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EFFECTIVE APPROACHES TO DISORIENTATION FAMILIARIZATION FOR AVIATION PERSONNEL

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I. Problem.

A number of general aviation pilots are unaware of the potential hazards of disorientation or vertigo, and many feel that they are immune to these undesirable aspects of flying. The major basis for this lack of experience is not immunity but the fact that most general aviation pilots are "weekend pilots" (i.e., infrequent flyers who rarely fly under anything other than good VFR conditions). Contributing to the latter is the fact that the vast majority of private pilots (about 96 per cent in 1969)[10] do not have instrument ratings, and many who are so rated do not maintain instrument proficiency. Since disorientation and "pilot's vertigo" are most likely to occur under IFR conditions, there is considerable danger in the feeling of security that pilots may develop regarding their ability not to suffer disorientation—a feeling that may be reinforced as a result of each VFR flight in which disorientation does not occur. In addition to those general aviation accidents which can be attributed directly to spatial disorientation, this unfortunate conviction is a possible contributing cause in many of the NTSB fatal accident reports which indicate that the pilot "continued VFR flight into adverse weather conditions."

In the past, instructors in the CAMI Aeromedical Education Branch felt that disorientation was one of the more difficult topics to present meaningfully in physiological training courses. As noted above, many pilots felt that it was not a problem of consequence (although, through the years, it has been repeatedly documented as a significant flying hazard),[4 17 20 22 27] and the usual Barany chair demonstration did not seem to be validly related to flight situations. As part of the CAMI Aeromedical Research Branch's contribution to safety education, teaching demonstrations were developed that proved to be enthusiastically accepted by students and instructors alike. Alternative teaching methods have evolved both as a result of assisting others in developing techniques, and from an extensive program of disorientation training for general aviation pilots conducted by the CAMI Aeromedical Education Branch.

The purpose of this report is to explain our approach to familiarizing aviation personnel with the hazards of disorientation and to provide suggestions for use in other training programs. Much of the information presented here is available in scientific and technical literature and the techniques detailed are not the only ones available; they have simply proven to be particularly effective and instructive, in the combinations in which we have used them, for the groups which have been exposed to them. It is important to note that our methodology is not designed to train pilots so that they will be immune to disorientation problems (no one with a normal vestibular system is immune), but only to familiarize them with many of the unusual and false perceptions of vestibular origin which can occur in flight, and to impress upon them the importance of obtaining an instrument rating and of maintaining instrument proficiency.

II. Disorientation Defined.

Disorientation refers, in general, to an incorrect appraisal of an individual's position, location, or movement. In aviation, the incorrect appraisal specifically relates to the attitude (orientation) or motion of the pilot and his plane with respect to the earth. On some occasions, disorientation in the air consists of true *vertigo* (sensations of rotary motion of the external world or of the individual himself) and/or *dizziness* (sensations of unsteadiness with a feeling of movement within the head). Indeed, the three terms "disorientation," "vertigo," and "dizziness" are frequently (if inaccurately) used interchangeably to describe a wide variety of symptoms such as false sensations of turning, of linear velocity, or of tilt. When used by pilots, "vertigo" almost invariably refers to their awareness of any of the various forms of disorientation.[13]

Assessments of pilot experiences indicate that most of the "disorientation" difficulties encountered by normal pilots in aircraft are referable to inadequate and unreliable sensory information.[2 3 4 18 19 21 26] In this regard, the visual and the vestibular systems are of critical importance.

III. Introductory Lectures.

To provide an effective understanding of what causes disorientation or "pilot's vertigo," to point out that the sensations are "normal," and to demonstrate that the illusions involved are powerful, even though predictable under many circumstances, students are first provided with background information. Sources for this material are plentiful.[8 9 12 13 14 15 16 17] Selections from Gillingham's[9 12] approach are generally used by Aeromedical Research Branch personnel at CAMI and, with slides, the material is covered in about 30 minutes in the sequence outlined below:

(a) Simple physiology of the vestibular system is presented.

(b) The stimulus to the system is defined as acceleration and gravity.

(c) The sensations and the eye-movement (nystagmus) responses which occur upon stimulating the vestibular system in the absence of visual information are explained.

(d) The importance in aviation of the interaction of the vestibular and visual systems is stressed.

(e) Types of illusions and disorientation which occur in flight include:

(1) the leans
(2) graveyard spirals and graveyard spins
(3) Coriolis illusions
(4) oculogyral illusions
(5) oculogravic illusions
(6) elevator illusions
(7) general disorientation
(8) autokinetic movement.

(f) The physiological and psychological bases for the illusions are detailed. For example, the concept of a perceptual threshold is introduced in explaining the "leans"; the responses generated by angular accelerations (decelerations) provide the basis for the graveyard spiral and the graveyard spin; the resolution of forces acting on the semicircular canals as a result of head movements during angular accelerations (these are called Coriolis vestibular effects) is specified.

(g) The adequacy of the vestibular system in earth-bound activities is contrasted with its inadequacy in some flight environments. The notion is introduced here that the eye-movement responses (nystagmus) to vestibular stimulation while making head movements under earth-bound conditions serve to keep objects from blurring. It is pointed out that in an air or space vehicle, however, the visual object (e.g., instrument panel) and the pilot's head may be fixed (i.e., unmoving) relative to each other and the stimulus may be initiated by motion of the vehicle; under these conditions, nystagmus will not serve to aid the pilot but will interfere with good foveal fixation and may cause blurring of vision.

(h) Problems in flight can arise when the pilot does not attend to sources of orientation information (the instruments and his vestibular sensations) for some period of time. When he resumes attending to them, he may expect one set of information and receive data contrary to his expectations and thereby suffer severe disorientation.

These forms of disorientation are discussed in terms both of the operation of the vestibular system alone, and of the interaction of that system with the visual system. In this format, illusions resulting from the distortion of visual cues, which may lead to such problems as landing short of the runway, are generally not discussed. Such illusions are primarily or solely errors in visual perception and are not peculiar to maneuvering air or space vehicles; however, a good review of these problems, as related to aviation, appears in a paper by Cocquyt.[5]

IV. Our Basic Techniques for Disorientation Familiarization.

As noted above, considerable emphasis is placed on the interaction of the various sensory systems, particularly those of vision and the semicircular canals. Since the pilot almost invariably has some visual frame of reference (e.g., if nothing else, at least the cockpit interior), his inflight

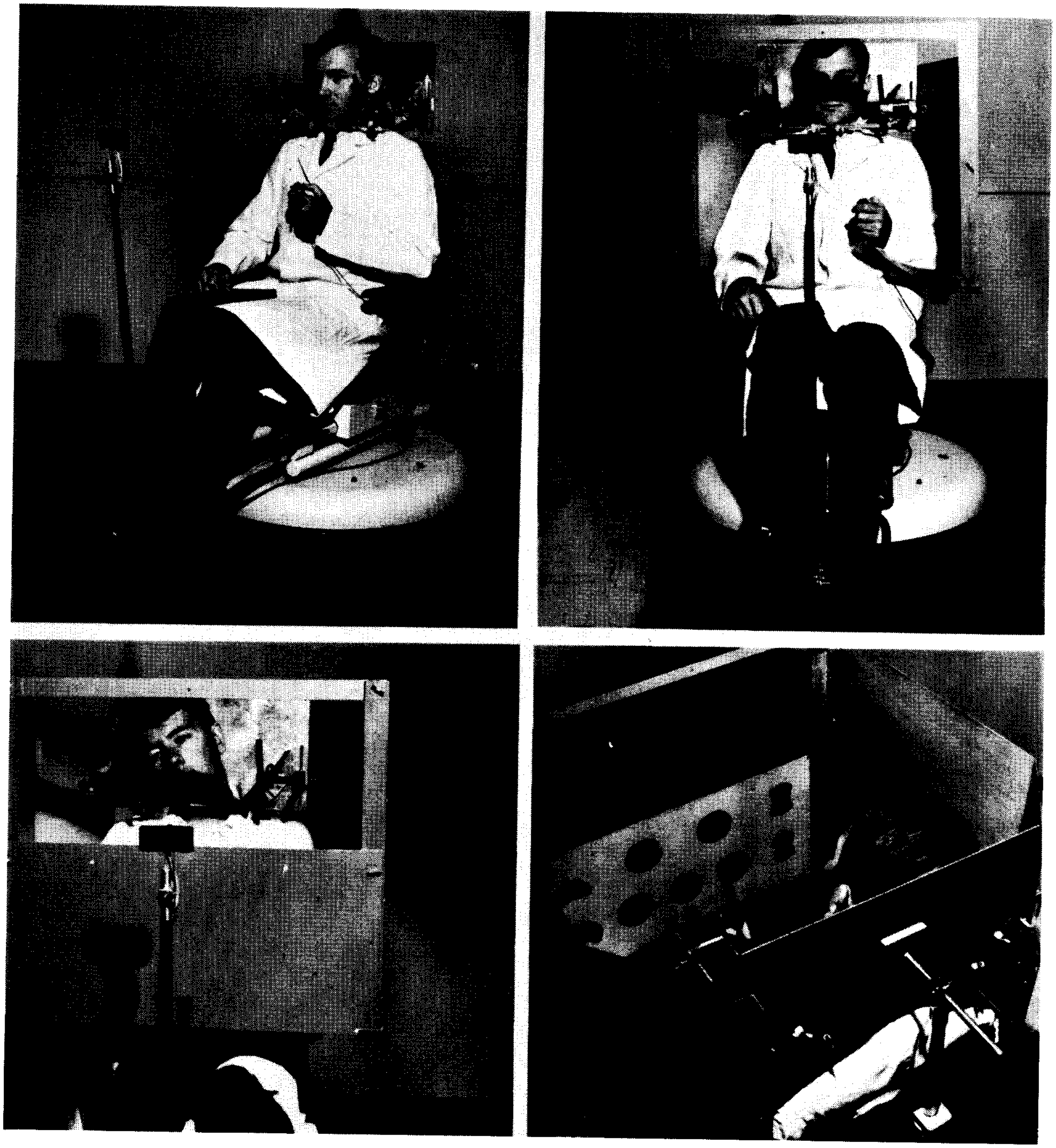


FIGURE 1. Modifications of a rotating device to control head movements and to introduce an aviation-related visual environment. The rod extending upward from the foot rest terminates in a plastic panel which contains three tiny lights (a red and a green "wing-tip" light and a flashing red "beacon") simulating an approaching aircraft. Upper left: rotation device without the "cabin" attachment (the chin rest depicted here is used for research rather than demonstration purposes). Upper right: the major section of the "cabin" has been bolted to the back of the head rest; its base is further supported by small metal extensions projecting outward from the arms of the chair. Lower left: the instrument panel is added to the "cabin" by means of four wing-nuts. Lower right: interior view of the "cabin" with a subject's head tilted to the right; the lights of the approaching aircraft were viewed through the "window" of the "cabin." The interior of the "cabin" was coated with luminous paint.

