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ABSTRACT

This paper attempts to relate aircraft accident investigation and aeromedical research efforts for the purpose of clarifying research needs. Such efforts ultimately can lead to a reduction in lightplane accidents, injuries, and fatalities. Recent statistical studies of lightplane crash injuries are summarized, and contributions that human biologists, physical anthropologists, and design engineers can make toward reducing or preventing injury in future crashes are discussed. Programs of biomedical and human engineering research as they relate to lightplane safety are described. Contributions that physicians can make to this program are outlined.

Human factors scientists are concerned with man, machine, and environmental compon- s of a system as they interact and determine formance. Insofar as component interaction non-optimal, total system performance will inefficient. In the case of private flying, to extent that system performance is ineffici- , correlated by-products in the form of acci- its and incidents can be expected. Presently vailing rates of lightplane accidents and in- ents, and the resulting fatalities and injuries istitute a challenge to human factors scien- s within the Federal Aviation Agency.

Contributions that human factors, engineering design, and flight standards specialists can make to lightplane safety are not often apparent to those not working in the area. The process by which research and development efforts are translated into the formulation, modification, and upgrading of standards is a deliberate one. This paper was written with the hope that a better integration of the investigatory and research aspects of lightplane safety could be realized. It is an attempt to relate the investigatory to the research effort for the purpose of clarifying subgoals which ultimately can lead to a reduction in lightplane accidents, injuries, and fatalities. In this attempt the paper will focus upon contributions that the Civil Aeromedical Research Institute (CARI) and other divisions of the FAA's Office of Aviation Medicine are making or can make toward the ultimate goal.

rtions of this paper were presented at the annual meet- g, Flying Physicians Association, Jekyll Island, Ga., ugust 30, 1962.

Figure 1 is a schema that presents a conception of how the investigatory and research efforts might be meaningfully integrated as one proceeds from the crash event itself to the ultimate goal, crash and injury prevention, which incidentally is the only desirable product of that event. This schema can also suffice as an outline for the discussion to follow. Starting with the crash itself the investigation of the cause of the crash is, in most accidents, normally carried forward apart from that of the injury and fatality causes. Independent statistical and case studies of the cause of the crash and of the injuries hopefully yield "Results" from which "Conclusions" and "Recommendations" are generated in the areas noted. These end products provide, in part, the justification for the research scientists' endeavors and the requirements that operations personnel must seek to obtain. The extent to which these independent efforts can be integrated upon implementation bears upon the degree to which the goal of crash and injury prevention can be achieved.

INVESTIGATION OF THE CRASH EVENT

Let us now begin to consider the parts of the schema in greater detail. First of all, what are the subgoals about which information is required from investigation of the crash event? A not unrelated question asks: Can prospective gains be better realized and be better integrated?

