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# Human Error Research and Analysis Program (HERAP)

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**The purpose of HERAP is to analyze the man-machine-environment system, to synthesize improvements in human performance and, thereby, to attenuate the frequency and severity of accidents. A typical mission was analyzed to map where demands upon the pilot, risk, and accidents are greatest. Existing computer files have been organized into a data bank in order to apply efficiently analytical statistical tools, and to evaluate the validity and reliability of the basic data. Methods are under study to optimize the collection of exposure data. Accident rates adjusted for risk will permit an unbiased baseline from which to judge future performance and attempts to decrease accidents. Emphasis has been placed upon supporting the accident investigator with rapid-access computer files of airframe changes and accident patterns. Work is in progress on how the accident investigator can code his findings to optimize the assistance obtained from such files. Certain data suggest that proper collection of exposure data can, in itself, improve pilot performance which, in turn, is likely to reduce accidents. The total analytical system has been designed to do in days what present methods do in months or years.**

## I. Introduction

In recent years, the U.S. Naval Aviation Safety Center (henceforth referred to as the Safety Center) has undertaken an all-out attack on human error as a source of naval aviation accidents. This led to extensive planning for a concerted effort on this difficult problem. The later stages of this planning were performed by the Douglas Aircraft Company in fiscal year 1966. Execution of the plan was initiated during the next fiscal year. The purpose of this paper is to report the progress of the two groups, the Safety Center and Douglas.

## II. Data Collection

A key task in this work was the collection of data. The Safety Center has kept records on naval aircraft accidents since 1922. Work progressed steadily with these data and culminated in punch-card files that could be processed by machine. Recently, with the aid of a new computer, these records were put on magnetic tape. A part of the concurrent Douglas effort concentrated on analyzing the present and future use of these data, and developing an appropriate data management system.

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Before the arrival of the first data file, work began on assessing the present status of naval aviation data summaries, i.e., U.S. Navy Aircraft Accident Statistics (Table 1). These assessments indicated that only accident data were used; i.e., there were no comparisons between the accident and nonaccident segments of the populations. Second, the comparisons were only descriptive; i.e., there were no analytical tests indicating that something was significantly different from anything else. Third, the rates cited were not adjusted for risk. It is well known that landings, flying hours, and

**Table 1 U.S. Naval Aircraft annual accident statistics**

| | | Statistics | | |
|---|---|---|---|---|
| | | Descriptive | | |
| Table | Title | Totals | Rates | Analytical |
| 1 | All Navy flying hours-accident-rates | X | X | |
| 2 | Aircraft exposure, accident data and dollar loss by command | X | X | |
| 3 | Aircraft accidents by type duty | X | X | |
| 5 | Atlantic Fleet aircraft accidents | X | X | |
| 5 | Pacific Fleet aircraft accidents | X | X | |
| 6 | Aircraft accidents by model | X | X | |

