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EFFECTIVENESS OF RESTRAINT EQUIPMENT IN ENCLOSED AREAS	February 1972
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15. Supplementary Notes

Research leading to preparation of this report was performed under Project AM-A-71-PRS-37.

16. Abstract

A series of 20-g decelerations of a crash sled was conducted to determine the magnitude of head impact decelerations while wearing various types of restraint equipment in small confined areas. Restraint webbing loads and head impact decelerations are presented for three directions of impact (straight forward, and 90° to left and right). Restraint webbing undoubtedly reduces head impact velocities, especially in the forward direction. However, this study shows that, in most instances, head strikes may be expected even while using upper and lower torso restraint because of the close proximity of surrounding structure in general aviation aircraft. Introduction of upper torso restraint along with lap belts in general aviation aircraft will not relieve the need for delethalizing surrounding structures.

17. Key Words	18. Distribution Statement
Crash injury, aircraft design, aviation safety, body flailing during deceleration, shoulder harness design, injury potential	Availability is unlimited. Document may be released to the National Technical Information Service, Springfield, Virginia, 22151, for sale to the public.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	28	$3.00

Form DOT F 1700.7 (8-69)

EFFECTIVENESS OF RESTRAINT EQUIPMENT IN ENCLOSED AREAS

I. Introduction.

Numerous research scientists have investigated the effectiveness of various restraint devices during deceleration utilizing instrumented dummies, volunteer human subjects, and various primates.[1 2 3 4 5 6 7 8] However, in all cases, tests were conducted with a seat mounted openly on a crash sled in such a manner as to allow freedom for kinematic motions in all directions, limited only by the restraint equipment being tested. Since man, as an operator of a vehicle, spends most of his time during transportation in a small enclosed area sitting next to rigid structure on his left, within 2 to 4 feet of structure on his right, and within 18 to 20 inches from rigid structure in front of him, this study was conducted to determine head impact forces on surrounding structures and body kinematics while wearing seven different designs of restraint equipment in an enclosed area. For economy reasons, sections of automobile bodies instead of aircraft fuselages were utilized in these tests. Decelerations were measured in the forward and in both lateral directions.

II. Test Equipment and Procedures.

Four automobile bodies (a 1961 Chevrolet, a 1961 Ford, a 1965 Mercury, and a 1965 Plymouth) sectioned just anterior to the firewall and just aft of the back of the front seat, were purchased from a local salvage yard and rigged for mounting on the CAMI crash sled, Sled impact velocity was programmed for approximately 29 miles/hour (42.53 ft./sec.) to produce a peak deceleration of 20 g's. Actual test results indicated a peak terminal sled velocity of 42.3±1 ft./sec. and all impact tests with the exception of test runs Numbers 3 (17 g's) and 20 (23 g's) had peak decelerations of 20 g's. Photographic coverage of the event was provided to record both top and side views at 24, 400, and 2000 frames/second.

Three 250–g CEC Model 4–202–0001 strain gage accelerometers were mounted tri-axially in the head of an Alderson F–50 anthropometric dummy to measure forward, lateral, and vertical head impact decelerations. Belt load transducers manufactured in the CAMI machine shops were calibrated on a 5000-pound capacity Dillon dynamometer prior to test procedures. Output signals for the belt load transducers and accelerometers were recorded on a CEC Model 5–124A oscillographic recorder in conjunction with a Sanborn 550M signal conditioning system.

A total of 24 tests was conducted to evaluate the effectiveness of whole body restraint systems for head protection. Seven different types of restraint equipment were used for these tests in the forward and in both lateral test positions. For comparison, one test was made in each of the three directions with the dummy unrestrained. These seven different designs of restraint equipment are shown diagrammatically in Figures 2 through 8, 10 through 16, and 18 through 24. The restraint equipment tested consisted of (1) a single diagonal chest strap without seat belt (as used in some foreign cars) (Figure 2), (2) a single diagonal chest strap with a separate seat belt (as installed on over 10,000,000 late-model American cars) (Figure 3), (3) the so-called three-point restraint system—diagonal chest strap with lower end attached to one-half of the seat belt and upper end attached to the "B" post (Figure 4), (4) a three-point harness identical to that described above with the exception that the upper end of the chest strap goes over the shoulder and seat back and is attached to the floor structure behind the seat (Figure 5), (5) a double chest strap arrangement with the lower ends sewn to the lap belt, near the seat back and pan intersection, and the upper ends joined behind the neck to form a single strap which, in turn, passes over the seat back and attaches to the floor structure behind the seat (Figure 6), (6) a restraint system the same as number 5 with the exception that the shoulder straps are crossed behind the neck and pass over the seat back to separate floor attachments (Figure 7), and (7) the Pacific Scientific quick-release harness in which shoulder straps and lap belts plug into a quick-release buckle. In these tests, the common upper torso strap passed over the seat back to a fixed floor attachment instead of going into an inertial reel (Figure 8).

III. Results.

Head impact forces with various structures and restraint webbing loadings, as well as vertical forces on the neck from centrifugal forces, along with time readings of each peak force occurrence from the time the crash sled began deceleration, are shown diagrammatically in Figures 1 through 24.

Forward Decelerations: Figure 1 demonstrates, as other researchers have shown repeatedly, that the unrestrained human body slides forward in an erect sitting posture until the knees contact the lower instrument panel, at which time the upper torso flexes forward into the windshield and/or control column. In the case depicted, the head penetrated the windshield (1965 Plymouth) at about the same time that the neck contacted the upper steering wheel rim.

In studying Figures 2 through 8, the following observations are made:

All harness configurations allowed the driver's head to impact the steering wheel rim and/or hub.

Deceleration impact force was proportional to the length of shoulder strap webbing in designs anchored to the "B" post and roof structure; i.e., the longer the webbing, the greater the impact force with increase in stretch distance.

In designs where shoulder straps traversed the top of the seat and anchored to the floor structure behind the seat, head impact force varied with yield characteristics of the seat back structure—the top of the seat flexed forward 6 to 8 inches.

Head impact force with steering structures varied between 45 and 107 g's (forward and lateral head forces were vectored since there was usually some degree of head rotation). These forces could be tolerated without serious injury on well-designed structures, but would cause serious facial fractures and head injuries in most current transportation vehicles.

A vertical peak force of 20 to 40 g's was recorded in all forward deceleration tests and, since this peak force occurred approximately 0.02 seconds before head impact, it may be assumed that the stress resulted from centrifugal force, producing considerable stretching of the neck along the radius of motion.

In general, as would be expected, the fewer the number of straps restraining the body, the higher the webbing loads. For example, when only a single upper torso strap was used without a seat belt (Figure 2), the total strap load exceeded 2200 pounds and would have been higher, but lack of a seat belt allowed the knees to impact the lower dash panel, taking some of the deceleration load off of the chest strap. With the body totally restrained by using both chest strap or straps and lap belt, total strap loading was approximately 3000 pounds. Attaching shoulder straps to the lap belt as in Figures 4, 5, 6 and 7 substantially increases (nearly doubles) the strap loading on that portion of the lap belt that serves as a common attachment for both a shoulder strap and a portion of the seat belt.

Lateral Impact—Occupants thrown to the left: In comparing Figures 10 through 16 with that of the unrestrained dummy in Figure 9, it is clear that none of the seven different restraint systems offers any appreciable protection against head impact in this direction (as attested to by low readings on the restraint webbing) since the occupant is seated in such close proximity to side structures on his left. The following observations are, however, worthy of note:

a. Impact of the side of the head may occur against the "B" post or against the door glass, depending on slight variations in the angle of impact. Head impact against the "B" post in this study ranged from 110 g's to 158 g's; these levels would probably be fatal since the loads were concentrated on such a small area of the head due to rigid, nonyielding construction of the post. Head impact forces to break the door glass were 100 and 122 g's for pre-1965 laminated glass as compared with only 44 and 60 g's for tempered glass used in 1965 and later-model vehicles. According to Lissner,[9] none of these forces against yielding glass is sufficient to produce skull fracture.

b. As shown in Figure 10, the lap belt is an absolute necessity in this type of impact to prevent ejection. Use of the single shoulder strap without a seat belt in Figure 10 allowed the buttocks to be ejected out the door, and permitted the strap to catch under the chin, putting an 800-pound load on the webbing. In such situations, the body slides down the strap and a knife-action is produced on the neck which has been reported to decapitate the occupant.[10]

c. In Figures 14 and 15 (double shoulder straps), it will be noted that the strap forces are considerably higher, especially on the strap over the left shoulder. A double shoulder strap system running *through* a strong integrated seat could offer considerable protection against left side impacts.

20-g Right Side Impact: In the unrestrained test, the dummy (Figure 17) slid across the seat in a sitting position in less than 0.3 seconds and the right side of its head impacted on the right "B" post with a force of 150 g's. Body impact caused the door to open and the dummy was ejected.

In all instances of single strap restraint over the left shoulder, the upper torso slipped sideways out of the shoulder strap and the body folded to the right, over the seat belt, with the head striking the seat cushion (Figures 18, 19, 20 and 21). These lateral head impacts with the seat cushion, varying between 20 and 50 g's, are insignificant; however, lap belt loads between 1675 and 2550 pounds cutting into the side of the abdomen would probably cause some internal injuries.

Double strap shoulder restraint over the seat back in conjunction with a seat belt allowed some lateral motion of the trunk, but held it almost upright (Figures 22, 23 and 24). In these tests the side of the head hit the top of the seat back with insignificant forces varying from 49 to 73 g's and abdominal loads from seat belts were significantly reduced (975 to 1925 lbs.).

IV. Discussion.

Caution should be used when the results of the kinematics of the body along with head impact forces presented in this study are applied to general aviation aircraft because of the difference of internal measurements of the occupant spaces. The front seat of an automobile is approximately 5 feet wide, while that of popular general aviation aircraft varies from 3 to 4 feet, with a large majority of seats only about 3.5 feet wide. A previous study [11] has shown a side displacement of the head from the centerline of the body (in the sitting position, with seat belt restraint) in excess of 36 inches during application of a one-g force. Since the centerline of the body is approximately 12 inches from the left side of the aircraft, only 2 to 2½ feet of clearance are available to the right side for prevention of head impact with side structures. Hence, the kinematic motions allowed to the right side (without head impact) with the types of restraint equipment shown in Figures 18 through 21 would be expected to allow head impact with the right side of the cabin in most general aviation aircraft. Only the double shoulder strap designs shown in Figures 22 through 24 sufficiently restrained side motions of the body to protect the head in small aircraft.

In the forward deceleration tests, the maximum motion of the head was approximately 14 inches in the horizontal plane and 14 inches in the vertical plane. This compares favorably with Chandler's study [12] of human subjects in which he reports a forward horizontal motion of the head of 1.03 feet during a 12-g deceleration. Young [13] has reported 22 to 24 inches of horizontal displacement of a dummy's head with a vertical drop of 16 to 18 inches, while the dummy was restrained by a single strap shoulder harness during decelerations from velocities between 40.6 and 41.3 feet/second. In the same report [13] he showed that double shoulder strap harnesses restrict the forward motion of the head to a range of 10 to 18 inches and the vertical motion to 16 to 20 inches. It is probable, therefore, that forward head motions in the tests presented in this report were limited by impact with the steering assembly and that, when these measurements are corrected and applied to general aviation aircraft, occupants of the front seat can be expected to experience head impact with the upper instrument panel and control wheel, even while wearing shoulder harness restraint, if they are exposed to decelerations of the magnitude tested in these studies.

V. Conclusions and Recommendations.

As demonstrated by the test dummy, restraint of the human body by the use of belts during crash decelerations is difficult. In the small cockpit area of general aviation aircraft, a single diagonal chest strap used in conjunction with a lap belt may reduce, but will not prevent, head impacts during forward and side decelerations. A double shoulder strap-lap belt design of restraint equipment can further reduce crash injuries, especially in crashes involving deceleration forces which will throw the pilot to the right side of the cockpit, provided that it is designed as an integral part of a strong seat or fastened to a strong aircraft structure near the seat. The findings given in this report indicate that even with the upper torso and lap belt restraints, front seat occupants will suffer injuries from forward and side crash impact forces under the acceleration conditions of the test; therefore, engineers should stress design of structures in the cockpit area to minimize injuries from head impact.

REFERENCES

1. Snyder, R. G., J. W. Young, and C. C. Snow: "Experimental Impact Protection With Advanced Automotive Restraint Systems: Preliminary Primate Tests With Air Bag and Inertia Reel/Inverted-Yoke Torso Harness." *Proceedings of Eleventh Stapp Car Crash Conference*, New York, SAE, 1967.
2. Lewis, S. T. and J. P. Stapp: "Human Tolerances of Aircraft Seat Belt Restraint." *Journal of Aviation Medicine* Vol. 29(1958), pp. 177–198.
3. Ewing, C. L., D. J. Thomas, G. W. Beeler, L. M. Patrick, and D. B. Gillis: "Dynamic Response of the Head and Neck of the Living Human to $-G_X$ Impact Acceleration." *Proceedings of Twelfth Stapp Car Crash Conference*, New York, SAE, 1968.
4. Provost, E. L. and D. J. Schrum: "Dynamic Research of Upper Torso Restraints." *Proceedings of Ninth Stapp Car Crash Conference*, University of Minnesota, Printing Department, 1966, pp. 83–92.
5. Bohlin, N. I.: "Studies of Three-Point Restraint Harness Systems in Full-Scale Barrier Crashes and Sled Runs." *Proceedings of the Eighth Stapp Car Crash and Field Demonstration Conference*, Wayne State University Press, Detroit, 1966, pp. 258–319.
6. Aldman, Bertil: "A Protective Seat for Children—Experiments with a Safety Seat for Children between One and Six." *Proceedings of the Eighth Stapp Car Crash and Field Demonstration Conference*, Wayne State University Press, Detroit, 1966, pp. 320–328.
7. Provost, Emile L. and John O. Moore: "Dynamic Research of Human Restraining Devices." *Proceedings of Seventh Stapp Car Crash Conference*, Springfield, Ill., Charles C. Thomas, 1965, pp. 143–154.
8. Tourin, Boris, Bertil Aldman, Irving Michelson, and Jeremy Mitchell: "Restraining Characteristics of Harnesses." *Proceedings of Sixth Stapp Car Crash and Field Demonstration Conference*, Minneapolis, Minn., University of Minnesota, 1962, pp. 138–149.
9. Haynes, A. L. and H. R. Lissner: "Experimental Head Impact Studies." *Proceedings of Fifth Stapp Automotive Crash and Field Demonstration Conference*, Minneapolis, Minn., University of Minnesota, 1962, pp. 158–170.
10. Saldeen, T.: "Fatal Neck Injuries Caused by Use of Diagonal Safety Belts." *The Journal of Trauma*, Vol. 7(6):856–862, June 1967.
11. Swearingen, J. J., A. H. Hasbrook, R. G. Snyder and E. B. McFadden: "Kinematic Behavior of the Human Body During Deceleration." Reprinted from *Aerospace Medicine*, Vol. 33, Feb. 1962, 188–197.
12. Chandler, Richard F. and Robert A. Christian: "Crash Testing of Humans in Automobile Seats." New York, SAE Reprint No. 700361, 1970.
13. Young, Joseph W.: "A Functional Comparison of Basic Restraint Systems." FAA Office of Aviation Medicine Report No. 67–31, June 1967.

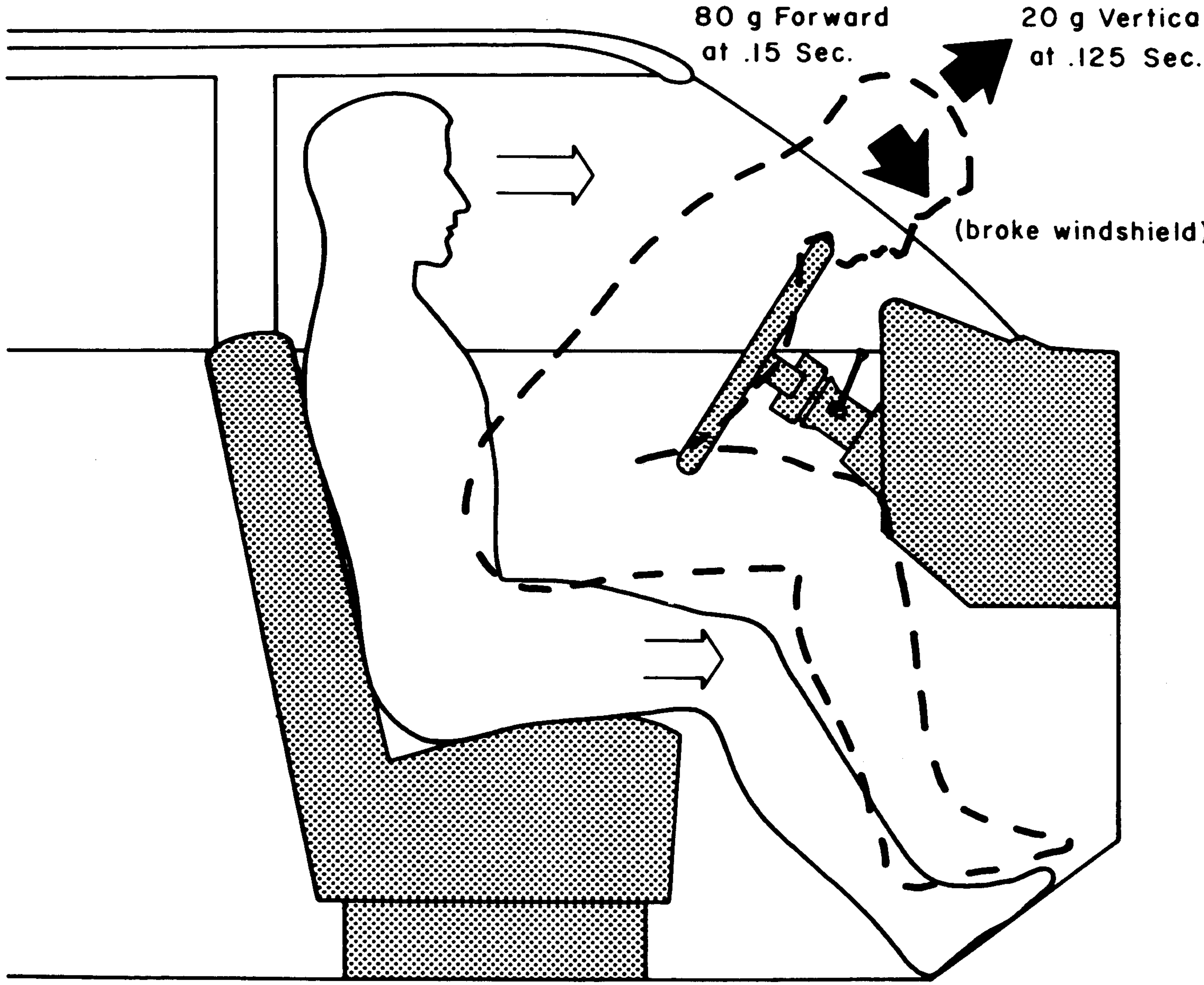

FIGURE 1. Dummy unrestrained, forward deceleration.

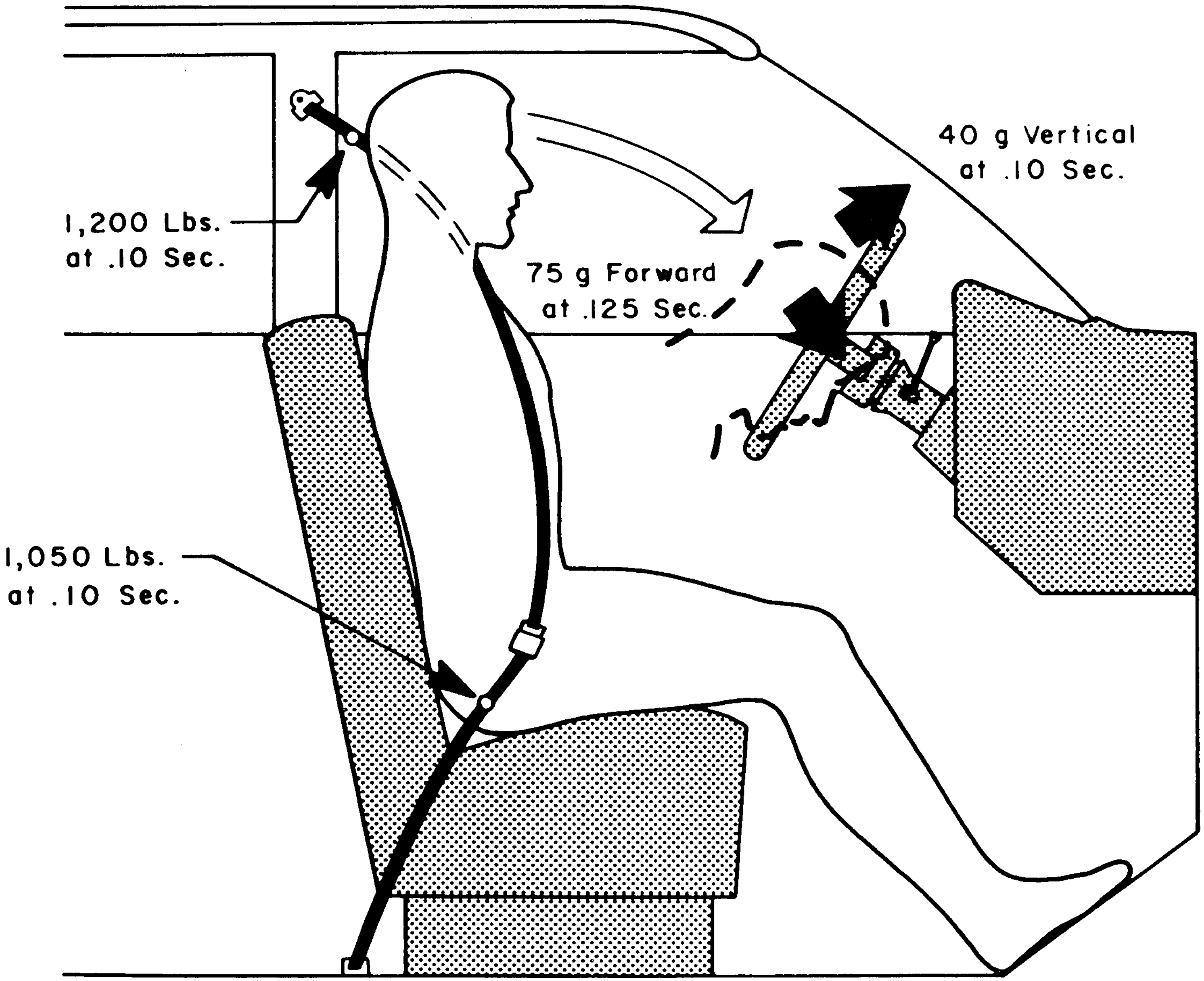

FIGURE 2. Dummy restrained by single diagonal chest strap, no seat belt, forward deceleration.

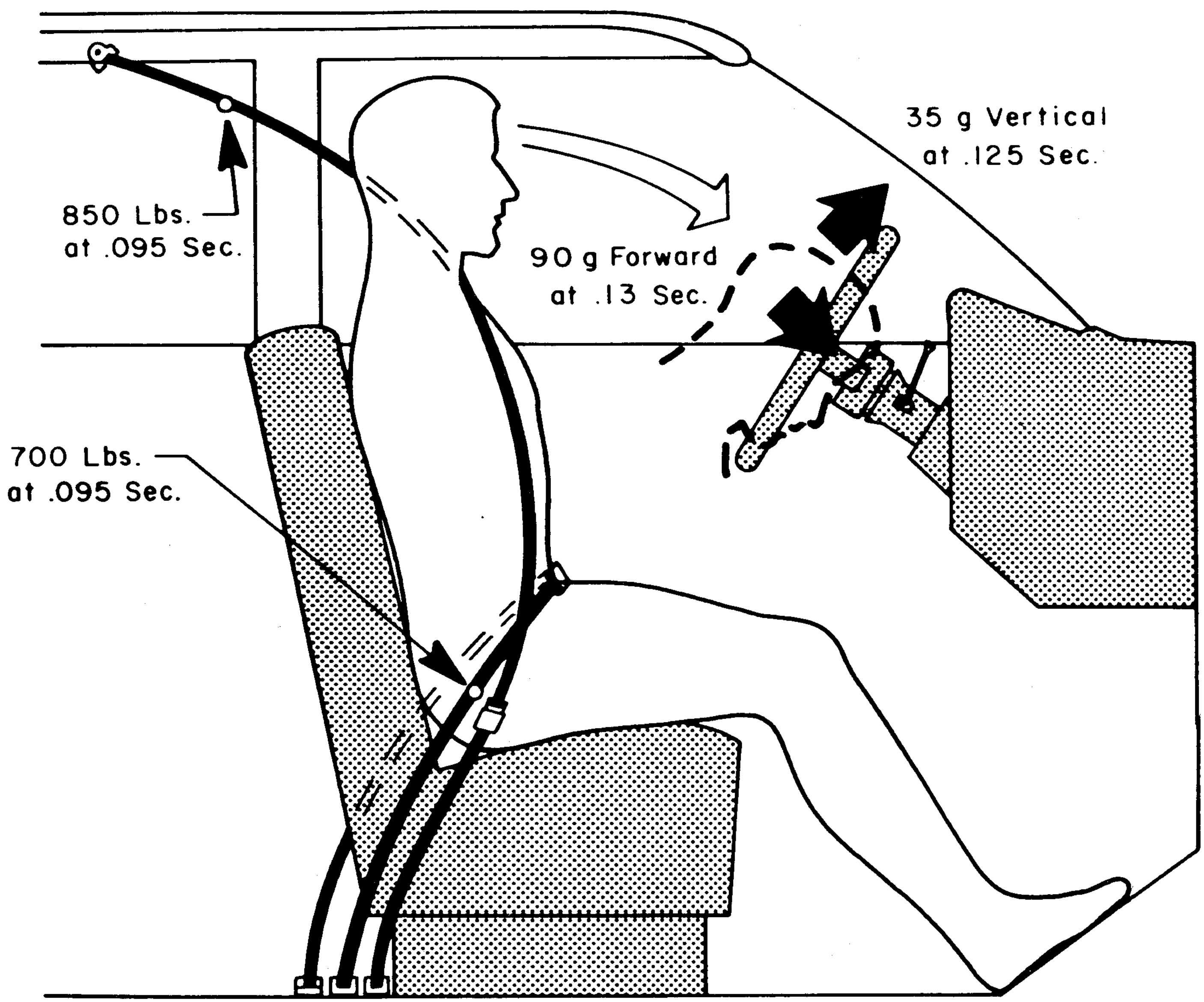

FIGURE 3. Single diagonal chest strap and a separate seat belt, forward deceleration.

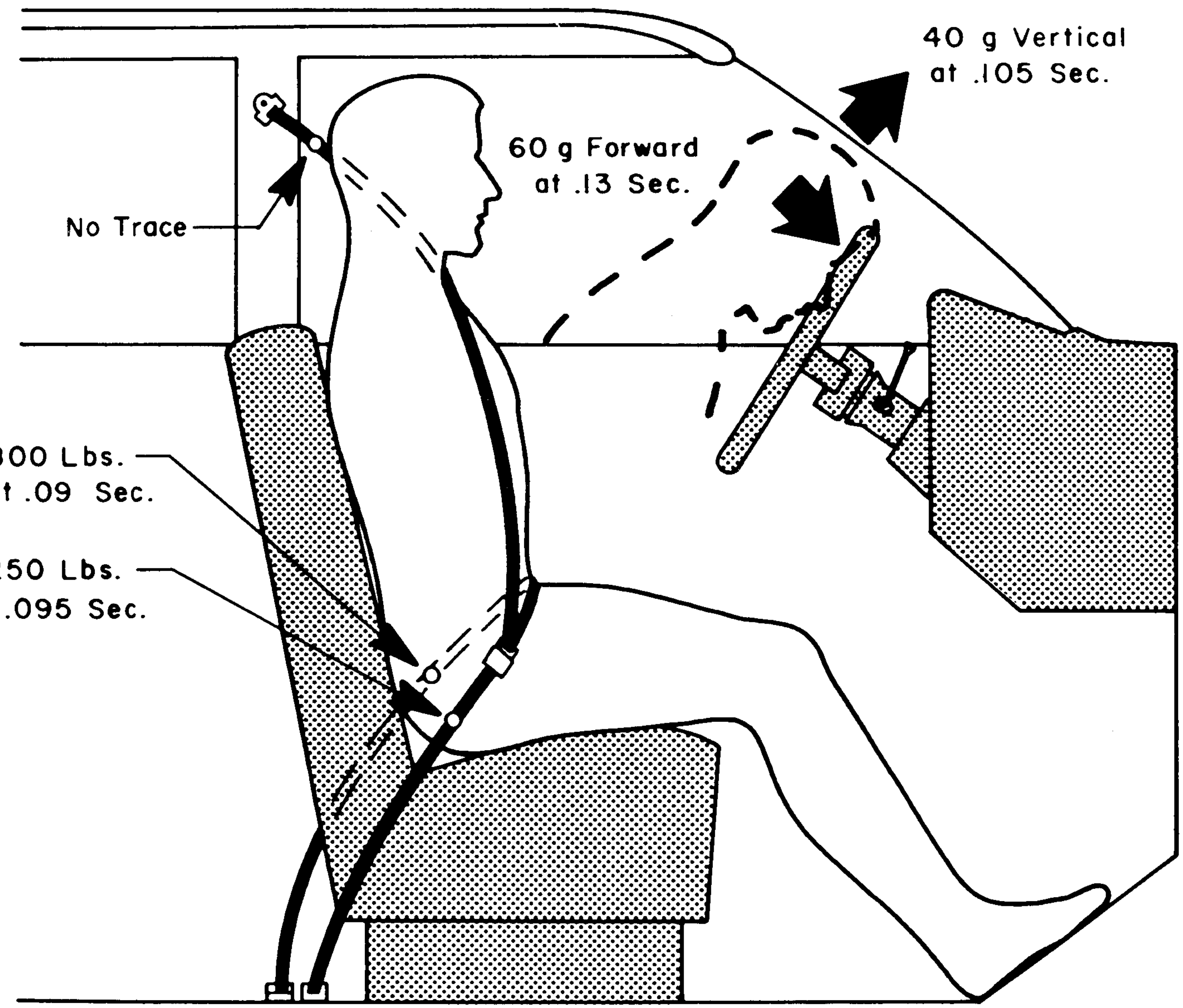

FIGURE 4. Three-point restraint system (diagonal chest strap with lower end attached to one-half of the seat belt and upper end attached to the "B" post), forward deceleration.

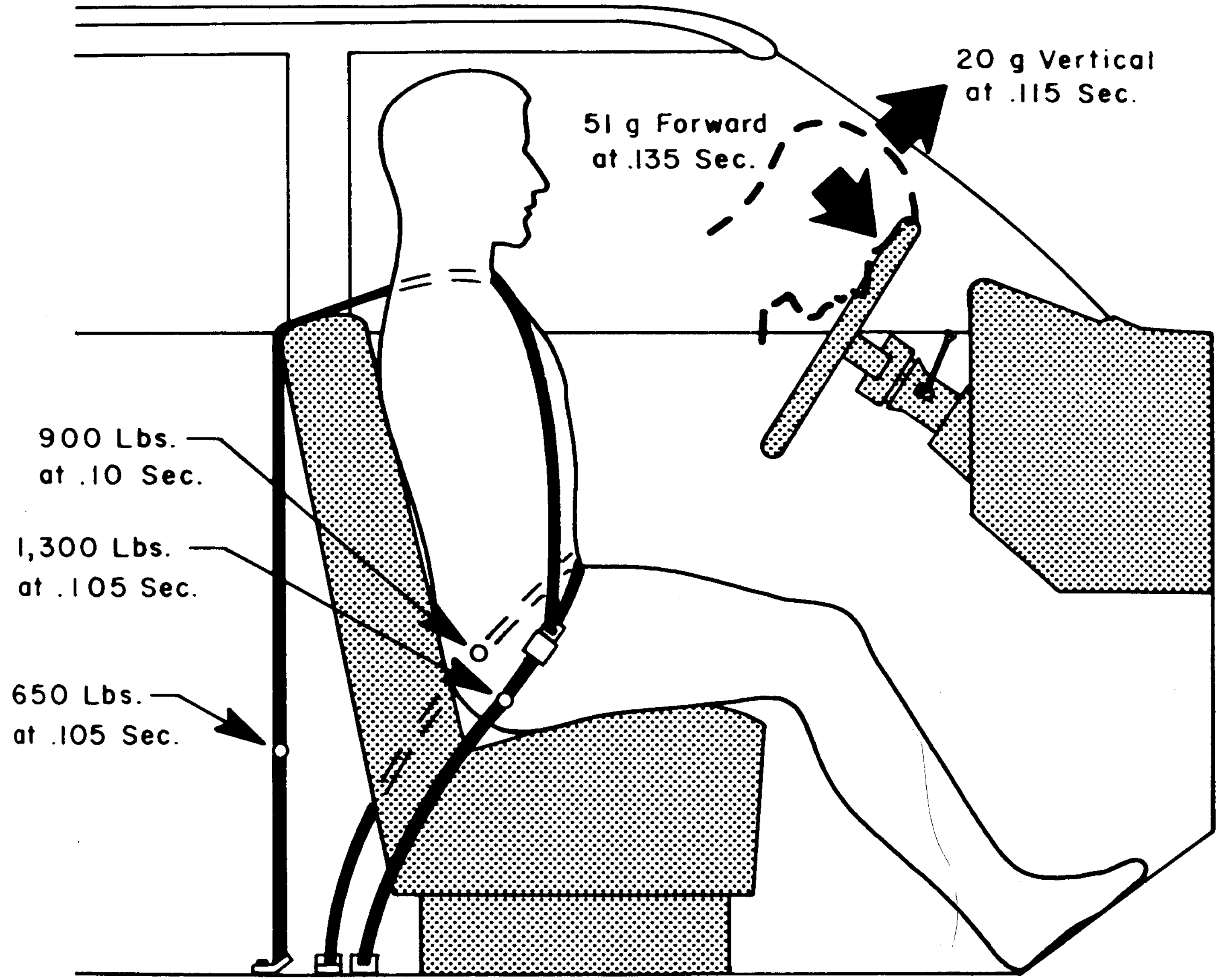

FIGURE 5. Three-point restraint system with chest strap going over seat back and anchored to the floor behind the seat, forward deceleration.

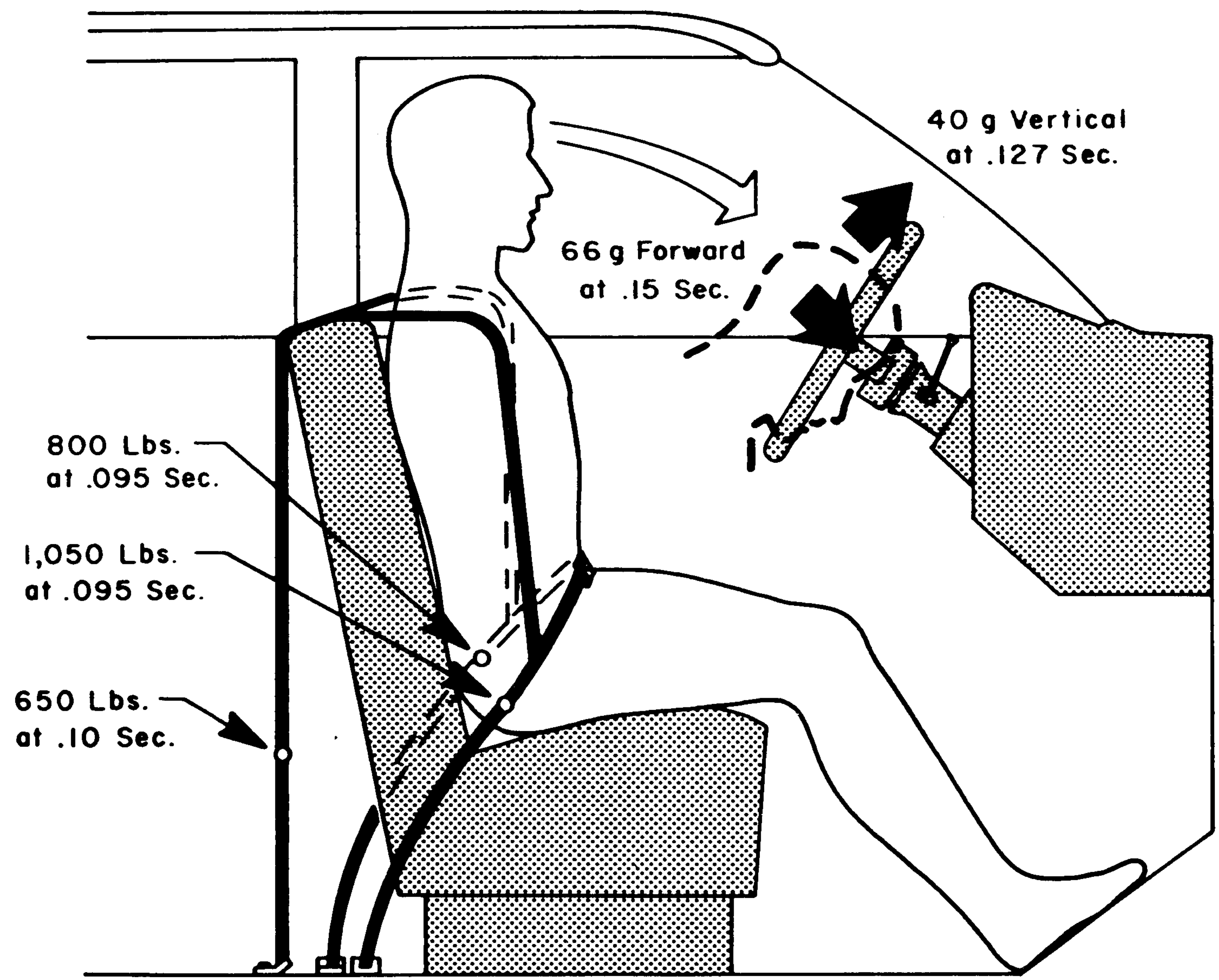

FIGURE 6. Double chest strap with lower ends sewn to lap belt near the seat intersection and upper ends joined behind the neck to form a single strap which, in turn, passes over the seat back to a floor attachment, forward deceleration.

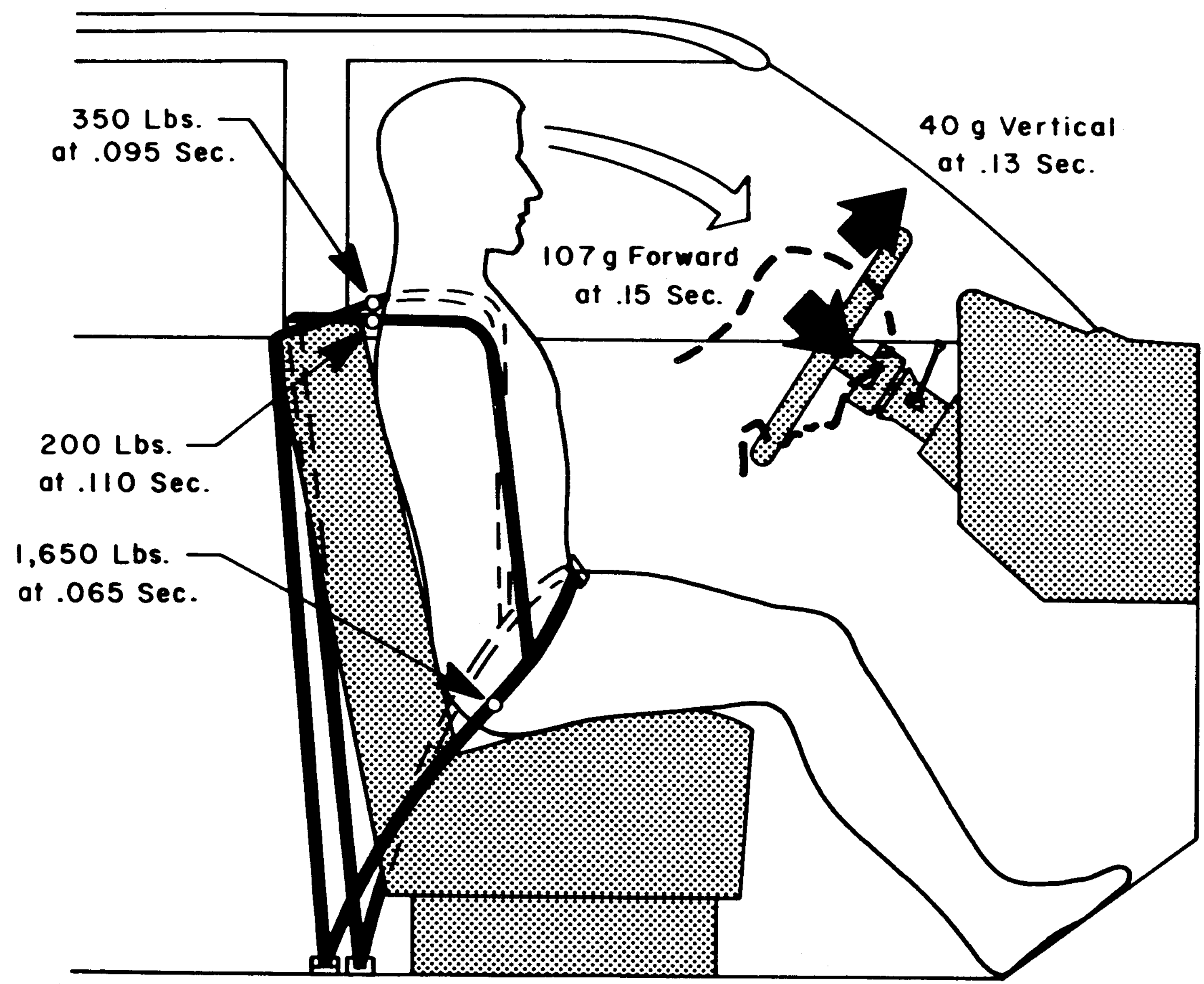

FIGURE 7. Double chest straps sewn to seat belt, crossed behind seat, and extending to separate floor attachments, forward deceleration.

