A Look at Aircraft Accident Analysis in the Early Days: Do Early 20th Century Accident Investigation Techniques Have Any Lessons for Today?

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Keywords: accidents, investigation, causes, lessons

Abstract

In the early years of powered flight, the National Advisory Committee on Aeronautics in the United States produced three reports describing a "method of analysis of aircraft accidents." The first report was published in 1928; the second, which was a revision of the first, was published in 1930; and the third, which was a revision and update of the second, was published in 1936. This paper describes the contents of these reports, and compares the method of analysis proposed therein to the methods used today.

1 Introduction

In early 1928, the Assistant Secretaries for Aeronautics in the Departments of War, Navy, and Commerce in the United States, asked the National Advisory Committee for Aeronautics (written as N. A. C. A. at the time, but as NACA here) to develop a common approach for the analysis and reporting of aircraft accidents within the country. In response to this request, the NACA organized the Special Committee on the Nomenclature, Subdivision, and Classification of Aircraft Accidents. This brought together representatives of the NACA, the Army Air Corps, the Bureau of Aeronautics of the Navy, and the Aeronautics Branch of the Department of Commerce.

The NACA committee met sixteen times from March to July 1928, and issued a report in August 1928 [5]. Subsequent to the issuing of the initial report, the NACA. established a standing committee, which published updated reports on the subject in January 1930 [6] and June 1936 [7]. The remainder of this paper presents an overview of the contents of these reports and compares the methods proposed to the methods used today.

2 Overview of the NACA Reports

This section presents an overview of the content of the three reports. Unless otherwise indicated, all quotations are taken from the relevant NACA report. The first report is described in the most detail, with the discussion of the other two reports concentrating solely on their differences from the 1928 report.

2.1 1928 Report

The first NACA report was "undertaken in recognition of the difficulty of drawing correct conclusions from efforts to analyze and compare reports of aircraft accidents prepared by different organizations using different classifications and definitions." The special committee that developed the method of analysis described in the report had as its purpose "to prepare a basis for the classification and comparison of aircraft accidents, both civil and military." Towards fulfilling this purpose, the committee developed a 14 page report, consisting of six main sections, the contents of which are described below.

2.1.1 Introduction

The Introduction describes the history of the development of the report, noting that the proposed method of accident analysis was presented to representatives of four foreign governments (Britain, France, Italy, and Japan). At this meeting, "great interest was expressed" and the foreign representatives were invited to submit comments and suggested changes, "but none had been received up to the date of the last meeting of the committee."

2.1.2 General Considerations

The second section of the report has five sub-sections: Definition of an Aircraft Accident, Immediate Causes, Cross-Analysis, Aircraft-Accident Analysis Form, and Weighting of Accidents.

An aircraft accident is defined as follows: "An aircraft accident is an occurrence which takes place while an aircraft is being operated as such and as a result of which a person or persons are injured or killed, or the aircraft receives appreciable or marked damage through the forces of external contact or through fire." The report notes that "a collision of two or more aircraft should be analyzed and reported statistically as one accident." Note that this definition is not substantially different in effect from the definition currently in use in civil aviation world-wide, but it is much simpler

The ICAO define an accident to be "An occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked, in which: a) a person is fatally or seriously injured as a result of: — being in the aircraft, or — direct contact with any part of the aircraft, including parts which have become detached from the aircraft, or — direct exposure to jet blast, *except* when the injuries are from natural causes, self-inflicted or inflicted by other persons, or when the injuries are to stowaways hiding outside the areas normally available to the passengers and crew; or b) the aircraft sustains damage or structural failure which: — adversely affects the structural strength, performance or flight characteristics of the aircraft, and—would normally require major repair or replacement of the affected component, *except* for engine failure or damage, when the damage is limited to the engine, its cowlings or accessories; or for damage limited to propellers, wing tips, antennas, tires, brakes, fairings, small dents or puncture holes in the aircraft skin; or c) the aircraft is missing or is completely inaccessible" [4]. The difference in complexity between the initial and current definitions arguably illustrates the increasing diversity of modern aviation operations.