The Cause of the Crash

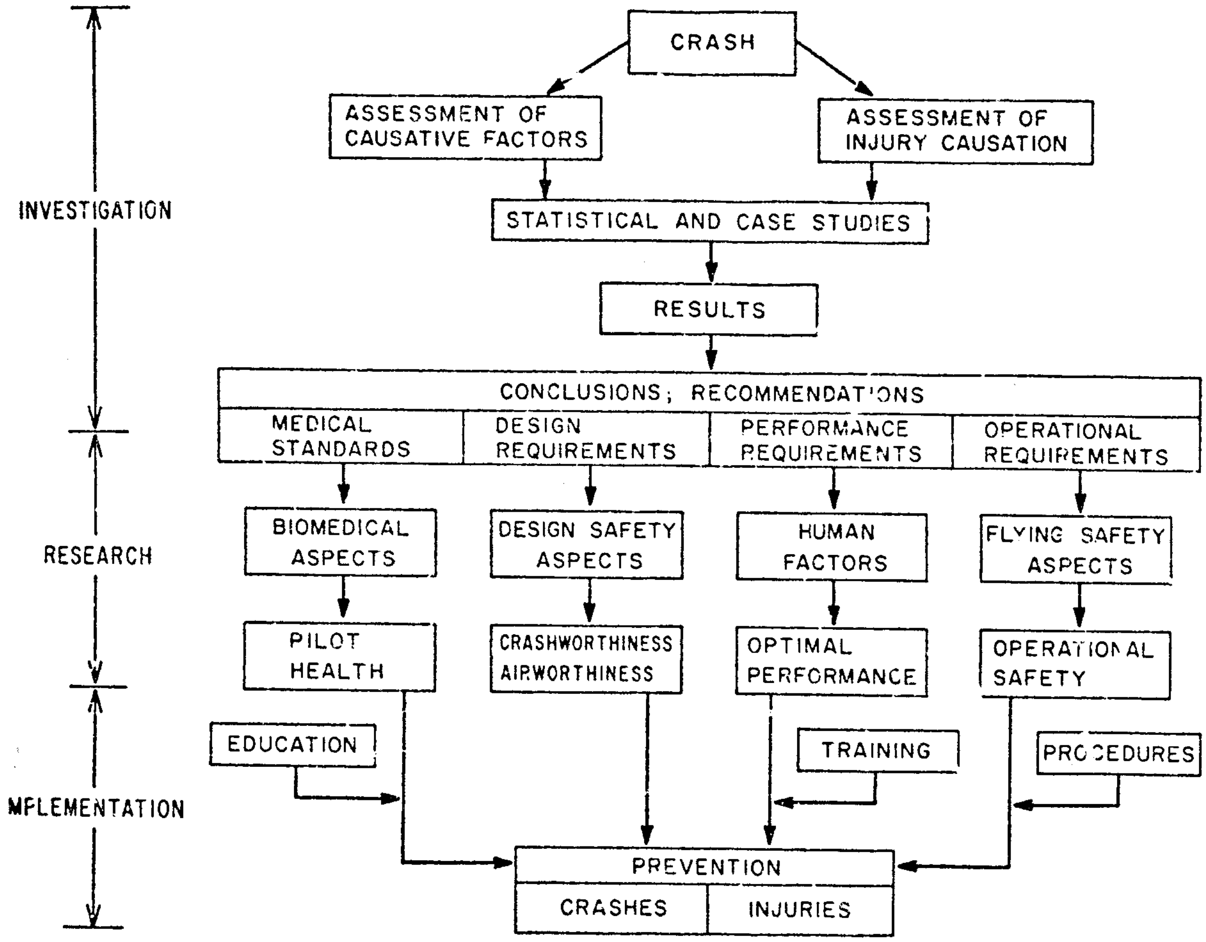
Investigation into the cause of civil lightplane crashes falls within the jurisdiction of the Civil Aeronautics Board. Often authority is delegated to the FAA which provides investigators out of District Offices. Various elements of the FAA are, of course, intimately concerned with causative aspects insofar as aircraft design, maintenance, navigational aids, pilot proficiency or air traffic control involvement are implicated. When "pilot error" is suspected, data from the investigation become of *primary* interest to the Aeromedical Standards Division of the Office of Aviation Medicine and also of interest to certain offices within the Flight Standards Service. In turn there may be consultations with CARI if environmental toxicities, drugs, poor cockpit human engineering, etc., enter the picture, or with the Armed Forces Institute of Pathology or FAA consultant pathologists if pre-crash pathology (as in the case of a heart attack) is likely to have been involved (47).

The Cause of Injuries

Research effort expended over the years on problems of crash *injury* prevention is less well known and documented as contrasted with that devoted to problems of *crash* prevention (e.g. 27, 49, 51, 52, 53, 54). In part this state of affairs can be attributed to modern air power based upon high performance aircraft in which reason most often dictates that *ejection* be made mandatory if critical injury and death are to be avoided. Military aeromedical research efforts generally have not been focused upon the kinds of problems relevant to civil aircraft accidents and injuries. Attention to the problems of preventing aircraft crash injuries is perhaps best identified with Aviation Crash Injury Research, once part of Cornell University, now AvSER division of Flight Safety Foundation (6, 7, 8, 16). The deceleration research of Colonel Stapp and associates in the Air Force and of the NACA are contributions not to be overlooked (9, 25). The Civil Aviation Medical Research Laboratory of the old CAA has been incorporated into FAA's CARI. Studies of post-crash fire, rescue, and evacuation problems are conducted and sponsored by the FAA's Flight Standards Service. With the increased role of lightplanes in the U.S. Army the Army's Board of Aviation Accident Review has become increasingly concerned with problems of crash injury prevention.

A general picture of the cause of most injuries in lightplane accidents has emerged from individual accident case analyses made over the last 20 years. Injuries are *not* to be attributed to primary crash forces *per se* but rather to factors that are indirectly a function of such forces, principally structural collapse, tie-down failure, and flailing of the head and extremities against injury-producing structures within the occupant's environment (4, 16). But lacking from this work was knowledge of more precise relationships between the variables created at impact, structural collapse, tie-down chain effectiveness, and injury severity (14). Recent statistical studies conducted at AvSER with the

FIGURE I. SCHEMA FOR LIGHTPLANE CRASH/INJURY PREVENTION STUDY



aid of automatic data processing equipment and based upon over 1400 accident cases now permit more specific statements (15, 36, 37, 38).