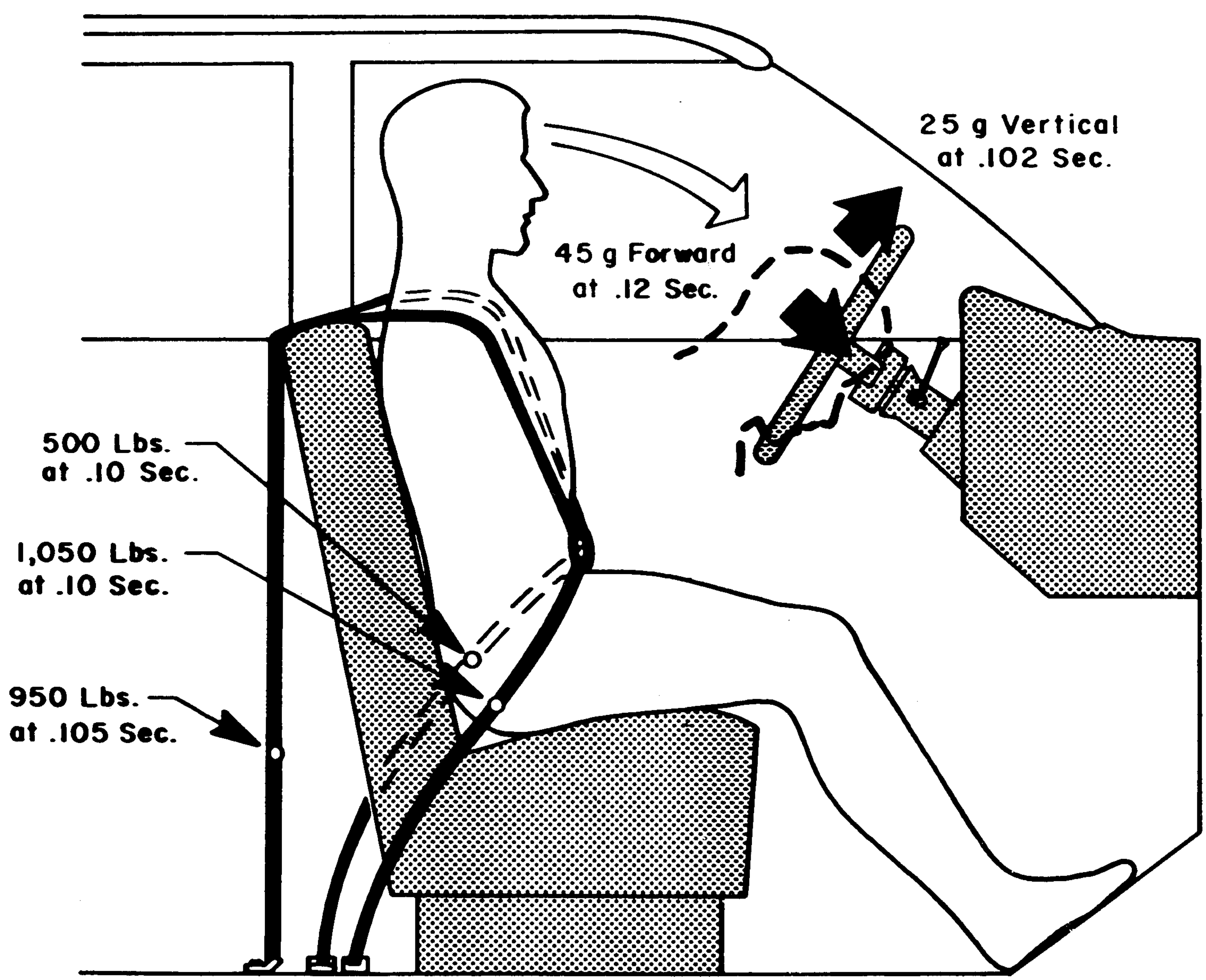

FIGURE 8. Pacific Scientific quick-release restraint equipment. Double chest straps converge to one behind the neck and attach to floor structure behind the seat, forward deceleration.

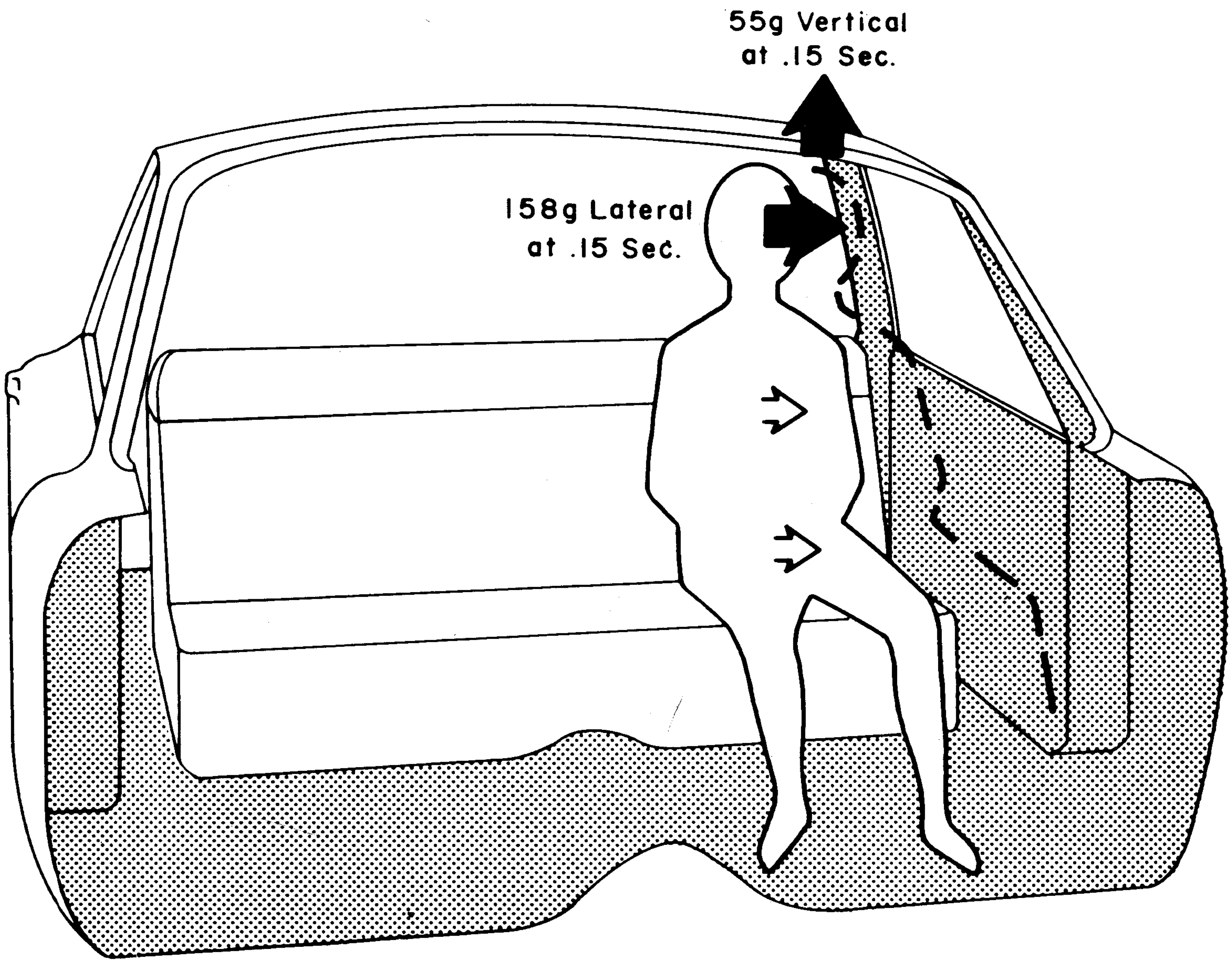

FIGURE 9. Dummy unrestrained, left side impact.

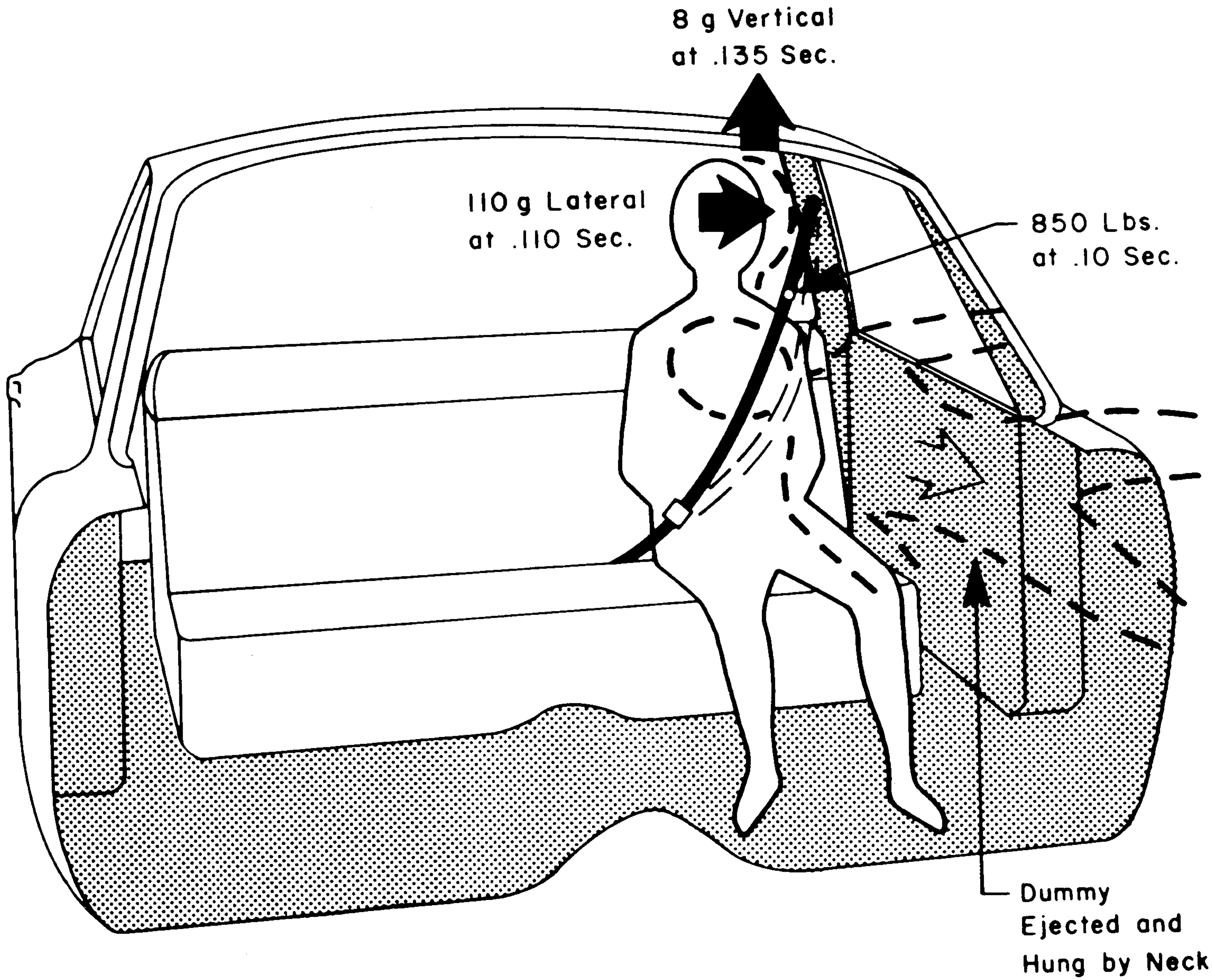

FIGURE 10. Dummy restrained by single diagonal chest strap, no seat belt, left side impact.

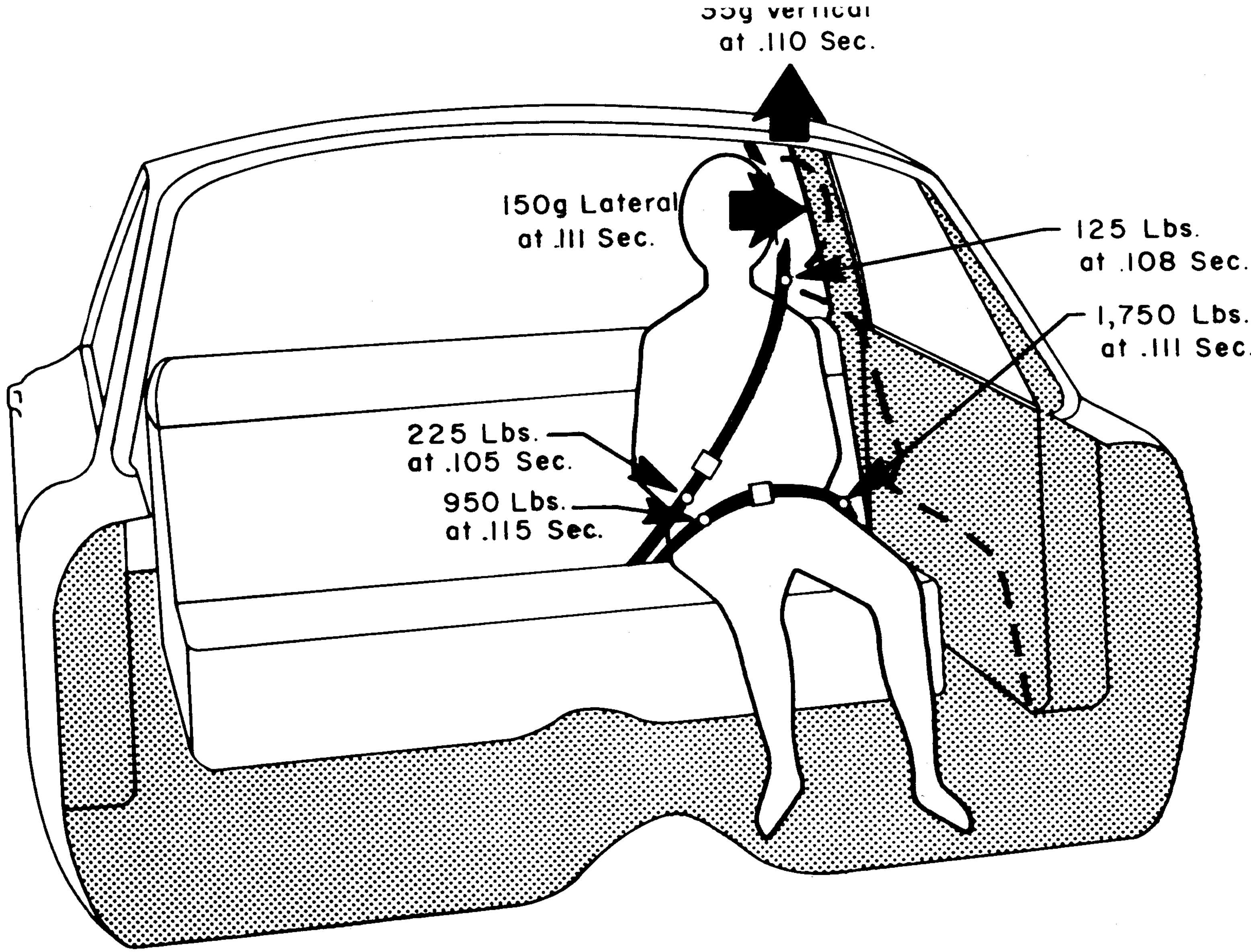

FIGURE 11. Single diagonal chest strap and a separate seat belt, left side impact.

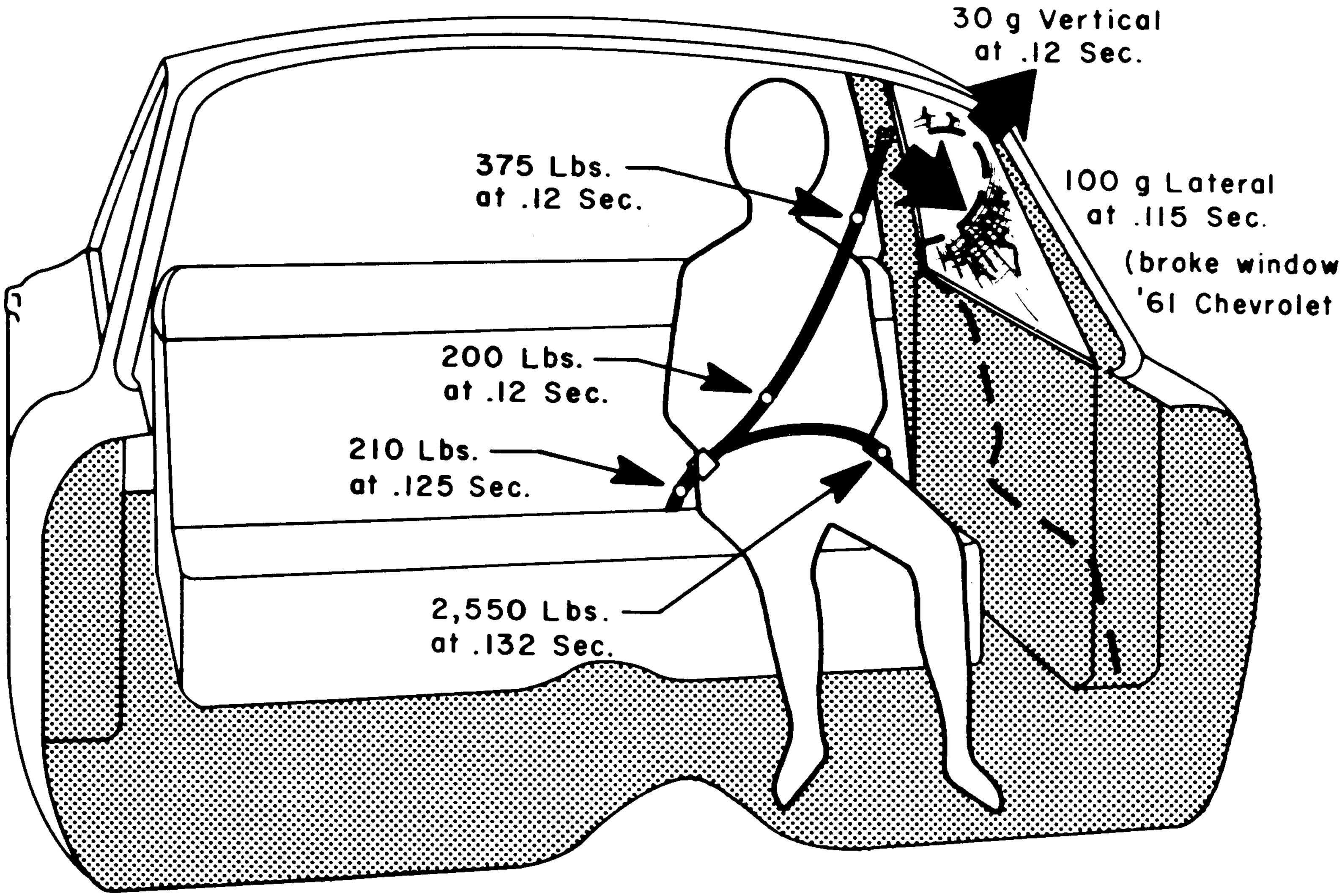

FIGURE 12. Three-point restraint system (diagonal chest strap with lower end attached to one-half of the seat belt and upper end attached to the "B" post), left side impact.

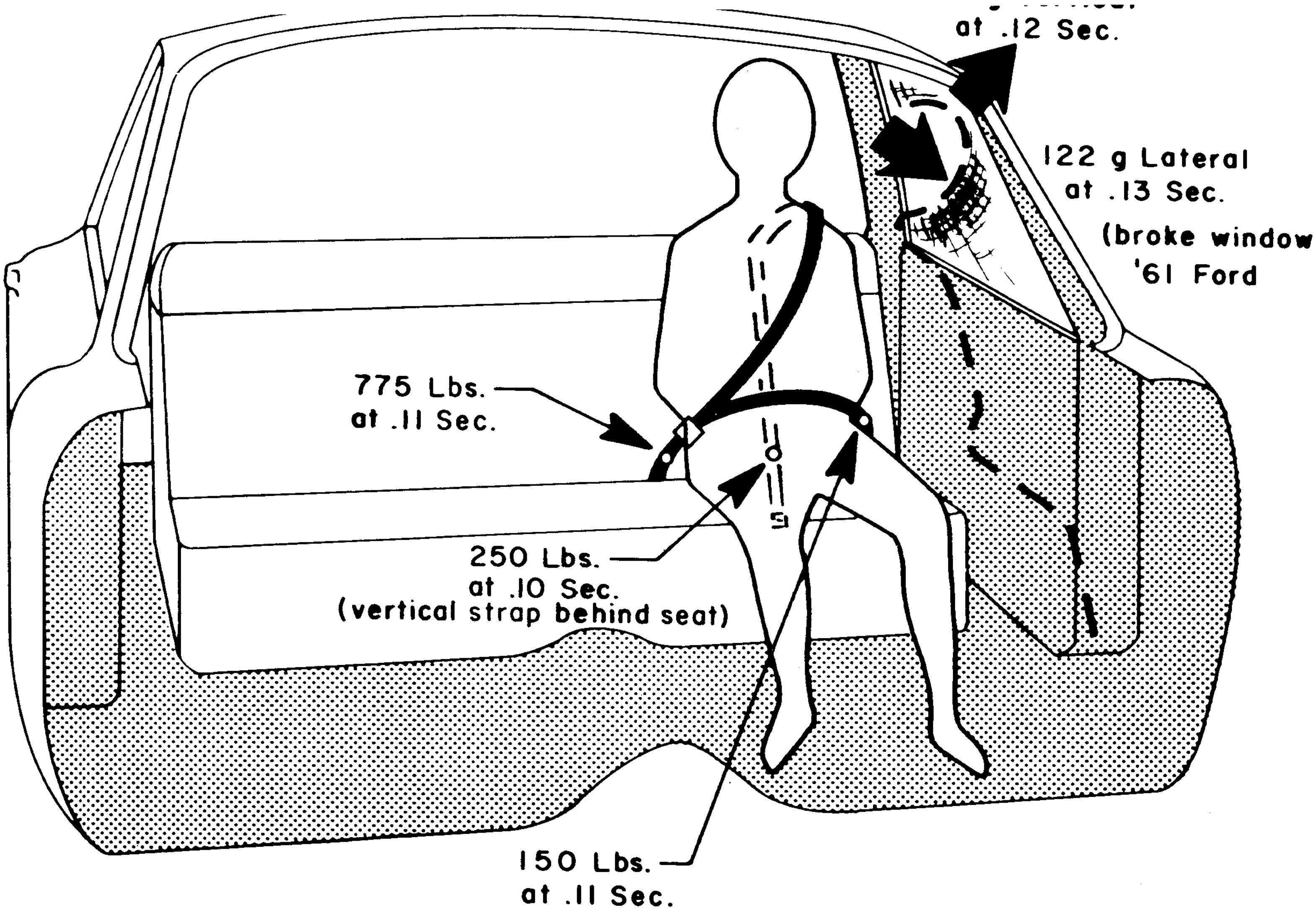

FIGURE 13. Three-point restraint system with chest strap going over seat back and anchored to the floor behind the seat, left side impact.

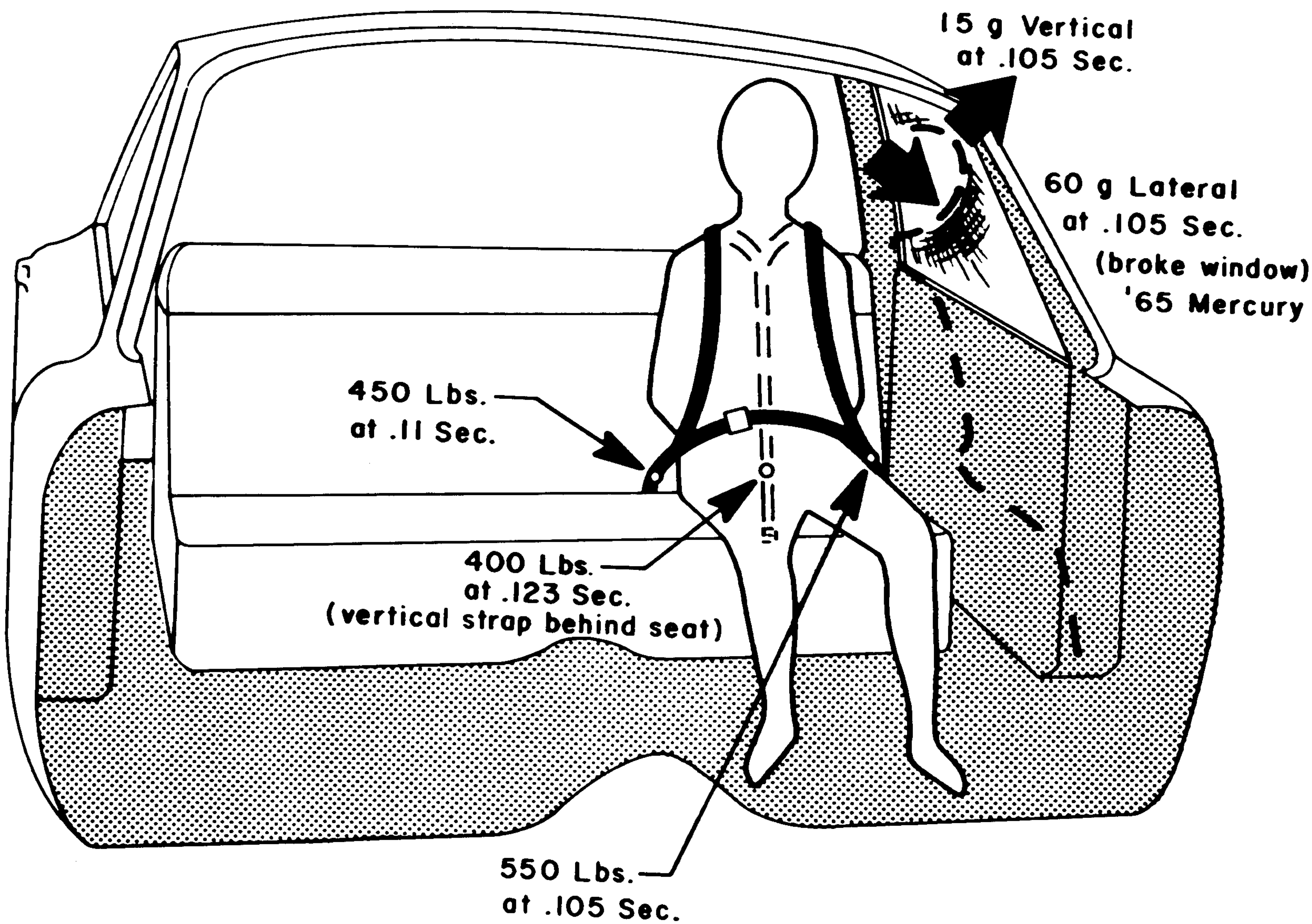

FIGURE 14. Double chest strap with lower ends sewn to lap belt near the seat intersection and upper ends joined behind the neck to form a single strap [illegible] seat back to a floor attachment left side impact.

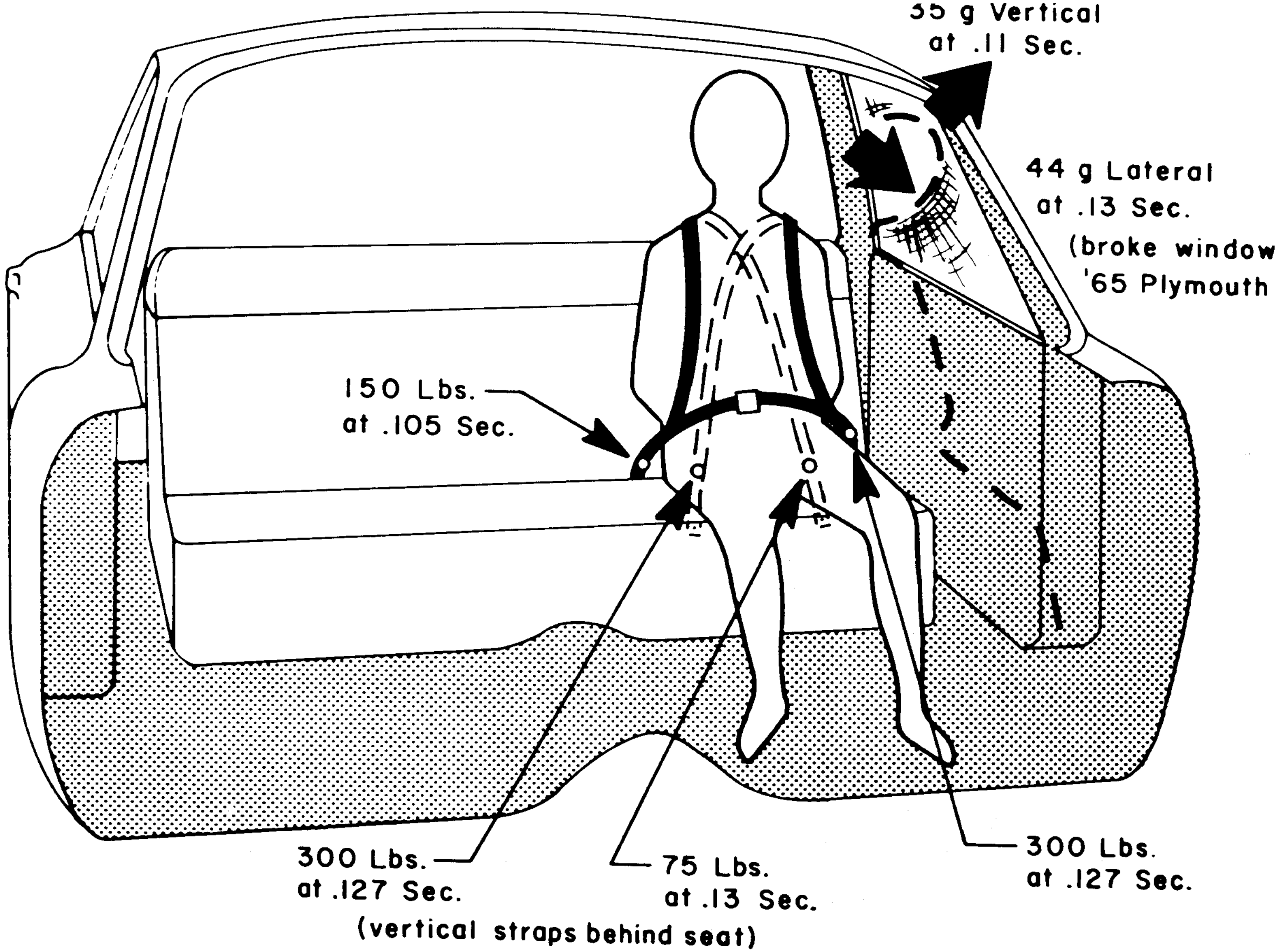

FIGURE 15. Double chest straps sewn to seat belt, crossed behind seat and extending to separate floor attachments, left side impact.

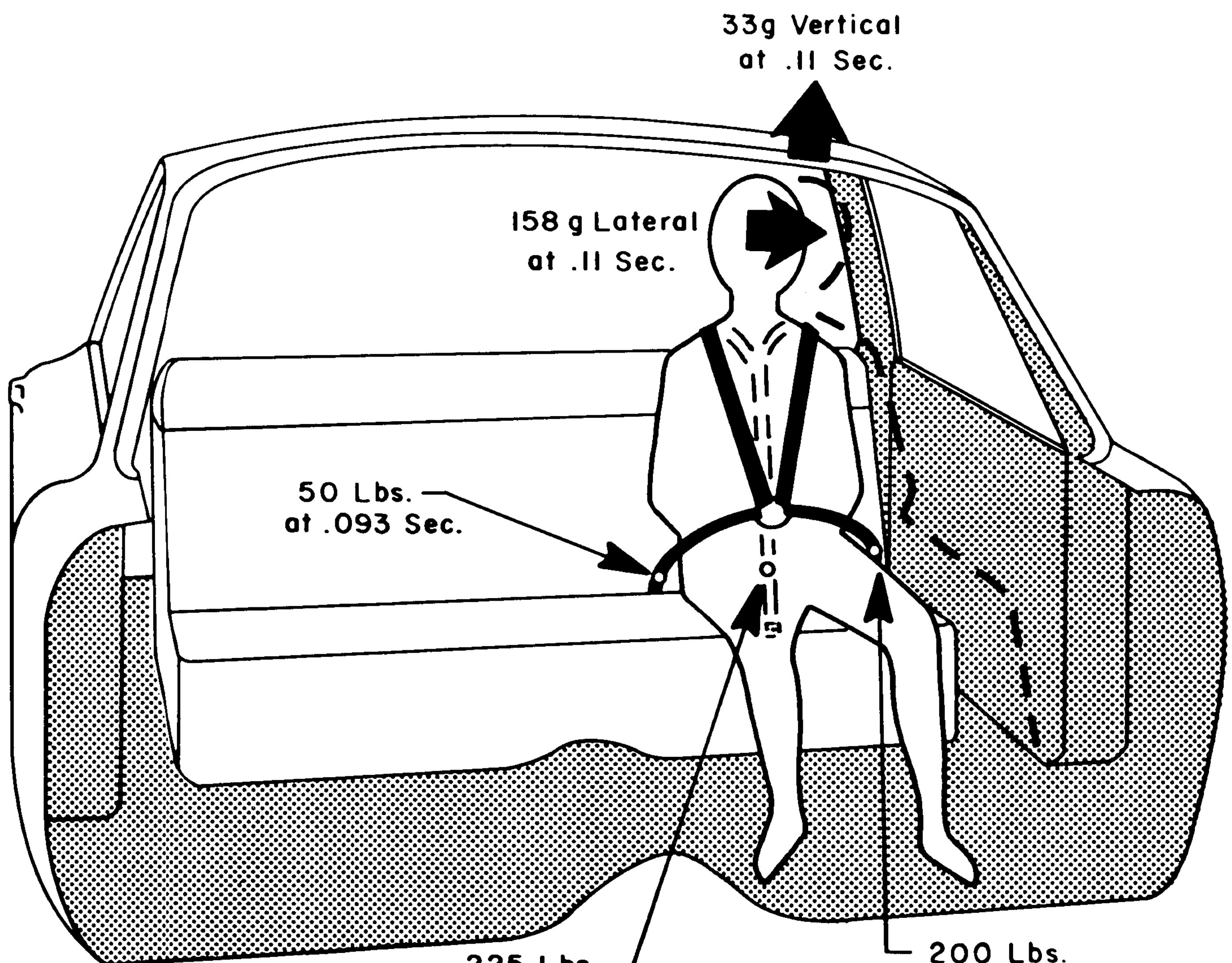

FIGURE 16. Pacific Scientific quick-release restraint equipment. Double chest straps converge to one behind the neck and attach to floor structure behind the seat, left side impact.

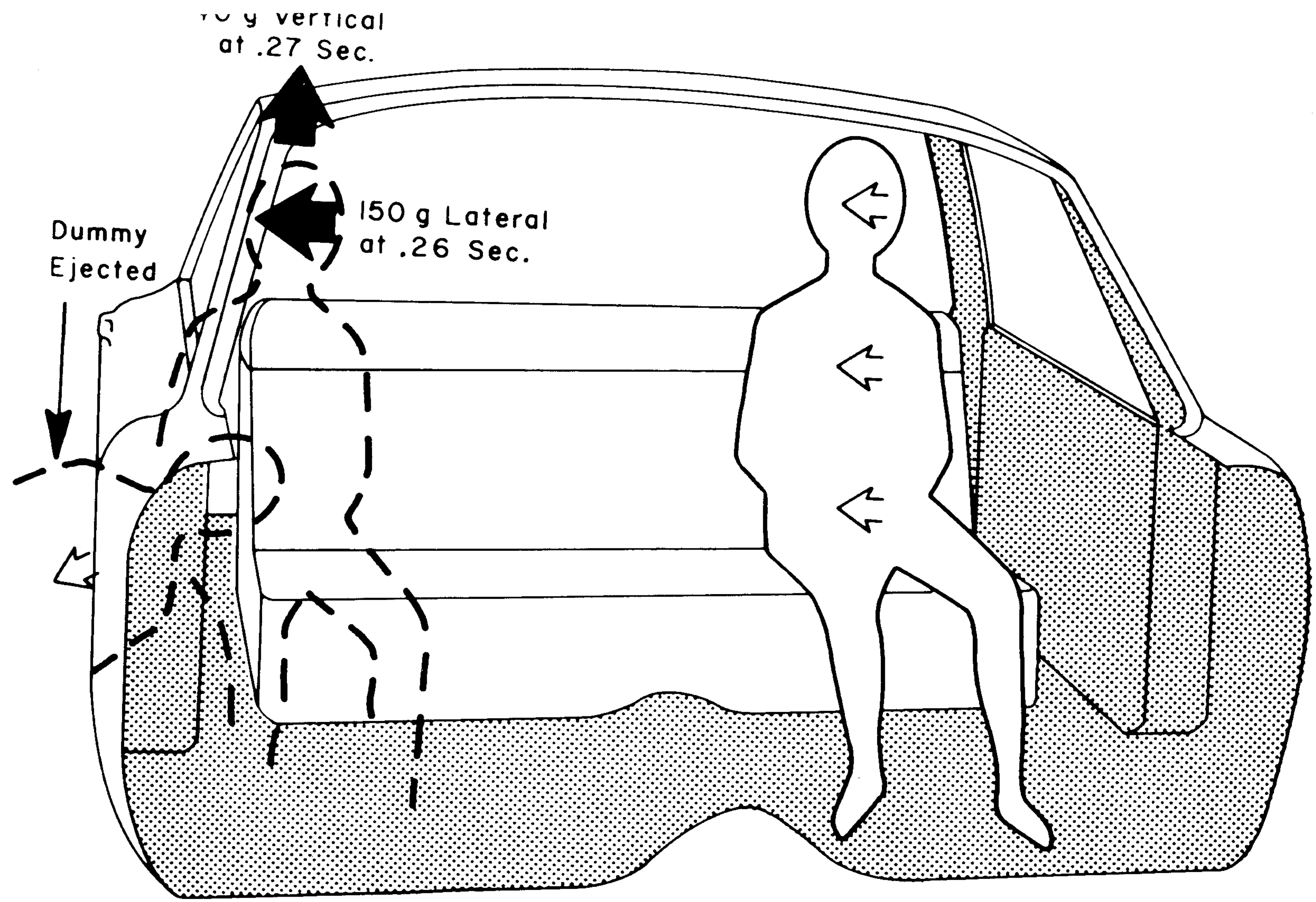

FIGURE 17. Dummy unrestrained, right side impact.