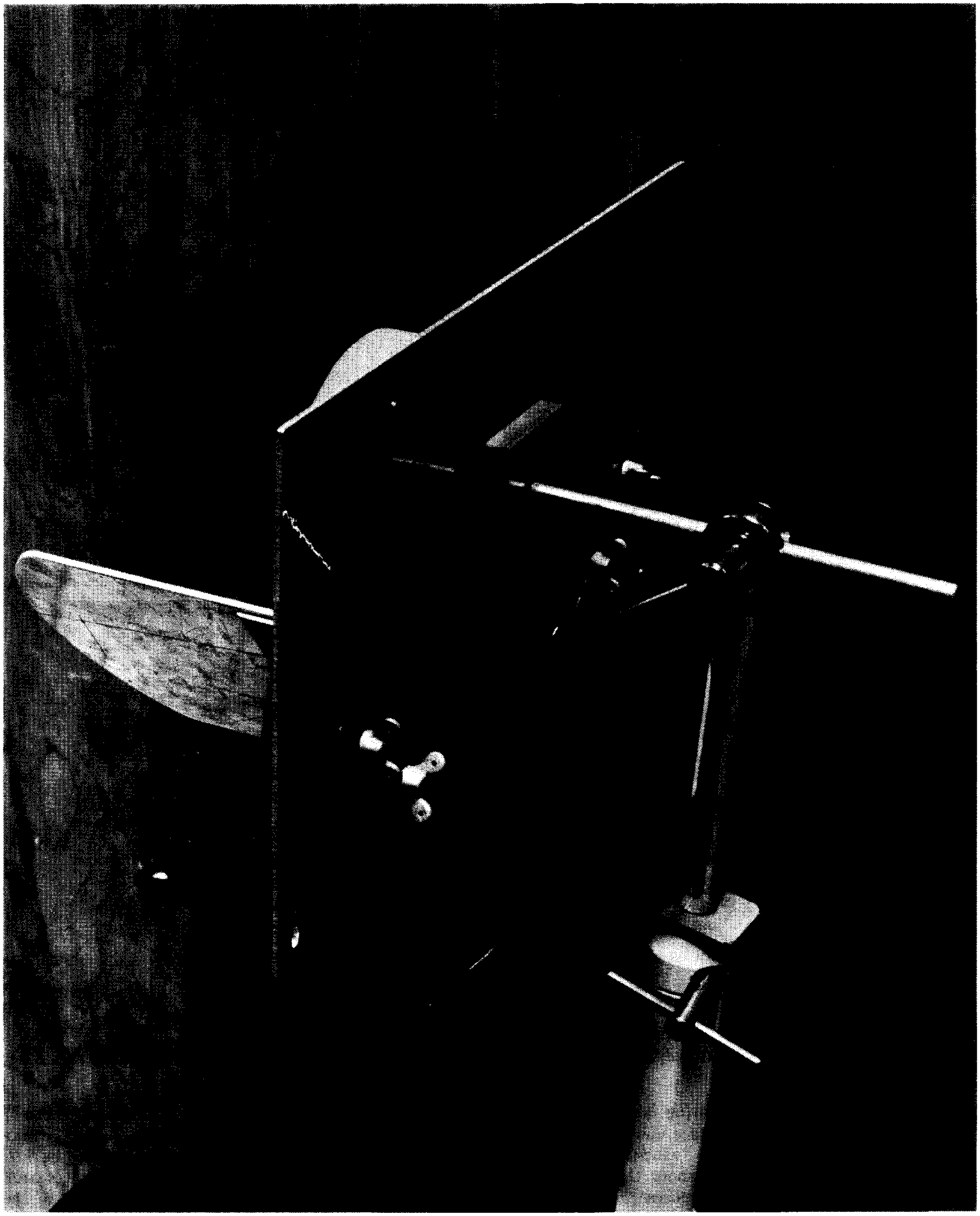


FIGURE 2. The head rest allows adjustment of the side pieces to control amount of head movement. The pivot arrangement permits the head rest to be rotated upward; when the "cabin" is attached (by means of wing-nuts through the vertical slots along the sides of the head rest), the entire frame (see Figure 1) can be so rotated.

experience with disorientation will involve vision in some way. This is also one of the major reasons why the traditional demonstration in the Barany chair is frequently not as effective as it might be; the subject is either blindfolded or shuts his eyes, is rapidly whirled, and is asked to make a head movement. The resulting sensation (Coriolis illusion) is usually striking, but appears to have little relation to the problems that might be encountered by a pilot in flight. Past-pointing is also a method of demonstrating disorientation, but again, the pilot frequently may not see a clear relation between it and in-flight activity.

The Apparatus.

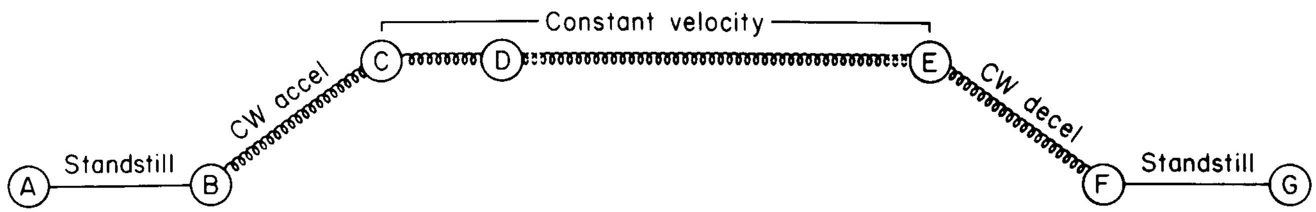
Our first approach to providing adequate disorientation demonstrations involved a simple modification of a rotating device.[6] Specifically, (a) a partial enclosure (see Figure 1) was introduced around the upper part of a motor-driven rotating chair (a Stille-Werner RS–3 Rotation Device), and (b) a removable headrest (which could be rotated upward) was fabricated with adjustable angled side pieces (see Figure 2) to control the amount of lateral head movement. The enclosure comprised a simple light-weight metal frame of two pieces (primarily for ease of handling) that could be bolted to the back of the headrest (see Figure 1). The major section of the frame was two feet high and extended from the back of the rider around the front of him; the second piece, one foot high and two feet wide, was attached by means of wing-nuts to the sides of the major frame and directly in front of the subject. The side of the smaller section facing the rider had a number of cardboard instrument faces glued to its surface. The entire inside of the frame (and the facing of the headrest) was coated with luminous paint and then sprayed with clear enamel as a radiation safety precaution. Since the front-piece extended only halfway up the height of the frame, the rider had a "window" through which he could observe a set of three tiny lights which simulated an "approaching aircraft" (red and green "wing-tip" lights and a flashing red "rotating beacon"). The lights were imbedded in a small plastic frame which was attached to the end of a rod. The base of the rod was secured to the rider's footrest and extended upward and away from him at a slight angle. A power source for the lights was located behind the chair. Usually, the major section of the cabin-frame was left bolted to the headrest so that the rider (pilot) could easily slide under and seat himself (the pivot arrangement which allowed the headrest and frame to be rotated upward facilitated this); the "instrument panel" was then attached (see Figure 1).

Procedure.

Prior to rotation, the pilot is instructed to keep his head and body very still during the demonstration until he is asked to do otherwise. An outline and depiction of the complete sequence of procedural events and the concomitant subjective reactions appear in Figure 3. In making lateral head movements (30°–45°), he is instructed to keep the back of his head against the headrest and simply to slide his head laterally until his cheek or temple touch the side-piece of the headrest. The head movement is to be made briskly and is to involve no body movement, i.e., the axis about which the head is to move is designated as around the "Adam's apple." The rider is told that he will be asked questions during the demonstration, which will be conducted in darkness. He is to describe his experience as accurately as he can.

Acceleration. Room lights are turned off and, since the room is light-proof, the pilot can see only the "approaching aircraft," framed through his "window," and the dimly lit interior of his "cabin"; nothing else in the room is visible to him. After a few seconds, observers in the room can see the pilot dimly outlined against the luminous "cabin."

The pilot is asked to report the onset of his experience of motion and his direction of turn. A smooth clockwise acceleration of $5°/sec^2$ for 18 seconds is then applied. During the acceleration period, the pilot is asked if his speed is changing at all. He, of course, replies that his turning speed to the right is increasing. He is then requested to indicate any further change in direction or in speed and is asked whether the lights of the other aircraft are moving smoothly with him or if they appear to be jerking in the direction of the turn, as though trying to "lead" him. Although most riders report smooth movement of the lights, many will see them jerk to the right (usually at the peak of the acceleration period), due to a vigorous nystagmic eye response.



Ⓐ→Ⓑ Rotator at standstill.

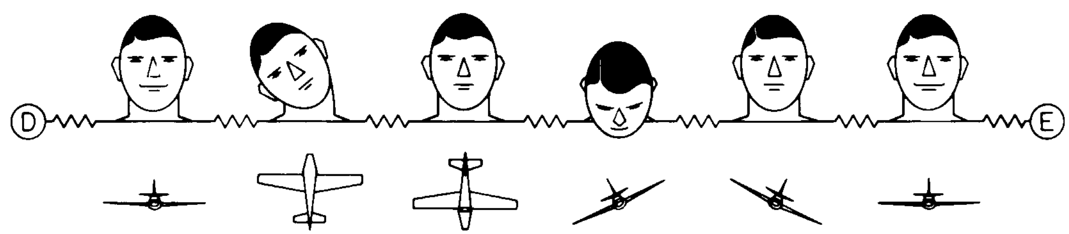
Ⓑ→Ⓒ CW acceleration ($5°/sec^2$ for 18 sec).
Subject detects start of turning, direction of turn (to the right), and increasing velocity.