Table 1 tabulates statistics that bear upon the role played by tie-down chain conditions in causing or preventing injury. The data come from a study of 623 cases representing pilots and occupants of 342 aircraft involved in accidents occurring during the period 1953-1960 (38). Analyses were limited to those cases involving spin-stall crashes or collisions with the ground while in flight. Data from accidents in which the aircraft burned, crashed inverted, or cart-wheeled after impact were not used. Excluded from consideration in this study were cases involving collapse of major structures adjacent to an occupant's seat and in which there was evidence of impact upon the front seat from rear-seated occupants. This was done to control for conditions likely to cause injuries beyond those attributable to tie-down failure.

As shown in Table 1, statistical comparisons were made between six subgroups: one in which occupants did not use seat belts; a second in which seats tore free; a third in which the seats held but the belt was torn, its anchorage failed, or its buckle slipped; a fourth in which belts and seats did *not* fail; and a fifth in which the shoulder harness was used and effective in addition to belts and seats not failing. The sixth subgroup was comprised of 15 occupants whose belt or seat failed or who did not use a belt, all of whom were thrown out of the aircraft at or after impact.

One encouraging fact emerging from the data of Table 1 is that, over all subgroups, injury severity is considerably less than that found from comparable studies of data collected during the period 1942-1952 (37). Approximately nine percent of the occupants used a shoulder harness as compared with one percent from the earlier data. Those wearing the harness were least severely injured; in fact, 36 percent escaped injury altogether. This figure should be compared with the three percent value for those whose seat failed and the 16 percent value for those whose belt failed. The fatality rates data provide further support for the value of effective tie-down and restraint.

Contrary to the earlier findings, seat failure occurred more frequently than belt failure (38). Belt failures represented only 8 percent of the recent cases as contrasted with 22 percent of the earlier cases. Seat failures actually increased! They represent 12.4 percent of the recent data, only 9 percent of the earlier data. But overall, there was an increase in the percentage of cases in which tie-down could be considered effective — from 67 percent for the 1942-1952 data to 77.2 percent for the 1953-1960 data. Fifteen occupants, 2.4 percent of the total, did not make use of their seat belt — a small decrease from

TABLE 1

Relation of Tie-Down Effectiveness to Sustained Injuries

		Harness, Seat, and Belt Tie-Down Effectiveness						
		1. Harness Held	2. Seat and Belt Held	3. Seat Failed	4. Belt Failed	5. Belt Not Used	6. Thrown from Aircraft	7. All Occupants
Number of Observations		55	426	77	50	15	(15)	623
Percentage of Total		8.8	68.4	12.4	8.0	2.4	(2.4)	
Percentage Fatal		6	11	19	20	27	20	12
Percentage Uninjured		36	28	3	16	33	27	25
Area of Injury	Cranial	11*	8	17	26	27	13	11
	Brain	24	22	45	36	33	27	26
	Facial Bones	9	13	17	16	7	7	13
	Upper Torso	11	15	30	22	20	13	17
	Lumbar Spine	11	11	19	10	7	13	12
	Upper Extremities	11	9	19	24	13	13	12
	Lower Extremities	25	22	40	44	13	13	26

* Values indicate percentage of total number of occupants within column receiving injury to specified area.

he rate of 4.2 percent found previously. Of hose 142 occupants experiencing tie-down failire or not using seat belts, 15 (or 10.6 percent) vere thrown out of the aircraft — a decrease rom the rate of 17.3 percent found in the arlier data.

As regards area of body injury (Table 1) ranial and facial bone fractures, extremity ractures or dislocations, and intra-cranial or ıtra-thoracic lesions occurred, as one would exect, considerably more often when tie-down as considered ineffective. Particularly prominnt were the following statistics: Brain injuries ere sustained by 45 percent of those occupants nose seat failed and by 36 percent of those hose belt failed. Head area injuries were susined by occupants using a shoulder harness, ut the severity was judged to be less than for ccupants not using a harness. In agreement ith the previous findings, lumbar spine, lowertremity and upper-torso injuries are observed occur in significant numbers when seats tear ee. Lumbar spine fractures are noticeably fewer when belts are *not* worn — another confirmation of an earlier finding. Data for cervical spine, thoracic spine, and lower torso injuries were not substantial and thus are not tabulated.

The data presented in Table 1, of course, do not take into account the role played by impact conditions. In accordance with this need Table 2 relates injury severity to impact conditions for those occupants whose tie-down did not fail. Those cases in which the shoulder harness was used are included in these data.

