ANALYSIS OF FACTORS CONTRIBUTING TO 460 "PILOT-ERROR" EXPERIENCES IN OPERATING AIRCRAFT CONTROLS*

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A. Purpose

1. *It should be possible to eliminate a large proportion of so-called "pilot-error" accidents by designing equipment in accordance with human requirements.* In order to determine methods of designing and locating aircraft controls so as to improve pilot efficiency and reduce the frequency of accidents, accounts of 460 errors made in operating controls have been collected and analyzed. Results of this analysis are presented in the present report.

B. Factual Data

2. Accounts of errors in using aircraft controls were obtained through recorded interviews and written reports. The following question was used to elicit the desired information:

> Describe in detail an error in the operation of a cockpit control (flight control, engine control, toggle switch, selector switch, trim tab, etc.) which was made by yourself or by another person whom you were watching at the time.

3. Pilots [illegible] the Air *Materiel Command, the Air Training Command, and* the Army Air Force Institute of Technology, and former pilots in civilian universities contributed error accounts. In order to minimize personal opinion, only detailed factual information furnished by an eyewitness or by the pilot who made the error was accepted.

4. It was found that all errors in using controls could be classified under six major categories. This classification is given in Exhibit A. In order to provide examples of errors in each category, forty typical error descriptions are reproduced verbatim in Part II.

5. *Substitution errors, in which the wrong control was operated,* constituted exactly 50 per cent of all the error descriptions collected. The most common subtypes of errors under this general category were confusion of throttle quadrant controls (19 per cent), confusion of flap and wheel controls (16 per cent) and implementation of the wrong engine control or feathering button (8 per cent).

6. *Adjustment errors* and *Forgetting errors* each accounted for an additional 18 per cent of all errors.

7. Three additional categories, *Reversal errors, Unintentional activation*, and *Unable to reach* accounted for the remaining 14 per cent of error reports.

C. Conclusions

8. Practically all pilots of present-day Army Air Force aircraft, regardless of experience or skill, report that they sometimes make errors in using cockpit controls.

9. The frequency of these errors and therefore the incidence of aircraft accidents can be reduced *substantially* by designing and locating controls in accordance with human requirements.

10. The most likely causes of each type of error are discussed in Part I. *Nineteen suggested* design changes for eliminating or reducing these errors also are listed in Part I. The principal conclusions and suggestions arrived at are listed below. Credit for originating the various suggested design changes is due to many different agencies and individuals. The present report simply emphasizes the *support given these suggestions* by the factual data collected from pilots.

a. More than half of [illegible] in operating cockpit controls can be attributed directly or indirectly to *lack of uniformity* in the location and mode of operation of controls.

b. Substitution errors can be reduced by: (1) uniform pattern arrangement of controls; (2) shape-coding of control knobs; (3) warning lights inside the appropriate feathering b[illegible]on; and (4) adequate separation of controls.

c. Adjustment errors can be reduced by: (1) automatic fuel flow control; (2) simplified one-step operation of wheels and flaps; (3) easily accessible and continuously operable trim controls; and (4) improved throttle locks.

d. Forgetting errors can be reduced by: (1) making it impossible to start the take-off run until all vital steps are completed; (2) uniform "off" positions for all switches; (3) more functional check lists; and (4) more effective warning systems.

e. Reversal errors can be eliminated almost entirely by adherence to uniform and "natural" directions of control movement.

f. Unintentional activation of controls can be reduced by adoption of un[illegible]form, thoroughly service-tested cockpit designs, by "cleaning up" the co[illegible]nd by adequate separation of controls.

[illegible]eprinted from Memorandum Report TSEAA-694-12, Aero Medical Laboratory [illegible]iel Command, Wright-Patterson Air Force Base, Dayton, Ohio, July 1, 1947. P[illegible] *g. Inability to reach controls* can be remedied by application of existing anthropometric data on body size, and use of a maximum reaching distance of 28 inches from the shoulder for all controls used during critical procedures.

h. A number of problems raised by this investigation such as optimal location and separation of controls, optimal directions of control movement for special functions, and design of warning devices, require additional research before adequate solutions are found.

D. Recommendations

11. That the Aircraft Laboratory review the suggestions listed in Part I with respect to early incorporation into the current program to improve cockpit design.

12. That the Equipment Laboratory, Components and Systems Laboratory, and Power Plant Laboratory review the suggestions listed in Part I with respect to the implications for equipment modification or development.

13. That the Army Air Force member of the Aeronautical Board Subcommittee on Cockpit Standardization submit the findings and suggestions contained in the present report to the Subcommittee for review and appropriate action.

14. That the present report be reviewed in Headquarters, Army Air Forces by the Research Division, Office of the Air Surgeon and by the Training Division, AC/AS 3, and in Headquarters, Flying Safety Service in order that implications of the findings for policies and procedures for selection and training of Army Air Force pilots and for flight safety can be considered and appropriate action taken if indicated.

Exhibit A

Classification of 460 Errors Made by Pilots in Operating Aircraft Controls

	No. of Errors	*Per cent Errors*
1. *Substitution errors:* confusing one control with another, or failing to identify a control when it was needed		
a. Using the wrong throttle quadrant control (confusing mixture, prop pitch, throttle, etc.)	89	19
b. Confusing flap and wheel controls	72	16
c. Operating a control for the wrong engine (feathering button, ignition, mixture, prop pitch, throttle, etc.)	36	8
d. Failing to identify the landing light switch or confusing it with some other control	11	2
e. Confusing other controls (alarm bell, bomb-bay door, carburetor heat, cockpit heater, droppable gas tanks, emergency bomb release, engine heat, intercooler, oil bypass, oil cooler, parking brake, pitot heat, radio tuning control, salvo switch, trim tab, wobble pump)	21	4

	No. of Errors	*Per cent Errors*
2. *Adjustment errors:* operating a control too slowly or too rapidly, moving a switch to the wrong position, or following the wrong sequence in operating several controls		
a. Turning fuel selector switch to the wrong tank	19	4
b. Following wrong sequence in raising or lowering wheels	18	4
c. Failing to obtain desired flap setting	17	4
d. Adding power too suddenly without proper change in trim	9	2
e. Failing to lock or unlock throttles properly	5	1
f. Failing to roll in trim fast enough	4	1
g. Failing to adjust other controls properly	11	2
Total	83	18
3. *Forgetting errors:* failing to check, unlock, or use a control at the proper time		
a. Taking off with flight controls locked (aileron, elevator, rudder, or all controls locked)	16	4
b. Forgetting generator or magneto switch	14	3
c. Forgetting to make proper engine or propeller control adjustments (mixture, prop pitch, etc.)	11	2
d. Forgetting to lower, lock, or check landing gear	7	2
e. Taking off with wrong trim settings	6	1
f. Taking off without removing pitot cover	4	1
g. Forgetting to operate other controls (bomb-bay doors, bomb-rocket selector switch, coolant shutter, flaps, auxiliary fuel pump, fuel selector, hydraulic selector, lights, PDI switch, pitot heat, tail wheel lock)	25	5
Total	83	18
4. *Reversal errors:* moving a control in a direction opposite to that necessary to produce a desired result		
a. Making reversed trim correction	8	2
b. Making reversed wing flap adjustment	6	1
c. Making reversed movement of an engine or propeller control (mixture, prop pitch, etc.)	6	1
d. Making reversed movement of some other control	7	2
Total	27	6
5. *Unintentional activation:* inadvertently operating a control without being aware of it		
(Brakes, carburetor heat, cowl flaps, wing flaps, generator, ignition, inverter, landing gear, lights, master switch, pitot heat, radio, supercharger)	24	5
6. *Unable to reach a control:* accident or near-accident resulting from "putting head in cockpit" to grasp a control, or inability to reach a control at all		
(Carburetor heat, fuel selector, hydraulic switch, landing gear, nose wheel crank, rudders)	14	3

PART I

Detailed Analysis of 460 Errors Made by Pilots in Operating Aircraft Controls: Probable Cause and Suggested Remedies

I. Introduction

1. Aircraft accidents usually are classified as due to pilot error ... materiel

accidents attributed to the "pilot-error" category. It has been customary to assume that prevention of accidents due to materiel failure or poor maintenance is the responsibility of engineering personnel and that accidents due to errors of pilots or supervisory personnel are the responsibility of those in charge of selection, training, and operations. [redacted]

2. Not only should it be possible to reduce pilot-error accidents by designing more functional equipment, but it should be possible to increase the over-all performance of aircraft through proper consideration of pilot comfort and efficiency. This point of view agrees with the statement on Human Factors contained in the ninth edition of the Handbook of Instructions for Aircraft Designers,[11] which reads: "As aircraft become more complex, and as their performance characteristics make greater demands on the physical and mental capabilities of the crew, the designer must recognize and cater to these definite limits lest the best conceived aircraft from the mechanical, aerodynamic or tactical standpoints fall short to the extent that it makes inordinate demands on the flyer" (par. 0.12).

