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Improvement of Aircraft Accident Investigation Through Expert Systems

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Research has been conducted at the Royal Melbourne Institute of Technology University in Melbourne, Australia on the improvement of aircraft accident investigation through expert systems. The aim of this research is to pursue a thorough analysis of the aircraft accident investigation, followed by identifying areas where significant improvements could be achieved, and finally demonstrating an expert system tool for improving investigation outcomes. Discussion on the development of applied methodology for aircraft accident investigation is presented.

I. Introduction

AVIATION is in a period of sustained growth, and that growth is likely to continue. Every year, millions of consumers use airlines to convey them to their destinations, helping airline travel to remain an economical and convenient means of long-distance transport.

Much of the success in air traffic safety has been due to knowledge gained from prior aircraft accident investigations carried out with the aim of ensuring that accidents in similar circumstances will never recur. However, despite the huge progress in air safety, accidents and incidents do still happen and can cause injuries, fatalities, and the destruction of property. Also, although accident rates are decreasing, the total number of aircraft accidents is most likely to remain stable or increase slightly mainly due to current growth in the number of airline flights annually worldwide [1,2].

In addition, statistics related to aircraft accidents reveal that the causes for a number of them remain unknown [3,4]. Even after many modern advances in detection techniques, the causes of several calamitous accidents are still undetermined, leaving the possibility that these unexplained causes may recur [5].

Thus, the conclusion has arisen that despite all of its current strengths, aircraft accident investigation needs to be improved to both help understand the causes of accidents and to prevent future reoccurrences. In this regard, the research presented in this paper has shown that expert systems methodology is a robust approach to analyzing the aircraft accident investigation. The research framework is presented in Fig. 1.

II. Research Methods to Aircraft Accident Investigation

The first challenge faced in this work was choosing the research approach to accident investigation and, thus, creating research strategies to help answer posed research questions.

A summary of the current research and literature relevant to air traffic safety has shown that survey methods [6–22], statistical data [23–35], and advanced classification of statistics [36–45] are a solid approach to analyzing the aircraft accident investigation. Thus, one major tool in the battle against an overall increase in aircraft accidents is the use of accident analysis to detect patterns within accidents and to identify areas where improvements are required [45]. In addition, Malcolm [44] says that every accident site is different but there are always some similarities, and for a large number of accidents these similarities are alarming [46].

There are a number of written materials in progress and research currently being undertaken, however, toward the enhancement of investigation outcomes, but most of these focus on a particular segment of the investigation process. Whilst developing individual segments of an investigation is essential for a holistic approach and the improvement of investigation outcomes, a strong sense of cohesiveness within the investigation must be maintained. This is only possible by analyzing the investigation as a whole. Therefore, finding research tools for analyzing the aircraft accident investigation and its demonstration is still a challenging task.

On the other hand, in the last few decades there has been considerable growth in the development of scientific methodologies for examining complex issues through establishing a set of priorities where significant improvement is possible and desired [47,48]. As a result, an interdisciplinary approach and intuition have shown to be vital elements in developing contemporary methods for creating strategic decisions, known as intuitive methods. For instance, in the 1980s there were over 130 different methods for creating scientific decisions [49]. These methods, according to procedure for creating decisions, can be divided into three groups: trend interpolation methods, methods of simulations, and methods of convergent concordance [50,51]. Interpolation methods, such as statistical analysis, provide a picture of the future condition of a system based on interpolation of the trends from the past, whereas the methods of convergent concordance are based on deliberating and creating a consensus of experts. Methods of simulations include creating a model whereby the future behavior of a system is simulated by applying variables with different values.

As experimental methods were clearly not appropriate techniques for considering the aircraft accident investigation process, nonexperimental research methods for the thorough analysis of aircraft accident investigation, including statistical analysis, classification, interviews, intuition, and other prospective techniques, were focused on. In this regard, to date the most developed intuitive methods include the Delphi technique, Scenario, Utopia, and Method of strategic games, among others [50].

Considering aircraft accident investigation as an issue to be developed along with research methods available, it has been deduced that an analysis of accident statistics and the application of a Delphi exercise will initially provide a comprehensive picture of aircraft accident investigation.

III. Air Traffic Safety Analysis Through Statistics

Investigators have performed very useful tasks in the enhancement of air traffic safety by analyzing air accidents in the past [5]. To help

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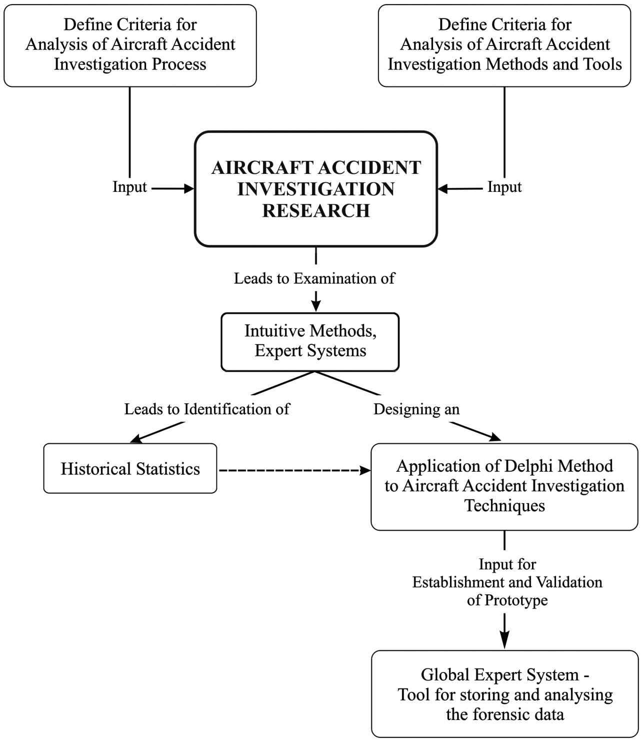


Fig. 1 The design and development process for expert systems applied to aircraft accident investigation.

prevent future accidents, using statistics, investigators strive to objectively understand the many factors associated with air safety discovered during prior investigations. Moreover, according to the International Civil Aviation Organization, "statistics is a tool for understanding the past, explaining the present and planning for the future" [52].

Despite statistics related to air accidents and their conclusions being well-known among aviation experts, the authors have decided to delve into this area for the following reasons:

1) Statistical analysis belongs to the group of interpolation trend methods within the intuitive methods that were recognized as appropriate tools for analyzing aircraft accident investigation.

2) Statistics from different sources can differ for certain sampling periods. Conflicting information can be seen in the number of accidents, number of fatalities, and other relevant information [53].

3) When analyzing an accident, the authors faced a challenge due to the multiple causal factors approach to accidents, which states that before an accident occurs a number of adverse events must have preceded it [1,54], and, as such, the major cause of accidents can be difficult to identify when there are two or more strong contributing factors.

4) Determining the cause of an aircraft accident is often not straightforward and different conclusions can be drawn among different investigative teams. Moreover, there are cases when there is a serious disagreement in the reports among experts of the same investigative team [46].

5) Some experts argue that with such a disproportionately high percentage of accidents involving human error or omissions, the blame will often fall on the crew when there is an accident with no survivors [55].

The statistical data examined contained the number of accidents that occurred between 1950 and 2004, including accident distribution in the past, causal factors, and casualty count [4]. The main references used for obtaining data on aircraft accidents were [56–59], which provide general information, database collections relating to aircraft safety and news, and reports of aircraft accidents. The aim of this material was to illustrate the overall trends in aircraft accidents and to draw some broad conclusions.

The analysis of the historical statistics of accidents between 1950 and 2004 had a significant impact on proceeding with this work. In particular, they emphasized the importance of 1) the existence of sustained risks to air traffic of repeated human errors, omissions, or aircraft malfunctions, 2) the need for continued efforts in preventing future reoccurrences, and 3) uniform collecting and storing of data of air traffic safety occurrences worldwide.

Therefore, in order to continue and improve aircraft safety as well as mitigate severe accident consequences, it is clear that we must learn from aircraft accidents and implement measures to avoid reoccurrences. Consequently, it is certain that statistics and advanced computer tools for collecting and analyzing data could contribute to an improvement in aircraft accident investigation and air traffic safety itself.

IV. Application of the Delphi Method to Aircraft Accident Investigation

The Delphi exercise, as one of the most developed techniques within intuitive methods for analyzing complex issues [60], was the second tool used to consider aircraft accident investigation.

The Delphi method is named in deference to the legend of the Greek Delphic oracle [61] and presents one of the most useful methods for establishing a set of priorities to further develop and improve a complex system [60,62]. The Delphi technique was established and primarily used in the framework of a study undertaken by the Rand Corporation for the needs of the American Air Force. That is to say, the basis of the Delphi technique was set up in the Rand Corporation, and the first characteristics of the method can be found in the article "Prediction for Social and Technological Events" by Kaplan, Skogstad, and Girshick, published at the Rand Corporation in 1949; these characteristics are related to statistical analysis of individual opinions [50]. From the United States, Delphi spread to Western Europe, Eastern Europe, and the Far East gaining extensive popularity across many scientific disciplines as a method of inquiry [43].

In the first period of its application, the Delphi technique was mainly used for forecasting future international situations and forecasting scientific technological development. Nowadays, the Delphi technique is not only a method for forecasting, but also a method for the systematic gathering of opinions given by experts, which may be used to foresee developments in technology and other areas. Therefore, an adequate name would be the method for creating group estimation [63]. Moreover, Dalkey [64] portrayed the modern Delphi method as a technique that restructures the group communication process to bring together expert opinions to "formulate a prediction or set of priorities." Hence, regardless of the primary application of the Delphi technique, today its usage is significantly extensive in the areas of economics, engineering, medicine, science, and so on for technological forecasting and creating a set of priorities.

