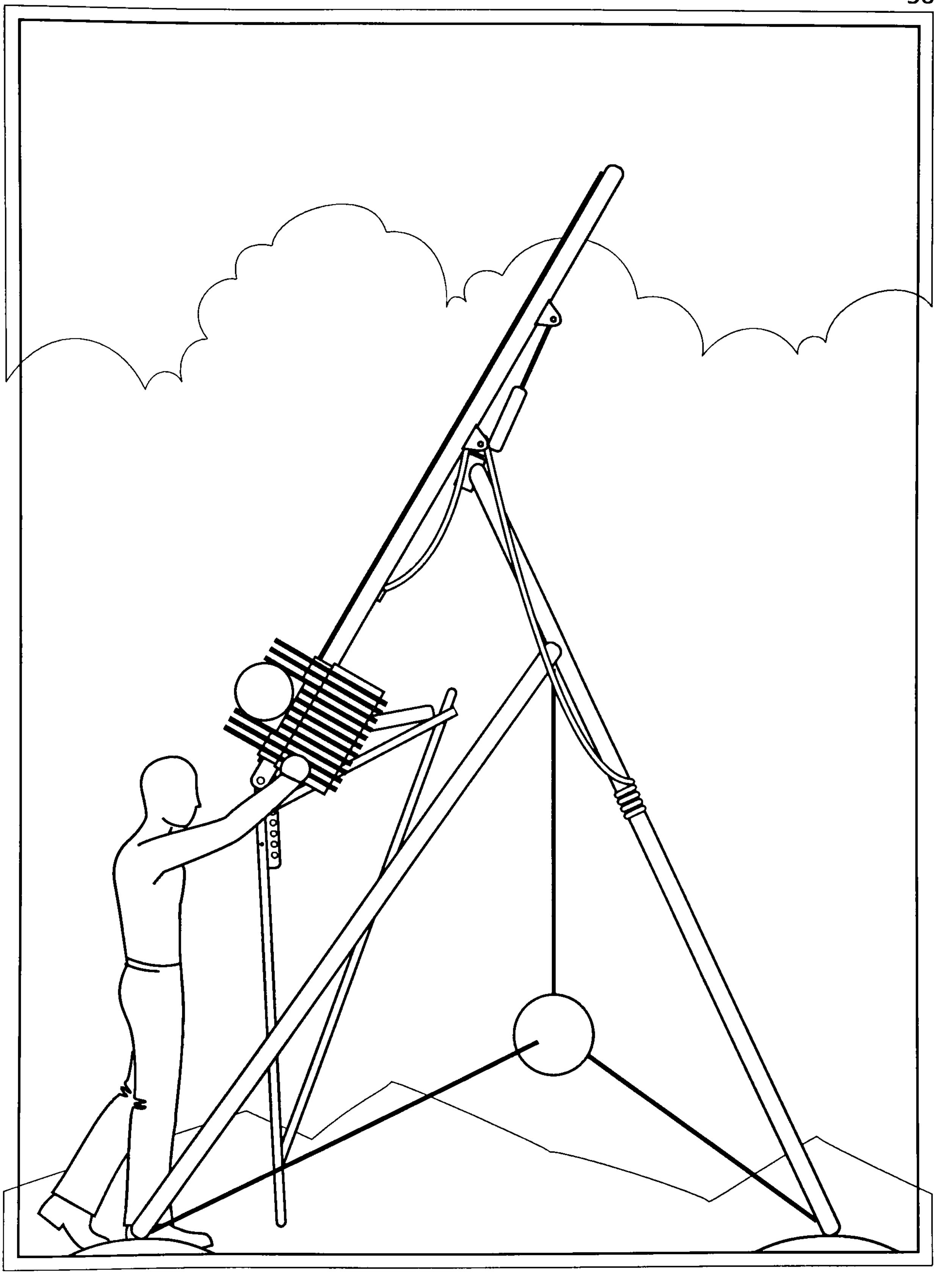

Fig. 11 LOADING COUNTER WEIGHTS

The power cord runs from the drive motor on the weight carriage, down the inside of one of the front legs to a cable remote switch, and then to a twelve volt power supply (fig. 3). The power supply may be a car battery alone, for simplicity during short term use; a car battery with battery charger, for indoor instruction or demonstrations; or attached to a car battery in an automobile, for use at a remote training site.

