IMPROVEMENT OF AIRCRAFT ACCIDENT INVESTIGATION THROUGH EXPERT SYSTEMS

by

Goranco Milosovski

BSc (Mechanical Engineering), MSc (Mechanical Engineering)

Submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

at the

School of Aerospace, Mechanical and Manufacturing Engineering
Royal Melbourne Institute of Technology

December 2008

DECLARATION

I, Goranco Milosovski declare that:

- a.) Except where due acknowledgement has been made, the work is that of the candidate alone,
- b.) The work has not been submitted previously, in whole or in part, to qualify for any other academic award,
- c.) The content of the thesis is the result of the work which has been carried out since the official commencement date of the approved research program,
- d.) Any editorial work, paid or unpaid, carried out by a third party is acknowledged.

Goranco Milosovski

December 2008

Preface

Intent: This work has been carried out under an International Postgraduate Research Scholarship Award 2005 granted by RMIT University under the grant schemes within the Department of Education, Science and Training in the framework of the Australian Government. This work is intended for the aviation public whose primary concern is investigation of aircraft safety occurrences and enhancement of air traffic safety.

Publications: During the course of this research, several papers have been published. These are listed here for the reader's reference.

Milosovski, G., Bil, C., and Simon, P., 'Improvement of Aircraft Accident Investigation through Expert Systems', *Journal of Aircraft* [accepted for publishing]

Milosovski, G., Bil, C., and Simon, P., 'GP1020 Computer Tool - The 'AFIS' of Aircraft Accident Investigation', *Safety*, Skopje [accepted for publishing]

Milosovski, G. and Bil, C., 'Recent Applications in Air Traffic Safety for Development of an Expert System for Enhancing Aircraft Accident Investigation Outcomes', *Thirteen Australian International Aerospace Congress*, Melbourne, 2009 [accepted for publishing]

Milosovski, G. and Bil, C., 2009, 'Conceptual Development of Aircraft Accident Survivability', *Thirteen Australian International Aerospace Congress*, Melbourne, 2009 [accepted for publishing]

Milosovski, G., Bil, C. and Simon, P., 'Demonstration of Expert Systems to Aircraft Accident Investigation', *SimTecT 2008 Conference*, Melbourne, 2008

Milosovski, G., Bil, C. and Kosevski, M., 'Application of Expert Systems to Aircraft Accident Investigation', *46th ALAA Aerospace Sciences Meeting and Exhibit*, Reno, 2008

Milosovski, G., Bil, C. and Kuzinovski, M., 'Application of Expert Systems to the Improvement of Aircraft Accident Investigation', *Twelfth Australian International Aerospace Congress*, Melbourne, 2007

Milosovski, G. and Bil, C., 2007, 'Air Traffic Safety Analysis through Statistics', *Twelfth Australian International Aerospace Congress*, Melbourne 2007

Acknowledgements

Much help, assistance and advice was received from many people throughout the research and preparation of this thesis and I am deeply indebted to all those who contributed to bringing this work to fruition. Below are some of these people who I want to especially acknowledge and thank.

- My senior supervisor, Associate Professor Cees Bil, for his guidance over the duration of the research project. His constant support in providing advice and suggestions as well as his advice on my thesis drafts has been invaluable.
- My second supervisor and consultant, Professors Milan Kosevski and Mikolaj Kuzinovski respectively, whose knowledge and experience about conducting a Delphi enquiry proved extremely valuable during the course of this research.
- All the aviation experts who voluntarily participated in the Delphi exercise. Without their generous support, this work would not have been possible.
- Staff from the Australian Transport Safety Bureau and the Defence Science and Technology Organisation, for their time, patience and advice, as well as the other numerous consultants who have helped shape this thesis.
- Paul Simon, for his assistance in creating the GP1020 computer tool for analysing air traffic safety events.
- Biljana Petrevski and Ted Kanhere, for their assistance in helping me to proofread the initial thesis draft.
- All of my supportive colleagues and friends from Wackett Aerospace Centre, particularly Axel Schauenburg and Omar Erik Ilaya for their friendship and support over the past three years. Further appreciation and special thank to Dr. Arvind Sinha for his support and encouragement.
- The Damceski family for their hospitality and support throughout the period of research.
- The staff and students at Whitley College, which has been an extraordinary residential environment throughout this research.

- The indirect contribution of Kiril Causevski and Kiro Stankovski, under whom I studied and worked many years ago. Their excellences in thinking and teaching have always been an inspiration.
- My family for their patience and assistance over the duration of this research.
- My parents, for their support and encouragement.

Finally, I would like to thank the examiners for their time and patience in reviewing this work.

Contents

Preface	iii
Acknowledgements.....	v
Contents	vii
List of Figures	xi
List of Tables	xv
Abstract.....	1
1. Introduction	4
1.1. The Contribution of this Thesis	7
1.1.1 Research Methodology Contribution.....	7
1.1.2 Demonstration of Expert Systems Contribution.....	8
1.2. Thesis Outline	9
2. Background	11
2.1 International Standards to Aircraft Accident and Incident Investigation: Annex 13 to the Convention on International Civil Aviation	11
2.1.1 Aviation Safety Investigations Worldwide.....	13
2.1.1.1 Aviation Safety Investigation in Australia.....	13
2.1.1.2 Aviation Safety Investigation in the United Kingdom	15
2.1.1.3 Aviation Safety Investigation in the United States	16
2.1.1.4 Aviation Safety Investigation in Canada, France and Germany.....	17
2.1.1.5 Summary.....	19
2.2 Overview of Aircraft Accident Investigation	22
2.2.1 Accident Scene Recording and Collecting Evidence	23
2.2.2 Wreckage Analysis	26
2.2.3 Power-plant Analysis.....	29
2.2.3.1 Turbine Engine Examination	31
2.2.3.2 Common Turbine Engine Problems	33
2.2.3.3 Reciprocating Engine Examination	35
2.2.3.4 Propeller Examination	36

2.2.4 Aircraft Systems Examination	38
2.2.4.1 Mechanical Systems Examination	39
2.2.4.2 Hydraulic Systems Examination	41
2.2.4.3 Pneumatic Systems Examination	42
2.2.4.4 Electrical Systems Examination	42
2.2.5 Aircraft Recorders Examination	44
2.2.5.1 Cockpit Voice Recorders	47
2.2.5.2 Air Traffic Control Radar	48
2.2.6 Operation and Maintenance Investigation	49
2.2.6.1 Operation Examination	50
2.2.6.2 Maintenance Examination	52
2.2.7 Airfield, Air Traffic Control and Weather Examination	53
2.2.8 Human Factors	54
2.2.8.1 Human Factors Examination	55
2.2.9 Aircraft Accident Reports	58
3. Literature Review	59
3.1 Improvements in Aviation Recommended by the NTSB	60
3.2 Works Most Relevant to the Research	61
3.3 Other Works Relevant to the Research	63
3.3.1 Statistics as a Research Tool	63
3.3.1.1 Detection of Patterns within Accidents as a Tool for Enhancement of Air Safety	66
3.3.2 Human Factors	67
3.3.3 Aircraft and Aircraft Systems	73
3.3.4 Weather Induced Factors	77
3.3.5 Discussion	78
4. Application of Expert Systems to Aircraft Accident Investigation	80
4.1 Strategic Decisions and Forecasting – The Theory of Intuitive Methods	83
4.1.1 Intuitive Methods and their Features	84
4.1.2 The Delphi Method	86
4.1.2.1 The procedure of the Delphi Method	88
4.1.2.2 Aircraft Accident Investigation and the Delphi Technique	91
4.1.2.3 Advantages of the Delphi Method – Providing Credible and Accurate Results	92

4.1.2.4 Disadvantages of the Delphi Method.....	93
4.1.2.5 Organisational Problems within the Delphi Exercise	95
4.1.2.6 Mathematical Models - Criteria of Objectivity.....	98
4.1.2.7 Discussion.....	102
5. Air Traffic Safety Analysis through Statistics	104
5.1 Aircraft Accidents during the Period 1950 to 2004.....	106
5.2 Number of Casualties Involved in Aircraft Accidents.....	110
5.3 Causes of Aircraft Accidents during the Period 1950 to 2004	112
5.4 Significant Examples of Aircraft Accidents that occurred during the period 1950 to 2004	118
5.5 Statistics - Concluding Remarks.....	119
6. Application of the Delphi Method to Aircraft Accident Investigation	121
6.1 Preparation and Application of the Delphi Enquiry	121
6.2 Data Analysis of the Delphi Exercise Application	127
7. Demonstration of Expert Systems to Aircraft Accident Investigation	155
7.1 An Outline of Expert Systems	156
7.2 Expert Systems to Aircraft Accident Investigation – GP1020	159
7.2.1 Forensic Approach to an Aircraft Accident/Incident Occurrence within GP1020	160
7.2.1.1 GP1020 Enquiry of Human, Aircraft, and Weather Induced Causal Factors..	162
7.2.1.2 Classification of the Causes of Aircraft Accidents within GP1020.....	165
7.2.1.3 Expert knowledge stored in GP1020	169
7.3 GP1020 Prototype.....	170
7.3.1 Programming Software	170
7.3.2 Knowledge Base	171
7.3.3 User Interface.....	173
7.3.4 Inference Engine	175
7.3.5 GP1020 Prototype – User Instructions	180
7.4 GP1020 Computer Tool – The ‘AFIS’ of Aircraft Accident Investigation.....	187
7.4.1 An Overview of the Automated Fingerprint Identification Systems (AFIS)...	187
7.4.2 AFIS Identification versus GP1020 Enquiry	189
7.5 Case Study: GP1020 Prototype Enquiry into the Aircraft Accident on 05 March 1993 at Skopje Airport, Macedonia.....	191

7.5.1	Background	191
7.5.2	GP1020 Prototype Enquiry into the Skopje Accident	195
8.	Conclusions	20201
8.1	Discussion	202
8.2	Limitations	206
8.3	Future Work	208
8.3.1	Application of Global Expert System to Improvement of Aircraft Accident Investigations and Air Traffic Safety	209
8.3.2	Issues Related to Improvement of Survivability of Aircraft Accidents	209
8.4	Concluding Statements	211
	References	214
	APPENDIX A	226
	APPENDIX B	231
	APPENDIX C	240
	APPENDIX D	241

List of Figures

Figure 1: The design and development process for expert systems applied to aircraft accident investigation.....	1
Figure 2: Icarus	5
Figure 3: Universal investigation kits.....	22
Figure 4: Aerial view of a wreckage distribution	23
Figure 5: Wreckage distribution (polar diagram).	24
Figure 6: Approach profile (in red) derived from FDR data and terrain profile overlaid on an extract approach chart.	25
Figure 7: Evidence of impact at slow forward speed and low angle of attack	27
Figure 8: Scrape marks on pilot's encoding altimeter face from pointer	28
Figure 9: A single fracture zone representing an overstress failure.....	29
Figure 10: Evidence of corrosion and fatigue patterns on the metal fraction.....	29
Figure 11: An engine lateral section	30
Figure 12: Blades bending: the compressor section was turning upon impact.....	32
Figure 13: Detection of traces of arson at an accident site	36
Figure 14: Propeller under power and propeller wind milling at impact, respectively.	37
Figure 15: Cable fracture (evidence of failure of some strands prior to the final failure).....	40
Figure 16: Fluid leakages due to improper sealant	41
Figure 17: Evidence of an electrical short-circuit.....	43
Figure 18: Flight data and cockpit voice recorder	45
Figure 19: Simulation of a flight by recovering the flight data recorded.	47
Figure 20: ATC Radar display.....	48
Figure 21: Exterior safety inspection.....	52
Figure 22: Automated fingerprint identification.....	55
Figure 23: Analysis of blood sample for blood-alcohol concentration	57
Figure 24: Relationships between human, environmental and aircraft factors.....	81
Figure 25 The Delphi Technique. Identification of the Expert Opinion.....	90
Figure 26: Number of aircraft accidents that occurred worldwide between 1950 and 2004...	107
Figure 27, 28: Correlation between rates 1 and 2 and number of departures	108
Figure 29: Distribution of aircraft accident by decades according to the place of accident....	109

Figure 30: Distribution of the rate of killed passengers in aircraft accidents	111
Figure 31: Causes for aircraft accidents 1950-2004 (by decades).....	114
Figure 32: Aircraft causal factors for accidents during the period 1950 to 2004	116
Figure 33: Distribution of the human sub-causal factors by decades	117
Figure 34: Distribution of the weather sub-causal factors 1950-2004.....	118
Figure 35: Expert group opinion on the general principles within aircraft accident investigation	128
Figure 36: Expert group opinion concerning the possibility of answering the general investigation questions.....	130
Figure 37: Expert group opinion concerning the importance of the stages of an aircraft accident investigation.....	132
Figure 38: Expert group opinion on the complexity of the phases of an aircraft accident investigation.....	134
Figure 39: Expert group opinion concerning the potential for improvement of the stages of an aircraft accident investigation.....	136
Figure 40: A ranking of the various parts of an aircraft accident investigation in 3-D space based on their importance, complexity and potential for improvement	137
Figure 41: A ranking of the various parts of an aircraft accident investigation in 3-D space based on their importance, complexity and potential for improvement	138
Figure 42: Expert group opinion concerning the complexity of examination within an investigation.....	140
Figure 43: Expert group opinion concerning the potential for improvement of examination within an investigation.....	143
Figure 44: Complexity and potential for improvement of examination of the given factors within an aircraft accident investigation.....	143
Figure 45: Expert group opinion concerning the likelihood of verifying the causes of accident	146
Figure 46: 3-D presentation of expert group opinion concerning the examination of aircraft, human and environmental causal factors.....	147
Figure 47:3-D Presentation of expert group opinion concerning the examination of aircraft, human and environmental causal factors.....	148
Figure 48: Expert group opinion concerning the statements 75-98.....	151
Figure 49: Classification by decision tree induction	157
Figure 50: The answer ‘A Jet’ provided by the Q20 after the 20th question.....	159

Figure 51: Front page of the application GP1020.....	159
Figure 52: Conversion of the original matrix into GP1020 format	168
Figure 53: GP1020 Prototype – Current Knowledge Base – General Detail Vs Occurrences	172
Figure 54: GP1020 Prototype – Current Inference Engine – Occurrences Vs Score	176
Figure 55: GP1020 Prototype - Current Inference Engine – Event Frequency & Question Rank	177
Figure 56: GP1020 Prototype – Relevancy Variation	178
Figure 57: GP1020 Prototype - Introduction Page	180
Figure 58: GP1020 Prototype – Query Page	181
Figure 59: GP1020 Prototype – Drop Down Menu.....	182
Figure 60: GP1020 Prototype – Yes/No Drop Down Menu.....	183
Figure 61: GP1020 Prototype – Fourth Question	184
Figure 62: GP1020 Prototype – Relevancy Variation	185
Figure 63: GP1020 Prototype – New Investigation.....	186
Figure 64: The four basic patterns of fingerprint ridges.....	188
Figure 65: Minutia points of fingerprint ridges	188
Figure 66: GP1020 Prototype versus AFIS (SAGEM ‘Morpho’) system.....	189
Figure 67: GP1020 Prototype versus AFIS (SAGEM ‘Morpho’) system.....	190
Figure 68: GP1020 enquiry into the accident that occurred on 05 March 1993 at Skopje.....	195
Figure 69: Start Position from all Cases	196
Figure 70: Question 1: ‘What occurred?’ Answer 1: ‘In flight collision with terrain/water’..	196
Figure 71: Question 2: ‘During what phase did it occur?’ Answer 2: ‘Takeoff – initial climb’	197
Figure 72: Question 3: ‘Did a loss of control – in flight occur?’ Answer 3: ‘No’	197
Figure 73: Question 4: ‘Did anything occur during Landing – flare/touchdown?’ Answer 4: ‘Yes’	198
Figure 74: Question 5: ‘Did a forced landing occur?’ Answer 5: ‘No’	199
Figure 75: Question 6: ‘Did anything occur during landing – roll?’ Answer 6: ‘No’	199
Figure 76: Question 7: ‘Did an in flight collision with object occur?’ Answer 7: ‘Yes’	200
Figure 77: Unsafe Events – A chain of events leading to an accident.....	205
Figure 78: A chain of events leading to an accident.....	206
Figure 79: Outcomes derived by application of the Expert System to aircraft accident investigation.....	211

Figure B1: Expert group opinion from the first and second round of Delphi exercise with respect to Question 1.....	231
Figure B2: Expert group opinion from the first and second round of Delphi exercise with respect to Question 2.....	232
Figure B3: Expert group opinion from the first and second round of Delphi exercise with respect to Question 3.....	233
Figure B4: Expert group opinion from the first and second round of Delphi exercise with respect to Question 4.....	234
Figure B5: Expert group opinion from the first and second round of Delphi exercise with respect to Question 5.....	235
Figure B6: Expert group opinion from the first and second round of Delphi exercise with respect to Question 6.....	236
Figure B7: Expert group opinion from the first and second round of Delphi exercise with respect to Question 7.....	237
Figure B8: Expert group opinion from the first and second round of Delphi exercise with respect to Question 8.....	238
Figure B9: Expert group opinion from the first and second round of Delphi exercise with respect to Question 9.....	239
Figure C1: A model for representing the stereoscopic 3-D graph of quantification method III.	240

List of Tables

Table 1: Values of coefficient ‘u’ for calculating the distribution (σ).....	101
Table 2: Number of aircraft accidents that occurred worldwide between 1950 and 2004.	107
Table 3: Monthly distributions of aircraft accidents that occurred between 1950 and 2004...	109
Table 4: Top five countries where most aircraft accidents occurred over the period 1950-2004.	110
Table 5: Casualties in aircraft accidents in the period 1950-2004.....	110
Table 6: Aircraft involved in accidents.....	112
Table 7: Average age of aircraft involved in accidents 1950-2004.....	112
Table 8: Distribution of accident causes according to the flight phase.	113
Table 9: Distribution of accidents in sub phases within approach & landing phase.	113
Table 10: Accidents occurring on the runway before takeoff or during landing.....	113
Table 11: Distribution of contributing causal factors.	115
Table 12: Aircraft sub-factors leading to accidents during the period 1950 to 2004.	116
Table 13: Human sub-factors leading to accidents during the period 1950 to 2004.	117
Table 14: Severe weather conditions as major causal factors for accidents 1950 – 2004.....	117
Table 15: Distribution of the 100 deadliest aircraft accidents over the period 1950-2004.	119
Table 16: Expert group opinion with respect to question 1.....	127
Table 17: Testing the non-randomness of C_k and the Spearman rank coefficient.....	127
Table 18: Expert group opinion with respect to question 2.....	129
Table 19: Testing the non-randomness of C_k and the Spearman rank coefficient.....	129
Table 20: Expert group opinion with respect to question 3.....	131
Table 21: Testing the non-randomness of C_k and the Spearman rank coefficient.....	131
Table 22: Expert group opinion with respect to question 4.....	133
Table 23: Testing the non-randomness of C_k and the Spearman rank coefficient.....	133
Table 24: Expert group opinion with respect to question 5.....	135
Table 25: Testing the non-randomness of C_k and the Spearman rank coefficient.....	135
Table 26: Expert group opinion with respect to question 6.....	139
Table 27: Testing the non-randomness of C_k and the Spearman rank coefficient.....	139
Table 28: Expert group opinion with respect to question 7.....	141
Table 29: Testing the non-randomness of C_k and the Spearman rank coefficient.....	142

Table 30: Expert group opinion with respect to question 8.....	144
Table 31: Testing the non-randomness of C_k and the Spearman rank coefficient.....	145
Table 32: Expert group opinion with respect to question 9.....	149
Table 33: Testing the non-randomness of C_k and the Spearman rank coefficient.....	150
Table 34: A list of 20 questions and answers provided by the user of the Q20 game.....	158
Table 35: A list of possible causes of accident versus their distinguishing features.	168
Table 36: Event/Flight Phase Code Likelihood.	192

Abstract

Research has been conducted at RMIT University, Melbourne, Australia on the ‘Improvement of Aircraft Accident Investigation through Expert Systems’. This research project aims to analyse aircraft accident investigation and to review some of the off-the-shelf tools that support these investigations. An analysis of the investigation process and tools will provide a possible avenue for updating the aircraft accident investigation and for implementing mitigation measures to enhance air traffic safety. The research framework is presented below in Figure 1.

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

The work starts with discussing the aircraft accident investigation which is defined as a process conducted for the purpose of accident prevention and focused on the circumstances of the accident including gathering, recording and analysing all of the available information, the drawing of conclusions, and the determination of accident causes [116].

Despite the attitude and commitment to achieving the above purpose, accident investigations may become a cumbersome task associated with significant costs and uncertainty. This can potentially contribute to some accidents being assigned an unknown cause as seen in global aircraft accident statistics for the past 50 years. Thus, the investigation process has been subjected to constant review in order to improve its outcomes and to help enhance air traffic safety.

This research work aims to contribute to this constant review process by examining possible methods of improving the efficiency of aircraft accident investigation. As a result, initially the question of how to comprehensively consider the complex investigation procedure was raised.

The work concludes that an intuitive and interdisciplinary approach must be vital elements of any contemporary method used for establishing a set of priorities for further improvement of aircraft accident investigation. Hence, the interpolations methods, including an analysis of accident statistics and Delphi enquiry, are appropriate tools in analysing and drawing conclusions for further improving the investigation. The statistical data examined contained the number of accidents which occurred between 1950 and 2004 worldwide including accident distribution over the past, causal factors, and casualty count. The importance of statistics as a research tool has long been appreciated by ICAO (International Civil Aviation Organization) which sees accidents statistics as a tool for ‘understanding the past, explaining the present and planning for the future’ [114].

In addition, a Delphi enquiry, which is formalised regarding the procedure for carrying out research activities, has provided a comprehensive analysis of the investigation procedure including investigation techniques. A team of experts created for this purpose has conducted a qualitative and quantitative analysis of the factors having an impact on investigation outcomes. The Delphi application, by conducting a comprehensive survey without bringing the participants physically together, reflects the modern age of highly developed technology, experts, specialisation, and the period of globalisation.

The Delphi study has indicated that there is great potential for further improvement of aircraft accident investigation. It has pointed out areas of the investigation process where significant improvements could be achieved. Moreover, the Delphi method has shown that

investigations could be significantly improved with the application of a global expert system as a tool for storing and analysing the forensic data of aircraft accidents worldwide.

As a consequence, the computer program GP1020 has been created in order to demonstrate how expert systems could contribute to facilitating and enhancing investigation results. The outcome of GP1020 is a novel investigation tool in the form of a data mining method designed to improve forensic data use by the aircraft accident investigators. The GP1020 program interface asks the user a tree-based set of questions related to conditions of wreckage, accident site and other circumstances relevant to accidents/incidents. Given enough information, the program is capable of narrowing down all known possibilities to indicate the most probable causes of the accident/incident.

This work provides the answers to several questions relating to the improvement of investigation outcomes. First of all, the research indicates the factors that could contribute to obtaining better results of an aircraft accident investigation. Next, this research shows the facilities and procedure resources that have an impact on outcomes of aircraft investigations. Additionally, this study explains that a global expert system is a useful tool in aircraft accident investigation. This work also demonstrates how an expert system could enhance the investigation results. Moreover, in view of the growth in air traffic, this research points out the possible measures for reducing the number of aircraft accidents and their severe consequences.

This research concludes by stating its limitations and possible solutions for overcoming them. Finally, several areas requiring further research are suggested.

Man must rise above the Earth to the top of the atmosphere and beyond, for only thus will he fully understand the world in which he lives.

SOCRATES (469 BC – 399 BC)

Introduction

One of the biggest achievements of mankind has been the rapid growth in the aerospace industry, in particular air traffic. At the beginning of the twenty first century, airlines operate more than 22 million passenger flights annually worldwide, transporting over one billion passengers globally.¹ Consequently, air traffic has become the prevalent means for carrying passengers and transporting goods over long distances, far exceeding marine and road traffic.² Aircraft frequently cross great oceans, vast featureless deserts, immense ice wastelands, and enormous desolate regions in complete safety in spite of the adverse conditions of the terrain below.

Despite the huge progress in air traffic safety, human errors, equipment malfunctions as well as unusual events³ occur and therefore accidents still do take place [129, 171]. Air accidents are relatively rare, but when they do happen they are devastating. In the past 50 years, over 1600 accidents have occurred worldwide resulting in more than 64,000 deaths⁴, indicating that air traffic is still imperfect.

¹ Figure 27, 28 (page 108)

² The human ambition to fly was manifested even in an ancient Greek legend about Daedalus and Icarus. But, it was not until 21 November, 1783, that human efforts to fly literally got off the ground, when a balloon designed by Montgolfier brothers, Joseph and Etienne, ascended into the air and drifted 5 mi across Paris. However, Orville and Wilbur Wright's demonstration of the world's first powered, controlled, and sustained flights on 17 December 1903 marked a turning point in human history. One century after the first flight of the Wright brothers, airplanes are commonplace. They can fly with speed beyond 2000 km/hour performing varieties of different services.

³ For instance, in the case of the crash landing of a DC10 at Sioux City on 19 July 1989, experts say that the odds of a rear engine malfunction, which severs all hydraulic connections to the rudder and flaps, leaving the aircraft in the air out of control, are a billion to one [85, 75].

⁴ Table 2, 5 (page 107, 110)

The first mishap⁵ can be traced back to the ancient Greek legend of Daedalus and Icarus. According to the legend, Daedalus was an engineer who was imprisoned in Crete by King Minos. To escape his confinement, he made wings of wax and feathers for both himself and his son, Icarus, to fly away with. Daedalus flew successfully from Crete to Naples, but Icarus tried to fly higher and higher and eventually flew too close to the sun. The wings of wax melted and Icarus fell to his death in the sea. According to the legend, the cause of the crash was Icarus flying too high, from which a lesson can be learnt. Similarly, through aircraft accident investigation the causes of accidents are determined and measures to improve aircraft and air traffic safety are established.

Figure 2: Icarus [143].

The major objective of an aircraft accident investigation is to determine the causes of an accident and to help establish consistent measures to avoid similar occurrences under related circumstances. To accomplish this objective, all circumstances and details within an aircraft accident are examined, documented and correlated. In most occurrences there is a chain of factors that combine to form the causes of the accident/incident.

Within an investigation all aspects of the accident are equally important, including determining the cause of the accident, the circumstances relating to the survivability of passengers and damage to the aircraft, as well as issuing recommendations. However, the sole objective of the investigation of an accident or incident is to help prevent future reoccurrences or, in other words, it is not the purpose of the accident investigation to apportion blame and/or

⁵ The first known aviation crash with fatalities occurred on 15 June 1785 in which the balloonists Pilatre de Rozier and Pierre Romain lost their lives, whereas the first powered fixed-wing aircraft fatality in history occurred on 17 September 1908 when Thomas Selfridge was killed in the plane piloted by Orville Wright.

liability. Determining personal errors or responsibilities are thus not included in the duties of aircraft accident investigators. Yet it is inevitable that in the course of an investigation, any omissions or errors made by individuals or organisations will be revealed. Simply, investigators determine what happened, how it happened and why it happened. During this procedure, investigators seek out evidence, analyse suspicious equipment, draw conclusions and, where appropriate, issue recommendations.

The main cause of an accident is occasionally ambiguous. For instance, the failure of a system can result from poor control or maintenance. Similarly, if a human error appears as an accident cause then it is investigated from all aspects relevant to the procedure. Moreover, the investigation does not finish when a failure is deduced or detected, but rather it strives to find out why this failure occurred. Within this capacity, experience shows that poor design, human error, inconsistency or poor procedure may significantly distract or confuse the crew and other personnel. However, statistics indicate that most aircraft accidents occur due to human error, or circumstances that lead to human error, including deficient design, manufacturing, testing, maintenance, control and/or operation. Identification of these elements can occasionally be very difficult, but can still be discovered by careful, comprehensive and persistent examination.

Sometimes accidents can result from an organisational deficiency such as a lack of training or poor management. For instance, the aircraft owner could have issued procedures or instructions that do not meet all aspects of air traffic safety. Therefore, the relevant aircraft accident investigation is usually extended to other organisational services and departments that are not directly linked to the accident.

Within an investigation, particularly when the causes are unclear, all assumptions are investigated in detail to help find possible causes for the accident. This approach leads to a lengthy procedure, but this is the only way to investigate thoroughly an aircraft accident occurrence.⁶

The main aim of this thesis can be summarised as:

⁶ For instance, crash investigation of Swissair Flight 111, which crashed into the Atlantic Ocean on 2 September, 1998 after an in-flight fire, is one of the biggest investigations in aviation history [92]. NTB of Canada spent 4.5 years and 40 million dollars on the investigation concluding that flammable materials must be removed from commercial aircraft. The FAA gave the deadline of 2005 to remove flammable material from all commercial aircraft.

Moreover, investigations can change aviation history such as the investigation of the Concorde accident that occurred on 24 July 2000 in Paris, whose conclusions grounded all Concorde flights forever.

To pursue a thorough analysis of the aircraft accident investigation process, followed by identifying areas where significant improvements could be achieved, and finally demonstrating an expert system tool for improving investigation outcomes.

1.1. The Contribution of this Thesis

The contribution of this thesis is twofold: a contribution to the methodology for analysing the process of aircraft accident investigation as a complex multi-factorial issue, and a contribution to the demonstration of expert systems as an effective tool for enhancement of aircraft accident investigation outcomes.

The contribution to the research methodology is the introduction of the Delphi method as an efficient technique for comprehensively analysing an investigation, whilst the demonstration of an expert system is the creation of a novel investigation tool in the form of a data mining method for the improved use of a large database of stored expert knowledge.

1.1.1 Research Methodology Contribution

The first challenge faced in this work was the research approach to accident investigation and creating research strategies to help answer posed research questions. As experimental methods were clearly not appropriate techniques for considering aircraft accident investigation procedures, non-experimental research methods for the thorough analysis of aircraft accident investigation including statistical analysis, classification, interviews, intuition and other prospective techniques were focused on.

By considering current research in the field of accident investigation, it is easy to conclude that an analysis of the investigation process is still a challenging task. There are, however, a number of written materials and research currently being undertaken towards the enhancement of investigation outcomes, but most of them focus on a particular segment of the investigation process. Whilst developing certain 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 analysing the investigation **as a whole**. Thus, by using this approach this work makes a significant contribution to research methodology in the field of aircraft accident investigation.

Due to the variety of disciplines participating within an investigation, the proposed methodology suggests using expert systems as the most effective tools for analysing the accident investigation process. Thus, comprehensive conclusions have been drawn by considering the statistics (forensic data) of accident investigations carried out worldwide, followed by an application of the Delphi enquiry. The Delphi exercise has surveyed a team of aviation experts in order to extract estimates for further improving the accident investigation procedure.

This research approach managed to identify the areas and stages of aircraft accident investigation where significant improvements can be made by employment of contemporary technology and science. Additionally, expert systems methodology has pursued a qualitative and quantitative analysis of the factors that have an impact on investigation outcomes. Finally, this methodology has suggested that investigation outcomes could be significantly improved with the application of a global expert system as a tool for storing and analysing the forensic data of aircraft accidents worldwide.

This research contribution is not limited to the entire aircraft accident investigation procedure, but can be extended to portions of the investigation as well. This could include potential uses in both technical investigation of aircraft systems and analysis of human factors.

The methodology used can also be applied to other fields where complex multi-factorial issues are considered.

1.1.2 Demonstration of Expert Systems Contribution

Two main areas have been actively used within this contribution. The first one involves the previous results of a Delphi enquiry into aircraft accident investigation which suggested the use of expert systems for improving the investigation process. Whilst this procedure does not present any new theoretical approach for analysing complex issues (the Delphi enquiry is formalized through procedures for research activities), its specific use in accident investigation is an original work. The second aspect of this contribution is the demonstration of an expert system for accident investigation via the GP1020, a computer program which is a novel investigation tool for enhancing investigation outcomes. This computer program uses a data mining method to sift through a database containing a large number of causal factors for accidents/incidents and their associated evidence.

The GP1020 interface asks the user of the program a series of questions related to various factors of the accident/incident and, based on the information provided, the tool

narrows down all known possibilities to indicate the most probable causes of the accident/incident.

The success of this solution lies in the amount of stored and classified expert knowledge designed to give aircraft accident investigators improved use of forensic data.

1.2. Thesis Outline

The thesis is comprised of 8 main chapters, including the *Introduction* and *Conclusion*. The content of these chapters is briefly outlined below.

It is assumed that the reader has a general understanding of aircraft theory and the general procedure of an aircraft safety investigation.

Chapter 1: Introduction describes both the scope of the research as well as the nature and span of the study. This chapter also elaborates on the benefits of this research, followed by a brief overview of the thesis structure.

Chapter 2: Background provides the reader with brief relevant information related to the procedure of aircraft accident investigation. The first section of this chapter gives an overview of international standards of aircraft accident and incident investigation by discussing parts of Annex 13 to the Convention of International Civil Aviation, followed by a concise description of air safety investigations in several developed countries.

In addition, this chapter provides technical details about conducting an investigation including an analysis of the accident site, wreckage analysis, and the examination of other factors relevant to a safety event.

Chapter 3: Literature Review. In this chapter comments on recently published works pertinent to airline accident investigation are given regarding the relevancy of techniques used and their technical merits. For more technical details the reader is referred to the works cited.

Chapter 4: Application of Expert Systems to Aircraft Accident Investigation discusses the research tools available to comprehensively examine the aircraft accident investigation process. This chapter introduces the intuitive methods and, in particular, trend interpolation methods and the Delphi method as the most suitable tools for examining the aircraft accident investigation process. This chapter advocates the use of those methods and the credibility of their prospective conclusions.

Chapter 5: Air Traffic Safety Analysis through Statistics contains some original conclusions in relation to air traffic safety derived by analysing the statistics of accidents that occurred worldwide between 1950 and 2004. Due to several reasons addressed in the chapter,

this technique helped demonstrate the benefits of interpolation methods within intuitive methods that were introduced in Chapter 4 as appropriate tools for analysing aircraft accident investigation.

Chapter 6: Application of the Delphi Method to Aircraft Accident Investigation describes the Delphi enquiry carried out for the purposes of this research. It explains the whole procedure conducted following an analysis of results derived from a two round Delphi exercise. The results of this survey method with feedback have provided the answers to most research questions posed and directed the further course of research towards creating a computer tool for analysing the forensic data of aircraft accidents occurring worldwide.

Chapter 7: Demonstration of Expert Systems to Aircraft Accident Investigation follows on from the conclusions drawn in Chapter 6 and introduces the computer program named GP1020. The chapter discusses the application of the GP1020 to aircraft accident investigation including its design, features, and limitations.

Chapter 8: Conclusions discusses the key results of the research. The chapter includes a brief critique of the research methodology. The areas requiring further work are identified along with possible areas of future research. Finally, a brief conclusion to the research is given.

The major research area of this work is the *investigation of an aircraft accident or incident occurrence*. For clarification, this candidate uses in the proceeding chapters several different expressions such as ‘*accident investigation*’, ‘*accident/incident investigation*’, and ‘*investigation*’. All of these phrases have an identical or very similar meaning. Similarly, the expressions ‘*investigation procedure*’, and ‘*investigation process*’ are used interchangeably.

Every accident has its own forerunners, and every one happens either because somebody did not know where to draw the vital dividing line between the unforeseen and the unforeseeable or because well-meaning people deemed the risk acceptable.

STEPHEN BARLAY, *The Final Call: Airline Disasters Continue to Happen*, 1990.

Background

This chapter will provide the reader with a brief overview of current international aircraft accident and incident investigation standards, followed by an outline of a safety investigation in several developed nations including Australia, United Kingdom, USA, Canada, Germany and France. Additionally, a general overview of standard investigation procedures with some specific techniques for analysing wreckage, its systems, human involvement and other factors relevant to investigation outcomes is given.

This chapter assumes that the reader has a basic knowledge of aircraft accident/incident investigation procedures, and will therefore use some terms that have special meanings when considered within this context.

2.1 International Standards to Aircraft Accident and Incident Investigation: Annex 13 to the Convention on International Civil Aviation

The International Civil Aviation Organization was established in 1944 by 52 nations whose aim was to enhance the safe, orderly and economic development of international air transport [114]. It is a United Nations specialised agency presenting the ‘global forum for civil aviation’ [117].

ICAO realises its objectives of safe and secure air transport as well as sustainable development of civil aviation through cooperation amongst its member States. The Organisation is currently working on implementation of the following strategic objectives [118]:

1. Safety - enhance global civil aviation safety,
2. Security - enhance global civil aviation security,
3. Environmental protection - minimise the adverse effect of global civil aviation on the environment,
4. Efficiency - enhance the efficiency of aviation operations, and
5. Continuity - maintain the continuity of aviation operations.

The most significant document issued by ICAO relating to aircraft accident occurrences and investigations is Annex 13 of the Convention on International Civil Aviation. This annex presents a collection of standards and recommended practices for aircraft accident inquiries and has been adopted worldwide in accordance with Article 37 of the Convention on International Civil Aviation (Chicago, 1944) subject to Article 26 of the Convention [114]. Article 26 imposes an obligation on the State in which the aircraft accident occurs to conduct the inquiry in accordance with ICAO procedures. Furthermore, in order to obtain a superior investigation outcome, Annex-13 addresses the importance of using a uniform procedure and specialised knowledge of competent experts as well as co-operation among all contracting States. The content of Annex-13 applies to activities associated with accidents and incidents where they have occurred.

Annex-13 defines and regulates the important issues relating to aircraft accident/incident inquiry. It provides definitions for all relevant terms used within an investigation including accident, incident, investigation, recommendation and so forth. Hence, the definition of an accident involves some degree of damage or injury associated with the operation of an aircraft, whereas an investigation is defined as follows [116]:

‘A process conducted for the purpose of accident prevention which includes the gathering and analysis of information, the drawing of conclusions, including the determination of causes and, when appropriate, the making of safety recommendations.’

The annex emphasises that the purpose of investigation is not to establish blame, liability or claims. It also deals with other pertinent issues including dealing with notification, responsibility within the process of an investigation and other relevant concerns.

2.1.1 Aviation Safety Investigations Worldwide

Investigators from investigative agencies worldwide do an extraordinary job of piecing together the evidence in major airline accidents and determining the causes of these accidents under the most difficult circumstances. They correctly try to identify and assess evidence of these events so that corrective actions can be undertaken to prevent future accidents in similar circumstances.

Safety investigations being conducted by investigating agencies in several developed nations are presented below. This section aims to introduce and compare briefly the duties of those specialized institutions within the framework of Annex 13, rather than detailing their tasks and responsibilities.

2.1.1.1 Aviation Safety Investigation in Australia

Australia's agency for transport safety investigations is the **Australian Transport Safety Bureau** (ATSB), which is an independent body within the Australian Government Department of Transport and Regional Services. The goal of the ATSB is to maintain and improve transport safety and it does so through conducting independent investigations of transport accidents including **aircraft accidents**. Among other tasks, the ATSB is responsible for recording safety data, carrying out analysis and research, and raising safety awareness and knowledge [13, 14].

Australian law has entirely adopted the provisions of Annex-13 to the Convention of International Civil Aviation (Chicago Convention 1944) through the Transport Safety Investigation Act 2003 (TSI). Consequently, investigations are completely focused on enhancement of air transport safety, rather than assignment of blame or liability. The Bureau is separate from transport regulators (Civil Aviation Safety Authority) and from service providers.

The Bureau does not investigate all accidents or incidents. In accordance with Annex-13 it is focused on fatal accidents and the most significant 'serious incidents'. Thus, the ATSB concentrates its resources on in-depth investigations that will most likely initiate recommendations to enhance aviation safety.

The ATSB has classified aircraft accidents into five categories based on the priority list of activities, upon which it allocates its resources. The first category includes accidents involving passenger aircraft (large aircraft) with or without fatalities; the second category –

cargo aircraft with or without fatalities, and so on, with the last category including accidents involving sport aviation aircraft. The decision making process of whether or not to conduct an on-scene investigation depends on the findings of the assessment. The various aspects taken into consideration include the potential safety value that may be gained by conducting an investigation, on board fatalities and/or serious passenger injuries, provision of support to state coroners, the public profile of the occurrence, the resources available and any risks associated with not investigating.

The Bureau investigates, as do many equivalent organisations overseas, in accordance with TSI Regulations 2003. The owner, operator or crew of an aircraft must notify the ATSB of all aviation occurrences. The Bureau communicates with police, emergency services, air traffic control, coroners and the aircraft operator to ensure that the scene of the accident is secured, and that investigators can be dispatched to the accident site and conduct the investigation.

Investigators photograph and record all evidence on the ground and later examine the aircraft's logbooks and maintenance records. They may then arrange for the aircraft wreckage, components and other material evidence to be transported to the Bureau's Canberra office, or some other secure area, for further examination and testing. ATSB investigators will, where possible, interview the pilot, passengers and other witnesses. They may also visit the departure and destination airfields and interview the pilot's acquaintances and officials, including air traffic controllers who came in contact with the pilot before the flight. They may ask for records relating to the pilot's training and experience and may require company documents relating to the aircraft's operation. Maintenance records and interviews with maintenance personnel may also be required.

Since the ATSB's aim is future safety, it cannot use the power of the TSI Act against individuals or companies regardless of the role they have played in the accident. The Act allows investigators to interview persons directly or indirectly involved in an accident or to remove and retain relevant documentation and physical evidence for further examination and analysis.

Issuing the final report of an accident occurrence generally takes several months. It includes findings relating to interviewing individuals, examination of suspect equipment and advice given by other technical experts. As required under the TSI Act, reports are not produced with purpose to blame or to determine liability. If appropriate, the report will include safety recommendations. A copy of the final report is sent directly to the involved individuals

and organisations or their representatives. Since the ATSB is not a regulatory authority, the Bureau cannot enforce the other interested parties on adoption of the recommendations issued.

The state or territory coroner may conduct an inquest into a fatal aviation accident. The coronial investigation and the ATSB investigation are complementary.⁷

2.1.1.2 Aviation Safety Investigation in the United Kingdom

The Air Accidents Investigation Branch (AAIB) is responsible for the investigation of civil aircraft accidents and serious incidents within the United Kingdom (UK). It also assists in UK military accidents and investigations abroad. The AAIB is an independent part of the Department for Transport, separate from the Civil Aviation Authority. The AAIB's power to investigate the accidents comes from the Civil Aviation Act, Civil Aviation (Investigation of Air Accidents) Regulations [2].

In accordance with Annex-13, the AAIB investigates the occurrences in order to prevent future accidents through conducting a thorough investigation and establishing safety recommendations. Since the AAIB is not a regulatory authority it cannot enforce its recommendations. Investigations are not conducted with the intention of establishing blame or liability.

According to the procedure of accident notification, when an accident occurs the AAIB must be notified of the occurrence. It then liaises with the police, emergency services, air traffic control and the aircraft operator in order to secure and impound the evidence associated with the accident. Investigators are dispatched to the scene of the accident and conduct the investigation.

Operations investigators carry out investigations relating to the flying procedures and techniques, human factors, aircraft performance, survivability, weather, airfields, air traffic control and so on. Other engineering inspectors examine aircraft airworthiness, systems, engines, structure, failure and fault analysis, maintenance procedures, records and documentation. Investigators are authorised to take signed statements from anyone involved directly or indirectly with the accident. Pertinent books, papers and other relevant documents can be removed and retained by investigators and, if needed, investigators may enter the aircraft for the purposes of completing their inquiries.

⁷ ICAO's audit report *Universal Safety Oversight Audit Program* states that the ICAO team was highly satisfied with the legislative and organisational framework established by Australia and the ATSB enabling the conduct of aircraft accident and incident investigations [27].

As with any forensic investigation, all evidence at the scene of the accident is photographed and recorded. The log books and maintenance records are examined as well. The AAIB investigators (inspectors) are responsible for the wreckage and the safety of the site. In addition, the recording devices and suspect parts of the aircraft are removed and transported to the AAIB headquarters, where this material is examined.

Another group of investigators is responsible for obtaining statements from witnesses and proceeding with their enquiries with the intention of determining the circumstances and causes of the accidents. The investigators have the authority to investigate all human factors associated with an accident by taking statements from individuals that may contribute to determining the causes of the accident. Thus, the pilot's training, experience and other important documents are made available to the investigators.

When inspectors return to the AAIB headquarters they present their initial findings to the chief inspector of air accidents. The chief inspector then decides how the investigation will proceed and the form of the final report.

The preparation and release of the final report can take several months. It includes details of the data recovered and the results of analysis carried out. It also contains interviews from various individuals, the results of the examination of suspect equipment and other significant findings. If appropriate, the final report contains safety recommendations which can be issued earlier during the investigation.

A draft copy of the report is sent to the pilot and other representatives who may be affected by the content of the report. The final report includes the remarks and suggestions from the involved parties and it is sent to those persons and organisations before it is published.

2.1.1.3 Aviation Safety Investigation in the United States

All investigations of civil aviation accidents in the United States of America (USA) are conducted by or on behalf of the **National Transportation Safety Board (NTSB)**. The NTSB can also participate in investigations abroad if a US carrier or US manufactured plane is involved in an accident. The NTSB is an independent agency not affiliated with any of the Department of Transportation's agencies including the Federal Aviation Administration (FAA). The NTSB has no regulatory or enforcement powers.

The NTSB has responsibility for determining the probable causes of transportation accidents and promoting transportation safety. Within its activities, the Board investigates

accidents, conducts safety studies, evaluates the effectiveness of other government agencies' programs for preventing transportation accidents, and reviews appeals of enforcement actions [158].

To meet its mission of preventing future accidents, the Board develops safety recommendations. Safety recommendations are one of the more important aspects of the investigation. They can be issued immediately after an accident (often before completion of investigations) or as part of the final report. Recommendations are based on findings of the investigation, and shall prevent the accidents from happening again and correct the deficiencies identified during the investigation. The recommendations are issued to federal, state and local government agencies including industry and other organisations which are in a position to improve transportation safety.

NTSB investigation is based on the “Go Team” investigations of major aviation accidents which engages specialists for clearly defined sections including operations, structures, power plants, systems, air traffic control, weather, human performance, and survival factors. An investigation of this type could involve more than 100 technical specialists and other representatives of a number of interested parties including federal and local government agencies. Each investigating group establishes the facts which each member of the group approves. These factual reports go into the public docket and are available to the Board. When the field investigation is complete, the investigator in charge prepares an analytical report covering their analysis of the accident and proposed findings.

Realisation of the final report typically takes several months and includes a number of tests and analysis carried out by safety board staff. The final report then is deliberated in a public Board Meeting. Once a major report is adopted at a Board Meeting, an abstract of that report containing the Board's conclusions, probable causes and safety recommendations is released. The results relating to the determination of probable causes of an accident along with other outcomes of the Board's analysis cannot be used as evidence in a low court.

The NTSB does not investigate criminal activity. In cases of suspected criminal activity, the FBI becomes the lead federal investigative body, with the NTSB providing any required support.

2.1.1.4 Aviation Safety Investigation in Canada, France and Germany

Aircraft accidents in Canada are independently investigated by the **Transportation Safety Board** (TSB). The TSB occasionally aids in foreign investigations involving aircraft that are

registered, licensed or manufactured in Canada. In addition, the Board monitors general trends and emerging safety issues including developments in transportation safety and safety risks [179, 177]. The TSB does not investigate all aircraft accidents. An individual occurrence will be investigated when there is high probability that an investigation will reduce the future risk to persons, property or the environment, and when an investigation has the potential to improve transportation safety.

The TSB's methodology of investigation addresses the field phase, the post-field phase and the report production phase. The ultimate goal of every investigation, as adopted worldwide, is the establishment of safety recommendations. These recommendations are an essential part of the TSB's efforts to improve safety in the nation's transportation system.

The **Bureau of Investigations and Analysis** (Bureau Enquêtes Accidents - BEA) is responsible for conducting the technical investigations of civil aviation accidents and incidents in France. It is established within the Ministry of Transportation and carries out independent investigations including final reports and recommendations. The sole objective of investigations is determining the causes of accidents as far as possible with the intention of preventing future accidents and incidents [77]. In accordance with Annex-13 to the Convention on International Civil Aviation, European Directive 94/56/CE and the French Civil Aviation Code, the investigation into an accident or incident is intended neither to apportion blame, nor to assess individual or collective responsibility. In view of Annex-13 the BEA can be required to issue recommendations before the publication of the report.

The **German Federal Bureau of Aircraft Accidents Investigation** (Bundesstelle fuer Flugunfalluntersuchung - BFU), as an independent body in the framework of the Federal Ministry of Transport, is responsible for the investigation of civil aircraft accidents and serious incidents within Germany. The goal of the BFU is to improve aviation safety by determining the causes of accidents and serious incidents and making safety recommendations intended to prevent recurrence. The investigation does not serve the purpose of establishing blame, liability or claims. The investigation of accidents and incidents in civil aviation in Germany is based on the law relating to the Investigation into Accidents and Incidents Associated with the Operation of Civil Aircraft, which is harmonised with Annex-13 to the ICAO Convention and the European Union Directive on accident and incident investigation (94/56/EC) [79].