Ⓒ→Ⓔ Period of constant velocity at 15 rpm.

Ⓒ→Ⓓ Subject perceives velocity of right turn diminishing and, finally, all turning sensations cease.

Ⓓ→Ⓔ Subject makes head movements upon given signals.

Head movement:	Upright	Tilt Right	Return to Upright	Tilt Forward	Return to Upright	Upright



Sensation:	Level	Climb	Dive	Roll to Right	Roll to Left	Level

Ⓔ→Ⓕ CW deceleration ($5°/sec^2$ for 18 sec).
Subject detects start of turning, direction of turn (to the left), and increasing velocity.

Ⓕ→Ⓖ Rotator at standstill.
Subject perceives velocity of left turn diminishing and, finally, all turning sensations cease.

FIGURE 3. Outline of the procedure for the CAMI disorientation demonstration. The entire procedure is conducted with the subject able to see only the "cabin" which surrounds him and the "approaching aircraft." Note that: (1) The sensations are reversed if CCW rotation is used; (2) returning the head to upright from a tilt to the right is equivalent to tilting the head to the left; (3) at least 30 seconds should be allowed between head movements; (4) the sensation experienced as a result of deceleration is directionally opposite that resulting from the acceleration and is perceived as a speeding-up rather than a slowing down.

Constant Velocity. After the 18-second acceleration period, a constant turning velocity (15 rpm) is maintained. A few seconds after reaching constant velocity the pilot reports a slowing of his turning rate (if he does not report spontaneously, he is asked about it). Within another 5–20 seconds, he indicates that he no longer feels turning, i.e., that he is motionless. Shortly after this, some riders report a slight turning sensation in the opposite direction (a secondary sensation). This apparent motion to the left is a normal experience and, when the pilot spontaneously notes it, a strong impression is usually made on the observers. (The secondary sensation is considerably weaker than that experienced during acceleration and, in most cases, does not last longer than a few (10–15) seconds; in other cases, it may be quite persistent and last for well over 30 seconds.)

Some individuals fail to report that their initial turning sensation ever ends following the acceleration; all report a clear slowing down of the turning experience, but some will maintain that they continue to feel very slow movement to the right. (Note: This perception is probably unrelated to sensing the actual turn; these same individuals often report similar prolonged turning experience while actually stopped following deceleration.) In any event, after the first 30 seconds of constant velocity, the vestibular system has returned from a stimulated condition to sufficiently near its normal "at rest" state, to allow head movements to be introduced. In order to maximize the "Coriolis vestibular effects" produced by these head movements, it is important to allow sufficient time between them, as well as between the end of the acceleration and the start of the head movement. Note that the direction of the illusory experiences (e.g., "pitching up") specified below are for CW rotation; the directions are reversed during CCW rotation.

Head Movements. The pilot is reminded about how to make the head movement and is asked to tilt his head to the right at the count of "three" (and to hold it there), and then to report what he experiences. The count is made and the subject tilts his head. The sensation is one of pitching up (sometimes up and to the right). The pilot is asked how many degrees "up" (between 20°–60° in most cases), and whether he "saw" the whole "cabin" pitch up with him and the "approaching aircraft" climb with him. It is important to note that this Coriolis reaction is not a simple feeling of tilt; the rider experiences a change in attitude (pitching up, for example) and an acceleration in that direction. Moreover, he not only "feels" a body motion, but his visual information, the "cockpit," and the "approaching aircraft" all change attitude in a corresponding manner. Some pilots also report sensations of pulling positive "G."

The sensation of pitching up and climbing has a sudden onset and then gradually decays, i.e., the pilot's apparent rate of climb decreases and he gradually returns to a "straight and level" condition. The amount of time required for this return can vary considerably among individuals but in any event, after 60 seconds (but no less than 30 seconds, even if the pilot indicates "straight and level" earlier) a signal for the return-to-upright head movement (this is equivalent to a left tilt of the head from an upright position) is given. The rider is usually warned that the sensation accompanying this head movement is likely to be somewhat stronger than that resulting from his tilt to the right (for certain physical and/or psychological reasons, it almost invariably is).

The signal is given and the pilot briskly moves his head to upright from its tilted position; his sensation is one of diving (sometimes down and to the right). Again he is asked how many degrees of "dive" he experienced (between 30°–90° in most cases) and whether the "cabin" and the approaching aircraft "dove" with him. This return-to-upright head movement occasionally produces sensations similar to negative "G" in experienced pilots. (Again, it should be noted that the experience is not one of simple tilt forward, but of accelerating downward, and the "cabin" appears visually to be displaced and "diving" in that same direction.)

After 30–60 seconds elapse following the head movement, nodding motions are introduced. Here, the rider is instructed to look toward the floor or at his lap (as though he were seeking a dropped pencil) by simply dropping his chin toward his chest (i.e., by moving only his head). As with the other head movements, he is to hold his head in that anteverted position until signalled to return it to upright. The questions and timing are similar to those presented above for lateral tilts but, in this case, the pilot perceives roll of his aircraft to the right as a result of the forward movement of his head, and roll to the left upon returning his head to upright. It is sometimes necessary to clarify a rider's description of these experiences; some report a "turning" to the right or left, but, if questioned, they indicate that it is not a sensation in the yaw plane, but rather in the roll plane, i.e., as though about a barbecue spit.

(Note that the head movement should be straight forward and back, not at an angle, just as the lateral tilts should not involve twisting of the head. This recommended approach orients the semicircular canals in such a way that, for the most part, the sensations and visual impressions are relatively pure rolls and (vertical) climbs and dives. Subjects who move their heads differently have sensations which tend to be more complex, e.g., spiraling down and to the right, and therefore less simple for them to describe and more difficult for the instructor to predict with accuracy.)

Sensations generated by the last (return-to-upright) head movement are allowed to dissipate for the usual 30–60 second period. At the end of this time, the vast majority of riders perceive themselves as "straight and level" and still experience no turning sensation. At this point, either instructions to the pilot regarding the deceleration are introduced or he is allowed to see that he is actually rotating by turning on the room lights for a very brief period (one or two seconds).

If the room lights are turned on, the pilot usually expresses considerable surprise to find that he is turning. (Note that the lights should be on only briefly and that the light sources should not be bulbs or tubes which glow, however dimly, for a while after being turned off.) When the lights are extinguished, most riders have no sensation for several seconds; there then may occur a feeling of turning in the correct direction.[7] The onset of this sensation is usually sudden and the apparent speed is quite rapid, although the "intensity" of the sensation may be described as relatively weak. (The basis for this perception of motion is apparently in the central processing of the visual information obtained during the brief interval of room illumination.[7]) At any rate, from the viewpoint of the disorientation demonstration, it is necessary to wait approximately 45 seconds after the interval of room illumination before initiating the deceleration. If this waiting period is not allowed, the rotatory sensation experienced by the pilot following the light interval may counteract the opposed sensation which would ordinarily occur during deceleration; the latter, then, may not occur at all, or may be present for only a few seconds near (and following) the end of the deceleration.[7]

Deceleration. Prior to initiating the deceleration, the pilot is told that he is turning to the right (although he is not experiencing that turn) and will very soon be slowed down in that same direction, and brought to a complete stop. (This gives the pilot intellectual information about what will transpire.) However, he is to report when he feels motion, in which direction he perceives his turn, and is to give a running account of his experiences (i.e., to indicate when he is going faster, when he begins to slow down, and when he feels that he is stopped).

A smooth deceleration of $5°/sec^2$ for 18 seconds is then applied. If the pilot neglects to indicate that he detects motion, he is asked; he is then asked the direction and whether or not he is turning at a faster or at a slower rate (his experience is that of turning faster and faster to the left, although he is actually slowing down in a right-hand turn, and he reports maximum turning velocity at, or very shortly after, reaching a complete stop). He then experiences a gradual slowing down and, after 5–20 seconds at a complete standstill, finally feels stopped. Room lights are then turned on and the demonstration is terminated.

Some Cautions.

Too many head movements and higher turning velocities can cause the rider considerable discomfort and can lead to motion sickness; hence, the four movements noted above, at the turning rate specified, are usually sufficient to provide an adequate appreciation of disorientation problems. It is worthwhile to inquire of the pilot following the first or second movement whether or not he feels comfortable. A very few individuals (considerably less than 10 per cent) may experience early symptoms of motion sickness ("stomach awareness," sweating, coldness, very slight headache, etc.). If riders report discomfort, or if they indicate that the demonstration should be discontinued, they should be asked to keep their heads very still (even if in a tilted position) and should not be requested to make additional head movements; the rotation device should then be brought to a gentle stop. The rider's head should remain motionless for an additional 30 seconds after the device is stopped.

There are no formal data which indicate that pilots might be "sensitized" to experience disorientation, discomfort, or motion sickness in flight following a demonstration such as that outlined above. However, too many head movements during rotation (or, in some few individuals, the four movements described above) may produce a mild feeling of unease that might last for several hours. As a general rule, therefore, it is advisable for riders who feel no ill effects following the familiarization experience to abstain from flying for at least one hour; where possible, the demonstration might best be given on a day when the pilot is not going to fly at all. In any event, if a rider suffers discomfort or any stage of motion sickness during the familiarization (this is unlikely), he might best not fly at all that day.

There is a relation (non-linear) between the intensity of the sensations occasioned by the head tilts and the amount and speed of the movements. Thus, a very slow, cautious, head tilt of just a few degrees will elicit a relatively weak sensation whereas a head tilt of average speed through a greater arc will produce a much stronger response. Adequate disorientation experiences can be accomplished with tilts of 30°–45° when the head movements are made briskly.

Advantages.