In the Immediate Causes sub-section, the process is briefly described by which the committee settled on a particular analysis method, after considering a variety of possible methods. According to the report the plan developed "permits of the analysis of a given accident into two or more distinct causes and makes possible, by the use of percentages, the indication of the relative weight of each cause in any particular accident." Interestingly, the report does not give a definition for immediate cause, but rather seems to assume the reader will know what is meant by the phrase. The subsequent two reports delete this sub-section entirely, but continue to use the phrase without definition.

Most modern investigatory techniques have also moved away from the notion that it is possible to accurately quantify the weight or importance of particular causal factors. Organisations such as the NTSB and Canadian TSB will distinguish between causes and contributory factors but percentages are not used. There is a recognition that it may not be possible to derive an objective priority over the role played by, for instance human error or managerial failure compared to problems in system engineering. Such decisions are, typically, deferred to the litigation that often follows major accidents where courts will decide the liability to be associated with key actors in the events leading to an adverse event. It is unfortunate that some of the judgements handed down by legal agencies are not well grounded in the engineering issues that led to the accident.

The Cross Analysis sub-section explains that the developed analysis method "provides for the analysis of crashes according to the nature of the accident (take-off accidents, tail spins following engine failure, etc.), the degree of seriousness of personnel injuries, and the amount of damage to material." Also, the method provides for "analyzing pilot errors and material failures according to the underlying causes of these errors or failures." The sub-section concludes by noting that "it is the belief of the committee that if all aircraft accidents occurring in all agencies are classified in the manner recommended a composite of all the accidents will offer a basis upon which a study may be made and correct conclusions drawn." To date, only partial progress has been made towards this goal of the NACA first report. Accident investigation agencies around the world continue to use a vast array of non-standardised techniques. Most aircraft operators now have classification schemes for incidents and accidents; however, there are few general agreements about the ontologies to be used and there is little or no exchange of data, in spite of initiatives such as the GAIN program.

The Aircraft Accident Analysis Form sub-section, presents and explains a form to be used in analysing accidents. This form is shown in figure 1. The left-hand side lists four broad categories of possible immediate causes for an accident: personnel, material, miscellaneous, and underdetermined and doubtful. The first three of these are further divided into additional categories, with the first two having a third subdivision. Concerning the broad categories, the report notes "that the division of immediate causes between personnel and material as set forth in the chart and definitions was more or less arbitrary, since all defects of aircraft can be in the last analysis be attributed to errors of personnel, whether in operation, inspection, maintenance, manufacture, or design." In the opinion of the committee its purposes were best served by drawing a line at the "operating personnel of the aircraft." That is, the Personnel category includes only those people directly operating the aircraft. "Errors due to personnel other than those immediately accessory to the operation of the aircraft are shown in the 'Underlying causes' or 'cross analysis' … rather than in the main headings of immediate causes."

These underlying causes are enumerated along the top of the form, with two main divisions: errors of pilot and material failures, along with a column for indeterminate. Both main divisions are further sub-divided to three levels in some cases and two in others. The final sub-section discusses how the form may be used to assign a weighting to various causes of a particular accident. This weighting process is described below in section 2.1.5 when a typical accident is described.

2.1.3 Classification of Accidents

This section of the report presents a three-way classification scheme to aid the study of accidents. The three elements of this classification are the nature of the accident, injury to personnel, and damage to material. Before describing each of these, the report presents a rationale for the importance of appropriate classification schemes.

To explain the rationale, the report notes that "studies of accident causes point out needed remedies more clearly when they are supplemented by certain studies based upon the nature and results of accident." An example is then given concerning accidents involving tail spins, where it is noted that if accidents are "classified according to their nature and results, it is noted that the tail spin is the kind of accident that is by far the most prevalent among those which produce fatal consequences. It is apparent that new designs which decrease the tendency of airplanes to spin, or new training methods which increase the ability of pilots to avoid falling into spins and to recover from them quickly, will have a marked influence toward the prevention of fatal accidents.”