2.1.1.5 Summary

The information presented above clearly illustrates that Annex-13 of the Convention of International Civil Aviation has been adopted universally. Worldwide, investigations are carried out following the same or similar procedures, addressing the two major objectives of:

- Enhancement of air transport through independent investigation, and
- Determination of the circumstances leading to the accident, rather than establishing blame, liability or claims.

Minor differences in conducting an investigation amongst countries exist and those variations depend on air traffic intensity and influence from the local aviation industry. Nevertheless, investigative teams around the world represent a very important part within aviation transport safety and they are generally composed of a number of specialists responsible for a certain segment of the investigation.

In some cases, the causes of accidents are revealed in the early stages of the investigation and all efforts of the investigation are then focused on one relatively confined field. On the other hand, when the causes of accidents are not obvious (in most cases) the investigation is extended to a larger scale, engaging a large number of experts and external specialists. However, when a larger accident occurs, the investigation includes a wide range of examination, testing and analysis provided by both independent and coordinated expert groups. Some of the activities of the various groups may overlap, although through proper management and feedback, results can be achieved successfully. The following is a (general) example of the distribution of investigation activities through the various working groups operating within an investigative team [180].

Investigator in Charge (Chief Inspector, Director) - The Investigator in Charge (IIC) is responsible for organising, conducting and managing the process of investigation. The IIC establishes a base within the zone of accidents that is used for supervising all activities associated with the investigation and meeting investigators during the field investigation. The IIC decides how the investigation will proceed and the form of report appropriate to the type and seriousness of the accident or incident.

Operations Group – Investigators in this group examine the circumstances associated with pilot qualifications and experience, operational procedures, aircraft loading, flight plan, aircraft performance, operational technique and history of the flight seeking to determine if the

crew was qualified to fly the plane and whether the plane was operated within performance limits.

Group for interviewing witnesses - This group interviews and examines the statements given by all persons that have seen or heard a part of the flight or possess information about flight or meteorological conditions at the time of accident. This group may provide information about the altitude, sound, and attitude of the aircraft at the moment of the accident.

Group for aircraft structure analysis - This group examines the main structure of the aircraft and its control devices. It usually includes reconstruction of the aircraft structure and is used to determine the first impact of the aircraft and to examine the process of disintegration.

Meteorology Group - This group is responsible for gathering and dealing with data relating to weather conditions. Specialists consider the actual weather information on the ground and at flight altitude and the forecast issued thereof. Once the experts have established the weather at the time of the accident they determine its affect on the airplane.

Air Traffic Control Group - Investigators of this group inspect original documentation of air traffic control services and examine radio and phone as well as radar records. Outcomes of this analysis may provide determination of the flight path of the aircraft and other significant information including ground speed, acceleration, rate of climb, or descent.

Group for registration of flight data and conversation - This group is responsible for reading out the data recorded in flight data recorders, cockpit voice recorders and other recording devices, as an essential source of information for determining the circumstances of the accident.

Human Factors Group - This portion of investigation is performed by medical personnel or individuals with specialised training in the human performance area. The group examines injuries and determines the cause of death of passengers as well as a number of psychological and physiological factors such as fatigue, spatial disorientation, drugs, alcohol, nutrition and other factors that may have contributed to the accident.

Power-plant Group - This group conducts an examination in order to determine if the engines and their attached accessories were working normally or abnormally during the accident.

Aircraft Systems Group - Specialists in this group examine the contribution of aircraft systems to the accident. This portion of the investigation considers the hydraulic system, electrical and electronic systems, radio communication system, air-conditioning system, pneumatic system and anti-icing system. Due to the severity of some aircraft accidents, it is not always possible to examine all systems.

Maintenance Group - This Group is responsible for inspection of the maintenance records available in order to determine if the aircraft was properly maintained. Hence, specialists check the airworthiness of the aircraft, the number of working hours of the engine and other pertinent parts as well as records focusing on defects and their repair.

Evacuation and Rescue Group - This group examines the circumstances associated with the search, evacuation, and rescue of passengers and crew aboard the aircraft.

Group for determining the circumstances of accidents - Specialists from this group are responsible for determining the circumstances that lead directly to the accident based on their knowledge and experience. Investigators use different methods to determine or confirm certain facts so that an accident is considered from many different aspects. The progress of the investigation, as a whole, is achieved by regular exchange of findings among investigators from all groups. The mass of work can occasionally be completed during the field examination, although often laboratory analysis reveals most of the circumstances leading to the accident.

2.2 Overview of Aircraft Accident Investigation

Upon receiving notification of an accident, initial actions of liaising with police, emergency services, air traffic control and the aircraft operator are undertaken. This is to ensure that evidence associated with the accident is secured. Subsequently, the investigative team is dispatched to the accident site and the long process of aircraft accident investigation begins.

At the base of operations (located near the scene of the accident) the first meeting is conducted where investigators are advised about the circumstances of the accident. This includes information about the rescue procedures, the injured, casualties, condition of the wreckage, cargo features, and other important information. This meeting also addresses the potential hazards to the investigative team associated with the accident site including chemical hazards, liquid oxygen pressure, vessels, pyrotechnic hazards, and so forth. However, the list of potential dangers depends on the type of aircraft and cargo involved in the accident.

The investigation process and its outcomes depend very much on the preparation of the investigation. Therefore, the results of the investigation are a reflection of experts' knowledge, the investigation equipment available and effective management of the investigation. In order to conduct a proper investigation, investigators take a number of tools and other apparatus to the accident site. The type of equipment that is taken depends on the accident location, weather, type of aircraft and the investigator's specialty.

The general equipment list includes personal survival items (appropriate severe weather clothing, gloves, hat and so forth), diagramming and plotting equipment (compass, GPS receiver, notebook and so on), technical data (catalogues, handbooks, investigation manual), witness interviewing equipment (recorders, hand microphone), evidence collection equipment (investigation kits), administrative equipment, personal items, and certainly photographic equipment.

Figure 3: Universal investigation kits [81].

On arrival at the accident site, expert groups within the investigative team conduct an initial walkthrough of the wreckage. This is carried out to create a first impression about the condition of the wreckage and the components that affect the whole process of further searching and preservation of evidence.

Nonetheless, the first priority of the investigation scene is more than likely to be searching for human remains and their identification. The process of identification is conducted by the forensic identification unit along with pathologists.

2.2.1 Accident Scene Recording and Collecting Evidence

Recording of the accident scene is conducted as soon as humanely possible subsequent to accident notification and location of the wreckage. Within an investigation a number of general, macro and micro photographs and a large amount of video material are taken that present a tremendous source for completing the further analysis and preparation of the final report. It is also advantageous for the accident scene to be recorded by stereo-camera, which can (if required) recover the factual (real) positions of all objects located on the photographs.

Figure 4: Aerial view of a wreckage distribution.
(Aircraft accident on 20 November, 1993 at approach phase near Ohrid, Macedonia)

Firstly, depending on the circumstances, photographs and video material of the crash aftermath or rescue in progress are taken following the recording of the general view of wreckage and the terrain where the accident occurred. If possible, aerial view records are taken, which present the greatest constellation of wreckage and the terrain where the accident happened. After that the other perishable evidence, such as cockpit instrument panel readings, switch positions and flight control position, that last for a period of time and are most likely to change or disappear during the field investigation, are recorded.

Investigators pay particular attention to impact scars, craters and anything hit by the aircraft prior to impact that is also matter for still and video recording. Other significant marks such as fracture patterns, scratches and gouges, fuel faucet position, radio equipment, suspicious cracks, engine lever systems, fire damage and land marks are also recorded.

All items recorded are associated with markers (usually numbers), which commonly appear in the diagrams of the final report. It is common practice to prepare one or more accident diagrams for inclusion in the written report. The accident type and wreckage distribution will ultimately determine the type of diagram that will be used. For instance, wreckage or scene diagrams plot the location of the impact and the subsequent distribution of the wreckage, whereas the flight path diagrams depict the flight path of the aircraft prior to impact.

Figure 5: Wreckage distribution (polar diagram) [115].

A high quality scene or wreckage diagram is essential for most calculations involving crash sequence and survivability. A flight path diagram can be very helpful in depicting information from various sources such as the flight data recorder (FDR), cockpit voice recorder (CVR), and air transport control (ATC) radar (Figure. 6). A plot of this information by time and location enables the investigator to see how a number of different events are related to each other. Depending on the accident several techniques can be used including grid system, polar system, single point system, and straight line systems to create diagrams.

Figure 6: Approach profile (in red) derived from FDR data and terrain profile overlaid on an extract approach chart [73].

After recording the terrain, wreckage and all significant marks at the accident scene, investigators collect the evidence. They start with perishable evidence such as fluid samples (fuel, oil and hydraulic samples), then evidence of icing as well as loose papers, maps and other documents. Also, included in this list are switch positions and instrument readings, control surface and trim tab positions, flight data recorders and cockpit voice recorders. The location and recovery of the aircraft recorders including the cockpit voice recorder and flight data recorder, is a vital key to the investigation.

If there is suspicion that some of the wreckage systems are directly associated with the accident, the equipment is primarily examined at the accident site and then transported to the authorised organisation for further examination. For some accidents only a field investigation is conducted, whereas for others a cursory field investigation may be carried out, however engines and other key components of the aircraft are taken and examined in detail.

Where possible, investigators will interview the witnesses of the accident in separate groups. The first group of witnesses is comprised of flight participants including crew members, passengers and flight controllers. In the second group are eyewitnesses that were by coincidence around the accident site and finally, statements may be taken from crew members' next of kin and friends, then mechanics, the weather briefer and so forth. The process of

witness interviewing could be one of the most important parts of an investigation, especially if there is no recoverable wreckage, survivors or recorded information.

2.2.2 Wreckage Analysis

Taking an inventory of the wreckage is common procedure, which can also at times contribute to revealing the circumstances of the accident. In particular, if there is a missing part of an airplane, this finding is likely to be significant to the investigation. Moreover, the inventory can recognise some parts that may originate from another aircraft⁸. The location of wreckage and other parts of the plane along with field traces are entered into a wreckage diagram.

Accidents can occur anywhere in the world and sometimes a wreckage scene is inaccessible so that wreckage recovery is difficult or even impossible. In the case of underwater wreckage, location and recovery may be very difficult and expensive. However, the wreckage will be recovered if there is the potential of gaining significant knowledge by investigating this particular accident, regardless of the cost of the procedure.

As mentioned above, all relevant facts at the accident site including wreckage, impact marks, land scars, and many others, are located, secured and recorded in detail. Based on this information a number of diagrams are created as important elements of the further examination and the final report. This is very important because well drawn diagrams may present the sequence of wreckage disintegration. Consequently, although aircraft accidents can occur in different ways, there are certain elements that are common to aircraft impacts and wreckage distribution. By organising those common elements, most impact situations can be explained.

Wreckage distribution and crash dynamics are influenced primarily by aircraft velocity and the impact angle. Thus, the velocity of the aircraft affects the degree of disintegration of the wreckage, whereas the impact angle has an effect on distribution manner. It is clear that except for aircraft velocity and the impact angle, the terrain configuration has a vital influence on wreckage distribution. Consequently, by considering the wreckage distribution at the accident site, the attitude, impact velocity and impact angle including the survivability of the accident may be determined.

In cases of water impacts, distribution of the wreckage primarily is dependant on aircraft velocity. The water acts as a solid object if the aircraft is going fast and it breaks into many pieces similar to a crash on land. On the other hand, an aircraft that is deliberately ditched probably sinks to the bottom undamaged. The impact angle may be determined by

⁸ A typical example is the 'Concorde' accident that occurred on 25 July, 2000 at Paris

examination of the wreckage taking the influence of waves into account. Distribution of wreckage on the bottom of a lake or ocean is influenced by depth, current and the tendency of various parts to float or to sink in different ways. This means that distribution of submerged parts does not contribute significantly to determining the accident circumstances. The situation is quite different when the distribution of wreckage has resulted from an in-flight break-up.

When considering land impacts, the wreckage distribution can be categorised into several types depending on the impact velocity and angle. If an aircraft crashes at a very high angle and high velocity, the aircraft creates a crater and the front parts of the aircraft may stay in the crater covered by dirt. Other parts of the aircraft are distributed randomly around the crater. The bulk of this distribution will occur on the side in the direction of the aircraft.

Figure 7: Evidence of impact at slow forward speed and low angle of attack [104].

In addition, when an aircraft has impacted the ground with high velocity and low angle, the wreckage creates an initial impact scar and the aircraft starts to break apart immediately. In general, the wreckage is distributed in a fan-shaped pattern from the impact point. The heaviest portions of the wreckage such as engines travel farthest.

Furthermore, when a plane crashes at a high angle and low velocity, the impact crater is shallow and the plane is largely intact. At low velocity and low angle impact (Figure 7), the plane hits the ground several times and during the deceleration wings and engines can be torn.

Stall or spin impacts have specific features that are a result of low velocity and high angle impacts. In these accidents, the planes are not in control and do not necessarily impact nose first. If a spin is involved then distribution of wreckage can suggest the nature of the spin.

Determining the impact attitude and impact angle is gained from the evidence on the ground, and it is usually captured by the nose of the aircraft. Another way to obtain the impact angle is by the condition of damaged objects that the plane hit prior to impact. In terms of impact velocity, there are several possible sources. The impact velocity can be recovered from a flight data recorder or an ATC radar plot can help establish velocity prior to the impact. In

some accidents, the impact velocity can be captured by the airspeed indicator in the cockpit (Figure 8). Finally, after determining the impact velocity and impact angle, the forces involved in the accident can be assessed to find the impact survivability.

Figure 8: Scrape marks on pilot's encoding altimeter face from pointer [73].

If there is suspicion of in-flight disintegration, then the inventory can reveal this information. In such cases, parts of the wreckage are usually scattered over a wide area that may include forest, lands, and resident areas. Then searching for missing parts is an important stage of the investigation.

Finally, if the circumstances allow, a reconstruction is conducted that is a useful technique for structural and fire investigation. It is not often that the whole plane is reconstructed; only the parts of the wreckage of particular interest are moved from the accident site and reconstructed in an open space or hanger. The damage to every part is defined and analysed to determine if it is a result of impact on the ground or other obstacles, or due to in-flight failure.

In terms of defining the wreckage damage, an examination for a possible structural failure is conducted. First of all, overstress on a part can occur and later cause a structural failure by improper pilot operation or adverse weather conditions including turbulence, wind shear, downwash, and wing tip vortices. Secondly, a part can fail as a result of improper design, manufacture, maintenance and inspection. Finally, a structural in-flight failure can occur because of aerodynamic overstress, which means that in the course of the flight a part may be overloaded beyond its capacity.

Determining the type of failure is mainly based on appearance of metal fracture. Additionally, these findings must be consistent with wreckage distribution, accident site conditions and crash dynamics. This segment of the investigation becomes very complicated if the aircraft sustains severe mechanical damage and post impact fire.

When analysed, there may be either a single fracture zone or two or more distinct zones. If there is only a single fracture zone, then it refers to an overstress failure, which is the most common type of failure found in aircraft wreckage (Figure 9).

Figure 9: A single fracture zone representing an overstress failure.

In contrast, if the fracture has more than one distinct zone then it may suggest in-flight failure. Evidence of this type of structural failure is the existence of corrosion or metal fatigue patterns on the metal fractions (Figure 10).

Figure 10: Evidence of corrosion and fatigue patterns on the metal fraction.

At this point of the investigation, the accident site is recorded and examined. Some parts of the aircraft equipment are taken for further laboratory analysis and the process of investigation is moved from the accident site to the headquarters, laboratory and other specialised offices.

2.2.3 Power-plant Analysis

Failure or malfunction of any of the power-plant systems will most likely cause an accident. Therefore it is essential to the investigation to determine if the engines were working at the

time of the accident. Generally, engine failure is mostly associated with accidents during takeoff when full engine power is needed and a sudden loss of power will most likely cause an accident, rather than during the approach or landing phases when the engines are at lower power and when the demand for power from the engines is less.

Engines cannot be examined completely at the accident site because their inspection requires special tools and conditions, although, on-field examination may give a good idea of whether the engine contributed significantly to the accident and requires further laboratory examination.

The first stage of engine examination includes reviewing the basic facts of the accident, witness statements and radio transmissions that may provide some information about the engine condition at the moment of the accident. If there is a flight data recorder (FDR) or cockpit voice recorder (CVR), the engine investigation is mainly focused on the recorder. However, there are some basic techniques that are used by the field investigators.

On-field engine investigation begins with searching for all of the engine components and looking at them for evidence of mechanical failure or over-temperature that preceded the impact. Since the engines are the heaviest components of the airplane, it is common for them to separate from the aircraft at impact and travel a great distance from the wreckage trail. Engine examination for gross evidence of failure is based on obvious indications of mechanical failure such as holes that were either burned or punched through the casing from the inside. If the engine components that would have been inside the hole match the damage, then the investigation already has significant evidence regarding the cause of the accident.

Figure 11: An engine lateral section [112].

In addition, on-field engine examination includes checking for fuel capacity and inspecting the engine for any obvious evidence of fuel leak. Similarly the amount and quality of oil and other components of the lubricating system are examined. Samples of fuel, in

particular engine oil, may be taken for laboratory analysis. However, some engines can be comprehensively examined by using a bore scope. The remainder of the engine examination procedure depends on whether the aircraft involved in the accident was equipped with a turbine or reciprocating engine. Although there are differences in engines made by different manufacturers, turbine or reciprocating engines have the same basic components leading to a similar engine investigation procedure being adopted for both engine types.

Taking an engine apart on the field is impractical, although sometimes a small reciprocating engine can be disassembled at the accident site. However, if the engine within an investigation needs to be disassembled, it is usually taken to an engine facility where all conditions needed such as hoists, mounting stands, tools and sufficient lighting are provided. Further engine examination is focused on determining the engine power or thrust and engine range temperature at impact.

2.2.3.1 Turbine Engine Examination

The accurate value of engine torque at impact, if any at all, can be recovered from an FDR or CVR. Conversely, if the aircraft flight data is not recorded then determining whether the engine was turning or not and whether it was turning fast or slow is provided by an examination of any rotational damage present (or lack of it). The determined value of engine power or thrust based on the evidence of rotational damage has only approximate accuracy. This is because there are a number of factors affecting the value of engine torque and upon further analysis would lead to several approximations and assumptions.

The internal engine examination is based on several postulates and facts whereby the engine power and RPM (revolutions per minute) at impact can be determined.

- First of all, a turbine engine does not develop a wear pattern internally in normal use. The only metal-to-metal contact points are the bearings and the accessory drive gears. Therefore if there is rotational evidence elsewhere, then the engine was either turning at impact or there was an in-flight failure or malfunction.
- Next, the compressor is the first moving part of the engine encountered by anything entering it. Thus, at an accident occurrence, the compressor will impact the ground or other obstacles first and receive the most damage.

- Furthermore, an engine in normal use does not produce traces of combustion, melting or soot in the compressor section. If there is such evidence then it refers to engine abnormalities.

When the rotating compressor section of the engine hits the ground, the compressor blades are bent in the opposite direction of rotation and they are bent alike. This consistent bending is evidence that the compressor section was turning at impact (Figure 12). In contrast, if the blades are not bent or bent in different directions, it is most likely because of impact damage and not rotational damage.

In terms of determining the engine RPM, the distance that ingested quantities of dirt and debris that travel through the engine may be taken as an indication. If the engine was not running, the debris will not travel very far.

If the engine was turning at high RPM, the debris can be found deeply in the turbine section. Another indication of RPM is presence (or lack) of signs of turbine section interference with the casing. The investigators can conclude that the engine was running at high RPM if the turbine blade tips are bent down and if there is rotational scoring inside the casing. Moreover, evidence of rotational damage providing an indication of RPM can be seen on compressor rotor blades and the adjacent stator vanes, as well as engine shaft or transitional casing.

Figure 12: Blades bending: the compressor section was turning upon impact [104].

In particular, when the engine has seized, the ends of the compressor blades may leave blade-shaped marks on the inside of the casing where the impact forces were felt. These typical marks suggest that the engine was not running at impact.

When an engine goes into the water, rotational damage of the compressor blades will occur depending on the power developed by the engine. If the engine was running, the blades are bent opposite the direction of normal rotation and most likely the compressor casing will be torn due to hydrodynamic effect.

When engines with variable geometry are examined, investigation is focused on the condition of mechanisms that change the size and shape of the intake such as variable inlet guide vanes (IGV) and variable stators. Both of these devices move as a function of RPM and are directly related to it. Thus, if the IGV or variable stator position is determined then the RPM and thrust can be calculated.

Another indication of engine power can be obtained by examining the condition and position of bleed air valve, fuel flow and cockpit instrument indications. Depending on certain circumstances, these findings may be credible evidence in determining the engine power at impact.

The second essential issue facing investigators is whether the engine in an accident flight was operating within a normal temperature range. Investigators endeavour to find out this answer by focusing on turbine section analysis. Evidence of traces of combustion, melting or soot in the compressor section suggests that the engine was running at high temperature. If the engine temperature is very high then the turbine can melt rapidly. Other evidence of over temperature exposure is the existence of longitudinal cracks of turbine blades or a metallic grit layer on the blade surfaces. Otherwise, if the turbine blades are intact and have not picked up any metallization, the engine was in all probability operating within its normal temperature range.

2.2.3.2 Common Turbine Engine Problems

Investigation of a turbine engine is associated with several common problems which include:

- Foreign object damage
- Volcanic ash ingestion
- Compressor stall
- Accessory failure
- Thrust reverser failure
- Bearing failure

Foreign object damage (FOD) is the most common source of damage to turbine engines. It is likely that the ingestion of any solid object will produce some amount of damage to the compressor section. In an aircraft accident, FOD may occur as a result of impact and the resulting damage may be of no significance to the accident. Differentiating between the rotational damage due to impact and pre-existing FOD damage can be difficult to determine.

In general, rotational damage during ground impact is most severe at the front of the engine and tends to become less severe in the internal compressor stages. Thus, a metal object may hit a blade hard enough to leave an imprint on it and this can be seen during the engine inspection. Moreover, microscopic traces of objects causing the damage can be spectrographically analysed to determine the composition of the object.

On the other hand, the in-flight FOD tends to produce opposite indications. The early compressor stages may be relatively undamaged. The foreign object may be ingested through the first stage not causing significant damage to the blades.

The three principal sources of in-flight FOD are birds, ice and metal parts from the aircraft itself. Birds leave sufficient traces that can be proven by simple laboratory examination. Ice can come from a leak in a lavatory drain system, aircraft wings, or on the intake or cowlings lips during flight and can cause severe engine damage and result in accidents. Most aircrafts have anti-icing systems to preclude this. The investigation is focused on the anti-icing system to determine if it was on and working.

If the ingestion of a metal object is suspected, the investigation is focused on the intake, cowlings and aircraft structure forward of the engine searching for imprint marks.

Volcanic ash ingestion is a special form of FOD. Volcanic ash is a dust that is almost pure silicon and when it gets into the engine, it is converted into glass in the combustion section and the turbine guide vanes, nozzles, blades and cooling passages are coated with this molten glass. If the volcanic ash is suspected as a factor in the accident then the glazed coating in the turbine section should be visible.

Compressor stall can occur in special circumstances and witnesses, if any, may report that there was fire coming out of the front of the engine. Since the compressor is supposed to be clean and cool, marks of combustion and molten material is evidence that severe compressor stall has occurred.

Examination of *engine accessory* is based on marks of rotation and external forces if it was turning at impact, or lack of evidence of external forces that may suggest in-flight malfunction. The analysis refers to understanding the external damage and defining the fractures.

Thrust reverser failure can be exhibited as breakdown or unwanted deployment. Thrust reverser examination is based on witness statements, if any, and analysis of surrounding impact damage of reversing devices including clamshells, buckets, shields or spoilers. Examination includes determining whether the damage occurred before or after the reversers were deployed. Additionally, thrust reversing systems can be examined by checking the cockpit controls and comparing it to the reversers' position at the accident site.

Bearing failure occurs in most cases because of lack of lubrication. If the bearings fail the engine suffers massive destruction and the bearing parts (races, retainers and rollers) may be widely scattered. The bearing examination is focused on determining the intensity of the wearing pattern and checking the oil for formation of metallic elements.

2.2.3.3 Reciprocating Engine Examination

When reciprocating engines require further investigation, great attention is paid to the propellers. This is because inside the reciprocating engines there is always evidence of normal wear pattern, and existence of other marks may be difficult to identify and define. Essential for this examination is determining if the propeller feathered or stopped at impact as well as the power performance. Moreover, if it is concluded that a deliberate shutdown was made by the pilot, the investigation seeks to discover the reasons for this operation. The reciprocating engine examination also includes analysis of the feeding and lubricating system, cockpit instruments and switches. However, most of these answers could be provided by examination of the propellers.

Before taking the engine for further laboratory examination, investigators at the accident site attempt to determine if the engine was fed properly with fuel and oil. Thus the fuel quantity and quality on board is checked. The fuel quantity can be determined indirectly by considering fuel consumption and the duration of the flight since last refueling, and directly by examining the tanks if they have not been destroyed. Evidence of fire in the accident suggests the presence of fuel, which also can be detected by chemical analysis of ground samples (Figure 13).

In addition, the tank, fuel lines and carburettor are examined for any obstruction that would prevent the fuel from flowing freely to the engine. The induction system and the throat of the carburettor are also inspected for any obstacles or damage. This part of the investigation finishes by examining the electrical system, spark plugs, and magneto switch in the cockpit.

Figure 13: Detection of traces of arson at an accident site.

If an engine fails then the internal engine inspection will reveal the damages that led to this malfunction. Otherwise, if an engine was not producing full power, then the investigation is focused on the induction system of ice, ignition system failure etc. Induction system ice or carburettor ice can be possible causes for partial engine failure. With reduced air flow the engine may quit and cause an accident. For this particular type of accident finding the positive evidence of carburettor ice is very difficult as it melts before on-field investigation starts. Another possible cause for partial engine failure is spark plug or cylinder failure, dirty filters, and lubricating system failure. In terms of the lubrication system, examination includes checking the oil tank, lines, oil pump as well as oil filters and sump drains for the presence of contaminants. If needed, samples of the oil are tested in a laboratory.

2.2.3.4 Propeller Examination

Propellers are common to reciprocating and turbine engines (turboprops). An examination of the propeller damage sometimes can be very useful in determining the engine condition during the accident. In any case, it is not possible to completely explain all of the bends and twists that can occur, because the propeller's final condition depends on many variables such as RPM, airspeed, attitude and the nature of the surface or soil where the propeller hit.

In the case of a turning propeller, all blades are bent opposite the direction of rotation. There must be similar curling or bending at the tips of all blades as well as the damage to the leading edge of the blades. Additionally, torsion damage to the propeller shaft or attachment fittings can be seen. Propeller examination is focused on identifying and defining this evidence. However, the procedure becomes more complicated because the propeller is almost always

turning at impact. Even if the engine failed or was shut down, the propeller will windmill at an RPM high enough to produce these indications of rotation.

Figure 14: Propeller under power and propeller wind milling at impact, respectively [115].

Taking the above into account there are two major phases in investigating the engine:

- First, finding absolutely no evidence of rotation leads to in-flight engine failure. Thus, if the engine seized internally, there will be evidence of intensive damage that should be defined during the investigation.
- Second, if there is evidence of rotation then this examination requires additional analysis.

In terms of determining the impact engine RPM and power, the deformation of the propeller's blade tips may provide a rough idea of the RPM related to velocity. This analysis includes examining the curling of blade tips that must be similar in appearance to all blades. Thus, the tips of blades may bend either forward or backward depending on the relationship between the RPM and forward velocity. If the RPM is high compared to the forward velocity, then the end of the blades are bent forward. On the other hand, if the RPM is low compared to the forward velocity, then the end of the blades are curled backward. This analysis provides only the ratio of RPM and velocity and not the absolute value of RPM. For instance, the RPM may be high, but if forward velocity is also high, the blade tips are likely to curl backward and so on. The above phenomenon occurs at relatively low angles of impact (by 5 degrees) whereas if the angle of impact is high then the blade tips are going to bend backward regardless of the RPM. Within an engine examination, investigators try to identify and define this deformation.

In the case of propellers with constant speed, propellers maintain constant engine (or propeller) RPM, where the power is adjusted by the changing blade pitch angle. The blade angle is maintained by hydraulic powered pistons. The aim of such an examination of the propeller is to determine the impact pitch angle, although this analysis in many cases is

unsuccessful. This is because when the aircraft crashes, engine oil pressure is lost and the oil in the propeller dome either leaks out due to damage or bleeds back into the oil system. Therefore when this occurs, there is nothing holding the blades in any particular pitch angle and they are free to move in any direction.

In addition to this, if the aircraft involved in the accident was fitted with full feathering propellers the propeller dome oil may be lost and the propeller blades tend to twist themselves toward the feathered position due to a feathering spring. Thus it is normal to find the propellers in the high pitch position after an accident. By disassembling the propellers, the pitch angle can be measured, although there are difficulties in determining the correct pitch angle, particularly if the propeller is damaged.

The existing slash marks made by the propeller as the aircraft impacted can allow determination of the propeller RPM in terms of velocity. There is a linear mathematical relationship involving the distance between the slash marks, the number of blades on the propeller, the RPM of the propeller, and the forward velocity of the aircraft. To work out this calculation either RPM or velocity must be known. Satisfactory results can be obtained by applying the appropriate data of RPM related to engine features and aircraft velocity limitations.

2.2.4 Aircraft Systems Examination

Aircraft systems investigation can become very complicated for several reasons. Firstly, they are spread across the whole aircraft and during the accident may suffer sustained damage. Secondly, the actual condition of the aircraft systems does not necessarily show their state in the course of the accident. Finally, the post impact damage or fire can completely destroy all credible evidence. However, an aircraft system examination along with any witness statements and recorded data may provide an overall indication of their contribution to the accident.

On the other hand, the basis of aircraft systems operation is rather simple. They transfer the power or energy from the source or reservoir to the working devices such as actuators or motors in order to perform aircraft functions. The energy transfer can be carried out by using the mechanical, electrical, hydraulic, and pneumatic systems. This indicates that although all aircraft systems are not alike, they all have significant similarities.

As a result, investigation of aircraft systems actually means examining the aircraft mechanical, electrical, hydraulic, and pneumatic systems, or a combination of these, for any evidence (or lack) of abnormalities that affect the aircraft operation.

Aircraft systems investigation applies some common techniques to examine the aircraft systems from several aspects. Consequently, this methodology firstly includes examining the supply that is a fluid reservoir for pneumatic or hydraulic systems, then the generator or battery for electrical systems, or pilot actions for mechanical systems which, through the force applied to levers, control columns and pedals. Next, the system investigation is focused on the pump and other devices which furnish the pressure or power, followed by an inspection of the cockpit control devices. In addition, the protection devices such as pressure regulators, fuses and circuit breakers, along with emergency reservoirs and pumps, are examined. Special attention is paid to power distribution such as electrical wiring, hydraulic and fuel plumbing, cables, pulleys, and so forth, that is frequently destroyed or severely damaged in an accident. Finally, the universal approach to investigation includes examining the working devices that include a number of electrical motors, and other electrical appliances, actuators, as well as a number of levers.

However, the first part of an on-field examination includes searching for essential components of the aircraft systems such as motors, actuators, switches, valves, and so on, identifying them and verifying that they are the correct parts. In accordance with the field investigation as a whole, they are marked and still and video recorded. This procedure then allows the laboratory to restore the moving parts of the aircraft devices to the positions they were discovered in at the accident site. In order to protect evidence from being destroyed, some components such as switches or pumps can be recorded via x-ray. After that point the components can be tested or opened for internal inspection. The further procedure of aircraft systems examination reflects the type and features of the systems that are analysed.

2.2.4.1 Mechanical Systems Examination

Performing some of the aircraft operation by mechanical systems includes employment of a number of mechanical components such as levers, pulleys, rods, torque tubes, and cables. All these parts are movable and they can be subject to restriction or blockage if some foreign objects are caught or pinched in the machinery.

There is a list of several possible malfunctions of the mechanical systems that are subject to the field and laboratory examination. First of all and most obvious is cable failure. Cables are a common method of transferring mechanical force to perform some of the aircraft functions such as open landing gear doors or release gear up locks, and then to operate the rudder, and trim surfaces. Some systems are single cables which incorporate a spring or

retraction device which brings the cable back to neutral position, whereas cables used on flight controls are almost always two-cable systems; for instance one moves the rudder left, the other moves it right. There are cable systems incorporating tensioning springs so that when a cable breaks, the system will be driven by the spring in the opposite direction. In normal use cables are tensioned to a specific value and in a severe impact accident, most of the cable systems will be loose and not working due to the impact.

Since the cables are exerted to tension the in-service cable failures are always tension failures. If the cable shows evidence of some other failure mode, shear for example, then the cable was probably cut during impact. Cables are composed of spirally wound bundles consisting of individual strands of wire. When the cable fails, the strands fail individually one at a time. Viewed with high magnification, the fracture surfaces have a cup and cone mode characteristic of ductile tension failure. If a cable did fail in flight, it is likely that some individual strands had already failed and weakened the cable prior to the final failure (Figure 15).

Another possible cause of system malfunction is failure of any pulley or bell crank in the system resulting in instant loose cable. Investigation techniques include checking the parts of the system for consistency followed by detailed laboratory analysis of fracture surfaces.

Figure 15: Cable fracture (evidence of failure of some strands prior to the final failure).

The laboratory examination can identify fatigue crack, corrosion or metallurgical defect that implies in-flight failure, although it could also have occurred during the impact. If the fracture suggests an overload that is consistent with the impact forces or the way the part was normally loaded in service, this failure probably is not significant to the accident.

However, the final failure mode does not depend on the time when the failure occurred (in-flight or post impact), but it depends on the manner in which the component was

overloaded (tension, bending). This means that investigators communicate all findings of the investigation in order to determine the nature of failure of mechanical systems.

2.2.4.2 Hydraulic Systems Examination

Examination of hydraulic systems includes inspecting their components: working fluid, hydraulic actuators, hydraulic pumps, hydraulic accumulators, and filters.

Firstly, the fluid is checked for its correctness and any evidence of contaminants that may affect its features. If there are such abnormalities they will be revealed by inspecting the system filters. After that, the procedure strives to understand the fluid system leaks that could be the result of in-flight failure or impact forces.

Figure 16: Fluid leakages due to improper sealant.

Hydraulic systems use actuators which translate the hydraulic pressure into linear motion and can operate flight control surfaces, flaps, spoilers, air brakes, thrust reversers, landing gear, nose wheel steering systems, propellers and wheel brakes. As a result of this, any failure of these systems suggests a possible actuator malfunction.

The actuator fails when the positive hydraulic pressure on one side of the piston is lost. Therefore, examination is focused on determining the position of the actuator piston at the moment of malfunction and reasons why it failed. This is important because the known extension of the actuator can tell the position of the operating device. Thus, a common actuator examination includes all known non-destructive analysis and inspection of the inside, in particular the cylinder, searching for impact-marks left by the edge of the piston.

There are a variety of types of pumps that could be installed in an aircraft (that can be either engine driven or electrical). If they were working at the time of impact there will be evidence of damage to the movable parts of the pumps. Otherwise, if pump damage does not show evidence of rotational marks then it most likely occurred during impact when nothing was turning. Hydraulic pumps can be subject to overheating and cavitations that can be

revealed by examining the internal surface of the pumps for evidence of excessive operating temperature or local rough surface damage.

Hydraulic systems use accumulators to dampen pressure surges and store hydraulic power for emergency use. Accumulators can fail if the tank or internal diaphragm or piston is damaged and they are subject to examination.

Hydraulic systems are fitted with filters to keep fluid clean and avoid damage to system components. Laboratory analysis of fluid samples taken from the filter can examine the fluid for any contaminants. Moreover, viscosity, moisture and flash point also can be checked within a laboratory examination.

2.2.4.3 Pneumatic Systems Examination

Pneumatic systems in an aircraft use a compressed gas to perform some of the aircraft operations and are associated with heat and pressurization systems, anti-icing systems, fire extinguishing systems and oxygen systems. Pneumatic systems can operate emergency brakes, emergency landing gear extension, cabin heat, anti-ice, fire extinguishers, breathing oxygen and so forth. The compressed gas can be manufactured by the turbine engine or stored in pressurized containers.

Pneumatic systems have a lot in common with hydraulic systems and many of the above investigative techniques can be applied to pneumatic systems. The air pressure of pneumatic systems is significantly lower than the fluid pressure in the hydraulic systems, and therefore the damage or marks created by movable parts of the system components have less intensity. Leaks from pneumatic systems are difficult to detect, particularly after a severe crash when the system probably has many leaks. Moreover, engine bleed air systems are potential sources of ignition and can aggravate the possibility of in-depth examination.

2.2.4.4 Electrical Systems Examination

The investigation of an aircraft electrical system is a very difficult task. This is because, from the time between when the plane first hits the ground and the time it finally comes to a stop, the condition of the electrical appliances may change and become severely damaged.

Thus during the impact, some circuits can show evidence of a short-circuit, although at initial impact they were 'off'. Understanding all of these marks and determination of the time when they occurred is practically impossible. Therefore, electrical systems examination relies

on information and findings provided by witness interviews, air traffic control communication and FDR/CVR information. That is to say, evidence in the recordings or statements may be more credible than the ‘electrical’ evidence in the wreckage.

However, there are investigative techniques that examine electrical appliances and, depending on the evidence available, can draw conclusions on their contribution to the accident.

Electrical systems examination can start by examining the electrical supplies which can be DC (direct current) or AC (alternating current) generators or batteries. Nowadays, almost all large modern aircrafts have AC systems. A DC generator can be coupled directly to the engine, whereas an AC generator needs a constant speed drive (CSD). This CSD is the first potential source of failure of electrical systems. Examination of the generator itself is a matter of looking for internal shorting or arcing or mechanical interference between the stator and the rotor. Similar analysis is applied to examine the emergency power supplies such as auxiliary power unit (APU) and ram air turbine (RAT).

In addition, the electrical systems examination continues with inspecting electrical appliances such as motors, lights and electronic equipment. For instance, if a motor was damaged during impact, there will be evidence of scoring on the inside of the case if it was rotating or lack of scoring if the motor was not engaged. Evidence of locale head damage to AC motors indicates that this device failed or was working abnormally during the flight. Analysis of electronic equipment, in general, does not provide any evidence of whether it was on or off at impact.

Figure 17: Evidence of an electrical short-circuit⁹.

⁹ Analysis of an electrical system is closely associated with an in-flight fire investigation. That is to say, overloaded electrical systems, damaged or poor insulating material in the presence of combustible material and oxidizer can ignite an in-flight fire. If the fire is not extinguished and the aircraft crashes, a post-impact fire can occur, which destroys considerable evidence of the nature and origin of the in-flight fire. Therefore, differentiating the in-flight fire from post impact fire is an extremely difficult task within an investigation. However, there are common techniques to investigation in-flight occurrence. They are based on a consistent pattern of evidence to

In an electrical circuit, the condition of fuses and circuit breakers may provide valuable information. Unfortunately, the post impact damage might change their positions and therefore they do not have great significance for the investigation process.

Examination of distribution systems, if the present condition of electrical wiring allows, can provide answers on the state of the electrical circuits during the accident and information about the dynamics of the post-impact damage and fire. This procedure includes analysis of the heavy duty wiring that runs motors and electrical commands coming from the cockpit.

The wiring examination starts with inspecting the electrical terminals and fuses, followed by looking into the internal and external appearance of wires and searching for evidence of electrical arcing and shorting. When evidence of shorting is found, it must be defined as a primary or secondary short-circuit and in many cases this is practically impossible. In addition, the wires are examined along their full length (when applicable). If a wire was overheating the circuit itself, then the inside wire would be discoloured, showing a sign of excessive working temperature. Otherwise, if the damage is a result of post impact fire the wire strands inside should be shiny and bright. In cases of severe post impact fire this evidence is destroyed.

In practice, aircraft systems operate by using one or more basic systems, as discussed above. For example, flap systems in modern aircraft are most likely to be electro-mechanical. Landing gear systems may be either hydraulic or electric, whereas brake systems are part of hydraulic systems and so forth. By examining the components of the basic systems and applying logic to understand their final position with respect to the crash dynamics, conclusions can be drawn as to their contribution to the accident.

2.2.5 Aircraft Recorders Examination

Aircraft recording devices, where they exist, are an essential source of information for the investigators. There are four general sources providing information about the airplane, its performance and its configuration as follows: air-to-ground communications tapes, ATC radar data, Flight Data Recorder (FDR) and Cockpit Voice Recorder (CVR).

The FDR and the CVR have been designed to monitor and record aircraft and crew performance and this data is used only in the course of an aircraft accident investigation. They

support an argument for an in-flight fire including the flow pattern of the products of combustions and molten metal, as well as a logical pattern of impact effects and wreckage damage.

have emerged as an irreplaceable tool for determining the causes of accidents particularly if there are no survivors, no witnesses, and wreckage destroyed to the point where technical investigation is impossible. In such cases the investigation depends primarily on recorded data. As a result of this, FDRs and CVRs were first required on scheduled air transports and, over time, they have been required on smaller aircraft. In many countries worldwide the FDRs are required on all aircraft operating commercially and carrying ten or more passengers.

Figure 18: Flight data and cockpit voice recorder [78].

The first FDRs were analogue recorders recording five basic parameters on steel or aluminum tape. Later they were upgraded to 11 parameters. The new aircraft manufactured, which require an FDR, have a digital FDR recording 17 parameters. In spite of all this, there are still foil FDRs in use throughout the world and they are still encountered during investigations.

The analogue recorder records the data by scratching a trace on a roll of stainless steel or aluminium tape placed in a crash-survivable container. Recovery of data requires microscopic analysis of the traces and the ability to read the traces is limited to the manufacturer of the recorder and major government investigation agencies. When the data is transferred to a graph it has limited accuracy.

The features of a digital data recorder far exceed the analogue recorder. The digital recorders improve data collection and readout accuracy. They can record a number of different parameters that can be measured and reduced to digital form depending mainly on type, age and use of the aircraft. Wood & Sweginnis [184] list 88 parameters which are most required

worldwide. They also add that the following 18 parameters may also be most required, depending on aircraft certification and the recorder fitted.¹⁰

- Time	- Autopilot engagement status
- Pressure altitude	- Longitudinal acceleration
- Indicated airspeed	- Pitch control input
- Heading	- Lateral control input
- Normal acceleration (vertical)	- Rudder pedal input
- Pitch attitude	- Primary pitch control surface position
- Roll attitude	- Primary lateral control surface position
- Manual radio transmission keying	- Primary yaw control surface position
- Thrust/power on each engine	- Lateral acceleration

In most cases the data is recorded on Mylar tape and stored on the aircraft in the FDR. Access to the data usually requires removal of the FDR and computer analysis of the tape. Some installations allow the data to be extracted to a portable recorder plugged into the aircraft.

The whole procedure of data storage and its successful recovery is associated with several features or problems that may directly affect the aircraft accident investigation outcomes. First, the storage device must survive the impact forces and post impact damage of fire and water. To ensure this, the data recorders meet demanding design standards and are usually located in the tail of the aircraft. Next, recorders are usually painted a bright orange colour in order to facilitate their finding. Furthermore, the recorders are fitted with a ‘pinger’ to make it easier to find in the water.

Investigations from the past reveal that a number of recovered recorders failed, that is to say, did not record the data required. In addition, recovery of the recording device particularly from the ocean is both expensive and time-consuming.

The above suggests that although an aircraft involved in an accident may be fitted with a recorder this does not necessarily mean that the investigators will always manage to recover the flight data. This conclusion has imposed a need for improvement in data recording and its recovery. One solution is the current ACARS (Arinc Communications Addressing and

¹⁰ Some operators record only the required parameters, whereas others record as many as 250 different parameters per aircraft [184]

Reporting System), which transfers, collects and stores the data at a central location on the ground [184].

Readout of flight parameters is performed through computer analysis of recorded digital data. The readout product presents a collection of charts and tables available for further use. For instance, a computer can use the data readout to operate the flight instruments graphically depicted on the screen and portray a graphic image of the airplane from any vantage point or simulate the actual flight in the course of an accident (Figure 19).

Figure 19: Simulation of a flight by recovering the flight data recorded [73].

2.2.5.1 Cockpit Voice Recorders

Cockpit voice recorders (CVR) as well as cockpit area microphones (CAM) are designed to record cockpit sound and conversation not otherwise recorded through the radio or interphone circuits. The CVR usually has a separate channel for each flight deck crew member and records everything that goes through those audio circuits.

The CVR records everything including engine noise, cockpit switches, motors, warning chimes, stick shakers, and runway noises and therefore it would be more properly termed a CSR – cockpit sound recorder. Determining the source of the sound is a matter of isolating it and matching its signature on an oscilloscope with a known sound. For instance, investigators, by using consistent identification techniques, may be able to determine the RPM of each

engine based on sound recorded, or identify the sound of an in-flight crack. The CAM records cockpit conversations that are not usually recorded by any other recording devices.

The recording tape is usually a continuous loop 30 minute tape which automatically erases and records over itself. It means that events occurring more than 30 minutes before landing (or crash) are not recorded. There is no technical reason why the recording is only 30 minutes in length, although investigators are interested in expanding the current recording duration.

In terms of the CVR data, there are a number of public restrictions related to its use. For instance, the information cannot be used in any disciplinary proceedings arising from the accident. However, the recordings of CVR and CAM contain valuable information regarding crew resource management, cockpit discipline and communication problems, as well as the condition of aircraft systems that are significant to determining the causes of an accident.

2.2.5.2 Air Traffic Control Radar

Modern ATC radar systems are digital systems recording the plane location by converting the radar return to electronic symbology that is displayed on the controller's scope (Figure 20). This data is stored in memory and, when needed, can be replayed on another scope. The recorded data is used to plot the aircraft flight path or to recreate the situation in a computer or simulator. Early air traffic control radar systems were analogue without memory and did not contribute at all to the aircraft accident investigation.

Figure 20: ATC Radar display [123].

Radar antennas sweep once every 12 seconds (in many countries worldwide), so the recorded data is composed of a series of data points at 12 second intervals. The stored data provides information about aircraft identification including time, altitude as reported by the aircraft's encoding altimeter, and location in latitude and longitude. Aircraft location also can be depicted in an x-y coordinate system with the radar antenna at the coordinate origin. Consequently, by using the data recorded, the investigator can determine: position every 12 seconds, ground track (average point-to-point heading), reported altitude, ground speed, acceleration and rate of climb or descent of the aircraft. Additionally, by adding the known wind data and aircraft characteristics the true airspeed and aircraft heading as well as angle of attack and 'g' loading can be determined.

The readout data is usually plotted on a large scale map using latitude and longitude information. Since the radar takes data of the aircraft's radar return every 12 seconds, the resulting plot is not a smooth line. However, by extrapolation or by applying an interactive computer program the most probable flight path and other aircraft performance can be reconstructed (Figure 6, page 25).

In the case of a missing aircraft, plotting the recorded data may indicate the aircraft location. Moreover, a plot of the aircraft pathway can indicate an in-flight structural failure by taking into consideration the accident sequence. This analysis includes correlation of changes in heading, airspeed and altitude with changes in aircraft performance and aerodynamics. A plot of radar data can be upgraded by including the data relating to witness statements, weather data, and air-to-ground transmission data to the plot. For mid-air collisions, the radar data may locate the collision in space and, along with examination of the wreckage, determine the actual collision geometry.

Finally, the recorded digital data from FDR and ATC radar can be used by a simulator to replicate the route the accident aircraft flew. This is an important tool for analysing the accident sequence in order to determine the events contributing to the accident and this significantly enhances the investigation results.

2.2.6 Operation and Maintenance Investigation

Operation investigation within an aircraft accident investigation aims to examine all facts relating to flight operation and crew activities during the accident including assessing the crew's qualifications. In addition, the maintenance investigation strives to determine the aircraft condition during the flight followed by inspecting the circumstances associated with

weather, air traffic control and the airport. This portion of the investigation involves less intuition and is mainly focused on a number of regulatory requirements that have to be met by the operator and owner of the aircraft.

2.2.6.1 Operation Examination

The operation investigators begin the investigation by searching for any documents that may have been in the aircraft at the time of the accident. The documents that might be in the cockpit include: licenses and medical certificates of the pilots, pilot's log books, charts, maps, flight manuals, weather briefings, and flight plans. Recovering the above perishable documents is the initial action undertaken by the operation investigators which can provide valuable information with respect to understanding the causes of the accident.

When pilots and their qualifications are examined, the investigation considers several factors including:

- Pilot qualifications and experience
- Pilot training and
- Pilot flying experience
- Competency.