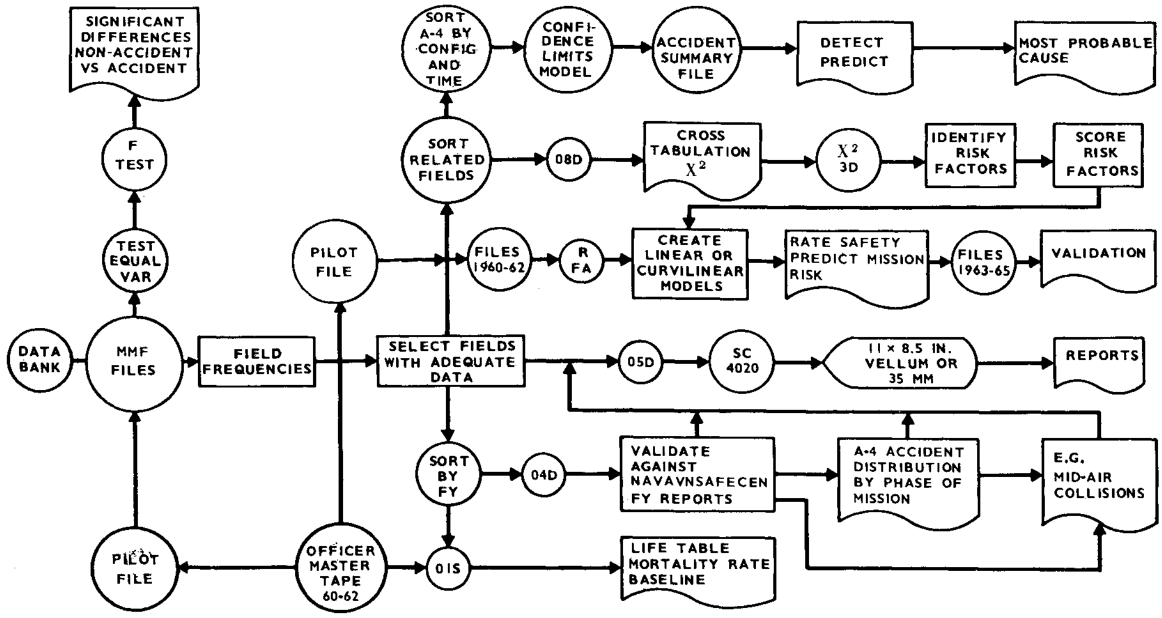


**Fig. 1 Data analysis plan HERAP FY 67.**

number of flights vary in risk, depending upon weather, the kind of field, carrier or land base; the kind of aircraft; the kind of mission, etc. Fourth, there seemed a need for a baseline on morbidity and mortality, regardless of influx and efflux, for this population called "designated naval aviators." In other words, one would wish to establish beforehand an unbiased yardstick to measure risks and accidents under present activity conditions and the magnitude of future changes in accidents adjusted for risk under presumedly different activity conditions. Therefore, major objectives considered were: obtaining an extant file of all designated naval aviators, making a life and mortality rate table for epidemiologic analysis, and obtaining an index of exposure to risk. Effort was directed toward achieving all of the preceding objectives.

The first copy of the Mishap Master File served as a model for the problem. This file is a conglomeration of data brought together from 24 punch cards kept by several naval agencies, testimony to not an insignificant feat in data management. The length of each record in the Mishap Master File depends upon the number of aircraft and personnel involved in the accident. In general, the length is 1656 characters for 782 variables. These records were reorganized into 23 card images of 80 characters each to facilitate the use of statistical programs in FORTRAN. A map was made of these card images cross-indexed to the code book to permit concurrent analytical statistical work and programmer activity (Table 2). Validity checks also were made between Douglas and Safety Center analyses.

There were two concurrent objectives to be achieved with the Mishap Master File. The first was to apply systematically analytical tools and, as this experience accrued, the second was to design a data bank system to permit such

**Table 2 Mishap master file**

| REPORTING CUSTODIAN | | | TYPE DUTY (OP-501) | | | MAJOR COMMAND | TIME OF MISHAP CONDITION | TIME OF MISHAP LOCAL TIME | | | | ACCIDENT DMG | AIRCRAFT DMG | ACCIDENT INJ | AIRCRAFT INJ | HULL NUMBER | | | KIND OF FLT | | | CLEARANCE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 |
| 100. | | | 99. | | | 99. | 99. | 0. | | | | | 100. | 100. | | 26. | | | 22. | | | 19. |
| 100. | | | 99. | | | 99. | 100. | 0. | | | | | 100. | 100. | | 23. | | | 14. | | | 16. |
| 100. | | | 99. | | | 99. | 100. | 0. | | | | | 100. | 100. | | 21. | | | 12. | | | 11. |
| 100. | | | 99. | | | 99. | 100. | 0. | | | | | 100. | 100. | | 16. | | | 15. | | | 9. |

activity with great facility and efficiency. The first activity was concerned with finding out what was in the Mishap Master File. This was attempted with a frequency-count program. It soon became clear, however, that a count of single columns would not permit the exploration of many multicolumn fields, so the program was modified. Initial experience showed that frequencies varied from zero to complete data and that codes varied from less than ten to many thousands. Thus, the program was modified again to express frequencies for fields and codes additionally as percentages of total possible data (see Table 2) and to sort the fields with large numbers of codes. This permitted the fundamental investigative experience of examining the data. It also suggested that statistical programs generally available were not designed for the size and complexity of the Mishap Master File. This was an important finding for those working on the data bank system.

A milestone event for the analysts was that of being able to look at the data. As usual, this alone permitted the formulation of many intriguing hypotheses and the uncovering of numerous leads worthy of follow-up. For illustration, only one will be given here. There seemed to be no point at all to search the aircraft serial number field but, on a hunch and for the sake of completeness, it was done anyway. As expected, most numbers turned up with a frequency of one or two. Surprisingly, several turned up with frequencies of from 10 to 18 mishaps for one year. Whether true or false, combat or noncombat, such a finding suggests further investigation.