The Delphi technique is formalized through the procedure of carrying out research activities (refer to Fig. 2). It includes establishing the working group for coordination, identification of team of experts, creating and delivery of the questionnaire, completing the questionnaire, results analysis, and attaining the concordance of the opinions of experts.

The duty of the working group for coordination is to introduce the research issue, then to carry out a survey procedure, and finally to work out and present the final results. The working group is composed of experienced and skilled persons in that particular area and specialists for forecasting. The working group establishes a team of experts that are surveyed. After that, the working group set up a questionnaire composed of a list of questions or factors relevant to the issue to be considered, whereby the answers will contribute to establishing a set of priorities for further growth of the issue. Within the Delphi exercise all questions are asked in a way in which the answers must be given numerically (scale rate), although there is great freedom in choosing the type and scale size for ranking the factors.

When the questionnaire has reached its final form, a sample of it is delivered to every single expert. The questionnaire contains all information needed with respect to the goal of the research, role of the expert and the way of giving the answers. After that, experts express their own opinion about every question individually. The Delphi procedure does not allow interaction among experts themselves. Forecasting and expression of opinions is completely given to experts; the working group only appropriately operates the data.

The Delphi exercise is carried out in further rounds or iterations. When experts have given their answers, supported with appropriate evidence, the questionnaires are delivered to the working group and the first round concludes. After that, the working group calculates the mean of the experts' numerical answers for every question and identifies the extreme answers. Respondents then give an explanation for their answers that deviated significantly from the group mean. After identifying areas of agreement and discord as items requiring clarification, the working group prepares and distributes a second questionnaire. This questionnaire includes statistical and qualitative summaries of the group responses to the first questionnaire along with additional information or explanations requested by participants.

Answers given from the second round are treated the same way as answers after the first iteration. The means of the answers are calculated, extreme answers are identified, additional explanation from the experts is required, and this information is presented to the experts. This poll process with feedback finishes at the moment when the working group evaluates that there is a reasonable consensus of experts' answers with respect to every single question. The practice shows that after the third round of the Delphi exercise almost all answers needed are obtained.

The final report offers a summary of the goals, process, and results of the Delphi exercise. The working group along with other interested parties may use these results in various ways, including improvement of systems, long-range strategic planning, and forecasting.

The results from the implementation of the Delphi technique are not supposed to last forever. They express expert opinions and estimates at current conditions, which have to be periodically reviewed and developed.

It is common for the calculation of the experts' opinions, which are given numerically, to be carried out by the working group in two phases: 1) determination of experts' competency, and 2) determination of the coefficient of concordance of expert opinions, the coefficient of the concordance C_k.

Spearman's rho (ρ_i) rank correlation coefficient test (Spearman estimator) is used as a criterion to calculate the experts' competencies, whereas determination of the expert consensus is attained through calculation of the coefficient of concordance C_k. The coefficient of concordance C_k and Spearman's rho (ρ) rank correlation coefficient are random functions, and their distributions are tested against χ^2 criterion and t distribution, respectively [65,66].

Finally, there were no limitations for applying the Delphi method to aircraft accident investigation. Thus, the issue to be considered has been established as an aircraft accident investigation. The investigation presents a well-known process of gathering, recording and analyzing information, and determining the causes for an accident. Furthermore, there is a lot of information available regarding aircraft accident occurrences as well as the investigation carried out, and so conclusions originating from statistics are known. Moreover, the strategic objectives of the investigation are clear, which in turn means a more efficient and economical process of obtaining the causes of accidents as well as enhancing air traffic safety.

V. Application of Delphi Method to Aircraft Accident Investigation

Based on the arguments given earlier, a Delphi exercise has been conducted in order to examine aircraft accident investigation. The research was conducted between April and June 2007, although the preparation for implementing the research started months beforehand.

Initially, authors created six groups of factors (in total 98 factors) that may affect the outcome of the aircraft accident investigation processes. Each factor group contained a collection of important elements from one particular aspect of the investigation so that all six groups comprehensively considered the entire process of aircraft accident investigation.

These six groups were incorporated into a questionnaire that asked respondents to rank factors within each group in order of importance. The respondents ranked the factors according to nine questions posed within the questionnaire. Experts were allowed to rank more factors with the same ranks.

The next stage of the Delphi procedure was selection of respondents. According to positive Delphi practices, it was decided that 10 respondents would provide sufficient response for drawing credible conclusions. Respondents were chosen experts, members of aircraft accident investigation teams, who were recommended by their colleagues as very knowledgeable and experienced investigators. On the respondent list were investigators from the Australian Transport Safety Bureau (ATSB), Australian Defense Science Technology Organisation, QANTAS (the national airline of Australia), and other international services.

The Delphi survey started with the well-known "zero round" in order to provide feedback about the quality of the questionnaire in terms of its structure and content. In the zero round several experts were surveyed, who responded that the questionnaire was composed of clearly defined questions (factors) and that every factor included was important for the purpose of this research, which is improvement of the process of aircraft accident investigation. Those respondents also suggested very few changes to the questionnaire (which were accepted by authors), most of them related to the wording of the questions. After finishing the zero round, the questionnaire was sent to the respondents, and the first round of the Delphi survey started. The experts confirmed receiving the questionnaire, and within the scheduled deadline they returned the completed questionnaire. Meanwhile, some experts asked for more information, which was provided immediately by the working group, and that resulted in finishing the first round very quickly.

In accordance with the Delphi procedure, after the questionnaires were returned, authors summarized the responses and, based on the results, developed a new questionnaire for the respondent group. The respondents were asked to reevaluate their original answers based on examination of the group response from the first round so that they could have changed their original answers from the first round accordingly. In compliance with the procedure of checking the expert opinions and asking for argumentative explanations of answers that differed significantly from the group average opinion, the whole Delphi procedure finished in two rounds. After the second round, there was an impression that the experts quite clearly ranked the factors in the first and second rounds so that the additional third round would not have enhanced the Delphi results.

When the survey procedure was completed and expert responses were available, authors began to analyze the data. The data analysis included determining the expert group opinion about every single factor in the questionnaire and working out the expert competency and the coefficient of concordance of expert opinions. After the second round, consensus of expert opinions was reached and the drawing of conclusions could have started.

VI. Data Analysis of the Delphi Method Application

As mentioned earlier, the Delphi survey was completed in two rounds. Experts provided their opinions for every single factor in the first round, and through the feedback in the second round they upgraded their original answers. The final results, including ranking the 98 factors with respect to the nine questions posed, are presented here.

A. Factors Group 1

The first group includes 10 factors relating to general investigation principles. Experts ranked their importance from 1 to 10, (unfeasible to definitely feasible) according to question 1 "How much are the

Table 1 Expert group opinion with respect to question 1

		Mean	σ
1.	Principle of technical–tactical liberty of conducting the investigation and principle of adequacy	7.9	1.0
2.	Principle of methodical approach and planning	7.7	0.9
3.	Principle of critical approach of the procedure	8.3	0.8
4.	Principle of operational approach	7.4	1.6
5.	Principle of profundity and persistence	7.9	0.8
6.	Principle of objectivity	8.7	0.8
7.	Principle of solitary governance of investigation	8.3	1.1
8.	Principle of coordination and cooperation	7.6	1.1
9.	Principle of economical procedure	6.8	1.2
10.	Principle of secrecy	7.3	1.2

below mentioned principles met within an aircraft accident investigation?" The expert group opinion is presented in Table 1.

Table 1 points out that all principles are met considerably within an aircraft accident investigation. In particular, the process of investigation satisfies the criteria with respect to the principle of objectivity, the principle of critical approach of the procedure, and the principle of solitary governance of investigation, which are factors 6, 3, and 7, ranked highly with 8.7, 8.3, and 8.3, respectively.

On the other hand, the principle of economical procedure, which is factor 9, has a rank of only 6.8, which indicates that it is not met completely within an aircraft accident investigation. In addition, the principle of operational approach, which is factor 4, was ranked 7.4 and associated with a high dispersion of 1.6. The results also reveal that within an investigation the principles of secrecy, coordination, and cooperation as well as methodical approach and planning (factors 10, 8, 2), ranked 7.3, 7.6, and 7.7, respectively, are not entirely met.

B. Factors Group 2

The second group comprises the factors 11–17 relating to general investigation questions (where, when, what, why, and so forth). Experts ranked their importance from 1 to 10 (unfeasible to definitely feasible) according to question 2 "What are the odds of determining the answers of the questions below within an aircraft accident investigation?" The expert group opinion is presented in Table 2.

Table 2 illustrates that an investigation of aircraft accident occurrence will most likely reveal the answers to questions regarding where and when the accident happened and identify the identity of the occupants of the aircraft, which refer to factors 12, 11, and 15 ranked with 9.3, 9.1, and 9.1, respectively.

Table 2 Expert group opinion with respect to question 2

		Mean	σ
11	When did the accident happen?	9.1	0.54
12	Where did the accident happen?	9.3	0.46
13	How did the accident happen?	6.3	0.78
14	How has the plane been maintained?	8.2	1.08
15	Who were the occupants of the aircraft?	9.1	0.70
16	Why did the accident happen?	6.8	0.98
17	What may have prevented the accident?	7.2	0.98

As expected, the experts ranked factors 13, 16, and 17 significantly lower, with ranks of 6.3, 6.8, and 7.2, respectively. This means that within an investigation the most difficult task is determining the answers to questions involving how and why the accident happened and what may have prevented the accident.

In terms of aircraft maintenance, experts ranked factor 14 with a rank 8.2, which means that investigators do not have a big problem discovering the maintenance history of an aircraft involved in an accident.

C. Factors Group 3

The third group is composed of the factors 18–27, representing portions of the investigation. Experts ranked their importance from three different aspects according to questions 3, 4, and 5 as follows:

1) "In reference to obtaining a better investigation outcome, how important is [the given item] within the process of aircraft accident investigation?" (The rankings available were from 1 to 10, ranging from unimportant to very important, respectively.)