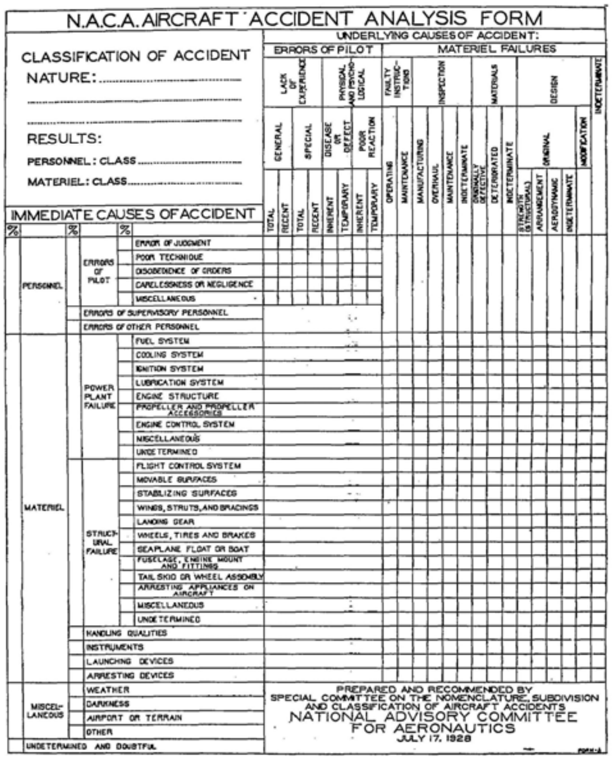

Figure 1: 1928 NACA Aircraft Accident Analysis Form

Clearly concerns have moved on in the years since the publication of this report; however, similar techniques are still being used. For example, the Flight Safety Foundation has been instrumental in persuading several investigatory agencies to look more closely at issues such as Controlled Flight into Terrain. The European Working on Runway Incursions continues this tradition of conducting detailed investigations of key safety problems based on the analysis of several previous accidents.

For the nature of an accident, the report presents 13 different possibilities. Class A involves collisions in full flight with other aircraft, while Class B involves collisions in full flight with objects other than aircraft. Class C (D) includes fail spins following engine failure (without engine failure). Class E encompasses forced landings, while Class F includes landing accidents where the landing was not forced. Classes G and H are for take-off accidents and taxiing (spelled taxying in the report) accidents respectively. Fires in the air are classified as Class I. Class J includes carrier, platform, and arresting-gear accidents; while launching gear accidents are called Class K. Classes L and M include miscellaneous and indeterminate/doubtful respectively.

The injury to personnel category has only four possibilities. An accident that results in death of an individual within 90 days is Class A. Class B includes accidents resulting in a serious injury to an individual, while Class C accidents result in only a minor injury, and Class D accidents result in no injury. Concerning the classification of injuries, the report suggestions that “the opinion of a physician should be obtained whenever possible as to whether an injury is severe or minor.” In the absence of a physician, the report provides general rules. Unconsciousness, fracture to any bones other than fingers or toes, lacerated muscles, severe hemorrhage, injury to internal organs, and incapacitation for more than five days are considered severe; all other injuries are minor.

As in previous sections of the NACA report, these distinctions are similar to those that guide modern accident investigation. For example, 49 CFR Part 830 guides the investigation of accidents by the NTSB: it defines fatal injury as any injury which results in death within 30 days of the accident. In contrast, serious injury means any injury which: (1) Requires hospitalization for more than 48 hours, commencing within 7 days from the date of the injury was received; (2) results in a fracture of any bone (except simple fractures of fingers, toes, or nose); (3) causes severe hemorrhages, nerve, muscle, or tendon damage; (4) involves any internal organ; or (5) involves second- or third-degree burns, or any burns affecting more than 5 percent of the body surface. As with the previous ICAO definitions of an accident, the intent is largely the same as that of the NACA definition, but the specific provisions add levels of detail that arguably not only reflect the complexity of modern aviation operations but which also reflect almost a century of aviation litigation.

Damage to materiel has six possibilities. Class A accidents include those in which “the aircraft is of no further value except for salvage of usable parts.” Class B includes accidents “as a result of which it is necessary to completely overhaul the aircraft before it would be again airworthy.” Accidents in which some major component must be replaced fall into Class C. Class D accidents are those in which there is only minor damage to the aircraft, while class E are those in which there is no damage. Class F is a special category consisting of materiel failures that did not result in an accident.