The apparatus and procedures noted above provide the pilot with a disorientation familiarization experience that is considerably more meaningful than the usual Barany chair demonstration. The pilot has an opportunity to receive correct information from his motion-detecting system (during acceleration) and then can experience the failure of the system to provide accurate information during the remaining phases of the demonstration. The Coriolis effects are perceived in a more appropriate perspective when the head movements are made within the lighted "cabin" and the power of this form of disorientation is better appreciated when the pilot not only "feels" a false change of attitude and acceleration, but also "sees" it occurring. The interaction between the visual and vestibular systems and the manner in which the visual information is made to agree with the vestibular sensations (when the visual objects are not fixed relative to the earth) is a very significant feature of this type of familiarization. All of these sensations are, of course, referred back to the lecture material so that the pilot will understand what has happened and why.

The fact that the device does not tilt or move in any plane other than yaw seems to be an advantage. It appears to intensify the impression made on the pilot when he sees that the device "only turns," although, as a rider, he experienced clear pitching and rolling sensations.

When done as described, i.e., in a light-proof room with the pilot reporting his experiences, responding to questions, and visible (this can be enhanced, if desired, by the addition of a small, dim, battery-operated light source secured to the "instrument panel" and directed on the pilot's face), the demonstration is not only effective for the rider, but also holds the interest of spectators while providing them with a learning experience. A most desirable situation is to provide at least two of the group with the familiarization experience; this procedure allows the initial pilot to see exactly what the stimulus conditions were, permits an interchange between the two (or more) riders regarding their experiences, and frequently provides the spectators with some notion of the individual differences in disorientation experiences (e.g., a 45° "dive" vs. a 90° "dive") as well as differences among subjects in their reaction to the Coriolis effects (some subjects, for example, will become extremely excited, others will simply appear to tense up, while others enjoy it). Virtually every pilot who has ridden in the device has indicated that everyone who flies ought to have this experience.[e.g., 23 24]

There is one final advantage for the instructor: the demonstration "works" every time.

Expense. In addition to providing a meaningful experience for the rider and spectators, and in demonstrating many of the aspects of functioning of the human sensing systems involved in disorientation, the approach and type of device specified above are also inexpensive. The "cabin" framework is easily and inexpensively constructed (and may be modified in a number of ways so that it might be used in a dimly lighted room), and almost any motor and

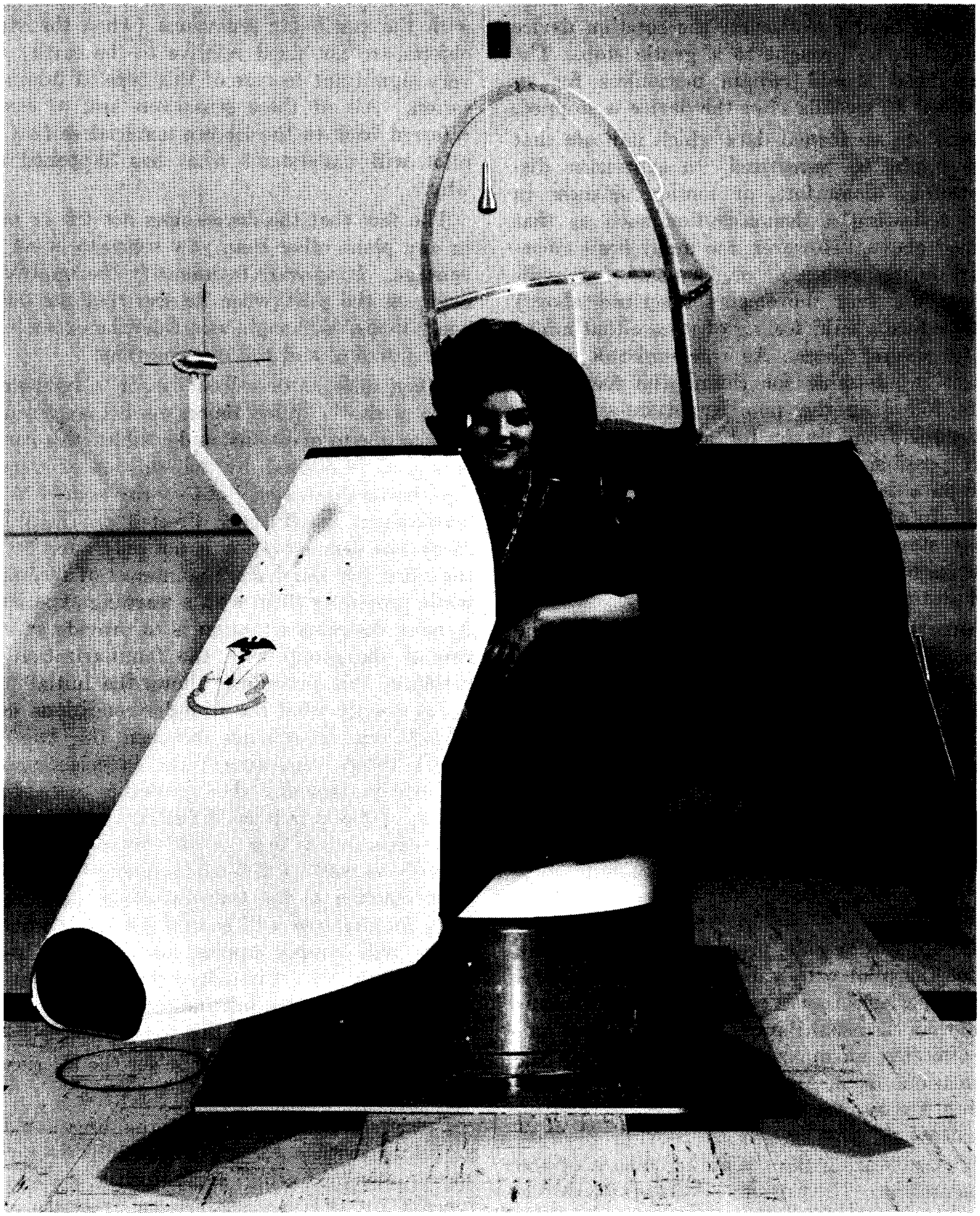


FIGURE 4. The CAMI Disorientation Device. The chair from the basic Stille-Werner RS-3 Rotator (see Figure 1) was removed and was replaced by a relatively light-weight "cockpit" fabricated by the CAMI Technical Staff. The canopy is made of molded, clear plexiglass. A small light source mounted in the instrument panel is directed at the subject and, with the room in total darkness, permits observers to see the subject but the latter can see only the interior of the "cockpit" and the lights of the "approaching aircraft" (mounted on the "fuselage"). The head rest depicted here is padded, has fixed side pieces, and can be adjusted vertically. The electrodes taped by the subject's eye are used (to record nystagmus) only during research procedures.

drive system can be hooked up to any light rotary structure (such as a chair or platform) which provides smooth and easy turning. For purposes of disorientation familiarization, the device does not require the precision and control one would incorporate in a vestibular research tool.

A Modification of our Apparatus. For purposes primarily related to research, the basic Stille-Werner Rotation Device was modified by the CAMI Technical Staff by removing the standard chair and installing a cockpit seat and a lightweight "cockpit" with a door and plastic canopy which totally encloses the seated pilot (see Figure 4). A light source, located in the "instrument panel," serves to light dimly the interior of the "cockpit"; the rider can then be viewed by spectators in a totally dark room, but cannot himself see them. An "approaching aircraft" (the triad of red and green lights) was installed in the center of a small device on the fuselage which the pilot can see dimly through the plastic canopy (see Figure 4). The functioning of the apparatus so modified is, of course, not different from our first model (although the aviation-orientation of our demonstration is improved), and the procedures for disorientation familiarization detailed above are the same with one exception: either an inter-com is required, or the canopy must be raised an inch or two to permit communication between the rider and the instructor.

V. Other Approaches to Disorientation Familiarization.

The Vertigon.

During a visit to CAMI, engineers (and pilots) from Flight Products, Incorporated (Moonachie, New Jersey) were given the CAMI disorientation demonstration and became convinced that the experience could be of benefit to all pilots. They agreed to build an instrument to be used specifically as a familiarization tool and were provided with basic specifications and timing procedures. CAMI purchased the first two production models, one of which was installed in the laboratory to remove the training load from research equipment; the second has been used throughout the country by the CAMI Aeromedical Education Branch as part of an FAA display at flight meetings, air shows, conferences, seminars, and the like.

The Vertigon (see Figure 5) totally encloses the pilot in a one-place "cockpit" and provides reasonably smooth angular accelerations and decelerations. Sound movies projected on the windshield depict a flight from engine start through taxi, take-off, climb, and bank into clouds (where the head movements occur); following the period of head movements while "flying IFR," the plane breaks out of the clouds and begins a landing approach. In the original version, the sound portion of the film gives an introduction to the problem of vertigo, indicates the possible thought processes of a pilot choosing to fly through clouds, adds realism to the head movements by having the pilot make some of them by performing tasks (such as reaching for a pencil and writing, on a pad in his lap, a simulated air traffic clearance, then returning the pencil), emphasizes how powerful the illusory effects are (while assuring the rider that he is still straight and level), and indicates that only the instruments can provide the pilot with correct information. The sound track concludes by encouraging the pilot to earn an instrument rating and to maintain instrument proficiency. The entire "flight" takes only four minutes. The model used by the CAMI Aeromedical Education Branch also employs a closed-circuit TV system so that observers can watch the facial expressions and head movements of the subject.

The Vertigon has been notably successful as a familiarization technique. Riders are impressed with the illusions and, as with the CAMI Disorientation Device, accept the procedural conditions as pertinent to the aviation environment. The importance of "seeing" the instrument panel, "windshield," and "cabin" surroundings pitch or roll in agreement with the vestibularly induced sensations cannot be over-emphasized.

The Vertigon has several advantages. It is durable and requires exceptionally little maintenance. The entire run can be programmed (there is a switch for manual or program control) so that minimal skill is needed to operate the device (see Figure 6). It moves only in the yaw plane, requires very little space (about 6 feet by 6 feet) and can be used in a lighted room. Its acceleration characteristics and the smoothness of its start and stop are more than adequate for a good demonstration. It can also be modified to introduce other tasks, program meter deflections, require movements of the con-

FIGURE 5. The Vertigon. The subject is totally enclosed and a sound movie depicting a flight from engine warm-up through a landing approach is projected on the "windshield."

