HUMAN FACTORS ASPECTS OF LIGHTPLANE SAFETY

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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 components of a system as they interact and determine formance. Insofar as component interaction is non-optimal, total system performance will be inefficient. In the case of private flying, to the extent that system performance is inefficient, correlated by-products in the form of accidents and incidents can be expected. Presently, prevailing rates of lightplane accidents and incidents, and the resulting fatalities and injuries constitute a challenge to human factors scientists 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.
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 aero medical research efforts generally have not been focused upon the kinds of problems relevant to civil aircraft accidents and injuries. Attention to the problem 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 1. SCHEMA FOR LIGHTPLANE CRASH/INJURY PREVENTION STUDY

INVESTIGATION

CRASH

ASSESSMENT OF CAUSATIVE FACTORS

ASSESSMENT OF INJURY CAUSATION

STATISTICAL AND CASE STUDIES

RESULTS

CONCLUSIONS; RECOMMENDATIONS

MEDICAL STANDARDS

DESIGN REQUIREMENTS

PERFORMANCE REQUIREMENTS

OPERATIONAL REQUIREMENTS

BIOMETRICAL ASPECTS

DESIGN SAFETY ASPECTS

HUMAN FACTORS

FLYING SAFETY ASPECTS

PILOT HEALTH

CRASHWORTHINESS

AIRWORTHINESS

OPTIMAL PERFORMANCE

OPERATIONAL SAFETY

EDUCATION

TRAINING

PROCEDURES

IMPLEMENTATION

PREVENTION

CRASHES

INJURIES
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, i.e., 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

<table>
<thead>
<tr>
<th>Harness, Seat, and Belt Tie-Down Effectiveness</th>
</tr>
</thead>
</table>

| Percentage of Total | 55 | 426 | 77 | 50 | 15 (15) | 623 |
| Percentage Fatal | 8.8 | 68.4 | 12.4 | 8.0 | 2.4 (2.4) |
| Percentage Uninjured | 6 | 1 | 19 | 20 | 27 | 12 |

| Cranial Area | 11* | 8 | 17 | 26 | 27 | 13 | 11 |
| Brain Area | 24 | 22 | 45 | 36 | 33 | 27 | 26 |
| Upper Torso | 9 | 13 | 17 | 16 | 7 | 7 | 13 |
| Lumbar Spine | 11 | 15 | 30 | 22 | 20 | 13 | 17 |
| Upper Extremities | 11 | 11 | 19 | 10 | 7 | 7 | 13 |
| Lower Extremities | 11 | 9 | 19 | 24 | 13 | 13 | 12 |

* Values indicate percentage of total number of occupants within column receiving injury to specified area.
The rate of 4.2 percent found previously. Of those 142 occupants experiencing tie-down failure or not using seat belts, 15 (or 10.6 percent) were thrown out of the aircraft — a decrease from the rate of 17.3 percent found in the earlier data.

As regards area of body injury (Table 1) cranial and facial bone fractures, extremity fractures or dislocations, and intra-cranial or intra-thoracic lesions occurred, as one would expect, considerably more often when tie-down as considered ineffective. Particularly prominent were the following statistics: Brain injuries were sustained by 45 percent of those occupants nose seat failure and by 36 percent of those hose belt failed. Head area injuries were sustained by occupants using a shoulder harness, at the severity was judged to be less than for occupants not using a harness. In agreement with previous findings, lumbar spine, lower extremity and upper-torso injuries are observed to 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 restraining the total number of occupants within a particular category irrespective of tie-down effectiveness. For example, there were a total of 63 cases in the 30-39 mph, impact velocity category and 70 of these, 34 percent, involved no tie-down failure.

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**TABLE 2**

**Relation of Impact Variables to Injury Severity**

**For Occupants With No Tie-Down Failure**

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

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

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

*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 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

<table>
<thead>
<tr>
<th>Pilot's Environment Condition</th>
<th>N</th>
<th>Mean Degree of Injury</th>
<th>Percent Fatal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intact</td>
<td>110</td>
<td>2.37</td>
<td>1</td>
</tr>
<tr>
<td>Distorted</td>
<td>74</td>
<td>3.33</td>
<td>14</td>
</tr>
<tr>
<td>Partly Collapsed</td>
<td>79</td>
<td>4.91</td>
<td>27</td>
</tr>
<tr>
<td>Collapsed</td>
<td>5</td>
<td>8.40</td>
<td>80</td>
</tr>
</tbody>
</table>

— 6 —
e fact structural collapse was not extensive. the light of this evidence what then is caus- ing these injuries if it is not abrupt deceleration, shoulder harness, or structural collapse?