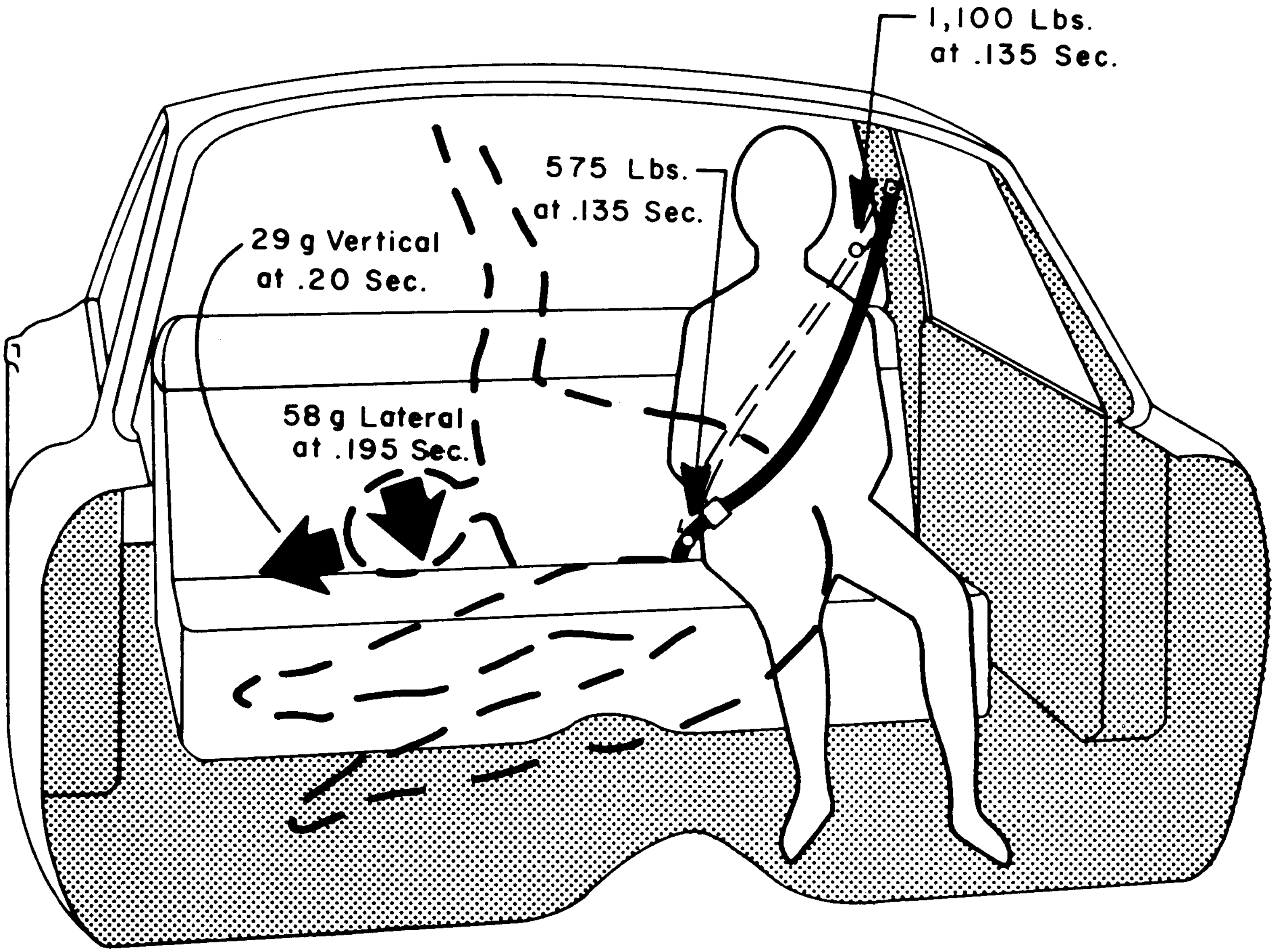

Figure 18. Dummy restrained by single diagonal chest strap, no seat belt, right side impact.

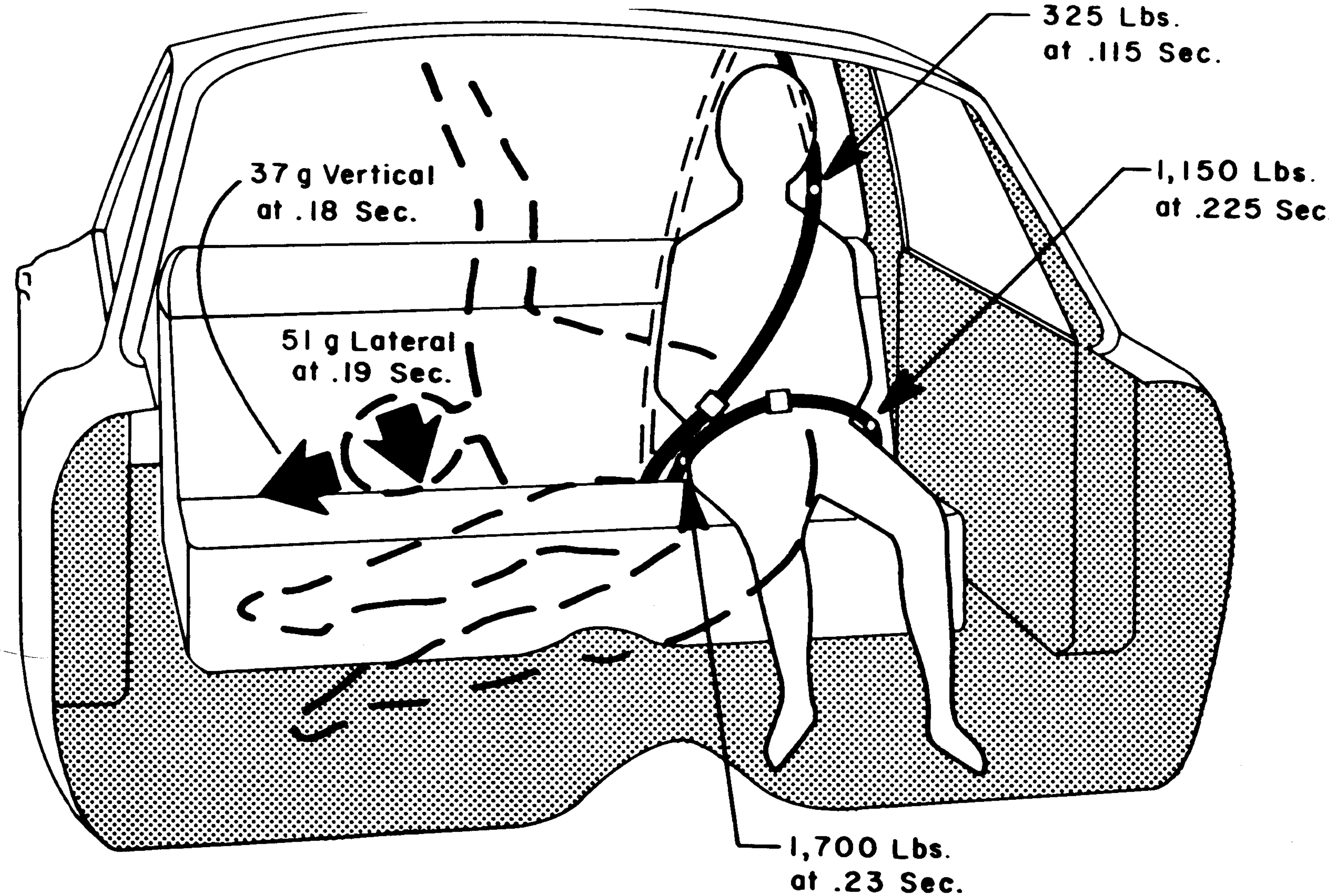

FIGURE 19. Single diagonal chest strap and a separate seat belt, right side impact.

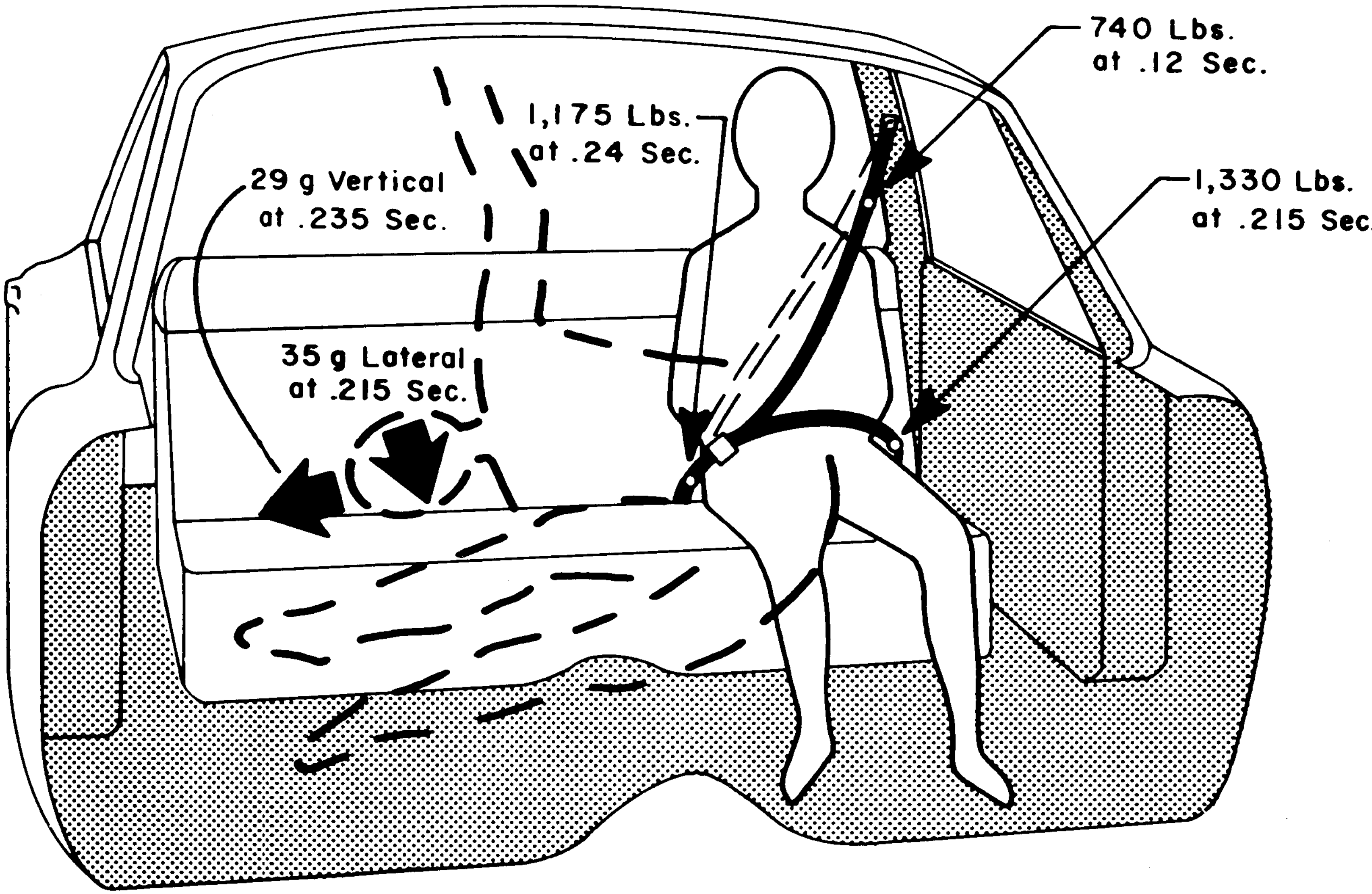

FIGURE 20. Three-point restraint system (diagonal chest strap with lower end attached to one-half of the seat belt and upper end attached to the "B" post), right side impact.

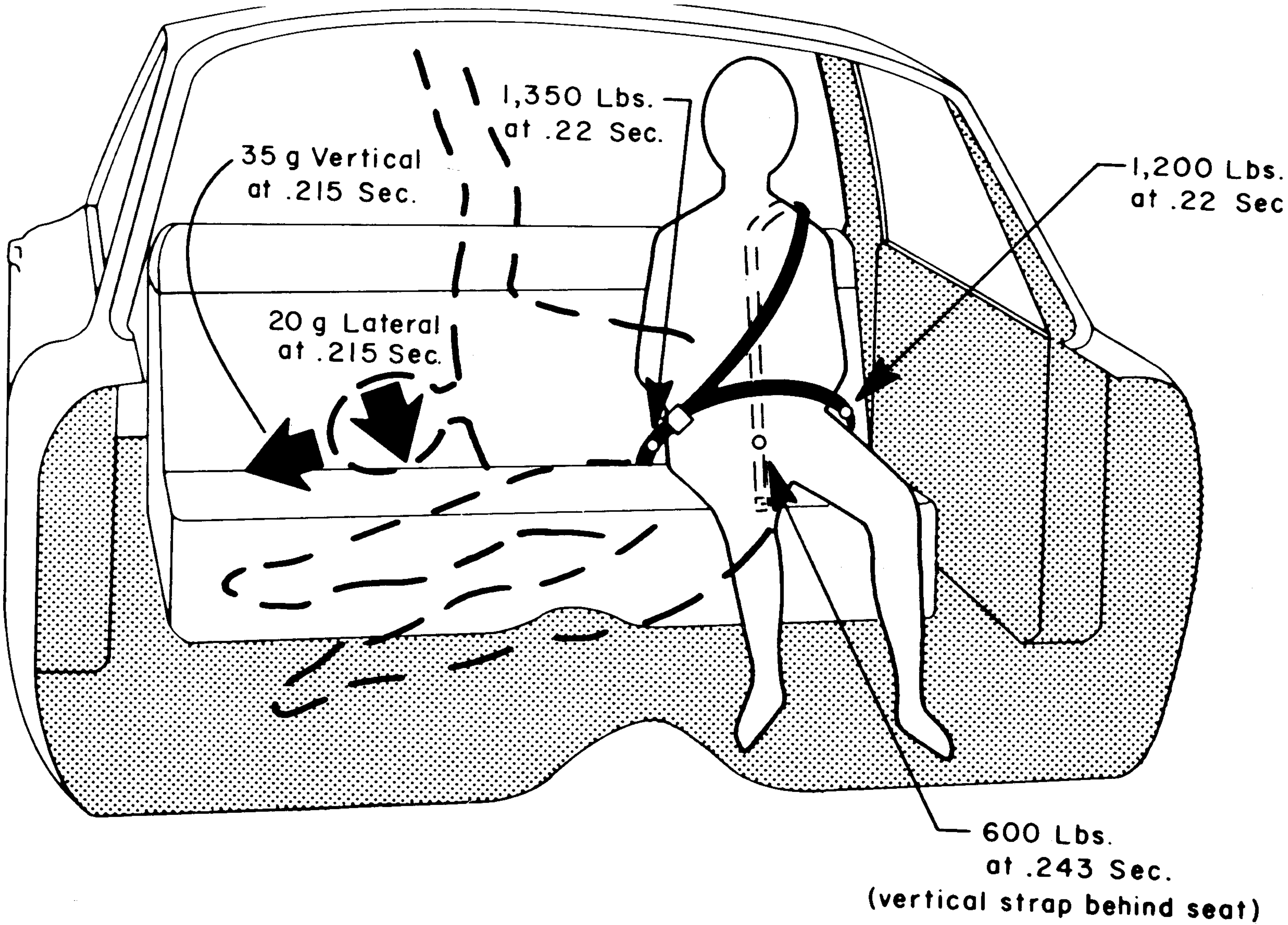

FIGURE 21. Three-point restraint system with chest strap going over seat back and anchored to the floor behind the seat, right side impact.

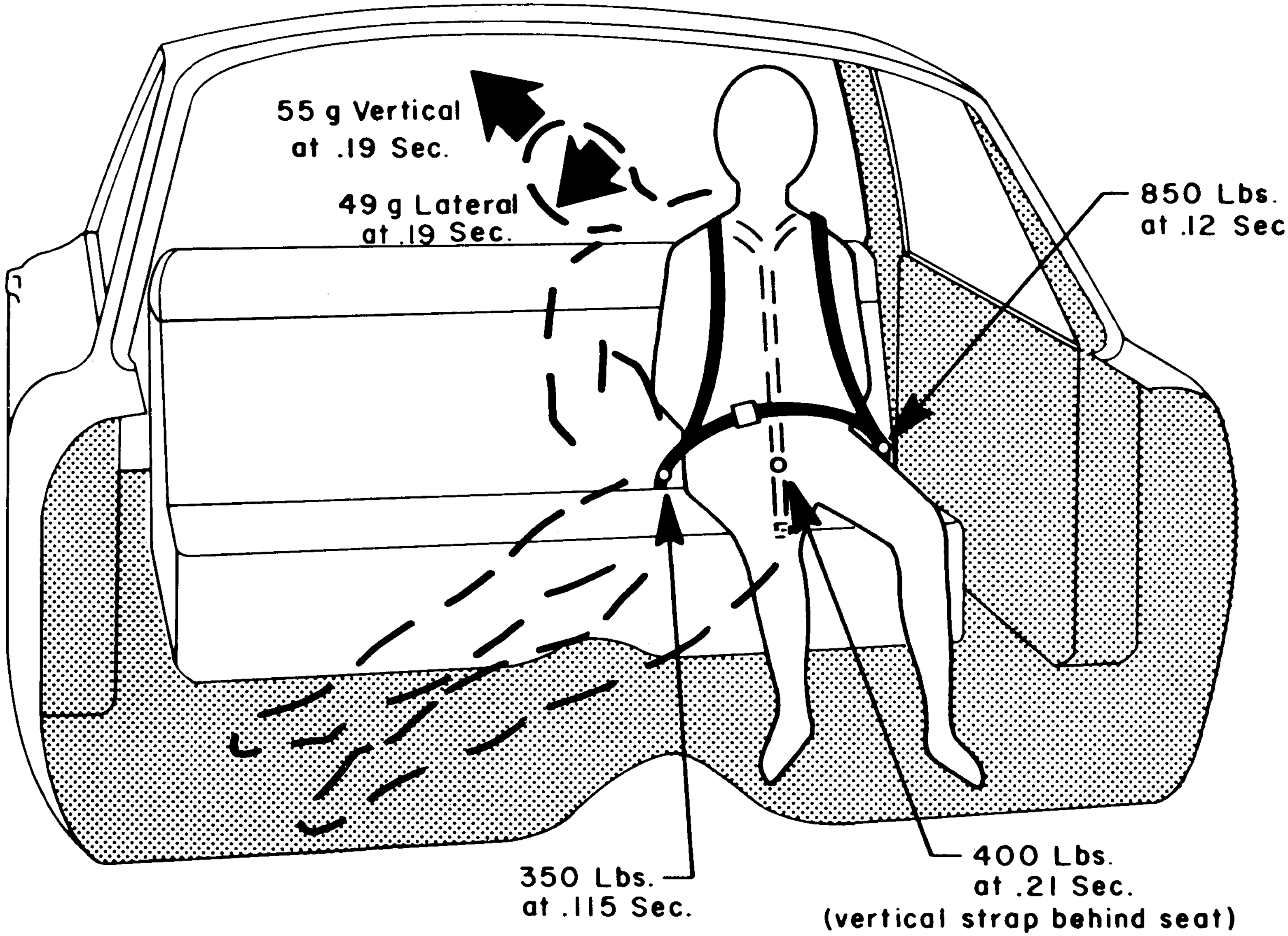

FIGURE 22. Double chest strap with lower ends sewn to lap belt near the seat intersection and upper ends joined behind the neck to form a single strap ... the seat back to a floor attachment, right side impact.

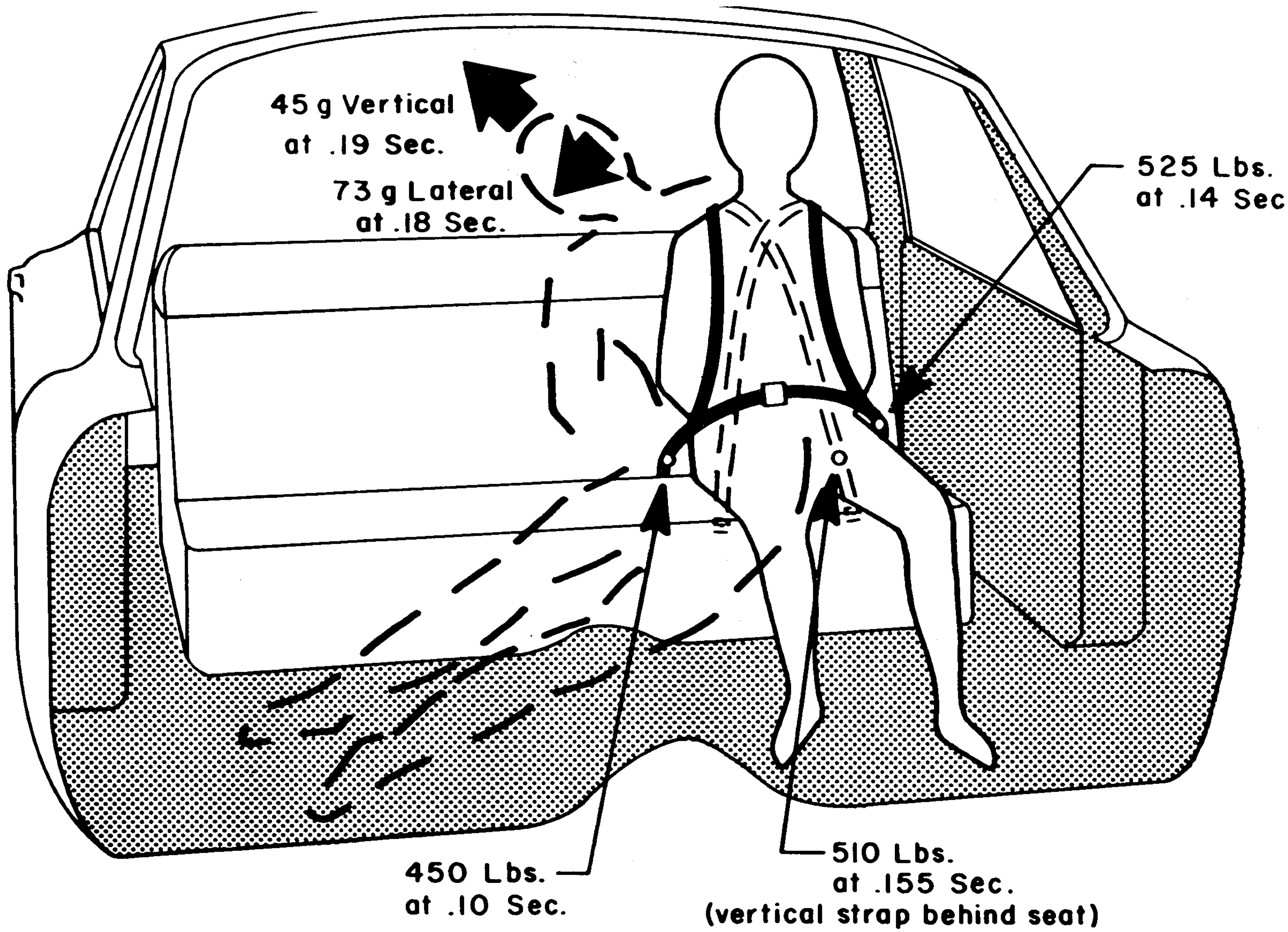

FIGURE 23. Double chest straps sewn to seat belt, crossed behind seat and extending to separate floor attachments, right side impact.

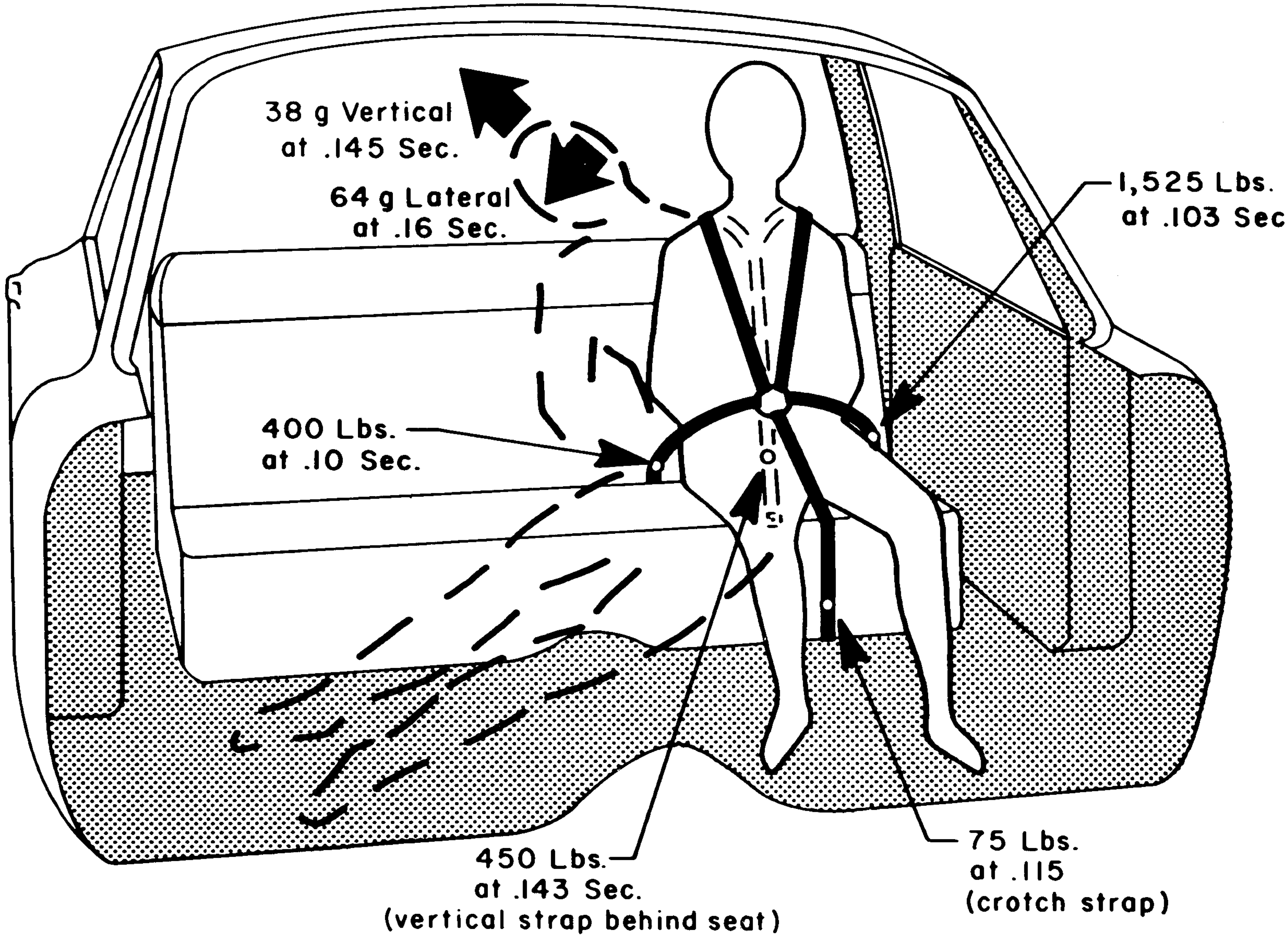

FIGURE 24. Pacific Scientific quick-release restraint equipment. Double chest straps converge to one behind the neck and attach to floor structure behind

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EVALUATION OF A FIBERGLASS INSTRUMENT GLARE SHIELD FOR PROTECTION AGAINST HEAD INJURY	February 1972
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16. Abstract

An all fiberglass prototype glare shield has been evaluated in terms of head injury protection. In 30-ft. /sec. head impacts, the 9-1/2-inch protrusion folded down over the heavy instruments, offering significant improvement in head injury protection when compared to current aircraft instrument panel design. However, in this particular design the fiberglass broke, allowing the forehead to contact a thin, sharp edge with sufficient force to produce fatal head injuries. Design changes to eliminate this fracture point and incorporation of fiberglass glare shields of similar design in future general aviation aircraft could lead to a significant reduction of head injuries during crash decelerations.

17. Key Words	18. Distribution Statement
Crash safety, engineering design, crashworthiness	Availability is unlimited. Document may be released to the National Technical Information Service, Springfield, Virginia, 22151, for sale to the public.

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EVALUATION OF A FIBERGLASS INSTRUMENT GLARE SHIELD FOR PROTECTION AGAINST HEAD INJURY

I. Introduction.

In view of the large number of serious or fatal head injuries resulting from head impact against upper instrument panels during crashes of general aviation aircraft,[1 2 3 4] the Protection and Survival Laboratory at CAMI maintains interest in new design concepts which may offer protection against head trauma.

II. Test Equipment and Procedures.

Two fiberglass instrument panels (without instruments), along with their integrated glare shields, were submitted to the laboratory for evaluation. These were mounted at the end of the CAMI crash decelerator (Figure 1). The position of the glare shield was adjusted to conform with measurements provided by the manufacturer. An instrumented dummy head, taken from an Alderson F–50 anthropometric dummy, was rigidly attached to a weighted arm which was free to swing about a pivot on the decelerator sled. The sled was braked prior to impact, allowing the head to swing forward in an arc, impacting the protruding edge of the glare shield in the orientation shown in Figure 2. Yellow chalk applied to this protruding edge allowed determination of maximum area of initial face contact and strips of adhesive tape indicated depth of head penetration. Sled decelerations were calibrated to produce head impact velocities of 30 and 35 ft./sec. since these head impact velocities will occur in crashes of approximately 7–G magnitude as measured on the floor structure under the seat.[5 6] Head impact deceleration was measured by a single 250–G CEC Model 4–202–0001 strain gage accelerometer mounted in the dummy head with data recorded using a Sanborn 550 M signal conditioning system and a CEC Model 5–124A oscillographic recorder. Time lines on the oscillograph paper, a sweep-second clock and time marks on all high-speed motion picture film allowed synchronization of deceleration peaks on the tracing with structural collapse of the fiberglass glare shield. Motion picture coverage was provided by four cameras, one operating at 24 fps, two at 400 fps, and one at 2,000 fps.

III. Description of Glare Shield.

The glare shield shown in Figure 3 consisted of a basic structure of a thin fiberglass layer covered with a ¼-inch thick layer of Ensolite and a thin layer of plastic vinyl. It extended 9½ inches from the instrument panel toward the pilot and was elevated about 13 degrees above the horizontal. On the protruding edge nearest the pilot the shield was rolled down and under with an inside radius of curvature of approximately ¼-inch. After impact testing had been completed, the covering was removed from a portion of the shield so that the thickness of the fiberglass could be measured. The first five inches (nearest the pilot) were of a uniform thickness of .020 inches, increasing to 0.025 inches at six inches, to .050 inches at seven inches, and .065 at eight. At nine inches the thickness abruptly increased to 0.200 inches due to the lap with the instrument panel.

It should be noted at this point that the glare shield protruded only in front of the left pilot and that the right side dropped back such that the head impact area for the right seat occupant consisted of a layer of the thin padding over a rigid structure at the top of the instrument panel (Figure 1).

IV. Results.

Figure 4 presents a pictorial sequence of events correlated with deceleration measured during Test One (30 ft./sec. head impact velocity). The initial head contact with the edge of the glare shield was with the maxilla just below the nose producing an initial deceleration peak of 10 G's followed by a second peak of 30 G's as the shield began to collapse. Chalk deposited on the head form from the edge of the glare shield during this phase of the impact was lifted by means of masking tape and the area of facial contact determined to be 3.75 square inches. Based on previous research,[7] it appears unlikely that major facial fractures would occur during this initial head impact. From 0.025 seconds to 0.04 seconds, the glare shield folded down over the instruments and prevented head contact with them. However, beginning at about 0.04 seconds, the fiberglass broke about 6½ inches from the edge of the glare shield. The thin edge of the shield, supported by the instrument panel flange penetrated the ¼-inch padding and cut the rubber head form covering, as shown in Figures 5 through 8. A peak head form deceleration of 60 G's was produced as the rigid head form contacted this thin edge. In Reference 7 it is stated that the forehead can tolerate 80 G's on one square inch without bone fracture. If we assume that the forehead contacted a four-inch length of this 0.035-inch-thick fiberglass edge, we can calculate a contact area of 0.14 square inch and any impact deceleration in excess of 12 G's would be expected to produce injuries. The impact of 60 G's in this test would produce severe lacerations (Figure 8) and extensive fracture of the anterior cranium.

The results of this test were confirmed by a second test which produced almost identical failure patterns and head form decelerations.

V. Conclusions.

Since the fiberglass glare shield folded down over the heavy instruments and sharp knobs and edges and produced a maximum deceleration force on the head of only 60 G's while distributing the load over large facial areas, as compared to 300-G forces produced on small areas of the head in similar impact tests of conventional light aircraft instrument panels without the glare shield (Reference 2), it must be concluded that a glare shield constructed of fiberglass or of some similar material could substantially reduce the large number of severe head injuries now occurring in general aviation crashes. The failure of the glare shield in these tests exposing a relatively rigid sharp edge to the head could cause fatal injuries, even in the relatively low impact velocities represented by these tests. Correction of this fault by a minor design modification could lead to a significant improvement in crashworthiness.

REFERENCES

1. Swearingen, J. J.: General Aviation Structures Directly Responsible for Trauma in Crash Decelerations. FAA-AM-71-3, January 1971.
2. Swearingen, John J: Injury Potentials of Light-Aircraft Instrument Panels. AM 66-12, April 1966.
3. Marrow, D. J.: Analysis of Injuries of 1942 Persons in 1422 Light Plane Accidents. CAA Medical Service Records, Washington, D.C., unpublished data, 1949.
4. Pearson, R. G.: Human Factors Aspects of Light Plane Safety. OAM Report AM 63-35, 1963.
5. Boeing head impact tests against the 747 door slide cases. Boeing Document D6-30667, October 1969.
6. Haley, J. L., Jr.: Presentation at the ALPA 3rd Annual Air Safety Forum, Steward and Stewardess Division. J. L. Haley, Jr., Av. Ser Div., Flight Safety Foundation, Inc.
7. Swearingen, J. J.: Tolerances of the Human Face to Crash Impact. OAM Report 65-20, July 1965.

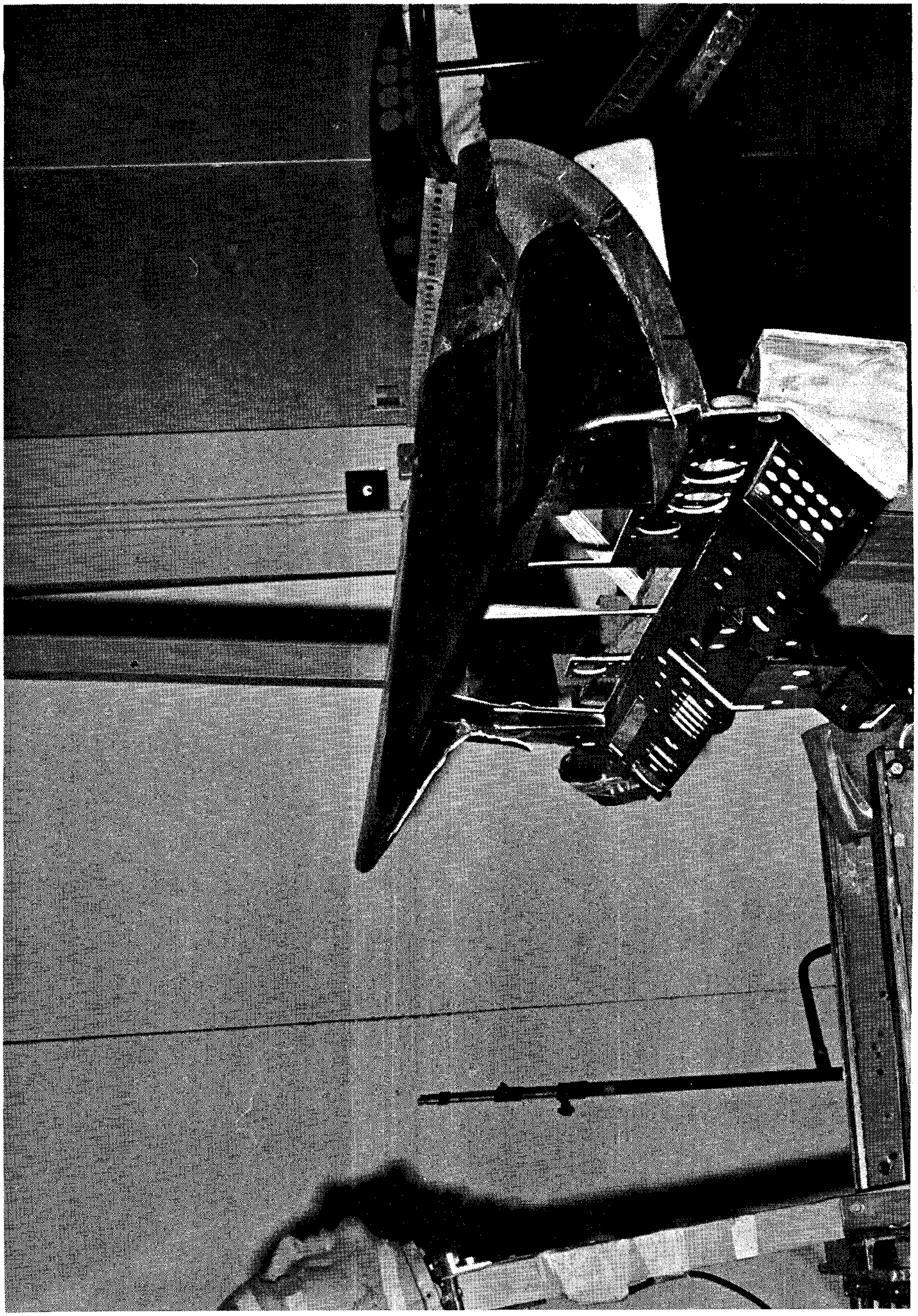

FIGURE 1. Fiberglass instrument panel and glare shield mounted at the end of the crash sled.

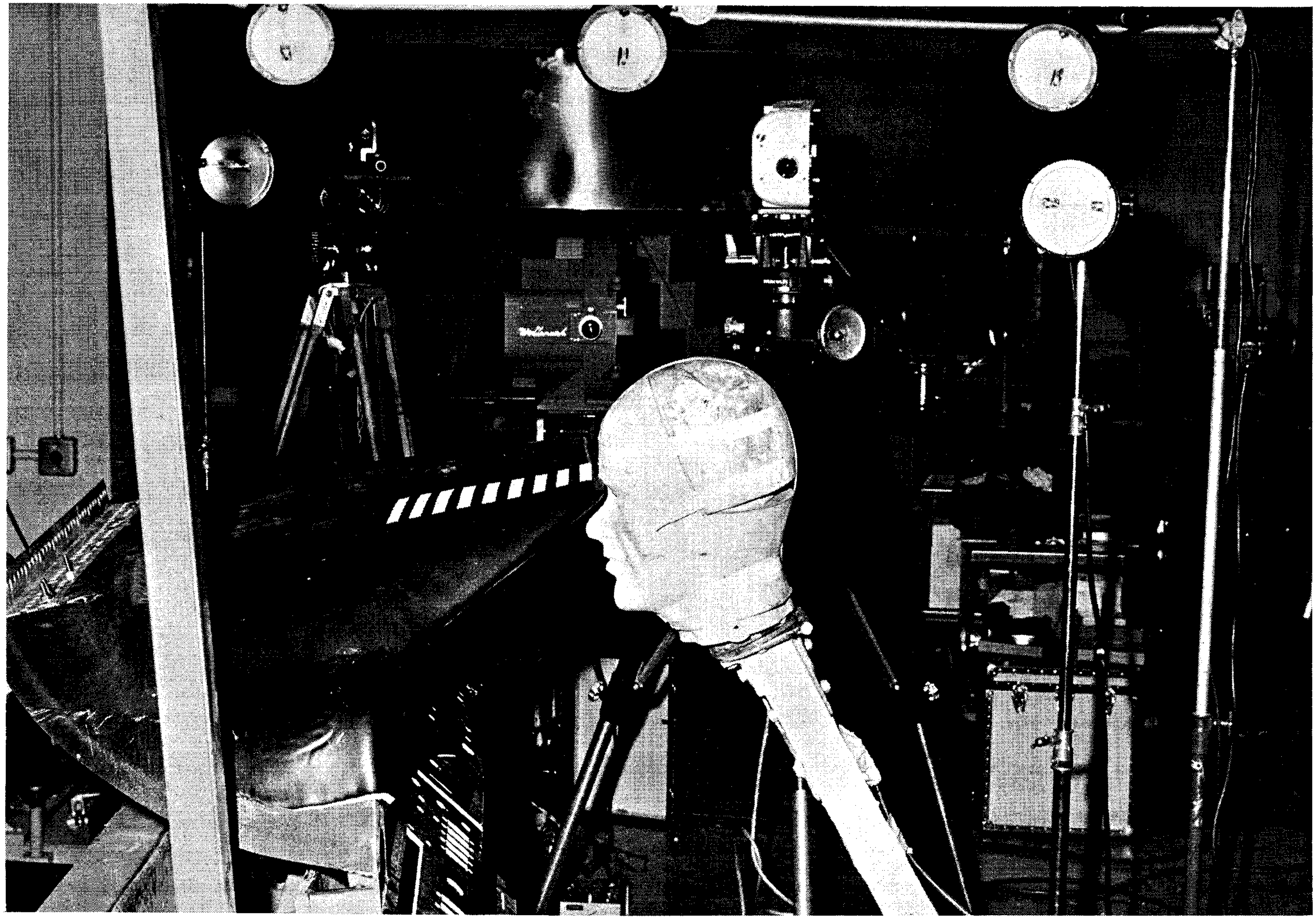

FIGURE 2. Strips of adhesive tape were added to show depth of head penetration.