3. The method employed in the present study involved collection of accounts of actual experiences of Army Air Force pilots in using existing equipment, and analysis of these experiences to determine what the major types of errors are and how such errors can be prevented through better equipment design.

4. The study was initiated in December, 1945. It has been conducted by means of individual and group interviews with pilots and by collection of written reports. The results reported herein are based on transcriptions of recorded interviews and on written reports describing errors in the operation of aircraft controls. Each description concerns a specific experience that happened to or was personally observed by the individual reporting the event. In order to minimize the effect of personal opinion or preconceived ideas, the study has been limited to factual reports of actual flying experiences. Although the present report deals only with control errors, data have also been collected on errors made in reading instruments. Subsequent reports in this series will deal with errors in reading instruments, and with general "peeves" regarding the cockpits and equipments in present-type Army Air Force aircraft.

5. The findings of this study have many implications for selection and training of pilots. While these applications are not emphasized in the present report, they will be readily apparent to individuals who desire to use the findings in improving selection and training.

6. The methods employed in collecting and analyzing "pi[illegible] error" records are described in the following section. Later sections [illegible] eport contain a summary of results and a discussion of probabl[illegible] es and suggested remedies for errors in using cockpit controls.

II. Methods Employed in Collection and Analysis of Data

1. The first step in beginning the study was to develop suitable questions and procedures for obtaining critical factual information from pilots. Different questions were tried out and a list of seven finally selected.* The present report is concerned only with the answers to one of these questions, which reads as follows:

> Describe in detail an error in the operation of a cockpit control (flight control, engine control, toggle switch, selector switch, trim tab control, etc.) which was made by yourself or by another person whom you were watching at the time.

2. Fifty pilots were interviewed individually using all seven questions.† [redacted] Everything that was said during the interview either by the pilot or the interviewer was recorded on a magnetic wire recorder and subsequently transcribed. Interviews carefully refrained from suggesting answers to the questions and limited themselves to comments that would elicit additional information when accounts were not clear or complete.

3. Fifty additional pilots were interviewed in groups ranging from five to ten persons. The same seven questions as before were used. All individuals in a group were given an opportunity to contribute an experience in answer to a question before the group went on to the next. Several one-hour meetings were held with each group in order to cover all of the questions.

4. After preliminary analysis of the interview data secured from these 100 pilots, a printed form was prepared which gave a brief explanation of the purpose of the study and provided space for writing answers to three of the original list of questions. These three questions, which were chosen because it was found that they elicited the greatest amount of useful information, included the one on errors in using controls, a similar question on instrument reading errors, and a question asking for "pet peeves" regarding the cockpit. These printed forms were then distributed to pilots at Wright and Patterson Fields and to pilots attending the Army Air Force Institute of Technology. Colonel B. S. Kelsey, Chief of Base Services, Air Materiel Command, arranged for distribution of the forms at all outlying bases of the Command. Arrangements were made through the Surgeon and the Director of Training, Air Training Command, for circulation of forms within that Command. In addition, a group of former Army Air Force pilots in universities around the country were contacted and asked to complete the forms.‡ Submission of information was on a voluntary basis and replies were anonymous.

*Dr. Wilse B. Webb assisted in trying out the initial list of questions.

†These and other interviews were conducted by one of the following individuals: Dr. P. M. Fitts, Capt. R. E. Jones, Capt. G. Kosinck, Lt. R. Showalter, and Dr. W. B. Webb.

‡Replies from former pilots were obtained through the cooperation of the following individuals: Dr. C. W. Crannell, Miami University; Dr. D. G. Ellson, I[illegible]ana University; Dr. S. C. Fairhorn, Vanderbilt University; Dr. B. von H. Gilmer, U[illegible]y of Virginia; Dr. N. Hobbs, Columbia University; Dr. R. F. Jarrett, University of [illegible]nia; Dr. J. G. Jenkins, University of Maryland; Dr. W. E. Kappauf, Princeton [illegible]ity; Dr. E. L. Kelly, University of Michigan; Dr. R. B. Loucks, University of Wa[illegible]on; Dr. A. W.

5. Over 500 pilots sent in replies to the printed forms. Some did not answer the question on control errors, and a few described experiences that were due entirely to mechanical failure, or to errors of judgment. The two latter types of experiences are not included in the present analysis nor are answers to the questions on instrument interpretation or "pet peeves."

[redacted]

III. Summary of Results

1. It was found that 86 per cent of all reported errors in operating aircraft controls could be classified in one of the following three categories: *Substitution errors*—operating the wrong control as a result of failure to identify a control properly (50 per cent); *Adjustment errors*—failing to adjust a control properly (18 per cent); and *Forgetting errors*—forgetting to operate a control at the proper time (18 per cent). The remaining 14 per cent of errors could be placed in one of three additional categories: *Reversal errors* (6 per cent); *Unintentional activation* (5 per cent); and *Unable to reach* (3 per cent).

2. The frequencies with which different types of errors were described by the pilots who cooperated in the study do not represent precisely the true relative frequency with which each type of error occurs. Pilots were only asked to describe one error in answer to each question and incidents which they chose to describe were ones which happened to stand out in memory. It is believed, however, that the frequency counts indicate in a general way the relative frequency and importance of different errors in using controls.

3. Complete frequency counts and definitions of major error categories and subtypes are given in Exhibit A. Forty representative error descriptions are reproduced in Part II exactly as given during the interview or in the written reports. At least one example of each subtype of error is included, and several examples are provided for the subtypes with highest frequency.

IV. Discussion of Results and Recommendations for Reducing Errors

A. Confusion Errors

1. *Operating the wrong throttle quadrant control* (19 per cent of errors). In any skilled motor activity, such as walking, driving an automobile, or piloting an aircraft, the highest level of performance is reached when movements ... arms, hands, and legs occur simultaneously or successively in coord... ...tterns appropriate to the task at hand, with a *minimum of conscio...* ...ntrol *over separate acts*. The skilled automobile driver, for example...

pedal. Safe aircraft operation demands similar skill. The Handbook of Instructions for Aircraft Designers,[3] for example, contains the following requirement: "Insofar as possible, all controls shall be shaped and located so that a crewman reasonably familiar with their arrangement will be able to operate them without visual reference." (par. 9.11). Yet, in spite of this requirement, the results of the present study show that pilots of Army Air Force aircraft seldom are able to become sufficiently familiar with the location of controls in the cockpit of a particular aircraft to avoid occasionally operating the wrong control. This is particularly true of controls on the throttle quadrant. The error occurs most frequently in multiengine aircraft, but in some cases is reported by single-engine pilots.

2. Careful study of accounts of pilot-error experiences and consideration of relevant research studies leads to the conclusion that three principal reasons account for most errors involving operation of the wrong throttle quadrant control. They are: [redacted] of controls; (2) [redacted] controls; and (3) lack of a coding [redacted] of controls by the sense of touch alone.