The answer, it is felt, is flailing of the body against injury-producing structures within the occupant's environment. Now it is true that the extent of flailing cannot be objectively determined from post-crash data — it can only be inferred. It will deny that flailing occurs? Studies individual cases in which effort was made to determine whether contact had occurred between the object and a particular body area certainly support the above argument. The work of Swearengen and his associates (41) is also relevant. They have photographed the motions of a body during deceleration for 100 subjects strained by a two-inch seat belt. The obtained ad clearance curve, when superimposed on an outline of a typical lightplane instrument panel, adds further support to the above conclusion. Their work also supports the conclusion that injury severity in modern lightplane crashes is largely a function of severity of head injury. Data from a study conducted by Gregg and arson (15) demonstrate that 76 percent of a variation in injury severity can be attributed severity of head injury. It should be obvious that violent contact between the head and structures must be prevented through use of the shoulder harness, of the crash helmet, and of wash-safe design principles within the cockpit.

At the same time there is still room for improvement in design, manufacture, and installation of components of the tie-down chain. The use at which seats are free was higher for the recent crashes and is now higher than the use at which seat belts fail. Apparently seat improvement have not kept pace with developments along other lines (e.g., increased seat strength). Unfortunately, the data were insufficient to determine whether increased use of the shoulder harness would lead to an increase in the frequency of lumbar spine fractures. This inference, suggested by previous lightplane accident and Air Force studies (28, 37) is based upon the premise that adequate restraint could contribute to lumbar spine injury insofar as it acts as a counterforce against vertical forces are applied. Certainly ex-

perience 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 AVS 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.

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

This section discusses the focus on aeromedical research and the importance of statistical studies in understanding injury causation data. Key aspects include:

1. **Design Safety Aspects**
   - The role of the engineer in producing an accident-free aircraft.
   - The design must incorporate safety features from the outset.
   - Elements include human factors, such as pilot comfort and visibility.

2. **Biomedical Aspects**
   - Study of the effects of altitude on the human body.
   - The heart's response to high altitudes and the implications for flight.

3. **Statistical Studies**
   - Importance of data analysis in identifying patterns and trends.
   - Role of statistical methods in validating research findings.

The report emphasizes the need for interdisciplinary research involving engineers, biologists, and statisticians to ensure comprehensive and effective aeromedical research.
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 discriminability, variety of sensory input, control movement-display movement compatibility, and efficient display design and layout. Guides for the accomplishment of these objectives are certainly not lacking (11, 18, 22, 32, 39).

One way to make a task difficult is to violate the principle of S-R (Stimulus-Response) Compatibility. This principle dictates that the direction of control movements should be compatible with old habits of response to the direction of display movements, e.g., to cause a pointer or a dial to turn clockwise the desired control movement should also be clockwise. The phrase “population stereotype” is used to define habits patterns that are characteristic of a specific population of individuals (e.g., housewives, pilots). Design engineers should capitalize on such patterns in the layout of displays and controls.

Habit interference is a concept defined by a situation in which alternative, yet nearly identical stimulus situations require different responses but instead identical responses are made. For example, in two current models of light aircraft comparable in performance and now in use by one of our military groups, the gear and flap handles found in one model are reversed in their location in the second. Old habits cannot be depended upon here! When such situations are allowed to exist it is not surprising then that in 1961, 80 lightplane accidents, for example were attributed to inadvertent activation of gear...

Findings from neurophysiological research appear to have implications for the specification of information-input channels (21; 39, ch. 11). Efficient functioning of the cerebral cortex appears to be dependent upon continued and varied stimulation coupled with the alerting action of the brain stem reticular formation. Confinement to a relatively unchanging and restricted task environment can lead to boredom and inattention. Recent studies of vigilance behavior have found that, under certain conditions, adding to the workload can lead to increased alertness (23). Optimal utilization of the senses seem important too, e.g., witness recent studies showing reaction times involved in choices among sense modalities to be shorter than those involved in choices among levels of the same modality (24). With the feasibility of using tactile communication as a channel of information transmission 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 light plane 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 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. 11, 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 biomedically, 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, aero-medical 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 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 activities 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.

REFERENCES


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