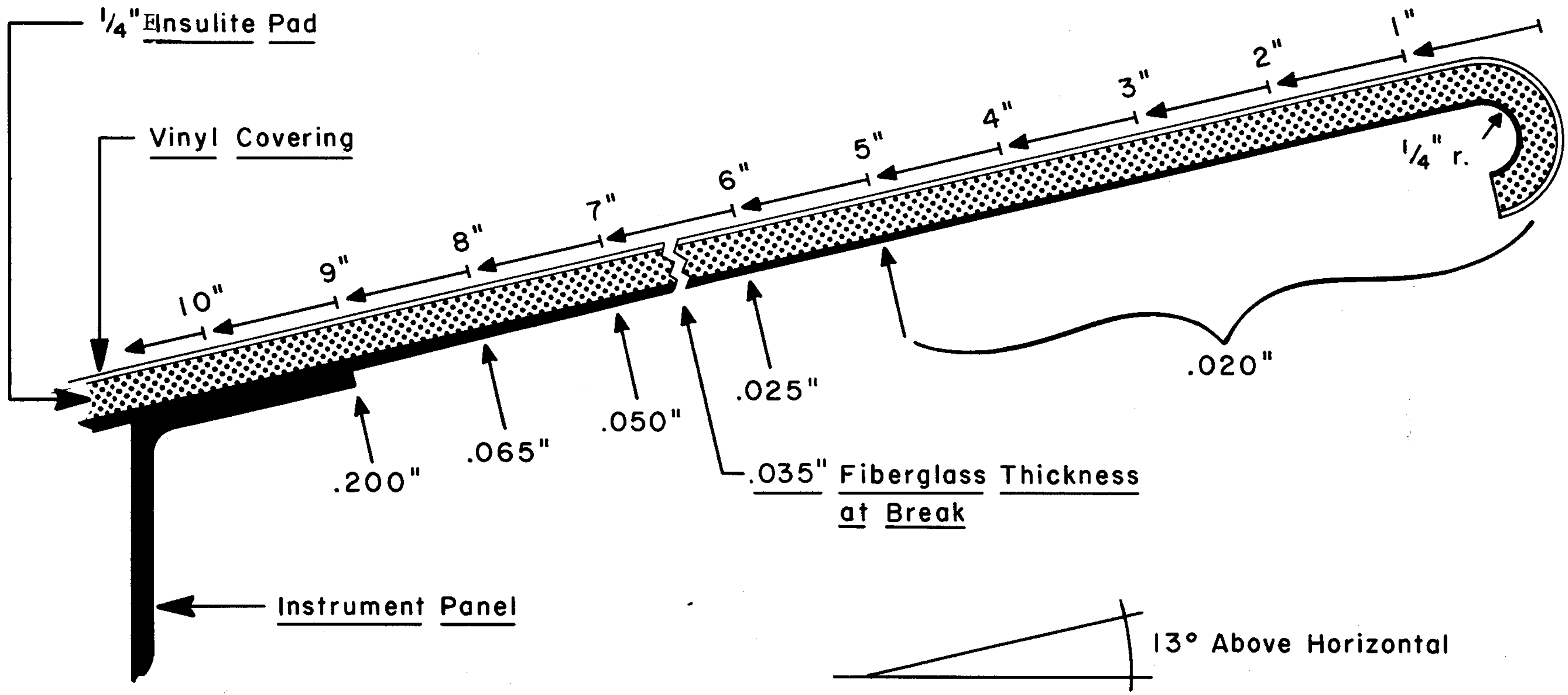

FIGURE 3. Cross section of the glare shield showing thicknesses at various points.

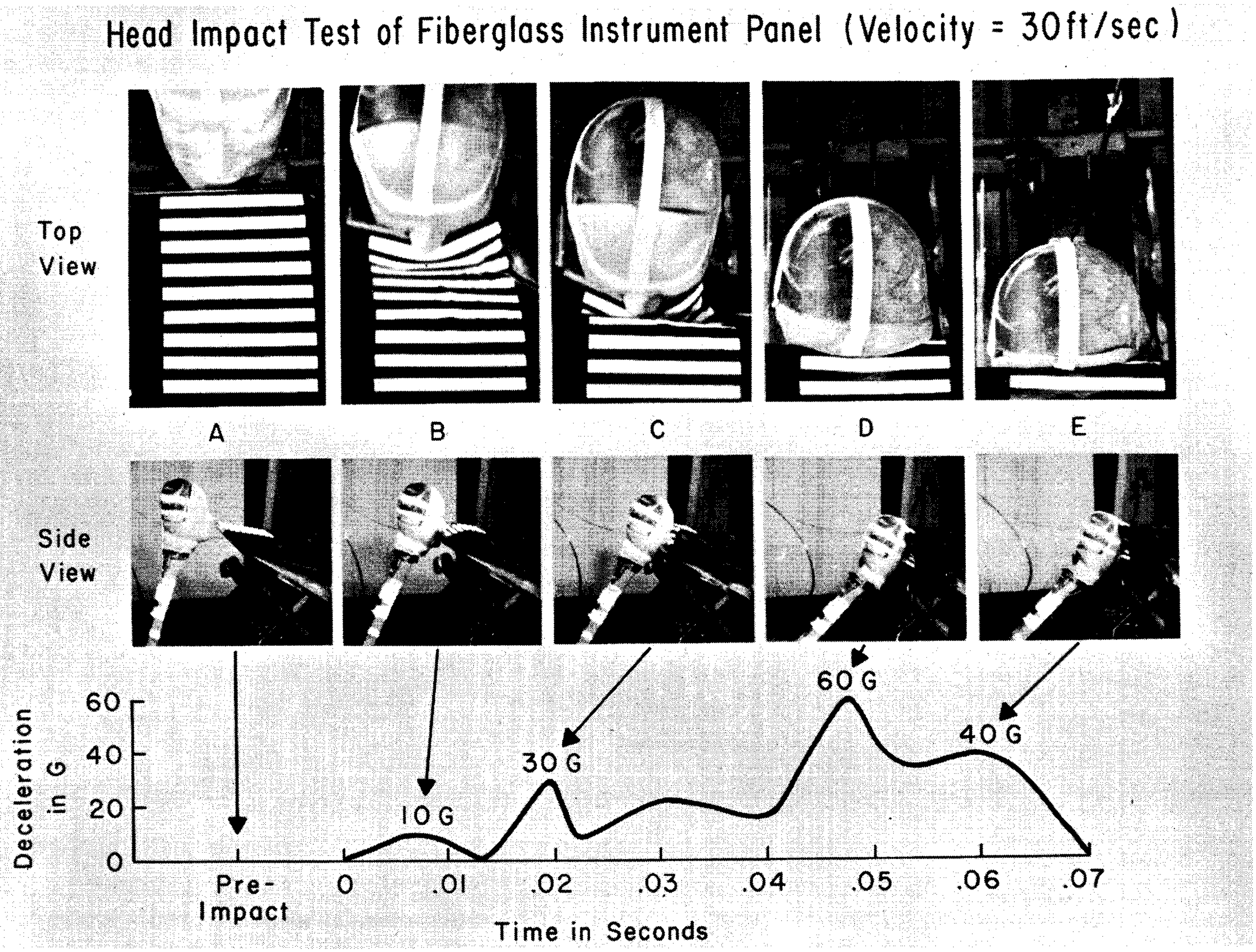

FIGURE 4. Results of a 30-ft./sec. head impact against the fiberglass glare shield.

FIGURE 5. Broken edge of fiberglass cut through thin padding (note arrow).

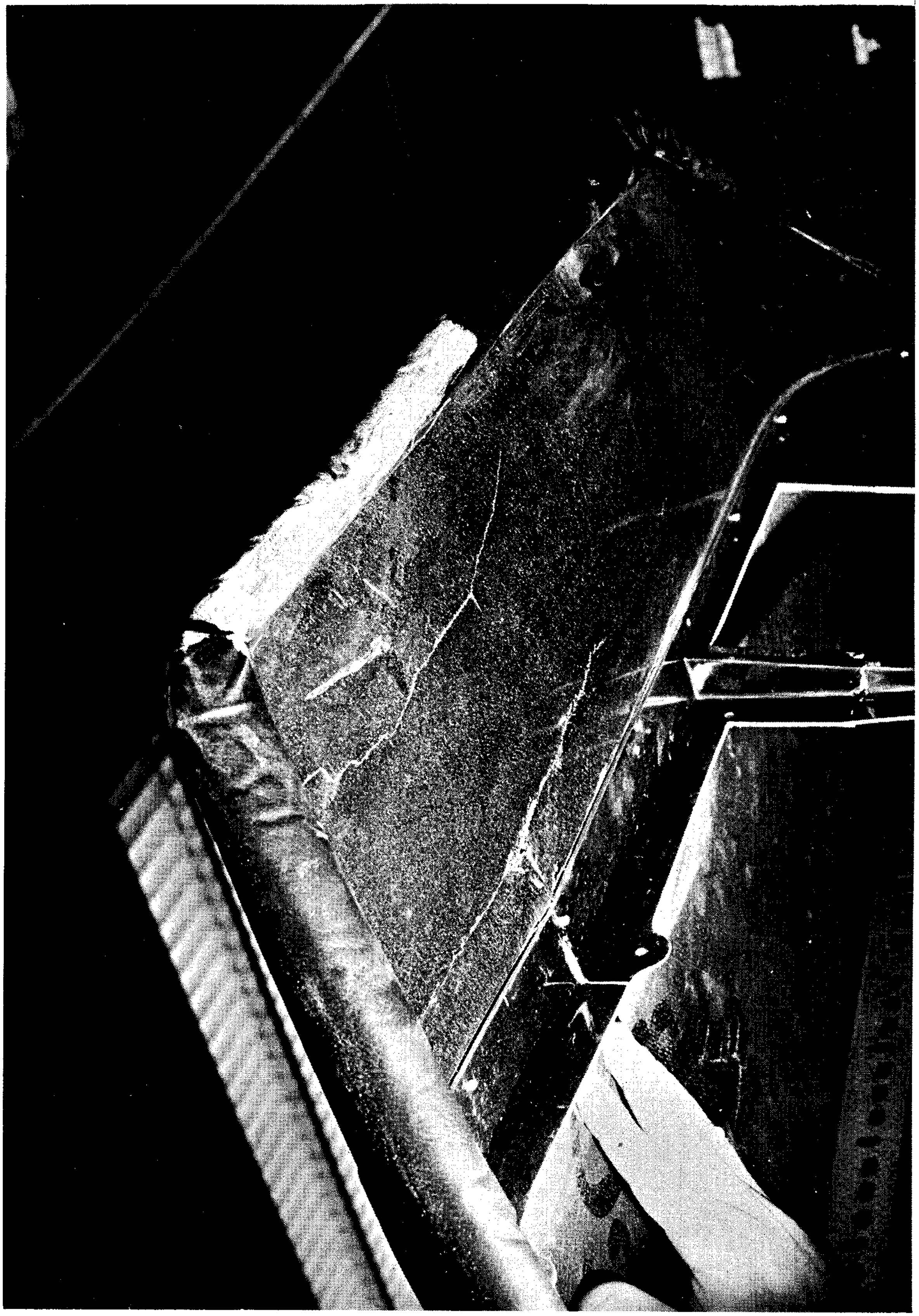

FIGURE 6. Lower view showing fractures in fiberglass.

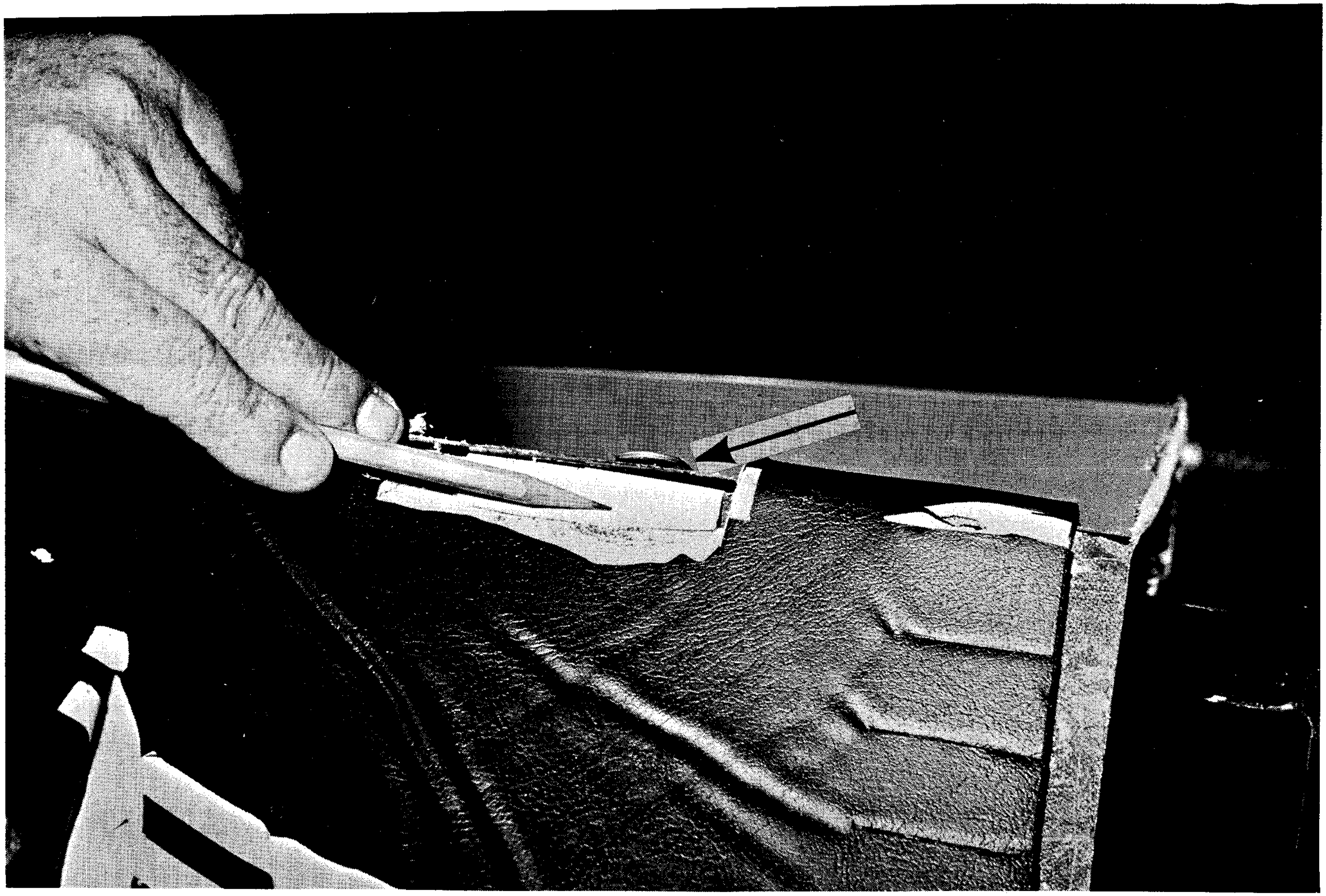

FIGURE 7. Fiberglass edge at break (see arrow). Dime is shown for thickness reference.

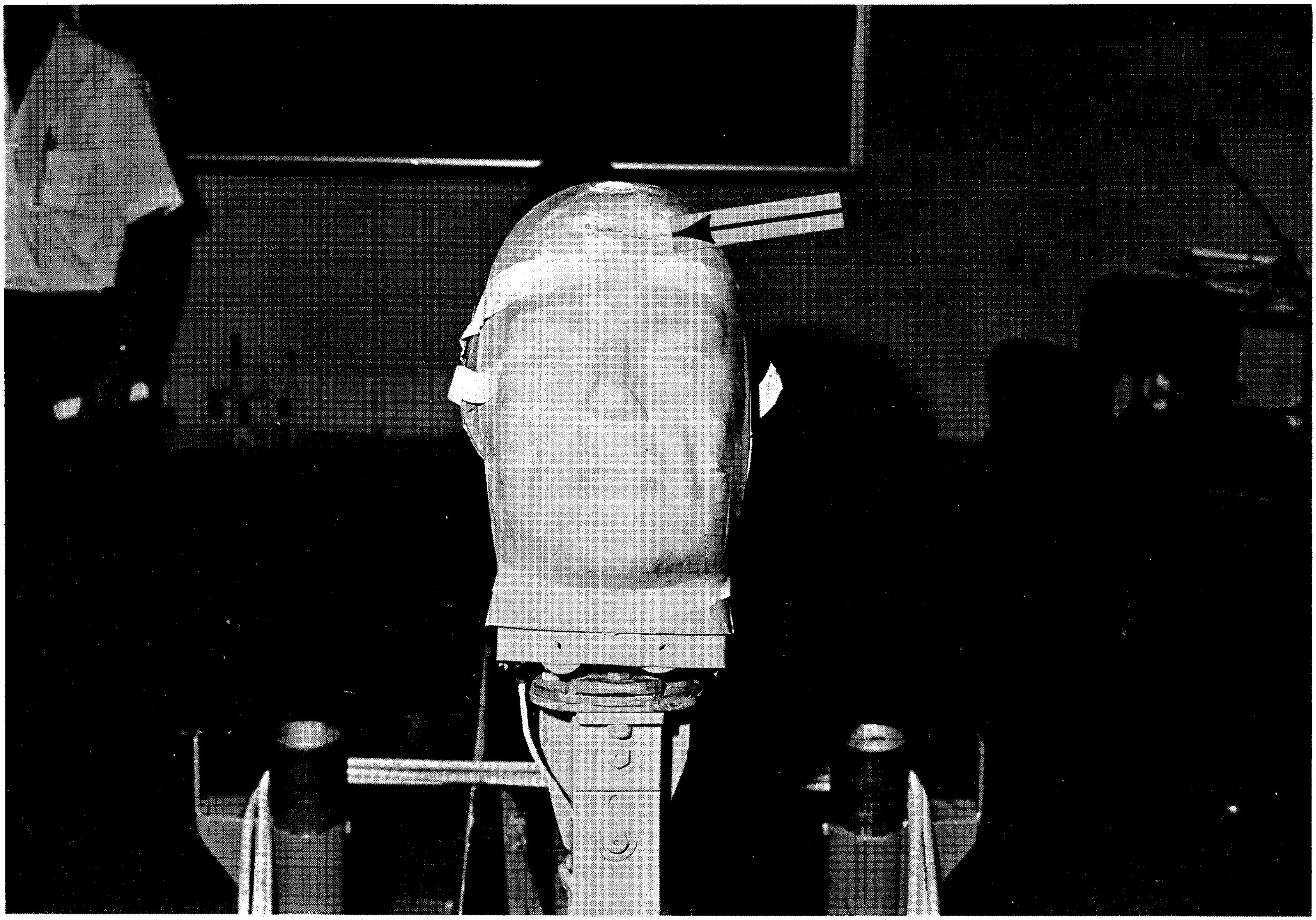

FIGURE 8. Lacerations (at arrow) in rubber covering on dummy head forehead from impacting broken fiberglass.

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16. Abstract

Thirty-nine human subjects were exposed to repetitive backscatter light stimulation (off a white wall or fog) from a Grimes capacitance discharge airplane anticollision light flashing at 1.27 Hertz. Both tonic (light stimulus absent) and phasic (light stimulus present) stimulus-bound occipital EEG, heart rate, respiration, skin potentials, and eyeblinks were recorded. In the first experiment, response decrement (habituation) to the flashing light occurred only with one out of five response measures (skin potential) over a 40-trial session indicating that the flashing light was a potent stimulus. None of the subjects demonstrated photic driving, seizure activity, or theta wave activity in his EEG. Most subjects reported the light as noxious, none became nauseated, but many became drowsy over the course of the experiment and several reported dark deadaptation from the flashing light. In Experiment II, eyeblink and skin potential measures differentiated between an instrument-rated pilot group and an age-matched control group of non-pilot professional men.

The results suggest that, although the flashing anticollision light induces changes in physiological measures which are resistant to habituation, these changes do not extend to the induction of nausea.

17. Key Words Effects of Backscatter, EEG, Heart Rate, Respiration, Skin Potential, Eyeblinks, Anticollision Light		18. Distribution Statement Availability is unlimited. Document may be released to the National Technical Service, Springfield, Virginia 22151, for sale to the public.	
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EFFECTS OF BACKSCATTER OF BRIEF HIGH INTENSITY LIGHT ON PHYSIOLOGICAL REPONSES OF INSTRUMENT-RATED PILOTS AND NON-PILOTS

The view is fairly common that some of the mmediate effects of intermittent photic stimula-ion may result in altered states of consciousness, 'ertigo, fear and visceral disturbances.[2,3,17,18,19] 'his has wide implications for people exposed o flickering light stimulation. Of most concern s the effect of intermittent light stimulation on irplane pilots since impairment of ability to unction can have the gravest consequences in he event of an emergency.

The nature of the evidence for the view that ıtermittent photic stimulation can cause impair-ıent of ability to function comes from several ›urces. First, much of the evidence is of an necdotal sort and as such presents problems of valuation. The second form of evidence comes rom clinical EEG laboratories where intermit-›nt photic stimulation is used as a tool in assess-ıg epilepsy. The third type of evidence comes :om experimental research laboratories. Since ıere are wide variations in research methodol-ɡy, the intensity of the photic stimuli used, the ıte at which the light pulses were presented, ıd in the subject populations employed, there room for contradictory claims. Discussion of ifferent aspects of the problem as well as good ›views of the literature are abundant.[1,4,7–11,15,16,20]

Most of the earlier experiments dealing with ıe effects of intermittent light stimulation on ıysiological indices and performance have em-oyed frequencies higher than the flash rates of ost airplane anticollision lights and have used ectroencephalograms almost exclusively as the dex of physiological response. These studies › not bear as directly on the problem confront-g pilots flying through clouds or fog as would ıdies which use flash frequencies in the range countered by pilots. It was the purpose of the st experiment to determine under controlled nditions the effects of brief high intensity light pulses from an actual airplane anticollision light flashing at 1.27 Hertz on a variety of physiological measures in a normal non-pilot population. Post-experimental verbal reports of the experience were also obtained from the subjects.

EXPERIMENT I

Methods

Subjects. A group of 13 young adult males (age range 17–25 years) comprised of medical students from the University of Oklahoma Medical School and introductory psychology classes from Oklahoma City University with no history of epilepsy participated in the experiment. Each experiment lasted for about one hour. Subjects were paid for participation in the experiment.

Procedure. Upon arriving at the laboratory, subjects were told that they would be part of a visual stimulation experiment and that a variety of physiological responses would be monitored. Skin surfaces where recording electrodes were to be attached were cleaned with acetone. Grass silver cup electrodes were used to record EEG and eye blinks. The occipital EEG lead was attached 1 cm above and 1 cm to the right of the occiput. This lead was referenced to the ipsilateral ear lobe. For eye blinks, leads were attached above and below the left eye. Plate EKG leads were attached on the right shoulder and on the chest below the heart. Beckman skin potential leads were attached to the second finger tip of the left hand and to the volar surface of the left arm. A common ground lead was attached to the volar surface of the left arm above the reference skin potential lead. A strain gauge respiration lead was attached across the chest at the bottom of the rib cage. Physiological responses were recorded on a Beckman Type RM rectilinear inkwriting dynograph running at a paper speed of 10 mm/sec.

Design. The experiment was set up to provide 40 trials, each of which was 10 seconds in duration, of high intensity condenser discharge light stimulation. The light source was a Grimes model no. 30–360–1 high intensity condenser discharge airplane anticollision light. Flash rate was constant at 1.27 flashes per second. The intertrial interval between each 10 seconds of flash stimulation was 30–90 seconds, varying randomly in 15-sec steps as determined by a table of random numbers. A Gerbrands tape programmer turned on a Hunter 111C timer for 10-second periods at the randomly prescribed intervals. The Hunter timer, in turn, controlled the power source to the Grimes light. Preliminary tests indicated that the sound of the capacitor charging in the Grimes light was a confounding cue which would trigger physiological responses not due to the light flashes. To circumvent this problem, a Grason-Stadler 901B white noise generator was employed in conjunction with a Koss Pro 4A headphone set. Further testing revealed that an 80 db re: .0002 dyne/cm^2 white noise effectively masked the capacitor charging sound and other equipment sounds.

Response quantification. Occipital EEG was recorded with a 0.3-second time constant and at a gain of 50 μ volts/cm. To be scored as alpha wave activity, two or more consecutive brain waves of 8–12 Hertz had to be present in the EEG. Visually, alpha stands out from the background EEG in the awake subject by being of larger amplitude than the background activity and by exhibiting synchrony (i.e., when alpha occurs, it is generally present in "bursts" of several waves in a row). The percent alpha in the 10 seconds preceding each stimulus was scored as well as the percent alpha in the 10 seconds during flashing light stimulation.

Eye blinks were recorded at a gain of 0.2 mv/cm with a 0.1-sec time constant. Since spontaneous blinks occur with a frequency greater than zero and the spontaneous blink rate varies among individuals, blinks were scored both during the 10 sec preceding each stimulus and during the 10 sec of each stimulus.

Skin potential responses were recorded with a 1.0-sec time constant at a gain of 0.5 millivolts/cm. Response amplitude was measured in millivolts from response onset to peak of response. Response amplitudes were summed separately for the 10-sec pre-stimulus periods and 10 sec during light stimulation periods to yield baseline and stimulus-elicited responding scores, respectively.

Respiration rate was recorded with a 1.0-se time constant. A flexible tube, which change its resistance when stretched, was taped to th subject's chest. This changing resistance wa part of one arm of a Wheatstone bridge circuit The distance between respiration peaks wa measured and converted to rate/min. Rate i the 10 sec preceding a stimulus and the firs complete respiration cycle during the stimulu were recorded for each trial.

Heart rate was recorded by a cardiotachomete coupler. It was qualified in terms of mean beat per minute change from the mean of the 10-se period before stimulation compared to the 10 se during stimulation.

Results

All trials effect comparisons were based on th nonparametric Friedman analyses of varianc pre-during stimulus comparisons and specif trial comparisons were based on correlated di ference between means t-tests. The $p<.05$ tw tailed rejection region was adopted throughou

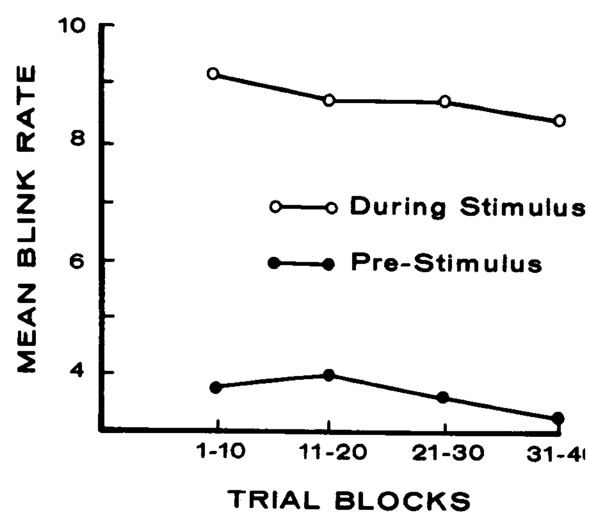
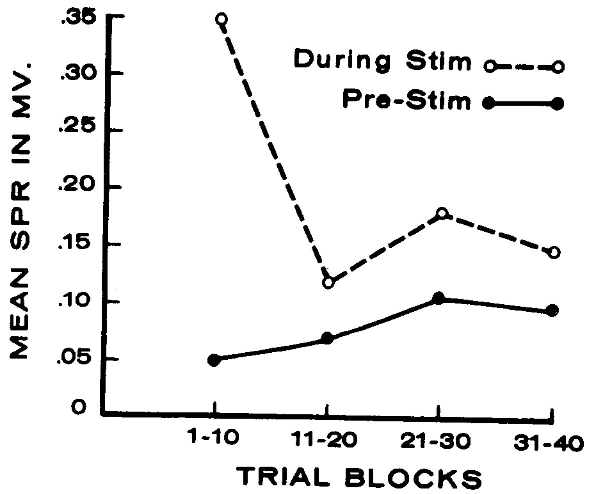


FIGURE 1. Mean number of eye blinks in 10 trial blo pre- and during- light flash stimulation.

Figure 1 summarizes the results for the e blink data. Both the mean pre-stimulus bl rate and the mean rate of blinking during ph stimulation are presented in 10 trial blo Several results are evident from this fig First, collapsing the data across trials, there a highly significant increase in blinking to the light flashes when compared with the pre-stimulus blink rate ($t=8.30$, $df=12$, $p<.001$). Second, *the blinking* rate to the flashing lights did not habituate as indicated by a nonsignificant Friedman nonparametric analysis of variance for trend across trials. Third, no significant changes in basal blink rate occurred over trials as indi-:ated by a second Friedman analysis of variance.



IGURE 2. Mean magnitude of skin potential responses in millivolts for 10 trial blocks pre- and during-light flash stimulation.

Figure 2 summarizes the results for the skin otential data. A Friedman nonparametric ıalysis of variance indicated that the decrement ı responding across trial blocks was significant $C=12.15$, $df=3$, $p<.01$). Further testing in-cated that a significant decrement occurred be-reen the first and second trial blocks ($t=2.51$, $=9$, $p<.05$). None of the other comparisons as significant. Thus, most of the decrement curred in the first 10 trials with no consistent ange occurring thereafter.

Figure 3 summarizes the results for respiration ıta in 10 trial blocks. Collapsing across trials, significant difference in respiration rate was und with rate increasing during photic stimu-tion when compared to the rate just preceding otic stimulation ($t=2.83$, $df=9$, $p<.02$). The spiration changes across trial blocks were not gnificant for either the pre- or during-stimulus te.

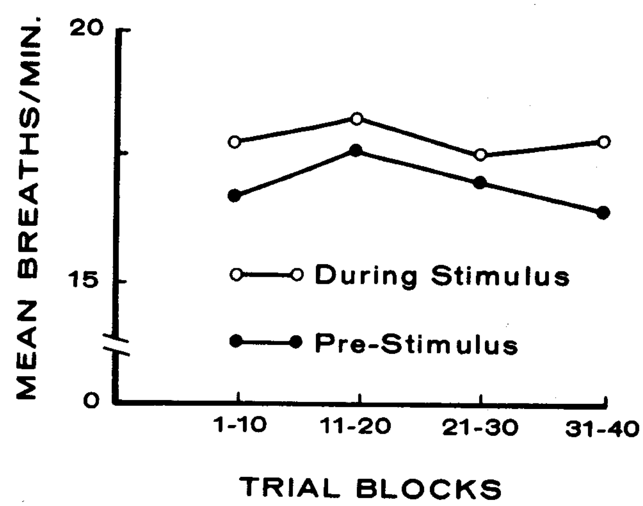


FIGURE 3. Mean rate of respiration in 10 trial blocks pre- and during- light flash stimulation.

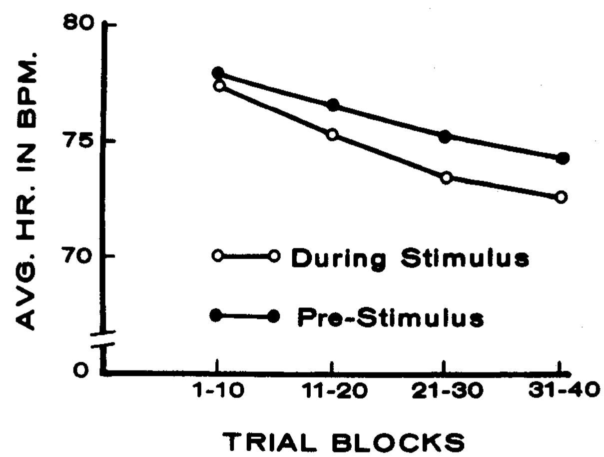


FIGURE 4. Mean heart rate over 10 trial blocks pre- and during- light flash stimulation.

Figure 4 summarizes the results for heart rate data over trial blocks. Collapsing across trials, a small but highly reliable heart rate deceleration was found when comparing pre- with during-stimulus heart rate ($t=5.65$, $df=12$, $p<.001$). The decrease in basal heart rate as measured over trial blocks in the pre-stimulus interval was not significant ($C=4.88$, $df=3$, $p<.05$). However, the heart rate decrease across trial blocks during light stimulation was significant ($C=13.3$, $df=3$, $p<.01$).

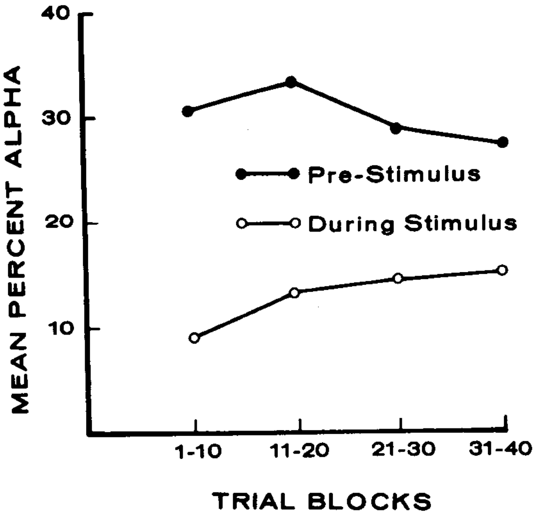


FIGURE 5. Mean percent brain wave activity in the alpha range (8–12 Hertz) for 10 trial blocks in the pre- and during- light flash periods.

Figure 5 presents the mean percent brain wave activity in the alpha range (8–12 Hertz) in the pre-stimulus period and in the light stimulus period across trial blocks. As is evident from Figure 5, there was a highly reliable reduction in alpha activity while the light was flashing when compared to the pre-stimulus alpha baseline ($t=3.68$, $df=12$, $p<.001$). Although Figure 5 shows an increase in percent alpha over trial blocks in response to the light stimulus, the trend was not significant ($C=2.82$, $df=3$, $p>.05$). Similarly, the changes in percent baseline alpha over trial blocks were also nonsignificant ($C=1.2$, $df=3$, $p>.05$). In summary, these tests indicate that habituation of alpha blocking to light stimulation did not occur.

Questionnaire data indicated that none of the subjects became nauseated during the experiment. A majority found the light flashes irritating or annoying. A couple of subjects claim that they experienced "eye strain" or "eye fatigue" from exposure to the light flashes. Several reported that for about 1–2 seconds after photic stimulus offset the room background illumination seemed to dim and the room and everything in it appeared subjectively darker. Most of the subjects reported drowsiness toward the end of the experiment.

EXPERIMENT II

Since the subjects in the first experiment were not pilots and the possibility exists that pilots may respond differently to flashing lights than non-pilots, the first experiment was repeated, but it utilized instrument-rated pilots as subjects as well as an age-matched control group of non-pilots. Secondly, the actual back-scatter conditions were simulated more closely by using back scatter from man-made fog as the stimulus.

Methods

Subjects. A group of 12 instrument-rated pilots from the Oklahoma City area and a group of 14 non-pilot professional men from the University of Oklahoma Medical School served a subjects in the experiment. The average age o the subjects was 40 years. Pilots and non-pilot did not differ significantly on average age. Eac session lasted about 80 minutes. At the end c the experiment subjects were administered post-experimental questionnaire. Post-exper mental verbal reports and ratings were also ol tained from the subjects. Subjects were paid fc participation in the experiment.

Procedure. Upon arriving at the laborator subjects were told that they would be a part of visual stimulation experiment and that a variet of physiological responses would be monitore Electrode placements and data quantificatic were the same as in Experiment I except th the pulse train duration in Experiment II w extended to 40 seconds for pre- and durin stimulus measures. For eye blinks, skin pote tial responses, and alpha EEG activity, da were quantified over 40-second intervals inste of the 10-second intervals of Experiment I. F heart rate the data were scored over the 10 se onds preceding a stimulus and the first ten se onds during the stimulus because prelimina data indicated that that is where the chang were taking place. Respiration was not scor in the second experiment because of recordi difficulties with the transducer.

Experiment II was performed in the f chamber of the Civil Aeromedical Institute the FAA Center in Oklahoma City. After bei instrumented, the subject, clad in a surgi gown, was placed in a semi-reclining position a plastic lawn chair in the fog chamber. T temperature was 72° F.±2° and the humid ʀas 100%. A flashing Grimes airplane anti-ollision strobe light was placed below and be-ɪind the subject. The fog density was such that ɪeither the experimenters nor the subject could ee more than five feet in the fog chamber. On wo occasions the fog generator iced up and the ata from the subjects were not used because the og density thinned visibly.

Design. The experiment was designed to pro-ide 20 trials, each 40 seconds in duration, of epetitive high intensity condenser discharge ght stimulation. The light source was a Grimes ɪodel no. 30–360–1 high intensity condenser ischarge airplane anticollision light. Flash rate ʼas constant at 1.27 flashes per second and flash uration was $\approx$ 10 μsec. The intertrial interval ʼas 30–90 seconds, varying randomly in 15-sec ːeps as determined by a table of random num-ɜrs. A Gerbrands tape programmer operated Hunter 111C timer for 40-second periods at the ɪndomly prescribed intervals. The Hunter timer, ɪ turn, controlled the power source to the Grimes ght. Sound masking was provided by a Grason-tadler 901B white noise generator via a Koss ro 4A headphone set. The white noise gen-ʼator was set to provide 80 db re: 0.0002 dyne/n² white noise at the earphones.

Both instrument-rated pilots and the control ːoup of non-pilots received the same sequence ˑ 20 trials of flashing light stimulation. For .e pilot group a 100-watt overhead light was ɪ in the fog chamber at all times during the ːperiment.

The non-pilot matched control subjects re-ived the flashing light under two conditions. or one-half of the control subjects the overhead ɡht was on for the first half of the experiment ɪd was turned off for the second half of the ːperiment. For the second half of the control bjects, these conditions were reversed. This ʼocedure tested the hypothesis that the physi-ɔgical and subjective effects of the flashing ɡht stimulus are determined, in part, by con-ast or amount of light change.

For each response measure the data were .alyzed by 3-factor repeated measures (Case 1) .alyses of variance.[21] Factor one was the in-ːument-rated pilot versus non-pilot dimension. ɪctor two was the pre-stimulus basal measure mpared with the during-stimulus measure. ɪctor three was repetition, i.e., response change over 4 trial blocks. In all cases two-tailed tests were used and the criterion for rejection of the null hypothesis was set up at $p<.05$ or better.

Results

Figure 6 summarizes the results for the eye-blink data. Both the mean pre-stimulus blink rate and the mean rate during light flash stimulation are presented for the four trial blocks. The instrument-rated pilots did not differ significantly in overall blink rate from the age-matched non-pilot group ($F<1$, $df=1, 22$, $p>.05$) indicating that the blink rate between groups was nondifferential. There was a significant groups-by-stimulus interaction ($F=11.46$, $df=1, 22$, $p<.01$), with the instrument-rated pilot group having a higher pre-stimulus blink rate than stimulus rate, whereas the group of non-pilot showed increased blinking during the flashing light stimulus over their pre-stimulus rate.