In terms of pilot qualification and experience, pilot licenses and certifications are examined. By doing so, investigators determine whether the pilot was qualified to operate the given aircraft on the critical flight. Moreover, investigators inspect the pilot's current medical certificate and also check if the pilot was in compliance with any medical waivers.

There are several other sources that can assist in finding further information about a pilot's flying experience. Investigators can obtain this information by inspecting the pilot's log books or other records. For example, flight experience may be part of his training records, i.e. some aviation operators keep separate records of their pilots' experience. Another source of pilot flight experience can be the pilot's employment application. In evaluating experience, investigators assess the pilot proficiency for the critical flight. In this regard, a pilot may be technical current in an aircraft, but not proficient in it. Similarly, a pilot may be proficient in flying the aircraft, but not proficient in the particular phase of flight or circumstances in which the accident occurred. This part of the investigation is covered by examining the certification, violation records and medical information.

Next, investigators examine the pilot's records relating to his training. The investigators check the training records for compliance with both company and federal requirements followed by interviewing other pilots or instructors. Finally, investigators assess the

competency of the pilot for the critical flight, which is most important within aircraft accident investigation.

In addition, investigators examine the operations manual which describes company operational procedures. This document is usually approved by a regulatory governmental agency and it is an obligatory document for aircraft that operate as a commercial or air transport aircraft. Within this part of the investigation, further examination is carried out to determine whether the procedure undertaken was appropriate for the situation encountered.

Operation examination also considers the aircraft load. There are two aspects to this question. First, investigators have enough resources to determine how the aircraft was supposed to be loaded, although how it was actually loaded can be something completely different. Information relating to the number of passengers, the amount of cargo, along with interviewing the people who performed the loading, can provide an appropriate value of actual weight of cargo and passengers. When considering aircraft loading, investigators examine gross weight and location of centre of gravity and their impact on aircraft control and stability. If these are the major causes of the accident then they usually happen during or shortly after takeoff. If the plane crashed during the cruise or approach phases then gross weight and location of centre of gravity probably did not contribute significantly to the accident. The actual gross weight and location of centre of gravity at the time of the accident can be determined by assuming the takeoff weight, which is balanced for fuel burned during the critical flight

The flight path is another aspect of accident investigation. The aim of this examination is to determine if there were any deviations between the actual and planned track. Investigators compare the planned track with the actual track by using information obtained from flight record devices (ATC radar, air-to-ground communications) as well as information provided by inertial and GPS navigation system.

In many accidents in the past, air-to-ground communications have explained the major circumstances that led to accidents. Here, investigators search for relevant information on the accident not only on the scheduled frequency, but also on other frequencies, and provide transcripts of them. Voice tapes are usually collected by investigators immediately after the accident and are transcribed by people with transcription skills. Information obtained by air-to-ground (A/G) communication is closely associated with data from ATC radar data, the FDR and the CVR. Therefore, investigators correlate all the information available to the same timeline. Practise shows that usually there is a spread of several seconds among the same events recorded by different devices. The time signal on the A/G tape is likely to be the most

accurate, whereas the CVR time line is probably the least accurate. However, information on a cockpit microphone is recorded on both the CVR and A/G tape that allows mutual correlation. Microphone keying also allows correlation with the FDR system.

Finally, based on all information available, investigators develop a history of the flight from the earliest event of significance to the flight to the time of accident. This actually presents a sequence of pertinent events that preceded the accident and is a basis for further investigation.

2.2.6.2 Maintenance Examination

Another investigative team examines the aircraft conditions prior to the accident by looking into the required and performed inspection, major modification, maintenance or repair and airworthiness directive compliance. In general, this information can be sourced from the aircraft log books.

Figure 21: Exterior safety inspection [8].

In terms of requirements, investigators determine if the aircraft complied with the all-over airworthiness directives that are obtained from the manufacturer. Since the maintenance records do not always contain day-to-day maintenance activities, investigators usually first conclude who was actually maintaining the aircraft. In this way all maintenance and repairs operations are available to the investigators.

Concerning this area of investigation, the FAA agency (Federal Aviation Administration in the United States) has established two computer files that are accessible and potentially valuable to the aircraft accident investigation [184]. These files refer to

Accident/Incident and Service Difficulty Report data bases. It is a great example of usage of the gained knowledge through investigation to prevent future accidents.

The above indicates that operation and maintenance investigation is a well known process without any questionable issues. By simply using the information available, investigators assess pilot competency and determine whether the aircraft was properly operating. This part of the investigation also includes analysis of airfield, air traffic control and weather conditions, and these are discussed below.

2.2.7 Airfield, Air Traffic Control and Weather Examination

Investigation of airfield, air traffic control and weather conditions represent the last portion of the human-aircraft-environment investigation concept. When conducting airfield examinations, investigators first collect published information about the airfield at the time of the accident including diagrams, approach and departure charts, instructions to pilots and aerial photographs.

In addition, investigators collect the records of airfield certifications and inspections that usually are conducted by a state regulatory agency. Moreover, investigators inspect the airfield operations manual that describes the airport and its operation. The airfield operation manual may contain useful information important to the investigation, particularly if the accident occurred in the landing or taxiing phase. Among them the most significant items are: airfield limitations, emergency plan including coping with a number of accidents and incidents, airport self inspection program, snow and ice control plan, hazardous materials. In terms of airfields, Annex 14 to the ICAO Convention has specified the airport standards that have been universally adopted by ICAO members.

If an accident occurs on or near an airport, then the investigation evaluates the disaster response and rescue issues. Although the results of this examination will most likely not contribute to the determining of the circumstances of the accident, they may affect the final recommendations. Within this portion of the investigation, investigators assess if the disaster response and rescue were adequate for the accident in question. This is mainly conducted by checking and ensuring that the recommended standards were adopted including issues related to notification, time of response, adequacy of the response plan and procedure.

In addition, investigators determine the action undertaken by the air traffic control services and evaluate their adequacy. Since most of this information is recorded, investigators examine audio and video tapes including some of the following information: transcripts of

recorded voice transmissions, report of aircraft accident, controller statements, flight plan, ATC radar data and many others.

Although statistics show that weather is a significantly less causal factor to an accident than human and aircraft factors, adverse weather conditions may affect the aircraft flight and precede human errors or omission and finally cause a malfunction of aircraft systems. Therefore, within an aircraft accident investigation, the weather conditions and their influence on aircraft flight are examined in detail.

Providing information about the weather at any location is not a difficult task. There is a seemingly endless supply of weather information such as surface weather observations, weather radar data, satellite data, barograph records, rainfall records, severe weather reports, pilot reports, ATC radar data, wind data, area forecasts, and weather briefing records. In addition, weather information can be provided by witnesses, although the major sources are national weather services and the airline meteorological office.

After collecting all of the available data and establishing the weather at the time of the accident, investigators assess its affect on the airplane. This analysis includes considering severe weather phenomena such as turbulence, hail, icing, windshear and other adverse weather conditions.

2.2.8 Human Factors

There is a general expert opinion that human factors are involved somehow in every aircraft accident. Therefore, within every single aircraft accident investigation, the analysis of human factors and their contribution to the accident is very important. Thus, there are three major questions relating to human factors that need to be answered in almost any investigation. The first question is related to identification of human factors that were involved in the accident, then questions to determine accident survivability and finally establishing cause of the injuries and fatalities.

There are a number of sources for obtaining information relating to contribution of human factors to the accident. Among them the most significant are the wreckage scene, survivor and witness statements, human remains and post mortem results. In addition, valuable information can also be obtained from family member statements, personal history, and medical histories. Investigation of human factors in an aircraft accident investigation is usually conducted by medical personnel or individuals with specialised training in human performance areas.

In an accident with fatalities the investigators first deal with the human remains. This analysis includes identification of occupants and determination of the cause of death. Identification of human remains is one of the investigation requirements and its conduct sometimes is a long and demanding process. This includes several forensic techniques including fingerprints and footprints, dental records, physical attributes, body marks and scars, and DNA method.

Figure 22: Automated fingerprint identification.

Alternatively, if there are survivors, the investigation is focused on their medical and psychological treatment including the cause of injuries. Nevertheless, within an investigation most concerns are related to the flight crew with respect to their physical condition before and at the time of the accident. Investigators examine the crew's actions and identify the contributing factors that led to the accident. Findings derived from examination of human factors usually present one of the most important parts of the final report.

2.2.8.1 Human Factors Examination

The investigation will probably start with a physical examination of the survivor(s). This includes present state of health and assessment of any injuries as well as toxicological tests. This part of the investigation is coordinated and organised to ensure that all information possible is collected.

Crew member investigation focuses on their activities during the previous 72 hours including food, rest, sleep, duty time, and physical condition. Additionally, the investigator collects information related to stress, stability, recreation, family and financial status followed by an inspection of the individual's flying history. This includes prior accidents and incidents, career progression, peer evaluations, relationships with other crew members and so forth. The investigators also inspect the individual's general medical history, particularly any prescriptions, glasses or contact lenses and medical waivers.

If any of the aircraft occupants died at the time of the accident an autopsy is performed. It may provide some information that may assist in determining the causes or factors contributing to the accident (this will depend on the nature of the accident and the condition of the remains). Firstly, the autopsy is focused on determining if the accident was survivable. That is to say, the autopsy strives to determine if the person died at impact or due to some post-impact problem such as fire, asphyxiation, drowning and so on. Secondly, by carrying out the physical examination and toxicological tests of the remains, information about the physical condition of the individual can be obtained. Likewise, the presence of alcohol or drugs in the blood or bodily fluids can be also identified. Additionally, this analysis can provide evidence of fatigue and other diseases that may have impacted on the accident sequence.

Next, in a multi-crewed cockpit, it is important to know who was actually operating the aircraft. Determination of the location and injury features can provide answers to this question. Furthermore, the examination of the remains can determine if there was a toxic environment present prior to impact. For instance, if smoke is present in the lungs this can be sufficient evidence of an in-flight fire accident. Next, in the case where there is an in-flight explosion, the autopsy can easily recognise the blast injuries and identify fragments of the explosive device.

Human factors that may have an impact on aircraft accident occurrence can be divided into two major groups. They are psychological and physiological human factors, although they sometimes overlap.

Psychological factors are a very difficult area to investigate. This is because, first, it is very difficult to provide any positive evidence of crew member actions during the accident. Second, it is very difficult to prove a particular crew action, although there could be a lot of supporting evidence for it. However, an aircraft accident investigation considers factors being present in accidents and assesses their contribution to accidents. In this regard, there are a number of conditions or situations that could apply to a particular accident and are usually subject to further classification and cluster analysis.

Investigators dealing with this part of the investigation are faced with a number of issues that are a matter of identification and proof. Thus, investigators within an aircraft accident investigation commonly evaluate the influence of psychological factors in order to determine whether:

- The crew should have been able to cope with the critical situation,
- The crew failed to respond properly to the critical environmental conditions,
- The crew failed to perceive the potential threat of an accident due to overconfidence or under motivation.

On the other hand, the physiological factors such as drugs, alcohol, nutrition, food poisoning, carbon monoxide poisoning and sudden incapacitation are a little easier to investigate. This is because they usually leave some evidence behind and by applying advanced chemical techniques the presence of these factors can be proven. Thus, while breath analysers are used for alcohol detection in the breath, which is closely related to the blood alcohol level, drugs are usually screened by immunoassay methods, gas chromatography or liquid chromatography and confirmed by using mass spectrometry. Liquid chromatography is the preferred technique for analysis of toxic substances and food poisoning, but still confirmation is done by coupling chromatographic methods to mass spectrometry. Analysis of carbon monoxide is routinely done by classical colorimetric tests.

Figure 23: Analysis of blood sample for blood-alcohol concentration.
(A chromatogram of blood alcohol measurement)

Reports of human factors investigations sometimes are written separate to the main accident report, although some authors argue about this approach.

2.2.9 Aircraft Accident Reports

The product of any aircraft accident investigation is a report incorporating all facts and circumstances associated with the accident. Reports are generally narrative following the facts-analysis-conclusions format that is suggested in Annex-13 to the ICAO Convention. The material presented in an aircraft accident investigation report is divided into four major sections: factual information, analysis, conclusions and recommendations.

Following the narrative format of explaining the accident, the first part of the report shows the factual information about the accident. This includes information relating to conditions associated with the accident and its consequences such as injuries to persons, damage to aircraft, flight recorders, personnel information, aircraft information, meteorological information, wreckage and impact information, medical and pathological information, fire and survival aspects.

The second portion of a safety report presents the analysis undertaken within the investigation and introduces the relevant information to the determination of causes of the accident. This section considers the impact of operational factors, maintenance and material factors, and human factors. Next, the report reveals a list of findings and causes that significantly contributed to the accident occurrence.

In the fourth part of the report the safety recommendations are introduced. They, as sole objectives of an investigation, are derived from the analysis carried out and conclusions drawn with the purpose of accident prevention. Commonly, in a safety report there is a list of appendices that provide other important information for better understanding of the report. Thus, in this part of the report a number of maps, photographs, diagrams, flight data recorder readout, and communication transcripts can be found.

Apart from the narrative reports that are released and accessible to the public, there are also data reports that are commonly issued on each accident. These are designed to facilitate the data collection of a number of accidents and they present an important tool for investigating accidents (particularly with similar circumstances) and conducting research as well.

Take nothing for granted; do not jump to conclusions; follow every possible clue to the extent of usefulness . . . Apply the principle that there is no limit to the amount of effort justified to prevent the recurrence of one aircraft accident or the loss of one life.

ACCIDENT INVESTIGATION MANUAL OF THE U.S. AIR FORCES

Literature Review

This chapter provides a summary of some of the current research and literature relevant to this work. In particular, research techniques and methods used by aircraft accident investigators are examined, as well as fields where their application and contribution to an investigation is the most effective.

There are many sources of information on aircraft accident investigation in both printed and electronic forms. There are several journals, conferences and magazines devoted to the subject of aircraft safety including aircraft accident and incident investigation. However, the ICAO and national investigating agencies such as ATSB, NTSB, and AAIR produce most of the research studies relevant to aircraft accident and incident investigation issues. Most of this information is available online so that keeping up-to-date with investigation news is significantly easier than it once was.

Since aircraft accident investigation covers a variety of topics, the articles discussed are categorised into the following sections:

- Most wanted improvements in aviation issued by the NTSB,
- References having the greatest impact on this research,
- Articles using statistics as a research tool,
- Articles devoted to analysing human, aircraft and weather induced causal factors.

These articles create a concise picture about the current level of knowledge on aircraft accident investigation and have provided some conclusions that have had a significant impact on proceeding with this work.

3.1 Improvements in Aviation recommended by the NTSB

With more planes and more accidents, along with their clear attitude of preventing future accidents by a thorough and independent investigation, the United States and the NTSB can be regarded as the world leader in crash investigations. Based on investigation outcomes, the NTSB issues special reports or study reports that incorporate the findings of a number of prior accident investigations. In accordance with these findings, along with sustained efforts towards air traffic safety enhancement, the NTSB has introduced the following six most wanted improvements [150].

1. Reducing the danger of flying in icy conditions by analysing both aircraft design and icy condition approval methods.
2. Design changes to eliminate the danger of flammable fuel and air vapors in all transport category aircraft.
3. Improving runway safety by enacting procedures such as giving immediate warnings of probable collisions or incursions directly to flight crews, and providing landing distance assessment with an adequate safety margin for every landing.
4. Upgrading data recorders with current technologies and installing video recorders in cockpits to give investigators more information to potentially work with.
5. Setting work hour limits for flight crew and air traffic controllers in order to reduce the rate of accidents and incidents caused by human fatigue.
6. Better crew resource management via additional crew resource management training.

Furthermore, the NTSB has issued a number of safety alerts and actions in order to improve air traffic safety such as alerts related both to aircraft ground icing and to thunderstorms [150].

To achieve its goals the NTSB uses both traditional investigation techniques and an alternate research methods approach in its technical accident investigations to help determine the failure process of systems [130]. A traditional investigation may be employed if the complete failure process can be identified with sufficient accuracy primarily through observation, examination of evidence and/or via full-scale demonstrations, whereas the alternate approach uses research, testing, and analysis targeted to specific areas of insufficient or inadequate information.

Moreover, the NTSB stresses the importance of collecting and classifying any evidence derived. Thus, NTSB staff members are evaluating two new investigation approaches, with one designed to address interacting system elements and the other to document the evidence gathering process [169]. The first approach employs accident fault trees, qualitative models depicting the events, conditions, and/or actions that are considered during an investigation as being potential contributors to the accident. The second approach focuses on Investigation Organizer, a Web-based tool developed by the National Aeronautics and Space Administration (NASA) Ames Research Centre.

Additionally, the NTSB aviation accident database now is available on the NTSB web site [156]. It contains highly classified and downloadable datasets of more than 140,000 aviation accidents and incidents. The computerised findings are identified in a sequence of events as occurrences, phases, causes, factors, and events.

3.2 Works Most Relevant to the Research

In the course of conducting this work a number of books, reports, papers, and other articles were consulted and the most relevant to this research are listed in the References. Among these, ‘Aircraft Accident Investigation’ by Wood & Sweginnis [184] and ‘Serious Accident and Human Factors’ by Miyagi [142], had the greatest impact on the course of the research. These references have both indicated some prospective research methods suitable for the comprehensive analysis of aircraft accident investigation and also suggest possible techniques for accomplishing it.

Wood and Sweginnis [184] in particular provide a thorough review of the philosophy, thinking, methods and associated implications that are applied within an accident (and incident) investigation. The authors combine over fifty years of practical experience in aircraft accident investigation, and both authors are pilots, engineers and certified safety professionals.

Wood and Sweginnis begin their book by discussing the investigation procedures required by the NTSB and the ICAO. In addition, the basics of field investigation as well as laboratory examinations are highlighted across all aspects of aircraft accident investigation. Thus, the book deals with the examination of wreckage distribution, structural failures, power plants, aircraft systems, aircraft recorders and many others areas relevant to an investigation. The book also provides information on investigation management and report writing that is useful both for investigators and researchers.

Overall, Wood and Sweginnis seem quite positive about the benefits of investigation. For example, they point out that ‘you can take a lot of pride’ in the contribution of investigations to enhancement of air traffic safety. Nevertheless, the authors retain their objectivity and address a number of controversial issues associated within the business of investigation and these issues have had a great impact on this research work. Using a thought-provoking writing style, they raise many contentious issues such as whether investigators have appropriate and sufficient skills to handle accident investigations and if reports of completed investigations are always accurate and professional.

This book was one of the essential sources for creating the comprehensive questionnaire within the Delphi enquiry discussed in Chapter 4 and 6 of this work.

In ‘Serious Accidents and Human Factors’, Miyagi [137] analytically investigates incident reports and reveals the critical information hidden therein for the purpose of preventing future accidents. The central issue of this book is the Incident Reports Analysing System (IRAS). In particular it offers a broad understanding of the accident causation chain, events contributing to that chain, and reveals a method for identifying those causal factors. Miyagi applies an analytical technique – multi dimensional analysis of incident reports (MAIR) using a particular model (Quantification Method III) to a collection of accounts of major accidents drawn mainly from the aviation industry.

Miyagi addresses the importance of results of technical analysis of events in accidents that have already occurred and is focused primarily on breaking the chain of events and human errors leading to accidents. The goal of her book is to seek out the conditions (the background causal factors) and determine why the individuals made errors, thus gaining an objective understanding of the conditions from a comprehensive perspective so as to contribute to future accident prevention.

Miyagi also demonstrates a method of quantifying qualitative factors which contribute to the occurrence of an unsafe event, and this helps clarify the relevant interrelationships. She also introduces a statistical method for the multidimensional analysis of contributing factors and positions analytical results in a multidimensional Euclidean space. Thus, factors that occur simultaneously have a strong mutual correlation and are distributed close together, and vice versa (an example is shown in Appendix C).

This reference thus contains, amongst other things, a possible technique on how to deal with the large amount of stored data required within this research work.

3.3 Other Works Relevant to the Research

Below, several representative examples of current published works pertinent to aircraft accident investigation are examined with respect to the relevancy of the techniques used and their technical merits. According to their content and the research methods used, they are divided and discussed within several broad categories. Most of the articles have been published by the ATSB which is responsible both for aircraft accident investigations, and maintaining and improving transport safety in Australia.¹¹

3.3.1 Statistics as a Research Tool

Aircraft accident statistics are frequently used by aviation experts when presenting both aviation safety and accident prevention information, owing to their inherent power. They show the overall picture of many danger factors to air safety and may indicate areas of potentially significant improvement.

Research report [68] enhances public awareness of aviation safety in Australia by providing a readily accessible analysis of the aviation sector with a strong focus on safety trends. Furthermore, safety data collection and processing systems highlight successes in mitigating operational errors and can therefore lead to more insightful conclusions about safety [99].¹² Moreover, ‘access the information you need to reduce the number of accidents and incidents while insuring higher levels of safety’, says the International Air Transport Association [113].

In addition, the NTSB [155] addresses the importance of statistics during accident investigation, safety studies and special investigations and states that the Board’s ability to study important safety issues is often affected by poor data quality. The goal of the report is to establish data quality standards, identify information gaps, encourage improvements in these areas and ensure compatibility among the safety data systems.

In order to improve the procedure for collecting aviation accident data, safety report [158] includes a survey conducted on a sample of registered aircraft owners. Based on the

¹¹ Australia has an excellent air transport safety record, particularly with respect to maintenance safety deficiencies issues and the control of continuing airworthiness of aircraft [24]. Major Australian airlines have long been regarded as being among the world’s safest, and there have been no fatalities involving an Australian high capacity jet aircraft.

¹² Legal guidance developed by ICAO is designed to prevent the inappropriate use of information collected solely for the purpose of improving aviation safety.

answers given, a number of positive conclusions were drawn in relation to current procedure for collecting and reporting accident data.

Dodd [97] in his article states that the most comprehensive sources of aviation safety data are the ICAO Accident/Incident Data Reporting (ADREP) system and Bird Strike Information System (IBIS), the IATA Safety Trend Evaluation, Analysis and Data Exchange System (STEADES) and the archive of the LOSA Collaborative (ARCHIE), which contains data collected from numerous airlines worldwide. The author adds that all of these sources are designed to address different aspects of flight safety, and each has differing strengths and weaknesses. This article concludes with the suggestion that by integrating safety data from different sources and applying a risk model, a better estimate of the rate at which flights are subject to threats can be derived, and thus reduce the risk to a reasonable level.

Finally, NASA's Aviation Safety Reporting System (ASRS), the confidential reporting system widely used by the aviation community to identify potential safety hazards, is now also available online.

In addition, several articles which consider the statistics based on past air accident investigations are presented below. Report [39] presents data concerning Australian aviation activities, the aviation industry, aviation accidents and incidents, and also highlights broad trends and developments in aviation safety.

Research papers [30, 60] examine fatal Australian civil aviation accidents 1990-2005 and 1991-2000 respectively, and both cover fatal accident numbers and rates by aircraft type and operational grouping, the timing of accidents, injury levels, pilot demographics and fatal accident types. The ATSB aviation database was searched to identify all fatal accidents involving civil aviation aircraft operating in Australian airspace in the considered periods. The findings show that both commercial and non-commercial operations experienced a significant decrease in the number of fatal accidents.

Similarly, research paper [43] examines the number and rate of fatal accidents in Australia and specifically Far North Queensland involving aircraft with a maximum takeoff weight of 11,000 kg or less between 1990 and 2005. Furthermore, article [46] compares fatal accident and fatality rates in Australia with those of other Western countries including the United States, Canada, the United Kingdom and New Zealand between 1994 and 2004. Overall, the findings showed that Australia's rates were mostly similar to the corresponding rates of the other countries examined.

Paper [33] reviews midair collisions in Australia between 1961 and 2003. The objectives of the review were to identify common characteristics and contributing factors,

assess whether there had been a change in midair collision rates in recent years and to compare the characteristics and rates of midair collisions with those of other countries.

The ATSB in its research study [53] analyses the characteristics of wire-strike occurrences using accident and incident data collected by the ATSB. The findings document the clear danger to pilots flying at low level in the vicinity of power-lines and the need to be proactive in reducing such risks. In addition, paper [29] reviews and analyses data related to runway incursions in Australia that may result in accidents with catastrophic consequences.

Occupant survivability of accidents for air carrier operations in the U.S. is analysed in report [153]. It also examines cause of death information for serious accidents. The report emphasises that there are two ways to prevent fatalities in air traffic: by preventing accidents, and by protecting aircraft passengers in accidents that do occur.

In terms of causes of aircraft electrical failures, a survey of data on aircraft electronic and electrical component failure was conducted to identify problematic components [105]. This article concludes that problems with interconnections are major contributors to aircraft electrical equipment failures, and environmental factors, especially corrosion, are significant contributors to connector problems.

Report [125] describes the results of an independent analysis of the primary and contributory causes of aviation accidents in Canada between 1996 and 2003. The results suggest that the majority of these accidents were attributed to human error. This paper addresses the controversy over such a systemic view of failure saying that it is difficult to identify precisely which factors play a significant role in the latent causes of an accident or incident.

In addition, report [160] reveals several recurring safety issues for EMS (emergency medical services operations): less stringent requirements for operations conducted without patients on board, a lack of aviation flight risk evaluation programs, a lack of consistent and comprehensive flight dispatch procedures and no requirement to use available technology such as terrain awareness and warning systems (TAWS) to enhance EMS flight safety.

There are a number of other, similar, studies and discussion papers using statistics that explore some of the main issues associated with the development of comparative safety measures across air traffic worldwide [41].

3.3.1.1 Detection of Patterns within Accidents as a Tool for Enhancement of Air Safety

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 [172]. Every accident site is always different but there are always some similarities [140], and for a large number of accidents these similarities are alarming [101].

Aviation expert Greg Feith, in considering the accident which occurred on 2 August 2005 [84] when Air France 358 skidded off the runway after a difficult landing at Toronto airport during a raging thunderstorm, says *DÉJÀ VU*. He explains that even just the initial information about the Air France accident reminded him of a similar American Airlines accident in 1999 in Little Rock, Arkansas. Moreover, in 2005 there were 37 other overruns worldwide and the causes of all these accidents were remarkably similar to the Arkansas accident.

Next, in analysing the Helios Airways crash which occurred on 14 August 2005 on a mountain north of Maathon and Varnavas, Greece, safety expert Kame O'nil [88, 119] decided to investigate the previous depressurisation accidents onboard Boeing 737's. He made the alarming discovery that this accident was not an isolated case mainly by focusing on the main and back-up wiring of cockpit instruments rather than on blaming the crew.¹³

Another example is the Concorde accident which occurred on 25 July 2000 in Paris, when investigators discovered that flat tyre on a Concorde was a common event. They identified over 50 cases of burst tyres during takeoffs and landings over the previous 25 years. One of the worst incidents involving Concorde was in Washington in 1979.

Commonly, accident investigation agencies worldwide regularly disseminate information on current accidents that have significant similarities with previous accidents. Below are several such examples published by the AAIB:

- AAIB in the special report [1] explains that the incident which occurred on 11 November 2005 at Midhurst was caused by contamination within the Horizontal Stabiliser Trim Control Unit (HSTCU) of a Bombardier CL600 where the two channels of trim command are physically close with no mechanical back-up. A similar occurrence had been previously recorded with a different HSTCU on this aircraft [1].

¹³ Later on, the AIAB recommended to Boeing that the main and back-up wire should be reinforced and separated across the all Boeing 737s in service.[88]

- During a landing at Aberdeen on 22 June 2006 in a Dornier 328, the co-pilot was unable to release the latches on the power levers and the aircraft overran the runway by over 300 metres. This occurrence has similarities to a fatal overrun accident at Genoa in 1999 [3].
- On 25 November 2005 an Airbus A319-131 lost both the commander's and co-pilot's primary flight and navigation displays (PFD and ND) and the ECAM (Electronic Aircraft Centralised Monitor) upper display. This was the sixth such event reported [4].
- In the accident which occurred on 16 February 2006 at Nottingham Airport, a propeller blade detached during a touch-and-go landing of a Socata TB10. The resulting imbalance caused both the crankshaft to fracture (allowing the propeller to be released) and the engine to partly separate from the structure [5]. Metallurgical examination indicated the presence of fatigue in the propeller hub. The location and nature of the fatigue was similar to that described in an existing Service Bulletin.
- On 26 February 2007 at Heathrow Airport while taxiing a fire occurred on a Boeing 777-222 in the Main Equipment Centre located beneath the flight deck and forward vestibule. The manufacturer had investigated 11 in-service reports of similar power panel events on B777 aircraft [6].

A typical demonstration of air accident patterns as a tool for enhancing air safety is the Warwick Air Accident Database (WAAD) which has been established specifically to facilitate the accident analysis process [172]. The WAAD contains details of over 2700 major accidents over a 21-year period. Being online, WAAD can be accessed from anywhere in the world and is available free of charge to anyone working or researching in this area. One of the strengths of the database lies in its range of powerful search facilities that permit accidents to be selected to match any combination of a wide range of characteristics.

3.3.2 Human Factors

According to current statistics, human factors have accounted for approximately 50-60% of aircraft accidents worldwide [164, 174, 182]. While crew factors are of great importance within human errors, most accidents have their origins in systematic or organisational failings [17]. Even the results of the first safety investigation of an unmanned aircraft accident

conducted by the NTSB indicates that the major probable cause of the accident was human error in the form of the pilot's failure to use the checklist procedure [162].

Understanding the human contribution to accidents is an important component of reducing aviation accidents [70, 72]. The articles presented below show the research approaches and tools recently used by aviation experts in achieving this goal. Surprisingly, a lot of studies devoted to human factors analysis have been done by the application of survey methods. Studies using the survey method examine all areas of the airline operations, including cabin safety, flight operations, maintenance, airspace management, regulation and surveillance. For instance, survey [21] shows that overall in 1996-97 the safety condition of the aviation industry was good and indicated the areas where there was room for improvement.

Five thousand commercial pilots throughout Australia were surveyed in 2003 by ATSB in order to provide information concerning common errors that pilots perceived to be most detrimental to flight safety [31, 40, 152]. The survey asked pilots about their safety experiences during the previous year and to report the most serious error they had made or seen during that time. They were also asked to describe the main factors contributing to the error and how the situation had been resolved, if applicable. Similarly, [32] investigates the safety climate factors of Australian aviation as perceived by five thousand commercial pilots throughout Australia.

Another example is article [42], which presents the results of a survey conducted on 3500 Australian pilots with an RNAV/GNSS (area navigation global navigation satellite system approach) endorsement. The respondents were asked to rank their perceived workload, situational awareness, chart interpretability and safety on a number of different approach types. The questionnaire then asked pilots to outline the specific aspects of the RNAV (GNSS) approach that affected these assessments.

Next, thirty-two senior managers from Safety Departments and Flight Operations Divisions were interviewed in order to examine the factors perceived to facilitate a safety culture and institutional resilience within airlines [47]. Findings single out the importance of leadership roles undertaken by the board, senior management, chief pilots, and safety departments and the influence of both formal and informal performance management systems. Strategies are then presented which support the presence or absence of safety cultures within the airline industry and thus impact on the ability to assess institutional resilience. Similarly, study [59] discusses organisational factors impacting on an airline's safety outcome that are subject to influence by managers in their flight operations divisions. Particular attention is given to evidence of the concept known as 'institutional resilience'. The study used both qualitative data (interviews) and quantitative data (audits). The audits were conducted by

means of a questionnaire sent to one senior manager in each airline. The study identifies three areas suitable for further research. These are: further development of reactive and proactive measures, following an application of a suitable checklist and development of a process to improve the reporting rate of flight crew error.

Paper [18] shows the results of a survey distributed to all licensed aircraft maintenance engineers in Australia. This survey was the first such study undertaken world-wide. The ATSB considers that the issues identified in the survey are not specific to Australia and would be of use to safety agencies around the world. The issues found included: the need for refresher training for aircraft maintenance engineers, the need to remove barriers which discourage aircraft maintenance engineers from reporting incidents, the need for fatigue management programs, human factors training for management and engineers, and minimising the simultaneous disturbance of multiple or parallel systems such as both engines on twin-engine aircraft.

In addition, report [17] uses face-to-face interviews to ask maintenance technicians to report examples of maintenance incidents which they had experienced first-hand. The report concludes with suggesting safety actions intended to both reduce the frequency of human error and maintenance incidents and to reduce the consequences of any such errors which do occur.

A three round survey was conducted to show how the New Zealand aviation industry was managing fatigue by considering the advantages and disadvantages of different fatigue management strategies and also the barriers that companies faced in managing fatigue [58]. The findings suggest that fatigue is not particularly well understood or managed by many operators.

Research study [57] examines the evacuation commands used by cabin crew in managing passengers during evacuations. The outcomes of this study came from conducting a best practice forum and survey as well as experimental work with members of the public participating as passengers. The results indicated that participants generally had little understanding of why they might be required to take certain actions in emergency situations. Moreover, NTSB's findings about a number of accidents that involved emergency evacuation of commercial airplanes are illustrated in safety report [154]. In this report the NTSB investigated 46 evacuations of 2,651 passengers and, based on information collected from the passengers, the flight attendants, the flight crew, the airlines and the aircraft rescue and firefighting units, the Safety Board found the following safety issues to be relevant to the study: certification issues related to airplane evacuation, the effectiveness of evacuation

equipment, the adequacy of air carrier and ARFF guidance, procedures related to evacuations and communication issues related to evacuations.

A recent ICAO initiative promotes global approaches to SMS (Safety Management System) implementation [106]. With an emphasis on achieving worldwide standardisation, the organisation's initial efforts to foster safety management have focused on the development of new regulatory provisions, publishing guidance material and creating a special training program. Compliance with ICAO standards and recommended practices is a cornerstone of international civil aviation safety. An SMS standard for use by aircraft operators of all types and sizes was issued by the Federal Aviation Administration (FAA) in late June 2006 [12].

In addition, report [28] aims to both identify aspects of best-practice and explore the curriculum foundations of error management training. The study highlights three important new directions for error management training: 1) Focusing more on cognitive skill development and the affective domain; 2) Integrating technical and non-technical skill development; 3) Increasing the experiential components of error management training.

On the other hand, study [20] stresses that the methods, which proactively monitor airline safety, may be useful in preventing air safety occurrences. This study outlines a new proactive safety method for the airline industry, called INDICATE (Identifying Needed Defences in the Civil Aviation Transport Environment). The paper explains that INDICATE is an airline self-management safety tool, which encourages regular passenger transport operators to critically evaluate and continually improve the strength of their safety system.

Research report [54] uses a flight simulation-based study to examine different visual strategies that pilots could use to time the flare. For this trial non-pilots and student pilots were required to judge the appropriate time to make contact with the ground or an idealised time to initiate the flare. Results show that pilot performance was generally superior to non-pilot performance.

Spatial disorientation is a very common factor contributing to aviation accident and incidents. Spatial disorientation (SD) is likely to be encountered by all pilots during the course of a lifetime's flying, irrespective of if they are experienced professionals or inexperienced amateurs [63, 111, 93]. The reports offer a comprehensive explanation of the various types of SD in the aviation environment and suggest strategies for managing the risk associated with SD-based events. Report [111] provides an informative overview of the three basic types of SD and the circumstances under which disorientation might be more likely. Furthermore, this report also encourages pilots who have experienced SD episodes to share their experiences

with their aviation colleagues, either informally, or through magazines, journals and web-based forums.

Report [70] provides a systematic analysis of the types of human errors occurring in Australian civil aviation accidents and compares these results against a larger sample of accidents which had occurred in the United States. The report shows that while the types of accidents and flying operations varied slightly between Australia and the U.S., the pattern of unsafe acts within each type of flying operation was remarkably similar. The report concludes that the greatest gains in reducing aviation accidents could be achieved by reducing skill-based errors.

On the same topic, paper [62] discusses why individuals and organisations involved in the design, manufacture, maintenance and management of aircraft operations make errors that either lead to or have the potential to lead to aircraft accidents.

Pilot performance, based on a sample of general aviation pilots, is examined in [55] during a simulated flight. The observations of pilot performance revealed perceived behaviour that did not correlate with the pilots' level of qualification. The article concludes that there is a significant level of variability in the performance of pilots who conducted the simulated approach, particularly during the final stage of the flight when the demands on them were most acute and when the impact of fatigue was most likely to occur.

Study [61] examines the characteristics of pilot distraction and explores the range of distraction sources that have contributed to aviation safety occurrences. It was done by an examination of the Australian Transport Safety Bureau's aviation occurrence database with respect to cases in which distraction has contributed to aviation accidents and incidents. The results showed that distraction affected all operational groups and occurred during all phases of flight. Many sources of pilot distraction were associated with equipment malfunctions, problems with radio communication, passengers, and the weather.

The purpose of research [71] was to investigate the type, nature and significance of in-flight medical conditions and incapacitation events which occur in civil aviation. Within the report, results are obtained by conducting a search of the Australian Transport Safety Bureau's accident and incident database for medical conditions and incapacitation events between 1 January 1975 and 31 March 2006. Overall, the results of this study demonstrate that the risk of a pilot suffering from an in-flight medical condition or incapacitation event is low.

Fatigue issues take a prominent place among other contributing factors to serious incidents and accidents and are the largest identifiable and preventable cause of accidents in transport operations (fatigue is believed to have contributed to between 15 and 20% of all

accidents) [167]. This paper outlines a systematic approach to examining the role of fatigue factors in an accident investigation. In addition, the aim of study [67] was both to provide objective data to inform fatigue risk-management processes by determining the quantity and quality of sleep obtained by airline pilots during transcontinental ‘back of clock’ operations, and to observe any changes to subjective fatigue and neurobehavioural performance during these sectors. Participants were required to undertake complete sleep and duty diaries providing detailed information about the quality and quantity of sleep. In report [152] operator fatigue is also discussed within the context of accidents which occurred during the 1980s. This report stresses the need for research, education and revision to hours of service regulations.

A search of the ATSB accident and incident database was conducted for medical conditions and injuries in passengers between 1975 and 2006 in order to determine the most common in-flight medical problems for passengers, and what proportion of these events result in an aircraft diversion that may affect air safety [44]. The results indicate that there is a low risk of passengers sustaining either an injury or a medical event as a consequence of travel on a civil aircraft that has been diverted.

Paper [45] examines the application of auditory icons as warning signals in a civil aviation cockpit environment. This research combines results of two experiments: Experiment 1 investigated effects of signal iconicity (iconic, abstract), whereas Experiment 2 investigated recognition speed and accuracy in response to four auditory iconic and four abstract warnings in an Advanced Aviation Training Device. These experiments suggest that there is potential for the use of auditory iconic warnings and bimodal warnings as the means not only to alert, but also inform pilots about the nature of a critical incident.

Research study [55] discusses the effectiveness, passenger attitudes, and potential of further improvement of aircraft cabin safety communications in Australia. In addition, study [49] introduces a methodology for representing and analysing recorded voice data in investigations of aviation occurrences. The first part of this research includes a series of sample transcriptions and analyses of recorded voice data, whereas the remainder establishes a tool for using conversation analysis to inform and guide analysis of recorded voice data in investigations. Study [66] was designed to explore the relationship between excess or non-standard words in readbacks and its effect on frequency congestion. This issue has also been considered from other aspects such as report [151] which examines the outages involving computer and related equipment in certain air route traffic control centres.

Paper [51] examines the prevalence and nature of drug and alcohol-related accidents and incidents in Australian civil aviation. The search of the Australian Transport Safety

Bureau's accident and incident database for all occurrences in which drugs or alcohol were recorded revealed 36 such events in the period between 1 January 1975 and 31 March 2006. The results show that the prevalence of drug and alcohol-related accidents and incidents in Australian civil aviation is very low, but that the related accident and fatality rates are high. In addition, report [34] documents the significant detrimental effects of alcohol on pilot performance both in the acute stages and for up to 48 hours after having the last alcoholic drink. Furthermore, study [35] examines the effects of cannabis on pilot performance including effects on behaviour, cognitive function and psychomotor performance.

See-and-avoid concepts are an important issue among investigators, as discussed in [15]. In addition, article [183] points out that the issue of runway incursions has been identified as a serious threat to aviation safety. Thus, recent initiatives to enhance runway safety by European States include the implementation of the European Action Plan for the Prevention of Runway Incursions. In discussing the circumstances surrounding a runway incursion the author demonstrates that the prime contributing factor is a breakdown in communication between the ATC and the pilot or vehicle driver, rather than a loss of awareness by the pilot or vehicle drivers as commonly assumed before this survey. Therefore, the authors conclude that improving communication is a matter of priority, but in their opinion, difficult to accomplish. The action plan introduces more than 50 recommendations and, among others, they state that runway safety can truly be enhanced by learning from experience, enhancing the standard of ATC-pilot-vehicle driver communication and system improvements.

Article [7] confirms the conclusion of the previous study. The author stresses that non-adherence to established procedures by the flight crew, airport operator and ATS provider in terms of planning and managing runway maintenance is the cause of many serious incidents involving vehicles at work on an active runway. In addition study [120] introduces the practical tools and educational material assembled by ICAO that can assist with establishing runway safety initiatives emphasizing clear communication and planning measures.

Paper [178] highlights the need for reviewing air traffic control (ATC) and administrative procedures at the aerodrome and in particular the use of certain ATC phrases that are open to misinterpretation by flight crews.

3.3.3 Aircraft and Aircraft Systems

The articles discussed below present some methods, tools, and research approaches used by aviation experts in analysing aircraft and their systems.

The impact of ageing aircraft on aviation safety is a common issue among aviation experts. Research study [69] examines the relationship between ageing aircraft and flight safety and reviews current and future directions for the management of ageing aircraft. Thus, the report concludes that ageing of an aircraft is a safety issue but with adequate maintenance, the potential consequences of ageing aircraft can be mitigated. Additionally, this study states that maintenance programs must act as a preventative measure to reduce the safety risk associated with ageing aircraft, but their success is dependent on the extent to which operators adhere to the programs.

A questionnaire within a survey study was sent to Licenced Aircraft Maintenance Engineers in Australia in 2001 in order to identify safety issues in maintenance [23, 76]. Maintenance workers were asked to describe occurrences that had had the potential to threaten the safety of an aircraft and/or the safety of maintenance workers. Respondents gave details of six hundred and ten occurrence reports addressing two common unsafe occurrences. The most common form was one in which an aircraft system was activated in an unsafe manner, followed by the incomplete installation of components.

Similarly, NTSB [159] discusses the concerns about certification of systems that had been examined by NTSB in several completed accident investigations (rudder actuator, center wing fuel tank, horizontal stabilizer, rudder system). This report discusses the concerns about certification raised in those investigations and identifies possible improvements to the FAA's type certification of safety-critical systems.

Engine maintenance is vital to safe aircraft operation because engine problems are very likely to cause a serious incident or accident. In terms of engine problems the NTSB's view is that jet engines in use on today's commercial airliners are generally quite reliable. However, one NTSB report [159] indicates that engine malfunctions or failures occasionally occur that require an engine to be shut down mid-flight. There are two types of engine failures. A 'contained' engine failure is one in which components might separate inside the engine, but either remain within the engine case or exit the engine case through the tail pipe. This is a design feature of all engines and generally should not pose an immediate flight risk. An 'uncontained' engine failure can be more serious because pieces from the engine exit the engine at high speeds, and thus pose a potential danger to aircraft structure and passenger safety.

Due to a number of safety events including in-flight reciprocating engine shutdown, engine failure and forced landing, engine failure combined with in-flight fire and other events, ATSB in its paper [64] documents the factors that affect reciprocating engine reliability. The

study found that powertrain structural failure was not restricted to one engine model or component but rather the events that led to engine in-flight failure can be listed as follows: combustion chamber component melting, bearing break-up, and powertrain component fatigue cracking. The research report concludes that corrective actions are needed and they are affected by the complexity of reciprocating engine systems. In addition, article [38] analyses twin-engine power loss accidents. Results show that ten of the eleven fatal accidents after a power loss in twin-engine aircraft were the result of an in-flight loss of control. In contrast, the majority of non-fatal accidents after a power loss were primarily the result of a forced landing due to degraded aircraft performance.

Fuel-related safety events are another tangible air safety topic commonly discussed by aviation experts. For instance, study [26] investigates the overall frequency of factors contributing to fuel-related accidents between 1991 and 2000. This study shows that fuel exhaustion and fuel starvation accidents continued to be a problem in the Australian aviation industry, accounting for over 6 per cent of all accidents between 1991 and 2000. In addition, an ATSB based study indicates that fuel contamination was the cause of grounding a large number of piston-engine aircraft across Australia in early January 2000 [22]. This research revealed a number of factors related to manufacture, standards and procedures that can contribute to fuel contamination.

Birds and other wildlife are an increasing problem for the aviation industry, as shown by the 7,000 wildlife strikes during 2005 alone in the United States [98]. Report [25] examines Australian bird-strike data between 1991 and 2001 and discusses the magnitude of some of the impact forces exerted during a bird-strike. The study shows that there was a significant increase in the rate of bird-strikes being recorded in Australia since 1992 (most notably between 1998 and 2001). The paper is focused on bird control and avoidance methods, especially the use of hand held laser devices and the use of the US-developed Avian Hazard Advisory System (AHAS), which allows aircraft to avoid high-risk bird-strike areas. Furthermore, Delbeer [98] indicates that there is a need to better educate pilots and air carrier personnel on reporting wildlife strikes and the actions that can be taken to reduce the probability of strikes. Paper [98] discusses many questions relevant to this issue but still concludes that additional research is needed to obtain a better understanding of behavioural reactions of birds to approaching aircraft as well as methods of enhancing the awareness of birds to these aircraft.

With respect to examining bird-strikes, [55] points out that DNA identification of strike species is a reliable method for identifying the species involved in collisions. This is achieved

by extracting DNA samples from any remaining bird tissue and comparing it against unknown samples from the databanks of species classified as being high risk for performing strikes.

Recorded voice data such as Cockpit Voice Recorder (CVR) or air traffic control tapes are an important source of evidence for accident investigation [37, 19]. Moreover, the Flight Data Recorder (FDR) is often the most critical source of data that can provide information about the sequence of events that led to an accident occurring. However, sometimes a parameter of interest may not be available or may have become corrupted. Kakar and Crider [126] present an example which shows how the NTSB can extract any necessary parameters, if required, using the Board's simulation tool and the available FDR and radar data. In addition, [175] describes an example of the successful use of a vertical motion simulator (VMS) in support of an accident investigation conducted by NTSB in cooperation with NASA. Observation and tests were conducted by using the VMS as part of the investigation of the accident involving American Airlines Flight 587.

In order to improve FDR and CVR outcomes, Gregor [109] presents a new method for performing timing correlations between flight data recorder and cockpit voice recorder information. This method involves the use of the cross correlation function to 'search' the typically larger FDR data file for a best match to the event pattern present in the CVR data file. In addition, NTSB [163] introduces three-dimensional (3-D) graphics and animations to show how animation can be used to support complex aviation accident investigations. Problems encountered when attempting to derive empirical evidence for the benefits of 3D auditory cues in aircraft cockpits are described in [124].

Icing, as one of the biggest threats to air safety, is examined and discussed widely among aviation experts. For example Trunov [176] discusses the effect of a very thin layer of wing ice or frost on an aircraft's aerodynamic performance and how it affects both the maximum coefficient of lift and the critical angle of attack. Despite this issue being well known, as the author states, accidents due to it still occur. The author concludes that human factors have an essential role in overcoming this problem. Additionally, airframe icing is discussed in [138] within the continuing series of pilot reports of weather encounters.

Searching for missing parts is an important stage of many investigations, particularly in the case of in-flight disintegration. A ballistic trajectory analysis is described in [110] that assisted in the investigation of an accident which occurred on 25 May 2002 when a Boeing 747-200 had an in-flight break-up and crashed into the ocean. The results of this analysis have been validated with ATC radar.

Another field of safety analysis is assessing the suitability of certain types of aircraft for a given operation. For instance ATSB in research study [65] considers the suitability of the R22 helicopter for mustering operations, with the importance of handling technique and especially good engine management being a major focus of the work.

In addition, report [50] suggests that there is a high chance of surviving a pressurisation system failure if the failure is recognised and the corresponding emergency procedures are carried out immediately. Within this report, the type and nature of decompression events was documented, as well as the consequences of such events, especially hypoxia and pressure-related medical effects. It was conducted by searching on the ATSB database for pressurisation failure events between 1 January 1975 and 31 March 2006.

Finally, report [56] examines a large number of new composite materials which are being developed for cabins and external structures that have the potential to increase the fire resistance of an aircraft. This report assesses the fire hazard of current and next-generation polymer composites for an aircraft and identifies those materials with improved fire resistance. A database has been developed on the fire properties of a large number of polymer composite materials. The database ranks the composite materials in order from best to worst. In addition, a number of advanced structural composites with superior fire properties are identified.

3.3.4 Weather Induced Factors

Weather related general aviation accidents and incidents have become a global safety concern. Several articles that discuss the weather induced accidents are presented below. This review indicates that statistics are widely used as a tool for analysing weather related events.