Considering first the data for Impact Velocity note that injury severity increases only slightly over the range of values observed. The bottom row of this section presents data on tie-down effectiveness as a function of Impact Velocity. The percentages were obtained by dividing the number of cases with effective tie-down and restraint by the total number of occupants within a particular category irrespective of tie-down effectiveness. For example, there were a total of 83 cases in the 30-39 mph. impact velocity category and 70 of these, 84 percent, involved no tie-down failure.

TABLE 2

Relation of Impact Variables to Injury Severity For Occupants With No Tie-Down Failure

A. Impact Velocity (mph)	30-39	40-49	50-59	60-69	70-89	90-over
Number of Observations	70	79	113	89	52	42
Percentage Fatal	6	8	10	11	13	14
Percentage Uninjured	39	33	29	31	29	14
Percentage Effective Tie-Down*	84	75	81	82	75	71

B. Angle of Impact	0°-22°	23°-37°	38°-52°	53°-90°
Number of Observations	126	108	92	69
Percentage Fatal	4	6	16	20
Percentage Uninjured	52	24	21	12
Percentage Effective Tie-Down*	86	73	74	79

C. Stopping Distance	0'-5'	6'-24'	25'-50'	51'225'	225'-over
Number of Observations	84	71	111	168	22
Percentage Fatal	26	10	9	5	0
Percentage Uninjured	12	11	35	34	50
Percentage Effective Tie-Down*	74	75	81	84	100

* Computed as a percentage of total number of occupants within column category irrespective of tie-down effectiveness.

Next note that as a function of Angle of Impact, injury severity increases quite rapidly. Only 12 percent of the occupants escape injury in high-angle crashes whereas 52 percent escape in low-angle crashes. Apart from this relationship, tie-down effectiveness is observed to be somewhat *greater* at high angles of impact as contrasted with moderate angles (23° - 52°). This finding, also observed in the earlier data, appears to be related to a decline in the rate of seat failures at high angles, which may in turn be a function of design requirements for seats to withstand greater loads in the forward as contrasted with the downward direction.

The value of a long deceleration distance is documented by the fact that at distances exceeding 225 feet, tie-down failure was not to be observed. There are 22 occupants in this category; exactly half of these escaped injury, while the other 11 sustained only facial-bone and extremity fractures. On the other hand, note that effective tie-down begins to lose importance as an element in reducing injury at extremely short deceleration distances, as one would predict from the load factor equation.

Having considered the relation both of tie-down effectiveness and of impact conditions to sustained injuries, we next asked the question of how critical was the factor of structural collapse in causing injury. Table 3 presents data on the relation of environmental damage to injury severity for 268 pilots whose tie-down did not fail under impact. Note that in only five cases was structural collapse so extensive as to preclude survivability. In the remaining cases, considerable injury and fatality were observed despite the fact that these cases met the criterion of survivability. "Mean Degree of Injury" is derived from ratings of injury severity along the AvSER 10-point Scale of Injury, where higher values necessarily reflect more severe trauma. Scale values of 7-10 represent injuries with fatal consequences.

To further clarify the picture, intercorrelations were derived between the primary impact variables, environmental damage, and injury severity. None of the impact variables (velocity, angle, or stopping distance) correlated too high with injury severity. A moderate correlation was found between environmental damage and injury severity, but from a knowledge of environmental damage, this correlation enables one to predict or account for only 22 percent of the variation in injury. At the same time, this fact need not be interpreted to mean that structural collapse *caused* injury — occupants could have been thrown against collapsed structures.

A number of factors have been evaluated above as to their role in determining injury severity. Tie-down failure can be a major determinant of injury, especially when impact conditions are severe. However, tie-down failure was observed in only 23 percent of the cases studied, and undoubtedly many of the injuries in these cases could have been attributed to other factors. One *might* argue *in some cases* too that if crash forces were so great as to cause belts to fail, then they could also be sufficiently abrupt to account for the severe brain concussion or ruptured aorta often found with rapid decelerations — even under conditions where belts would be effective (5). But when impact variables were evaluated in this study, only a fraction of the cases could be classed as severe impacts (i.e., high angle, short deceleration). There were still large numbers of cases for which injury severity was unaccounted.

An analysis of the role of structural collapse revealed that by a large margin considerable injury and fatality were still in evidence despite

TABLE 3

Relation of Pilot Environment Damage to Injury Severity

Pilot's Environment Condition	N	Mean Degree of Injury	Percent Fatal
Intact	110	2.37	1
Distorted	74	3.53	14
Partly Collapsed	79	4.91	27
Collapsed	5	8.40	80

e fact structural collapse was not extensive. the light of this evidence what then is causg these injuries if it is not abrupt deceleration, :-down failure, or structural collapse?