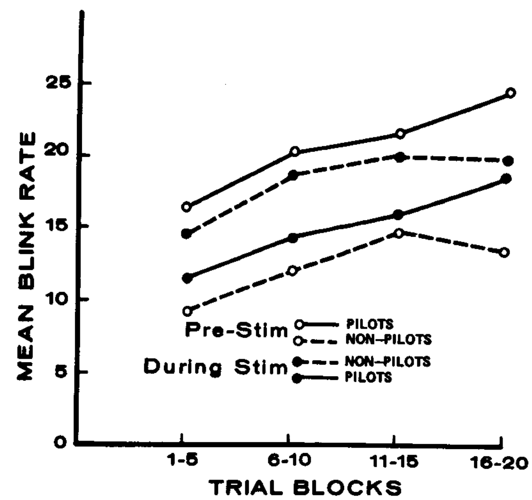


FIGURE 6. Mean number of eye blinks in 5 trial blocks pre- and during- light flash stimulation.

There was a significant trials effect ($F=4.64$, $df=3,66$, $p<.01$) indicating that blink rate increased over the course of the experiment. The groups-x-trials interaction was not significant, suggesting that both pilots and non-pilots contributed about equally to the significant trials effect.

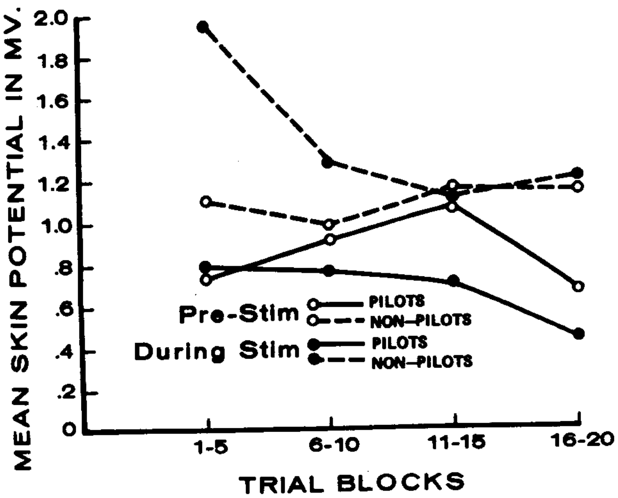


FIGURE 7. Mean magnitude of skin potential responses in millivolts for 5 trial blocks pre- and during- light flash stimulation.

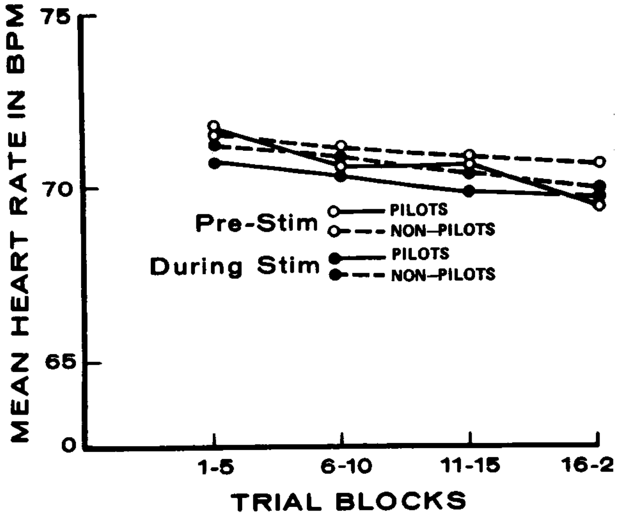


FIGURE 8. Mean heart rate in 5 trials blocks pre- anc during- light flash stimulation.

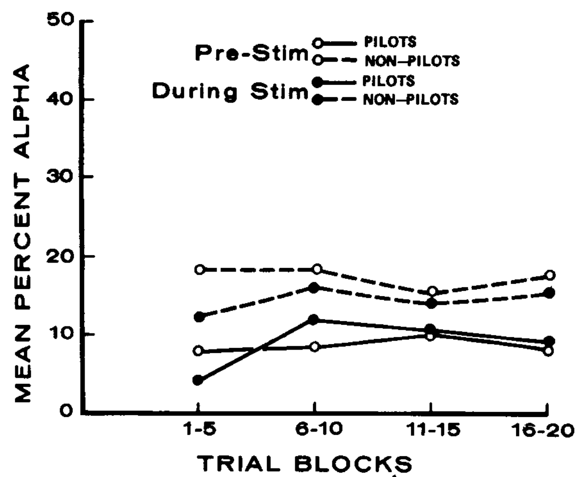


FIGURE 9. Mean percent brain wave activity in tl alpha range (8–12 Hertz) for 5 trial blocks in tl pre- and during- light flash periods.

Figure 7 presents the skin potential response data in summary form. The three-factor analysis of variance for the skin potential data indicates that (1) pilot and non-pilot groups did not differ in their overall level of skin potentail responding ($F=1$, $df=1,22$, $p>.05$); (2) there was a significant groups-x-trials interaction ($F=3.48$, $df=3,66$, $p<.05$). The interaction was due to the fact that pilots did not differ in their pre-stimulus or during-stimulus responses nor did they change their responding over trials. The non-pilot group, on the other hand, had a stable pre-stimulus response rate over trials but their response to the flashing light stimulus was largest initially and showed steady decrement (habituation) over trials.

Figure 8 summarizes the heart rate data. The analysis of variance of the heart rate data did not disclose any significnt differences between groups in either basal heart rate or in pre-during stimulus heart rate changes, although there was a non-significant decrease in rate from pre-stimulus base to stimulus for both groups. There was a significant trials effect ($F=4.5$, $df=3,66$, $p<.01$) indicating that for both groups heart rate decreased over trial blocks.

Figure 9 summarizes the EEG data. Figure 9, inconjunction with a three-factor analysis of variance, indicates that neither groups, nor stimulus, nor trials had any significant effect on percent alpha rhythm.

In the control group there was suggestive ev dence with the physiological measures that tl degree of change or contrast determines tl amount of physiological responding to the flasl ing light. The control subjects who received tl flashing lights with the overhead light off r sponded with larger responses than did subjec who received the flashing light with the ove head lights on. The effect was not statistical significant because there was one reversal ar the sample size was too small to tolerate such reversal.

The post-experimental questionnaire results ndicated that none of the subjects in either pilot r non-pilot groups experienced any subjective eelings of nausea. Eight out of 12 pilots and even out of 12 non-pilots developed severe rowsiness over the course of the experiment. ome felt that had the experiment continued onger they could not have stayed awake. There as no difference in the noxiousness rating assigned to the flashing light by pilots or non-pilots. he non-pilot controls who received the flashing ght under overhead light-on and overhead ght-off conditions, rated the flashing light significantly more noxious when the overhead light as off ($t=5.05$, $df=11$, $p<.001$).

DISCUSSION

In Experiment I, 13 young adult males rang-g from 17–25 years of age were exposed to ery intense reflected intermittent light flashes om a Grimes condenser discharge airplane ticollision light. Their EEG, eye blinks, skin otential responses, heart rate, and respiration te were monitored. Over a 40-trial session, bituation (response decrement) occurred only ith the skin potential response.

In Experiment II, 26 adult males ranging om 31 to 51 years of age were exposed to very tense backscatter off man-made fog produced a Grimes condenser discharge airplane antillision light. Brain wave activity, eye blinks, in potential responses and heart rate were ntinuously monitored over the course of twenty -sec trains of light pulses. Heart rate and ain wave activity did not differentiate between oups, but significant differentiation occurred th eye blinks and skin potential measures.

In our sample of subjects neither photic driv-g nor EEG seizure activity occurred. These dings are in line with the results of previous periments which indicate that for both photic iving and EEG seizure activity, the adequate mulus is a light flashing at faster than 4 ertz.[8]

Data of the present experiment readily fit into framework of the habituation literature.[6,14] r finding that the skin potential response bituates sooner than does the occipital alpha ocking responses to intermittent light stimula-n supports the findings of Sokolov[12,13] and his workers.

The fact the eye blinks to the anticollision light flashes showed no decrement over trial blocks in either Experiment I or II suggests that the reflected light may have been intense enough to elicit a protective reflex. None of the commercially made photic stimulators on the market puts out a light even approaching the intensity of the Grimes anticollision light. Thus, there is a scarcity of data with which to compare our findings on this point.

In Experiment II there was actually a significant increase in blinking in the pilot and non-pilot groups over trials. Since the increase occurred not only to the light stimulus but also during the pre-stimulus base level periods, it was probably not due to the effects of the light becoming more noxious over repeated presentations. A more parsimonious explanation would ascribe the increase to the humid environment. This interpretation is supported by statements of subjects from the post-experimental questionnaire.

The fact that pilots blinked less to the flashing light than during the pre-stimulus period can be ascribed to a combination of greater familiarity and possible adaptation to flashing light and to greater defensiveness by the pilots than non-pilots. Support for the latter interpretation comes from the post-experimental questionnaire. Several pilots volunteered the information that they actively resisted the effects of the flashing lights by concentrating on their great toe or on an imaginary instrument panel. Non-pilot subjects did not report engaging in such activities.

The skin potential data also offer support for the view that instrument-rated pilots were more defensive than non-pilot subjects. Whereas non-pilot subjects showed habituation of responding to the flashing light as had college students in Experiment I, the pilots by concentrating on something else while the light was flashing, were able to suppress their responses so that there was no difference in their pre-stimulus base versus during-stimulus response measures.

In our first experiment in which a younger, more responsive college student population was utilized for subjects, significant physiological changes to backscatter off a white wall from the Grimes light occurred in all measures (occipital EEG, skin potential, heart rate, respiration, eye blinks). In the second experiment, responses with occipital EEG and heart rate measures were not significantly different although they were in the same direction as had been the case in the first experiment. A plausible explanation for this discrepancy is attributable to either (1) the fact that the intensity of backscatter from fog in the second experiment was much less than the backscatter from the white wall in the first experiment, or (2) the fact that young college-age subjects are more responsive than are older subjects.

Our finding, that none of the subjects in either experiment became nauseated, does not mean that under actual flying conditions pilots may not be affected. A potentially significant factor which was not present in our experiment but which is present under actual flying conditions is vestibular input and its interaction with visual phenomena.

Our finding that there was a consistent decrease in heart rate to the flashing light which did not habituate cannot be accounted for as an epi-phenomenon or by-product of respiration change. Since the first complete respiration cycle during light stimulation showed a consistent increase over the pre-stimulus respiration rate, then, if anything, heart rate during the light should have increased if it were positively related to respiration. Graham and Clifton[5] in reviewing the literature on heart rate change to a variety of stimuli have concluded that the orienting response to stimuli is heart rate deceleration, a conclusion in line with our findings.

Subjects in other experiments[9] as well as subjects in our experiments have noted that the experimental chamber appears appreciably darker just after light offset. This finding suggests that a marked degree of dark de-adaptation occurs which may lead to a brief temporar interference with seeing the instrument pane under conditions of backscatter from clouds o fog.

Conclusion

The purpose of the experiments was to deter mine, under controlled conditions, the effects o short, high-intensity light pulses from an actua aircraft anticollision light flashing at 1.27 Hert on a variety of physiological measures. Pos experimental verbal reports of the subjectiv experience were also obtained from the partic pants. Three groups of subjects composed c instrument-rated pilots, age matched non-pilot and medical students without flying experien were used for experiments in the laboratory c the University of Oklahoma Medical School ar in the fog chamber of the FAA Civil Aeromed cal Institute in Oklahoma City. The light sour was a Grimes model No. 30–360–1 high-intensi condenser discharge flash tube. Heart, respir tion and blink rates, EEG, and galvanic sk response were recorded. In general, heart ra and skin potential were slightly elevated in t early part but decreased in the later part of t experiments. The blink-rate responses were di ferent for the three groups: the pilots showed decrease, and the non-pilots and medical studer showed an increase in eye blinks in the course exposure. None of the subjects demonstrat photic driving, seizure or theta-wave activity his EEG, or nausea but experienced the bac scattered light as noxious, and many becai drowsy. The results bear directly on the prc lem of anticollision lights used during flig under backscatter conditions.

REFERENCES

1. Davidoff, R. A., and Johnson, L. C. Photic activation and photoconvulsive responses in a non-epileptic subject. *Neurology*, 13:617–621, 1963.
2. Gastaut, H. Combined photic and metrazol activation of the brain. *EEG Clin. Neurophysiol.*, 2:249, 1950.
3. Gastaut, H., and Hunter, J. An experimental study of the mechanisms of photic activation in idiopathic epilepsy. *EEG Clin. Neurophysiol.*, 2:263, 1950.
4. Gerathewohl, S. J., and Taylor, W. F. The effect of intermittent light on vision. USAF School of Aviation Medicine, Project No. 21–1205–0014, Report No. 1, 1953.
5. Graham, F. K., and Clifton, R. K. Heart rate change as a component of the orienting response. *Psychol. Bull.*, 65:305–320, 1966.
6. Harris, J. D. Habituatory response decrement in the intact organism. *Psychol. Bull.*, 40:385–422, 1943.
7. Johnson, L. C. Flicker as a helicopter pilot problem. *Aerosp. Med.*, 34:306–310, 1963.
8. Johnson, L. C., Ulett, G. A., and Gleser, G. C. Studies of the photically stimulated EEG quantification and stability of photic driving patterns. SAM Report #57–54, 1957.
9. Melton, C. E., Higgins, E. A., Saldivar, J. T., and Wicks, S. M. Exposure of men to intermittent photic stimulation under simulated IFR conditions. OAM Report #66–39, 1966.
10. Mundy-Castle, A. C. An analysis of central responses to photic stimulation in normal adults. *EEG Clin. Neurophysiol.*, 5:1–22, 1953.
11. Orlansky, J. The use of flashing light to perturb human behavior. Research paper P–172, Inst. for Defense Analyses, Res. and Engr. Support Div., Contract DS–50.
12. Sokolov, E. N. *Perception and the conditioned reflex.* New York: Pergamon Press, 1963.
13. Sokolov, E. N. The orienting reflex, its structure and mechanisms. In L. G. Voronin, A. N. Leontiev, A. R. Luria, E. N. Sokolov, and O. S. Vinogradova (Eds), *Orienting reflex and exploratory behavior.* Baltimore: Garamond/Pridemark Press, 1965.
14. Thompson, R. F., and Spencer, W. A. Habituation: A model phenomenon for the study of neuronal substrates of behavior. *Psychol. Rev.*, 173:16–43, 1966.
15. Ulett, G. A. Flicker sickness. *Arch. Opthal.*, 50:687–695, 1953.
16. Ulett, G. A., Gleser, G., Winokur, G., and Lawler, A. The EEG and reaction to photic stimulation as an index of anxiety-proneness. *EEG Clin. Neurophysiol.*, 5:23–32, 1953.
17. Walter, W. G., Dovey, V. J., and Shipton, H. W. Analysis of the electrical response of the human cortex to photic stimulation. *Nature*, 158:540–541, 1946.
18. Walter, V. J., and Walter, W. G. The central effects of rhythmic sensory stimulation. *EEG Clin. Neurophysiol.*, 1:57–86, 1949.
19. Walter W. G., and Walter, V. J. The electrical activity of the brain. *Annual Review of Physiology*, 11:199–230, 1949.
20. Watson, C. W., and Hunter, J. Detection of light-evoked cerebral electrical abnormalities among helicopter pilot trainees. Progress report to the Research and Development Division, Office of the Surgeon General.
21. Winer, B. J. *Statistical principles in experimental design.* New York: McGraw-Hill, 1962. P. 319.

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16. Abstract

Eight instrument rated pilots with flying experience ranging from 600 to 12,271 hours each flew 10 simulated ILS instrument approaches in a single engine, general aviation aircraft equipped with a primary flight display arranged in a conventional "T" configuration. Continuous glide slope and localizer tracking performance were recorded during each approach. Approaches were flown consecutively at approximately ten-minute intervals, with a one-minute in-flight rest period prior to each approach.

The principal finding was that there were no statistically significant changes in glide slope tracking with respect to accuracy of tracking or consistency of performance as a result of the practice afforded by the ten approaches. Some performance measures did yield statistically significant changes in localizer tracking performance, but these changes were of a small order of magnitude. Results are discussed in terms of the factors operating to limit the precision with which the glide slope and localizer can be tracked.

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PILOT TRACKING PERFORMANCE DURING SUCCESSIVE IN-FLIGHT SIMULATED INSTRUMENT APPROACHES

I. Introduction.

Making an instrument approach is a complex, multi-element task that requires extensive and rapid information acquisition and processing, decision making, and highly skilled psychomotor inputs to maneuver the aircraft within the constantly narrowing electronic "beam" of the Instrument Landing System (ILS) approach.[1,5] It is generally accepted that such a task requires a high degree of instrument flying proficiency and that practice and currency of experience are important factors in achieving the necessary flying skills. In spite of the critical requirements on human capability for making an ILS approach, there appears to be a paucity of quantitative data defining the limits of human performance in relation to individual components of the total system requirement.

Most evaluations of pilot performance during actual or simulated instrument approaches (e.g., pilot proficiency check flights) are generally subjective and summary in nature. Except for extreme cases, it is practically impossible to rate one performance against another, or against an absolute standard, with the degree of precision or discrimination necessary to characterize subtle but real differences among individual performances. This is not to say that observational judgments are necessarily inadequate for the purpose of determining if a performance meets certain established criteria. In fact, specified flight maneuvers can be rated with a high degree of reliability between independent observers.[4] However, such subjective judgments frequently fail to identify the extent to which the component tasks contribute to, or subtract from, the performance of the overall task. Quantitative data, such as is obtained by continuous, automated recording of selected elements of pilot performance or of flight parameters, are required for most of the research work on pilot performance, whether it is for the purpose of evaluating training techniques or designing a more effective man-machine interface.[2,7]

The Control group from an earlier study[4] provided an opportunity to study the glide slope and localizer tracking behavior of a group of instrument rated pilots and to investigate the effects of practice afforded by an extended series of successive approaches.

The data to be reported here are not presented as being definitive since they cover only a limited number of performance parameters in one type of aircraft and for a relatively small number of subjects. It is believed, however, that the data suggest several potentially productive lines of investigation which could lead to the establishment of objective performance criteria with special reference to training, proficiency, and currency requirements, compatible control-display relationships, and the composition and structuring of complex, multi-element flying tasks.

II. Equipment and Methodology

Research Device. A four-place, single engine general aviation aircraft was used for the study. Figure 1 shows the aircraft instrument panel. It is representative of the "T" configuration frequently found in this type of aircraft except that the position of the vertical speed indicator has been moved to the right to provide a more centrally located space for the glide slope/localizer indicator. Quick-removal slats installed in the windshield area, and to the left of the subject, were used to simulate an instrument environment without obstructing the outside view of the safety pilot.

A portable, battery-powered tape recorder automatically recorded the deviations from glide slope and localizer centerlines by taking its input directly from the ILS receiver output. Event information such as passage over geographical "fixes", calibration checks, and narrative comments were supplied to the recorder by the observer who operated the equipment.

safety pilot placed the aircraft on the centerline of the glide slope/localizer "beam" at a fixed geographical point. Speed, power, gear, and flaps were set in "approach configuration" before turning control of the aircraft over to the subject. In this manner all subjects started their approaches in identical approach geometry from the same point in space. Upon completion of each approach at the middle marker, the safety pilot raised the landing gear and flaps, and instructed the subject to "go-around". After go-around, the subject climbed back to initial approach altitude. He was then given a one-minute rest period while the safety pilot made a 180° turn in-bound to the glide slope/localizer centerline. The same procedure was repeated for each approach and the flight was terminated after the tenth approach.

III. Results.

The performance data were evaluated by several criteria that emphasize different aspects of the ILS tracking task. Only quantitative data are presented. No specific claims are made that any performance measure, or combination of measures, accurately reflect the overall "quality" of an ILS approach. The practical relevance of any given measure must be judged on the basis of how well the criteria for the individual measures reflect actual demands of the tracking task portion of the ILS approach.

All values are given in terms of the number of "dots" of deviation from the centerlines of the glide slope and localizer paths as indicated on the crosspointer instrument, except for the composite weighted scores which are expressed as percentages. Angular deviation (expressed in "dots" of instrument indication) is used, rather than linear distance, because this is the information that is displayed to the pilot and on which he must act without translation into linear distances. The relationship of indicated "dot" deviations to linear distances is also a changing ratio as a function of the distance between the aircraft and point of origin of the two signals. This makes it impractical to attempt to use linear deviation as a means of comparing performance at varying distances along the approach.

Position of Aircraft at the Middle Marker

This measure considers only the position of the aircraft with respect to the glide slope and localizer centerlines at the time the aircraft passed over the middle marker. It does not reflect performance prior to that point and gives no indication as to how well the pilot handled the aircraft with respect to such things as attitude, or rate of change with respect to the glide slope and localizer centerlines.

(1) *Glide Slope Data.* Figure 3 presents the arithmetic means of the deviations from glide slope centerline at the middle marker for each of the ten approaches. These values express only the magnitude of the deviations, not the direction above or below centerline. The means range from 0.76 to 2.36 "dots". Individual performances range from 'on centerline" to "off scale" (more than 5.0 "dots"). Eight of the 80 individual approaches resulted in deviations at the middle marker of more than 3.0 "dots". Two o these larger deviations occurred as late as ap proach #9 in the sequence of ten approaches.

The algebraic means for the same glide slop data all fell within one dot of the centerline Individual deviations range from 3.4 "dots" be low, to off scale (more than 5.0 "dots") above centerline. There are no significant difference among the means for the ten approaches as teste by analyses of variance.

Consistency of performance was examined b comparing the arithmetic differences betwee deviations on successive approaches for each sub ject, i.e., between approaches 1 and 2, 2 and etc. The means of the differences between su cessive approaches range from 0.98 to 1.73 "dots and differences by individual subjects range fro zero to 4.6 "dots". There are no significant di ferences among the difference values for th successive approaches as tested by analysis variance.

(2) *Localizer Data.* The results for localiz deviations from centerline are presented Figure 4. The arithmetic means range from 0. to 1.49 "dots" and individual deviations ran from zero to 4.6 "dots" for the ten approache There are no significant differences among a proaches as tested by analysis of variance.

Consistency of performance was examined the same method as for the glide slope da The means of the differences range from 0.59 1.09 "dots" and differences by individual su jects range from zero to 4.1 "dots". There a no significant differences among the differen values for the successive approaches as test by analysis of variance.

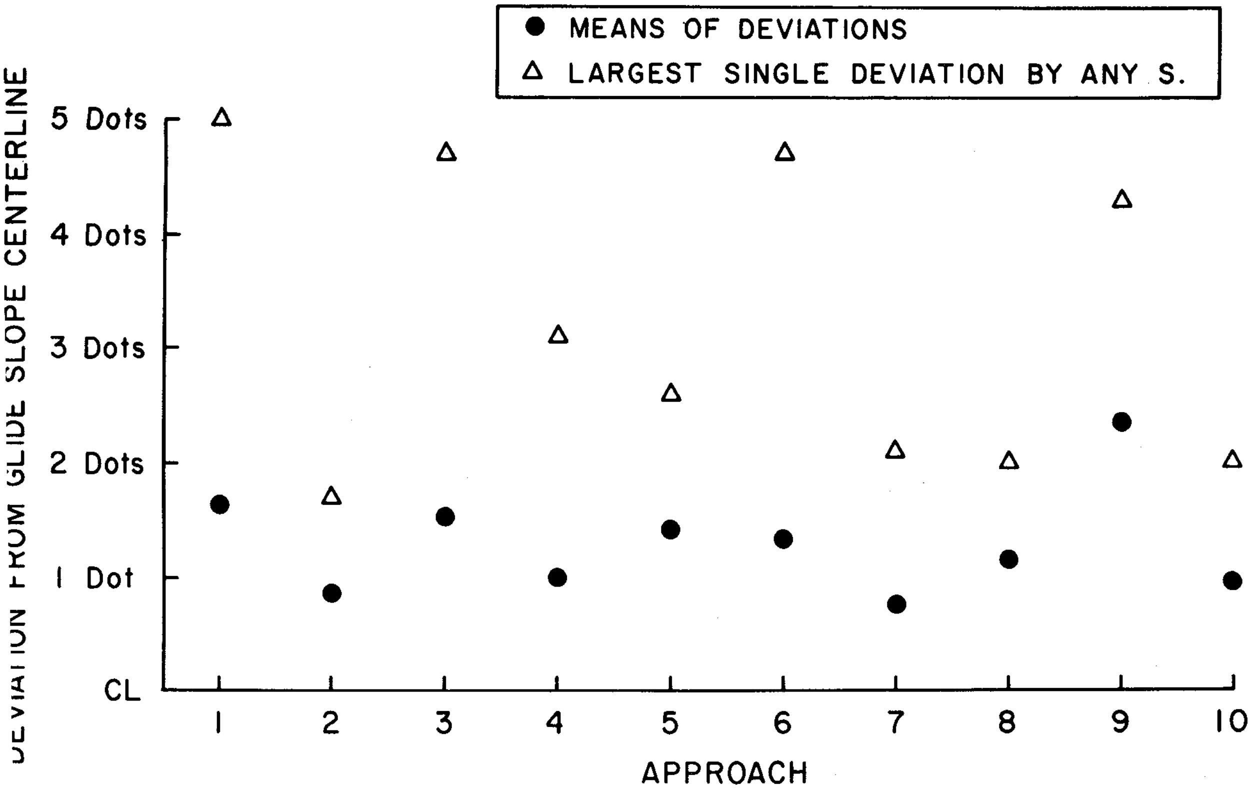


FIGURE 3. Arithmetic means and maximum deviations from glide slope centerline at the middle marker.

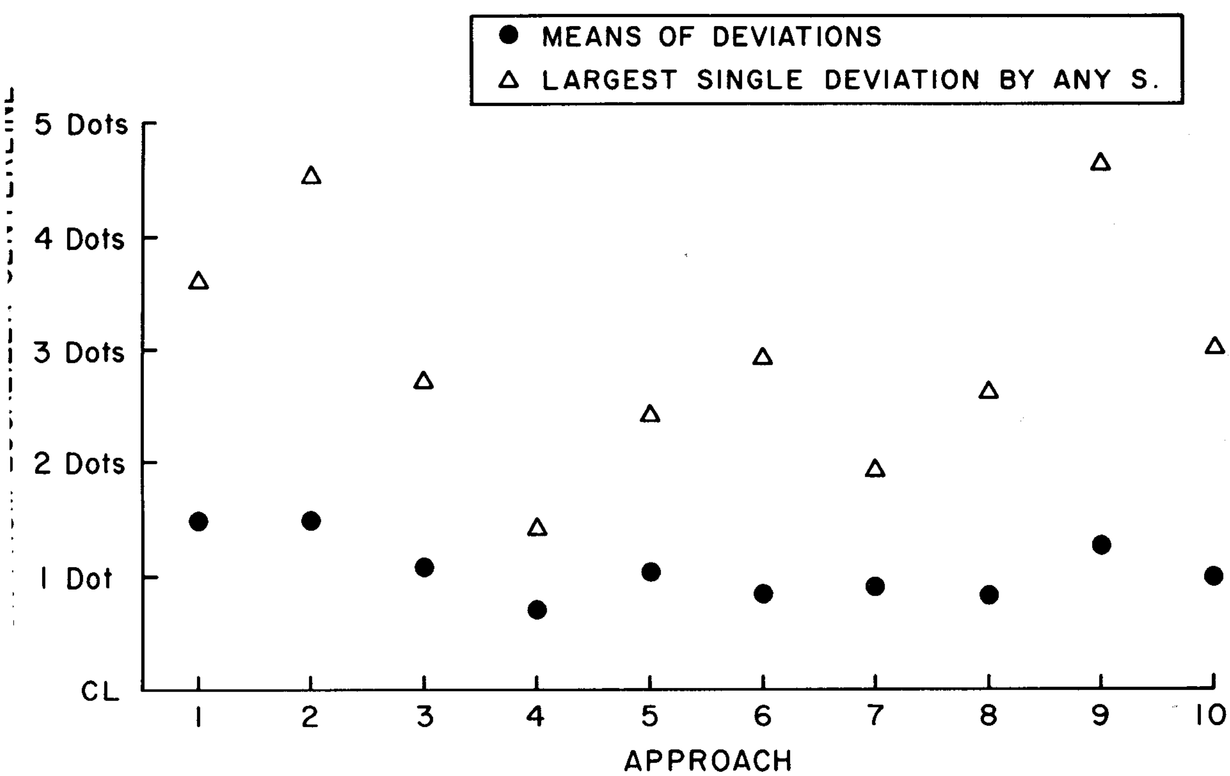


FIGURE 4. Arithmetic means and maximum deviations from localizer centerline at the middle marker.

Range of Glide Slope Deviation Changes During the Last Thirty Seconds of Approach

This measure is a numerical expression of the range of the aircraft's vertical excursions relative to the glide slope centerline during the last half-minute of the approach prior to reaching the middle marker. It is derived by determining the number of equivalent "dots" between the highest and lowest position of the aircraft relative to the glide slope centerline during the specified period. The resulting value can be interpreted as a simple indication of the vertical stability of the aircraft's track. The score does not reflect accuracy in tracking the glide slope centerline because a small value can indicate both large and small, but relatively constant deviations from centerline. The frequency and appropriateness of the indicated changes in deviations do not enter into the resulting values.

The means and maximum values of these changes in glide slope deviations during the last thirty seconds of the approach are given in Figure 5. With the exception of one approach, the means of the changes all fall between two and three "dots". Individual values range from 0.7 to 7.4 "dots". There are no significant differences among approaches with respect to this performance measure as tested by analysis of variance.

Consistency of performance was examined by taking the differences in magnitude of the range of glide slope deviation on successive approaches by the same subject. The means of the differences tend to be slightly more than the equivalent of one "dot". The range of individual values falls between zero and 4.7 "dots". There are no significant differences among the difference values for successive comparisons as tested by analysis of variance.

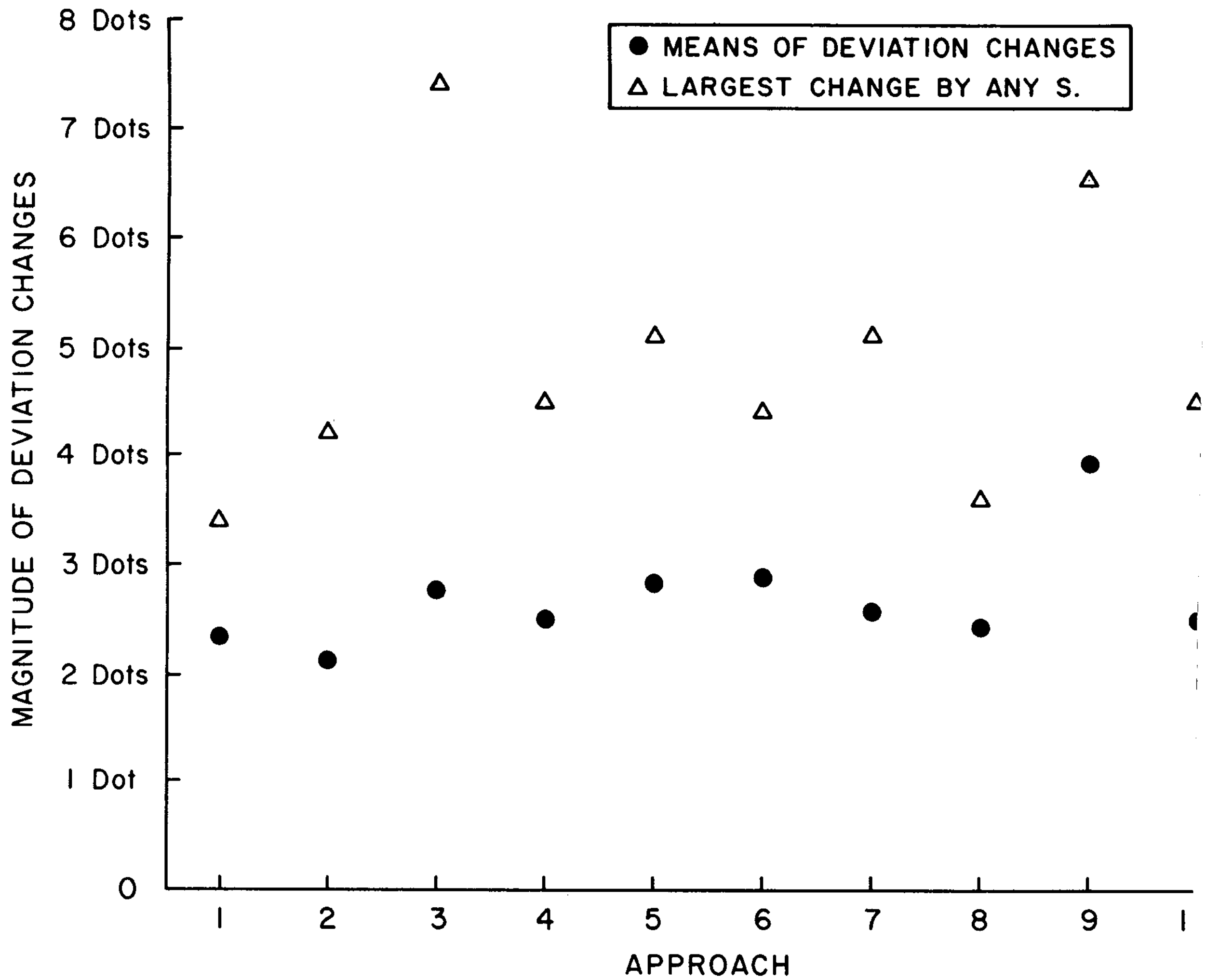


FIGURE 5. Means and maximum glide slope deviation changes during the last 30 seconds of the approaches.

Composite Weighted Tracking Scores

A composite weighted score was developed to ›rovide a single overall tracking score for each f the two elements of the ILS system. These cores express the level of tracking performance or the whole approach between the outer and niddle markers. The scores were derived by ssigning an arbitrary value of 16 to deviations qual to, or less than, one "dot" (equivalent to taying within the "bulls-eye" or "donut"), and uccessively smaller values to larger deviations ccording to a fixed ratio as follows:

Range of Deviations From Centerline	*Point Value*
ne "dot" or less	16
reater than 1 but not more than 2 "dots"	8
reater than 2 but not more than 3 "dots"	4
reater than 3 but not more than 4 "dots"	2
reater than 4 but not more than 5 "dots"	1
ore than 5 "dots"	(−16)

These values were then multiplied by the numer of seconds the indicated deviations fell within the respective ranges. The sum of these products was the raw score. The raw score was converted to a percentage of the maximum possible score for that approach based on the lapsed time between the outer and middle markers. Maximum performance is represented by 100% and is achieved by keeping the needle within the "bullseye" continuously between the outer and middle markers.

(1) *Glide Slope Data.* The means and ranges of the composite glide slope tracking scores are presented in Figure 6. The means range from 77.6% to 89.5%. The range of individual scores is from 49.7% to 100.0%.

There are no significant differences among approaches on the basis of this criterion as tested by analysis of variance. The slight upward trend of scores during the first few approaches is significant only at a low level of confidence ($p<.10$).

Consistency of performance was examined by taking the difference between scores on successive

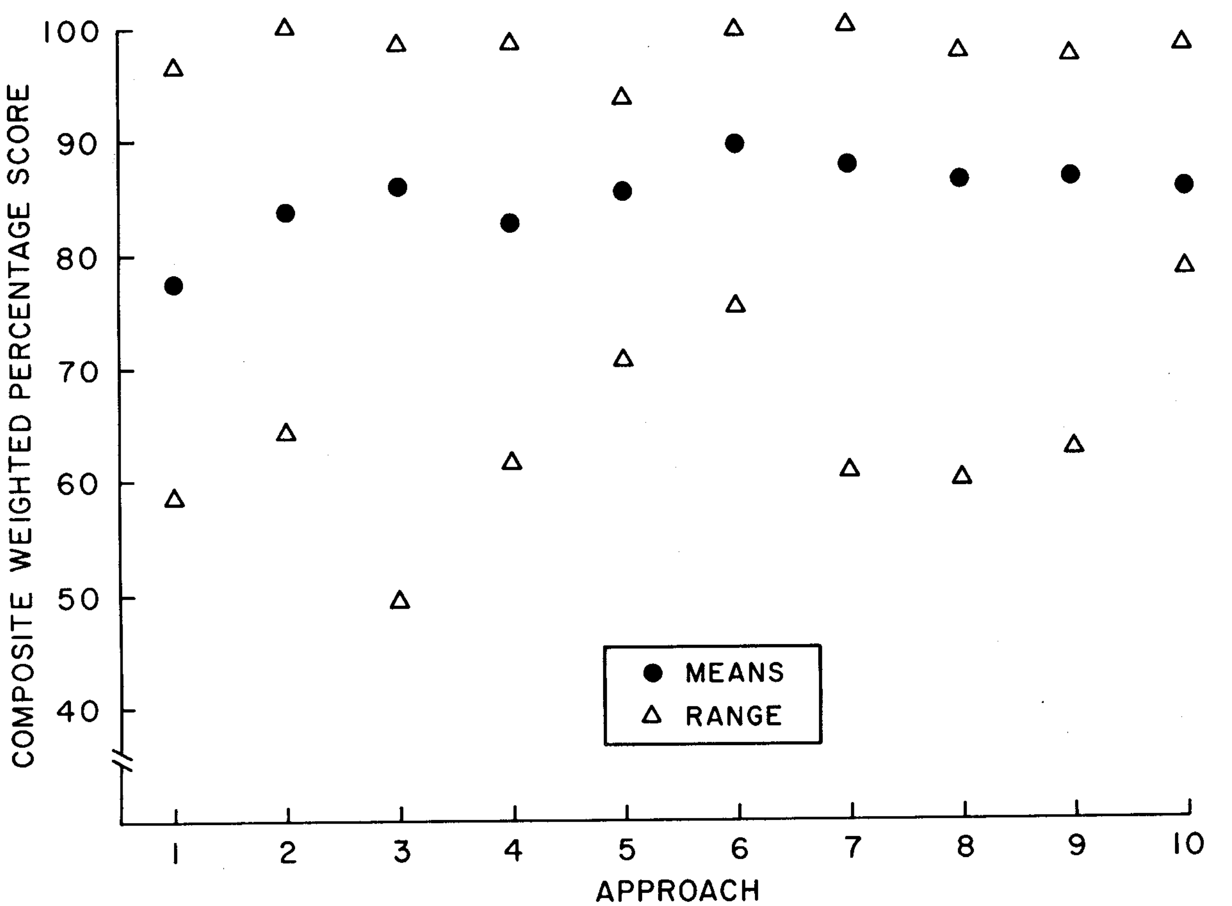


FIGURE 6. Means and ranges of weighted glide slope tracking scores.

approaches by the same subject. The means of these differences range from 2.2 to 17.3 percentage points. Individual difference scores range from zero to 36.2 percentage points. There are no significant differences among the comparison pairs as tested by analysis of variance but the trend of the scores is significant ($p<.05$).

(2) *Localizer Data.* The means and ranges of composite localizer tracking scores are presented in Figure 7. The means range from 82.1 to 94.4%. Individual scores range from 58.8 to 100.0%. The differences among approaches are statistically significant ($p<.01$) and the trend is essentially linear ($p<.005$). The analysis is summarized in Table 1.

TABLE 1.—Composite Weighted Localizer Tracking Scores

(Analysis of Variance)

Source	df	MS	F	P
Subjects	7	384.31		
Approaches	(9)	149.41	2.96	<.01
Linear	1	822.87	16.28	<.005
Quadratic	1	167.60	3.31	<.10
Other	7	50.60	1.00	
Error	63	50.56		
Total	79			

Consistency of performance was examined by the same method as the other scores. The means and maxima of the difference scores are presented in Figure 8. The means range from 2.8 to 13.3 percentage points. Individual difference scores range from zero to 30.1 percentage points. Differences among successive comparisons are significant ($p<.01$) and the trend is essentially linear. The analysis of variance is summarized in Table 2.

TABLE 2.—Consistency of Localizer Tracking on Successive Approaches
(Analysis of Variance)

Source	df	MS	F	P
Subjects	7	191.54		
Approach Pairs	(8)	112.68	3.26	<.01
Linear	1	409.22	11.83	<.01
Quadratic	1	3.31	.10	
Other	6	81.48	2.36	<.05
Error	56	34.58		
Total	71			

Maximum Deviations from Centerlines Withi Successive Segments of Approach

This performance measure examines the rela tive accuracy of glide slope and localizer track ing at various stages of the approach. Each ap proach was divided into ten equal time segment based on the transistion time between the oute and middle markers. The magnitudes of th maximum deviations from centerline during eac segment were used as the performance measure Unlike the procedure for the weighted trackin scores, the duration of the deviation was nc taken into consideration. Consistency by ir dividual subjects was not evaluated for th performance measure.