FIGURE 6. Control system for the Vertigon. The system is simple, compact, and easy to operate.

trol wheel, etc. The film and sound track, of course, can also be modified as desired.

Disadvantages of the Vertigon include the following: under standard operating conditions there is no communication between observers and the pilot; watching the pilot via closed-circuit TV has somewhat less interest-appeal to observers than seeing him and communicating with him; the pilot is less attentive to angular acceleration experience. With respect to the latter, some riders report that they never perceive turning at all. The disadvantage here is that the deceleration experience (perceived as an increasing turning speed in the opposite direction) is missed by the pilot.

These disadvantages are minor considering the effectiveness of the demonstration provided by the Vertigon. During exhibitions of the device, the manufacturers distributed paper badges, following completion of Vertigon rides, which stated "Wow! I flew the Vertigon!" The "Wow!" was well-selected. It is the first expression most pilots make in describing their Vertigon experiences. The CAMI Aeromedical Education Branch provides its riders with similar tokens.

Modified Link Trainer.

Based on their CAMI experiences, several visitors have modified their own equipment to provide an approach to disorientation familiarization similar to that of CAMI. A good example is the modified Link trainer (Figure 7) used by the Ken Hoffman Flying School (Broomfield, Colorado). The trainer was stripped down except for the pedestal and cockpit box and modi-

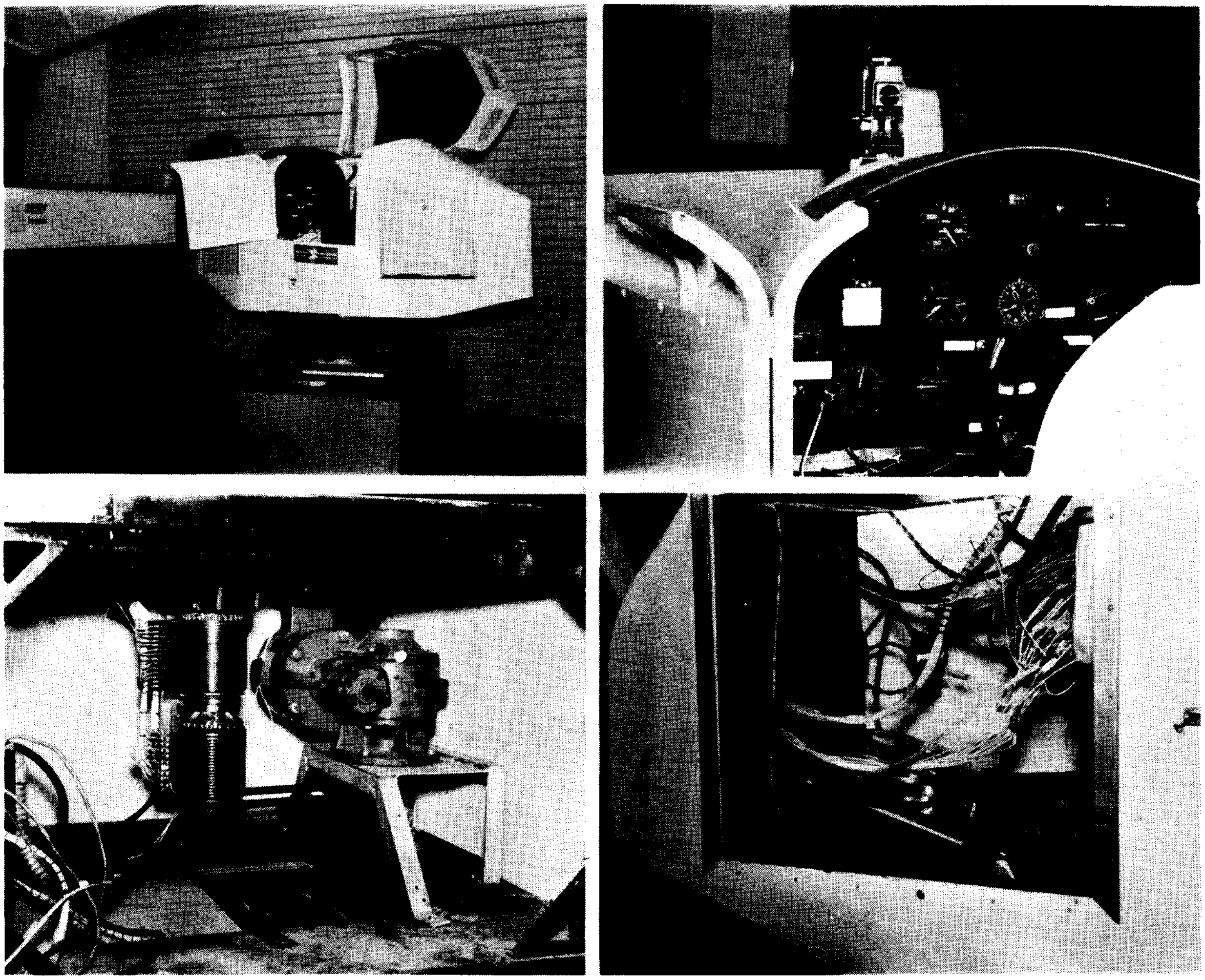


FIGURE 7. A modified Link trainer used by a flying school to provide disorientation familiarization.

fied so that only vertical-axis (yaw) movement was possible. The base of the trainer was fitted with a pulley and belt drive connected to a geared-down electric motor. A motor mount was fabricated and bolted to the base of the simulator and a pulley size was selected to drive the device at 16 rpm. Existing wiring was used to provide power (1) to the motor through a switch controlled from the cockpit box, (2) to separate plugs for a movie projector and a tape deck, each with a separate switch, (3) to warning lights connected to microswitches on the control quadrant which are activated if the rider attempts "corrective action" during the demonstration, and (4) to a single cockpit light and switch (not often used since ample light from overhead illumination filters through the translucent covering on the canopy). A platform was attached to the front of the trainer to support a rear-projection system which uses the front panel of the translucent canopy for a screen. A tape deck was provided in the front compartment, just forward of the existing rudder pedals, for narration. The rider is provided with a pad and pencil to accomplish workload, assigned by means of the narration. It might be noted that the seat initially was off center and appeared to produce some (minor) undesirable effects on the pilots; moving the seat close to the center of rotation corrected this difficulty.

VI. Familiarization Devices vs. Classroom Demonstrators.

All of the devices described above are particularly effective in safely, but dramatically and personally, familiarizing the individual pilot

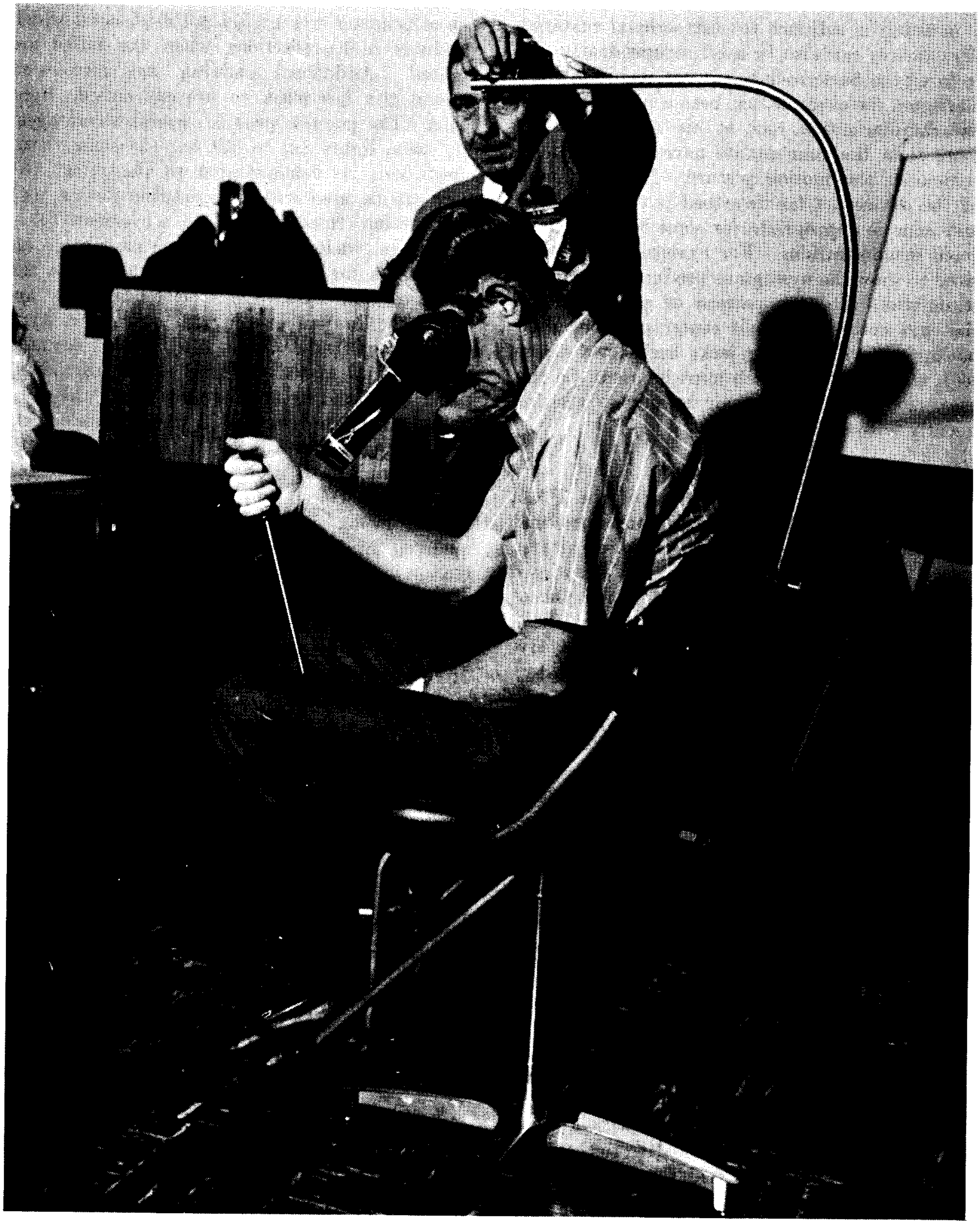


FIGURE 8. The converted kitchen stool and goggles used by the FAA's Southwest Regional Office in disorientation training.

with disorientation experiences and in providing a meaningful adjunct to instructional material. The devices can also be used independently, i.e., lecture-type backgrounds are not required. The Vertigon, for example, has been a highly successful familiarization tool at air shows with no more than the four-minute narrative which accompanies the motion picture. However, none of the devices so far described is truly portable and none is appropriate for some types of classroom demonstrations. For example, if it is desired to show the nystagmus produced by angular stimulation (i.e., the pattern of slow drifts of the eyes away from their center position, alternating with fast ocular jerks back toward center), a different approach must be used. In this case, modified Barany chair techniques are frequently adequate.