3. Differences in the throttle quadrant arrangements between the B-25, the C-47, and the C-82 illustrate the lack of uniformity which leads to frequent and serious cockpit errors. The arrangements of controls in these three aircraft are as follows:

Aircraft	Control Sequence on Throttle Quadrant		
	Left	Center	Right
B-25	Throttle	Propeller	Mixture
C-47	Propeller	Throttle	Mixture
C-82	Mixture	Throttle	Propeller

It is easy to understand why pilots who are required to fly these three types of aircraft report that they have cut the throttles or mixture controls just after take-off when intending to reduce rpm. The need for uniformity of location exists for all controls in the cockpit, but is believed to be especially acute for throttle quadrant controls because constant use of these controls results in well-established habits which are a constant source of conflict and confusion when the pilot changes to an aircraft with a different pattern arrangement of controls. [redacted] However, the writers have no evidence on this point. Imagine the difficulty most car drivers would experience in learning to brake with the left foot and to use the clutch with the right.

4. In achieving uniformity, *the over-all pattern of control arrangement*, and not the precise location of any control, is believed to be the essential re... ...nent. Recent psychological research has shown the great importa...

though the specific elements are varied considerably. Applying this to aircraft design, it appears that it is important to maintain uniformity of right-left and up-down relationships, but that rigid standardization of all dimensions is not absolutely necessary.

5. Another important factor which may lead to operation of the wrong throttle quadrant control is the close proximity of controls. When a pilot reaches out to grasp a control without looking, he will not position his hand to exactly the same location on successive tries. Accuracy in locating a control varies with the position of the control, with practice, and with different individuals, but limits of accuracy can be established. Just as visual acuity can be defined in terms of the visual angle subtended by the smallest letter that can be seen on a test chart, so location discrimination can be defined in terms of the vertical or horizontal angular separation necessary to avoid confusion of controls. An investigation of this problem has been underway at the Aero Medical Laboratory for the past year and the results will be published in the near future.

6. In addition to lack of uniform location and spacing of controls, it is believed that controls are often confused because pilots have no positive method of identifying a control by the way it feels without looking at it. This is especially likely to lead to an error during take-off and landing, during combat, during night flight, and at other times when the cockpit is dimly lighted or when the pilot does not want to look down into the cockpit. Most of the necessary research on shape-coding of controls has already been carried out. In 1944 and 1945, the Army Air Force School of Aviation Medicine reported studies which showed clearly that the number of errors made in learning a new control arrangement is greatly reduced when shape coding of knobs is provided.[8, 9, 10] The Aero Medical Laboratory has recently published three reports[3, 4, 6] on the ability of pilots to recognize different shapes through the sense of touch, and one report[5] on the preferences of pilots regarding which controls should be coded and which shapes assigned to each control. As is true for uniformity of position and separation of controls, coding also should be extended to other controls than those on the throttle quadrant. Action to achieve shape coding is now being taken by the Aircraft Laboratory and is under discussion by the Aeronautical Board's Subcommittee on Cockpit Standardization.

7. *Confusing wing flap and landing gear controls* (16 per cent of errors). Confusion of flap and wheel controls was not reported as frequently as mistakes in operating controls on the throttle quadrant, but the flap-gear substitution error was described more frequently than any other error involving a single pair of controls.

8. One reason that is frequently given for confusing wheels and flaps is the proximity of the two controls. This source of error has now been corrected in most aircraft, and the requirement for new aircraft is that "the flap actuating control handle shall be located above and at least 12 inches the landing gear control handle . . ."[1 par. 9.4(b)]. Rigorous enforc- of this requirement at all mock-up inspections should materially red incidence of this error. Confusion of wheels and flaps still occ

that other psychological factors besides spatial proximity contributed to this error. Pilots themselves usually do not try to explain the cause of this particular error but refer to it as an example of "heads-up-and-locked" behavior, or of reacting without thinking.

9. It is proposed that a basic psychological cause of the confusion of wheels and flaps may lie in the fact that these controls frequently are operated in sequence, the most common sequence being *operation of the wheel control immediately preceding operation of the flap control.* After take-off, for example, the sequence is to raise wheels, then flaps. In preparing to land, the usual sequence again is to lower wheels, then flaps. After landing, if a pilot is not attending carefully to what he is doing, he may start to repeat the sequence which he has just completed prior to landing. This theory, of course, does not explain the error of raising flaps instead of wheels immediately after take-off or in a go-around nor does it suggest a practical solution to the problem.

10. In addition to causal factors already mentioned, it is believed that flap and wheel confusion may be due sometimes to the fact that the mode of action of these two controls is very similar; for example, a toggle switch may be used for both.

11. *Operating the wrong engine control* (8 per cent of errors). This error may be much more serious when it happens than the two types of errors discussed in the preceding paragraphs since it frequently occurs in an emergency caused by loss of one engine. The error includes feathering the wrong engine, or operating the ignition switch, mixture, or throttle for the wrong engine.

12. The cause of errors in which pilots operate a control for the wrong engine of multiengine aircraft are complex. In training, emphasis is placed on the necessity for "thinking before acting," but in the case of an engine failure, the urgency of the situation gives many pilots a case of "featheritis." In the case of many accidents it is not clear whether a pilot became confused as to which engine was out (an error of comprehension), became confused as to which control should be operated for the engine that was out, or whether he inadvertently pushed one feathering button when intending to hit another. Errors in reading engine instruments and suggested instrument design changes are discussed in a separate report (MR No. TSEAA-694-12A).

13. Some pilots comment that feathering buttons are too close together. It may be possible that sometimes a pilot will hit one button when actually reaching out for another.

14. When an engine goes out suddenly, one of the first indications of trouble often is an increase in back pressure from the rudder *on the opposite side* to the dead engine. When the right engine goes out, for example, the pilot must compensate with left rudder pressure. It is suggested that this may be a source of confusion, since the pilot may instinctively sense "get rid of the drag on the left side," and hence reach automatically for the left feathering button. However, the writers have no direct evidence in ort of this hypothesis.

15. Action of most feathering buttons is ambiguous with respe the

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forward movement of a control should be associated with increase in power or decrease in drag. Feathering an engine reduces drag if the engine is windmilling, but if a good engine is feathered by mistake, then power is reduced. This factor, added to possible confusion in interpreting the rudder-pedal cue, may account for some errors.

16. *Unable to identify landing light switches* (2 per cent of errors). Instances are reported of landings made without lights because of inability to locate light switches during the final approach, or of near accidents due to turning off some other switch than the landing lights immediately after take-off. This difficulty is easy to understand, since the error is made at a time when pilots do not want to look down into the cockpit and when there is no means other than vision for identifying the light switches.

17. *Confusing other controls* (5 per cent of errors). A large number of additional controls are involved in one or more pilot-error reports. Many of these controls were located where it was difficult to see or to check them before they were operated. The causes of such errors are similar to those discussed in connection with other substitution errors.

18. *Suggested design changes for preventing substitution errors.* The ideas represented by the following list of suggestions have been collected from many different pilots, engineers, and agencies. It would not be possible to assign credit to any one individual or group for most of the proposals. The writers of the present report wish to make it clear, however, that no originality is claimed for the list. It is believed, however, that all of the suggestions follow logically from and are supported by the analysis of pilot-errors in using controls. Omitted from the list are requirements already included in the Handbook of Instructions for Aircraft Designers.[12]

Suggestion 1. Provide uniform pattern-arrangement of all cockpit controls, particularly of throttle quadrant controls.

Suggestion 2. Provide uniform shape-coding of all control knobs which must be grasped quickly or without looking.

Suggestion 3. Provide warning lights *inside* each feathering button to go on whenever the throttle for an engine is forward and engine torque falls below a critical value. Separate feathering buttons sufficiently to prevent unintentional operation of an adjacent button.