In terms of weather induced accidents and incidents, aviation expert Gregory Feith, [91] says that despite reliable aircrafts and extensive training, modern airlines and crews face enormous pressure. Intense industry competition demands that flight crew and ground staff are efficient and on schedule. He adds that every effort is made to ensure that nothing disrupts this fragile schedule, but there is one variable that no airline can control – the weather. Severe weather conditions can cause both delays and extreme danger to commercial jets. For example, flight recorders of the McDonnell Douglas MD-82 involved in an accident on 1 June 1999 reveal the pilot's statement that he hates flying at night when he does not know where he is [91] (this statement accurately summarises flights in severe weather conditions). Later on, with respect to this accident, the investigation discovered that flying during thunderstorms was widespread.

Visual Flight Rules (VFR) flight into Instrument Meteorological Conditions (IMC) has attracted special attention because of the high rate of fatalities associated with them [173]. Consequently, aviation safety research professionals are attempting to explain the genesis and mechanisms of such accidents. The current results show that Spatial Disorientation training could prevent fatalities in such weather related accidents.

In addition, report [157] aims to better understand the risk factors associated with accidents that occur in weather conditions characterized by IMC or poor visibility. Within this report, a case control methodology is used which compared a group of accident flights to a matching group of non-accident flights to help identify patterns of variables that distinguished the two groups from each other. The final conclusions are results from a statistical comparison of accident and non-accident flights. It allows for the generalization of those findings to the wider population of GA pilots and flights that may be at risk of a weather-related accident.

Study [48] analyses the level of statistical confidence that had been achieved with destination weather forecasts under various conditions. This work stresses the importance of managing available data which can affect flight safety. One of these sets of knowledge is confidence that the facilities at the destination will provide a qualitative service to give confidence of a safe landing. Paper [36] analyses the different behaviours that pilots exhibit in the face of adverse weather. The study compares three groups of pilots who differed in their response to adverse weather conditions encountered during their flight. The results are based on a set of 491 aviation accident and incident reports drawn from the Australian Transport Safety Bureau (ATSB) occurrence database.

Keanon [128] addresses the importance of development and deployment of a wind shear detection system, explaining that wind shear-related accidents have caused more than 1,400 fatalities worldwide since 1943. He adds that various warning systems deployed at the most vulnerable locations across the United States provide varying levels of protection against wind shear, with collocation of certain systems offering the most effective safety solution.

In terms of volcanic ash, studies [103, 86] propose an improvement in the effectiveness of volcanic ash advisories by developing a centre with the capability for the early detection of volcanic activity via a satellite-based system.

3.3.5 Discussion

As stated earlier, the aim of this chapter is to present the current approaches and methods used by aviation experts in order to examine the issues related to aircraft accident investigation.

Since the goal of investigation is to improve air traffic, the review shows that a lot of relevant research studies are directly related to analysing air safety. Due to the variety of topics included in the air accidents and incidents there are a number of different studies focused on a particular field of the safety issue. However, despite this variety of topics, the research approaches and techniques used are overall quite similar.

An example of this similarity is the frequent use of statistical data by aviation experts. They use every opportunity to define the current situation in a particular area by considering the pertinent statistics of past accidents and the results of the consistent investigations carried out. Furthermore, the literature review shows that the survey method is a commonly used technique among experts in order to analyse a given area of investigation particularly when considering human factor issues. Finally, the recently published articles relevant to air traffic accidents and air safety itself have raised the importance of advanced classification of statistics and other kinds of stored data as a valuable tool for the enhancement of accident investigation outcomes and air traffic safety itself.

Top Management is responsible for Safety ... Every accident, no matter how minor, is a failure of the organization.

JEROME LEDERER, *American aviation – safety pioneer (1902 -2004).*

Application of Expert Systems to Aircraft Accident Investigation

An aircraft accident or incident is an undesirable event which usually involves the dynamic interplay of human, aircraft and environmental factors. In terms of dependencies, the aircraft is located between the human operating the aircraft and the environment in which the vehicle is moving. Familiarity with these three factors is necessary in order to both prevent an aircraft accident/incident and to assist in determining probable causes when accidents/incidents do occur.

No one profession encapsulates all of the factors that can be involved in aircraft accident investigations. Hence, the modern aircraft industry has already consulted not only general engineering disciplines, but also other scientific fields such as psychology, medicine, and biomechanics in their efforts to improve air safety. Therefore, cutting edge aircraft design represents a complex interdisciplinary effort and continues to stand at the pinnacle of engineering design in contemporary civilization.

Within the chain of interaction between human, aircraft and environmental factors, the crew, along with other personnel, can influence the likelihood of an accident by both how they perform their duties and how they react to an adverse situation. As such, an aircraft accident occurs when there is an unfavorable combination of these factors, leading to the loss of control and stability of the aircraft.

Therefore, one important area of aircraft accident investigation is related to understanding the interrelationships among crew and other personnel, the aircraft, and the environment just before and during the accident. Hence, as stated before, ICAO has defined aircraft accident investigation as a process focused on the circumstances of the accident

including gathering, recording and analysing all available information, and then drawing conclusions to enable them to determine the causes of the accident [116].

Figure 24: Relationships between human, environmental and aircraft factors.

As an aircraft is a complex machine consisting of a number of interconnected systems, there are a number of different factors that may result in the loss of control and stability of an aircraft and potentially lead to an accident. These causal factors involve the malfunction of aircraft systems, exceeding exploitation limits and design faults. Similarly, there are a number of events associated with the human and environmental factors that may lead to an accident occurrence. In order to show the extent and complexity of the processes involved in aircraft accident investigation, a general classification of all possible causes of aircraft accidents is presented below [146].

✚ Aircraft causal factors:

In this group of possible causes for accidents are: deficiencies in the design, manufacture, maintenance, operation, and operating environment of the aircraft or its systems, including inadequate overhaul or inspection, foreign object damage and the effects of failures of other aircraft systems.

✚ Human causal factors:

The human causal factors can be divided into three major groups: personnel errors and other crew factors, factors associated with air traffic management, and maintenance-related factors.

The personnel errors comprise the following: inadequate preparation or supervision, poor judgment, poor execution, insufficient crew rest, carelessness, improper use of equipment,

alcohol and/or drug abuse, exceeding aircraft operating limitations, improper aircraft modification, failure to use proper safety precautions, slow response times during critical moments, inadequate procedures, and the failure to execute proper procedures.

In addition, the human factors associated with air traffic management include: deficient regulations, incorrect directives or procedures, problems with air traffic control and runway facilities (such as navigational aids, communications systems, crash/fire/rescue equipment, runways, runway lighting, and taxiways), as well as personnel errors associated with the above.

Maintenance-related causal factors are focused on improperly performed maintenance and inadequate maintenance procedures and plans.

Environmental causal factors:

Environmental causal factors include events associated with: unexpected hazardous environmental conditions, failure to report hazardous conditions and inappropriate response to actual or forecasted hazardous conditions.

If a typical aircraft accident investigation taskforce is examined then one would be able to identify a number of different specialists and experts from a variety of professions including technical investigators, legal authorities, and accredited representatives. In order to determine the causes of the accident, investigators must not only deal with the direct circumstances of the accident, but they also need to pursue comprehensive examinations of the scene of the accident, any wreckage and any witness information. Additionally, they are required to pursue recorded media analysis, component examinations, tests, and simulations.

The possibilities mentioned above clearly illustrate the large number of potential factors which may contribute to an aircraft accident and confirm that an investigation thereof is an extremely complex matter in terms of factors, personnel, the scene and analysis. As a result, the following two questions are raised:

How can aircraft accident investigation be appropriately analysed?

What methods can be applied to further improve the aircraft accident investigation?

Finding research tools for analysing aircraft accident investigation and demonstration of them was the major challenge of this research work. The proposed solution is elaborated on in the next part of this chapter.

4.1 Strategic Decisions and Forecasting – The Theory of Intuitive Methods

In the past few decades there has been considerable growth in the development of scientific methodologies for investigating complex issues through establishing a set of priorities where significant improvement is possible and desired. The essence of these methodologies is to provide the optimal selection of these priorities based on the information available, the strategic objectives and the prediction of future considerations. The most difficult problem is predicting the future and understanding what improvements will be required.

Intuition and an interdisciplinary approach have shown to be vital elements in developing contemporary methods for creating strategic decisions. A number of intuitive methods have been developed over the past few decades. One of the most successful among these methods is the Delphi technique. Initially, the Delphi technique was used mainly for forecasting, but nowadays it is also applied to creating group estimation to formulate a forecast or a set of priorities. The Delphi technique is used extensively in economics, engineering, medicine, and many other disciplines for the purposes of technological forecasting and creating a set of priorities.

The Delphi technique is a formal procedure for carrying out research activities. In this technique, a working group designs a questionnaire which is sent to a larger respondent group. After the questionnaire is returned the working group summarises the results and develops a new questionnaire based on these results for the respondent group to answer. The respondent group is usually given at least one opportunity to re-evaluate their original answers based upon examination of the group response, although the process can be carried out as many times as required.

This chapter proposes that the Delphi technique is a possible tool for analysing aircraft accidents. The ability to conduct a comprehensive survey without bringing the respondents together physically is a tremendous advantage of the Delphi exercise and one that appropriately reflects the modern age of highly developed technology, experts, specialisation, and the advantages of globalisation. Taking into account all of the above, this chapter will present the potential of the Delphi technique in helping to create a holistic approach to aircraft accident investigation and the possibility of creating credible scientific findings.

4.1.1 Intuitive Methods and their Features

The basis of each methodology for creating a set of priorities for improvement of an issue involves the information available, the strategic objectives and prediction of the future of the issue. It is clear that determination of the future is the hardest problem and seeking scientific methodology in the area of forecasting since, without predicting the future of a system, it is not possible to draw optimal decisions for its growth.

According to Dobrov [96], during the 1970's there were more than 130 different methods for creating scientific decisions. He divided these methods into the three basic groups of research forecasts, program forecasts and organisational forecasts all of which applied to different fields of science. On the other hand, according to the procedure for creating strategic decisions, the methods can be divided into three classes:

- a) Trend interpolation methods. These methods provide a picture of the future condition of a system based on interpolation of the trends from the past.
- b) Methods of simulations. These methods include creating a model whereby the future behaviour of a system is simulated by applying variables with different values.
- c) Methods of convergent concordance. These are based on deliberating and creating a consensus of respondents being chosen to express their opinions on the issue.

The first two methods are not applicable in each situation and they do not provide satisfactory outcomes for all systems with respect to creating set priorities. Thus, the need for further development of a system in accordance with the theory for optimal system management, has introduced the interdisciplinary approach and intuition as vital elements of contemporary methods known as intuitive methods. The word 'intuitive' literally means a directly gained sense which is not a result of experience and deliberation that actually excludes any options of their (intuitive methods) application. Yet in reality, intuitive methods used as a means for creating strategic decisions include qualitative analysis, well organised scientific opinions, as well as social aspects of the issue.

In general, intuitive methods are less exact than quantitative methods with respect to mathematic formulation and the decision making process. However, experience of their application shows that their results are more credible, more comprehensive and closer to reality. As a result, they are significantly more adaptable than quantitative methods for considering complex systems [149]. Because of this, there have been a number of different types of intuitive methods developed so far. Among them the most successful are the following:

1. Forecasting by expert – individual.

This method is based on the confidence and the capability of forecasting by a person who is an expert. The person chosen has knowledge in the field in which the forecast is carried out as well as skills in forecasting. However, when an expert is identified, there is a certain suspicion that his future prediction will not be credible. The suspicion is based on the fact that the structure and complexity of events and processes almost always overwhelms the knowledge and capacity of only one expert.

2. Group forecasting – panel discussion, brainstorming.

All variants of ‘brainstorming’ can be characterised as methods based on intuitive reflection that lead to the appearance of new ideas and reasonable concordance among experts. This method is based on the idea that the most appropriate solution for a particular system must emerge from an accumulation of many different solutions within a scientifically approved process, where experts create a consensus. By using a team of experts the drawbacks of decisions made by one expert are eliminated. However, new disadvantages appear which may reduce the reliability of forecasting. In this type of decision-making process there is direct communication between experts and it presents a creative contemplation of the issue by active exchange of ideas and opinions. A major characteristic of these methods (usually in the negative context), is the strong influence of authoritative persons that may stimulate a consensus among experts who do not support the proposed solutions.

3. Group forecasting in which experts individually give their opinions.

In this type of method for creating a set of priorities for improvement of an issue, experts convey their opinion individually regarding the issue concerned and after that the researcher deliberates the outcomes and provides feedback to the experts. After that the researcher calculates the mean of the expert opinions and when a consensus is reached, he defines the final conclusions.

To date, the most developed intuitive methods are the following: the Delphi technique, Method of strategic games, Scenario, and Utopia method. Considering the Aircraft Accident Investigation as an issue to be developed, it has been deduced that the Delphi method (well known as the Delphi technique) is the most appropriate tool for creating a set of priorities regarding improvement of aircraft accident investigation. Therefore, the following part of this chapter is devoted to the Delphi technique, its definition and procedure, as well as its features.

4.1.2 The Delphi Method

The Delphi method is named in deference to the legend of the Greek Delphi oracle [127] and presents one of the most useful methods for establishing a set of priorities to further develop and improve a complex system [136, 168]. The name of the method may be considered adequate, where instead of gods a team of experts is created whose opinions are the most competent for a given issue.

The basis of the Delphi technique is through a systematic use of expert knowledge from different fields to determine the ongoing condition of the system considered, then to simulate its future in order to bring out decisions for its progress. The Delphi method includes the organised gathering of experts' opinions and is based on assumptions looking onto a complex system essentially an interdisciplinary employment of science is required. Furthermore, the Delphi technique as a scientific tool for doing research introduces a combination of quantitative and judgmental processes. Namely, the Delphi exercise uses interviews and questionnaires to extract estimates or prognostication on a specific issue from a valid sample of experts.

Moreover, the Delphi technique is often used to combine and refine the opinions of a heterogeneous group of experts in order to establish a judgment based on the information collectively available to the experts. Hence, the Delphi method provides an opportunity for experts to communicate their opinions and knowledge, to see how their evaluation of the issue aligns with others, and to change their opinions after reconsideration of the findings of the group's work [83]. The work continues over a series of interactive rounds until consensus or stability is reached on the current issue, where all participants contribute to gaining knowledge. Delphi studies have the potential to provide valuable information and this mutual judgment-opinion is used for further development of the issue. Thus, the basic steps of the Delphi method are: defining the problem, determining the type of expertise required, selecting a sample of experts, preparing and distributing a questionnaire to respondents, and analysing their responses in order to determine whether consensus among the experts has been reached.

The Delphi technique was established and primarily used in the framework of a study undertaken by RAND Corporation to cater for the needs of the American air forces. According to Trocki [135], the basis of the Delphi technique was set up in the RAND Corporation and that 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 RAND Corporation in 1949; these characteristics are related to statistical analysis of individual opinions. In addition,

a great contribution to the development of the Delphi technique, as well as to its popularisation, was from Dalkev and Helmer who in 1963 published the article 'An Experimental Application of Delphi Method to the use of Experts'. 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 [102]. For instance, in Japan in 1969 the Science and Technology Agency applied the Delphi technique for forecasting the development of science and technology by the year 2000, surveying approximately 4,000 individuals.

In the first period of its application, the Delphi technique was mainly used for forecasting future international situations and forecasting scientific-technological development. Nowadays, in practical terms, 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, a more adequate name would be the 'method for creating group estimation' [181]. Moreover, Dalkey [cited in 136] 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'. This is obviously one of the most appropriate definitions resulting from the widespread use of the Delphi method as not only a tool for prediction but also as a tool for creating strategic decisions. Hence, regardless of the primary application of the Delphi technique, today its usage is significantly extensive in the areas of economics, engineering, medicine, and science for technological forecasting and creating a set of priorities. As a result of this, within the theory for optimal system management, the Delphi technique has taken first place as the most important method among all methods available for preparing and creating strategic decisions with respect to future technological innovations, development and changes [141, 148].

The procedure of the Delphi technique allows for the consideration of very complicated and even controversial issues for which primarily there are different or opposing expert opinions for their further progress. This is because within the Delphi exercise there are no restrictions on the use of expert opinions with respect to any issues, regardless of their nature and origin. Dissension helps experts to focus their judgment in order to improve their approach to getting a collective consensus within a procedure where expert opinions may be divergent.

The results from the implementation of the Delphi technique are not supposed to be valid eternally. They express expert opinion and estimates at current conditions which have to be periodically reviewed and developed. In the case of aircraft accident investigation, an issue to be considered could be fitted trend interpolation or analytical methods for additionally considering the Delphi outcomes.

4.1.2.1 The procedure of the Delphi Method

The Delphi technique is formalised through the procedure of carrying out research activities. It is usually composed of four phases: organising the procedure, selection of experts, conducting the exercise and data analysis [134, 135]. Some experts suggest that there are in fact five phases within a Delphi exercise but that generally does not affect the essence of the method (as and it mainly depends on the technique by which the Delphi exercise is carried out). Alternatively Wdowiak [135] says that within the implementation of the Delphi technique there are three different levels: emergence of the research issue, identification of the experts' opinions and data analysis. However, the procedure of the Delphi exercise is composed of the following steps: 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 the 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 the particular area and specialists for forecasting. The working group establishes a team of experts which are later surveyed. After that the working group creates 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 that 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 been finalised a sample of it is delivered to every single expert. The questionnaire contains all of the 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 (Figure 25). 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 in 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 requested, and this information is represented 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, the 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 whole process of the Delphi method is distinguished by three main characteristics [165]:

- Anonymity

Within the Delphi exercise there is no communication among respondents. The interaction between members of the expert team is precluded and therefore absolutely independent answers (opinions) are assured. The opinions of the experts in a Delphi exercise are presented in statistical form as an average so that the anonymity of the answers is assured until the end of the procedure.

- Presence of an iterative process and feedback and
- Conclusions present a collective experts' opinion

The Delphi procedure is repeated several times and through the feedback all respondents are informed with group results from the previous round. Thus, at each successive interrogation, the participants are given new and refined information in order to achieve a mutual consensus. This process of iterations continues until a satisfactory consensus of respondents' opinions is achieved.

Figure 25 The Delphi Technique. Identification of the Expert Opinion.

When a sufficient consensus appears, the procedure finishes and the final result presents collective answers for all questions individually. In the process of forecasting or creating a set of priorities for improvement of a given system the individual expert opinions do not occur at any stage of procedure.

Apart from the main three features, other distinguishing features of the Delphi technique include team work and an interdisciplinary approach to the issue. Thus, as said above, decisions made through the Delphi exercise show the opinion of the team of experts, which is usually composed of specialists from different fields in science. Hence, each respondent has an important role in forming the group opinion which additionally could result in creating a set of priorities for improvement of the issue under consideration.

4.1.2.2 Aircraft Accident Investigation and the Delphi Technique

The Delphi method is considered to be one of the most truthful techniques of data derived from many sources [127]. Therefore the application of a Delphi exercise provides an opportunity to comprehensively analyse the aircraft accident investigation as all propositions for a successful Delphi exercise exist. 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 analysing information and determining the causes for an accident. It is clear that the investigation is associated with air traffic safety and therefore enhancement of safety has to be included within the study. Furthermore, there is a lot of information available regarding aircraft accident occurrences as well as the investigation carried out, so that 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.

The question regarding the future condition is included within the Delphi technique, so there are no limitations on applying it and creating a set of priorities or strategic decisions for further development of aircraft accident investigation.

It is clear that the prospective conclusions will reflect the whole procedure carried out in the Delphi exercise. Obviously the quality of the work done by this candidate in preparing the questionnaire and selecting the expert team will significantly impact on the credibility of the final results. It is most likely that a well-established working group and a well-prepared questionnaire will provide credible and accurate results. It is also clear that the Delphi method,

as for any other, has its drawbacks, but they are far outweighed by the advantages. Because of this, the Delphi conclusions in terms of improvement of aircraft accident investigation will contain some especially desirable features ensuring the quality of outcomes.

4.1.2.3 Advantages of the Delphi Method – Providing Credible and Accurate Results

The outcomes in terms of improvement of aircraft accident investigation obtained by applying the Delphi technique will be credible and accurate. This is because of the many advantages included within the Delphi procedure.

1. The Delphi conclusions result from an organised and systematic employment of the scientific experts' opinions, because within the Delphi exercise a systematic approach to the issue is considered which enables usage of an interdisciplinary approach with a tendency towards a trans-disciplinary approach.

2. The Delphi outcomes are objective and ensure that the forecast will occur or will enhance the quality of the issue. This is because the Delphi procedure is based on a scientifically approved procedure ensuring the success of the issue.

3. The Delphi results must be credible due to the fact that procedures include using the scientific opinion of many respondents whose combined knowledge is almost always greater than the knowledge of the individuals.

4. The Delphi outcomes must be credible and accurate because the issue is regarded from many aspects. Thus, the respondent team is usually composed of experts with different specialisations that guarantee comprehensive analysis of the issue.

5. The final collective opinion incorporates not only qualitative but also quantitative parameters of the survey technique which is most relevant for creating a set of priorities. So, the group opinion always results from an organised and systematic concordance of individual opinions.

6. The final experts' opinion is attained through the use of iterations together with feedback which guarantees qualitative outcomes.

7. The credibility of the results is high because of the anonymity of team members and individual answers. In this way the application of the Delphi survey removes any disadvantages that may occur such as:

- a. Opinion of an authoritative expert,
- b. Opinion of expert with oratorical skills,

- c. Opinion gained by experts having the skill to impose their views on other experts,
- d. Imposition of the grouped (herd) opinion.

8. The final findings result from a fast and efficient procedure which is able to recognise the most important factors leading to growth of the issue considered. When the questionnaire is well prepared and the team is composed of knowledgeable specialists, the working group needs a short time to establish a consensus of expert opinions.

9. Credible results can also be obtained in uncertain cases within aviation issues, where there is a lack of objective or significant data. Credibility is maintained even when other formal methods cannot be applied or the creation of a model is impossible. The Delphi technique can also analyse phenomena that are mainly from a qualitative nature and cannot be converted into quantitative form for further consideration.

10. The Delphi outcomes are obtained by applying a very convenient procedure with respect to expenditure for its undertaking. In terms of factors such as costs and the number of working hours required for participation and processing the results, the Delphi technique is more favourable than other techniques.

4.1.2.4 Disadvantages of the Delphi Method

Although the application of the Delphi technique for considering aircraft accident investigation is strongly supported by this candidate, it does not mean that it is an ideal method. Therefore, within a Delphi exercise, the working group must cope with several challenges in order to retain the credibility of the outcomes. Among those, the most severe drawbacks are the following:

A. Possibility of subjectivity and elitism while undertaking the Delphi exercise.

A concern that is often raised about the credibility of Delphi outcomes is that experts may give responses that reflect their personal interests and therefore their answers may be biased. Therefore, the Delphi exercise in essence has the potential to be subjective and elite. In terms of subjectivity, it is clear that it exists almost in each qualitative analysis undertaken by a researcher. However, for Delphi itself, there is the risk of elitism or subjectivity within an expert group (class, elite or ideology) that must be overcome by the selection of an appropriate team of respondents.

B. Positive approach to the issue considered.

The working group has to deal with a positive attitude commonly taken by experts on the future of an issue. This arises from the social aspect and it occurs when experts suppose a positive development on an issue, not taking into account the structure and nature of all factors affecting the issue.

C. Outcomes focusing strictly on the aim of the research.

Another negative aspect of the Delphi technique is the fact that respondents almost always fill out the questionnaire directly according to the questions and they do not take into consideration the whole process of the development of certain phenomena. Thus, very important aspects of the issue may fail which will lead to less credible outcomes. The working group can retain credibility by providing a well prepared questionnaire together with all information needed for undertaking a correct survey.

D. A cumbersome procedure.

The Delphi method as an exercise for committing a systematic and broad analysis of an issue includes a number of influential factors of a different nature which may fail to separate the more important factors from the less important ones. However, a good decision or forecast can be obtained if questions are worked out thoroughly and posed properly, that once again emphasises the great importance of the coordination role of the working group. In addition, asking the experts the same questions several times may affect the quality of the answers, particularly when there is a delay between two successive iterations and when the environment can have an impact on their opinion. This may happen because of the lack of the experts' competency in posing diverse questions or through inappropriate question wording.

It should be noted that the above mentioned drawbacks also occur in other survey techniques and sometimes there are even more severe implications. Nevertheless, within the prospective Delphi study for creating a set of priorities for improvement of aircraft accident investigation, this candidate must seek the most appropriate way to create the questionnaire and select the team of experts to overcome the above mentioned drawbacks. The researcher, in order to retain the credibility of the findings must also eliminate the organisational problems that may appear during the Delphi exercise.

4.1.2.5 Organisational Problems within the Delphi Exercise

In the actual practice of carrying out the Delphi technique there are several potential organisational problems which may appear during the course of a Delphi procedure. The predicaments related to the organisation of the Delphi exercise are the following.

a) Obstacles related to establishing the expert team

In the framework of this issue are the obstacles associated with:

- Selection of scientific fields or occupations that will be consulted,
- Selection of experts of already chosen areas,
- Size of the expert team, the number of experts.

Typically, the question remains of how to choose a ‘good’ respondent group. The selection of respondents is a real and significant problem, but it is not a problem unique to Delphi. The selection of the expert team depends on the nature of the issue to be considered and conclusions that should be drawn. There is an opinion that because of the correlation of all elements in the society, each issue considered must be viewed from many different aspects and only then will the results be the most accurate and close to the reality [149]. Alternatively, including a number of different fields of science i.e. engaging a large number of experts, may have negative consequences on the efficiency of the Delphi exercise. In addition, the participation of certain occupations during the decision making process can considerably upgrade the final decision, whereas contributions of other professions may be negligible, or even negative. Therefore, the process of the selection of occupations should include only the most important ones that will contribute to creating the optimal decisions.

Next, the selection of the experts individually, in the framework of previously selected scientific areas, sometimes may cause organisational obstacles. Thus, that selection of a reliable and efficient expert team includes not only individuals with scientific knowledge, but also experts who possess skills to identify proper alternatives i.e. experts who will contribute the most to the creation of accurate strategic decisions. In terms of knowledge, the selection is committed to reputation, because knowledge of a person is expressed by achievement in his/her own profession, whereas inspection of forecasting skills is a more complicated task. In general, a person can be considered to have skills for forecasting if a large percentage of his/her forecasts have been fulfilled.

Another organisational problem is the size of the expert team that generally is not known in advance. In terms of the size of the respondent team, it is clear that homogeneity in participants governs the size of the sample, and 10 to 15 respondents can be sufficient if the group is homogeneous. Generally, there is an opinion that a larger number of experts will provide better outcomes, but including experts from many different fields often does not mean that the results are more credible; it is likely that greater numbers will reflect on the time required to undertake the exercise and may worsen the quality of the outcomes.

However, it is certain that selection of qualitative specialists is much more of an important issue than the size of the expert team. Thus, the working group (researcher) must select knowledgeable respondents in the subject area, who have a good performance record, time to participate, and a rational approach to problem solving.

b) Lack of information, unclear questions

The Delphi supposes providing maximum favourable conditions to completely utilise the knowledge and experience of the experts chosen. Therefore, the working group should eliminate the existence of ambiguous questions which may create possible confusion among respondents. Additionally, the working group, creating the questionnaire, aims to avoid posing questions that may suggest or include part of the answers which then may create confusion and uncertainty among the experts. In this regard, the working group has a responsibility to provide the best conditions in which experts can convey their opinion about the issue.

c) Partial competency of experts

The next predicament that may occur is partial competency of experts. It is common that the competency of some experts may not be adequate to answer certain questions in the questionnaire and that should be appropriately indicated. It is clear that selection of the respondents is one of the most important tasks within a Delphi study and is the best way to overcome this problem.

d) Unjustifiably long process of Delphi exercise

During the Delphi exercise experts should be given enough time for individual reflection and creation of personal statements whereas the feedback provided by the working group must be sent to the experts as quickly as possible. For many reasons, the time for

undertaking the Delphi exercise can be prolonged, particularly between two successive rounds. However, it can be eliminated by the active role of the working group.

e) Quality of the answers created and partial suppleness of experts

The objective of the Delphi study is in the framework of several rounds to be realised through deliberate and spontaneous consensus among members of the expert team and through argumentative explanations for all answers that considerably deflect from the group mean. At this stage of the survey some of the respondents may correct their opinions from the previous round, not upon arguments, but with the aim of attaining group consensus, although they are aware of the correctness of their answers. It is clear that inflexibility of experts weakens the group's opinion and the final outcomes. On the other hand, such a phenomenon in some cases may even be useful, because experts sometimes may lean towards conservatism without the presence of any arguments. Therefore, the goal of the working group is to provide favourable conditions and communication with the experts so that their answers are always based on individual reflection, personal attitudes and convictions, i.e. opinions based on facts.

f) Instability of the members of the expert team

The Delphi method may allow some of the respondents during the exercise to leave the survey which may affect the final outcomes. On the other hand, this characteristic may be considered advantageous because the procedure of strategic decision-making does not depend on any one given expert.

g) Not changing the mean

Practice shows that, in some cases, during the Delphi exercise the value of the mean does not change or the shift is negligible. However, the experience of the Delphi study so far shows that convergence of responses is more common than divergence over a number of rounds.

h) Organisational complexity of the procedure

Although a Delphi exercise does not allow any direct interactions among respondents there are complex relations between the working group and the experts. Managing the whole process of the Delphi technique is a very important task that must be done properly by the working group (researcher).

It is quite clear that in any application it is impossible to eliminate all problems associated with the Delphi method. There is no ‘best’ or ‘unique’ method which underlies any scientific procedure or theory, although there are procedures that provide more credible results than others and they are of special interest to researchers. Thus, it is most likely that a well-established working group and a well-prepared questionnaire within a Delphi study for considering aircraft accident investigation will not allow the above mentioned problems and predicaments to significantly affect the credibility of the final results.

4.1.2.6 Mathematical Models - Criteria of Objectivity

The main objective of the Delphi technique is attaining a restraint of 50% interval of confidence in which all expert opinions are located. This task is achieved by a confrontation of the experts’ opinions by employment of feedback within the multistage Delphi procedure.

It is common for the calculation of the experts’ opinions, which are given numerically, to be carried out by the working group (or researcher) in two phases, as follows:

- Determination of experts’ competency,
- Determination of the coefficient of concordance of expert opinions, i.e. the coefficient of the concordance C_k .

1. Determination of experts’ competency

Below is presented the mathematical model of the Spearman Rho (ρ_i) rank correlation coefficient test (Spearman estimator) as a criterion which is used to calculate the experts’ competencies. This procedure allows a greater impact on the final Delphi results for the answers originating from respondents with greater competency.

First of all, according to the procedure, all data from the questionnaire is entered in a matrix $|a_{ij}|_{m \times n}$ by order $m \times n$, where ‘m’ is the number of experts and ‘n’ is the number of questions/factors to be considered, whereas ‘ a_{ij} ’ is the answer of j^{th} question given by i^{th} expert. The matrix created is the basis for the whole procedure and analysis.

Working out the Spearman Rho (ρ_i) rank correlation coefficient depends on the way experts give their opinions about the factors to be considered. There are two possibilities:

- a) When experts allocate different ranks for all factors, the Spearman Rho (ρ_i) rank correlation coefficient is calculated according to equations 1, 2 and 3, shown below [139]:

$$\rho_i = 1 - \frac{6S_i}{n^3 - n} \quad \dots (1)$$

$$S_i = \sum_{j=1}^n (a_{ij} - \bar{a}_{ej})^2 \quad \dots (2)$$

$$\bar{a}_{ej} = \frac{1}{m} \sum_{i=1}^m a_{ij} \quad (j=1, 2, 3 \dots n) \quad \dots (3)$$

- b) When experts give the same ranks for k - questions (same answer for different factors), the Spearman Rho (ρ_i) rank correlation coefficient is calculated in accordance with equations 4, 5 and 6 [139].

$$\rho_i = \frac{\frac{1}{6}(n^3 - n) - S_i - T_i - U}{\sqrt{\left[\frac{1}{6}(n^3 - n) - 2T_i \right] \left[\frac{1}{6}(n^3 - n) - 2U \right]}} \quad \dots (4)$$

$$T_i = \frac{1}{2} \sum_{k=1}^{H_i} (t_k^2 - t_k) \quad U = \frac{1}{2} \sum_{k=1}^{H_I} (u_k^2 - u_k) \quad \dots (5, 6)$$

t_k – number of same answers (ranks) to different questions (factors) given by i^{th} expert,

u_k – number of same answers to different questions referring to the expert group opinion,

H_i - number of groups with same answers for i^{th} ranking,

H_I – number of groups with same answers including all expert answers.

The Spearman Rho (ρ_i) rank correlation coefficient yields values between 0-1 and a higher value means the greater the competence of the expert. A direct parameter expressing the expert competence is the weight coefficient δ_i , which is worked out according to the equations 7, 8, and 9 [135]:

$$\delta_i = a + b\rho_i \quad \dots (7)$$

a, b – coefficients that are calculated according to the equations (8 and 9):

$$a = \frac{\rho_{i \max} - 2\rho_{i \min}}{\rho_{i \max} - \rho_{i \min}}, \quad b = \frac{1}{\rho_{i \max} - \rho_{i \min}} \quad \dots (8, 9)$$

The expert with the highest Spearman Rho (ρ_i) coefficient obtains the value of the weight coefficient $\delta_i = 2$, whereas the expert with lowest Spearman Rho (ρ_i) coefficient has $\delta_i=1$. Other experts are given the value of the weight coefficient δ_i between 1 and 2. After that the expert numerical answers are multiplied by the weight coefficients δ_i worked out and the

original matrix of expert opinions $|a_{ij}|_{m \times n}$ is converted into $|\delta_i a_{ij}|_{m \times n}$. The matrix $|\delta_i a_{ij}|_{m \times n}$ is used when the experts' competency is included in the final results of the Delphi exercise.

2. Determination of concordance of expert opinions

Determination of the expert consensus is attained through calculation of the coefficient of concordance C_k . There are several equations providing determination of the C_k , and they include the following cases [139]:

- a) When experts give different opinions (answers) for all questions, and their competence is not taken into account.

$$C_k = \frac{12 \sum_{j=1}^n (\sum_{i=1}^m a_{ij} - \frac{1}{n} \sum_{i=1}^m \sum_{j=1}^n a_{ij})^2}{m^2 (n^3 - n)} \quad \dots (10)$$

- b) When experts give different opinions for all questions and their competence is taken into account.

$$C_k^\delta = \frac{12 \sum_{j=1}^n (\sum_{i=1}^m a_{ij} \delta_i - \frac{1}{n} \sum_{i=1}^m \sum_{j=1}^n a_{ij} \delta_i)^2}{(n^3 - n) (\sum_{i=1}^m \delta_i)^2} \quad \dots (11)$$

- c) When experts give the same opinions for several different questions, and competence is not taken into account.

$$C_k = \frac{\sum_{j=1}^n (\sum_{i=1}^m a_{ij} - \frac{1}{n} \sum_{i=1}^m \sum_{j=1}^n a_{ij})^2}{\frac{1}{12} m^2 (n^3 - n) - m \sum_{i=1}^m T_i} \quad T_i = \frac{1}{12} (\sum_{k=1}^{H_i} (t_k^3 - t_k)) \quad \dots (12, 13)$$

- d) When experts give the same opinions for several questions and competence is taken into account.

$$C_k^\delta = \frac{m (\sum_{j=1}^n (\sum_{i=1}^m a_{ij} \delta_i - \frac{1}{n} \sum_{i=1}^m \sum_{j=1}^n a_{ij} \delta_i)^2)}{(\frac{1}{12} m^2 (n^3 - n) - \sum_{i=1}^m T_i) (\sum_{i=1}^m \delta_i)^2} \quad \dots (14)$$

T_i – parameter for same ranks (answers) of different factors (questions) given by i^{th} expert,

H_i – number of groups with same ranks given by i^{th} expert,

t_k – number of same opinions in the k -group given by i^{th} expert.

What case will occur depends mainly on the nature of the issue to be considered. The coefficient of concordance C_k receives values between 0 and 1 and the value closer to 1 means that expert concordance is greater.

Coefficient of concordance C_k and the Spearman Rho (ρ) rank correlation coefficient are statistical functions and their non-randomness have to be tested by applying appropriate statistical tests [170]. The coefficient of concordance C_k is tested against χ^2 criterion and therefore, first of all, the value of χ^2 according to the expression 15 is calculated. The variable χ^2 is complied with χ^2 distribution with $n-1$ degrees of freedom.

$$\chi^2 = C_k m(n-1) \quad \dots (15)$$

After that, the value χ_T^2 is read out using the table of χ^2 distribution for 95 or 99% interval of confidence and $n-1$ degrees of freedom. This value presents the basis for testing the non-randomness of the coefficient of concordance C_k .

If the calculated value of $|\chi^2|$ is greater than the table value of χ_T^2 then the hypothesis for randomness of the coefficient of concordance C_k is rejected, leading to acceptance of the hypothesis that non-randomness of expert concordance is correct. On the other hand when $|\chi^2|$ is smaller than χ_T^2 then the hypothesis for randomness of C_k cannot be rejected and the procedure for making a decision must be repeated.

The dispersion of expert opinions for every single question associated with an interval of confidence are calculated according to equations 16 and 17 [135].

$$\sigma_j = \sqrt{\frac{1}{m} \sum_{i=1}^m (a_{ij} - \bar{a}_{ej})^2} \quad \dots (16)$$

$$\bar{a}_{ej} - u\sigma_j < a_{ej} < \bar{a}_{ej} + u\sigma_j \quad \dots (17)$$

Coefficient ‘u’ depends on the probability of the final result and its values are given in the Table 1 below [135]:

Table 1: Values of coefficient ‘u’ for calculating the distribution (σ).

u	$P(\bar{a}_{ej} - u\sigma_j < a_{ej} < \bar{a}_{ej} + u\sigma_j)$
0.6745	0.5000
1.0000	0.6827
1.9600	0.9500
2.0000	0.9545
3.0000	0.9973

Testing the non-randomness of the Spearman Rho (ρ) rank correlation coefficient is conducted by employment of the student's criteria, which is compiled with t-distribution for $n-2$ degrees of freedom. Accordingly, the basis for checking the Spearman Rho (ρ) rank correlation coefficient is the table t_T value, read out for 95 or 99% interval of confidence and $n-2$ degrees of freedom.

$$t = \rho_i \frac{\sqrt{n-2}}{1-\rho_i^2} \quad \dots (18)$$

When the worked out value of $|t|$ is greater than value t_T read out from the table for t-distribution for $n-2$ degrees of freedom, then the hypothesis for non-correlation of ρ_i is rejected as incorrect against the hypothesis that there is correlation among ρ_i , which means ρ_i differs considerably from zero. When the calculated value $|t|$ is smaller then the read out value t_T then the hypothesis for randomness of ρ_i cannot be rejected [80].

After reaching consensus among expert opinions, which is proven by statistical testing of the non-randomness of expert competency and opinions, the stage of drawing final conclusions can start. It includes identification of significant factors that have great impact on the issue considered, then presentation of findings and proposing further analysis and research.

4.1.2.7 Discussion

In the group of intuitive methods, the Delphi technique has become widely accepted in recent times by a broad range of institutions, government departments, and policy research organisations. Application of the Delphi exercise can be found in many different areas such as [83]:

- Forecasting important events in science, technology, society and so on,
- Exposing priorities of personal values, social goals, etc.,
- Developing causal relationships in complex economic or social phenomena,
- Evaluating possible budget allocations,
- Exploring urban and regional planning options,
- Examining the significance of historical events.

The analytical technique is not essential within a Delphi exercise, but the subjective expert judgments on a collective basis are necessary. Thus, the quality of a Delphi study is based on the strength of its design, sample, and the process by which consensus is identified

[127]. At first glance the Delphi study seems so simple that many people have found it an easy thing to do. As a result of this, there have probably been more poorly completed Delphi exercises than successfully completed ones.

Considering all the features previously mentioned, the conclusion emerges that the Delphi technique is an objective method for creating a set of priorities or a forecast. A meaningful property of the Delphi method is its broad approach to the issue of considering several influential factors, including respected interests and the positions of all interested parties. Furthermore, the Delphi technique does not restrict additional application of other methods for system optimisation to further increase its usefulness. The aim of the Delphi study is to eliminate drawbacks existing in other methods which use experts' opinions. It is obvious that the method still has drawbacks, but the positive features far exceed the disadvantages. In addition, the findings provided by the Delphi technique can be improved, or modified, because they represent expert reflections at only a particular timeframe. Hence, additional methods can be applied that lead to comprehensive estimates and outcomes within the process of preparation of a set of priorities.

To summarise, this candidate is certain that the rating-scale method well known as the Delphi technique is one of the most appropriate tools for analysing the aircraft accident investigation process, and therefore research activities for its application have been undertaken. However, despite all of the favourable features of the Delphi technique and its credibility, a literature search conducted on e-journals and e-books using combinations of the terms Delphi, aviation, aircraft accidents, and investigation has not retrieved any articles. Therefore, this presents a great opportunity to research new aspects of aircraft accidents within aviation safety issues that have not been explored so far.

It is clear to us all that a tyre burst alone should never cause a loss of a public-transport aircraft.

SIR MALCOLM FIELD, *Head of Britain's Civil Aviation Authority,*
(Regarding the Concorde, 16 August 2000)

Air Traffic Safety Analysis through Statistics

Investigators have performed very useful tasks in the enhancement of air traffic safety by analysing air accidents in the past [145]. In order to help prevent future accidents, investigators, using statistics, strive to objectively understand the many factors associated with air safety discovered during prior investigations. For instance, the continuous growth of air traffic leads to extensive demands and competition between airlines worldwide, which in turn may significantly affect air traffic safety. Statistics can help in recognizing such trends.

According to ICAO statistics are ‘a tool for understanding the past, explaining the present and planning for the future’ [116]. At their Chicago Convention in 1944, ICAO foresaw the importance of reliable and complete statistics on international air transport which led to the establishment of requirements included in a number of statutory provisions from this convention. Thus, when an aircraft accident occurs, the State conducting the investigation must send the final report to all relevant parties, including ICAO where the report is processed. As a result of this information-gathering, statistics have become a meaningful tool for understanding the causes of aircraft accidents and enhancing air traffic safety.

There is a large volume of information relating to historical aircraft accident statistics. Many of these can be found in research studies, reports, books, bulletins, brochures, magazines, other scientific editions, and on the Internet.

Despite statistics related to air accidents and their conclusions being ‘well known’ amongst aviation experts, this candidate has 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, recognised in the previous chapter as appropriate tools for analysing 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, causal factors, and other relevant information.¹⁴
3. The relatively *new approach* to an air accident that has been widely adopted amongst aviation experts worldwide states that there is no such thing as a single cause aircraft accident. All accidents result from multiple causes that have major and contributing causal factors [184, 142]. Contributing factors often worsen the situation and in correlation with the major factors bring about accidents. This new approach has significantly helped in reducing the aircraft accident rate. However, determining whether a factor is cited as major or contributing can sometimes be difficult.¹⁵
4. Determining the cause of an aircraft accident is often not straightforward and different conclusions can be drawn amongst different investigators.¹⁶
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 [88].

¹⁴ One of the possible explanations for this discrepancy is the manner in which incorporated data is commonly aggregated that leads to comparative errors in most data fields including: number of fatal accidents, fatalities, and accident classification [144].

¹⁵ For instance, crew error was cited as the cause of accident of a Boeing 737-400 which occurred on 8 January 1989 near Kegworth, when after a no.1 engine failure, the pilot mistakenly shut down engine no.2. The broken down engine had been in operation for only three months. Six months after this crash two more engines of Boeing 737-400 suffered identical engine failure [107]. A conclusion has arisen that if the engine did not fail the accident would not have occurred. There are a number of similar accidents in aviation history.

¹⁶ For instance, on 6 February 1958, the aircraft Airspeed AS 57 Ambassador crashed on takeoff at Munich airport in a snowstorm. The German investigation into the accident cited ice build-up on the wings as the cause, while an English investigation cited excessive drag from slush build-up on the runway [9].

In the case of the deadliest accident in aviation history (27 March 1977 on the island of Tenerife), when two Boeing 747 airliners collided on the runway killing 583 people, the Spanish report found that the accident was caused by the Dutch captain taking off without clearance, whereas the Dutch board said that there was simple misunderstanding with ATC.

There are many other cases similar to these ones, when investigators from different agencies split their expert opinions. Moreover, there are cases when there is a serious disagreement with the report among experts of the **same investigative team** [101].

Due to the above reasons, this candidate decided to look at aircraft accidents that occurred worldwide between 1950 and 2004. The main references used for obtaining data on aircraft accidents were [9, 10, 100]. These resources provide general information, database collections relating to aircraft safety and news, and reports of aircraft accidents.¹⁷

After considering the data available from the resources chosen, a number of conclusions were drawn and some original findings relevant to air traffic safety are presented below. Some of the data presented is clearly stated, whereas other data, in particular information relating to the causes of accidents, was obtained by analysing the reports available in [9]. By doing so, this candidate had an opportunity to look deeply into the chain of events that led to these accidents and create ‘his own’ database of accident causes. Thus, taking the aviation experts’ ultimate goal of zero accidents, the candidate decided that the first event which occurred within the chain of events that had a significant impact on air safety was cited as the major cause for the accident.¹⁸ It is not a matter of a biased (author’s) view, but only the attitude in analysing the accidents and reducing the accident rate.

The aim of this material is not to provide exact statistics on aircraft accidents between 1950 and 2004. Rather, the aim is to illustrate the overall trends in aircraft accidents and to draw some broad conclusions. These conclusions are based on data analysis relating to the number of accidents and their distribution, number of casualties and causal factors available in [9, 10, 100].

5.1 Aircraft Accidents during the Period 1950 to 2004

In the period from 1950 to 2004 1630 accidents were recorded worldwide. The first and most significant conclusion regarding this work is that on average the causes for 31% of accidents are not completely explained. Even in the period 2000-2004, in spite of advances in detection techniques, the percentage of aircraft accidents with unknown causes is still large, about 26% as shown in Figure 31 (page 114).

The number of aircraft accidents that occurred worldwide during the period from 1950 to 2004 fluctuated between 17 accidents in 1981 and 1984 as the safest years, 46 in 2001, 50 in 1972 and 60 accidents in 1950 (Table 2). The distribution of the number of accidents is

¹⁷ All three websites are recommended as credible sources for conducting research [166].

¹⁸ For instance, if all engines of an aircraft failed and the pilot did not manage to cope with this situation, the engine failure will be cited as the major cause for this accident.

depicted in Figure 26, which shows certain peaks in 1950 and at the beginning of the 1970's. In the period around 2000, there was also an increase in the number of aircraft accidents.¹⁹

Table 2: Number of aircraft accidents that occurred worldwide between 1950 and 2004.

	'1	'2	'3	'4	'5	'6	'7	'8	'9	'10	Total
1950's	60/32*	21	27	23	21	23	25	28	30	37	<u>327</u>
1960's	28	36	29	19	25	24	27	29	29	33	<u>279</u>
1970's	28	50	43	30	23	31	26	24	32	20	<u>307</u>
1980's	17	26	21	17	27	23	27	35	38	26	<u>257</u>
1990's	31	24	26	31	32	29	31	30	44	40	<u>318</u>
2000's	46	43	25	28	Total 1630						<u>142</u>

* This cell shows the number of aircraft accidents which occurred in 1950 and 1951.

Figure 26: Number of aircraft accidents that occurred worldwide between 1950 and 2004.

The number of aircraft accidents is commonly associated with data about air traffic intensity. Since the intensity of air traffic has been rising continuously over the past few decades, it is of particular interest to present the distribution of the number of accidents versus the number of flights.

Figure 27 illustrates the distribution of the number of departures and the number of fatal accidents per million departures (rate 1) in the period 1970-2004. It can be seen that in the recorded period there was a constant climb in the number of departures from 6 million in 1970 to around 22.2 million in 2004, whereas the rate fell considerably from 11.5 in 1970 to around 0.9 in 2004. In addition, Figure 28 shows the correlation between the number of departures and

¹⁹ Military aircraft accidents are excluded.

number of fatalities per million departures (rate 2). It reveals that there was a reduction in the rate 2 from around 264 in 1970 to 23 fatalities per million departures in 2004.

The data from Figures 27 and 28 poses the question of the shape that the given trends will continue in the following years and decades. It is anticipated, due to the ongoing processes of globalisation and growth of the aviation business that the number of flights will continue to increase, whereas the number of accidents per million departures will continue to fall. In this regard Wood and Sweginnis [184] state that due to the growth of aviation, the total number of aircraft accidents in the future will increase. They also add that although there are more accidents we are getting safer due to the decreasing rate at which the accidents occur. However, if the aim is to reduce the number of fatalities due to aircraft accidents in absolute terms, the decrease in the number of fatalities per departure (rate 2) must remain strong to outperform the steady increase in the number of flights.