Converted Chairs.

The Southwest Regional Office of the FAA, in extending the CAMI disorientation training program, converted a number of padded kitchen stools (other stools and chairs had been used earlier by the FAA's Central Regional Office) with assistance from the CAMI Technical Staff (see Figure 8). These relatively inexpensive chairs were lowered to improve balance characteristics, a more substantial bearing system was introduced, and a footrest, a "control stick," and a seat belt were added. Based on a technique employed at the FAA's Houston GADO (where it was used with a modified beauty operator's chair), a finger-tip turn-control unit was attached. This was accomplished by securing a torque-arm underneath the rear portion of the seat and to the back of the chair. The torque arm curves up and over the head of the rider. A turning knob allows the instructor manually to maintain a fairly smooth turning motion of the chair with relative ease.

In conjunction with the stool, a special pair of goggles is frequently used. These were developed in the CAMI Aeromedical Education Branch[25] to permit rotation of the pilot in a lighted room and to provide him with a visual reference that was not fixed relative to the earth. A blue filter was substituted for the usual lens in a pair of welder's goggles, and a lightweight rectangular extension was secured to the frames. Openings for two battery-operated pen-light bulbs were made in the sides toward the front of the rectangular attachment. The interior of the attachment was highly polished metal which produces multi-reflections when the bulbs are lighted. Additional padding was introduced around the face-mask to prevent outside light leaks. The goggles provide several advantages: (1) room lights can be left on; (2) some visual effects can be demonstrated to the pilot; (3) they can be used with any rotating device; (4) they permit freedom of head movement. Disadvantages include: (1) some visual rivalry effects since the bulbs are directly opposite the pupils of the eyes; (2) Coriolis illusions are attenuated in comparison with a "cockpit"-type surround; (3) the visual field viewed through the goggles does not stay fixed (as an instrument panel or a landing strip would) when the pilot makes a head movement, i.e., when the pilot tilts his head, he tilts his visual field at the same time, regardless of whether or not he is rotating. One of the convincing features of the CAMI Disorientation Device, the Vertigon, and the modified Link trainer is the fact that illusory motion of the instrument panel occurs in the absence of physical movement of that panel.

The modified stools are reasonably effective. They are relatively portable and inexpensive. However, they do not readily permit an exploration of the full range of illusions that the other devices do, and, without modifications, probably present a safety problem under some conditions.

The CAMI Aeromedical Education Branch uses a chair with safety features as an adjunct to many of its classroom lectures. Thus, for example, a student with eyes closed is rotated in the chair and brought to an abrupt stop facing the class; upon opening his eyes, a brisk nystagmus can be observed by everyone if the class is not too large. Moreover, the extent to which vision is impaired by nystagmus can be demonstrated to the class by asking the student as soon as he is braked to a stop, to open his eyes and read from a card (held by the instructor). The text on the card usually contains a repeated word (e.g., ". . . the the . . .") which the student invariably misses.

The rotating chair used with these classroom techniques is a highly portable one (very similar to those described above and also fabricated by the CAMI Technical Staff), which can be easily broken down into three sections, quickly packed in a carton, and carried by hand. The base and the bearing system of this chair are of sufficient quality to insure safety, close tolerance, and minimal friction; thus, a simple manual push of the chair can set it and a student in motion for a minute or more of smooth, non-wobbling rotation. The procedures used with the device are outlined below.[25] Note that each of the five demonstrations described involves a different student.

PROCEDURAL STEPS IN CLASSROOM DEMONSTRATION

First Demonstration

1. Explain to the student-demonstrator and the class how rotation of the Barany chair relates to aircraft turning.

2. Have the student indicate, by pointing with his thumbs or a joy stick, his position or the direction of the sensation he is experiencing. Caution him not to correct for illusions.

3. Place a hood (or goggles) over the student's eyes and have him sit erect. Rotate the chair to the right. Rotate the chair so that the seat will turn for at least one minute without additional pushing.

4. The student should first experience a sensation of rotating to the right, then almost a halt in rotation; as the chair slows down, he should experience a sensation of rotating to the left, and finally he will report stopping.

5. The student's eyes should sweep or click to the left and right, thus demonstrating nystagmus.

Second Demonstration

1. Rotate the student to the right with eyes closed and with no hood.

2. As soon as the student feels no sensation of rotation (or in about 20 seconds), stop the chair abruptly.

3. Stop the student in front of the class and have him read from material on an appropriate chart or sign.

4. Have the class focus its attention on the student's eyes.

5. The student's eyes should sweep or click from left to right, thus demonstrating nystagmus.

Third Demonstration

1. Have the student don a hood.

2. Rotate the student until he no longer experiences turning.

3. Have the student tilt his head to the right while rotating.

4. He should experience an illusion of a climb to the right.

Fourth Demonstration

1. Using a hood, rotate the student to the right with his head tilted to the right.

2. Continue rotation until no sensation of turning is reported; then have the student return his head to the upright position.

3. The student should experience an illusion of diving.

4. *Caution!* The student may have a violent reaction to this stimulus.

Fifth Demonstration

1. Again using a hood, have the student look down at the floor or at his lap belt.

2. Rotate him to the right with his head tilted downward.

3. Continue rotation until no sensation of turning is reported; then have the student return his head to upright.

4. The student should experience an illusion of tumbling or spiraling.

5. *Caution!* A strong sensation of falling from the chair may be experienced.

VII. Additional Techniques.

The approaches noted above are not the only ones available. For example, the Spatial Orientation Trainer (SOT) at Brooks AFB (Texas) is a highly sophisticated device which has four degrees of freedom of movement; totally encloses the rider in a cockpit that moves on rubber wheels around a circular track 10 feet in diameter; and permits the pilot to control the attitude of the cockpit (at the discretion of the console operator) by stick, rudder, and throttle. The device can be rotated about its own axis (30 rpm) or around the track, can be pitched $\pm 30°$ from the horizontal, and can be rolled $\pm 90°$ from the vertical. A preliminary evaluation of the device using students from the Air Force Undergraduate Training Program indicated its usefulness and acceptability to the students in augmenting the regular flight training program.[11]

Still other techniques exist, e.g., those used at the USN Aerospace Medical Institute (Pensacola, Florida) in tests of motion sickness susceptibility and of factors associated with attrition in flight training.[1] However, the purpose of the present report was simply to provide suggestions and procedures for inexpensive but meaningful disorientation familiarization based on the enthusiastic responses of general aviation pilots who have experienced the CAMI approach, and to encourage pilots to obtain instrument ratings. It is hoped that this material will contribute to aviation safety.

VIII. Requirements of a System for Disorientation Familiarization.

To present a really effective disorientation familiarization, an experience that will be accepted by pilots as meaningful to aviation, any adequate rotating device can be modified inexpensively and used as long as certain conditions are met.

(1) The rotator should be sturdy and well-balanced. (Ordinary bar stools and the like are probably dangerous unless additional support is provided in the base; the rider may tip over the entire chair.)

(2) A seat belt should be provided.

(3) The rotators should have a headrest, backrest, footrest, and chairarms.

(4) A "cabin" or a "cockpit" visual framework is essential for a good aviation-oriented demonstration. Our approach involves conducting the demonstrations in the dark. However, inexpensive canopies which will enable spectators to watch the pilot, but will prevent the pilot from seeing anything but the canopy surroundings, can probably be constructed so that the room need not be totally dark.

(5) The drive system should provide a reasonable period of acceleration and of deceleration (15–18 seconds) at a moderate rate ($5°/sec^2$).

(6) The period of constant velocity should be at a rate between 12–18 rpm. At lower rates, the sensations are reduced and, at higher rates, they are more extreme than required for familiarization purposes. We usually run at 15 rpm.

(7) The acceleration rate need not be perfectly linear. However, there should be no bumping or "pulsing" at the start or end of either positive or negative accelerations.

(8) The drive system must be quiet so that external cues regarding rotation will not be available to the rider.

(9) The rider must not be able to see the floor, walls, or ceiling of the room nor any of the spectators (i.e., he must have no visual references fixed relative to the earth). Lighted cigarettes or any other source of light, however small or dim, must be eliminated if the tests are done in darkness.

For some purposes other than familiarization (e.g., demonstrations associated with classroom lecture materials), chairs similar to those described elsewhere in this report are adequate. However, the chairs are not as effective in providing the pilot with memorable experiences of disorientation which he clearly relates to his flying environment, they cannot be used in the absence of a trained instructor, and they do not permit a full range of disorientation experiences. Still other (more complex) devices are required if response training (e.g., control of attitude) during disorientation stimuli is desired. However, in providing a safe but meaningful experience for general aviation pilots, one that gives them a direct acquaintance with the various types and intensity of disorientation experiences, and one that encourages them to earn instrument ratings, a cockpit type of rotating environment and the procedures outlined in this report appear particularly pertinent.