Suggestion 4. Investigate the speed and accuracy of pilots in reaching for controls in different cockpit areas without the aid of vision.

Suggestion 5. Investigate the desirability of designing wing flap and landing gear controls which have distinctly different modes of operation.

B. Adjustment Errors

1. *Selecting the wrong fuel tank* (4 per cent of errors). The most common errors in this category are turning the fuel selector valve so that it is half[illegible] [illegible]een two tanks and leaving it in a position where fuel can flow [illegible] tank, or actually turning the valve to the wrong tank. In both c[illegible]

right-wing and left-wing tanks, especially in aircraft in which selector valves are on the left-hand side of the cockpit with the selector for the left-wing tanks forward, so that as the pilot turns sideways to look at the controls, the one for the left wing is on his right and the one for the right wing is on his left.

2. *Improper sequence in lowering wheels* (4 per cent of errors). Errors in adjustment of wheel controls on landing and take-off can be attributed principally to the number of different steps required in some aircraft to lower, lock, and check the landing gear. Errors of this type are made most frequently by pilots not thoroughly checked out in the aircraft. However, it appears that a substantial number of cockpit errors can be eliminated if the procedure required for lowering the wheels can be simplified.

3. *Difficulty adjusting flaps* (4 per cent of errors). Errors involving failure to obtain the desired flap setting appear to be due to difficulty in operating the flap control in cases where the pilot does not make careful and frequent visual checks. Pilots repeatedly describe errors which are made when they rely on feel of the flap control position to tell them they have made the desired setting. In several cases, pilots thought they had placed the control in a "neutral" position but actually had it in the "up" or the "down" position instead.

4. *Adding power too suddenly without proper change in trim* (2 per cent of errors). Serious difficulties may occur as a consequence of the sudden applications of power when an aircraft is not properly trimmed, for example, when the aircraft has been trimmed for landing and the pilot suddenly decides he wants to go around. Although errors such as this can be reduced through training, trim controls that work rapidly and are easily accessible might also prevent many accidents. Needless to say, it would not be desirable to make the trim control operate too rapidly.

5. *Difficulty locking throttle* (1 per cent of errors). The present design of throttle locks contributes to several kinds of errors. It is common practice for the copilot to operate the locks while the pilot keeps his hand on the throttles. This use of a second person is a cockpit procedure which sometimes contributes directly to an accident. Also, it is often difficult for the pilot to obtain the exact tension he wants. Serious mistakes in interpreting hand signals during take-off have been due directly to confusion accompanying efforts of a pilot to correct for inadequate throttle locks. The accident in which the Commanding General of the Second Air Force was fatally injured while piloting a B-25 during the war was due to misunderstanding a hand signal which was intended to mean "hold the throttles."

6. *Failing to roll in trim fast enough* (1 per cent of errors). This difficulty is due to the fact that in rolling in a large change in trim, it is necessary in many aircraft to turn the trim wheel part of a revolution, then remove the hand and "hitch" it to a new position before turning the wheel again. In a number of situations, such as when an engine cuts out, a pilot may want to grasp the trim control quickly and to change trim rapidly. Thi[illegible] [illegible]ulty becomes more serious in cases where a pilot cannot compens[illegible] [illegible] the

7. *Failing to adjust other controls properly* (2 per cent of errors). Pilots occasionally make errors in the operation of a large number of other controls. Probable causes and remedies for all of these errors need not be discussed in detail since in most cases they are similar to those already reviewed. In general, three kinds of difficulties are experienced in adjusting controls: inability to move a control fast enough, inability to make a sufficiently precise setting, and difficulty due to the complexity of a sequence of control adjustments.

8. *Suggested design changes for preventing adjustment errors.* The following suggestions follow logically from the preceding discussion and are offered for consideration as means for reducing the probability of errors in adjusting controls. As was true for preceding suggestions, it is desired to make clear that the writers do not claim credit for originating these ideas.

Suggestion 6. Make all fuel flow control automatic (with manual override for occasional use in combat) so that the pilot will be relieved of this responsibility and will not be able to make errors in selecting fuel tanks.

Suggestion 7. If the technical problems of obtaining automatic fuel flow control cannot be solved, then it is suggested that fuel valves be redesigned to give positive selection so that it is impossible to leave a valve inadvertently in an intermediate position where no gas will flow and that some type of indication be added to fuel gauges to indicate the tanks that are feeding the engines.

Suggestion 8. Simplify the procedure for lowering wheels so that only one step is required of the pilot.

Suggestion 9. Design the flap actuating control to provide indication of flap position both by direct vision and by feel of the control, and eliminate the use of a "neutral" position, thus reducing flap adjustment to a single operation such as moving a lever-type control to one of a small number of detent positions.

Suggestion 10. Locate the trim controls where they can be grasped quickly and provide for continuous operation (i.e., avoid the necessity for shifting the hand during operation) so that moderately rapid change in trim can be secured when desired.

Suggestion 11. Design new type throttle locks that can be operated by one hand simultaneously with the throttles.

C. Forgetting Errors

1. *Forgetting to operate a control* (10 per cent of errors). It is desirable to consider together all of the subtypes of errors included in this general category since forgetting errors have much in common regardless of the specific act that is forgotten.

2. The most frequently reported forgetting error is *taking off with flight controls locked* (4 per cent). Other errors included *forgetting magneto or inverter switches* (3 per cent), *forgetting to change engine settings* (2 per cent) *forgetting landing gear* (2 per cent). Failure to operate more than a ... other controls accounted for the remaining 7 per cent of errors

3. Forgetting some part of a well-established habit is a psychological phenomenon that occurs for a variety of reasons. In most cases, well-established habits enable a pilot to carry out cockpit procedures more or less automatically with little thought or deliberation. Forgetting may occur when something unusual happens to interrupt or momentarily distract the pilot from his normal routine. Even cockpit routines that have become entirely automatic may be disrupted in this manner by seemingly unimportant stimuli. Sometimes a special effort to be more careful than is one's habit may unexpectedly turn out to be a distracting or disorganizing influence. No one is entirely free from these seemingly stupid forgetting errors.

4. The most critical forgetting errors are those which are impossible or difficult to remedy in flight, for example, taking off with controls locked in an aircraft in which they can only be unlocked on the ground or when there is little pressure on the flight surfaces.

5. Most forgetting errors occur at the time of take-off. Apparently, the take-off check list which is designed to minimize these errors frequently is not used or is used incorrectly.

6. Procedures in which an exact series of sequential control adjustments is required are particularly subject to error if there is no logical *pattern* of sequential acts, and no way of checking easily to make certain that no step has been omitted. Responses that are to be made at infrequent and irregular intervals also are easily forgotten.

7. In connection with forgetting errors, the improvement of warning devices and their most effective use should be considered. The relative attention-getting value of visual versus auditory warnings, of steady versus intermittent signals, and of still versus moving indications should be investigated from a psychological point of view. Methods of attaching meanings to warning devices, methods of alerting the pilot without creating unnecessary tension, and the optimal number of warning signals also should be studied. Some experimental investigations of this problem are already under way but many questions pertaining to the effectiveness of warning devices still remain unanswered.

8. *Suggested design changes for reducing the frequency of forgetting errors.* It will never be possible to design equipment and train pilots so well that human operators will never forget. However, the following suggestions, which have been collected from various sources, appear to be obvious ways of reducing the frequency and seriousness of such errors.

Suggestion 12. Design aircraft so that it will be impossible for a pilot to advance the throttles and start the take-off run if any essential step in the cockpit check, such as unlocking flight controls, removing pitot tube cover, uncaging gyros, turning on generators, or adjusting trim for take-off has been forgotten.

Suggestion 13. ... the preceding goal is achieved, design or modify aircraft having internal control locks in such a way that control ... can be freed quickly under any condition.