Figure 27, 28: Correlation between rates 1 and 2 and number of departures.

Rate 1 - the average number of fatal accidents per million departures

Rate 2 - the average number of fatalities per million departures

Next are the statistics regarding the time and place of accident occurrences. Overall, the data reveals that aircraft accidents can happen at any time of the year and anywhere in the world. Accidents occurred regularly throughout the year and there was only a slight difference between the number of accidents in summer and winter months. Thus, from 1950 to 2004 on average the smallest number of accidents occurred in the months April, May and July with participation of 6.7 %, whereas most accidents happened in January with 9.8 % and December with 11%.

Table 3: Monthly distributions of aircraft accidents that occurred between 1950 and 2004.

	Jan (%)	Feb (%)	Mar (%)	Apr (%)	May (%)	Jun (%)	Jul (%)	Aug (%)	Sep (%)	Oct (%)	Nov (%)	Dec (%)
1950-60	10.7	8.3	10.4	10.1	7.6	7.6	4.6	7.0	7.3	7.0	8.3	11.0
'60-70	7.5	10.0	12.5	7.5	5.7	5.4	9.7	7.2	10.8	3.9	10.4	9.3
'70-80	12.1	6.2	9.8	5.9	6.2	7.5	4.6	8.5	11.7	7.2	8.5	12.1
'80-90	9.3	9.3	7.0	3.9	6.2	8.9	7.8	9.3	9.7	9.3	7.4	11.7
'90-00	6.9	11.3	7.9	6.3	5.0	6.0	11.6	8.5	9.4	6.6	8.8	11.6
'00-04	14.1	7.0	7.0	4.9	12.0	2.8	7.0	9.2	4.9	8.5	12.7	9.9
1950-2004	9.8	8.8	9.3	6.7	6.7	6.7	7.5	8.2	9.3	6.9	9.0	11.0

In terms of distribution of aircraft accidents with respect to the seasons of the year, 22% of the accidents occurred in spring, 23% in summer, 25% in fall and the remainder, 30%, in winter, which means that the seasons do not significantly affect the likelihood of aircraft accident occurrence. This data should be regarded as a rough approximation, because the effect of the same seasons differs in different countries in the world.

Figure 29: Distribution of aircraft accident by decades according to the place of accident.

In terms of the place of occurrence, most of the accidents in the period 1950-2004 occurred in Asian countries (around 30%), followed by countries in the North American continent, Europe, South America, Africa and lastly Australia & Oceania with rates of 24%, 17%, 16%, 10%, and 1 %, respectively (Figure 29). The remaining 2% of the aircraft accidents occurred over international waters.

In the 1950's most accidents occurred in the North American continent, with around 30 % of the total number of accidents (fatal accident rate and number of fatalities rate are not

included in this analysis). In contrast, the statistics show that presently most accidents occur in Asia. Furthermore, according to Figure 29, there was a significant increase in the number of accidents which occurred on the African continent from 7% in 1970's to 20% in 2004. This is probably due to the growth of air traffic in these areas.

Over the period 1950 – 2004, 280 accidents or 17 % occurred in the U.S., followed by Russia (including the former USSR) with 142 accidents or 9% of the total number of accidents (fatal accident rate and number of fatalities rate are not included in this analysis as well). Further behind these countries are Colombia, Brazil and India. However, for all countries over the recorded period there was a downward trend in the number of aircraft accidents.

Table 4: Top five countries where most aircraft accidents occurred over the period 1950-2004.

	1950-60	1961-70	1971-80	1981-90	1991-00	2001-04	Total
USA	79	58	41	35	47	20	280
Russia	8	20	49	35	19	11	142
Colombia	12	12	16	13	15	8	76
Brazil	22	12	7	10	8	6	65
India	17	9	7	6	6	0	45

5.2 Number of Casualties Involved in Aircraft Accidents

During the period from 1950 to 2004, 1630 accidents occurred worldwide. Those 1630 accidents involved 89,817 occupants and 64,377 of them suffered fatal injuries, which means on average 39.5 people per accident or 72% of the total number of occupants died (Table 5). Most passengers in aircraft accidents died in 1985 when this number reached a peak of 2,392. After that 1972 and 1973 were the next series of the worst years, in which 2,391 and 2,123 occupants were killed, respectively. In contrast, in 2004 and 1955 there were just 517 and 495 fatalities.

Table 5 depicts the distribution of the number and the rate of passengers who died in accidents by decades. The rate during the whole period is very high and it fluctuates between 55% and 84%. For instance the rate started at 84 % in the 1950's followed by a drop to 55% until the 1990's when it again climbed and reached a value of 70 % in the period 2001-2004.

Table 5: Casualties in aircraft accidents in the period 1950-2004.

	1950-60	1961-70	1971-80	1981-90	1991-00	2001-04	1950-2004
Killed	8,228	11,797	16,104	12,322	11,992	3,934	64,377
Pass. & crew	9,822	13,896	20,308	18,194	21,981	5,616	89,817
% killed	83.77%	84.89%	79.30%	67.73%	54.56%	70.05%	71.68%

In order to obtain a clear picture of the accidents versus mortality rate, Figure 30 portrays a distribution of the aircraft accidents which occurred during the period from 1950 to 2004 with mortality rates of 0% and 100% as well as rates of 25, 50 and 75%.

Figure 30: Distribution of the rate of killed passengers in aircraft accidents.

In the 1950's the rate of accidents without casualties started at around 5% and remained stable until the 1980's when it rose gradually, and in the period 2000-2004 it reached a peak of 20%. On the other hand, the rate of the accidents in which all passengers suffered fatal injuries fluctuated between 70% in the 1960's and 1950% in the period from 2001-2004. The rate of accidents, in which by 25, 50 and 75% of occupants died, fluctuated between 5% and 20% in the period 1950 - 2004.

In terms of aircraft involved in the accidents (Table 6), the highest ratio of events versus number of flights has the Aerospatiale Concorde with 12.5 occurrences per 1 million flights. Next are the McDonnell Douglas MD, Embraer 110 Bandeirante and Fokker F-28 with 5.71, 3.73, 2.35 events per 1 million flights, respectively. The smallest ratio has the Saab 340 with 0.33 events per million flights followed by the McDonnell Douglas MD-80 with 0.45 and Boeing 767 with 0.46 events per million flights.

Table 7 points out the average age of aircraft involved in accidents in the period 1950-2004 by decades. For these statistics there was a significant lack of information particularly in the period before 1980. According to the data available, the average age of aircraft involved in the accidents was 13 years. In the period 2000-2004 (when the information regarding the age is

known) the average age was 19. This suggests that the actual age of the aircraft involved in the accidents 1950-2004 is higher than the worked out age of 13 years.

Table 6: Aircraft involved in accidents²⁰.

Model	Events	No. Flights
Aerospatiale Concorde	1	0.08 Million
Airbus A300	9	8.0 Million
Airbus A310	5	2.7 Million
Airbus A319/320/321	4	6.0 Million
Boeing 727	46	70.0 Million
Boeing 737	47	76.0 Million
Boeing 747	24	14.8 Million
Boeing 757	4	7.2 Million
Boeing 767	3	6.5 Million
British Aerospace BAe 146	4	4.5 Million
Embraer 110 Bandeirante	28	7.5 Million
Embraer 120 Brasilia	5	7.0 Million
Fokker F-28	20	8.5 Million
Fokker F-70/F-100	3	4.5 Million
Lockheed L-1011 Tristar	5	5.5 Million
McDonnell Douglas DC-9	42	55.5 Million
McDonnell Douglas DC-10	15	7.6 Million
McDonnell Douglas MD-80	9	20 Million
McDonnell Douglas MD	4	0.7 Million
Saab 340	3	9.0 Million

Table 7: Average age of aircraft involved in accidents 1950-2004.

	1950-60	1961-70	1971-80	1981-90	1991-00	2001-04	1950-2004
Average Age	4.58	2.33	6.81	11.78	15.33	18.62	12.76

The statistics above are stated directly from the sources chosen or obtained by simple calculation. The following part of this chapter, relating to causes of accidents, has been calculated through analysing the brief accident reports available in [9] (one of the brief reports available is shown in Appendix D).

5.3 Causes of Aircraft Accidents during the Period 1950 to 2004

As mentioned previously the reports of accidents between 1950 – 2004 in [9] were read and analysed by the candidate rather than only considering the conclusions already derived and present within the aviation safety field. By doing so the candidate managed to gain fundamental knowledge about the circumstances and chains of events that led to those

²⁰ The safest airline in the world is QANTAS, which has never had an accident [140].

accidents which was very important in proceeding with this research work. Table 8 illustrates the accident statistics by phase of flight when the initial problems occurred and which led to accidents. Thus, on average 32% of aircraft accidents occurred in the approach-and-landing phase, which is composed of the initial approach, final approach and landing phase. After that are the cruise and takeoff phases in which 26% and 18% of causal events happened and led to accidents.

Table 8: Distribution of accident causes according to the flight phase.

Take Off	Cruise	Approach and Landing	Collision	Runway	No Information
17.7 %	26 %	31.9 %	3.6 %	1.7 %	19 %

Table 8 shows that for 19% of the accidents there is no reliable information about the time when the accident occurred. The data from Table 8 also points out that an actual collision accounted for about 4% of accidents, whereas nearly 2% of accidents happened on the runway either before takeoff or during landing.

The approach-and-landing phase can be additionally considered with respect to its components of initial approach, final approach and landing phase. This analysis shows that around 40% of aircraft accidents occurred in the landing phase, 38% in the initial approach, and 22% occurred in the final approach phase (Table 9). Analysing this data by decades shows that these trends are stable and fluctuated at relatively small intervals.

Table 9: Distribution of accidents in sub phases within approach & landing phase.

	Initial Approach	Approach	Landing
Ratio (%)	38.3 %	21.5 %	40.2 %

Table 10 shows the distribution of aircraft accidents 1950-2004 by decades that occurred on the runway, either before takeoff or during landing. The data illustrates that since 1970 the ratio of these accidents has stabilized between 2 and 4%.

Table 10: Accidents occurring on the runway before takeoff or during landing.

	1950-60	1961-70	1971-80	1981-90	1991-00	2001-04
Ratio (%)	0	0.4	3.1	2.8	2.2	2.1

In addition, the data regarding the causes of aircraft accidents that occurred during the period 1950-2004 was sourced with respect to human error, mechanical failures and environmental causal factors. Since an aircraft accident is usually a result of a sequence of

undesirable events, when analysing an aircraft accident one must consider both major and contributing factors. As said earlier, major factors are mainly responsible for the accident, whereas contributing factors aggravate the situation and along with the major factors cause the accidents.

An analysis of brief reports available in [9] has led to several conclusions regarding the distribution of human, aircraft and environmental causal factors. The results are presented in Figures 31-34.

First of all, the conclusion emerges that the causes for 31% of the aircraft accidents that happened in the period 1950-2004 are not completely determined, i.e. are unknown. This is a very high rate and obviously needs further consideration. On the other hand, the contribution of human, aircraft and weather as major causal factors were on average 32%, 25%, and 12 %, respectively.

Figure 31: Causes for aircraft accidents 1950-2004 (by decades).

Figure 31 presents the distribution of the causal factors that brought about aircraft accidents in the period from 1950 to 2004. It is clear that the rates fluctuated slightly except the trend of the accidents for which the causes are unknown. During the recorded period there was a downwards trend in the number of accidents with unknown causes, but the rate of 26% in 2004 is still high. Furthermore, human causal factors varied from 26% in the 1950's to 38% in the 1980's, whereas the causes associated with the technical condition of the aircraft were the major causal factor in 19% of the cases in the 1950's, going up to 31% in the period 2000-

2004. With respect to the weather, the rate fluctuated between 9% in the 1950's and 15% in the 1990's, an average of 12% over the whole period.

When this data is compared with prevalent statistics of aircraft accidents, slight differences can be noticed. For instance, human error as a major cause varied between 31% in the 1970s and 40% in the 1990s according to [164]. This indicates that the approach used by the candidate in determining the major cause of accidents (as stated above: the major cause is the first significant event within the chain of events leading to the accident) increases the importance of the technological level and the condition of aircraft.²¹

In terms of contributing factors, human error was a strong contributing factor in an average of 7.7% of the accidents. Additionally, the weather was a strong contributing factor in 4% of the accidents whereas mechanical problems were significant in only 1.3% of the cases.

Table 11 shows the distribution of contributing factors during the period 1950-2004. In the recorded period there was a dramatic increase in the involvement of the weather as a contributing factor from 2.3% in the 1970's to 10.6% in the period 2000-2004. The rate of contribution of human error remained steady within the interval 6-10%, whereas the impact of mechanical failure as a contributing factor during the whole period was very low.

Table 11: Distribution of contributing causal factors.

	1950-60	1961-70	1971-80	1981-90	1991-00	2001-04
Human Factors	7.0%	6.1%	6.8%	8.9%	9.7%	7.0%
Aircraft Causal Factors	1.2%	2.2%	0.7%	1.9%	1.3%	0.0%
Environmental Factors	2.8%	2.5%	2.3%	4.7%	5.0%	10.6%

In order to provide more tangible data regarding the causes of aircraft accidents the major causal factors were broken down further into sub-factors. In the case where the aircraft was the major causal factor for an accident (Figure 32), the most common sub-factor was engine problems with 32%, followed by mechanical problems, fatigue, fire occurrences, and icing with 13%, 11%, 10% and 8%, respectively. In addition, causes relating to gear failures accounted for 6% of the accidents, and load and lighting 4% each. Over the period, other events such as bird strike, fuel leak, falsely indicated conditions, instrument failure and many

²¹ In many reports can be seen the rates between 50% and 60% (even more) of human errors as major causes for accidents [16, 95, 108, 132]. These figures refer to accidents where a cause could be identified and excluded accidents where a cause could not be determined. The statistics presented in this chapter include accidents where a cause could not be identified.

others (often associated with emergency landing attempts), were causes for 13% of the accidents.

In addition, Table 12 illustrates the distribution of sub-factors which account for the aircraft as a major causal factor for accidents by decades. Overall the distribution of sub-factors as stable, except the fatigue-cases and accidents associated with gear/tyre malfunction. Over the period 1950-2004, there was a significant decline in the percentage of fatigue-accidents, but a remarkable rise in the number of accidents due to gear/tyre malfunction.

Figure 32: Aircraft causal factors for accidents during the period 1950 to 2004.

Table 12: Aircraft sub-factors leading to accidents during the period 1950 to 2004.

	1950-60	1961-70	1971-80	1981-90	1991-00	2001-04	1950-2004
Engine	38.7%	28.1%	32.5%	30.3%	31.9%	35.6%	32.7%
Landing Gear	1.6%	5.3%	9.1%	3.0%	5.5%	11.1%	5.8%
Mech. Problems	1.6%	19.3%	11.7%	10.6%	19.8%	8.9%	12.6%
Fire	11.3%	8.8%	11.7%	10.6%	7.7%	11.1%	10.1%
Fatigue	27.4%	8.8%	10.4%	12.1%	4.4%	4.4%	11.1%
Load	1.6%	7.0%	2.6%	4.5%	5.5%	2.2%	4.0%
Icing	8.1%	5.3%	5.2%	10.6%	11.0%	2.2%	7.5%
Lightning	3.2%	8.8%	2.6%	3.0%	2.2%	2.2%	3.5%
Other	6.5%	8.8%	14.3%	15.2%	12.1%	22.2%	12.8%

As stated above, human factors were the main cause for 32% of aircraft accidents which occurred between 1950 and 2004 (Figure 31), and 67% of these accidents were caused by crew errors.

Contribution of crew error within human factors was 57% in the 1980's and reached a peak of 74% in the 1950's and 1990's. In contrast, a significantly lower number of accidents in the recorded period were caused by traffic control error, which accounted for around 15%.

Table 13: Human sub-factors leading to accidents during the period 1950 to 2004.

	1950-60	1961-70	1971-80	1981-90	1991-00	2001-04	1950-2004
Crew	73.8%	69.7%	61.6%	57.1%	73.8%	65.9%	66.8%
ATC	14.3%	15.7%	17.0%	18.4%	14.6%	7.3%	15.4%
Crime	8.3%	13.5%	13.4%	14.3%	8.7%	22.0%	12.5%
Shot down	3.6%	1.1%	8.0%	10.2%	2.9%	4.9%	5.3%

Figure 33: Distribution of the human sub-causal factors by decades.

A high percentage of accidents during the period 1950-2004 occurred due to criminal activities. This percentage fluctuated between 8% in the 1950's to 14% in the 1980's or on average 12.5%. Here there are also a surprisingly high percentage of accidents associated with intentional military fire (shot down events) and therefore they are presented separately. Those events were common in the 1970's and 1980's when they reached a peak of 10%, whereas in the other decades they accounted for between 1 and 4% (Table 13).

Severe weather conditions as major causal factors were broken down into several sub-factors and their distribution over the period is shown in Table 14. The weather sub-factors include: turbulence, thunderstorm, runway ice/snow, poor weather (general), strong wind, and intensive rain. While the impact of the sub factors over the decades varied, the category 'poor weather' remained as a main sub factor; it is responsible for 36% of those accidents, followed by the severe storm and thunderstorm conditions accounting for 28% of accidents, and so forth. The statistics reveal that the number of accidents caused by strong turbulence decreased during the recorded period, so that from 1990 there were no such registered accidents.

Table 14: Severe weather conditions as major causal factors for accidents 1950 – 2004.

	1950-60	1961-70	1971-80	1981-90	1991-00	2001-04	1950-2004
Turbulence	10.0%	12.5%	12.1%	6.9%	0.0%	0.0%	7.1%
Thunderstorm	36.7%	40.0%	24.2%	27.6%	19.1%	15.8%	27.8%
Icing	10.0%	0.0%	0.0%	13.8%	4.3%	5.3%	5.1%
Poor weather	36.7%	40.0%	42.4%	17.2%	29.8%	63.2%	36.4%
Wind	6.7%	5.0%	21.2%	20.7%	8.5%	10.5%	11.6%
Rain	0.0%	2.5%	0.0%	13.8%	38.3%	5.3%	12.1%

Figure 34: Distribution of the weather sub-causal factors 1950-2004.

5.4 Significant Examples of Aircraft Accidents that occurred during the period 1950 to 2004

Listed below are several of the most significant and deadliest accidents in aviation history that had the greatest impact on air traffic, and aviation in general. This data is presented in order to emphasise again the existing risks in air traffic and raise the awareness of the continued efforts in preventing future reoccurrences.

1. 3 March 1953 at Karachi, Pakistan, the aircraft de Havilland DH-106 Comet crashed on takeoff due to excessive nose-high attitude, which resulted in a stall. This was the first crash of a commercial jet transport aircraft.
2. 22 May 1962 at Unionville, Missouri, USA. The Boeing 707-124 crashed due to a bomb explosion at 39,000 feet. This was the first known bombing of a commercial jet airliner.
3. 27 March 1977 in Tenerife, Spain. The aircraft Boeing 747-121 collided with a Boeing 747-206B on the runway while backtracking the runway for departure. With a total of 583 killed, this accident remains the deadliest accident in aviation history.
4. 12 August 1985 on Mt. Osutaka, Japan. A Boeing 747SR-46 suffered an explosive decompression while climbing through 23,000 feet. The crew was attempting to return to Tokyo when the aircraft clipped a mountain ridge, flew across a valley, and impacted a second mountain approximately 400 feet from the summit. This accident remains the deadliest single-airplane accident in aviation history.

5. 11 September 2001. A Boeing 757-222 on a flight from Newark, New Jersey to San Francisco, California, crashed shortly after being hijacked. It was the fourth and final aircraft to crash in a series of coordinated terrorist hijackings on September 11.²²

In terms of distribution of the deadliest aircraft accidents over the period 1950-2004, 5 out of 100 deadliest accidents occurred in the period 1950-60, followed by 5, 28, 26, 28 and 8 accidents in the next decades 1960-70, 1971-80, 1981-90, 1991-2000 and 2000-2004, respectively, as shown in Table 15.

Table 15: Distribution of the 100 deadliest aircraft accidents over the period 1950-2004.

	1950-60	1961-70	1971-80	1981-90	1991-00	2001-04
100 deadliest accidents	5	5	28	26	28	8

In addition, there were several accidents that had a significant impact on the accident investigation process and were results of uncommon chains of events including strange human errors, omissions, or aircraft malfunctions. These include: opening of the rear cargo door (08/05/2003), ignoring the takeoff warning horn for the entire 37-seconds takeoff roll (31/08/1999), mistaken determination of engine failure that led to inappropriate operating (13/12/1994), pilot accidentally entering 270 instead of 027 deg (03/09/1989), accidentally shot down by a missile (03/07/1988), forgetting to lower the landing gear (10/07/1988), blocking the main door during the emergency landing (02/06/1983), inadequately entered aerospace followed by shooting down (01/09/1983), mistakenly shooting down the engine (11/10/1983), false warning (06/06/1982), accidentally lowering the flaps during cruise (29/08/1979), malfunctioning altimeter (08/11/1963), and so forth.

5.5 Statistics - Concluding Remarks

Several conclusions have been drawn from the statistics presented in this chapter as follows:

- Besides the specific improvements in the area of air traffic safety, the fact that in the period 1950-2004 1630 accidents occurred worldwide resulting in 64,377 passengers killed is a matter of concern (Table 2 and Table 5).
- Although the rate of the number of accidents and the number of fatalities per million departures decreased significantly in the recorded period, in the future, due to the

²² After 11 September 2001 all aspects of air traffic safety have come under review.

growth of air traffic, the number of accidents, victims and material damage resulting from the accidents is likely to remain stable or slightly decrease (Figure 26 and 27). Some experts state that because of the expansion of air traffic, the number of accidents in the future will increase. This will be the case if the rate of accidents cannot outperform the increase in air travel.

- The likelihood of an aircraft accident is not affected by the time of year or the place of the occurrence.
- Statistical data shows that 72% of the total number of occupants died in aircraft accidents over the period 1950-2004 (84%, 85%, 80%, 68%, 55%, 70% from 1950 to 2004 resolved per decade respectively), which requires action to increase the survivability of accidents (Table 5).
- In terms of an aircraft accident, the impact of the human-aircraft-environment causal factors is complex. Weather conditions are in many cases strong contributing factors in aircraft accidents but the cause of the accident may be sometimes listed as human error.
- The causes for 31% of aircraft accidents that occurred between 1950 and 2004 are unknown (Figure 31).

Overall, the analysis of the historical statistics of accidents between 1950 and 2004 had a significant impact on proceeding with this work. In particular, they emphasised the importance of the following points:

- Existence of sustained risks to air traffic of repeated human errors, omissions, or aircraft malfunctions,
- Need for continued efforts in preventing future reoccurrences, and
- Uniform collecting and storing of data of air traffic safety occurrence worldwide.

Therefore, in order to continue to 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 analysing data could contribute to an improvement in aircraft accident investigation and air traffic safety itself.

The cost of solving the Comet mystery must be reckoned neither in money nor in manpower.

SIR WINSTON CHURCHILL

Application of the Delphi Method to Aircraft Accident Investigation

6.1 Preparation and Application of the Delphi Enquiry

Based on the arguments given in the previous chapters, a Delphi exercise has been conducted in order to examine the aircraft accident investigation. During the entire course of this research, this candidate has followed a general definition of the Delphi technique as being a complex combination of intuition and logic which is formalised through the procedure of carrying out research activities. This is important in order to retain the credibility of the final conclusions and to keep the benefits of intuition and logic intact. The research was conducted between April and June 2007, although the preparation for implementing the research started months beforehand.

Initially, this candidate, along with other members of the working group, created six groups of factors (in total 98 factors) which may affect the outcome of aircraft accident investigation processes. The working group consisted of the candidate as well as a few aviation experts and a Delphi technique expert. 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 [Appendix A: The Delphi Questionnaire]. For this purpose within every group of factors a question(s) was asked in which the respondents provided the ranking of those factors. The questionnaire contained a series of guidelines to help complete the survey properly and was composed of the following six groups of factors:

Group I	
1.	Principle of technical – tactical liberty of conducting the investigation and principle of adequacy
2.	Principle of methodical approach and planning
3.	Principle of critical approach of the procedure
4.	Principle of operational approach
5.	Principle of profundity and persistence
6.	Principle of objectivity
7.	Principle of solitary governance of investigation
8.	Principle of coordination and cooperation
9.	Principle of economical procedure
10.	Principle of secrecy

For the first group of factors the question posed was (Q1) ‘*How much are the below mentioned principles met within an aircraft accident investigation?*’ upon which experts ranked the factors. Experts expressed their opinions numerically ranking the factors from 1 to 10, ranging between *definitely unfeasible* and *definitely feasible*, respectively. In this instance a rank 10 means that this particular principle is met completely, whereas a lower rank indicates that this principle is met partially within an aircraft accident investigation.

Group II	
11	When did the accident happen?
12	Where did the accident happen?
13	How did the accident happen?
14	How has the plane been maintained?
15	Who were the occupants of the aircraft?
16	Why did the accident happen?
17	What may have prevented the accident?

The second group of factors was associated with the question (Q2) ‘*What are the odds of determining the answers of the questions below within an aircraft accident investigation?*’ upon which experts ranked these factors. The ranks available were from 1 to 10, ranging between *definitely unfeasible* and *definitely feasible*, respectively.

Group III	
18	Managing the investigation (Plan, Report, Monitor)
19	Notification and arriving at the scene of the accident
20	Examination of the scene of the accident
21	Wreckage analysis
22	Finding and interviewing the witnesses
23	Investigation of Air Traffic Control records & Radar Data
24	Laboratory examination

25	Reconstruction
26	Report writing (Structure & Quality)
27	Data management

For the third group of factors three questions were posed (Q3, Q4, and Q5) upon which experts ranked the factors from three different aspects. The associated questions were: ‘*In reference to obtaining a better investigation outcome, how important is [the given item] within the process of aircraft accident investigation?*’, then ‘*How complex is [the given item] within the investigation process as to the requirement of special skills and technique by the examination team?*’, and ‘*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 to these questions were from 1 to 10 (*unimportant – very important*), from 1 to 10 (*not at all – very complicated*), and from 1 to 5 (*small - large*), respectively.

Group IV	
28	Operations, The Flight Path
29	Cockpit
30	Engine and accessories
31	Mechanical, electrical, hydraulic, pneumatic systems
32	Landing gear systems and brake systems
33	Deicing and anti-icing systems
34	Fuel (quality and amount)
35	Foreign Object Damage (FOD)
36	Cockpit Voice Recorder (CVR)
37	Cockpit Sound Recorder (CSR)
38	Flight Data Recorder (FDR)
39	Aircraft loading
40	Hydroplaning
41	In-flight explosion
42	In-flight failure (Structural failure–fatigue)
43	In-flight fire
44	Lightning
45	Mid-air collision
46	Crime activities
47	Weather conditions
48	Downwash and wing tip vortex hazards
49	Microburst, wind gust, wind shear
50	Stability and control of an airplane
51	Human error or omission
52	Psychological factors (fatigue, illusion, etc)
53	Design inadequacy

This group of factors was associated with two questions (Q6, Q7) as follow: ‘*How complex is the examination of [the given item] as to the requirement of special skills and technique by the examination team?*’, and ‘*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 ranks available for these questions were from 1 to 10 (*not at all – very complicated*) and from 1 to 5, (*small - large*), respectively.

Group V	
54	Engine malfunction
55	Brake systems malfunction
56	Landing gear systems malfunction
57	Icing
58	Foreign Object Damage (FOD)
59	Inappropriate fuel
60	Inappropriate aircraft loading
61	Hydroplaning
62	Downwash and wing tip vortex
63	Severe weather conditions
64	Microburst, wind gust, wind shear
65	Lightning
66	In-flight explosion
67	In-flight failure (Structural failure)
68	In-flight fire
69	Crime activities
70	Human error or omission
71	Psychological factors
72	Stability problems and lost the control of the airplane
73	Design inadequacy
74	Mid air collision

For the fifth group of factors the question asked was (Q8) ‘*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?*’ upon which experts ranked the factors. Experts ranked the factors from 1 to 10, ranking from definitely *unreliable* to *certain*, respectively.

Group VI	
75	The process of investigation meets the procedures regarding the quality assurance (QA) and quality control (QC)
76	It is justifiable waiting for a couple of months before releasing the accident investigation report
77	Reports of investigation carried out are always accurate and well done
78	Investigators have appropriate and sufficient skills to handle aircraft accident investigation

79	The excellent knowledge of theory compared to an average one significantly improves the investigation outcomes
80	The contamination of the scene of the accident is a serious problem within the process of aircraft accident investigations
81	The presence of landmarks on the scene of the accident provides sufficient information for carrying out accurate mathematical calculations
82	It is likely at times inconsistent material is sent for lab analysis
83	Investigators should believe witnesses of aircraft accident
84	The cockpit recorders (FDR, CVR, CDR) record sufficient parameters
85	We never have a real accident with enough readable data
86	The severe aircraft manoeuvre can be revealed during the investigation
87	The aircraft is equipped with appropriate accessories, which provides ice protection during the whole flight
88	The stall is a serious hazard for the aircraft
89	The downwash and wing tip vortex is a serious hazard for the aircraft
90	Investigators have enough resources available to find out the weather conditions during the accident
91	Human factors have been involved somehow in every single aircraft accident that has ever occurred
92	It is possible to answer the question if the pilot should have been able to cope with the critical situation
93	There are always problems with airfield papers analysis (documentation)
94	The handbook is well composed material
95	There is a great possibility for increasing the survivability of an aircraft accident
96	Determining the cause of the accidents is a very tough task if there is not data recorded
97	The process of investigation as a whole can be improved significantly, by applying new methods and advanced technology
98	The experience of the land traffic accident investigation can contribute to considerable increase in air traffic safety

For the last group of factors the question posed was (Q9) ‘*Do you agree with the statements below?*’ Experts ranked the factors from 1 to 10, ranging between strong disagreement and strong agreement, respectively.

It can be seen that there are the same or similar factors included in several of the groups created. It was carried out in this manner in order to facilitate the survey process as well as provide comprehensive outcomes of this research. In terms of ranking, one should clarify that respondents, if considered, were allowed to rank more factors with the same ranks.

The next stage of the Delphi procedure was selection of respondents and that was done while the questionnaire was being created. Thus, taking all circumstances and features of the Delphi procedure into account, 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 Australian Transport Safety Bureau (ATSB), Defense Science Technology Organisation (DSTO), 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 some 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 a few changes to the questionnaire (which were accepted by the candidate), most of which 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 questionnaire completed. 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, this candidate summarised the responses and, based on the results, developed a new questionnaire for the respondent group. The respondents were asked to re-evaluate their original answers based on examination of the group response from the first round so that they accordingly could have changed their original answers from the first round. 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 round so that the additional third round would not have enhanced the Delphi results.

When the survey procedure was completed and expert responses were available, the candidate began to analyse the data. The data analysis included determining the expert group opinion about every single factor on the questionnaire and working out the expert competency and the coefficient of concordance of expert opinions. All calculations were conducted on an Excel spreadsheet and the results obtained are presented in the following part of this chapter.

6.2 Data Analysis of the Delphi Exercise Application

As mentioned, 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 opinions, which present numerical answers or ranks, were transferred into Excel tables created for this purpose. After that, according to equations 1-14, the average group ranks were calculated for every single factor, followed by determining the coefficient of competency and coefficient of concordance. The final results, including ranking the 98 factors with respect to the 9 questions posed, are presented below.

Question 1

With respect to the question ‘*How much are the below mentioned principles met within an aircraft accident investigation?*’ the experts provided the following group opinion.

Table 16: Expert group opinion with respect to question 1.

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

Table 17: Testing the non-randomness of C_k and the Spearman rank coefficient.

ρ_i	0.56	0.85	0.88	0.77	0.92	0.81	0.89	0.90	0.74	0.85
δ_i	1.00	1.81	1.89	1.59	2.00	1.69	1.90	1.93	1.49	1.81
$C_k(\rho_i)$	0.315									
$C_k(\delta_i)$	0.324									
χ^2	28.31									
χ^2 (table)	21.67									
t_i (test)	2.32	8.95	11.44	5.44	17.73	6.68	11.91	12.94	4.63	8.95
t_T (table)	2.31									

The non-randomness of the coefficient of concordance C_k and the Spearman Rho (ρ) rank correlation coefficient were tested by applying χ^2 and student's criteria (t-distribution).

According to equation 15, the value of χ^2 was calculated, which is complied with χ^2 distribution with n-1 degrees of freedom. From Table 17 it can be seen that the calculated $|\chi^2|$ is greater than the table value of χ^2_T read out for 99% interval of confidence. As a result of this, the hypothesis for randomness of the coefficient of concordance C_k is rejected and that leads to acceptance of the hypothesis that non-randomness of expert concordance is correct.

In addition, the Spearman Rho (ρ) rank correlation coefficient was checked by employment of the student's criteria (t-distribution), which is complied with t-distribution for n-2 degrees of freedom (equation 18). All values calculated are greater than the table value of t-distribution for n-2 degrees of freedom chosen for 95% interval of confidence. As a result of this, the hypothesis of non-correlation of ρ_i is rejected as incorrect against the hypothesis that there is correlation among ρ_i that means that ρ_i differs considerably from zero.

After reaching consensus among expert opinions, which was proved by statistically testing the coefficient of concordance C_k and the Spearman Rho (ρ) rank correlation coefficient, the drawing of conclusions related to the answers of question 1 could have started. Hence, using the data from Table 16, Figure 35 was created.

Figure 35: Expert group opinion on the general principles within aircraft accident investigation.

Figure 35 points out that all principles from Table 16 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 the factors 6, 3, 7 highly ranked 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 clearly indicates that it is not met completely within an aircraft accident investigation. In addition the principle of **operational approach** (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), which were ranked 7.3, 7.6, and 7.7 respectively, are not entirely met.

The ultimate objective in an aircraft accident investigation is meeting absolutely all principles that will provide the best outcomes. In this regard the gap between the maximum rank available and the worked-out one can be viewed as potential for further improvement of investigation. However, this enquiry is very general and all conclusions have to be considered very carefully.

Question 2

This question considers the general investigation questions mentioned in the table below, which are posed in almost all types of investigation, regardless of the nature or character of accident/incident. Thus, with respect to the question ‘*What are the odds of determining the answers of the questions below within an aircraft accident investigation?*’ the experts provided the following group opinion.

Table 18: Expert group opinion with respect to question 2.

		Min	Max	Mean	σ
11	When did the accident happen?	8	10	9.1	0.54
12	Where did the accident happen?	9	10	9.3	0.46
13	How did the accident happen?	5	7	6.3	0.78
14	How has the plane been maintained?	7	10	8.2	1.08
15	Who were the occupants of the aircraft?	8	10	9.1	0.70
16	Why did the accident happen?	5	8	6.8	0.98
17	What may have prevented the accident?	6	9	7.2	0.98

Table 19: Testing the non-randomness of C_k and the Spearman rank coefficient.

ρ_i	0.67	0.89	0.88	0.75	0.93	0.77	0.81	0.94	0.90	0.90
δ_i	1.00	1.81	1.79	1.29	1.95	1.36	1.51	2.00	1.83	1.83
$C_k(\rho_i)$	0.685									
$C_k(\delta_i)$	0.706									

χ^2	41.10									
χ^2 (tab)	16.81									
t_i (test)	2.72	9.64	9.10	3.82	15.40	4.17	5.24	19.06	10.27	10.27
t_i (tab - 95%)	2.57									

The non-randomness of the coefficient of concordance C_k and the Spearman Rho (ρ) rank correlation coefficient were tested by applying χ^2 and student's criteria (t-distribution). The worked out values of $|\chi^2|$ and t_i are greater than the corresponding read out ones of χ^2_T and t_T leading to acceptance of hypotheses of non-randomness of expert concordance and hypotheses that there is correlation among experts opinions (ρ_i). After that Figure 36 was created to express the data from Table 18.

Figure 36 illustrates that an investigation of aircraft accident occurrence will most likely reveal the answers to questions regarding **where/when the accident happened** and **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.

Figure 36: Expert group opinion concerning the possibility of answering the general investigation questions.

As expected, the experts ranked significantly lower factors 13, 16, and 17 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 of questions **how/why the accident happened** and **what may have prevented the accident**.

The relatively low ranks of those factors indicate that despite the global efforts of the investigative agencies to improve air safety through independent investigation, it is evident that the investigation is not a perfect procedure. Moreover, the results of question 2 suggest that investigation enhancement can be achieved by improving the stages directly related to determination of causes of the accident.

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

Question 3

Questions 3, 4, and 5 refer to the factors 18-27 and examine them from different aspects within the framework of an investigation, which provides comprehensive outcomes about their condition. As a result of this, with respect to the question '*In reference to obtaining a better investigation outcome, how important is [the given item] within the process of aircraft accident investigation?*' the experts provided the group opinion presented in Table 20 and Figure 37.

Table 20: Expert group opinion with respect to question 3.

		Min	Max	Mean	σ
18	Managing the investigation (Plan, Report, Monitor)	7	10	8.6	1.02
19	Notification and arriving at the scene of the accident	8	10	8.6	0.80
20	Examination of the scene of the accident	9	10	9.3	0.46
21	Wreckage analysis	9	10	9.5	0.50
22	Finding and interviewing the witnesses	7	9	8.2	0.87
23	Investigation of Air Traffic Control records & Radar Data	8	10	8.8	0.87
24	Laboratory examination	8	9	8.7	0.46
25	Reconstruction	7	9	7.9	0.70
26	Report writing (Structure & Quality)	7	9	8.2	0.75
27	Data management	7	10	8.5	1.12

Table 21: Testing the non-randomness of C_k and the Spearman rank coefficient.

ρ_i	0.75	0.93	0.75	0.91	0.87	0.89	0.89	0.92	0.77	0.87
δ_i	1.01	2.00	1.00	1.90	1.66	1.78	1.77	1.96	1.14	1.66
$C_k(\rho_i)$	0.347									
$C_k(\delta_i)$	0.357									
χ^2	31.19									

χ^2 (tab)	21.67									
t_i (test)	4.84	19.95	4.81	15.65	10.09	12.30	11.96	17.85	5.48	10.04
t_i (tab - 95%)	2.31									

According to the Delphi procedure, the non-randomness of the coefficient of concordance C_k and the Spearman Rho (ρ) rank correlation coefficient were tested by applying χ^2 and student's criteria (t-distribution). Hence the calculated value of $|\chi^2|$ was greater than the table value of χ^2_T read out for 99% interval of confidence, as well as worked out values of t_i compare to the table value of t-distribution. This means that there was a consensus among expert opinions and the drawing of conclusions related to answers of question 3 could have started.

Figure 37 shows that experts highly ranked factors 18-27 with respect to their importance within an investigation. That is to say in the framework of an aircraft investigation process, experts said that all factors from the list are very important. Yet, experts emphasised the importance of **wreckage analysis** (21)²³ and **examination of the scene of accident** (20) allocating them ranks of 9.5 and 9.3 respectively. As less ranked factors within the list provided was the **reconstruction of an aircraft accident** (25) with a still high rank of 7.9, followed by **the report writing** (26) and **finding and interviewing the witnesses** (22) ranked with 8.2 each.

Figure 37: Expert group opinion concerning the importance of the stages of an aircraft accident investigation.

²³ These numbers refer to the factors given in Table 20

The analysis of Figure 37 points out that in terms of better investigation outcomes all factors from the list above are important. Moreover it underlines the importance of direct examination of wreckage and scene of the accident, which were also emphasised through the answers of question 2.

Question 4

As stated earlier, question 4 treated the same factors from 18 to 27, only in respect to complexity. The question 4 asked: '*How complex is [the given item] within the investigation process as to the requirement of special skills and technique by the examination team?*' The experts provided the group opinion shown in Table 22.

Table 22: Expert group opinion with respect to question 4.

		Min	Max	Mean	σ
18	Managing the investigation (Plan, Report, Monitor)	5	9	7.2	1.33
19	Notification and arriving at the scene of the accident	2	7	4.8	1.66
20	Examination of the scene of the accident	6	9	7.7	1.10
21	Wreckage analysis	7	9	8.3	0.78
22	Finding and interviewing the witnesses	5	8	6.5	1.02
23	Investigation of Air Traffic Control records & Radar Data	5	8	7	1.18
24	Laboratory examination	7	9	8.1	0.70
25	Reconstruction	8	10	8.9	0.70
26	Report writing (Structure & Quality)	4	8	6.4	1.50
27	Data management	6	8	7	0.89

Table 23: Testing the non-randomness of C_k and the Spearman rank coefficient.

ρ_i	0.94	0.85	0.76	0.86	0.91	0.86	0.95	0.97	0.94	0.89
δ_i	1.89	1.43	1.00	1.48	1.73	1.50	1.94	2.00	1.88	1.65
$C_k(\rho_i)$	0.572									
$C_k(\delta_i)$	0.585									
χ^2	51.49									
$\chi^2(\text{tab})$	21.67									
$t_i(\text{test})$	23.52	8.36	4.99	9.10	14.79	9.35	28.90	39.95	23.30	12.40
$t_i(\text{tab} - 95\%)$	2.31									

The non-randomness of the coefficient of concordance C_k and the Spearman Rho (ρ) rank correlation coefficient were tested by applying χ^2 and student's criteria (t-distribution). The worked out values of $|\chi^2|$ and t_i are greater than the corresponding values read out from the tables of χ^2 and t-distribution, which means that the hypothesis that non-randomness of

expert concordance is correct, as well as hypothesis of correlation among expert opinions. These results show that the results from Table 22 are scientifically accepted and conclusions can be drawn.

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** (25), **wreckage analysis** (21), and **laboratory examination** (24), ranked with 8.9, 8.3, and 8.1, respectively. On the other hand the **notification and arriving at the scene of accident** (19), as expected, was ranked as less complicated with a rank of 4.8 followed by **report writing** (26) and **finding and interviewing the witnesses** (22) with ranks of 6.4 and 6.5, respectively. Other factors on the list were ranked 7.

Figure 38: Expert group opinion on the complexity of the phases of an aircraft accident investigation.

In terms of ranking factors 18, 19 and 26, (**managing the investigation, notification and arriving at the scene of the accident and report writing**) Table 22 shows that dispersion of those answers has relatively high values of 1.33, 1.66, and 1.5, respectively. This refers to the need for further consideration of these factors with respect to the associated question. Experts ranked these factors (individually) very stable in the first and second round providing supportive arguments for these answers. Based on these results and also the fact of non-randomness of expert concordance and competency, this candidate concluded the survey procedure after the second round.

Question 5

In the first period, the Delphi technique mainly was used for forecasting future international situations and forecasting the scientific-technological development. Therefore by taking advantage of this feature, question 5 asked experts to express their opinion about the potential of further improvement of the investigation viewed across factors 18-27. Thus, with respect to the question ‘*Is there potential for further improvement of [the given item] within the aircraft accident investigation by applying the new methods and contemporary technology?*’, the experts provided the group opinion presented below.

Table 24: Expert group opinion with respect to question 5.

		Min	Max	Mean	σ
18	Managing the investigation (Plan, Report, Monitor)	3	4.5	3.8	0.56
19	Notification and arriving at the scene of the accident	2	4	2.9	0.70
20	Examination of the scene of the accident	2.5	4	3.3	0.51
21	Wreckage analysis	3	4.5	3.8	0.56
22	Finding and interviewing the witnesses	1.5	3	2.6	0.61
23	Investigation of Air Traffic Control records & Radar Data	2.5	4	3.2	0.56
24	Laboratory examination	3	4	3.4	0.49
25	Reconstruction	2.5	4	3.4	0.54
26	Report writing (Structure & Quality)	2	4	3	0.77
27	Data management	3	4	3.6	0.44

Table 25: Testing the non-randomness of C_k and the Spearman rank coefficient.

ρ_i	0.758	0.842	0.724	0.849	0.833	0.636	0.879	0.872	0.815	0.683
δ_i	1.50	1.85	1.36	1.88	1.81	1.00	2.00	1.97	1.74	1.19
$C_k(\rho_i)$	0.292									
$C_k(\delta_i)$	0.325									
χ^2	26.30									
$\chi^2(\text{tab})$	21.67									
$t_i(\text{test})$	5.05	8.18	4.30	8.62	7.70	3.03	10.96	10.29	6.88	3.62
$t_i(\text{tab } 95\%)$	2.31									

As shown, the non-randomness of the coefficient of concordance C_k and the Spearman Rho (ρ) rank correlation coefficient were tested by applying χ^2 and student's criteria (t-distribution). The worked out values of $|\chi^2|$ and t_i are greater than the values read out from the tables of χ^2 and t-distribution, which means that the hypothesis of non-randomness of expert concordance, as well as hypothesis of correlation among expert opinions are correct. As a

result of this Figure 39 was created, which points out the distribution of expert opinions related to question 5.

Figure 39 illustrates that experts ranked all factors higher than 2.5, which is 50% of the rank span available. In other words this means that 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** (18), **wreckage analysis** (21) and **data management** (27) with very high ranks of 3.8, 3.8, and 3.6, respectively, followed by **laboratory examination** (24) and **reconstruction** (25) with ranks of 3.4 each. As expected, the factors **finding and interviewing the witnesses** (22) and **notification and arriving at the scene of accident** (19) were ranked the lowest, although considered high at 2.6 and 2.9, respectively.

Figure 39: Expert group opinion concerning the potential for improvement of the stages of an aircraft accident investigation.

Answers to questions 3, 4 and 5 provide useful information about the investigation phases presented individually in Figures 37-39 and Tables 20-25. As those answers 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). Figure 40 and additionally Figure 41 provide a much better outlook of the data from questions 3, 4 and 5.

Overall, Figure 40 indicates that all factors 18-27 are located in the space with high ranks of the x, y, and z axis. In order to provide a better location of those ranks, those results were additionally resolved into three planes ('xy', 'xz', and 'yz' elevation) shown in Figure 41.

Figure 41 clearly illustrates the position of the expert group opinions of questions 3, 4, and 5, related to the factors 18-27. It can be seen that the most dominant position among all factors has the factor **wreckage analysis** (21), with the coordinates/ranks of (9.5, 8.3, and 3.8) followed by **laboratory examination** (24) and **reconstruction** (25), also with high ranks of (8.7, 8.1, 3.4) and (7.9, 8.9, 3.4), respectively.

Moreover, Figure 41 shows that the factors **managing the investigation** (18), **data management** (27), and **examination of the scene of the accident** (20) also have high rankings, but are a little lower than the above mentioned factors 21, 24, 25. We can also see that the factors **notification and arriving at the scene of the accident** (19), **finding and interviewing the witnesses** (22), and **report** (26) were ranked the lowest among all factors with (8.6, 4.8, 2.9), (8.2, 6.5, 2.5), (8.2, 6.4, 3), respectively.

The results of question 3, 4, 5, as a whole, point out that in order to obtain significant enhancement of the aircraft accident investigation process, interested parties must focus their efforts towards development of the three general factors of **wreckage analysis** (21), **laboratory examination** (24) and **reconstruction** (25).

Figure 40: 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)

Figure 41: 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)

Question 6

The next three questions 6, 7 and 8 are focused on the process of examination of wreckage and aircraft systems including examination of human and weather related factors within an aircraft accident investigation. Thus, with respect to the question ‘*How complex is the examination of [the given item] as to the requirement of special skills and technique by the examination team?*’ the experts provided the following group opinion.

Table 26: Expert group opinion with respect to question 6.

	Min	Max	Mean	σ
28 Operations, The Flight Path	7	9	7.9	0.83
29 Cockpit	7	10	8.4	1.20
30 Engine and accessories	7	10	8.3	1.10
31 Mechanical, electrical, hydraulic, pneumatic systems	7	10	8.4	1.11
32 Landing gear systems and brake systems	4	8	6.3	1.49
33 Deicing and anti-icing systems	4	9	6.7	1.85
34 Fuel (quality and amount)	3	9	6.3	2.19
35 Foreign Object Damage (FOD)	5	9	7	1.61
36 Cockpit Voice Recorder (CVR)	7	9	7.9	0.83
37 Cockpit Sound Recorder (CSR)	7	9	8.1	0.70
38 Flight Data Recorder (FDR)	7	9	8.1	0.70
39 Aircraft loading	3	9	6.4	2.20
40 Hydroplaning	6	9	7.5	1.20
41 In-flight explosion	8	10	9.2	0.75
42 In-flight failure (Structural failure–fatigue)	8	10	9	0.89
43 In-flight fire	6	10	8.2	1.54
44 Lightning	5	9	7.6	1.50
45 Mid-air collision	3	9	7.2	2.18
46 Crime activities	6	9	7.7	1.10
47 Weather conditions	7	9	7.8	0.75
48 Downwash and wing tip vortex hazards	7	9	8	0.77
49 Microburst, wind gust, wind shear	7	9	8	0.77
50 Stability and control of an airplane	7	10	8.1	1.22
51 Human error or omission	8	9	8.8	0.40
52 Psychological factors (fatigue, illusion, etc)	8	10	8.9	0.70
53 Design inadequacy	8	10	8.6	0.66

Table 27: Testing the non-randomness of C_k and the Spearman rank coefficient.