Non-threatening Attractive Appearance

The name. Every effort was made to develop a design that would reduce the anxiety of students, this includes the name: the Gooney Bird Trainer. "Gooney Bird" is a nickname for the albatross, a soaring bird that is known for it's graceful flight and clumsy landings. This is a tongue-in-cheek reference to the sport of hang gliding. Hang gliders are also quite easy to operate in the air and often exceptionally awkward on the ground, even for experienced pilots. The name also suggests that this simulator can help students become better "gooney birds".

Appearance. The anxiety level of beginning students can be quite high, but the imposing size or mechanical appearance of a simulator shouldn't contribute to this stress.

The Gooney Bird Trainer has a playful, almost toy-like, appearance to stimulate interest in the simulator itself, as well as reduce the anxiety of first time students. Because of the sports-oriented nature of the product, it was given a spontaneous-looking spattered paint finish, similar to those that have become popular on other types of sports equipment and athletic apparel.

The painted surface makes a transition from a chaotic multicolored spattered finish on the lower portion of the simulator, to a simple purple background with yellow flecks at the top. This transition from complex to simple is a visual metaphor for the student's transition from earthbound to airborne.

There are certain elements of the mechanical design that are important to the stability of the simulator: the three foot pads, the central cable connection, and the counterweight carriage. These elements were given a simulated granite finish to emphasize their role as components of strength and stability.

Each of the stainless steel support cables has a fluorescent pink covering to symbolize the force or energy transmitted through them. A rather large granite textured sphere covers the central cable connection. The combination of all of these elements give the simulator the look of an over sized Tinker Toy™ sculpture; a look that serves to put the students at ease without diminishing their confidence.

Safe to Use

Safety is the primary reason for using a hang glider flight simulator. If the simulator itself presents a significant risk to the student, the instructor, or the spectators, there is really no benefit in using it. As discussed earlier, it is generally accepted that the higher the fidelity of a simulator, the greater the transfer. The problem that arises, is that a simulator capable of realistically simulating a poor landing may cause injury to the student.

The Gooney Bird Trainer was designed so that a student in the prone position cannot contact the ground while the control bar is locked in the flight position (fig. 4). When the control bar is unlocked and the student is in the standing position, the student is able to touch the ground feet first (fig. 6). But ascent and descent at this point is controlled more by the instructor moving the counterweight than the student's control movements. The counterweight drive motor has a very low maximum speed, eliminating the risk of lowering the student too abruptly.

During a simulated flight, while most people are watching the person doing the flying, there is a 300 pound counterweight at the other end of the lever arm that is moving rather quickly at times. To minimize the risk to people standing nearby, the rear portion of the lever arm is short enough that it can come no closer than 6'6" to the ground while the lever arm is in the maximum pitch up position (fig. 5).

Low Cost Manufacturing

The target market for the Gooney Bird Trainer is hang gliding schools. The very small and specialized potential market for this product dictated the need for low cost and low volume manufacturing processes. Where ever possible, off-the-shelf materials and components were used to keep manufacturing costs down. The leg tubes and lever arm are made of 3.5" steel pipe with standard end caps. An actual hang glider control bar is used in the control bar assembly, and the struts are pre-anodized aluminum tubing that match the control bar. Hang gliding hardware and stainless steel cable is used to build the control bar assembly. The foot pads are actually farm equipment harrow disks that have been modified slightly.

The use of off-the-shelf components minimizes the need for machining during fabrication. Whenever possible, welding is used in manufacturing to further reduce the need for machining and expedite the manufacturing process. The only components that require fasteners for manufacturing are those that must be disassembled for transporting or repair of the simulator. Steel components that were susceptible to rusting are primed and painted.

Manufacturing costs will be in the $1000 to $1500 range. The simulator probably can be marketed successfully at a retail price of $3000 to $4000.

CHAPTER 5

THE COMPUTER AS A TOOL FOR INDUSTRIAL DESIGN

The designer's ideas are developed and communicated to others largely through renderings and mechanical drawings. As the power and sophistication of computer hardware and software increases, and as the cost drops, computers are being used increasingly to develop and communicate design concepts. One of my objectives in this thesis was to explore the use of the computer as a design tool.