The frequency-count program also permitted the greatest saving of analyst, programmer, and computer time. Of the 782 variables, it indicated that only 245 had data for the past four years. Therefore, 69% of the variables could be eliminated from further analytical consideration for the present. Subsequent analyses of these variables showed that many of them had no magnitude and that only 24 concerned causes of accidents. This was considered vital information for the selection of statistical tools.

Subsequent analytical work followed the broad outline of a tentative plan (Fig. 1). Note that the central section of the plan suggests the computer production of U.S. Navy Aircraft Accident Statistics, thereby providing for the release of manpower to analytical statistical work. The officer master tape (bottom section) shows its use in defining the entire population of designated naval aviators, formulating the life table, and permitting tests between accident and nonaccident samples. The upper sections of the plan refer to the formulation of risk and predictive models, some of which will be discussed later. Much of this work is still in progress.

## III. Data Bank Design

The experience of our investigators, analysts, and programmers identified additional constraints for the data bank. The initial constraints were that the languages be limited to FORTRAN and COBOL, and that the system be compatible with the Safety Center computer. The analytical work with the Mishap Master File indicated that the system should be simple, versatile, and conducive to growth. The system also should have the capability to handle several files with facility and, if necessary, to bring to bear on extracted data several statistical programs in succession. The level of aspiration also required all of this with no more than four control cards that could be filled out by anyone unschooled in programming. Figure 2 shows a block diagram of this data bank system. The following control cards permit the investigator to demand what he wishes for the extraction of data and for statistical analysis:

1) Case N-M field 1 (constraint 1, constraint 2, . . .)
2) Variable (A/N field 1, field 2, . . .field N)
3) Count (%) field 1 (value 1, value 2 . . .) field 2 (value . . .)
4) Program name (parameter 1, parameter 2 . . .)

For example, he may wish to test the hypothesis that severity of landing accidents is related to aircraft landing speed. He extracts from the file only the data that he needs; i.e., only landing accidents for the aircraft of interest with only the aircraft damage code. The aircraft damage code is an alphabetic field ordered according to severity. The data bank permits the conversion to appropriate numeric values. The program selected is a correlational analysis between aircraft, scored according to landing speed, and aircraft damage, scored according to severity. The data bank will permit all of these typical operations in one pass through the file and will require only four control cards. Another feature of this system is that provision has been made in the user's module for growth. For example, one may work problems requiring data from two distinct files through use of this module. Altogether, the system provides the simplicity, the versatility, and the efficiency to encourage analytical investigative efforts at the Safety Center.

## IV. An Auxiliary Accident-Investigation System

For accident investigation, the Navy has evolved a thorough procedure that is performed by officers of the squadron involved. From time to time, criticism has arisen because the squadron must execute its normal duties, while expending great blocks of time on accident investigation. One of the first activities in this area was to perform a tradeoff study on the squadron vs a brother squadron vs a specialist group as

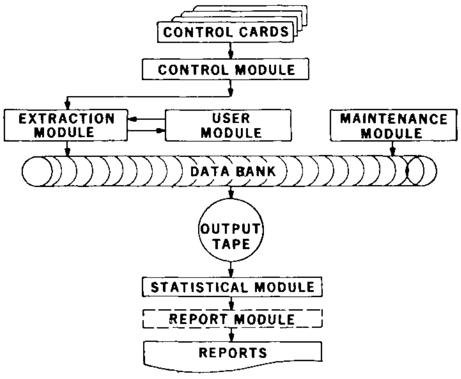


**Fig. 2 NAVAVNSAFCEN Honeywell 1200 data bank system.**

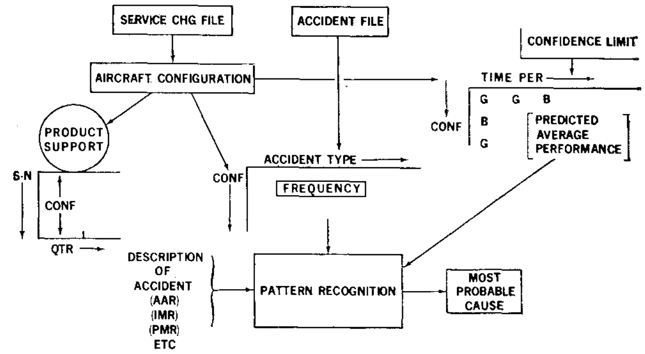


**Fig. 3 Auxiliary system.**

the responsible investigative agency. The study showed conclusively that the present system was the best; i.e., the involved squadron should investigate the accident. Attention was then turned to an examination of the Douglas methods of supporting accident investigations associated with the A-4 aircraft. This aircraft has a long history in the Navy which permitted several groups in Douglas to evolve a number of methods of time-proven value. These methods were researched and a system was developed that may be considered an amplification and integration of Safety Center and Douglas methods of investigating accidents.