(1) *Glide Slope Data.* The means of th maximum deviations from glide slope centerlir during successive segments of the approach, t gether with the ranges of the means for the i dividual approaches, are presented in Figure Data for all approaches have been combined b cause the individual means all fall within relatively narrow range. The means of the max mum deviations within segments tend to be at near the equivalent of one "dot" during the fir half of each approach and then gradually increa to approximately twice that value as the midd marker is approached. With a few notable e ceptions, individual deviations by subjects tend to be fairly consistent. There were four instanc in which deviations exceeded four "dots" and o instance of an "off scale" (more than five "dots" deviation. There are no significant differenc among approaches with respect to this perforn ance measure. The differences among segmen however, are significant ($p<.001$). The analy is summarized in Table 3.

(2) *Localizer Data.* The means of the ma mum deviations from localizer centerline duri successive segments of the approaches, togeth with the ranges of means for all approaches, a presented in Figure 10. As with the glide slo data, results for all approaches have been co bined. The means tend to be less than t equivalent of one "dot" throughout most of t approach, but exhibit a gradual increase duri the last three segments before reaching t middle marker. Deviations by individual su jects of 3.0 "dots" or more occurred during of the 800 segments. A disproportionate numb

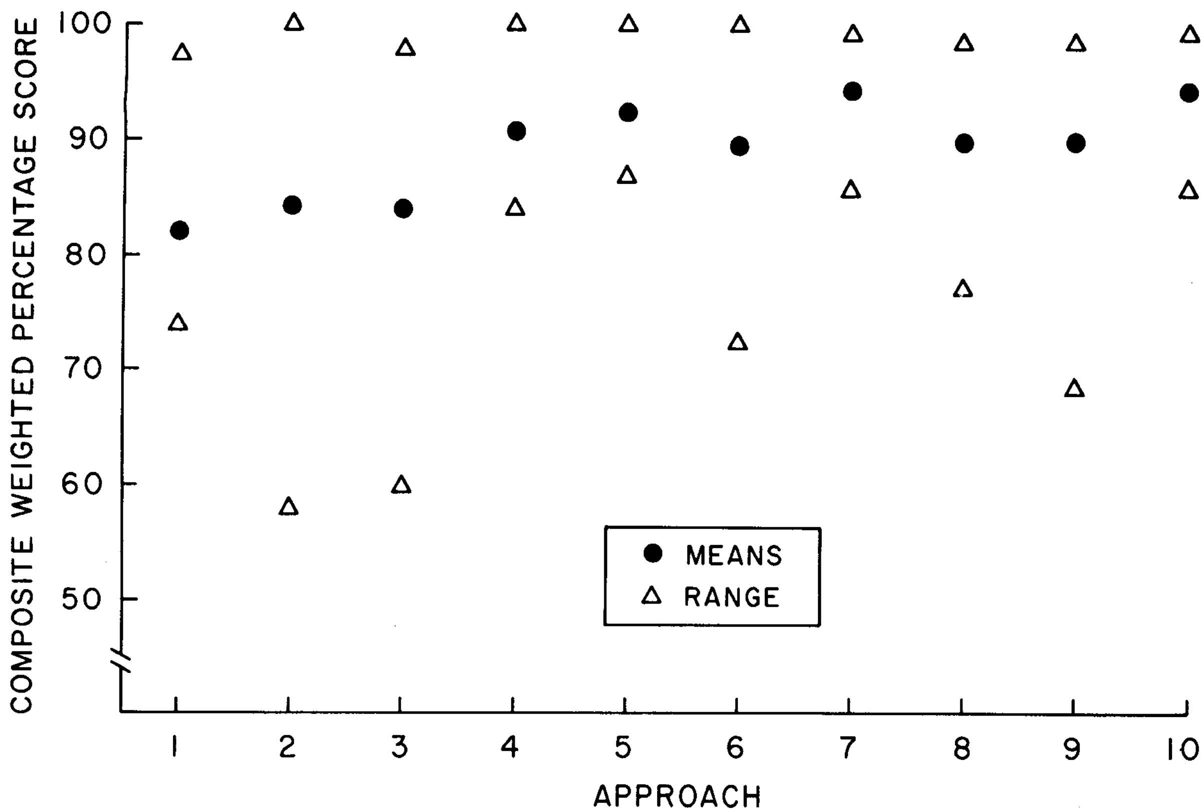


FIGURE 7. Means and ranges of weighted localizer tracking scores.

ıBLE 3.—Maximum Deviations from Glide Slope Centerline Within Successive Segments of Approach

(Analysis of Variance)

Source	df	MS	F	P
—Approaches	(9)	59.23	.63	
A—Lenear	1	104.50	1.11	
A—Quadratic	1	184.28	1.96	
A—Other	7	34.92	.37	
—Segments	(9)	1,032.26	17.18	<.001
B—Linear	1	7,011.21	116.68	<.001
B—Quadratic	1	2,140.20	35.62	<.001
B—Other	7	15.56	.26	
—Subjects	7	563.11		
A x B	81	27.18	1.09	
A x C	63	94.01		
B x C	63	60.09		
A x B x C	567	25.03		
Total	799			

these larger deviations were contributed dur-ş isolated instances where a single subject uld introduce a single large deviation over a :iod of several segments of a single approach. Differences among approaches are significant <.01) as are differences among segments (p<.001). There are no significant interactions between approaches and segments. The trend of both variables has a definite linear component. The analysis of variance is summarized in Table 4.

TABLE 4.—Maximum Deviations from Localizer Centerline Within Successive Segments of Approach

(Analysis of Variance)

Source	df	MS	F	P
A—Approaches	(9)	236.87	2.89	<.01
A—Linear	1	1,104.14	13.48	<.001
A—Quadratic	1	456.86	5.58	<.05
A—Other	7	80.26	.98	
B—Segments	(9)	493.01	7.51	<.001
B—Linear	1	2,269.81	34.58	<.001
B—Quadratic	1	1,821.69	27.76	<.001
B—Other	7	49.37	.75	
C—Subjects	7	729.27		
A x B	81	24.48	.79	
A x C	63	81.89		
B x C	63	65.63		
A x B x C	567	30.93		
Total	799			

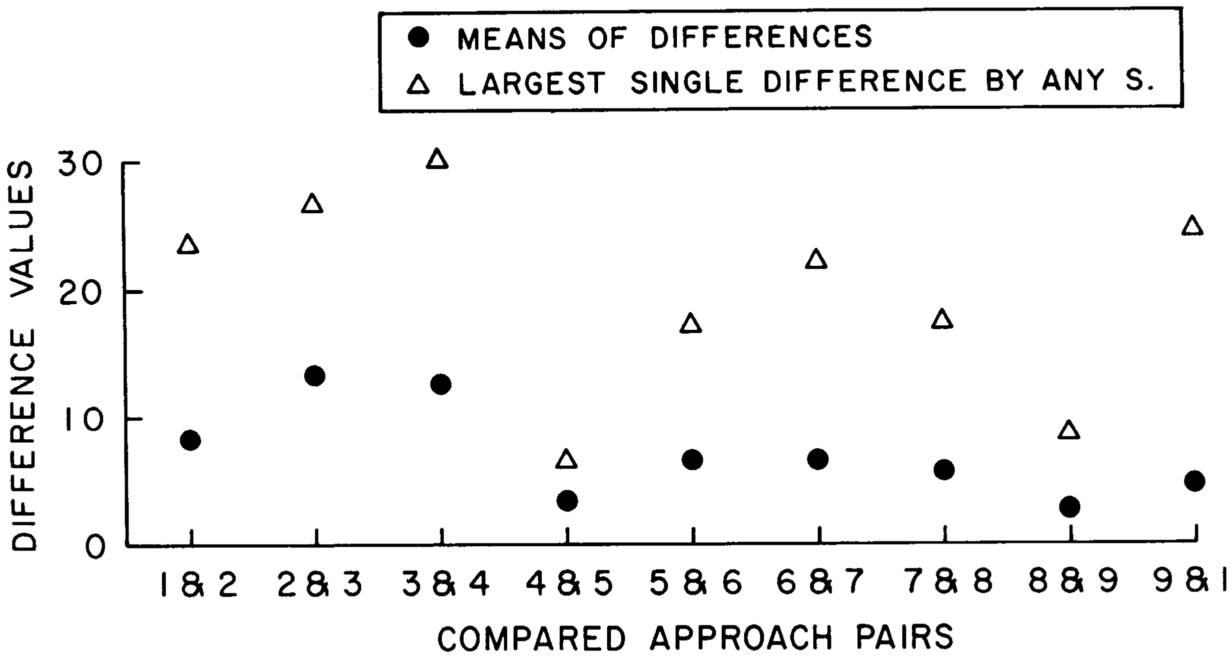


FIGURE 8. Means and maximum differences between weighted localizer tracking scores on sucessive approache

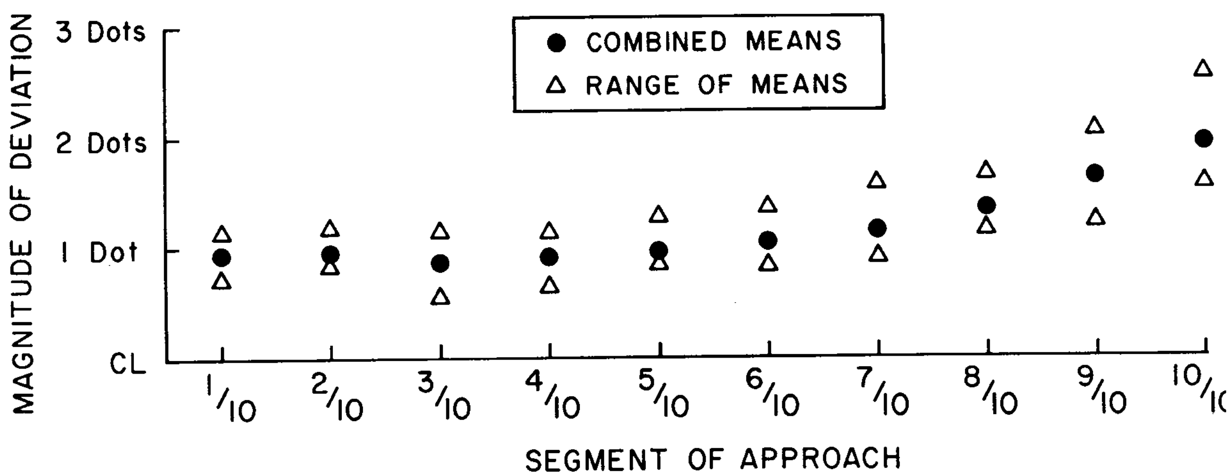
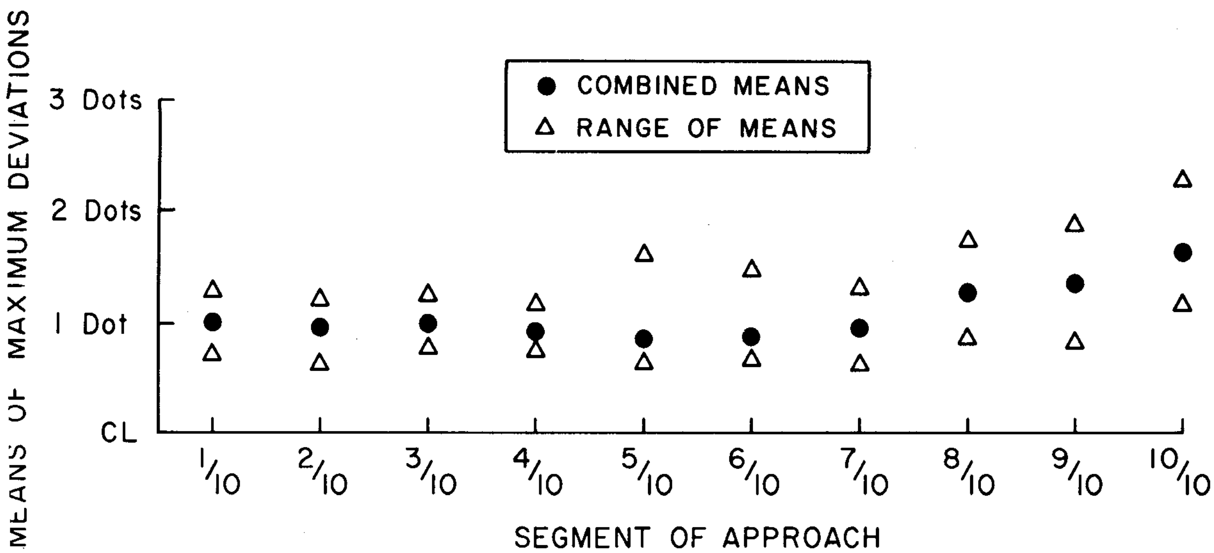


FIGURE 9. Combined means and range of means of maximum deviations from glide slope centerline during ten eq segments of the approaches.

IV. Discussion.

Probably the most significant finding resulting from this study is that there was practically no change in glide slope tracking performance as a function of the practice gained by the ten successive approaches. There was a small, but statistically significant, improvement in localizer tracking on two of the measures. This improvement may be attributed to increasing familiarity with the prevailing wind conditions, which turn made possible an earlier and more accur heading correction and thus tended to minim the effects of incipient localizer deviations. T result of this input would contribute more raising performance scores than to improvi basic tracking ability.

The lack of overall improvement was express not only in terms of unchanged tracking accura



URE 10. Combined means and ranges of means of maximum deviations from localizer centerline during ten equal segments of the approaches.

: also by an undiminished variability in per- mance and the continuation of the instability the track during the last stages of the ap- ach. This evaluation does not deny the tistical significance of the differences reported some of the localizer performance scores, but her evaluates the magnitude of the improve- nt as having little, if any, practical implica- n from the standpoint of actual operational plications.

here are several significant factors that may e been operating to limit the effects of prac- during the ten approaches. These may in- le, but are not necessarily limited to, one or e of the following: (1) the subjects initially ibited a high degree of tracking proficiency : left little room for improvement in terms increased overall accuracy; (2) system in- bility introduced by external variables such as eorological conditions; (3) lack of instruc- al input to the subject coupled with a limited wledge of results; (4) monotony or lack of ific motivation; (5) the subjects may have pted lower performance standards than they e capable of attaining.

onsidering the performance data as a whole, ppears that, as a group, the subjects per- ned at a relatively high degree of proficiency permitted only a very limited opportunity increased accuracy. This is perhaps best essed by the tracking accuracy reflected by the means of the maximum deviations from centerline illustrated in Figure 9 and Figure 10. This level of tracking performance appears to be somewhat better than that generally found during actual ILS approaches by pilots of comparable experience. Unfortunately, quantitative data are not available from actual instrument weather ILS approaches for comparison purposes. If the apparent differences are accepted as real, they are readily explained by the operational differences between the approaches flown as part of this study and those encountered during actual ILS approaches, i.e., the subjects were not required to read approach plates, conduct ATC communications, or to monitor power plant performance. The initiation of the approach by the safety pilot, and the subject's knowledge that the safety pilot had constant visual contact outside the aircraft, may also have had some effect on the subject's subsequent performance. This unburdening of the pilot permitted concentrated attention to the primary tracking task with an adequate margin of residual attention for airspeed and attitude control, which, subjectively judged, were adequately accomplished.

As indicated by the ranges for the respective performance measures, the extreme values that comprise the worst performance by any subject during a given approach, are well below the group mean. Though a disproportionate number of these data points were contributed by relatively few subjects, the latter by no means account for all of them. This aspect of individual performance is emphasized by the data comparing the differences on successive approaches by the same subject. The means of the differences are frequently equal to or greater than, the means of the absolute deviations from glide slope and localizer centerlines. This makes individual variability on the same order of magnitude as the absolute deviations. This variability would seem to indicate that a few instances of demonstrated proficiency may not be adequate to determine an individual's practical performance level. It is, after all, the occasional extreme deviation from an otherwise acceptable performance level that poses the greatest threat to the safety of the pilot and the aircraft.

The fact that the group as a whole did perform at a high level of proficiency in spite of the differences in total flying experience, would seem to call for a closer examination of the present standards and requirements of proficiency and currency. Such an evaluation cannot be made on the basis of the limited data reported here. However, considering that the present standards apparently have been established on less substantive evidence, it would appear that certain economies might be realized in initial and recurrent training if more accurate data were available to define the practical limits of performance imposed by the whole man-machine system. If, for example, the level of tracking accuracy exhibited in the present study can be accepted as an approximation of an optimal level, then training and performance standards should probably be more heavily weighted toward the management of the whole approach task, rather than toward increasing accuracy beyond a practical level. It may be that improvement in overall performance should be sought by somehow achieving a better degree of repeatability or predictability of successive performances.

Of particular interest, and not unexpectedly, there is a significant increase in tracking error, as measured by the maximum angular deviation from centerlines, during successive segments of the approach. This increase in tracking error occurs primarily during the last half of the approach between the outer and middle markers. This increase is only slightly larger for glide slope tracking error than for localizer error in terms of "dots" of deviation. This small difference in indicated tracking error is particular noteworthy in that the ratio of the beam widtl is such as to make the glide slope indicat roughly four times more sensitive with respect registering linear deviations of the same magr tude at any given point along the approac Absolute linear accuracy may actually impro even though the angular deviation increases the aircraft approaches the middle marker. Ho ever, the pilot is required to react more rapid to the angular deviations indicated by the cro pointer instrument in order to achieve the great degree of absolute linear accuracy required dı ing the last stage of the approach. Since the ra of indicated angular error to absolute linear (viation from centerlines is a constantly changi value as a function of the aircraft's progr along the approach, it is impossible for the pi to translate angular error to linear deviatic with any degree of practical usefulness. T deterioration in tracking accuracy as measu by angular deviation errors is, therefore, the sult of the increasing requirement for absol accuracy as measured by angular deviation. Sı demands impair the pilot's ability to maintai consistent track within the framework of the m machine system dynamics. This situation is f ther aggravated by the pacing stress imposed the pilot. His control inputs must be conti ously more rapid, but of a diminishing mag tude, to correct indicated deviations of a c parable magnitude from centerlines dur successive segments of the approach.

Perhaps of the greatest practical significa is the tracking behavior exhibited during period immediately prior to reaching the mid marker. When we consider the instantane deviations from centerlines registered at middle marker, we have a rough indication the proximity of the aircraft to the desired fli path at a critical point in the approach, but s values do not reflect any indication of the bility of the track at that point in time. examining the period immediately prior to rea ing the middle marker (in this case arbitra set at thirty seconds) it is found that there often large excursions in glide slope deviati These excursions must be attributed to untim excessive, or inappropriate control inputs tended to correct what were actually relati minor tracking errors in terms of linear distar The excursions frequently appear as a sequ

›f oscillatory reversals that can best be inter-›reted as indicating the aircraft was "getting ›head of the pilot". Such a condition occurs vhen proper control actions lag far enough be-ıind the appropriate point in time to be no longer ›pplicable and to become potentially inappro-›riate. Though the mean values of these excur-ions are equivalent to less than three "dots", a .umber of individual instances of more than five dots" (and one spanning more than seven "dots") rere recorded. Many of these occurred over a eriod of only a few seconds, indicating rapid ut excessive attempts at correction. Though ıch control actions never caused a serious threat › adequate control of the aircraft, they are ıdicative of an inadequate control-display rela-onship with respect to the dynamic character-tics of the system and the ability of the human perator to respond reliably with a high degree f precision. It is not improbable to speculate ıat it would be possible for the pilot of a high ›rformance aircraft to introduce such excessive ›cillatory control inputs that the aircraft might › forced outside its acceptable performance ıvelope with potentially serious consequences.

Considering that performance measures were fectively limited to glide slope and localizer acking, it is possible that less obvious practice fects did in fact occur, but were not recorded otherwise observed. One possibility is that ther than being reflected as a performance ange in a relatively consistent and controlled uation, the added practice on the tracking task ıy have resulted in an increase in residual atten-›n. Such an increase could make it possible r the pilot to deal more effectively with the cillary sub-tasks that comprise the total ILS proach or to handle the added demands of an ıergency condition. There are no direct per-rmance data to support this possibility, but ırt-rate data on the subjects which have been ›orted elsewhere[3] may be suggestive of this. ıe mean heart rate for the group of subjects clined significantly as a function of the number approaches flown. This has been interpreted indicate a reduction of anxiety-induced stress. ›wever, if a relatively low degree of residual ention in the performance of a task can be epted as being stress-inducing, and conversely, an increase in residual attention is, therefore, ely to result in a reduction in stress, it is pos-le that the reduction in heart rate may in part be due to an increasing residual attention resulting from extended practice. If further investigation were to verify this assumption, it would support the desirability, stated earlier, for re-evaluating the criteria for proficiency and currency.

V. Summary and Conclusions.

There were few significant changes in tracking behavior as a result of the practice on ten successive approaches flown under the conditions of this study. Whether this overall lack of change was due to an artificial performance ceiling attributable to an initially high proficiency level, or whether the practice effects were limited by system characteristics, cannot be determined by the present data. It is suggested that a number of complex and interrelated factors may be operating.

It appears that the difficulties encountered in performing an ILS approach with a high degree of precision are related only in part to the difficulty of the tracking task involved in following the glide slope and localizer centerlines to the middle marker. Under optimized conditions, this task can apparently be accomplished with a relatively high degree of precision even though certain undesirable tracking characteristics remain operative. Under actual ILS conditions, the main difficulty may be associated with the pacing stress introduced by ancillary activities that must be performed, as well as by the psychological stress experienced by the pilot. This would suggest that once an acceptable level of tracking proficiency has been attained, further improvement of the whole task should perhaps be sought in exercising the management and allocation of attention to the component tasks.

Though the conventional crosspointer instrument can be considered generally adequate for most of the approach there appears to be an inherent deficiency in the control display ratio and relationship with respect to the requirements for rapid and precise control adjustments at the most critical stage of the approach at the middle marker.

Individual variability by subjects on successive approaches raises the question of what constitutes an adequate criterion for an acceptable level of performance. Further study will be required to determine suitable methods for increasing consistency of performance.

REFERENCES

1. Airman's Information Manual, Part 1. Basic Flight Manual and ATC Procedures. Department of Transportation, Federal Aviation Administration. Government Printing Office, Washington, D.C. (current issue date).
2. Fox, J. G., I. Ferguson and I. D. C. Andrews: An Annotated Bibliography of Presentation of Information in Aircraft Cockpits, S & H Memo 3/66, p. 77–78. Technical Information and Library Services, Ministry of Aviation, England, May 1966. (Available as AD 634575).
3. Hasbrook, A. H. and P. G. Rasmussen: Pilot Heart Rate During In-Flight Simulated Instrument Approaches in a General Aviation Aircraft. FAA Office of Aviation Medicine Report No. AM–70–7, Oklahoma City, Oklahoma, April 1970.
4. Hasbrook, A. H. and P. G. Rasmussen: Aural Glide Slope Cues: Their Effects on Pilot Performances During In-Flight Simulated ILS Instrument Approaches FAA Office of Aviation Medicine Report No. AM–71–24 Oklahoma City, Oklahoma, May 1971.
5. Instrument Flying Handbook AC–61–27A. Depart ment of Transportation, Federal Aviation Administra tion. Government Printing Office, Washington, D.C 1968.
6. Povenmire, H. K., K. M. Alvares and D. L. Damos Observer-Observer Flight Check Reliability. Technica Report LF–70–2. Aviation Research Laboratory, In stitute of Aviation, University of Illinois. Octobe 1970.
7. Williams, A. C., Jr., M. Adelson and M. L. Ritchie A Program of Human Factors Engineering Researc on the Design of Aircraft Instrument Displays an Controls. WADC Technical Report 56–526, Wrigl Air Development Center, WPAFB, Ohio. Decemb 1956. (Available as AD 110424.)

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6. Abstract This paper describes altitude chamber experiments conducted with human sub- ects using a new continuous-flow disposable passenger mask applicable for emergency se to maximum altitudes of 41,000 feet. This mask design differs in configuration rom the previous omni-directional maska designed to meet the requirements of National erospace Standard 1179 and FAA Technical Standard Order C-64 in that the inner face lap or seal has been eliminated and the cylindrical shape reduced to a modified one. The primary goal of this study was to determine if design modification of the ask induced an increase or decrease in physiological efficiency. Of paramount con- ern was the possibility that modification of the configuration and facial seal might icrease the leakage rate of ambient air into the mask, and thereby compromise its ility to provide the level of protection required at the maximum altitude of the rcraft. Subjects were instrumented to obtain a variety of physiological data. is included EKG impedance pneumograph, ear oximetry, and expiratory nitrogen, and nute volume. The continuous flow of oxygen delivered to the passenger mask was ntrolled and precisely measured. The mask was evaluated at altitudes of 14,000 ,500, 29,000, 35,000 and 40,000 feet. The average inspired tracheal oxygen partial essure remained above 83.8 mm Hg under all conditions of rest and exercise at all titudes except for the third and last minute of exercise at 40,000 feet. If a derate degree of physical activity is to be maintained for more than a few minutes, ygen-flow rates should be increased commensurate with the anticipated level of tivity. Larger subjects with increased body surface areas exhibit lower blood ygen saturations and tracheal oxygen partial pressures at a standardized oxygen ow due to increased oxygen consumption.

. Key Words
ygen masks, decompression, hypoxia, otection, altitude, passengers

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PHYSIOLOGICAL EVALUATION OF A MODIFIED JET TRANSPORT PASSENGER OXYGEN MASK

. Introduction

This report describes altitude chamber experi- ıents conducted with human subjects using new ierra Engineering Series 289–601 disposable assenger oxygen masks. These masks, applic- ɔle for emergency use to 40,000-foot altitudes, iffer in configuration from the previous Sierra .ask (although both are designed to meet re- ıirements of NAS 1179 and FAA TSO C–64) ι that the inner face flap or seal has been elim- .ated and the cylindrical shape reduced to a .odified cone.

The unique characteristics of continuous-flow ɛygen masks, in terms of human respiration, 'e frequently not well understood. Although ss costly than crew masks and deceptively mple in appearance, continuous-flow passenger asks have physiological performance character- tics that are relatively complex.

Continuous-flow, phase-dilution type masks, ısigned to the NAS 1179 and FAA TSO C–64 quirements, employ a unique design in which e reservoir is interposed between the delivery be and the mask. The reservoir is separated om the mask by a sensitive check valve. The ntinuous flow of oxygen fills the reservoir bag ıring the respiratory pause and exhalation. ıe flow also continues at the same rate during spiration. The mask-wearer receives 100% ygen from the reservoir during an entire in- iration unless the bag is emptied; if this occurs, spring-loaded valve in the mask opens, and ıbient air is introduced to provide sufficient lume to meet the remainder of the inspiration. ıe flow of 100% oxygen is provided at the ɔst advantageous point in the respiratory cycle, the beginning of inspiration. For example, a human subject's tidal volume is 650 cc, and ɜ reservoir contains only 500 cc at the begin- ıg of inspiration, the 500 cc of 100% oxygen ll be inspired first and delivered to the active ɜas of the lungs. The ambient air valve will then open and deliver 150 cc of ambient air, which will enter the mouth, trachea, and other "dead" or inactive spaces of the respiratory system. Upon expiration, this dead-space air is the first to exit through the exhalation valve. This process is repeated with each respiratory cycle. In normal practice, the reservoir bags are capable of containing a maximum of 1,100 cc which provides for increased tidal and minute volumes.

In summary, continuous-flow, phase dilution masks offer the following advantages:

1. Oxygen economy is afforded by use of a reservoir bag that fills and retains the oxygen flow during both the respiratory pause and exhalation.

2. At lower altitudes, reduced oxygen flow rates may be employed and the air-oxygen dilution controlled in a manner more reliable than other methods employed in constant-flow oxygen masks.

3. Oxygen concentrations approaching 100%, required at 35,000 to 40,000 feet, may be obtained with moderate and reasonable flow rates.

One basic disadvantage of all continuous-flow oxygen systems is their inability to adjust automatically to the respiratory changes associated with changes in emotional and physical activity of the wearer. A healthy young male breathing air at rest normally exhibits a (volume/breath) tidal volume of about 550 cc and a minute volume (volume/minute) of 7,700 cc. Emotional and/or physical activity may cause these values to increase greatly. Concern with this problem is reflected in the Federal Aviation Regulations Part 25 (formerly Part 4B), 25.1443,[1] which requires maintenance of a mean tracheal oxygen partial pressure of 83.8 mm Hg at a tidal volume of 1,100 cc, and a 30-liter BTPS (body temperature pressure saturated) minute volume for altitudes of 18,500 to 40,000 feet.

With the introduction of jet-transport passenger aircraft certified to operate at high altitudes, new oxygen systems and masks were designed and evaluated.[2 3] Subsequently, standards for passenger oxygen masks were compiled and published. The National Aerospace Standard 1179[4] and Federal Aviation Administration Technical Standard Order (TSO) C-64[5] set forth manufacturing, material, and testing standards for passenger oxygen masks.

An excellent description of the basic physiological rationale of oxygen equipment design for aircraft has been prepared by the SAE A-10, Aircraft Oxygen Equipment Committee.[6] An additional report delineates the basic criteria and design philosophy of jet transport passenger oxygen systems.[7]

II. Methods

Procedure. The altitude chamber flight profile is shown in Figure 1. Six subjects who had received altitude indoctrination within the past two years were employed. Instrumentation i shown in Figures 2 and 3. The mask was no donned until after air-breathing baselines wer established at 10,000 and 14,000 feet. A safet observer accompanied each subject.

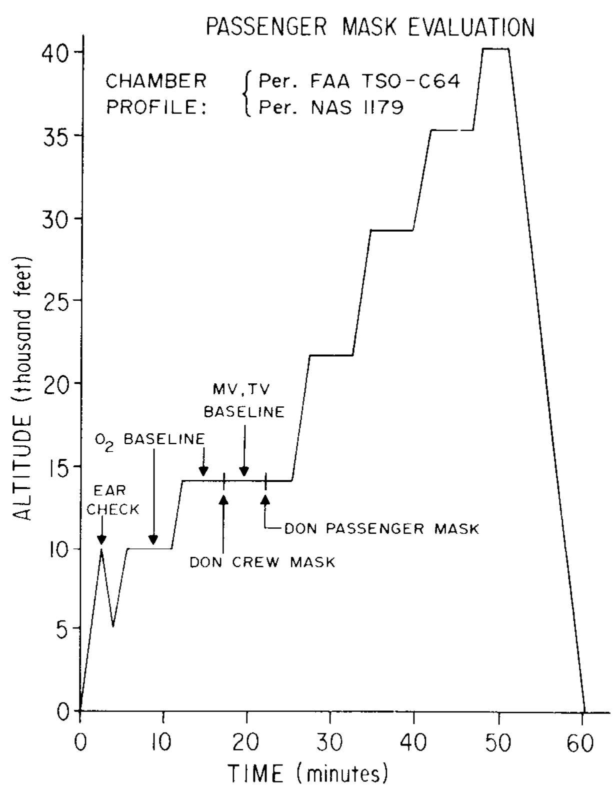


FIGURE 1. Altitude chamber profile used in evaluation of the Sierra 239-601 series prototype disposable passenger oxygen mask.

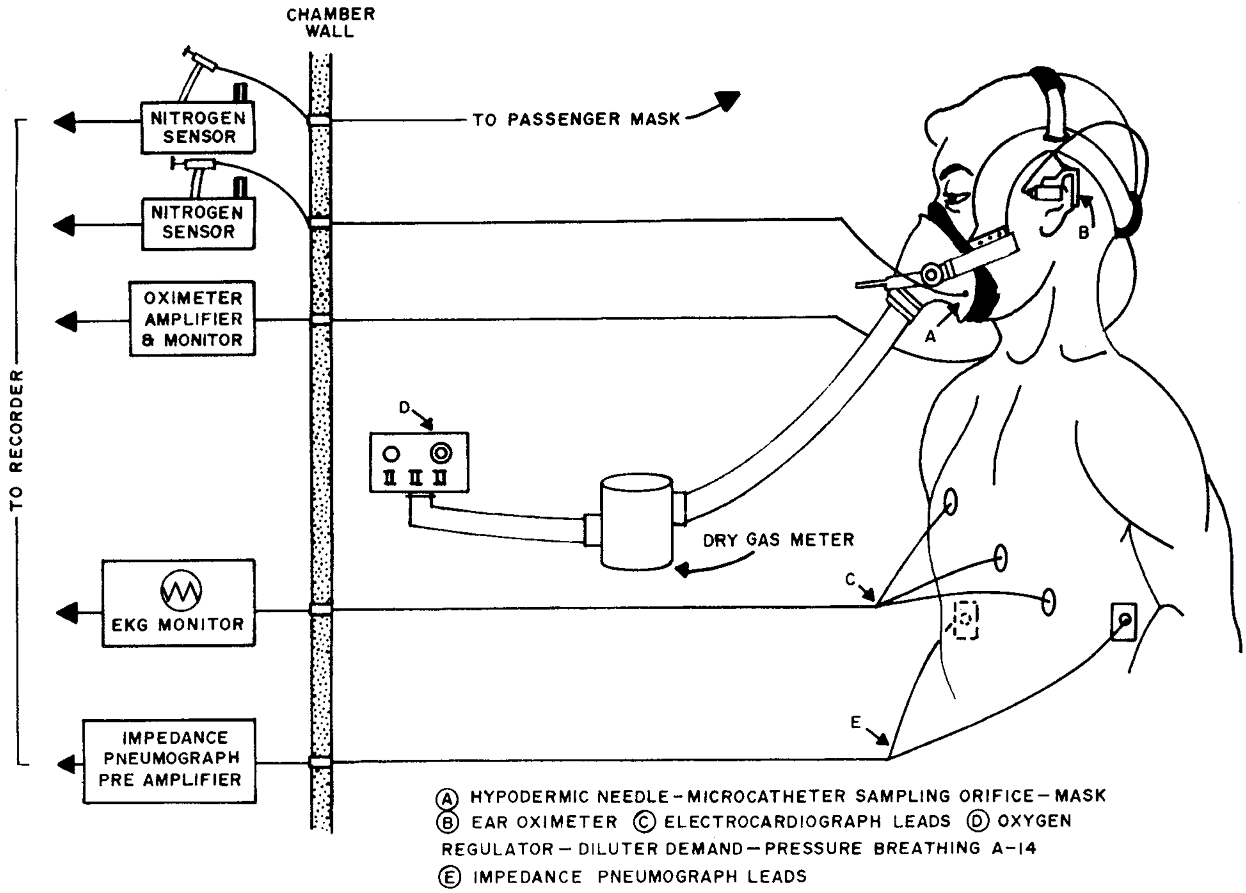
A Waters ear oximeter, Model XE 350, wa affixed to the antihelix of the subject's ear 10 t 15 minutes prior to the chamber flight, to allo stabilization. The output of the earpiece wa fed into an XE-350 oximeter and continuousl recorded on a Physiograph. The latter was als used to record signals from EKG electrodes an the output from impedance pneumograph ele trodes attached to the subjects. The impedan pneumograph was included in the experime to attempt to determine if changes in the re piratory activity baseline occurred during su sequent ascent to altitude. At the present tin there is no satisfactory method of measuri respiratory volumes and activity while weari a passenger mask without compromising t performance of the mask.

After a preliminary assurance of the subjec capability to equalize ear pressures, the subje rested quietly at 10,000 feet until the ear oximet reading indicated a stabilization of blood oxyg saturation. Then the subject was depressuriz to 14,000 feet to establish similar resting a exercise baselines at this altitude.

When it appeared the blood saturation w stabilized at 14,000 feet, the subject donned crew-type demand oxygen mask and commenc breathing 100% oxygen. Immediately followi crew-mask donning, exercise on a bicycle ergo eter (modified so that it could be operated each subject while seated in a passenger ty aircraft seat) was initiated. The exercise le was set at 45 rpm (speed) and 45 watts (loa to obtain the desired respiratory activity (a proximately 25 to 30 liters/minute). This regarded as a light to moderate work load a proximately equivalent to walking at 3.0 to mph.

Exercise was continued until the desired m ute volume, as indicated by a dry gas meter, v obtained and stabilized. The subjects beca denitrogenated during this period, thereby ducing the possibility of bends with exercise the subsequent higher altitudes.

After completion of nitrogen washout at 14, feet, the subject removed the crew mask a



'IGURE 2. Instrumentation of subjects prior to nitrogen washout and determination of minute volume at an altitude of 14,000 feet. Subject wearing a crew-type mask.

apidly donned the Sierra passenger mask Figure 3). Each subject wore a new mask; ıus six masks were used in this evaluation. 'he flow of oxygen to the mask was regulated y an altitude-sensitive regulator of the type sed in multi-passenger oxygen systems of transort aircraft. The flow from this regulator, ıstead of being transmitted directly to the subect, was first routed outside the chamber through flowmeter and needle-valve arrangement in rder to obtain precise measurement and control f the flow (Figure 3). Excess oxygen as provided by the regulator was vented outboard outde the chamber.

The subject exercised for three minutes at each titude and rested during the climb to each ıccessive higher altitude level. The chamber as leveled off at 14,000, 21,500, 29,000, 35,000 ıd 40,000 feet and readings were taken pre-ercise, during the first minute and last minute exercise followed by post-exercise recordings at 14,000, 21,500, 29,000, 35,000 and 40,000 feet. Motion pictures were taken of the subjects during the maximum altitude portions of the flights and closed-circuit television was used to monitor the subjects at all times.

Mask Efficiency. Two Custom Engineering and Development Company Model 300 AR Nitralyzers were used to continuously measure the mask nitrogen. These instruments exhibit an initial response latency of 0.024 second, 90% response being obtained in 0.044 second. A vacuum pump, regulated to 0.6 mm, set the sampling rate at 3 cc per minute. The continuous sample was drawn through a needle valve and microcatheter tubing (PE 60) of 0.030 inch internal diameter. The small, extremely lightweight, microcatheter tubing connected to the mask did not require extensive modification of the mask nor did it add significant weight; thus, fit and operational characteristics of the mask were not compromised.

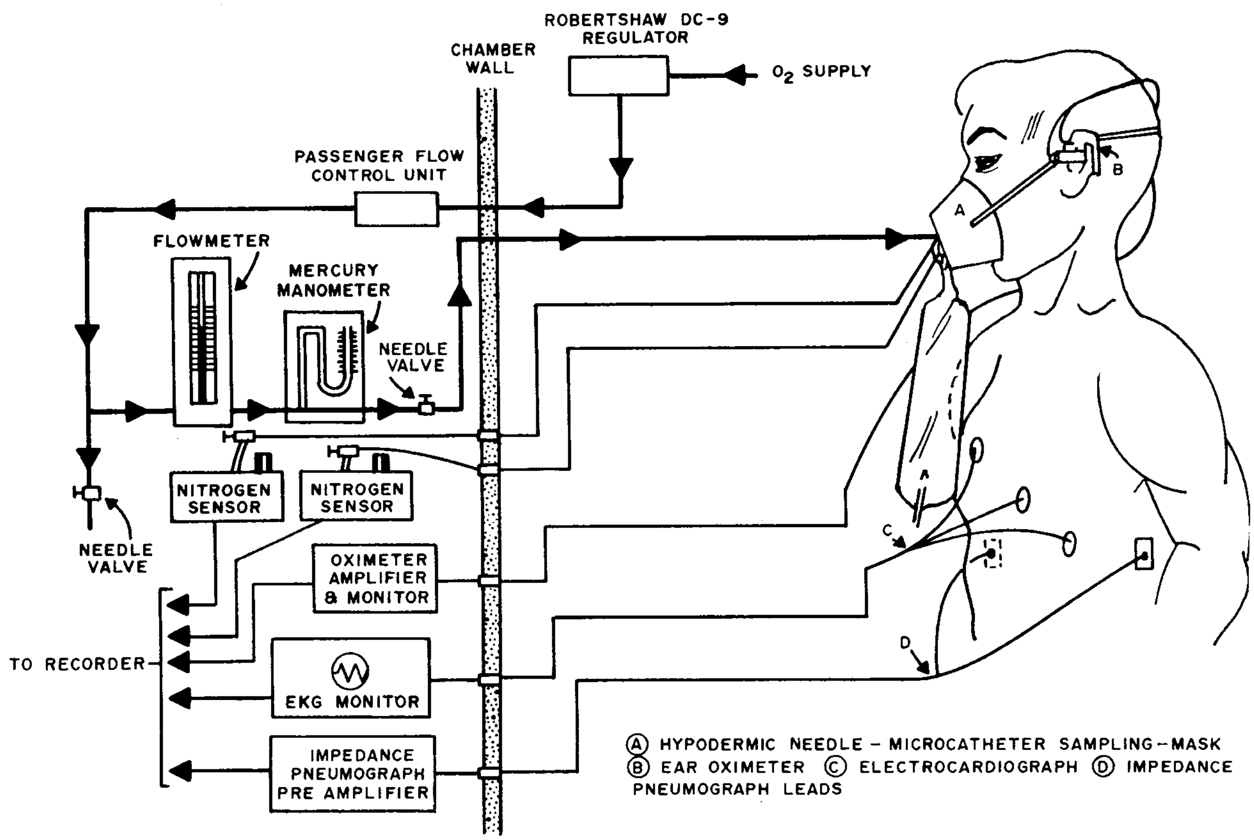


FIGURE 3. Instrumentation of subjects following completion of nitrogen washout and determination of minu volumes. Subject has completed passenger mask-donning. Oxygen flow to the mask was routed from a pre sure control regulator within the chamber through the passenger flow orifices outside the chamber where was reduced to standard conditions and returned to the mask. Excess oxygen from the regulator was dump overboard.