In contrast, the CFR that guides today’s NTSB investigations focuses on ‘substantial damage’ which is defined to include damage or failure which adversely affects the structural strength, performance, or flight characteristics of the aircraft, and which would normally require major repair or replacement of the affected component. The CFR also notes that engine failure or damage limited to an engine if only one engine fails or is damaged, bent fairings or cowling, dented skin, small punctured holes in the skin or fabric, ground damage to rotor or propeller blades, and damage to landing gear, wheels, tires, flaps, engine accessories, brakes, or wingtips are not considered “substantial damage". It can be argued that these exemptions illustrate the resource pressures that increasingly affect investigatory agencies given the substantial rise in aviation traffic since the NACA report was published.

2.1.4 Causes of Accidents

The report proposes a standard list of possible causes, both immediate and underlying, which can be seen on the accident analysis form shown previously in figure 1. Rather than describing all of the various causes discussed, we present only representative examples.

As an example of an immediate cause, consider the carelessness or negligence subdivision of the errors of pilot division of the personnel category. The report describes this category as including "all accidents resulting from the absence of care on the part of the pilot according to circumstances or the failure to use that degree of care which the circumstances justly demand, either on the ground, or in the air, such as careless manipulation of the controls of an aircraft, failure to ascertain the amount of gasoline on board before taking off, failure to ascertain the conditions of the instruments, etc." These distinctions remain applicable within the modern aviation environment. In the United States, for instance, there is no special law of aviation negligence; the same provisions apply as they do in any other spheres of activity. Pilots must, however, exercise a greater standard of care because of the potential harm that could be caused by any mishap.

As an example of an underlying cause, consider the deteriorated materials subdivision of the faulty materials division of the materiel failures category. This causal category "includes all accidents traceable to faulty materials where the defects of such materials occurred through deterioration after delivery." The importance of this category of causal factors cannot be underestimated in modern aviation. Composite materials are being introduced into areas that were conventionally only fabricated using metal, for example in the A380 and the B-787. These composite structures may well create particular challenges for accident investigators, as illustrated by the recent NTSB investigation into the possible failure of components in the composite vertical stabilizer involved in American Airlines flight 587, which eventually showed that there was no such failure.

2.1.5 Description and Typical Analysis of an Accident

To illustrate the application of the proposed analysis method, the NACA report introduces an example. Figure 2, which is taken from the report, provides an overview. The explanation of the accident in the report is as follows:

Pilot John Doe was flying a seaplane at 200 feet altitude over a point of land between a bay and the open sea when the engine stopped. Pilot Doe had an opportunity to land either directly into the wind in the open sea or cross wind in the bay. He started to land in the ocean, but at 100 feet altitude he changed his mind and attempted to turn so as to land in the bay. In turning, Doe held the nose of the seaplane up, stalled it, and spun into the land. The seaplane was demolished, the pilot was seriously injured, and the passenger was killed.

Doe, according to his record, was an experienced aviator with 30 hours flying during the preceding month and with recent experience in stunting seaplanes.

Examination of the engine showed that one of the teeth in the magneto timing gear had stripped, the broken tooth having been drawn into the other teeth, causing the eventual stripping of all teeth. The original break was determined to be a visible hardening crack.

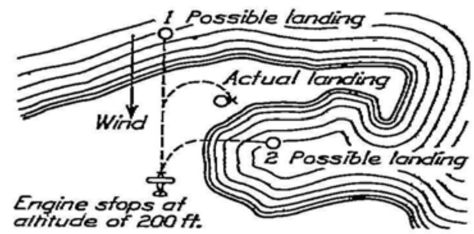

Figure 2: NACA Example Accident Scenario

Following the method of the report, the analysis of this accident begins by classifying it by nature, results to personnel, and results to materiel. The nature of the accident is Class C: tail spin following engine failure. The results to personnel are Class BA (that is, one major injury and one fatality). Finally, the destruction of the seaplane means that the results to materiel classification is A.

Figure 3 shows the results given in the report for the analysis of the causes of this hypothetical accident. Only the relevant upper part of the full form is shown here.