The answer, it is felt, is flailing of the body ;ainst injury-producing structures within the cupant's environment. Now it is true that the t of flailing cannot be objectively determined om post-crash data — it can only be inferred. it who will deny that flailing occurs? Studies individual cases in which effort was made to termine whether contact had occurred between object and a particular body area certainly pport the above argument. The work of Sweargen and his associates (41) is also relevant re. They have photographed the motions of body during deceleration for 100 subjects strained by a two-inch seat belt. The obtained ad clearance curve, when superimposed on an tline of a typical lightplane instrument panel. ıds further support to the above conclusion. eir work also supports the conclusion that in-:y severity in modern lightplane crashes is :gely a function of severity of head injury. ıta from a study conducted by Gregg and arson (15) demonstrate that 76 percent of variation in injury severity can be attributed severity of head injury. It should be obvious :n that violent contact between the head and uctures must be prevented through use of the ›ulder harness, of the crash helmet, and of ısh-safe design principles within the cockpit.

At the same time there is still room for im-›vement in design, manufacture, and installan of components of the tie-down chain. The e at which seats tore free was higher for the ›re recent crashes and is now higher than the e at which seat belts fail. Apparently seat -down improvements have not kept pace with provements along other lines (e.g., increased it belt strength). Unfortunately, the data were : sufficient to determine whether increased : of the shoulder harness would lead to an in-:ase in the frequency of lumbar spine fraces. This inference, suggested by previous htplane accident and Air Force studies (28, . 37) is based upon the premise that adequate traint could contribute to lumbar spine iny insofar as it acts as a counterforce against ich vertical forces are applied. Certainly experience supports the use of the shoulder harness. However if lumbar spine injuries are the price that one has to pay for protection against, say, fatal head injuries, then even greater attention should be given to the incorporation of energy-absorbing features in seat design.

From the statistical studies conducted at AvSER a fairly good picture is beginning to emerge as to the cause of seat and belt failure. Seats were found to fail at a lower median angle of impact than belts and at a higher median impact velocity. Belts on the other hand failed at a much shorter median deceleration distance than seats. Generalizing, in low-angle crashes the mass of the occupant is directed downward so that at the same time the body is responding to the effects of vertically-acting forces, it is also contributing to the failure of the seat. At moderately high angles, an increased rate of belt failure can be attributed to the load imposed upon it by the human occupant undergoing transverse deceleration. Since the occupant is not physically in his seat under these circumstances, a reduction in the amount of loading on it can follow (at least in the case where belts are not attached to the seat); this may account in part for the lower rate of seat failure found at higher angles of impact.

Results of this work suggest another generalization: Most lightplane crashes can be classified into one of two types: (a) the low-angle, higher-speed, long-deceleration crash typified by the forced landing and in which tie-down effectiveness is of particular importance in reducing injury; and (b) the high-angle, moderate-speed, short-deceleration crash typical of the spin-stall accident and in which the value of effective tie-down decreases in importance and the role of energy-absorbing forward structures must be emphasized if one is to reduce injury. Besides design considerations, this generalization has obvious implications for pilot behavior and training. The first type of crash is obviously much safer, whereas the second type is definitely to be avoided, if possible, since injury severity increases rapidly as a function of impact angle. But high-angle lightplane crashes can be survived if crash safety design principles are adopted as has been done in certain agricultural aircraft. In these aircraft, structures are designed to absorb energy by progressive collapse and the cockpit is located as far aft in the fuselage as possible — behind the wing. Records to date on file at AvSER involving these aircraft contain not a single instance in which a fatal crash injury was incurred by an occupant who was making proper use of shoulder harness, crash helmet, and seat belt.

The above discussion should suffice for an overview of the determinants of injury severity in lightplane crashes. Various factors that should be considered in both crash-causation and injury-causation are outlined in Figure 2. In effect this figure could serve as a form of investigator's checklist. In searching for the cause of the crash, the accident investigator will consider the possible contributions of weather, air traffic control, and navaid operations; the design of the aircraft and its maintenance record will be studied; also the health, attitude, and proficiency level of the pilot as they might contribute to "pilot error" would be investigated. In attempting to isolate the cause of injuries the crash-injury investigator will try to re-create the impact conditions and determine whether the crash configuration and terrain characteristics led to a multiplication or attenuation of forces; contributions of fuselage and cabin structures would be evaluated as to their role in injury causation or prevention; effectiveness of the restraint system and of protective equipment in preventing or reducing injury would then be fitted into the picture. With greater amounts of objective data collected on the factors in Figure 2, the generation of conclusions and recommendations that can define further research and operational requirements is facilitated.

At this point it may be well to refer back to the schema presented at the beginning of this paper that outlines the relationship between investigatory and research efforts in pursuit of the goal, Prevention. Having discussed various aspects of crash and injury causation, we now turn to a discussion of aeromedical research whose goal is crash and injury prevention.