In the evaluation of oxygen mask efficiency, one of the most important measurements is that of the partial pressures of inspired gases. A continuous flow mask, while worn by a human subject, defies direct measurement of these parameters (without compromise of mask performance) due to the rapid changes in gas composition at the facepiece. The percentage of gases in the facepiece of the mask may be averaged by an integrating reservoir; this average indicates a trend, but is influenced by the inactive gases of the facepiece and anatomical dead space. In order to estimate the composition of inspired gases an indirect approach was used; this technique is based on the assumption that the end-expiratory gases are completely mixed and have equilibrated with the blood in the alveoli.

Nitrogen is not involved in metabolic exchange. If the absorption of O_2 and the production of CO_2 were exactly the same, the amou of nitrogen inspired would equal the amou expired; i.e., nitrogen molecules inspired=nitr gen molecules expired. The metabolic respir tory quotient (R.Q.) would equal one. Howeve

the metabolic $\text{R.Q.}=\dfrac{CO_2 \ \text{produced}}{O_2 \ \text{consumed}}$ and is n

normally equal to one, or unity. Under the conditions there may be a relative difference the nitrogen composition of inspired and expir gases. The metabolic R.Q. depends upon t predominance of carbohydrates (1.0), prote (0.82), or fat (0.71) being metabolized and usually about 0.83. The respiratory R.Q. m vary temporarily from the metabolic R.Q. du ing unsteady states such as hyperventilati The increased lung ventilation produces a blo off of CO_2 from the blood with an apparent, l misleading, increase in CO_2 production and an R.Q. greater than 1.0. Conversely, hypoventilation and retention of CO_2 indicate an apparent, but misleading, decrease in CO_2 production resulting in a decreased R.Q. which may be less than 0.7.

One must keep in mind that in a steady state condition the unequal exchange of oxygen and carbon dioxide involves only that portion of the gases consumed and produced. For example, if during a one-minute period at rest 0.3 liters of O_2 were consumed and 0.25 liters of CO_2 were produced (R.Q.=0.83), the resultant volumetric difference of 0.05 liters in the seven or eight liters passing through the lungs during this one minute would be relatively small, and the error (only a few per cent) would be well within the experimental error of the determinations of end expiratory nitrogen.

All of the nitrogen which dilutes the inspired gas originates from air by mask leakage or dilution-valve activation with the exception of that derived from the tissues; after six to eight minutes of breathing oxygen under a steady state condition this constitutes less than one per cent of the lung volume.

Using calculations suggested by Luft,[8] the admixture of air can be determined; i.e.:

$$\frac{\text{Admixture of air}}{100} = \frac{\text{Inspired nitrogen fraction}}{\text{Nitrogen fraction of air}}$$

By substituting end expiratory nitrogen for inspired nitrogen:

$$\text{Admixture of air} = \frac{\text{End expiratory nitrogen}}{\text{Nitrogen fraction of air}} \times 100$$

Using these formulas, the percentage of dilution, supply oxygen, oxygen from the ambient air, and total oxygen may be derived according to the following calculations:

$$\text{Per Cent Dilution} = \frac{\text{End expired } N_2 \text{ x } 100}{N_2 \text{ of air } (79.03)}$$

% Oxygen from Supply = 100% − % dilution

Oxygen from Ambient = Per cent dilution x oxygen contained in ambient air.

Total oxygen = oxygen from supply + oxygen from ambient air.

Calculated inspired oxygen partial pressure = $(P_B - 47)$ x Per cent total O_2.

Where: P_B = Total pressure in mm Hg at ambient altitude.

47 = Pressure, in mm Hg, of saturated water vapor at body temperature.

III. Results

The oxygen flow of the passenger mask NTPD (normal temperature pressure dry, 70° F.—760 mm-dry) and BTPS (body temperature pressure saturated, 37° C.—ambient—saturated) is shown in Figure 4. The flow to Subject 5 was increased at 29,000 and 35,000 feet during exercise due to a precipitous fall in blood oxygen saturation. Flows to the remaining subjects were adjusted to the minimal values, according to FAR Part 25.

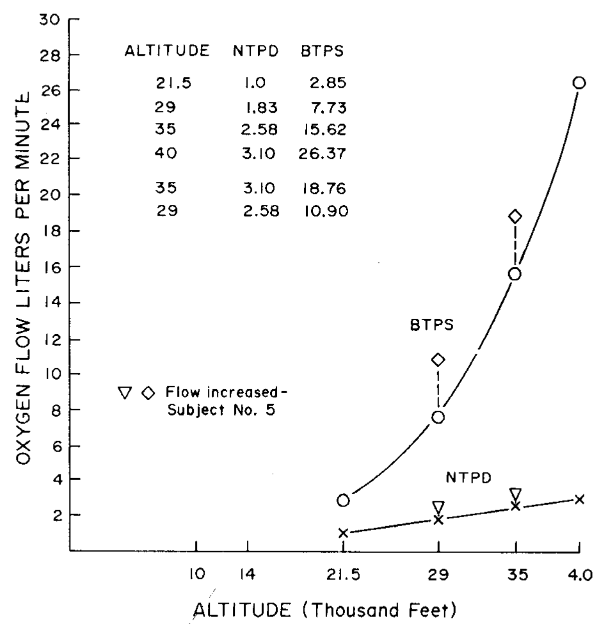


FIGURE 4. Oxygen flow rate.

Heart Rate. Predictably, the mean heart rates increased with exercise, this being more pronounced in the third minute of exercise. There was also an over-all increase in mean heart rate with increase in altitude (Figure 5). These latter increases at similar exercise levels may have been partially due to subject apprehension with increase in altitude; however, the main stimulus appears to be hypoxic stress as indicated by lower blood oxygen saturations and lower oxygen partial pressures at the higher altitudes (Figures 6 and 7). At 40,000 feet, the average tracheal oxygen partial pressure dropped from 86.4 mm Hg at the end of the first minute to 77.2 at the end of the third minute (Figure 7). A typical nitralyzer record is shown in Figure 8. The oximeter earpiece used on Subject

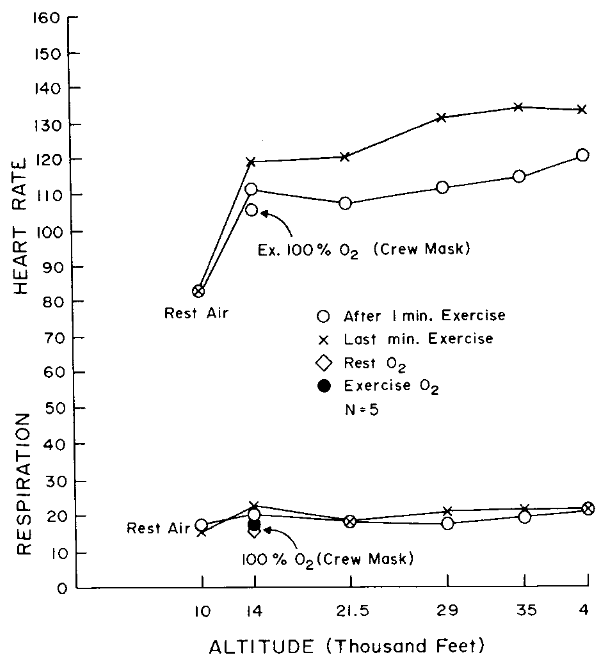


FIGURE 5. Average heart and respiratory rates. Note the increase in heart rate from the first to the last minute of exercise at altitude.

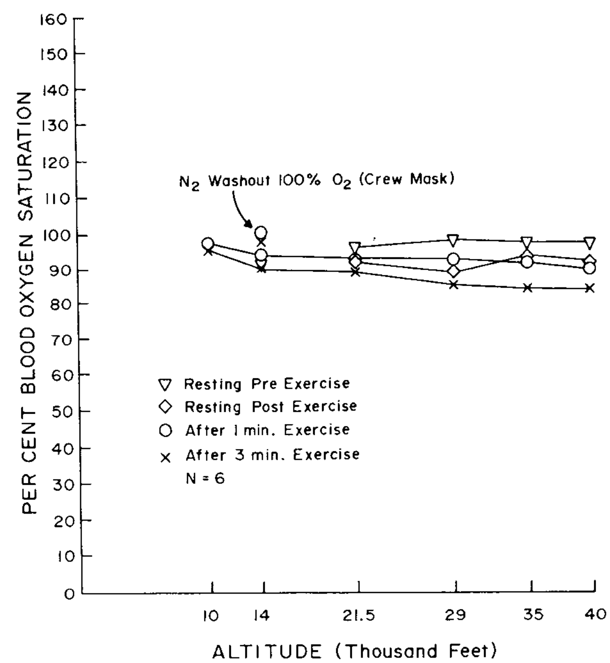


FIGURE 6. Average blood oxygen saturation as determined by ear oximetry. Note the decrease in blood oxygen saturation from the first to the third minute of exercise.

No. 1 appeared erratic and unstable with readings, for example, of 90% blood saturation while breathing 100% oxygen at 14,000 feet. The earpiece and amplifier were replaced. The average blood oxygen saturation dropped to its minimum value at the end of three minutes of exercise at 40,000 feet (83.6%); however, re-saturation to an average of 90.8% occurred within a short period of time (30–45 seconds) following cessation of exercise (Figure 6).

Blood Oxygen Saturation. The National Aerospace Standard states that blood oxygen saturation baselines established at 10,000 and 14,000 feet should be obtained with the subject engaged at the same level of activity as during the evaluation at higher altitudes. Comparison as the mean blood oxygen saturation of the subjects at rest breathing air at 14,000 feet (93.8%) to that at the last minute of exercise (89.9%) indicates a difference of 3.9% which agrees with results obtained in a previous study.[9] Average blood oxygen saturation levels prior to exercise exceeded the resting baseline (93.8%) at all altitudes. Post-exercise saturations were 1.3% to 4.6% lower than the above baselines.

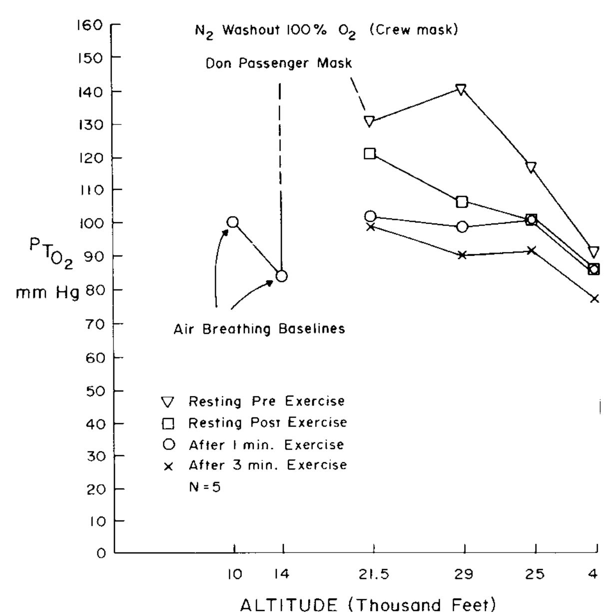
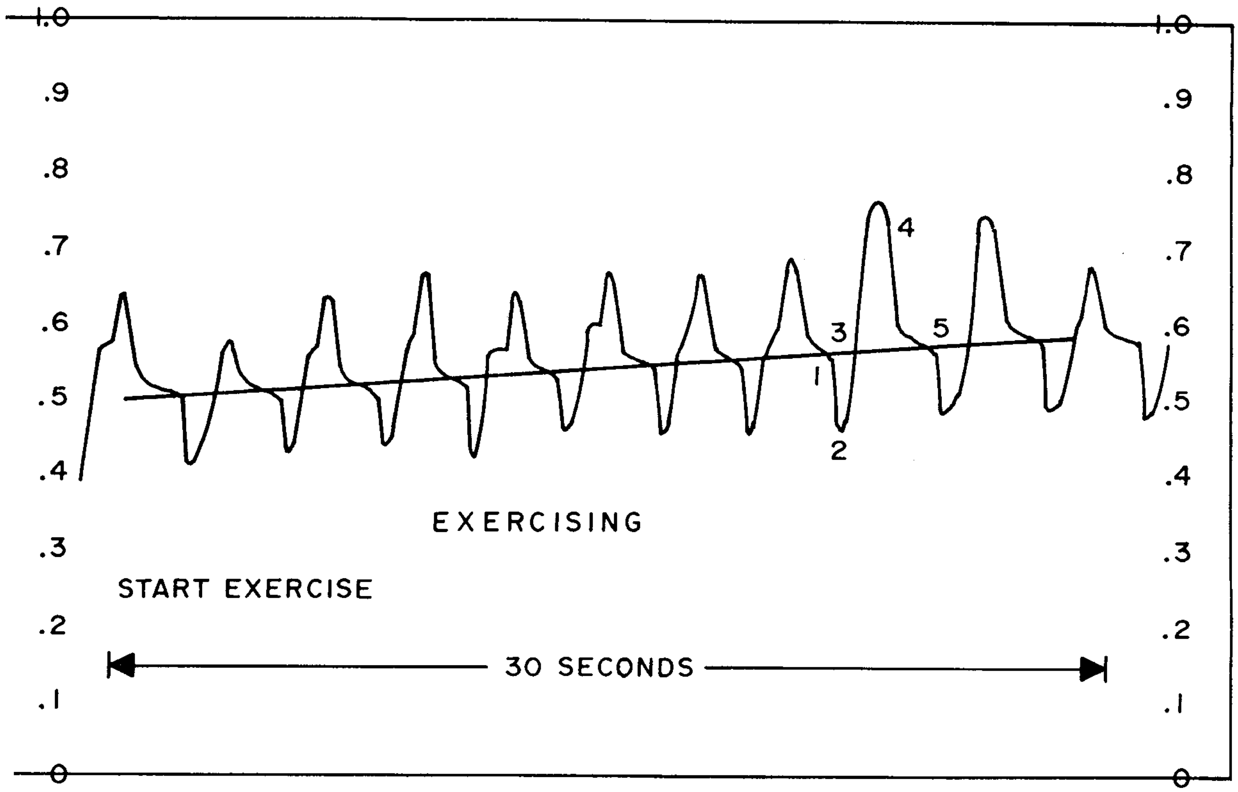


FIGURE 7. Average inspired oxygen partial pressure The air breathing baseline at 10,000 and 14,000 fe is merely a function of barometric pressure; i.e (P_B–47) x 20.94% and is identical irrespective physical activity. The combination of a crew mas and breathing 100% oxygen at 14,000 feet caus the inspired tracheal oxygen partial pressure to g off scale to a calculated value of approximate 400 mm Hg.



[FIG]URE 8. Nitralyzer record of Subject No. 4 at 29,000 feet. Slope of line indicates increased dilution and re[duc]ed P_TO_2 due to exercise. Numbers 0–1.0 equal 0–100% nitrogen subject to calibration correction. Nitrogen [cur]ve should not be confused with flow, volume or mechanics of respiration. (1) Inspiration of oxygen from [rese]rvoir. (2) Dilution valve activated. (3) Continuing. (4) Oxygen, inspired primarily at (1) above, exhaled. [(5)] End expiratory nitrogen concentration.

[O]xygen Partial Pressure. The tracheal oxy[gen] partial pressure remained above 83.8 mm Hg [in a]ll subjects under all conditions of altitude for [the] first minute of exercise except for Subject [No.] 5, who experienced a drop in P_TO_2 [to] 71 mm Hg at the end of the first [min]ute of exercise at 40,000 feet. In the third [(las]t) minute of exercise, the P_TO_2 of this sub[ject] dropped to 70, 71, and 64 mm Hg at altitudes [of 2]9, 35, and 40 thousand feet, respectively. To [offs]et the precipitous drop in P_TO_2 and blood [oxy]gen saturation at 35,000 feet, the flow was [incr]eased from 2.58 lpm to 3.10 lpm; the post-[exer]cise P_TO_2 climbed to 93 mm Hg and 99%. [Rap]id recovery after 1½ minutes of exercise, in [whi]ch the P_TO_2 and blood oxygen saturation [dro]pped to 64 mm Hg and 80%, was accom[plish]ed at 40,000 feet by merely discontinuing [exer]cise; this produced a rapid climb in P_TO_2 [and] blood oxygen saturation to 93 mm Hg at [...].

[R]espiration. Subject No. 5 was the oldest (age [...] and the largest (225 lbs.) of the subjects used in this series of experiments. His larger body surface area undoubtedly increased his oxygen consumption in comparison to the other subjects. He exhibited marked increases in respiratory rate from 14 respirations per minute at 14,000 feet (at which time the baseline minute volume was determined) to 24, 25 and 24, respectively, at 29, 35 and 40 thousand feet. A crude estimate of this effect may be made by assuming that the baseline tidal volume (determined during exercise at 14,000 feet) remained constant (1,857 cc) during subsequent ascent to higher altitudes. The indicated increase in respiratory rate would, therefore, increase the baseline minute volume from 26 lpm (BTPS) at 14,000 feet to 44.6 lpm at 29,000 and 40,000 feet, and 46.4 lpm at 35,000 feet, an overall minute volume increase of 48% to 54% above the specified lpm. With these conditions prevailing, the basic design criterion of the mask is exceeded by approximately 50%.

Subject No. 2 exhibited satisfactory P_TO_2 and blood oxygen saturation levels at the end of the first minute of exercise; however, oximetry indi-

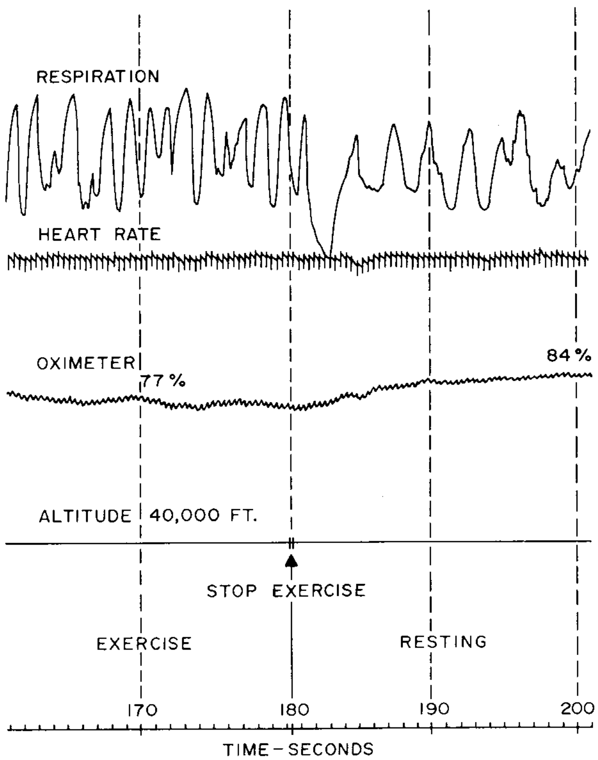


FIGURE 9. Sample. Physiograph recording showing rapid blood oxygen re-saturation following cessation of exercise at 40,000 feet. Subject No. 2.

cated a relatively low blood oxygen saturation (without a commensurate lowering of tracheal oxygen partial pressure) at the end of the third minute at 29, 35, and 40 thousand feet. Rapid recovery of blood saturation following cessation of exercise is shown in a sample recording from this subject (Figure 9). This subject did not exhibit a marked change in respiration when compared to the 14,000-foot baselines; however, he exhibited one of the most consistently elevated heart rates during exercise at 35 and 40 thousand feet, which may be indicative of his response to hypoxic stress, state of physical condition, or both.

IV. Discussion

The National Aerospace Standard (NAS) recognizes gas analysis and blood-oxygen-saturation determination as the two principal alternate methods to be used in altitude-chamber evaluations of passenger masks.

In this study, the experiments were designed to measure both of these variables simultaneously.

Exercise time at altitude was held to a mi mum in order to minimize the probability bends and to reduce fatigue.

Previously, high altitude evaluations of p senger masks have been carried out on resti subjects. In some evaluations, a brief episc of voluntary hyperventilation took place to crease minute volumes to 30 liters/minute. T procedure is recommended in NAS 1179, but is practically impossible for a sedentary subj to maintain this level of respiration for m than 30 to 45 seconds without experiencing sev symptoms of hypocapnia (dizziness, paraesthe muscular cramps, etc.).

In addition, voluntary hyperventilation duces the alveolar and blood carbon diox partial pressures by the washout effect. By mere physical reduction of the carbon diox partial pressure, an increase in alveolar oxy partial pressure is induced. As pointed previously, this physiologically unsteady st may be maintained for only brief peri Changes in blood chemistry and cerebral bl flow induced by voluntary hyperventilation detract from its usefulness in mask evaluati

A controlled and measured work load used in these experiments to stimulate resp tion to the 30 liters/minute standard witl imposing severe changes in respiratory blood-gas composition.

Admittedly, increased work load produces increase in oxygen consumption. The leve work load used in these experiments should duce an increase in oxygen consumption of proximately .35 to .50 liters/minute above resting value.[10]

Neither voluntary hyperventilation nor e cise is entirely a satisfactory means of eleva the minute volume; voluntary hyperventila tends to over-estimate the physiological effec ness of a mask, and exercise tends to un estimate this value. The use of exercise, how increases the margin of safety and assur that an adequate blood oxygen saturation be maintained during periods of increased piration.

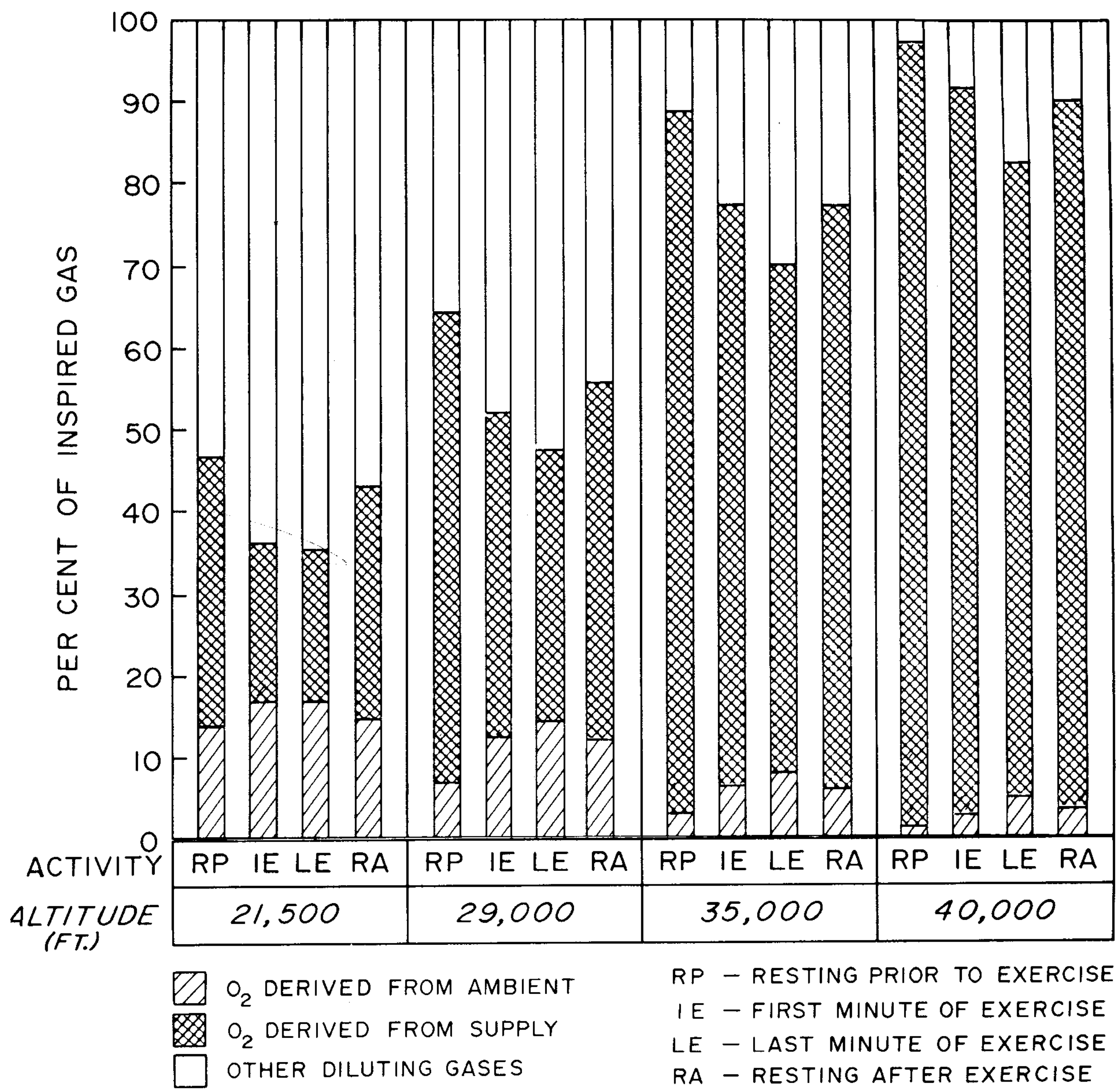
One disadvantage of using exercise in evaluations at altitude is the increased susc bility to the development of bends. The de of denitrogenation, altitude profile, and exp time must be carefully considered in relatic the use of exercise.

The increased minute and tidal volumes de-eloped during exercise impose efficiency require-ıents of mask performance in excess of similar *valuations* conducted on the sedentary, resting ıbject.

At 40,000 feet, 3.1 liters/minute NTPD equals 6.4 liters/minute BTPS. A subject breathing 0 liters/minute will empty the reservoir bag and raw in air through the ambient air valve. The verage composition of inspired gas is shown in 'igure 10.

If, however, there are significant and uncontrolled openings around the periphery of the mask, ambient air may be drawn through these during peak inspiration rather than through the check valve of the reservoir bag.

The ear-oximeter determinations exhibit some degree of variability, depending upon physical activity and subject movement. Fluctuation of the ear oximeter was pronounced during resting and air breathing at 14,000 feet, became more stable with 100% oxygen and exercise at 14,000



ɜURE 10. Histogram showing dilution of inspired gas with ambient air as calculated from the end expiratory nitrogen concentrations.

feet, and again fluctuated to a marked degree at 40,000 feet on oxygen. It appeared that this "hunting" phenomenon was more marked when some degree of hypoxia was present. In general, the ear-oximeter readings appeared to be more stable during exercise than at rest.

Maintenance of an adequate blood-oxygen saturation is the desired end result. Instrumentation artifacts and variations in the physiological response of the mask-wearer may result in considerable variation in the ear-oximetry indications of blood-oxygen saturation.

The function of the mask is to deliver sufficient oxygen to produce an adequate tracheal oxygen partial pressure. Since pressure breathing is not involved in passenger systems, the mask cannot provide partial pressures in excess of those provided by a 100% concentration of oxygen. A hypothetical leak-free passenger mask, capable of delivering undiluted 100% oxygen to the alveoli throughout inspiration would therefore exhibit maximum efficiency. The resulting oxygen partial pressure, therefore, becomes merely a function of the ambient barometric pressure minus the vapor pressure of saturated gas inspired, i.e.: (P_B-47).

It should be pointed out that a discrepancy exists between the performance of any oxygen equipment evaluated at constant altitude, as presented in this report, and the dynamic changes which occur during rapid decompression. Experiments have been conducted in this area by Bryan and Donaldson,[11 12] but are beyond the scope of this report.

V. Conclusions

1. The average inspired tracheal oxygen partial pressure remained above 83.8 mm Hg under all conditions of rest and exercise at all altitudes except for the third (last) minute of exercise at 40,000 feet.

2. The average blood oxygen saturation during exercise remained above the 14,000-foot air breathing baseline (90.8%) during the first minute of exercise except at an altitude of 40,0(feet where it dropped to 89.6%.

3. Following three minutes of exercise, mea blood oxygen saturation dropped below tl 14,000-foot air breathing control baselines at a altitudes by differences of 0.7, 4.8, 5.9, and 6 per cent at 21.5, 29, 35 and 40 thousand fe€ respectively.

4. The average respiratory rate at the max mum altitude increased 20% during the fir minute of exercise, and 37% during the la minute of exercise when compared to baseli minute volumes determined at 14,000 feet breat ing 100% oxygen. Providing tidal volumes ı mained constant, the mean volumes wou approximate 28.8 to 32.8 liters minute. The were large individual variations, however, wi the 30 lpm minute volume requirements of TS C–64 being exceeded by as much as 50%.

5. As in previous evaluations[13 14] larger sı jects with increased body surface area exhibit lower blood oxygen saturations and tracheal p: tial pressures at a standardized oxygen flow d to increased oxygen consumption.

6. An ideal technique for increasing the r piratory minute volume to the levels specified NAS–1179 and TSO C–64 is not readily atta able. Originally formulated by general conc sus of a number of physiologists, physicians, a engineers, these levels are representative of anticipated minute volume that a naive pass ger would exhibit during the excitement of aircraft rapid decompression.

7. Voluntary hyperventilation leads to overestimation of the efficiency of a mask desi whereas evaluation during exercise undere mates mask efficiency within the framework ; intent of NAS 1179 and the Federal Aviat Regulations.

8. If a moderate degree of physical acti is to be maintained for more than a few minu oxygen flow rates should be increased c mensurate with the anticipated level of activ

REFERENCES

. Federal Aviation Regulations, Part 25. Airworthiness Standards, Transport Category Airplanes.

. Evaluation of Prototype Passenger Oxygen Mask Assemblies, Boeing Airplane Company Report D6–1954, Transport Division, Renton, Washington, Feb. 9, 1959.

. Qualification Test Report, Passenger Oxygen Mask, QTR–59–6. Aro Equipment Company of California, Los Angeles, Calif., Jun. 24, 1959.

National Aerospace Standard, 1179, Revised. Aerospace Industries Association of America, Washington, D.C., Mar. 31, 1961.

Federal Aviation Agency: Technical Standard Order C–64, Aug. 23, 1961.

Oxygen Equipment for Aircraft, Aerospace Information Report 825. Society of Automotive Engineers, New York, N. Y., Feb. 25, 1965.

A Design Analysis of a Jet Transport Passenger-Oxygen System. Douglas Report SM–42564. Missile and Space Systems Division, Douglas Aircraft Company, Santa Monica, California, March 1963.

Luft, U. C.: Evaluation of the K-S Disposable Oxygen Mask. Special Project. USAF School of Aviation Medicine, January 1951.

9. McFadden, E. B.: Evaluation of the Physiological Protective Efficiency of a New Prototype Disposable Passenger Oxygen Mask. Office of Aviation Medicine Report AM 66–7, Federal Aviation Agency, April 1966.

10. NASA Life Sciences Data Book, First Edition, June 1962.

11. Bryan, C. A., and Leach, W. G.: Physiological Effects of Cabin Failure in High Altitude Passenger Aircraft. *Aerospace Medicine* 31(4):267–275, 1960.

12. Donaldson, R. T.: A Study of Arterial Oxygen Saturation During Rapidly Changed Barometric Pressure. Ohio State University. M. S. Thesis, 1957, Department of Physiology.

13. McFadden, E. B., Harrison, H. F., and Simpson, J. M.: Performance Characteristics of Constant-Flow Phase Dilution Oxygen Mask Designs for General Aviation, Office of Aviation Medicine Report AM 67–9, Federal Aviation Administration, May 1967.

14. McFadden, E. B., Harrison, H. F., and Simpson, J. M.: Physiological Evaluation of a Cessna Mask Design for Unpressurized General Aviation Aircraft, unpublished report. Office of Aviation Medicine, Federal Aviation Administration, April 1966.

EFFECTS OF ALCOHOL ON A PROBLEM SOLVING TASK

Introduction.

In a previous study (Chiles and Jennings, 70) we found alcohol (an average blood ›ohol level of 105 mg%) to produce significant crements in skills important to flying. Spe- ically, both monitoring and two-dimensional ıcking performance suffered, although decre- ›nts were not found in the performance of a ıple mental arithmetic task with subjects who ·re given substantial practice before testing. .e tasks were performed in different combina- ns which required time sharing, and we con- .ded that the subjects probably tended to place ıigher priority on the arithmetic task and thus ›tected their performance of that task.

Carter, Jones, Simpson, and Vega (1971) re- ·ted decrements in performance on a variety tasks with (Breathalyzer) blood alcohol els of 80 mg%; included were tests of short- m memory (WAIS Digit Span and dichotic ·sentation of digits), simple and choice visual ction time, and abstracting and conceptual lity (Shipley-Hartford). However, with re practiced subjects, alcohol effects were nd only on one of these tasks—3-choice reac- ı time.

;imilarly, Carpenter and Ross (1959) reported rements in short-term memory with an alcohol e of 1 ml/kg of body weight. (Blood alcohol ·ls were not specified.) Again, this effect was ;ely mitigated by increased practice.

'he present study examines the effect of a lerately high level of blood alcohol on a ple problem-solving task. Basically, the : required the subject to discover the correct ıence in which to push five buttons in order :urn on a green light; a red light provided ›r feedback to the subject. The solution ob- ed had to be remembered for 10 seconds and ı re-entered. Thus, performance of the task primarily dependent on short-term memory perceptual-motor speed, both of which are ortant elements in aviation operations.

II. Method.

A. *Subjects.* Thirty-one paid volunteer male subjects were tested; they were college students in their twenties who described themselves as "moderate social drinkers." The subjects served concurrently in another experimental study that involved rotational stimulation of vestibular mechanisms. (The testing schedule in that other experiment was such that the subjects could serve in the problem-solving study without additional subject costs.)

B. *Apparatus.* The apparatus consisted of a small metal box (approximately 11 x 18 x 9 cm) on which five push buttons were mounted in a row. The buttons were 8 mm in diameter and were spaced with 2.4 cm between edges; they were labeled with the numbers one through five. The subjects were required to make all responses with the index finger of the preferred hand. Three indicator lights (amber, red, and green) were mounted about 10 cm above the box on a panel in front of the subjects. The lights provided information in the following manner. At the beginning of a problem the red light was illuminated to indicate to the subject that he should begin to search for the problem solution. Whenever any button was pushed, the amber light would come on and remain on until the button was released; this light indicated that the response had been registered by the programming and scoring equipment. Coincident with the onset of the amber light, the red light would go out. When the subject released the button, the red light would come back on if the response were incorrect, but it would remain out if the response were correct. Thus, the number-one button for a given problem was the button that would keep the red light out when the button was released. If the next button pushed after finding the first correct button was the correct second button, the red light would remain out; if it were not the correct second button, the red light would be re-illuminated and the correct first button would have to be pushed again in order to continue the search for the second button. Similarly, if at any time during the search the red light came on, the subject had to re-enter the partial solution he had already discovered before he could continue the search for the next button in the problem sequence. Since the correct solution used each button only once, those buttons which were included in a partial solution were to be eliminated from the search. The onset of the green light indicated that the problem had been solved. Thus, if the solution for a given problem were 3, 5, 1, 4, 2, a subject who used the search sequence would enter the following sequence of button pushes (an *R* representing the onset of the red light): R, 1, R, 2, R, 3, 4, R, 3, 5, 1, 2, R, 3, 5, 1, 4, 2, Green Light. After a 10-second delay, the green light would go out, the red light would come on, and the same problem would be presented a second time. Thus, each problem was solved twice—once by discovering the sequence by a trial-and-error process through application of the search procedure and once by re-entering the already obtained sequence; the error light functioned the same during the second solution as it did for the first solution. The green light was also illuminated for a 10-second interval following the entry of the second solution. Thus, the subject also had to remember whether the onset of the red light meant that he was to repeat the preceding problem solution or that a new problem was present.

The subjects were required to search for the problem solution by trying buttons in a left-to-right sequence; for this purpose, the left hand button was to be considered as following the extreme right hand button. This procedure was chosen because it provided an easily-learned way of simplifying and standardizing the memory load during search. It also provided a means of standardizing error detection during search; specifically, the number of errors (red lights) for a given problem can be predicted exactly for a given problem by relating the problem solution back to the search sequence. For example, the sample problem shown in the preceding paragraph should be solved with only four "errors" if the search sequence is followed properly; of course, it is *possible* to make fewer errors by chance deviations from the search sequence at the risk of forgetting what one has done an thus, making redundant responses.

Responses were recorded on punch tape b means of an automatic scoring system. Th time at which each event occurred with respe to the beginning of the experimental session w recorded to the nearest 1/100 sec. The butto pushed, whether or not it was in the corre sequence, and whether it was associated with a initial or re-entered solution were also recorde The punch tapes were then compiled and a alyzed by computer.

Four time measures were taken separately f the first and second solution phases. These we mean time per response, mean time per corre response, mean time per incorrect response, a mean time per solution. In addition, a me time per problem with first and second soluti data combined was computed.

An error measure for first solution perfor ance was derived by taking the mean differe between the number of incorrect responses a the number of incorrect responses which wo be expected if the search procedure were f lowed correctly. Since the subject should make any errors during the second solution, error measure for second solution was simply number of incorrect responses.

C. *Procedure.* The 31 subjects were randor divided into three groups; the control group l an N of 11 and two experimental groups had N of 10 each. One experimental group recei alcohol on the first day of testing and the ot received alcohol on the second day of testi The experimental subjects were given alcohol the amount of 2.5 ml of 100-proof Wild Tur bourbon or Smirnoff vodka per kg of b weight. This is equivalent to slightly over absolute alcohol per kg of body weight and calculated to give a peak blood alcohol level about 100 mg%. The vodka or bourbon diluted with orange juice to a total volume about 30 fluid ounces. Control subjects recei a placebo of equal volume with a few drops rum extract added to simulate the addition alcohol. The subjects were given 30 minute which to drink the beverage. Six of the alco first subjects were given bourbon and four v given vodka; in the alcohol-second group, subjects were given bourbon and six were g vodka.

Blood alcohol level (BAL) determinations vere made on all subjects before they were given he alcohol or placebo. In addition, the experi-iental subjects had blood samples drawn for 3AL determinations at one and two hours after iey were given the alcohol. Testing on the roblem-solving task occurred about halfway etween the first and second hour BAL deter-iination. Results of these BAL determinations re summarized in Table 1. The mean BAL cross subjects was 94.5 mg% which approxi-iated the target figure of 100 mg%.

TABLE 1.—Blood Alcohol Levels in mg%.

		1 hour after ingestion	2 hours after ingestion	Mean of 1 and 2 hours
roup A	M	99	95	97
	S	25	22	19
roup B	M	96	87	92
	S	22	18	18

The subjects were trained and tested indi-dually with all training and testing sessions llowing essentially the same procedure. Dur-g training, the task was explained to the sub-t and the experimenter demonstrated the lution of one complete problem (first and cond solution). Then the experimenter "talked e subject through" one other problem. Addi-nal instruction was given if necessary until e subject solved one complete problem by fol-ving the correct procedure with essentially no sistance from the experimenter. The subject s then allowed to work five practice problems ile the experimenter observed through a half-vered mirror from the adjoining room. When cessary, the subject was reminded, via inter-n, to follow the proper procedure.

The testing sessions consisted of 18 problems vo solutions each). The duration of each ting session was dependent on the length of e it took each subject to complete the 18 prob-s. Prior to each testing session, the subject rked one complete practice problem and the erimenter corrected any errors in procedure. he subject was then reminded to work as idly as possible while trying to avoid making ecessary errors. The experimenter then entered the adjoining room and momentarily turned the task off while activating the scoring circuitry. The subject was alerted via the inter-com system, and the task device was turned on to start the testing session. Voice contact with the subjects during the testing period was kept to a minimum.

The testing schedule for the three groups is summarized below.

1. Pre-Alcohol Day. Only the alcohol-second group was tested on a pre-alcohol day, and these subjects were not exposed to vestibular stimulation on this day. The subjects were trained on the task and, immediately following training, were tested on 18 problems, with each problem being solved twice.