2) "How complex is [the given item] within the investigation process as to the requirement of special skills and technique by the examination team?" (The rankings available were from 1 to 10, ranging from not at all to very complicated, respectively.)

3) "Is there potential for further improvement of [the given item] within the aircraft accident investigation by applying the new methods and contemporary technology?" (The rankings available were from 1 to 5, ranging from small to large, respectively.)

Expert responses for questions 3, 4, 5 are presented in Table 3.

Table 3 shows that experts highly ranked factors 18–27 with respect to their importance within an investigation. Yet experts emphasized the importance of wreckage analysis (factor 21) and examination of the scene of the accident (factor 20), allocating them ranks of 9.5 and 9.3, respectively. Lower ranked factors within the list provided include the reconstruction of an aircraft accident (factor 25) with a still high rank of 7.9 followed by the report writing (factor 26) and finding and interviewing the witnesses (factor 22) ranked with 8.2 each.

Table 3 Expert group opinion with respect to questions 3, 4 and 5

		Question 3		Question 4		Question 5	
		Mean	σ	Mean	σ	Mean	σ
18	Managing the investigation (plan, report, monitor)	8.6	1.02	7.2	1.33	3.8	0.56
19	Notification and arriving at the scene of the accident	8.6	0.80	4.8	1.66	2.9	0.70
20	Examination of the scene of the accident	9.3	0.46	7.7	1.10	3.3	0.51
21	Wreckage analysis	9.5	0.50	8.3	0.78	3.8	0.56
22	Finding and interviewing the witnesses	8.2	0.87	6.5	1.02	2.5	0.61
23	Investigation of air traffic control records & radar data	8.8	0.87	7	1.18	3.2	0.56
24	Laboratory examination	8.7	0.46	8.1	0.70	3.4	0.49
25	Reconstruction	7.9	0.70	8.9	0.70	3.4	0.54
26	Report writing (structure & quality)	8.2	0.75	6.4	1.50	3	0.77
27	Data management	8.5	1.12	7	0.89	3.6	0.44

If experts said that all factors from 18 to 27 are very important within an investigation in reference to obtaining better outcomes, they ranked their complexity significantly different. Thus, in the expert group opinion the most complicated phases of an investigation are reconstruction (factor 25), wreckage analysis (factor 21), and laboratory examination (factor 24), ranked with 8.9, 8.3, and 8.1, respectively. On the other hand, the notification and arriving at the scene of accident (factor 19), as expected, was ranked as less complicated with a rank of 4.8 followed by report writing (factor 26) and finding and interviewing the witnesses (factor 22) with ranks of 6.4 and 6.5, respectively. Other factors on the list were ranked 7.

Table 3 also shows that experts ranked all factors higher than 2.5 with respect to question 5. Experts consider that all factors from 18 to 27 have the potential of further significant improvement by applying contemporary technology. In this regard, experts ranked the managing of investigation (factor 18), wreckage analysis (factor 21) and data management (factor 27) with very high ranks of 3.8, 3.8, and 3.6, respectively; followed by, laboratory examination (factor 24) and reconstruction (factor 25) with ranks of 3.4. As expected, the factors finding and interviewing the witnesses (factor 22) and notification and arriving at the scene of accident (factor 19) were ranked the lowest, although considered high at 2.5 and 2.9, respectively.

As the answers to questions 3, 4, and 5 are related to the same factors 18–27, they can also be plotted in a 3-D space with respect to importance (x axis), complexity (y axis) and improvement (z axis). Thus, Fig. 3 illustrates that the most dominant position among all factors includes the factor wreckage analysis (factor 21), with the coordinates/ranks of 9.5, 8.3, and 3.8 followed by laboratory examination (factor 24) and reconstruction (factor 25), also with high ranks of 8.7, 8.1, and 3.4; and 7.9, 8.9, and 3.4, respectively. Moreover, Fig. 3 shows that the factors managing the investigation (factor 18), data management (factor 27), and examination of the scene of the accident (factor 20) also have high rankings but are a little lower than the already mentioned factors 21, 24, and 25. We can also see that the factors notification and arriving at the scene of the accident (factor 19), finding and interviewing the witnesses (factor 22), and report writing (factor 26) were ranked the lowest among all factors with 8.6, 4.8, and 2.9; 8.2, 6.5, and 2.5; and 8.2, 6.4, and, respectively.

D. Factors Group 4

The fourth group includes the factors 28–53 relating to the examination of causal factors of accidents. These factors were examined by questions 6 and 7, as follows:

1) “How complex is the examination of [the given item] as to the requirement of special skills and technique by the examination team?” (The rankings available were from 1 to 10, ranging between from not at all to very complicated, respectively.)

2) “Is there potential for further improvement of examination of [the given item] within the aircraft accident investigation by applying new methods and contemporary technology?” (The rankings available were from 1 to 5, ranging from small to large, respectively.)

Expert group opinions with respect to questions 6 and 7 are shown in Table 4.

Table 4 shows that examination of factors 28–53 is complex and requires specialized skills from the examination team. Experts allocated maximum ranks to the factors in-flight explosion (factor 41), in-flight failure (factor 42), psychological human factors (factor 52), human error and omission (factor 51), and design inadequacy (factor 53), with ranks of 9.2, 9, 8.9, 8.8, and 8.6, respectively.

Other factors such as landing gear systems and brake systems (factor 32), fuel (factor 34), and aircraft loading (factor 39) were considered as less complex among all factors from the list, with ranks of 6.3, 6.3, and 6.4, respectively. The ranks of other factors range between 6.3 and 9.2.

In terms of question 7, experts ranked all factors (except the factor fuel examination) greater than 2.5. The maximum ranks of 4, 3.9, 3.9, 3.8, 3.8, 3.8, and 3.7 were allocated to the examination of the following factors: psychological factors (factor 52), human error or omission (factor 51), cockpit voice recorder (factor 36), flight data

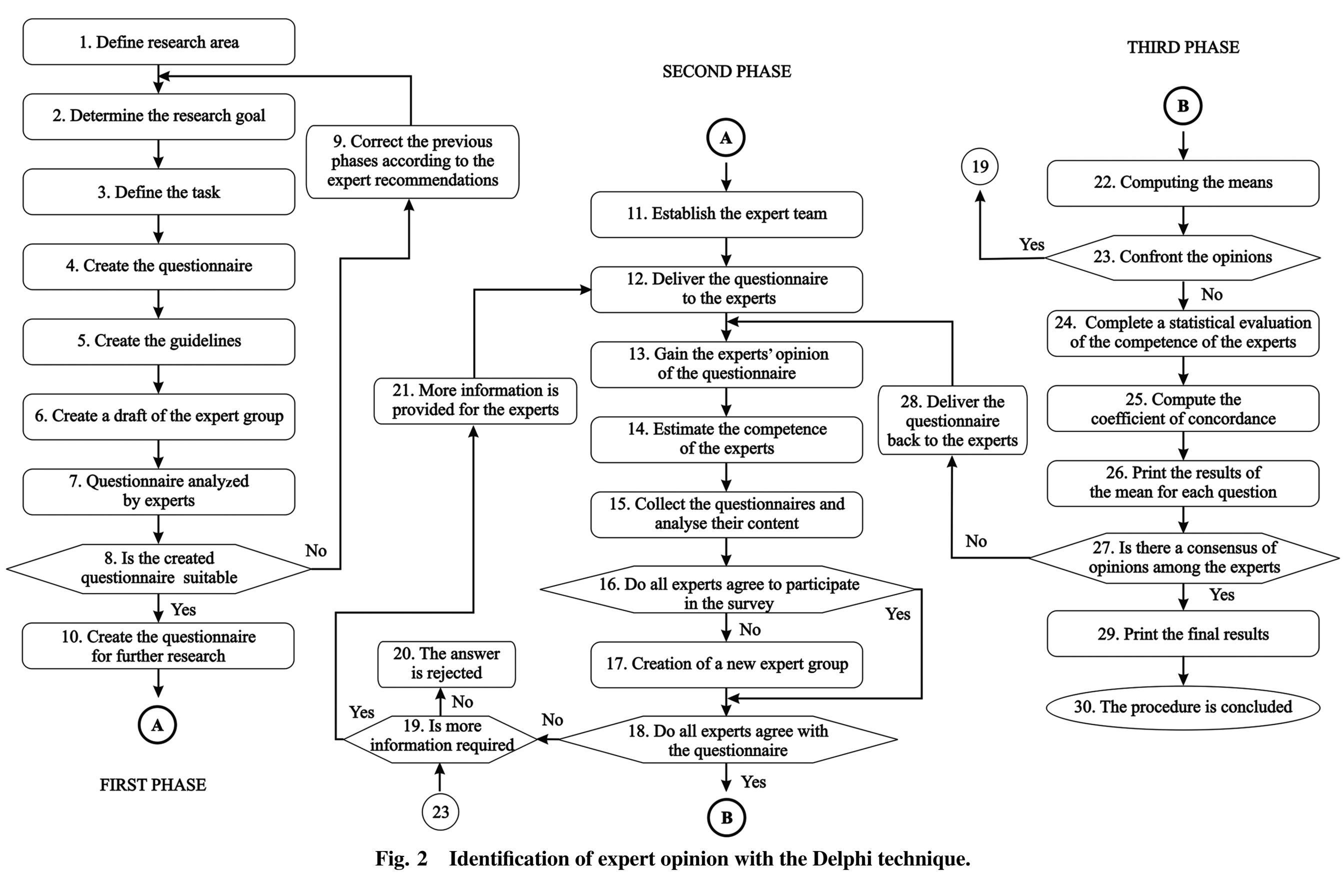


Fig. 2 Identification of expert opinion with the Delphi technique.