REFERENCES

1. Ambler, R. K., and Guedry, F. E.: Cross-validation of a brief vestibular disorientation test administered by a variety of personnel. *Aerospace Medicine*, 39:603, 1968.
2. Benson, A. J.: Spatial disorientation in flight. In J. A. Gillies (Ed.): *A textbook of aviation physiology*. New York: Pergamon, 1965.
3. Bonner, R. H.: Spatial disorientation—current concepts and aeromedical implications. *USAFSAM Aeromedical Review*, No. 7–63, Brooks AFB, Texas, 1963.
4. Clark, B., and Nicholson, M. A.: Aviator's vertigo: a cause of pilot error in naval aviation students. *Journal of Aviation Medicine*, 25:171, 1954.
5. Cocquyt, P.: Sensory illusions. *Shell Aviation News* #178 (April), 1953. (Reprinted and obtainable from the Flight Safety Foundation, Inc., New York.)
6. Collins, W. E.: Coriolis vestibular stimulation and the influence of different visual surrounds. *Aerospace Medicine*, 39:125, 1968. (Also published in *FAA OAM Report* No. 67–19, 1967.)
7. Collins, W. E.: Modification of vestibular nystagmus and "vertigo" by means of visual stimulation. *Transactions of the American Academy of Ophthalmology and Otolaryngology*, 72:962, 1968. (Also published in *FAA OAM Report* No. 68–28, 1968.)
8. Department of the Air Force: Instrument flying. *AF Manual* No. 51–37. Washington, D.C., 1966 (reprinted 1968).
9. Department of the Air Force: Physiology of flight. *Air Force Pamphlet* No. 161–16. Washington, D.C., 1968.
10. Department of Transportation, Federal Aviation Administration, Office of Management Systems: *1969 U.S. Civil Airman Statistics*. Washington, D.C., 1970.
11. Dowd, P. J., Cramer, R. L., Wolfe, J. W., and McKean, S. H., III. Responses of USAF undergraduate trainees to indoctrination in the spatial orientation trainer. *Aerospace Medicine*, 41:544, 1970.
12. Gillingham, K. K.: A primer of vestibular function, spatial disorientation, and motion sickness. *USAFSAM Aeromedical Reviews*, No. 4–66, Brooks AFB, Texas, 1966.
13. Guedry, F. E.: Visual disorientation. Paper presented at Ohio State University, 1964.
14. Johnson, W. H.: Disorientation in flight. Part I—Vertigo. *Flight Comment* (Nov.-Dec.), 1957.
15. Johnson, W. H.: Disorientation in flight. Part II—Spatial disorientation. *Flight Comment* (Sept.-Oct.), 1958.
16. Lehwess-Lutzmann, I.: Illusionen im Fluge—Eine Literaturstudie zur Problematik der Flugzeugfuhrung. *Verkehrsmedizin und Ihre Grenzgebiete*, 12:577, 1965.
17. Melvill Jones, G.: Review of current problems associated with disorientation in man-controlled flight. *FPRC Report* No. 1021, RAF Institute of Aviation Medicine, Farnborough, England, 1957.
18. Melvill Jones, G.: Disorientation in flight. In Th. von Karman (Ed. Chmn.): *Advances in aeronautical sciences*. New York: Pergamon, 1959.
19. Melvill Jones, G.: Vestibulo-ocular disorganization in the aerodynamic spin. *Aerospace Medicine*, 36:976, 1965.
20. Moser, R., Jr.: Spatial disorientation as a factor in accidents in an operational command. *Aerospace Medicine*, 40:174, 1969.
21. Neely, S. E.: Patterns of interference with the ability of pilots to control their aircraft. In A. B. Barbour and H. E. Wittingham (Eds.): *Human problems of supersonic and hypersonic flight*. New York: Pergamon, 1962.
22. Nuttall, J. B., and Sanford, W. G.: Spatial disorientation in operational flight. In E. Everard, P. Bergeret, and P. M. Van Wulfften Palthe (Eds.): *Medical aspects of flight safety*. New York: Pergamon, 1959.
23. Skinner, J. E.: Seeing is believing, feeling is not. *American Aviation*, 32:72, 1968.
24. Tinker, F. A.: Vertigo! *AOPA Pilot*, 12:40, 1969.
25. Valdez, C.: Personal communication, 1970.
26. Vinacke, W. E.: Illusions experienced by aircraft pilots while flying. *Journal of Aviation Medicine*, 18:308, 1947.
27. Vinacke, W. E.: Aviator's vertigo. *Journal of Aviation Medicine*, 19:158, 1948.

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cate within 30 months or an airman rating issued within 30 months, the airman is also considered active. From a regulatory standpoint, an airman must possess medical certification commensurate with airman rating usage, but in no event can the medical certificate be older than 24 calendar months for private pilot purposes. This latter definition applies to the population data utilized in our analysis.

The extent to which the six month grace period inherent in the FAA Statistical Handbook data affects the older age intervals can only be surmised. Attrition from an active airman status can occur the day after medical certification and/or airman rating and is recognized in both definitions of the population. However, to define the active population six months beyond regulatory limitations would obviously inflate population data.

Additionally, if one follows the data contained in the FAA Statistical Handbook over the years 1964 through 1968, the frequency of airmen in

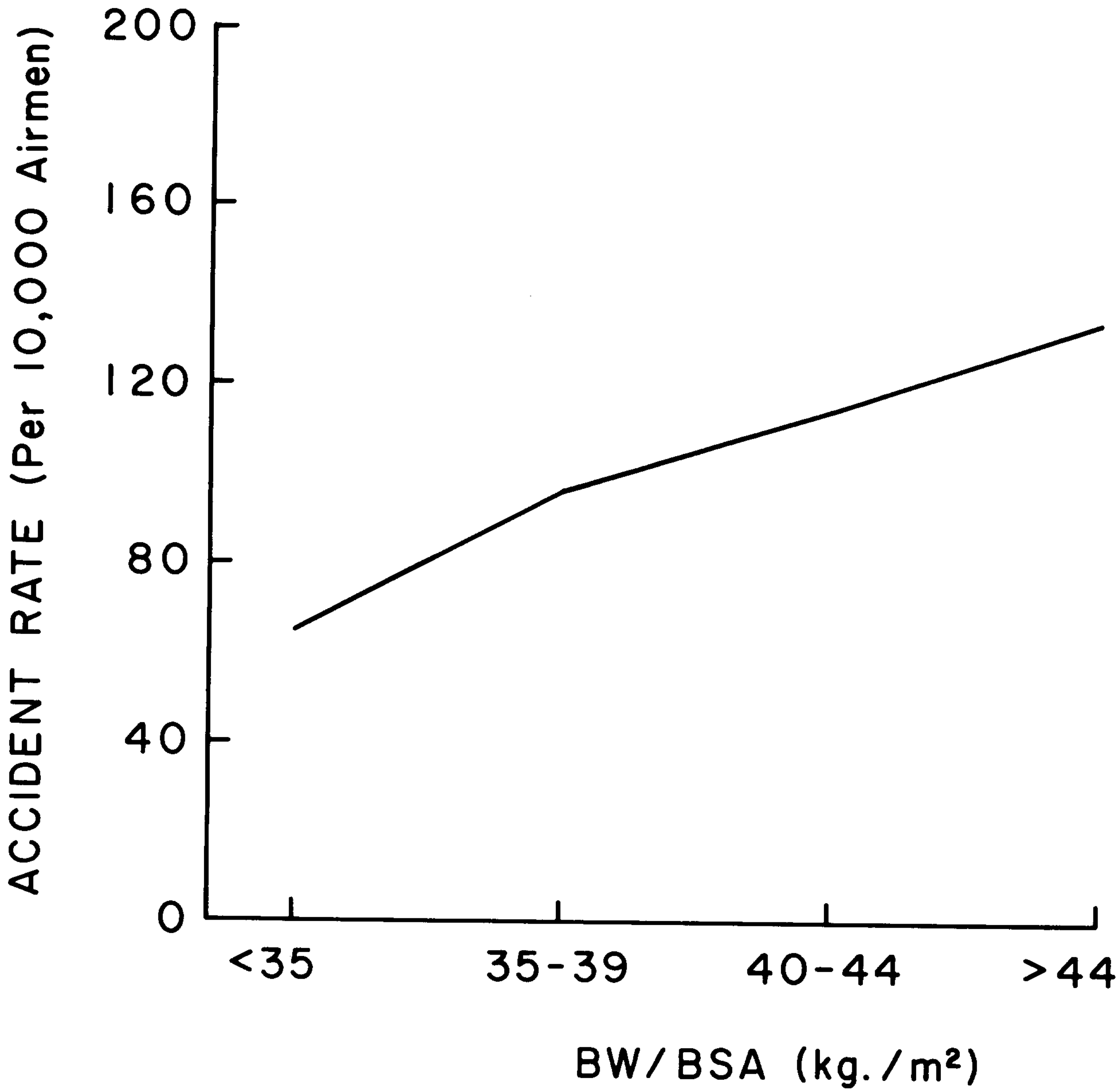

FIGURE 4.2. General Aviation Accident Rate by Weight Per Unit of Body Surface Area (BW/BSA).