When an A-4 is involved in a mishap, the commanding officer can call Douglas product support groups for information and assistance. Information generally is required on the configuration of the aircraft. The group that keeps the service change file publishes a booklet of summaries. A search of the summary booklet is made for the changes that list the serial number under investigation. Copies of the drawings are obtained and given to the Douglas accident investigator to take to the scene.

Another Douglas group keeps an accident summary file derived from the Aircraft Accident Report. These summaries contain limited information, i.e., serial number and observations (e.g., fire) on systems and components affected. From these and from memory, technical assistance is given to the accident board as to the possible causes of the accident. A good understanding of the interrelationships between the airframe changes and accidents is obtained by keeping this summary file. This information is valuable to the accident board because it gives them a logical place from which to start the investigation.

Both groups worked independently and did the best that could be expected with the methods, materials, and budgets provided. These systems, however, were difficult to keep going because technically qualified people were required to do clerical work. As the accident file became larger, memories were not as dependable. Nevertheless, these are still considered valuable services to the accident investigating team.

The approach was to shore up the system's components where they were weak, then organize, coordinate, and complete them. This is shown in Fig. 3. The Service Change File was computerized and permits look-up tables called Aircraft Configuration. These tables give configuration of serial numbers and serial numbers in a configuration, permitting analytical activity not possible with the summary book. These tables will be put on the IBM 2250, on-line to the IBM 360/65, and will be displayed immediately on a large cathode ray tube (permitting photos of the display, if necessary). This, by itself, will significantly enhance Douglas support of the Navy for any A-4 aircraft accident.

Subsequently, the configurations for the serial numbers will be recorded quarterly to permit the study of changes with time and accidents. One step further was to record what was left to human memory. Therefore, included in this portion of the system is information on why the service change was made and with what sort of mishap it may be associated.

Thus, this permits a stringent assessment as to whether the service change had a good, bad, or no effect on what it was meant to fix.

The central portion of Fig. 3 shows the computerized Accident Summary File. From this file and the Aircraft Configuration File, accident types can be plotted against configuration. This matrix can quickly show on the IBM 2250 any configurations becoming active in mishap patterns because of airframe changes or lack of them.

From the description of an accident that has just occurred and from the instant display of accident type vs configuration, together with state-of-the-art pattern recognition techniques, one can produce the most probable cause of the accident. If no description is fed in, then this module will produce a generalized answer, i.e., the most frequent cause on record. To the extent that the description is more specific, the cause given will carry a higher probability of being correct. Expectations are that this will significantly aid the accident investigator because it not only tells him where to start the investigation, but also the precise odds from all past experience that this is a correct guess.

The confidence limits module was the model that led to the design of the remainder of this system. This tool uses past accident experience to indicate, at any specified level of probability, that the accident system has changed to a significantly better or worse situation. It accounts for the erratic way that accidents happen and provides control over falsely becoming alarmed or complacent which is not possible by viewing the raw data. Another attribute is the ability to predict, as well as detect. That is, there would be the possibility of saying, at any given level of probability, that we shall have an epidemic of accidents. Thus, this permits a wide-angled look at an entire accident world and permits the most effective planning and strategy, whereas the pattern recognition module permits scrutiny of each accident and the rapid, precise selection of tactics. We believe that both are needed.

The advantages of this system are that present subjective methods become objective with known odds. The tool permits decisions that will be correct 95 times in a 100, 99 times in 100, 999 times in 1000, or any other probability. Manpower and funds can be directed with accuracy and speed. This system will tell in days what may not be obvious to people in months or years. This system also encourages people to be more objective and precise because the help that it gives these same people, the accident investigators, is proportional to the precision and accuracy of the data that they feed into it. People in this area already have expressed a cheerful willingness to change their procedures, if it would increase the accuracy of the probabilities obtained from such a system. If procedures need to change, then the people putting forth the effort will be the ones to benefit immediately.

This approach squarely faces the fact that aircraft number and model designation are no longer sufficient for the investigation of accidents. Accident investigators require aircraft resolution right down to the last airframe change. We may as well give the investigators this resolution with a configuration number. If it is an A-4E795, then we may as well say it and put it on the records that way.