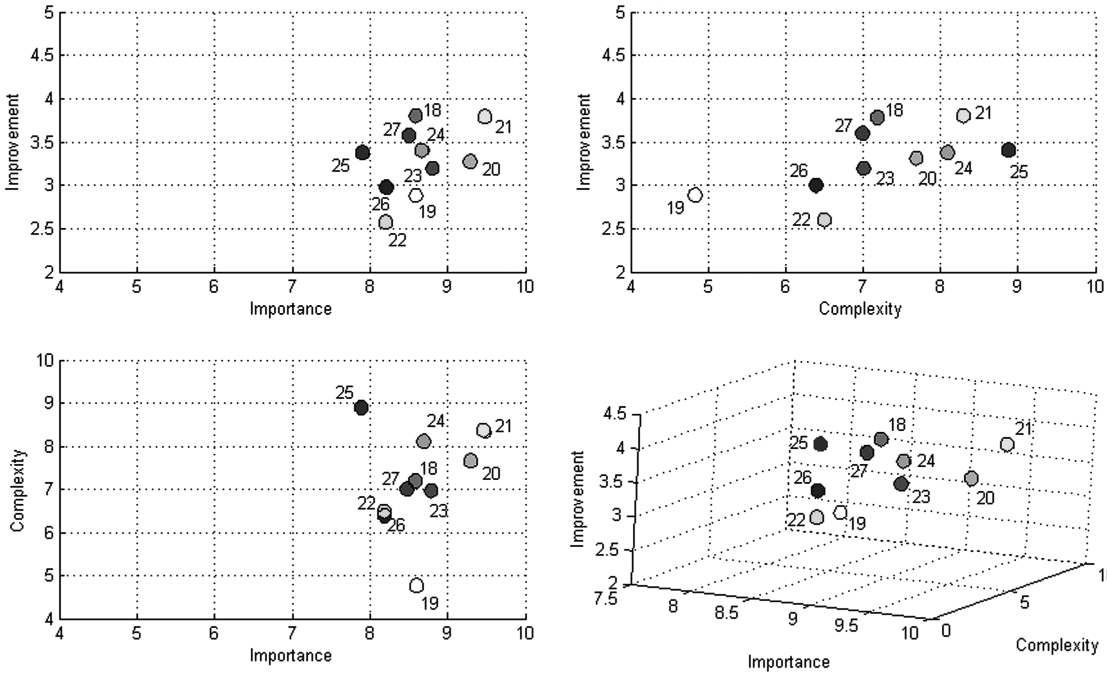


Fig. 3 A ranking of the various parts of an aircraft accident investigation in 3-D space based on their importance, complexity, and potential for improvement (expert group opinion with respect to questions 3, 4, and 5).

recorder (factor 38), in-flight explosion (factor 41), cockpit sound recorder (factor 7), and in-flight failure (factor 42), respectively.

In contrast, experts ranked the factors fuel (factor 34), landing gear and brake systems (factor 32), deicing and antiicing systems (factor 33), foreign object damage (factor 35), and lightning (factor 44) with significantly lower ranks of 2.2, 2.9, 2.9, 3, and 3, respectively.

In addition, Fig. 4 combines the answers from questions 6 and 7 and illustrates the mutual correlation of complexity and potential for improvement of examination of factors 28–53 in a 2-D coordinate system, where the x axis is complexity and the y axis is improvement.

According to the location of factors in Fig. 4, two different groups of factors with different features were created. The first group is located in the upper right corner of the chart, and those factors have both high ranks of complexity and improvement, whereas the second group is composed of factors with significantly smaller values of complexity and slightly lower ranks of improvement. Hence, in the first group most factors from 28–53 are located, and among them the most distinguished are the following: in-flight explosion (factor 41), in-flight failure (factor 42), psychological factors (factor 52), and human error or omission (factor 51) with coordinates/ranks of 9.2 and 3.8, 9 and 3.7, 8.9 and 4, and 8.8 and 3.9, respectively.

The second group is composed of the factors fuel (factor 34), landing gear systems and brake systems (factor 32), deicing and antiicing systems (factor 33), foreign object damage (factor 35), midair collision (factor 45), aircraft loading (factor 39), ranked as 6.3

Table 4 Expert group opinion with respect to questions 6 and 7

		Question 6		Question 7	
		Mean	σ	Mean	σ
28	Operations, the flight path	7.9	0.83	3.4	0.49
29	Cockpit	8.4	1.20	3.25	0.68
30	Engine and accessories	8.3	1.10	3.3	0.78
31	Mechanical, electrical, hydraulic, pneumatic systems	8.4	1.11	3.65	0.55
32	Landing gear systems and brake systems	6.3	1.49	2.9	0.83
33	Deicing and anti-icing systems	6.7	1.85	2.9	0.83
34	Fuel (quality and amount)	6.3	2.19	2.2	0.95
35	Foreign object damage (FOD)	7	1.61	3	0.63
36	Cockpit voice recorder (CVR)	7.9	0.83	3.9	0.70
37	Cockpit sound recorder (CSR)	8.1	0.70	3.75	0.81
38	Flight data recorder (FDR)	8.1	0.70	3.8	0.75
39	Aircraft loading	6.4	2.20	3.3	0.71
40	Hydroplaning	7.5	1.20	3.1	0.83
41	In-flight explosion	9.2	0.75	3.8	0.95
42	In-flight failure (structural failure or fatigue)	9	0.89	3.7	0.87
43	In-flight fire	8.2	1.54	3.5	0.67
44	Lightning	7.6	1.50	3	0.59
45	Midair collision	7.2	2.18	3.2	0.75
46	Crime activities	7.7	1.10	3.6	0.89
47	Weather conditions	7.8	0.75	3.6	0.62
48	Downwash and wing tip vortex hazards	8	0.77	3.6	0.80
49	Microburst, wind gust, wind shear	8	0.77	3.4	0.49
50	Stability and control of an airplane	8.1	1.22	3.25	0.78
51	Human error or omission	8.8	0.40	3.95	0.85
52	Psychological factors (fatigue, illusion, etc.)	8.9	0.70	4	0.77
53	Design inadequacy	8.6	0.66	3.45	0.57

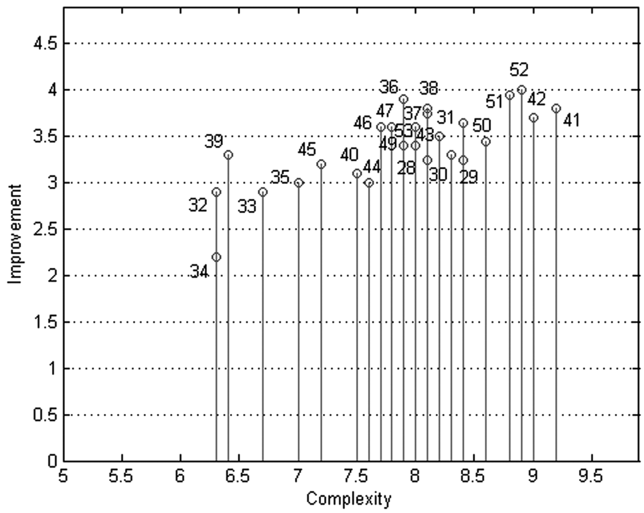


Fig. 4 Complexity and potential for improvement of examination of the given factors within an aircraft accident investigation (expert group opinion with respect to questions 6 and 7).

and 2.2, 6.3 and 2.9, 6.7 and 2.9, 7.2 and 3, and 6.4 and 3.2, respectively.

E. Factors Group 5

The fifth group comprises the common causal factors that may lead to accidents. Experts expressed their opinions about these factors according to question 8 "What are the odds of proving within the process of an aircraft accident investigation that [the given item] is one of the major causes for an accident?" Available rankings for this question were from 1 to 10, ranging from unreliable to certain, respectively.

The aim of this question was to provide more information about the examination of wreckage and aircraft systems as well as examination of the human and environmental factors that were also considered through question 6. Expert group opinion with respect to question 8 is shown in Table 5.

Table 5 shows the rank of how difficult it is to identify or determine the items mentionsed in the table as major causes of an accident.

Thus, experts ranked the factors midair collision (factor 74), landing gear systems malfunction (factor 56), and brake system malfunction (factor 55) with very high ranks of 9.2, 8.9, and 8.5, respectively, which show that these events are most likely to be identified during an investigation and examined properly. After that follows a group of factors such as in-flight failure (factor 67), engine malfunction (factor 54), and in-flight fire (factor 68), still highly ranked with 8.3, 8.1, and 8.1, respectively.

Table 5 Expert group opinion with respect to question 8

		Mean	σ
54	Engine malfunction	8.1	1.14
55	Brake systems malfunction	8.5	0.50
56	Landing gear systems malfunction	8.9	0.83
57	Icing	5.9	1.45
58	Foreign object damage (FOD)	7.3	0.78
59	Inappropriate fuel	7.6	1.43
60	Inappropriate aircraft loading	6.6	1.20
61	Hydroplaning	6.9	0.70
62	Downwash and wing tip vortex	5.3	1.42
63	Severe weather conditions	7.4	1.02
64	Microburst, wind gust, wind shear	7.1	0.83
65	Lightning	7.2	1.17
66	In-flight explosion	7.8	0.75
67	In-flight failure (structural failure)	8.3	1.10
68	In-flight fire	8.1	1.14
69	Crime activities	6.1	0.54
70	Human error or omission	6.6	0.80
71	Psychological factors	5.4	0.80
72	Stability problems and lost the control of the airplane	6.6	1.02
73	Design inadequacy	6.8	0.87
74	Midair collision	9.2	0.40

In the lowest ranked group are the factors downwash and wing tip vortex (factor 62), psychological factors (factor 71), and crime activities (factor 69), with ranks of 5.3, 5.4, and 6.1, respectively. According to those results, examination of these factors is complex, and to prove that those factors are a major cause for accident is a considerably difficult task.