ρ_i	0.95	0.85	0.93	0.85	0.95	0.91	0.97	0.95	0.93	0.96
δ_i	1.85	1.00	1.65	1.00	1.82	1.52	2.00	1.84	1.63	1.86
$C_k(\rho_i)$	0.486									
$C_k(\delta_i)$	0.535									
χ^2	121.56									

χ^2 (tab)	44.31									
t_i (test)	51.88	15.35	33.68	15.41	48.15	27.38	85.13	50.38	32.54	53.66
t_i (tab 95%)	2.06									

The calculations derived according to equations 15 confirm the credibility of ranks provided by experts, which means that the value of $|\chi^2|$ is greater than the table value of χ^2_T read out for 99% interval of confidence and n-1 degree of freedom. Similarly the values of t_i were greater than the table value of t-distribution for n-2 degrees of freedom chosen for 95% interval of confidence. After reaching consensus among expert opinions, which was proven by statistical testing the coefficient of concordance C_k and the Spearmen Rho (ρ) rank correlation coefficient, Figure 42 was created.

Figure 42: Expert group opinion concerning the complexity of examination within an investigation.

According to Figure 42, examination of all factors 28-53 is complex and requires specialised skills by the examination team. Experts allocated maximum ranks to the factors **in-flight explosion** (41), **in-flight failure** (42), **psychological human factors** (52), **human error and omission** (51), and **design inadequacy** (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** (32), **fuel** (34), and **aircraft loading** (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.

From Table 26 it can be seen that there are high values of dispersion σ for the factors **landing gear and brake systems** (32), **de-icing and anti-icing systems** (33), **fuel** (34), **aircraft loading** (39), **in-flight fire** (43), **lightning** (44), and **mid-air collision** (45). This indicates that there is a considerable difference in expert opinions for these factors which deserve further attention. Considering this situation, this candidate, along with the other members of the working group, deduced that experts did not alter their original answers significantly from the first and second round providing supportive arguments for these rankings. Yet, the positive tests of non-randomness of expert concordance and competency for all questions was a satisfactory argument for this candidate in these circumstances to accept those rankings as final. It should be clarified that the current extreme answers did not significantly affect the mean of answers presented in Table 26.

Question 7

Table 28 presents the expert group answers to the question ‘*Is there potential for further improvement of examination of [the given item] within the aircraft accident investigation by applying new methods and contemporary technology?*’ related to the factors from 28 to 53.

Table 28: Expert group opinion with respect to question 7.

		Min	Max	Mean	σ
28	Operations, The Flight Path	3	4	3.4	0.49
29	Cockpit	2	4	3.25	0.68
30	Engine and accessories	2	4	3.3	0.78
31	Mechanical, electrical, hydraulic, pneumatic systems	2.5	4	3.7	0.55
32	Landing gear systems and brake systems	2	4	2.9	0.83
33	Deicing and anti-icing systems	2	4	2.9	0.83
34	Fuel (quality and amount)	1	3.5	2.2	0.95
35	Foreign Object Damage (FOD)	2	4	3	0.63
36	Cockpit Voice Recorder (CVR)	3	5	3.9	0.70
37	Cockpit Sound Recorder (CSR)	2.5	5	3.8	0.81
38	Flight Data Recorder (FDR)	3	5	3.8	0.75
39	Aircraft loading	2.5	4.5	3.3	0.71
40	Hydroplaning	2	4	3.1	0.83
41	In-flight explosion	2.5	5	3.8	0.95
42	In-flight failure (Structural failure–fatigue)	2.5	5	3.7	0.87
43	In-flight fire	3	5	3.5	0.67
44	Lightning	2	4	3	0.59
45	Mid-air collision	2	4	3.2	0.75
46	Crime activities	2.5	5	3.6	0.89

47	Weather conditions	2.5	4.5	3.6	0.62
48	Downwash and wing tip vortex hazards	3	5	3.6	0.80
49	Microburst, wind gust, wind shear	3	4	3.4	0.49
50	Stability and control of an airplane	2	4.5	3.3	0.78
51	Human error or omission	2.5	5	3.9	0.85
52	Psychological factors (fatigue, illusion, etc)	3	5	4	0.77
53	Design inadequacy	3	4.5	3.45	0.57

Table 29: Testing the non-randomness of C_k and the Spearman rank coefficient.

ρ_i	0.85	0.93	0.90	0.91	0.95	0.88	0.96	0.95	0.90	0.91
δ_i	1.00	1.72	1.46	1.59	1.94	1.30	2.00	1.94	1.46	1.56
$C_k(\rho_i)$	0.286									
$C_k(\delta_i)$	0.322									
χ^2	71.60									
$\chi^2(\text{tab})$	44.31									
$t_i(\text{test})$	14.56	32.13	22.61	26.45	48.76	18.97	56.40	48.91	22.50	25.54
$t_i(\text{tab } 95\%)$	2.06									

As stated earlier, the non-randomness of the coefficient of concordance C_k and the Spearman Rho (ρ) rank correlation coefficient were tested by applying χ^2 and student's criteria (t-distribution). The worked out values of $|\chi^2|$ and t_i are greater than the corresponding read out ones of χ^2_T and t_T leading to acceptance of a hypothesis of non-randomness of expert concordance, and the hypothesis that there is correlation among expert opinion (ρ_i). Accordingly Figure 43 was created.

Figure 43 presents the expert opinions on the potential for further improvement in the examination of the factors 28-53. Overall, experts ranked all factors (except the factor fuel examination) greater than 2.5, which is 50% of the rank span available. In contrast to Table 26 (refer to question 6), here all factors were ranked very stable by the experts thus creating small values of dispersion σ .

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** (52), **human error or omission** (51), **cockpit voice recorder** (36), **flight data recorder** (38), **in-flight explosion** (41), **cockpit sound recorder** (37), **in-flight failure** (42), respectively.

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

Figure 43: Expert group opinion concerning the potential for improvement of examination within an investigation.

In addition, Figure 44 combines the answers from questions 6 and 7 referring to factors 28-53. Figure 44 illustrates the mutual correlation of complexity ('complexity') and potential for improvement of examination ('improvement') of factors 28-53, plotted in 'xy' area, where 'x' axis is 'complexity' and 'y' axis is 'improvement'.

Figure 44: 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)

According to the location of factors in Figure 44, two different groups of factors with different features have been 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 are located most of factors 28-53 and among them the most distinguished are the following ones: **in-flight explosion** (41), **in-flight failure** 42, **psychological factors** (52), and **human error or omission** (51) with coordinates/ranks of (9.2, 3.8), (9, 3.7), (8.9, 4), (8.8, 3.9), respectively.

The second group is composed of the factors: **fuel** (34), **landing gear systems and brake systems** (32), **de-icing and anti-icing systems** (33), **foreign object damage** (35), **mid-air collision** (45), **aircraft loading** (39), ranked as follows: (6.3, 2.2), (6.3, 2.9), (6.7, 2.9), (7.2, 3), (6.4, 3.3), respectively.

The presented distribution from Figure 44 may indicate the prospective direction of improvement in the process of aircraft accident investigation. This analysis refers to factors with the highest ranks such as **in-flight explosion** (41), **in-flight failure** (42), **psychological factors** (52), and **human error or omission** (51).

Question 8

The next question ‘*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?*’, which may appear similar to question 6 (*How complex is the examination of [the given item]...*), considered the factors 54-74 from another, different aspect. The aim of this question was to provide more information about the examination of wreckage and aircraft systems, as well as examination of human and environmental factors. The group expert opinion is presented in Table 30 below.

Table 30: Expert group opinion with respect to question 8.

		Min	Max	Mean	σ
54	Engine malfunction	7	10	8.1	1.14
55	Brake systems malfunction	8	9	8.5	0.50
56	Landing gear systems malfunction	8	10	8.9	0.83
57	Icing	4	8	5.9	1.45
58	Foreign Object Damage (FOD)	6	8	7.3	0.78
59	Inappropriate fuel	6	10	7.6	1.43
60	Inappropriate aircraft loading	5	8	6.6	1.20
61	Hydroplaning	6	8	6.9	0.70

62	Downwash and wing tip vortex	3	7	5.3	1.42
63	Severe weather conditions	6	9	7.4	1.02
64	Microburst, wind gust, wind shear	6	8	7.1	0.83
65	Lightning	6	9	7.2	1.17
66	In-flight explosion	7	9	7.8	0.75
67	In-flight failure (Structural failure)	7	10	8.3	1.10
68	In-flight fire	7	10	8.1	1.14
69	Crime activities	5	7	6.1	0.54
70	Human error or omission	6	8	6.6	0.80
71	Psychological factors	4	7	5.4	0.80
72	Stability problems and lost the control of the airplane	5	8	6.6	1.02
73	Design inadequacy	6	8	6.8	0.87
74	Mid air collision	9	10	9.2	0.40

Table 31: Testing the non-randomness of C_k and the Spearman rank coefficient.

ρ_i	0.94	0.93	0.92	0.94	0.96	0.94	0.96	0.97	0.94	0.96
δ_i	1.45	1.19	1.00	1.27	1.87	1.34	1.84	2.00	1.32	1.89
$C_k(\rho_i)$	0.581									
$C_k(\delta_i)$	0.584									
χ^2	116.26									
$\chi^2(\text{tab})$	37.57									
$t_i(\text{test})$	37.55	30.91	27.39	32.75	56.53	34.50	55.13	67.36	34.03	57.86
$t_i(\text{tab } 95\%)$	2.09									

The non-randomness of the coefficient of concordance C_k and the Spearman Rho (ρ) rank correlation coefficient were tested by applying χ^2 and student's criteria (t-distribution). The worked out values of $|\chi^2|$ and t_i are greater than the corresponding values read out from the tables of χ^2 distribution and t-distribution, which means that the hypothesis of non-randomness of expert concordance is correct, as well as hypothesis of correlation among expert opinions. These results show that the results from Table 30 are scientifically accepted and conclusions can be drawn.

Figure 45 illustrates very tangible data revealing the items which are likely to be identified (determined) during an investigation as major causes of an accident, or otherwise, items that are very difficult to determine although they have a significant contribution to an accident occurrence.

Thus, experts ranked the factors **mid-air collision** (74), **landing gear systems malfunction** (56), **brake system malfunction** (55), with very high ranks of 9.2, 8.9, and 8.5, respectively, which show that these events are most likely to be recognised during an

investigation and examined properly. After that follows a group of factors such as **in flight failure** (67), **engine malfunction** (54), **in flight fire** (68), still highly ranked with 8.3, 8.1, and 8.1, respectively.

In the lowest ranked group are the factors: **downwash and wing tip vortex** (62), **psychological factors** (71), and **crime activities** (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.

Figure 45: Expert group opinion concerning the likelihood of verifying the causes of accident.

The ranks provided for questions 6, 7 and 8 can be combined and presented in a 3-D distribution format. Hence, in Figure 46 distribution of factors from 54 to 74 are shown (except 55) in the 3-D coordinate system of ‘improvement’, ‘complexity’, and ‘proving’ as ‘x’, ‘y’, ‘z’ axes. Figure 46 points out that all factors are located in the space with high values of x, y, and z coordinates/ranks. In order to provide a better outlook of factors, these results were plotted in three planes (‘xy’, ‘xz’, and ‘yz’ planes, respectively) shown in Figure 47.

Figure 47 clearly illustrates the position of expert group opinions related to factors 54-74. According to the location of these factors, several different groups of factors (with similar ranks) can be created as follows:

- Complex factors that have potential for further improvement but are very difficult to be determined through analysis. In this group are the factors **downwash and wing tip**

vortex (62), psychological factors (71), crime activities (69) and human error or omission (70) ranked with (3.6, 8, 5.3), (4, 8.9, 5.4), (3.6, 7.7, 6.1), and (3.9, 8.8, 6.6) , respectively.

- Complex factors with high ranks of improvement and proving. In this group are factors such as **in-flight failure (67), in-flight explosion (66), in-flight fire (68), engine malfunction (54)**, with ranks (3.7, 9, 8.3), (3.8, 9.2, 7.8), (3.5, 8.2, 8.1) and (3.3, 8.3, 8.1), respectively.
- Factors with moderately high ranks of improvement, complexity and proving. In this group there are a number of factors such as **foreign object damage (58), inappropriate aircraft loading (60), hydroplaning (61)** and others with ranks of (3, 7, 7.3), (3.3, 6.4, 6.6), (3.1, 7.5, 6.9), respectively.

Figure 46: 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)

The above analysis shows that experts with their answers again indicate a general potential for significant improvement in aircraft accident investigation. Accordingly, a prospective improvement in investigation can be expected particularly in the examination of human factors followed by examination of aircraft systems.

Figure 47.3-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)

Question 9

The last group of factors presents a collection of statements for which experts expressed their agreement or disagreement. Thus, to the question ‘*Do you agree with the statements below?*’ experts provided the following group opinion:

Table 32: Expert group opinion with respect to question 9.

		Min	Max	Mean	σ
75	The process of investigation meets the procedures regarding the quality assurance (QA) and quality control (QC)	5	8	7.2	0.98
76	It is justifiable waiting for a couple of months before releasing the accident investigation report	6	9	7.6	0.92
77	Reports of investigation carried out are always accurate and well done	5	8	6.5	1.20
78	Investigators have appropriate and sufficient skills to handle aircraft accident investigation	5	8	6.7	1.10
79	The excellent knowledge of theory compared to an average one significantly improves the investigation outcomes	7	9	8.1	0.83
80	The contamination of the scene of the accident is a serious problem within the process of aircraft accident investigations	5	9	7	1.41
81	The presence of landmarks on the scene of the accident provides sufficient information for carrying out accurate mathematical calculations	5	7	5.9	0.70
82	It is likely at times inconsistent material is sent for lab analysis	5	7	5.7	0.78
83	Investigators should believe witnesses of aircraft accident	3	6	4.8	1.25
84	The cockpit recorders (FDR, CVR, CDR) record sufficient parameters	2	8	5.5	2.11
85	We never have a real accident with enough readable data	2	5	4.1	1.22
86	The severe aircraft manoeuvres can be revealed during the investigation	4	9	6.9	1.70
87	The aircraft is equipped with appropriate accessories, which provides ice protection during the whole flight	4	8	6	1.34
88	The stall is a serious hazard for the aircraft	4	8	6	1.34
89	The downwash and wing tip vortex is a serious hazard for the aircraft	6	9	7.2	0.87
90	Investigators have enough resources available to find out the weather conditions during the accident	5	9	8	1.18
91	Human factors have been involved somehow in every single aircraft accident that has ever occurred	4	8	7.2	1.25

92	It is possible to answer the question if the pilot should have been able to cope with the critical situation	5	8	6.3	1.10
93	There are always problems with airfield papers analysis (documentation)	4	7	5.4	1.11
94	The handbook is well composed material	5	8	6.2	1.08
95	There is a great possibility for increasing the survivability of an aircraft accident	4	8	6.4	1.50
96	Determining the cause of the accidents is a very tough task if there is not data recorded	3	8	6.2	1.89
97	The process of investigation as a whole can be improved significantly, by applying new methods and advanced technology	5	9	7	1.34
98	The experience of the land traffic accident investigation can contribute to considerable increase in air traffic safety	5	8	6.2	1.25

Table 33: Testing the non-randomness of C_k and the Spearman rank coefficient.

ρ_i	0.96	0.96	0.96	0.94	0.96	0.94	0.97	0.95	0.93	0.95
δ_i	1.76	1.67	1.72	1.42	1.87	1.40	2.00	1.48	1.00	1.63
$C_k(\rho_i)$	0.427									
$C_k(\delta_i)$	0.416									
χ^2	98.29									
$\chi^2(\text{tab})$	41.64									
$t_i(\text{test})$	56.87	51.53	54.40	41.01	64.55	40.23	77.19	43.04	30.44	49.25
$t_i(\text{tab } 95\%)$	2.07									

The non-randomness of the coefficient of concordance C_k and the Spearman Rho (ρ) rank correlation coefficient were tested by applying χ^2 and student's criteria (t-distribution). The worked out values of $|\chi^2|$ and t_i are greater than the corresponding values read out from the tables of χ^2 distribution and t-distribution, which means that the hypothesis of non-randomness of expert concordance is correct, as well as hypothesis of correlation among expert opinions. As a result of this Figure 48 was created, which shows the distribution of expert opinion related to question 9.

The statements included in the questionnaire were carefully selected as an important part of this survey. However, the first impression is, 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. Experts firmly kept their opinions after the second round of the survey so that the high values of dispersion could not have been reduced through the feedback. The results remain scientifically acceptable, since the statistical tests of expert competency and

concordance justify the non-randomness of expert opinions. According to the results, several groups of factors were created, which include:

Figure 48: Expert group opinion concerning the statements 75-98.

- a) 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 (79) as well as determining that the **weather condition** during an accident is not a very tough task (90).
- b) Experts granted several factors with ranks between 7 and 8. These factors are (76), (91), (75), (89), (97) which state that:
 - ✓ Waiting for a couple of months before releasing the accident investigation report is justifiable (rank 7.6).
 - ✓ Human factors are involved somehow in every single aircraft accident (rank 7.2).
 - ✓ The process of investigation meets the high standards of quality assurance and quality control procedures (7.2).
 - ✓ The downwash and wing tip vortex are serious hazards for the aircraft (7.2).
 - ✓ The process of investigation as a whole can be improved significantly by applying new methods and advanced technology (7).

- c) The lowest ranks were allocated to factors 83, 85, 84, 93, 82 that state:
- ✓ Investigators should believe witnesses of aircraft accidents (rank 4.8).
 - ✓ We never have a real accident with enough readable data (4.1).
 - ✓ The cockpit recorders record sufficient parameters (5.5).
 - ✓ There are always problems with airfield papers analysis (5.4).
 - ✓ It is likely at times that inconsistent material is sent for lab analysis (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 if 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. And lastly, 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 another three issues that, along with other questions, reflect the entire procedure of aircraft accident investigation, as follows:

- ✚ Potential hazards for investigators within the process of investigation,
- ✚ The new definition and approach to aircraft accidents and investigations which has been widely accepted and which introduces more causes of an accident or assumes existing major and contributing factors, and,
- ✚ Prospective actions that could significantly improve the process of investigation.

Discussing the accident site safety precautions, investigators emphasise the risks of adverse terrain, adverse climatic conditions, biohazards, and airborne hazards. In particular, respondents state that the personnel involved in the recovery and examination of wreckage may be exposed to physical hazards including hazardous cargo, flammable or toxic materials, sharp or heavy objects, pressurised equipment and disease. Experts also addressed the risk of blood-borne pathogens including viruses, bacteria and parasites that are present in the blood, tissue of infected persons at an accident site, and, in particular, the hepatitis B and C virus and the human immunodeficiency virus (HIV) that causes AIDS. Respondents assessed those risks in a considerable aircraft accident with ranks from 5 to 7 out of 10.

In terms of the new definition of an accident which introduces more causes of an accident, stated below is one of the respondents' comments that incorporates the expert group opinion with respect to this question.

'The acceptance that multiple factors are involved in causing accidents has been a positive move in reducing the accident rate. Prior to the 'multi-causal factor' approach, it was common to focus on one particular factor and declare it as 'the cause'. This is a short-sighted approach as it ignores significant antecedent factors that led up to 'the cause'.

In practice, we conclude that the accident occurred because of factor X, but that factors A, B, C, and D, allowed factor X to exist and hence we suggest remedial actions to deal with all factors, in the hope that adoption of the remedial actions will lead to a more robust system.'

Last, but not least, the respondents provided a list of actions that may significantly enhance the outcome of an aircraft accident investigation. The following items were addressed: advanced application of simulators, more cameras installed in aircraft, using massive accident files, using more external experts and so on. However, experts said that the most significant improvement in investigation will be achieved by:

1. Creating and using the advance databases of an aircraft's components, structure, and systems, so that pieces can be readily identified.
2. Creating and using the advance databases for storing and analysing the data of aircraft accidents.
3. Video camera recording of various functions and aircraft zones and data transmitted to the ground stations and continually recorded.

Overall, by applying these actions (measures), experts ranked the prospective improvement in an aircraft accident investigation between 5 and 7 out of 10.

To conclude, it is clear that the Delphi exercise has provided very valuable information with respect to the aircraft accident investigation. Expert opinions have considered the process of investigation from many different aspects defining its current state and areas where significant improvements could be made.

To summarise, the above conclusions have also emphasised that increasing the amount of expert knowledge and experience available within an investigation will significantly enhance the aircraft accident investigation. Consequently, in order to obtain a better investigation outcome, the Delphi conclusions finally address the need for creating a tool which:

- ✚ Will include and contain specific knowledge and the analytical skills of a large number of experts, and
- ✚ Communicate the impact of a huge number of causal factors on air traffic safety.

The high level of safety achieved in scheduled airline operations lately should not obscure the fact that most of the accidents that occurred could have been prevented. This suggests that in many instances, the safety measures already in place may have been inadequate, circumvented or ignored.

INTERNATIONAL CIVIL AVIATION ORGANIZATION, *Accident Prevention Manual*.

Demonstration of Expert Systems to Aircraft Accident Investigation

The Delphi enquiry results, along with a literature review and the results obtained by analysing global aircraft accident statistics, have addressed the importance of several points about air accident outcomes:

- Every accident occurs as a result of a chain of errors, omissions, and/or malfunctions.
- Although all aircraft accidents are different, there are certain common elements in accident causes, and there are a number of causes which frequently result in accidents.
- Investigations by a lone investigator are difficult as 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.
- 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.
- Improving aircraft accident investigation could be achieved by creating and using advanced databases for storing and analysing the data of aircraft accidents.

These points lead to the conclusion that applying tools using the specific knowledge and skills of a large number of aviation experts could potentially improve the aircraft accident investigation process and help communicate the impact of a huge number of causal factors on

air traffic safety. This in turn addresses the need for creating such a tool in the form of a computer program which can use stored expert knowledge coupled with an inference engine to process this knowledge and provide safety event analysis to users of the program.²⁴

To summarise, the current conclusions suggest that the application of an advanced Expert System could significantly enhance investigation outcomes.

7.1 An Outline of Expert Systems

The most common form of an expert system is an interactive computer program that examines data stored and provides a problem solution following a set of predefined rules. Thus, an expert system involves two principal components: a problem dependent set of data stored known as knowledge data and a problem independent program known as the inference engine. Interaction between the user and the inference engine is performed via the user interface which asks questions and supplies the user's replies to the engine. Overall, an expert system uses knowledge in a form similar to human experts [147, 185].

In accordance with the theory of expert systems, there are two main problem-solving techniques when using inference rules: backwards and forward chaining. Forward chaining uses the data available and through an inference engine extracts more data until an optimal goal is reached. In contrast, backwards chaining starts with a list of goals or a hypothesis and works backwards to determine if there is data available to support the original statement.

Within an expert system, the specific knowledge that it contains forms the basis of the problem solving procedure, and the specific technique is the only tool to accomplish this. Thus the possession of expert knowledge is vital for the successful application of expert systems.

Expert systems are very successful in organisations that have an established level of experience and expertise available that cannot be easily transferred to other personnel. These systems are able to convey the intelligence and information derived from the experts to other personnel for problem-solving purposes. Within the application of expert systems, the amount of stored data is used to simulate the human reasoning process that experts pursue in analysing a problem and drawing conclusions.

Users of the program usually see an expert system through an interactive dialog. The dialog is composed of a set of questions whereby through complex feedbacks, conclusions are drawn. Dialogs are created from the current information and the content of the knowledge base. The expert system enquiry does not stop if users are unable to answer a particular question.

²⁴ This entirely refers to the definition of Expert Systems

In general, the knowledge basis of an expert system contains a large number of ‘if then’ type of clauses that gives the expert systems the ability to use them together to draw conclusions. The knowledge that is stored in the expert systems appears in the rulebase which is composed of four different types of objects [121, 185]:

- Classes – these are questions asked of the user,
- Parameters – A place holder for a character string that is inserted into a class question,
- Procedures,
- Rule nodes – the procedure of expert systems is based on a tree structure that aims to simulate the rules or logic within human reasoning. The nodes of these trees are called rule nodes.

The rulebase comprises many such trees. The top node of the tree is the goal node which contains the conclusion. The leaves of the tree are also referred to as rule nodes, which may be an evidence node, an external node, or a reference node. An evidence node asks a specific question of the user of the program who is instructed to answer ‘yes’, or ‘no’, as well as ‘maybe’ for certain questions.

Among the many different approaches available to classifying a huge amount of data is the widely used method of classification by decision tree induction. It constructs a tree in which internal nodes are split as a result of yes/no decisions (Figure 49).

Figure 49: Classification by decision tree induction.

Expert systems can be found within many areas, including accounting, medicine, process control, and financial services as they provide consistent answers for repetitive decisions, processes and tasks. However, the main disadvantage of expert systems is that they are not able to adapt as readily as human experts in unusual circumstances.

An example of an expert system is the Artificial Intelligence game ‘Q20’, by Radica Games. The Q20 plays a guessing game where the user thinks of an item and answers 20 questions about the item, after which Q20 attempts to guess what the item was.

Below is a sample Q20 set of questions and answers provided by the user for the unknown item ‘**Aeroplane**’. The device allows the user of the game to choose one of the following answers to questions asked: ‘Yes’, ‘No’, ‘Sometimes’, and ‘Unknown’.

Table 34: A list of 20 questions and answers provided by the user of the Q20 game with respect to the item ‘Aeroplane’.

Questions	Answers
Q1. Animal? Vegetable? Mineral? Other?	Other - Yes
Q2. Does it have buttons?	Yes
Q3. Is it smaller than a loaf of bread?	No
Q4. Would you give it as a gift?	No
Q5. Do most people use this daily?	No
Q6. Do you find it in the sky?	Yes
Q7. Does it bring joy to people?	Sometimes
Q8. Does it use electricity?	Yes
Q9. Can you use it with your friends?	No
Q10. Can it protect you from the rain?	Yes
Q11. Can you buy it?	Yes
Q12. Is it multicoloured?	Yes
Q13. Does it provide protection?	Yes
Q14. Can it be used for recreation?	Sometimes
Q15. Does it break if dropped?	Yes
Q16. Is it colourful?	Yes
Q17. Is it dangerous?	No
Q18. Does it usually have four corners?	No
Q19. Does it make sound?	Yes
Q20. Is it made of metal?	Yes

After the twentieth question the Q20 device offers the answer ‘A Jet’ that fits the unknown item ‘Aeroplane’ (Figure 50).

The interactive dialog and problem solving approach of the Q20 game was considered to be generally appropriate to the prospective application of expert systems to aircraft accident investigation, particularly in determining the probable causes of accidents. Thus, the user of the program will be asked a number of questions related to the condition of wreckage, accident site

and other circumstances relevant to an accident/incident event. According to the answers entered by the user, the program will narrow down the choices to the most probable major cause of this particular event.

Figure 50: The answer 'A Jet' provided by the Q20 after the 20th question.

As a result of this, the next stage of this research was to demonstrate the application of an expert system to aircraft accident investigation, which meant creating a computer program that would be able to facilitate the process of determining the causes of aircraft accidents.

7.2 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.

Figure 51: Front page of the application GP1020.

The user of this program is asked several questions related to an accident/incident event (in simulated or real circumstances), based on which the program determines the most probable causes of this particular event. Depending on the user input, the number of questions before finishing the procedure can vary significantly.

GP1020 includes two major features:

- 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, and
- Being a simple and efficient IT solution in determining the probable causes of an aircraft accident occurrence mainly based on stored expert knowledge.

7.2.1 Forensic Approach to an Aircraft Accident/Incident Occurrence within GP1020

The procedure of a GP1020 accident enquiry follows the steps of a real investigation of an accident/incident occurrence. That is to say, GP1020 intends, via answering its questions, virtually to convey the user of the program to an investigation scenario.

GP1020 asks a broad range of questions relating to the factual information and analysis undertaken of a safety event. The user's answers to the factual-information questions are expected to derive the data below that is usually covered in an accident report:

- History of flight	- Aerodrome information
- Injuries to persons	- Flight recorders
- Damage to aircraft and other damages	- Wreckage and impact information
- Personal information	- Medical and pathological information
- Aircraft information	- Fire
- Meteorological information	- Survival aspects
- Aids to navigation	- Organisational and management information
- Communications	- Human factors and crew resource management training, and so on.

At the initial stages of data collection the GP1020 program intends to learn general information about an accident/incident event. This in turn expresses the stage of notification of the 'Go Time' of a safety occurrence and the phase of preparing for dispatching to an accident site. These questions are common for every accident investigation regardless of the event type

and its consequences and thus form the basis of the accident/incident determination process. In this list are questions relating to the following aspects of an accident/incident event:

- Event type (accident, incident, occurrence)
- Aircraft type and category (airplane, rotorcraft, glider, etc)
- Aircraft (make, model)
- Type of flying (scheduled air carrier, ferry, flight test, air taxi, etc)
- Event local time
- Event highest injury
- Mid air (yes, no)
- Aircraft missing (yes, no)
- Witnesses (yes, no)
- Condition of accident site and so on.

In a real occurrence the investigators would be advised about other circumstances of the event that are important in a given stage of the investigation. Consequently, GP1020 will ask the user if the accident/incident occurred at an airport, at departure or destination city and other similar questions.

The next set of questions moves the user (investigator) to the accident site. Thus, GP1020 initially asks for the phase as well as specific phase of flight in which the accident/incident occurred. In addition, there are questions which intend to ascertain any problems experienced by aircraft reported to Air Traffic Control by crew or witnesses of the accident (lift, thrust, flight control problems and so on).

After that the GP1020 program may ask whether the aircraft was flown in visual or instrument meteorological conditions and if the plane was fitted with an FDR or other recording devices. Questions about the aircraft load data and centre of gravity might also be asked.

In a real incident/accident investigation, determining the weather conditions is generally an important issue. Similarly within GP1020 there are a number of questions relating to weather conditions such as visibility, sky condition, and the intensity of precipitation experienced during the accident.

After collecting the general information of a safety event, investigators usually relocate to the accident site for the purpose of examining the wreckage and defining the landmarks of the scene of accident. Similarly, within GP1020 there is a set of questions relating to the following data:

- Aircraft damage (none, minor, substantial, destroyed)

- Wreckage distribution
- Witness location
- Probable flight path
- Approximate altitude on impact in relation to horizon
- Stopping distance after principle impact
- On ground collision (no, yes)
- Collision with other obstacles on the ground
- Obstacles struck before principle impact (wire, tree, building, fence, and so on)
- Occurrence of fire or explosion occurred (nil, in flight, on ground)²⁵.

GP1020 includes a number of questions that aim to examine injuries to passengers and crew just as investigators do. This includes defining and determining the cause of injuries. Thus GP1020 will ask for information about the injury category, injury level, injured person count, crew injury level and so on. With fatalities the cause of death and toxicology test results are also examined.

7.2.1.1 GP1020 Enquiry of Human, Aircraft, and Weather Induced Causal Factors

After collecting all the general information needed about the critical flight and accident site, GP1020 focuses on determining the causes of the accident/incident event. Thus, using a number of questions, GP1020 examines the human, aircraft, and weather induced causal factors.

With respect to human factors there are a set of questions exploring the following major aspects:

- Flight crew data	- Air traffic management system
- Maintenance performed	- Actions undertaken by flight crew during the accident.
- Environmental aspects	

Regarding the flight crew, the program may ask for data related to crew categories and experience including any special experience, the validity of the crew members' medical certificate, and if they were wearing corrective spectacles. In addition, maintenance issues are covered by questions that look at potentially harmful maintenance or inadequate maintenance procedures and plans. The environmental aspect is examined by questions that check if inaccurate forecasts of hazardous environmental conditions, failures to report hazardous

²⁵ In this part of the GP1020 software there are a number of questions that originate from the 'Accident Investigation Sheet' [82], used by CASA (Civil Aviation Safety Authority Australia).

conditions, or inappropriate responses to actual hazardous conditions were carried out. In terms of the air traffic management system, GP1020 investigates the procedures and navigation aids through the questions related to clearance delivery, ground control guidance, tower operations, approach, and departure control.

Just like real investigators, GP1020 considers the actions undertaken by the flight crew such as the in-flight shutdown of one or more engines, delayed departure, rejected takeoff, dumping fuel, air turn back, ditching, go around, forced landing, and taking evasive action.

Overall, GP1020, by asking a number of questions 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 judgement, improper use of equipment, alcohol or other drug use, improper maintenance, improper aircraft modifications, and inadequate procedures.

Analysing the aircraft and its systems is the next task of GP1020. A number of questions are included within the program, all of which are designed to examine the aircraft systems condition and assess the involvement of those factors as possible cause(s) for an accident/incident. Among them the most frequently asked are questions relating to:

- Wreckage and its systems condition,
- Possible breaking of aircraft limits such as airspeed, power, oil pressure, oil temperature, cylinder, fuel flow and so on,
- Weight and centre of gravity limits,
- Readings of instruments within the emergency procedures carried out (engine failure, smoke and fire, fuel system failure, electrical system generator failure and other).

Like a real investigation, the initial questions from this set correspond to wreckage, systems, wings, and engine condition; namely, the program learns the condition of the fuselage, airframe cockpit components as well as flight control, electrical, hydraulic, landing gear, and other systems. Wings, as a very important part of the investigation, are examined by analysing their controls, condition, and position of wings, flaps ailerons, horizontal stabiliser, elevators, vertical fin, and rudder.

Engine condition is expressed through questions including those about the propellers, power plants, accessories, controls systems, lubrication systems, fuel systems, transmissions, engine controls, and fuel. Special attention is given to the readings of engine components such

as the throttle, power, and thrust levers, propeller, ignition and ignite-switches, tachometer (engines), cylinder head temperature, oil pressure, and oil temperature.

Aircraft accident statistics indicate that a number of accidents have occurred due to failure or misuse of the de-icer equipment. Hence, GP1020 contains a set of questions that look at the condition of this equipment as a possible cause of the accident including propeller de-icers, wing de-icers, windshield de-icers, windshield wipers, fuel tank and other de-icers.

Another set of GP1020 questions looks at the condition and readings of flight instruments including the altimeter, airspeed indicator, attitude indicator, directional gyro, rate of climb, autopilot, and stall warning indicator. Here there are also questions about the battery master switch, landing light, navigation light, instrument light, radio master switch, anti collision light, and the instrument reading (altimeter, airspeed). As investigators do, GP1020 will ask for information about aircraft history such as the number of flight hours and landings, as well as occurrence reports, and official recommendations.

The aircraft question set also examines the likelihood of events occurring such as depressurisation, fuselage shell opening, uncommanded actuation or aircraft systems or controls, oxygen system problems, hazardous cargo, air conditioning and pressurization problems, pneumatic system malfunctions, hydraulic system malfunctions, electrical system malfunctions, fuel system problems, exceeding 'g' limits, and the separation of parts in flight.

In terms of facility problems, GP1020 also has a set of questions that investigate other issues such as possible airfield obstacles, inadequate braking because of runway contamination, poor lighting, and malfunctions of air traffic control equipment.

After collecting the data relating to the aircraft involved in the accident, GP1020 may ask several more questions designed to consider in detail the weather conditions during the accident. The program will ask for the source of the weather information (pilot, witness, weather observation facility) and weather briefing completeness. Next, it learns whether the aircraft experienced events like air turbulence, bird strike, volcanic ash, and dust.

Within GP1020 there are also questions that ask for the event temperature, dew point, as well as sky condition (lowest ceiling, cloud condition, non-ceiling height). Several questions are directly focused on wind attributes such as direction, speed, velocity, and gust indicators.

If the user of GP1020 answers that the aircraft involved in an accident was fitted with data recorders, then the program would generally ask a broad range of questions that are essential in every investigation. The first group of those questions are related to the master warning, air/ground sensor & ground proximity warning system, traffic alert and collision avoidance system, and engine warnings (vibration, over temperature, oil pressure low, over speed, yaw and

roll trim surface position). The next group asks about the automatic flight control system modes and engagement status including auto-throttle, glide-slope deviation, icing, windshear, loss of cabin pressure, computer failure, selected barometric setting, selected altitude, speed, vertical speed, heading, flight path, temperature, wind speed and direction, normal/longitudinal/lateral acceleration, and thrust reverser position on each. In addition the program asks about details including the cockpit trim control input position (pitch, roll, and yaw), pitch/lateral control input, pitch trim surface position, trailing edge flap or cockpit flap control selection, leading edge flap or cockpit flap control selection, angle of attack, landing gear position or landing gear cockpit control selection, ground spoiler position and speed brake selection.

Determining the causes of an aircraft accident is a complex process including a number of areas, all of which have been represented through the variety of GP1020 questions. Symptoms can significantly facilitate the investigation process; therefore, GP1020 also considers them by a set of questions, including questions related to visual symptoms such as instrument indication, warning or advisory lights, observations of smoke, fire, or other abnormal condition, followed by aural, tactile and olfactory symptoms. Aural symptoms are covered by questions of possible activation of horns, bells and verbal warnings (central warning system), whereas tactile ones refer to control forces, head, cold, pressure change, electrical shock, and vibration [146].

It must be noted that mainly because of a lack of expert knowledge stored within the program the GP1020 prototype is currently unable to ask a number of the questions mentioned above. This limitation is discussed in Chapter 8.

7.2.1.2 Classification of the Causes of Aircraft Accidents within GP1020

As stated above, GP1020 asks 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 the set of most appropriate questions in order to determine the causes of the 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.

In accordance with GP1020's approach to determining the causes of an accident/incident, the causal factors within GP1020 are stored and available to the program in several different ways.²⁶ First of all, the contributory factors are sorted within the three well-

²⁶ As addressed earlier, detecting similarities between accidents is one of the biggest concerns among investigators in order to prevent future similar reoccurrences. One of the most convenient ways is through classification. [137]

known causal factors, namely human, design and manufacturing factors, as well as environmental factors. These factors include [146]:

- Human factors: errors of flight crew, errors of air traffic control, errors of maintenance and dispatch, and crime & terrorism.
- Design and manufacturing factors: airplane (airplane failure, airplane systems failure, and propulsion systems failure), ground support (air traffic control systems failure and maintenance facilities and equipment failure).
- Environmental factor including severe weather conditions.

Secondly, for the purposes of GP1020, the causes of accidents are additionally sorted in accordance with the nature of accidents [11]:

- Taxiing accidents	- Fires while midair
- Takeoff accidents	- Forced landings
- Collisions	- Landing
- Tail spins (following engine failure, without engine failure)	- Other accidents

In the taxiing accidents group are listed the causes that can occur while the aircraft is moving under its own power on land. In the takeoff group are listed all causes that can occur during the takeoff, and in the landing group all causes that can occur during landing. Causes of collision accidents include a list of causal events which can lead to collisions with other aircraft or objects while the colliding aircraft is at flying speed. The tailspins accidents group are sorted into causes that can result in spins, stalls, and collisions with the earth while the airplane is out of control. Causes of fire in the air group present a collection of events that can lead to a fire while the aircraft is in flight. In the forced landing group are listed all causes that can create engine trouble and any defects of aircraft systems that will lead to an emergency landing. In the other accidents group are located the causes that are not included in the other groups.

Finally, the list of all possible causes of accidents within GP1020 is classified according to problems that may be experienced during the accident as follows [146]

- Lift problems	- Smoke, fire and fumes
- Thrust problems	- Explosion
- Flight control problems	- Collision
- Weather and environmentally induced problem	- Other problems

In the lift problems group are stored causes that can result in loss of lifting surfaces, contaminated lifting surfaces, emergency extension, improper configuration of slats, flaps, etc. The causes of thrust problems present events that can lead to thrust problems such as in-flight engine shutdowns, failure or asymmetric thrust reversers, inadvertent thrust reverser deployment in flight, inadvertent thrust reverser, engine flameout, engine fire warning, engine separation, high exhaust gas temperature, engine stab or surge, engine power loss, multiple engine failure, foreign object damage to engine, and engine over-speed.

Causes of the flight control problem are focused on gross weight and center of gravity problems, jammed or locked controls, aircraft stall, instrument error or false indications, wake turbulence, vibrations caused by structural failures, improper actions by the pilot or autopilot, uncommanded actuation of control surfaces, and adverse weather. The weather induced problems group includes all environmental causes for accidents such as ice formation, ice shedding, turbulence, lightning strike and/or static discharge, thunderstorms, wind shear, microburst, and all forms of precipitation. The fire and explosion problems group lists the events that can cause fire and explosions while the aircraft is midflight. In the collisions problems group are causes such as impacting birds, engines, terrain, and foreign objects in flight.

This approach of multiple classifications of causes of accidents within GP1020 allows the creation of a huge and flexible database appropriate for a quick across search. Thus through the interactive dialog of questions and answers provided by the user, GP1020 is able to determine the chain of events as well as the factors and causes that led to this occurrence.

As stated earlier, when GP1020 matches a significant amount of evidence by asking a range of different questions, it finishes the procedure and indicates the consistent causes as possible causes for this particular accident/incident event. During this process, a large ' $m \times n$ ' matrix has been created, where ' m ' represents the number of all possible causes²⁷ of the accident (rows of the matrix) and ' n ' represents the number of different portions of evidence (including findings, parameters and evidence) that may be recovered during an investigation (columns of the matrix). (An example of such a matrix is presented in Table 35; data is randomly chosen).

²⁷ It is clear that the author's intention of providing an entire list of all possible causes (as mention above) 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 Chapter 8 when discussing limitations and the future work of the GP1020 prototype.

Table 35: A list of possible causes of accident versus their distinguishing features.

			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

The original matrix (for instance the first table of Figure 52) is then converted into another format (the second table of Figure 52), which is appropriate to the needs of the GP1020 program²⁸.

	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

Figure 52: Conversion of the original matrix into GP1020 format.

C1, C2 ... C8 - an assumed list of 8 possible causes of accident

E1, E2 ... E6 - consistent portions of evidence (randomly chosen) to the above causes

The second table of Figure 52 shows how GP1020 may ask the user questions in order to determine the causes of the accident/incident. Each column of the matrix, which represents a different portion of evidence, must be associated with a question. This means that GP1020 is composed of a large number of questions similar to the number of distinguishing features of all possible causes of accidents. Thus, GP1020 asks questions and depending on answers provided

²⁸ The same approach of conversion of the original matrix is performed in the procedure of the Quantification Method III used for multidimensional analysis of incident reports and human factors involved in those occurrences [142, p.238].

by the user, the program narrows down the choices to the most probable causes of this particular accident/incident.

For instance (in the case presented in Figure 52) 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 the 'Cause 4' (C4) 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, and so on.

7.2.1.3 Expert knowledge stored in GP1020

As discussed previously, the first condition for the successful application of an expert system in any scientific field is the amount of specific expert knowledge stored. Therefore, providing and storing expert knowledge of aircraft accident investigations within GP1020 was the first goal of this part of the research. The GP1020 program must be supplied with a database of all possible causes for accidents/incidents as well as evidence whereby those causes could be revealed. While this candidate was attempting to solve this task, the following conclusions emerged:

- Creating a comprehensive database of causes of accidents and their distinguishing features is far beyond an individual's or a small group's capacity, therefore
- The efforts of providing GP1020 with expert knowledge must be focused on International Civil Aviation Organization (ICAO), and the main national agencies for transport safety investigations worldwide such as ATSB, and NTSB as credible sources of expert knowledge.

After considering the above conclusions in detail this candidate was certain that the NTSB aviation accident database as stored expert knowledge is an appropriate resource available for accomplishing the task of creating an expert system for aircraft accident investigation²⁹. The NTSB aviation accident database is available on the NTSB's web site (<ftp://www.nts.gov/avdata/>), which contains highly classified and downloadable datasets of more than 140,000 aviation accidents. The computerised 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

²⁹[184, p.8, 168] states that the NTSB has computerised summaries of over 90% of the accidents in the United States in 'brief format' reports. Reports list the factors (findings) and the number of the factors that are considered to be causal. These reports as well as FAA files (Accident/Incident files and the Service Difficulty Report files) are accessible and **potentially valuable to the aircraft accident investigators and researchers.**

probable cause modifier codes, 52 probable cause person codes. This code system indicates how thoroughly the accidents are classified thus making the resource a potentially great base of expert knowledge for the GP1020 program.

For the purposes of GP1020, these causes of accidents are additionally rearranged with respect to type (nature) of accidents and problems experienced during the accident (as discussed above). Because of this, in the application of GP1020 there are a number of questions that are similar to each other or even overlapping in scope, but this is the only way to investigate thoroughly a safety event and determine the causes of accidents/incidents.

7.3 GP1020 Prototype

Reiterating the aim of this software, what was essentially wanted was a program that could effectively compare and analyse the causes and factors of an immense number of previous aviation incidents and accidents in order to predict and prevent future accidents or to hasten air crash investigation efforts.

As indicated by some of the data requirements previously shown, 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. In other words, 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. It was expected that by proving the capability of the fundamental mechanisms of the basic components, they could be further developed to handle some of the more complex codes/instructions at a later date.

The following sections contain a summary of discussion regarding the initial needs, development, results, limitations and recommendations, for each component of the program. More detailed information regarding the use of the program can be found in Section 7.3.5.

7.3.1 Programming Software

The use of Excel to develop this software turned out to be the most appropriate choice for GP1020. It had 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 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. In the following sections, emphasis has been placed on what occurred due to the presence of these limitations as well as what could occur if they were absent. It should be noted that while these limitations often caused significant changes in intended performance and capability, the usefulness of Excel in developing the fundamental logic, as well as its inherent ability to be easily transferred to other programming languages, often outweighed using any other programming software.

7.3.2 Knowledge Base

Originally it was hoped to develop a program that could interface with raw historical data and be ready for questions moments after the integration. However, given the varying types of classifications that different air safety organisations use, 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. For instance, in the records of the NTSB each investigation that had taken place had their generic data recorded simply in classifications by type, however the most important data to the program (namely causes, factors and sequences of events) had been recorded in a rather particular fashion. First, occurrences were recorded with the specific phase they had occurred in, with position determined by their chronological order in the sequence of events. Second, each occurrence had its own sequence of events made up of subjects and their associated subject modifiers. Each individual flight phase, occurrence, subject and subject modifier had a numeric code to describe it (i.e. "500" = "Standing", "140" = "Decompression", "10400" = "Landing Gear", "1104" = "Bent"). The historical records carrying this data were in a format that separated flight phase and occurrence events from their associated subjects and subject modifiers. This form, while great for searches and queries, would require significant computing time to handle the comparative programming within GP1020.

The simplest, and therefore currently 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. Thus with the NTSB records previously mentioned, the

generic data would simply be transplanted or copied into the table with column titles indicating the classification types. However, details that have to be pieced together from multiple sources need to be constructed prior to interaction with the inference engine. In practical terms, the sequence of events as described by the occurrences and their associated flight phases, and subjects and their modifiers, all had to be converted into a single string of variables to represent the entire sequence of events.

As this prototype is fairly basic, the only historical data that was really needed to create a fundamental program was some generic information to easily identify the case (essentially, who was flying what, where, when, and where to?) as well as the causes and factors pertaining to the case (as defined by the case's combined sequence of events, occurrences, flight phases, subjects and modifiers). The initial preprocessing spreadsheet contained formulae and other extraction methods to create a sufficiently detailed table as defined above including the single string of characters representing the combined sequence of events.