FIGURE 2

Factors to be Considered in Lightplane Crash and Injury Causation.

I. The Crash	II. The Injuries
A. *The Context* 1. Weather 2. Air traffic control; navaid failure 3. Other aircraft; occupants	A. *The Context* 1. Impact configuration — velocity, angle, attitude. 2. Terrain characteristics — water, trees, soil, rock; physical structures. 3. Post-crash fire; other aircraft; occupants
B. *The Aircraft* 1. Airworthiness 2. Maintenance 3. Instrument reliability 4. Poor human engineering in cockpit design	B. *The Aircraft* 1. Crashworthiness 2. Cabin structures 3. Instrument panel design 4. Control wheel design
C. *The Pilot* 1. Training; experience; ability 2. General health; physiological impairment due to adverse environment, toxins, etc.; fatigue; drugs, including alcohol 3. Psychological state	C. *Personal Equipment* 1. Crash helmet effectiveness 2. Shoulder harness and seat belt effectiveness 3. Seat tie-down failure

AEROMEDICAL RESEARCH

n this section, discussion will be focused ın current and proposed research within the A's Office of Aviation Medicine as it falls ler the following three headings: Biomedical, ıign Safety, and Human Engineering.

Biomedical Aspects

n order to achieve the goal of better pilot lth, reasonable and objective physical stand- s are required. Facts are also needed about hazards of commonly-used drugs, alcohol, c chemicals, etc.

Iore specifically there is a need to know e about the relationship between aging and sorimotor functions, i.e., when is a particu- pilot too old to fly? Research on auditory, ıal, and vestibular tests that are more com- ısurate with the demands of pilotry is under '. In the area of pharmacology there must be lies of the effects of antihistaminics and ıquillizers upon perceptual-motor and cog- ve processes in particular and aircrew pro- ency in general. Also in need of study is the raction between alcohol and altitude.

he hazards associated with crop dusting re- e a good deal of attention. Here CARI ntists are trying to determine what dusts and ıys affect bodily functions and are search- for ways to better protect the pilot (40).

n the area of pathology the effect of bio- nical changes on the functional capacity of heart is being evaluated. Clinical research ocused upon the evaluation of cardiovascular ction prior to and following myocardial in- tion and of the effects of emphysema upon nonary function at altitude.

Design Safety Aspects

t is the engineer's responsibility to produce airworthy aircraft. The definition of air- thiness that puts emphasis upon airframe ils must also include consideration of crash- thiness, comfort, and workplace layout cri- ı. Design of a crashworthy, human-engineer- lightplane should be part of the same de- pmental program that leads to an airworthy raft if the rate of lightplane fatalities is to educed. A coordinate effort is needed. Evi- ce that this view is already accepted within government, military, and industry is tening.

Statistical studies of injury causation data should ultimately yield more precise recommendations as to where efforts to prevent injury should be focused. Dynamic crash testing of full-scale aircraft is beginning to justify its cost. Strain gages record the magnitude of crash forces to be correlated time-wise with the results of high-speed motion picture coverage in order to trace the transfer of energy thru aircraft structures, and determine where energies are multiplied or absorbed (48). Thru the use of instrumented anthropomorphic dummies in such tests, data can also be gathered to postulate the dynamic response of the human structure to the crash event. Such tests can also be used to evaluate both causative and preventative factors in the area of post-crash fires. The evaluation of seat designs incorporating energy-absorption concepts is, of course, an inherent part of the program underway at CARI.

Recent laboratory studies conducted at CARI have demonstrated that nearly half of the body weight is supported on eight percent of the sitting area under or adjacent to the ischial tuberosites (43). Keeping this fact in mind, engineers and physical anthropologists need to coordinate their efforts if a seat is to be designed providing comfort, support, yet a minimum of energy transmission to the vertebral column in the event of rapid application of vertical forces. Relevant to this need, anthropologists at CARI are currently investigating the breaking point of lumbar vertebrae through a program of dynamic testing. Related work has demonstrated that such substances as polyvinyl chloride and crushable foam can greatly attenuate vertical impact forces and thus should be considered in seat construction. Parenthetically it might be noted that the use of foam rubber seat padding is not the answer to preventing spinal injury, since such padding merely increases the vertical deceleration distance while not providing much in the way of energy absorption.

Collaboration of human biologists and anthropologists is needed in the design and layout of controls. Research on the strength of grip required to operate controls and the ease in which they can be reached at various locations around the cockpit is relevant. Installations of inertia reels with the shoulder harness need to be evaluated to determine whether forward controls can be reached at all positions of the seat if the reel should happen to be activated.