The ranks provided for questions 6, 7, and 8 have been combined and presented in a 3-D distribution format of improvement, complexity, and proving as x, y, and z axes (Fig. 5). According to the location of these factors, several different groups of factors (with similar rankings) can be created as follows:

1) The first group includes complex factors having the potential for further improvement of their examination, which are currently very difficult to prove during the examination. In this group are the factors downwash and wing tip vortex (factor 62), psychological factors (factor 71), crime activities (factor 69), and human error or omission (factor 70) ranked with 3.6, 8, and 5.3; 4, 8.9, and 5.4; 3.6, 7.7, and 6.1; and 3.9, 8.8, and 6.6, respectively.

2) The second group includes complex factors with high ranks of improvement and proving. In this group are factors such as in-flight failure (factor 67), in-flight explosion (factor 66), in-flight fire (factor 68), and engine malfunction (factor 54), with ranks 3.7, 9, and 8.3; 3.8, 9.2, and 7.8; 3.5, 8.2, and 8.1; and 3.3, 8.3, 8.1, respectively.

3) The third group includes factors with moderately high ranks of improvement, complexity, and proving. In this group there are a number of factors such as foreign object damage (factor 58), inappropriate aircraft loading (factor 60), hydroplaning (factor 61) and others with ranks of 3, 7, and 7.3; 3.3, 6.4, and 6.6; and 3.1, 7.5, and 6.9, respectively.

F. Factors Group 6

The last group of factors presents a collection of statements for which experts expressed their agreement or disagreement according to question 9 "Do you agree with the statements below?" The rankings available were from 1 to 10, ranging from strong disagreement to strong agreement, respectively. Expert opinions are presented in Table 6.

An analysis of results presented in Table 6 shows that experts did not allocate extremely high ranks to any of those statements so that most factors were moderately ranked between 6 and 7. Another remark is that dispersion of expert opinions on several questions reached exceedingly high values. However, the results remain scientifically acceptable because the statistical tests of expert competency and concordance justify the nonrandomness of expert opinions. According to the results, several groups of factors were created, which include

1) The highest ranks were allocated to the factors 79 and 90, with 8.1 and 8, respectively. Namely, experts said that excellent knowledge of theory can significantly improve the investigation outcomes (factor 79), and determining that the weather condition during an accident is not a very difficult task (factor 90).

2) Experts granted several factors with ranks between 7 and 8. These factors are 76, 91, 75, 89, and 97, which state that

a) Waiting for a couple of months before releasing the accident investigation report is justifiable (rank 7.6).

b) Human factors are involved somehow in every single aircraft accident (rank 7.2).

c) The process of investigation meets the high standards of quality assurance and quality control procedures (rank 7.2).

d) The downwash and wing tip vortex are serious hazards for the aircraft (rank 7.2).

e) The process of investigation as a whole can be improved significantly by applying new methods and advanced technology (rank 7).

3) The lowest ranks were allocated to factors 83, 85, 84, 93, and 82 that state

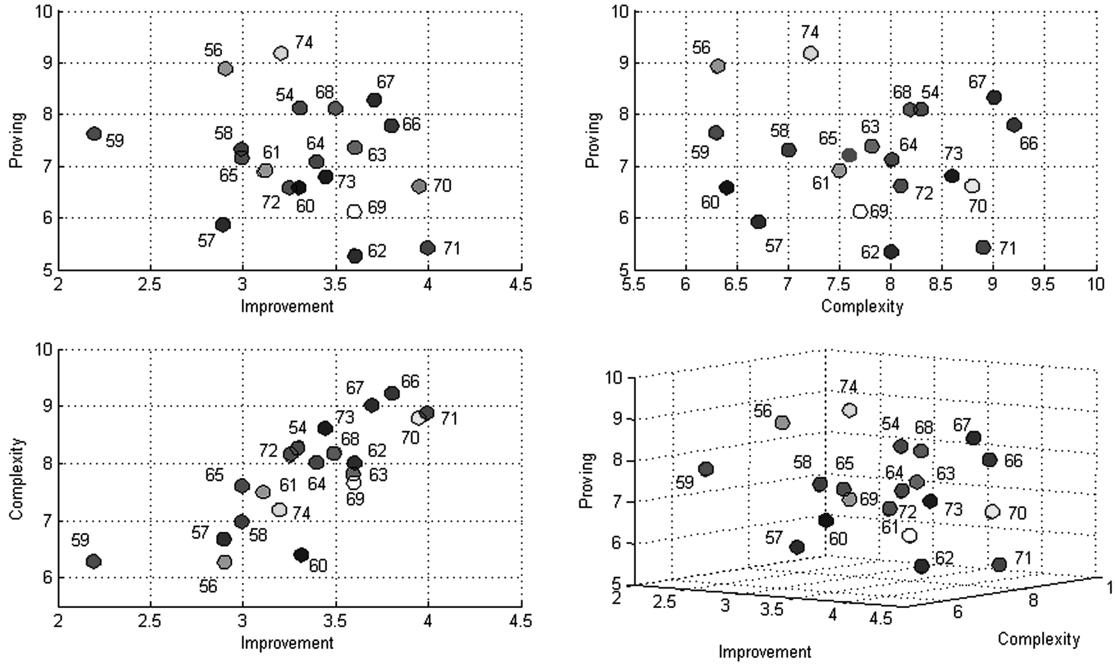


Fig. 5 3-D presentation of expert group opinion concerning the examination of aircraft, human, and environmental causal factors (expert group opinion with respect to questions 6, 7, and 8).

a) Investigators should believe witnesses of aircraft accidents (rank 4.8).

b) We never have a real accident with enough readable data (rank 4.1).

c) The cockpit recorders record sufficient parameters (rank 5.5).

d) There are always problems with airfield papers analysis (rank 5.4).

e) It is likely at times that inconsistent material is sent for lab analysis (rank 5.7).

In addition, experts ranked with 6.7 the statement that investigators have sufficient skills to conduct investigations (factor 78). Furthermore, they ranked factor 92 with 6.3, which states that during the examination it is possible to answer the question of whether or not the pilot was able to cope with a critical situation. Moreover, experts ranked the factor 96 with a rank of 6.2, which states that determining the cause of the accident is a very hard task if there is no sufficient data recorded. Finally, one can address the rank of 6.2 of the factor 98, which states that the experience of the land traffic accident investigation can contribute to a considerable increase in air traffic safety.

The last section of the Delphi questionnaire provided a space where respondents discussed the prospective actions that could significantly improve the aircraft accident investigation. Thus, experts said that the most significant improvement in investigations will be achieved by 1) creating and using the advanced databases of an aircraft's components, structure, and systems so that pieces can be

Table 6 Expert group opinion with respect to question 9

		Mean	σ
75	The process of investigation meets the procedures regarding the quality assurance (QA) and quality control (QC).	7.2	0.98
76	It is justifiable waiting for a couple of months before releasing the accident investigation report.	7.6	0.92
77	Reports of investigation carried out are always accurate and well done.	6.5	1.20
78	Investigators have appropriate and sufficient skills to handle aircraft accident investigation.	6.7	1.10
79	The excellent knowledge of theory compared with an average knowledge of theory significantly improves the investigation outcomes.	8.1	0.83
80	The contamination of the scene of the accident is a serious problem within the process of aircraft accident investigations.	7	1.41
81	The presence of landmarks on the scene of the accident provides sufficient information for carrying out accurate mathematical calculations.	5.9	0.70
82	It is likely that at times inconsistent material is sent for lab analysis.	5.7	0.78
83	Investigators should believe witnesses of aircraft accidents.	4.8	1.25
84	The cockpit recorders (FDR, CVR, CDR) record sufficient parameters.	5.5	2.11
85	We never have a real accident with enough readable data.	4.1	1.22
86	The severe aircraft maneuvers can be revealed during the investigation.	6.9	1.70
87	The aircraft is equipped with appropriate accessories, which provide ice protection during the whole flight.	6	1.34
88	The stall is a serious hazard for the aircraft.	6	1.34
89	The downwash and wing tip vortex is a serious hazard for the aircraft.	7.2	0.87
90	Investigators have enough resources available to find out the weather conditions during the accident.	8	1.18
91	Human factors have been involved somehow in every single aircraft accident that has ever occurred.	7.2	1.25
92	It is possible to answer the question of whether the pilot should have been able to cope with the critical situation	6.3	1.10
93	There are always problems with airfield papers analysis (documentation).	5.4	1.11
94	The handbook is well composed material.	6.2	1.08
95	There is a great possibility for increasing the survivability of an aircraft accident.	6.4	1.50
96	Determining the cause of the accidents is a very tough task if there is not data recorded.	6.2	1.89
97	The process of investigation as a whole can be improved significantly by applying new methods and advanced technology.	7	1.34
98	The experience of the land traffic accident investigation can contribute to a considerable increase in air traffic safety	6.2	1.25

readily identified, 2) creating and using the advance databases for storing and analyzing the data of aircraft accidents, and 3) video camera recording of various functions and aircraft zones along with data transmitted to the ground stations and continually recorded.

To summarize, these conclusions have indicated that increasing the amount of expert knowledge and experience available within an investigation will significantly enhance the aircraft accident investigation outcomes. Consequently, in order to obtain a better investigation outcome, the Delphi conclusions finally address the need for a tool that will include and contain specific knowledge and analytical skills of a large number of experts and communicate the impact of a huge number of causal factors on air traffic safety.

VII. Demonstration of Expert Systems to Aircraft Accident Investigation

The Delphi inquiry results, along with the results obtained by analyzing aircraft accident statistics between 1950 and 2004 worldwide, as well as a summary of the current research and literature relevant to air traffic safety, have addressed the importance of several points about air accident outcomes as follows:

1) Every accident occurs as a result of a chain of errors, omissions, and/or malfunctions.