Suggestion 14. Design all types of toggle switches with a ... "off"

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position, as recommended in Engineering Division Memorandum Report No. TSEAA-694-4F, *in order to* increase the accuracy and ease of checking switch positions.

Suggestion 15. *Investigate the usefulness and practicability of a mechanical* abbreviated check list for use before take-off and landing to indicate which items have still to be checked.

D. Reversal Errors

1. *Moving a control in a direction opposite to that which would produce the intended result* (5 per cent of errors). The mistake of moving a control in the direction opposite to the appropriate one is closely related psychologically to reversed interpretation of an instrument reading. Such errors occur when the control movement required for a particular purpose is the reverse of what is most "natural" or "expected" or when the direction of control movement conflicts with habits which have been established in flying other aircraft. Errors occur frequently when there is a conflict between the responses required in operating different controls (see Engineering Division Memorandum Report No. TSEAA 694-4C). Such a conflict in direction of movement relationships requires the pilot to change his mental set each time he goes from one task to the other.

2. *Suggested design changes that would prevent reversal errors:*

Suggestion 16. Design controls so that the relationships between all control-aircraft-indicator movements are the "natural" or "expected" ones and no mental process is required between comprehension and response. Where necessary, conduct research to determine the optimal direction-of-movement relationships.

E. Unintentional Activation

1. *Unknowingly activating a control* (5 per cent of errors). The number of different controls which are sometimes activated without the pilot's being aware of operating them is very large. Such errors usually result from the crowding of many controls into the small space available in the cockpit, which makes it possible for a switch to be activated by the pilot's arm or sleeve without his knowing it.

2. Reduction of this type of error should result from development and careful testing of prototype cockpits. It is believed that the only satisfactory way to minimize unintentional activation of controls is through continued modification of cockpits on the basis of pilot-error experiences involving inadvertent control activation. Since this is a slow and costly procedure if accomplished separately for each type of aircraft, it is concluded that the most practical alternative is development of uniform "ideal" cockpits which can be thoroughly service-tested before actual use in new aircraft. This general approach *to development of uniform cockpits is now being* [f]ollowed by the Aircraft Laboratory of the Air Materiel Command.

[3. *Sugg*]*ested design changes for reducing unintentional activation of controls:*

[Sugges]*tion 17.* Subject the "ideal" cockpits being developed by the Ai[r]

actual flight tests in order to discover and correct any tendencies toward unintentional activation of controls.

Suggestion 18. Accelerate the present program to "clean up" the cockpit through such means as the use of consoles, flush mounting, and smooth edges. Enclose all connecting tubes and cables. Provide sufficient separation of controls so that any control can be operated independently without probability of hitting an adjacent switch or lever, even if the pilot is wearing gloves.

F. Reaching Controls

1. *Failing to reach a control when needed* (3 per cent of errors). The errors in this category are believed to arise from two sources: inability to reach far enough to grasp a control, and necessity for reaching so far down that vision outside of the cockpit or vision of the instruments is *momentarily restricted.*

2. Anthropological data collected by the Aero Medical Laboratory indicate that if *it is desired to design* aircraft so that Army Air Force pilots can grasp a control without moving their eyes from the normal position, it is *necessary that* controls be located no farther than 28 inches from the point of rotation of the arm using it. This reference point is approximately 7 inches to the side of the mid-line of the body. The distance can be extended for a few inches directly ahead of the pilot if he is free to lean forward.

3. *Suggested design changes that would eliminate errors due to difficulty in reaching controls:*

Suggestion 19. Locate all controls and switch panels that must be used during take-off, landing, and other critical *maneuvers within* 28 inches of the point of arm rotation at the shoulder. This is particularly important for controls located *near* the floor of the cockpit.

V. Summary

1. The results of the present analysis, based on 460 detailed accounts of pilot errors in using cockpit controls, indicate conclusively that the incidence of human error can be reduced substantially by designing controls and cockpits in relation to human *requirements.*

2. An occasional pilot may claim, as one did in the present study, that he *has never made a mistake* in cockpit procedure. However, the facts show that practically all pilots, regardless of their training and experience or their level of skill, sometimes make errors in using cockpit controls.

3. The present study does not cover *all human problems in the design* of controls. Some problems are not recognized by pilots and hence are not described. Other difficulties may be encountered so often that they are accepted as a normal part of flying and therefore are not reported. For such reasons, it is felt that the present list of errors has some important gaps.

4. Many of the suggestions which are included in the present re[po]rt have already been generally recognized and accepted. The engineeri[ng ch]anges necessary to meet many of these suggestions are *obvious ones.* In [m]any

has since been modified along the lines indicated. On the other hand, some of the remedial design changes supported by findings of the present study can be stated only in very general terms at the present time and additional research will be necessary before specific human requirements can be formulated or engineering solutions found. The broad requirements indicated by the present analysis are summarized in the following paragraphs.

5. *Uniformity.* One of the most obvious requirements is uniformity in the location and operation of controls. The difficulties of achieving uniform cockpits are great, but the benefits in terms of human life and equipment will be tremendous. It has been pointed out that uniform principles of arrangement and mode of action, together with a similarity in the pattern of control location, will achieve most of the benefits desired. It is obviously desirable to use the best arrangements and designs of controls. Therefore, standardization should not be so rigid in the beginning as to prevent future refinements. It is conservatively estimated that over half of all of the errors made in using cockpit controls result directly or indirectly from lack of uniformity.

6. *Speed and precision of operation.* Aircraft controls should be designed to give the required speed of precision of action in relation to the functions which they perform. In some cases, it is necessary to provide both for rapid adjustment and for slower and more precise settings.

7. *Simplification of sequential operations.* Controls should be arranged so that the steps of a complex procedure are minimized, and so that each operation follows logically after the preceding one. Whenever possible, only one control movement should suffice for any one operation such as lowering wheels or setting flaps.

8. *Natural directions of movement for controls.* The direction of control movement required for effecting a desired response should be the "natural" or "expected" one, so that in an emergency the correct movement can be made rapidly without unnecessary deliberation.

9. *Efficient location of controls.* Adequate location of controls requires consideration of maximum distance from the operator, adequate separation between controls, and locations permitting most accurate grasping and manipulating.

10. *Automatic actuation.* Too often in the past, whenever the technical solution of automatic or single-movement actuation has been difficult, the tendency has been to "let the pilot do it." In an ideal design, the pilot should decide *what* he wants and *when* he wants it, and should use the simplest and most direct control movement possible to achieve the desired result. The pilot's responsibilities are too great to burden him with unnecessary mechanical operations.

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PART II

Selected Accounts of Pilot Errors in Operating Aircraft Controls

(Error experiences are grouped by type and are given in the exact words of the pilot.)

1. Operating the Wrong Control

Using the Wrong Throttle Quadrant Control. "This was a case of mistaking prop pitch controls for throttle controls in C-47 while the pilot was flying a GCA approach under the hood. We were on the final approach at about 600 feet when we noticed an unusual sound in the engines. What had happened was that the pilot had taken hold of the prop controls and was using them for throttles. They were next to the pilot while the throttles were in the center. This was a bad installation also because the gauge for the props was on the right of the manifold pressure gauge while the prop controls were on the left of the throttle controls."

"I was acting as control for basic students shooting a stage. At completion of the day's flying and after all students had been dispatched to home base, I started up my airplane, BT-13, taxied out to the take-off strip, ran through pre-take-off check and proceeded to advance the throttle. I held the plane down to pick up excess airspeed and as it left the ground, proceeded to pull back the prop control to low rpm. Immediately, the engine cut out and I could see nothing but fence posts at the end of the field staring me in the face. Luckily, I immediately pushed the prop control forward to high rpm's and the engine caught just in time to keep from plowing into the ground. You guessed it. It wasn't the prop control at all. It was the mixture control."