Finally, statistical studies based upon larger number of cases known to be a random sample from the population of all lightplane accidents are essential in order to relate damage to the human structure in a crash to such factors as control wheel design, landing gear characteristics, wing attachment, and cabin location. Findings would bear on recommendation for crashworthiness.

Human Engineering

The largest single cause to which lightplane accidents are attributed is pilot error which stems from inattention, poor judgment, distractions and fatigue. It is in this area where the greatest contribution can be made toward the reduction of accidents. Hence it is fitting that somewhat greater detail be devoted to the topics of this section concerned with optimization of performance.

Performance decrement which can have hazardous effects is normally attributed to "fatigue" and "stress" — terms which frequently imply a physiological impairment. If this implication were accepted then the topic of performance decrement would have been covered earlier in the discussion of biomedical research. The great majority of the time the basis of performance decrement is psychological, rather than physiological, involving such things as boredom, distractions, discomforts, frustration, and worry (cf.2). Pilots should have sufficient motivation with which to offset the effects of distractions inherent in operational requirements, of worries caused by family problems, of frustrations resulting from delays and adverse weather, and of discomforts due to environmental stressors that should have been designed out of the system or otherwise made minimal in the first place. But to the extent that motivation or training are not the answer to these problems, then perhaps human engineering is. Insofar as the indices of performance decrement include such things as stimulus equivalence, loss of flexibility of set, and narrowed attention, then it is up to the human factors scientist to provide a task environment characterized by control discriminibility, variety of sensory input, control movement-display movement compatibility, and efficient display design and layout. Guides fo the accomplishment of these objectives are cer tainly not lacking (11, 18, 22, 32, 39).

One way to make a task difficult is to violat the principle of S-R (Stimulus-Response) Com patibility. This principle dictates that the direc tion of control movements should be compatibl with old habits of response to the direction o display movements, e.g., to cause a pointer o a dial to turn clockwise the desired contro movement should also be clockwise. The phras "population stereotype" is used to define habi patterns that are characteristic of a specifi population of individuals (e.g., housewives pilots). Design engineers should capitalize o such patterns in the layout of displays and con trols.

Habit interference is a concept defined by situation in which alternative, yet nearly identi cal stimulus situations require different respons es but instead identical responses are made. Fo example, in two current models of light aircraf comparable in performance and now in use b one of our military groups, the gear and fla handles found in one model are *reversed* in thei location in the second. Old habits cannot be de pended upon here! When such situations ar allowed to exist it is not surprising then th in 1961, 80 lightplane accidents, for example were attributed to inadvertent activation of gear

Findings from neurophysiological researc appear to have implications for the specificatio of information-input channels (21; 39, ch. 11) Efficient functioning of the cerebral cortex ap pears to be dependent upon continued and varie stimulation coupled with the alerting action o the brain stem reticular formation. Confinemen to a relatively unchanging and restricted tas environment can lead to boredom and inatten tion. Recent studies of vigilance behavior hav found that, under certain conditions, adding t the workload can lead to increased alertnes (23). Optimal utilization of the senses seem important too, e.g., witness recent studies show ing reaction times involved in choices amon sense modalities to be shorter than those invol ed in choices among levels of the same modalit (24). With the feasibility of using tactile com munication as a channel of information trans mission now demonstrated in the laborator

(19), the use of cutaneous signaling for warning and alerting should not be overlooked.

Human factors' scientists at CARI are interested in a number of other problems relevant to optimal performance. These include the design of dials for maximum legibility, evaluation of colored lights for instrument illumination at night, the design of displays for maximum information transmission, the layout of displays so as to achieve optimum visual search without diverting attention from tasks required during critical stages of flight, the location of dials and controls so that attention to them does not induce vertigo, and evaluation of the conditions under which auditory signals can most efficiently be selected from background noise.

Many aspects of the work in human factors discussed so far are relevant to Project Little Guy, FAA's program concerned with the training and skills of the average lightplane pilot and with the aircraft instruments required for safe flight from Point A to Point B under both VFR and IFR conditions. A fresh approach to the development of the Little Guy cockpit is here recommended. This would regard the pilot as a part of a man-machine system in which the systems engineering approach would be followed in an attempt to achieve optimum allocation of task functions (11). This approach would begin with a study of mission and task profiles in order to specify control and information requirements basic to reasonable performance. Studies of control-display combinations can be made to assess compliance with human engineering principles previously discussed and with existing standards such as the Aeronautical Recommended Practices of the Society of Automotive Engineers. Hopefully, practical questions, such as the following, will not be ignored: How much room does the pilot require? Will restrictions due to fuselage structures be such as to interfere with desirable control locations? How far away and in what direction should controls be located? Can controls be identified actually and/or operated efficiently during turbulent weather? Clearly the Little Guy effort to achieve its goal will require considerable cooperation and compromise among engineers, human factors scientists, and operational safety personnel in industry and government.