2) Although all aircraft accidents are different, there are certain common elements in accident causes, and there are a number of causes that frequently result in accidents.

3) Investigations by a lone investigator are difficult because some aspects of the accident/incident are beyond the knowledge or experience of one person. That is to say, investigation outcomes could be significantly improved by increasing the amount of expert knowledge available within an investigation.

4) Accident investigation could be facilitated if its distinguishing features could be quickly identified from large amounts of data in order to help predict possible causes of the accident.

5) Improving aircraft accident investigation could be achieved by creating and using advanced databases for storing and analyzing the data of aircraft accidents.

These points address the need for creating a tool in the form of a computer program that can use stored expert knowledge coupled with an inference engine to process this knowledge and provide safety event analysis to users of the program. That is to say, this research indicates that investigation could be significantly improved with the application of a global expert system as a tool for storing and analyzing the forensic data of aircraft accidents worldwide.

As a consequence, the computer program GP1020 was created in order to demonstrate how expert systems could contribute to facilitating and enhancing the investigation results. This section is focused on the GP1020 computer tool, its design, and its features.

A. Expert Systems to Aircraft Accident Investigation GP1020

Using the positive practices of expert systems applications in many fields of science, the computer program GP1020, designed for assisting aircraft accident investigation, was created. The user of this program is asked a number of different questions that initially look at the wreckage and accident site followed by examining the human, aircraft, and weather causal factors. According to the answers given, the program will choose a set of most appropriate questions in order to determine the causes of accident/incident. Finally, when GP1020 assesses that there is a significant amount of evidence derived it will release the probable causes of this particular safety event.

GP1020 includes two major features:

1) It is a forensic approach to the procedure of an aircraft accident investigation, such that the flow of information, procedures, and the rise of knowledge about the occurrence during a real investigation is followed by GP1020.

2) It serves as a simple and efficient information technology solution in determining the probable cause(s) of an aircraft accident occurrence.

B. Forensic Approach to an Aircraft Accident/Incident Occurrence Within GP1020

The procedure of a GP1020 accident inquiry follows the steps of a real investigation of an accident/incident occurrence. GP1020 asks a broad range of questions relating to the factual information and analysis undertaken of a safety event.

First of all, the GP1020 program intends to learn general information about an accident/incident event such as event type, aircraft type and category, and type of flying, as well as whether the aircraft was flown in visual or instrument meteorological conditions or/and experienced any problems during the flight. Next, by asking a number of questions, GP1020 investigates aircraft damage, wreckage distribution, witness location, probable flight path, person injury category, cause(s) of death, and so forth.

GP1020 uses a number of questions to examine the human-, aircraft-, and weather-induced causal factors. Thus, GP1020 learns if the crew undertook voluntary acts that were poorly performed, failed to act when particular actions were appropriate, or failed to take immediate action, follow air traffic control instructions, use checklists, maintain direction control, monitor weather, and/or monitor instrumentation. There are also questions that assess potentially inadequate preparation or supervision, poor judgment, improper use of equipment, alcohol or other drug use, improper maintenance, improper aircraft modifications, and inadequate procedures [67].

Another set of questions examines the aircraft systems conditions and assesses the involvement of those factors as possible causes for accident/incident. This is where the questions relating to wreckage and its systems condition, possible breaking of aircraft limits, readings of instruments, data recorders, and emergency procedures carried out. GP1020 will also ask several questions designed to consider the weather conditions during the accident. It learns event temperature, dew point, sky condition, and whether the aircraft experienced events like air turbulence, bird strike, volcanic ash, and dust.

C. Classification of the Causes of Aircraft Accidents Within GP1020

The causal factors and their consistent evidence within GP1020 are stored and highly classified. This allows the creation of a huge and flexible database appropriate for a quick cross search. Thus, within GP1020 a large $m \times n$ matrix was created, where m represents the number of all possible causes of the accident (rows) and n represents the number of different portions of evidence that may be recovered during an investigation (columns) (Table 7). It is clear that the authors' intention of providing an entire list of all possible causes (as mentioned earlier) is probably very difficult to achieve. However, this task could be completed with high accuracy by the development of a global expert system, as suggested in Secs. X and XI, when discussing limitations and the future work of the GP1020 prototype.

The matrix is then converted into another format, which is appropriate to the needs of GP1020 (Fig. 6).

Each column of the matrix, which represents a different portion of evidence, must be associated with a question. This means that GP1020 includes a large number of questions similar to the number of distinguishing features of all possible causes of accidents.

The second table of Fig. 6 shows how GP1020 may ask the user questions in order to determine the causes of the accident/incident. For instance (in the case presented in Fig. 6), if GP1020 asks the question associated with E5 (or QE5), then a positive answer provided by the user will automatically finish the procedure as only Cause 4 includes evidence E5. On the other hand if GP1020 asks the QE1 and the user provides a positive answer to it, then the program will generate further questions related to C4, C8, C2, C1, and C7 that include this evidence.

D. Expert Knowledge Stored in GP1020

The first condition for the successful application of an expert system in any scientific field is the amount of specific expert knowledge stored. While the authors were attempting to solve this task, the conclusion emerged that creating a comprehensive database

Table 7 A list of possible causes of accident versus their distinguishing features (randomly chosen)

	List of all possible causes		Distinguishing features								
			I			II			. . .		
			E1	E2	. . .	E1	E2	. . .	E1	E2	. . .
Human factors	1	Cause 1	x			x					x
	2	Cause 2	x		x		x		x		
	3	Cause 3		x		x				x	
	. . .	. . .	x			x			x		
Design and manufacturing factors	1	Cause 1		x							
	2	Cause 2			x	x	x				x
	3	Cause 3	x					x			
	. . .	. . .	x			x				x	
Environmental factors	1	Cause 1		x	x				x		
	2	Cause 2				x		x			x
	3	Cause 3	x			x	x		x		
	. . .	. . .		x						x	x

of causes of accidents and their distinguishing features is far beyond an individual's or a small group's capacity. Therefore, authors decided that using the NTSB (National Transportation Safety Board) aviation accident database as stored expert knowledge is a tremendous resource available for accomplishing the task of creating an expert system for aircraft accident investigation ([1], see pages 8 and 168).

The NTSB aviation accident database is available on the NTSB's web site, which contains highly classified and downloadable datasets of more than 140,000 aviation accidents. The computerized findings are identified in a sequence of events as occurrences, phases, causes, factors, and/or events. The existing code system includes 51 phase codes, 54 occurrence codes, 1593 probable cause subject codes, 422 probable cause modifier codes, and 52 probable cause person codes.

VIII. GP1020 Prototype

GP1020 is a comparative program that uses the understanding of causes and factors from an immense number of previous aviation records in order to simulate possible future accidents or to hasten air crash investigation efforts. It is assumed that the amount of historical data stored regarding aviation incidents and accidents is sufficient to provide such analysis.

The current version of the GP1020 software was to act as a prototype purely to test some of the fundamental mechanisms required by components of the expert system methodology. Thus, a basic version of a knowledge base, inference engine, and user interface had to be developed in order to further understand the required interaction between each component of the program. The front page of the GP1020 program is shown in Fig. 7.

A. Programming Software

The most appropriate choice for developing GP1020 turned out to be Microsoft Excel. It has built-in commands for data mining, sorting, statistical analysis, and linguistics analysis. It also has numerous accuracy checks to ensure that any cell formulae and scripts are as correct as possible. Essentially it allowed for focus on the development of the fundamental logic over any of the program codes required for allowing application execution in any specific operating system. It also avoided the entire issue regarding how to insert the historical data into the program as Excel is already capable of handling numerous table data formats. About the only thing it may, and apparently did, lack is efficiency in terms of computation speed. Throughout the development of the GP1020 prototype, this relatively high level of inefficiency was the most prevalent limiting factor to the prototype's capabilities.

B. Knowledge Base

The initial intent for the program was that it would interface with raw historical data and be ready for questions moments after the integration. However, it was apparent early on that a separate program would be needed to alter the historical data records into a form that the inference engine could use. In Excel, the ideal form for the knowledge base to suit the comparative programming that GP1020 uses would be as a table where each investigation or case is represented by a single row, with consistently occurring types of information represented by various columns.

In testing the program software for effectiveness, only a limited amount of data, in the form of some generic information used to easily identify the case as well as the causes and factors pertaining to the case (sequence of events, occurrences, flight phases, subjects, and modifiers), would be needed, especially because this prototype is fairly basic.

The inefficiencies given by Excel should be largely reduced when the fundamental logic in the knowledge base's preprocessing is transferred or altered to suit the chosen operating system or program of its future users. At the very least, the data limitations of the knowledge base and its preprocessor should grow parallel to the increase in computing power that will probably become available to it. Given that the program was computed on a personal computer, increasing the knowledge base to include all forms of relevant recorded data should be fairly feasible.

C. User Interface

As a fundamental program, only the basics were required in creating a sufficient user interface, including the ability to ask questions, the ability to receive questions, and the ability to display cases that bear the most resemblance to the case currently being

	E1	E2	E3	E4	E5	E6
C1	x			x		x
C2	x		x	x		
C3				x		x
C4	x		x		x	
C5		x				x
C6		x		x		x
C7	x					x
C8	x		x			

	E5	E3	E1	E4	E6	E2
C4	x	x	x			
C8		x	x			
C2		x	x	x		
C1			x	x	x	
C7			x		x	
C3				x	x	
C6				x	x	x
C5					x	x

Fig. 6 Conversion of the original matrix into GP1020 format where C1, C2,...,C8 are an assumed list of possible causes and E1, E2,...,E6 are consistent portions of evidence (randomly chosen) to the causes.