For the immediate causes, the report justifies allocating 75% to personnel and 25% to materiel by stating "that the account of the accident shows that the pilot had two chances to make a safe landing and took advantage of neither of them" For the materiel immediate cause, the further allocations are explained as follows: "the entire 25 per cent obviously should be assigned to 'power-plant failure,' in the second order of subdivision, and again in the third order of subdivision the entire 25 per cent should be charged to 'ignition system.'

For the personnel immediate causes, the report reasons "it is obvious that this is chargeable neither to 'errors of supervisory personnel' nor to 'errors of other personnel,'" so the entire 75% goes to 'errors of pilot.' To explain the 35/40 allocation, the report explains: "It appears further that the errors of the pilot involved errors of judgment in that he lost altitude while wavering indecisively between landing in the ocean and attempting to land in the bay. It appears that poor technique was the most important single factor in that he continued to pull the nose up, still further stalling the seaplane, when he should have sensed the approaching stall. It is considered that a charge of 35 per cent to 'error of judgment' and 40 per cent to 'poor technique' represents as near an approximation as can be arrived at in the this case."

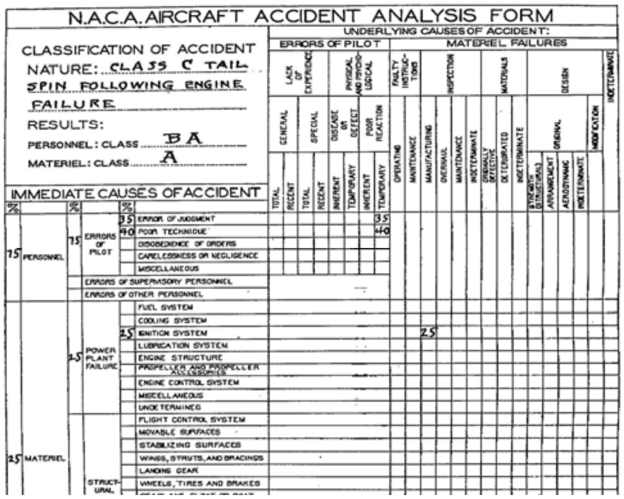

Figure 3: Completed form for hypothetical accident

The analysis of the underlying causes for the pilot's errors states "that it would appear that the 'error of judgment' and 'poor technique' were both due to a 'temporary poor reaction', citing the absence of any stated history of the individual upon which to conclude that the poor reaction was inherent. For the materiel failure, "the underlying cause of this materiel failure is unquestionably faulty manufacturing and accordingly on the cross analysis it would be placed under the head of 'manufacturing inspection.'

In spite of the similarities noted in previous sections, there are many differences between modern investigatory practices and the techniques illustrated in this case study. In particular, human factors experts and psychologists are now well integrated into the teams that analyze the causes of aviation accidents. Rather than simply identifying 'errors in judgement' and 'poor technique', today's reports often spend many pages identifying the cognitive and perceptual factors that contribute to such adverse events. Hence, the simple interpretation of these early NACA forms has led to more sustained multi-disciplinary investigations that are rooted deeper in the social sciences than might be apparent from the early investigations.

2.1.6 Conclusion and Recommendations

The final section of the report made three primary recommendations. One, that the method of accident analysis proposed in the report be adopted for use in the War, Navy, and Commerce departments. Two, that copies of the report be sent to appropriate representatives of interested foreign governments. And, three, that the personnel of the special committee "be reorganized into a standing committee on aircraft accidents on the National Advisory Committee for Aeronautics for the purpose of considering from time to time such new matter regarding aircraft accidents as may appear desirable or as may be brought before it." All three of these recommendations were adopted.

Today there are strong differences in the investigatory processes operated in the civil and military sectors of most countries, although there are frequent contacts between the individuals concerned. Such informal exchanges are critically important given that technical, engineering innovations often propagate from military to civil aircraft while operational and organisation techniques tend to flow in the opposite direction. However, the close integration of techniques envisaged by NACA has long since ceased to be the norm.

2.2 1930 Report

The Committee on Aircraft Accidents, which was established by the NACA in response to the recommendation of the 1928 report, produced a revision and extension of that report in 1930. The revisions to the report were minor, involving changes to definitions and explanatory material, an expanded discussion of the example accident, the introduction of a new class N (Structural Failure) to the nature of accidents, and the re-lettering of classes L and M to X and Y respectively. The accident analysis form was unchanged. The extensions to the report consisted of a response to a particular criticism of the method, and a description of the results obtained from applying the method.