There is one more area where human engineering research is vital. This is the area of crash and crash-injury investigation itself. The results of research based upon accident data can only be as reliable as the data itself. Hence there is a strong need for research on investigative procedures, on the design of accident and injury report forms, and on the reliability of damage judgments (cf. 14, 15, 50). For example, accident report forms typically place unnecessary burdens upon the investigator by requesting information that either is not needed or can be obtained elsewhere. Once the make and model of the aircraft is known, for instance, certain descriptive data immediately become available to the analyst. The criterion for inclusion of an item on a report form by one who designs it should be resolved by answering the question "What data do I need to answer Question X or to test Hypothesis Y?" Responses required of investigators to items included on a report form should take into account limitations in human judgment. Why, for example, ask investigators to report angle of impact in a crash to the nearest degree when it may be that post-crash estimates cannot be made more reliably than to the nearest ten degrees? Furthermore, statistical studies would probably not demand more precise estimates; studies using automatic data processing equipment, for example, would normally code impact angles between 0° and 9° a "0", those between 10° and 19° a "1", etc., using a single column of a punched card.

CONCLUDING REMARKS

As will be recalled from Figure 1 the ultimate goal of the research efforts in the biomedical, design safety, and human engineering areas discussed above is one of prevention. The achievement of this goal requires that scientists collaborate with operations' personnel so that the recommendations emerging from research will be considered for *implementation* rather than be left in the back pages of a technical report. This need is reflected in the incorporation of operational efforts in the schema. With the centralization of CARI and other elements of the Office of Aviation Medicine in new quarters at Will Rogers Field, Oklahoma City, aeromedical research efforts will be "next door" to operational activities at the FAA Aeronautical Center. Additionally it is clear that for the implementation of research findings to have greatest value in prevention also requires programs of health education, proficiency training, and flying safety indoctrination.

Because of the important contribution made by Aviation Medical Examiners (AME's) to the work of the FAA it is appropriate to conclude with a few remarks in answer to the question "What can the physician contribute to this program?"

First of all, the physician can help provide better crash-injury data (44, 46). At the crash site, comprehensive external examination of the body may reveal specific causes of injuries. Bodies should be photographed in the position where they came to rest. Color plates provide more information for the case analyst than do black-and-white plates. During autopsy the physician should look for signs of pre-existing disease that may have been a *cause* of the crash (12). Complete details on all lesions, fractures, etc., are essential. For example, it is not enough to know that multiple internal injuries caused death. There is a need to know in such a case whether ribs or vertebrae were fractured in order to specify the biomechanics of injury.

Secondly, the physician can aid in the prevention of crashes by helping the pilot maintain his health. In this regard, efforts of AME's in addressing pilot groups are to be commended. The physical examination can be an opportune time to establish rapport and educate the pilot on pilot health. The pilot should be appraised of the effects that recent illnesses or the process of aging can have on his skills (26). He should be cautioned in the use of drugs that may affect performance (31, 33, 35).

Recently a case was brought to our attention where a highly competent and experienced pilot refused to exercise reasonable judgment and took off shortly before noon to fly thru a thunderstorm in mountainous country. Why authorities were ignored under the circumstances we may never know. As a matter of interest, certain airport employees observed the pilot to be unusually hyperactive and euphoric. Could drugs have been a factor? A bottle of capsules found on the pilot at the crash scene stimulated a contact with the physician who prescribed the drug. This physician was not a designated AME, therefore, not the same one who gave the pilot his flight physical. The prescription was for 30 mg. of dextro-amphetamine in time-release capsule form, to be taken by 10:00 A.M. each day, a dosage of six times the normal analeptic dose although considered by some authorities to be a reasonable weight reducing dose. In addition, the pilot was also taking thyroid extract. The side effects of such a dose of dextro-amphetamine certainly might have the result of impairing a pilot's judgmental skill.

A final point — the FAA has enlisted the support of roughly half of the nearly 5,000 AME's to aid in aircraft accident investigation as part of the program of the Aeromedical Standards Division. The cooperation of all physicians with these AME's is solicited. Meanwhile there exists a need for more physicians to serve the FAA as AME's. Those interested in the responsibilities and role of the AME will find these topics lucidly discussed in the "Outline of Procedures for FAA Medical Examiners Participating in Aircraft Accident Investigation." This document, available from FAA Regional Flight Surgeons, also contains a discussion of recommended investigative procedures.

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