Fig. 7 Front page of the GP1020 program.

investigated. It would have been a very large task had not the NTSB's database already made numerical designations for occurrences, flight phases, subjects, and their modifiers. Also, all the important decisions regarding the relative positions of all the cases and all possible questions were determined by the inference engine, and so the user interface only had to interact with the inference engine in terms of inputting answers and displaying results.

The perceived needs of the user and program developer caused the display of multiple similar cases as opposed to showing only the most similar case. A program developer needs to see how the displayed result evolves, or is calculated, to ensure that the appropriate functions are occurring. Constant checking of the top 20 results heavily assisted in making sure formulae and calculations were performing accurately. From the user's perspective there was an obvious requirement, in that one lone case record could hardly be expected to meet the user's information needs. While the most similar case to the user's investigation could well be entirely useful to the user's investigation, unless it is exactly the same the most similar case could not fully assist the user in understanding his or her investigation. It would be more likely that the sequence of events that the user is trying to establish in his or her investigation could be derived from the combination of events from two or more different historical records. Essentially, the more relevant historical records that are available to the user, the better off the user should be.

The details shown in the 20 most similar cases effectively tell who was flying what where, when, and where to. These details include the cases' event ID (a unique numeric code designation for the incident/accident), date, aircraft make, operator's name, departure location, and destination location. The only other detail shown is the level of relevancy, which indicates the proportionate number of questions (and therefore answers) that positively match the case shown against the total number of questions asked.

D. Inference Engine

It is important to note that the capability of the program is dependant on its ability to use causes and factors determined in previous investigations to predict future investigations. Essentially a likely sequence of events for the user's investigation is created from a) the user's answers, and b) the probabilities those answers imply.

Basically, the main concept to be used in the program is that causes and factors have relationships that can be defined by verifiable statistics.

Given a partial sequence of event data (question answers), the engine calculates a score for each historical case indicating the number of exact matches between its events and the events contained within the partial data. Positive matches increase the case's score, negative matches decrease it. Cases are then ranked according to this score, and the events from cases above a certain rank are collected and their frequency in that collection determined. The next question that is asked of the user is whether or not the event with the highest frequency had occurred. From here, further questions are asked regarding other highly frequent possibilities. Questioning ceases when a significant amount of variation occurs between the levels of relevancy between the cases displayed.

Given more processing power, the next level of computation to be implemented is more representative of the work done in previous section of this paper (refer to Table 7 and Fig. 6). It improves case score calculation by also considering matches with events statistically related to the partial data and not just the events within the partial data alone. It would effectively increase the rate of relevancy variation significantly.

E. GP1020 Prototype User Instructions

User instructions are given on the introduction page of the program. By clicking on the spreadsheet titled "Query Page" the process begins. On the sheet query page, two distinct sections will appear; the one at the top shows the top 20 cases most likely to resemble, and thus be used as a reference in understanding, the case that the user is currently investigating (Fig. 8). The one at the bottom shows the questions that the software would ask depending on the data given.

To begin using the software, answers to the two questions already shown in the bottom must be provided (Fig. 8). This is done by clicking on the gray box next to each question and choosing an appropriate answer from the drop-down menu (Fig. 9). Soon after, a third question should appear. Similarly, it is answered by clicking on the gray cell next to the question and choosing an answer from the drop-down menu. Consequently the top 20 most similar cases will be displayed on the top box, and a fourth question should appear in the bottom box (Fig. 10).

The software user continues answering questions until the relevancy column (in dark-gray) begins to show different values. From here, two choices become available; either start to use the top 20 cases to gain understanding on your case, or answer more questions to increase the relevancy or to cause further differences in relevancy.

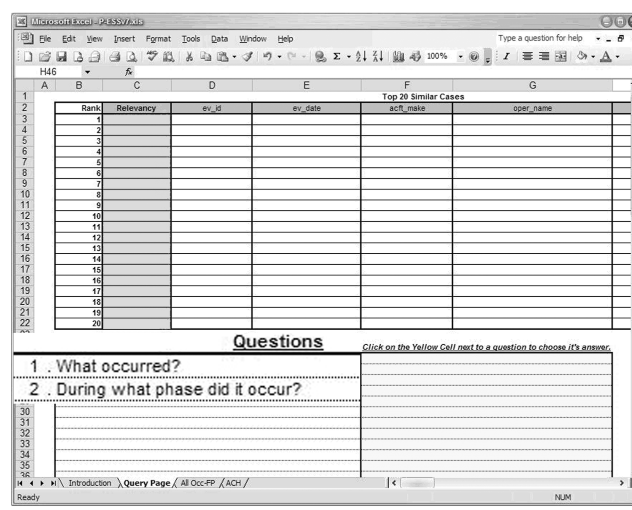


Fig. 8 Query page of the GP1020 prototype.

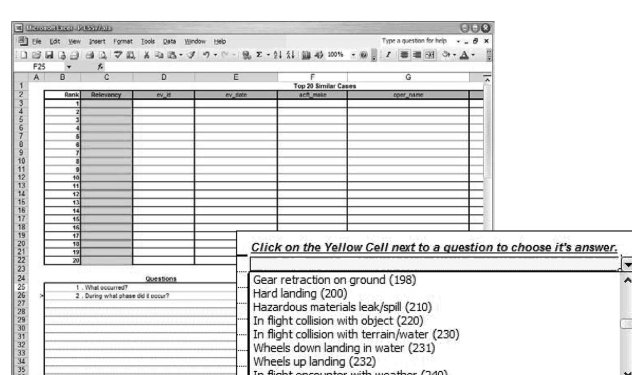


Fig. 9 Drop-down menu of the GP1020 prototype.

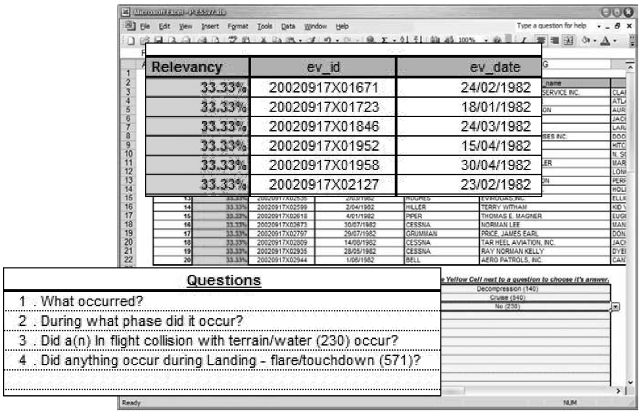


Fig. 10 Fourth question on the GP1020 prototype.

Ideally, with an increasing amount of variation in relevancy, the 20 cases shown should become more suited to assisting understanding of the case that is being analyzed.

IX. GP1020: The "Automated Fingerprint Identification System" of Aircraft Accident Investigation

As described earlier, GP1020 is a comparative program that uses the understanding of causes and factors from an immense number of previous aviation records in order to simulate possible future accidents or to hasten air crash investigation efforts. The GP1020 computer tool and its features resemble the well-known automated fingerprint identification systems (AFIS). Therefore, a brief review of AFIS systems is given in order to provide insight into these systems and the features they have in common with the GP1020 tool.

A. Automated Fingerprint Identification Systems

AFIS systems are primarily used by law enforcement agencies for criminal identification initiatives, mainly for identifying a person suspected of committing a crime or linking a suspect to other unsolved crimes. However, the greatest use of AFIS systems lies in the area of latent print identifications.

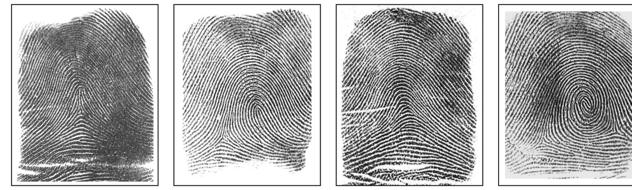
As systems, the AFIS technology has automated an already-existing process for identifying individuals. Fingerprint images, used as the crucial elements of this identification system, have been collected for over 100 years. To clarify, a fingerprint is an impression of the friction ridges, which are raised surfaces on the palmar surface of the hands and feet.

The practical use of fingerprint identification is based on three well-known premises. First of all, the friction ridges on each person's fingers are persistent and unique; even identical twins do not have the same fingerprints. Second, although all patterns are distinct in their ridge characteristics, their overall pattern appearances have similarities that permit a systematic classification of the impressions. Finally, when friction ridges come in contact with a surface that is receptive to a print, material on the ridges, such as perspiration, oil, grease, ink, or other contaminants, can be transferred to the item.

The analysis of fingerprints for matching purposes generally requires the comparison of several features of the print pattern. These include patterns, which are aggregate characteristics of ridges, and minutia points, which are unique features found within the patterns. There are four basic patterns of fingerprint ridges shown in Fig. 11.

However, identifiable fingerprint attributes originate from minutia points. The major minutia features of fingerprint ridges are bifurcation, ridge ending, and short ridge (or dot) (Fig. 12).

On the other hand, automated fingerprint identification is the process of automatically matching one or many unknown fingerprints against a database of known and unknown (latent) prints. A known print is the intentional recording of the friction ridges, such as fingerprint images from persons arrested and charged with a crime. A latent print is the chance reproduction of the friction ridges deposited on the surface of an item at a crime scene. AFIS



a) Tent b) Loop c) Arch d) Whorl

Fig. 11 The four basic patterns of fingerprint ridges.

Fig. 12 Minutia points of fingerprint ridges showing 1) bifurcation, 2) ridge ending, and 3) short ridge.

systems may contain databases of one, two, three, or more records such as the ten-print database, the latent cognizant database, and the unsolved latent database.