	B	C	D	E	F	N	O	P
1						Occurrences		
2	ev_id	ev_date	ev_city	ev_state	ev_country		1	2
3	20001218X45445	3/10/1982	KENNER	LA	USA	-430-522-		
4	20020909X01558	1/01/1982	TUSKEGEE	AL	USA	-230-571-		
5	20020909X01559	1/01/1982	HOBBS	NM	USA	-390-564-220-564-190-572-		
6	20020909X01560	1/01/1982	JACKSONVILLE	FL	USA	-352-541-220-560-		
7	20020909X01561	1/01/1982	EAST HANOVER	NJ	USA	-340-572-320-572-		
8	20020909X01562	1/01/1982	PULLMAN	WA	USA	-340-520-320-520-		
9	20020917X01623	10/01/1982	QUINHAGAK	AK	USA	-240-541-230-551-300-572-		
10	20020917X01624	17/01/1982	ANCHORAGE	AK	USA	-240-522-250-522-220-522-		
11	20020917X01625	15/01/1982	NEAR NUIQSUT	AK	USA	-320-572-		
12	20020917X01626	21/01/1982	PORT GRAHAM	AK	USA	-230-571-		
13	20020917X01627	9/02/1982	FORT YUKON	AK	USA	-320-512-		
14	20020917X01628	19/01/1982	TUNTUTULIAK	AK	USA	-260-521-320-520-		
15	20020917X01629	20/02/1982	N CAPE YAKATAGA	AK	USA	-350-541-150-571-		
16	20020917X01630	26/02/1982	BETHEL	AK	USA	-191-513-		
17	20020917X01631	3/03/1982	POORMAN	AK	USA	-260-572-320-572-		
18	20020917X01632	2/03/1982	NEAR GULKANA	AK	USA	-300-600-		
19	20020917X01633	5/03/1982	ANCHORAGE	AK	USA	-200-571-250-570-230-570-310-572-		
20	20020917X01634	10/03/1982	MCGRATH	AK	USA	-230-522-		
21	20020917X01635	13/03/1982	WILLOW	AK	USA	-250-563-230-565-		
22	20020917X01636	16/03/1982	DELTA JUNCTION	AK	USA	-230-540-		
23	20020917X01637	27/03/1982	ANCHORAGE	AK	USA	-230-571-		
24	20020917X01638	28/03/1982	WULIK RIVER STR	AK	USA	-390-564-230-571-191-571-		
25	20020917X01639	3/04/1982	KENAI	AK	USA	-260-572-320-572-		
26	20020917X01640	5/04/1982	JUNEAU	AK	USA	-351-564-180-571-220-571-300-571-		
27	20020917X01641	8/04/1982	AKIACHAK	AK	USA	-340-520-191-520-		
28	20020917X01642	9/04/1982	NEAR NIGHTMUTE	AK	USA	-240-541-230-582-		
29	20020917X01643	11/04/1982	MONTAGUE ISLAND	AK	USA	-230-520-		
30	20020917X01644	29/04/1982	NEW STUYAHOK	AK	USA	-220-522-		
31	20020917X01645	17/01/1982	TULUKSAK	AK	USA	-230-570-		
32	20020917X01646	25/01/1982	BETHFI	AK	USA	-240-540-250-540-230-553-		

Figure 53: GP1020 Prototype – Current Knowledge Base – General Detail Vs Occurrences.

Using the spreadsheet was simple; place the relevant tables in their respective places and the spreadsheet calculated the result. Unfortunately the entire process took over 1.5 hours

to format a single years worth of historical data for use with the inference engine. As the creation of this software was the first test of Excel's calculation speed, this result indicated the need for verification of program data requirements in order to reduce the spreadsheet's formatting time. Thus, development of the inference engine occurred with only one year's worth of data to guide it. After various tests of the engine utilising the knowledge base it was shown that only the generic data, occurrences and associated flight phases were required to effectively demonstrate the program. The subjects and subject modifiers could have been used but the number of designations in the two types was so much that effective demonstration of the program was not possible. However, by that time the effectiveness of the program was already fairly obvious and while inputting additional information from other years may have increased its scope somewhat, the corresponding percentage increase in information would have come at an equivalent increase in computation time for the inference engine (i.e. adding another year's worth of data would have doubled computation time, two years would have tripled it). Doing so would decrease the program's demonstration potential so putting in additional years worth of data was avoided.

In the future, when the program's operating environment is known, the inefficiencies of Excel should be largely reduced when the fundamental logic in the knowledge base's preprocessing is transferred or altered to suit the environment's chosen operating system or program. 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.

7.3.3 User Interface

In terms of the development timeline the creation of the user interface was the last to be initiated. As a fundamental program, only the basics were required; 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 investigated. It would have been a very large task had not the NTSB 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, so the user interface only had to interact with the inference engine in terms of inputting answers and displaying results. An in-depth graphical explanation for the use of the user interface can be found in Section 7.3.5.

The decision to show multiple similar cases as opposed to showing only the most similar case was a product of practicality from two perspectives: the user and the program developer. 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.³⁰ 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 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 are available to the user, the better off the user should be. The amount shown should only be limited by the speed with which the user can assess previous investigation records. The decision to show the top 20 cases was just to improve the effective demonstration of the program and may have to be altered (or at least have the option to be altered) at a later date to improve functionality.³¹

The details shown in the 20 most similar cases are its event ID (a unique numeric code designation for the incident/accident), date, aircraft make, operator's name, departure location and destination location. These details effectively tell who was flying what where when and where to. 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. Obviously the greater this is the better, however with the possibility to give negative ("something did not happen") or null ("I do not know") answers, the determination of a suitable common (between different investigations) percentage, at which questioning can cease, is not possible. Instead, what Level of Relevancy aims to give is the variation in relevancy between the top 20 or so cases; this variation effectively determines whether or not a case should be considered as useful research. For instance, among a pool of thousands of case records, prior to the 10th question answered, the displayed cases usually would share the same Level of Relevancy, suggesting that all of those cases were equally relevant to the case being investigated. However between the 10th and 15th question answered a

³⁰ This is reminiscent of Automated Fingerprint Identification Systems (AFIS), which are used by law enforcement agencies for criminal identification initiatives (for more details please refer to Section 7.4)

³¹ **This is an important feature of GP1020** because it does not exclude the cases which are missing portions of evidence in later considerations. This is important due to the fact that in massive accidents some evidence cannot be recovered during the investigation, though it may have probably occurred.

single case would begin to have a level of relevancy that would be noticeably higher than the rest. Given more questions, more cases begin to be noticeably more relevant than the mainstream. While the appearance of these noticeably more relevant cases is subject to the unlikeliness of the events within the user's investigation, it still is an effective indicator for the point at which questioning can cease.

Perhaps the aspect of the user interface that will require the most work in the future is its linguistics capability, or ability to ask questions. In the current program, the numeric designations and their English interpretation were used with a fairly simple "Did a <insert English interpretation of occurrence numeric designation> happen?" command to represent the questions regarding occurrences or "Did anything happen during <insert English interpretation of flight phase numeric designation >?" for queries regarding flight phase. Future variations of this portion of the interface will probably have to allow for possible explanations of the questions asked. At the very least, the English interpretations will have to be corrected for grammar when using the above commands.

7.3.4 Inference Engine

When discussing the inference engine, the entire capability of the program is dependent on its ability to use causes and factors determined in previous investigations to predict future investigations. So 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. As a fairly simple analogy, if someone were to state that a plane had a damaged wing, it would be fair to assume the plane had experienced an in air or on ground collision of some sort. Previous experience would have suggested such. If later evidence found that there were excessive bird sightings on the runway used by the plane, the likelihood of a collision becomes even more likely. If however, evidence found that maintenance had recklessly used inappropriate equipment to handle the wing thereby damaging it in the process, then the likelihood of a collision becomes less likely. Discussion in this section from here on prominently features the development of methods of statistical analysis that would effectively and accurately replicate such logic.

Basically the main concept to be used in the program is that causes and factors have relationships that can be defined by verifiable statistics. However, it is important to remember that the only distinction between causes and factors in terms of investigation is as a starting point for the sequence of events. Considering that factors can become causes under different situations, the distinction becomes a nominal one, and it was considered appropriate, especially

for the experimental development of this prototype, that when determining the sequence of events that there would be no active distinction between the two. Rewriting the main concept, unanticipated events that affect an aircraft often have statistically verifiable causative relationships with other unanticipated events.

Microsoft Excel - P-ESSV7.xls

File Edit View Insert Format Tools Data Window Help

Type a question for help

Q784

N	AO	AP	AQ	AR	AS	AT	AU	AV
Occurrences	Score	Rank	Rank	Queried Event	*140*	*540*	*230*	*571*
	Score	Agg	Stnd	Multiplier	1	1	-1	1
1	0	1400	1400					
2	0	1401	1400				-1	1
3	0	1402	1400					
4	2	154	154					
5	-1	2525	2525					
6	0	1403	1400					
7	-1	2526	2525				-1	
8	1	518	518					
9	-1	2527	2525					
10	0	1404	1400				-1	1
11	0	1405	1400					
12	0	1406	1400					
13	2	155	154					1
14	0	1407	1400					
15	-1	2528	2525					
16	0	1408	1400					
17	-1	2529	2525				-1	1
18	-1	2530	2525				-1	
19	-1	2531	2525				-1	
20	0	1409	1400			1	-1	
21	0	1410	1400				-1	1
22	0	1411	1400				-1	1
23	-1	2532	2525					
24	3	17	17					1
25	0	1412	1400					
26	0	1413	1400				-1	
27	-1	2533	2525				-1	
28	1	519	518					
29	-1	2534	2525				-1	
30	0	1414	1400			1	-1	

Introduction / Queried

Ready

Sum=31169

NUM

Figure 54: GP1020 Prototype – Current Inference Engine – Occurrences Vs Score.

The current method used in the program utilises exact match data mining. Given 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 asks 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.

No regard has been made for the sequence of events, or for the possibility that other events may have occurred. Obviously the current method can be vastly improved, and during the development of the code to replicate the main concept, three other methods or higher levels of computation were found that could possibly work. However it is the only one that could be successfully demonstrated within the time required. Each of the others has significant advantages but come at the cost of other requirements. For future reference the current program requires twenty seconds on average to determine a question from a set of answers. It holds approximately 3500 cases and uses 102 defined unanticipated event possibilities, and has an average appearance of the first variation in relevancy (and thus the first possible solution) after 12 questions.

	A	B	C	D	E	F	G	H	I	J	K	L
	Ev_Code	Ev_Frequency	Question Rank	Asked?								
1												
2	100	6	56	0								
3	110	3	64	0								
4	120	0	75	0								
5	130	109	13	0								
6	131	0	76	0								
7	132	0	77	0								
8	140	-4999	104	1								
9	150	51	24	0								
10	160	10	48	0								
11	170	7	53	0								
12	171	33	32	0								
13	172	4	60	0								
14	180	-4247	97	1								
15	190	36	29	0								
16	191	59	22	0								
17	192	91	15	0								
18	193	0	78	0								
19	194	40	28	0								
20	195	10	49	0								
21	196	0	79	0								
22	197	0	80	0								
23	198	0	81	0								
24	200	260	2	0								
25	210	0	82	0								
26	220	-4458	98	1								
27	230	-4681	100	1								
28	231	0	83	0								
29	232	0	84	0								
30	240	127	9	0								
31	250	157	7	0								
32	260	113	11	0								

Figure 55: GP1020 Prototype - Current Inference Engine – Event Frequency & Question Rank

The next level of computation is more representative of the work done in previous sections of this chapter (refer to Table 35 and Figure 52). It is defined as the complete causative linkage method and improves upon the previous method of computation by altering the calculation of case score in the inference engine, as well as adding additional data to the knowledge base and more calculation steps in the knowledge base preprocessor. A possible problem with the previous method was that it was possible for the inference engine to ask

numerous questions before, or even miss, asking a possibly contentious question simply because it was not frequent enough among each of the other already asked questions. Imagine having 10 incidents that all have different obvious causes, then imagine that all of those incidents have a common, but less frequently known, cause. Under the current program, the question regarding that common cause would not be asked till all the other obvious causes were taken out of contention. The solution to this was to make sure that in calculating the case score (as previously determined by matches between the case and the question alone), further increases in score could be gained on any positive matches between the case and possibilities linked to the question asked. This addition would obviously increase the accuracy of the program, however note the amount of computation required. First and foremost, the preprocessor would have to, after performing its 1.5 hours of formatting, create a list for each defined event possibility containing any event possibility that the event has ever occurred with. The increase in computation time required for the program due to the changes to case score calculation is equivalent to that used by the program to ask questions (you are essentially asking a question after another question), so the effective questioning time of 20 seconds would be doubled.

Rank	Relevancy	ev_id	ev_date	acft_make	oper_name	location
1	55.56%	20020917X02232	29/04/1982	BEECH	H. L. MAHIEU	LON
2	44.44%	20020917X01703	17/04/1982	Ayres	DIKELAND AVIATION	EVER
3	44.44%	20020917X02565	29/03/1982	PIPER	GEN. ENTERPRISES, INC.	HYA
4	44.44%	20020917X02684	31/05/1982	STINSON	C. NEWELL	MER
5	44.44%	20020917X02862	9/05/1982	BRANTLEY	R.E. DAVENPORT	WEL
6	44.44%	20020917X02944	1/06/1982	BELL	AERO PATROLS, INC.	CAN
7	44.44%	20020917X02945	5/06/1982	ENSTROM	RONALD DELVECCHIO	RAY
8	44.44%	20020917X03019	5/08/1982	BREEZY	EARL VIEAUX	OSH
9	44.44%	20020917X03059	9/05/1982	PIPER	AVIATION UNLIMITED	MILV
10	44.44%	20020917X03561	12/06/1982	LUSCOMBE	DONALD C. SPRANKLE	POR
11	44.44%	20020917X03959	9/07/1982	ENSTROM	SPRING HOUSE LEASING INC.	OCE
12	44.44%	20020917X04145	19/08/1982	AUSTER	PETE JORGENSEN	BELL
13	44.44%	20020917X04258	11/09/1982	CESSNA	DAVID HENDLEY, JR.	NAS
14	44.44%	20020917X04326	30/12/1982	PIPER	PALATKA AVIATION INC.	ATLA
15	44.44%	20020917X04695	30/10/1982	PIPER	CREST AIR INC.	OKL
16	44.44%	20020917X04942	26/11/1982	MAULE	VICTOR BELTRAM	VENI
17	33.33%	20020917X01640	5/04/1982	CESSNA	BRIAN A. EMERICH	AUK
18	33.33%	20020917X01672	1/03/1982	HOMEBUILT	PAUL GLEN SUMRALL, SR.	LAUI
19	33.33%	20020917X01704	17/04/1982	BEECH	WILLIAM D. BRENEMAN	COLI
20	33.33%	20020917X01710	25/04/1982	CESSNA	WILLIAM PRINCE	MAR

Questions	Click on the Yellow Cell next to a question to choose it's answer.
1. What occurred?	Decompression (140)
2. During what phase did it occur?	Cruise (540)
3. Did a(n) In flight collision with terrain/water (230) occur?	No (230)
4. Did anything occur during Landing - flare/touchdown (571)?	Yes (571)
5. Did a(n) Forced landing (180) occur?	Yes (180)
6. Did anything occur during Landing - roll (572)?	No (572)
7. Did a(n) In flight collision with object (220) occur?	Yes (220)
8. Did a(n) Loss of engine power (total) - nonmechanical (353) occur?	No (353)
9. Did anything occur during Cruise - normal (541)?	Yes (541)
10. Did anything occur during Takeoff - initial climb (522)?	

Figure 56: GP1020 Prototype – Relevancy Variation.

While undoubtedly that method would have increased accuracy, there was some concern that if a question were to arise in this manner, there was a possibility that a chosen event could be one that generally occurs frequently or may have next to no relevance at all to the investigation at hand (i.e. “Did the aircraft experience a hard landing?” The fact that it did would usually be of little importance compared to why it landed hard). This would largely be due to the fact that all events correlations were considered in that method’s additional score calculation. To temper this, the next level, aggregated causative linkage, was considered. Basically, it would have reduced the effect of severely unlikely event correlations, by introducing degree of separation limits in the sequence of event (altering the amount added by event correlations by how far the correlating event is, on average, from the questioned event within a given sequence of events). This method is calculated in much the same way as the previous one, however, significantly more complex formulae would have had to be created to assess, and then handle, the portions of the sequences of events that are wanted. Further testing would have had to be conducted in order to determine what degree of separation would have generated the best results.

The last level of computation is still largely theoretical; no attempts have been made to try to replicate it as such, particularly since it is essentially designed towards dealing with investigations which have largely complete sequences of events. It would also have required a method for the program to perceive causative direction in the sequence of events (something that due to the limitations in the raw data is not entirely possible yet; it can be done with the linear representations of the sequence of events, however, more historical knowledge regarding factor relationships within sequence of events is required for the process to be suitably accurate). It was perceived that after a significant number of questions were asked time issues may come into play and that these would inhibit the possibility of asking the right questions. For instance the presence of fire would, in any of the previous models, have totally eliminated events that could not have occurred with a fire. However, there would have been points within the sequence of events that the fire was not present, and other events could have occurred. Essentially, this method is a time sensitive variant of the complete causative linkage method. It would require coding to, as already mentioned, define the direction of the sequence of events (what caused what caused what?), and it would also require the determination of a period of existence for each event in the sequence. Admittedly there are numerous questions to ask but it is anticipated that this software would be heading in this direction.

7.3.5 GP1020 Prototype – User Instructions

The use of the GP1020 program requires Microsoft Office Excel 2003 or better. To use simply follow the instructions indicated below or as indicated on the introduction page of the program. Click on the spreadsheet titled “Query Page” to begin the process.

Figure 57: GP1020 Prototype - Introduction Page.

On the sheet titled "Query Page", two distinct sections will appear; the one at the top shows the top 20 most similar cases, and thus be used as a reference in understanding the case that the user is currently investigating. The one at the bottom shows the questions that the software would ask depending on the data given.

The screenshot shows a Microsoft Excel spreadsheet titled "Microsoft Excel - P-ESSV7.xls". The interface includes a menu bar (File, Edit, View, Insert, Format, Tools, Data, Window, Help) and a toolbar with various icons. The spreadsheet has columns labeled A through G. Row 1 contains the text "Top 20 Similar Cases". Rows 2 through 22 contain a table with the following headers: Rank, Relevancy, ev_id, ev_date, acft_make, and oper_name. The "Rank" column contains numbers 1 through 20. The "Relevancy" column is highlighted in green. The "ev_id", "ev_date", "acft_make", and "oper_name" columns are empty. Below the table, there is a section titled "Questions" with two questions: "1. What occurred?" and "2. During what phase did it occur?". To the right of the questions is a large yellow area for answers. The status bar at the bottom shows "Ready" and "NUM".

Rank	Relevancy	ev_id	ev_date	acft_make	oper_name
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

Questions

1. What occurred?

2. During what phase did it occur?

Click on the Yellow Cell next to a question to choose it's answer.

Figure 58: GP1020 Prototype – Query Page.

To begin using the software, answer the two questions already shown in the bottom box by clicking on the yellow box next to each question and choosing an appropriate answer from the drop down menu (the little downward arrow to the right of the cell appears after clicking on the cell).

Figure 59: GP1020 Prototype – Drop Down Menu.

Soon after, a third question should appear (should nothing occur, please set Calculation (Tools>Options>Calculation Tab>Calculation) to automatic or press F9 after choosing each answer). Similarly, choose an answer to the question that just appeared by clicking on the yellow cell next to the question and choosing an answer from the drop down menu.

Figure 60: GP1020 Prototype – Yes/No 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.

Microsoft Excel - P-ESSV7.xls

Type a question for help

F27 fx No (230)

	A	B	C	D	E	F	G
1						Top 20 Similar Cases	
2							
3		Rank	Relevancy	ev_id	ev_date	acft_make	oper_name
4		1	33.33%	20020917X01671	24/02/1982	EAGLE	PLANTERS DUSTING SERVICE INC.
5		2	33.33%	20020917X01723	18/01/1982	PIPER	WORLEY M. GLOVER
6		3	33.33%	20020917X01846	24/03/1982	CESSNA	EXE RICHARD JOHNSON
7		4	33.33%	20020917X01952	15/04/1982	CESSNA	JAMES D. GOLLADY
8		5	33.33%	20020917X01958	30/04/1982	Funk Aircraft Co.	
9		6	33.33%	20020917X02127	23/02/1982	Bell	DOOLITTLE ENTERPRISES INC.
10		7	33.33%	20020917X02135	1/02/1982	AEROSPATIALE	ENERGY HELL INC
11		8	33.33%	20020917X02220	17/04/1982	CESSNA	MICKELE A. FOLEY
12		9	33.33%	20020917X02221	17/04/1982	HUGHES	GLENN EDWARD MILLER
13		10	33.33%	20020917X02232	29/04/1982	BEECH	H. L. MAHIEU
14		11	33.33%	20020917X02372	25/03/1982	PIPER	BEAR CREEK AVIATION
15		12	33.33%	20020917X02394	3/04/1982	PIPER	AERIAL SIGN CO. INC.
16		13	33.33%	20020917X02535	2/03/1982	HUGHES	EVIROGAS,INC.
17		14	33.33%	20020917X02599	2/04/1982	HILLER	TERRY WITHAM
18		15	33.33%	20020917X02618	4/01/1982	PIPER	THOMAS E. MAGNER
19		16	33.33%	20020917X02673	30/07/1982	CESSNA	NORMAN LEE
20		17	33.33%	20020917X02797	29/07/1982	GRUMMAN	PRICE, JAMES EARL
21		18	33.33%	20020917X02809	14/08/1982	CESSNA	TAR HEEL AVIATION, INC.
22		19	33.33%	20020917X02935	28/05/1982	CESSNA	RAY NORMAN KELLY
23		20	33.33%	20020917X02944	1/06/1982	BELL	AERO PATROLS, INC.
24							
25		Questions				Click on the Yellow Cell next to a question to choose it's answer.	
26		1 . What occurred?				Decompression (140)	
27		2 . During what phase did it occur?				Cruise (540)	
28		3 . Did a(n) in flight collision with terrain/water (230) occur?				No (230)	
29		4 . Did anything occur during Landing - flare/touchdown (571)?					
30							
31							
32							
33							
34							
35							
36							

Ready NUM

Figure 61: GP1020 Prototype – Fourth Question.

Continue answering questions till the Relevancy column (the one in green) 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. Ideally, with an increasing amount of variation in Relevancy, the 20 cases shown should become more suited to assisting understanding of your case.

Rank	Relevancy	ev_id	ev_date	acft_make	oper_name	
1	55.56%	20020917X02232	29/04/1982	BEECH	H. L. MAHIEU	LON
2	44.44%	20020917X01703	17/04/1982	Ayres	DIXIELAND AVIATION	EVER
3	44.44%	20020917X02565	29/03/1982	PIPER	GEN. ENTERPRISES, INC.	HYA
4	44.44%	20020917X02684	31/05/1982	STINSON	C. NEWELL	MER
5	44.44%	20020917X02862	9/05/1982	BRANTLEY	R.E. DAVENPORT	WEL
6	44.44%	20020917X02944	1/06/1982	BELL	AERO PATROLS, INC.	CAN
7	44.44%	20020917X02945	5/06/1982	ENSTROM	RONALD DELVECCHIO	RAY
8	44.44%	20020917X03019	5/08/1982	BREEZY	EARL VIEAUX	OSH
9	44.44%	20020917X03059	9/05/1982	PIPER	AVIATION UNLIMITED	MILV
10	44.44%	20020917X03561	12/06/1982	LUSCOMBE	DONALD C. SPRANKLE	POR
11	44.44%	20020917X03959	9/07/1982	ENSTROM	SPRING HOUSE LEASING INC.	OCE
12	44.44%	20020917X04145	19/08/1982	AUSTER	PETE JORGENSEN	BELL
13	44.44%	20020917X04258	11/09/1982	CESSNA	DAVID HENDLEY, JR.	NAS
14	44.44%	20020917X04326	30/12/1982	PIPER	PALATKA AVIATION INC.	ATL
15	44.44%	20020917X04695	30/10/1982	PIPER	CREST AIR INC.	OKL
16	44.44%	20020917X04942	26/11/1982	MAULE	VICTOR BELTRAM	VENI
17	33.33%	20020917X01640	5/04/1982	CESSNA	BRIAN A. EMERICH	AUK
18	33.33%	20020917X01672	1/03/1982	HOMEBUILT	PAUL GLEN SUMRALL, SR.	LAUI
19	33.33%	20020917X01704	17/04/1982	BEECH	WILLIAM D. BRENNEMAN	COLI
20	33.33%	20020917X01710	25/04/1982	CESSNA	WILLIAM PRINCE	MAR

Questions	Click on the Yellow Cell next to a question to choose it's answer.
1 . What occurred?	Decompression (140)
2 . During what phase did it occur?	Cruise (540)
3 . Did a(n) In flight collision with terrain/water (230) occur?	No (230)
4 . Did anything occur during Landing - flare/touchdown (571)?	Yes (571)
5 . Did a(n) Forced landing (180) occur?	Yes (180)
6 . Did anything occur during Landing - roll (572)?	No (572)
7 . Did a(n) In flight collision with object (220) occur?	Yes (220)
8 . Did a(n) Loss of engine power (total) - nonmechanical (353) occur?	No (353)
9 . Did anything occur during Cruise - normal (541)?	Yes (541)
10 . Did anything occur during Takeoff - initial climb (522)?	

Figure 62: GP1020 Prototype – Relevancy Variation.

Should you wish to begin a new case simply delete all of your answers (Warning: Do not change an answer after it already has been answered, as this basic program does not yet have the functionality required to deal with such circumstances).

Figure 63: GP1020 Prototype – New Investigation.

7.4 GP1020 Computer Tool – The ‘AFIS’ of Aircraft Accident Investigation

As described earlier, GP1020 is a comparative program that utilises 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. GP1020 computer tool and its features resemble the well-known automated fingerprint identification systems (AFIS). Thereby, GP1020 is often called by this candidate the ‘AFIS’ of aircraft accident investigation. Below a brief review of AFIS systems is given in order to provide an insight into these systems and the features they have in common with the GP1020 tool.

7.4.1 An Overview of the Automated Fingerprint Identification Systems (AFIS)

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, AFIS technology has automated an already existing process for identifying individuals. Fingerprint images 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. Secondly, although all patterns are distinct in their ridge characteristics, their overall pattern appearances have similarities which 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 contaminant 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 Figure 64.

Figure 64: The four basic patterns of fingerprint ridges.

However, identifiable fingerprint attributes originate from minutia points. The major minutia features of fingerprint ridges are: bifurcation, ridge ending, and short ridge (or dot) (Figure 65).

Figure 65: Minutia points of fingerprint ridges.
(1-bifurcation, 2-ridge ending, 3-short ridge)

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 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 digitised. 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 point 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.

7.4.2 AFIS Identification versus GP1020 Enquiry

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 cognisant 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 (Figure 66). For instance, AFIS, utilising the SAGEM ‘Morpho’ operating system, usually provides a list of 30 candidates for a match.

A list of candidates for a match displayed on AFIS (SAGEM ‘Morpho’) system

A list of 20 top similar cases displayed on GP1020 program

Figure 66: GP1020 Prototype versus AFIS (SAGEM ‘Morpho’) system.

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, although in several countries the number required varies between 14, 16, and 17 minutia points.

A match between two fingerprints

A match within GP1020 enquiry

Figure 67: GP1020 Prototype versus AFIS (SAGEM ‘Morpho’) system.

The photo in Figure 67 shows a match between two fingerprints within AFIS (SAGEM ‘Morpho’) identification. In addition, the table from Figure 67 presents an assumed list of accident causes (C1, C2 ... C8) and their consistent portions of evidence (E1, E2 and so on), stored within GP1020. The red and blue circles show the matches in evidence during the GP1020 enquiry, indicating the accident associated with C3 (cause three) from the GP1020 database will most likely assist in facilitating the investigation of the current accident.

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 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 [131]. Despite the low rate of identification, AFIS systems are **irreplaceable tools** in a police investigation worldwide.

Similarly GP1020, as described before, 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.

Results obtained during the testing of the GP1020 prototype program encourage the application of a global expert system, and suggests the program’s knowledge pool should be increased to include historical data from many other sources than those currently being used.

7.5 Case Study: GP1020 Prototype Enquiry into the Aircraft Accident on 05 March 1993 at Skopje Airport, Macedonia

This exercise refers to the accident that occurred on 05 March 1993 at Skopje, Macedonia. At the time it was the deadliest aircraft accident in Macedonia killing 83 of the 97 occupants on board.

According to [8, 140] the Fokker 100 seconds after takeoff, experienced heavy vibrations followed by a sudden 10° right bank, a 50° left bank and a 55° right bank. The right wingtip struck the ground, 382m past the runway end with a 90° bank. The wing separated and the fuselage broke into three pieces.

The investigation into the accident determined the cause of the accident to be a lack of ice-awareness of the flight crew and the Flight Station Engineer to carry out spraying of the aircraft with de-icing or anti-icing fluid in meteorological conditions conducive to icing.

7.5.1 Background

In the above description, both visible events and the causes for those events are shown with a significantly high level of detail. Before using the GP1020 prototype, it is first necessary to set the situation as if the accident had just occurred, and it is obvious that the GP1020 program should be utilised in an investigation that begins in earnest. In other words, all that is currently known are the rough visible (as in from a very far distance) events that spectators would have seen:

Shortly after the Fokker took off, it banked suddenly right, then left, then right again. At this point the right wingtip struck the ground. The wing separated and the fuselage broke into several pieces.

The causes are not yet known nor are the measurements in bank angle, or distance/time from runway. It is possible to speculate that perhaps not all of the rough description would be found shortly after the accident either, but for this case study it is assumed as such. The next thing to consider is to try and match up the rough visible events with the events and flight phases utilised by GP1020. It would be acceptable to go right into questioning, but doing this first will highlight in a layman's mind the kind of answers they should be giving for each question.

Table 36 below lists all event and flight phase codes that GP1020 can identify (1XX-4XX for events, 5XX for flight phases), as well as the likelihood³² that that code had taken place³³ from the rough description.

Table 36: Event/Flight Phase Code Likelihood.

	Did this occur?
Abrupt manoeuvre (100)	Yes
Altitude deviation, uncontrolled (110)	Unknown
Cargo shift (120)	Unknown
Airframe/component/system failure/malfunction (130)	Unknown
Propeller failure/malfunction (131)	Unknown
Rotor failure/malfunction (132)	Unknown
Decompression (140)	Unknown
Ditching (150)	Unknown
Dragged wing, rotor, pod, float or tail/skid (160)	Yes
Fire/explosion (170)	Unknown
Fire (171)	Unknown
Explosion (172)	Unknown
Forced landing (180)	No
Gear collapsed (190)	Unknown
Main gear collapsed (191)	Unknown
Nose gear collapsed (192)	Unknown
Tail gear collapsed (193)	Unknown
Complete gear collapsed (194)	Unknown
Other gear collapsed (195)	Unknown
Gear not extended (196)	Unknown
Gear not retracted (197)	Unknown
Gear retraction on ground (198)	Unknown
Hard landing (200)	Yes
Hazardous materials leak/spill (210)	Unknown
In flight collision with object (220)	Yes
In flight collision with terrain/water (230)	Yes
Wheels down landing in water (231)	No
Wheels up landing (232)	Unknown
In flight encounter with weather (240)	Unknown
Loss of control - in flight (250)	Unknown
Loss of control - on ground/water (260)	Unknown
Midair collision (270)	No
Collision between aircraft (other than midair) (271)	Unknown
Near collision between aircraft (280)	Unknown
Nose down (290)	Unknown
Nose over (300)	Unknown
On ground/water collision with object (310)	Unknown

³² i.e. highly certain = yes, highly certain it did not happen = no, anything else = unknown.

³³ That is to say whether an event code had happened or whether something had happened during a flight phase code.

On ground/water collision with terrain/water (320)	Unknown
On ground/water encounter with weather (330)	Unknown
Overrun (340)	Unknown
Loss of engine power (350)	Unknown
Loss of engine power (total) - mechanical failure/malfunction (351)	Unknown
Loss of engine power (partial) - mechanical failure/malfunction (352)	Unknown
Loss of engine power (total) - nonmechanical (353)	Unknown
Loss of engine power (partial) - nonmechanical (354)	Unknown
Engine tearaway (355)	Unknown
Propeller blast or jet exhaust/suction (360)	Unknown
Propeller/rotor contact to person (370)	Unknown
Roll over (380)	Unknown
Undershoot (390)	Unknown
Vortex turbulence encountered (410)	Unknown
Missing aircraft (420)	Unknown
Did something occur during this?	
Standing (500)	Unknown
Standing - pre-flight (501)	Unknown
Standing - starting engine(s) (502)	Unknown
Standing - engine(s) operating (503)	Unknown
Standing - engine(s) not operating (504)	Unknown
Standing - idling rotors (505)	Unknown
Taxi (510)	Unknown
Taxi - pushback/tow (511)	Unknown
Taxi - to takeoff (512)	Unknown
Taxi - from landing (513)	Unknown
Taxi - aerial (514)	Unknown
Takeoff (520)	Unknown
Takeoff - roll/run (521)	Unknown
Takeoff - initial climb (522)	Yes
Takeoff - aborted (523)	Unknown
Climb (530)	Unknown
Climb - to cruise (531)	Unknown
Cruise (540)	No
Cruise - normal (541)	No
Manoeuvring - holding (IFR) (542)	No
Descent (550)	No
Descent - normal (551)	No
Descent - emergency (552)	No
Descent - uncontrolled (553)	No
Approach (560)	No
Approach - VFR pattern - downwind (561)	No
Approach - VFR pattern - turn to base (562)	No
Approach - VFR pattern - base leg/base to final (563)	No
Approach - VFR pattern - final approach (564)	No
Go-around (VFR) (565)	No
Approach - Initial approach fix to final approach fix (FAF) /outer marker (IFR) (566)	No
Approach - final approach fix (FAF) /outer marker to threshold (IFR) (567)	No

Approach - circling (IFR) (568)	No
Missed approach (IFR) (569)	No
Landing (570)	Yes
Landing - flare/touchdown (571)	Yes
Landing - roll (572)	Unknown
Landing - aborted (573)	No
Emergency landing (574)	No
Emergency landing after takeoff (575)	No
Emergency descent/landing (576)	No
Manoeuvring (580)	No
Manoeuvring - aerial application (581)	No
Manoeuvring - turn to reverse direction (582)	No
Manoeuvring - turn to landing area (emergency) (583)	No
Hover (590)	No
Hover - in ground effect (591)	No
Hover - out of ground effect (592)	No

It is clear that the majority is unknown. All events with a ‘yes’ come from the rough description, all events with a ‘no’ stem from the understanding of timeline and the flight phases that an airplane can go through³⁴. The only discrepancy with the generic way ‘no’ works is with regards to any code with the word ‘landing’; without a specific code for ‘crashing’, landing is sometimes confused between the ‘intention to land’ and ‘landed’ definitions³⁵.

Now it is possible to just put the highly certain codes into a generic search program and look that way, but it will not usually be possible to appropriately filter the results or gather suitable questions that should be considered during the investigation. From the above table it is easy to see the large number of unknowns regarding this accident, far too many to determine each one’s possibility. Each question that gets asked is indicative of the cumulative experience recorded within the GP1020 program and implies that each question that is asked is somehow³⁶ significant given the data mentioned to the program.

For now, and in most uses of the GP1020 program, the first thing to do is to choose the most obvious/likely event with a known associated flight phases from the above table³⁷ to begin questioning in GP1020. It is highly obvious that there is a link between the plane somehow colliding with the ground and it occurring shortly after takeoff. The corresponding

³⁴ That is to say a plane cannot have gone through cruise if it crashed while performing its initial climb; also planes can’t hover.

³⁵ i.e. Hard landing implies having a hard landing, forced landing implies being forced to land and not necessarily having landed yet.

³⁶ With increasing importance the more numerous the questions asked.

³⁷ And thereby making a rough description that could be understood by the program.

codes would be: ‘Inflight collision with terrain/water’ and ‘Takeoff - Initial Climb’. As an explanation of the first, it was the most obvious and the least unlikely out of all the ‘yes’ answers. As for the second, the visible definition of takeoff is off the ground but close to the runway, so at a far visual distance, only ‘Takeoff - Initial Climb’ of the code subgroup beginning with ‘Takeoff’ would be certain. Additionally you could say that it occurred during ‘Climb’, but since the rough description indicated the occurrence right after takeoff, ‘Takeoff - Initial Climb’ would be more likely.

7.5.2 GP1020 Prototype Enquiry into the Skopje Accident

Before beginning to input the two previous codes, a diagrammatic description of what is occurring within the program is given. An initial look at the program would have yielded Figure 68 below.

Top 20 Similar Cases								
Rank	Relevancy	ev_id	ev_date	acft_make	oper_name	dot_city	dot_state	
1	57.14%	20020917X01907	13/01/1982	BOEING	AIR FLORIDA, INC	WASHINGTON	DC	FT
2	42.86%	20020917X02025	02/03/1982	BELL	AIR LOGISTICS INC.	GALVESTON BKA	GM	NE
3	42.86%	20020917X02099	11/03/1982	CESSNA	BRYAN AERO INC.	BRYAN	TX	BR
4	42.86%	20020917X02128	15/04/1982	PIPER	CURTIS LEWIS	RUIDOSO MUNI	NM	AM
5	42.86%	20020917X02162	23/01/1982	BELL	KENNETH L. MASON	WATSONVILLE	CA	WA
6	42.86%	20020917X02192	09/03/1982	HILLER	SAN JOAQUIN HELICOPTERS	DELANO	CA	DE
7	42.86%	20020917X02217	15/04/1982	BELL	VALLEY HELICOPTERS	STOCKTON	CA	ST
8	42.86%	20020917X02502	03/03/1982	CESSNA	GOGUEN'S NORTH EASTERN ELECTRI	PALMER	MA	WE
9	42.86%	20020917X02665	17/08/1982	ENSTROM	KEAN & ASSOCIATES	NEAR SUTTON	AK	NE
10	42.86%	20020917X02668	25/08/1982	PIPER	PETER REICHARD	NEAR DILLINGHAM	AK	DIL
11	42.86%	20020917X02698	25/08/1982	CESSNA	COASTAL AVIA.	BETHEL	AK	BE
12	42.86%	20020917X02700	22/08/1982	CESSNA	ROBERT BASHAM	KODIAK	AK	KO
13	42.86%	20020917X02709	25/06/1982	PIPER	KARL MONETTI	FAIRBANKS	AK	FAI
14	42.86%	20020917X02909	08/05/1982	PIPER	DONALD J. MCCORMICK			
15	42.86%	20020917X02922	16/05/1982	OLDFIELD	JOHN PHILLIPS	MIDDLEFIELD	OH	MIC
16	42.86%	20020917X02996	23/07/1982	PIPER	OMNI FLIGHT HELICOPTERS	ANTIOCH	IL	JAI
17	42.86%	20020917X03231	28/05/1982	QUICKIE	JOHN BINGHAM	OGDEN	UT	OG
18	42.86%	20020917X03424	28/08/1982	CESSNA	SPEARMAN FLYING CLUB	BORGER	TX	SPI
19	42.86%	20020917X03428	30/08/1982	CESSNA	JAMES EARL ALEXANDER	FARMERVILLE	LA	FAI
20	42.86%	20020917X03430	31/08/1982	AMERICAN AVIATION	DELFIN SALAZAR, JR.	GEORGETOWN	TX	GE

Questions		Click on the Yellow Cell next to a question to choose it's answer.	
1. What occurred?		In flight collision with terrain/water (230)	
2. During what phase did it occur?		Takeoff - initial climb (522)	
3. Did a(n) Loss of control - in flight (250) occur?		No (250)	
4. Did anything occur during Landing - flare/touchdown (571)?		Yes (571)	
5. Did a(n) Forced landing (180) occur?		No (180)	
6. Did anything occur during Landing - roll (572)?		No (572)	
7. Did a(n) In flight collision with object (220) occur?		Yes (220)	

Figure 68: GP1020 enquiry into the accident that occurred on 05 March 1993 at Skopje.

This, while very efficient, does not show exactly what is happening within the program. The graph below (Figure 69), however, does. It indicates the relative distribution of the cases currently stored within the program³⁸ with regards to their current score.

The current score is determined by how well the given data fits the case data:

- ‘+1’ for each positive event/flight phase code matches (or ‘yes’ answer), and

³⁸ Due to limitations previously discussed, only 3546 cases are stored within the GP1020 prototype.

- ‘-1’ for each negative event/flight phase code (or ‘no’ answer).

The same graph type for the rest of this Chapter shows what occurs as section 2 in Figure 68 (red square) is filled in. Figure 69 below indicates the starting position of all investigation scenarios.

Figure 69: Start Position from all Cases

As you can see, every case has a score of zero. The tiny maroon part on the top of the ‘0’ column (the magnified part of Figure 69) represents the portion of cases that would currently be seen in the top 20 list (for programming reasons, the top 20 are not shown during the first 2 questions). Inputting the next two initial codes gives you the following two graphs.

Figure 70: Question 1: ‘What occurred?’ Answer 1: ‘In flight collision with terrain/water’.

Figure 71: Question 2: ‘During what phase did it occur?’ Answer 2: ‘Takeoff – initial climb’.

As you input the two codes, two important things changed; first is the decrease in maximum score. Obviously, the more variation in possible scores, the smaller the peak in the graph becomes and the wider the distribution. Secondly, the variation in score only went in a positive direction. This is due to the way the questions are asked i.e. only positive matches were possible. Although repeated questioning would have retrieved the same results, these two positive only questions ensured a fast transition to useful cases in the top 20 list, which would not have been the case had the first answers been negative in nature. The next figure is of the case scores after the third question.

Figure 72: Question 3: ‘Did a loss of control – in flight occur?’ Answer 3: ‘No’.

Again, two things to note: an increased peak and the presence of a negative score. With a negative match, cases that may have had a positive score are driven back, effectively squeezing the case scores together again (and unintentionally increasing the peak at the same time). As intended however, it does refine the top 20 list of candidates somewhat.

You can see that this code within Table 36 had an ‘unknown’ likelihood. Unfortunately, during testing the “unknown” option (which gave a modifier of +0, and effectively nullified the question from being asked again) was shown to cause a lack of change in code ranks (i.e. which code would be asked next) in between questions. While great for fine tuning questions (i.e. when the list of questions is near the end of being clearly appropriate), such stasis would inhibit the program’s ability to proactively search for more appropriate questions early on. Additional handling protocols were developed to enable the program to more effectively use the “unknown” answer, but would have increased the system’s already high processing requirements. Thus currently any question that would have normally required an ‘unknown’ answer is treated as requiring a ‘no’ answer. This is actually appropriate since, as the figures above just demonstrated, ‘yes’ answers give more possible cases, ‘no’ answers cull those possible cases down; what were needed were not more possible cases, but a more refined list of those possible cases. It is possible that an appropriate case would have been culled prematurely, but it would have been hoped that it, or a very similar case to it, would have eventually made it to the top 20 list.

Figure 73: Question 4: ‘Did anything occur during Landing – flare/touchdown?’ Answer 4: ‘Yes’.

The above Figure 73 is an affirmative question and, imagining the curve between the peak and the highest possible score, has curved outwards, giving the impression of more

possible cases being considered at the higher end. True to form as a ‘yes’ answer, the peak drops a bit more.

Figure 74: Question 5: ‘Did a forced landing occur?’ Answer 5: ‘No’

Figure 74 is a fairly standard, increased peak; sharper tail (if one should choose the graph’s resemblance to a normalized bell curve).

Figure 75: Question 6: ‘Did anything occur during landing – roll?’ Answer 6: ‘No’.

Again from Table 36 it can be seen that the above figure’s question was initially ‘unknown’. Saying ‘no’ here, while admittedly culling the higher section, caused the peak to drop. Such an instance could imply that a significant number of cases had their scores dropped, and heavily begs the question on whether saying no was appropriate. Alternatively, perhaps,

cases that were just maintaining a zero score and had next to no reference to the case except for this code finally had their score degraded for the first time. Further research would have to look into this effect.

Figure 76: Question 7: 'Did an in flight collision with object occur?' Answer 7: 'Yes'

At this stage, the program highlights “BOEING | AIR FLORIDA, INC | WASHINGTON” (square 1, in green, in Figure 68) as the first on the list. According to the NTSB data base, this is of the event that occurred on 13 January 1982 at Washington:

According to the NTSB data base a Boeing 737-222 crashed on takeoff from Washington National Airport in severe weather conditions.

The investigation of this accident revealed that the major cause for this tragedy was crew failure to activate the engine anti-ice systems.

It is obvious that the accident on 13 January 1982 at Washington has similarities with the accident that occurred on 05 March 1993 at Skopje and would most likely have assisted in understanding the circumstances and causes of the Skopje accident.

Unfortunately this is not indicative of how long it would normally take to arrive at such a neat case solution; however it does point out that the chance for finding such is there. Additionally it saves the effort of having to repeat showing the similar pattern that would have been shown after the ‘top 20 list’ (in maroon, currently spread over two categories) spreads itself over 3 or 4 score categories (and their requisite number of questions), which would have been required to consistently present highly useful cases.

If you are looking for perfect safety, you will do well to sit on a fence and watch the birds; but if you really wish to learn, you must mount a machine and become acquainted with its tricks by actual trial.

WILBUR WRIGHT

Conclusions

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 owing to airline travel being an economical and convenient means of long distance transport.

Successful airline operation worldwide is largely due to the high standards applied within the aviation industry that ensure the system works, in spite of existing problems and challenges [89, 90, 94]. Overall, commercial aviation is extremely safe, yet safety standards throughout the world differ significantly. Airline travel in developed countries tends to be very safe, but there are regions in the world where the standards are much lower. The current level of safety attained by major airline companies in developed countries is one of the great achievements of modern industry.

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. As a result of this, investigations have helped alter the course of aviation history by maintaining and improving air safety.³⁹

Despite the huge progress in air safety, accidents and incidents do still happen and can cause injuries, fatalities and the destruction of property. Also, while accident rates are decreasing, the total number of aircraft accidents is most likely to remain stable or increase slightly mainly due to current growth.⁴⁰

³⁹ An example of investigation impact on airlines was creation of the European black list of airlines. If an EU State bans an airline due to safety violation then other EU States would automatically ban it as well [87].

⁴⁰ In 2020, when more than 7 billion passengers annually are expected to use airline services worldwide, experts predict on average there will be a fatal accident every week (122}.

In addition, statistics related to aircraft accidents reveal that the causes for a number of them remain unknown. 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.⁴¹

Thus the conclusion has arisen that despite all of its current strengths, the aircraft accident investigation process needs to be improved to both help understand the causes of accidents and to prevent future reoccurrences. In this regard, the research contained in this work has shown that expert systems methodology is a solid approach to analysing the aircraft accident investigation process. The methodology presented has provided a thorough picture of the current condition of investigation and has suggested possible solutions for its further improvement.

This chapter discusses the methodology developed and the application of this methodology for considering the aircraft accident investigation. The limitations of this methodology are examined and possible areas for further research are also suggested.

8.1 Discussion

The famous Jim Lovell⁴² message, “Houston, we’ve had a problem here” best expresses the way in which all important clues were derived and used in accomplishing this work. Namely, this message suggests that aircraft accident investigation and aircraft safety can be improved by focusing on current and past problems of aircrafts.

Improvement in aircraft accident investigation is a challenging task which has required substantial efforts to accomplish. This is because air accident investigation is a broad area including a number of different disciplines. However this research has produced several key results that accomplish the main aim of this thesis, restated below:

To pursue a thorough analysis of the aircraft accident investigation process, followed by identifying areas where significant improvements could be achieved, and demonstrating an expert system for improving investigation outcomes.

⁴¹ For instance, the accident at Colorado Springs in 1991, and US Air’s flight 427 from Chicago to Pittsburgh in 1994, both involving Boeing 737s, have not been satisfactorily explained so far [145].

⁴² Jim Lovell was the commander of Apollo 13 which crashed on 13 April, 1970.

As mentioned earlier, the research contained in this work has shown that expert systems methodology is an appropriate approach to analysing the aircraft accident investigation process. It includes an analysis of accident statistics, application of a two-round Delphi enquiry and introduces the GP1020 computer program as a novel investigation tool in the form of a data mining method designed towards giving aircraft accident investigators improved use of forensic data.

There are two main factors which initially determined the course of this research. These were the international standards of aircraft accident and incident investigation (Annex 13) and the literature review. The international standards describes aircraft accident and incident investigation as a process conducted for the purpose of accident prevention which includes gathering and analysing information, drawing conclusions, determining causes and making safety recommendations when appropriate. Thus the investigation initially examines what has happened (generally the easier part) and then determines the events that have contributed to the accident.

In addition, the literature review has shown that there are several prospective methods used to consider air safety and the investigation process, the most common of which are statistics and comparable statistics, thus addressing the importance of advance data classification and the application of survey methods.

The investigation process, within this work, was initially considered through a brief review of statistics of aircraft accidents which occurred between 1950 and 2004. Analysing this data with respect to the number of accidents and incidents, their distribution over this time period, their causal factors and casualties (if any) has led to overall conclusions regarding air traffic safety and accident causes. As mentioned earlier, it is interesting to note that this review indicated that the causes for 31% of aircraft accidents between 1950 and 2004 have not been completely determined. Another concerning outcome is that a number of accidents which have occurred due to human errors or equipment malfunctions are more common in unpleasant weather conditions.

In accordance with the derived methodology, a two-round Delphi survey was then conducted which, as discussed in Chapter 6, is a powerful method for establishing a set of priorities to further develop and improve a complex system. Originally the Delphi technique was mainly used for forecasting future scientific-technological development, but recently it has been adopted as a method of systematic opinion gathering from experts. However, this data may then be used to foresee developments in technology and other areas.

Surprisingly, despite all of these recognised features, a literature search conducted on e-journals and e-books using combinations of the terms Delphi, aircraft, accidents, and investigation retrieved no articles, and was another challenge in undertaking this work.

The Delphi survey for this work was conducted in mid-2007 although the preparation involved had started several months beforehand. Ten experienced investigators from the ATSB, DSTO and other international services considered and ranked the impact of 98 different factors on investigation outcomes. The Delphi exercise was concluded after the second round when a satisfactory consensus of expert opinions was achieved.