CAD. A Macintosh computer was used in the design, development, and presentation of the Gooney Bird Trainer. The initial design began with 3D CAD drawings using Intergraph's MicroStation. Working in 3D quickly resolved many questions of clearances and range of motion. Dimensioned part drawings could then be developed for building the prototype simulator.

Rendering. Before going to prototype, however, several computer renderings were developed to determine the most appropriate appearance of the simulator. The scene depicted in figure 12 never really existed. The picture was created from a combination of traditional photography, ray tracing software, and image editing software.

Because it was not possible to transfer the drawing of the simulator from MicroStation to another 3D drawing package, it was necessary to redraw the simulator in StrataVISION3d. StrataVISION3d is a three dimensional drawing and ray tracing software package.

Objects in StrataVISION3d are first drawn as three dimensional wire frame structures which can then be assigned various surface attributes such as color, texture, pattern, reflectivity and degree of transparency. Components of the simulator with solid colors were assigned the appropriate color and given a gloss finish. Aluminum components were given a mirror finish.

The spattered paint finishes were created as two dimensional surfaces in Adobe's Photoshop (image editing software) using the gradation and airbrush tools. The surfaces were then brought into StrataVISION3d and "wrapped" around the appropriate components in a process called image mapping.

Even though the surface attributes had been chosen, the simulator still appeared as a wireframe drawing. The next step involved a process called ray tracing in which the computer calculates the path of light rays between the light source, the object, and the viewer. Ray traced objects look realistic partly because they cast shadows and are properly shaded. But the primary reason these objects are so convincing is that they reflect their surroundings. For this reason, it was necessary to surround the flight simulator three dimensionally with images scanned from photographs of trees, grass, and sky, before ray tracing. This gave the gloss surfaces something to reflect.

Once the ray tracing was completed, the simulator was "cut" from the surrounding images. It was then "pasted" into an appropriate background scene as a two dimensional image by using Photoshop. Care was taken before beginning the ray tracing to set the position and intensity of the light source as well as the perspective of the wireframe simulator to match the light source and the perspective of the background scene.

The images of people were then scanned from photographs, scaled to the proper size, and "pasted" into the background picture. The people were photographed at the same time of day and from the same general direction as the background scene in order to maintain the illusion of a single light source. Since the simulator was a two dimensional image at this point it was necessary to draw in the cast shadows. After blending the jagged edges between the scanned images and the background the picture was complete.

The process is in its infancy and the technology is still developing, but even at this early stage the implications for concept development in industrial design is tremendous.

CHAPTER 6

CONCLUSION

There is a tendency in the field of industrial design to place great emphasis on the physical appearance of products, and with good reason. The visual aesthetics of products is the part of design that is most readily noticed, most frequently publicized, and most aggressively marketed. It is the part of design with which designers are commonly associated and for which they are most frequently awarded.

But, industrial design involves much more than visual appearance. The primary reason for the existence of any product is to perform a function. The design process needs to address the user's total aesthetic experience; the visual, auditory, tactile, psychological and emotional experience of using a product to perform a task. Additionally, when a product is not in use, it should still be a welcome addition to the living or working environment. The industrial designer, in creating a product, is creating an aesthetic experience that has an effect on all of the senses and perceptions of the end user.

Designing a hang glider flight simulator demanded that I look beyond the problems of simply developing the product's visual aesthetics. In developing the Gooney Bird Trainer, it was imperative to use a comprehensive approach to the design process; to develop a prototype hang glider flight simulator that is an effective, safe, and easy to use tool for hang gliding instruction.

After clearly defining the problem, studying the relevant human factors literature, and establishing design criteria for the aesthetics, I set out to optimize the user interface in each facet of the design. The computer proved to be a valuable tool in each step of this process.

As part of a comprehensive training program, the Gooney Bird Trainer can help student pilots gain useful hands-on "flight" experience prior to their first flight. Students and instructors will be able to see and correct improper procedures before they cause accidents or become habits. The Gooney Bird's playful appearance and comprehensive design insure an enjoyable and rewarding experience for both the student and the instructor, which, after all, is the reason for learning to fly.

GOONEY BIRD
TRAINER
HANG GLIDER FLIGHT SIMULATOR

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