2. Alcohol Day. First, subjects in all groups had pre-drinking BAL blood samples drawn, immediately after which *S*s in the control group and the alcohol-first group were trained on the problem solving task. Then they were given their drink, either alcohol or placebo. One hour after ingestion, blood samples were drawn on *S*s who had received alcohol and all subjects then experienced a period of rotational vestibular stimulation. Following this, (about 1½ hours after receiving their drink) all subjects were tested on the problem solving task; another blood sample was drawn after code-lock testing was completed, i.e., at two hours after they received alcohol.

3. Post-Alcohol Day. Following a period of rotational vestibular stimulation, control and alcohol-first subjects were again tested on code-lock.

All subjects were tested on the same set of 18 problems on the alcohol day; a second set of 18 problems was used on the post-alcohol sessions; the alcohol-second group was given a third set for their pre-alcohol testing.

III. Results.

The data from the experimental groups were analyzed using a Lindquist Type II design in which day of receipt of alcohol was the Latin square factor. The sources of variance in each of the 11 analyses were: day of testing (first vs. second day); alcohol (vs. no alcohol); group (order of testing with respect to the alcohol/no alcohol conditions); and subjects. The results of these analyses are summarized in Table

2. For each measure, the means for the two levels of each of the variables and the "F" value for the test of the effect are shown.

The order of testing with respect to the day of administration of alcohol is reflected in the difference between groups in this design. In no case was that difference significant.

The practice effect was significant for all but three of the 11 measures. With the exception of those three measures, performance on day 2 was significantly better than on day 1. Two of the measures that did not show a significant difference between day 1 and day 2 were error measures, namely, errors per solution for first solution and errors per solution for second solution. The third measure for which no difference was found was the time per incorrect response for the second solution. However, this latter measure is based on a relatively small number of responses and a reduced number of subjects. Since seven of the 20 subjects made no incorrect responses during the second solutions on one or both testing sessions, the four subjects in the alcohol-first group and the three subjects in the alcohol-second group who made no errors wer dropped from the analysis, along with one sub ject selected at random from the alcohol-secon group. For the remaining six subjects per grou the time per incorrect response for the secon solution was based on an average of only si responses per session. For all of the other tim measures, the difference between day 1 and da 2 was significant with better (i.e., faster) pe formance occurring on day 2. Specifically, tin per response, time per correct response, and tin per solution for both first- and second-solutio phases of performance treated separately differe significantly for the two days of the study; tin per incorrect response differed significantly f the first solution only; and time per proble differed significantly for the two solutions con bined.

The main effect of alcohol was significant f only one measure taken during the first-soluti phase of testing; that measure was the time-pe correct response. The alcohol effect was signi cant for three second-solution measures—tir per response, time per solution, and errors p

Table 2.—Means and F Ratios for Analysis of Variance.

	Time Per Response	Time Per Correct Response	Time Per Incorrect Response	Time Per Solution	Errors Per Solution	Time Per Problem
First Solution						
Mean Day 1	1.35	1.26	1.46	23.3	.88	14.7
Mean Day 2	1.14	1.11	1.20	18.1	.50	10.9
F (df=1/18)	15.53**	17.23***	23.83***	16.22***	1.19	23.78**
Mean with Alcohol	1.27	1.23	1.36	21.6	.97	13.7
Mean without Alcohol	1.22	1.14	1.30	19.7	.41	11.9
F (df=1/18)	1.07	5.09*	1.09	20.7	2.51	5.09*
Mean Group A	1.27	1.23	1.36	20.7	.74	13.2
Mean Group B	1.21	1.04	1.30	20.6	.64	12.4
F (df=1/18)	X	X	X	X	X	X
Second Solution						
Mean Day 1	.92	.90	1.18	5.5	.46	
Mean Day 2	.77	.77	.88	4.3	.27	
F (df=1/18)	17.53***	15.52***	3.84	5.95**	1.29	
Mean with Alcohol	.89	.86	1.08	5.5	.55	
Mean without Alcohol	.80	.80	.99	4.3	.18	
F (df=1/18)	5.91*	3.40	X	6.39**	5.43**	
Mean Group A	.91	.89	1.06	5.4	.47	
Mean Group B	.78	.77	1.00	4.4	.26	
F (df=1/18)	1.07	1.99	X	1.78	2.83	

* p<.05 ** p<.01 ***p<.001 X F<1.0

solution. Time per problem (first and second solutions combined) also showed a significant effect.

The individual cell means for the five measures for which a significant alcohol effect was found are shown in Tables 3 through 7 along with the day-1 and day-2 means for the control group. Individual "t" tests were applied to the differences between days for each of the alcohol groups treated separately. The performance of the alcohol-first group was significantly better on day 2 than on day 1 ($p<.05$) for five of the measures (Tables 3, 4, 5, and 7); only errors on the second solution did not differ significantly across days (Table 6). The only significant difference found across days for the alcohol-second group was in the case of the time per problem measure (both solutions combined). It can be seen in Table 7 that, for this measure, performance on day 2 (the alcohol day) was significantly superior to that on day 1 ($p<.05$); note also that the direction of the effect for this test is opposite that found with the overall "F" test for the effect of alcohol (Table 2). For two of the measures, the performance of the alcohol-second group was faster on their alcohol day (day 2) than on day 1, but the differences were not significant; the measures were time per correct response (first solution) shown in Table 3 and time per response (second solution) shown in Table 4. For time per solution (second solution), the mean performance on the two days was the same for the alcohol-second group (Table 5). Only the error measure on the second solution (Table 6) was in the direction of better performance on day 1 than on day 2 for the alcohol-second group, but that difference was not significant.

TABLE 3.—Cell Means for Time Per Correct Response—First Solution.

	Day	
	1	2
Alcohol First	1.35*	1.11
Alcohol Second	1.17	1.10
Control	1.29	1.14

*The value underlined is for the session on which the group received alcohol.

TABLE 4.—Cell Means for Time Per Response—Second Solution.

	Day	
	1	2
Alcohol First	1.03*	.79
Alcohol Second	.81	.75
Control	.91	.72

*The value underlined is for the session on which the group received alcohol.

TABLE 5.—Cell Means for Time Per Solution—Second Solution.

	Day	
	1	2
Alcohol First	6.6*	4.2
Alcohol Second	4.4	4.4
Control	5.4	4.0

*The value underlined is for the session on which the group received alcohol.

TABLE 6.—Cell Means for Errors Per Solution—Second Solution.

	Day	
	1	2
Alcohol First	.66*	.16
Alcohol Second	.16	.35
Control	.44	.16

*The value underlined is for the session on which the group received alcohol.

TABLE 7.—Cell Means for Time Per Problem—First Plus Second Solution.

	Day	
	1	2
Alcohol First	32.0*	20.8
Alcohol Second	26.8	22.8
Control	29.4	20.0

*The value underlined is for the session on which the group received alcohol.

In addition to the above "across-days tests," individual "t" tests were applied to the differences between groups for each day treated separately. For the day-1 comparisons, significant differences between groups were found only in the case of the time per response measure (second solution). For this measure, shown in Table 4, the performance of the alcohol-first group was significantly poorer than that of both the alcohol-second ($p<.05$) and the control groups ($p<.05$). And the performance of the control group was significantly poorer than that of the alcohol-second group ($p<.05$). (Note that the control group underwent vestibular stimulation immediately prior to testing whereas the alcohol-second group did not). For the day-2 comparisons, no significant differences were found. However, for the errors per solution (second solution), the differences between the alcohol-second group and the other two groups approached significance ($.10>p>.05$) with the performance of the alcohol-second group being inferior to that of the other two groups (Table 6). Since the control group and the alcohol-first group did not differ on this meansure, these two groups were combined and an "F" test was applied to the difference between the combined groups and the alcohol-second group. This difference was significant at the .05 level of confidence.

IV. Discussion.

The significant practice effect for time but not error measures suggests that subjects followed a strategy of trying to minimize errors by holding their speed of performance to a value that would permit achievement of that goal. The subjects apparently followed the search procedure rather carefully on the first solution as seen by the very small number of surplus errors when a correction is made for the expected errors for a given problem. And the errors were even less frequent for the second solution. The error-minimization strategy is also revealed by the fact that between-subject variance accounted for about 40% of the total variance for the error measures whereas it accounted for about 70% of the variance on the time measures. This finding that individual differences on this task are measured primarily by time measures is consistent with the findings of an earlier study by Chiles and Smith (1971) in which significant correlations with the Otis test of mental abilities were found for the time measures but not for the error measures.

Although a significant main effect of alcohol was found for five of the measures, the interpretation of the findings with respect to the effects of alcohol on problem-solving performance is rather complicated. First, the fact that the study here "attached to" the vestibular stimulation study creates a problem. Specifically, in the comparisons on day 1 between the alcohol first and the alcohol second groups, the effects of the two variables (alcohol and vestibular stimulation) are confounded. The alcohol-first group was exposed to vestibular stimulation prior to testing on day 1 whereas the alcohol-second group was not. Similarly, on day 2 there is partia confounding of the two variables in that th alcohol-second group was exposed to the ves tibular stimulation for the first time on tha day. Second, of the five significant F-ratios fo the alcohol effect, in only one case was the per formance of the alcohol-second group actuall poorer with than without alcohol, and even i that case (errors on the second solution), per formance was not significantly poorer unde alcohol.

The simple effects of alcohol on day 1 for th time per response measure (second solution) ar relatively clear-cut. For this analysis, there i both a significant effect of alcohol and a signifi cant effect of the vestibular stimulation and/o the placebo. The alcohol-second group responde the fastest, the control group (placebo and ves tibular stimulation) second fastest, and th alcohol-first group (their alcohol day) responde the slowest, all of these differences being signif cant. The possibility that it was the vestibula stimulation that produced the significant effe on the performance of the control group make interpretation of the day-2 findings for secon solution errors rather difficult. Although th alcohol-second group differed significantly fro the combined control and alcohol-first group this was the first exposure of the alcohol-secon group to the vestibular stimulation. Considerin the performance of the control group, the in proved performance of those subjects on day is probably reflective of practice effects but may also be reflective of some kind of adaptatic to the vestibular stimulation. Thus, the great number of second-solution errors made on day by the alcohol-second group relative to the oth two groups may have been in part a result of an alcohol effect, in part a residual of this having been their first exposure to vestibular stimulation, and in part an interaction of the two variables. The significant differences on this measure between the alcohol-first and the alcohol-second groups on day 1 is even less clear. The control group was also poorer than the alcohol-second group but better than the alcohol-first group, though not significantly so in either case. Thus, again, the apparent effect cannot be unambiguously attributed to any one of the experimental variables.

The effect of the order of testing with respect to the administration of alcohol could not be measured with any great degree of sensitivity in this study. Since this was a between-subjects comparison, 10 subjects per group does not afford much statistical power for the direct test of the order effect. However, there were indications in the individual tests of the simple effects of alcohol and the simple effects of practice that suggest that there was in fact an interaction between the two variables. For one measure, time per problem (first and second solutions combined), the alcohol-second group performed significantly faster on day 2 (with alcohol) than on day 1 despite the fact that the overall effect of alcohol was significant and in the other direction for this measure. This suggests the possibility that subjects who are motivated to do well on a task will adjust their speed to take account of what they perceive to be possible effects of alcohol on their performance. And it also suggests that the amount of adjustment (reduction in speed) will be greater on a relatively new task (alcohol-first group) than on a task with which the subject has become somewhat familiar (alcohol-second group). It may well be that this is an important aspect of the increased errors for the alcohol-second group on day 2. They incorrectly perceived the potential for disruption caused by the alcohol and, as a result, went too fast to avoid making second-solution errors. One is tempted to conclude that their judgment was impaired by the alcohol, but that conclusion would be an unwarranted extrapolation in view of the confounding noted previously.

There are three primary mechanisms in the performance of the code-lock task that might be affected by the blood alcohol levels found with these subjects, namely, perceptual-motor skill, short-term memory, and "memory-response" encoding. Although the first solution phase of the code-lock task is ostensibly a problem-solving situation, performance generally becomes a rather simple, repetitive process that is fairly automatic when the subject has a small amount of practice. The limiting factors on performance during this phase are motor skill in pressing buttons, speed of reaction to the error feedback light, short-term memory, and memory-response encoding. Short-term memory is clearly important in re-entering partial solutions following an error. It is also important in executing the search sequence, since any button that is a member of the already-discovered partial solution must be eliminated from the search sequence.

Short-term memory is perhaps even more important in the second solution phase; the subject must remember the correct sequence discovered in the first solution phase and, after a 10-second delay, re-enter that sequence. Speed of response to the feedback lights was generally not important since the subjects tended to enter the second solution without reference to the lights. Since the lights were separated from the push-buttons by a vertical distance of about 10 cm (4 inches), it was possible to determine by observation where many of the subjects were focusing their attention. They seemed not to be looking at the feedback lights during the second-solution phase. This can also be inferred from the fact that it was not uncommon for a subject to enter a complete 5-button sequence even though intermediate responses were incorrect.

The pattern of significant effects on the code-lock measures suggests that the most likely mechanism for an effect of alcohol was interference with short-term memory and/or the memory-to-response encoding mechanism. During the first solution phase, only time per correct response and solution time were affected by alcohol. The number of correct responses during this phase of the task is constituted primarily of responses made in re-entering partial solutions, a process that depends heavily on short-term memory. Solution time for a given problem is a function of both speed of response and the number of surplus errors, but, because relatively few surplus errors were made (an average of less than one error per problem), speed of response in re-entering partial solutions is the dominant component. Hence, short-term memory and/or memory-to-response encoding are also implicated for this measure.

Efficient performance during the second solution is almost entirely dependent on short-term memory and the memory-to-response encoding process. However, the occurrence of errors during the second solution could also be the result of motor involvement. Although this study does not afford a means for clearly distinguishing between these two possibilities, the separation between buttons (2.4 cm) would seem to make "aiming" a relatively small factor. Thus, we are inclined to conclude that the obtained effects are in the informational rather than the motoric domains.

Several factors that are present in the aviation environment were not included in this experiment. Three of these are of direct relevance to the interpretation of the findings in relation to flying skills. First, the problem-solving task can be thought of as involving a homogeneous set of behaviors. In contrast, the pilot is required to exercise a variety of behaviors, and, of even greater importance, he is required to time share their performance. Thus, as suggested by our previous study (Chiles and Jennings, 1970), if time sharing were added to the situation, the detrimental effects of alcohol would be expected to be enhanced. Second, the nature of the problem solving task is such that the subject can adjust his speed of response as a way of avoiding errors if he interprets the potential effects of alcohol to be likely to lead to errors; this is in fact what the subjects in this study did. In the operation of an aircraft, the pilot has rather limited freedom in making such adjustments and, in emergencies, may have no room for adjustment of his "speed of response." And, third, the pilot is subjected to a variety of potentially disturbing motions of the aircraft which, as reported by Collins, Gilson, Schroeder, and Guedry (1971), tend to enhance the effects of alcohol on performance. Factors such as these are undoubtedly the reason that Billings, Wick, Gerke, and Chase (1971) found significant decrements in pilot performance at blood alcohol levels that were substantially lower than those used in the present study.

V. Summary and Conclusions.

Three groups of subjects were tested on two separate days on a simple problem-solving task which required them to discover the correct sequence in which to push five buttons in order to turn on a green light; the correct sequence was then re-entered after a 10-second delay. One group of subjects (N=10) received alcohol on the first day and nothing the second; a second group (N=10) received nothing the first day and alcohol the second; the third group (N=11) received a placebo the first day and nothing the second. The group that received alcohol the first day and the placebo group were also subjected to vestibular stimulation on both days; the alcohol-second group received vestibular stimulation only on the second day of testing. The average blood alcohol level for the experimental groups was about 94.5 mg%.

Alcohol as a main effect was significant for five of the 11 measures analyzed; three of the significant effects found were for second-solution performance, one was for first-solution performance, and one was for the solution time per problem which included both solutions. One of the measures that was affected by alcohol was errors on the second solution; the other four were time measures. Analysis of the simple effects showed that alcohol has a greater effect during the time when the task is still being mastered than after a day's practice (18 problems) has been given. However, there is suggestive evidence from the error measure, second solution performance, that the performance of practiced subjects may also be adversely affected by alcohol. There was also suggestive evidence of a residual effect of the vestibular stimulation on the problem-solving performance of the control group.

We conclude that alcohol does have an effect on problem solving of the sort used in the present study and that the effect is greater on subjects when they are less practiced than when they are more experienced on the task. We also tentatively conclude that there may be a residual effect of vestibular stimulation per se on performance even though some time has elapsed since the rotational experience. Further research is required to clarify this point, but, if the finding does prove reliable on replication, then the implications with respect to recovery times in the case of pilots could be very important.

REFERENCES

1. Billings, Charles E., Robert L. Wick, Jr., Ralph J. Gerke, and Robert C. Chase: The Effects of Alcohol on Pilot Performance During Instrument Flight. Final Report, FAA Contract No. FA68AC-6089-2, Project No. RF-2626, Office of Aviation Medicine, Washington, D.C., 1971.
2. Carpenter, John A., and Bruce M. Ross: Effect of Alcohol on Short Term Memory, QUARTERLY JOURNAL OF STUDIES ON ALCOHOL, 26:561-579, 1965.
3. Chiles, W. Dean, and Alan E. Jennings: Effects of Alcohol on Complex Performance, HUMAN FACTORS, 12:605-612, 1970.
4. Chiles, W. Dean, and Roger C. Smith: A Non-Verbal Technique for the Assessment of General Intellectual Ability in Selection of Aviation Personnel. FAA Office of Aviation Medicine Report No. FAA-AM-71-28, 1971.
5. Collins, William E., Richard D. Gilson, David J. Schroeder, and Frederick E. Guedry, Jr.: Alcohol and Disorientation-Related Responses. III. Effects of Alcohol Ingestion on Tracking Performance During Angular Acceleration. FAA Office of Aviation Medicine Report No. FAA-AM-71-20, 1971.
6. Lindquist, E. F.: *Design and Analysis of Experiments in Psychology and Education,* Houghton Mifflin Company, Boston, 1953.
7. Tarter, Ralph E., Ben M. Jones, C. Dene Simpson, and Arthur Vega: Effects of Task Complexity and Practice on Performance During Acute Alcohol Intoxication, PERCEPTUAL AND MOTOR SKILLS, 53:307-318, 1971.

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6. Abstract
Among aerial applicator personnel, the primary value of periodic blood cholinesterase (ChE) assays is the detection of pesticide poisoning indicated by a decrease in enzyme activity since the previous (or pre-season) assay. Comparison of these values is difficult if they are based on different methodologies and expressed in different units, which is frequently the case. This report provides an evaluation of four serum or plasma ChE methods which are currently in use and establishes the relationships for interconversion among their respective units. This was accomplished by performing simultaneous assays by each method on a series of samples whose activities covered the range from normal levels down to the very low level found in organophosphate-poisoned individuals. The resulting conversion data (regression equations) are also compatible with those described in Report No. AM-70-13, thereby providing direct interconversion capability among the units of seven commonly-used serum ChE methods.

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A COMPARISON OF SERUM CHOLINESTERASE METHODS: II

. Introduction.

The utility of measurement of the activity of he acetylcholine-hydrolyzing enzyme present in lood plasma as a diagnostic tool in organophoshate poisonings and for monitoring the healthıfety aspects of aerial applicator operations has een previously discussed.[1]

The activity of this enzyme in unexposed inividuals varies widely, with the normal range ktending above and below the population mean y as much as 30%. Therefore, any such value otained after potential contact with an antiıolinesterase should be compared to the inividual's normal, pre-exposure value to deterine whether inhibition is present. Such a mparison can be made only if both values are pressed in the same units. Unfortunately for e purpose of comparison, the various methods r cholinesterase (ChE) assay produce dismilar units, and no single "standard" method ists; consequently, a means of converting tivity units obtained by one analytical method those of another is required.

This paper represents the second in a series ıich will provide conversion data to transform ıE activity units obtained by one method into e corresponding units of other methods. Most the methods developed primarily to measure e activity of the pseudocholinesterase present in e fluid portion of blood, including those comred in this study, customarily utilize serum for e determination. However, plasma can be used r the measurement, with identical results, proled that the presence of fibrinogen does not roduce interference. There is a distinct adntage in performing the assay on plasma if method permits, since it allows the measurent of erythrocyte enzyme activity on the same ood specimen. Therefore, plasma was utilized this study.

The procedure used to develop these comparin data was to perform simultaneous assays by h method on aliquots of the same sample of plasma, using the pH-Stat method as a primary reference. Heparinized, whole blood was purchased from a local blood bank. Part of the separated plasma was heated in a water bath at 60° C. until pH-Stat assay indicated a loss of about 95% activity (10–20 minutes). The inactivated plasma was then mixed in varying proportions with fresh plasma to obtain a gradient of enzyme activity.

II. pH-Stat Reference Method.

Materials and Method. Butyrylcholine iodide (Mann Research Laboratories, New York, N.Y.) was dried overnight in a vacuum desiccator and stored therein until used. An aqueous solution, 0.163M (49 mg/ml), was prepared weekly and stored at 4° C. The sodium hydroxide titrant was prepared at a concentration of approximately 0.005N using CO_2-free distilled water. The solution was stored in the titrant reservoir of the pH-Stat and protected from CO_2 absorption by a drying tube filled with Mallcosorb, 30–50 mesh, indicating type CO_2 absorbent (Mallinckrodt). This solution was standardized daily by titration of a potassium hydrogen phthalate standard. Ringer's salts solution for diluting plasma samples was prepared as needed using 9.00 g NaCl, 0.20 g KCl, 0.26 g $CaCl_2$, and 0.20 g $NaHCO_3$ brought to a 1 liter final volume with distilled water.

A Radiometer pH-Stat (Radiometer A/S; Copenhagen, N.V., Denmark) was used for all constant-pH titrations, and consisted of the following units:

- PHM26—expanded scale pH meter
- TTT11b—electronic titration control unit
- ABU1b—semi-micro automatic buret for titrant delivery, 2.5 ml capacity
- TTA3—glass-jacketed reaction vessel, 3 ml, with plastic-coated magnetic strring disc
- VTS13c—constant-temperature water bath and circulator, set to maintain 25° C. in reaction vessel
- SBR2c—recorder for indicating volume of titrant delivered per unit time

Aliquots of samples were diluted 1:10 with Ringer's salts solution. One ml of the diluted plasma was added to the reaction vessel, the magnetic stirrer was started and the solution was allowed to come to temperature equilibrium (25° C.). The pH was adjusted with the automatic titrator to the pre-set value of 8.1. One-half ml of butyrylcholine iodide substrate was added to the reaction vessel using a 1.0 ml tuberculin syringe and the recorder chart drive was turned on. The reaction was allowed to continue until the recorder had plotted a straight line (titrant volume vs time) for a minimum of 3 minutes, or until a minimum titrant volume of 0.5 ml had been added.*

Calculations:

All activities were expressed as micromoles of substrate hydrolyzed/minute/ml of plasma. Calculations were made as follows:

$$\text{Activity} = \frac{\text{S.D.} \times (0.025) \times (\text{N}) \times (1000) \times (\text{D.F.})}{t}$$

Where S.D. = recorder scale divisions (linear portion)
t = time in minutes for linear portion of trace
1000 = μmoles/mmole
0.025 = ml of titrant per S.D.
N = normality of titrant
D.F. = dilution factor (i.e., 10)

III. Michel Method.

The Michel method is an electrometric determination based on the measurement of the acid produced by the action of ChE on acetylcholine.[2] The acetic acid produced is measured in terms of the change in pH produced in a buffer-substrate mixture during a specific incubation period. The decrease in ChE activity with decreasing pH is taken into consideration by selecting a buffer whose capacity closely parallels the activity loss over the range from pH 8 to pH 6; the buffering effect of plasma is minimized by sufficient dilution (1:111). As performed in this laboratory, the basic method of Michel[2] as modified by Larson[3] was used.

Materials and Method. Acetylcholine perchlorate (K & K Laboratories, Plainview, N.Y.) was dried overnight in a vacuum desiccator over Drierite and stored therein until used. The substrate was prepared by dissolving 0.405 g of the salt in a final volume of 10.0 ml of water This solution is stable for up to four weeks i refrigerated.

A buffer stock solution was prepared by dis solving 4.124 g sodium barbital, 0.545 g KH_2PO and 44.730 g KCl in distilled water and dilutin to a final volume of 200 ml. Immediately befor use, the plasma buffer was prepared by dilutin 6.4 ml of the stock solution with 75 ml o distilled water; the pH was adjusted to 8.00 wit 0.1N HCl and the solution adjusted to a fina volume of 100 ml with distilled water.

Plasma aliquots of 20 μl were withdrawn usin a Sahli pipet and expelled into 12-ml test tube containing 1.0 ml of distilled water. One ml o buffer solution was added and the mixture wa allowed to equilibrate in a 25° C. water bath fc 10 minutes. After recording the pH to th nearest 0.01 pH unit, 0.2 ml of substrate wa added and the tubes were allowed to incubate a 25° C. for one hour. The pH was read again an the change in pH/hr was calculated. Contr tubes containing only distilled water, buffer an substrate were treated similarly and the chang in pH in the control tubes was subtracted fro the values obtained from plasma to correct fc non-enzymic hydrolysis.

Calculated Michel units ($\triangle$pH/hr) we plotted against pH-Stat units obtained for th same plasma samples assayed simultaneousl The linear regression equations and correlatic coefficients were calculated, each point represen ing the mean of duplicate assays of the sam sample by each method. The statistical regre sion of the pH-Stat units on Michel units graphically represented in Figure 1.

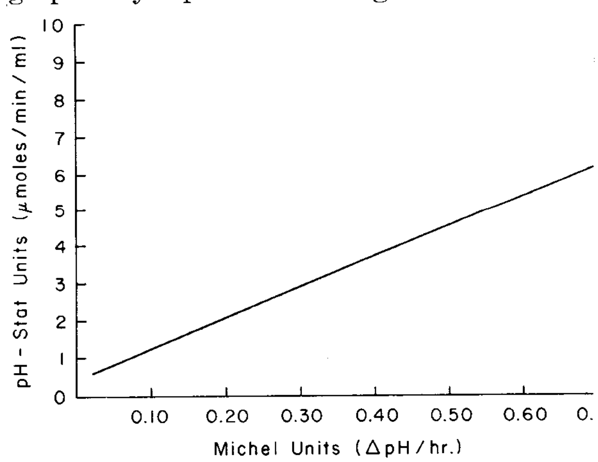


FIGURE 1. Correlation between pH-Stat units and Mich units. N=20 points; correlation coefficient =0.986

*Since full scale on the recorder (100 scale divisions) represents 2.5 ml of titrant, 0.5 ml is represented by 20 scale divisions. The recorder trace can be read to 0.2 scale division; therefore, the precision in reading titrant volume is 1%. With a chart speed of 2 cm per min, the precision in reading elapsed time of 3-min trace is also 1%.

IV. Pfizer ChE-tel Method.

The Pfizer method is a colorimetric determination based on Garry and Routh's[4] modification of the earlier work of Ellman.[5] In this reaction, the artificial substrate, propionylthiocholine, is hydrolyzed by cholinesterase and the released thiocholine displaces the yellow anion of 5-thio-2-nitrobenzoic acid from 5,5′-dithiobis-2-nitrobenzoate (DTNB). The rate of color production s measured at 410 nm. Quinidine sulfate, an nhibitor, is used to stop the reaction at the end of the incubation period.

Materials and Method. All materials used for he assay were supplied in the Pfizer #5360 ChE-tel Test Set (Pfizer diagnostics, 300 West 3rd St., New York, N.Y. 10036) and the method utline supplied with the kit was followed. Spectrophotometric measurements were performed using a Beckman DU monochromator atached to a Gilford Model 222 photometer and ower supply.

Individual assays were performed by adding 0μl of plasma to a tube containing 4.0 ml of uffered DTNB (0.1 mg/ml DTNB in 0.05M Tris uffer, pH 7.40, with ionic strength increased to .153 with NaCl) previously equilibrated at 37° . With the tube immersed in the incubation ath, 0.50 ml of substrate (propionylthiocholine dide, 0.028M) was added and mixed. After xactly 3 minutes incubation, 1.0 ml of quinidine lfate (0.5% w/v) was added to stop the retion and the absorbance was read at 410 nm. ero absorbance calibration was provided by a ank prepared exactly as described for the mple except that the quinidine sulfate was lded prior to the substrate.

ChE-tel units were calculated by multiplying e absorbance by 120, the conversion factor for -mm cuvettes. Calculated ChE-tel units over e range of 9.5 to 90 were plotted against pH-at units obtained for the same plasma samples sayed simultaneously. The linear regression uations and correlation coefficients were callated, each point representing the mean of iplicate assays of the same sample by each ethod. The regression of pH-Stat units on E-tel units is shown in Figure 2.

Caraway Method.

The Caraway method is a colorimetric produre utilizing the acid-base indicator, phenol d, to measure the reduction in pH which accompanies the hydrolysis of acetylcholine.[6] The phenol red absorbance is decreased as the acetic acid produced lowers the pH of the buffered reaction mixture. The ratio of the final to initial absorbance in each sample is compared to a standard curve, similarly prepared by substituting known quantities of acetic acid for the substrate. The method requires equipment ordinarily possessed by a clinical laboratory and the reagents are relatively stable.

Materials and Method. Acetylcholine perchlorate (K & K Laboratories, Plainview, N.Y.) was dried overnight in a vacuum desiccator; a 0.663M solution was prepared by dissolving 4.074 g of the reagent in distilled water and diluting to 25 ml. The buffer-indicator mixture was prepared by grinding 100 mg phenol red with 28 ml of 0.01N NaOH until dissolved; then 10 ml of the phenol red solution was added to a solution containing 6.65 g of anhydrous Na_2HPO_4 and 0.43 g of anhydrous KH_2PO_4, and diluted to a final volume of 1 liter with distilled water.

For each assay, duplicate tubes containing 0.5 ml of plasma and 5.0 ml of the buffer-indicator solution were allowed to come to temperature equilibrium for 10 minutes in a 25° C. water bath. The substrate was added (0.5 ml), mixed,

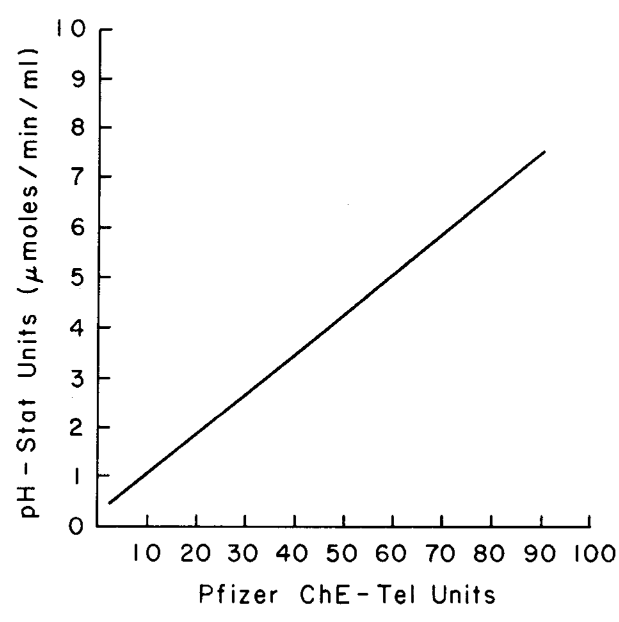


FIGURE 2. Correlation between pH-Stat units and Pfizer ChE-Tel units. N=25 points; correlation coefficient = 0.980

and the absorbance was determined at 540 nm on an instrument zeroed with a distilled water blank. After 30 minutes of incubation, the absorbance was determined a second time and the ratio of the final absorbance (A_2) to the initial absorbance (A_1) was determined (i.e. A_2/A_1). Two control tubes, with 0.5 ml of distilled water substituted for the plasma, were prepared and incubated, then the A_2/A_1 ratio was obtained as before. The average value of A_2/A_1 for the control tubes was subtracted from the ratio for each test replicate to correct for non-enzymic hydrolysis.

A standard curve was prepared by reading the absorbances of a series of eight tubes, each containing 5.0 ml of buffer-indicator solution, 0.5 ml of pooled plasma, and 0.5 ml of 0.01N–0.15N acetic acid (corresponding to 10–150 Caraway activity units/ml) and plotting the ratios of each of these absorbances to the absorbance of a tube similarly prepared but containing no acetic acid. These ratios were plotted on the log axis of semi-log paper against the corresponding Caraway units on the linear axis and the sample activity was read directly from the curve.

Calculated Caraway units were plotted against the pH-Stat units obtained for the same plasma samples assayed simultaneously. Regression equations and correlation coefficients were calculated, with each point representing the mean of duplicate assays by each method. The regression of pH-Stat units on Caraway units is depicted in Figure 3.

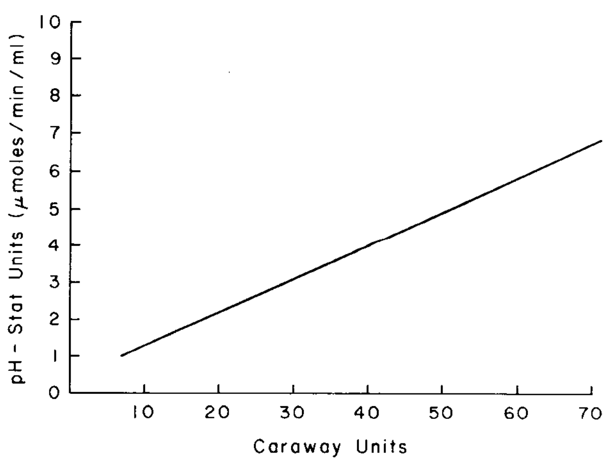


FIGURE 3. Correlation between pH-Stat units and Caraway units. N=20 points; correlation coefficient = 0.987

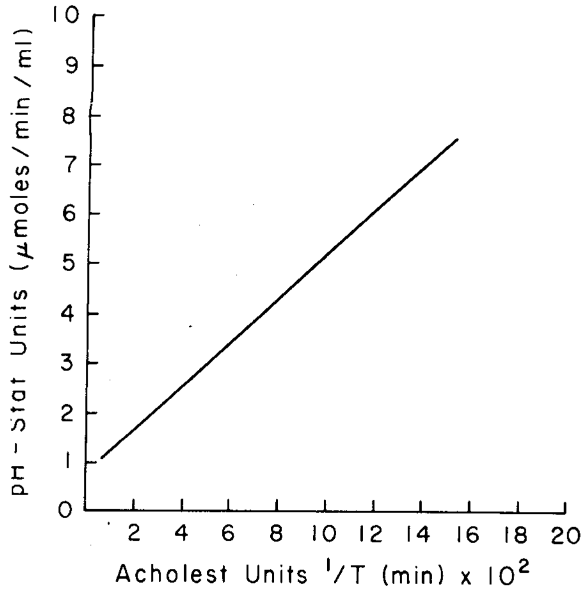
VI. Acholest Method.

The Acholest method is a simple "test-paper" procedure of the type used for field screening where multiple cases of suspected pesticide exposure have occurred. The method is based on the time required for the enzyme activity of a plasma sample to change the color of a piece of filter paper impregnated with buffer, substrate, and pH indicator to match a filter paper similarly treated but containing no substrate. Under stable temperature conditions, we have found the results from this method to correlate well with those obtained by more sophisticated techniques. The principal advantages are inexpensive materials with long storage life and very simple equipment requirements. These factors might induce some clinical laboratories having few requests for ChE assays to maintain this capability.

Materials and Method. All materials used for the assay were supplied in the Acholest Test Paper Kit (donated by E. Fougera & Co., Inc. Hicksville, New York, Distributor) and the modified procedure described by Braid and Nix was followed. These modifications consisted of cutting both test and control strips into ¼-inch discs with a paper punch prior to use and utilizing an incandescent light source for viewing the color change against a dull-black background.

Individual plasma samples were assayed by placing six 7-μl drops on a clean microscope slide; three test discs and three control discs were lowered onto the drops with tweezers and the timer was activated. A second slide was lowered onto the first and pressed gently to assure saturation of the discs with the plasma. The time required for the color of the test discs to match the color of the control discs was recorded. All tests performed during the unit conversion study were at 25° C.

Reciprocal Acholest units (i.e., 1/minutes to color match) were plotted against pH-Stat units obtained by simultaneous assays of the same samples. Regression equations and correlation coefficients were calculated, each point representing the mean of duplicate assays of the same sample by each method. The regression of pH-Stat units on Acholest reciprocal units is shown in Figure 4.



'IGURE 4. Correlation between pH-Stat units and Acholest units. N=13 points; correlation coefficient = 0.991

'II. Conclusions.

The relative precision of the methods in this ıboratory as represented by the coefficient of ariation (standard deviation/mean) for repliıte samples was 1.70%, 1.45%, 2.0%, 2.79% for ıe pH-Stat, Michel, Caraway, and Pfizer ChE-ıl methods respectively. A precision study was ɔt performed for the Acholest method, however raid advises that the procedure produces a coficient of variation of approximately 8%. Any ! the methods discussed would be satisfactory ›r confirming cases of acute organophosphate ɔisoning. The more precise methods would obously be more satisfactory for the routine onitoring of low-level chronic exposure.

Regression equations were calculated from the :perimental data for the following conversions:

a. To convert Michel units to pH-Stat units:
pH-Stat units = (8.32) (Michel units) + 0.41

b. To convert pH-Stat units to Michel units:
Iichel units = (0.117) (pH-Stat units) − 0.039

c. To convert Pfizer (ChE-tel) units to pH-Stat units:
pH-Stat units = (0.08) (ChE-tel units) + 0.30

d. To convert pH-Stat units to Pfizer (ChE-tel) units:
ChE-tel units = (12.07) (pH-Stat units) − 1.83

e. To convert Caraway units to pH-Stat units:
pH-Stat units = (0.092) (Caraway units) + 0.366

f. To convert pH-Stat units to Caraway units:
Caraway units = (10.67) (pH-Stat units) − 3.15

g. To convert Acholest units (minutes to color match at 25° C.) to pH-Stat units:
pH-Stat units = (44.9/T) + 0.827 where T = minutes to color match by the Acholest method

h. To convert pH-Stat units to Acholest units:
Acholest units = (81.4/pH-Stat Units) − 5.19

Conversion equations for the relationships between the units of the Michel, Pfizer, Caraway, and Acholest methods may be readily derived from the preceding equations. Also, since the same pH-Stat primary method was used in an earlier paper to interconvert the units of the Sigma and Boehringer methods,[1] these two papers provide the clinical worker with the necessary data to effect a conversion of units between any of seven commonly used serum (or plasma) ChE methods.

Thus, it is possible to directly compare pre-exposure ChE units with post-exposure units, even when these values were determined by different techniques. Such a comparison can frequently identify a case of low-level chronic ChE inhibition which would be undetectable by comparing a single ChE value with the broad normal range of values for a specific method. With direct interconvertibility of units, any one of these methods best suited to the resources and facilities of the laboratory can be used for the medical monitoring of aerial applicator personnel or for confirmatory diagnosis in acute organophosphate poisoning. Regardless of the method selected, however, each aerial applicator should have a pre-exposure test from which any subsequent depression of ChE activity can be measured.

REFERENCES

1. Crane, Charles R., Sanders, Donald C., and Abbott, John K.: A Comparison of Three Serum Cholinesterase Methods, Dept. of Transportation, Office of Aviation Medicine Report No. AM-70-13, August 1970.
2. Michel, Harry O.: An Electrometric Method for the Determination of Red Blood Cell and Plasma Cholinesterase Activity; *J. Lab. Clin. Med.* 34:1564, 1949.
3. Larson, E. F.: Microelectrometric Method for Blood Cholinesterase Determinations; Div. of Labs., Calif. State Dept. of Public Health, Oct. 22, 1957.
4. Garry, Phil J. and Routh, Joseph I.: A Micro Method for Serum Cholinesterase, *Clin. Chem.* 11:91, 1965.
5. Ellman, George L., Courtney, K. Diane, Andress, Valentino, Jr., and Featherstone, Robert M.: A New and Rapid Colorimetric Determination of Acetylcholinesterase Activity. *Biochem. Pharmacol.*, 7:88, 1961.
6. Caraway, Wendell T.: Photometric Determination of Serum Cholinesterase Activity. *Am. J. Clin Pathol* 26:945, 1956.
7. Braid, Phillip E. and Nix, Maatje S.: Modification of a Test Paper Procedure for Determination of Human Serum Cholinesterase Activity. *Arch. Environ. Health* 17:986, 1968.

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