2.2.1 Response to Criticism

A major criticism of the 1928 report was that the weighting process was likely subject to considerable individual variation. The response given to this criticism was to discuss a test conducted by the original special committee, but not mentioned in the first report. Each member of that committee was given 6 identical accident reports, which each person analyzed independently. The results were then averaged and compared with the individual weightings. "Every member was willing to accept the average values as a fair analysis of the various accidents and the differences between the values assigned by the individuals and the averages were remarkably small."

Today, similar trials have been conducted into the impact of subjectivity in the application of accident investigation techniques. For instance, Johnson and Holloway compares the different insights derived by the use of the STAMP approach by two different investigators on a single accident [2]. Holloway and Johnson analyse the role of subjectivity across several hundred investigations [1]. It is ironic to find that the criticisms of the original NACA report raise concerns that continue to be the topic of workshops and research papers even today.

2.2.2 Results from Use of the Method

The second extension was a description of the results that had been obtained in application of the method for a little over a year by the Army, Navy, and Department of Commerce. The accidents analyzed all occurred before January 1929, and extended back in time for several years. There were 1432 military accidents and 1400 civil accidents that were analyzed. The report presents two tables, one of which shows the percentages of accidents in each of the 14 'nature of accident' categories, and the other of which shows percentages according to immediate causes. For the immediate causes, slightly less than 50% of the military and civil accidents were attributed to pilot error, a result which corresponds fairly well to recent studies of major civil aviation accidents in the United States [1, 3].

2.3 1936 Report

In 1936, the Committee on Aircraft Accidents produced another report, based on the occurrence of some accidents "for which the specified classifications seemed inadequate." The major changes included subdivision of some the classes describing the nature of an accident, elimination of class F in the damage to material classification (note also the change in spelling from materiel to material), and modification of and addition to the categories for immediate causes. These modifications resulted in corresponding changes to the analysis form.

The 1936 report does not include the results presented in the 1930 report, but it does include the response to the early criticism. It also notes the existence of a procedure for providing guidance on interpretation of the definitions and use of the methods, saying "these questions have generally been referred to the committee for opinions or the interpretations followed have been communicated for approval. In this manner there has been established a sort of approved procedure."

The need to update and maintain an accident classification taxonomy between the 1928, 1930, and 1936 reports illustrates a problem that continues for modern investigatory agencies and commercial aviation organisations. Changes in technology, in organisational and operation practice can force continual changes in the categories that are used to codify accident data. As mentioned previously, the increasingly multi-disciplinary nature of many investigations also introduces new concepts, not just in the area of human error analysis but also in causal modelling. Recent work has been conducted into the use of computational techniques to minimise the overheads that arise when new classifications force the re-codification of previous accidents; however, this novel generation of accident search and retrieval tools is not yet widely used in many investigatory agencies.

3 Concluding Remarks

The NACA led a pioneering initiative to establish common approaches to the investigation and analysis of aviation accidents. Their reports in 1928, 1930 and 1936 laid the seeds that in 1967 led to the establishment of the US National Transportation Safety Board. By studying these early attempts to establish common methods of investigation, we can see the generic nature of many of the issues that continue to complicate accident investigations. For example, there is a common concern to develop objective analytical techniques that enable lessons to be shared between different investigators across a number of different organisations. There is also a common concern to identify multiple causes that consider both engineering and human factors issues. A common misconception today is that considering such issues is a relatively recent innovation. Our study of these early investigatory procedures shows this is not the case, as the reports illustrate a degree of sophistication in the analysis of pilot interaction.

There are, however, some important differences between the NACA reports and current investigatory practices. In particular, the committees' desire to develop common techniques between civilian and military reporting systems is very far from being achieved in the US or Europe. This creates problems when engineering innovations are often transferred from military to civil systems. Similarly, the NACA focus on establishing the weighting of causal factors has largely been abandoned, although it persists in civil litigation where the courts may assign civil liability to individuals and organisations in proportion to their involvement in an accident.

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