"This error occurred in a C-47 aircraft. The pilot, after the usual procedure of lowering the gear and other landing checks, turned on the final approach leg and reduced power. Shortly afterwards, he found it necessary to increase power to avoid undershooting. In reaching for t[illegible] throttle, the pilot grasped the propeller control. Advancing the prop [illegible]l, the engines sounded as if power were being applied. This occurre[illegible] though occurred. The pilot was familiar with control panel of a B-25; hence, he automatically grasped the set of controls nearest or, in other words, those on the left side."

Confusing Flap and Wheel Controls. "A B-25C with full bomb and gas load was taking off from a 3,500-foot strip with trees at both ends. We crossed the end of the runway at an altitude of two feet and were pulling up over the trees *shortly ahead when I gave the 'wheels up' signal.* The airplane mushed and continued to brush the tree tops at a constant 125-mph speed with T.O. power. The copilot had pulled up the flaps instead of the wheels."

"Normal take-off was made in a heavily loaded F-13. After leaving the ground, I gave the signal to the copilot for gear up. *The aircraft began to settle back toward the ground as the flaps were retracted instead of the gear.* Elevator control was sufficient to prevent contacting the ground again and flying speed was maintained. The copilot, in a scramble to get the gear up, was unable to operate the two safety latches on the gear switch and I was forced to operate this switch to raise the gear. Everything would have been all right had not the number-one engine quit at this point. Full rudder and aileron would not maintain directional control and the airspeed and altitude would not permit any retarding of power on the opposite side. As the gear retracted, the airspeed built up sufficiently to enable me to maintain directional control and finally to gain a few feet of altitude. The combination of difficulties almost caused a crash. I believe that the error of raising the flaps instead of the gear was caused by inexperience of the copilot and the location of two switches. Numerous instances of this error were reported by members of my squadron while overseas although no accidents were known to be caused by it. However, it could result in very dangerous situations especially when combined with some other failure."

"In a B-17-type aircraft, I know of five instances where the copilot retracted the wheels instead of the flaps. In one instance, the offender was an instructor pilot with over a thousand hours in a B-17 and, who had also served a tour overseas."

Operating a Control for the Wrong Engine. "On take-off in a C-47 with approximately fifty persons on board, the right engine quit. The pilot and copilot both reached for the left feathering switch and finally got the left engine feathered. No one was close enough, or realized in time, to prevent this mistake. *It was very fortunate that several open fields were straight ahead*—no one was killed but several persons were bruised."

"On a routine combat mission, a recently checked-out copilot flying as first pilot had been given a position as wing man. Going over the target, an engine was damaged by flak and heated up and lost considerable oil. Therefore, he had his copilot feather the engine. *He remained in formation over the target and all the way home.* On arriving at the field, he requested the copilot to unfeather this damaged engine. The copilot was a [illegible]ilot on his initial combat mission, and had the benefit of transi[illegible] and considerable experience in emergency procedures. He tol[illegible]

procedures and insisted on the engine being unfeathered. The argument continued and finally the first pilot became angry and reached for the feathering button. *He hit the wrong one*, feathering the second engine. At this time, both pilots put their heads in the cockpit trying to get their engines unfeathered. All this time, they were still in formation. As a result of concentrating *on the unfeathering* procedure, they skidded into the flight leader, cutting his fuselage off just in front of the vertical stabilizer and his plane plummeted to the earth 1,000 feet below killing the eleven occupants."

"*I was flying* with a buddy in a B-26, demonstrating the fact that it could fly as well on one engine as any other airplane. He feathered one engine all right. Then he started to shut the ignition switch off on that engine and got hold of the wrong switch and shut off the good engine. After he realized the engine was off, he turned it back on again and it came back to life. That is a serious error *when you have* only two engines."

Difficulty Identifying Landing Light. "After a night take-off in a 'follow-through' landing in an AT-6, I turned off my *battery and generator* switches *instead of my landing lights.* I then became rattled, thinking I was having engine failure, as well as electrical failure, and belly-landed."

Confusing Other Controls. "A captain with 18 months' combat experience in P-40's was out on a rocket-firing mission in a P-51-D. In a dive on the target, his airspeed was in the vicinity of 400 mph. *As he started* his pull up *from the target*, it is believed that he reached for the rudder trim tab and by mistake took hold of the aileron trim. His left wing was seen to hit the ground, killing him instantly. Evidence showed the *aileron trim* to be in the full left-wing-down position, and it is believed that the rudder trim and aileron trim were placed too close together for immediate and positive identification."

"At the time, the pilot had about 40 hours in F-5E aircraft. The occurrence took place at a depot in India, where the pilot was test-flying ships on a TD status. The ship had been fueled the evening before, except for the *droppable* 'belly' tanks, under the pilot's supervision. Overnight the left main tank had drained into the 'belly' tank. Upon starting the engines the next morning in preparation for a test flight, he noticed the left fuel gauge indicated an empty tank and because it had happened a few times previously, supposed that the gauge was inoperative. *Proceeding to take off*, he attained about 500 feet altitude when the left engine died. Immediately recollecting the indicated empty main tank, he reached down to switch to a full tank and did not feather the propeller because *it should* have picked up immediately. However, the engine failed to 'catch' and following a 'head-up-and-locked' procedure, the pilot lost all but a very few feet of altitude trying to restart the left engine before he finally '*feathered*' the dead prop. After climbing to 1,000 feet on the remaining engine, he found that he had been changing the fuel selector of the right engine while the *left* engine remained on *an empty* tank. All *gauges and controls* in the cockpit, with exception of the fuel selectors, are for the right and left engines, respectively, as you face [illegible] and although many mistakes were made, in this instance, *if the* [illegible] had

II. Failing to Adjust a Control Properly

Turning Gas Selector Switch to the Wrong Tank. "We used gasoline from the main tanks of the A-20 until we turned on the bombing run. At that time, we always turned our gasoline selectors to the bomb-bay tank because we were sure that there was sufficient gasoline in the tank to see us through the bombing run and well on our way home. On my first combat mission, I thought that I had turned my gasoline selector to the bomb-bay tank, but just before bombs away my engines suddenly stopped. I was a bit excited, and finally noticed that the gasoline selectors were turned to auxiliary. I'd used up all the gasoline in my auxiliary tank. While I was discovering what was wrong, the rest of the formation got ahead of me and I was unable to drop my bombs the same time they did."

"This was the first combat mission of this particular P-47 pilot. He had flown well and been okay all the way through the mission. However, about 15 miles from our home base in Burma, he reported a fluctuation in his carburetor pressure gauge. He grew very excited and tried everything he could think of—changed the prop to manual; put mixture on full rich; then leaned mixture out. He did everything but the important thing—he didn't switch gas tanks until told to do so by the flight leader. After switching tanks, he still reported the same trouble, and about 8 miles out his engine quit. He was advised to jump by the flight leader; however, not wishing to tangle with the jungle, he decided to belly in on a sand bar in a river below. The river banks were about 15 feet high. He misjudged the bank and stalled out so that his plane hit the bank with the tail, consequently nosing up and going straight down into the river. The pilot drowned.

"When we pulled the damaged plane from the river, we found the cause of the accident. The switch lever on the empty tank had been turned toward the reserve tank, but not far enough to induce adequate gas supply, i.e., it was halfway between the two. This accident was called 100 per cent pilot error on the basis of the above. However, it seems to me under the circumstances the pilot was not totally to blame. He was upset and excited because it was his first mission. He thought he turned the selector switch all the way. The man who wrote 'pilot error' on the report was an inspector and safety man from Headquarters who found it easy to laugh off the 'foolish thing this pilot did' as 100 per cent pilot error, but never thought *about the fact that something could be done about selector switches. If it* hasn't already been done, the selector switch should be designed so that there can be no possible way to switch it part of the way."