The (AFIS) latent print identification process includes the following steps. First, the latent fingerprint is recorded and the image is digitized. Next, the examiner, with the help of the coder, identifies and marks each minutia on the image of the fingerprint displayed on the input workstation and repeats the process with each additional latent print. The examiner may choose to add additional minutiae points not found by the coder or remove points considered marginal. In this regard, AFIS systems are capable of extracting the minutia points of fingerprints and translating the images into identifiable equations that could be understood by any other fingerprint examiner. Pattern-based and minutia-based algorithms compare the latent print in question with those stored in the AFIS data base within minutes, completing the work of hundreds or even thousands of latent examiners.

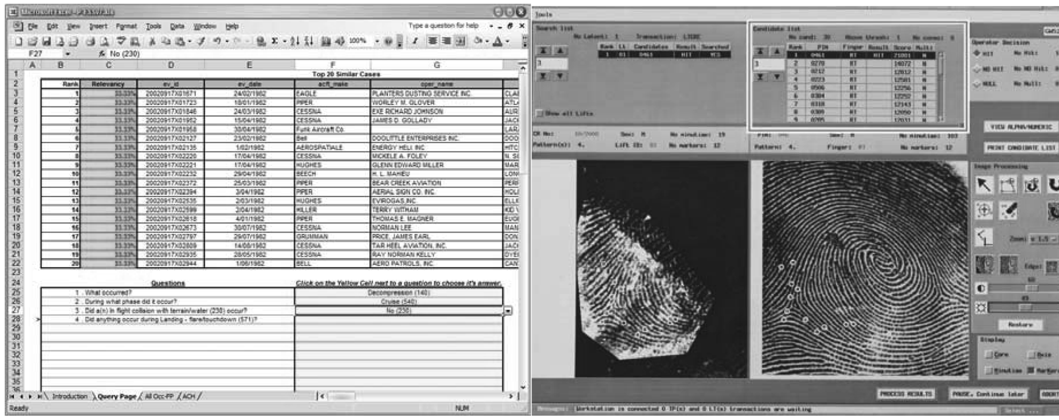
B. Fingerprint Identification Versus GP1020 Inquiry

After all latents have been entered, the latent examiner checks the work and launches the case. The latent fingerprint is searched by the matchers against a latent cognizant database within AFIS, containing hundreds of thousands or even millions of images. For instance, the FBI database is composed of 46 million records, which can be searched within minutes.

After that, candidates for a match, associated with some numerical measure of the probability of a match, are made available and are retrieved for verification. For instance, AFIS, using the Sagem Morpho operating system, usually provides a list of 30 candidates for a match.

The confirmation of system-suggested candidates is usually performed by two examiners in forensic systems. There is a general international agreement among experts that a successful match requires 12 points to match between the two fingerprints.

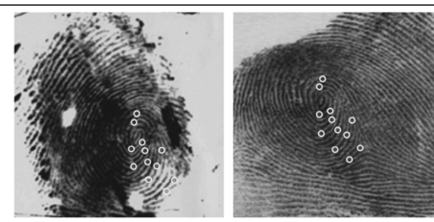
Similarly (as described in Sec. VIII) within a GP1020 inquiry the program retrieves a list of the 20 most similar cases (associated with their level of relevancy) that will most likely assist in investigating the given accident. Yet it is user's decision whether the information from the top 20 cases will be considered as useful in determining the circumstances and causes of the given accident or will continue to answer more questions in order to retrieve more suitable cases that may assist in this investigation. Thus, Fig. 13 shows the similarities



a) A list of top 20 similar cases displayed on GP1020 the program **b) A list of candidates for a match displayed on AFIS (Sagem Morpho) system**

Fig. 13 GP1020 Prototype vs AFIS (Sagem Morpho) system.

	E1	E2	E3	E4	E5	E6	…
C1	x		(x)	(x)			…
C2			(x)	(x)		x	…
C3		(x)	(x)	(x)	(x)		(…)
C4				(x)	(x)	x	…
C5			(x)	(x)		x	…
C6				(x)		x	…
C7					(x)	x	…
C8						x	…



a) A match within GP1020 inquiry **b) A match between two fingerprints**

Fig. 14 GP1020 Prototype vs AFIS (Sagem Morpho) system.

between GP1020 and AFIS (Sagem Morpho) programs in retrieving the list of cases/candidates for a match (area within black squares).

In addition, the table from Fig. 14 presents a list of accident causes (C1, C2, … C8, randomly chosen) and their consistent portions of evidence (E1, E2, …) stored within GP1020. The circled xs show the matches in evidence during the GP1020 inquiry, indicating the accident associated with C3 (Cause 3) from the GP1020 database will most likely facilitate the current investigation. Likewise, the photo in Fig. 14 shows a match between two fingerprints within AFIS (Sagem Morpho) identification.

It must be addressed that AFIS systems are only a tool used by the latent examiner. Namely, the examiner determines if the latent image is of value, then selects the search criteria, and then examines the lists of candidates produced by the search. At the end, the latent examiner makes the identification. However, not every latent print search will result in identification. Actual figures show that only 2–3% of latent print searches will result in identification [68]. (Despite this low rate of identification, AFIS systems are irreplaceable tools in police investigations worldwide).

Similarly, GP1020, as described earlier, is a tool that assists in aircraft accident investigations. Namely, the GP1020 program is designed to facilitate the conventional investigation of an air safety event and enhance the investigation outcomes by retrieving a list of top 20 most similar cases.

X. Limitations

The GP1020 computer program does have certain limitations which are mainly related to the specific knowledge stored as well as the limitation of the design technique used. Addressing these limitations was beyond the goals of this work, and, therefore, the GP1020 tool was created to successfully demonstrate that using expert system methodology can assist in accident investigation.

As stated earlier, the NTSB aviation accident database was used as expert knowledge in creating the GP1020 computer tool. Although this database is comprehensive in its contents, it has been created according to its owner's intent and does not precisely fit the data requirements of GP1020. Hence, the first and major current limitation is that there is no uniform data classification method and so it is impossible to combine all statistics to form a broad database, which is desirable for effective GP1020 operation. Thus, the main limitation of this application lies in the lack of specific expert knowledge that can be used by the GP1020 program. Because of this limitation a number of the stored investigative questions are not called by the GP prototype, which significantly reduces its efficiency.

The other significant limitation is that of computer power. Either changing the code to suit a particular operating system or using hardware with greater computing power would rectify this problem.

XI. Future Work

An immediate area for further work would be the full implementation of the proposed global expert system solution for aircraft accident investigation. To achieve this, the limitations of the GP1020 prototype must first be overcome.

The biggest challenge of this undertaking would be collecting and collating all global forensic accidents and incident data to date and then using this as stored knowledge within the expert system program. From here, additional testing of the accuracy of the historical data would be necessary to ensure the validity of the system's results. Once successful, implementation of the software into the systems of various air safety organizations would have to be considered so that the program code can be altered, changed, or rewritten to suit the new environmental operating system. It is certain that this task would be a massive and expensive effort but nevertheless achievable and potentially very useful in the following areas:

1) It would help in facilitating and enhancing aircraft accident investigation outcomes. This program would be able to determine the causes of aircraft accidents and incidents with a high rate of accuracy.

2) It would offer a permanent assessment of safety threats to aircraft. The program would be able to rapidly link updated safety

data from many different sources including aircraft, ATC, and other relevant sources in order to continuously assess the possible danger factors for aircraft accidents and provide instant measures to remove or reduce these threats. Once this software reaches a certain level of maturity, by significantly increasing computation time and accuracy it may well be able to handle emergencies on the fly.

XII. Conclusions

The expert system methodology developed for this application has proven to be a robust method of analyzing the aircraft accident investigation process. With an analysis of the statistics of accident that occurred between 1950 and 2004, a two-round Delphi study, and the development of the novel investigation tool GP1020, the methodology has drawn several valuable conclusions related to improvement of investigation outcomes and air safety.

The results have indicated that there is great potential for further improving aircraft accident investigation, particularly the areas of managing the investigation, wreckage analysis, and data management. Also, the procedure of dispatching investigators on the scene of an accident and the process of coordination and cooperation between investigators within an investigation can be improved. There is also a significant potential for further improving the investigation of human errors, omissions, and psychological factors as well as data recorders and in-flight occurrences such as aircraft system failures and explosions. This study indicates an avenue for further improvement that could be focused on analyzing criminal activities as a possible cause for accidents. Managing the amount of time and money spent within investigations can potentially be optimized.

In terms of prospective solutions for improving aircraft accident outcomes, this research indicates that a solid knowledge of theory by investigators can significantly enhance investigation results.

This study emphasizes the importance of recorders and recorded data within accident investigations. Hence, the results propose creating and using an advanced database for easy identification of an aircraft's components and, more important, for creating and using comprehensive databases for storing and analyzing aircraft accident forensic data. Furthermore, this study does address the importance of the common video recording of various functions in different aircraft zones and then transmitting the data to ground stations for storage.

This research concludes that aircraft accident investigation can be improved with the application of a global expert system as a tool for storing and analyzing global aircraft accident forensic data, with the option to learn from aircraft accidents using an inference engine to propose possible causes based on any forensic data provided. Such a system will ensure that this database is used to its maximum potential.

Thus, the novel GP1020 investigation tool has been a successful demonstration of applying an expert system concept to aircraft accident investigation. The GP1020 has been designed towards giving aircraft accident investigators improved use of forensic data by sifting through a considerable amount of data related to accidents and indicating the most probable accident cause(s). Results obtained during the testing of the GP1020 prototype encourage the application of a global expert system. In other words, the results promote increasing the program's knowledge pool to include historical data from many other sources other than those currently being used.

Finally, the expert system methodology developed for this application could be successfully used in improving air traffic safety. A fully developed global expert system would be able to provide a continuously updated assessment of safety threats to aircraft in flight and provide crews with instant measures to remove or reduce those dangers. This could be achieved via a continuous communication of current information related to air safety assessed with respect to prior historical data stored in the expert system program.

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