The Delphi conclusions have shown that there is great potential for further improving aircraft accident investigation, and additionally have indicated specific parts of the investigation process in which significant improvements could be made. With respect to improving investigation outcomes the Delphi results suggested the need for a tool which would be able to capture and store the specific knowledge and analytical skills of a large number of aviation experts. This research then proceeded with creating such a tool which would be able to demonstrate the efficacy of the methodology developed in facilitating air accident investigations.

Hence, taking all research results already derived into account, it was concluded that further work should be focused on long-term accident patterns using the benefits of the contemporary approach to accidents. This approach views an air accident as a result of a chain of events including errors, omissions, or equipment malfunctions (Figure 77). Furthermore, the definition also states that if this chain of events is not broken at some point then an accident will occur.⁴³

This idea was the milestone in developing a tool for facilitating the accident investigation process, and was further developed by breaking down accidents to a number of events leading to occurrences that could be determined during the investigation. Consequently the next challenge of the work was to determine whether there is always a logical relationship between these events and if these events could be both identified and listed chronologically in the investigation process.

Such a relationship is supported by the theory of investigation which states that nearly every accident contains evidence which, if correctly identified and assessed, will allow the circumstances and the causes to be ascertained. Furthermore it states that although all aircraft accidents are different there are commonalities in aircraft impacts, wreckage distribution,

⁴³ Heinrich's law for Industrial Accident Prevention states that prior to the occurrence of one major accident, there occur 29 minor accidents and 300 problems that do reach the point of becoming accidents [142].

equipment failure, attendance injuries, and many other relevant concerns within accident investigations. Additionally, the conventional method of ‘learning from past accidents’ appears to be at the root of many accidents to date. By organising all these elements, many different causes of accidents can be classified and more easily identified.

Figure 77: Unsafe Events – A chain of events leading to an accident.
(Modified from Figure 6 [142])

The GP1020 computer program discussed in Chapter 7 incorporates all of the above considerations and shows that a global expert system as a tool for storing and retrieving global aircraft accident forensic data can significantly facilitate and improve the aircraft accident investigation process. The GP1020 program asks the user a number of questions related to various factors of the accident/incident and, based on both the information provided and its validity the program indicates the most probable causes of the accident/incident.

To summarise, the expert system methodology developed for this application has proven to be extremely capable in examining the aircraft accident investigation process. It is also effective and flexible enough to be applied when considering many other complex systems. The GP1020 program, which was developed in the final stages of this work, covers a diverse range of accident causes and their consistent evidence shows that the methodology has resulted in creating a valuable tool for enhancing investigation outcomes.

8.2 Limitations

Like all research, several limitations do exist with the expert system methodology developed within this research. Since the methodology contains accident statistics, a Delphi enquiry and applying the novel GP1020 program, the limitations of each individual aspect will be discussed accordingly.

Statistics have been shown as an important constituent of two major parts of this work: in Chapter 5 statistics about accidents which occurred between 1950 and 2004 were analysed to illustrate overall trends in aircraft accidents and to draw some overall conclusions, and in Chapter 7 statistics were used as expert knowledge stored in the computer program GP1020. Limitations of GP1020 analysis were discussed in the previous chapter and will be briefly addressed again when discussing the GP1020 program.

One noteworthy point is that statistics from different sources can differ for certain sampling periods. Conflicting data can particularly be seen in the number of accidents and the distribution of accident causes. Therefore this candidate tried to consider the causes of accidents which occurred globally between 1950 and 2004 by analysing the brief reports available in [9]. He faced another obstacle originating from the ‘multiple causal factors’ approach to accidents, which states that before an accident occurs a number of adverse events must have preceded it, and as such the major cause of accidents can be difficult to identify when there are two or more strong contributing factors (Figure 78)⁴⁴.

Figure 78: A chain of events leading to an accident.

⁴⁴ For instance in Figure 78 there are two events that have significantly contributed to the accident. Event 1 is the first event from the chain, whereas Event 5 has the strongest contribution to the accident. Which one will be cited as the major cause for this accident? There are examples such as [94], which cite all strong contributing factors as major causes of accidents. For such an analysis the total causal figure is greater than 100 %.

However, since the goal of this part of the work was creating overall conclusions, these obstacles were not insurmountable in reaching the final conclusions of this research but nevertheless deserve to be mentioned (as mentioned in Chapter 5, the first event within the chain of events that had a significant impact on air safety was cited as the major cause for an accident).

The Delphi technique and its methodology had several limitations. Some of the relevant limitations have already been explored in Chapter 4 when discussing the disadvantages and organisational problems of the Delphi method, and in this section only those that have had an actual impact on the results of this work are addressed.

The main limitation with applying the Delphi method is that despite its ability to draw conclusions for further development of an issue, it does not explain how to implement its findings. Therefore a Delphi enquiry is usually associated with another method that implements the Delphi outcomes. In the case of this research this is done by introducing the GP1020 computer program for facilitating the investigation process.

Another considerable limitation of the Delphi exercise is the lack of an analytical tool to evaluate the quality of questionnaires, as created by the researcher, which is essential for a successful survey method.⁴⁵ Questionnaire quality can however be verified by conducting the 'zero' round, in which a small group of respondents discuss the structure, contents and quality of the questionnaire.

The last major set of limitations of this work originates from problems related to establishing the expert team, including team selection and deciding on the number of respondents. Since the expert participations in this survey were done on a voluntary basis, there was a concern of expert attitude towards providing credible and punctual answers.⁴⁶ Only by careful management of the pool process with feedback were these limitations overcome, and this is important in minimising the influence of these limitations on the results of this research.

The GP1020 computer program does also have certain limitations which are mainly related to the specific knowledge stored as well as the limitation of the design technique used.

⁴⁵ It is fundamental to know whether the questionnaire contains all factors relevant to the issue and if they are asked in the way that will provide the best expert outcomes. There is no analytical tool to assess this.

⁴⁶ It is debatable whether the results of the Delphi enquiry will be the same if another team of experts was to be surveyed. With respect to this question, based on past experience with Delphi studies, this candidate states that if the whole Delphi procedure is followed then very similar conclusions will be drawn.

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 accident investigation.

As mentioned in Chapter 7, the NTSB aviation accident database was used as expert knowledge in creating the GP1020 computer tool. It is available online and contains highly classified and downloadable datasets of more than 140,000 aviation accidents. 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. Due to 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 utilising hardware with greater computing power would rectify this problem.

8.3 Future Work

The results derived from this study suggest several possible areas for further research. An immediate area for further research would be the full implementation of a global expert system (mainly via the collection of increased stores of historical data) which has been demonstrated as an effective tool for enhancement of investigation outcomes via examining the GP1020 program's functionality.

Whilst the GP1020 program is currently working acceptably there is much room for upgrades and improvements in its current implementation. Additional analysis on the impact of incorporating the ability to define causative direction as well as unanticipated event time duration would greatly assist in increasing the program's scope and accuracy.

Another major area for further research which has arisen from this study is in the general issues related to improvement of aircraft accident survivability.

8.3.1 Application of Global Expert System to Improvement of Aircraft Accident Investigations and Air Traffic Safety

One immediate pathway for future research would be a complete implementation of the proposed global expert system solution for aircraft accident investigation. In order to achieve this, the limitations of GP1020 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 validity of the system's results. Once successful, implementation of the software into the systems of various air safety organisations 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 difficult and time-consuming but nevertheless achievable and potentially very useful in the following areas:

- **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.
- **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.

8.3.2 Issues Related to Improvement of Survivability of Aircraft Accidents

Several other areas have been identified that could be useful avenues for future research. These issues concern the survivability of accidents and have been identified via both the Delphi enquiry and accident statistics.

Perfect safety is rare because almost every activity has associated dangers. Sooner or later these dangers and/or unexpected interactions will occur resulting in an accident [133]. However it is possible to minimise fatalities in air accidents, and this can be accomplished via two methods: by preventing accidents or by protecting occupants in accidents that do occur.

The NTSB has introduced the most wanted improvements in aviation as discussed in Chapter 3. This list includes: reducing the risk of aircraft accidents in icy conditions, design changes to eliminate the danger of flammable fuel, improving runway safety, upgrading data recorders, reducing the number of accidents caused by human fatigue, and improving crew resource management.

In this research there have been several findings which have not only introduced this area for further research but also suggested prospective ways of improving accident survivability. For instance, the expert group opinion of factor 98 within the Delphi study states that the experience of land traffic accident investigation can contribute to considerable increases in air traffic safety. Therefore the positive practices of road traffic and industry as well could improve air safety.

There are studies that have examined the most serious aircraft accidents with respect to crash forces, structural collapse or failure, crash fires and crash related injuries, cause-of-death information, and design features which diminish the chances of survival and increase the risk of injury [153]. This list of possible injuries to a human body in an aircraft is numerous and includes injuries to the eardrum by rapid decompression, burns from fires and suffocation due to inhalation of toxic gas released from burning cabinet trim as well as broken bones, contusions, lacerations, and internal organ injuries, all of which may occur in an accident [184]. Furthermore, although fire can kill and injure directly through heat, the toxic fumes and smoke produced when material in the aircraft interior burn are more likely to be the direct cause of death. As a consequence, the two major factors in causing fatalities in survivable crashes are a post crash fire and the inability to quickly exit a damaged aircraft.⁴⁷

Thus an obvious avenue for future research is the enhancement of survivability by upgrading aircraft structure and introducing new personal safety accessories. These accessories would reduce the impact forces and mitigate other severe effects such as fire and toxic gases that may impact human health and life during an accident.

Since this research is not directly related to accident survivability, in Appendix E this candidate only expresses his thoughts with respect to improvement of accident survivability that are based on his working experience⁴⁸ and the results derived from this research.

⁴⁷ For instance on 11 July 1973, when a Brazilian Boeing 707 crashed while approaching Orly Airport near Paris, 123 of the 134 passengers were overcome by smoke and carbon monoxide before the plane could be evacuated.

⁴⁸ The candidate has worked for over a decade as an *Expert for Technical Investigation* within the National Forensic Science Laboratory in his native Macedonia.

8.4 Concluding Statements

The expert system methodology developed for this application has proven to be a robust method of analysing the aircraft accident investigation process. Via an analysis of accident statistics which 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, shown below.

Figure 79: Outcomes derived by application of the Expert System to aircraft accident investigation.

First of all, statistics have indicated that 31% of aircraft accidents that occurred between 1950 and 2004 worldwide have unknown causes, which is a matter of concern (Figure 31). Next, in contrast to the low rate of fatal aircraft accidents per million departures, the accident fatality rate in accidents 1950-2004 is very high: 72% of occupants involved in these accidents were killed, and so action is required to help increase passenger survivability in aircraft accidents (Table 2 and Table 5).

In addition, the Delphi exercise has shown that there is great potential for further improvement of aircraft accident investigation, particularly in the areas of:

- Dispatching investigators to the scene of the accident and the process of facilitating coordination and cooperation between investigators within an investigation (Table 16),
- Managing the investigation, wreckage analysis, and data management (Table 20),
- The investigation of human errors, omissions and psychological factors (Table 30),
- Examination of data recorders (Table 28),
- Examination of in-flight safety occurrences such as aircraft system failures and explosions (Table 28),
- Investigating criminal activities as a possible cause for accidents (Table 28, Factor 46),
- Managing the amount of time and money spent on investigations (Table 16, Factor 9).

In terms of prospective solutions for improving aircraft accident outcomes, this study emphasises the importance of recorders and recorded data. Hence, the investigation results could be enhanced through creating and using an advanced database for easier identification of an aircraft's components, and more importantly, through creating and using comprehensive databases for storing and analysing aircraft accident forensic data. Furthermore, this study addresses the importance of common video recording of various functions in different aircraft zones and transmitting the data to ground stations for storage as an ultimate measure for improving accident investigation outcomes. This work also indicates that training individual investigator knowledge can also significantly enhance investigation results (Table 32, Factor 79).

The research concludes by showing that aircraft accident investigations can be improved with the application of a global expert system as a tool for storing and analysing 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 by increasing the program's knowledge pool to include historical data from many other international sources other than those currently being used.

Finally the expert system methodology developed for this application could potentially be successfully used in improving air traffic safety. A fully developed global expert system will 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.

References

- [1] AAIB, *Bombardier CL600-2B16*, AAIB, Hampshire, 2005.
- [2] AAIB, *The Investigation of accidents to general aviation aircraft*, AAIB, Hampshire, 2005.
- [3] AAIB, *Dornier 328 Serious 100 TF-CSB*, AAIB, Hampshire, 2006.
- [4] AAIB, *Airbus A319-131 G-EU08*, AAIB, Hampshire, 2006.
- [5] AAIB, *Socata TB10 G-BNRA*, AAIB, Hampshire, 2006.
- [6] AAIB, *Boeing 777-222 N786UA*, AAIB, Hampshire, 2007.
- [7] AAIB, 'Incident at Manchester airport puts focus on runway safety', *ICAO Journal*, 62(1), p.11, 2007.
- [8] Aerosim Technologies, *Flight Training Program Development B737*, [CD-ROM], American Airlines, 2000.
- [9] Airdisaster.com, *Statistics*, <http://www.airdisaster.com/statistics> [retrieved 10 October 2005].
- [10] Airsafe.com, *Fatal events and fatal event rates of airlines*, <http://www.airsafe.com/airline.htm> [retrieved 31 March 2006].
- [11] Ames, J. S., 'Aircraft accidents: Method of Analysis', *Seventeenth Safety Congress: Passenger Safety*, Chicago, 1984.
- [12] Arendit, D., Yanties, W., and Vegega, A., 'Concept of safety management system embraced by many countries', *ICAO Journal*, vol. 61(6), pp.9-11, 2006.
- [13] ATSB, *Aviation safety investigation in Australia*, ATSB, Canberra, 2007.
- [14] ATSB, *About the Australian Transport Safety Bureau*, ATSB, 2007.
- [15] ATSB, *Limitations of the see-and-avoid principle*, ATSB, Canberra, 1991.
- [16] ATSB, *Human factors in fatal aircraft accidents*, ATSB, Canberra, 1996.
- [17] ATSB, *Human factors in airline maintenance: A study of incident reports*, ATSB, Canberra, 1997.
- [18] ATSB, *Aircraft maintenance safety survey*, ATSB, Canberra, 1997.

- [19] ATSB, *An analysis of incidents involving aircrew failing to comply with air traffic clearances June to August 1996*, ATSB, Canberra, 1997.
- [20] ATSB, *Proactively monitoring airline safety performance: INDICATE (Identifying Needed Defences in the Civil Aviation Transport Environment)*, ATSB, Canberra, 1999.
- [21] ATSB, *Regional Airlines Safety Study Project*, ATSB, Canberra, 1999.
- [22] ATSB, *Systemic investigation into fuel contamination*, ATSB, Canberra, 2001.
- [23] ATSB, *Survey of licensed aircraft maintenance engineers in Australia*, ATSB, Canberra, 2001.
- [24] ATSB, *Investigation into ansett Australia maintenance safety deficiencies and the control of continuing airworthiness of class A aircraft*, ATSB, Canberra, 2002.
- [25] ATSB, *The hazard posed to aircraft by birds*, ATSB, Canberra, 2003.
- [26] ATSB, *Australian aviation accidents involving fuel exhaustion and starvation*, ATSB, Canberra, 2003.
- [27] ATSB, *ICAO universal safety oversight audit program*, ATSB, Canberra, 2004.
- [28] ATSB, *Error management in aviation training*, ATSB, Canberra, 2004.
- [29] ATSB, *Runway Incursions: 1997 to 2003*, ATSB, Canberra, 2004.
- [30] ATSB, *General aviation fatal accidents: How do they happen? A review of general aviation fatal accidents 1991 to 2000*, ATSB, Canberra, 2004.
- [31] ATSB, *Aviation safety survey - Common flying errors*, ATSB, Canberra, 2004.
- [32] ATSB, *Aviation safety survey - safety climate factors*, ATSB, Canberra, 2004.
- [33] ATSB, *Review of midair collisions Involving general aviation aircraft in Australia between 1961 and 2003*, ATSB, Canberra, 2004.
- [34] ATSB, *Alcohol and human performance from an aviation perspective*, ATSB, Canberra, 2004.
- [35] ATSB, *Cannabis and its effects on pilot performance and flight safety*, ATSB, Canberra, 2004.
- [36] ATSB, *General aviation pilot behaviours in the face of adverse weather*, ATSB, Canberra, 2005.

- [37] ATSB, *A context for error: Using conversation analysis to represent and analyse recorded voice data*, ATSB, Canberra, 2005.
- [38] ATSB, *Power loss related accidents involving twin-engine aircraft*, ATSB, Canberra, 2005.
- [39] ATSB, *Aviation safety indicators 2005 - A report on safety indicators relating to Australian aviation*, ATSB, Canberra, 2005.
- [40] ATSB, *Aviation safety survey - Pilots' flying experiences*, ATSB, Canberra, 2005.
- [41] ATSB, *Cross modal safety comparisons*, ATSB, Canberra, 2005.
- [42] ATSB, *Perceived pilot working and perceived safety of RNAV (GNSS) approaches*, ATSB, Canberra, 2006.
- [43] ATSB, *Transport safety research report: Fatal aircraft accidents: Far North Queensland in context*, ATSB, Canberra, 2006.
- [44] ATSB, *An analysis of in-flight passenger Injuries and medical conditions: 1 January 1975 to 31 March 2006*, ATSB, Canberra, 2006.
- [45] ATSB, *Design and evaluation of auditory icons as informative warning signals*, ATSB, Canberra, 2006.
- [46] ATSB, *International fatality rates: A comparison of Australian civil aviation fatality rates with international data*, ATSB, Canberra, 2006.
- [47] ATSB, *Assessing institutional resilience: A useful guide for airline safety managers?*, ATSB, Canberra, 2006.
- [48] ATSB, *Destination weather assurance risks associated with the Australian operational rules for weather alternate minima*, ATSB, Canberra, 2006.
- [49] ATSB, *Communication in context: A conversation analysis tool for examining recorded voice data in investigations of aviation occurrences*, ATSB, Canberra, 2006.
- [50] ATSB, *Depressurisation, accidents and incidents involving Australian civil aircraft: 1 January 1975 to 31 March 2006*, ATSB, Canberra, 2006.
- [51] ATSB, *Accidents and incidents involving alcohol and drugs in Australian civil aviation: 1 January 1975 to 31 March 2006*, ATSB, Canberra, 2006.
- [52] ATSB, *Forensic identification of aviation bird strikes in Australia*, ATSB, Canberra, 2006.

- [53] ATSB, *Wire-strike accidents in general aviation: Data analysis 1994 to 2004*, ATSB, Canberra, 2006.
- [54] ATSB, *Investigation of visual flight cues for timing the initiation of the landing flare*, ATSB, Canberra, 2006.
- [55] ATSB, *An assessment of general aviation pilot performance during simulated flight*, ATSB, Canberra, 2006.
- [56] ATSB, *Fire safety of advanced composites for aircraft*, ATSB, Canberra, 2006.
- [57] ATSB, *Evacuation commands for optimal passenger management*, ATSB, Canberra, 2006.
- [58] ATSB, *Fatigue management in the New Zealand aviation industry*, ATSB, Canberra, 2006.
- [59] ATSB, *Organising for flight safety*, ATSB, Canberra, 2006.
- [60] ATSB, *Analysis of fatality trends involving civil aviation aircraft in Australian airspace between 1990 and 2005*, ATSB, Canberra, 2006.
- [61] ATSB, *Dangerous distraction: An examination of accidents and incidents involving pilot distraction in Australia between 1997 and 2004*, ATSB, Canberra, 2006.
- [62] ATSB, *A Layman's Introduction to human factors in aircraft accident and Incident investigation*, ATSB, Canberra, 2006.
- [63] ATSB, *An overview of spatial disorientation as a factor in aviation accidents and incidents*, ATSB, Canberra, 2007.
- [64] ATSB, *Aircraft reciprocating engine failure: An analysis of failure in a complex engineered system*, ATSB, Canberra, 2007.
- [65] ATSB, *Robinson R22 helicopter aerial mustering usage investigation*, ATSB, Canberra, 2007.
- [66] ATSB, *Radiotelephony readback compliance and its relationship to surface movement control frequency congestion*, ATSB, Canberra, 2007.
- [67] ATSB, *The impact of Australian transcontinental 'Back of Clock' operations on sleep and performance in commercial aviation flight crew*, ATSB, Canberra, 2007.
- [68] ATSB, *Australian aviation safety in review*, ATSB, Canberra, 2007.

- [69] ATSB, *How old is too old? The impact on ageing aircraft on aviation safety*, ATSB, Canberra, 2007.
- [70] ATSB, *Human factors analysis of Australian aviation accidents and comparison with the United States*, ATSB, Canberra, 2007.
- [71] ATSB, *Pilot Incapacitation: Analysis of medical conditions affecting pilots involved in accidents and incidents*, ATSB, Canberra, 2007.
- [72] ATSB, *Regional airline line operations safety audit*, ATSB, Canberra, 2007.
- [73] ATSB, *Collision with terrain, 11 km NW Lockhart river aerodrome*, ATSB, Canberra, 2007.
- [74] Aviation Safety Network, *Statistics*, www.aviation-safety.net/statistics [retrieved 28 February 2006].
- [75] BBC, *The unflyable plane*, [videorecording], BBC Education, London, 1996.
- [76] BBC, *A cut-proce tragedy*, [videorecording], Future Media, Sydney, 1998.
- [77] BEA, *Bureau Enquites Accidents*, <http://www.bea-fr.org/anglaise/bea/bea.htm> [retrieved 22 February 2007].
- [78] BEA, *Cockpit Voice Recorder and Flight Data Recorders*, <http://www.bea-fr.org/francais/bea/enregistreur.htm> [retrieved 10 November 2007].
- [79] BFU, *Bundesstelle fuer flugunfalluntersuchung-BFU*, http://www.bfu-web.de/cln_010/nn_41948/EN/The_20BFU/General_20Information/generalInformation_node.html_nnn=true [retrieved 27 February 2007].
- [80] Burns, R., *Introduction to research methods*, Thousand Oaks, London, 2000.
- [81] BVDA, *Investigation Kits*, BVDA, Haarlem, 2007.
- [82] CASA, *Accident Investigation Sheet*, CASA, Canberra, 1999.
- [83] Chorafas, D., *Modelling the survival of financial and industrial enterprises*, Palgrave Macmillan, New York, 2002.
- [84] Ciniflix, *Air Crash Investigation: Miracle Escape*, [videorecording], Englewood, Colo, 2007.
- [85] Ciniflix, *Air Crash Investigation: Crash Landing at Sioux City*, [videorecording], Channel 7, Melbourne, 2007.

- [86] Ciniflix, 'Air Crash Investigation: All Engine Failed', *Season 4, Episode 2*, [videorecording], National Geographic Channel, 2007.
- [87] Ciniflix, 'Air Crash Investigation: Vertigo', *Season 4, Episode 9*, [videorecording], National Geographic Channel, 2007.
- [88] Ciniflix, 'Air Crash Investigation: Helios crash investigation', *Season 4, Episode 10*, [videorecording], National Geographic Channel, 2007.
- [89] Ciniflix, 'Air Crash Investigation: Flying on Empty', *Season 1, Episode 3*, [videorecording], National Geographic Channel, 2007.
- [90] Ciniflix, 'Air Crash Investigation: Ripped from the Cockpit', *Season 2, Episode 1*, [videorecording], National Geographic Channel, 2007.
- [91] Ciniflix, 'Air Crash Investigation: Racing the Storm', *Season 1, Episode 1*, [videorecording], National Geographic Channel, 2007.
- [92] Ciniflix, 'Air Crash Investigation: Hanging by a Thread', *Season 3, Episode 1*, [videorecording], National Geographic Channel, 2007.
- [93] Ciniflix, 'Air Crash Investigation: Mountain Plane', *Season 2, Episode 5*, [videorecording], National Geographic Channel, 2007.
- [94] Department, *Profile of an accident*, [videorecording], National Audiovisual Center, Washington, 1980.
- [95] Dismukes, K., *The limits of expertise: rethinking pilot error and the causes of airline accidents*, Aldershot, Hampshire, 2007.
- [96] Dobrov, G.M., *Prognostik der wissenschaft und technik*, Dietz Verlag, Berlin, 1971.
- [97] Dodd, B., 'Safety data integration can lead to better understanding of risk', *ICAO Journal*, vol. 62(2), pp.21-22, 2007.
- [98] Dolbeer, R.A., 'Birds and aircraft are competing for space in crowded skies', *ICAO Journal*, vol. 61(3), pp.21-24, 2006.
- [99] Espinola, S., Costa, M., and Maurino, D., 'Guidance material addresses concerns about protection of safety information ', *ICAO Journal*, vol. 61(6), pp. 26-28, 2005.
- [100] FAA, *Data & Statistics*, http://www.faa.gov/data_statistics [retrieved 11 October 2005]
- [101] Faith, N., *Black box*, Boxtree, London, 1998.

- [102] Ferguson, S., *Researching the public opinion environment: theories and methods*, Sage Publications, Thousand Oaks, California, 2000.
- [103] Flores, G.A., 'Volcanic ash advisory centre highlights ways to optimize procedures', *ICAO Journal*, 62(3), pp.6-8, 2007.
- [104] Fuente, C., *Photos*, www.airlines.net [retrieved 10 October 2007].
- [105] Galler, D., and Slenski, G., 'Causes of aircraft electrical failures', *Aerospace and Electronic Systems Magazine*, vol. 6, pp.3-8, 1991.
- [106] Galotti, V., 'ICAO initiative promotes global approach to SMS (Safety Management System) implementation', *ICAO Journal*, vol. 61(6), pp.6-8, 2006.
- [107] Geoghegan, A., *Fatal Error*, [videorecording], ABC, Sydney, 2005.
- [108] Gero, D., *Aviation Disasters*, P.Stephens, Sparkford, 2000.
- [109] Gregor, J., 'A Mathematical Cross-Correlation for Time-Alignment of Cockpit Voice Recorder and Flight Data Recorder Data', *Journal of accident investigation*, vol. (2)1, pp. 43-53, 2006.
- [110] Guan, W., and Yong, K., *Ballistic Trajectory Analysis for the CI611 Accident Investigation*, Aviation Safety Council, Taiwan, Taipei, 2004.
- [111] Guinness Centre, *Fatal accident in advanced technology aircraft: A critical survey*, Research and Market, Dublin, 2007.
- [112] International Aero Engines, *IAEV 2500*, IAEV, Dahlewitz, 2007.
- [113] International Air Transport Association, 'Safety is everyone's top priority', *ICAO Journal*, vol. 61(6), pp.42-44, 2006.
- [114] ICAO, *Convention on international civil aviation done at Chicago on the 7th day of December 1944*, ICAO, 1944, <http://www.icao.int/icaonet/arch/doc/7300/7300orig.pdf>, [retrieved 20 April 2006].
- [115] ICAO, *Manual of aircraft accident investigation*, ICAO, Montreal, 1970.
- [116] ICAO, *Aircraft accident and incident Investigation: international standards and recommended practices: annex 13 to the Convention on International Civil Aviation*, ICAO, Montreal, 2001.
- [117] ICAO, *Aviation Safety*, <http://www.icao.int/fsix> [retrieved 11 May 2006].

- [118] ICAO, *Strategic objectives of ICAO*, www.icao.int/icao/en/strategic_objectives.htm [retrieved 11 May 2007].
- [119] ICAO, 'Information gleaned from recent accidents provides basis for safety improvements', *ICAO Journal*, vol. 61(6), pp.29-30, 2006.
- [120] ICAO, 'Runway incursions pose a risk at every airport, but accidents are not inevitable', *ICAO Journal*, vol. 62(2), pp.24-26, 2007.
- [121] Imhoff, C., Geiger, J., and Galemme, N., *Mastering data warehouse design*, Wiley Pub, Indianapolis, 2003.
- [122] Japan Aircraft Development Corporation, *Worldwide market forecast for commercial air transport 2001-2020*, JADC, Tokyo, 2001.
- [123] Japan International Cooperation Agency, *Ship Handling Simulator*, www.jica-itu.f.itu.edu.tr/Photo%20Album.htm [retrieved 10 November 2007].
- [124] Johnson, C., and Dell, W., *Limitations of 3D Audio to Improve Auditory Cues in Aircraft Cockpits*, Dept of Computing Science, Univ. of Glasgow, Scotland, Glasgow, 2004.
- [125] Johnson, C., and Holloway, C., *Systemic Failures and Human Error in Canadian TSB Aviation Reports between 1996 and 2002*, University of Glasgow, Glasgow, 2003.
- [126] Kakar, A., and Crider, D., 'Parameter Extraction Using Simulation for Aircraft Accident Investigation', *AIAA Modeling and Simulation Technologies Conference and Exhibit*, Hilton Head, 2007.
- [127] Kennedy, H.P., 'Enhancing Delphi research methods and results', *Journal of Advanced Nursing*, vol. 45(5), pp.504-511, 2004.
- [128] Keonan, C., 'Ground-based wind shear detection systems have become vital to safe operations', *ICAO Journal*, vol. 62(2), pp.16-19, 2007.
- [129] King, C., Keaton, M., and Harris, D., *Dangerous Skies*, [videorecording], Visual Corporation, London, 1996.
- [130] Kolly, J., and Blanchet, T., 'Applying Research Methods to Accident Investigations', *Journal of Accident Investigation*, 1, pp.13-20, 2005.
- [131] Komarinski, P., *Automated Fingerprint Identification Systems (AFIS)*, Academic Press, Burlington, 2005.

- [132] Krause, S., *Aircraft Safety*, McGraw-Hill, New York, 1996.
- [133] Kritzing, D., *Aircraft system safety*, Woodhead Publishing, Cambridge, 2006.
- [134] Kuzinovski, M., Chihosh, P., and Tujarova, S., 'Computer aided realization of the Delphi method', *Collection of articles, Faculty of Mechanical Engineering, St 'Kyril and Methodious', Skopje*, 1998.
- [135] Kuzinovski, M., Tudzarova, S., Chihosh, P., and Zembrovski, H., 'Application of the Delphi technique - A guarantee to perform successful investigation', *Collection of articles, Faculty of Mechanical Engineering, St 'Kyril and Methodious', Skopje*, 1994.
- [136] Harold, L, and Murray, T., *The Delphi method: techniques and applications*, Addison – Wesley Publishing Company, Don Mills, 1975.
- [137] Ladkin, P.B., *On classification of factors in failures and accidents*, Bielefeld University, Bielefeld, 1999.
- [138] Lenz, M., 'Icing - Hope is not a Strategy', *FAA Aviation News*, (46)6, pp.22-26, 2007.
- [139] Litvak, B.G., *Ekspertnaja informacija. Metody poluchenija i analiza*, Radio i svjaz, Moskva, 1982.
- [140] Malcolm, M., *The Black Box*, [videorecording], Panther, London, 1984.
- [141] Matejic, V., *Forecasting by applying the Delhpi technique*, Institute 'Mihajlo Pupin', Beograd, 1974.
- [142] Miyagi, M., *Serious accident and human factors*, John Wiley & Sons Ltd, West Sussex, 2005.
- [143] Morford, O., and Lenardon, J., *Classical Mythology*, 3rd ed., Longman, London, 1985.
- [144] Motevalli, V., and Salmon, C., 'Developing Greater Flexibility and Resolution in Aviation Accident Analyses', *ITS Transportation Safety and Security conference*, Miami, 2004.
- [145] National Geographic Channel, *Air Crash Investigation: Most Extraordinary Cases*, A compilation, [videorecording], NGC, 2007
- [146] National Research Council, *Improving the continued airworthiness of civil aircraft: A strategy for the FAA's aircraft certification service*, National Academy Press, Washington, 1998

- [147] Navarro, G., and Raffinot, M., *Flexible pattern matching in strings*, Cambridge University Press, New York, 2002.
- [148] Novacevski, D., *Annuaire de la faculte des sciences economiques de Skopje*, L'Universite 'Cyrile and Methode', Skopje, 1978.
- [149] Novacevski, D., *Methods of creating set priorities*, Contemporary administration, Beograd, 1980.
- [150] NTSB, *Most wanted transportation safety improvements*, http://www.nts.gov/recs/mostwanted/aviation_issues.htm [retrieved 1 September 2007]
- [151] NTSB, *Air traffic control equipment outages*, NTSB, Washington, 1996.
- [152] NTSB, *Evaluation of U.S. department of transportation efforts in the 1990s to address operator fatigue*, NTSB, Washington, 1999.
- [153] NTSB, *Survivability of accidents involving part 121 U.S. air carrier operations 1983 through 2000*, NTSB, Washington, 2001.
- [154] NTSB, *Emergency evacuation of commercial airplanes*, NTSB, Washington, 2001.
- [155] NTSB, *Transportation safety database*, NTSB, Washington, 2002.
- [156] NTSB, *Aviation accident statistics*, <http://www.nts.gov/aviation/Stats.htm> [retrieved 28 April 2006].
- [157] NTSB, *Risk factors associated with weather - related general aviation accidents*, NTSB, Washington, 2005.
- [158] NTSB, *Current procedures for collecting and reporting U.S general aviation accident and activity data*, NTSB, Washington, 2005.
- [159] NTSB, *Safety report on the treatment of safety - critical systems in transport* NTSB, Washington, 2006.
- [160] NTSB, *Special investigation report emergency medical services* NTSB, Washington, 2006.
- [161] NTSB, *Aviation investigation manual major team investigations*, 2007, <http://www.nts.gov/Aviation/Manuals/MajorInvestigationsManual.pdf> [retrieved 15 February 2007].
- [162] NTSB, 'Safety board conducts its first unmanned aircraft accident investigation', *Air Safety Week*, 21, Washington, 2007.

- [163] Park, A., and Spangler, C., 'Developing Animations to Support Complex Aviation Accident Investigations', *Journal of Accident Investigation*, 2, pp.23-30, 2006.
- [164] PlanCrashInfo, *Statistics*, <http://www.planecrashinfo.com/cause.htm> [retrieved 15 May 2006].
- [165] Quade, E.S., *Analysis for Public Policy decisions*, RAND Corporation, Santa Monica, 1972.
- [166] RMIT, *Finding information on aerospace engineering*, <http://www.rmit.edu.au/browse;ID=ugwn1vc254xs> [retrieved 28 November 2005].
- [167] Rosekind, M., Gregory, K., and Miller, D., *Examining Fatigue Factors in Accident Investigations: Analysis of Guantanamo Bay Aviation Accident*, NTSB, Washington, 2001.
- [168] Sandelovski, M., 'Combining qualitative and quantitative sampling, data collection, and analysis techniques in mixed-method studies', *Research in Nursing & Health*, vol. 23(3), pp. 246-255, 2000.
- [169] Schulze, D., and Panontin, T., 'Information Management in Aviation Accident Investigation', *Journal of Accident Investigation*, 1, pp. 22-26, 2005.
- [170] Spata, A., *Research methods*, John Wiley & Sons, Inc., New York, 2003.
- [171] Stewart, S., *Emergency: crisis on the flight deck*, Airline, Shrewsbury, 2002.
- [172] Storey, N., and Little, A., *An Internet-based, Searchable Database of Air Accidents*, University of Warwick, Coventry, 2000.
- [173] Taneja, N., 'Weather related fatal general aviation accidents : Can spatial disorientation training be an effective intervention strategy?' *Ind J Aerospace Med*, vol. 46, pp. 59-64, 2002.
- [174] Taneja, N., 'Human Factors in Aircraft Accidents:a Holistic Approach to Intervention Strategies', *46th Annual Meeting of the Human Factors and Ergonomics Society*, Santa Monica, 2002.
- [175] Tran, D., 'Use of the Vertical Motion Simulator in Support of the American Airlines Flight 587 Accident Investigation', *AIAA Modeling and Simulation Technologies Conference and Exhibit*, Rhode Island, 2004.

- [176] Trunov, O, 'Ground icing remains a safety issue that warrants further research', *ICAO Journal*, vol. 61(4), pp. 22-25, 2006.
- [177] TSB, *Investigation process*, Montreal, <http://www.tsb.gc.ca/en/investigationprocess/index.asp> [retrieved 20 February 2007}.
- [178] TSB, 'Non-standard ATC practices and procedures unveiled by incident investigation', *ICAO Journal*, 62(3), pp. 18-21, 2007.
- [179] TSB, *Mandate of Transportation Safety Board of Canada*, 2007, <http://www.tsb.gc.ca/en/common/mandate.asp> [retrieved 5 January 2008].
- [180] Vodinelic, V., *Metodika Ispitivanja udesa vazduhoplova*, Beograd, 1986.
- [181] Vrcelj, D., Bajic, V., Zivotic, P., and Petrovic, P, *Measuring of the technological progress and methods for forecasting* Institute of economic industry, Beograd, 1973.
- [182] Wells, A., *Commercial aviation safety*, McGraw-Hill, New Yord, 2001.
- [183] Wilson, P., 'European action plan promotes best practices for preventing runway incursions', *ICAO Journal*, vol. 62(1), pp. 9-10, 2007.
- [184] Wood, R., and Sweginnis, R, *Aircraft accident investigation*, Endeavour Books, WY, 1995.
- [185] Zhu, X., and Davidson, I., *Knowledge discovery and data mining*, Information Science Reference, Hershey, 2007.

APPENDIX A

THE DELPHI TECHNIQUE – QUESTIONNAIRE

- ✚ Write down your answers in the appropriate cell provided. If you would like to add new items and their consistent impacts please do so at the end of the table.

Q1. How much are the below mentioned principles met within an aircraft accident investigation?										
	1	2	3	4	5	6	7	8	9	10
	Definitely unfeasible				↔	Definitely feasible				
1.	Principle of technical – tactical liberty of conducting the investigation and principle of adequacy (Having the opportunity of applying all means available in order to obtain the cause of accident)									
2.	Principle of methodical approach and planning (Fluency of the whole procedure and its carrying out according to the plan)									
3.	Principle of critical approach of the procedure (Expert's capability of critical thinking about his working within the whole procedure. Ability to recognize his own mistakes done during the procedure and fix them)									
4.	Principle of operational approach (Quick response to notification of accident occurrence)									
5.	Principle of profundity and persistence									
6.	Principle of objectivity									
7.	Principle of solitary governance of investigation									
8.	Principle of coordination and cooperation									
9.	Principle of economical procedure									
10.	Principle of secrecy									

- ✚ Write down your answers in the appropriate cell provided. If you would like to add new items and their consistent impacts please do so at the end of the table.

Q2. What are the odds of determining the answers of the questions below within an aircraft accident investigation?										
	1	2	3	4	5	6	7	8	9	10
	Definitely unfeasible				↔	Definitely feasible				
11.	When did the accident happen?									
12.	Where did the accident happen?									
13.	How did the accident happen?									
14.	Who owns the plane and how has it been maintained?									
15.	Who were the occupants of the aircraft?									
16.	Why did the accident happen?									
17.	What may have prevented the accident?									

✚ Write down your answers in the appropriate cell provided. If you would like to add new items and their consistent impacts please do so at the end of the table.

You are expected firstly to give all answers for Q3 (question 3), after that your answers for Q4, and finally for Q5.

Q3. In reference to obtaining a better investigation outcome, HOW IMPORTANT is [the given item] within the process of aircraft accident investigation? <div style="display: flex; justify-content: space-between; width: 100%;"> 1 2 3 4 5 6 7 8 9 10 </div> <div style="display: flex; justify-content: space-between; width: 100%;"> Unimportant ↔ Very Important </div>						
Q4. HOW COMPLEX is [the given item] within the investigation process as to the requirement of special skills and technique by the examination team? <div style="display: flex; justify-content: space-between; width: 100%;"> 1 2 3 4 5 6 7 8 9 10 </div> <div style="display: flex; justify-content: space-between; width: 100%;"> Not at all (Simple) ↔ Very complicated </div>					X	
Q5. IS THERE POTENTIAL for further improvement of [the given item] within the aircraft accident investigation by applying the new methods and contemporary technology? <div style="display: flex; justify-content: space-between; width: 100%;"> 1 2 3 4 5 </div> <div style="display: flex; justify-content: space-between; width: 100%;"> Small ↔ Large </div>						
18.	Managing the investigation (Plan, Report, Monitor)					
19.	Notification and arriving at the scene of the accident					
20.	Examination of the scene of the accident					
21.	Wreckage analysis					
22.	Finding and interviewing the witnesses					
23.	Investigation of Air Traffic Control records & Radar Data					
24.	Laboratory examination					
25.	Reconstruction					
26.	Report writing (Structure & Quality)					
27.	Data management					

✚ Write down your answers in the appropriate cell provided. If you would like to add new items and their consistent impacts please do so at the end of the table.

You are expected firstly to give all answers for Q6, after that your answers for Q7.

Q6. HOW COMPLEX is the EXAMINATION of [the given item] as to the requirement of special skills and technique by the examination team? <div> <div>12345678910</div> <div>Not at all (Simple) ↔ Very complicated</div> </div>			
Q7. IS THERE POTENTIAL for further IMPROVEMENT OF EXAMINATION of [the given item] within the aircraft accident investigation by applying new methods and contemporary technology? <div> <div>12345</div> <div>Small ↔ Large</div> </div>			
28.	Operations, The Flight Path		
29.	Cockpit		
30.	Engine and accessories		
31.	Mechanical, electrical, hydraulic, pneumatic systems		
32.	Landing gear systems and brake systems		
33.	Deicing and anti-icing systems		
34.	Fuel (quality and amount)		
35.	Foreign Object Damage (FOD)		
36.	Cockpit Voice Recorder (CVR)		
37.	Cockpit Sound Recorder (CSR)		
38.	Flight Data Recorder (FDR)		
39.	Aircraft loading		
40.	Hydroplaning		
41.	In-flight explosion		
42.	In-flight failure (Structural failure – fatigue)		
43.	In-flight fire		
44.	Lightning		
45.	Mid-air collision		
46.	Crime activities		
47.	Weather conditions		
48.	Downwash and wing tip vortex hazards		
49.	Microburst, wind gust, wind shear		
50.	Stability and control of an airplane		
51.	Human error or omission		
52.	Psychological factors (fatigue, illusion, perception ...)		
53.	Design inadequacy		

- ✚ Write down your answers in the appropriate cell provided. If you would like to add new items and their consistent impacts please do so at the end of the table.

Q8. What are the odds of PROVING within the process of an aircraft accident investigation that [the given item] is cause for an accident?			1	2	3	4	5	6	7	8	9	10
			Unreliable				↔					Certain
54.	Engine malfunction											
55.	Brake systems malfunction											
56.	Landing gear systems malfunction											
57.	Icing											
58.	Foreign Object Damage (FOD)											
59.	Inappropriate fuel											
60.	Inappropriate aircraft loading											
61.	Hydroplaning											
62.	Downwash and wing tip vortex											
63.	Severe weather conditions											
64.	Microburst, wind gust, wind shear											
65.	Lightning											
66.	In-flight explosion											
67.	In-flight failure (Structural failure – fatigue)											
68.	In-flight fire											
69.	Crime activities											
70.	Human error or omission											
71.	Psychological factors (fatigue, illusion, perception, etc)											
72.	Stability problems and lost the control of the airplane											
73.	Design inadequacy											
74.	Mid air collision											

- ✚ Write down your **OPINIONS** about the **STATEMENTS** below in the appropriate cell provided. If you would like to add new items and their consistent impacts please do so at the end of the table.

Q9. STATEMENTS:			1	2	3	4	5	6	7	8	9	10
			Strongly disagree				↔					Strongly agree
75.	The process of investigation meets the procedures regarding the quality assurance (QA) and quality control (QC)											
76.	It is justifiable waiting for a couple of months before releasing the accident investigation report											
77.	Reports of investigation carried out are always accurate and well done											
78.	Investigators have appropriate and sufficient skills to handle aircraft accident investigation											
79.	The excellent knowledge of theory compared to an average one significantly improves the investigation outcomes											
80.	The contamination of the scene of the accident is a serious problem within the process of aircraft accident investigations											
81.	The presence of landmarks on the scene of the accident provides sufficient information for carrying out accurate mathematical calculations											

82.	It is likely at times inconsistent material is sent for lab analysis	
83.	Investigators should believe witnesses of aircraft accidents	
84.	The cockpit recorders (FDR, CVR, CDR) record sufficient parameters	
85.	We never have a real accident with enough readable data	
86.	The severe aircraft manoeuvres can be revealed during the investigation	
87.	The aircraft is equipped with appropriate accessories, which provides ice protection during the whole flight	
88.	The stall is a serious hazard for the aircraft	
89.	The downwash and wing tip vortex is a serious hazard for the aircraft	
90.	Investigators have enough resources available to find out the weather conditions during the accident	
91.	Human factors have been involved somehow in every single aircraft accident that has ever occurred	
92.	It is possible to answer the question if the pilot should have been able to cope with the critical situation	
93.	There are always problems with airfield papers analysis (documentation)	
94.	The handbook is well composed material	
95.	There is a great possibility for increasing the survivability of an aircraft accident	
96.	Determining the cause of the accidents is a very tough task if there is not data recorded	
97.	The process of investigation as a whole can be improved significantly, by applying new methods and advanced technology	
98.	The experience of the land traffic accident investigation can contribute to considerable increase in air traffic safety	
Add items in the list of the two questions below:		
99.	The potential hazards for investigators within the process of investigation are: <div></div>	
100.	The following actions could significantly improve the process of investigation: <div></div>	

<p>Your comment about the definition of aircraft accidents, which has been widely accepted, and which introduces more causes for an accident or assumes existing major and contributing factors. How does it apply in practice?</p> <div></div>
--

IDENTIFICATION OF EXPERT OPINIONS (THE DELPHI TECHNIQUE)

Figure B1: Expert group opinion from the first and second round of Delphi exercise with respect to Question 1. (Question 1: ‘How much are the below mentioned principles met within an aircraft accident investigation?’)

Figure B2: Expert group opinion from the first and second round of Delphi exercise with respect to Question 2.
(Question 2: ‘What are the odds of determining the answers of the questions below within an aircraft accident investigation?’)

Figure B3: Expert group opinion from the first and second round of Delphi exercise with respect to Question 3.
 (Question 3: ‘In reference to obtaining a better investigation outcome, how important is [the given item] within the process of aircraft accident investigation?’)

Figure B4: Expert group opinion from the first and second round of Delphi exercise with respect to Question 4.
 (Question 4: ‘*How complex is [the given item] within the investigation process as to the requirement of special skills and technique by the examination team?*’)

Figure B5: Expert group opinion from the first and second round of Delphi exercise with respect to Question 5.
 (Question 5: *'Is there potential for further improvement of [the given item] within the aircraft accident investigation by applying the new methods and contemporary technology?'*)

Figure B6: Expert group opinion from the first and second round of Delphi exercise with respect to Question 6.
 (Question 6: ‘How complex is the examination of [the given item] as to the requirement of special skills and technique by the examination team?’)

Figure B7: Expert group opinion from the first and second round of Delphi exercise with respect to Question 7.
 (Question 7: *‘Is there potential for further improvement of [the given item] within the aircraft accident investigation by applying new methods and contemporary technology?’*)

Figure B8: Expert group opinion from the first and second round of Delphi exercise with respect to Question 8.
 (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?’)

Figure B9: Expert group opinion from the first and second round of Delphi exercise with respect to Question 9.
(Question 9: ‘Do you agree with the statements below?’)

APPENDIX C

Quantification Method III A Statistical Method of Multidimensional Analysis

Figure C1: A model for representing the stereoscopic 3-D graph of quantification method III
[142, p122]

Quantification method III: A method for quantifying the qualitative factors with the concept of the coefficient of correlation and clarifying the interrelationships among the factors.

APPENDIX D

A Brief Report of an Aircraft Accident Investigation

Shown below is one of many reports available on [9] used by this candidate to produce the statistics presented in Chapter 5.

This particular example refers to the accident that occurred on 01 July 2002, Ueberlingen, Germany.

‘Accident Description:

The aircraft, on a flight from Moscow, Russia to Barcelona, collided with a DHL Aviation Boeing 757 near Ueberlingen on the northern shore of Lake Constance, which borders Switzerland and Austria, around 11:43pm local time. Both aircraft were level at FL360, under Swiss air traffic control (Zurich). Approximately 50 seconds before the collision, Swiss ATC instructed the Russian Tupolev to descend from FL360 to FL350 to avoid a conflict with the DHL Boeing 757. No response was registered by the Russian crew. A second descent instruction was made by Swiss controllers’ seconds later, and the Tupolev crew acknowledged the instruction. The TU-154 initiated its descent about 25 seconds before the collision. At nearly the same instant, the Boeing 757’s TCAS (Traffic Collision Avoidance System) issued a Resolution Advisory (RA) in response to the threat of a collision with the TU-154, and the pilots began a descent in an attempt to avoid the Russian aircraft. The aircraft collided at FL354, broke apart and crashed, with debris scattered over an area nearly 40km wide.’