## V. Pilot Tasks during Mission Phases

A representative mission was identified for a typical naval aircraft. The purpose was to analyze the mission and the pilot tasks in detail in order to identify areas of high risk. Toward this end, function/task analyses were placed on what may be considered a baseline map of phase of operation. This baseline map provides a tool for investigators to pinpoint, as epidemiologists do, where accidents cluster. Thus, this provides an objective way out of the accident narrative to data points on a continuous scale. It is the position and the cumulative risk experience on this scale that permits widespread direct application to accident prevention. Through another channel, accident investigation, these raw data also would be applied to accident prevention. Ultimately, however, this is the type of refined input that could optimize the output called "most probable cause" in the auxiliary accident investigation system (Fig. 3).

For prevention of accidents, this system also permits pinpointing areas of weakness where there have been no past failures. For example, on recent carrier observations, wind measurements for catapult operations made from several instruments did not agree. Efforts to standardize these instruments still resulted in equivocal readings. Because only a plus 8- or 10-knot allowance above flying speed is made, there was real concern. Planes had been observed sinking at the end of the catapult shot, but there was no way of knowing which one of the many factors was involved. So far, this crew has had no known mishaps attributable to inaccurate wind-speed measurements. A map for systematically plotting safety weaknesses and for systematically applying preventive measures should permit a more efficient conservation of men and resources than waiting for accidents.

These analyses have also focused attention on the possible causes of accidents, like the inadvertent losses of external stores during ordnance delivery. Test pilots prepared a comparison of tasks required for bomb release on various ordnance release systems. In one family of systems, the pilot tasks involved have increased stepwise from 10 to 17 in the latest system. If loss of stores has been a problem in the past, and it has, then these analyses suggest that it will increase. Clearly, here is another spot on the map of phase of operation where preventive work should be done.

## VI. Resolution of Causes and Risks

Library activity for this program mainly served as over-all support for the research activity. Descriptions of human error, accidents, safety, and aviation were collected and systematized to develop tactics for literature searches. This led to reorganization of cataloging schemes in this area and coping with the problem of defining causes of accidents. Some of the schemes examined are in terms of factors, problems, errors, faults, failures, or observations. Some of these schemes are organized according to the occurrence of these terms in the human, the machine, or the environment. Altogether, one can sense a need for improvement in this area. Blame still seems to impede investigations, checks and balances notwithstanding. One can sense the need for a tidy continuum upon which to plot causes, but an all-inclusive scheme is elusive.

Work in another area, exposure, suggested a different way to think about this problem. The problem with developing an exposure index is that all activity must be counted and it is too expensive to obtain an index for the various phases of operation if one must wait for accidents. An alternative is to rate performance, like carrier landings, for example, according to an objective scale under steady-state conditions. One then can rate field landings under the same conditions and, presumably, obtain higher mean scores. The constant that equates the two sets of scores signifies the degree of difficulty or risk that distinguishes the two types of landing activity. Then, one could adjust landing accident rates for risk by applying the appropriate factor. If one wishes to improve the men or the machines, then one can rely on the same scoring scheme as an objective yardstick.

This alternative of scoring performance, rather than mishaps, to obtain risk has the attractive property of giving key personnel distinct objectives for the key phases of their assignments. This philosophy emphasizes performance, improvement, recognition, and praise, rather than just pass (i.e., land), fail (bolter, bingo), or stigma (mishap, human error). In addition, by putting up scores, one capitalizes on the millennia-old phenomenon: post a score and watch the crowds beat it in the ensuing competition. The motivation, "How well can one perform?", seems more positive and exciting than the present one, "How can one stay free of accidents?" The philosophy instigates striving against high degrees of difficulty, whether presented by the enemy or by a degrading aircraft or by a difficult environment. One thereby approaches a single continuum to rate risk.

Now, let us go back to causation of accident based on problems, errors, faults, or failures in the human, the machine, or the environment. Instead, this scheme suggests that causation be defined in terms of a magnitude of risk or difficulty in the performance of a defined task or portion of the mission. Thus, this alternative is in direct terms for instruction or practice for preventive activity. In addition, one can handle causal data with analytical statistics because there would be magnitudes and distributions. And, once again, the generated philosophy is positive and instigates striving up the gradient of difficulty to eliminate systematically any threatened defeat of a mission. Such attributes seem to have advantages that overshadow those of some present systems of defining causes of accidents.

## VII. Conclusion

Present resolution of the accident system has been outstripped by the advances in complexity and speed of aircraft operation. The hazards produced by these complexities in equipment and operating procedures inevitably lower the reliability of human accident-free activity. The thought and technology that produced the complexities must be marshalled to master them. Toward this end, our groups find a common cause.