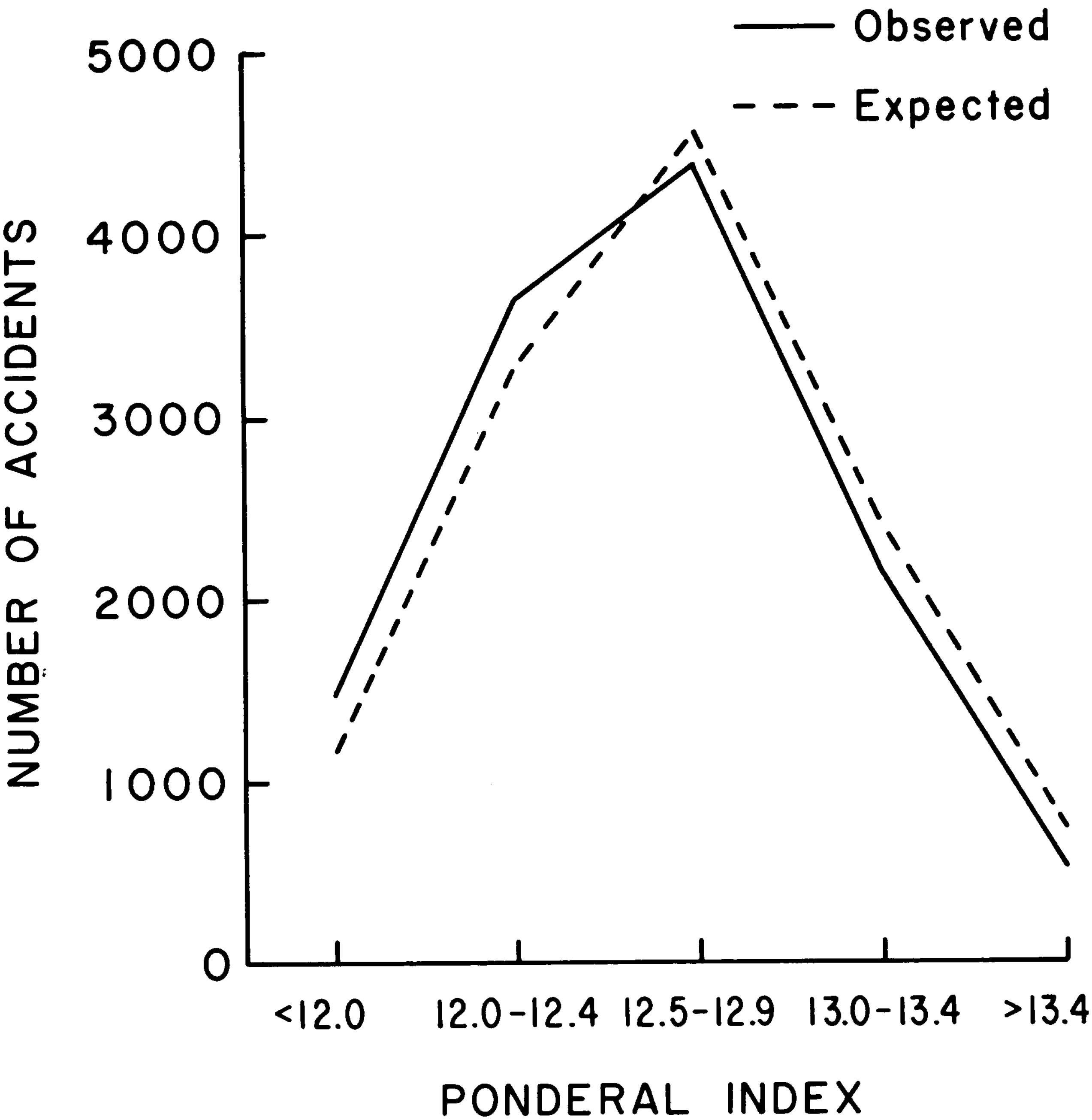

FIGURE 5.1. Observed Versus Expected General Aviation Accidents by Ponderal Index.

the older age interval suggests a possible change in programming criteria or possibly a records change, i.e., for year ending 1964, active pilots 60 and over were reported as 8,513; for 1965, active pilots 60 and over were 11,317; for 1966, active pilots 60 and over were 17,362; for 1967, active pilots 60 and over were 10,844; a drop of some 6,500 airmen in the age interval 60 and over from 1966 to 1967, while medical summaries indicate a gradual increase during the same time period. This latter total of 10,844 compares favorably with medical record summaries based on the 24 month criteria for the year ending 1967, i.e., 10,844 versus 9,884 from medical summaries. The 960 difference is probably due to the six month grace period inherent in the FAA Statistical Handbook data.

There are problems with the medical definition of the active airman population also. The problem of attrition during the 24 month period, which is common to both population definitions, has been discussed. Additionally, the medical population contains some air traffic controllers who are not pilots and who do not intend to become pilots.

In the opinion of the authors, the 24 month medical definition offers a better definition of the active airman population recognizing the limitations of both. It should be noted that criteria have recently been changed to the 24 month definition in the FAA Statistical Handbook data by rating.

The statistically significant differences in the frequency distributions of accident and non-accident airman populations on the basis of the status variables age, weight, BW/BSA, and PI suggest that factors associated with these variables should be given closer attention in the

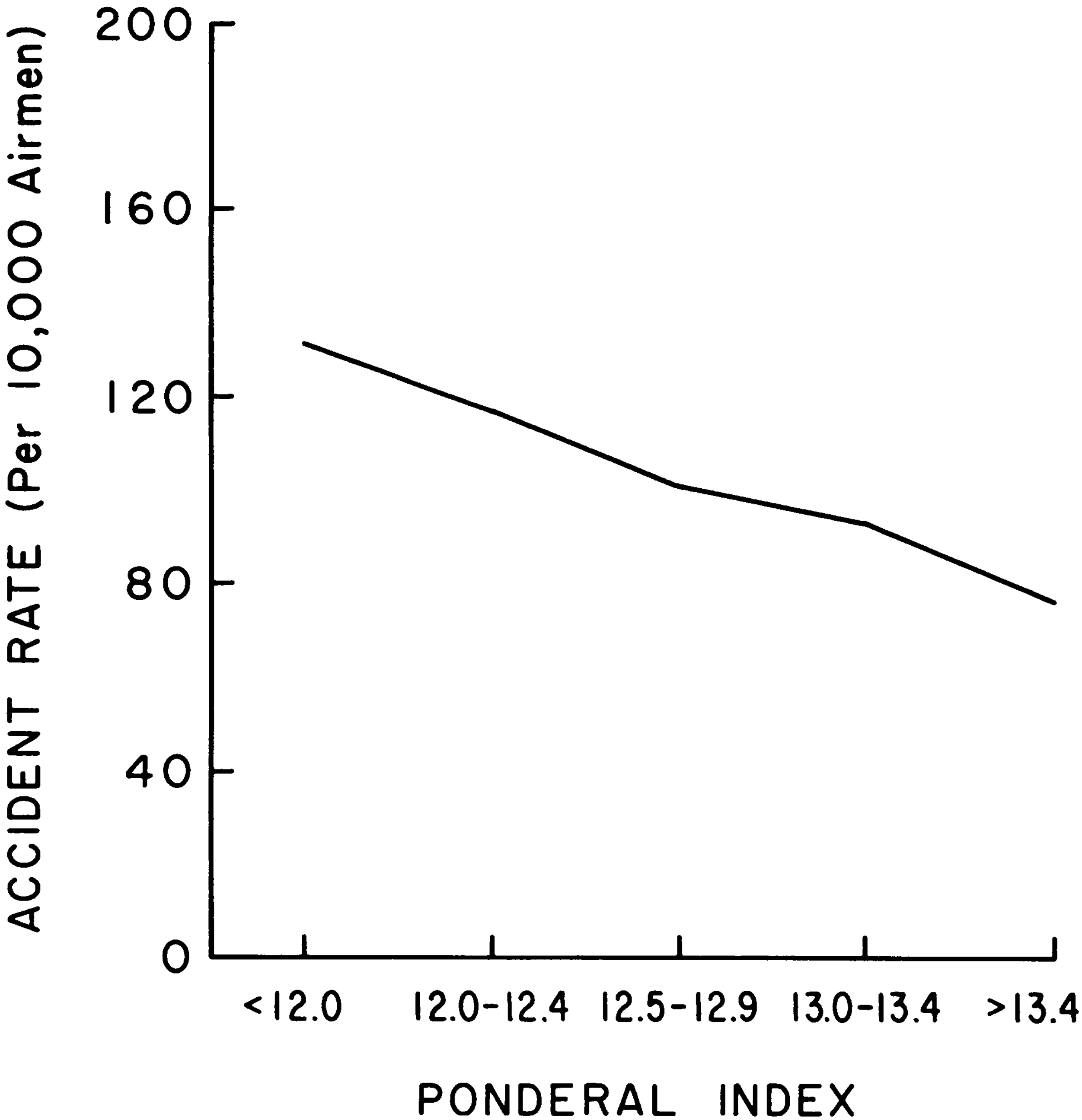

FIGURE 5.2. General Aviation Accident Rate by Ponderal Index.

analysis of the causes of general aviation accidents. The manner in which the body weight factors (body weight, BW/BSA, and PI) may operate is as yet unknown. Whether the fundamental problems are psychological, biological, or simply reflect a discrepancy at the man-machine interface can only be speculated at present.

Several lesser points uncovered in this study deserve some specific comment, although adequate explanations are not immediately apparent. In general, the accident rate increases with increasing age (Figure 1.2). However, the decade 40–49 years appears to deviate from a smooth trend line suggesting that the accident rate in this decade is less than that of the decade immediately preceding (30–39 years) or immediately following (50–59 years). The characteristics peculiar to this decade which might be responsible for the lower than expected accident rate are not known. However, one might speculate from observing Table 1 that this age interval is a "staging area" for attrition from an active status.

The observation that the "short" ($<63''$) and "tall" ($>75''$) class intervals have a slightly higher accident rate than adjacent intervals (Figure 2) also suggests that unidentified factors are operating within these classes. While this finding offers an interesting point for further study of man-machine interface, an attempt to explain it at present is beyond the scope and limitations of this report.

Identification of age as a significant variable differentiating the accident and non-accident distributions deserves some additional comment as related to the weight factors. It is generally recognized that as age increases in American men, body weight on the average also increases[19]. This fact poses the additional problem of deciding whether weight or age is the more significant variable affecting the frequency distributions reported here. The present analysis of accident data does not permit a further discussion on this point, but the question is a fundamental one and deserves further attention, particularly because the combination of advanced age and obesity are known to be partially implicated in the susceptibility of American men to coronary heart disease[20 21]. It may be possible that age and weight are additive in their effects on the distributions. This could explain why age has not been found to be an important accident factor in populations which are highly selective in terms of physical fitness (military pilots and commercial air transport pilots)[10]. The involvement of age and age-associated variables (physical defects) in general aviation accidents has been analyzed recently by Dougherty and Harper[13]. However, the age/weight relationship was not considered.

The observations that weight and variables derived from weight have a relationship to general aviation accident frequencies is interpreted here as only a first approximation to the problem. It seems reasonable that further exploration into this area should be considered from both a statistical and biological viewpoint in order to better characterize the mechanism(s) through which the gross variable operates.