Selecting the Wrong Flap Setting. "I took off in a B-25 with a student pilot on a 50-foot authorized low-level cross-country mission. Since I intended to maintain 50 feet the entire mission, right after take-off, I retracted the gear and flaps normally. However, being at a low altitude, I did not visually move the flap handle to the neutral position, rather placing it in neutral by feel. In doing so, I inadvertently placed the handle slightly bey[ond] neutral position toward flaps down, at the same time making a medi[um] [...] to leave the traffic area. Being in a bank, I did not notice the flaps going

As a result of improper movement of the handle in this manner, I found myself at this low altitude in a fairly steep bank with 120-mph airspeed."

"We started down the runway and we didn't have any flaps, so the copilot tried to put them down. You need 15° for take-off. We had a new copilot. He didn't know his way around inside a B-25 and so put them down all the way. We couldn't get any airspeed then so he tried to pull them halfway up and they just kept coming up. Pretty soon we were at the end of the runway with no flaps. We were just hoisted off the ground."

Wrong Sequence in Raising or Lowering Wheels. "I put the landing gear handle of a P-47D to neutral instead of to down position while in the traffic pattern for a night landing. The landing warning light failed to function properly—consequently, a wheels-up landing was made."

"When returning from a day practice formation flight in a B-24, with *number-one engine feathered, due to the prop governor being inoperative,* the following error in operation of controls occurred. The pilot planned to make a close pattern and to drop his gear on the final approach. Turning from a short base leg, with plenty of altitude, the pilot placed the gear handle in the down position. After the main gear had extended, and before the pilot had received the 'gear-down-and-locked' signal from the engineer, the pilot placed *the flap handle in the down position. The flap selector valve* bypassed all the hydraulic fluid from the main gear selector valve and as a result the nose gear failed to fully extend and lock. As the landing roll slowed down and the nose gear touched the runway, the nose gear collapsed and caused considerable damage to the nose section of the plane."

Adding Power Too Suddenly. "The trim tab had been set for landing. The cadet overshot and had to go around again. He hit full throttle and the BT-13's nose went right up. Before he could get the nose down again, he had stalled and crashed."

Failing to Lock or Unlock Throttles Properly. On take-off, the copilot of a C-47 failed to tighten throttle tension sufficiently, so that throttle control slipped back the instant the first pilot released it. Recovery was made in sufficient time to prevent serious loss of power. This has happened several times and might easily prove fatal."

Failing to Roll in Trim Fast Enough. "On a B-29 mission out of India, I was to take another airplane I wasn't familiar with, so I went down in the afternoon of the night flight and checked everything in the aircraft. I noticed that the elevator trim had been set 2° aft, nose high, and I assumed that the pilot who had flown the aircraft last had set it that way in landing. On take-off that night, I gained flying speed around 120 and tried to get the nose off the runway but she wouldn't give. I gave her more trim. By that time, I was at 130 airspeed and running out of runway. Finally I had to take my left hand off the throttle, put it up on the wheel, and jerk her up by force. After the mission, we checked and found out that the trim tab control wheel had slipped about 4°. The trim tab is down to the left of the pilot and is about an 8-inch disk. It takes a good deal of time to re[ach] [d]own there and turn it. I'd say it takes about a revolution to put in a [...] of trim."

Failing to Adjust Other Controls Properly. "The switch for m[...] and autofoot. In some B-17's this switch is spring loaded in the automatic position. In others, it is a 3-position switch—manual, off, and automatic. I was familiar with the former type and got into the embarrassing position of having no hydraulic pressure when I needed it."

III. Forgetting to Operate a Control

Taking Off with Flight Controls Locked. "We were headed overseas in a B-24, taking off at night. There were other planes taking off ahead of us and it was a fairly windy night so I locked my controls. The runway was rather short. We turned on the runway with full power and started down with the wind taking us off to the left. I tried to use my rudders and found they were locked. For a second, I thought it was the wind. I tried them again, then tried the aileron, and found it was locked. So I had the copilot unlock them. By that time were going about fifty or sixty miles an hour but we finally got off okay."

"The only error I can recall at the moment is one time when two aviation cadets were killed in an AT-17. They took off with the rudders locked. I suppose a more experienced man could have gotten off and come in with just the ailerons, but in this case they didn't get off the ground more than ten feet and then went back in."

Forgetting Generator or Magneto Switch. "After scramble take-off in a P-40 for a night defensive mission and normal climb to altitude, an interception was attempted on enemy bombers. Some thirty minutes later, complete failure of the electric system occurred. After attempting to solve the difficulty to no avail, the pilot circled the area until the alert was over and after some difficulty, managed to pump the gear down and effect a landing. Later investigation found the trouble to be in the generator switch. The pilot had missed it in his cockpit check prior to take-off."

Forgetting to Make Proper Engine Control Adjustments. "Student was on a dual transition flight in an AT-6 letting down from about 7,000 feet where we had been practicing acrobatics. The mixture control was pulled back for a very lean mixture at 7,000. Student forgot mixture during let down, so at 3,000 feet engine began cutting out. He went through all of the emergency gas procedure—changing tanks, using wobble pump, cutting throttle, all to no avail. Student was preparing for forced landing at 1,000 feet when I pushed mixture forward and restarted engine. At the time, he had completely given up restarting the engine."

Forgetting to Lower, Lock, or Check Landing Gear. "While at an English gunnery school, flying Spitfires, we always made very short patterns coming in for a landing. As a result, we became a little careless on checking our gears. One day I failed to check my gear selector, came in, and landed. It was a fairly decent landing but when I touched, I rolled about 10 feet and the gear just folded up, and all of a sudden the props began flying every which way. I skidded about 50 feet on the runway and there I sat."

Taking Off with Wrong Trim Settings. "I was returning from my fir ...ght in the P-47. I had received landing instructions and had m

trim tab was turned a considerable portion to the left as I broke my glide preparatory to landing. While upstairs, I had given quite a bit of thought to this particular landing, my speed down the approach, when I would start to break my glide—everything. As it happened, I made a perfect three-point landing in the first hundred feet of the runway. Frankly, it surprised me for I had not expected half as good for my first try. I suppose it halfway convinced me that all my fears upstairs were ungrounded where landing was concerned, so, the landing over, I forgot everything except the fact that I had made a perfect landing on my first night flight.

"After having smoked a cigarette and shot the bull with the fellows, I entered the ship again for my second flight of the night. This time, I wasn't worried, only bored because I had to hang around the line so late at night. I taxied out to the take-off runway without a care in the world, still congratulating myself on the perfect landing. After checking my engine instruments, I received the go-ahead signal and gave her the gun. At about 80 mph, the ship tried to leave the ground but settled back down again so I gave it more mercury. All the time I noticed the stick pressing harder and harder back in my stomach and the plane had a tendency to veer viciously to the left. In a second, the ship was off the runway and bouncing across the grass to the left. Then—too late—I realized that I had forgotten to set the trim tabs for take-off. They were still in the same position I had turned them for the previous landing. By this time, I had forgotten about the rudder (I couldn't possibly hold it) and was concentrating all my effort on holding the stick down and keeping wings level. It took practically all my strength to do this in order to keep the plane from going straight up. I could only reach over and turn the elevator tab a little at a time until it was back to normal. Then, after also adjusting the rudder tab, I took stock of my situation and found that I had taken off 30° to the left of the direction of the runway and had narrowly missed a jeep as I bounced across another runway. Once I got those tabs okay, I had no more trouble and there were no serious results."

Taking Off with Pitot Cover On. "The following experience can be directly attributed to carelessness on the part of the pilot; however, it has been experienced by most pilots and some instrument could probably be devised to remedy the situation. The pilot took a P-47D off with the pitot cover on, thereby necessitating an extremely 'hot' landing due to the fact that no indication of the airspeed was available. This caused a potential hazard to both the aircraft and the pilot. Some sort of warning light could be placed on the instrument panel which would light up when the master switch is turned on and the pitot cover is still on."

Forgetting to Operate Other Controls. "Our plane, a C-47, had a load of 33 persons with baggage. At the time, we were flying at 4,000 feet with a near-solid overcast at 1,200 feet. This happened in India and there were no regular airways or radio facilities in the vicinity. Approximately an hour and a half after take-off, the left oil pressure started to decrease. A few minutes later, the left prop ran away. It was immediately ...red. A letdown was made through the nearly solid overcast so t... might caused by my mixture control being pushed into 'Idle cutoff' accidentally by my arm when I was struggling with the bomb release."

VI. Unable to Reach a Control when Needed

"I was taking off from Clark Field on Luzon, Philippine Islands, in a P-51. As I left the ground, the plane nosed down and the prop almost hit the runway. The reason was that the gear handle in the P-51 is so far forward that when the pilot reaches for it, he is flying blind from the time he reaches for the handle until he is in an upright position again. This defect has caused several accidents that I know of. In my opinion, the gear handle should always be where the pilot can reach it without going on instruments or 'seat-of-the-pants' flying."

"This is an experience I had flying P-51's in Germany. On this particular mission, we had gotten a little bit off course and flew directly over a large city in the overcast. They shot up some flak at us. In breaking away, I ran out of gas on one of my drop tanks. Reaching down to change over to an internal tank, I stuck my head way down in the cockpit and at the same time I leveled out of my turn. Unconsciously, I must have pulled back on the stick, because the next time I looked out of the cockpit, I had come up right beside another P-51. I was inches from hitting him. Just had my head down in the cockpit and wasn't watching what I was doing."

PSYCHOLOGICAL ASPECTS OF INSTRUMENT DISPLAY. I:—ANALYSIS OF 270 "PILOT-ERROR" EXPERIENCES IN READING AND INTERPRETING AIRCRAFT INSTRUMENTS*

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A. Purpose

1. In order to determine methods of designing aircraft instruments so as to improve pilot efficiency and reduce the frequency of accidents, accounts of 270 errors made by pilots in reading and interpreting instruments have been collected and analyzed. Results of the analysis are presented in the present report.

B. Factual Data

2. Accounts of errors were obtained through recorded interviews and written reports. The following question was used to elicit the desired information:

> Describe in detail some error which you have made in reading or interpreting an aircraft instrument, detecting a signal, or understanding instructions; or describe such an error made by another individual whom you were watching at the time.

3. Pilots in the Air Materiel Command, the Air Training Command, and the Army Air Force Institute of Technology, and former pilots in civilian universities contributed error accounts. Only detailed factual information furnished by an eyewitness or by the pilot who made the error was accepted. All reports were given anonymously.

*Reprinted from Memorandum Report TSEAA-694-12A, Aero Medical Laboratory, Air Materiel Command, Wright-Patterson Air Force Base, Dayton, Ohio, October 1 [illegible]

on the right engine to maintain 115–120 mph. The right cylinder head temperature ran up to 230 degrees Centigrade after five minutes of operation at this setting. The passengers were then told to jettison their baggage. After this command was effected, the plane held altitude at a lesser power setting. We were able properly to orient ourselves and proceed to a British emergency landing strip some 50 miles distant.

"A long, high straight approach was made and at an altitude of 1,200 feet, the pilot ordered gear down. The engineer put the handle in the down position. I watched the pressure gauges on the right of the copilot and after a few seconds saw the pressure was not building up at all. By this time, the plane was at 500–600 feet and the pilot was nearly ready for flaps. I turned to the engineer and asked him what the hell was the trouble. At that instant, he remembered he had not changed the hydraulic selector valve to the right engine. This was done immediately and the gear was down and locked just a few seconds before the plane touched the runway. The pilot landed the plane in the first two-thirds of the strip. No damage resulted to the plane or to the personnel aboard—but it was *very* close indeed to being another story."

"A C-109 that took off in front of our C-46 in India did not use landing lights and almost flew into the ground out of a turn immediately after take-off. The pilot straightened the plane up in time, however, and made a normal climb from the field. Checking on this later, it was found that the pilot had taken off with gyros caged. I have heard of this happening on several occasions since."

IV. Moving a Control in the Reverse Direction

Making Reversed Trim Correction. "During a demonstration flight of single engine procedure in a B-25C type aircraft, it was necessary to make the rudder adjustment using the rudder trim tab on the floor between the pilot and copilot seat. To make this adjustment, I had to take my eyes off of the instrument panel and bend down to reach the trim tab control. The trim tab control trims in the opposite direction for which the correction is desired. Because of the design of the trim tab, opposite trim was put in, giving the aircraft a tendency to snap roll. An accident was narrowly averted."

Making Reversed Wing Flap Adjustment. "As an aviation cadet, I was making an instrument take-off (under a hood) in a B-25-type aircraft. The take-off itself was uneventful. After becoming airborne, I retracted the gear, made power reductions, etc. After reaching 300 feet and at least 160 mph, I reached down for the flap handle to raise the flaps. Due to the natural strain that simulated instrument flight under an exacting instructor has upon a lowly aviation cadet, I mistakenly moved the lever to the *rear*, instead of forward, putting the flaps all the way *down*.

"Naturally, the aircraft slowed down and I was quite busy keeping it [illegible]der control while the instructor searched for the trouble. He foun[illegible] [illegible]tly and everything turned out all right but we both had a few an[illegible] [illegible]moments because of my error."

normal cruise for about one hour when a change in altitude of our B-24 was needed. The pilot reached for the mixture control and, probably thinking he was in a conventional type, pushed one mixture in idle cutoff and started to push the others in the same position. The copilot immediately noticed this and corrected the mistake before anything happened. It seems to me that the B-24 and the B-17 are the only planes whose mixtures worked from front to rear instead of rear to front."

Making Reversed Movement of Some Other Control. "Pilot's coolant was very hot so he was instructed to open coolant shutters. Instead of opening them, he closed them which made things hotter and he was forced to bail out."

V. Unknowingly Activating a Control

"Coming in on the final approach in a B-17, the pilot asked for landing lights. The flaps were one-half down and we were about 2,500 feet short of the runway. When reaching for the landing lights the flap switch was accidentally hit, knocking the flaps up causing the ship to mush into the ground. Major damage was done to the plane. I think this could have been prevented had the switches been further apart."

"While flying through a cold front at night in a C-47, icing conditions were encountered and it was necessary to apply carburetor heat to the right engine. While handling the carburetor heat controls, the copilot unknowingly moved the right-engine gas selector switch out of its proper position. The gas selector switch vibrated around to the off position and approximately two minutes after the carburetor heat had been adjusted, the right engine cut out. A possible tragedy was averted by the quick thinking of the engineer who turned his flashlight on the gas selector gauge immediately. The engine caught again as soon as the selector switch was returned to its correct position. The rest of the flight was uneventful."

"My P-51 squadron was making the first fighter-escort mission from Iwo Jima to Japan as escort for a strike force of B-29's. All went well until we reached the rendezvous point with the bombers just south of the mouth of Tokyo Bay. At this point, the signal was given for the fighters to drop external gas tanks. My altitude at this time was 21,000 feet. Before dropping, I switched to an internal tank in the prescribed manner. When I pulled the manual release, only one tank dropped, so I gave the release another and harder pull. Almost immediately, my engine cut out without warning. I called the flight leader, told him of my trouble, and turned out toward the ocean, for by that time we were about 30 miles inland. As I passed over the bomber stream, some trigger-happy gunner gave me a help with his 50 caliber. I was very puzzled as to the trouble with my engine and did not find the trouble until I was down to 9,000 feet and all by myself over Tokyo Bay.

"On the P-51, the mixture control is on the lower half of the throttle quadrant. The manual bomb release is on a straight line fr[illegible] [illegible] pilot's shoulder past the mixture control. If the pilot grasps the [illegible] release palm up, there is no trouble, but if he grasps the release p[illegible] [illegible]own, his